DEVELOPMENT OF AN IMPROVED DYNAMIC ALGORITHM TOENHANCE ENERGY SAVING IN LONG TERM EVOLUTION MOBILE ACCESS NETWORKS

BY

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FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY ZARIA, NIGERIA

OCTOBER, 2015

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA,

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE (M.Sc.) DEGREE IN TELECOMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY ZARIA,

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DECLARATION

I, Elvis OBIdeclare that the work in this dissertation entitled "**Development of an Improved Dynamic Algorithm to Enhance Energy Saving in Long Term Evolution Mobile Access Networks**" has been carried out by me in the Department of Electrical and Computer Engineering, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for any degree or diploma at this or any other institution.

Elvis OBI

Signature **Date**

CERTIFICATION

This dissertation entitled "**DEVELOPMENT OF AN IMPROVED DYNAMIC ALGORITHM TO ENHANCE ENERGY SAVING IN LONG TERM EVOLUTION MOBILE ACCESS NETWORKS**" by Elvis OBI meets the requirement for the award of Master of Science (M.Sc.) Degree in Telecommunications Engineering and has been approved by the Department of Electrical and Computer Engineering, Ahmadu Bello University Zaria for its contribution to knowledge and literary presentation.

Dr. S. Garba ______________ ______________
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(Dean, School of Post-graduate Studies) Signature Date

DEDICATION

This research work is dedicated to God Almighty for His guidance, kindness, mercy and grace.

ACKNOWLEDGEMENT

I thank God almighty for His mercies, faithfulness, divine protection and love throughout my life and the period of this research work.

My appreciation goes to my parents Mr. Paul Obi (ASP) and Mrs. Susana Obi, my lovely brothers and sisters for all their prayers, financial supports and encouragement throughout my studies. My extreme appreciation goes to my lovely wife Ogechi Patience Obi. You have been the best throughout. Your patience, encouragement, care and love were not taken for granted. Thank you very much.

My appreciation also goes to the chairman of my supervisory committee - Dr. S. Garba for his motivation, assistance and valuable contributions throughout this research work. He gave me the impression that I can complete this program. Thank you very much.

I sincerely wish to express my profound gratitude and appreciation to the member of my supervisory committee - Dr. S. M. Sani for valuable contributions and support throughout this research work. I am very grateful to him for shaping this research to a new direction and providing insight towards the solution and its contribution to knowledge. May the Almighty God reward him for the immeasurable service in ensuring that this Department lives up to its standard.

Special thanks to my Academic fathers, Prof. B.J. Bajoga, Prof. M. B. Mu’azu and Prof. Boyi Jimoh for their patience and time for going through my manuscripts.

I am grateful to all my lecturers and colleagues., Dr. A. D. Usman, Dr. K.A. Abu-Bilal, Dr. I.J. Umoh, Dr. Y. Jibril, Mr. Emmanuel Okafor, Mr. Adamu Saidu, Mr. Bashir Sadiq, Mr. O.E Ochia, Engr. M. J. Mu’azu, Mr. Abdulrashid Muhammed Kabir and all those whose names could not be mentioned for their support during the cause of this research work. I personally thank Mal. Abdullahi Tukur for all the administrative support rendered to me during my master program here in this Department.

Finally, my sincere appreciation goes to Etisalat Nigeria for the Etisalat Telecommunication Engineering Postgraduate Program (ETEPP) of which I am a beneficiary. Thanks for bridging the gap between theoretical telecommunication and practical telecommunication.

Elvis OBI

October, 2015

ABSTRACT

This research work presents a dynamic algorithm for improving energy saving in Long Term Evolution (LTE) mobile access networks through off mode, sleep mode and multi-cell cooperation utilization at the eNodeBs. The LTE mobile access network environment and the eNodeBs energy saving models were developed with a view to implementing a dynamic energy saving algorithm. The dynamic energy saving algorithm is an integration of two algorithms, namely: energy estimation algorithm and load/traffic sharing algorithm. The energy estimation algorithm is use to estimates the energy consumption of the eNodeBs when they are powered on, irrespective of the traffic loading. The load/traffic sharing algorithm transfers traffic between eNodeBs which enabled the off mode, sleep mode and multi-cell cooperation of the eNodeBs. The dynamic energy saving algorithm wasimplemented in MATLAB 2013b environment. The performance of the dynamic energy saving algorithm was carried out by simulation using the developed MATLAB graphical user interface (GUI) program called the LTE network energy saving analysis software based on dynamic scheduling. Energy savings were analysed for call blocking probabilitiesof $0.001\%, 0.01\%, 0.1\%, 1\%,$ and $10\%,$ while varying the energy load proportionality constant between0 and1 in steps of0.1. An optimum energy saving for the network was achieved when maintaining a call blocking probability of 1% which corresponded to 51.84%, 49.82%, 46.08%, 44.35%, 41.14%, 34.71%, 28.03%, 22.95%, 17.95%, 13.34% and 7.56% for the energy-load proportionality constant of $1,$ $0.9,$ $0.8,$ $0.7,$ $0.6,$ $0.5,$ $0.4,$ $0.3,$ $0.2,$ 0.1 and 0respectively. Validation of the proposed dynamic energy saving algorithm was carried out by comparison with the “always-on” algorithm by Chiaraviglio *et al.*, (2012) and the “sleep-wake” algorithm by Hossain *et al.*, (2013). The result showed that the proposed dynamic energy saving algorithm achieved the highest energy saving of 51.84% and 11.84%as compared to the “always-on” algorithm by Chiaraviglio *et al.*, (2012)and the“sleep-wake” algorithm by Hossain *et al.*, (2013)which achieve an energy saving of 0% and 40% respectively while guaranteeing a call blocking probability of 1% at an energy-load proportionality constant of 1.

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LIST OF ABBREVIATIONS

Acronyms	Definition
LTE	Long Term Evolution
GUI	Graphical User Interface
ICT	Information and Communication Technology
3GPP	3rd Generation Partnership Project
GSM	Global System for Mobile Communication
UMTS	Universal Mobile Telecommunications System
HSPA+	Evolved High-Speed Packet Access
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
MS	Mobile Stations
eNodeB	Evolved Base Station
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EPC	Evolved Packet Core
SGWs	Serving Gateways
MMEs	Mobility Management Entities
FDM	Frequency Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access

SC-FDMA	Single-Carrier Frequency Division Multiple Access
SON	Self-Organizing Network
SINR	Signal-to-Interference-Noise-Ratio
QoS	Quality of Service
AMC	Adaptive Modulation and Coding
MATLAB	Matrix Laboratory

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The information and communication technology (ICT) systems consume up to 10% of the world's energy accounting for about 2% of global CO_2 emissions(Marsan *et al.*, 2009). The telecommunications network is one of the main energy consumer of the information and communication technology sector(Yigitel *et al.*, 2014). About 37% of the total emissionsfrom ICT devices and systems are due to the telecommunication infrastructure and devices (Oh and Krishnamachari, 2010), where about a tenth of the estimate is due to cellularmobile communication networks (Son *et al.*, 2013). This accounts for about 0.2% of the global CO_2 emissions and 1% of the world energy consumption(Richter *et al.*, 2009). The mobile cellular communications sector alone consumes approximately 60 billion kWh per year(Dufková *et al.*, 2010).Correspondingly, energy consumption as well as CO_2footprint of mobile cellular networks are increasing at an alarming rate due to the exponential growth in mobile data traffic (Wu *et al.*, 2015). A projection showing the exponential growth in global mobile data trafficis illustrated in Figure 1.1("Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017," 2013).

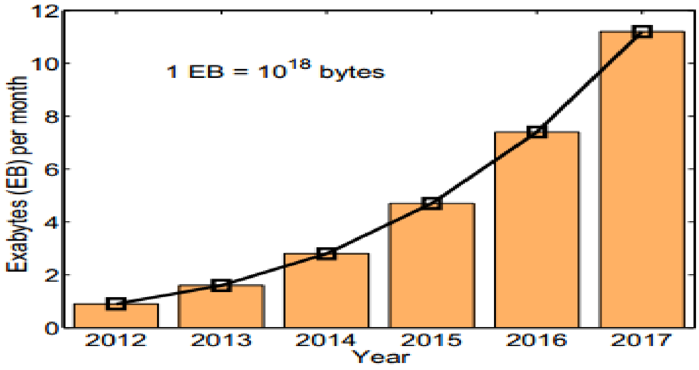


Figure 1.1: A Projection of Mobile Data Traffic Growth("Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017," 2013)

This leads to high network operating costs and a considerable contribution to the worsening global warming phenomenon respectively(Son and Krishnamachari, 2012).A typical power consumption of a mobile cellular network is shown in Figure 1.2 (Han *et al.*, 2011).

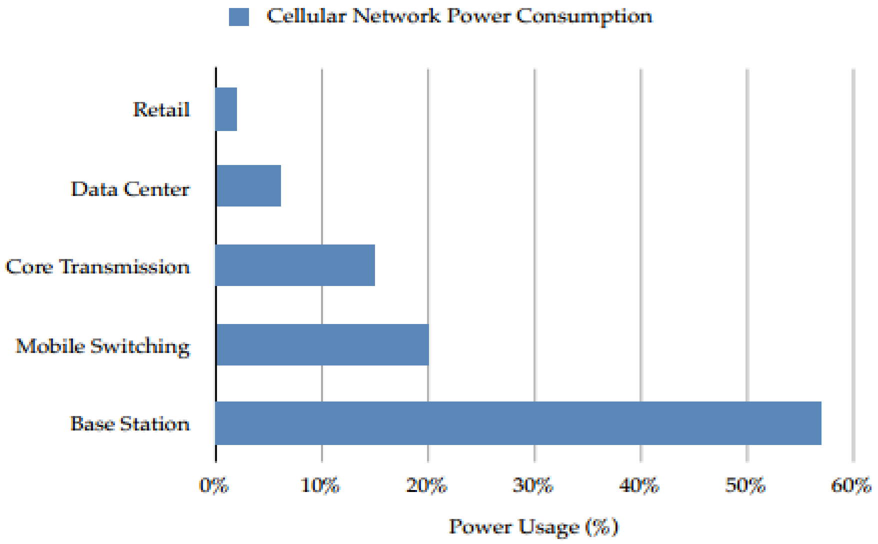


Figure 1.2: Power Consumption of a Mobile Cellular Network(Han *et al.*, 2011)

As can been seen from Figure 1.2, in amobile cellular network, the base station consumes the highest amount of energy which represents about 58% of the total energy utilization, whereas the accumulated energy requirement for mobile stations is approximately 3% of the total energy utilization. However, current mobile cellular networks are typically designed and operated to meet a given coverage and capacity level by considering the peak traffic demand, while energy efficiency takes a minor (or no role at all) at the design and operation stages(Oh *et al.*, 2013).

Consequently, minimization of energy consumption at base stations will considerably enhance the energy efficiency of cellular networks(Zhang and Wang, 2013). Remarkably, contemporary base stations have a high-degree of non-load-energy proportional consumption characteristic and consume significant amount of energy even atno-load condition (Xiang *et al.*, 2013). For example, a typical active base station consumes 800-1500W, while its power amplifier output needed to transmit from the antennas amounts to 40-80W only during the high-traffic hours (Han *et al.*, 2013). This implies that a base station consumes more than 90% of the operational power when there is no transmission (Han *et al.*, 2013).

On the other hand, cellular mobile network traffic exhibits a high-degreeof temporal-spatial diversity, which means that traffic demand varies both in time and space (Peng *et al.*, 2011). This variation is directly related to the random call making behaviour and mobility pattern of the mobile users(Paul *et al.*, 2011). A typical normalized traffic profile of a mobile cellular network for a week is as shown in Figure 1.3(Oh and Krishnamachari, 2010).

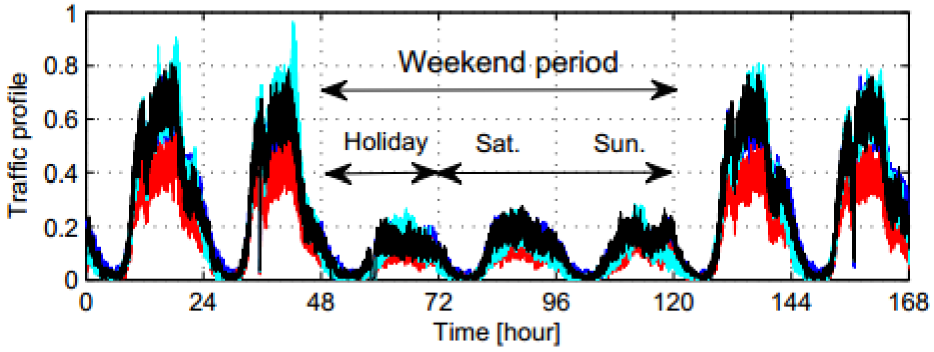


Figure 1.3: A Normalised Traffic Profile of a Cellular Mobile Network(Oh and Krishnamachari, 2010)

As shown in Figure 1.3, the traffic load decreases dramatically during the late night hours. There is also low traffic all day long during weekends or holidays in particular places such as government (or private) offices, schools etc., which operate mostly on week days. Therefore, infrastructures of the cellular access networks are underutilized during the low traffic periods(Yigitel *et al.*, 2014).

However, under the current network operation approach, all base stations are keptpowered on irrespective of traffic load (Wu and Niu, 2012).This traditional network operation and the aforementioned non-load-energy proportional utilization at base stationsare the major causes of the substantial amount of energy wastage in existing cellular networks(Chiaraviglio *et al.*, 2012).

Correspondingly, a cellular network is a radio network distributed over geographical areas called cells, each served by at least one fixedlocation transceiver known as a cell site or base station. (Murthy and Kavitha, 2012). Cellular networks run on technology platforms which evolved from the first generation (1G) to the current fourth generation (4G) Long Term Evolution (LTE) mobile networks.The LTE standard was developed by the 3rd Generation Partnership Project (3GPP) to cope with the rapid increase of mobile data usage (Sesia *et al.*, 2009).

The LTE is marketed as 4G LTE. LTE is a standard for wireless data communications technology and a development from the Global System for Mobile communication (GSM) and Universal Mobile Terrestrial System (UMTS) standards(Sesia *et al.*, 2009). The main goal of LTE is to provide a high data rate, low latency and packet optimised radio access technology supporting flexible bandwidth deployments. The network architecture of an LTE mobile network is as shown in Figure 1.4.

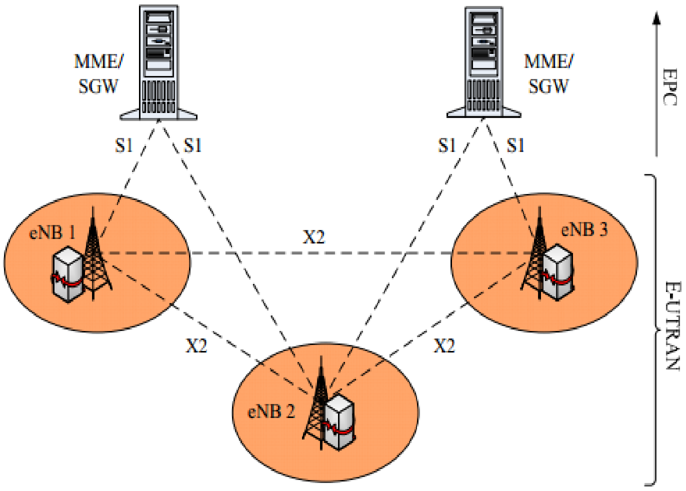


Figure 1.4: LTE Mobile Network Architecture(Sesia *et al.*, 2009)

As illustrated in Figure 1.4, the network architecture of LTE consists of two network domains – an access network and a core network. This research work focuses on the access network which contains the base stations that consumes the highest amount of energy in the LTE mobile network. The network architecture of LTE comprises the following three main components (Sesia *et al.*, 2009):

i. The Mobile Station (MS)
ii. The Evolved Universal Terrestrial Radio Access Network (E-UTRAN)
iii. The Evolved Packet Core (EPC)

The E-UTRAN comprises of the evolved base stations called eNodeBs which handles the radio communicationbetween the MS and the EPC.The eNodeBs are connected to EPCvia serving gateways (SGWs) and mobility management entities (MMEs) using the “SI” interface. The eNodeBs are interconnected with each other using an “X2” interface, which is introduced for inter-eNodeB message exchange in various coordination and cooperation phases (Sesia *et al.,* 2009). The X2 interface is used for signalling and packet forwarding during handover.

The E-UTRAN which consists the eNodeBs is the major energy consumer of the LTE mobile network. Thus, it is imperative to exploit the non-load-energy proportional utilization ofeNodeBs to devise techniques that manage the energy consumption of LTE mobile access networks more efficiently (Hasan *et al.*, 2011).Switching-off eNodeBs during low traffic situations has been proposed for future LTE systems, however the standard so far does not specify implementation schemes (Hossain *et al.,* 2011). This is the primary focus of green cellular mobile communication. It finds radio networking solutions that can greatly improve energy saving and resource efficiency without compromising the quality of service of the mobile stations (Han *et al.*, 2014).Given the nature of energy wastage, natural traffic diversity and the projection of traffic growth trend, it is crucial to develop dynamic algorithms to improveenergy savingin LTE mobile access networks.Many algorithms have been developed by researchers in the area of green wireless communication for minimizing the energy consumption of base stations using sleep mode utilization. Most of the researchers validate the performance of their algorithms against standard algorithms which are the “always-on” algorithm by Chiaraviglio *et al*., (2012) and the “sleep-wake” algorithm by Hossain *et al*., (2013)(Bousia *et al.*, 2014).

1.2 STATEMENT OF PROBLEM

The non-load-energy consumption proportionality of eNodeBs are the major causes behind the substantial amount of energy wastage in LTE cellular access networks, especially in the low traffic periods (Chiaraviglio *et al.*, 2012)**.** The existing dynamic switching off/on energy saving algorithms of LTE cellular access network eNodeBs was developed using the constant eNodeB power consumption model (Oh *et al*., 2013). This leads to the non-load-energy consumption proportionality of the eNodeBs which results to an increased energy consumption at low traffic period. Consequently, there is a need to develop a robust dynamic energy saving algorithm for LTE mobile access networks that will incorporate the load-proportional power consumption model of eNodeBs and allowing all eNodeBs under a cluster coordinate with their neighbouring eNodeBs to turn off/sleep the least loaded eNodeBs through load sharing with any moderately loaded eNodeBs.The algorithm will incorporate the inherent temporal -time traffic diversity of cellular access networks and the load-proportional power consumption model of eNodeBs. The proposed algorithm is expected to improve the energy savings by at least 50% while guaranteeing the quality of service offered to the mobile stations using off mode, sleep mode and active mode utilization of eNodeBs in a muti-cell cooperation and self-organizing manner.

1.3 AIM AND OBJECTIVES

The aim of this research is the development of a dynamic algorithm to improve energy saving in LTE mobile access networks while guaranteeing the quality of service offered to mobile stations.

The objectives of this research work are as follows:

i. Development of a dynamic algorithm for improving energy saving of LTE access network.
ii. Development of an energy saving analysis MATLAB graphical user interface (GUI).
iii. Evaluation of the energy savings resulting from the developed algorithm.
iv. Validation of the developed algorithm by comparing its performance in terms of the energy saving and blocking probability with the“always-on” algorithm by Chiaraviglio *et al*., (2012) and the “sleep-wake” algorithmby Hossain *et al*., (2013).

1.4 METHODOLOGY

The step by step approach of the proposed methodology is itemized as:

i. Development of mathematical model for the LTE cellular environment to represent the cell structure, location of an eNodeB, mobile station distribution factor and adjacent eNodeBs.
ii. Development of mathematical model for the energy saving of the LTE mobile access networks and the quality of service constraint (blocking probability).
iii. Development of an energy estimation algorithm, a load/traffic sharing algorithm and the integration of the two algorithms to form the dynamic energy saving algorithm for the LTE mobile access networks.
iv. Development of a MATLAB GUI for the simulation and analysis of the LTE access network energy saving.

v. Simulation and analysis of the energy consumption of the LTE access network resulting from the energy estimation algorithm.
vi. Validating the developed dynamic energy saving algorithm by comparing its performance in terms of the energy saving and blocking probability with the “always-on” algorithm and the “sleep-wake” algorithm’.

1.5 SCOPE

This dissertation entails the energy saving in homogeneous LTE mobile access network by implementing dynamic algorithm at the eNodeBs to enable inter-base station cooperation while guarantee the quality of service offered to the mobile station using the downlink communication (that is from eNodeB to mobile station).

1.6 SIGNIFICANT CONTRIBUTIONS

The significant contributions of this research work are as follows:

i. Development of a distributed sleep-wake, self-organizing and dynamic energy saving algorithm for LTE mobile access networks that uses three different modes of operation: off mode, sleep mode and active mode.
ii. Development of an LTE network energy saving analysis software (MATLAB graphical user interface) based on dynamic scheduling for energy saving analysis.
iii. The proposed dynamic energy saving algorithm achieved a maximum energy saving of 51.84% and 11.84% with respect to the “always-on” algorithm by Chiaraviglio *et al.,* (2012) and “sleep-wake” algorithm by Hossain *et al.,* (2013)which achieve an energy saving of 0% and 40% respectivelywhile guaranteeing a call blocking probability of 1%.

1.7 DISSERTATION ORGANIZATION

The general introduction has been presented in Chapter One. The rest of the chapters are presented as follows: A review of the fundamental concepts of LTE, energy saving in LTE mobile access networks and a review of similar research works are presented in Chapter Two. Modeling of the LTE cellular environment, development of the energy saving model in the LTE mobile access networks, the quality of service constraint model as well as the proposed dynamic energy saving algorithm are presented in Chapter Three. Analysis and discussion of the results are presented in Chapter Four. Conclusion, Limitation and recommendation for further works are discussed in Chapter Five.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is divided into two parts. The first part discussed the fundamental concepts relevant to the study and the second part provides a review of related prior research works.

