Chapter 1

Introduction

1.1 Relevance

Mobile communication of today is inherently more complex than fixed point communication. As a consequence, the full potential of radio communication is far being realized. In December 1947, Douglas H. Ring and W. Rae Young, Bell Labs engineers, proposed hexagonal cells for mobile phones in vehicles.

In 1969 Amtrak equipped commuter trains along the 225-mile, New York-Washington route with special pay phones that allowed passengers to place telephone calls while the train was moving. The system re-used six frequencies in the 450 MHZ band in nine sites, a precursor of the concept later applied in cellular telephones.

In December 1971, AT&T submitted a proposal for cellular service to the Federal Communications Commission (FCC). In 1971’s they built the first network in Chicago and had 1300 customers on the system by the end of 1978. After years of hearings, the FCC approved the proposal in 1982 for Advanced Mobile Phone System (AMPS) and allocated frequencies in the 824–894 MHz band. Analog AMPS was eventually superseded by Digital AMPS in 1990.

1.1.1 The First Generation (1G)

In 1979 a cellular network (1G) was launched in Japan by NTT. The next 1G network to launch was the Nordic Mobile Telephone (NMT) system in Denmark, Finland, Norway and Sweden in 1981. NMT was the first mobile phone network to feature international
roaming. With the introduction of 1G phone, the mobile market showed annual growth rate of 30 to 50 per cent, rising to nearly 20 million subscribers by 1990.

1.1.2 The Second Generation (2G)

The 2G systems designed in the 1980s were still used mainly for voice applications but were based on digital technology, including digital signal processing techniques [2]. 2G cellular systems include GSM, digital AMPS (D-AMPS), code-division multiple access (CDMA), and personal digital communication (PDC). GSM is the most successful family of cellular standards. It includes GSM900, GSM-railway (GSM-R), GSM1800, GSM1900, and GSM 400 [3].

1.1.3 The Third generation (3G)

3G mobile telecommunication is a generation of standards for mobile phones and mobile telecommunication services fulfilling the International Mobile Telecommunications-2000 (IMT-2000) specifications by the ITU. Application services include wide-area wireless voice telephone, mobile Internet access, video calls and mobile TV, all in a mobile environment [4].

To meet the growing demands in network capacity, rates required for high speed data transfer and multimedia applications, 3G standards started evolving. The 3G technology allows video, audio, and graphics applications. Over 3G phones, one can watch streaming video or have video telephony.

1.1.4 The fourth generation (4G)

In telecommunications, 4G is the fourth generation of cellular wireless standards. It is a successor to the 3G and 2G families of standards. In 2009, the ITU-R organization specified the IMT-Advanced (International Mobile Telecommunications Advanced) requirements for 4G standards, setting peak speed requirements for 4G service at 100
Mbit/s for high mobility communication (such as from trains and cars) and 1 Gbit/s for low mobility communication (such as pedestrians and stationary users).

IMT-Advanced compliant versions of LTE and WiMAX are under development and called “LTE Advanced” and “Wireless MAN-Advanced” respectively. ITU has decided that LTE Advanced and Wireless MAN-Advanced should be accorded the official designation of IMT-Advanced. ITU recognized that current versions of LTE, WiMAX and other evolved 3G technologies that do not fulfill “IMT-Advanced” requirements could nevertheless be considered “4G”, provided they represent forerunners to IMT-Advanced and a substantial level of improvement in performance and capabilities with respect to the initial third generation systems now deployed.

Long Term Evolution (LTE) network promises higher data rates, 100 Mbps in the downlink and 50 Mbps in the uplink; in addition to that, LTE has support for scalable bandwidth, from 1.25 MHz to 20 MHz. All these features are making LTE a very attractive technology for operators as well as the subscribers.

1.2 Research Motivation

The field of wireless network systems has witnessed tremendous growth in recent years causing it to become one of the fastest growing segment of the telecommunication technology. The fast development of wireless communication services is reflected in the transition from the second generation (2G) systems to the third generation (3G) cellular systems. To fulfill the high data rate and low latency requirements of future communication services, the spectral efficiency of future wireless networks needs to be further improved allowing for increased flexibility to serve a large number of simultaneous users and different services.

