Physical Communication 18 (2016) 125–139

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

Radio access technology selection in heterogeneous networks

Kinda Khawam [a,*], Samer Lahoud [b], Marc Ibrahim [c], Mohamad Yassin [b,c], Steven Martin [d], Melhem El Helou [c], Farah Moety [e]

[a] University of Versailles, France
[b] IRISA, University of Rennes 1, France
[c] ESIB, Saint-Joseph University of Beirut, Lebanon
[d] LRI Laboratory, Paris-Sud University, France
[e] Orange Labs, Issy-Les-Moulineaux, France

ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form 29 October 2015
Accepted 30 October 2015
Available online 2 December 2015

Keywords:
RAT selection
Centralized and distributed resource allocation
Heterogeneous networks
Non-linear optimization
Non-cooperative game theory

ABSTRACT

The migration of wireless networking towards the 5G era is distinguished by the proliferation of various Radio Access Technologies (RAT). As no existing technology can be surrogated by another one, the coexistence of today wireless networks is the best solution at hand when dealing with the incessantly growing user demand for bandwidth. Hence, in this heterogeneous environment, users will be able to utilize services through diverse RATs. RAT selection is crucial and must be designed astutely to avoid resource wastage. In this paper, we consider the downlink of a heterogeneous network with two broadband RATs: a primary RAT such as LTE, and a secondary RAT such as WiFi. We start by formulating a centralized approach for the RAT selection as an optimization problem. Then, two distributed approaches are proposed for adequate RAT selection: first, we put forward distributed heuristic algorithms based on the peak rate perceived by users from available RATs. Second, we devise a distributed RAT selection scheme portrayed as a non-cooperative game with a learning-based algorithm to reach the Nash Equilibriums of the RAT selection game. Extensive simulation results show that the proposed distributed algorithms give efficient results compared to the centralized optimal approach. The analysis of the simulation results enables to define pertinent use cases that delimit the scope of the proposed optimal centralized and distributed approaches.

1. Introduction

Every year, the demand in mobile broadband communications increases spectacularly. Practical solutions need to be proposed to face this imminent thousand-fold traffic augmentation. To address this challenge, ubiquitous radio access will be offered by forthcoming 5G heterogeneous network deployments. On the one hand, the advent of mmWave technology and carrier aggregation mechanisms is inevitable to support higher capacity [1]. On the other hand, improved spectral efficiency and novel heterogeneous network deployments with astute resource sharing are vital to meet the predicted traffic demands for the next decade.

For increased efficiency, heterogeneous networks will be self-organized. Operators will profit from the abundance of diverse Radio Access Technologies (RATs) in the same operating area and devise advanced Radio Resource Management (RRM) schemes to take advantage of the available system resources. Hence, RATs will need to be integrated, with any combination of 3G, WiFi [2], WiMAX [3] and LTE [4]. As highlighted by the seminal paper [5], heterogeneous networks are undeniably presented as a major

* Corresponding author.
E-mail address: kinda.khawam@uvsq.fr (K. Khawam).

http://dx.doi.org/10.1016/j.phycom.2015.10.004

cornerstone of the upcoming 5G networks. The authors particularly focus on the challenge of integrating different RATs. Moreover, the Horizon 2020 [6] European framework programme for research and innovation identifies that future networks will need to become significantly more heterogeneous and use multiple RATs. This challenge is tackled particularly by the METIS project that lays down the foundations of 5G networks [7]. In such a heterogeneous network, when a new or a handover session arrives, a decision must be astutely made as to which technology it should be associated with. This is known as *RAT Selection*. In such a context, a mobile user will be able to connect concurrently to different RATs by enabling device support for carrier aggregation.

The straightforward approach in apprehending the RAT selection issue is to formulate the problem as centralized optimization task whose objective is to maximize throughput or equivalently minimize delay. In order to derive the expression of the delay, we use an analytical model whose key feature lies in accounting for the effect of interference as well as for the physical layer and channel characteristics in an easy and straightforward manner. On the one hand, the model takes into consideration frequency planning and scheduling aspects; and on the other hand, it provides tractable formulas of the end user mean delay.

