A Radio Resource Management Framework for the
3GPP LTE Uplink

By
Amira Mohamed Yehia Abdulhadi Afifi
B.Sc. in Electronics and Communications Engineering – Cairo University

A Thesis Submitted to the
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in Partial Fulfillment of the
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Electronics and Electrical Communications Engineering

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Giza, Egypt
2011
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<th>Description</th>
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<tbody>
<tr>
<td>AMC</td>
<td>Adaptive Modulation and Coding</td>
</tr>
<tr>
<td>ARQ</td>
<td>Automatic Repeat Request</td>
</tr>
<tr>
<td>ARP</td>
<td>Allocation and Retention Priority</td>
</tr>
<tr>
<td>ATB</td>
<td>Adaptive Transmission Bandwidth</td>
</tr>
<tr>
<td>AWGN</td>
<td>Additive White Gaussian Noise</td>
</tr>
<tr>
<td>BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Rate</td>
</tr>
<tr>
<td>BLER</td>
<td>Block Error Rate</td>
</tr>
<tr>
<td>BSR</td>
<td>Buffer Status Reports</td>
</tr>
<tr>
<td>CDF</td>
<td>Cumulative Distribution Function</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>CQI</td>
<td>Channel Quality Indicator</td>
</tr>
<tr>
<td>CSI</td>
<td>Channel State Information</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier Transform</td>
</tr>
<tr>
<td>DL</td>
<td>Downlink</td>
</tr>
<tr>
<td>eNB</td>
<td>E-UTRAN Node B</td>
</tr>
<tr>
<td>ECR</td>
<td>Effective Code Rate</td>
</tr>
<tr>
<td>EPS</td>
<td>Evolved Packet System</td>
</tr>
<tr>
<td>E-UTRAN</td>
<td>Evolved-UTRAN</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
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<td>-------------</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier Transform</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency Division Duplexing</td>
</tr>
<tr>
<td>FDPS</td>
<td>Frequency Domain Packet Scheduling</td>
</tr>
<tr>
<td>FPC</td>
<td>Fractional Power Control</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GBR</td>
<td>Guaranteed Bit Rate</td>
</tr>
<tr>
<td>HARQ</td>
<td>Hybrid-ARQ</td>
</tr>
<tr>
<td>HOL</td>
<td>Head Of Line</td>
</tr>
<tr>
<td>HSPA</td>
<td>High Speed Packet Access</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter-Symbol Interference</td>
</tr>
<tr>
<td>ICIC</td>
<td>Inter-Cell Interference Coordination</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicators</td>
</tr>
<tr>
<td>LA</td>
<td>Link Adaptation</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MAC</td>
<td>Media Access Control</td>
</tr>
<tr>
<td>MBR</td>
<td>Multi-Bit Rate</td>
</tr>
<tr>
<td>MCS</td>
<td>Modulation and Coding Scheme</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>NLOS</td>
<td>Non Line Of Sight</td>
</tr>
<tr>
<td>NaN</td>
<td>Not any Number</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
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<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Modulation</td>
</tr>
<tr>
<td>OFDMA</td>
<td>Orthogonal Frequency Division Multiple Access</td>
</tr>
<tr>
<td>PAPR</td>
<td>Peak to Average Power Ratio</td>
</tr>
<tr>
<td>PC</td>
<td>Power Control</td>
</tr>
<tr>
<td>PDU</td>
<td>Protocol Data Unit</td>
</tr>
<tr>
<td>PELR</td>
<td>Packet Error Loss Ratio</td>
</tr>
<tr>
<td>PRB</td>
<td>Physical Resource Block</td>
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<tr>
<td>PHY</td>
<td>Physical Layer</td>
</tr>
<tr>
<td>PUSCH</td>
<td>Physical Uplink Shared Channel</td>
</tr>
<tr>
<td>PHR</td>
<td>Power Headroom Report</td>
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<tr>
<td>QCI</td>
<td>QoS Class Identifier</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RRM</td>
<td>Radio Resource Management</td>
</tr>
<tr>
<td>RB</td>
<td>Resource Block</td>
</tr>
<tr>
<td>RT</td>
<td>Real Time</td>
</tr>
<tr>
<td>SAE</td>
<td>System Architecture Evolution</td>
</tr>
<tr>
<td>SC-FDMA</td>
<td>Single Carrier – Frequency Division Multiple Access</td>
</tr>
<tr>
<td>SINR</td>
<td>Signal to Interference plus Noise Ratio</td>
</tr>
<tr>
<td>SISO</td>
<td>Single Input Single Output</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
</tr>
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<td>---------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>SR</td>
<td>Scheduling Request</td>
</tr>
<tr>
<td>SRS</td>
<td>Sounding Reference Symbols</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplexing</td>
</tr>
<tr>
<td>TTI</td>
<td>Transmission Time Interval</td>
</tr>
<tr>
<td>TPC</td>
<td>Transmitter Power Control</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UL</td>
<td>Uplink</td>
</tr>
<tr>
<td>UTRAN</td>
<td>Universal Terrestrial Radio Access Network</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice over Internet Protocol</td>
</tr>
<tr>
<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
</tr>
</tbody>
</table>
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Amira Mohamed Yehia Abdul Hadi Afifi
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ABSTRACT

