Distributed Cell Selection in Heterogeneous Wireless Networks

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Abstract—A critical issue in many wireless networks is how to establish the best possible quality connections between users to base stations. This is in particular challenging when users are randomly located over a geographical region, and each covered by a number of heterogeneous base stations. To this end, we design a smart and efficient cell selection mechanism to improve the user-base station connection in heterogeneous wireless networks. We formulate the cell selection problem as an asymmetric congestion game with consideration of users’ heterogeneity in their locations and their data rates to various cells. We show the existence of pure Nash equilibria (PNE) and propose a concurrent distributed learning algorithm to converge to them. In the algorithm, we allow users to perform random error-tolerant updates synchronously, and guarantee them to reach one or multiple PNE with the largest utilities. In addition, we do a systematical investigation on the implementation of the algorithm in practical networks. Simulation results show that the algorithm can achieve satisfactory performance with acceptable convergence rate.

Keywords—Heterogeneous Wireless Networks, Congestion Games, Cell Selection Mechanism

I. INTRODUCTION

The integration of heterogeneous wireless access networks over an Internet Protocol (IP) backbone is one of the most important trends in future communication systems. In such a heterogeneous network, the concept of being always connected becomes being always best connected (ABC) [1]. With ABC functionality, a user is allowed to choose the best available access networks in a best possible way anytime anywhere. To this end, a smart and efficient cell selection mechanism is crucial for users.

In heterogeneous networks, to avoid high burden to the system, it is unrealistic to implement an algorithm with a central controller leading all the users. Thus, an alternative approach is to design a decentralized cell selection mechanism, by which each user makes its own decision without coordination. This is feasible because the Cognitive Radio (CR) technologies are popularized, whereby devices have capabilities to obtain knowledge and reconfigure parameters such as the access networks. In essence, the distributed cell selection scenario is closely related to the heterogeneous type CR system [2]. A key challenge of designing the mechanism is to resolve the competition among users in a fully distributed style, especially when they have no information about the resources, such as the availabilities and qualities.

Game theory is an effective tool to model the users’ competition. Directed by some learning algorithms, the users can get information and behave correspondingly to achieve equilibrium. However, when the theory is applied into a cell selection problem, some critical features should be considered. First, due to users’ different locations and cells’ different coverage areas, the users each have their own sets of resources. Second, the strictly asynchronous learning algorithms, which are often adopted in theoretical models, are hard to be directly implemented in a practical system. This is because the heterogeneous access networks always belong to different operators, which makes it impossible to do an accurate scheduling of users’ accessing. Last, the learning errors cannot be eliminated in complicated wireless environments (which include noise and fading), leading to the inaccuracies of learning results and hence the users’ erroneous decisions.

Based on the above considerations, we propose our game model and the distributed learning algorithm. We consider a practical scenario where heterogeneous networks coexist, and each user is covered by multiple base stations (BSs). The users are selfish to select their believed best cells, hence causing network congestion and performance degradation. We formulate the cell selection problem as an asymmetric congestion game, in which we consider both the users’ positions (which decide their distinct strategy sets) and their specific data rates of accessing heterogeneous networks. We study the distributed learning algorithms which allow synchronous updates. Moreover, we allow the users to make mistakes when changing their strategies. The main contributions of this paper are as follows.

- **General game model formulation:** We formulate the cell selection problem in heterogeneous networks as an asymmetric singleton congestion game with player-specific payoff functions and show the existence of PNE, at which each user chooses the best cell taking into account the decisions of others.

- **Distributed learning algorithms leading users to satisfactory PNE:** We propose the error-tolerant concurrent distributed learning algorithm, which converges to satisfactory PNE by the local one-step observations of users. Furthermore, we prove that it has the property of eliminating all the weakly dominated PNE and leading the users to a more satisfactory one. In addition, we provide detailed discussions on the implementation of the algorithm in practical networks in terms of terminal conditions, non-uniform probe and error probabilities,
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