Chapter 11

Stackelberg Game Theoretic Framework in Cognitive Green Heterogeneous Networks

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ABSTRACT

Game theory has found an extensive application in wireless communication networks including cognitive radio networks, heterogeneous cellular networks, cooperative relay networks. Also, cognitive radio networks, green communications and heterogeneous cellular networks have attracted a wide attention on improve the spectrum efficiency and energy efficiency; therefore, the capacity, the coverage and the energy consumption. However, interference problem and energy consumption are critical for these networks. Introducing hierarchy among different decision-making players in cognitive, heterogeneous, green, cooperative cellular networks can both save energy and mitigate interference, thus enhance throughput. Stackelberg game suits to model, analyze and design the distributed algorithms in these hierarchical decision-making networking scenarios. In this chapter, we introduce basics of Stackelberg game and survey the extensive applications of Stackelberg game in cognitive, heterogeneous, cooperative cellular networks with the emphasis on resource management, green commutations design and interference management. This chapter highlights the potentials and applications with the promising vision of Stackelberg game theoretic framework for future cognitive green heterogeneous cellular networks.

INTRODUCTION

Game theory is a branch of mathematics modeling, analyzing and designing the strategic interactions among autonomous decision makers. These players are usually assumed to be selfish and rational, which mean that they are always pursuing the utility maximization without considering the others’ strategy,
utility the context. However, these actions have mutual, probably conflicting, consequences. Game theory has developed for decades to model problems in the field of economics, and it has recently been applied to wireless network problems, in most cases to solve the resource allocation problems in a competitive environment. Certainly, with its promising applications in particular for the decade, game theory including both strategic non-cooperative game and cooperative game is also used in access control, scheduling, network security, interference management and mitigation, even in the field of network information theory.

The reason that game theory is an appropriate choice for studying various problems in communications is multi-fold. First, nodes in the network are autonomous agents, making decisions only for their own interests. Game theory provides us sufficient theoretical tools to analyze the network users’ behaviors and actions. Second, game theory primarily deals with distributed optimization, which often requires local information only. Thus, it enables us to design distributed algorithms.

Games can be classified into two categories, strategic form game and extensive form game. The strategic form game is a one-shot game. In this game, the players make their decisions simultaneously without knowing what others will do. On the contrary, the extensive form game represents the structure of interactions between players and defines possible orders of moves. The repeat game is the most simple dynamic game as an example of the extensive form game, in which each stage is a repetition of the same strategic game. At the beginning of each stage, players observe the past history of strategies before making decisions. The number of stages may be finite or infinite. The utility of each player is the accumulated utility through all the stages. Therefore, players care not only the current utility but also the future utilities. The Stackelberg game is another extensive form game, which is used to model the competition between one player, called the leader, and a set of players, called the followers. In this game, the leader takes action first and then the followers take actions. The leader knows that the followers observe its action and take actions accordingly. The Nash equilibrium in the Stackelberg game is called Stackelberg equilibrium. Although non-cooperative game also has found extensive application in wireless networks, we concentrate on the survey of Stackelberg game theoretic applications in the recent promising wireless communication networks including cognitive radio networks, heterogeneous cellular networks, cooperative relay networks.

The existing iterative power water-filling algorithm is regarded as one type of non-cooperative game application has found extensive use to allocate power among competing users in wireless communication networks. As we known, strategic non-cooperative games have been well explored in wireless community. However, it always leads to a non-social optimal solution, let alone the fairness among selfish and rational players. For instance, if selfish users choose their transmission probabilities independently without any coordination mechanism with other players, then it results in a network collapse. In (Park & Schaar, 2009), a methodology that transforms the non-cooperative game into a Stackelberg game is proposed. Stackelberg equilibrium solution of the Stackelberg game can overcome the deficiency of the Nash equilibrium solution of the original non-cooperative game. A particular type of Stackelberg intervention is constructed to show that any positive payoff profile feasible with independent transmission probabilities can be achieved as a Stackelberg equilibrium payoff profile. In (Lasaulce et al., 2009), hierarchy in wireless networks is modeled by a decentralized multiple access channel and for which energy-efficiency is the main performance index. In these networks users are free to choose their power control strategy to selfishly maximize their energy-efficiency. Two kind of hierarchies are included: first, assuming single-user decoding at the receiver, a Stackelberg formulation of the game is investigated where one user is the leader whereas the other users are assumed to be able to react to the
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