Radio resource management (RRM) attracts enormous attention while utilizing available resources to provide users with enhanced system throughput. Radio resource management includes scheduling of radio resources, transmission power management, and mobility management, etc. An intelligent radio resource management is at the heart of LTE to make it a stout. The general goal of the study is to provide a set of QoS to be
responsive for RRM functionalities for OFDM based wireless networks. RRM is a technique in wireless network that can have different objectives such as maximization of system capacity, cell coverage, user QoS, fairness in resource distribution etc. In general all these objectives cannot be achieved at the same time.

- **Coverage verses QoS**: Due to propagation losses, the QoS of the users in the cell edge is usually worse than the user near the base station. In case of planning the cellular system, the cell radius is determined on the basis of required number of users that should be allowed. The trade-off is also evident. In this cell radius determination procedure, because higher the minimum QoS requirement, the smaller the cell radius will be.

- **Capacity verses Coverage**: Excessive capacity can have a negative impact on the coverage of the interference limited system. This is the case in CDMA based systems, where they become heavily loaded. Another aspect is that the base station with high power provide good coverage, and also generates excessive interference to the neighboring cells, which results into reduction in the overall system capacity.

- **Capacity verses QoS**: A clear compromise between system capacity and users QoS is the fact that the existence of more users in the system decreases the QoS per capacity, because less resources will be available for each users. Furthermore, a common way to determine system capacity is to decide the number of admitted users that corresponds to given percentage of satisfied users.

- **Fairness versus coverage**: The quality variability in the coverage area is directly proportional to the cell coverage; the larger the cell size, more the variability. Normally resource allocation algorithms take into account the channel state information of the users. Therefore, the higher the variability of the user’s channel state information, lowers the fairness of the corresponding resource allocation.
• **Fairness versus QoS**: Since the wireless resources are limited, the QoS of the users cannot be improved indefinitely. If the QoS of few users is maximized the other will feel the lack of resources. This imbalance is translated into reduction in fairness. In the other hand if a high fairness is assured the users have more or less the same QoS; the maximum achievable QoS in this situation is upper-bonded.

• **Capacity versus fairness**: In order to maximize system capacity. The wireless resources must be allocated in the most efficient way. This is accomplished by using opportunistic resources allocated, which assigns the resources to the users who have the best channel condition with respect to these resources. Cellular system presents a high variability on the channel quality experienced by the users.

The use of opportunistic RRM in order to maximize the throughput will be inevitably concentrating the resources in the hands of best users, while the once in worse condition it will suffer significantly. This situation is characterized by low fairness. On the other hand if a high fairness is required, the system is faced to cope with bad channel conditions of the worst users and allocate resources to them.

The above mentioned trade-offs for cellular system are technology dependent. In the system design the deployment of specific technologies and the use of suitable Radio Resource Management (RRM) technique can help the network operation to reduce the above mentioned trade-offs. If these trade-offs cannot be solved simultaneously on appropriate RRM strategy will still be very useful to satisfy the most demanding trade-off depending on technology and the performance matrix.

1.3 **Literature Survey**

Rappaport et. al. [5], have described a traffic model and analysis for cellular mobile radio telephone systems with handoff. They have considered three schemes for call traffic handling. One is nonprioritized and two are priority oriented. They have given general formulas and specific numerical results for nominal system parameters.
Hua Jiang et.al. [6] suggested a new scheme that allows cell gateways to borrow channel from adjacent gateways in cellular communication. A novel method was devised to characterize the performance using multidimensional birth-death process and decomposition methods. The results proved the significant increase in traffic capacity compared to non borrowing scheme in homogeneous environment.

I. Katzela et.al. [7] have discussed various schemes like fixed, dynamic and hybrid for wireless resource allocations. Channel allocation schemes were investigated based on distributed, centralized and adaptability to traffic conditions. A sensible discussion on reuse partitioning schemes, the effect of handoffs, and prioritization schemes have been presented for overlay cells, frequency planning, and power control issues.

Christian Hartmann et. al. [8] have presented their work on cell splitting in order to meet the demand in increase in the capacity. In order to be able to adapt the system parameters to temporal and spatial changes of traffic and mobility properties, in this paper two adaptive algorithms are described, which control the threshold velocity as well as the division of resources among the layers, dynamically. The performance of these algorithms is evaluated by means of computer simulations.

Taesoo Kwon and Dong-Ho Cho [9] have proposed an adaptive radio resource management in CDMA based hierarchical cell structure for efficient use of radio resources. The performance of proposed scheme is evaluated by means of computer simulation. The results show that proposed scheme improves call blocking, call dropping and utilization of radio resource compared with conventional schemes.

