UNIVERSITI PUTRA MALAYSIA

SELF-CONFIGURED LINK ADAPTATION USING CHANNEL QUALITY INDICATOR-MODULATION AND CODING SCHEME MAPPING WITH PARTIAL FEEDBACK FOR GREEN LONG-TERM EVOLUTION CELLULAR SYSTEMS

MUSTAFA ISMAEL SALMAN

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By

MUSTAFA ISMAEL SALMAN

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

August 2015

DEDICATION

To My

Father, A Shoulder to Lean On

Mother, Number One for Me

Wife, My Soul Mate

Little Boy, A Reason to Get Through Another Day.

Little Girl, Sugar And Spice And Everything Nice

Brother, The Greatest Gift My Parents Ever Gave Me

Sisters, My Day and Night.

"Without Your Support and Encouragement,
My Success Wouldn't Have Been Possible."

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

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MUSTAFA ISMAEL SALMAN

August 2015

Chair : Professor Nor Kamariah Noordin, , PhD
Faculty: Engineering

The continuous growth in wireless communication demands has led to a rapid increase in energy consumption and spectrum utilization. Therefore, a green radio technology is proposed recently to optimize the energy and spectrum resources. One of the main challenges in optimizing the energy and spectrum resources at the cellular downlink transmission is the provisioning of quality-of-service (QoS) when real time traffic is considered. Moreover, improving the energy and spectrum utilization at the downlink while maintaining QoS will require perfect channel state information (CSI) at the transmitting base station (eNodeB). However, reporting the channel status of the whole bandwidth in a multi-carrier communication system requires huge feedback signaling overhead at the cost of uplink performance. Therefore, the aim of this thesis is to optimize the energy and bandwidth resources while maintaining QoS at the downlink when a partial feedback is considered.

In this thesis, an analytical model that represents the tradeoff between energy efficiency (EE), spectral efficiency (SE), and transmission delay in both green and conventional Long-Term Evolution (LTE) eNodeB is formulated. Consequently, a modified downlink scheduler based on a Packet Prediction Mechanism (PPM) is conducted at the eNodeB. In the frequency domain of this scheduler, a new mapping between channel quality indicator (CQI) and modulation and coding scheme (MCS) is proposed to find the tradeoff between conflicting criteria. On the user side, a partial channel feedback scheme based on an adaptive CQI threshold is developed. A primary concern of this feedback scheme is to reduce the uplink signaling overhead required by the eNodeB without a substantial loss in downlink throughput and outage capacity. To achieve this objective, an iterative approach based on swarm intelligence is used to find the optimal CQI threshold at which the competing criteria are optimized.

Since the developed downlink scheduler and the partial feedback scheme affect the QoS, self-configured versions of both algorithms are developed to provide QoS provisioning. Specifically, the downlink frequency domain scheduler will reconfigure the criteria priorities such that the EE is maximized as long as the QoS is guaranteed. On the other hand, the partial feedback algorithm will search for the threshold value that minimizes the uplink overhead given that the QoS is achieved at the downlink.

Otherwise, optimizing QoS parameters will be targeted at the cost of other system parameters. Finally, a self-configured link adaptation with partial feedback (SCLAPF) is developed such that the downlink packet scheduling and the partial feedback are jointly evaluated to further enhance the system performance.

The system-level simulation shows that the modified PPM (MPPM) scheduler achieves an improvement in EE of up to 60% compared to the PPM scheduler. On the receiving side, the CQI partial feedback with adaptive threshold reduces the signaling overhead down to 41% compared to the full feedback reporting. Besides, it achieves the most acceptable tradeoff between uplink and downlink performances compared to previous works. More enhancements in downlink and uplink parameters are obtained when the energy efficient MPPM scheduler and the adaptive threshold feedback scheme are jointly implemented. It is shown that the proposed SCLAPF algorithm achieves a high gain in EE of more than 120% compared to that obtained by stand-alone partial feedback performance. Based on simulation results, it is concluded that the proposed energy-efficient scheduling has led the eNodeB to transmit with low power through modified MCS. Besides, it minimizes the degradation in downlink performance which is caused by partial CQI feedback. Therefore, the SCLAPF algorithm, which jointly evaluates the energy-efficient scheduling and partial feedback, gives the best tradeoff between uplink and downlink performances.

