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Load balancing and handover joint optimization in LTE networks using Fuzzy Logic and Reinforcement Learning

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ABSTRACT

With the growing deployment of cellular networks, operators have to devote significant manual effort to network management. As a result, Self-Organizing Networks (SONs) have become increasingly important in order to raise the level of automated operation in cellular technologies. In this context, Load Balancing (LB) and Handover Optimization (HOO) have been identified by industry as key self-organizing mechanisms for the Radio Access Networks (RANs). However, most efforts have been focused on developing a stand-alone entity for each self-organizing mechanism, which will run in parallel with other entities, as well as designing coordination mechanisms in charge of stabilizing the network as a whole. Due to the importance of LB and HOO, in this paper, a unified self-management mechanism based on Fuzzy Logic and Reinforcement Learning is proposed. In particular, the proposed algorithm modifies handover parameters to optimize the main Key Performance Indicators related to LB and HOO. Results show that the proposed scheme effectively provides better performance than independent entities running simultaneously in the network.

1. Introduction

In the last years, cellular networks have experienced a large increase in size and complexity. As a result, mobile operators have focused attention on reducing capital expenditures (CAPEX) and operational expenditures (OPEX) of their networks [1]. This fact has stimulated strong research activity in the field of Self-Organizing Networks (SON), which is a set of principles and concepts defined by the 3rd Generation Partnership Project (3GPP) for automating network management while improving network quality [2]. In the context of SON, certain functions have been identified as key enablers by the 3GPP, among which are Load Balancing (LB) and Handover Optimization (HOO). The former is an automated function where cells suffering occasional congestion can transfer load to neighbor cells, which have spare resources, by e.g. adjusting mobility parameters. The latter is a solution for automatic detection and correction of errors and suboptimal settings in the mobility configuration, which may lead to a degradation of user performance. Many efforts in the research community have been devoted to the so-called Mobility LB (MLB) and Mobility Robustness Optimization (MRO), for which the 3rd Generation Partnership Project (3GPP) has specified particular features [3]. Typically, these functionalities are implemented at a low-level in the network architecture, meaning that they operate quickly (i.e. at time scales of the order of seconds or less) and they are located in each base station on the access network. In this sense, less or no attention has been paid to LB and HOO at higher levels, e.g. at the level of the Operations, Administration, and Maintenance (OAM) system, which typically operates slower (i.e. at time scales of the order of minutes or even hours) and they are not necessarily located in the base stations (e.g. they can be located in a

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server on the core network). Thus, network management at this level copes with slower changes in the network, whose impact on performance can be even more important, since the underlying variations to be tracked are typically rather slow as well [4]. In addition, the data available in the OAM system is much more abundant than in the base stations, thereby allowing more efficient and powerful network management. As a result, the implementation of this kind of algorithms will provide great benefits and cost-savings to operators.

As the deployment of stand-alone SON functions is growing, the number of conflicts and dependencies between them increases. A conflict can happen if, for example, two individual SON functions optimize the same parameter with different goals at a network element [5]. As expected, conflicts may have a negative impact on network performance. The common solution in SON research has been to create an additional entity, usually called coordinator, which manages the conflict. Typically, an entity causing conflict is switched off or limited in the control strategy, e.g. by decreasing the allowed range, the maximum allowed step sizes or the periodicity at which parameter control takes place. The study of SON coordination is a topic recently addressed in the bibliography. On the one hand, there are several studies with the aim of developing a functional framework for SON coordination [6–10]. On the other hand, further efforts have been devoted to specific solutions for coordination of two or more SON functionalities [11]. Special attention has been devoted to the coordination of MLB and MRO, addressed by the SOCRATES project [12]. In particular, the study assumes the control parameters of the MLB and MRO algorithms to be independent of each other, i.e. the two algorithms do not tune the same parameters. While the MLB function adjusts the HO margin (HOM), the MRO function adjusts the Time-To-Trigger (TTT) and hysteresis parameters. The interactions exist because these two functions influence the same Key Performance Indicators (KPIs) that are used as input for the optimization algorithms. In [13], a constraint for the connection quality more restrictive than the one assumed in the SOCRATES project is considered. In this sense, the MLB function is restrained in favor of the HO performance optimization. In [14], to avoid the conflict between MLB and MRO, the HOM range of MLB is dynamically adjusted according to the TTT and the hysteresis parameters, which are first adjusted considering the effect of the user speed.

Although the coordinator-based schemes have been well accepted by the research community, there are some related issues. Specifically, the definition of operator policies becomes a complex task, since there exists a trade-off between proper controllability and ease of use [10]. In addition, when some limitations are applied to the control strategy (e.g. by restricting the step size), the optimal configuration may lie outside the space of possible solutions. Another problem is related to the prioritization of SON functions in a centralized coordination scheme, which is the typical implementation due to the required integration with a (centralized) legacy OAM system [15]. Under this situation, the coordination entity has to process many parameter configuration requests, so that the risk of monopolization by high priority functions is high. Due to this, the joint optimization of SON functions has also been addressed. In [16], the problem of coordinating capacity and coverage optimization and MLB is addressed. Instead of implementing an additional entity that coordinates the outcomes of each independent function, these functions are combined into one algorithm and then the cellular network is optimized towards a joint target. Similarly, in [17], instead of controlling the conflict between independent MRO and MLB functions, a joint optimization algorithm is proposed. Such an algorithm adjusts the same HO parameters for individual users (i.e. each user has individual values of the same HO parameters). This solution reduces unnecessary HOs for some users that should not be handed over to the neighbor cell. However, it is noted that, at the level of the OAM system, this feature is hard to be implemented since statistics are rarely given per user-level, in addition to the high signaling cost that this kind of optimization would involve. In [18], the proposed MRO and MLB algorithm prioritizes the MRO part, since KPIs related to the connection quality (e.g. the radio link failure) are considered first. However, other important KPIs from the MRO viewpoint, such as those associated with unnecessary HOs, are not taken into account in the study, which makes more difficult to achieve optimal performance.

For all those reasons, in this paper, a novel unified algorithm for both LB and HOO in Long-Term Evolution (LTE) networks is proposed. This algorithm is based on a Fuzzy System (FS) that tunes the handover (HO) parameters at the cell adjacency level to improve network performance. The FS is optimized by the *Q*-Learning algorithm, which drives it to select the most appropriate action either due to LB and/or HOO reasons. The decision of which action the FS should take depends on past actions which were taken by the FS and whose impact on network performance was measured through the KPIs. With the proposed solution, the complexity of the SON coordination entity would be reduced, as it is freed from the coordination of two important SON functions. In addition, the proposed algorithm is expected to achieve better performance, as its space of all candidate solutions is not as restricted as if a coordinator-based scheme or some type of prioritization algorithm would be used.

The rest of the paper is organized as follows. Section 2 formulates the problem and introduces the mobility algorithm in LTE networks and the system performance metrics. In Section 3, the design of the proposed FS as well as its optimization process is described. Section 4 presents the simulation setup and discusses the simulation results. Finally, Section 5 presents the main conclusions of the study.

2. System model

The HO is the procedure that preserves the connection when the user moves around the network. As LTE is being deployed with a frequency reuse of one (i.e. the same frequency is shared by all cells), the intra-frequency HO is very common in these networks. More specifically, the most widely extended algorithm for the HO-triggering decision is the 3GPP A3 event [19]. Roughly, this algorithm