Younguk Chung and Dong-Ho Cho [10] have proposed an algorithm which analyzed the interference to signal ratio and reverse link capacity. This proposed algorithm lends frequency spectrum of macro-cell to microcells when mass hot spot occurred. Algorithm performance is evaluated in view of blocking, the handoff refused probability, and the spectrum efficiency. Numerical result shows that the proposed algorithm can increase the capacity and solve a mass hot spot problem.

In his thesis Wang Bin [11], radio resource management for CDMA based Cognitive Radio Networks and Co-operative Communication Networks has been studied. He presented how to manage the transmission power which determines other aspects of
the network resource allocations, such as transmission time and rate allocations. The main objective of the RRM is to efficiently utilize the available network resources for providing the mobile users with satisfactory quality of service (QoS).

Considering the infeasibility of imposing any modification on existing infrastructures, Shao-Yu Lien, et.al. [12] leverage the cognitive radio technology to propose the cognitive radio resource management scheme for femtocells to mitigate cross-tier interference.

Yiouli Kritikou et.al. [13] have presented a Cognitive Device Management System, with specific focus on functionalities and methodology for obtaining and dynamically managing information related to user preferences and elements of the user behavior.

Oriol Sallent et.al. [14] have proposed the Cognitive Pilot Channel (CPC) concept as a solution for providing the terminal with the necessary radio awareness at a given time and place, in a possible flexible spectrum management context. As more and more wireless LANs are deployed in many popular locations, there is a need for dynamic radio resource management (RRM) schemes.

Ming Yu et.al. [15] have proposed a new dynamic RRM technique for multiple access point (AP) network. They proposed a dynamic RRM algorithm that not only significantly increases network performance but also reduces the co-channel interference.

Won-Hyoung Park and Saewoong Bahk [16] have considered some radio resource management policies like, path selection rule, frequency reuse pattern matching, and frame transmission pattern matching among cells. They evaluated the performances of RRM using relays under these policies by varying parameter values such as the relay station’s position and frequency reuse factor. Using Monte Carlo simulations and mathematical analysis, they suggested some optimal values of parameters and policies.

F. Berggren et.al [17] have presented scheduling ideas for intracell nonreal time data of DS-CDMA. Cristina Comaniciu et.al. [18] presented an auctioning strategy proposed for cellular networks that ensures net energy savings. The pricing scheme, in
conjunction with the two dimensional bid structures, incentivizes co-operation at the terminal nodes for better interference management at receivers and for cooperative relaying. It is shown that for the proposed auctioning strategy, network operators are guaranteed revenue gain.

Cooperative transmissions have been shown to be able to greatly improve system performance by exploring the broadcasting nature of wireless channels and cooperation among users. Zhu Hanet.al. [19] have focused on leveraging cooperation for resource allocation among users such that the network performance can be improved.

Philipp Hasselbach1 et.al. [20] in his paper stated that the autonomous, self-organizing adaptation of the assignment of the resources, power and bandwidth according to the time-varying capacity and demand of the users are an important topic.

Power-Bandwidth Characteristics represent the interdependence of transmit power and cell bandwidth considering behavior and environment of cells and users. Therefore they provide important information required for the efficient assignment of resources. In the framework, Theodoridis, G. et.al. [21] have introduced a Radio Resource Management (RRM) algorithm capable of minimizing bandwidth demands via adequately manipulating the subcarrier’s assignment.

In his thesis, Sajid Hussain [22] presented the work on OFDMA downlink multiple access schemes in 3GPP LTE. The different ICI mitigation techniques are presented. The same are analyzed with different frequency allocation schemes and transmission power. Different radio resource scheduling algorithms to enhance bandwidth efficiency and throughput are also proposed.

George Dimitrakopoulos et.al. [23] have discussed the functional architecture (FA) for the efficient radio and spectrum resource management of the anticipated future compound communication systems. Their work comprises an advancement of the FA that has been initially proposed within end-to-end reconfigurability - phase 2 (E2R II) project and has been enhanced to incorporate cognitive and self-x capabilities to address the newly born B3G challenges.

J. Ikuno et.al. [25] have introduced system level simulation environment for UMTS Long Term Evolution (LTE). In this work, they explained how link and system level simulations are connected.

