IMPROVING FAIRNESS IN LOAD BALANCING AMONG RADIO ACCESS TECHNOLOGIES IN HETEROGENEOUS WIRELESS NETWORK

BY

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NIGERIA

MARCH, 2018

DECLARATION

I declare that the work in this Dissertation entitled “IMPROVING FAIRNESS IN LOAD BALANCING AMONG RADIO ACCESS TECHNOLOGIES IN HETEROGENEOUS WIRELESS NETWORK” was carried out by me in the Department of Communications Engineering. 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 another degree or diploma at this or any other institution.

Mahmud ABDULKARIM	__________________	__________________
(Student)	Signature	Date

CERTIFICATION

This Dissertation entitled **“IMPROVING FAIRNESS IN LOAD BALANCING AMONG RADIO ACCESS TECHNOLOGIES IN HETEROGENEOUS WIRELESS NETWORK"** by Mahmud ABDULKARIM meets the regulations governing the award of the degree of Master of Science in Telecommunications Engineering by Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literature.

Dr. A. M. S. Tekanyi ________________ ______________

(Chairman, Supervisory Committee) Signature Date

Dr. A. D. Usman ________________ ______________

(Member, Supervisory Committee) Signature Date

Dr. A. D. Usman ________________ ______________

(Head of Department) Signature Date

Prof. S.Z. Abubakar ________________ ______________

(Dean, School of Postgraduate Studies) Signature Date

DEDICATION

This dissertation is dedicated to Almighty Allah then to my wife and children; Nafisa Ismail, Nabeela Mahmud and Haneef Mahmud.

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In the name of Allah Whose mercies upon us are countless and boundless, I thank Him for life, health and support throughout this research work.

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ABSTRACT

The major problems of most wireless technologies such as EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi and LTE are the imbalance of radio resources allocation as well as unfairness and difficulty to achieve unity index. These result in overstressing the networks while leaving some idle. This imbalance of resources amongst the networks brings about poor quality of service. Most researchers including Donoso et al (2014) tried to resolve the problem using different techniques such as the Round Robin Algorithm (RRA), the Least Connected Algorithm (LCA) and the Min- Max strategy. In an effort to resolve the same problems in heterogeneous wireless networks, the combination of Monte Carlo scheduling algorithm and Load leveling algorithm were used in this research as a developed algorithm for this purpose. The results obtained in this research were then compared with those from Donoso et al (2014). The improvement made by this developed 2- step algorithm of Monte Carlo and Load leveling algorithm achieved global fairness of 2.72% better than Donoso et al (2014), it also showed a strong and steady convergence towards unity which is the desired optimal index in fairness. The significance of the achieved result translates to better resource utilization among the wireless access technologies.

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LIST OF ABBREVIATIONS

3GPP	3rd Generation Partnership Project
ABC	Always Best Connection
BGAN	Broadband Global Network
CSI	Channel State Information
EDGE	Enhanced Data Rate For GSM
ETEP	Etisalat Telecommunications Engineering Program
FDD	Frequency Division Duplex
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Evolved
HSUPA	High Speed Uplink Packet Access
HWN	Heterogeneous Wireless technologies
LAN	Local Area Network
LB	Load Balancing
LC	Least Connected
LLA	Load Leveling Algorithm
LTE	Long Term Evolution
MAN	Metropolitan Area Network
MCA	Monte Carlo Algorithm
MLB	Mobility Load Balancing
QoS	Quality of Service
RA	Randomized Algorithm

RAT	Radio Access Technology
RR	Round Robin
RSSI	Received Signal Strength Indicator
SINR	Signal to Noise plus Interference Ratio
TDMA	Time Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
VHO	Vertical hand over
WAN	Wide Area Network
WiFi G	Wireless Fidelity G (802.11g)
WiFi N	Wireless Fidelity N (802.11n)
WiBRO	Wireless Broadband
WLAN	Wide Local Area Network
WPAN	Wireless Personal Area Network
WMAN	Wireless Metropolitan Area Network
WRRA	Weighted Round Robin Algorithm
WWAN	Wireless Wide Area Network

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF STUDY

The concept of wireless access networks emerged in the late 1980s as a byproduct of cellular wireless technology. As the demand for cellular service exploded worldwide, the cost of wireless network components decreased, while the cost for deploying and maintaining the conventional copper-based subscriber network increased (Gi & Choi, 2008).

The subscriber network, though it appears to be a small part of the overall telecommunications network, in reality occupies a considerably large portion of the overall network expenses, most of which is spent for deployment, operation, and maintenance of the subscriber lines. For this reason, the wireless subscriber network was first deployed in rural areas in the beginning where the initial cost is comparatively low. Later, it has become an effective alternative to the copper-based subscriber network in urban areas. It is very recent that the concept of mobile wireless access network was introduced (Gi & Choi, 2008)

In the past decade, there has been a remarkable growth in the use of wireless and mobile communications while on one hand the number of users accessing such services has increased, the amount of data traffic and types of applications have also increased. Though mobile networks were predominantly for voice communications in the past, the advent of 3G technology has seen a rise in the use of data services also. Hence, these wireless and mobile networks are now used for different types of voice and data communications. The users of these networks expect good service anytime and at anyplace. To cater for this ever increasing demand for data services has led to the development of various radio access technologies like 3G, 4G and IEEE 802.16 WiMAX that support high data rates and long communication ranges(Ali, 2012).

Following the trend of increased mobile usage and high data demand, a global rollout of one new single radio access technology is not to be foreseen because of various needs in different parts of the world due to an unaligned distribution of radio spectrum, and network operators protecting their old investments. There will rather be a variety of existing and new wireless access technologies cooperating in delivering services to the users. This development is leading us into the field of heterogeneous wireless technologies where multiple radio access technologies (UMTS, WLAN, WiMAX, LTE, and coming radio access technologies) are simultaneously used (Andersson, 2010).

1.2 STATEMENT OF RESEARCH PROBLEM

When wireless access networks co-exist to provide services for a number of mobiles, the heterogeneity creates serious issues from how mobiles are seamlessly handed over across the access technologies to how fairly the limited radio resource is utilized. This research considers load balancing in terms of the radio resource and in the end, measures the degree of fairness of the balancing across the heterogeneous wireless technologies.

1.3 SIGNIFICANCE OF THE RESEARCH

Dealing with unequal load distribution of traffic load over different wireless technologies coexisting in the same location and in such a way that there is an even and load sensitive distribution across the networks is a serious concern for researchers in the field of Hetrogeneous Wireless technologies (HetNets) (Mengistie& Ronoh, 2012)

The aim of load balancing is to try to improve the performance of a distributed system, mainly in terms of resource availability or response time by distributing workload amongst a set of cooperating networks (Magade& Patankar, 2014)

Balancing the limited radio resource will avoid over stretching access technologies and in turn reduces call drop rates and frequent handovers which all culminate to bad QoS.

1.4 AIM AND OBJECTIVES

The aim of the work is to develop an efficient decision-making algorithm to perform fair load balancing of radio resource among heterogeneous wireless technologies through the following objectives:

I. To adopt a heterogeneous wireless network model of seven different co-existing seven wireless technologies; EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi and LTE from the work of Donoso et al (2014)

II. To develop a two-step load balancing scheme comprising Randomized algorithm(RA) which is Monte Carlo based and Load leveling algorithm (LLA)

III. To validate the performance of the developed load balancing scheme against Min-Max strategy as presented in Donoso *et* al's work in terms of fairness index.

1.5 SCOPE OF REEARCH

The research was undertaken in the field of Heterogeneous wireless networks comprising seven wireless access technologies; EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi and LTE. The sample considered was a thousand mobiles trying to access these technologies for either of three services; voice, data and video.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

To carry out the research, literature review was carried out, which served as a guide towards achieving the set goals. The review of literature is categorized in to two parts namely: review of fundamental concepts, and review of similar works, which are further discussed as follows.

2.2 REVIEW OF FUNDAMENTAL CONCEPTS

This is an overview of concepts relevant to the study. This includes the overview of Heterogeneous Wireless technologies, a brief on the candidate technologies considered in the research work, Load balancing (LB) as it applies to HWN, LB algorithms pertinent to this work.

2.2.1 Heterogeneous Wireless Technologies

This subsection presents a brief description of the different wireless communication technologies that are considered in this dissertation.

Wireless technologies can be grouped into four categories according to their ranges of coverage, namely: Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN) and Wireless Wide Area Network (WWAN)(Ali, 2012)

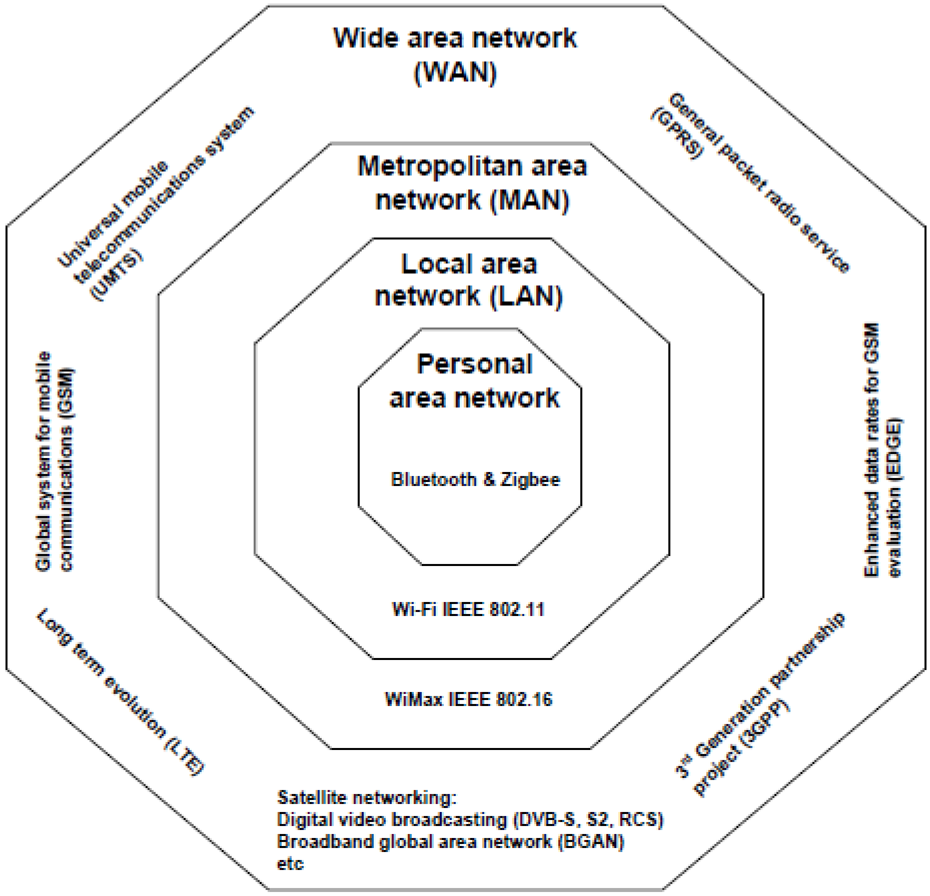

Figure 2.1: Classification of Wireless Technologies(Ali, 2012)

2.2.1.1 Enhanced Data GSM Environment (EDGE)

In the June, 1999 issue of IEEE Personal Communications in titled "EDGE: Enhance Data Rates for GSM and TDMA/136 Evolution" GSM is recognized as one of the second generation wireless technologies with worldwide success(FALL Report, 1999)

Today, three quarters of GSM networks support EDGE, representing more than 350 networks in approximately 150 countries. Because of the very low incremental cost of including EDGE capability in GSM network deployments, virtually all new GSM infrastructure deployments are also EDGE-capable and nearly all new mid- to high-level GSM devices include EDGE radio technology (Rysavy Research, 2008).

The general architecture for the GSM/EDGE network is given in figure 2.2

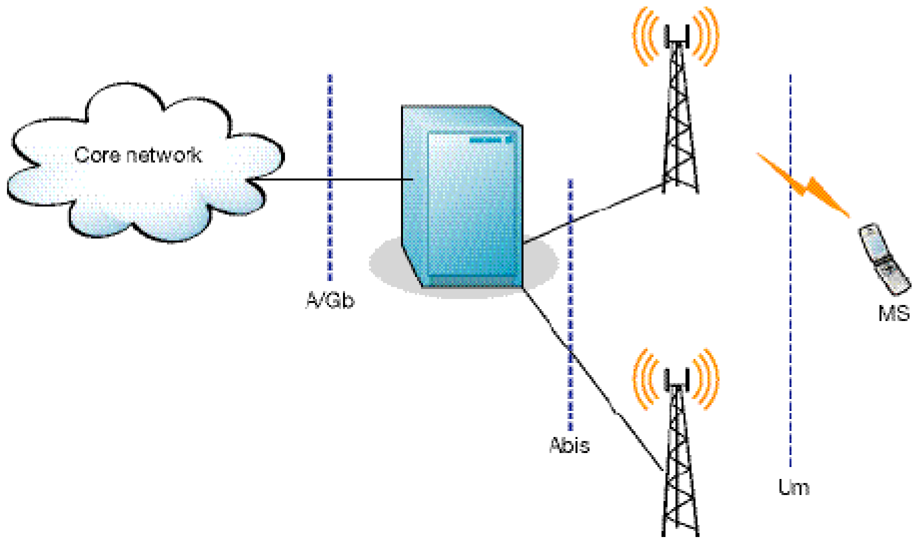

Figure 2.2: GSM/EDGE Architecture (Hakan*et al,* 2006)

2.2.1.2 Universal Mobile Telecommunications System (UMTS)

The UMTS is a third generation (3G) mobile communications system that provides a range of broadband services to the world of wireless and mobile communications. The UMTS delivers low cost, mobile communications at data rates of up to 2 Mbps. It preserves the global roaming capability of second generation GSM/ General Packet Radio Service (GPRS) networks and provides new enhanced capabilities. The UMTS is designed to deliver pictures, graphics, video communications, and other multimedia information, as well as voice and data to mobile wireless subscribers. UMTS also addresses the growing demand of mobile and Internet applications for new capacity in the overcrowded mobile communications sky. The new network increases transmission speed to 2 Mbps per mobile user and establishes a global roaming standard. UMTS allows many more applications to be introduced to a worldwide base of users and provides a vital link between today's multiple GSM systems and the ultimate single worldwide standard for all

mobile telecommunications such as International Mobile Telecommunications–2000 (IMT–2000).

