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EFFICIENT RADIO RESOURCE MANAGEMENT ALGORITHMS FOR DOWNLINK LONG TERM EVOLUTION NETWORKS

MAHARAZU MAMMAN

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By

MAHARAZU MAMMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2018

DEDICATIONS

To the most important person in my life: my late Alhaji father Mamman Danhaya Dan-Musa, my mother Aisha for the love care they displayed, which influences me throughout my life.
Also to the big part of my life, my wife Maryam Kasim, my kids Aisha, Abukasim, Muhammad, and Abdulhakim for their tolerance, patient, encouragement to me to try my best from the beginning of this programme until I succeed.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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July 2018

Chairman: Zurina Mohd Hanapi, PhD
Faculty: Computer Science and Information Technology

The increasing demand for wireless network services, particularly for downlink broadband communication has triggered the evolution of cellular networks. The Third Generation Partnership Project (3GPP) introduced the Long Term Evolution (LTE) in response to the forthcoming fourth-generation (4G) cellular networks. LTE is a very complex and large standard. Its performance is dependent on the large range of elements. One of the key essential elements is Radio Resource Management (RRM). RRM has a great impact on the system performance due to many problematic aspects such as packet scheduling, Call Admission Control (CAC) and Energy Efficiency (EE).

With the aim to meet the LTE QoS requirements (i.e. Quality of Service (QoS), fairness provisioning, minimal delay, packet loss, and throughput maximization), the objective of scheduling algorithm is critical to use limited available spectrum. As long as choosing an appropriate scheduling algorithm is not standardized by the 3GPP specification for LTE, vendors are free to adopt, configure and implement their own algorithms depending on the problems of the system. Nevertheless, achieving all the intended objectives simultaneously is difficult. Each problem solved can lead to additional ones. For instance, radio resource algorithms intended to maximize system throughput are not appropriate for handling guaranteed bit rate traffic. Hence, the major problem is developing a scheduling algorithm which creates a trade-off between the system performances.

It is imperative to note that, in spite of the network-wide control schemes to ease transmission order, mobile data content overwhelms the available bandwidth

for each node in many high traffic times. According to this premise, it is understandable that the transmission order is an inevitable issue in LTE mobile networks. Therefore, this thesis examines the efficient resource scheduling algorithms to be resistant to the unpredicted transmission order patterns.

Firstly, a QoS channel quality identifier algorithm is proposed, to support the transmission order of users while considering the QoS requirements as well as the channel condition. The algorithm is based on the idea of the optimization problem in which resource allocation problem is formulated as an optimization problem. Optimal priority algorithm uses minimum data rate to guarantees resource allocation to users but increases the average delay and deteriorate the network performance. Therefore, the proposed algorithm minimizes the average delay and improves the network performance.

In addition to network deterioration, the admitting of users to the network environment contributes to the ineffective use of resources. Thus, we proposed a call admission control algorithm that admits users to utilize available resources. It adaptively defines how users should be admitted, by considering the network conditions.

Furthermore, to deal with the energy consumption problem and provide a trade-off between spectral and energy efficiency, we proposed a spectral and energy efficiency trade-off algorithm. Unlike other algorithms that prolong the battery lifetime by considering the idle state of the base station, thus increasing the average delay and increases the energy consumption. Our algorithms prolong the battery life by adjusting the base station using initial and final states. Consequently, minimizes the average delay as well as low energy consumption. Similarly, the use of omnidirectional antenna to spread radio signals to UEs in all directions causes high interference and low special reuse. We proposed the used of the directional antenna to replaces the omnidirectional antenna by transmitting signals in one direction 60^0 and 120^0 which resulted in no or less interference as well as high spatial reuse.

Substantial simulations have been extensively carried out to evaluate the performance of the proposed algorithms compared with the existing RRM algorithms. The findings demonstrate that the proposed algorithms have shown significant improvements, which includes: lowering delay, minimizes packet loss, improve fairness, and increases the throughput of the system in the proposed QoS channel quality indicator algorithm. Secondly, the proposed call admission control algorithm improved the resource utilization algorithm thus reducing the call block, call dropped, call degradation. This has further enabled the improvement of data throughput. Lastly, reducing the amount of energy consumed and lowering delay is shown in the proposed spectral-energy efficiency algorithm.

