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Investigation on MDP-based radio access technology selection in heterogeneous wireless networks

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ABSTRACT

The new generation of wireless networks is characterized by heterogeneity i.e. the coexistence of two or more radio access technologies (RAT) in the same geographical area. While this coexistence of RATs offers various advantages, it also imposes many challenges for the network operator, whose aim is to maximize the generated revenue while satisfying the customers' increasing demands. One important mechanism in heterogeneous wireless networks (HWN) is the RAT selection. It is normally triggered when a new call arrives, and provides the decision on whether the call can be admitted or not, and by which RAT it has to be served. Different approaches can be used to tackle the problem of RAT selection in HWNs. In this paper, we study Markov Decision Process (MDP)-based RAT selection in a cellular/WLAN heterogeneous network where the maximization of the revenue is considered as objective. An optimal RAT selection policy is therefore derived. The performance of the optimal scheme is evaluated in comparison with two other policies, namely Cellular-First policy and Load Balancing policy.

1. Introduction

The new generation of wireless networks is characterized by heterogeneity where two or more radio access technologies (RATs) coexist in the same geographical area. The coexisting RATs may have different, but often complementary characteristics in terms of coverage, latency and link capacity. This trend of multiplicity of RATs is also expected to be dominating in the future for the many advantages it offers. These advantages include, among others, multiple connectivity options, and an expansion of the coverage at a relatively low structure cost [1]. However, this imposes additional challenges for the operator especially in finding means of coordination among the coexisting RATs.

Getting full advantage of the combined features of the deployed RATs is crucial for the network operator. On one hand, this can be explained by the fast increase of demands from users with high Quality of Service (QoS) requirements, coupled with the proliferation of bandwidth-hungry applications widely available on smart phones, and electronic devices. On the other hand, the wireless resources are very scarce as compared to the growing demands. Therefore, the operator has interest in making the best utilization of all available resources to increase the capacity of the network and meet, as much as possible, the users' expectations and demands.

Heterogeneous wireless networks (HWNs) provide many opportunities for capacity improvement. Considering the case of a cellular/WLAN overlay network, WLAN can play an important role in alleviating some of the problems encountered by the cellular network in terms of congestion and coverage (WLAN offloading [2]). By deploying access points (APs) in specific targeted areas such as cell edges, and hotspots, considerable amount of traffic can be carried by the WLAN [3], thus increasing the network capacity.

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Cellular and WLAN have complementary characteristics. On one hand, broadband cellular networks such as 3GPP Long Term Evolution (LTE) can implement quite complex resource management schemes, more efficient QoS and wider coverage than WLAN. On the other hand, WLAN is characterized by its cheap deployment and access costs, small coverage and limited QoS guarantees. A network operator can, through an efficient management of the joint pool of resources of both RATs, take advantage of their combined features to increase the overall system performance and consequently generate higher profit.

Managing resources in HWNs involves setting up policies that regulate the amount and type of traffic served by each of the RATs. These regulations may vary depending on whether the adopted scheme is user-centric or operator-centric. For instance, considering the user's perspective, the objective is usually to guarantee the best achievable QoS such as low delay and blocking probabilities or high throughput. The operator, however, would be more interested in maximizing the network's capacity in order to accommodate the maximum number of users and increase the generated revenue.

A well known key mechanism for resource management in HWNs scenarios is RAT selection. It consists of taking a decision, at each arrival of a new call request, on whether to accept this call or not, and the RAT to which it can be admitted. A well-designed RAT selection policy allows a better assignment of the traffic to the available access networks, increasing the number of sessions that the system can accommodate.

Different approaches can be used to tackle the RAT selection problem in HWNs. In the present work, we investigate Markov Decision Process (MDP)-based RAT selection with the objective of maximizing the operator's revenue. Different user profiles with their respective QoS requirements and charged prices are considered, and a preferential treatment is provided to the profile that is charged higher fees. Moreover, the spatial distribution of the base stations (BSs) and APs (for the cellular and WLAN respectively), and that of the users in the HWN are taken into account in modeling the traffic.

The main contributions of this paper can be summarized as follows:

(1) Investigation of the MDP-based approach for RAT selection, with focus on revenue maximization as objective.
(2) Considering the operator's policy of granting different levels of priority to the different classes of service, the reflection of this policy by tuning the parameters of the MDP model is discussed.
(3) The coverage probability of WLAN is analytically modeled with the help of Poisson Point Process (PPP).
(4) The spatial distribution of the users is also captured with PPP.
(5) Evaluation of the performance of the MDP-based RAT selection with comparison to two other static RAT selection schemes.
(6) Highlight on the role of WLAN in traffic offloading and improving the perceived QoS.

The remaining of the paper consists of the following parts: Section 2 presents the motivation and related work in the literature. Section 3 describes the system model. In Section 4, the components of the MDP problem are presented. Section 5 discusses the revenue maximization problem. Section 6 presents and analyzes the obtained results. Finally, we conclude this study in Section 7.

2. Motivation and related work

Broadband cellular networks, despite their great promises, might not be able to fulfill the expected increase in demands of data traffic in the near future [4]. This incites the network operators to be in perpetual search for solutions that alleviate the problem of increasing traffic load, and WLAN has been considered as one appealing candidate to complement the cellular network. For example, WiFi offloading is of great importance for the different advantages it provides, namely the usage of unlicensed spectrum, being a well-established technology, and more importantly all new smart phones, and electronic devices planned for 4G have the features of WiFi radio embedded, a trend that is likely to continue for 5G as well.

In order for the network operator to benefit from the WLAN capacity to alleviate the load on cellular network, a strategy for the distribution of traffic among the two RATs is needed. This can be partly realized through the implementation of an efficient RAT selection mechanism. While different approaches can be used in dealing with RAT selection problem, MDP is a good candidate for this optimization owing to its appealing properties.

MDP can be defined as a Markov chain with the addition of an action model and a performance criterion. It has been widely applied in various areas such as ecology, economics, and network routing [5]. In the case of RAT selection problems, MDP is also an intuitive stochastic control approach. Even though MDP suffers from a dimensionality problem when the number of states in the MDP is increased to represent a large number of connections, some approaches have been suggested in the literature (such as in [6]) where approximation solutions are provided. One other example can be found in [7] where a reduced dimension MDP-based call admission control scheme has been proposed. The results in [7] show a great reduction in the complexity of the original MDP model, making it practical and cost-effective for implementation in HWNs. We believe, with such solutions, the effectiveness and the promising results of MDP-based schemes can be exploited by the network operators. Nevertheless, in this paper, our focus is on investigating the effectiveness of using MDP to maximize revenue generation in HWNs. For this reason, we shall only consider the original MDP, leaving its simplification to future study.

In the literature, several RAT selection policies have been proposed. In [5], a threshold-based framework for call admission control has been provided and different objective functions have been proposed and investigated. In [8], the authors proposed a heuristic RAT selection scheme in co-located wireless networks which aims to enhance the user's QoS in terms of minimizing the call blocking probability. In [17], a stochastic process algebra is used to build a framework for network selection strategies in 3G-WLAN networks. Different strategies are evaluated, namely general non-deterministic strategies (random strategy and relative received signal strength (RRSS)-based strategy), WLAN-first