Figure 2.3 gives the general network architecture of the UMTS, where CN, RNS and UE stand for the core network, radio network subsystem and user equipment respectively.

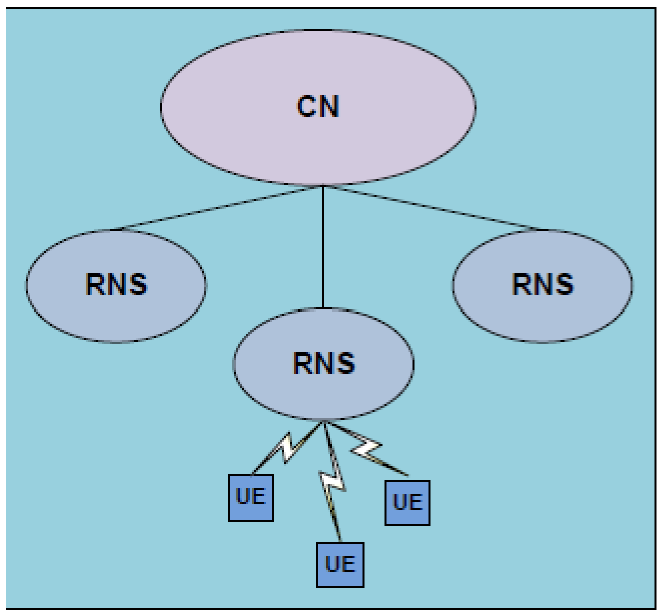

Figure 2.3: UMTS Network Architecture (Ali, 2012)

2.2.1.3 World Wide Interoperability for Microwave Access (WiMAX)

World Wide Interoperability for Microwave Access (WiMAX). It is an effective metropolitan area access technology with many encouraging features such as high speed, cost efficiency and flexibility. The coverage area of WiMAX spans 30 to 50 km. Data rates of more than 100 Mbps in a 20MHz channels are offered(Ali, 2012).

Figure 2.3 gives the general architecture of WiMax, where CSN, ASN, BS, AS and MS stand for Connectivity Service Network, Access Service Network, Base Station, Access Network and Mobile Station respectively.

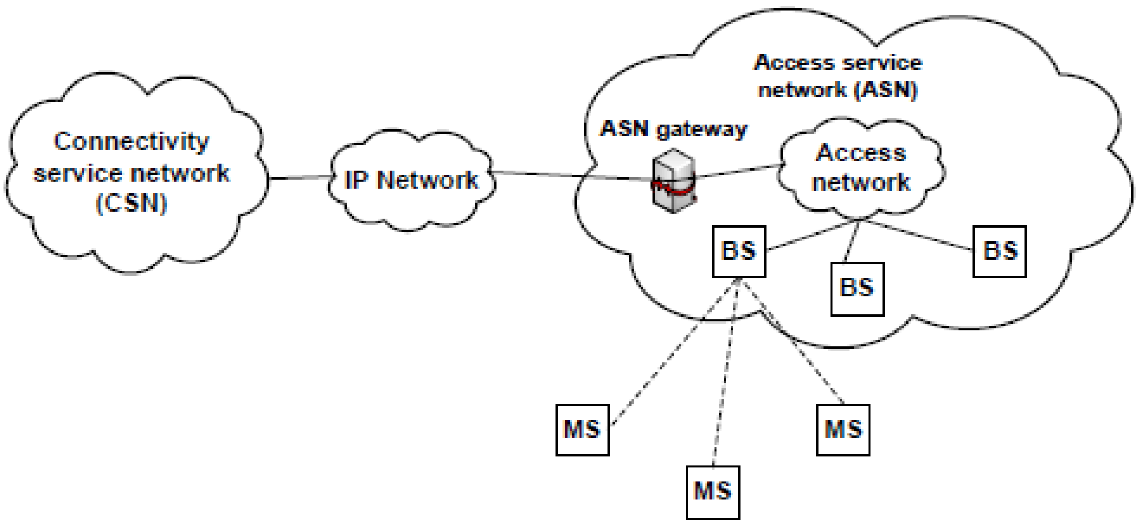

Figure 2.4: WiMAX Network Architecture (Ali, 2014)

2.2.1.4 Wireless Local Area Network (WLAN)

Wireless local area networks (WLANs), like their wired counterparts, are being developed to provide high bandwidth to users in a limited geographical area. WLANs are being studied as an alternative to the high installation and maintenance costs incurred by traditional additions, deletions, and changes experienced in wired LAN infrastructures. Physical and environmental necessity is another driving factor in favor of WLANs. Typically, new building architectures are planned with network connectivity factored into the building requirements. However, users inhabiting existing buildings may find it infeasible to retrofit existing structures for wired network access. Examples of structures that are very difficult to wire include concrete buildings, trading floors, manufacturing facilities, warehouses, and historical buildings. Lastly, the operational environment may not accommodate a wired network, or the network may be temporary and operational for a very short time, making the installation of a wired network impractical. Examples where this is true include ad hoc networking needs such as conference registration centers, campus classrooms, emergency relief centers, and tactical military environments(Crow*et al*, 1997). A simple architecture for WLAN is given in figure 2.5

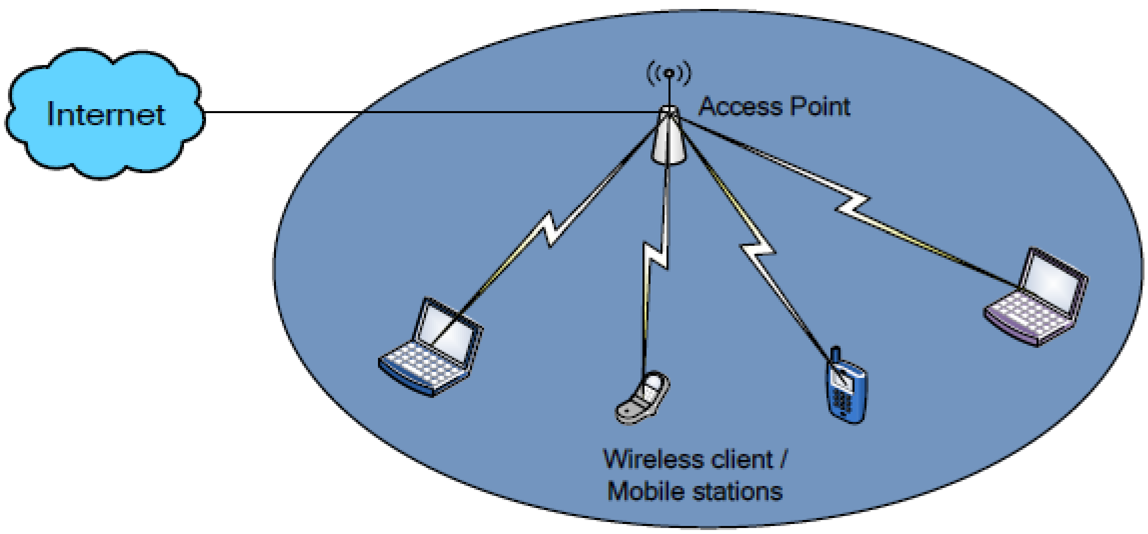

Figure 2.5: Basic WLAN Architecture (Ali, 2012)

2.2.1.5 High Speed Packet Access (HSPA) and HSPA+

HSPA is a third-generation (3G) mobile broadband communications technology. It refers to networks that support both High speed downlink packet access (HSDPA) and High-speed uplink packet access (HSUPA).

HSDPA, specified in 3GPP Release 5, is a high-performance packet-data service that delivers peak theoretical rates of 14 Mbps. Peak user-achievable throughput rates in initial deployments are well over 1 Mbps, and as high as 4 Mbps in some networks. HSDPA is fully backward-compatible with UMTS Release 99, and any application developed for Release 99 will work with HSDPA. The same radio carrier can simultaneously service UMTS voice and data users as well as HSDPA data users. HSDPA also has significantly lower latency, measured today on some networks as low as 70 msec on the data channel(Rysavy Research, 2008).

HSPA+ was introduced in 3GPP Rel.7 and is a combination of HSDPA (3GPP Rel.5) and HSUPA (3GPP Rel.6).HSPA+ is a further enhancement of HSPA that introduces higher order modulation and MIMO, CPC, carrier aggregation, Layer-2 enhancements, architecture improvements in the uplink and downlink. The HSPA+ architecture is shown in figure 2.6.

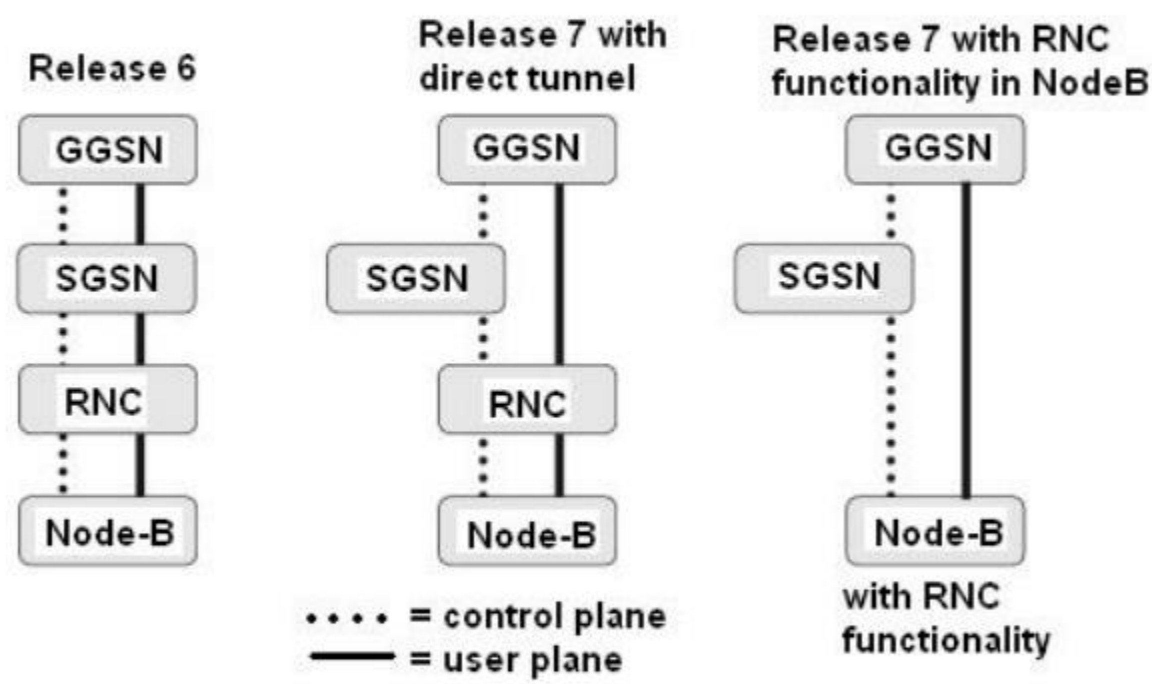

Figure 2.6: HSPA+ Architecture(TEC,2014)

2.2.1.6 Wireless N (IEEE 802.11n) and Wireless G (IEEE 802.11g)

Wireless-N and Wireless-G refer to 802.11n and 802.11g respectively. The 802.11n completely redefines Wi-Fi speed, ushering in a whole new level of network performance.

This standard, 802.11n, promises far greater bandwidth, better range, and reliable than its predecessor 802.11g. Indeed 802.11n has vast advantage in terms of network configurations. WLAN clients may migrate from 802.11g standard to 802.11n because wireless N standard offers better throughput and increased coverage than wireless G standard(Member, Kwantwi, & Akotam, 2011).

Figure 2.7 gives the basic architecture of the WLAN, where ESS,BSS,STA,AP and DS stand for Extended Service Set, Basic Service Set, Station, Access Point and Distribution System respectively.