2.2 REVIEW OF FUNDAMENTAL CONCEPTS

This sub-section presents an overview of concepts fundamental to the research work and a review of standard algorithms for energy saving in mobile cellular networks:

2.2.1 LTE Radio Access Scheme

LTE, marketed as fourth generation (4G) LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. The standard is developed by the 3GPP(Adeyemi and Ike, 2013). LTE as a wireless access standard supersedes the GSM and UMTS for increased network capacities. This is because LTE develop a framework for the evolution of the 3GPP radio access technology towards a high-data-rate, low-latency and packet-optimized radio access technology(Mishra and Mathur, 2014). Thus, the main objective of LTE among others are as follows(Adeyemi and Ike, 2013):

i. Significant increase in peak data rate e.g. 100Mbps (downlink) and 50Mbps (Uplink)
ii. Significantly improved spectrum efficiency
iii. Scalable bandwidth up to 20MHz (lowest possible bandwidth is: 1.25MHz)
iv. Low-latency of 1 ms

Orthogonal frequency division multiple access (OFDMA) is used in the LTE downlink access technology. The system supports a scalable bandwidth of up to 20MHz, with smaller bandwidths of 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz and 15 MHz to allow for the operations of different sized spectrum allocations(Adeyemi and Ike, 2013).OFDMA breaks the available bandwidth into many narrowsubcarriers and transmits the data in parallelstreams. Orthogonal frequency division multiplexing (OFDM) extends the Frequency division multiplexing(FDM) to provide a very flexible high capacity multiple access scheme. OFDM is a radio access technology that subdivides the bandwidth available for signal transmission into a multitude of narrowband subcarriers. The transmission duration is divided into short slots to create an OFDM block. In LTE, such an OFDM block is labelled a resource element. The available bandwidth and a duration called frame are divided into a number of resource element. Multiple resource elements are combined to constitute a resource block. When OFDM is used to grant mobile stations access to the shared transmission medium, the wireless medium is inherently shared and wireless transmissions occur simultaneously in resources such as frequency and time. The access scheme using the OFDM technology is called OFDMA. The basic LTE downlink physical resource can be seen as a time-frequency resource grids which are grouped into resource blocks as can be seen in Figure 2.1(Adeyemi and Ike, 2013):

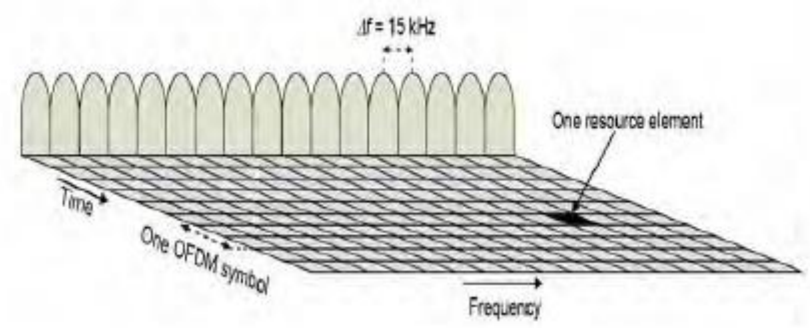


Figure 2.1: The LTE Downlink Physical Resource(Rathi *et al.*, 2014)

The number of available resource blocks over a frequency domain is given as(Rathi *et al.*, 2014):

$$N_{RB} = \frac{(-\varepsilon)W}{12\Delta w}$$

(2.1)

Where:W is bandwidth (Hz)

$\Delta w$is sub-carrier spacing (Hz)

$\varepsilon$is the guard band percentage

An LTE system assumes a subcarrier spacing Δw of 15 $kHz,$ 12 subcarriers per resource block with spacing of 15kHzand a 10% guard band(Rathi *et al.*, 2014). Therefore equation (2.1) is used to calculate the number of physical resource block in an LTE OFDMA system with a given bandwidth. A downlink carrier can have 6 resource blocks up to 100 resource blocks which corresponds to the downlink transmission bandwidth ranging from 1.25 MHz to 20 MHzusing equation (2.1) (Atayero *et al.*, 2012).

LTE uplink radio access scheme is based on single carrier frequency division multiple access(SC-FDMA). SC-FDMA is similar to OFDMA because the SC-FDMA physical resource can be seen as atime-frequency grid with the additional constraint that the overall time-frequency resource assigned to a mobile terminal must always consist of consecutive subcarriers(Adeyemi and Ike, 2013).

2.2.2 Load Utilization Factor

The load utilization factor in an LTE system is defined as the ratio of the number of resource blocks in use by the mobile stations to the number of the available resource blocks. Therefore $\rho_j(t)$is the load utilization factor at the jth eNodeBat time t. This is represented mathematically using (Wang *et al.*, 2010):

$$\rho_j(t) = \frac{N_{used.rb.j}(t)}{N_{rb.j}} \qquad (2.2)$$

$N_{used.rb.j}(t)$is the number of used physical resource block at the jtheNodeB at time t.,

$N_{rb.j}$is the number of available resource block in the jth eNodeB.

Also,

The number of used physical resource block at the jth eNodeB at time t is given as (Wang *et al.*, 2010):

$$N_{used.rb.j}(t) = \sum_{i=1}^{N_u} z_{i,j}(t) w_{i,t}(t) \qquad (2.3)$$

Where:

$z_{i,j}(t)$is an assignment indicator variable which is equal to 1 when ith mobile station is served byjth eNodeBat time t and zero otherwise.,

$w_{i,t}(t)$is the approximate number of physical resource block allocated by thejth eNodeB to the ith mobile station at time t and it is given as (Hossain *et al.*, 2013):

$$w_{i,t}(t) = \frac{R_{i,j}(t)}{W_{RB} e_{i,j}(t)} \qquad (2.4)$$

Where:

$W_{RB}$is the bandwidth per physical resource block which is equal to$180\ kHz$.,

$R_{i,j}(t)$is the bit rate requirement of the ith mobile stationfrom the jth eNodeBat time t.,

$e_{i,j}(t)$is the average bandwidth efficiency of the ith mobile stationfrom the jth eNodeBat time t. It is usually expressed using equation (2.5) when considering adaptive modulation and coding (AMC) (Adeyemi and Ike, 2013):

$$e_{i,j} = \begin{cases} 0 & if\ SINR_{i,j} < SINR_{min} \\ \xi \log_2(1 + SINR_{i,j}) & if\ SINR_{min} \leq SINR_{i,j} < SINR_{max} \\ e_{max} & if\ SINR_{i,j} \geq SINR_{max} \end{cases} \qquad (2.5)$$

Where:

$0 \leq \xi \leq 1$is the attenuation factor accounting the implementation loss

$SINR_{min}$is the minimum signal-to-interference-noise-ratio

$SINR_{max}$is the maximum signal-to-interference-noise-ratio

$e_{max}$is the maximum bandwidth efficiency

$SINR_{i,j}(t)$is the instantaneous received signal-to-interference-and-noise ratio of the ith mobile stationfrom the jth eNodeB.

Adaptive modulation and coding (AMC) set parameters are given as $\xi = 0.75$,$SINR_{min} = -6.5\ dB$,$SINR_{max} = 19\ dB$ and $e_{max} = 4.8\ bps/Hz$(3GPP, TR 36.942 Ver. 11.0.0 Rel. 11).

2.2.3 Architecture and Power Consumption of eNodeBs

An architecture of anLTE, 4G eNodeBswith it various components is shown in Figure 2.2(Han *et al.*, 2011).

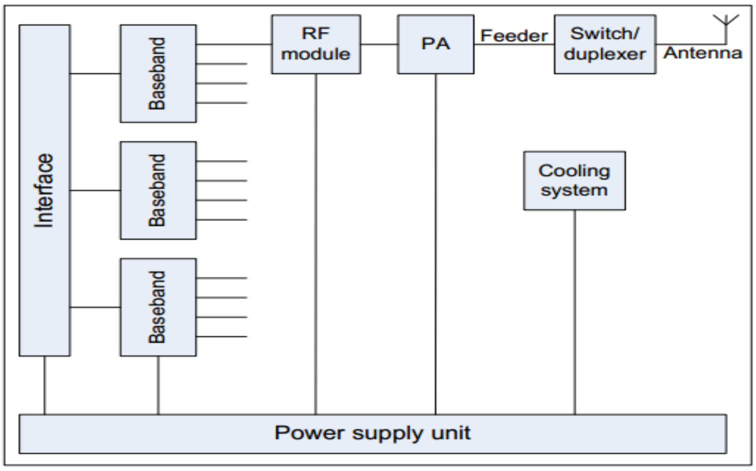


Figure 2.2: Architecture of anLTE 4G eNodeB(Han *et al.*, 2011)

An eNodeB transceiver chain consists of: (i)a radio frequency (RF) module which is an equipment for generating and transmitingsignals to the mobile terminals, (ii) apower amplifier (PA) that amplifies the transmit signals from the radio frequency module to power level suitable for transmission, (iii) anantenna feeder, (iv) a transmission antenna for radiating the signals, (v) a switch/duplexer, (vi)a base-band modulefor both uplink and downlink, (vii) a power supply unit and (viii)a cooling system. A single power supply unit and a cooling system is normally shared by all the transceivers of a base station(Han *et al.*, 2011).

A typical breakdown of the total power consumption by the different components of anLTE 4G eNodeB is shown in Figure 2.3(Correia *et al.*, 2010).

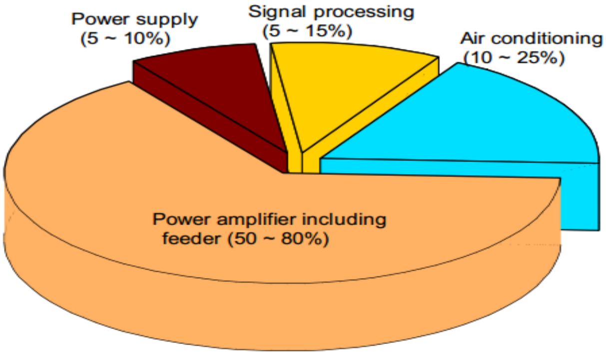


Figure 2.3: Power Consumption of Components of an LTE 4G eNodeB(Correia *et al.*, 2010)

As shown in Figure 2.3, the power amplifier and the cooling system are the two major energy consuming equipment in a base station. The power amplifier isthe most energy inefficient element accounting for more than 50% of power consumed at high traffic load (Correia *et al.*, 2010).The air conditioning system also consumes a significant amount of power even at no traffic load. Thus, both the power amplifier and the cooling system are the two major contributors to the non-load-energy proportional consumption at eNodeBs(Hasan *et al.*, 2011).

2.2.4 Multi-Cell Cooperation in Cellular Networks

The whole concept behind multi-cell cooperation is to reduce the number of active eNodeBs required to serve mobile stations in a coverage(Niu *et al.*, 2012). When some eNodeBs are put in sleep mode, radio coverage and service provisioning are provided by neighbouring cells (Zhang and Wang, 2013). Thus, the ultimate goal of multi-cell cooperation is to maximize network capacity, and improve service quality by optimizing bandwidth utilization and minimizing inter-cell interference (Zhang and Wang, 2013). The stringent multi-cell coordination is essential for energy saving dynamic network reconfigurations, where some eNodeBs are put into sleepmode. The active eNodeBs cooperate by adjusting their transmission ranges to cover areas serviced by sleep mode eNodeBs (Niu *et al.*, 2012).

2.2.5 Self-Organizing Networks

Self-Organizing Network (SON) is an intelligent, optimization structure in theLTE cellulartechnology that save operational expenditures. The Self-Organizing Networks are applied to achieve self-configuration for load balancing, self-optimization and self-healing, and cell outage management (Murthy and Kavitha, 2012). Therefore, Self-Organizing Networks with autonomous operation, control and maintenance have been identified as the most efficient way of running networkswith minimal human intervention which leads to reduced cost and complexity.Such automation in networks has great potential for attaining lower energy requirements, improved mobility management, better load balancing, and efficient resource utilization (Hu *et al.*, 2010).

2.2.6 Power Consumption Model

The eNodeB power consumption model is used for evaluating the energy consumption of an LTE cellular network.The power consumed by an LTE access network depends on the network operating conditions and the eNodeBs equipment. The eNodeBs are modelled to consume power that is partly constant and partly variable with the load utilization factor at any given instant of time (Shahab *et al.*, 2015). The eNodeBs can exist in three distinct modes which are active, sleep, and off mode (Adhikary *et al.*, 2012). The mathematical representation of the instantaneous power consumed by the jth eNodeB at the various modes is given by(Son *et al.*, 2011):

$$P_j(t) = \begin{cases} (1-q)\rho_j(t)P_j^a + qP_j^a \,., & active\ mode \\ P_j^s \,., & sleep\ mode \\ 0\,., & off\ mode \end{cases} \quad (2.6)$$

Where:

$P_j(t)$is the operational power of the jth eNodeB at time t,

$P_j^a$is the maximum operational power of the jth eNodeB,

$P_j^s$is the sleep mode power of the jth eNodeB,

$\rho_j(t)$is the load utilization factor of the jth eNodeB at time t,

$q \in [0,1]$is called energy-load proportionality constant of the eNodeBs(Son *et al.*, 2011).

2.2.7 Energy-Load Proportionality Constant

Energy-load proportionality constant (q)determines the level of dependency of the operational power of an eNodeB on it load utilization factor. When the energy load proportionality constant (q) is zero, theeNodeBs are assumed to consist of only energy-load proportional devices. Such eNodeBs would ideally consume no power when idle and gradually consume more power as the utilization level increases. This type of eNodeB is referred to as anenergy-load proportional eNodeB. However, energy-load proportional eNodeBs are still far from reality because several devices in the eNodeBs dissipate standby power while inactive, such as, the power amplifier(Son *et al.*, 2013). Thetype of eNodeB which consumes fixed power irrespective of its utilization level, (that is, $q\ is\ 1$),is referred to as non-energy-load proportional eNodeB(Oh *et al.*, 2013).

2.2.8 Power Consumption Parameters

The operational power of an eNodeB ,P_j^a is defined as the power consumption of an active eNodeBand it is given as (Hossain *et al.*, 2012):

$$P_j^a = AP_{TX,j} + B \tag{2.7}$$

$P_{TX,j}$is the transmit power of the jtheNodeB.,

The power consumed by an eNodeB, P_j^sin sleep mode is given as (Hossian *et al.,* 2013):

$$P_j^s = qB \qquad (2.8)$$

The parameters ‘A’ and ‘B’ are termed as the power profile parameters. The coefficient ‘A’ accounts for the power consumption that scales with the transmitted power due to the amplifier, feeder losses and the cooling of the eNodeB. The term ‘B’ denotes power offsets which are consumed independent of the transmitted power. These offsets are due to signal processing, battery backup and eNodeB cooling. Cooling equipment is considered to impact both the transmit power dependent as well as the offset power consumption because both transmit power dependent as well as independent components contribute to thermal radiation. The power consumption parameters for different eNodeB type are given in Table 2.1:

Table 2.1: Power Consumption Parameters(Tombaz *et al.*, 2011)

Base Station Type	**A**	**B (W)**
Macro	21.45	354.44
Micro	7.84	71.50
Pico	5.5	38

2.2.9 Blocking Probability

The blocking probability is the probability that a new call will be blocked. The probability of a new call to be blocked at the jth eNodeB at time t can be evaluated using Erlang B formula which is given as (Hossain *et al.,* 2011):

$$Pr_{b,j} = \frac{A^{N_{rb}}/_{N_{rb}!}}{\sum_{n=0}^{N_{rb}} A^k/_{n!}} \qquad (2.9)$$

Where:A is the traffic in Erlangs and N_{rb} is the number of resource blocks in thejth eNodeB.

2.2.10 Load Curve

The load curve gives the traffic arrival pattern of a real recorded traffic pattern or simulated traffic pattern of an eNodeB. The poisson distribution model is use to simulate the traffic arrival pattern of an eNodeB, because it gives the near approximation of a real traffic arrival pattern and it is given as:

$$A(t) = \frac{p(t,\mu)}{\max\,[p(t,\mu)]}\,.,\qquad t = 0,1,2,3\ldots\ldots\ldots.24 \qquad (2.10)$$

$$p(t,\mu) = \frac{\mu^t}{t!}e^{-\mu} \qquad (2.11)$$

Where:

$A(t)$is normalized traffic at time t, p is poisson distribution function, t is the specific time in a day and μ is mean value where peak number of traffic occurred.

Figure 2.4 shows the simulated traffic arrival pattern in a cell with a mean value of 15 (Tun and Kunavut, 2014). This was done to match the behaviour of a real traffic arrival pattern as shown in Figure 1.3. Thus, the peak traffic rate during a day occurs at 3:00pm.

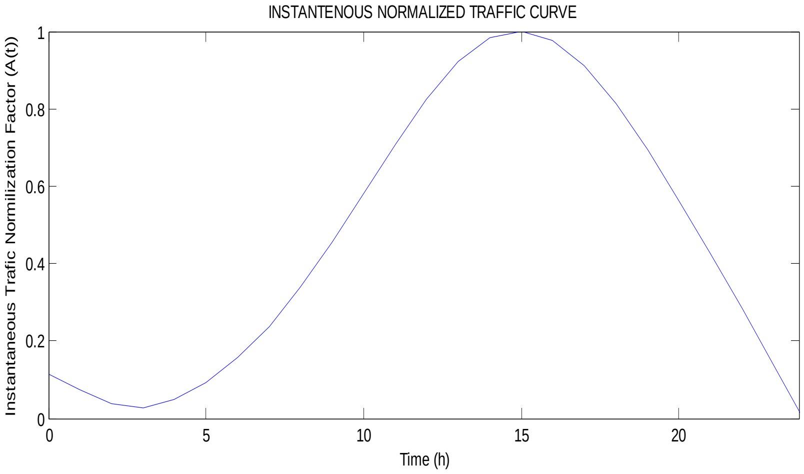


Figure 2.4: Instantaneous Traffic Normalization Factor(Tun and Kunavut, 2014)

2.2.11 Review of Existing Algorithms

Many algorithms have been developed by researchers in the area of green wireless communication for minimizing the energy consumption of base stations using sleep mode utilization.Most of the researchers validatethe performance of their algorithms against standard algorithms which include(Bousia *et al.*, 2014):

(i) Always-On algorithm
(ii) Sleep-Wake algorithm

These standard algorithms are reviewed as follows:

2.1.11.1 Always-On Algorithm

The network energy consumption of the "always-on" algorithm when all base stations are always poweredon for a time period T is given as (Chiaraviglio *et al.*, 2012):

$$EC = \sum_{j=1}^{N} \int_{0}^{T} P_j(t)dt \qquad (2.12)$$

Where:

$P_j(t)$is the power consumption of the jth base station at time t,

Nindicates the total number of base stations.

$P_j(t)$is computed when the transmission power $P_{TX,j}$ is always equal to the power required to serve the mobile stations such as during the peak traffic period. This leads to a high energy consumption and represents a worst case.

Analogously, if the energy consumption of the network when sleep mode management is applied is EC_S.$P_j(t)$is approximately equal to zero if base station j is powered off.

Thus the energy saving of the sleep mode algorithm with respect to an "always-on" algorithm is given as(Chiaraviglio *et al.*, 2012):

$ES = \frac{EC - EC_s}{EC} \times 100\%$(2.13)

Where:

$ES$is the energy saving

$EC$is the energy consumption of the Always-On algorithm

$EC_s$is the energy consumption of the network when sleep mode management is applied

However, in the "always-on" algorithm there is no energy saving in the network because all the base stations are kept powered even at low traffic condition leading to high energy consumption in the network.

2.1.11.2 Sleep-Wake Algorithm

A wake-up scheduling approach for base stations in cellular network was introduced by Hossain *et al.,* (2011). The "sleep-wake" algorithm uses sleep and on states of base stations. The "sleep-wake" algorithm form pairs for sharing load between base stations. The algorithm utilizes three traffic threshold normalized to unity which are lower threshold, L_f, upper threshold, H_f and acceptance threshold, A_f. The base station, B_i accept traffic from it neighbouring active base station matrix $C_{i,a}$if and only if it's total traffic is not more than the acceptance threshold, A_f. The flow chart for the"sleep-wake" algorithm is shown in Figure 2.5 (Hossain *et al.*, 2013).

