

1 Introduction

Long Term Evolution (LTE) is one of the latest releases of the Third Mobile Generation Partnership Project (3GPP). The idea behind standardizing LTE was to create a system that can surpass the older mobile standards (e.g., UMTS and HSPA), and stay competitive at least for the next 10 years. One of the main features of LTE is that it has a flat and IP packet based architecture. In addition, LTE standards define a new air interface that is based on the concept of Orthogonal Frequency Domain Multiple Access (OFDMA). Several QoS classes are supported in LTE, where services QoS requirements are guaranteed by defining the so called “bearer” concept. A bearer (EPS bearer) is an IP packet flow between the user side and the LTE core network with predefined QoS characteristics.

The LTE MAC scheduler is an important and crucial entity of the LTE system. It is responsible for efficiently allocating the radio resources among the different mobile users, who might have different QoS requirements. The scheduler design needs to take different considerations into account, for example, user throughput, QoS and fairness, in order to properly allocate the scarce radio resources. As mentioned earlier, LTE is a packet based system that adds several challenges in guaranteeing the QoS. In addition, LTE has a number of services each with their own QoS requirements. The scheduler has to be aware of the different service requirements and should try to satisfy all of them. Within this thesis a novel Optimized Service Aware scheduler (OSA) is proposed, implemented and investigated to address all of the aforementioned challenges. The OSA scheduler differentiates between the different QoS classes mainly by defining several MAC QoS bearer types, such as, Guaranteed (GBR) and non-Guaranteed (nonGBR) Bit Rate. At the same time, it gains from the multi-users-diversity by exploiting the different users’ channel conditions in order to maximize the cell throughput. The OSA scheduler creates a balance between QoS guarantees and system performance maximization in a proportionally fair manner.

Another interesting research topic, which is discussed in this thesis, that is receiving immense attention in the research community is “Network Virtualization”. Virtualization is a well known technique that has been used for years, especially in computing systems, e.g., use of virtual memory and virtual operating systems.

Nevertheless, the idea of using virtualization to create complete virtual networks is new. Looking at the Future Internet research one emerging trend is to have multiple coexisting architectures, in which each is designed and customized to fit one type of network with specific requirements. Network Virtualization will play a vital role in diversifying the Future Internet into, e.g., separate virtual networks that are isolated from each other, and can run different architectures within. In this thesis work a general framework for virtualizing the wireless medium is proposed and investigated. This framework focuses on virtualizing mobile communication systems so that multiple operators can share the same physical resources, while being able to stay isolated from each other. Although, the framework is applied to LTE, it can be generalized to fit other similar wireless system, e.g., WiMax. Several scenarios have been investigated to highlight the advantages that can be obtained from virtualizing the LTE system, more specifically virtualizing the air interface (i.e. spectrum sharing).

Simulations often take considerable time to run and produce results. In order to validate the simulation model, and to be able to produce results at a much faster pace, several analytical models have been proposed and developed by the author. The analytical models differentiate between three types of time domain schedulers: Maximum Throughput scheduler (MaxT), Blind Equal Throughput scheduler (BET), and Optimized Service Aware scheduler (OSA). The models are also split into two categories: One with no QoS differentiation, and another with QoS differentiation that can support two traffic classes.

The thesis work is organized as follows: Chapter 2 gives an introduction of the mobile communication history, with special focus on the 3rd Generation Partnership Project (3GPP) standards. It introduces first the second mobile generation, that is Global System for Mobile Communication (GSM), explaining the main features of GSM, as well as its network architecture and its main entities. Then, the third mobile generation, the Universal Mobile Telecommunication System (UMTS) is introduced, highlighting the main differences between UMTS and GSM. In addition, a short overview on UMTS extensions (i.e. High Speed Downlink Packet Access (HSDPA), and High Speed Uplink Packet Access (HSUPA)) is also given.

Chapter 3 introduces the Long Term Evolution (LTE), which is the main focus of this thesis. The main motivation and targets of LTE are explained, as well as the LTE radio related topics: e.g., the multiple access schemes used. Then, the LTE network architecture with each of the LTE entities and the protocols used in each are described in detail. In addition, the LTE quality of service bearer concepts are discussed. Finally, the chapter gives a short introduction on what is beyond LTE, i.e., LTE-advanced, explaining some of its main new features.

Chapter 4 describes the design and development of the detailed LTE network simulator developed in this thesis work. The LTE simulator is implemented using the OPNET simulation tool. This chapter describes the implemented nodes and their functionalities, as well as the developed channel model. Furthermore, this chapter explains the different traffic models used in this work with their corresponding parameters. Finally, the statistical evaluation methods used to perform the evaluations are explained.

Chapter 5 presents the network virtualization concept. The main focus of this chapter is the wireless virtualization of the LTE mobile system. A novel wireless virtualization framework, that is proposed by the author, is introduced and explained in detail. The work done in this chapter is part of the European project 4WARD [4Waf]. The objective of this chapter is to provide the concept of using wireless virtualization in LTE, and to highlight the potential gain in sharing the spectrum between several network operators, as well as the gain coming from the multi-user diversity exploitation. Several performance analyses are shown in this chapter highlighting the aforementioned gains.

Chapter 6 targets the design of an efficient and novel LTE radio scheduler. The proposed Optimized Service Aware scheduler (OSA) is explained in this chapter. The motivation of the OSA scheduler is to design a scheduler that can provide service differentiation, and guarantee the user Quality of Service (QoS), while at the same time provide good overall system performance. Several performance evaluations are discussed, comparing the OSA scheduler against other well known schedulers.

Chapter 7 presents the different novel LTE radio analytical models. Those models are based on the Continuous Time Markov Chain, and are extensions of the general analytical model presented in [DBMC10]. First, the general model of [DBMC10] is described, then the model adaptations and extensions to the LTE system are discussed. Two categories of analytical models are developed: one with no QoS differentiation, and the other with QoS differentiations. The results of these analytical models are compared against the simulation results.

Chapter 8 gives the overall conclusion of the thesis, highlighting all the main points and achievements. Finally, an outlook concerning future work is given.

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