



# Dynamic traffic steering based on fuzzy Q-Learning approach in a multi-RAT multi-layer wireless network



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## ABSTRACT

The infrastructure of current cellular networks must evolve to cope with the increasing demand for mobile-broadband services. Heterogeneous networks are an attractive solution for operators to expand network capacity, based on deploying different Radio Access Technologies, cell sizes and carrier frequencies in the same environment. As a result, operators gain flexibility to distribute traffic across the different networks (or layers) in order to make a more efficient use of resources and enhance network performance. In this work, a dynamic traffic steering technique in multi-RAT multi-layer wireless networks is proposed. In particular, a fuzzy rule-based reinforcement learning algorithm modifies handover parameters according to a specific policy set by the operator, which typically searches for a trade-off between key performance indicators. Results show that the proposed optimization algorithm provides good flexibility to support different policies by simply adjusting some weighting factors. In addition, the Q-Learning algorithm is shown as an effective solution to adapt the network to context variations, such as those produced in the user spatial distribution.

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## 1. Introduction

The evolution of next-generation wireless networks is envisioned to satisfy the growing traffic demand of new services. The increasing complexity and capability of terminals (or smartphones) has encouraged the development of new applications with higher requirements of bandwidth. To deal with this traffic demand, multiple Radio Access Networks (RANs) will be deployed covering the same area. Heterogeneous Networks (HetNets) will be characterized by the presence of networks with different technologies, frequencies, cell sizes, etc. Future Radio

Access Technologies (RATs), such as Long-Term Evolution (LTE), LTE-Advanced (LTE-A) and Worldwide Interoperability for Microwave Access (WiMAX) must co-exist and co-operate with existing technologies such as Global System for Mobile Communications (GSM), High-Speed Packet Access (HSPA) and Wireless Fidelity (WiFi) to provide high data rates and good quality of service. In addition, hierarchical cellular structures involving cells with different sizes (e.g., macro, micro, pico and femto cells) allow to provide more capacity in crowded areas or hotspots.

Since the coverage areas of the deployed networks in HetNets are partially or totally overlapped, network operators could determine toward which network a user connection should be routed to utilize resources more efficiently. The concept of Traffic Steering (TS) involves a powerful mechanism based on sending users to the correct network (or layer) with the aim of optimizing the usage of

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radio resources. TS is a very recent topic in the research activity due to the increasing complexity of future mobile network deployments. As a result, the existing solutions to this kind of heterogeneous scenarios are scarce [1–3]. In addition, the range of new challenges and questions that traffic steering poses is enormous, not only because scenarios can be very different but also because there are many variables to optimize.

TS objectives can be achieved by utilizing mechanisms of mobility management, which are standardized by the 3GPP in the case of mobile networks, providing support for interoperability with other systems [4]. More specifically, TS can be carried out in both states, idle and connected mode. The idle mode is a state in which the User Equipment (UE) has no active connection and the lowest energy consumption is maintained. In idle mode, the cell selection algorithm has been used to define a wide range of RAT selection policies [5,6]. However, mechanisms carried out in idle mode may not be as effective as those performed in connected mode, where dedicated resources have been established for the UE, and the user satisfaction directly depends on the data transmission performance. A powerful TS mechanism in connected mode is based on adjusting the offsets involved in the handover (HO) procedure. An HO is traditionally carried out when the UE moves between two cells to preserve the user connection. However, in the context of HetNets, a UE could trigger an HO due to traffic steering reasons as the coverage area of the network layers are partially overlapped [7–15]. An important issue, shown in [16,17], arises when the thresholds involved in the inter-RAT HO triggering condition are based on the signal level (instead of the signal quality), meaning that a more precise adjustment is required, especially in multi-layer scenarios, where the location of low-power nodes within the macrocell may determine the adjustment of those thresholds. In this sense, this paper further investigates the problem analyzed in [16,17], in which, as a first approach, a simple static algorithm was proposed.

On the other hand, Self-Organizing Networks (SONs) are a new concept to automate the operation of next-generation wireless networks with the aim of reducing operational cost and improving network quality [18,19]. Dynamic TS can be considered here as a SON mechanism provided that network parameters are automatically tuned to achieved the objectives of TS policies. In this sense, concerning automatic self-tuning techniques, Fuzzy Logic Controllers (FLCs) has been widely applied to mobile network parameter optimization in many references [8,20–22]. All these references prove that FLCs are very useful for automatic network parameter optimization. Fuzzy Logic benefits come from its ability to translate human knowledge into a set of basic rules. These rules representing the mapping of the input to the output in linguistic terms are usually derived from the knowledge and experience of a human expert. However, when knowledge is not available, different strategies have been investigated to create, adapt or refine rules, e.g. through learning using neural networks [23], genetic algorithms [24] and Reinforcement Learning (RL) [5,25,26]. Q-Learning is a RL method particularly appropriate for learning from interaction, where the

learning is performed via a reward mechanism. This method has been widely applied to wireless network optimization problems [27–30]. The combination of FLCs and the fuzzy Q-Learning algorithm is a powerful Self-Optimization mechanism where the FLC facilitates the modeling at a higher level of abstraction (i.e. human reasoning) and the Q-Learning allows to train/adapt the controller.

This paper investigates a dynamic TS technique based on adjusting HO parameters in a multi-RAT multi-layer wireless network. In particular, a fuzzy rule-based RL system that adapts the thresholds of the inter-RAT HO triggering condition to meet a TS policy is proposed. The scenario under study has been thoroughly deployed to cover hot-spots with LTE picocells, so that the TS policy is to offload traffic from the macrocells to the pico layers in order to use more efficiently the radio resources and improve service performance. The proposed algorithm has important benefits over the existing one, [16]: it provides (a) enforcement of multiple operator policies and (b) adaptation capability to context variations in HetNets.

Although the Q-Learning algorithm has been previously applied to other optimization problems, the problem addressed in this paper poses clearly different challenges. In [31], an FLC is firstly designed using a priori knowledge and then refined with the Q-Learning algorithm in order to achieve a specific target. This means that, initially, the rule base of the FLC (i.e. its behavior) has been set according to the expert knowledge. Then, those rules are dynamically adapted to the concerned scenario by using a trial-and-error search. In [32], no a priori knowledge is assumed, meaning that the rule base of the FLC has been randomly created. As a result, the FLC is optimized by the Q-Learning algorithm from the beginning in order to set effective rules. However, due to the large dimension of the solution space, a previous phase of coarse parameter tuning is carried out to speed up the learning process. In this work, neither a priori knowledge for the proposed scheme nor initial coarse parameter tuning phase are assumed. This is possible due to a reduced dimension of the solution space. Thus, the main benefit of this approach lies in its capability to rapidly adapt to changes in order to achieve a specific objective. In addition, both the scenario and the problem are entirely different from previous work. In [31,32], the problem of load balancing in scenarios with single RATs and layers is covered. Such a lack of heterogeneity in mobile networks cannot be assumed for future scenarios. In addition, the scope of load balancing is very limited. Conversely, TS can be carried out according to very different criteria. As a result, both the FLC and the optimization algorithm must be applied in a different way (e.g. different inputs, outputs, objective functions, etc).

The rest of the paper is organized as follows. Section 2 describes the system model for a heterogeneous network, including the main system measurements and HO parameters. In Section 3, the parameter optimization scheme for traffic steering is presented. Section 4 describes the structure of the proposed FLC. The fuzzy Q-Learning algorithm and its application to the FLC is explained in Section 5. Section 6 describes the simulation setup and discusses the results. Finally, Section 7 draws the conclusions.

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