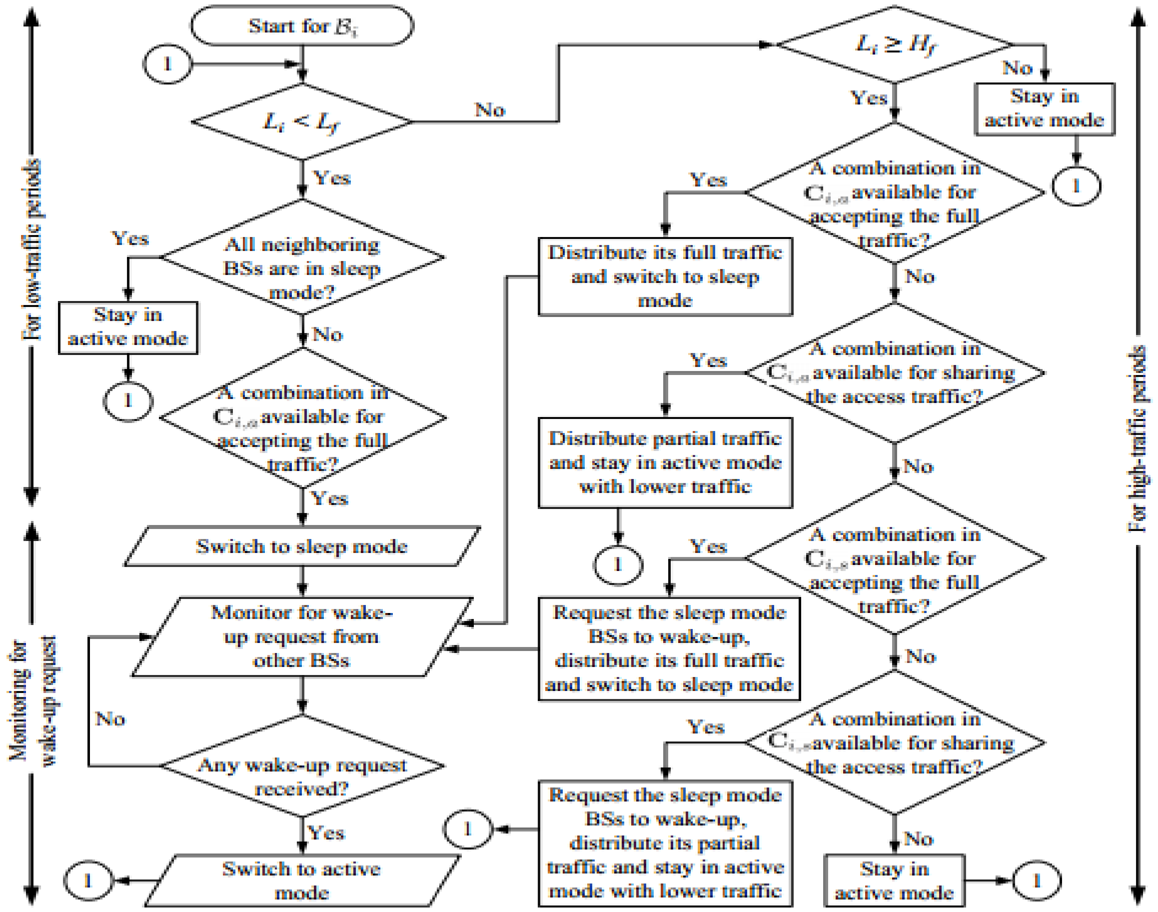


Figure 2.5: Flow Chart for Sleep-Wake Algorithm (Hossain *et al.*, 2013)

The acceptance threshold is selected based on the traffic generation characteristics and quality of service constraint.However, the “sleep-wake” allows a highly loaded base station to share it load with others, increasing the burden of the neighbouring base stations which lead to a higher traffic threshold which consequently reduces the possibilities for energy saving.There is a need to develop a robust dynamic energy saving algorithm for LTE mobile access networks that will allowing all eNodeBs under a cluster coordinate with their neighbouring eNodeBs to turn off/sleep the least loaded eNodeBs through load sharing with any moderately loaded eNodeBs.

2.3 REVIEW OF SIMILAR RESEARCH WORKS

The following presents a review of similar research works:

Marsan*et al.*, (2009) employed a simple optimal-off analytical model,to achieve energy savings in cellular access network usingpredefined deterministic base station switch-off patterns. The scheme used trapezoidal and real measured traffic pattern for several regular cellular topologies to evaluate the energy saving. The results showed that energy saving of the order of 25-30% was possible with an optimal power-off scheme. However, the schemeprovided no strategy for switching on the base stations during high-traffic times leading to its incompatibility for self-organizing networks. Thus, in case of an emergency situation of a sudden rise in traffic generation during the switched off times, many users may experience service interruptions.

Chiaraviglio*et al.*, (2009)developed an algorithm for the energy efficiency management of the cellular radio access network. The algorithm switched off base stations during low-traffic times using a predefined deterministic switching off pattern of base stations. Using a real traffic data, the algorithm enabled energy saving of 20%-40% and a blocking probability of 1% to ensure quality of service. However, the algorithm was developed based on a fairly unrealistic assumption of homogeneous traffic throughout the network. Thus, the impact of mobile terminal distribution and data rates werecompletely overlooked. Also, the algorithm provided no strategy for switching on the base stations during peak traffic leading to its incompatibility for self-organizing networks.

Zhou *et al.*, (2009)developed a centralizedand decentralized ‘greedy’ algorithms for dynamic base station energy saving in green mobile access network using the base station switch off scheme.The centralized greedy algorithm utilized the complete channel information and traffic requirement of the network to determine the base station on-off states. The decentralized algorithm was used to relax the information requirement of the centralized algorithm by triggering user-specific base station according to the maximum utility function (normalized traffic load) and the protection margin for load balancing. The energy efficiency of the developed algorithms and the trade-off between energy saving and coverage were guarantee using simulations. However, the algorithmprovided no strategy for turning on the base stations during high traffic demand leading to it incompatibility for self-organizing networks. Thus, in case of an emergency situation of a sudden rise in traffic generation during the switched off times, many users may experience service interruptions.

Oh and Krishnamachari (2010)studied thedynamic switching of base stations to reduce the energy consumption by considering the time varying characteristics of the traffic profile using a distributed base station switching strategy. The blocking probability was used as the quality of service requirement. The study, via first order analysis of energy saving, showed that the amount of energy saving was dependent upon the mean and variance of the traffic profile and the base station density. The performance of the base station switching strategy was evaluated using the ideal and real traffic profile through Monte Carlo simulation. Energy saving of the order of 13.13-16.91% was achieved without compromising the system performance. Analysis of the result assumed a fixed number of neighbouring base stations which is not the case in practice, because the number of neighbouring base stations could dynamically change by the switching-off action at each instant of time. Also, the analysis only considered the homogeneous traffic condition of base stations which is also infeasible in practice.

Niu *et al.*, (2010)developed centralized and distributed cell zooming algorithms for cost-efficient green cellular networks. The developed dynamic cell zooming algorithms adaptively adjusted the cell size according to traffic load, user requirements and channel conditions to minimize the energy consumption of base stationsand call blocking probability of users.

However, the algorithms were not developed based on a power consumption model for a base station that depended on its utilization. Instead, the fixed power base station consumption model was used which resulted in energy wastage during low traffic times.

Eunsung *et al.*, (2011)proposed a scheme for dynamically shutting down redundant base stations during low traffic periods using the daily traffic profile. The energy saving was quantitatively estimated through the first-order analysis based on real cellular traffic traces. A greedy algorithm was used to identify the minimal number of base stations to be switched-off when the traffic was less than 10% of the peak while ensuring net coverage of more than 95% of the area covered when all base stations were active. The result showed that energy saving of about 35% was feasible. However, the algorithm was not developed based on a power consumption model for a base station that depended on its utilization. Thus, the fixed power consumption model used resulted in energy wastage during low traffic times.

Peng *et al.*, (2011) designeda traffic-driven scheme for power savings for operational 3G cellular networks using a profile-based approach to green cellular base station. The scheme powered off under-utilized base stations under light traffic and powered on when the traffic load becomes heavy to cope with the temporal-spatial traffic dynamics. The energy saving of the scheme was evaluated using real traffic traces, actual base station deployment map and measured base station power consumption collected from four regional 3G networks. The scheme yielded up to 50% energy savings in a dense large city and 23% in a sparse, mid-sized city.However, the capacity of the network was not fully utilized due to lack of cooperation among neighbouring base stations. Also, the scheme assumed uniform distribution of mobile users around the base station which is infeasible in practice.

Chiaraviglio*et al.*, (2012)studied base stations energy-efficient management algorithms in a cellular access network taking into account different planning strategies of minimum transmitters, minimum power consumption and hybrid networks. Genetic algorithm was used to find the deployments for each of the considered network planning strategies. Given the generated deployments, the energy saving algorithms provided energy savings by adopting sleep modes at the base stations by using two switch-off strategies which were based on cell load or base station coverage overlap. Different heuristic algorithms were applied to find the minimum set of base stations to be powered on to satisfy a given traffic demand. This adapted the current network capacity to the actual traffic, while guaranteeing an adequate quality of service to users. The results showed that energy saving of between 8% and 40% can be achieved using real traffic profile. However, the study did not investigate the effects of non-uniform users' distribution on the overall energy savings.

Han*et al.*, (2012) proposed a predefined deterministic base station switching strategy that manually turned off base stations during low traffic times. The strategy employed base station cooperation and power control to mitigate the signal-to-noise ratio of mobile terminals due to the switched-off base stations. The energy savings of the proposed scheme was evaluated both analytically and numerically whistle using an outage probability of $10^{-3} - 10^{-5}$to ensure quality of service.The result showed that an energy saving of 50% was observed. However, the proposed scheme provided no strategy for switching on the base stations during high-traffic times leading to its incompatibility for self-organizing networks. Also, the scheme was based on a fairly unrealistic assumption of homogeneous traffic throughout the network and the impact of mobile terminal distribution, as well as data rates were not addressed.

Deng and Balakrishnan (2012) developed a make idle and make active algorithm to reduce the energy consumption of the 3G/LTE radio interface. The algorithm used the network traffic activity on the mobile devices and switch between the low-power idle and high-power active state by adapting to the radio network load. The energy saved by the algorithm was evaluated using a trace-driven simulation on a real usage data from 9 users over 28 total days on four different carriers (T-Mobile 3G, ATandT HSPA+, Verizon 3G and Verizon LTE). The energy savings range between 51% and 61% across the carriers for 3G and 67% on the Verizon LTEnetwork. However, the algorithm was based only on the energy consumed by the 3G/LTE radio interface which account only a few portion of the operational power consumption of a 3G/LTE base station.

Adhikary *et al.*, (2012) developed a distributed wake-up scheduling algorithm for base stations in green cellular networks. The distributed wake-up scheduling algorithm for the base stations use three different modes of operation: off mode, sleep mode and active mode. The algorithm dynamically takes decision on its operation mode according to the measured traffic load of itself and its neighbourhood base stations in a distributed manner. However, the power consumption of the base station was not modelled as a function of its traffic utilization and the quality of service of the mobile station was not guaranteed while achieving the energy saving.

Bousia *et al.*, (2013)developed an algorithm for base stations in multi-operator environment. The algorithm used cost-based functions to decide the suitable base stations to remain active, especially during low traffic periods when the base station's capacity is underutilized. The performance of the algorithm was evaluated on a typical 7-cell cluster of an urban network using a custom-made C simulation tool. The result showed that the algorithm provided up to 48% energy saving, without degrading the quality of service. However, in the algorithm developed, neither the randomness nor the spatial distribution of users were considered.

Han*et al.*, (2013) developeda schemefor an energy efficient base station switching strategy according to the varying offered traffic load using base station cooperation to effectively extend network service to the areas of the switched-off base stations.The performance of the developed model was evaluated using simulation. The results showed that during the low traffic periods(i.e. E< 5 Erlangs), with channel outage probability of $10^{-3}$and blocking probability of 2% as quality of service threshold, the proposed operation could save more than 50% of the energy consumed by the conventional all-on pattern. However, the scheme was based on a fairly unrealistic assumption of homogeneous traffic throughout the network and thus, the impact of mobile stations distribution and data rates werecompletely overlooked.

Oh*et al.*, (2013)developed a distributed dynamic algorithm for both switching on and off base stations using the average system load as the algorithm initiator. The algorithm utilized communications among neighbouring base stations for exchanging load information and disseminating the switchingon/off decisions. The energy saving was estimated through first order analysis and simulations demonstrated that the algorithm significantly reduced the total energy consumption of up to 50%.However, a more efficient algorithm is expected as the presented one does not implement any intelligence in finding the best subset of neighbours for distributing traffic leading to reduced energy savings. Also, the algorithm was developed based on an assumed fixed power consumption model instead of considering a power consumption model for base station that depends on its utilization.

Hossain *et al.*, (2013)developed a distributed cooperative algorithm with load balancing for improving the energy saving of LTE cellular access networks. The algorithm was developed based on the principle of self-organizing network. The algorithm used the network traffic to allow the mutual cooperation of base stations for distributing traffic among themselves and thus, dynamically adjusting the number of active base stations for energy saving. The energy savings of the algorithm was estimated through simulations and the results showed an energy saving of up to 40%. However, the algorithm allowed highly loaded base stations to share load with their neighbouring base stations and consequently increase the burden of the neighbouring base stations. This led to higher traffic threshold of neighbouring base stations and reduction of the possibilities of energy saving.

Yigitel *et al*., (2014)developed a greedy-heuristic algorithm for dynamic base station planning with power adaptation for green wireless cellular networks. The algorithm switched base stations on/off and adaptively adjusting their transmission power according to the current traffic conditions. The problem of saving energy and minimizing the on/off transitions of base stations was formulated using a non-linear programming model for the green dynamic base station planning to find the best possible topology which minimizes the energy consumption of the network while satisfying the quality of service measured in terms of blocking probability and outage probability. However, the algorithm was developed by assuming that mobile users are placed as chunks like group of workers in a floor of a building which is infeasible in practical scenario. Thus, the mobile stations were not modelled individually.

Shahab *et al*., (2015) carried out an assessment of the area energy efficiency of LTE base stations. The evaluation of the area energy efficiency was done using key performance indicators including transmit power, bandwidth, load utilization factor on urban, suburban and rural environment. Simulation results showed that the area energy efficiency increases as the bandwidth size increases, while the area energy efficiency of the LTE macro base station decreases with increasing the percentage of traffic load for the different environment. However, the energy consumption of the base station was not modelled to vary with the load utilization factor of the base station leading to increase energy consumption even at low traffic level.

In view of the imperfection associated with the reviewed work, there is aneed to develop a robust self-organizing energy efficient algorithm for LTEcellular access networks that will incorporate the inherent temporal-time traffic diversity of cellular access networks and the load-proportional power consumption model of eNodeBs. The proposed algorithm is expected to improve the energy savings whilst guaranteeing the quality of service offered to the mobile stations using off mode, sleep mode, and multi-cell cooperation utilization of eNodeBs

CHAPTER THREE

MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter describes the detailed procedure carried out in modeling the LTE cellular environment, energy saving of the LTE mobile network and the quality of service constraint. The development of the dynamic energy saving algorithm, MATLAB graphical user interface (GUI) for the simulation and analysis of the energy saving are also covered in this chapter

3.2 MODELING THE LTE CELLULAR ENVIRONMENT

The LTE environment comprises of the eNodeBs, the cell structure, and the mobile stations. The eNodeBs are static and located at the centre position of each cell. The mobile stations are randomly positioned in the LTE cellular environment.

The modeling of the LTE cellular environment is further categorized into the following:

i. Cell structure
ii. Location of eNodeBs
iii. Mobile stations
iv. Adjacent eNodeBs

3.2.1 Cell Structure

In the proposed model, cells are represented by regular hexagon with radius (R). The radius (R) isthe maximum allowable distance between the eNodeB and the mobile stations when considering the effect of path loss and fading on the transmitted signal. Consider the X and Y axes of the Cartesian plane. The hexagonal cells can be arranged in the X and Y plane such that the number of cells in the X and Y axes is given in a row matrix called the cell array (A). The size of ‘A’ is 1 by ‘a’, where ‘a’ represent the number of rows of cell in the Y-axis of the Cartesian plane. The number of columns of cells in the X-axis is given by the maximum of the matrix ‘A’. This is represented mathematically as follows:

$A = [c_i, c_{i+1}, c_{i+2}, \dots \dots \dots \dots, c_a]$ (3.1)

$N_X = \max(A)$(3.2)

$N_Y = length(A) = a$(3.3)

Where: A is the cell array matrix, N_X is the number of colums of cell in the X-axis, N_Y is the number of rows of cells in the Y-axis and is equal to ‘a’ and c_i to c_a are the elements of A

Let: Nbe the number of eNodeBs/cells, c be a largest interger less than or equal to $\sqrt{N}$ and A^k be the array matrix at the kth iteration. Then, the following pseudo code is used for the array matrix.

Pseudo code: Array Matrix

```
$A = [c]$.,
$n = N - c$.,
$k = 0$.,
$while\ n \neq 0$
    $k = k + 1$.,
    $if\ n \geq c - k$
        $A^k = [A^{k-1}, (c - k)]$.,
        $n = n - c + k$.,
    $end\ if$
    $if\ n \geq c - k$
        $A^k = [(c - k), A^{k-1}]$.,
```

```
$n = n - c + k.,$
    $end\ if$
$end\ while$
$A = A^k$
```

The MATLAB code for generating the array matrix, A is given in Appendix A1.

As an illustration, when$N\ is\ 7\ \ A\ is\ [2, 3, 2]$., while when$N\ is\ 37A\ is\ [4, 5, 6, 7, 6, 5, 4]$.

3.2.2 Location ofeNodeBs

The X and Y coordinates of an eNodeB in an LTE cellular environment can be determined in relation to its neighbouring eNodeB using the array matrix (A) and the cell radius (R). In the proposed model, eNodeBs coverage area are assumed to have equal cell radius and equally spaced in the LTE cellular environment. Cells are arranged in clusters. A cell is considered to have at most six (6) neighbours as a typical cluster of cells consists of seven cells and because of the six sided shape of the hexagonal cell. As an illustration, consider the three cell arrangement shown in Figure 3.1. The array matrix is given by A equal to $[2\ , 1]$, such that the X-axis consists of two columns of cells and the Y-axis consist of two rows of cells.In the proposed model, cells are numbered from the top most left cell to the bottom most right cell. The location of the eNodeB can be completely defined based on the X and Y axes of the Cartesian coordinate. In the proposed model, X and Y coordinates of the eNodeBs are represented by matrices$B_X$and B_Y, respectively, such that:

$$B_X = [b_{X_j}, b_{X_{j+1}}, b_{X_{j+2}}, \dots, b_{X_N}] \qquad (3.4)$$

and

$$B_Y = [b_{Y_j}, b_{Y_{j+1}}, b_{Y_{j+2}}, \dots, b_{Y_N}](3.5)$$

Where:

$N$is the number of eNodeBs in the LTE access network,

The elements ($b_{X_j}$to b_{X_N}) are the X coordinates of the $j\ th$ to$N\ th$ eNodeBs,

The elements ($b_{Y_j}$to b_{Y_N}) are the Y coordinates of the $j\ th$ to$N\ th$ eNodeB.

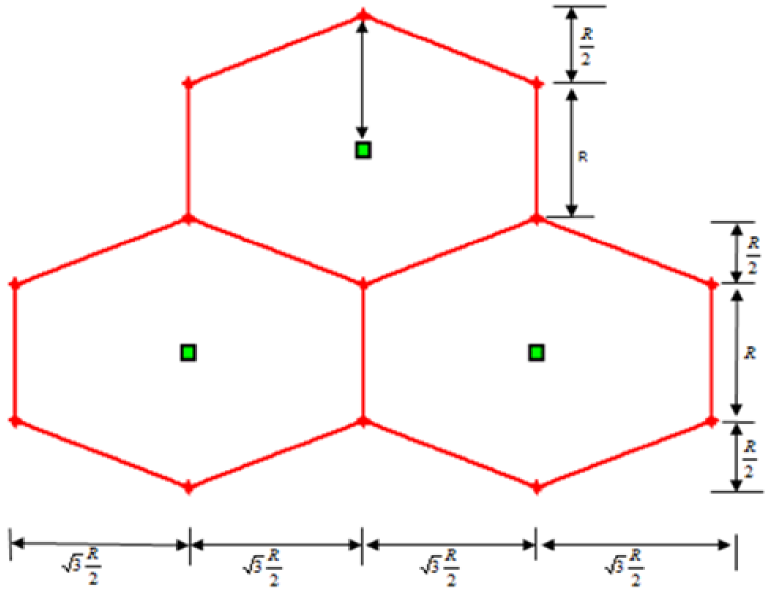


Figure3.1: A Three Hexagonal Cell Layout

In the three cells LTE cellularnetwork system shown in Figure 3.1, the B_X andB_Y matrices can be written as follows:

$$B_X = \left[\sqrt{3}R, \frac{\sqrt{3}R}{2}, \frac{3\sqrt{3}R}{2}\right] \quad (3.6)$$

$$B_Y = \left[\frac{5R}{2}, R, R\right] \quad (3.7)$$

The B_X andB_Y are extracted from the location matrices L_X and L_Y of the eNodeBs. The location matrices with N rows and ‘a’ column. $L_X$andL_Y are as follows:

$$L_X = \begin{bmatrix} l_{X.1,1} & l_{X.1,2} & \cdot\ \cdot\ \cdot & l_{X.1,a} \\ l_{X.2,1} & l_{X.2,2} & \cdot\ \cdot\ \cdot & l_{X.2,a} \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ l_{X.N,1} & l_{X.N,2} & \cdot\ \cdot\ \cdot & l_{X,N,a} \end{bmatrix} \quad (3.8)$$

$$L_Y = \begin{bmatrix} l_{Y.1,1} & l_{Y.1,2} & \cdot\ \cdot\ \cdot & l_{Y.1,a} \\ l_{Y.2,1} & l_{Y.2,2} & \cdot\ \cdot\ \cdot & l_{Y.2,a} \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ l_{Y.N,1} & l_{Y.N,2} & \cdot\ \cdot\ \cdot & l_{Y,N,a} \end{bmatrix} \quad (3.9)$$

The elements of theL_X andL_Y matrices are all zeros except those describing the location of the eNodeBs. For the three cells LTE cellular network of Figure 3.1, theL_X andL_Y matrices are are given as:

$$L_X = \begin{bmatrix} 0 & \frac{5R}{2} \\ R & 0 \\ 0 & R \end{bmatrix} \quad (3.10)$$

$$L_Y = \begin{bmatrix} 0 & \sqrt{3}R \\ \frac{\sqrt{3}R}{2} & 0 \\ 0 & \frac{3\sqrt{3}R}{2} \end{bmatrix} \quad (3.11)$$

The B_X andB_Y matrices as shown in equation (3.4) and (3.5) respectively are used in determining the possible position of eNodeBs within each and every cell. The positions of the eNodeBs are located using the developed MATLAB m-file called “eNodeB_location” given in Appendix A2 while the cell coverage of the eNodeB is generated using the developed MATLAB m-file called “cell_plotter” given in Appendix A3.