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

SATU KONFIGURASI DIRI PAUTAN PENYESUAIAN MENGGUNAKAN PEMETAAN PENUNJUK KUALITI SALURAN - SKIM MODULASI DAN PENGEKODAN DENGAN SEBAHAGIAN MAKLUM BALAS UNTUK SISTEM EVOLUSI JANGKA PANJANG CELLULAR HIJAU

Oleh

MUSTAFA ISMAEL SALMAN

Ogos 2015

Pengerusi: Profesor Nor Kamariah Noordin, PhD
Fakulti : Kejuruteraan

Pertumbuhan yang berterusan dalam permintaan komunikasi tanpa wayar telah membawa kepada peningkatan yang pesat dalam penggunaan tenaga dan spektrum. Oleh itu, teknologi radio hijau dicadangkan baru-baru ini untuk mengoptimumkan sumber tenaga dan spektrum. Salah satu cabaran utama dalam mengoptimumkan sumber tenaga dan spektrum pada penghantaran selular pautan turun adalah penyediaan kualiti-perkhidmatan (QoS) apabila trafik masa nyata dipertimbangkan. Selain itu, peningkatan tenaga dan penggunaan spektrum pada pautan turun sambil mengekalkan QoS akan memerlukan maklumat peringkat saluran (CSI) yang sempurna pada penghantaran eNodeB. Walau bagaimanapun, laporan status saluran pada seluruh jalur lebar dalam satu sistem komunikasi pelbagai pembawa memerlukan maklum balas isyarat overhed yang besar pada kos prestasi paut naik. Oleh itu, tujuan tesis ini adalah untuk mengoptimumkan sumber tenaga dan bandwidth di samping mengekalkan QoS pada pautan turun apabila separa maklum balas dipertimbangkan.

Dalam tesis ini, satu model analisis yang mewakili keseimbangan antara kecekapan tenaga (EE), kecekapan spektrum (SE), dan kelewatan penghantaran pada kedua-dua Evolusi Jangka Panjang (LTE) eNodeB yang hijau dan konvensional dirumuskan. Oleh yang demikian, satu penjadual pautan turun yang diubahsuai berdasarkan Mekanisme Packet Ramalan (PPM) dijalankan pada eNodeB itu. Dalam penjadual domain frekuensi ini, satu pemetaan baru antara penunjuk kualiti saluran (CQI) dan skim modulasi dan pengekodan (MCS) dicadangkan untuk mencari keseimbangan antara kriteria-kriteria yang bercanggah. Pada sebelah pengguna, skim separa maklum balas saluran berdasarkan penyesuaian ambang CQI dibangunkan. Kebimbangan utama skim maklum balas ini adalah untuk mengurangkan isyarat paut naik overhed yang diperlukan oleh eNodeB tanpa kerugian besar dalam pemprosesan pautan turun dan kapasiti gangguan. Untuk mencapai matlamat ini, satu pendekatan lelaran berdasarkan risikan kawanan digunakan untuk mencari ambang optimum CQI di mana kriteria-kriteria yang bersaing dioptimumkan.

Sejak penjadual pautan turun yang dibangunkan dan skim maklum balas separa menjejaskan QoS, versi pengkonfigurasian sendiri untuk kedua-dua algoritma itu dibangunkan untuk menyediakan peruntukan QoS. Secara khususnya, penjadual domain frekuensi akan menyusun semula keutamaan kriteria seperti EE dimaksimumkan selagi QoS dijamin. Sebaliknya, algoritma maklum balas separa akan

mencari nilai ambang yang mengurangkan overhed pautan naik yang diberikan di mana QoS dicapai pada pautan turun itu. Jika tidak, mengoptimumkan parameter QoS akan ditumpukan pada kos parameter sistem lain. Akhir sekali, pautan penyesuaian diri dikonfigurasikan dengan maklum balas separa (SCLAPF) dibangunkan supaya penjadualan paket pautan turun dan maklum balas separa dinilai secara bersama untuk meningkatkan lagi prestasi sistem.

Tahap sistem simulasi menunjukkan bahawa penjadual PPM yang diubahsuai (MPPM) mencapai peningkatan EE sehingga 60% berbanding dengan penjadual PPM. Pada pihak penerima, maklum balas separa CQI dengan ambang penyesuaian mengurangkan isyarat overhed turun kepada 41% berbanding dengan laporan maklum balas yang penuh. Selain itu, ia mencapai keseimbangan yang paling boleh diterima persembahan antara pautan naik dan pautan turun berbanding dengan kajian sebelumnya. Penambahbaikan yang berlebihan dalam parameter-parameter pautan turun dan pautan naik diperolehi apabila kecekapan tenaga pada penjadual MPPM dan skim maklum balas ambang penyesuaian dilaksanakan bersama. Ia menunjukkan bahawa algoritma SCLAPF yang dicadangkan mencapai kelebihan yang tinggi dalam EE 120% lebih daripada berbanding dengan apa yang diperoleh oleh prestasi maklum balas separa yang berdiri sendiri. Berdasarkan keputusan simulasi, ia dapat disimpulkan bahawa penjadualan cekap tenaga yang dicadangkan telah memimpin eNodeB untuk menghantarkan kuasa yang rendah melalui MCS yang diubahsuai. Selain itu, ia mengurangkan kemerosotan dalam prestasi pautan turun yang disebabkan oleh maklum balas CQI separa. Oleh itu, algoritma SCLAPF, yang bersama-sama menilai penjadualan cekap tenaga dan maklum balas separa, memberikan persembahan keimbangan yang terbaik antara pautan naik dan pautan turun.