Overall, the research has shown promising support and improvements to LTE networks scheduling algorithms and to associated challenges in wireless communication paradigm. Likewise, it would be valuable if the proposed scheduling algorithms are evaluated on anticipated networks covering a large number of users in further research.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA PENGURUSAN SUMBER RADIO YANG BERKESAN BAGI LALUAN MENURUN RANGKAIAN EVOLUSI JANGKA PANJANG

Oleh

MAHARAZU MAMMAN

Julai 2018

Pengerusi: Zurina Mohd Hanapi, PhD
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Permintaan yang semakin meningkat untuk perkhidmatan rangkaian tanpa wayar, terutamanya untuk komunikasi jalur lebar pautan turun telah mencetuskan evolusi rangkaian selular. Projek Perkembangan Generasi Ketiga (3GPP) memperkenalkan Evolusi Jangka Panjang (LTE) sebagai tindak balas kepada rangkaian selular generasi keempat (4G) yang akan datang. LTE adalah standard yang sangat kompleks dan besar. Prestasinya bergantung pada pelbagai elemen yang besar. Salah satu unsur penting ialah Pengurusan Sumber Radio (RRM). RRM mempunyai kesan yang besar terhadap prestasi sistem kerana terdapat banyak aspek yang bermasalah seperti penjadualan paket, Kawalan Kemasukan Panggilan (CAC) dan Kecekapan Tenaga (EE).

Dengan matlamat untuk memenuhi keperluan LTE QoS (iaitu Kualiti Perkhidmatan (QoS), peruntukan keadilan, kelewatan minimum, kehilangan paket, dan pengoptimuman masa penghantaran), objektif algoritma penjadualan adalah penting untuk menggunakan spektrum yang terhad. Pemilihan algoritma penjadualan yang sesuai oleh spesifikasi 3GPP untuk LTE, vendor bebas mengguna pakai, mengkonfigurasi dan melaksanakan algoritma mereka sendiri bergantung kepada masalah sistem. Walau bagaimanapun, mencapai semua matlamat yang dimaksudkan secara serentak adalah sukar. Setiap masalah yang diselesaikan boleh membawa kepada tambahan masalah. Sebagai contoh, algoritma sumber radio yang bertujuan untuk memaksimumkan masa penghantaran sistem tidak sesuai untuk menangani kadar bit lalu lintas. Oleh itu, masalah utama ialah membangunkan algoritma penjadualan yang mewujudkan pertukaran antara keupayaan sistem.

Adalah penting untuk diperhatikan bahawa, walaupun skim kawalan rangkaian bertujuan memudahkan penghantaran pesanan, kandungan data mudah alih melalui jalur lebar yang tersedia untuk setiap nod dalam kesibukan masa trafik yang tinggi. Menurut premis ini, ia dapat difahami bahawa pesanan penghantaran adalah isu yang tidak dapat dielakkan dalam rangkaian mudah alih LTE. Oleh itu, tesis ini mengkaji algoritma penjadualan sumber yang cekap agar bertahan menghadapi corak pesanan penghantaran yang tidak dijangka.

Pertama, algoritma pengecam kualiti saluran QoS dicadangkan, untuk menyokong arahan penghantaran pengguna sambil mempertimbangkan keperluan QoS serta keadaan saluran. Algoritma ini dibina berdasarkan kepada idea masalah pengoptimuman di mana masalah peruntukan sumber dirumuskan sebagai masalah utama pengoptimuman. Algoritma keutamaan optimum menggunakan kadar data minimum untuk menjamin peruntukan sumber kepada pengguna tetapi meningkatkan kelewatan purata dan merosot prestasi rangkaian. Oleh itu, algoritma yang dicadangkan mengurangkan kelewatan purata dan meningkatkan prestasi rangkaian.

Sebagai tambahan kepada kemerosotan rangkaian, pengakuan pengguna ke lingkungan rangkaian menyumbang kepada penggunaan sumber yang tidak berkesan. Oleh itu, kami mencadangkan algoritma kawalan kemasukan panggilan yang mengakui pengguna menggunakan sumber yang ada. Ia bersesuaian mendefinisikan bagaimana pengguna harus diakui, dengan mempertimbangkan keadaan rangkaian.