3.2.3 Mobile Stations

In the proposed model, active mobile stations are selected randomly from a set of uniformly distributed mobile stations. Each mobile station is defined by its X and Y coordinates. Mobility is simulated by randomly selecting a set $(u_{x,i}, u_{y,i})$ of positions within a particular cell. The distance of a mobile station i from an eNodeB j is given as(El-Beaino *et al.*, 2012):

$$d_{i,j} = \sqrt{((x_i - x_j)^2 + (y_i - y_j)^2)} \qquad (3.12)$$

Mobile stations are initially generated uniformly across the entire network. A set of active mobile stations is selected from the group ofN_u uniformly distributed mobile stations belonging to each cell. Let D be the distribution factor of the mobile stationsin each cell, such that the $X-axis$ is divided into $2(D+1)$ sub-divisions and the $Y-axis$ is divided into $4(D+1)$ subdivisions. If each point of intersection of the lines sub-dividing the $X-axis$ and $Y-axis$ mark the position of mobile stations, the number of mobile stationsthat are located within every cell for a given value of D can be derived considering Figure 3.2 (a) and (b) as follows:

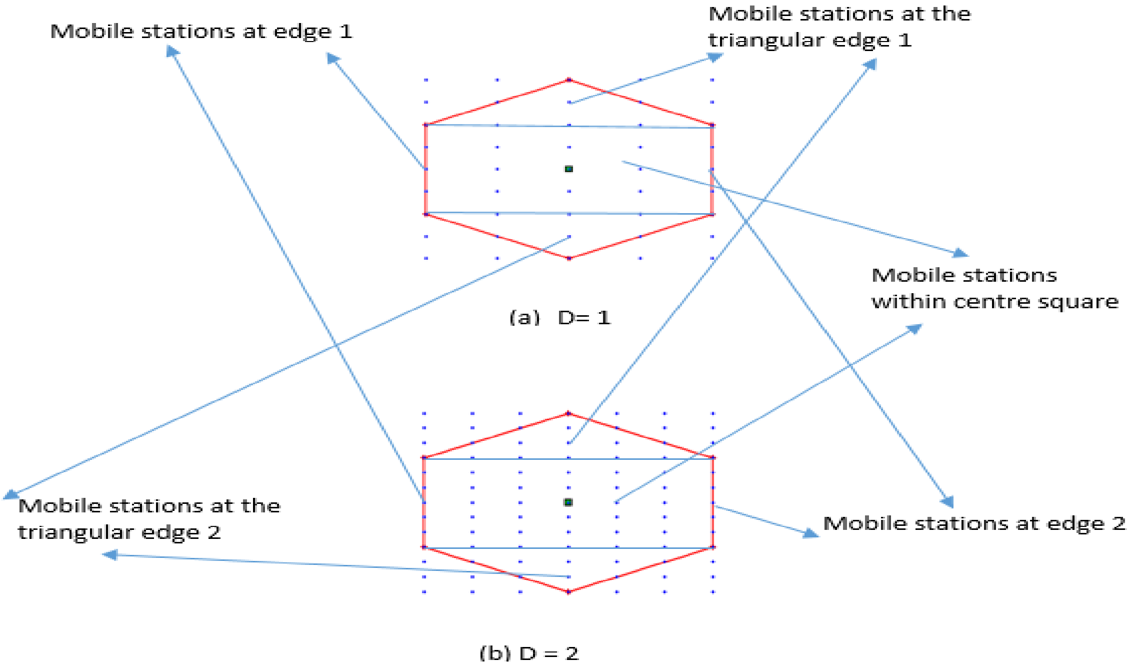


Figure 3.2: Mobile Station Distribution Factor

From Figure 3.2, since the $X - axis$ is divided into $2(D+1)$ divisions, where D is the mobile station distribution factor, and the $Y - axis$ is divided into $4(D+1)$ divisions, then the

following holds:

i. Mobile station positions within the square centre and edge are given as:

   $U_{cs} = (2(D+1)+1)^2$ (3.13)

ii. Mobile station positions on edge 1 and 2 are given as:

   $U_e = 2(2(D+1)+1)$ (3.14)

iii. Mobile station positions inside the triangular edges 1 and 2 of the hexagon can be given as:

   $U_{te} = 2D^2$(3.15)

Therefore the total number of mobile station positions within ahexagonal cell are given as:

$N_u = U_{cs} - U_e + U_{te}$(3.16)

$N_u = (2(D+1)+1)^2 - 2(2(D+1)+1) + 2D^2$(3.17)

$N_u = 4D^2 + 12D + 9 - 4D - 6 + 2D^2$(3.18)

Thus the number of mobile stations that can be distributed uniformly with every cell for a given value of D can be expressed using:

$N_u = 6D^2 + 8D + 3$(3.19)

During the cause of simulation, the desired number of active mobile stations per eNodeB can be specified., the active mobile stations can be selected from the uniformly distributed mobile stations using the following pseudo code:

Start

```
        While the desired number of active mobile stations is not reached, randomly select active mobile stations from the group of uniformly distributed mobile stations
        Compute the distance $d_{i,j}$ of the mobile station
        If $d_{i,j} < \frac{\sqrt{3}R}{2}$
                Store mobile station in the mobile station matrix
        Else
                Discard mobile station
        End
Stop
```

The desired number of active mobile stations allocated to each eNodeB must be less than or equal to N_u. As an illustration, if each eNodeB in the LTE mobile access network is to have 100 active mobile stations, the distribution factor (D) must be selected to be greater than or equal to 4 using equation (3.19) during simulation. This is because the values of distribution factor greater than or equal to 4 give a uniformly distributed mobile stations of equal to or greater than 131. Therefore 100 active mobile stations can be randomly selected from a uniformly distributed mobile stations of at least 131.

The MATLAB m-file called "Users" generate the mobile station position for a given distribution factor and it is given in Appendix A4. As an illustration, an LTE access network with 7 eNodeBs and uniformly distributed mobile stations given a distribution factor of $D\ is\ 4$, is shown in Figure 3.3 and it is generated using the MATLAB m-file called LTE_enviroment.The MATLAB m-file called "LTE_enviroment" is shown in Appendix A5. The cells are numbered from the top most left to the bottom most right cell for the purpose of identification.

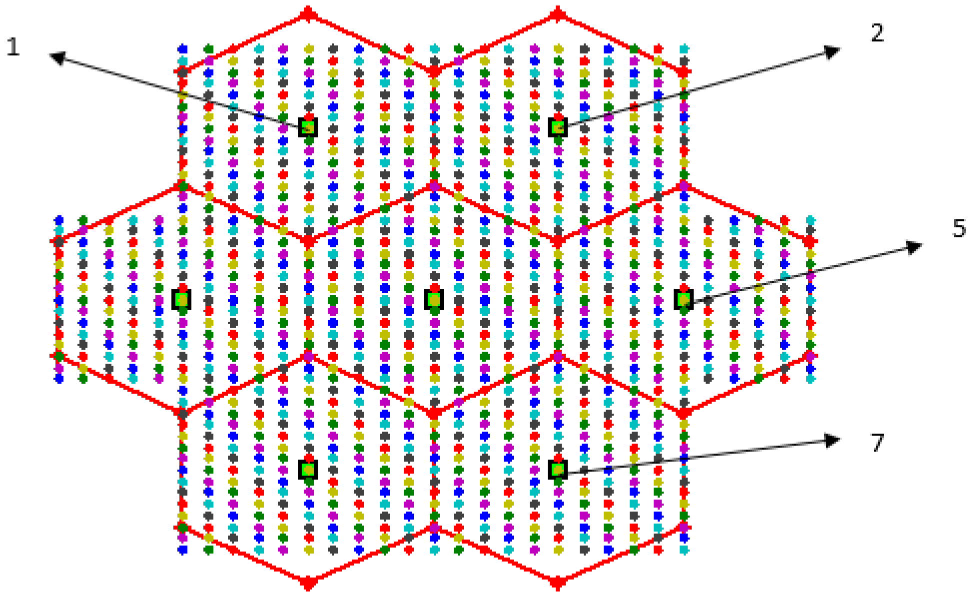


Figure 3.3: Relationship between eNodeBs, Cells and Uniform Distribution of Mobile Stations.

3.2.4 Adjacent eNodeBs

To establish communication between neighbouring eNodeBs for the purpose of traffic transfer and coverage extension, each eNodeB is modelled to intelligently know its neighbouring eNodeBs. Two eNodeBs are considered as neighbours if and only if the distance between their eNodeBs is less than or equal to$\sqrt{3}R$, which is the distance between the centers of two regular hexagonal cells. Where R is the radius of each cell.

The neighbouring eNodeBs of each eNodeB in the LTE access network are stored in a matrix (N_{MAT}). The N_{MAT} is a matrix with N rows and six column. Where$N$is the number of eNodeBs in the LTE access network. The maximum number of neighbouring eNodeBs of the jtheNodeB is six based on the six sides of a hexagonal cell. Thus,$N_{MAT}$is given by:

$$N_{MAT} = \begin{bmatrix} n_{i,1} & n_{i+1,1} & \cdot\ \cdot\ \cdot & n_{6,1} \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot\ \cdot & \cdot \\ n_{i,N-1} & n_{i+1,N-1} & \cdot\ \cdot\ \cdot & n_{6,N-1} \\ n_{i,N} & n_{i+1,N} & \cdot\ \cdot\ \cdot & n_{6,N} \end{bmatrix} \quad (3.20)$$

Where $n_{i,N}$ to $n_{6,N}$are the neighbouring eNodeBs of theNtheNodeB. The MATLAB code for generating N_{MAT} is given in Appendix A6 whose pseudo code is:

Pseudo code: eNodeB neighbors

```
Start
    From the first to the last cell
    Compute distance between base stations
    If      distance between base station is less than or equal to $\sqrt{3}R$
            Cells are neighbours
    Else
            Cells are not neighbours
    End
Stop
```

For the cellular network shown in Figure 3.4, the N_{MAT} is given as:

$$N_{MAT} = \begin{bmatrix} 2 & 3 & 4 & 0 & 0 & 0 \\ 1 & 4 & 5 & 0 & 0 & 0 \\ 1 & 4 & 6 & 0 & 0 & 0 \\ 1 & 2 & 3 & 5 & 6 & 7 \\ 2 & 4 & 7 & 0 & 0 & 0 \\ 3 & 4 & 7 & 0 & 0 & 0 \\ 4 & 5 & 6 & 0 & 0 & 0 \end{bmatrix} (3.21)$$

Equation (3.21) denotes that eNodeB 1 in Figure 3.4 has eNodeB 2 , 3 and 4 as its neighbouring eNodeBs.,eNodeB 2 has eNodeBs 1, 4 and 5 has its neighbouring eNodeBs., eNodeB 3 has eNodeBs 1, 4 and 6 as its neighbouring eNodeBs., eNodeB 4 has eNodeBs 1, 2, 3, 5, 6 and 7 as its neighbouring eNodeBs., eNodeB 5 has eNodeBs 2, 4 and 7 as its neighbouring eNodeBs., eNodeB 6 has eNodeBs 3, 4 and 7 as its neighbouring eNodeBs., And eNodeB 7 has eNodeBs 4, 5 and 6 as its neighbouring eNodeBs. In the dynamic mobile station sharing/transfer, an eNodeB can only transfer its mobile station to its neighbouring eNodeBs.

3.3 DEVELOPMENT OF THE ENERGY SAVING MODEL

The power consumption of the jth eNodeBin the active mode, sleep mode and off mode is modified using equation (2.6) as:

$$P_j(t) = \begin{cases} (1-q)\rho_{j,new}(t)P_j^a + qP_j^a\ ., & active\ mode \\ P_j^s\ ., & sleep\ mode \\ 0\ ., & off\ mode \end{cases} \tag{3.22}$$

Where:

$q$is the energy load proportionality constant ($0 \leq q \leq 1$), and is defined at the beginning of the simulation.,

$P_J^a$is the operational power of thejth eNodeBand it is given by equation (2.7).,

$P_j^s$is the power consumed by thejth eNodeB in sleep mode and it is given by equation (2.8).,

$\rho_{j,new}$is the instantaneous normalized load utilization factor of the jth eNodeB.

The normalized instantaneous load utilization factor, $\rho_{j,new}$of the jth eNodeB is achieved by multiplying the load utilization factor of the jth eNodeB given by equation (2.2) by the normalized traffic given by equation (2.10).

In the proposed model the mobile stations randomly originate different types of real-time constant bit rate traffic and signal-to-interference-noise-ratio requirement (SINR).This random selection of mobile station traffic types with different data rates introduces variation in the available traffic at each eNodeB at different time instances.The mobile station bit-rate and SINR are randomly selected from the category matrix (U_{cat}). The category matrix is a matrix that has n rows and 2 columns in which the first and second columns represents the set of mobile stations bit-rates and SINR respectively., while n is the number of possible mobile station traffic types that could exist per eNodeB. The category matrix is represented mathematically using:

$$U_{cat} = [u_{br}, u_{SINR}] \qquad (3.23)$$

Where:

u_{br} is a matrix of traffic type bit-rates given by:

$$u_{br} = \begin{bmatrix} u_{1.br} \\ u_{2.br} \\ . \\ . \\ u_{n.br} \end{bmatrix} \qquad (3.24)$$

$u_{SINR}$is a matrix of mobile station signal-to-interference-noise-ratio given by:

$$u_{SINR} = \begin{bmatrix} u_{1.SINR} \\ u_{2.SINR} \\ . \\ . \\ u_{n.SINR} \end{bmatrix} \qquad (3.25)$$

The traffic at each of the eNodeB is made to vary in accordance with the time of the day. The variation follows the pattern of a typical load duration curve given in Figure 2.4.This is to model the high degree of temporal traffic diversity experienced in a typical mobile cellular network and to match the behaviour of a real traffic arrival pattern which follows a poisson distribution.The normalized instantaneous load utilization factor is given as:

$\rho_{j,new}(t) = A(t)\rho_j(t)$

(3.26)

Where:

$\rho_{j,new}(t)$is the normalized instantaneous load factor of the jth eNodeB at time$t$.

$A(t)$is the instantaneous traffic normalization factor,

$\rho_j(t)$is the calculated load factor of the jth eNodeB at time$t$.

Thus, the instantaneous power consumed by the LTE access network of NeNodeBs at time$t$when they are all active from equation (3.22) is given as:

$P_N(t) = \sum_{j=1}^{N}[(1-q)\rho_{j,new}(t)P_j^a + qP_j^a]$(3.27)

The total energy consumed by the N eNodeBs over a period of 24hours when they are all power on is computed by modifying equation (2.12) and is termed as the original/base-case energyE_N^{orig} which is given as (Chiaraviglio *et al.*, 2012):

$$E_N^{orig} = \sum_{t=0}^{24}[\sum_{j=1}^{N}[(1-q)\rho_{j,new}(t)P_j^a + qP_j^a]] \quad (3.28)$$

Energy saving is achievedwhen an active eNodeB dynamically transfer it loads/traffic to it adjacent eNodeBs in order to switch to sleep or off mode depending on the status of the adjacent eNodeBs. This load/traffic sharing results in an instantaneous increase in power consumed by the adjacent eNodeBs due to the increase of their transmission power to extend their coverage area to the off or sleep mode eNodeB. The increase in the instantaneous power of the $j\ th$eNodeB to cover the coverage area of an off or sleep mode adjacent eNodeBs can be computed using (Hossain *et al.*, 2011):

$$P_{INC.j}(t) = \frac{m(t)P_{TX,j}}{6} \quad (3.29)$$

Where:

$m(t)$isthe number of off or sleep mode adjacent eNodeBs whose load are been transfered to the $j\ th$eNodeB at time t.

The total energy consumed by the$N$ eNodeBs over a period of 24 hours when some eNodeBs are allowed to sleep or off is obtained by modifying equation (3.28) and is termed as the energy-with-scheduling E_N^{wshc} which is expressed as :

$$E_N^{wshc} = \sum_{t=0}^{24}\left[\sum_{j=1}^{N}[S_j(t)\ ((1-q)\rho_{j,new}^{+}P_j^{a+} + qP_j^{a+}) + (\left(1-S_j(t)\right)P_j^{s})]\right] \qquad (3.30)$$

Where:

$S_j(t)$is the operating mode indicator of the $j\ th$ eNodeB at time t and it is given as:

$$S_j(t) = \begin{cases} 1 & active\ mode \\ 0 & sleep\ mode \end{cases} \qquad (3.31)$$

$\rho_{j,new}^{+}$is the new normalized load factor of the jthactive eNodeB after load/traffic transfer at time t.

$P_j^{a+}$is the new operating power of the jthactive eNodeB after coverage extension and it is expressed by modifying equation (2.7) as:

$$P_j^{a+} = A\left(P_{TX,j} + P_{INC,j}\right) + B(3.32)$$

Thus, the proposed net energy savings in the network is expressed by modifying equation (2.13) as:

$$E_S = \left(\frac{E_N^{orig} - E_N^{wshc}}{E_N^{orig}}\right) \times 100\% \qquad (3.33)$$

Where:

$E_S$is the energy saving,

E_N^{orig}original/base-case energy consumption,

$E_N^{wshc}$is the energy consumption with scheduling.

3.3.1 Quality of Service Constraint

In order to maintain the quality of serviceoffered to the mobile stations by the energy saving algorithm, certain number of resource blocks of the eNodeBs are usually left unused by the active mobile stations in order to prevent over-loading resulting from traffic with fluctuating bit-rates and sudden rise in total traffic. The quality of service offered by the energy saving algorithm is measured by a metric called blocking probability which is used to specify the reserve resource blocks(margin) at each eNodeB. The blocking probability of a call/mobile station at the jth eNodeB at time t is expressed by modifying equation (2.9) as:

$$Pr_{b,j}(t) = \frac{\frac{\left(N_{rb}\rho_{j,max}(t)\right)^{N_{rb}}}{N_{rb}!}}{\sum_{k=1}^{N_{rb}}\frac{\left(N_{rb}\rho_{j,max}(t)\right)^{K}}{K!}} \quad (3.34)$$

Where:

$\rho_{j,max}(t)$is the maximum allowable load utilization factor of the jth eNodeB at time t. The MATLAB code for evaluating equation (3.34) is given in Appendix A7.

The quality of service constrain is imposed at each eNodeB while performing scheduling/load transfer. The quality of service constrain is represented using:

$$Pr_{b,j}(t) \leq Pr_{b,max} \quad (3.35)$$

Where $Pr_{b,max}$ is the maximum allowable blocking probability at the jtheNodeB.

3.4 PROPOSED DYNAMIC ENERGY SAVING ALGORITHM

In order to simplify the process of energy saving estimation, the proposed dynamic energy saving algorithm is divided into two sub-algorithms. The two algorithms work together to achieve a robust energy saving algorithm. The two algorithms are termed as:

i. The energy estimation algorithm
ii. The load/traffic sharing algorithm

The two algorithms are further discussed as follows:

3.4.1 Energy Estimation Algorithm

This algorithm comprises the step by step approach required to estimate the energy consumed by eNodeBs in the LTEaccess network while considering the random nature of mobile stations traffic classes and the daily traffic variation of the eNodeBs. The following steps of instructions are executed logically in order to effectively estimate the energy consumed by the eNodeBs at any time of the day. However the proposed model considers hourly traffic variation to reduce the simulation time. The sequence of instructions are as follows:

i. Initialize timer
ii. Generate the eNodeBs coordinate matrices B_x and B_y
iii. Generate the uniformly distributed mobile stations coordinate matrices U_x and U_y
iv. Randomly select active mobile stations and generate their coordinate matrices from the set of uniformly distributed mobile stations obtained in (iii)
v. For each of the active mobile station in (iv), randomly select a traffic type from the traffic category matrix (data rate and signal-to-interference-noise-ratio)
vi. Compute the average bandwidth efficiency of each active mobile station based on its data rate and signal-to-interference-noise-ratio
vii. Determine the amount of resource block occupied by each active mobile station

viii. Determine the total number of resource blocks occupied by the entire active mobile station of an eNodeB
ix. Compute the load factor of each eNodeB in the LTE access network
x. Compute the instantaneous traffic normalization factor $A(t)$
xi. Normalize the load factor of each of the eNodeB
xii. Compute the power consumed at each eNodeB at that instant and store the result
xiii. Increment timer
xiv. Repeat (i) to (xiii) as long as the common duration is greater than timer readings
xv. Output the total energy consumed by the eNodeNs for the common duration

The flow chart for the energy estimation algorithm is given in Figure 3.4 andMATLAB code in Appendix A8.