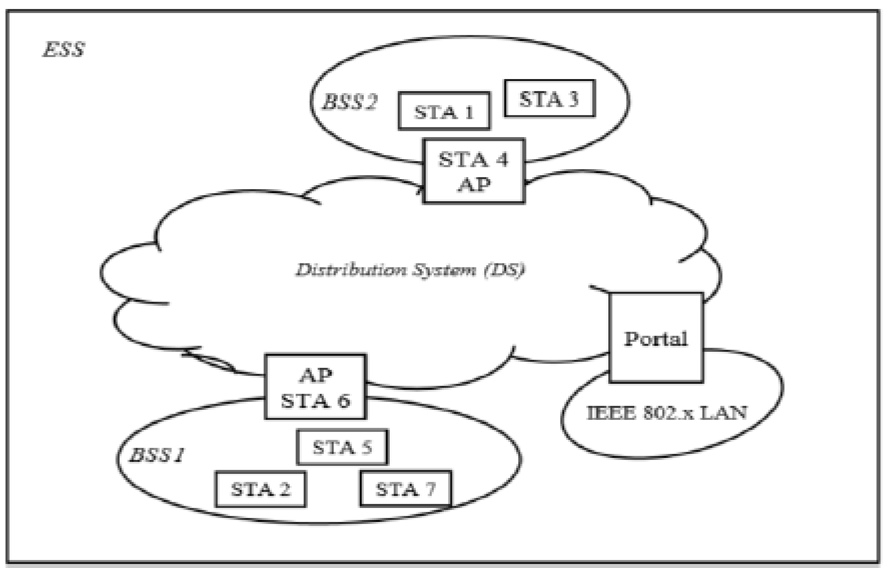

Figure 2.7: WLAN Basic Architecture (Singh *et al*, 2014)

2.2.1.7 Long Term Evolution (LTE)

LTE offers several important benefits for consumers and operators like Performance and capacity of about 100Mbit/s down speed rates. Due its Simplicity, LTE supports flexible carrier bandwidths, from below 5MHz up to 20MHz. LTE also supports both FDD (Frequency Division Duplex) and TDD (Time Division Duplex). Ten paired and four unpaired spectrum bands have so far been identified by 3GPP for LTE. And there are more bands to come. This means that an operator may introduce LTE in 'new' bands where it is easiest to deploy 10MHz or 20MHz carriers, and eventually deploy LTE in all bands. Also LTE provides Wide range of terminals other than mobile phones like many computer and consumer electronic devices, such as notebooks, ultra-portables, gaming devices and cameras (Ericsson, 2007). The general architecture for LTE is given by figure 2.8.

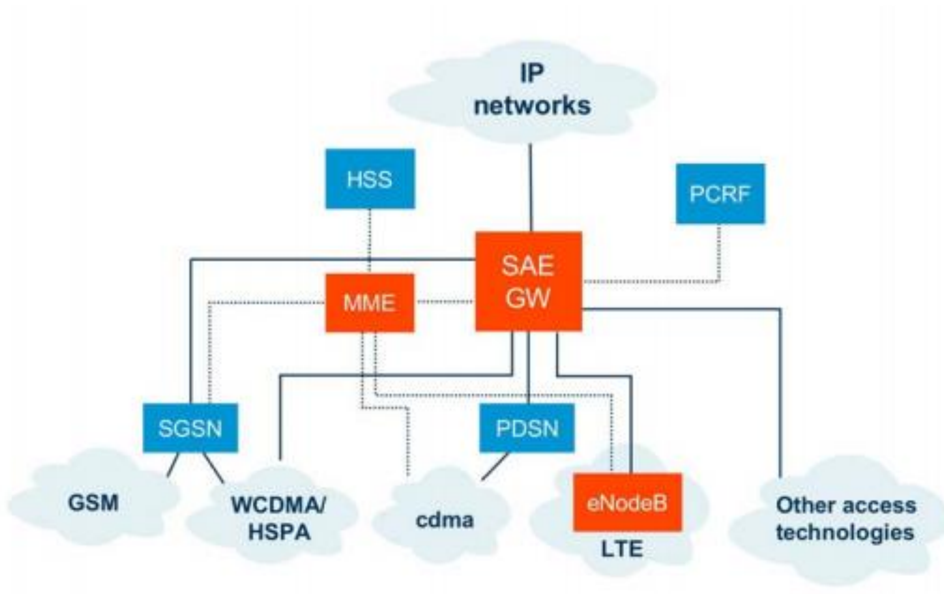

Figure 2.8: Flat Architecture for the LTE (Ericsson, 2007)

2.2.2 Interworking of Heterogeneous Wireless technologies

In modern days, the coverage areas of different wireless technologies overlap or coexist, and this can be utilized in numerous ways to provide connectivity to mobile users anytime, anywhere by providing seamless mobility and resource sharing, or load balancing between heterogeneous wireless technologies. In this topology shown in the Figure 2.9, the coverage areas of WLAN, WiMAX, UMTS, and satellite networks are overlapping each other.

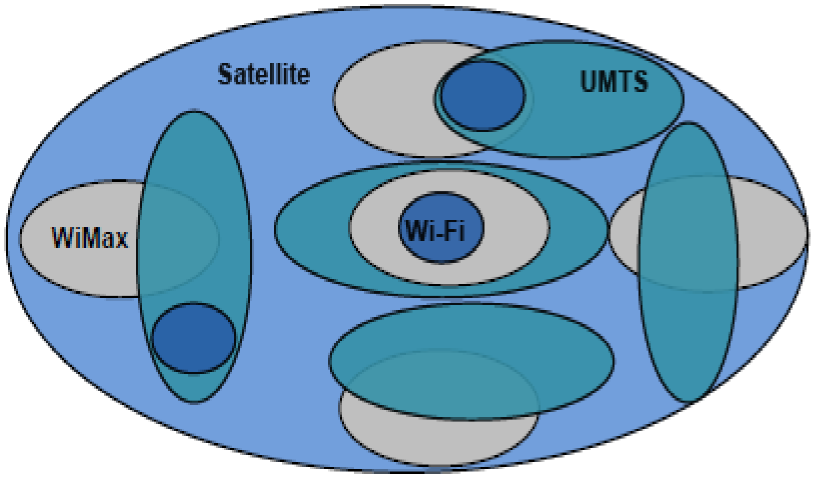

Figure 2.9 : Heterogeneous Wireless Technologies Coverage Areas Coexisting (Ali, 2012)

2.2.3 Load Balancing

In a Heterogeneous Wireless Network environment, load balancing could either mean balancing in terms of the transmit power or the radio resource which is limited. When considering the later, each Radio Access Technology (RAT) has a maximum capacity and over stretching the resource brings about load imbalance. If some RATs are overloaded whereas some other RATs are underutilized, it will result in poor utilization of radio resources. Balancing of traffic load among multiple RATs in heterogeneous wireless network allows for a better utilization of the radio resources (Falowo *et al.*, 2008)

Load balancing in Heterogeneous wireless systems aims to achieve efficient wireless resource utilization, seamless handoff, global mobility with QoS support through load balancing and tight integration with services and applications in the higher layers. After all, in such a heterogeneous wireless access network, a mobile user should be able to connect to the wireless network in a seamless manner. The wsireless resources need to be managed efficiently from the service providers point of view for maximum capacity and improved return on investment (Hossain, 2008)

An efficient load balancing framework would be able to seamlessly move user connections from one technology to another and achieve a more uniform balance across different networks without degrading or compromising the required QoS of users.

In general, load balancing provides an ability to avoid the situation where some resources of the systems are overloaded while others remain idle or under loaded.

There are many load balancing algorithms in use, some are presented in the following subsections.

2.2.3.1 Round Robin Algorithm (RRA)

Round-robin is one of the simplest algorithms used for load balancing, it assigns load to each network equally, handling all load assignment without priority. Round-robin scheduling is both simple, easy to implement and starvation-free. The name of the algorithm comes from the round-robin principle known from other fields, where each person takes an equal share of something in turns (Magade & Patankar, 2014).

Advantage of RRA is that it does not require inter process communication which means it is easy to implement (Vashistha & Jayswal, 2013).

The Round Robin scheduling process generally takes the following flow chart as presented in figure 2.10.

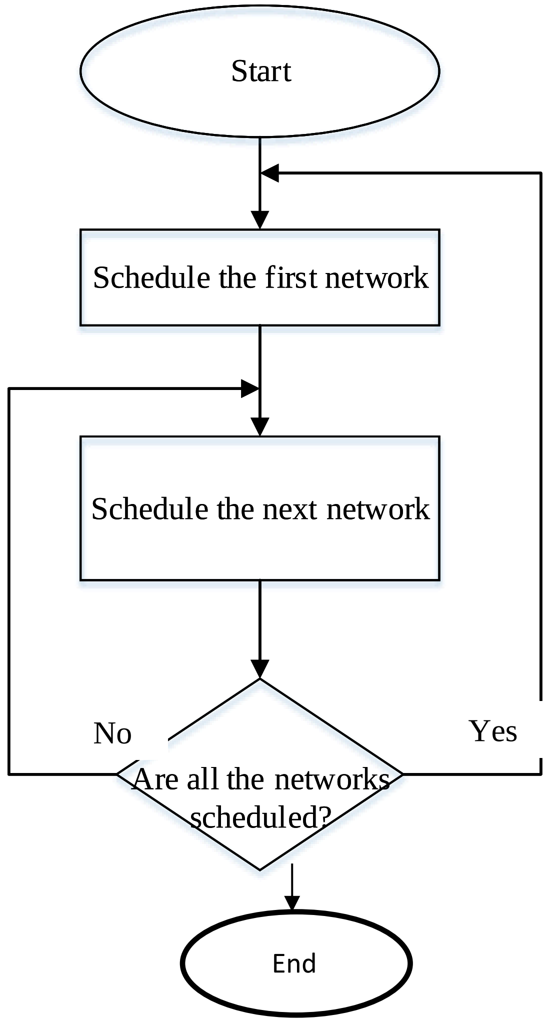

Figure 2.10: flow chart for round robin scheduling process (Abduljalil, 2014)

However, in scenarios where network capacities significantly vary, it cannot distribute the load efficiently. Due to this fact, several modified versions of Round Robin Algorithms are proposed for more robust load balancing which also consider dynamic parameters, these include the Weighted Round Robin Algorithm (WRRA) (Alam *et al.*, 2016).

The following equation represents the network traffic in the WRRA:

$$T_{s_i} = \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{2.1}$$

where T_{s_i} is the percentage of traffic sent to each server, W_i is the weight of the individual server, n is the number of servers and denominator represents the cumulative weight of all servers in the group. The WRRA performs better load distribution among the servers than RRA, however WRLBA shows no significant improvement in load distribution (Alam et al., 2016).

In general Round Robin is not expected to achieve good performance in general case (Vashistha & Jayswal, 2013).

2.2.3.2 Least Connected Algorithm (LCA)

The least-connection scheduling algorithm directs network loads to the network with the least number of established connections. This is one of the dynamic scheduling algorithms because it needs to count live connections for each network dynamically. Least-connection scheduling algorithm assigns new request to the network with the least connection. However, the system performance is not ideal when the processing capabilities of the networks are different (Mustafa, 2015).

At a first look, the least-connection scheduling can also perform well even when there are nodes of various processing capacities, because the faster node will get more connections. But in practice, the least-connection scheduling cannot get the loads well balanced among nodes with various processing capacities (Shengsheng *et al.*, 2005).

Generally speaking, the drawbacks of RRA include high average waiting time, low throughput, context switch, high response time and high turnaround time. While the LCA is very unlikely to perform well in real scenario since the network capacities are different and the algorithm is insensitive to that.

2.2.3.3 Randomized Algorithm (RA)

In random scheduling, an incoming request is sent to a randomly selected network. This policy equalizes the expected number of tasks at each network. The algorithm is very fast and over a period of time it ensures that the requests are fairly distributed. However, if the numbers of requests are small, the probability of imbalance will be very high (Vashistha & Jayswal, 2013).

There are two principal advantages to randomized algorithms. The first advantage is performance; randomized algorithms run faster than the best-known deterministic algorithms for many problems. The second advantage is that many randomized algorithms are simpler to describe and implement than deterministic algorithms of comparable performance (Osman, 1995)

The randomized algorithm used in this work is Monte Carlo based and the choice for it not Las Vegas is informed by ease and speed of implementation. The key to Monte Carlo algorithm is randomness, in this research work services are attached to available RATs at random.

2.2.3.4 Load Leveling Algorithm (LLA)

Load leveling is that the method of improving the performance of the system by shifting loads among the candidate networks. Load leveling is completed so that each RAT within the HWN will have an equivalent quantity of labor throughout, thus increasing the turnout and minimizing the latent period. Leveling the load of wireless technologies uniformly implies that none of the RATs will be idle or partly loaded whereas others are heavily loaded. The benefits of distributing the loads include enlarged resource utilization (Aruna *et al.*, 2014).

The load levelling adopted for this work is based on the randomize quick sort strategy for sorting an array of elements, it ultimate goal is sorting the RATs based on their available bandwidth in comparison to a pivot RAT chosen at random by the algorithm.

2.2.4 Fairness Index

In Wireless networking domain, generally, fairness is attributed to resource sharing or allocation. The consequence of an unfair resource allocation among different individuals may lead to resource starvation, resource wastage or redundant allocation. Jain’s index is one of the earliest proposed and widely studied fairness measures. It can be used generally and gives guidelines for fairness study in various domains. Fairness in an allocation can be represented by the index value. A large value of f(X) represents fairer resource allocation from the system perspective. (*Abduljalil M.A, 2014*)

The general representation of the Jain’s fairness index is given by equation 2.2;

$$f_1 = \frac{\left[\sum_{i=1}^{n} \alpha_i\right]^2}{n \cdot \sum_{i=1}^{n} \alpha_i^2}, \alpha_i \geq 0, \forall_i \tag{2.2}$$

where, n is the number of networks constituting the HWN and α_i is the networks’ load.

The advantages of the Jains’s fairness index are: it is continuous, applies to any number of users, and is bounded between 0 and1.

2.3 REVIEW OF SIMILAR WORKS

Many researchers have proposed different load balancing strategies in order to optimally utilize the available bandwidth without degrading the system performance. Pertinent research work similar to this dissertation are mentioned below:

Ha *et al*., (2009) proposed a dynamic load balancing architecture for heterogeneous wireless network environment constituting three wireless technologies; WLAN, WiMAX and WiBro.

