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Reinforcement learning for joint radio resource management in LTE-UMTS scenarios

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ABSTRACT

The limited availability of frequency bands and their capacity limitations, together with the constantly increasing demand for high-bit-rate services in wireless communication systems, require the use of smart radio resource management strategies to ensure that different services are provided with the required quality of service (QoS) and that the available radio resources are used efficiently. In addition, the evolution of technology toward higher spectral efficiency has led to the introduction of Orthogonal Frequency-Division Multiple Access (OFDMA) by 3GPP for use in future long-term evolution (LTE) systems. However, given the current penetration of legacy technologies such as Universal Mobile Telecommunications System (UMTS), operators will face some periods in which both Radio Access Technologies (RATs) coexist. In this context, Joint Radio Resource Management (JRRM) mechanisms are helpful because they enable complementarities between different RATs to be exploited and thus facilitate more efficient use of available radio resources. This paper proposes a novel dynamic JRRM algorithm for LTE-UMTS coexistence scenarios based on Reinforcement Learning (RL), which is considered to be a good candidate for achieving the desired degree of flexibility and adaptability in future reconfigurable networks. The proposed algorithm is evaluated in dynamic environments under different load conditions and is compared with various baseline solutions.

1. Introduction

When they were first created, digital mobile telecommunications penetrated mass markets with voice as the primary service. However, the development of mobile communications in the last decade has been characterized by the constant expansion of data services. Lower prices for mobile services encouraged heterogeneity in every sense: there is now a wide variety of mobile services and radio access technologies (RATs), and the number of wireless service providers and user profiles has grown as well. The optimized use of available radio resources is necessary to maximize capacity use under such complex and competitive circumstances. Spectral efficiency improvements require highly evolved technologies with higher data rates, but they also require smart radio resource management (RRM) mechanisms. RRM facilitate the dynamic use of radio resources to meet moment-to-moment user demands and to cope with network dynamics such as mobility and traffic generation. Furthermore, the progressive deployment of the different generations of mobile communications systems has led to the coexistence of multiple access technologies. This network heterogeneity creates a new challenge: the need to offer services to users via efficient and ubiquitous radio access by coordinating the available RATs, which provides an additional degree of freedom in the RRM through smart mechanisms that jointly take into account the available resources of the RATs. These mechanisms are referred to as Joint RRM (JRRM) or Common RRM (CRRM) [1].

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Beginning with Release 8, 3GPP adopted Orthogonal Frequency-Division Multiple Access (OFDMA) as the technology used for long-term evolution (LTE) [2] to achieve high traffic capacity on 4G mobile networks. Additionally, the penetration of wideband code division multiple access (WCDMA) as a 3G universal mobile telecommunications system (UMTS) in mobile markets is already significant. Therefore, it is expected that these two RATs will coexist for a significant period of time, thus preserving operator investment in 3G. During this period, WCDMA can be used to serve those mobile devices that do not support LTE. Moreover, thanks to the relatively high bit rates and good performance that can be obtained for some services with WCDMA, this technology can also be used to ensure the efficient use of the total spectrum allocated to UMTS and LTE through the intelligent distribution of the users that can utilize both technologies.

Based on the above considerations, this paper presents a novel JRRM solution for use in scenarios in which LTE and UMTS technologies coexist. The proposed mechanism can be used to choose the most suitable RAT dynamically for each session. Adaptability is achieved using reinforcement learning (RL) [3]. RL is chosen as a mechanism for coping with the dynamic changes in the radio environment; it provides the network with the necessary cognition capabilities to modify its operations in accordance with network needs [4].

Different studies have addressed the JRRM problem in the literature in recent years. The JRRM algorithms developed so far apply to different network aspects (see [5] and its references) and usually apply to heterogeneous radio access networks composed of UMTS, general packet radio service (GPRS), and wireless local area network (WLAN) [6]. JRRM solutions for these networks range from dynamic load distribution mechanisms [7] to complex fuzzy-neural solutions [8] for advanced network supervision. In contrast, until now, little effort has been devoted to the JRRM problem in scenarios in which LTE and UMTS coexist, and to the best of the authors' knowledge, no specific algorithms have been published so far.

The authors have introduced a Q-learning model intended to facilitate joint call admission control in a generic heterogeneous network with the objective of reducing session dropping rates [9]. No specific technology is considered; rather, it is assumed that the generic networks considered have a fixed and limited capacity expressed as a multiple of some number of elementary bandwidth units. Additionally, the previous study does not account for signal quality variations due to inter- and intra-cell interference in each access network [9]; instead, it only takes into account the number of requested elementary bandwidth units. Similarly, other authors have applied Q-learning for joint call admission control in a single-cell scenario with GPRS, UMTS and WLAN technologies [10]. They attempt to maximize a reward function that indicates the suitability of a given RAT for each traffic type and that reflects blocking and dropping effects.

Unlike in prior studies, the RL approach presented in this paper focuses on a scenario in which UMTS and LTE RATs coexist, and the aim is to improve user satisfaction in terms of the bit rates achieved for different services. The algorithm is then formulated from a multi-cell and multi-service perspective. Furthermore, evaluation captures a detailed characterization of mobile radio effects, such as intra- and inter-cell interference and shadowing, and of procedures such as power control in UMTS and scheduling in LTE, which allows us to capture short-term capacity variations in the technologies considered and their impact on the learning process and performance. In addition, the RL-based JRRM approach proposed in this paper considers fewer states than did previous works. This property reduces complexity and enables faster learning, which is especially important for real-time operation.

In a previous study, the authors developed the first version of the algorithm assuming a single-service, single-cell scenario with base stations (BSs) at the same site for both access networks [11]. Based on the encouraging results [11], which provide a reasonable basis for initial concept validation, this paper generalizes the algorithm to multi-cell and multi-service scenarios and considers a general situation in which the BSs of different RATs are not at the same site.

The rest of this paper is organized as follows. Section 2 describes the JRRM-RL (JRL) framework. Afterwards, Section 3 explains the reinforcement learning algorithm for the JRL model. The simulation parameters and results are presented in Sections 4 and 5, respectively. Finally, Section 6 summarizes the main conclusions.

2. JRRM-RL (JRL) framework

From an architectural point of view, the proposed JRRM-RL (JRL) algorithm assumes an RL agent is assigned to one JRRM domain consisting of a number of cells belonging to the two RATs (UMTS and LTE), as illustrated in Fig. 1. The agent works in real time and is responsible for allocating the appropriate technology to each user. This

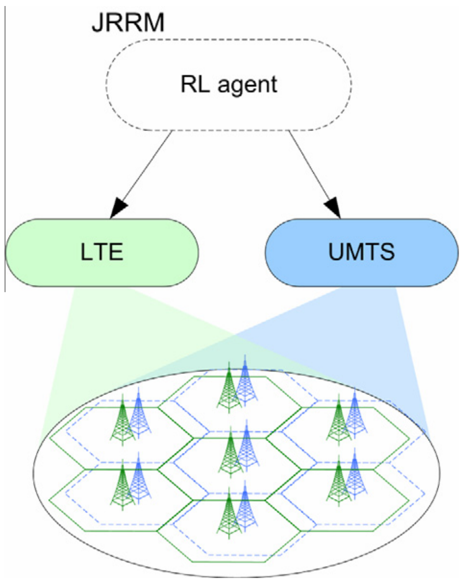

Fig. 1. Reinforcement learning for JRRM.