While optimization models give an insight into the upper bounds of achievable RAT selection gains, the implementation of these centralized optimal mechanisms are cost prohibitive in real systems. Indeed, RRM mechanisms studied in the state-of-the-art build upon markedly lower complexity distributed schemes. Consequently, the present work is threefold: the first part addresses the RAT selection issue as a centralized optimization problem. The second part proposes simple but cost effective and fully distributed heuristic algorithms. The third part resorts to non-cooperative game theory to put forward a distributed algorithm based on replication dynamics where each mobile user selfishly strives to improve its own performances.

Results are validated through extensive simulations in the practical setting of a geographical area covered by a global LTE network acting as the primary RAT overlapping with several local WiFi hotspots acting as the secondary RAT. This typically corresponds to a WiFi offloading scenario [8]. We begin by examining static scenarios chosen randomly then assess the algorithms performances in a dynamic setting.

The paper is organized as follows. Related work is presented in Section 2. The system model is described in Section 3 with adopted models for network structure, traffic, perceived rates, and cost function. The optimal centralized RAT selection scheme is formulated in Section 4 as a non linear optimization problem. The heuristic distributed approach is explained in Section 6. Furthermore, the RAT selection policy performances are assessed in a realistic dynamic setting. The game theoretic distributed approach is explained in Section 7 and a realistic distributed algorithm based on replicator dynamics is explained in 7.1 to reach the Nash equilibriums of the RAT selection game. Finally, in Section 8, simulations were conducted in a dynamic setting to compare all formulated approaches. We conclude in Section 9.

2. Related work

The need to fully profit from the large number of currently available RATs is the main driver behind the growing relevance of heterogeneity for future 5G networks. The subject is not only a hot topic for the scientific community but also for the related standardization bodies that are duly specifying procedures to support the interoperability between heterogeneous networks. In fact, the IEEE 802.21 group has defined [9,10] a framework to enable seamless handovers between RATs.

In the state-of-the-art, two approaches are proposed to tackle the RAT selection problem. First, the *centralized approach* where the network performs resource allocation in a way to satisfy all mobile users. Second, the *distributed approach* where mobile users strive to improve their performances on their own.

2.1. Centralized approach

The centralized approach is studied in [11–17]. In [11–13], a Semi-Markov Decision Process (SMDP) is proposed to find the optimal RAT selection that maximizes a long-term reward function. Besides load conditions and user spatial distribution, the authors in [13] have also considered different service classes. Recently, the paper in [14] proposes an optimal Joint Call Admission Control approach for initial RAT selection for heterogeneous wireless networks composed of two co-located networks supporting two different service classes. The framework of SMDP is used to formulate the problem as a joint call admission control and RAT selection problem that maximizes the system capacity while selecting the RAT that consumes the least amount of energy. A Markov model for users' network selection in a heterogeneous network is introduced in [17] that accounts for users' mobility, the quality of service, and the price charged by the operator for a given RAT.

Authors in [15] devise a utility-based resource management framework with multiple client classes distinguished by means of a risk-averse utility function. The optimization problem was not solved; instead simple heuristic algorithms were planned to approximate the optimal solution in a narrow set environment. In [16], various wireless networking scenarios embracing diverse technologies and operators are modeled as an optimization problem, using a utility function, able to modulate the weight given to multiple merit parameters (connectivity, preferred operator, handover, link quality), which reflect the requirements of both the network and end-users.

2.2. Distributed approach

The distributed approach is tackled in [18,19]. In [18], a measurement-based network selection technique that estimates QoS information by bootstrap approximation is proposed. Unnecessary handovers between RATs are filtered using Bayesian estimation and cumulative sum monitoring. In [19], a distributed RAT selection scheme based on utility function and integer linear programming is proposed, taking into account bandwidth, packet loss, delay and energy information. Unfortunately, it is