It was claimed that the corporative management strategy introduced in the research achieved fair load balancing among these three networks. However, the work had no provision for vertical handover as it treated all handovers as horizontal and had no metric to even measure the claimed fair load balance.

Zekri *et al.*, (2011) proposed a Vertical Hand Over (VHO) management solution taking quality of Experience (QoE) for decision-making. Each user's QoE on the three networks considered; Wifi, WiMax and UMTS are recorded and scored to be used as a criterion for handover. The latency period is already too high for three networks let alone adding more wireless technologies which will amount to higher decision processing delays, hence poor QoE.

Quoc-Thinh *et al.*, (2011) introduced a new load metric for load balancing that is to be used by a centralized scheduler to decide which network offloads to which. It treats vertical handovers as horizontal which is a major impairment to the algorithm that was designed to improve load balancing among heterogeneous wireless technologies operating on different technologies. The strategy used in the work will only be useful if loads are transferred among same wireless technologies, in which case heterogeneity is no more.

Sun *et al*., (2012) Also proposed solution for group vertical handoffs in heterogeneous environments. Two mobile controlled algorithms and one network assisted algorithm were used to modify the problem associated with mobile controlled algorithm where mobile terminals selfishly select the best network irrespective of the influence of other concurrent vertical handover users. They considered scenarios where mobile users especially in moving trains or vehicles would send handover requests at relatively close time. The obvious drawback of this approach is a poor scalability of the solution, scalability in the sense that the design is not flexible to accept a buildup of more and more users, only effective for few mobile users.

Hao *et al*., (2012) proposed a unified algorithm to achieve mobility load balancing (MLB) for users with different QoS requirements in the LTE network. In the proposed algorithm, a unified load balancing objective function for homogeneous users with the same kind of QoS requirement is constructed with the variables being cell-user connections. The mobile user is ensured to have a good QoS with no consideration to the new cell the user is arriving at which load imbalance as the new cell may at that instance full to capacity. In essence, the work addresses de-loading of congested cells while doing little on the real aspect of load balancing. Consequently, there would be high block rate in the new cell or new network, which is a disadvantage.

Ali, (2012) proposed three RAT selection algorithms for load balancing in heterogeneous wireless technologies, namely: base line least loaded algorithm, fuzzy logic algorithm and Neural – fuzzy algorithm. The least loaded is simple to design and implement. It takes list of parameters as inputs. These inputs include: network cost, data rate, signal strength, user’s required data rate, user’s network preferences (depending upon the cost) and load on each network. While the Fuzzy logic basesd and the Neural- fuzzy algorithms are very difficult to design and complex to implement, the base line least loaded algorithm would have been simpler to design which is an advantage but unfortunately, it will handover load to a least loaded network even if the signal strength from that network is weak, this means QoS is never guaranteed for users.

Sheng *et al*., (2012) adopted an entropy weight method to calculate the real-time performance of each network by considering its signal strength, remaining bandwidth and blocking rate.

These parameters constitute the weight of each network and are regarded as the network's real-time performance, networks are then arranged on a priority list based on their entropy weights. The problem with the algorithm is its trigger for load balancing which is user request, at instances where load imbalance occurs and no new user request is made, existing users may have to experience degraded services.

Kim *et al.*, (2013) presented spectrum breathing as a solution to load imbalance among wireless technologies in heterogeneous wireless environment. Spectrum breathing is a size control (cell breathing) scheme that uses adaptive transmission power control scheme through which heavily loaded cell decreases its coverage and lightly loaded cell expands its coverage by adjusting their transmission power. However, adjusting transmission power easily results in network coverage hole, furthermore the work did not provide effective strategy to quickly handover the pool of users to be moved out of the hitherto overcrowded cells before the breathing in and out. These issues make the load balancing scheme presented ineffective in a heterogeneous wireless environment.

Prasad *et al.*, (2014) studied the problem of maximizing the Proportional Fairness (PF) system utility over heterogeneous wireless technologies (HetNets). The work assumed ideal conditions such as the availability of perfect and instantaneous channel state information (CSI) which is practically not achievable and also availability of dormant cell within the area of consideration was assumed. This may not necessarily hold in crowded areas likely football pitch or market place.

Donoso *et al.*, (2014) initiated their study about the Always Best Connected (ABC) problem in HWN with an approach based on the possibility that the mobile user could make the decisions about which network it wants to be connected. Their algorithm is unlikely to perform well in the real HWN scenario because not all User equipment (UE) are enabled to access all wireless technologies.

Wu *et al.*, (2015) proposed a UE preference-aware network selection algorithm for a multi-RAT HetNet that consists of LTE, WiFi and integrated LTE femto-WiFi nodes. It has been argued that the proposed algorithm performs well in terms of fairness, throughput maximisation and energy saving. However, it has been assumed that the WiFi capacity is similar to the LTE, based on the perceived SINR. This is definitely not true as LTE is known to have larger bandwidth capacity than WiFi and again SINR is relative.

Appollonio, (2015) designed a self-management algorithm for high density wireless technologies which was defined as IEEE 802.11 b/g and are both WIFI specifications. The work proposed an optimized channel assignment in distributed and centralized manners. The distributed comprises the coordinated and the uncoordinated scenarios. The work is so limited in the sense that it has no room for scalability, it only works for WIFI and not every equipment is wifi-enabled. The field of Heterogeneous wireless technologies has grown so big that as much as seven wireless technologies are collocated for better user experience.

Hu *et al.*, (2016) proposed an adaptive network selection algorithm that selects networks based on their dynamic conditions like bandwidth and signal strength. The algorithm is said to achieve an efficient data off-loading while guaranteeing a good quality of services (QoS) for users. However, they assumed that the capacity of WiFi is fixed, if truly it is fixed then the basis upon which the algorithm is built stands no more because no network is having fixed capacity while it is partaking in load balancing.

From the literatures reviewed so far, it could clearly be seen that researches are ongoing in the heterogeneous wireless technologies scenario, all in an attempt to solve the load imbalance issue associated with Heterogeneous wireless technologies, but most works are either very complex to evaluate or not scalable and others who claimed fairness in load balancing have no metric to even measure the level of fairness, among other shortcomings. Hence there is need to develop an efficient decision-making algorithm to perform a load balancing in a heterogeneous wireless network to maximize the system performance by avoiding the load imbalance issue while still ensuring good QoS for users.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the detailed procedure carried out in developing the heterogeneous wireless network model and the algorithms used in solving the resource allocation problem in HWN.

3.2 METHODOLOGY

The following methodology was adopted in carrying out the research work:

I. Adoption of:

   a) A heterogeneous wireless network model comprising seven different Radio Access technologies co-existing to serve many mobile users. These Radio Access Technologies are: EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi and LTE.

   b) Development of A two-step load balancing scheme constituted by Randomised algorithm which is Monte Carlo based and Load levelling algorithm.

II. Implementation of (i) using system level simulator on Matlab 2013b.

III. Evaluation and comparison of the system level performance of the developed algorithm in terms of Load balancing against RRA, LCA and Min-Max strategy using the Jain's fairness index.

3.3 SYTEM MODEL

As a result of limited nature of resources, an improper allocation would impair seriously on the performance of the network and consequently give a wrong perception to the users. So, there is a need to define a mathematical model that encodes user requirements and factor in some constraints to make it perform well when deployed in real life scenario.

3.3.1 Network Model

Let N, M and S be the sets of *n*RATs, *m* mobiles and *s* services that compose a Cellular System, respectively as shown in Equation 3.1. Additionally, let $y_{j,K} \in [0,1]$ be a binary parameter that indicates if the service *k* of the mobile *j* is activated or not. We calculate the load of the network *i* (α_i) as the sum of demanded bandwidth (D_k) of each connected service (*k*),for each mobile (*j*) over the total capacity of the network channel (C_i) (Donoso et al., 2014)

$$\alpha_i = \frac{\sum_{j=1}^{m} \sum_{k=1}^{s} D_k \cdot x_{i,j}^{k} \cdot y_{j,k}}{C_i}, \forall_i \quad (3.1)$$

where $x_{i,j}^{k} = 1$ if the service *k* of the mobile *j* is connected to the network *i*,or 0 if otherwise.

3.3.1.1 QoS Constraints

The following equations represent the constraints factored into the network model to model it as a real scenario as adopted in the work of (Donoso et al., 2014):

The Bandwidth constraint is given equation 3.2

$$D_k \cdot x_{i,j}^{k} \leq AB_i \forall_i \in N, \forall_i \in M, \forall_i \in S \quad (3.2)$$

where $AB_i$is the available bandwidth of the network i

Equation (3.2) is so because the demanded bandwidth should not go beyond the available bandwidth.

The RSSI constraint is given by equation 3.3

$$x_{i,j}^{k} \leq Z_{i,j}^{k} \forall_i \in N, \forall_i \in M, \forall_i \in S \quad (3.3)$$

where $Z_{i,j}^{k} = 1$ if $\frac{RSSI_{i,j}^{k}}{RSSI_{th}} \geq 1, or\ 0\ if\ otherwise.$ (3.4)

The activated constraint which is given by equation 3.5 ensures that all activated services of each mobile *j* must be connected to some network in N, and it is given by;

$$x_{i,j}^{k} \leq \ y_{j,k} \forall_i \in N, \forall_i \in M, \forall_i \in S \quad (3.5)$$

while the connectivity constraint given by equation 3.6 ensures that each service by the mobile *j* is connected to only one network at a time and is represented as;

$$\sum_{i=1}^{n} x_{i,j}^{k} = \{z_{i,j}^{k}. y_{j,k}\} \forall_j \in M, \forall_k \in S \quad (3.6)$$

3.3.2 The received signal strength indicator (RSSI)

The received signal strength indicator (RSSI) is derived from the received signal strength, equation 3.7, and thus, within embedded devices, it is defined as a ratio of the received power to the reference power (p_{ref}) as adopted by (Raheemah*et al*, 2015).

$$RSSI[dBm] = 10 \cdot log_{10} \left(\frac{p_r}{p_{ref}}\right) \quad (3.7)$$

where p_r is the power of receiving device, and is given as;

$$p_r = p_t \cdot G_t \cdot G_r \left(\frac{\gamma}{4\pi d}\right)^2 \tag{3.8}$$

where p_t is power of at the transmitting device,

G_t and G_r are the transmitter and receiver gains,

γ is the signal wavelength

d is the separation distance between sender and receiver

Typically, the reference power represents an absolute value ofp_{ref} =1mWatts (Raheemah et al., 2015).

3.3.3 Jain's Fairness Index

Load balancing is aimed at achieving fair distribution of loads among networks. Usually, there would be a measure of fairness at the end of the load balance. One such measures is the Jain's fairness index is widely used for this purpose and is given by (Mengistie & Ronoh, 2012):

$$f_x = \frac{[\sum_{i=1}^{n} \alpha_i]^2}{n \cdot \sum_{i=1}^{n} \alpha_i^2}, \alpha_i \geq 0, \forall_i \tag{3.9}$$

where, n is the number of networks constituting the HWN and α_i is the networks' load.
$'f_x'$ is the objective function that the algorithm seeks to maximize.

3.4 ROUND ROBIN, LEAST CONNECTED AND THE DEVELOPED ALGORITHMS

This subsection presents the pseudo codes of the developed algorithm with the other two algorithms

3.4.1 Round Robin Algorithm

The RRA distributes traffic loads to the networks in rounds without priority and regardless of the network capacities. In Round Robin scheduling, no network will be regranted more load before all other networks are exhausted i.e. before the completion of the first round (Abduljalil, 2014).

The pseudo codes for the Round Robin are given as thus:

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \ldots, t_p\}$, $\forall_j \in M$, $\forall_k \in S$ and $p \leq n$
Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, \ldots, x^s_{n,m}\}$
Ensure: A (re) allocation of each used service by each connected mobile device.

$$i_{new} \leftarrow -1;$$

for $1 \leq j \leq m$ **do**

  for $1 \leq k \leq s$ **do**

    $i_{act} \leftarrow i | x^k_{i,j} = 1;$

    $i_{new} \leftarrow (i_{new} + 1) mod(n-1) + 1$

    If $t_{i_{new}} \in AN_{j,k}$ **then**

      $x^k_{i_{act,j}} = 0$, $x^k_{i_{new,j}} = 1;$

    else

      $i \leftarrow$ select a random network index from $AN_{j,k}$;

      $x^k_{i_{act,j}} = 0$, $x^k_{i,j} = 1;$

    end if

  end for

end for

return A set of connections of mobiles and their services X={$x^1_{1,1,........}x^s_{n,m}$}

(Donoso et al., 2014)

3.4.2 Least Connected Algorithm (LCA)

The least connected algorithm is common in the field of load balancing, it depends on the connection on a single node. The load balancer of this algorithm, firstly pick the network that have the smallest number of connection so load can be transferred. The load balancer also maintains the set of connection on every network. Also when new request arrives it connects to the least loaded network (Priyanka *et al*, 2016).

The pseudo codes for the LCA are given below:

Require: List of the set of Available Networks $AN_{j,k}$= {t_1, . . . , t_p}, $\forall_j \in M$, $\forall_k \in S$ and $p \leq n$
Require: Set of actual connection of mobiles and their services X = {$x^1_{1,1}$, . . . ,$x^s_{n,m}$}
Ensure: A (re) allocation of each used service by each connected mobile device.