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I certify that a Thesis Examination Committee has met on 9 July 2015 to conduct the final examination of Mustapha Yannabe Mustapha on his thesis entitled "Predictors of Tuberculosis among Patients Attending Government Hospitals in Yobe State, Nigeria" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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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. The members of the Supervisory Committee were as follows:

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School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name of Chairman of Supervisory Committee: Prof. Nor Kamarih Noordin, PhD

Signature: ______________________
Name of Member of Supervisory Committee: Prof. Borhanuddin Mohd Ali, PhD

Signature: ______________________
Name of Member of Supervisory Committee: Assoc. Prof. Aduwati Sali, PhD

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LIST OF ABBREVIATIONS

AMC	Adaptive Modulation And Coding
BEM	Bandwidth Expansion Mode
BET	Blind Equal Throughput
BLER	Block Error Rate
CO_2	Carbon Dioxide
CQI	Channel Quality Indicator
CSI	Channel State Information
ICT	Communications Technology
CE	Correlated Equilibrium
$D_{HOL,i}$	Delay Of The Head Of Line
DPS	Delay-Prioritized Scheduler
DEC	Dynamic Energy Control
ECG	Energy Consumption Gain
ECR	Energy Consumption Rate
ERG	Energy Reduction Gain
EECE	Energy-Efficient Correlated Equilibrium
EESBS	Energy-Efficient Score Based Scheduler
EUT	Equipment Under Test
EXP/PF	Exponential Scheduler
FFT	Fast Forier Transform
FLS	Frame Level Scheduler
GPF	Generalized Proportional Fair
HARQ	Hybrid Automatic Repeat Request
ICT	Information And Communication Technology
LTE-A	Long-Term Evolution Advanced
MT	Maximum Throughput
MAC	Medium Access Control
MFSK	Minimum Frequency Shift Keying
M-LWDF	Modified-Largest Weighted Delay First
MCS	Modulation And Coding Scheme
MCDM	Multi-Criteria Decision Making
MIMO	Multi-Input-Multi-Output

OPEX	Operational Expenditure
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
PDCP	Packet Data Convergence Protocol
PLR	Packet Loss Ratio
PPM	Packet Prediction Mechanism
PDCCH	Physical Downlink Control Channel
PSI	Plr Status Indicator
PMI	Precoding Matrix Indicator
PSS	Priority Set Scheduler
PF	Proportional Fair
QoS	Quality Of Service
RLC	Radio Link Control
RRM	Radio Resource Management
RI	Rank Indicator
RB	Resource Block
SCLA	Self-Configured Link Adaptation
SCLAPF	Self-Configured Link Adaptation With Partial Feedback
SCPF	Self-Configured Partial Feedback
SINR	Signal-To-Interference-Noise Ratio
SAW	Simple Additive Weight
SISO	Single-Input-Single-Output
SFBC	Space-Frequency Block Coding
SM	Spatial Multiplexing
TEEER	Telecommunications Equipment Energy Efficiency Rating
DCT	The Discrete Cosine Transform
3GPP	Third Generation Partnership Project
TTA	Throughput-To-Average
TCoM	Time Compression Mode
TTI	Transmission Time Interval
TBS	Transport Block Size
UAS	User Association Scheme
UE	User Equipment
VoIP	Voice Over Internet Protocol

CHAPTER 1

INTRODUCTION

The limited spectrum resources and the negative impact of carbon dioxide (CO_2) emission resulted from inefficient use of wireless technologies have led to the development of green radio. Both the energy efficiency (EE) and spectral efficiency (SE) should be considered together to meet green radio requirements. Moreover, the provisioning of the Quality of Service (QoS) is also required to guarantee user satisfaction. The optimization of those parameters depends on the channel information that should be available at the transmitting ends. This chapter first highlights the green communication trends by showing the level of CO_2 that can be emitted by the traditional cellular base station. Then, it gives a brief description of the relation between green transmission and the channel feedback. The chapter then states the thesis main objectives and the research question to be answered throughout this study. Besides, it gives a brief description of the methodology used in the study as well as the scope of research and its contributions. Finally, this chapter outlines the thesis organization.