Selain itu, untuk menangani masalah penggunaan tenaga dan menyediakan pertukaran antara kecekapan spektrum dan tenaga, kami mencadangkan algoritma pertukaran kecekapan spektra dan tenaga. Tidak seperti algoritma lain yang memanjangkan hayat bateri dengan mempertimbangkan keadaan terbiar stesen pangkalan, dimana ia meningkatkan kelewatan purata dan meningkatkan penggunaan tenaga. Algoritma kami memanjangkan hayat bateri dengan menyesuaikan stesen pangkalan menggunakan keadaan awal dan akhir. Oleh itu, ia mengurangkan kelewatan purata serta penggunaan tenaga yang rendah. Begitu juga, penggunaan antena Omni untuk menyebarkan isyarat radio ke UE dalam semua arah menyebabkan gangguan tinggi dan penggunaan yang rendah. Kami mencadangkan penggunaan antena arah untuk menggantikan antena Omni dengan memancarkan isyarat dalam satu arah $(60^0 dan 120^0)$ yang mengakibatkan kekurangan gangguan serta penggunaan semula ruang yang tinggi.

Simulasi substansial telah dijalankan secara meluas untuk menilai prestasi algoritma yang dicadangkan berbanding dengan algoritma RRM sedia ada. Penemuan menunjukkan bahawa algoritma yang dicadangkan telah menunjukkan penambahbaikan yang ketara, yang merangkumi: penundaan kelewatan, mengurangkan kehilangan paket, meningkatkan keadilan, dan meningkatkan keterlambatan sistem dalam algoritma penunjuk kualiti saluran QoS yang dicadangkan. Kedua, algoritma kawalan kemasukan panggilan yang dicadangkan meningkatkan algoritma penggunaan sumber sehingga mengurangkan blok panggilan, panggilan jatuh, dan degradasi panggilan. Ini seterusnya membolehkan peningkatan kadar penghantaran data. Terakhir, mengurangkan jumlah tenaga yang digunakan dan penurunan kelewatan ditunjukkan dalam algoritma kecekapan tenaga spektrum yang dicadangkan.

Secara keseluruhannya, penyelidikan ini telah menunjukkan sokongan dan peningkatan yang menjanjikan kepada algoritma penjadualan rangkaian LTE dan kepada cabaran yang berkaitan dalam paradigma komunikasi tanpa wayar. Ia juga adalah sangat berguna jika algoritma penjadualan yang dicadangkan dinilai pada rangkaian yang dijangka meliputi sejumlah besar pengguna dalam penyelidikan selanjutnya.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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1G	First-Generation
2G	Second-Generation
3G	Third-Generation
3GPP	Third Generation Partnership Project
4G	Fourth-Generation
5G	Fifth-Generation
6G	Sixth-Generation
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
ASE	Area Spectral Efficiency
AUT	Average User Throughput
BE	Best Effort
BFS	Brute Force Search
BLER	Block Error Ratio
CAC	Call Admission Control
CBP	Call Blocking Probability
CDMA	Code Division Multiple Access
CDP	Call Dropping Probability
CQI	Channel Quality Indicator
CRP	Channel Reservation and Preemption
CS	Circuit Switch
CSI	Channel State Information
DL	Downlink
DLSCH	Downlink Shared Channel
DR	Degradation Degree
DR-DD	Degradation Ratio and Degradation Degree
DRX	Discontinuous Reception Mechanism
EC	Effective Capacity
EDGE	Enhanced Data Rate For GSM Evolution
EE	Energy Efficiency
eNodeB	Evolved NodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
EXP-PT	Exponential Proportional Fair
FCFS	First Come First Serve
FD	Frequency Division
FDD	Frequency-Division Duplex
FDMA	Frequency Division Multiple Access
FDPS	Frequency Domain Packet Scheduler
FI	Fairness Index
FTP	File Transfer Protocol
GBR	Guaranteed Bit Rate
GNSSs	Global Navigation Satellite Systems