$i_{new} \leftarrow -1$;

for $1 \leq j \leq m$ **do**

for $1 \leq k \leq s$ **do**

$i_{act} \leftarrow i | x^k_{i,j} = 1$;

i_{new} ← Network with lesss number of connections;

If $t_{i_{new}} \in AN_{j,k}$ **then**

$x^k_{i_{act,j}}$ =0, $x^k_{i_{new,j}} = 1$;

else

i← select a random network index from $AN_{j,k}$;

$x^k_{i_{act,j}}$ =0, $x^k_{i,j} = 1$;

end if

end for

end for

return A set of connections of mobiles and their services X={$x^1_{1,1,........}x^s_{n,m}$}

(Donoso et al., 2014)

3.4.3 Developed Algorithm

The algorithm used to address the load balancing problem in this research work is a 2-step algorithm comprising Monte Carlo's algorithm (MCA) and Load Leveling algorithm (LLA), the interworking relation of the two algorithms is better explained by their flow charts which are as shown in figures 3.1 and 3.2.

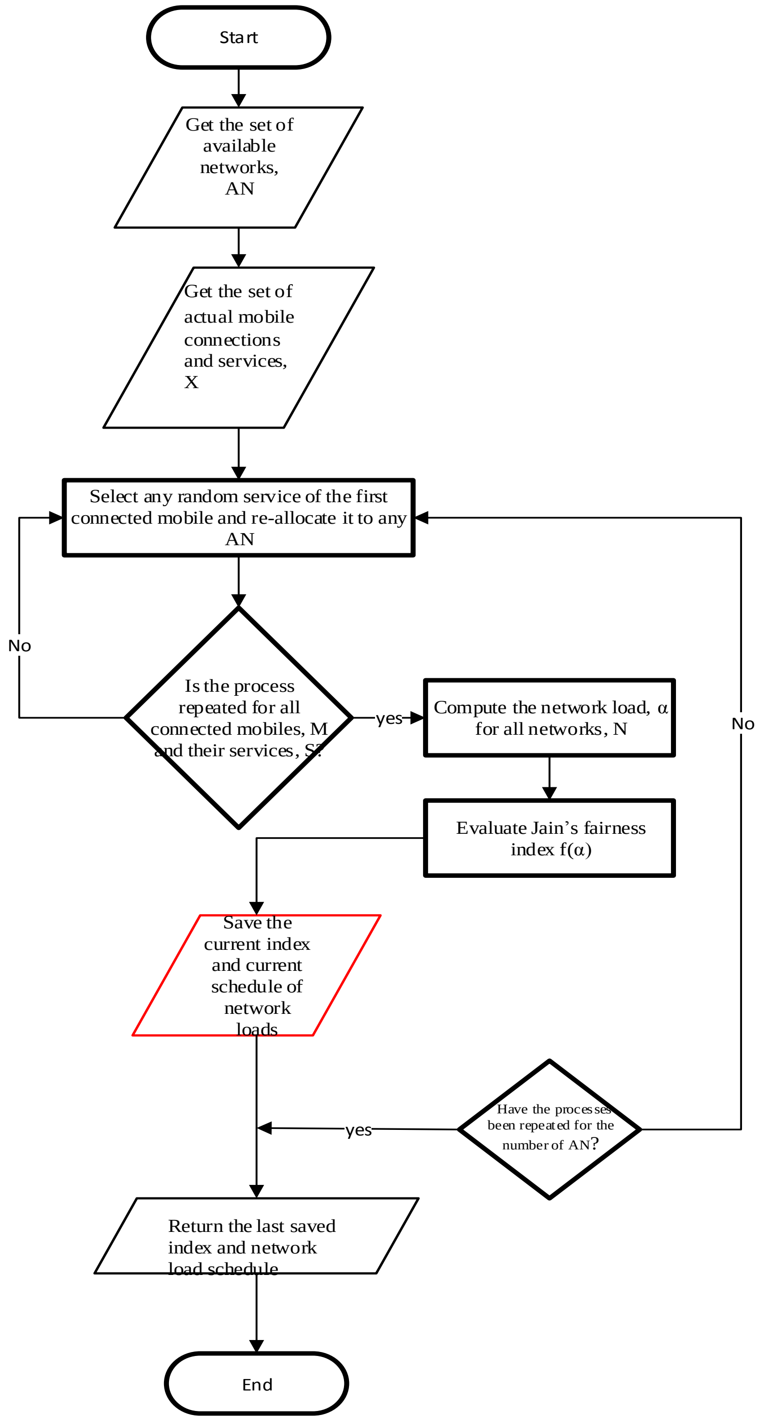

Figure 3.1: Flowchart of Randomized (Monte Carlo based) Algorithm

The flow chart presented in figure 3.1 is based on the Monte Carlo strategy. As noted in chapter two, the key to Monte Carlo scheduling process is randomness. From the flow chart, services and available RATs are selected at random. A final schedule load obtained from algorithm 1 is fed as input for the second algorithm which is the load leveling algorithm and is given as:

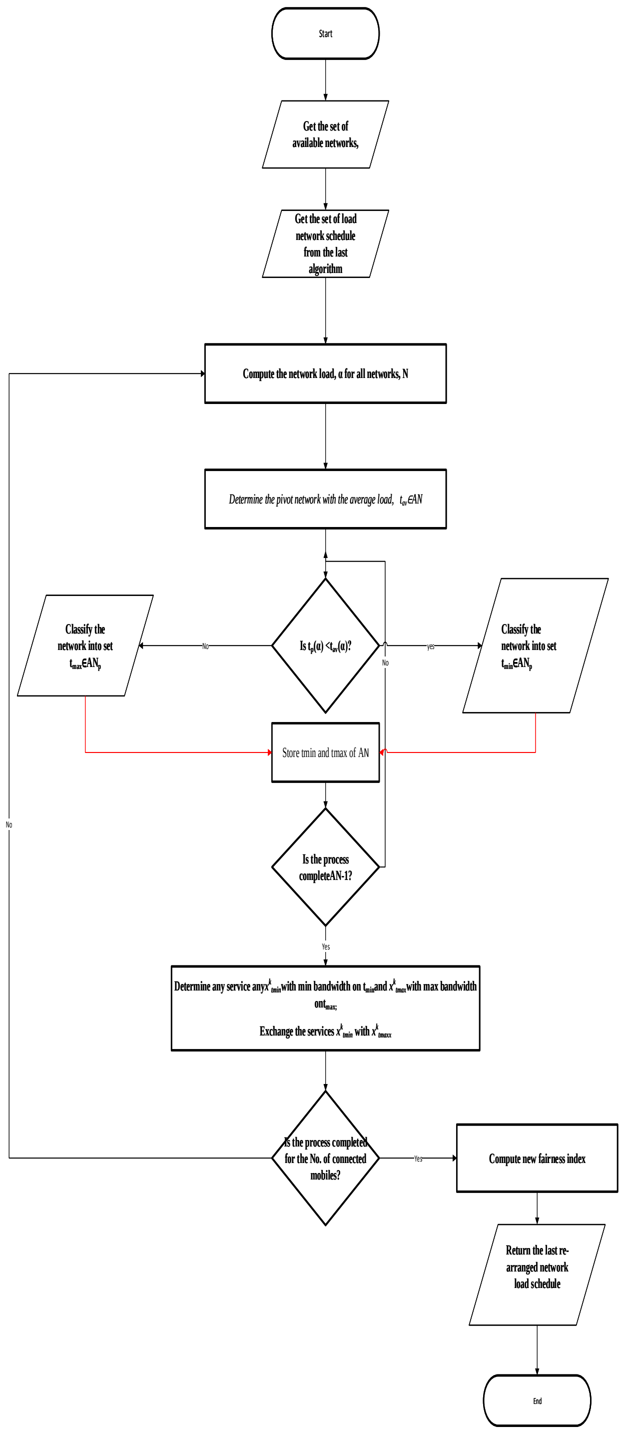

Figure 3.2: Flowchart for the Load Levelling Algorithm

Figure 3.2 gives the flowchart for the Load Levelling Algorithm, it completes the second step of the developed algorithm and basically it fine tunes the load balancing to achieve a fair allocation of the load across the heterogeneous wireless technologies. It utilizes the randomized quick sort strategy for sorting an array of elements. Precisely, the brute force method is applied by picking a network among the wireless technologies constituting the heterogeneous wireless environment at random and making it the pivot network otherwise called the 't_{av}'. In other to complete the sorting, a total of (n-1) comparisons are made against the the t_{av}, networks with load below the the t_{av} are labeled t_{min} while those above t_{av} are labeled t_{max}, logically this looks like arranging the remaining (n-1) networks along the two sides of the pivot. The algorithm further searches for any service with highest bandwidth on any of the networks classified as t_{min}, and also searches the corresponding mobile I.d. on any of the networks classified as t_{max} and then exchanges the services.

In the final lap, the algorithm calculates the new network loads for each network and the new t_{av} then repeats the processes until all the mobiles are sorted in terms of their services.

3.5 SIMULATION SETUP AND ASSUMPTIONS

The model considers a heterogeneous network situation comprising of 21 Base Stations (BS) strategically located in a configuration that can handle a densely populated area typical of a city centre of an urban setup. Each BS consists of switching cells that can connect up to 60 active mobiles requesting one of the three services considered in this research, namely; voice, data and video.

The BSs also provide the User equipment (mobiles requesting connections) with the list of available networks technology under which the requested services from the mobiles can be connected.

Tables 3.1 shows the network technologies used and their bandwidth requirements as adopted by (Donoso et al., 2014). Similarly, Table 3.2 gives the names of the services and minimum bandwidth requirements for obtaining good QoS, also adopted by (Donoso et al., 2014)

Table 3.1: Access Network Bandwidth(Donoso et al., 2014)

Networks	**EDGE**	**HSPA**	**WiMax**	**HSPA**	**WiFi G**	**WiFi**	**LTE**
Bandwidth(Mbps)	0.384	14.4	37.0	42.0	54.0	100	100

Table 3.1 gives the capacity in terms of bandwidth for each of the wireless technologies regarded in this work; these bandwidth capacities would be calculated iteratively by the developed algorithms as the load balancing goes on. This iterative measurement is necessary to achieve a fair load balancing. If the load balancing algorithms are unaware of the accommodated traffic load and the bandwidth capacities of the candidate wireless technologies, the load balancing algorithms would have stood no chance of achieving a fairly balanced load. As an example, Round Robin distributes the loads equally in rounds irrespective of the present load the networks accommodate and regardless of their capacities. While the Least connected algorithm is only aware of the networks' present loads for the sake of allocating more loads to the least connected networks mindless of the impairments that action would cause the networks and the users connected to them.

Table 3.2 gives the service Ids for Voice, Data and Video which are the three services considered in the research and their required bandwidths for a good QoS. Voice has the least bandwidth requirement while Video has the highest. From the table, it could easily be inferred that what a single user requires for a good Video service (0.128Mps) is sufficient for ten users in need of a good Voice service or 4 users in requesting for good Data service without any difficulty.

Table 3.2: Requested Bandwidth For Service (Donoso et al., 2014)

ID	**Service**	**Required Bandwidth (Mbps)**
1	Voice	0.012
2	Data	0.028
3	Video	0.128

The simulation considers a scenario of seven access technologies and three services as shown in Tables 3.1 and 3.2 RRA, LCA and Donoso *et* al's work, an ideal fairness index value of 1.0 was used because that the optimal value every load balancing algorithm seeks to achieve.

CHAPTER FOUR

RESULTS AND DISSCUSSION

4.1 INTRODUCTION

In this chapter, the achieved results in resource load balancing in terms of fairness is presented after been measured with the Jain's fairness index. The achieved results are compared to those of Round Robin, Least connected algorithms and the results of Donoso *et al* (2014). In addition, the errors of the algorithms relative to the ideal fairness index value of unity were presented.

The behavior of the proposed algorithm is observed from 10 mobiles to 1000 mobiles. The sample size of the number of mobiles considered is from 10 to 1000 only.

4.1.1 Distribution of mobiles among the wireless technologies

This subsection presents a number of mobiles with the 7 wireless technologies (EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi, LTE) offering three services, namely; Voice, Data and Video. The mobiles are randomly distributed within the network.

The decision-making strategy of the developed algorithm is noble as no technology is left idle at the expense of overstressing others. A sample of the distribution of 100 mobiles across the seven wireless technologies is presented in Table 4.1.