Stefan Schwarz et.al. [26] addressed the problem of downlink multiuser scheduling in practical wireless networks under a desired fairness constraint. Wireless networks such as LTE, WiMAX and WiFi provide partial channel knowledge at the base station by means of quantized user equipment feedback. Specifically in 3GPP’s LTE, the Channel Quality Indicator (CQI) feedback provides time-frequency selective information on achievable rates.

In their paper Jose F. Monserrat [27] presents the first set of innovative concepts for advanced Radio Resource Management that has been identified by the Innovation Group of WINNER+ for potential inclusion in IMT-Advanced. These concepts consist of promising innovative techniques that are ready to be included in current OFDMA-based cellular systems to enhance system performance.

Kwan, R. et.al. [28] presented the problem of allocating resources to multiple users on the downlink of a Long Term Evolution (LTE) cellular communication system. An optimal (maximum throughput) multiuser scheduler is proposed and its performance is evaluated. Numerical results show that the system performance improves with increasing correlation among OFDMA subcarriers.

Mobile multi-hop relay (MMR) network based on the IEEE 802.16j standard are able to extend the service area as well as it improves the performance of mobile WiMAX networks. In their paper, Dusit Niyato et.al. [29] have presented a relay-centric hierarchical optimization model for jointly optimizing the radio resource management (RRM) and network planning for the relay stations in MMR networks.

Stanislav Nonchev et.al. [30] proposed the fairness-oriented packet scheduling (PS) schemes with power-efficient control mechanism for future packet radio systems.
In general, the radio resource management functionality plays an important role in new OFDMA based networks.

Stefan Schwarz et.al. [31] addressed the challenge of multiuser scheduling in the downlink of 3GPP UMTS/LTE. Based on the Channel Quality Indicator (CQI) feedback a linearized model for multiuser scheduling is derived. The proposed framework can be applied to implement other scheduling strategies. This is demonstrated by comparing different standard schedulers in terms of achieved throughput and fairness.

Christian Mehlführer et.al. [32], have introduced MATLAB-based link and system level simulation environments for UMTS Long Term Evolution (LTE). In this work, they explained how link and system level simulations are connected and show how the link level simulator serves as a reference to design the system level simulator.

Mohamed Salem et.al. [33] provided an overview on the recent developments in RRM algorithms in OFDMA-based wireless networks enhanced with fixed relays employing decode-and-forward relaying technique. There is a noticeable similarity between RRM algorithm design for relay-enhanced OFDMA-based networks and earlier RRM algorithms for non-OFDMA relay networks.

Feng Qian et.al. [34] have focused on UMTS, one of the most popular 3G mobile communication technologies. The work is the first to accurately conclude for any UMTS network and the state machine (both transitions and timer values) that guides the radio resource allocation policy through a light-weight probing scheme.

Raymond Kwan et.al. [35] discussed the problem of allocating resources to multiple users on the downlink of a Long Term Evolution (LTE) cellular communication system. An optimal (maximum throughput) multiuser scheduler is proposed and its performance is evaluated.

Air interface and networking framework of long-term evolution (LTE) out of Third Generation Partnership Project (3GPP) is introduced by Mustafa Ergen [36]. M. Rupp et.al. [37] provided calculation of the Spatial Pre-processing and Link Adaption Feedback for 3GPP UMTS/LTE.
K. Seong and M. Mohseni [38], have proposed optimal resource allocation for OFDMA downlink systems. It adapts to both the channel’s condition and the bandwidth requirements of every user. Simulations are performed in a multi-cell network. Results show superior performance in terms of capacity over the well-known Round Robin, Maximum C/I and Proportional Fair algorithms.

1.4 Thesis Objectives

The ideas that will be considered throughout this thesis stand in the forefront of future broadband wireless system and are well in support with the requirements of 4G mobile communication network.

The general objective of this work is to contribute with the state-of-the-art by settling critical and original knowledge about RRM for OFDM based networks.

The main objectives of this thesis are summarized below.
1. To Study the performance of RRM in GSM and CDMA networks, with special exploration for adaptive RRM.
2. To study and design of RRM algorithm for CDMA based cognitive radio network to provide satisfactory quality of service.
3. Theoretically conceive and evaluate, using system-level simulations, RRM solutions for the OFDM based, mainly focusing on the dynamic radio resources allocation.
4. Propose and review adaptive scheduling techniques for the downlink multiuser OFDM based network, mainly focusing on fairness to improve the throughput.