GPF	Generalized Proportional Fair
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HCDP	Handoff Call Dropping Probability
HMM	Hidden Markov Model
HOL	Head of Line
HOP	Handover Protection
HSDPA	High Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IAT	Inter Arrival Time
IMS	Internet Protocol Multimedia Subsystem
IP	Internet Protocol
ITU	International Telecommunication Union
LOG Rule	Logarithmic Rule
LTE	Long Term Evolution
MAC	Medium Access Control
Max-Rate	Maximum Rate
MCS	Modulation and Coding Scheme
MLWDF	Modified-Largest Weighted Delay First
MME	Mobile Management Entity
MOP	Multi Objective Optimization
MRTR	Minimum Reserved Traffic Rate
MSTR	Maximum Sustained Traffic Rate
MU-MIMO	Multi-User- MIMO
MU-MIMO	Mobile User
Non-GBR	Non-Guaranteed Bit Rate
OFDM	Orthogonal Frequency Division Multiple
OFDMA	Orthogonal Frequency Multiple Access
PDB	Packet Delay Budget
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PER	Packet Error Rate
PF	Proportional Fair
PGW	Packet Gateway
PLR	Packet Loss Ratio
PRB	Physical Resource Block
PS	Packet Switch
QCI	Quality of Service Class Identifier
QoS	Quality of Service
RAN	Radio Network Access
ROI	Region of Interest
RR	Round Robin
RRC	Radio Resource Control
RRM	Radio Resource Management
RSS	Received Signal Strength
RT	Real-Time
SAE	Service Architecture Evolution

SCFDMA	Single Carrier Frequency Multiple Access
SE	Spectral Efficiency
SET	Spectral and Energy Efficiency Trade-Off
SGW	Service Gateway
SINR	Signal to Interference Plus Noise Ratio
SNR	Signal Noise Ratio
SOP	Single Objective Optimization
TCP	Transmission Control Protocol
TD	Time Division
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over Internet Protocol
W-CDMA	Wideband Code CDMA
WFQ	Weighted Fair Queue

CHAPTER 1

INTRODUCTION

For the past decade, the new generation of cellular networks and packet-based mobile broadband technologies have gained significant attention worldwide to support a wide area of services for the ever-increasing number of User Equipment (UE) even in high mobility situations. The expected growth in the increasing rate of mobile data is stimulating the evolution of mobile communication technologies. Third Generation Partnership Project (3GPP) introduced Long Term Evolution (LTE) technology as one of the candidate solutions for the increasing demand for mobile broadband communications (Roessler, 2015). LTE system is anticipated to be able to provide a substantial improvement over the previous mobile standard such as Global System for Mobile (GSM), Universal Mobile Telecommunications System (UMTS), and High-Speed Packet Access (HSPA) (Sesia et al., 2011).

The development of the LTE telecommunication technology to achieve system performance goal has initiate a number of issues to the capability of the radio base station (eNodeB) for managing the bandwidth resources (Qian et al., 2015). Actually, the effective use of scarce share bandwidth is critical to respond the user demands by supporting the current high range of services (Ali-Yahiya and Alagha, 2011). The packet scheduler located at the eNodeB allocates the system radio resources among users for downlink or uplink data transmission (Piro et al., 2011). In this research work, the design of the efficient resource scheduling approaches for downlink transmission in LTE networks will be studied.

Figure 1.1 represents a typical LTE downlink system architecture. The scheduler at the eNodeB manages data transmission in both directions by granting adequate resources to the UEs in Medium Access Control (MAC) layer. All packets from various applications are allotted to a defined bearer. A bearer is a logical connection established between UE and eNodeB. Usually, there are two types of services and subsequent bearers; namely Guaranteed Bit Rate (GBR) and Non-Guaranteed Bit Rate (Non-GBR) (Wang and Hsieh, 2016). When the data from application layer has been scheduled by the scheduler, they are mapped to Physical Resource Block (PRB) for specific frequencies, based on Modulation and Coding Scheme (MCS), and Signal to Interference plus Noise Ratio (SINR) values in physical layer (Salman et al., 2013).

This chapter briefly describes the background for this research, highlighted the research problems and motivations. The chapter also presents the main research objectives, the scope of the research, as well as the contributions of the research. Finally, this chapter concludes with an outline of thesis organization.