1.1 Background

Escalation of wireless and cellular systems continues to stir up new research avenues that enable these systems to meet the growing demands and to work under various limitations. “Green Radio Technology” [1, 2] is among areas which have been adopted recently to overcome the limitations in the radio spectrum as well as reducing the energy consumed by the wireless systems. The scarceness in radio spectrum comes from the fact that the spectrum is fixed and it is not free. The more wireless applications and technologies being used, the more bandwidth required. Wireless data traffic has increased in recent years due to the variety of applications and smart software and devices. It is also increased due to the presence of many social networking applications through the internet, such as Facebook and Twitter. Moreover, it has been expected that this growth will continue increasing exponentially, especially with the exploitation of the third generation partnership project (3GPP) Long-Term Evolution Advanced (LTE-A) cellular networks, which could support up to 1 Gbps in the downlink transmission. Therefore, the radio spectrum resources should be utilized as efficiently as possible to overcome the bandwidth limitations.

On the other hand, the continuous growth in wireless data traffic results in the increase of energy consumed by wireless networks, which leads to an undesirable increase in the emission of CO_2. For example, the total energy consumed by a network of 20,000 3G base stations is about 58 MW resulting in an annual cost of $62 million and a carbon footprint of 11 tons for each cell site [3]. The CO_2 emission is considered as the chief greenhouse gas that resulted from wireless networks and other human activities, and causes the global warming and climate changes. Stephen Ruth in [4] has investigated several leading approaches that have been used to reduce the CO_2 emitted by information and communications technology (ICT). Although there are serious efforts to reduce the amount of CO_2 emission per mobile subscriber, as shown in Figure 1-1, cleaner and efficient solutions to wireless communications is required.

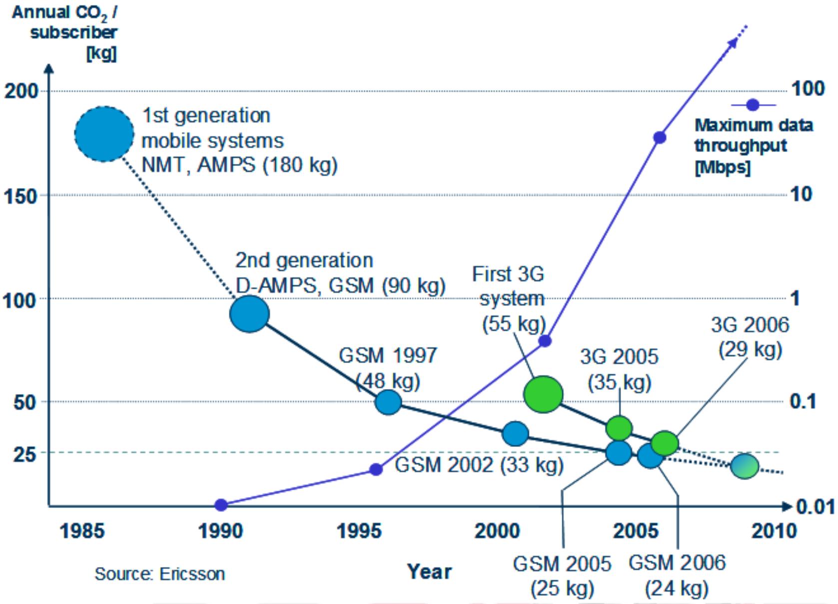

Figure 1-1 The amount of CO_2 emitted per subscriber [3]

The cellular network power consumption can be classified into five categories as shown in Figure 1-2 [5]. These categories give us an insight into the possible research avenues for reducing energy consumption in cellular networks. It is obviously noticed that the major amount of the cellular network power is consumed by the base stations. Specifically, the power amplifier is the major source of power consumption in the base station. The more energy-efficient base station, the less heat produced by the equipment and, thus, the less amount of air-conditioning required for cooling. While the improvement of efficiency of the power amplifier will reduce the power consumption of the main parts in a base station, the power consumed by transmission process is also momentous due to the sustainable growth of data rate requirements.

However, the allocation process in the downlink transmission of LTE cellular systems depends on the channel status of different users on a specific resource block (RB). In order to maximize LTE downlink performances, the eNodeB should have perfect channel state information (CSI) for all users with respect to the available RBs. Therefore, each user has to report its channel quality via a 4-bit uplink word, which is called a channel quality indicator (CQI). Although CQI feedback requires only few bits per RB, it is still impractical in modern LTE cellular communications to let all users report the CQI for all RBs. Specifically, the fullband CQI feedback scheme is not spectrum- and energy-efficient due to the high signaling overhead produced. Therefore, in this thesis, energy-efficient approaches that can reduce the energy consumption in the core transmission with complete and partial channel feedback will be addressed.