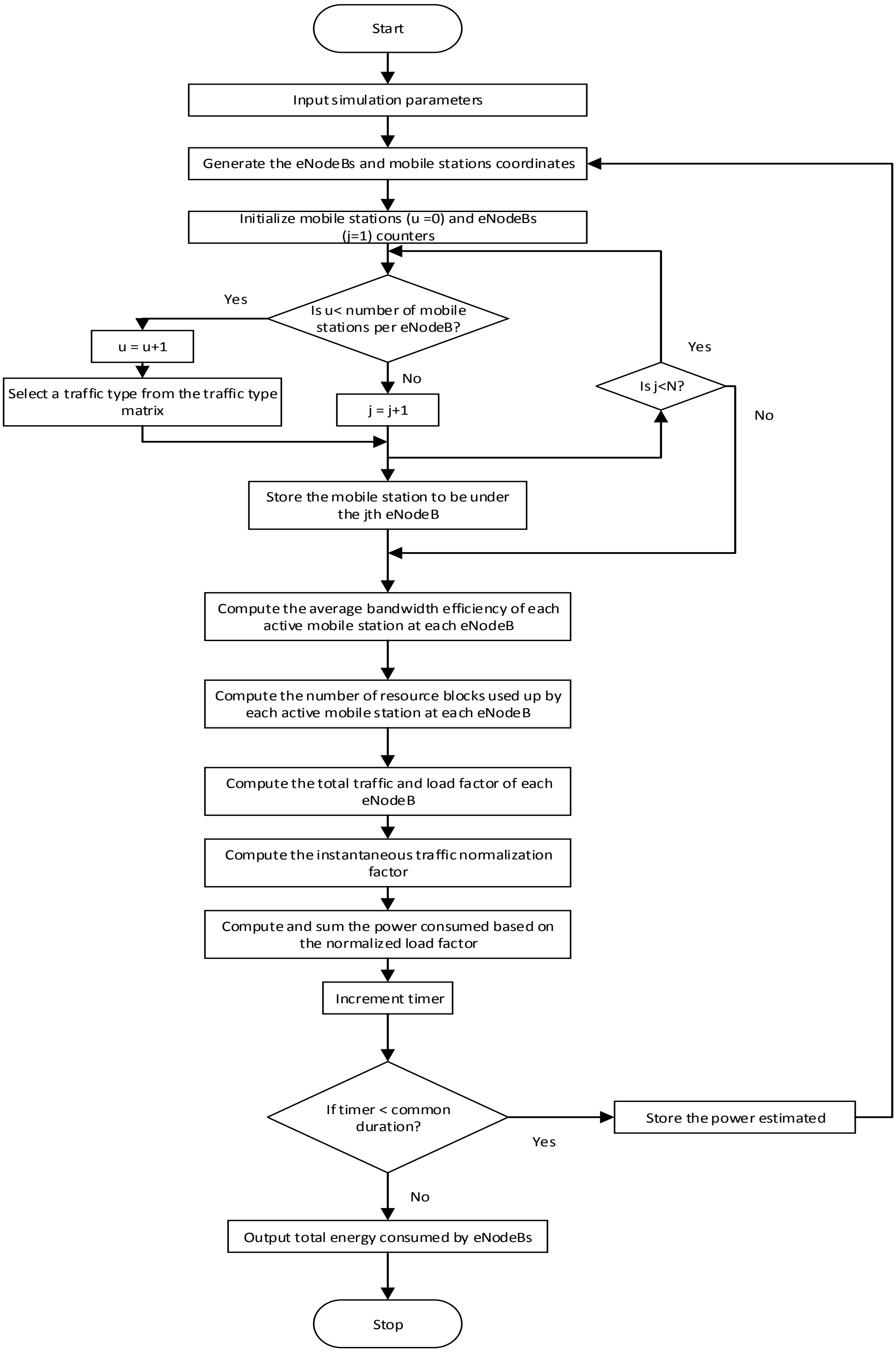


Figure 3.4: Flow Chart for the Energy Estimation Algorithm

3.4.2 Load/Traffic Sharing Algorithm

This algorithm dynamically transfer/share mobile stations among eNodeBs in a given LTE access network in order to achieve energy saving. In the proposed energy saving algorithm, the eNodeBs can either be in the following modes:

i. Active mode
ii. Sleep mode
iii. Off mode

Traffic sharing result in an increase in eNodeBs transmit power, while the eNodeB that has successfully shared its entire load decreases its power consumption to a level either equal to P_{sleep}orP_{off}. The load traffic sharing algorithm does not utilizes traffic threshold for initiating the traffic transfer to avoid arbitrary choosing of traffic threshold and for simplicity. However, the traffic in the cluster of eNodeBs is arrange in descending order to initiate the traffic distribution from the eNodeB with the lowest traffic. In the proposed model $P_{active}$is far greater thanP_{sleep}, and P_{off} is equal to zero. The following set of instructions form the proposed load/traffic sharing algorithm.

i. Generate the neighbour matrix
ii. Replace each neighbour by its traffic and sort the neighbours in descending order of their traffic size/load factor.
iii. Determine the available space in each neighbour while imposing the blocking probability constraint.
iv. For each of the eNodeB, attempt traffic sharing from the eNodeB with highest traffic to the eNodeB with the lowest traffic.
v. If traffic sharing is not possible for a particular eNodeB, go to the next eNodeB with the lower traffic and continue until the entire eNodeB are exhaust.

vi. For each successful sharing, increment the sharing counter.

vii. Determine the new load factor of each of the eNodeB after sharing process is completed

viii. Determine the number of sleeping and off eNodeBs

ix. Subtract the number of sleeping and off eNodeB to obtain the number of active eNodeBs.

The flow chart for the load/traffic sharing algorithm is shown in Figure 3.5 and MATLAB code in Appendix A9.

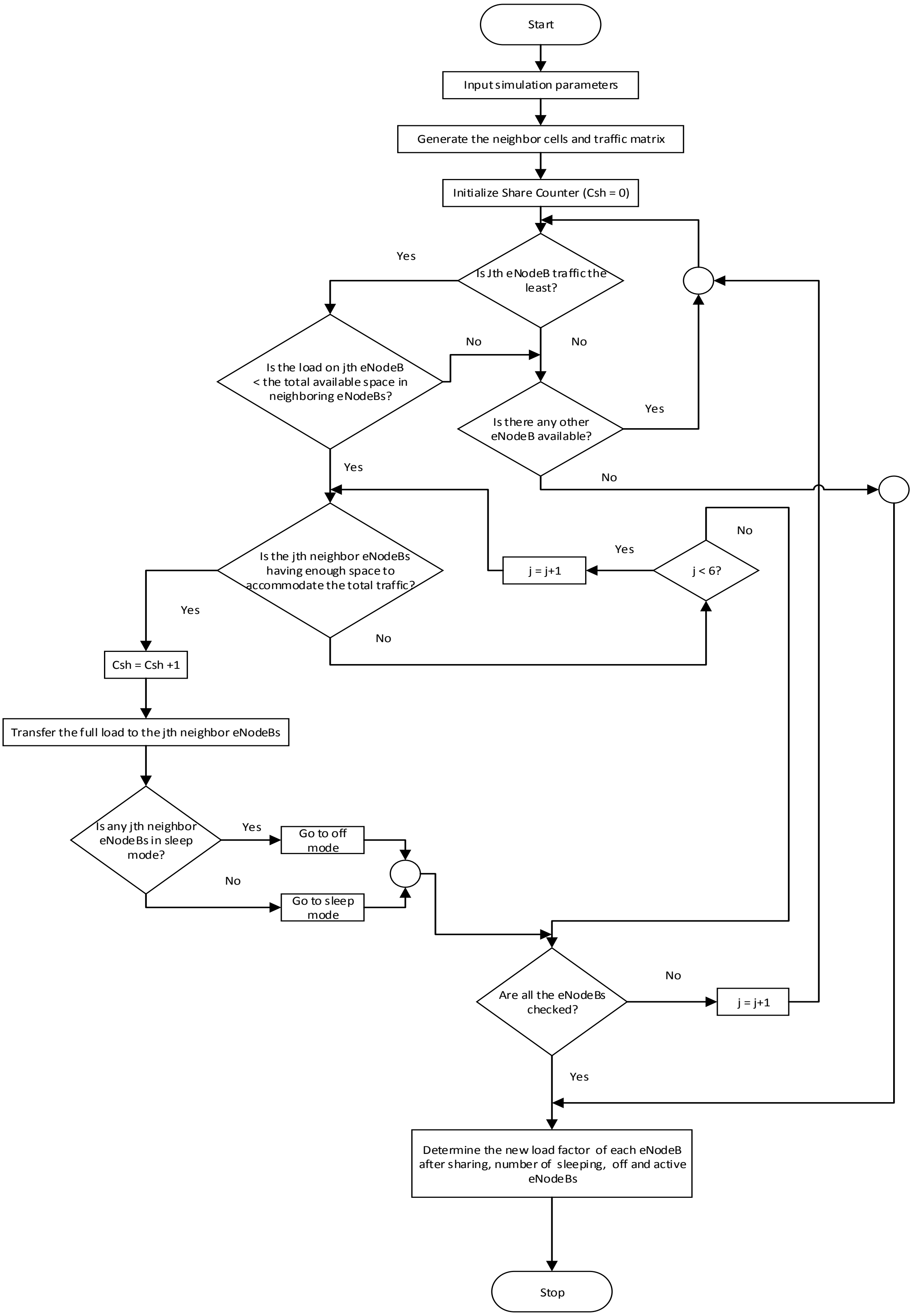


Figure 3.5: Flow Chart for the Load/Traffic Sharing Algorithm

3.4.3 Dynamic Energy Saving Algorithm

The energy estimation algorithm and the load/traffic sharing algorithm are integrated to form the dynamic energy saving algorithm. The following set of instructions are executed logically to achieve the proposed dynamic energy saving algorithm. The sequential steps involved are as follows:

i. Initializing the simulation parameter
ii. Estimate the energy consumed at time t using the energy estimation algorithm
iii. Extract the load factor of the eNodeBs from the energy estimation algorithm and feed it to the load/traffic sharing algorithm to generate a new load factor LF_{new}, number of sharing and number of sleeping and off base stations.
iv. Store the energy obtained from (ii) as the base case energy (E_{bc}).
v. Compute the new energy based on the parameters obtained from (iii) and store the energy as the energy with scheduling (E_{ws}).
vi. Repeat step (i) to (v) as long as the timer reading is less than the common duration.
vii. Compute the Energy savings

The flow chart for the energy saving algorithm is shown in Figure 3.6. The MATLAB code for the integration of the energy estimation algorithm and the load/traffic sharing algorithm is given in Appendix A8.

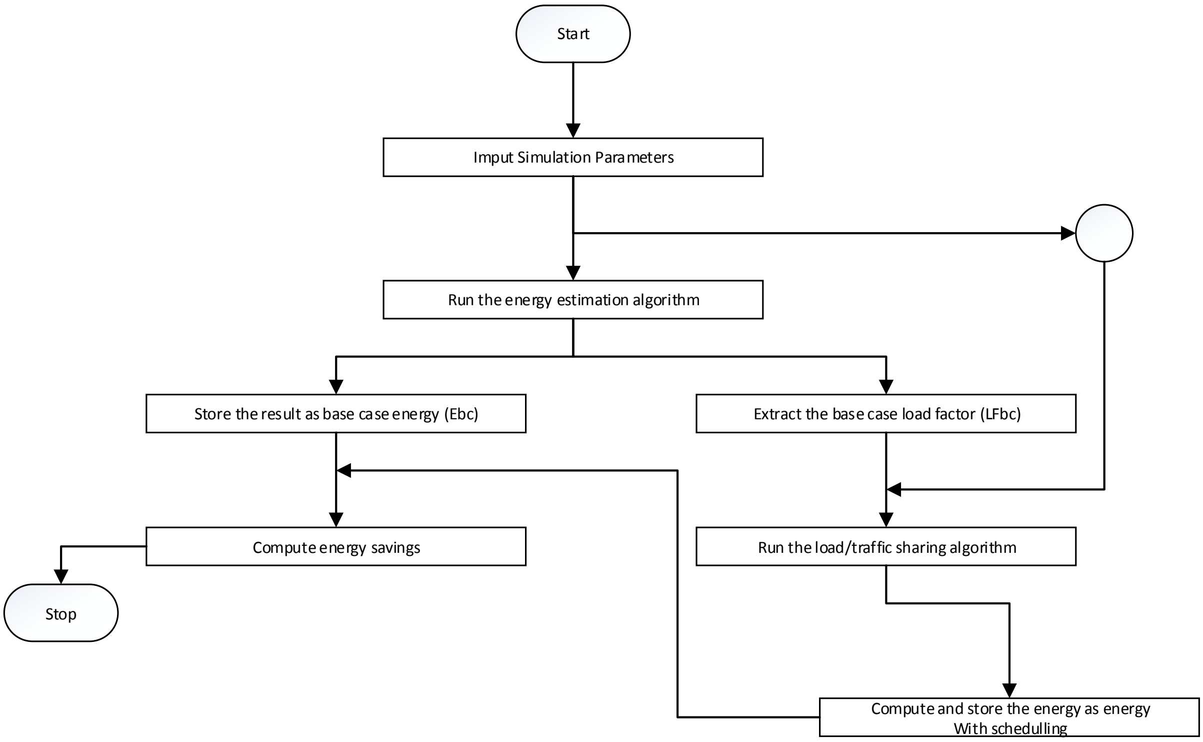
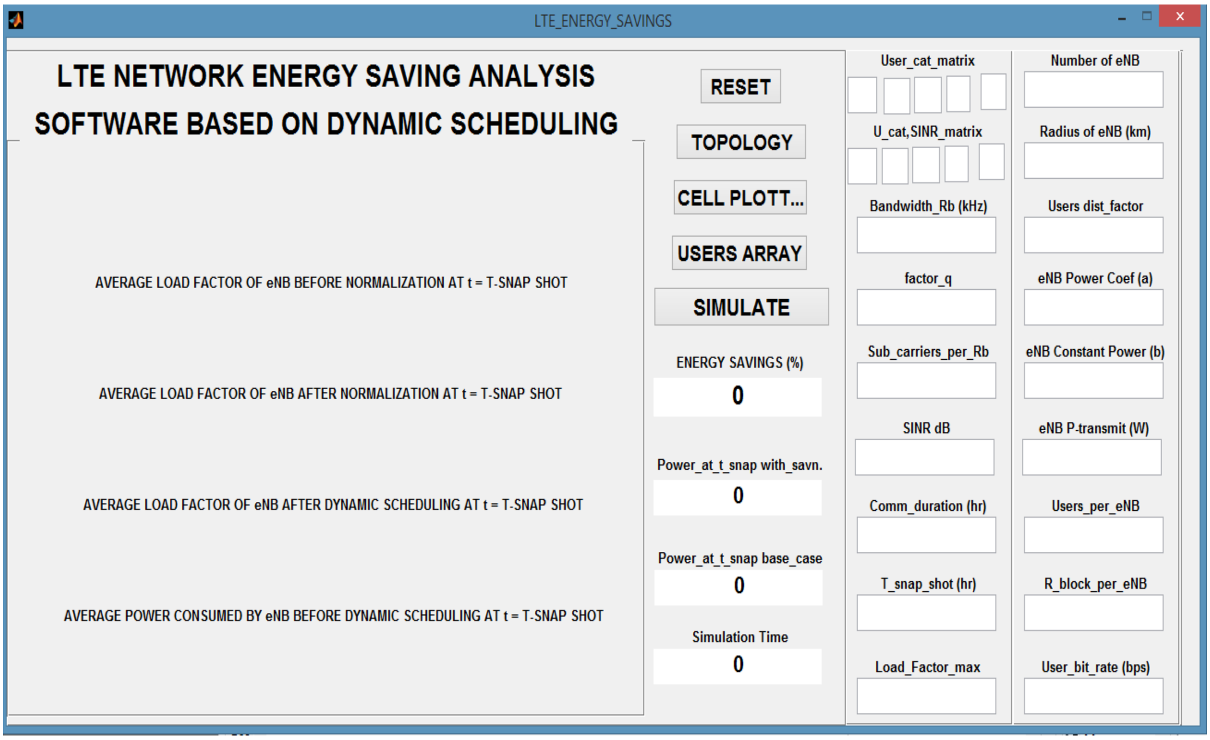


Figure 3.6: Flow Chart for Energy Saving Algorithm

3.4.4 The Developed MATLAB Graphical User Interface for Energy Saving Analysis

The developed MATLAB graphical user interface(GUI) for the energy saving analysis runs the proposed dynamic energy saving algorithm which utilizes off mode, sleep mode, active mode and multi-cell cooperation at the eNodeBs. The proposed dynamic energy saving algorithm is simulated using the MATLAB GUI.Figure 3.7 shows the developed MATLAB GUI. The GUI takes in inputs through the text boxes provided on the user interface. When the correct inputs are entered and the desired bottom is pressed, the GUI feeds the inputs to the set of MATLAB functions that perform the required tasks.If the Energy Saving bottom is selected the program run the energy saving algorithm and various results are displayed on the user interface.The energy saving analysis for the LTE mobile access network is carried out for various energy-load proportionality constant at a particular call blocking probability using the developed GUI for LTE mobile access network energy saving analysis based on dynamic scheduling. The MATLAB code for the developed GUI for energy saving analysis is given in Appendix A10.


LTE NETWORK ENERGY SAVING ANALYSIS SOFTWARE BASED ON DYNAMIC SCHEDULING

AVERAGE LOAD FACTOR OF eNB BEFORE NORMALIZATION AT t = T-SNAP SHOT

AVERAGE LOAD FACTOR OF eNB AFTER NORMALIZATION AT t = T-SNAP SHOT

AVERAGE LOAD FACTOR OF eNB AFTER DYNAMIC SCHEDULING AT t = T-SNAP SHOT

AVERAGE POWER CONSUMED BY eNB BEFORE DYNAMIC SCHEDULING AT t = T-SNAP SHOT

ENERGY SAVINGS (%): 0

Power_at_t_snap with_savn.: 0

Power_at_t_snap base_case: 0

Simulation Time: 0

Figure 3.7: The Developed MATLAB GUI for Energy Saving Analysis

The required inputs include:

1. Number of eNodeBs in the LTE access network (N)
2. Radius of each cell (R)
3. Transmit power of eNodeBs (P_{TX})
4. Power consumption parameters $(a \text{ and } b)$
5. Channel bandwidth (W)
6. Bandwidth per resource block (W_{RB})
7. Energy load proportionality constant (q)
8. Mobile station distribution factor (D)

9. Number of active mobile station per eNodeB (U)
10. Traffic types data rates matrix ($\boldsymbol{u_{br}}$)
11. Corresponding traffic type signal-to-interference-noise ratio matrix ($\boldsymbol{u_{SINR}}$)
12. Maximum load factor (ρ_{max})
13. Common duration
14. Time for snap shot

These parameters are imputed before simulation.

While the outputs include:

1. Energy Saving.,
2. Base case Power at t=t-snap-shot.,
3. Simulation time (CPU sec.).,
4. Power after scheduling at t=t-snap-shot.,
5. Average load factor of eNodeB before normalization at t=t-snap-shot.,
6. Average load factor of BS after normalization at t=t-snap-shot.,
7. Average load factor of BS after dynamic scheduling at t=t-snap-shot.,
8. Average power consumed by BS before dynamic scheduling at t=t-snap-shot.,

3.5 SIMULATION SETUP

The performance of the proposed dynamic energy saving algorithm was evaluated by simulation. The simulated LTE access network consist of 50 macro cells with a distribution factor of 4 and 100 active mobile stations per eNodeB as estimated in Appendix A11. The choice of 50 eNodeBs is based on the number of eNodeBs which was used in the energy saving algorithms for LTE access networks proposed by Hossain *et al.*,(2013).The standard parameters used for the simulation are shown in Table 3.1 which are consistent with the simulation scenario recommended by 3GPP (3GPP,TR 36.942 Ver. 11.0.0 Rel. 11).

Table 3.1: Standard Simulation Parameters

Parameter	**Value**
Transmit power of eNodeBs	$46\ dBm$
System bandwidth	$20\ MHz$
Carrier frequency	$2\ GHz$
Bandwidth per Resource	$180\ kHz$
Resource block per eNodeB	100

The radius of the macro cell is estimated as 1.5 km using the downlink budget for maximum data rate of 512 kbps which is shown in Appendix A12.Five classes of real time constant data rate having data rates equal to 64 kbps, 128 kbps, 256 kbps, 384 kbps and 512 kbps are randomly selected by mobile stations. It is assumed that only one resource block can be allocated to a mobile station from any class. Thus,the required signal-to-interference-noise-ratio of the five classes, calculated using equation (2.4) – (2.5), are found equal to $-4.1\ dB$, $-0.3\ dB$, $4.3\ dB$, $7.9\ dB$, and $11.1\ dB$ respectively. The eNodeBspower profile parameters are:$A = 21.45$ and$B = 354.44\ W$for macro cells. These parameters provide the maximum operating power of the eNodeBs. The simulation is carried out for a common duration of 24 hours which signifies the duration of a day. The energy load proportionality constant q ranges from 0 to 1. A snap shot of the simulated network is as shown in Figure 3.8.

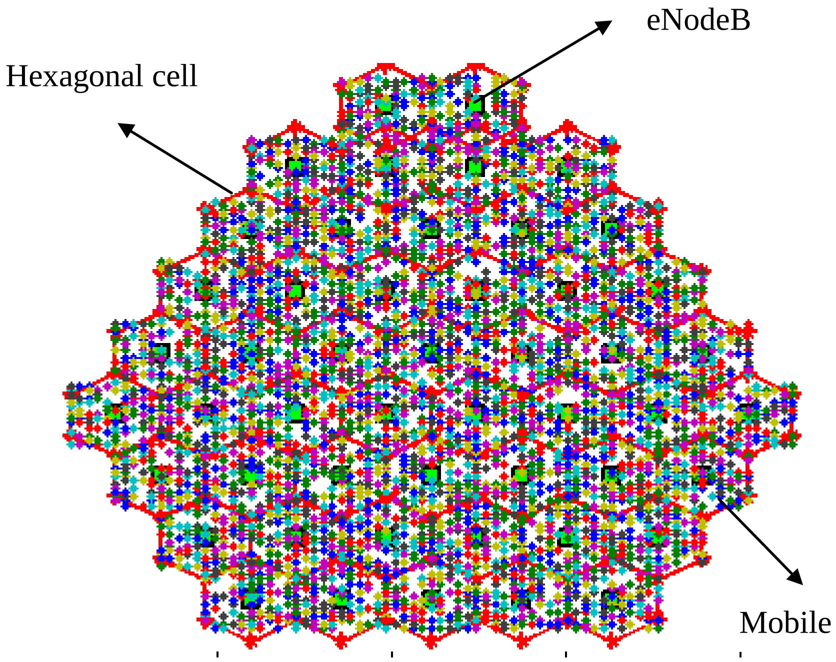


Figure 3.8: Simulated LTE Mobile Access Network of 50 eNodeBs

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents the result discussion ofthe mobile station distribution factor,instantaneous power consumption, total energy consumed by the simulated LTE access network eNodeBs, the energy saving of the proposed dynamic energy saving algorithm and its validation.

4.2 MOBILE STATION DISTRIBUTION FACTOR

Figure 4.1 shows the plot of uniformly distributed mobile stations N_u as a function of the distributed factor (D) using equation (3.19).

