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Utility-based RAT selection optimization in heterogeneous wireless networks

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ABSTRACT

Recent technological advances in wireless networks will enable the realization of an integrated heterogeneous wireless environment consisting of multiple Radio Access Technologies (RATs) within a network provider. One of the most important benefits is that this will allow providers to balance their traffic among their subsystems without compromising on QoS issues. In this paper we focus on the Network Selection problem to allocate terminals to the most appropriate RATs by jointly examining both users' and providers' preferences. We introduce three utility-based optimization functions based on the type of application that users request. We then formulate the terminal assignment problem as an optimization problem, which is recognized as NP-hard. We examine both offline and online selection and develop an optimal Branch and Bound (BB) algorithm, a Greedy heuristic, as well as three Strip Packing variations. BB behaves efficiently in both offline and online environments reducing the search procedure, while the proposed heuristics produce results close to the values we get from BB but with very low computational cost.

1. Introduction

During the past decades, wireless networks have improved significantly and became an integral part of our everyday life. Starting from 2G Networks with the support of voice-mainly services, we have ended up using mobile 3G+ Networks that support voice and data services as well. However, the use of wireless data services has increased tremendously by the wireless LAN technology, which offers much higher bandwidth but at shorter ranges. Other technologies that have also emerged in the past decade are 802.16 [1], DVB and HSPA [2,3], while even more latest technologies are recently emerging such as LTE [4], which is already being installed in many countries and 802.22 [5] which was published as an official IEEE Standard in July 2011 [6].

In parallel, considerable developments have occurred in users' terminals with the appearance of multimode terminals [7], which can connect to more than one Radio Access Technologies (RATs). It is worth mentioning that more and more mobile phone manufacturers announce the support of even more RATs in the coming years. This evolution, coupled with the users' desire to be "Always Best Connected" (ABC) [8], has led to the vision of Next Generation Wireless Networks (NGWNs) as an integrated heterogeneous environment where wireless networks coexist and users are able to seamlessly roam across different types of Wireless Access Networks.

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There have already been efforts from 3GPP to create an environment of coexistence between 3G and WLAN [9], while IEEE 1900.4 Standard [10] describes the architecture and protocols for distributed decision making to optimize radio resource usage in heterogeneous wireless networks. In addition IEEE 802.21 Standard supports algorithms enabling seamless handover between networks of the same type as well as handover between different network types also called Media independent handover (MIH) or vertical handover [11].

Recent research in the area of heterogeneous wireless networks is focusing on enabling simultaneous invocation of applications with different traffic and QoS characteristics by the user terminals. In this multi-service model, user satisfaction, which depends on the QoS perceived by each application, will become an important factor for successful network operation, as technological and market advancements will make it much easier for a user to migrate from one RAT to another, within a single or multiple cooperating providers, even on session level basis.

In this paper we examine the network selection problem, which deals with the assignment of each terminal request to the most suitable RAT and is similar to well-known NP-hard problems, such as the Knapsack and the Generalized Assignment Problems [12]. We follow the approach in [13] and formulate it as an optimization problem which attempts to maximize a utility-based objective function under requirement and capacity constraints. We examine both offline and online selection problems and develop a Branch and Bound (BB) algorithm, a Greedy heuristic which exploits the special characteristics of the problem and three Strip Packing variations. The proposed algorithms are first evaluated offline where users are examined and optimally allocated to the most suitable RAT. Subsequently, we evaluate the algorithms in an online dynamic environment where users' requests are dynamically served and depart from the system. In this online study users may pose requests for one or even two of the available services. A summary of our results is that BB behaves efficiently in both environments, reducing the search procedure, while the proposed heuristics produce results close to the values we get from BB but with very low computational cost.

The rest of this paper is organized as follows. In the next section we present previous related research works. In Section 3, we outline our system model and formulate the optimization problem of access selection in multi-RAT environments. In Section 4 we present the BB algorithm, while in Section 5 we present the Greedy heuristic and the Strip Packing variations. Finally, in Section 6 we present our simulation results for both online and offline environments and the paper is concluded in Section 7.

2. Related work

There have been many works that deal with the Network Selection problem in different ways. For example, in [14] users are assigned to subsystems, in order to minimize blocking probability and at the same time maximize the system capacity, while the formulation is done according to the Online Bin-Packing Problem. In a similar context, the authors in [15] study resource allocation in the context of Always Best Connected (ABC) using the Knapsack Problem formulation. The overall goal is to maximize users' utility, while taking their preferences and satisfaction into account through a quality-to-utility mapping.

A thorough study on the utility theory to define an appropriate decision mechanism in the frame of the access network selection was made by the authors in [16], who proposed new single-criterion and multi-criteria utility forms to best capture the user satisfaction and sensitivity facing up to a bundle of access network characteristics. In [17], the authors point out the need of the existence of a Common Radio Resource Management (CRRM) as a fundamental part of the upcoming next generation wireless systems. They formulate the problem as a Generalized Access Selection Problem (GASP) and expose the optimization criteria that define the solution. They also formulate a strict version of the Access Selection Problem (SASP) and in order to obtain the solution, they propose a strategy based on a Genetic Algorithm (GA).

The authors in [18] try to solve the problem using the multiple criteria decision making AHP method. One of the main factors they include is the application's requirement on network resources, which is depicted with a utility function. In their approach, they study four different applications (VoIP, Video Streaming, FTP, Web browsing) each one represented by a different utility function. In a similar concept of having different utility function for each available application, the authors in [19] present a user-centric network selection approach where negotiation between users and network operators is carried out using a multiple attribute auctioning mechanism. The authors also propose a method to reduce handovers (and ping-pong effect) using fuzzy logic.

In [20], users' allocation is compared to a competition among group of users in different service areas to share the limited amount of bandwidth in the available wireless access networks. Eventually, the problem is formulated as a dynamic evolutionary game where the evolutionary equilibrium is considered to be the solution to this game. Finally, in [21] the authors cast the problem as a non-cooperative game where users and access networks act selfishly according to their objectives while in [22] bandwidth allocation and admission control algorithms are presented based on the bankruptcy game.

Our work differs from previous works in that we jointly examine different applications (voice, video, web) in multi-RAT environments, which are included in our formulation by a combination of utility functions. We also propose a way to integrate in our model both users satisfaction and provider benefit. Furthermore, we introduce a new categorization of users based on their receptiveness regarding the allocated resources. Finally, we look both at offline and online formulations of the network selection problem.

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