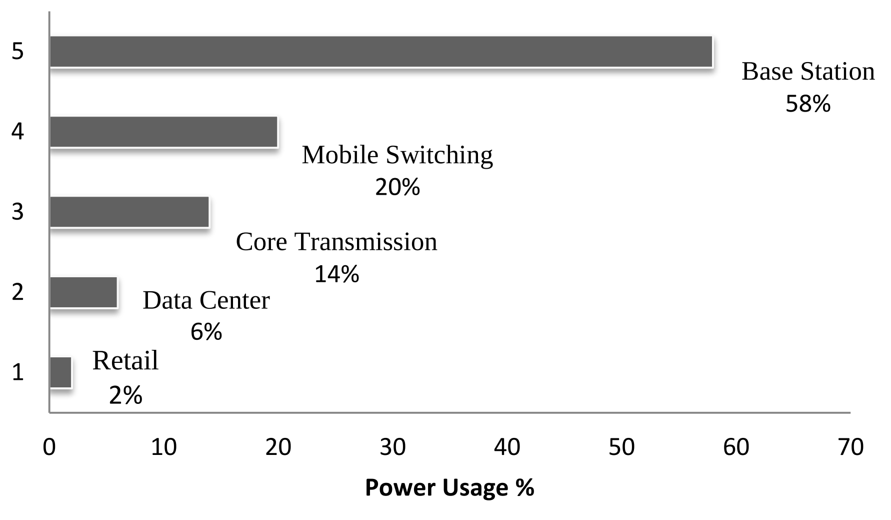

Figure 1-2 Power consumption of a typical cellular Network [5]

1.2 Problem Statement

Conventional design of LTE cellular systems aims to maximize the system capacity and SE due to sustainable growth of data rate requirements. As the energy consumption becomes relatively high, energy-efficient design for cellular systems is highly required to save energy as well as reducing the undesirable CO_2 emitted by these systems. However, reducing the energy consumption will degrade other system performances such as the data rate and QoS. Moreover, the optimization of these performance parameters depends on the accuracy of channel information reported by the user equipment (UE) to the base station (eNodeB) by using a specific channel feedback scheme. In particular, the following problems have been addressed throughout this study.

1. In the downlink transmission of 3GPP LTE, the link adaptation is introduced to maximize the SE, i.e. the highest allowable modulation and coding scheme (MCS), according to the reported CQI, will be selected to modulate the baseband signal. However, targeting such high SE requires the maximum utilization of transmit power, and thus minimizing the EE which is no longer acceptable due to green communication trends. On the other hand, minimizing the power consumption will violate other system performances, such as data rate requirement and transmission delay, which should be well optimized to achieve LTE targets [6].

2. Optimizing SE, EE and transmission delay depends on the accuracy of the channel information that should be reported by the UE to the eNodeB. The most accurate channel feedback scheme is the CQI fullband reporting. However, in multi-carrier multi-user LTE systems, the feedback signaling overhead required to report the status of the whole channel bandwidth for all of the served users is very high, and thus degrading the uplink performance [7].

3. Both, the energy-efficient link adaptation and the partial CQI feedback, have a negative impact on the QoS when real-time data traffic is used. On one hand, using a low-order MCS will save more energy at the transmitting side, but it will decrease the service rate, and therefore, the packets will probably be delayed beyond their acceptable delay budget. On the other hand, the partial CQI feedback might not indicate the actual status of some of the sub-channels. This channel feedback incongruity will lead to wrong scheduling decisions to be made at the eNodeB and thus increasing the wrong packets decoding at the receiver.

1.3 Aim and Objectives

In order to meet the requirements of green LTE networks, the radio resources should be allocated such that the transmission power will be minimized. However, in LTE networks, the higher power level is used to achieve the system high data rates. Therefore, the aim of this thesis is to optimize the energy and spectral efficiencies by minimizing the transmission power without sacrificing the data rate and QoS by managing the radio resources in different transmission scenarios. Consequently, this thesis aims to achieve three specific objectives which are listed below.

1. To determine a compromise MCS with a corresponding level of transmit power that achieves the best tradeoff between EE, SE and transmission delay at the downlink transmission to meet green LTE requirements.

2. To design a CQI partial feedback scheme with an optimal CQI threshold that achieves the required tradeoff between uplink signaling overhead and downlink performance.