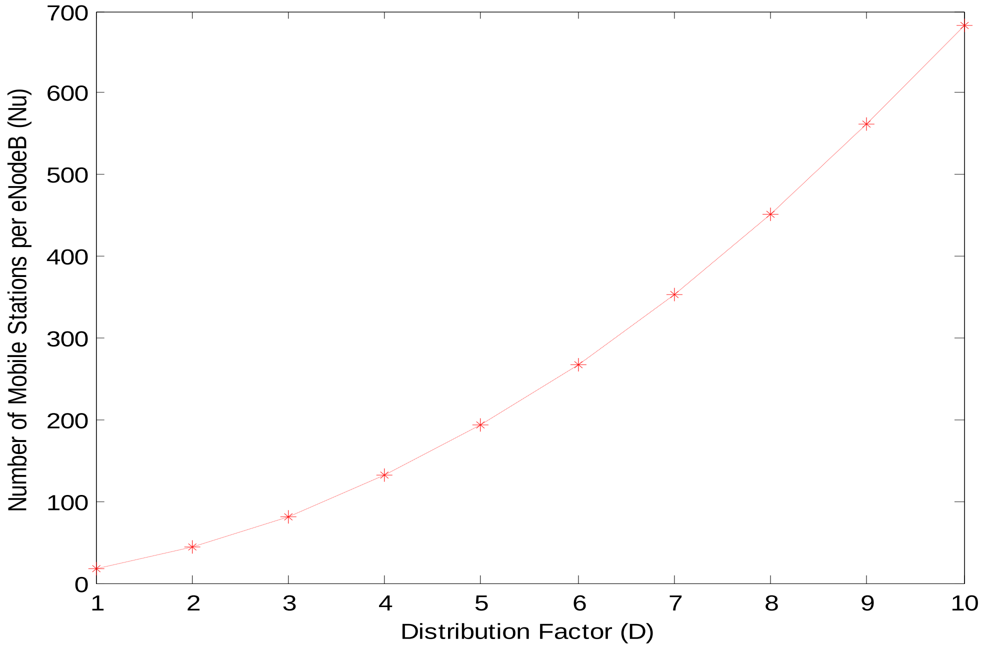


Figure 4.1: Number of Uniformly Distributed Mobile Stations per eNodeB against Distribution Factor

Figure 4.1 shows that the number of uniformly distributed mobile stations that can be specified per eNodeB by selecting a given distribution factor, and as the distribution factor increases the number of uniformly distributed mobile stations per eNodeB increases as a quadratic function given in equation (3.19).

4.3 INSTANTANEOUS POWER CONSUMPTION

The instantaneous power consumption of the eNodeBs in the LTE access network was simulated for 24 hours for the energy load proportionality constants which ranges from 0to1 at the interval of 0.1using equation (3.27) and the MATLAB code given in Appendix A8. Figure 4.2 shows the plot of the results obtained.

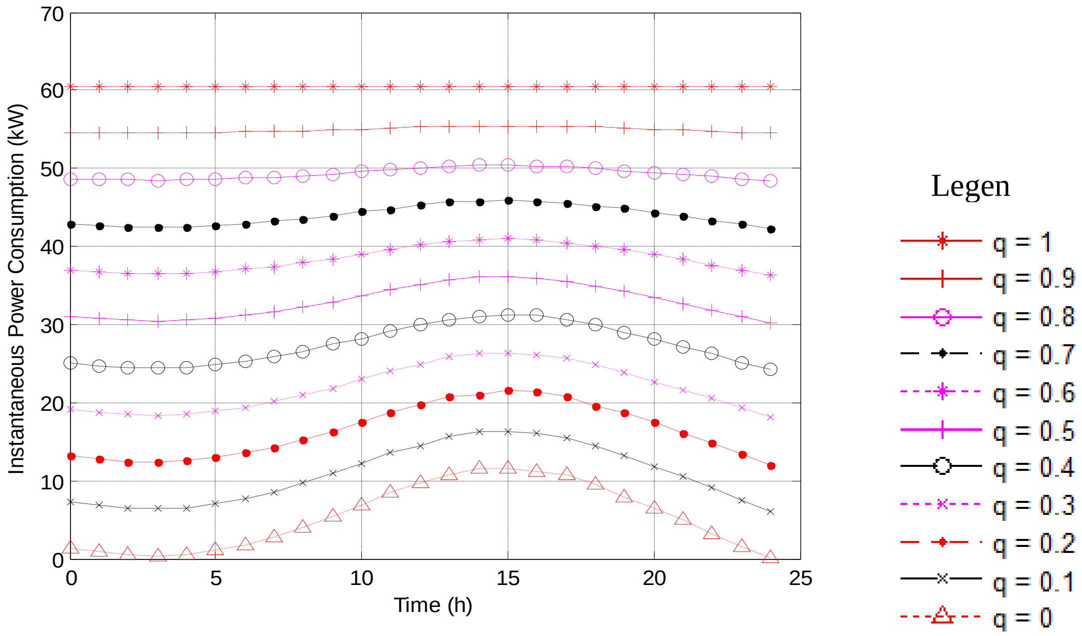


Figure 4.2: Instantaneous Power Consumption of the LTE Access Network

Figure 4.2 demonstrates the dependency of the instantaneous power consumption of the LTE access networkas a function of time for the various energy load proportionality constant ranging from 0 to 1 at a step of 0.1. For an energy-load proportionality constant of 1, the instantaneous power consumption by the LTE access network is constantand highest. Thisis because for an energy load proportionality constant of 1 the power consumption of the LTE access network does not vary with the normalized instantaneous traffic at the eNodeBs using equation (3.27). However, as the value of energy-load proportionality constant decreases, the instantaneous power consumption of the LTE access network decreases, but varies more with the instantaneous normalised traffic at the eNodeBs.The instantaneous power consumption of the LTE access network is minimum at an energy-load proportionality constant of 0 and varies completely with the normalized traffic at the eNodeBs. Also the maximum instantaneous power consumption of the LTE access network was found to be at 15 hours which correspond to the peak hour traffic of the simulated traffic arrival pattern for the various value of the energy-load proportionality constant. The shape of the graph follows the simulated traffic arrival pattern at the eNodeBs with is a Poisson distribution given by equation 2.10. Thus, this shows that the instantaneous power consumption of the LTE access network varies completely with the traffic for the various energy load proportionality constant.

4.4 ENERGY CONSUMPTION

The hourly energy consumption of the LTE access network was simulated for 24 hours forthe energy load proportionality constants which ranges from 0 to 1at an interval of 0.1. Hourly energy consumption was considered to reduce the simulation time. The simulation of the hourly energy consumption of the LTE access network was done using equation (3.28) and the MATLAB code given in Appendix A8. Figure 4.3 shows the plot of the hourly energy consumption of the LTE access network eNodeBs.

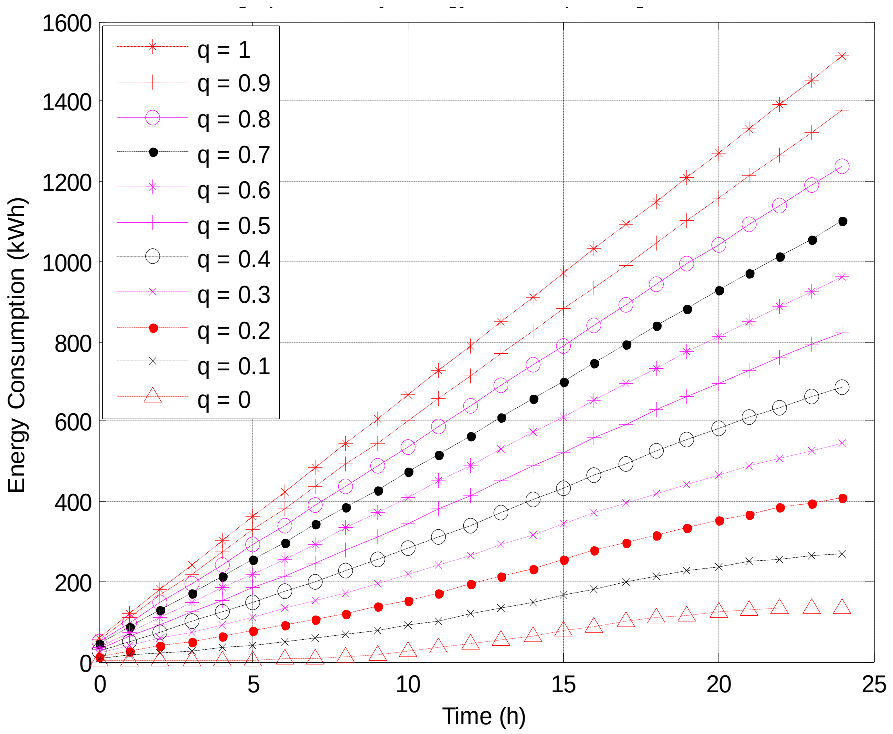


Figure 4.3: Hour Energy Consumption of the LTE Access Network

Figure 4.3 demonstrates the hourly energy consumption of the eNodeBs in a day while varying the energy load proportionality constant(q) from 0 to 1. The plot shows that the energy consumption increases as the time of the day increases. The energy consumption of the eNodeBs at a particular time of the day increases for higher value of energy load proportionality constant.

Thus, the daily energy consumption of the LTE access networkwhile varying the energy load proportionalityconstant ranging from 0to 1 at a step of 0.1 for 24 hours was derived from Figure 4.3. The plot of the variation of the daily energy consumption of the LTE access network with energy load proportionality constant is given in Figure 4.4.

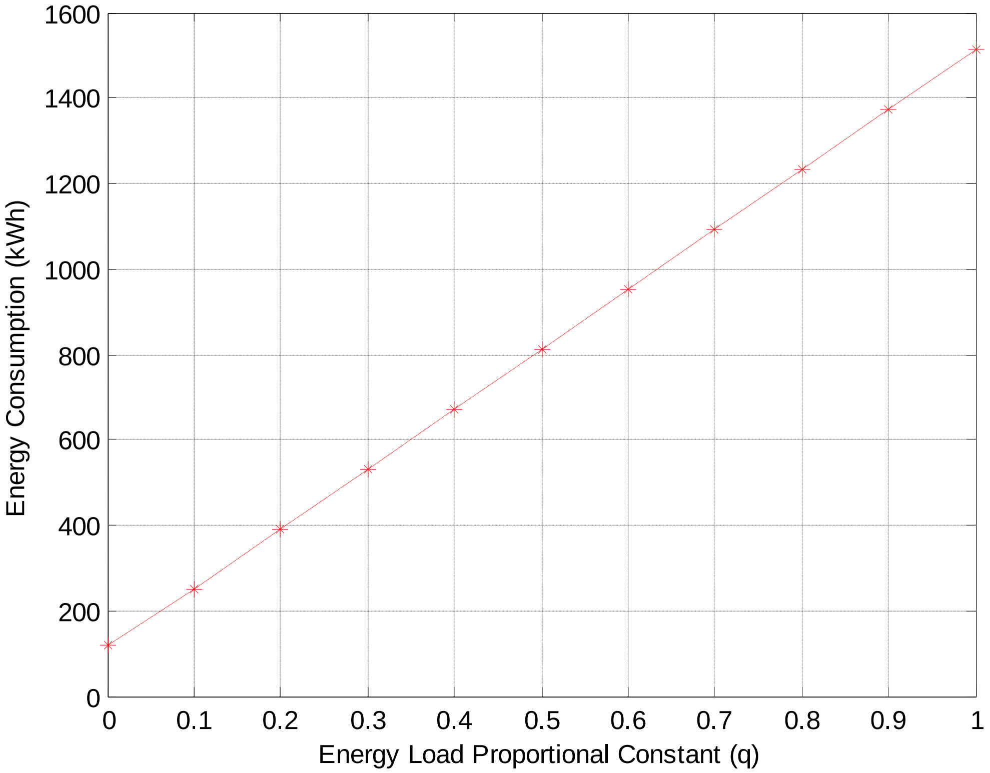


Figure 4.4: Energy Consumption with Change in Energy Load Proportionality Constant

Figure 4.4 demonstrates the variation of the energy consumption of the network with energy load proportionality constant. The daily maximum and minimum energy consumption of the simulated 50 LTE network eNodeBs are 1513.32 kWh and 113.97 kWh for an energy load proportionality constant of 1 and 0 respectively. Since, energy load proportionality constant of 1 corresponds to constant energy consumption of eNodeBs requiring constant power consumption irrespective of traffic level, it resulted to the highest amount of energy consumption. Similarly, energy-load proportionality constant of 0 corresponds to the energy consumption of the eNodeBs that completely varies with the traffic level of the eNodeBs leading to the lowest energy consumption in the network. Therefore the energy consumption of the network increases with the energy load proportionality constant.

4.5 DAILY ENERGY SAVING

The daily energy saving resulted from integrating the load/transfer algorithm with the energy estimation algorithm to form the energy saving algorithm of the LTE access network was plotted against the energy load proportionality constants which ranges from 0 to 1 at an interval of 0.1for the call blocking probability of 0.001%, 0.01%, 0.1%, 1% and 10%. The dependency of the energy saving on the energy-load proportionality constant for the various call blocking probability is as shown in Figure 4.5.

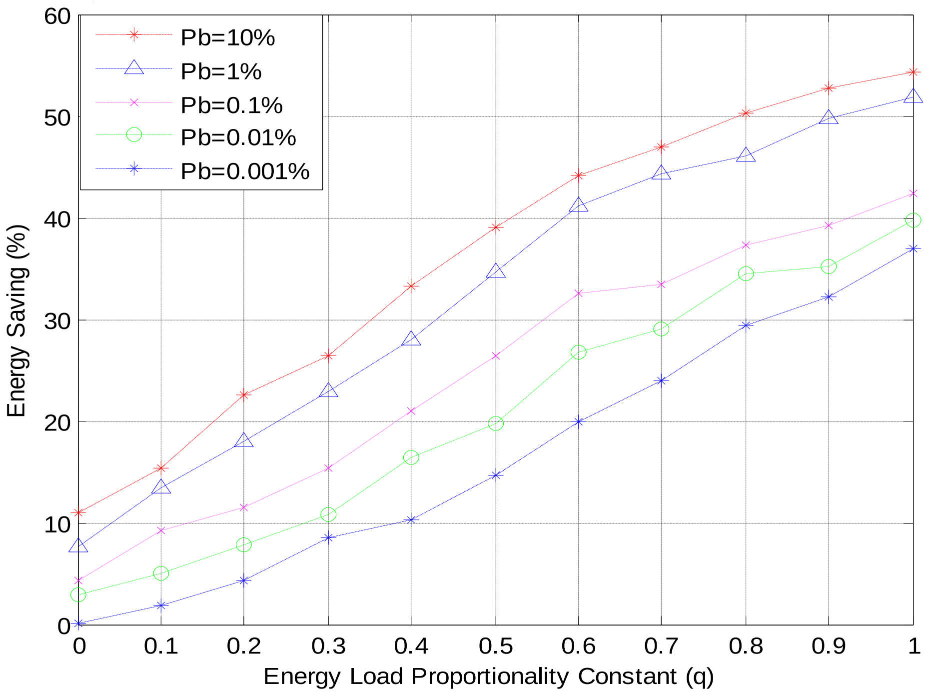


Figure 4.5: Energy Saving against Energy Load Proportionality Constant

The energy saving from Figure 4.5 is highest for the energy load proportionality constant of 1, which corresponds to constant energy-load proportionality constant. This is because for the constant energy load proportionality constant, the eNodeBs consume constant power irrespective of their traffic level which results in the highest amount of energy consumption of the LTE access network and consequently the highest amount of energy saving which correspond to 36.87%, 39.67%, 42.32%, 51.84% and 54.24% for the call blocking probability of 0.001%, 0.01%, 0.1%, 1% and 10% respectively. However, as the energy-load proportionality constant tends toward zero, the dependency of the energy consumption of the eNodeBs increases with its load utilization level, hence the energy consumption and energy saving decreases. Subsequently, for the energy load proportionality of zero, the energy consumption of the eNodeBs fully depends on its load utilization, and hence the energy saving is lowest and corresponds to 0.12%, 2.95%, 4.23%, 7.56% and 10.91% for the call blocking probability of 0.001%, 0.01%, 0.1%, 1% and 10% respectively. This is because the network incurs extra power (additional transmit power) in transferring the mobile stations from the off/sleep mode eNodeBs to the neighbouring active eNodeBs.Also, to further portrait the dependency of the energy saving on the call blocking probability for the various energy load proportionality constant range from 0 to 1 at an intervalof 0.1, the energy saving of the network was also plotted against the call blocking probability ranging from 0 to 10 at an interval of 1, for the various energy load proportionality constant as shown in Figure 4.6.

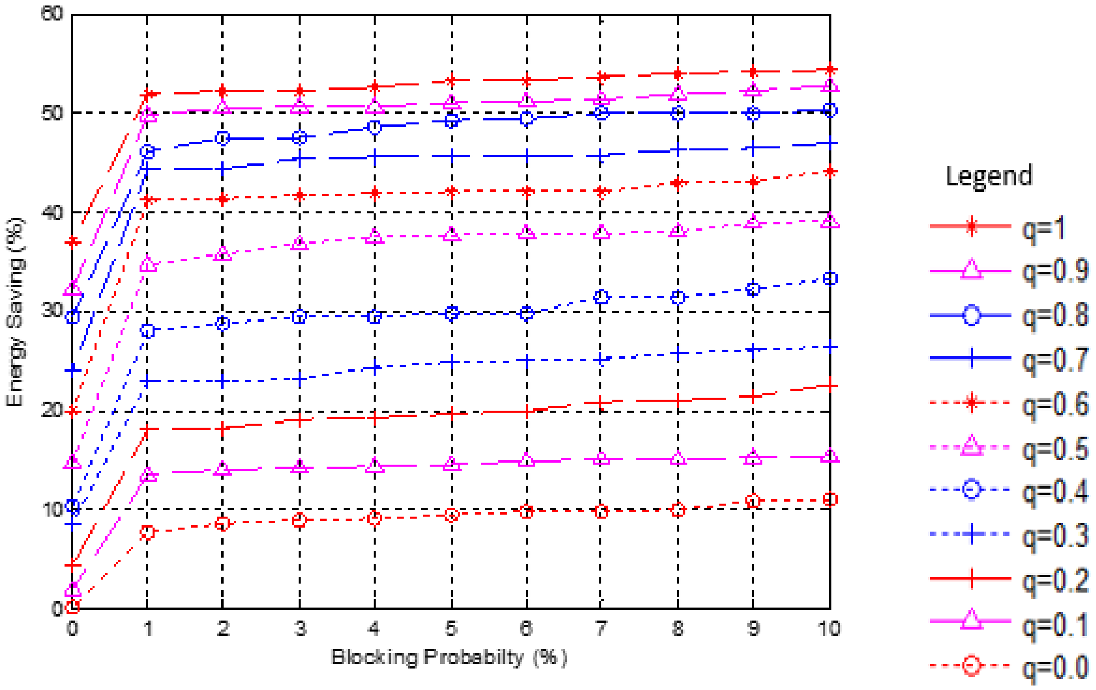


Figure 4.6: Energy Saving against Call Blocking Probability

Figure 4.6 depict the estimate of how much energy the network can save for a particular call blocking probability. The plot shows that the percentage energy saving of the network increases if the network allows higher call blocking in the network. This is because allowing higher call blocking means less eNodeBs are required to serve the active mobile stations, that is more eNodeBs are allowed to sleep/off by the energy saving algorithm and hence higher energy saving. Thus, for the call blocking probability of 10%, the energy saving is highest which corresponds to 54.24%, 52.77%, 50.21%, 46.87%, 44.16%, 39.05%, 33.28%, 26.40%, 22.50%, 15.34% and 10.91% for the energy-load proportionality of 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 and 0respectively. However, as the call blocking probability tends to zero, the energy saving in the network reduces gradually until a call blocking probability of 1% is reached, and there is a drastic reduction in the energy saving in the network for call blocking probability that is less than 1%. Thus, the optimum energy saving in the network was achieved while maintaining a call blocking probability of 1% which corresponds to 51.84%, 49.82%, 46.08%, 44.35%, 41.14%, 34.71%, 28.03%, 22.95%, 17.95%, 13.34% and 7.56% for the energy-load proportionality of 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 and 0 respectively.

4.6 VALIDATION

The proposed energy saving algorithm was validated by comparing its performance in terms of energy saving with the “always-on” algorithm Chiaraviglio et al., (2012) and the‘sleep-wake algorithm’by Hossian *et al.,*(2013) while using call blocking probability as the quality of service parameter. The energy saving of both the proposed energy saving algorithm and the “sleep-wake” algorithm are all reference to the energy consumption of the “always-on” algorithm which is the base-case energy saving. The plot of the energy saving against the energy load proportionality constant of the proposed energy saving algorithm and the “sleep-wake” algorithm by Hossain *et al.*, (2013) while guaranteeing a call blocking probability of 1% is as given in Figure 4.7.