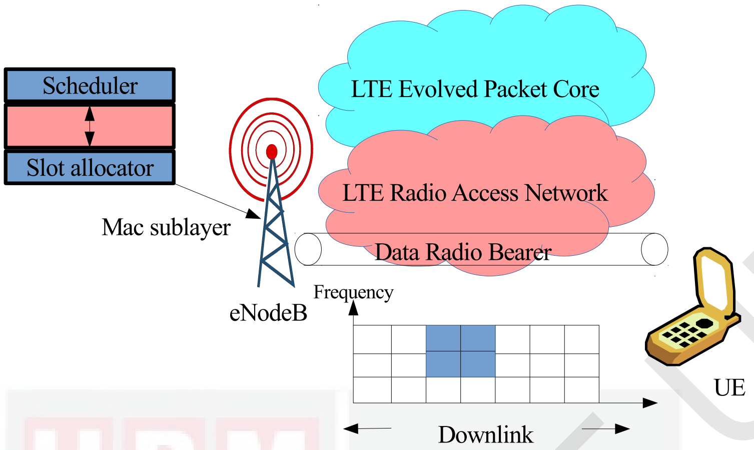

Figure 1.1: Downlink system architecture (Ali-Yahiya and Alagha, 2011)

1.1 Background

The technological expansion using wireless connectivity has played a major role in transforming how people's daily lives change drastically across the world. Wireless connectivity in conjunction with the Internet has been recently influencing technology changes for the past 50 years. The surging in demand for mobile data due to the proliferation of wireless and multimedia services such as Voice over Internet Protocol (VoIP), video conferencing, Skype, and GTalk continue to increase at unprecedented rates. This indicates that the demand for data rate increases 10 times for every 5 years and this development is expected to remain, with an increase of up to 1000 times in the next 15 years (Khan, 2016). In a wider outlook, changes in wireless communication generation are measured in every 5 years and may take 10 years timeframes with a major upgrade for each generation in 5 years after. Notably, the total global mobile traffic data was beyond 1 exabytes/month mark in 2013 and is predicted to grow by 10-fold, surpassed 10 exabytes/month within 5 years in 2018 (Khan, 2016). With this development by 2028, the global mobile traffic will exceed 1 zettabyte/month correspondent to 200 GB/month for 5 billion users globally (Khan, 2016).

Additionally, the surge in data rates of the 3GPP in particular LTE is also expected to follow the same development to grow exponentially. Precisely, the development in 3GPP LTE high data rates have been growing from 1 Mb/s in the year 2000 with third-generation (3G) and it is predicted to extended to 10 Gb/s in the year 2020 with fifth generation (5G) and 1 Tb/s with sixth-generation (6G) in 2030 providing 1000X growth in 30 years. To satisfy this increasing demand for high data rate in line with the proliferation of wireless devices and high demand data applications, the network operators increase their cell capacity to back this surging demand for LTE networks. However, it is clear that normal techniques for expanding wireless network capacity have reached their theoretical limits and are not adequately tackling this challenge to enable these networks realize their potentials.

To accommodate the data demand, there have been growing agitations for an urgent released of more spectrum. Particularly, the works presented in (Agrawal and Sharma, 2016; Pi et al., 2016) predicted to have the possibility of releasing about 30 GHz which is approximately 30 times the useful spectrum in the United State of America. Likewise, LTE provides a wider coverage area, high-speed peak data rate, and guaranteed Quality of Service (QoS) requirements. These characteristics can be achieved by considering radio resources such as available bandwidth and transmission power. The usage of these resources poses many threats which include insufficient bandwidth, handoff and power management. Abundance bandwidth and efficient power management are in urgent needs in order to effectively manage these resources as well as guaranteed QoS requirements. The term Radio Resource Management (RRM) usually denotes to the set of mechanisms and algorithms used to control parameters like bandwidth allocation, handover, power or energy transmission, and MCS etc. The goal is to use scarce radio resources available as effectively as possible while guaranteeing the users with the required QoS.

The LTE research issues in relation to RRM consist of resource utilization, QoS, and fairness. One of the utmost issues in LTE networks is resource utilization to achieve the target peak data for both downlink and uplink transmissions. Given the present issues such as low spectrum utilization, scarce spectrum availability, the effective utilization of radio resources is crucial for achieving such peak data rate. Another important research issue in RRM is fairness. The traditional fairness challenge in RRM is linked to the packet scheduling between UEs, where each UE should receive a fair share of radio resources for wireless access. QoS experience can be achieved if the number of UEs served by eNodeB is small. However, some eNodeB are expected to be deployed in public places such as shopping malls, train stations, and airports, where the number of UEs could be large and the available radio resources are not sufficient to fulfill the QoS requirement of each UE.