3. To develop a two-sided self-configured link adaptation with partial feedback algorithm to be implemented at the transceiving ends simultaneously to further optimize the uplink and downlink performances.

1.4 Research Questions

The following research questions have been outlined to be answered throughout this thesis.

A. Assuming a downlink transmission of a green LTE eNodeB, what is the relationship between EE and SE when circuit power consumption is accounted, and how does the CQI-MCS mapping affect the tradeoff between EE, SE and transmission delay?

B. Since the CQI partial feedback is crucial for the uplink cellular communications to reduce the signaling overhead, how does it affect the downlink performances, and what is the partial feedback scheme that can achieve the best tradeoff between LTE uplink overhead and downlink performances?

C. Considering that a real-time traffic is used, how do the CQI-MCS mapping and the partial feedback scheme affect the QoS, and why does the joint evaluation of link adaptation and CQI partial feedback enhance their stand-alone results?

1.5 Brief Methodology

Based on the three specific objectives listed before, the method used to achieve the main aim of this thesis is divided into three stages as shown in Figure 1-3. In the first stage, the EE is required to be enhanced to meet green requirements without significant loss in SE and transmission delay. To achieve this objective, an analytical model to prove the tradeoff between the competing criteria is developed based on a realistic power consumption model. It is shown that the behavior of this tradeoff in a conventional LTE eNodeB is different from that obtained by using a green eNodeB. Consequently, a downlink scheduling with a modified frequency domain phase is developed. In this scheduler, a new CQI-MCS mapping algorithm is developed based on a multi-criteria decision making (MCDM) technique. The MCDM is used to find a compromise MCS suitable for the targeted tradeoff out from a specific number of alternative solutions. Based on the chosen MCS for the reported CQI, the eNodeB adapts the level of transmit power by using an adaptive power allocation algorithm. The details of this stage are analyzed and explained in Chapter 3.

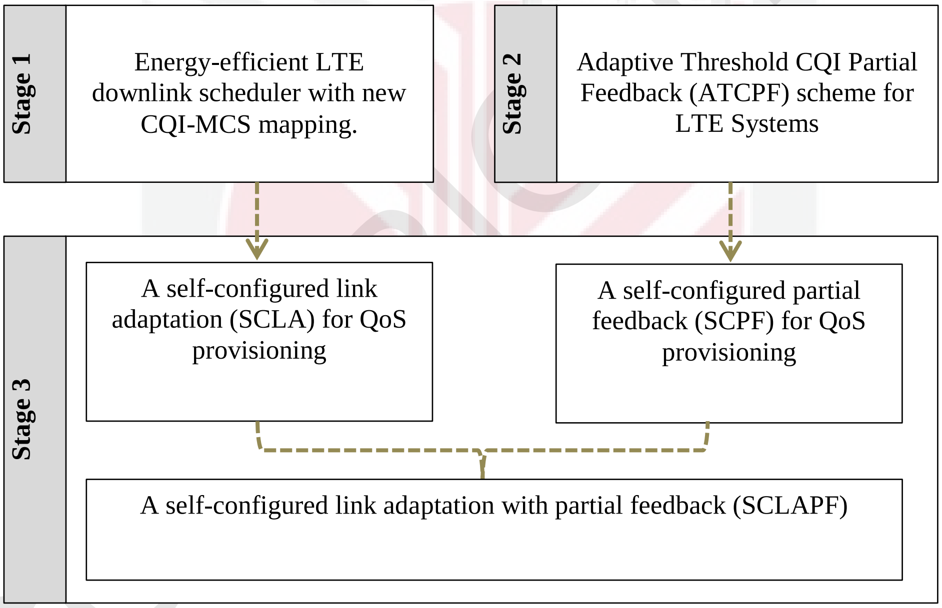

Figure 1-3 Mathodology Stages

Since the optimization of the downlink performance parameters considered in Stage 1 depends on the accuracy of channel information that should be reported to the eNodeB by different UEs, a huge amount of undesirable CQI signaling overhead is required. To find the minimum CQI signaling overhead at which the downlink performances are not violated, a new CQI partial feedback scheme, which is called as Adaptive Threshold CQI Partial Feedback (ATCPF), is developed in the second stage. Accordingly, a hybrid method of swarm intelligence and Simple Additive Weight (SAW) algorithm is used at the UE side to optimize the uplink and downlink performances as explained in

Chapter 4. The SAW method is used to change the multi-objective into single objective optimization, while the swarm intelligence is used to find the optimal SINR threshold required to maximize the system performances.