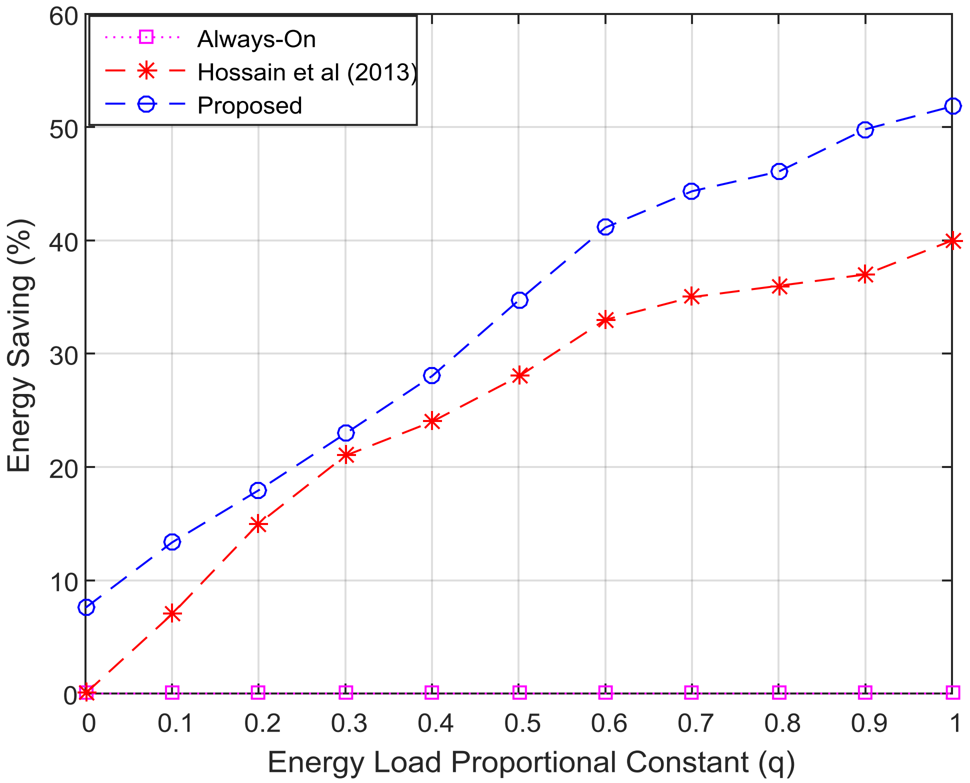


Figure 4.7: Comparison of the Energy saving of the Proposed Algorithm withExisting Algorithms

Figure 4.7shows a quantitative comparison of the proposed energy saving algorithm with the "sleep-wake" algorithm by Hossain *et al*., (2013). Comparison is presented for the energy saving against the energy load proportionality constant while guaranteeing a call blocking probability of 1%. As can be seen in Figure 4.7, the energy saving of the proposed energy saving algorithm is higher than the energy saving of the "sleep-wake" algorithm by Hossain *et al*., (2013) for the energy load proportionality constant ranging from 0 to 1 at a step of 0.1. The energy saving of the "sleep-wake" algorithm by Hossain *et al*.,(2013) and the proposed energy saving algorithm is highest for the energy-load proportionality constant of 1 with values of 40% and 51.84% as reference to the "always-on" algorithm respectively. The energy saving for the "always-on" algorithm for the energy load proportionality constant ranging from 0 to 1 a step of 0.1 is 0%. This is because the energy consumption of the “always-on” algorithm is the base-case energy consumption and all the eNodeBs in the LTE access network is kept powered on irrespective of the load utilization of the eNodeBs, thus there is no energy saving for the “always-on” algorithm. Therefore the proposed energy saving algorithm achieved a highest energy saving of 51.84% and 11.84% with respect to the “always-on” algorithm by Chiaraviglio *et al*., (2012) and “sleep-wake” algorithm by Hossain *et al*., (2013) respectively, while guaranteeing a call blocking probability of 1%.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter presents a summary of the research work, the limitations that were observed during the research work, the recommendation for further work and the conclusion.

5.2 SUMMARY

The dynamic algorithm for improving energy saving in LTE mobile networks through off mode, sleep mode and multi-cell cooperation utilization at the eNodeBs has been developed. The LTE network environment and the eNodeBs power consumption models were developed with a view to implementing the dynamic energy saving algorithm which comprises of the energy estimation algorithm and the load/traffic sharing algorithm. The energy estimation algorithm estimate the energy consumption of the eNodeBs when they are powered on irrespective of their utilization. The load/traffic sharing algorithm transfer traffic between eNodeBs which enables the off mode, sleep mode and multi-cell cooperation of eNodeBs.The dynamic energy saving algorithm was implemented on MATLAB 2013b environment. The simulation and analysis of the energy saving resulted from the energy saving algorithm was done using the developed MATLAB graphical user interface called the LTE network energy saving analysis software based on dynamic scheduling for the energy load proportionality constant ranging from 0 to 1 at a step of 0.1.Validation of the proposed energy saving algorithm was done by comparing its performance in terms of the energy saving and call blocking probability with the “always-on” algorithm by Chiaraviglio *et al.*, (2012) and the “sleep-wake” algorithm by Hossain *et al*., (2013).

5.3 CONCLUSION

The development of the proposed dynamic algorithm for improving energy saving in LTE mobile access networks through off mode, sleep mode, active mode and multi-cell cooperation utilization at the eNodeBs has been presented in this research work. The dynamic energy saving algorithm which is an integration of the energy estimation algorithm and the load/traffic sharing algorithm was implemented MATLAB 2013b environment. A MATLAB GUI program called LTE network energy saving analysis software base on dynamic scheduling was developed to run the proposed dynamic energy saving algorithm for the purpose of simulation and performance analysis. The results show that the energy saving in the network increases as the energy load proportionality constant and call blocking probability increases. The proposed energy saving algorithm achieved the highest energy saving of 51.84% and 11.84% when the energy load proportionality constant equals 1 with respect to the "always-on" algorithm by Chiaraviglio *et al*., (2012) and "sleep-wake" algorithm by Hossain *et al*., (2013) with energy saving of 0% and 40% respectively, while guaranteeing a call blocking probability of 1%.

5.4 LIMITATIONS

During the course of this research work, certain limitations were observed which are itemized as follows:

i. The proposed dynamic energy saving algorithm assumed constant number of uniformly distributed mobile stations and equal number of randomly distributed active mobile stations for each of the eNodeBs.

ii. The eNodeBs in the proposed dynamic energy saving algorithm were dimensioned to have equal capacity.

iii. The proposed dynamic energy saving algorithm considered only constant rate traffic types.

5.5 RECOMMENDATIONS FOR FURTHER WORK

Future works should consider the following areas:

i. This research work only focus on downlink communication (that is from eNodeB to mobile station). Nevertheless, it would be interesting to develop a dynamic energy saving algorithm for eNodeBs that considers downlink and uplink traffics jointly.

ii. Another extension of this research work can be to develop dynamic energy saving algorithms considering heterogeneous LTE networks, consisting of different types of eNodeBs, such as macro, micro, femto eNodeBs and even WiFi access points, which have different transmission powers as well as total operational powers.

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APPENDICES

Appendix A1:

MATLAB m-File ‘cell_array’

```
function Array=cell_array(N)
centre=ceil(sqrt(N)).,
Cell_Array=centre.,
n=N-centre.,
k=0.,
while n~=0
   k=k+1.,
if n>=centre-k
        Cell_Array=[Cell_Array,centre-k].,
        n=n-centre+k.,
end
if n>=centre-k
        Cell_Array=[centre-k,Cell_Array].,
        n=n-centre+k.,
end
end
Array=Cell_Array.,
```

Appendix A2:

MATLAB m-File ‘eNodeB_location’

```
function [X,Y,e_node_Bx,e_node_By]=topology(N,cell_radius)

array=cell_array(N).,
x_axis=max(array).,
%lent_xaxis=sqrt(3)*x_axis*cell_radius.,
y_axis=length(array).,
%lent_yaxis=(3*cell_radius*y_axis+cell_radius)/2.,
x_axisdivisions=2*x_axais+1.,
y_axisdivisions=3*y_axis+3.,
xi=(1-sqrt(3))*cell_radius/2.,
for x=1:x_axisdivisions
xi=xi+sqrt(3)*cell_radius/2.,
yi=0.,
for y=1:y_axisdivisaions
yi=yi+cell_radius/2.,
        x_matrix(x,y)=xi.,
        y_matrix(x,y)=yi.,
end
end
X_matrix=reshape(x_matrix,1,x_axisdiavisions*y_axisdivisions).,
Y_matrix=reshape(y_matrix,1,x_axisdivisions*y_axisdivisions).,
figure('name','Hexagonal_cells')
plot(X_matrix,Y_matrix,'.','MarkeredgeColor','w',...
                    'MarkerSize',1).,
%plot(X_matrix,Y_matrix,'.')     %..........show margins
hold on
X_matrix_new=[].,
Y_matrix_new=[].,
for change=1:y_axis
    X_matraix_new=[X_matrix_new,x_matrix(:,3*change)].,
    Y_matrix_new=[Y_matrix_new,y_matrix(:,3*change)].,
end
X_new=X_matrix_new.,
Y_new=Y_matrix_new.,
e_node_Bx=zeros(size(X_new)).,
e_node_By=zeros(size(Y_new)).,
enbx=[].,
enby=[].,
for changex=1:y_axis
for changey=1:array(changex)
```

```
        e_node_Bx_coordinate=X_new((x_axis-array(changex)+2+2*(changey-1)),changex).,
        e_node_Bx((ax_axis-array(changex)+2+2*(changey-1)),changex)=X_new((x_axis-
aarray(changex)+2+2*(changey-1)),changex).,
        e_node_By_coordinate=Y_new((x_axis-array(changex)+2+2*(changey-1)),changex).,
        e_node_By((x_axis-array(changex)+2+2*(changey-1)),changex)=Y_new((x_axais-
array(changex)+2+2*(changey-1)),changex).,
enbx=[enbx,e_node_Bx_coordinate].,
enby=[enby,e_node_By_coordinate].,
end
end
plot(enbxa,enby,'s','LineWidth',2,...
                       'MarkeraEdgeColor','k',...
                       'MarkerFaceColor','g',...
                       'MarkerSize',8).,
hold on
X=x_matrix.,
Y=y_maatrix
```

Appendix A3:

MATLAB m-File ‘cellploter’

```
function [e_node_BX,ke_node_BY]=cellploter(N,cell_radius)
[~,~,e_node_Bx,e_node_By]=topology(N,cell_radius).,
[a,b]=size(e_node_Bx).,
e_node_BX=[].,
e_node_BY=[].,
for lent=1:a
for bret=1:b
if e_node_Bx(lkent,bret)~=0
        e_node_BX=[e_node_BX,e_node_Bx(lent,bret)].,
end
if e_node_Bky(lent,bret)~=0
        e_node_BY=[e_node_BY,e_node_By(lent,bret)].,
end
end
end
for points=1:length(e_node_BX)
x1=e_node_BX(points).,
x2=e_node_BX(points)+sqrt(3)*cell_radius/2.,
x3=x2.,
x4=x1.,
x5=2*x1-x2.,
x6=x5.,
x7=x1.,
   y1=e_node_BY(points)+cell_radius.,
   y2=e_node_BY(pkoints)+cell_radius/2.,
   y3=y2-cell_radius.,
   y4=y3-cell_radius/2.,
   y5=y3.,
   y6=y2.,
   y7=y1.,
   marginx=[x1,x2,x3,x4,x5,x6,x7].,
marginy=[y1,y2,y3,y4,y5,y6,y7].,
plot(marginx,mkarginy,'-r*','LineWidth',2).,
end
```

Appendix A4:

MATLAB m-File ‘Users’

```
function [Ux,Uy,TNUE,hj]=Users(N,dist_factor,cell_radius)
[X,Y]=topologly(N,cell_radius).,
x_matrix=X.,
y_matrix=Y.,
Y(end,:)=[].,
X(:,end)=[].,
close('Hexagonal_cells')
dino=dist_factor.,
increasex=(-X(1,1)+X(2,1))/(dino+1).,
increasey=(-Y(1,1)+Y(1,2))/(dino+1).,
[lx,bx]=size(X).,
Ux_matrix=[].,
Uy_matrix=[].,
for changex=1:(lx-1)
for changey=1:dino+1
        Ux_matrilx=[Ux_matrix.,X(changex,:)+abs((changey-1)*increasex)].,
end
end
Ux_matrix=[Ux_matrix.,X(lx,:)].,
for changex=1:(bx-1)
for changey=1:dino+1
        Uy_matrix=[Uy_matrix,Y(:,changex)+abs((changey-1)*increasey)].,
end
end
Uy_matrix=[Uy_matrix,Y(:,bx)].,
[lux,bux]=size(Ux_matrix).,
[luy,buy]=size(Uy_matrix).,
for i=1:(buy-bux)
    Ux_matrix=[Ux_maltrix,Ux_matrix(:,1)].,
end
for j=1:(lux-luy)
    Uy_matrix=[Uy_matrix.,Uy_matrix(1,:)].,
end
Ux=Ux_matrix.,
Uy=Uy_matrix.,
[l,b]=size(Ux).,
Userx=[].,
Usery=[].,
[e_node_Bx,e_node_By]=cellplloter(N,cell_radius).,
for j=1:length(e_node_Bx)
for jj=1:l*b
```

```
        if Ux(jj)<(e_node_Bx(j)+((sqrt(3)/2)*cell_radius)+increasex)
if Ux(jj)>(e_node_Bx(j)-((sqrt(3)/2)*cell_radius)-increasex)
                if Uy(jj)<(e_node_By(j)+((sqrt(3)/2)*cell_radius)+increasey)
if Uy(jj)>(e_node_By(j)-((sqrt(3)/2)*cell_radius)-increasey)
                        Userlx=[Userx,Ux(jj)].,
                        Usery=[Usery,Uy(jj)].,
end
end
end
end
end
end
hj=floor(length(Userx)/lelngth(e_node_Bx)).,
k=hj*length(e_node_Bx).,
Userx=Userx(1,1:k).,
Usery=Usery(1,1:k).,
Ux=reshape(Userx,hj,length(e_node_Bx))'.,
Uy=reshape(Usery,hj,lengtlh(e_node_Bx))'.,
plot(Ux,Uy,'.')
TNUE=N*(6*dist_factor^2+8*dist_factor+3).,
```

Appendix A5:

MATLAB m-File ‘LTE_enviroment’

```
function [U]=LTE_environment(N,dist_factor,cell_radius)
[~,~,~]=Users(N,dist_factor,cell_radius).,
[~,~]=cellploter(N,cell_radius).,
disp('Number of Users in each cell is given by:')
U=6*dist_factor^2+8*dist_factor+3.,
```

AppendixA6:

MATLAB m-File ‘e_node_neighbors’

```
function [e_node_B_Neighbor_matrix]=e_node_B_neighbors(N,cell_radius)
[e_node_Bx,e_node_By]=cellploter(N,cell_radius).,
close('Hexagonal_cells')
[~,~,e_node_B_matrixx,e_node_B_matrixy]=topology(N,cell_radius).,
close('Hexagonal_cells')
cell_neighborx=zeros(N,6).,
Array=cell_array(N).,
[lent_e_node_B_matrixx,bredt_e_node_B_matrixx]=size(e_node_B_matrixx).,
%k=0.,%counter for non existing e_node_B
l=0.,%counter for existing e_node_B
for cell_coordx=1:lent_e_node_B_matrixx
for cell_coordy=1:bredt_e_node_B_matrixx
if e_node_B_matrixx(cell_coordx,cell_coordy)~=0
        l=l+1.,
if cell_coordx+2<=2*(max(Array))+1
if e_node_B_matrixx(cell_coordx+2,cell_coordy)~=0
for x1=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx+2,cell_coordy)==e_node_Bx(x1)
if e_node_B_matrixy(cell_coordx+2,cell_coordy)==e_node_By(x1)
            cell_neighborx(l,1)=x1.,
end
end
end
end
end
clear x1

if cell_coordx-2>0
if e_node_B_matrixx(cell_coordx-2,cell_coordy)~=0
for x2=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx-2,cell_coordy)==e_node_Bx(x2)
if e_node_B_matrixy(cell_coordx-2,cell_coordy)==e_node_By(x2)
            cell_neighborx(l,2)=x2.,
end
end
end
end
end
clear x2
if cell_coordx+1<=2*(max(Array))+1
if cell_coordy+1<=(length(Array))
```

```
if e_node_B_matrixx(cell_coordx+1,cell_coordy+1)~=0
for x3=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx+1,cell_coordy+1)==e_node_Bx(x3)
if e_node_B_matrixy(cell_coordx+1,cell_coordy+1)==e_node_By(x3)
	cell_neighborx(l,3)=x3.,
end
end
end
end
end
end
clear x3
if cell_coordx+1<=2*(max(Array))+1
if cell_coordy-1>0
if e_node_B_matrixx(cell_coordx+1,cell_coordy-1)~=0
for x4=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx+1,cell_coordy-1)==e_node_Bx(x4)
if e_node_B_matrixy(cell_coordx+1,cell_coordy-1)==e_node_By(x4)
	cell_neighborx(l,4)=x4.,
end
end
end
end
end
end
clear x4
if cell_coordx-1>0
if cell_coordy+1<=(length(Array))
if e_node_B_matrixx(cell_coordx-1,cell_coordy+1)~=0
for x5=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx-1,cell_coordy+1)==e_node_Bx(x5)
if e_node_B_matrixy(cell_coordx-1,cell_coordy+1)==e_node_By(x5)
	cell_neighborx(l,5)=x5.,
end
end
end
end
end
end
clear x5
if cell_coordx-1>0
if cell_coordy-1>0
if e_node_B_matrixx(cell_coordx-1,cell_coordy-1)~=0
for x6=1:length(e_node_Bx)
if e_node_B_matrixx(cell_coordx-1,cell_coordy-1)==e_node_Bx(x6)
if e_node_B_matrixy(cell_coordx-1,cell_coordy-1)==e_node_By(x6)
	cell_neighborx(l,6)=x6.,
end
end
```

```
end
end
end
end
clear x6
end
end
end

 e_node_B_Neighbor_matrix=sort(cell_neighborx,2,'descend').,
```

Appendix A7:

MATLAB m-File ‘ErlangB’

```
% B=erlangb(n,rho)
%
% This function computes the Erlang B probability that an eNodeB with n
% resource blocks, no waiting line, Poisson arrival rate ,
% and maximum allowable load utilization factor, rho of an eNodeB
% The probability is
%  B=(rho^m/m!)/(sum(rho^k/k!),k=0..m)
%  B(0,rho)=1
%  B(n,rho)=(rho*B(n-1,rho)/n)/(1+rho*B(n-1,rho)/n)
function B=erlangb(n,rho)
% Sanity check- make sure that n is a positive integer.
if ((floor(n) ~= n) || (n < 1))
warning('n is not a positive integer').,
   B=NaN.,
return.,
end.,
% Sanity check- make sure that rho >= 0.0.
if (rho < 0.0)
warning('rho is negative!').,
   B=NaN.,
return.,
end.,
% Start the recursion with B=1.
B=1.,
% Run the recursion.
for k=1:n,
  B=((rho*B)/k)/(1+rho*B/k).,
end.,
%  rho=findrhob(n,p)
% Finds the maximum allowable load utilization factor, rho for a given number of system
resourceof an eNodeB such that the blocking probability B(n,rho)=p.
% Note: Must have 0<p<1.  Returns NaN if p is not in this range.
function rho=findrhob(n,p)
% Sanity check- make sure that n is a positive integer.
if ((floor(n) ~= n) || (n < 1))
warning('n is not a positive integer').,
rho=NaN.,
return.,
end.,
% Sanity check- make sure that p is a probability with 0<p<1.
if ((p<0.0) || (p>1.0))
```

```
warning('Invalid p value!').,
rho=NaN.,
return.,
end.,
% We know that at rho=0, p=0, and at rho=+Inf, p=1.   We start by finding
% an interval [0,a] containing the root.
a=1.0.,
testp=erlangb(n,a).,
while (testp < p),
  a=a*2.0.,
testp=erlangb(n,a).,
end.,
% Now, the root is somewhere between 0 and a.  Use bisection to find it.
left=0.0.,
right=a.,
mid=(left+right)/2.,
midp=erlangb(n,mid).,
while ((right-left) > 0.0001*max([1 left])),
if (midp < p),
left=mid.,
mid=(left+right)/2.,
midp=erlangb(n,mid).,
else
right=mid.,
mid=(left+right)/2.,
midp=erlangb(n,mid).,
end.,
end.,
% Return the left end point of the current interval, which has prob < p.
rho=left.,
```