The improved performance of the 3GPP Long Term Evolution (LTE) over 3G comes at the cost of increased constraints and challenges for the design. In this thesis a complete radio resource management framework for the LTE uplink is proposed. The Radio Resource Management (RRM) framework fulfills the functionalities of transmission bandwidth allocation, power control and Modulation and Coding Scheme (MCS) assignment in accordance to the LTE specifications for uplink transmission.

The LTE specifies Single Carrier-Frequency Division Multiple Access (SC-FDMA) as the access scheme for the uplink transmission. SC-FDMA is used due to its lower Peak to Average Power Ratio (PAPR) feature, but it comes at the cost of imposing a challenge on the scheduler design that subcarriers assigned to one user must be contiguous.

With the advances in technology a wide range of applications now exist each with its specifications and requirements. For example while VoIP applications require small packet delay, FTP applications can tolerate high packet delays. The transmission bandwidth allocation algorithm considers these requirements and tries to fulfill them. An important issue to consider in power control algorithms is inter-cell interference, although Inter-Cell Interference Coordination (ICIC) may decrease the cell throughput but it eventually maximizes the system throughput. The framework maximizes throughput and spectral efficiency while taking into consideration the users’ different classes of Quality of Service (QoS) as well as performing Inter-Cell Interference Coordination (ICIC).
Chapter 1

Introduction

As the services provided to mobile users become more demanding, the mobile telecommunications systems must evolve to meet these expectations. Third Generation (3G) mobile systems which are based on the WCDMA technology are being deployed to meet the increased demand of higher data rates and QoS differentiation. The Third Generation Partnership Project (3GPP) efforts in standardizing the mobile networks has made it the leading choice for mobile operators and in response to the increased demand for higher performance released the first step in the WCDMA evolution, the High Speed Packet Access (HSPA) system which is classified as 3.5G. In parallel to evolving HSPA, 3GPP is also specifying the Long Term Evolution (LTE), a new radio access technology and network architecture, to stay competitive for a longer time frame by providing considerable performance improvement at a reduced cost. This thesis proposes a radio resource management (RRM) scheme within the LTE framework.

1.1 Thesis Scope and Objectives

To reach LTE's design goals set by 3GPP, LTE's new radio access technology and network architecture must be exploited when addressing the RRM design problem. The RRM functionalities include Admission Control (AC), Packet Scheduling (PS) including Hybrid Automatic Repeat Request (HARQ), and fast Link Adaptation(LA) including Adaptive Modulation and Coding (AMC) and Fractional Power Control(FPC). The RRM design problem can be summarized as providing these functionalities under the constraints introduced by the used technology such as contiguity constraint of SC-FDMA, and the constraints introduced by the design goals such as improving spectral efficiency and QoS provisioning.
This thesis addresses the RRM design problem in the LTE framework focusing on QoS-based PS, AMC and FPC. An investigation of the tradeoff between throughput and inter-cell interference for different SINR Target values is also included. A RRM scheme for the Frequency Division Duplex (FDD) mode is introduced. To assess the performance of the scheme it is simulated with four traffic models each belonging to a different QoS class under the assumption of finite buffer size and SISO antennae setup. Perfect channel knowledge is assumed throughout the study and accordingly HARQ is not considered.