For QoS provisioning purposes, both the link adaptation and partial feedback algorithms, which are developed in Stages 1 and 2 respectively, are upgraded in Stage 3. In particular, a Self-Configured Link Adaptation (SCLA) algorithm is developed at the eNodeB side such that the priority weights of the competing criteria are configured according to the obtained QoS. At the UE side, however, a Self-Configured Partial Feedback (SCPF) algorithm is developed to configure the partial feedback scheme based on the targeted QoS. Furthermore, a Self-Configured Link Adaptation with Partial Feedback (SCLAPF) algorithm is developed in this stage. The SCLAPF represents a joint evaluation of SCLA and SCPF algorithms that are implemented at the transmitting and receiving ends simultaneously to further enhance the system performance.

1.6 Thesis Contributions

Based on the three research stages mentioned above, the following contributions are obtained.

A. A New Mapping between CQI and MCS

The mapping between CQI and MCS, which is developed in Chapter 3, is different from the conventional one proposed by 3GPP in two folds. First, it is based on the optimization tradeoff between EE, SE and transmission delay, while the conventional mapping considers the maximization of SE only. The second difference is that the new mapping can be adapted according to the priority weight assigned to each criterion and, therefore, different CQI-MCS tables can be obtained by simply adjusting the operator priorities.

B. Introducing the Feedback Optimization Product (FOP) Parameter

Most of CQI partial feedback schemes aim to find an acceptable tradeoff between uplink signaling overhead and downlink performances. In Chapter 4, a figure of merit called the FOP parameter, which formulates the relation between performance metrics obtained by each feedback scheme, is introduced. The FOP is calculated based on Weighted Product Model (WPM) [8] which finds the product of the considered cost and benefit criteria. By calculating the FOP, a comparison between partial feedback schemes would be possible.

C. Achieving the Best FOP Compared to Previous Works

By using a hybrid of swarm intelligence and SAW, the ATCPF scheme developed in Chapter 4 has achieved the best FOP compared with the fixed-threshold and subband level feedback schemes. In this scheme, the UE searches for an optimal SINR threshold that can maximize the fitness function which represents the tradeoff between throughput, outage capacity and CQI overhead. It is shown that the best FOP is achieved when the maximum priority is assigned to the outage capacity.

D. Significant Reduction in CO_2 Emission in Low-Load Traffic

According to the SCLA algorithm developed in Chapter 5, a significant gain in EE and CO_2 reduction can be obtained in low-load traffic condition. In this condition, the spare bandwidth can be efficiently used to compensate for the potential loss in obtained data rate due to the use of low-modulation order. When the network traffic is high and the bandwidth is over utilized, the normal rate of power will be consumed to maximize the SE.

E. Defining a New Packet Loss Ratio (PLR) Status Indicator (PSI)

According to the SCPF algorithm developed in Chapter 5, the PSI, which is a new 1-bit indicator to indicate the status of the obtained PLR, is defined. The PSI is reported to the eNodeB by the UE via an uplink control channel such that the SCPF algorithm tunes criteria weight priority to maintain QoS. When the resulted PLR is still below the acceptable threshold, the PSI is set to (0), and SCPF increases the priority weight of uplink signaling overhead. Otherwise, the PSI is set to (1), and the SCPF increases the priority weight of downlink parameters. Such flexible design will optimize the network performance without complex modifications.

F. Better Uplink and Downlink performances by Using the SCLAPF Algorithm

One of the main contributions of this work is that the energy-efficient transmission enhances the performance of partial feedback when they applied together simultaneously. In particular, the outage capacity due to wrong decoding at the receiver will be minimized because of low MCS used for energy-efficient transmission, and thus minimizing the number of dropped packets. Consequently, the UE will seek for the lowest possible SINR threshold to reduce the feedback overhead without affecting the downlink performance. Therefore, better uplink and downlink performances are obtained by jointly evaluating the two-sided SCLAPF algorithm developed in Chapter 5.

1.7 Scope of the Study

The flow of our research is illustrated in **Error! Not a valid bookmark self-reference.**. The solid lines represent the direction followed in this thesis to achieve our goal and objectives while the dotted lines refer to other research areas that are out of the scope of this work. The figure shows that the thesis covers a communication between LTE eNodeB and UEs. At the eNodeB side, a multi-cell Single-Input-Single-Output (SISO) antenna is considered. To achieve the green LTE targets, the adaptive modulation and coding (AMC), and the power allocation is used in the downlink. On the UE side, the CQI feedback is considered to evaluate its impact on the downlink parameters.