Appendix A8

MATLAB m-File ‘LTE_energy_estimation_algorithm’

```
function[ENERGY_SAVING,Power_at_t_snap,sim_time,N_sub_carrier_used_at_e_node_Bs
ss,LF_e_node_Bss2s,Power_e_node_Bsss,LF_e_node_Bsss,LF_e_node_Bs_newss]=LTE_en
ergy_saving(N,cell_radius,dist_factor,A,B,Ptx,Nupe_node_B,Nrbpe_node_B,...
                    U_bit_rate,U_category_matrix,U_category_sinr_matrix,...
                    Brb,q,Nsub_carrier_per_rb,SINR,simulation_time,T_snap_shot,LF_max)
tic
EB=[].,
max_time=simulation_time.,
Energy_with_time=[].,
%initialising the energy evaluation
E_total_base_case=0.,
E_with_scheduling=0.,
Energy_Saving_with_time=[].,
Percentage_of_sleeping_e_node_B=[].,
Average_Traffic_e_node_B=[].,
Inst_normalized_trafic_matrx=[].,
g=15.,
pt=[].,
for t=0:24
a=(g.^t*exp(-g))/factorial(t).,
pt=[pt,a].,
end
A=max(pt).,
for timer=0:max_time
   [e_node_Bx,e_node_By]=cellploter(N,cell_radius).,
close
   [Ux,Uy]=Users(N,dist_factor,cell_radius).,
close
[lu,bu]=size(Ux).,
eNBx=(ones(bu,1)*e_node_Bx)'.,
eNBy=(ones(bu,1)*e_node_By)'.,
Due_enodeb=((Ux-eNBx).^2+(Uy-eNBy).^2).^0.5.,

%Random Selection of Users (Nupe_node_B)
UX=[].,
UY=[].,
Dij=[].,
for LU=1:lu
   User_matrix=[].,
   Nu_selected=0.,
while Nu_selected~=Nupe_node_B
```

```
U_possition=randi(bu,1).,
if isempty(User_matrix)==1
User_matrix=[User_matrix,U_possition].,
else
   w=0.,
for iu=1:length(User_matrix)
if User_matrix(iu)==U_possition
         w=w+1.,
end
end
if w==0
      User_matrix=[User_matrix,U_possition].,
end
end
Nu_selected=length(User_matrix).,
end
UX=[UX.,Ux(LU,User_matrix)].,
UY=[UY.,Uy(LU,User_matrix)].,
% the users respective distances from the e_node_B
Dij=[Dij,Due_enodeb(LU,User_matrix)].,
end
%Varying the traffict with time
%the traffic is varied base on a typical curve of Inst_normalized_trafic
      x=timer.,
      t=x.,
a=(g.^t*exp(-g))/factorial(t).,
Inst_normalized_trafic=a/A.,
Inst_normalized_trafic_matrx=[Inst_normalized_trafic_matrx,Inst_normalized_trafic].,
clear x
qw=[].,
for ii=1:length(U_category_matrix)
if U_category_matrix(ii)~=0
qw=[qw,ii].,
end
end
U_category_matrix=U_category_matrix(1,qw).,
qw=[].,
for ii=1:length(U_category_sinr_matrix)
if U_category_sinr_matrix(ii)~=0
qw=[qw,ii].,
end
end
U_category_sinr_matrix=U_category_sinr_matrix(1,qw).,
User_bit_rates=U_bit_rate*U_category_matrix.,
User_sinr=SINR*U_category_sinr_matrix.,
User_bit_rates_matrix=zeros(size(UX)).,
User_sinr_matrix=zeros(size(UX)).,
for uk=1:Nupe_node_B*lu
User_bit_rates_matrix(uk)=User_bit_rates(randi(length(U_category_matrix),1)).,
```

```
User_sinr_matrix(uk)=User_sinr(randi(length(U_category_sinr_matrix),1)).,
end
B_eff_avg_matrix=log2(ones(size(User_sinr_matrix))+10.^(User_sinr_matrix/10)).,
B_width_sub_carrier=Brb/Nsub_carrier_per_rb.,
N_sub_carrier_allocated_to_users=ceil(User_bit_rates_matrix./(B_width_sub_carrier*B_eff_
avg_matrix)).,
N_sub_carrier_used_at_e_node_Bs=((sum(N_sub_carrier_allocated_to_users,2)))'.,
N_sub_carrier_used_at_e_node_Bss=N_sub_carrier_used_at_e_node_Bs.,
%Load factor variation with time
Nsub_carrier_per_e_node_B=Nrbpe_node_B*Nsub_carrier_per_rb.,
LF_e_node_Bs=N_sub_carrier_used_at_e_node_Bs/Nsub_carrier_per_e_node_B.,
LF_e_node_Bss=LF_e_node_Bs.,
Average_Traffic_e_node_B=[Average_Traffic_e_node_B,sum(LF_e_node_Bs)*100/N].,
LF_e_node_Bs=LF_e_node_Bs*Inst_normalized_trafic.,
LF_e_node_Bss2=LF_e_node_Bs.,
Pmax_e_node_B=(A*Ptx)+B.,
%Determinig the power consumed by each base station
Power_e_node_Bs=(1-
q)*LF_e_node_Bs*Pmax_e_node_B+ones(size(LF_e_node_Bs))*q*Pmax_e_node_B.,
Power_e_node_Bss=Power_e_node_Bs.,
for i=1:length(LF_e_node_Bs)
if LF_e_node_Bs(i)>LF_max
        LF_e_node_Bs(i)=LF_max.,
        N_sub_carrier_used_at_e_node_Bs(i)=LF_max*Nsub_carrier_per_e_node_B.,
end
end
[No_Sharing,LF_e_node_Bs_new]=LTE_dynamic_scheduler(N,cell_radius,N_sub_carrier_u
sed_at_e_node_Bs,LF_max,Nsub_carrier_per_e_node_B).,
LF_e_node_Bs_news=LF_e_node_Bs_new.,
Power_Increase=No_Sharing*Ptx/6.,
sliping_off=0.,
Power_active=0.,
for h=1:length(LF_e_node_Bs_new)
if LF_e_node_Bs_new(h)==0
        sliping_off=sliping_off+1.,
else
        Power_active=Power_active+(1-
q)*LF_e_node_Bs_new(h)*Pmax_e_node_B+q*Pmax_e_node_B.,
end
end
if sliping_off>0
Power_sleeping=q*B.,
else
 Power_sleeping=0.,
end
Percentage_of_sleeping_e_node_B=[Percentage_of_sleeping_e_node_B,sliping_off*100/N].,
Power_e_node_Bs_with_scheduling=(Power_active+Power_sleeping+Power_Increase).,
%e_node_B_total_traffic=(sum(User_traffic_matrix,2))'.,
%estmating the total power consumed by the entire base station at time t
```

```
Power_e_node_Bs_total=sum(Power_e_node_Bs).,
if T_snap_shot==timer
   U=UX.,
   V=UY.,
   Power_at_t_snap=[Power_e_node_Bs_total,Power_e_node_Bs_with_scheduling].,
N_sub_carrier_used_at_e_node_Bsss=sum(N_sub_carrier_used_at_e_node_Bss)/N.,
LF_e_node_Bss2s=sum(LF_e_node_Bss2)/N.,
Power_e_node_Bsss=sum(Power_e_node_Bss)/N.,
LF_e_node_Bsss=sum(LF_e_node_Bss)/N.,
LF_e_node_Bs_newss=sum(LF_e_node_Bs_news)/N.,
end
%Accumulating the energy consumed over the simulation time t in hours
E_total_base_case=E_total_base_case+Power_e_node_Bs_total.,
Energy_with_time=[Energy_with_time.,E_total_base_case].,
EB=[EB,Power_e_node_Bs_total,].,
E_with_scheduling=E_with_scheduling+Power_e_node_Bs_with_scheduling.,
Energy_Saving_with_time=[Energy_Saving_with_time,((E_total_base_case-
E_with_scheduling)/E_total_base_case)*100.,].,
end
Energy_with_time
EB=EB'
[~,~]=cellploter(N,cell_radius).,
plot(U,V,'.')
ENERGY_SAVING=((E_total_base_case))-E_with_scheduling)/E_total_base_case)*100.,
sim_time=toc.,
T=0:max_time.,
```

Appendix A9

Load_Traffic_Sharing_Algorithm_Matlab_Code

```
function[No_Sharing,LF_BTSs_new]=LTE_dynamic_scheduler(N,cell_radius,N_sub_carrier_used_at_BTSs,LF_max,Nsub_carrier_per_BTS)

e_node_B_Neighbor_matrix=e_node_B_neighbors(N,cell_radius).,
[Ln,bn]=size(e_node_B_Neighbor_matrix).,
Neighbors_sub_carrier_table=e_node_B_Neighbor_matrix.,
for lent=1:Ln
for bret=1:bn
if Neighbors_sub_carrier_table(lent,bret)~=0

Neighbors_sub_carrier_table(lent,bret)=N_sub_carrier_used_at_BTSs(Neighbors_sub_carrier_table(lent,bret)).,
end
end
end
Neighbors_sub_carrier_table=sort(Neighbors_sub_carrier_table,2,'descend').,
Available_space_in_neighbors=Neighbors_sub_carrier_table.,
for lent=1:Ln
for bret=1:bn
if Neighbors_sub_carrier_table~=0
        Available_space_in_neighbors(lent,bret)=LF_max*Nsub_carrier_per_BTS-Available_space_in_neighbors(lent,bret).,
end
end
end
BTS_Nei=e_node_B_Neighbor_matrix.,
BTS_Nei_load=Neighbors_sub_carrier_table.,
BTS_space=sum(Available_space_in_neighbors,2).,
BTS_load=N_sub_carrier_used_at_BTSs.,
Load_max=LF_max*Nsub_carrier_per_BTS.,
A=BTS_Nei.,
B=BTS_Nei_load.,
C=BTS_space.,
D=BTS_load.,
share=0.,
for g=1:length(D)
   k=D.,
for ik=1:length(D)
if k(ik)==0
k(ik)=Nsub_carrier_per_BTS.,
end
end
```

```
for jk=1:length(D)
if k(jk)==min(k)
        m=jk.,
end
end
  i=m.,
if C(i)>=D(i)
D(i)=0.,
for ii=1:length(D)
for jj=1:6
if A(ii,jj)==i
B(ii,jj)=0.,
end
end
end
if (B(i,1)+BTS_load(i))<=Load_max
           B(i,1)=(B(i,1)+BTS_load(i)).,
D(A(i,1))=B(i,1).,
share=share+1.,
else
B(i,1)=Load_max.,
           if B(i,2)+((B(i,1)+BTS_load(i))-Load_max)<=Load_max
           B(i,2)=B(i,2)+((B(i,1)+BTS_load(i))-Load_max).,
D(A(i,2))=B(i,2).,
share=share+1.,
else
B(i,2)=Load_max.,
              if B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-Load_max)<=Load_max
                 B(i,3)=B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-Load_max).,
D(A(i,3))=B(i,3).,
share=share+1.,
else
B(i,3)=Load_max.,
                 if B(i,4)+(B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-Load_max)-
Load_max)<=Load_max
                    B(i,4)=B(i,4)+(B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-
Load_max)-Load_max).,
if A(i,4)~=0
D(A(i,4))=B(i,4).,
share=share+1.,
else
B(i,4)=Load_max.,
                    if B(i,5)+(B(i,4)+(B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-
Load_max)-Load_max)-Load_max)<=Load_max
                       B(i,5)=B(i,5)+(B(i,4)+(B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-
Load_max)-Load_max)-Load_max)-Load_max).,
if A(i,5)~=0
D(A(i,5))=B(i,5).,
share=share+1.,
```

```
end
else
B(i,5)=Load_max.,
B(i,6)=B(i,6)+(B(i,5)+(B(i,4)+(B(i,3)+(B(i,2)+((B(i,1)+BTS_load(i))-Load_max)-Load_max)-Load_max)-Load_max)-Load_max).,
if A(i,6)~=0
D(A(i,6))=B(i,6).,
share=share+1.,
end
end
end
end
end
end
end

end
No_Sharing=share.,
D=B(:,1)'.,
LF_BTSs_new=D/Nsub_carrier_per_BTS
```

Appendix A10

Matlab Code for the Energy Saving Algorithm GUI

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

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

% Last Modified by GUIDE v2.5 30-Apr-2015 13:35:38

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1.,
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @LTE_ENERGY_SAVINGS_OpeningFcn, ...
                   'gui_OutputFcn',  @LTE_ENERGY_SAVINGS_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []).,
if nargin andand ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1}).,
```

```
end

if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:}).,
else
   gui_mainfcn(gui_State, varargin{:}).,
end
function LTE_ENERGY_SAVINGS_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject.,
guidata(hObject, handles).,
function varargout = LTE_ENERGY_SAVINGS_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output.,
function U_category_matrix_Callback(hObject, eventdata, handles)
function U_category_matrix_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function U_category_sinr_matrix_Callback(hObject, eventdata, handles)
function U_category_sinr_matrix_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function Brb_Callback(hObject, eventdata, handles)
function Brb_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function q_Callback(hObject, eventdata, handles)
function q_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function Nsub_carrier_per_rb_Callback(hObject, eventdata, handles)
function Nsub_carrier_per_rb_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function SINR_Callback(hObject, eventdata, handles)
function SINR_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function simulation_time_Callback(hObject, eventdata, handles)
```

```
function simulation_time_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function T_snap_shot_Callback(hObject, eventdata, handles)
function T_snap_shot_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function LF_max_Callback(hObject, eventdata, handles)
function LF_max_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function N_Callback(hObject, eventdata, handles)
function N_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function cell_radius_Callback(hObject, eventdata, handles)
function cell_radius_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function dist_factor_Callback(hObject, eventdata, handles)
function dist_factor_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function A_Callback(hObject, eventdata, handles)
function A_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function B_Callback(hObject, eventdata, handles)
function B_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function Ptx_Callback(hObject, eventdata, handles)
function Ptx_CreateFcn(hObject, eventdata, handles)
```

```
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function Nupe_node_B_Callback(hObject, eventdata, handles)
function Nupe_node_B_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function Nrbpe_node_B_Callback(hObject, eventdata, handles)
function Nrbpe_node_B_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function U_bit_rate_Callback(hObject, eventdata, handles)
function axes1_CreateFcn(hObject, eventdata, handles)
function U_bit_rate_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function sim_time_CreateFcn(hObject, eventdata, handles)
function P_base_case_snap_CreateFcn(hObject, eventdata, handles)
function P_with_savings_s_shot_CreateFcn(hObject, eventdata, handles)
function ENERGY_SAVING_CreateFcn(hObject, eventdata, handles)
function us1_Callback(hObject, eventdata, handles)
function us1_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function us2_Callback(hObject, eventdata, handles)
function us2_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function us3_Callback(hObject, eventdata, handles)
function us3_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function us4_Callback(hObject, eventdata, handles)
function us4_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
```

```
set(hObject,'BackgroundColor','white').,
end
function u1_Callback(hObject, eventdata, handles)
function u1_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function u2_Callback(hObject, eventdata, handles)
function u2_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function u3_Callback(hObject, eventdata, handles)
function u3_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function N_sub_carrier_used_at_e_node_Bss_CreateFcn(hObject, eventdata, handles)
function LF_e_node_Bss_CreateFcn(hObject, eventdata, handles)
function LF_e_node_Bss2_CreateFcn(hObject, eventdata, handles)
function LF_e_node_Bs_news_CreateFcn(hObject, eventdata, handles)
function Power_e_node_Bss_CreateFcn(hObject, eventdata, handles)
function u4_Callback(hObject, eventdata, handles)
function u4_CreateFcn(hObject, eventdata, handles)
if ispc andand isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white').,
end
function TOPOLOGY_Callback(hObject, eventdata, handles)
N=str2double(get(handles.N,'string')).,
cell_radius=str2double(get(handles.cell_radius,'string')).,
topology(N,cell_radius).,
function CELL_PLOTTER_Callback(hObject, eventdata, handles)
N=str2double(get(handles.N,'string')).,
cell_radius=str2double(get(handles.cell_radius,'string')).,
cellploter(N,cell_radius).,
function USERS_Callback(hObject, eventdata, handles)
N=str2double(get(handles.N,'string')).,
cell_radius=str2double(get(handles.cell_radius,'string')).,
dist_factor=str2double(get(handles.dist_factor,'string')).,
Users(N,dist_factor,cell_radius).,
function Simulate_Callback(hObject, eventdata, handles)
set(handles.ENERGY_SAVING,'string',")
set(handles.sim_time,'string',")
set(handles.P_base_case_snap,'string',")
set(handles.P_with_savings_s_shot,'string',")
```

```
N=str2double(get(handles.N,'string')).,
cell_radius=str2double(get(handles.cell_radius,'string')).,
dist_factor=str2double(get(handles.dist_factor,'string')).,
A=str2double(get(handles.A,'string')).,
B=str2double(get(handles.B,'string')).,
Ptx=str2double(get(handles.Ptx,'string')).,
Nupe_node_B=str2double(get(handles.Nupe_node_B,'string')).,
Nrbpe_node_B=str2double(get(handles.Nrbpe_node_B,'string')).,
U_bit_rate=str2double(get(handles.U_bit_rate,'string')).,
U_category_matrix=str2double(get(handles.U_category_matrix,'string')).,
U_category_sinr_matrix=str2double(get(handles.U_category_sinr_matrix,'string')).,
Brb=str2double(get(handles.Brb,'string')).,
q=str2double(get(handles.q,'string')).,
Nsub_carrier_per_rb=str2double(get(handles.Nsub_carrier_per_rb,'string')).,
SINR=str2double(get(handles.SINR,'string')).,
simulation_time=str2double(get(handles.simulation_time,'string')).,
T_snap_shot=str2double(get(handles.T_snap_shot,'string')).,
LF_max=str2double(get(handles.LF_max,'string')).,
us1=str2double(get(handles.us1,'string')).,
us2=str2double(get(handles.us2,'string')).,
us3=str2double(get(handles.us3,'string')).,
us4=str2double(get(handles.us4,'string')).,
u1=str2double(get(handles.u1,'string')).,
u2=str2double(get(handles.u2,'string')).,
u3=str2double(get(handles.u3,'string')).,
u4=str2double(get(handles.u4,'string')).,
US=[us1,us2,us3,us4].,
U=[u1,u2,u3,u4].,
U_category_matrix=[U_category_matrix,U].,
U_category_sinr_matrix=[U_category_sinr_matrix,US].,
[ENERGY,Power_at_t_s,sim_t,N_sub_carrier_used_at_e_node_Bsss,LF_e_node_Bss2s,Pow
er_e_node_Bsss,LF_e_node_Bsss,LF_e_node_Bs_newss]=LTE_energy_saving(N,cell_radiu
s,dist_factor,A,B,Ptx,Nupe_node_B,Nrbpe_node_B,...
                    U_bit_rate,U_category_matrix,U_category_sinr_matrix,...
                    Brb,q,Nsub_carrier_per_rb,SINR,simulation_time,T_snap_shot,LF_max)
P_base_case_s=Power_at_t_s(1).,
P_with_savings_s_s=Power_at_t_s(2).,
ENERGY=num2str(ENERGY).,
sim_t=num2str(sim_t).,
P_base_case_s=num2str(P_base_case_s).,
P_with_savings_s_s=num2str(P_with_savings_s_s).,
set(handles.ENERGY_SAVING,'string',ENERGY)
set(handles.sim_time,'string',sim_t)
set(handles.P_base_case_snap,'string',P_base_case_s)
set(handles.P_with_savings_s_shot,'string',P_with_savings_s_s)
set(handles.N_sub_carrier_used_at_e_node_Bss,'string',N_sub_carrier_used_at_e_node_Bsss
)
set(handles.LF_e_node_Bss2,'string',LF_e_node_Bss2s)
set(handles.Power_e_node_Bss,'string',Power_e_node_Bsss)
```

```
set(handles.LF_e_node_Bss,'string',LF_e_node_Bsss)
set(handles.LF_e_node_Bs_news,'string',LF_e_node_Bs_newss)
function RESET_Callback(hObject, eventdata, handles)
set(handles.ENERGY_SAVING,'string',")
set(handles.sim_time,'string',")
set(handles.P_base_case_snap,'string',")
set(handles.P_with_savings_s_shot,'string',")
```

Appendix A11

Capacity Dimensioning

The maximum number of active mobile stations U that can be served simultaneously by an eNodeB at a time is given as:

$$U = \left\lfloor \frac{(1-\varepsilon)W \times e_{i,j}}{R_{max}} \right\rfloor$$

Where:

$W$is the system bandwidth.,

$\varepsilon$is the percentage guard band which corresponds to 10% for LTE systems

$e_{i,j}$is the spectral efficiency that corresponds to the maximum data rates of mobile stations in the system and it is given by equation (2.5).,

$R_{max}$is the maximum data rate of mobile stations.,

$\lfloor \quad \rfloor$denotes a floor function.

Thus., for $W = 20\ MHz$, and $R_{max} = 512\ kpbs$, the maximum number of active mobile stations U that can be served simultaneously by an eNodeB at a time is estimated as:

$$U = \left\lfloor \frac{(1-0.1) \times 20 \times 10^3 \times 0.75 \log_2(1+12.88)}{512} \right\rfloor$$

$$U = \lfloor 100.0683 \rfloor$$

$$U = 100$$

Appendix A12

Estimation for Cell Radius (Downlink Link Budget)

The down link budget is planned for a maximum data rate of 512 kbps using the parameters given as follows:

Transmitter (Base station)

A. e Node B Transmit power (dBm) = 46
B. TX antenna gain (dB) = 18
C. Cable loss (dB) = 2
D. EIRP (dBm) = $A + B - C = 62$

Receiver (UE)

E. UE noise figure (dB) = 9
F. Thermal noise (dBm) = $10\log_{10}(KTB_{RB}) + 30 = -121.27$

Where $K = 1.38 \times 10^{-23}\, J/K$ (Boltzmann constant), $T = 290\, K$(Kelvin temperature), $B_{RB} = 180\, kHz$ (Bandwidth per resource block)

G. Receiver noise floor (dBm) = $E + F = -121.27$
H. SINR (dB) = 11.1
I. Receiver sensitivity (dBm) = $G + H = -110.17$
J. Interference margin (dB) = 2
K. RX antenna gain (dBi) = 0
L. Body Loss (dB) = 0

Therefore the downlink maximum allowable path loss (DL MAPL) is calculated as follows:

$$DL\ MAPL = D - (I + J + K - L + SFM - SHG + PEL)$$

Where:

SFM: Slow Fading Margin (=9 dB)

SHG: Shadowing Handover Gain (=2.5 dB)

Pel: Penetration loss (=18 dB)

Thus.,

$$DL\ MAPL = D - (I + J + K - L + SFM - SHG + PEL) = 145.67$$

The path loss for the Winner + non–line–of–sight (NLOS) urban macro-cell channel model is given as:

$$P_L = 138.4 + 35.74 \log_{10} d_{i,j} \qquad (dB)$$

Where,

$d_{i,j}$is the distance between user equipment i and e Node B j

The cell radius R is calculated as follows:

$$R = d \quad when \qquad P_L = MAPL$$

Therefore,

$$145.67 = 138.4 + 35.74 \log_{10} R$$

Making R the subject of the formula will yield a cell radius of approximately $1.5\ km$. This was the rationale behind the choosing of a cell radius of $1.5\ km$ in the simulation set up.

(C. Han *et al.*, 2011)(F. Han *et al.*, 2013)(S. Han *et al.*, 2014)(Chiaraviglio *et al.*, 2009)(Niu *et al.*, 2010.,Zhou *et al.*, 2009)(Deng and Balakrishnan, 2012)(Li *et al.*, 2013)(J. Wu *et al.*, 2015)(M. Hossain *et al.*, 2013)(M. F. Hossain *et al.*, 2011)(M. F. Hossain *et al.*, 2012)("3GPP, “Technical Specification Group Radio Access Network., Evolved Universal Terrestrial Radio Access (E-UTRA)., Radio Frequency (RF) system scenarios,” Technical Report, 3GPP TR 36.942 Ver. 11.0.0 Rel. 11, Sep 2012.

,")(Tun and Kunavut, 2014){Wu, 2012 #41}{Wu, 2015 #46}