Table 4.1: Distribution of 100 Mobiles Across the Seven Wireless Technologies

Mobile ID	SERVICES ON NETWORKS VOICE	DATA	VIDEO
1	'WiFi G'	'WiFi N'	'LTE'
2	'EDGE'	'HSPA+'	'LTE'
3	'EDGE'	'WiFi G'	'WiFi N'
4	'HSPA'	'HSPA+'	'WiFi N'
5	'WiMax'	'WiFi G'	'LTE'
6	'EDGE'	'HSPA+'	'LTE'
7	'EDGE'	'HSPA+'	'WiFi N'
8	'HSPA'	'WiMax'	'LTE'
9	'EDGE'	'HSPA+'	'WiFi G'
10	'EDGE'	'WiMax'	'LTE'
11	'HSPA'	'HSPA+'	'WiFi G'
12	'WiMax'	'WiFi N'	'LTE'
13	'EDGE'	'HSPA'	'HSPA+'
14	'EDGE'	'WiMax'	'HSPA+'
15	'WiFi G'	'WiFi N'	'LTE'
16	'HSPA'	'WiFi N'	'LTE'
17	'EDGE'	'HSPA'	'HSPA+'
18	'HSPA'	'WiMax'	'LTE'
19	'EDGE'	'WiMax'	'WiFi N'
20	'EDGE'	'WiFi G'	'LTE'
21	'EDGE'	'HSPA'	'HSPA+'
22	'WiFi G'	'WiFi N'	'LTE'
23	'EDGE'	'HSPA'	'HSPA+'
24	'EDGE'	'HSPA'	'LTE'
25	'EDGE'	'WiMax'	'HSPA+'
26	'EDGE'	'WiMax'	'WiFi G'
27	'EDGE'	'HSPA+'	'LTE'
28	'EDGE'	'HSPA'	'WiFi N'
29	'EDGE'	'HSPA'	'WiFi G'
30	'EDGE'	'HSPA'	'LTE'

Table 4.1 gives a cross section of 100 mobiles where the first 30 mobiles were drawn and tabulated. Looking at the first five mobiles, the seven wireless technologies were all providing one service or the other which means the algorithm does not wait for one technology to be congested before the next one is utilized; instead it brings all capable technologies on board with the aim of achieving balanced load with respect to the radio resource. Another thing evident from Table 4.1 is the fact that no single mobile is connected to the same technology more than once for its requested services (voice, data and video), this is due to the connectivity constraint given by equation 3.6.

Furthermore, while the number of mobiles was varied, the Round Robin and Least Connected Algorithms were both implemented alongside the Developed Algorithm whose pseudo codes are presented in Appendix P and are coded in matlab using equations 3.1 and 3.9, thus used to generate Table 4.2. The superiority of the Developed algorithm in terms of fairness in load balancing was good enough as could be seen in Table 4.2.

Table 4.2: Computed Jain's Index for Varied Number of Mobiles Using the Developed Algorithm

Mobiles	RRA	LCA	Donoso	DA
10	0.7195	0.6754	0.7170	0.7484
30	0.7176	0.7319	0.8900	0.8900
50	0.8493	0.7779	0.7670	0.8827
70	0.8233	0.8310	0.7690	0.8473
100	0.7848	0.8301	0.8820	0.8871
200	0.8070	0.8077	0.7840	0.8870
300	0.8246	0.8181	0.8410	0.8901
400	0.7997	0.8305	0.8780	0.8835
500	0.8001	0.8254	0.9390	0.8836
600	0.8014	0.8079	0.9730	0.9845
700	0.8154	0.8159	0.9900	0.9990
800	0.8058	0.8229	0.9970	0.9850
900	0.8190	0.8304	0.9990	0.9999
1000	0.8052	0.8026	0.9980	0.9994
Total	0.7980	0.8115	0.8874	09119

Table 4.2 shows the fairness indices of varied number of mobiles from 10 to 1000 mobiles, for 10 mobiles the three algorithms performed relatively well though the developed algorithm performed better than the other two. As more mobiles are added to system, the developed algorithm moved closer to unity which is the desired fairness index.

For clarity, Figure 4.1 gives the graphical representation of the fairness indices for the Round Robin, Least connected and the developed algorithm.

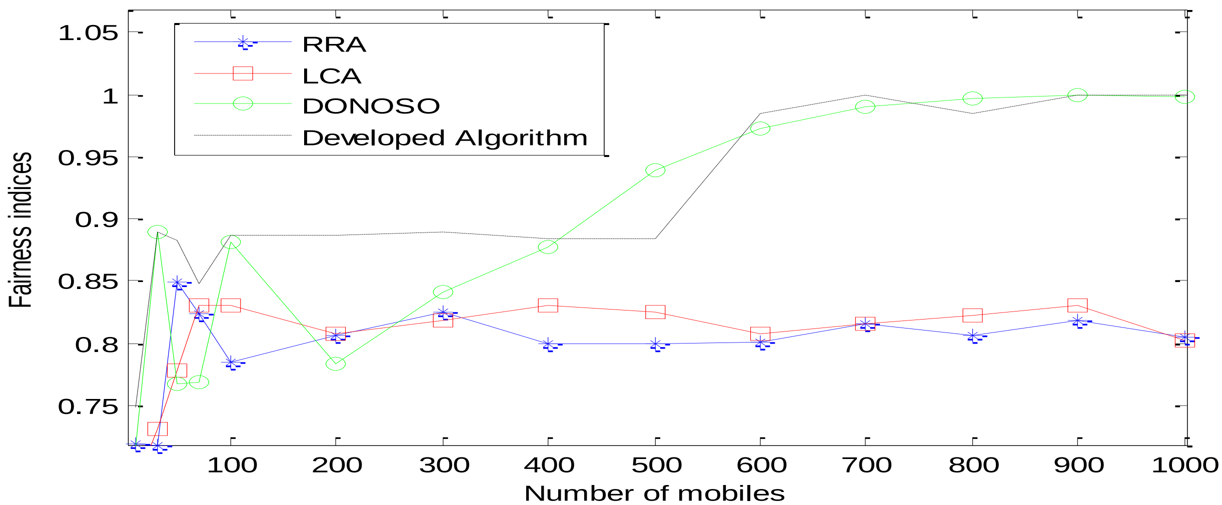

Figure 4.1: Fairness indices for the Round Robin, Least connected, Donoso *et al* and the developed algorithm.

As evident from the graph, aside from outperforming the Round Robin, Least connected, Donoso *et al* algorithms, the developed algorithm shows a steady convergence towards unity (1) which is the desired value for fairness.

From the graph, Donoso *et al'*s results suffer sharp aberrations right from the onset presenting the same problem as the RRA and LCA. This proves the reliability of the developed algorithm which saw a uniform rise from the onset. For mobiles less than 500 the algorithm shows a steady rise in fairness and furthermore, for mobiles more than 500 it shows a steady and strong convergence towards unity which is the desired fairness index.

At around 400 mobiles, the developed algorithm slightly dropped before a sharp rise in fairness, this is as a result of the Monte Carlo algorithm used which can fail at any given time unlike the Las Vegas, in which case the algorithm will continue to run endlessly until the desired result is achieved. The advantages of the Monte Carlo will be its ability to generate results within a finite time and again, such unavoidable failures are rare.

In the next subsection, the relative error of the algorithms was calculated. Table 4.3 gives the relative errors of RRA, LCA, Donoso's and the Developed algorithm.

4.1.2 The Relative Error of RRA, LCA Donoso *et al* and The Developed Algorithm

Another perspective of expressing the fairness of the DA in terms of balancing the radio resource is by measuring the deviation of the computed Jain's fairness index from the desired value of unity, this can be calculated using equation 4.1 and is here in referred to as error rate;

$$\text{Error rate} = \frac{(ideal - computed\ fairness\ index)}{ideal} \times 100\% \quad (4.1)$$

Using Eq. (4.1), Table 4.3 was generated.

Table 4.3: Error of RRA, LCA, Donoso *et al* and DA relative to the ideal value

Mobiles	**RRA**	**Error rate%**	**LCA**	**Error rate%**	**Donoso**	**Error rate%**	**DA**	**Error rate%**
10	0.7195	28.05	0.6754	32.46	0.7170	28.30	0.7484	25.16
30	0.7176	28.24	0.7319	26.81	0.8900	11.00	0.8900	11.00
50	0.8493	15.07	0.7779	22.21	0.7670	23.00	0.8827	11.73
70	0.8233	17.67	0.8310	16.90	0.7690	23.10	0.8473	15.27
100	0.7848	21.52	0.8301	16.99	0.8820	11.80	0.8871	11.29
200	0.8070	19.30	0.8077	19.23	0.7840	21.60	0.8870	11.30
300	0.8246	17.54	0.8181	18.19	0.8410	15.90	0.8901	10.99
400	0.7997	20.03	0.8305	16.95	0.8780	12.20	0.8835	11.65
500	0.8001	19.99	0.8254	17.46	0.9390	6.10	0.8836	11.64
600	0.8014	19.86	0.8079	19.21	0.9730	2.70	0.9845	1.55
700	0.8154	18.46	0.8159	18.41	0.9900	1.00	0.9990	0.10
800	0.8058	19.42	0.8229	17.71	0.9970	0.30	0.9850	1.50
900	0.8190	18.10	0.8304	16.96	0.9990	0.10	0.9999	0.01
1000	0.8052	19.48	0.8026	16.82	0.9980	0.20	0.9994	0.06
Total	0.7980	22.37	0.8115	19.73	0.8874	11.23	0.9119	8.51

Example of how table 4.4 was generated is demonstrated below for 10 mobiles;

a) Round Robin: its computed fairness index for 10 mobiles is 0.7650, using equation 4.1 we have; $Error_{RR_{21}} = \frac{1.0-0.7195}{1.0} \times 100\%$,

$Error_{RR_{21}} = 28.05\%$

b) Least Connected: its computed fairness index for 10 mobiles is 0.7507, $Error_{LC_{21}} = \frac{1.0-06754}{1.0} \times 100\%,$

$Error_{LC_{21}} = 32.46\%$

c) Developed Algorithm: its computed fairness index for the same number of mobiles is 0.7295,

$$Error_{RR_{21}} = \frac{1.0 - 0.7484}{1.0} \times 100\%,$$

$$Error_{RR_{21}} = 25.16\%$$

As means of validation, the average of the varied number of mobiles considered revealed that the developed algorithm has fairer resource utilization than the work of Donoso *et al* (2014). While the later has an average fairness of 0.8874, the developed algorithm has an average of 0.9119. As for the average deviation from the ideal fairness index of 1 (unity), the developed algorithm deviated only by 8.51% from the ideal while Donoso *et al* (2014) had of 11.23% deviation giving the developed algorithm an edge of 2.72%.

This tabular comparison put together all the algorithms considered in this research work including the work of Donoso *et al* (2014) which was used to validate the developed algorithm. Donoso *et al* used a two-step algorithm based on anchor-adjustment heuristic to solve resource allocation problem in HetNets, the first algorithm which is the Max-Min algorithm tries to move mobiles from access wireless networks with maximum load to available access wireless networks with minimum load. On the other hand, the second algorithm further optimizes the results based on local information.

As for the developed algorithm, it has two steps. The first is randomized and is basically Monte Carlo in nature. As with the general case of Monte Carlo which takes random inputs, this algorithm selects services at random and allocates them to any available access networks at random too. The algorithm saves the current fairness index and schedule of the access networks to be used as inputs to the second algorithm.

The second algorithm is the load leveling algorithm whose function is to optimize the results in algorithm 1 by employing the quicksort strategy to sort the access networks based on the available bandwidth resource. The algorithm picks an access network at random and tags it the pivot access network. It then compares the remaining technologies to it sorting them as minimum and maximum access networks accordingly. This brute-force sorting strategy is used to exchange services demanding high bandwidth from minimum access networks to maximum access networks. The final fairness index obtained shows a strong and steady convergence towards unity which is the desired fairness index and as captured in figure 4.1 which is generated from Equations 3.1 and 3.9, while for Donoso *et al* (2014), the pseudo codes presented in Appendix P were used.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter presents the conclusion and shortcomings encountered during the period of this research work as well as the direction for future research.

5.2 CONCLUSION

This research work studied the problem of radio resource load balancing in the field of Heterogeneous Wireless Network. It was established that even though many research works in the field are ongoing, the issue of fairness in balancing the loads across the coexisting wireless technologies is still demanding more attention as many previous research works are deficient in addressing that. `

The developed algorithm which is a two-step heuristic strategy made up of Monte Carlo based algorithm and Load Leveling Algorithm has proved to be a viable solution when compared to Round Robin, Least Connected Algorithms and Min-Max strategy.

The average Jain's Fairness Index for RRA, LCA, Donoso et al., (2014) and DA respectively are: 0.7980, 0.8115,0.8874 and 0.9119. While their Average relative errors are 22.37%, 19.73%, 11.23% and 8.51% respectively. This proves novelty of the DA which is very close to the optimal value of 1.

5.3 SIGNIFICANT CONTRIBUTIONS

The significant contributions of the work are:

i. The developed algorithm outperformed the Round Robin, Least connected algorithms and Donoso's work with an achieved a fairness index close to unity (0.9119).

ii. The work measured the deviation of the achieved fairness from unity (1) which is the ideal value and got a relative error of 8.51%.

5.4 LIMITATIONS AND FUTURE WORK

Even though the research is promising in the area of load balancing in heterogeneous wireless network, it must be acknowledged that it is limited to a maximum of 1000 mobiles. The research work also assumes that all mobile equipment in the model support all the wireless access technologies, but in reality, some mobiles only support older technologies.

For future work, it is recommended that mobile equipment that do not support latest wireless technologies are considered in the design, therefore given the work more real life perspective as these equipment are unlikely to be phased out soon.

Furthermore, the scope of the research could be expanded to accommodate more user equipment beyond the number considered in this research.

