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Cooperative user–network interactions in next generation communication networks

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ABSTRACT

Next Generation Communication Networks employ the idea of convergence, where heterogeneous access technologies may coexist, and a user may be served by anyone of the participating access networks, motivating the emergence of a Network Selection mechanism. The triggering and execution of the Network Selection mechanism becomes a challenging task due to the heterogeneity of the entities involved, i.e., the users and the access networks. This heterogeneity results in different and often conflicting interests for these entities, motivating the question of how they should behave in order to remain satisfied from their interactions. This paper studies cooperative user–network interactions and seeks appropriate modes of behaviour for these entities such that they achieve own satisfaction overcoming their conflicting interests.

1. Introduction

Converged Networks [1] allow different access networks, terminals and services to coexist bringing forth a new communication paradigm, which is *user-centric* [2], i.e., the user is no longer bound to only one access network but may indirectly *select* the *best* available access network to support a service session [3]. Upon a new service request or even any dynamic change affecting the session (e.g., mobility) one of the participating access networks needs to be selected in order to support the session. Next Generation Communication Networks – controlled by an IP Core Network – need to be equipped with a *Network Selection mechanism* to assign the *best* access network to handle service activation, or any dynamic session change. Such decision may result in a single access network or even multiple networks cooperating to handle a service (the multiple networks case is treated in [4]). This paper studies the resulting interaction between a user and a network, and seeks the best behaviour for each entity such that their conflicting interests are overcome and satisfaction is achieved.

Interactions between entities with conflicting interests, follow action plans designed by each entity in such a way as to achieve a particular selfish goal and are known as strategic interactions. *Game Theory* is a theoretical framework that studies strategic interactions, by developing models that prescribe actions in order for the interacting entities to achieve satisfactory gains from the situation. In this paper, we utilise Game Theory in order to model, analyze and finally propose solutions for the user–network interactions arising due to the Network Selection mechanism. Initially, we utilise Game Theory in order to model the relationship between the user and the network as a strategic game. Particularly, we utilise the notion of *Present Value* (PV) for a sequence of payoffs in a *repeated game* [5] in order to reach a decision that will be both user-satisfying and network-satisfying.

In an attempt to improve the user–network relationship according to the knowledge acquired during the interaction history, we define a notion of *adaptivity* for the user

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as a player in the access network selection decision game, and based on that, we propose a new user strategy for the repeated user–network interaction game. The proposed adaptive strategy, together with the rest of the strategies studied in this paper, are evaluated through simulations that explore their behaviour. The numerical results verify that the players gain more when cooperating, as expected from the theoretical analysis. Moreover, simulations show that the proposed adaptive user strategy results in profitable payoffs, also reinforcing the conclusions of the theoretical analysis.

The paper is organized as follows. Section 2 describes related work and motivates the subsequent work. Section 3 investigates the user–network interaction both as a one-shot and as a repeated interaction. The paper continues by a study of access network selection (Section 4) leading to a proposal of a new adaptive user strategy. A numerical evaluation of all strategies analyzed in the paper is found in Section 5 and finally, conclusions are drawn in Section 6.

2. Related work and motivation

Although network selection is a relatively young research area, it has been extensively studied in recent years [6–8]. The growing popularity of networks that promote technology convergence and allow the co-existence of heterogeneous access networks, has pushed towards the efficient resource management of the overall converged system upon a given dynamic change (e.g., service request, context change, and mobility).

From the earlier works on network selection various approaches describing and analyzing the effects of this new resource management mechanism have been introduced and investigated. Such approaches include fuzzy logic [9,10], adaptive techniques [2,11], utility-based and game-theoretic models [12,13], technology-specific solutions, especially focussing on the inter-operation of cellular systems with wireless LANs [8,14], as well as architectural models focussing on a more comprehensive architectural view [3]. Decision making in these works is either *user-controlled* [10,12,14] or *network-controlled* [3,8,11]. The interaction between them is not considered in detail and the selection decision mainly involves one entity, in some cases involving the other entity indirectly, i.e., decision is taken by the network with the consideration of some user preference [2,13], or the decision is taken by the user with the consideration of some network-specific rankings [9].

In addition to the above techniques, more recent research development explores more dynamic/automated solutions that, similarly to the earlier works, either are based on the user as a decision-making entity [15,16], or are network-controlled solutions proposing improvements to the user-perceived quality during network selection [6,17,18]. Besides the general solutions for network selection, specific solutions handling particular services such as multicast, have been recently proposed [19,20]. These focus on the effect of network selection on the particular service (e.g., multicast) in addition to user and network satisfaction aspects. Again, in these works the decision-making is either user-controlled or network-controlled.

Since network selection is a mechanism involving important decision making, it is essential to take into consideration some strategical planning on behalf of the entities involved in this decision. Game theory is a theoretical framework for strategical decision-making. It has been a very popular approach among recently presented research works [4,7,21,22]. These explore various game theoretic models such as non-cooperative games [21,22], and cooperation schemes where limited resources and/or need for quality guarantees exist [4,7].

Cooperative approaches [4,7] explore the formation of coalitions between the various networks, where a terminal is capable to simultaneously connect to and be served by more than one network. The game selects the best group of networks to serve a new connection or a service demand forecast. In the non-cooperative papers, Cesana et al. [21] study the competition between the mobile users when they are able to select from a set of available access networks, each aiming to minimize the potential selection cost, whereas Cesana et al. [22] consider network selection to be a non-cooperative game between the users and the networks instead of between the users themselves. A user in this game seeks to maximize quality of service and a network seeks to maximize its number of customers. Mathematical programming is used to find the equilibrium in this game.

The current paper is closer to [22] because it models a game where the interacting entities involve the mobile user and the candidate access networks. As in [22], both the user and the network have different payoff functions reflecting their own satisfaction: best predicted quality per unit payment for the user and greatest profit for the network. The current paper improves on the work of Cesana et al. [22] by capturing additional elements (e.g., user payment and network cost), and in addition it identifies and formalizes the cooperative properties instead of the non-cooperative aspects of the user–network interaction addressed in [22]. We utilise the mathematical framework and theoretical tools from Game Theory in order to capture the involvement of both interacting entities in the Network Selection mechanism, i.e., the user and the available networks. The game-theoretic framework enabled us to compute a solution for Network Selection that is both user- and network-controlled, and most importantly, the solution is satisfactory for both the user and the available networks.

3. User–network interaction

In this section we explore, using game theoretical tools, the relationship between the user and the network participating in a converged system. Particularly, we investigate the interaction resulting from the network selection procedure, and we aim through the proposed game model to reach a decision that is both user-satisfying and network-satisfying.

3.1. Incentives

The interaction between a user and a network in a converged system may be viewed as an exchange between