1.5. Research Methodology

The methodological approach used to fulfill the objectives presented in the previous section was based on two main fronts: theoretical analysis and system-level simulations.

Firstly, a continuous compilation of bibliographical database was conducted, in order to establish a solid foundation on the research subject. The sources used in this
bibliographical research were books, articles (journals, transactions, magazines), paper published in proceeding of international conferences, standardization technical specification and report and other database available in the Internet. This theoretical basis was important because of two reasons. Firstly, it allowed the formulation and proposal of the novel contributions presented in this thesis. Moreover, it was necessary to determine the models that would be implemented in the simulator used in our studies.

The performance evaluation of wireless communications system using only an analytical mathematical approach is a very complex task. This is due to the fact that many physical phenomena, like the time-variability of the mobile radio channel and fading in the space and time domains are very difficult to be tackled mathematically.

For that reason, system-level simulations are widely used to evaluate aspects such as system planning, dimensioning and adjustment of techniques and algorithms. In fact, simulations make possible the modeling of the system with a high level of details, which allows the validation of specific algorithms. In the ambit of this thesis, simulations are used with two objectives:

1. Validation of the propositions (hypothesis) inherent to the propounded RRM algorithms.
2. The performance evaluation and comparison of the corresponding RRM techniques.

To this end, a discrete-time system-level simulator that models the most important aspects of a wireless network in general, and the OFDM technology in particular, was developed using the simulation software package Matlab. The RRM techniques and framework proposed and studied in this thesis were implemented in this simulation tool.

The performance evaluation of the proposed RRM strategies carried out in this thesis is based on the statistical analysis of the simulation results. The simulation scenarios studied in this work are simulated several times according to the Monte Carlo approach in order to have a reliable statistical confidence. The simulator is flexible in the sense that each snapshot can have different time durations according to our purpose.
### 1.6 Contributions of the Thesis

Guided by the goals presented in section 1.4 and using the research methodology described in section 1.5, this thesis makes the following meaningful and novel contributions.

1. The design of case specific analytical and simulation model for GSM and CDMA based cellular network to evaluate radio resource allocation.

2. Based on the knowledge of simulation model, a CDMA based cognitive network simulator is designed. An interference model for scheduling is proposed and it is shown that there is limit to the threshold value of interference to achieve best possible allocation of resources for primary and secondary users.

3. A new scheduling scheme is proposed to mitigate intercell interference called cyclic switching scheduling scheme. It is proved that this scheduling algorithm provides better throughput with less blocking probability.

4. An adjustable fairness scheduler is designed which allows to specify a fairness constraint. This scheduler is specifically designed for LTE based (4G) wireless network. A quantitative fairness measure is used to calculate a cell fairness index. It is claimed that each value of the cell fairness index corresponds to a different performance in terms of throughput in the resource usage. Therefore if the mobile operator is able to force the network to operate on a desired fairness level, it can control the trade-off between throughput and fairness. This original idea is validated using different scheduling algorithms suitable LTE based network, which are evaluated in different simulation scenarios.

### 1.7 Organization of the Thesis

Chapter 1 introduces different Generations of Mobile Communications and provides the background on methods to accomplish Radio Resource Management in Mobile Communication. It also presents thesis objective.
Chapter 2 describes different Radio Resource Management techniques for Global System for Mobile Communication (GSM) and Code Division Multiple access (CDMA). Performance of FCA and DCA is evaluated. The case specific analytical and simulation model for GSM and CDMA based cellular network is designed to evaluate radio resource allocation. A new adaptive radio resource management scheme is proposed in CDMA based hierarchical cell structure called as MFA.

Chapter 3 is devoted for Radio Resource Management in CDMA-based Cognitive Networks. Interference model for scheduling algorithm in CDMA based CNR is designed. Also a throughput computation scheme for real-time data traffic is proposed and scheduling schemes for each type of the traffic are designed.

Chapter 4 states the Scheduling problems in 3GPP-LTE and LTE-A. A new scheme, Cyclic Switching Scheduling Scheme (CSSS) is proposed. Several schedulers are compared in terms of achieved throughput and fairness by simulations. An adjustable fairness scheduler is also proposed, that specifies a desired fairness constraint. This scheduler is specifically designed for LTE based (4G) wireless network. Verification and Validation of simulation model is done.

Chapter 5 deals with concluding remarks and future work.