The proposed scheme is evaluated through the following Key Performance Indicators (KPI):

- **Average throughput per user**: The average per-user data throughput is defined as the sum of the average data throughput of each user in the system divided by the total number of users in the system. The average per-user throughput is also referred to as average or mean user throughput.

- **Traffic class packet delay**: The delay is defined as the time between the packet arriving to the transmission buffer of a UE and the packet delivered to the physical layer for transmission. The cumulative distribution function (CDF) of the delay is obtained for each QoS class.

- **Average Interference Power**: The average amount of interference leaked from the cell users to the neighboring cells.

### 1.2 Contribution

When tackling the RRM problem previous work focused on one aspect only of the design. The work would either focus on Adaptive Transmission Bandwidth (ATB) only, AMC only, Power Control (PC) or QoS. Some authors combined two of the RRM functionalities in their work. The main contribution
of this thesis is providing a QoS-based RRM scheme that combines the ATB, LA and PC functionalities of RRM.

The proposed RRM scheme takes into consideration the QoS requirements for the different applications. [1]→[6] studied packet scheduling with the aim to maximize spectral efficiency while neglecting the QoS requirements, packets are scheduled without regards to the delay and packet loss. While [9]→[12] which considered the QoS requirements, focused on the downlink scheduling. The work in [13] and [14] focused on uplink scheduling with QoS requirements but did not consider maximizing the spectral efficiency.

The proposed RRM scheme also considers the inter-cell interference generated on neighboring cells. It combines RRM and inter-cell interference coordination (ICIC) in one scheme. This leads to maximizing throughput and minimizing inter-cell interference while respecting the QoS requirements and following the LTE power control method.

Most of the work done on RRM was evaluated using infinitely backlogged buffer traffic model or simple traffic models that generate packets according to a Bernoulli process. The scheme presented in this thesis is evaluated using realistic traffic models for four different applications: VoIP, Interactive Gaming, Video and FTP.

1.3 Thesis Outline

The thesis is organized as follows

Chapter 2 gives an overview of the 3GPP LTE standard and the SAE architecture. The frame structure and different signaling elements required to design the RRM scheme are presented. The uplink power control as defined by the standard is presented as well. The different QoS classes as specified by the 3GPP for LTE are described. Theoretical background on wireless
communication fundamentals is also given.

Chapter 3 describes the RRM design problem in LTE and provides a survey of previous work addressing the different issues discussed in this thesis. The resource allocation problem is studied from the frequency domain or channel dependant scheduling point of view. Literature addressing the QoS requirements and constraints is also reviewed, and finally studies done for the uplink power allocation and interference coordination are summarized.

Chapter 4 describes the proposed RRM scheme. The scheme performs three functionalities: PS, AMC and FPC. The scheme is also used to study the uplink closed loop power control problem with an emphasis on the SINR Target value selection.

Chapter 5 presents the simulation setup and results. An analysis of the results and comparison with work from the literature is then given. The different KPIs’ are evaluated and presented.

Finally, Chapter 6 concludes the thesis and presents some future work to be done.
Chapter 2
Overview of the 3GPP LTE Standard

LTE is the standard defined by 3GPP for radio access. It has two modes of operation Frequency Division Duplex (FDD) and Time Division Duplex (TDD). Due to the difference in capabilities between the mobile stations and the eNBs, the standard differentiates between Uplink (UL) transmission and Downlink (DL) transmission. Since the scope of this thesis is FDD UL resource management, we will only focus on these parts in the standard.

2.1 LTE Physical Layer

2.1.1 Transmission Scheme

The LTE standard adopts OFDM as the underlying technology for the transmission schemes with a difference in the multiplexing technology chosen for the downlink from that chosen for the uplink. OFDMA has been chosen for the downlink as the multiple access scheme. For the uplink SC-FDMA or DFT-Spread OFDM was chosen due to the difference in the capabilities between the UE and the eNB. The transmitter and receiver for OFDMA and SC-FDMA is shown in Figure 2-1. For the UE the power requirements play a big role in the design and implementation of the standard. SC-FDMA has been chosen due to its lower PAPR compared to multi-carrier transmissions which allow for more efficient use of the power amplifier as well as decreasing the complexity of the equalizer.

SC-FDMA has two types of sub-carrier mapping: (1) Interleaved and (2) Localized. In I-FDMA users are assigned subcarriers that are distributed over the entire bandwidth while in L-FDMA users are assigned consecutive or