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Integer linear programming optimization of joint RRM policies for heterogeneous wireless systems

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ABSTRACT

Wireless systems will be characterized by the coexistence of heterogeneous Radio Access Technologies (RATs) with different, but also complementary, performance and technical characteristics. These heterogeneous wireless networks will provide network operators the possibility to efficiently and coordinately use the heterogeneous radio resources, for which novel Joint Radio Resource Management (JRRM) policies need to be designed. In this context, this work proposes and evaluates a JRRM policy that simultaneously determines for each user an adequate combination of RAT and number of radio resources within such RAT to guarantee the user/service QoS requirements, and efficiently distribute the radio resources considering a user fairness approach aimed at maximizing the system capacity. To this aim, the JRRM algorithm, which takes into account the discrete nature of radio resources, is based on integer linear programming optimization mechanisms.

1. Introduction

The continuous evolution of wireless and mobile technologies is creating wireless communication ecosystems where several Radio Access Technologies (RATs) physically coexist. In addition, new user applications with diverse and more restrictive Quality of Service (QoS) requirements are emerging, raising the challenge of carrying out a more efficient use of the scarce available radio resources. In this context, there is a wide consensus in the research community that future heterogeneous wireless networks will require the coordinated management of the radio resources from the coexisting RATs. Such management will be conducted through Joint Radio Resource Management (JRRM) techniques, also referred to as Common Radio Resource Management (CRRM) techniques, aimed at efficiently distributing the available heterogeneous radio resources in order to satisfy the user QoS demands, while increasing the operators' system revenue. The JRRM concept was defined by the 3GPP (3rd Generation Partnership Project) in [1,2], where also different supporting network architectures were presented to ensure the interoperability between the different RATs.

JRRM policies are responsible for assigning incoming calls the optimum RAT over which to convey them. Several studies can be found in the literature investigating proposals to address the RAT selection dilemma. Gelabert et al. [3] propose some initial JRRM RAT selection mechanisms based on pre-established service-to-RAT assignments, and a load balancing criterion (the user is assigned to the lowest loaded RAT). Another interesting initial RAT selection strategy [4] defines a suitability factor for selecting each available RAT based on aspects such as the radio resources availability, the interference level, and the terminal and network capabilities. An innovative contribution is the evaluation of the suitability factor's dependency with varying operators' policies. Several RAT selection principles based on the signal strength (coverage) and instantaneous load are also suggested in [5]. Other initial RAT selection policies base their JRRM decisions on each RAT's load and

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the multi-technology capability of user terminals. In fact, it is possible to take advantage of the presence of multi-mode terminals by switching their assigned RATs in order to free the capacity required to accept new calls from single-mode terminals. Several strategies to perform this traffic rearrangement in a heterogeneous wireless framework are discussed in [6] and references therein. The load balancing strategies employed in [7] are aimed at achieving a uniform traffic distribution, which is pointed out to be desirable in order to maximize the trunking gain and minimize the probability of making unnecessary vertical handovers of multi-technology terminals. For non-real-time services, the load balancing is performed based on the measured buffer delay, while for real-time services a load balancing principle based on load thresholds is proposed. In [8], the authors evaluate a vertical handover strategy to simultaneously decide the target network for several users requesting a handover in the same base station. The vertical handover algorithm will decide the best target network for each user based on its QoS requirements and individual interests, but would also take into account the networks' load resulting from the handover process. Consequently, the algorithm improves its RAT selection decision when simultaneously receiving a high number of handover petitions. Finally, a centric RAT selection algorithm is proposed in [9]. The proposed approach selects the RAT providing each user the highest utility defined in terms of cost, power consumption, achievable data rate, network load and link quality. Nguyen-Vuong et al. [9] also demonstrate the need and benefits of exploiting context-aware preferences in the selection process.

In addition to decide the RAT over which each incoming call will be conveyed, certain JRRM policies have recently proposed to also determine the resources needed by each user to satisfy its QoS demands. An example is the work reported in [10], which proposes a Joint Call Admission Control (JCAC) algorithm based on the arrival rate of each class of calls. This algorithm simultaneously addresses the RAT selection and Call Admission Control (CAC) dilemmas, with the aim of reducing the call blocking and dropping probabilities, and ensuring fairness in the allocation of radio resources. Other interesting JRRM proposals jointly addressing the RAT selection and intra-RAT Radio Resource Management (RRM) dilemmas have been reported in [11,12]. These proposals are based on neural networks, and simultaneously determine the most appropriate RAT and bit rate allocation. In [11], the proposed JRRM algorithm is based on neural networks and fuzzy logic, and considers factors such as the signal strength, resource availability and mobile speed. However, this JRRM algorithm does not incorporate mechanisms to take into account the diverse QoS requirements of different service types. The JRRM proposal reported in [12] bases its decision criterion on user QoS demands in terms of required bit rate or maximum delay, and employs Hopfield neural networks to find its JRRM solutions. This algorithm simultaneously decides the optimum RAT for the incoming call, and the necessary radio resources at the assigned RAT. However, the diverse nature and characteristics of radio resources in heterogeneous environments is not actually considered in [12]. Since such diversity can considerably impact the capacity of the selected RAT to satisfy the user QoS demands, and therefore the optimum JRRM solutions to meet such demands, this work extends the current JRRM state of the art by proposing a JRRM algorithm that based on the radio resources' diversity, simultaneously determines for each user an adequate combination of RAT and number of discrete radio resources within such RAT to guarantee its QoS requirements while trying to maximize the system's capacity in terms of users satisfactorily served. In addition, the proposed JRRM algorithm also tackles the CAC dilemma given that the JRRM solution determines the most suitable RAT with available radio resources to support the new incoming call considering the current system conditions (load and QoS requirements). The proposed JRRM algorithm implements a user fairness policy, and aims to equally satisfy all users in the system. To this aim, the proposal is based on integer linear programming and optimization techniques.

The rest of the paper is organized as follows. Section 2 presents the integer linear programming based JRRM algorithm proposed in this work. Section 3 evaluates its performance, and proposes additional variants to further optimize its operation and the resulting user perceived QoS. The implementation and computational cost of the proposed algorithm is evaluated in Section 4, while Section 5 summarizes the contributions from this work and draws final conclusions.

2. Integer linear programming JRRM policy

This paper considers a multimedia scenario where email (background), web (interactive), and real-time video (with different mean bit rates) services coexist, and require different number of radio resources to achieve equal QoS levels. In this context, the proposed JRRM policy tries to exploit this QoS/resource flexibility to provide all users present in a multimedia environment with the highest possible homogeneous user satisfaction levels. The study is conducted considering a heterogeneous wireless ecosystem where the GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for GSM Evolution), and HSDPA (High Speed Downlink Packet Access) RATs physically coexist, and provide the same radio coverage from a multi-RAT base station. A radio resource is equivalent to a timeslot for GPRS and EDGE, and a code for HSDPA.

2.1. Traffic class utility functions

This work is based on utility functions that try to characterize the QoS satisfaction level experienced by a user based on the requested traffic service and the radio resources it has been assigned (combination of RAT and number of radio resources assigned within that RAT). This is a challenging task because user satisfaction is a subjective concept that heavily depends on user perceptions. The defined utility functions try to express the perceived user QoS as the link quality, and therefore data rate, varies. To establish the utility functions, the minimum, mean, and maximum QoS levels demanded by users are first defined per service class as illustrated in Fig. 1. This work considers