Computer Communications 35 (2012) 2218–2226

Contents lists available at SciVerse ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

# A performance evaluation tool for spectrum sharing in multi-operator LTE networks

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ARTICLE INFO

*Article history:*
Received 2 February 2012
Received in revised form 3 August 2012
Accepted 4 August 2012
Available online 17 August 2012

*Keywords:*
Spectrum sharing
Simulation
ns-3
LTE
Multi-operator cellular network

ABSTRACT

Recent advances in wireless networking introduce the concept of resource sharing as one promising way to enhance the performance of radio communications. As the wireless spectrum is a scarce resource, and its usage is often found to be inefficient, it may be meaningful to design solutions where multiple operators join their efforts, so that wireless access of their terminals takes place on shared, rather than proprietary to a single operator, frequency bands. In spite of the conceptual simplicity of this idea, the resulting mathematical analysis may be very complex, since it involves analytical representation of multiple wireless channels. Simulation studies may be extremely useful to obtain a correct performance characterization of wireless networks with shared resources. In this spirit, the present paper introduces and evaluates an original extension of the well known ns-3 network simulator, which focuses on multiple operators of the most up-to-date cellular scenarios, i.e., the Long Term Evolution of UMTS employing OFDMA multiplexing. Spectrum sharing is represented through a proper software architecture, where several sharing policies can be framed. A detailed simulation campaign is run to assess the computational performance of the proposed architecture, and to show its effectiveness in analyzing realistic scenarios.


## 1. Introduction

Although game theory started as a mathematical formulation of problems mostly belonging to economic and political systems, its application to wireless networking is becoming common practice [22]. Indeed, game theory is well suited to study problems where a scarce resource is contended for by multiple agents (players), as well as situations where these players have contrasting objectives, mostly because they are selfish, i.e., interested in their own good only. Incidentally, these aspects characterize the vast majority of wireless access problems, even though it can be noted that spectrum scarcity is due more to bad frequency planning than to a real lack of available frequencies [17]. In any event, it is the selfishness of the players, i.e., the network operators, that makes the radio access inefficient. This gives a strong motivation for replacing the classic scenario where network users are driven by self-interest with another where they cooperate [27].

A related early attempt at using game theory within wireless scenarios involves *cognitive networks*. In such a model, as defined by [24], two kinds of users co-exist, i.e., primary and secondary. The former are licensed users which access the frequency bands they are entitled to; the latter opportunistically access the subchannels which are unused by their legitimate owners (the primary users) for a given amount of time. The secondary users can act only after the primary users have made their decision. To some extent, cooperation is present in the sense that the primary users are aware of the secondary, but they let them be; after all, they are not threatening as they only exploit unwanted resources. This situation of cognitive networks is also reminiscent of some game theoretic investigations describing a duopoly situation with an incumbent and an outsider, known as a *Stackelberg game*, which has seen application to wireless networks problems [28].

Actually, an even more general form of collaboration can be thought of, without classifying players into primary or secondary, but rather considering an egalitarian approach, where similarly-minded players desire to use a common resource, or share a portion of their properties with the others. In the wireless network context, this would mean that network operators join their licensed frequencies for common wireless access. As hinted by several studies, such an idea may be beneficial for all the involved players if a collaborative access to the wireless resource is achieved [12,18,20,21]. Possible ways to quantify a gain can be in a larger number of users served, a wider network coverage, a higher network throughput.

However, the main challenge for analyzing this problem is in the adoption of realistic models for the physical layer. In principle, it can be easily argued that certain physical characteristics of the wireless channel, for example multi-user and frequency diversity, make it appealing to share its access, rather than competing for it [19]. Yet, an exact characterization of the wireless channel for

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http://dx.doi.org/10.1016/j.comcom.2012.08.004

several players is mathematically difficult. For this reason, the considered scenarios are often limited to small networks with few transmitter–receiver pairs, most of the times just two, i.e., a total of four nodes. We believe that a realistic performance evaluation of larger networks is key to get a clear understanding of the usefulness of the sharing concept in wireless scenarios.

In the scientific community it is quite common to resort to network simulation instruments to assess the performance of large networks which are not easy to tackle exactly. For example, the well known network simulator-3 (ns-3) [4] is currently considered as one of the most advanced and modular software tools to perform this task. The ns-3 simulator is entirely open source and comprises the entire protocol stack, from the physical layer up to the application. Although the focus of network simulation is often on the intermediate layers (data link, network, transport), ns-3 is extremely modular and therefore admits integration with detailed models of the physical layer, especially with the most up-to-date wireless technologies. A bottom-up representation of the protocol stack can be particularly appealing for the analysis of spectrum sharing, that involves both lower and higher layers. These reasons motivate our choice to employ an existing implementation [26] within ns-3 of the Long Term Evolution (LTE) of the Universal Mobile Telecommunications System (UMTS) [1].