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APPENDIX A
Main Function that simulates the network of connected services

```
clc
clear all
close all
dbstopiferror
tic

%  Main Function that simulates the network of connected services
%



%% Global file that stores all the network topology and UE related
parameters. Created in next step
globalSysPara

%% Specify network topology and UE related paramaters to be simulated and
accordingly create SysPara
ConfigureSimulatorInputs

%% Generate the hexagonal eNodeB layout
eNB = GenMacroTopology;

%% Generate UE and/or RRH locations and UE -> Macro/RRH channels for
different network technologies
for k = 1:NumNetworks,

disp(['Network Type',num2str(k) ,Networks(k)]);
%HetNet

% Generate the RRHs
            [rrh] = GenRRH(eNB);

% Generate UE topologies
UELocation = GenUEPosForHetNet(eNB, rrh);

% Generate the Channels
ChnlCap = GenChannelHetNet(eNB, rrh, UELocation);



% UE to Base Station Association
    [CouplingLoss, RxSSI] = UE2BSAssoc(ChnlCap);

CouplingLossAllUEs( (k-1)*NumUE + 1: k*NumUE ) = CouplingLoss;
RxSinrAllUEs( (k-1)*NumUE + 1: k*NumUE ) = RxSSI;

    Capacity(:,k) = abs(CouplingLoss');
    RSSI(:,k) = RxSSI';

end
```

```
toc
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
Algorithms;
NetConnections;
DataCompare;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
```

APPENDIX B

Script that defines the detailed parameters(for scenario one) of the system and stores all of them in SysPara.m

```
f = 1000/3600;
%%
% HetNet
UEHeight = 1.5 ;
BSHeight = 25 ;
InterSiteDist = 500;
theta_tilt = 12 + 90;
        theta_3db = 10;
        phi_3db = 70;
SLL_h = 25;
SLL_v = 20;
        SLL = 25;
MinDistMacroUE = 35;
UEVel = 3*f;
CenterFrequency = 2e9;
BSAntennaGain = 17;
TxPower = 46 + 10*log10(BandWidth/10);
IndoorUEProb = 0.8;
FeederLoss = 0;
NumUEperCell =2 ;

%%


NumUE = NumUEperCell * NumBS;
SysPara=struct('InterSiteDistance',InterSiteDist,...
'BSHeight',BSHeight,...
'MinDistMacroUE',MinDistMacroUE,...
'UEHeight',UEHeight,...
'UEVel',UEVel,...
'phi_3db',phi_3db,...
'theta_3db',theta_3db,...
'theta_tilt',theta_tilt,...
'rot',[0 2*pi/3 -2*pi/3],...
'SLL_h',SLL_h,...
'SLL_v',SLL_v,...
'SLL',SLL,...
'BandWidth',BandWidth,...
'CenterFrequency',CenterFrequency,...
'BSAntennaGain',BSAntennaGain,...
'TxPower',TxPower,...
'UENoiseFigure',7,...
'NumUEperCell',NumUEperCell,...
'NumBS',NumBS,...
'NumUE',NumUE,...
'NumNetworks',NumNetworks,...
'FeederLoss',FeederLoss,...
'HandOverMargin',HandOverMargin,...
'IndoorUEProb',IndoorUEProb);
```

APPENDIX C

Script that defines the detailed parameters(for scenario two) of the system and stores all of them in SysPara.m

```
f = 1000/3600;
%%
% HetNet
UEHeight = 1.5 ;
BSHeight = 25 ;
InterSiteDist = 500;
theta_tilt = 12 + 90;
        theta_3db = 10;
        phi_3db = 70;
SLL_h = 25;
SLL_v = 20;
        SLL = 25;
MinDistMacroUE = 35;
UEVel = 3*f;
CenterFrequency = 2e9;
BSAntennaGain = 17;
TxPower = 46 + 10*log10(BandWidth/10);
IndoorUEProb = 0.8;
FeederLoss = 0;
NumUEperCell =50 ;

%%


NumUE = NumUEperCell * NumBS;
SysPara=struct('InterSiteDistance',InterSiteDist,...
'BSHeight',BSHeight,...
'MinDistMacroUE',MinDistMacroUE,...
'UEHeight',UEHeight,...
'UEVel',UEVel,...
'phi_3db',phi_3db,...
'theta_3db',theta_3db,...
'theta_tilt',theta_tilt,...
'rot',[0 2*pi/3 -2*pi/3],...
'SLL_h',SLL_h,...
'SLL_v',SLL_v,...
'SLL',SLL,...
'BandWidth',BandWidth,...
'CenterFrequency',CenterFrequency,...
'BSAntennaGain',BSAntennaGain,...
'TxPower',TxPower,...
'UENoiseFigure',7,...
'NumUEperCell',NumUEperCell,...
'NumBS',NumBS,...
'NumUE',NumUE,...
'NumNetworks',NumNetworks,...
'FeederLoss',FeederLoss,...
'HandOverMargin',HandOverMargin,...
```

```
'IndoorUEProb',IndoorUEProb);
```

APPENDIX D

Round Robin Algorithm

```
[Ci, fu, Schedule] =
GetConnections(RSSI,Capacity,NetworkBandwidth,ServiceBandwidth,Services);

NumberOfMobiles=  NumUE%
NumberOfServices = length(Services)
FairnessIndexWithoutVHO=fu%This is the fairness index without vertical
handover

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Round Robin Algorithm begins here
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
ScheduleX = Schedule;
inew=0;
for j1=1:NumUE
for k1=1:length(Services)
        i0=find(Schedule(j1,:));
iact=i0(k1);
inew=rem(inew,(NumNetworks))+1;
if (ScheduleX(j1,inew)==0)
ScheduleX(j1,inew)=ScheduleX(j1,iact);
ScheduleX(j1,iact)=0;
else
            i1=randi(length(NumNetworks));
            w1=ScheduleX(j1,i1);
ScheduleX(j1,i1)=ScheduleX(j1,iact);
ScheduleX(j1,iact)=w1;
end
end
end
ScheduleX;
NewAlpha1=zeros(1,NumNetworks);
for r1=1:NumNetworks
NewAlpha1(1,r1)=sum(ScheduleX(:,r1))/Ci(r1);
end
FairnessIndexRRA=((sum(NewAlpha1))^2)/(NumNetworks*sum(NewAlpha1.^2));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
```

APPENDIX E
Least Connected Algorithm

```
ScheduleX1 = Schedule;
inew1=0;
for j2=1:NumUE

        i00=find(Schedule(j2,:));

        iact1=i00(randi(length(Services)));
NumConnectedUE=LeastConnect(NumNetworks, ScheduleX1);
        inew1=find(NumConnectedUE==min(NumConnectedUE));
if (ScheduleX1(j2,inew1)==0)
            ScheduleX1(j2,inew1)=ScheduleX1(j2,iact1);
            ScheduleX1(j2,iact1)=0;
else
            ix1=randi(length(NumNetworks));
            wx1=ScheduleX1(j2,ix1);
            ScheduleX1(j2,ix1)=ScheduleX1(j2,iact1);
            ScheduleX1(j2,iact1)=wx1;
end

end
ScheduleX1;
NewAlpha2=zeros(1,NumNetworks);
for r1=1:NumNetworks
NewAlpha2(1,r1)=sum(ScheduleX1(:,r1))/Ci(r1);
end
FairnessIndexLCA=((sum(NewAlpha2))^2)/(NumNetworks*sum(NewAlpha2.^2));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
```

APPENDIX F

Developed Algorithm

```
% Fisrt Stage: Randomized Algorithm (RA)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%

ScheduleX2 = Schedule;
f1=0;
Band = length(Services);

NewAlpha2=zeros(1,NumNetworks);
forqqq = 1:NumNetworks

for  q3 = 1:NumUE
BandIndex=LocalIndex(Band);
        q4=find(ScheduleX2(q3,:)~=0);
        ScheduleX2(q3,q4)=ServiceBandwidth(BandIndex);
end

for q5=1:NumNetworks
    NewAlpha2(1,q5)=sum(ScheduleX2(:,q5))/(Ci(q5));
end
end
ScheduleX2;
FairnessIndexRA=((sum(NewAlpha2))^2)/((NumNetworks)*sum(NewAlpha2.^2));


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Second Stage: Load Levelling Algorimth (LLA)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%

ScheduleX3=ScheduleX2;
CiX3=Ci;
NewAlphaX3=zeros(1,NumNetworks);

for q7=1:NumNetworks
    NewAlphaX3(1,q7)=sum(ScheduleX3(:,q7))/(CiX3(q7));
end
for lev=1:round(NumUE/length(Services))
Imax=find(NewAlphaX3==max(NewAlphaX3));
Imin=find(NewAlphaX3==min(NewAlphaX3));
NewAve=sum(NewAlphaX3)/length(NewAlphaX3);

if ((NewAlphaX3(Imin)) <NewAve)
    k3max=find(ScheduleX3(:,Imax)==max(ServiceBandwidth));
if (~isempty(k3max))
kx=randi(length(k3max));
wx=ScheduleX3(k3max(kx),Imin);
    ScheduleX3(k3max(kx),Imin)=ScheduleX3(k3max(kx),Imax);
    ScheduleX3(k3max(kx),Imax)=wx;
```

```
end
end

for q7=1:NumNetworks
        NewAlphaX3(1,q7)=sum(ScheduleX3(:,q7))/(CiX3(q7));
end
end
FairnessIndexLLA=((sum(NewAlphaX3))^2)/(NumNetworks*sum(NewAlphaX3.^2));
ScheduleX3;
disp('Fully Developed Algorithms (from RA & LLA) gives:');
FairnessIndexDA=FairnessIndexLLA;

FairnessWVORRALCADVA=[NumUEfuFairnessIndexRRAFairnessIndexLCAFairnessInde
xDA]
%%


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
% Displaying a table of Network Connection for number of Mobiles <=50
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
disp('THIS SECTION SHOWS THE SERVICES CONNECTIONS FOR THE FIRST 50 OR
LESS CONNECTED MOBILES FOR THE DEVELOPED ALGORITHM');
NumberOfServices = length(Services)
NumMobile=0;
[ConnectionsOfServicesToNetworks{NumUE:length(Services)}]=deal([]);
for m1=1:NumUE
    m2=1;
for m3=1:NumNetworks
if (ScheduleX3(m1,m3)~=0)
ConnectionsOfServicesToNetworks(m1,m2)=Networks(m3);
                m2=m2+1;
end
end
NumMobile=NumMobile+1;
if (NumMobile==50)
break;
end
end
ConnectionsOfServicesToNetworks
```

APPENDIX G

Script that appends System Parameters with fields specific to small cell deployments

```
SysPara.RRHHeight = 10;
SysPara.MinDistMacroRRH = 75;
SysPara.MinDistRRH = 40;
SysPara.MinDistRRHUE = 10;
SysPara.RRHAntennaGain = 5;
SysPara.TxPowerRRH=  30 + 10*log10(SysPara.BandWidth/10);
SysPara.NumRRHperMacro = 4;
SysPara.rho = 2/3;
SysPara.RRHRadius = 40;
```

APPENDIX H

```
function [phi,SectIndex] = CalcAngle(p,c)

%  Given a point with coordinates 'p' and a hexagon with center 'c', the
program computes the sector of the hexagon where the point falls.
%  The context of the overall program ensures that the point is contained
within the hexagon
%  For a point outside the hexagon the code is also valid if we assume
that the sectors have also been 'extended' out.
%
%  Inputs
%  p                  - 1 X 2 vector with the x-y coordinates of a point
%  c                  - 1 X 2 vector with the x-y coordinates of the
center of the hexagon
%
%  Outputs:
%  phi                - The azimuth angle of the point w.r.t. the
hexagon center
%  SectIndex          - The sector in which the point falls. Refer to
the main document for assumed sector orientations and coordinate axes.
%

%%
a = p(2) - c(2);
b = p(1) - c(1);

phi = atan2(a,b);
if phi >= pi/6 & phi <= 5*pi/6
SectIndex = 1;
elseif phi >= 5*pi/6 & phi <= pi | phi >= -pi & phi <= -pi/2
SectIndex = 2;
else
SectIndex = 3;
end
```

APPENDIX I

Antenna gain

```
functionAntennaGain = CalcAntennaGain(UEPos,eNB)

%  Generates the combined gains of the horizontal (azimuth) sectorized
and
%  the vertical (elevation) antennas for a given UE to all base
%  cells/sectors. Antenna gains and side lobe levels are specified in
%
%  Inputs:
%  UEPos                  - location of a UE in x-y plane of size 1 X 2
%  eNB                    - struct of eNBs of size 1 X SysPara.NumBS/3

%  Outputs:
%  AntennaGain            - Antennagain vector of size 1 X NumBS which
%                           contains antenna gains of all cells/sectors to
a
%                           given UE
%

%%
globalSysPara

theta_3dB = SysPara.theta_3db;
phi_3dB = SysPara.phi_3db;
theta_tilt = SysPara.theta_tilt;
SLL_h = SysPara.SLL_h;
SLL_v = SysPara.SLL_v;
SLL = SysPara.SLL;
NumBS = SysPara.NumBS;

BSLoc = NaN(NumBS, 3);
UELoc = NaN(NumBS, 3);
BSType = NaN(1, NumBS);

for j = 1:NumBS,
BSLoc(j,:) = [eNB.loc(ceil(j/3),:),SysPara.BSHeight];
UELoc(j,:) = [UEPos, SysPara.UEHeight];
BSType(j) = mod(j-1,3) + 1;
end

x_delta = -BSLoc(:,1) + UELoc(:,1);
y_delta = -BSLoc(:,2) + UELoc(:,2);
D = sqrt(x_delta.^2 + y_delta.^2);

phi = atan2(y_delta,x_delta);

i1 = find (BSType == 1);
phi(i1) = prin_value(phi(i1) - pi/2);
i2 = find (BSType == 2);
phi(i2) = prin_value(phi(i2) - 7*pi/6);
i3 = find (BSType == 3);
```

```
phi(i3) = prin_value(phi(i3) - 11*pi/6);

theta = atan2((BSLoc(:,3) - UELoc(:,3)),D) + pi/2;

theta = theta*180/pi;
phi = phi*180/pi;

AntennaGainH = -min(12*((phi/phi_3dB).^2), SLL_h);
AntennaGainV = -min(12*(((theta-theta_tilt)/theta_3dB).^2), SLL_v);
AntennaGain = -min(-(AntennaGainH+AntennaGainV), SLL);

function y=prin_value(x)
y=mod(x,2*pi);
y=y-2*pi*floor(y/pi);
```