1.2 Problem Statement

This thesis bridges the gaps illustrated below. The efficient scheduling of inadequate system spectrum is critical to meet the network QoS performance targets. A suitable RRM scheduling algorithm is not well standardized by the 3GPP specification for LTE networks. Otherwise, services providers and users are free to adopt and implements their own algorithms (Ferdosian et al., 2016) based on their concerns and problem of the system, which comprises of QoS provisioning, fairness guarantee as well as throughput maximization. Nevertheless, each problem solved can lead to additional ones. For instance, radio resource algorithms intended to maximize system throughput are not appropriate for handling guaranteed bit rate traffic (Sadiq et al., 2009).

It is imperative to note that, in spite of the network-wide control schemes to ease transmission order, mobile data content overwhelms the available bandwidth for each node in many high traffic times. Thus, it is clear that transmission order is an imminent issue in LTE mobile network. Therefore, this thesis examines the performance challenging issues of scheduling algorithm over the rapid transmission order of traffic patterns. The three major issues that inspire this research study are outlines as follows:

- The exponential growth of mobile applications and increasing demand for data rate increases the public deployment of LTE networks. However, the tens of megabits of the system bandwidth supported by the downlink LTE network are still inadequate by the physical laws. They are insufficient to hold the present large number of data rate demands, especially when the minimum data rate is used to determine the transmission order of the user traffic. Similarly, the types of applications and services applied by the users are also increasing and it is essential to support numerous QoS requirements of these services with minimal delay, low packet loss without sacrificing the system throughput.

- The channel bandwidth provided for downlink LTE network may not be efficiently utilized amongst the users, since best effort traffic may overwhelm the network and consume more resource block and subsequently prevent other traffic from earning the resources. Therefore admitting users in the network causes waste of network resources problem and consequently lead to the users' quality of experience to be considerably degraded.

- Furthermore, Discontinuous Reception Mechanism (DRX) and Radio Resource Control (RRC) state transmission to prolong the battery lifetime, will mostly suffer from high energy consumption. This is because the sleep and wake mode operations are not adjusted efficiently. Consequently, this cause an increase in packet delay poorly utilizes the wireless channel. Although the DRX operates efficiently in an idle state, yet using initial and final states, the average response delay will drastically increase. Besides, this will decrease the chance of prolonging the battery lifetime.

1.3 Motivation

The LTE network has come up as a fast-growing new technology, delivering different mobile broadband services in the telecommunication industry. The network environment may be overwhelmed by high traffic or viruses as well as the application such as video streaming and VoIP. The frequent demand on the network bandwidth may cause QoS degradation and unfair resource allocation (Laselva et al., 2009). Therefore, the major motive of undertaking this area of research problem are that efficient use of RBs is correlated to the need of the network operator with a high-level of suitable coverage area with affordable services that guarantee QoS requirements.

In relation to granting QoS requirements, several scheduling algorithms have been proposed in the literature which are unsuitable for achieving fairness, low latency, and the delay between users. Many challenges have been left unsolved that restrict the application of the state of the art RB schedulers to the upcoming cellular network generation, this because of their fragile scalability of the system traffic and critical performance targets. Additionally, LTE as the future of mobile broadband, it was anticipated that by 2022 more than 90% (Index, 2017) of all mobile broadband users. It is predicted by Ericsson Mobility Report in (Mattisson, 2017) that the mobile video traffic will grow by 50% annually until 2022 that will account for nearly 75% of the mobile data traffic.

To the best of our knowledge, no scheduling algorithm for downlink LTE networks has achieved all the QoS requirements with resistance to the transmission order. Therefore, to avoid performance degradation and surges users' quality of experience for the next generation cellular network undertaking research by considering transmission order is a prerequisite. The motivation for this research is to develop broad scheduling algorithms that can achieve high throughput, QoS provisioning without sacrificing fairness.

1.4 Research Objectives

The main objective of this research is to propose efficient RRM algorithms that aimed to ensure fairness provisioning as well as admitting various users to the network environment. The details are as follows:

1. To propose a Quality of Service Class Identifier (QCI) Radio Resource Allocation Algorithm for Downlink LTE Networks that allocate resources based on channel status and QoS requirements to minimize delay and packet loss without sacrificing system throughput.