1.8 Significance of the Study

Green radio is the ideal way for most of the wireless and cellular operators to make significant steps in minimizing their carbon footprint for several reasons. First, the green eNodeBs and network equipments are cost-effective, especially when renewable resources are used to generate power instead of diesel or anthracite. Second, green radio is proposed to optimize the EE in addition to the SE in a way such that the LTE high data rate requirement is still achievable. Finally, Green radio techniques give more flexibility in the design of cellular networks such that it can adapt its behavior according to different preferences and needs.

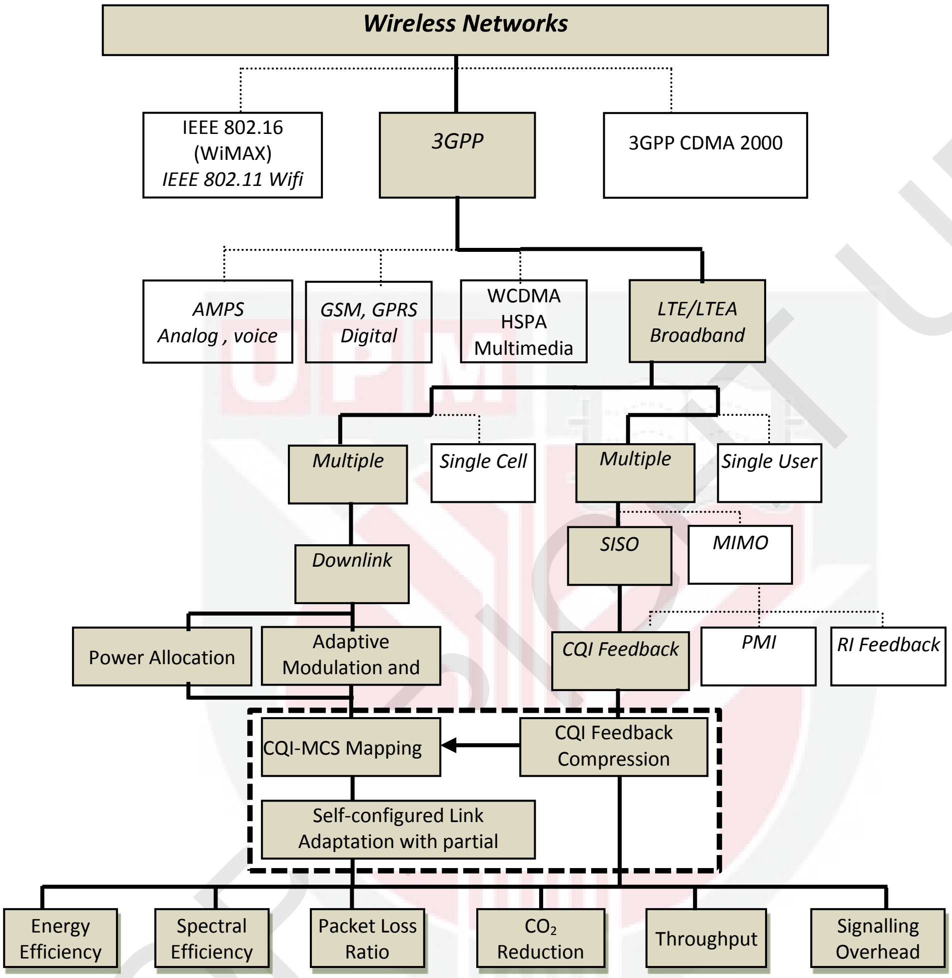

Figure 1-4 Study module.

1.9 Organization of the Thesis

After a short introduction presented in this chapter, which embeds the statement of the problem and the objectives of this study, in addition to research questions and scope, this thesis is organized as follows. In Chapter 2, different resource management and scheduling techniques are reviewed, analyzed and compared. Besides, the CQI partial reporting schemes are also reviewed in this chapter.

Chapter 3 first describes the system model and problem formulation of green LTE downlink transmission. Then, it presents the developed CQI-MCS mapping and the power allocation algorithm required to achieve the first objective of this thesis. This chapter also presents the system-level evaluation of the proposed algorithm.

In Chapter 4, the CQI partial feedback by overhead reduction is introduced. At first, the relation between CQI feedback and the downlink performance is highlighted, followed by the proposed CQI partial feedback algorithm. Then, the system level simulation is conducted to evaluate the proposed algorithm, and to compare it with the previous related works.

Chapter 5 includes the description of SCLA, SCPF and SCLAPF algorithms that are developed to jointly optimize the performance of uplink and downlink performances for green LTE cellular systems.

In Chapter 6, the thesis is summarized, followed by discussion of the research applicability and limitations. Then, several research issues and directions are suggested for further investigation.

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