The present paper completes the work already presented in [11], whose main contribution is to introduce a novel software extension of this ns-3 version to characterize spectrum sharing scenarios where cooperation is established among multiple operators, each with a considerable number of nodes. To realize this enhancement, original software structures are introduced. First of all, a class describing a virtual *frequency market* has been inserted in the simulator structure. This class implements the functionalities of a virtual arbitrator, and does not represent a physical entity of the network, but rather determines the sharing policy of the frequencies belonging to the common pool. In other words, its role is to abstract the set of rules agreed upon by the operators when determining the shared portion of the spectrum. Moreover, two main sharing meta-policies can be utilized, namely *orthogonal* and *non-orthogonal* sharing. In the former case, the frequencies of the shared pool are used by one and only one operator, although not necessarily the one that detains the legal property of the access on that frequency. In the latter, also simultaneous access of multiple users on the same frequency is possible. In both cases, the arbitrator structure is required to represent in an abstract manner the details of the sharing policy, such as priority rules among the operators in case of conflicting assignments or excessive mutual interference.

It is worth noting that the definition of efficient sharing policies is out of the scope of the present paper. For the sake of simplicity, we focus on orthogonal sharing, which is immediate to describe and does not require to detail any power control policy for shared frequencies. However, as the code developed is entirely modular, an extension to non-orthogonal sharing would be possible. Moreover, only competitive sharing was modeled, leaving the issue of identifying efficient and collaborative sharing mechanisms for a future analysis, possibly with more advanced game theoretic instruments.

Finally, besides introducing the details of the software extensions implemented within ns-3, this paper also provides the results of a simulation campaign meant to assess the effectiveness of the resulting simulator as a benchmark for testing spectrum sharing algorithms. A sample sharing algorithm is employed, and the evaluation of the modified version of the simulator in terms of computational requirements is given as well. The results confirm the ability of such a software instrument to give realistic assessments of the usefulness of spectrum sharing, and at the same time motivate further efforts with game theoretic approaches to implement efficient sharing algorithms where collaborative sharing is sought.

The rest of this paper is organized as follows. In Section 2 we review related works on simulation platforms for spectrum sharing analysis. In Section 3 we describe the system model, detailing the theoretical rationale behind the spectrum sharing characterization, while in Section 4 we discuss the modifications applied to the software architecture. In Section 5 we outline the simulation scenario and in Section 6 we present numerical results to validate our proposed contribution. We finally conclude in Section 7.

## 2. State of the art

Simulation platforms are a very common reference point to test protocols and assess the network performance, in particular for all those scenarios where the mathematical analysis becomes complex or cannot produce a solution in closed form.

In the literature, most of the works dealing with complex network systems include a performance evaluation part which leans on a simulator. This can be either a single-purpose simulator, specific to the scenario under investigation, or an adapted version of a general-purpose simulator. We believe that the latter alternative better fulfills scientific generality and reproducibility of the results, and enables future developments of individual findings. However, the software instruments chosen by the scientific community to this end are quite heterogeneous, from extremely general software platforms like SIMLIB [6] or MATLAB [3], which are properly customized to the particular context under evaluation, to more application specific tools which refer to particular systems, such as OMNET++ [5].

For what concerns computer networks, one of the most used tools in the research community is the Network Simulator ns [4], whose latest version is ns-3. It is an open source, free software managed by an active community of developers. The whole Internet suite protocol stack is implemented together with the most important protocols at the transport, network, and data link layers. Therefore, many different network scenarios can be created and simulated. One of the last implemented modules realizes LTE cellular networks [26]. The introduced framework enables the creation of Base Stations (called eNodeBs, or eNBs) and mobile terminals (called user equipments, or UEs) which can communicate with the eNBs. Most of the functionalities of the physical channel and medium access have been implemented. In [11], this basic framework has been extended by enabling a multi-cell scenario and allowing eNBs to share part of their frequencies in the downlink direction. Such a scenario is particularly interesting when the eNBs are managed by different cellular network operators. This paper further extends that work and introduces, together with a more detailed description of the system model, a different simulation scenario with an asymmetric cell traffic load.

Although the problems of interference channels and spectrum sharing have been addressed in several papers, e.g., [15,16], the scenario of inter-cell spectrum sharing was considered in a small number of them so far, and even fewer papers have focused on multi-operator networks. However, since in current network deployments the coexistence of multiple operators in adjacent regions is quite common, it makes sense to investigate the efficiency of the spectrum division policies adopted in common practice. The interest in this area has increased during the last years and has been involving not only researchers, but also telecommunication companies and regulatory bodies.

A first simple concept of spectrum sharing has been introduced and analyzed in [8]. Base Stations try to face their incoming requests first by using their initial spectrum, and then by exploiting frequencies not used by the others. Two algorithms for resource