2. To propose an Adaptive CAC Algorithm to illustrate how the demand of different types of the services should be accommodated fairly by allocating the available radio block such that, the QoS requirements and resources constraints in the network are satisfied, and admits more traffic into the network without waste of resources.

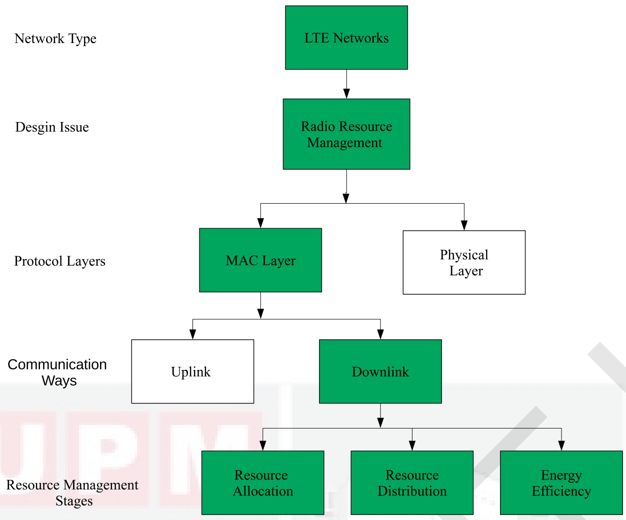

Figure 1.2: Thesis scope

3. To propose an Energy Resource Allocation Algorithm that incorporates enhancements in both initial and final states based on the sleep mode operations to minimize average delay and alleviate high energy consumption issue as well as prong the battery lifetime.

1.5 Research Scope

The proposed algorithms in this thesis focus on the MAC layer, which is the most challenging layer for RRM. At the MAC layer, the LTE radio resource scheduling process can be done either by time domain or the frequency domain, thus the main focus of this study is time domain packet scheduling. Similarly, packet scheduling can be managed in both downlink and uplink respectively; however, this research work focuses on the downlink direction to provide effective utilization of resources between users. Figure 1.2 shows the flow of the thesis scope, in which the boxes with green color indicate the scope followed by the thesis, while the other boxes indicate areas outside the scope of this thesis.

1.6 Research Contributions

The main contributions of this thesis are summarized as follows:

1. A QCI Radio Resource Allocation Algorithm for Downlink LTE Networks has been proposed to improve total sector throughput as well as reduces the packet loss by considering channel condition and QoS requirements.

2. An Adaptive CAC with Bandwidth Reservation Algorithm for Downlink LTE networks has been proposed to improve the performance of Reservation-Based and bandwidth degradation schemes. The new CAC criteria admit many users to the network environment to avoid starvation. An adaptive threshold value was used to adjust the network condition based on high traffic intensity scenarios.

3. A SET Algorithm for LTE networks has been proposed to prolong the battery lifetime at the Base Station (BS). Two parameters namely initial state and final state are adjusted dynamically using packet arrival pattern in order to minimize the average response delay as well as energy consumption.

1.7 Thesis Organization

In this research study, a novel downlink scheduling algorithms for LTE networks are presented. The rest of this thesis is organized as follows: Chapter 2 presents an overview of LTE networks, as well as scheduling strategies in LTE networks. It also shows some of the related works that address packet scheduling, CAC and power management schemes. Research framework of this thesis and its details, experimental setting simulation topologies, as well as performance metrics together with their validation techniques, are presented in Chapter 3. Chapter 4 presents the design and evaluation of the proposed QCI Radio Resource Allocation Algorithm for Downlink LTE Networks. The chapter ended with performance evaluation of the algorithm compared with optimal priority and some legacy algorithms in term of valuable metrics such as throughput, fairness, delay and Packet Loss Ratio (PLR). Exploring the designing and evaluation of An Adaptive CAC with Bandwidth Reservation for Downlink LTE networks scheme is presented in Chapter 5. It also presents the performance evaluation of the proposed algorithm and compares it with other algorithms in terms of throughput, handoff call blocking probability, new call blocking probability, and degradation ratio. Additionally, the simulation results and numerical results have been compared. Chapter 6 covers a proposed solution for power management with spectral and energy efficiency trade-off. This thesis concludes with Chapter 7 where conclusion and some promising directions for future research are presented.

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