APPENDIX J

Cell Index

```
function [CellIndex,SectIndex] = CalcCellSect(pos,eNB)

%  Given a point wiht x-y coordinates 'pos', the function first checks if
%  it lies within any of the hexagonal areas defined by the various eNBs.
%  If it does lie within a eNB hexagon the function also computes in
which
%  of the three sectors it lies in
%
%  Inputs
%  pos                 - 1 X 2 vector with the x-y coordinates of a
point
%  eNB                 - struct of eNBs of size 1 X SysPara.NumBS/3
%
%  Outputs:
%  CellIndex           - The eNodeB hexagon in which the point falls.
Refer to the main document for assumed sector orientations and coordinate
axes.
%  SectIndex           - The sector in which the point falls. Refer to
the main document for assumed sector orientations and coordinate axes.
%

%%
globalSysPara
NumBS = SysPara.NumBS;

CellIndex = -1;
SectIndex = -1;

for k = 1:NumBS/3
p(1) = pos(1) - eNB.loc(k,1);
p(2) = pos(2) - eNB.loc(k,2);
val = CheckInteriorHex(p);
ifval == 1
CellIndex = k;
c(1) = eNB.loc(k,1);
c(2) = eNB.loc(k,2);
        [~, SectIndex] = CalcAngle(pos,c);
end
end
```

APPENDIX K

Intersite distance

```
%  Given a point with coordinates 'p' and a hexagon with center at the
origin and dimensions as specified in SysPara,
%  the function computes if this point lies within the hexagon.
%
%  Inputs
%  p                    - 1 X 2 vector with the x-y coordinates of a point
%  c                    - 1 X 2 vector with the x-y coordinates of the
center of the hexagon
%
%  Outputs:
%  phi                  - The azimuth angle of the point w.r.t. the
hexagon center
%  SectIndex            - The sector in which the point falls. Refer to
the main document for assumed sector orientations and coordinate axes.
%

%%
globalSysPara
ISD = SysPara.InterSiteDistance;
a = ISD/2;
b = ISD/sqrt(3);

if (p(2) <= a) &&...
        (p(2) >= -a) &&...
        (2*a/b*p(1) + p(2) - 2*a <= 0) &&...
        (-2*a/b*p(1) + p(2) + 2*a >= 0) &&...
        (-2*a/b*p(1) + p(2) - 2*a <= 0) &&...
        (2*a/b*p(1) + p(2) + 2*a >= 0)
val = 1;
else
val = 0;
end
```

APPENDIX L

basic parameters used in the simulation

```
%  Script that defines the basic parameters to be used in the simulation
and also invokes SetSysPara that defines more detailed parameters and
stores all
%  of them in SysPara.m
%

%% Initial Paramaters
NumBS = 21; % Assuming 3 sectors and 7 BS/sector
BandWidth = 10; % units of MHz for wireless channel capacity generation
Networks = {'EDGE','HSPA','WiMax','HSPA+','WiFi G','WiFi N', 'LTE'};

NetworkBandwidth = [0.384, 14.4, 37.0, 42.0, 54.0, 100, 100];
Services = {'Voice', 'Data','Video'};
ServiceBandwidth = [0.012, 0.028, 0.128];

NumNetworks = length(Networks); %5 ;
HandOverMargin = 1;


%%  Specific Parameters

SetSysPara;


AppendSysParaHetNet


RSSI = zeros(NumUE, length(Networks));
Capacity = zeros(NumUE, length(Networks));

CouplingLossAllUEs = zeros(1, NumUEperCell*NumBS*NumNetworks);
RxSinrAllUEs = zeros(1, NumUEperCell*NumBS*NumNetworks);
```

APPENDIX M

Service bandwidth

```
function [NetXX]=Connections(Networks, ServiceBandwidth, Schedule)
NetXX = zeros(length(Networks),length(ServiceBandwidth));
for p3=1:length(Networks)
    Net=zeros(1,length(ServiceBandwidth));
for p4=1:length(ServiceBandwidth)
        Net(1,p4)=length(find(Schedule(:,p3)==ServiceBandwidth(p4)));
end
NetXX(p3,:)=Net;
end
end
```

APPENDIX N

UE Location

```
function [UELocation] = GenUEPosForHetNet(eNB, rrh)

%  Generates the UEs based on a clustered distribution over each 
cell/sector
%  and a minimum distance constraint from the base station and the small
%  cells in that cell/sector. A certain fraction of the UEs (given by
%  SysPara.rho) are clustered around the small cells.
%  Used for hetnet configuration 4b deployments
%
%  Inputs
%  eNB              - struct of eNBs of size 1 X SysPara.NumBS/3
%  rrh              - struct of rrhsos size 1 X SysPara.NumBS * 
SysPara.NumRRHperMacro
%
%  Outputs:
%  UELocation       - struct of UEs of size 1 X SysPara.NumUE with fields
%                     'loc'       : location in x-y plane
%                     'IsUEIndoor': Value '1' indicates an indoor UE, 
'0'an outdoor UE
%

%%
globalSysPara;

NumBS = SysPara.NumBS;
NumUEperCell = SysPara.NumUEperCell;
NumRRHperMacro = SysPara.NumRRHperMacro;
rho = SysPara.rho;
ISD = SysPara.InterSiteDistance;
MinDistMacroUE = SysPara.MinDistMacroUE;
MinDistRRHUE = SysPara.MinDistRRHUE;
NumUE = SysPara.NumUE;

Nrrh = floor(rho*NumUEperCell/NumRRHperMacro);
nMacro = NumUEperCell - Nrrh*NumRRHperMacro;

UELocation(1:NumUE) = struct('loc',NaN,'IsUEIndoor',NaN);
UEIndx = 0;

for k = 1: NumBS,
for n = 1: NumRRHperMacro,
rrhindex = (k-1)*NumRRHperMacro + n;
nUeRRH = 0;
whilenUeRRH<Nrrh
ps = GenUserPosCirc(rrhindex, rrh, eNB);
UEIndx = UEIndx + 1;
nUeRRH = nUeRRH + 1;
UELocation(UEIndx).pos = ps;
UELocation(UEIndx).IsUEIndoor = rand <SysPara.IndoorUEProb;
end
end
end
```

```
for k = 1: NumBS/3

UECount = zeros(1,3);

whileUECount(1) <nMacro || UECount(2) <nMacro || UECount(3) <nMacro
        check = 'true';

whilestrcmpi(check, 'true')
pos = GenIntHex(ISD);
            c = [0, 0];
            [~,SectIndex] = CalcAngle(pos,c);
            check = 'false';
if norm(pos) <MinDistMacroUE
                check = 'true';
else
for m = 1: NumRRHperMacro*NumBS,
if norm(rrh(m).loc - pos - eNB.loc(k,:)) <MinDistRRHUE
                        check = 'true';
break;
end
end
end

ifstrcmpi (check, 'false')
ifUECount(SectIndex) <nMacro
UECount(SectIndex) = UECount(SectIndex) + 1;
else
                    check = 'true';
end
end
end

ps = pos + eNB.loc(k,:);
UEIndx = UEIndx + 1;

UELocation(UEIndx).pos = ps;
UELocation(UEIndx).IsUEIndoor = rand <SysPara.IndoorUEProb;
end

end


functionpos = GenUserPosCirc(rrhindex, rrh, eNB)

globalSysPara;
Th_rrh = SysPara.MinDistRRHUE;
RRHRadius = SysPara.RRHRadius;
NumRRHperMacro = SysPara.NumRRHperMacro;
NumBS = SysPara.NumBS;

check = 'true' ;

% Generate points in the 19 cell hexagonal layout directly
```

```
whilestrcmpi (check, 'true')

pos(1) = -RRHRadius + 2*RRHRadius*rand;
pos(2) = -RRHRadius + 2*RRHRadius*rand;
if norm(pos) >= Th_rrh&& norm(pos) <= RRHRadius
        check = 'false';
end

pos = pos + rrh(rrhindex).loc;

for k = 1: NumRRHperMacro*NumBS,
if norm(rrh(k).loc - pos) <Th_rrh
            check = 'true';
break;
end
end

    [CellIndx, ~] = CalcCellSect(pos,eNB);
ifCellIndx == -1
        check = 'true';
end
end
```

APPENDIX O

The pseudo codes for the flow charts of the developed algorithm

Summary of Algorithms

Require: List of the set of Available Networks $AN_{j,k}= \{t_1, . . . , t_p\}$, $\forall_j \in M$, $\forall_k \in S$ and $p \leq n$
Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, . . . ,x^s_{n,m}\}$
Ensure: A (re) allocation of each used service by each connected mobile device.

Run: Randomized Algorithm based on random allocation to available network (Algorithm 1)
Return a set of connections of mobiles and their services $X = \{x^1_{1,1}, . . . ,x^s_{n,m}\}$
Run: Load Levelling Algorithm based on network demanded bandwidth (Algorithm 2)
Return a set of connections of mobiles and their services $X = \{x^1_{1,1}, . . . ,x^s_{n,m}\}$

Algorithm 1: Randomized Algorithm based on random allocation strategy

Require: List of the set of Available Networks $AN_{j,k}= \{t_1, . . . , t_p\}$, $\forall_j \in M$, $\forall_k \in S$ and $p \leq n$
Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, . . . ,x^s_{n,m}\}$
Ensure: A (re) allocation of each used service by each connected mobile device.

Select at random required services from $\{x^1_{1,1}, . . . ,x^s_{n,m}\}$
Allocate $AN_{j,k} \leftarrow \{x^1_{1,1}, . . . , x^s_{n,m}\}$
Repeat 1 and 2 $\forall_j \in M$, $\forall_k \in S$
Compute α_i, $\forall_i \in N$;
Evaluate $f(\alpha_i,)$
Repeat 1 to 5, $\forall_i \in N$,
Select $f(\alpha_i,) \leftarrow | f(\alpha_i,)_{max}$
Return a set of connections of mobiles and their services $X = \{x^1_{1,1}, . . . , x^s_{n,m}\}$ for selected $f(\alpha_i,)$

Algorithm 2: Load Levelling Algorithm based on randomized quick sort

Require: List of the set of Available Networks $AN_{j,k}= \{t_1, . . . , t_p\}$, $\forall_j \in M$, $\forall_k \in S$ and $p \leq n$
Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, . . . ,x^s_{n,m}\}$ (from Algorithm 1)
Ensure: A (re) allocation of each used service by each connected mobile device.

For $1 \leq j \leq m$ do
Compute α_i,
Determine the pivot network $t_{av} \leftarrow t \mid t \in AN_{j,k}$
For $1 \leq p \leq n-1$
Classify AN into a set of $t_{min} \leftarrow t_p | t_p\{\alpha_t\} < t_{av}\{\alpha_t\}$, and a set of $t_{max} \leftarrow t_p | t_p\{\alpha_t\} > t_{av}\{\alpha_t\}$
End for
Select any $x^k_{tmin} \leftarrow x^k | x^k \in t_{min}(\max x^k)$ and
Select the corresponding $x^k_{tmax} \leftarrow x^k | x^k \in t_{max}(\min x^k)$
Exchange $x = x^k_{tmin,j}$ and $x^k_{tmin,j} = x$

end for
Return a set of connections of mobiles and their services $X = \{x^1_{1,1}, \ldots, x^s_{n,m}\}$

APPENDIX P

Pseudo codes for Donoso*et al* (2014)

Algorithm 1 Two-Step algorithm based on anchor-adjustment heuristic

Require: List of the set of Available Networks $AN_{j,k} = \{t_1,...,t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, \ldots, x^s_{n,m}\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```
Call Anchor algorithm based on a Max-Min strategy at network level (Algorithm 2)
Call Adjustment algorithm based on local information (Algorithm 3)
return A set of connections of mobiles and their services X = {x^1_{1,1}, ..., x^s_{n,m}}
```

Algorithm 2 Anchor based on a Max-Min strategy at network level

Require: List of the set of Available Networks $AN_{j,k} = \{t_1,...,t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connections of mobiles and their services $X = \{x^1_{1,1}, \ldots, x^s_{n,m}\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```
i_max ← 0, i_min ← 0, l ← 0;
repeat
Compute α_i, ∀i∈N;
i_max ← i | i∈N and max{α_i};
    Select any x^k_{i,j} = 1 | i = i_max;
    i_min ← t | t ∈ AN_{j,k} and min_t{α_t};
    if α i_min < α i_max then
        x^k_{i_max,j} = 0, x^k_{i_min,j} = 1;
    end if
    l = l + 1
until l = m · s
return A set of connections of mobiles and their services X = {x^1_{1,1}, ..., x^s_{n,m}}
```

Algorithm 3 Adjustment based on local information

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \ldots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x^1_{1,1}, \ldots, x^s_{n,m}\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```
for 1 ≤ j ≤ m do
    for 1 ≤ k ≤ s do
        i_act ← i | x^k_{i,j} = 1;
        i_min ← t | t ∈ AN_{j,k} and min_t{α_t};
        if α_{i_min} < α_{i_act} then
            x^k_{i_act,j} = 0, x^k_{i_min,j} = 1;
        end if
    end for
end for
return A set of connections of mobiles and their services X = {x^1_{1,1}, ..., x^s_{n,m}}
```