Chapter 4
Game Theory for Wireless Ad Hoc Networks

ABSTRACT

An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network device in link range. In particular, ad hoc network often refers to a mode of operation of IEEE 802.11 wireless networks. A wireless ad hoc network is a decentralized type of wireless network. The network is ad hoc because it does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. The decentralized nature of wireless ad hoc networks makes them suitable for a variety of applications where central nodes cannot be relied on and may improve the scalability of networks compared to wireless managed networks, though theoretical and practical limits to the overall capacity of such networks have been identified. This chapter explores this.

INTRODUCTION

Since John von Neumann and Oskar Morgenstern established their book in 1944, game theory can also be applied to many fields of science where decision makers have conflicting interests. Not surprisingly, game theory has also been applied to networking, in most cases to solve routing and resource allocation problems in a competitive environment. In particular, game theory allows us to investigate the existence, uniqueness and convergence to a steady state operating point when network devices perform independent adaptations. Therefore, it serves as a strong tool for a rigorous analysis of distributed network protocols (Srivastava, Neel, MacKenzie, & Menon, 2005).

Nowadays, game theory was also applied to the wireless communication. Even if the research work were initially limited to conventional networks, the recent development of wireless networking motivated researches to seek for answers provided by game theory. A wireless ad hoc network is characterized by a distributed, dynamic, self-organizing architecture. Each node in the network is capable of independently adapting its operation based on the current environment according to predetermined algorithms and protocols. In a traditional game model, players are independent decision makers whose payoffs depend on other

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players' actions. Nodes in an ad hoc network are characterized by the same feature. This similarity leads to a strong mapping between traditional game theory components and elements of an ad hoc network. In the game model for wireless ad hoc networking, players are nodes in the network, and strategy is action related to the functionality being studied. Utility function is performance metrics, for example, throughput, delay, target signal-to-noise ratio (Srivastava, 2005), (Felegyhazi, &. Hubaux, 2006).

These days, the old description of 7-layer network system model has been replaced by the new 5-layer network system model that was invented for the Internet. 5 layers are the physical, data link, network, transport and application layers. However, the mathematical analysis to the study of each layer in wireless ad hoc networks has met with limited success due to the complexity of mobility and traffic models, the dynamic topology, and the unpredictability of link quality that characterize such networks. Instead of the mathematical analysis, game theory is particularly attractive to analyze the performance of ad hoc networks. Therefore, game theory can be applied to the modeling of individual, independent decision makers at each wireless network layer (Srivastava, 2005). This chapter comprehensively surveys the existing researches on game theoretic approaches for the wireless communication networks; different types of game models are broadly reviewed. The aim of this chapter is to familiarize the readers with the state-of-the-art research on this topic and the different techniques for game theoretic modeling of wireless network systems.

PHYSICAL LAYER

Power control is a hot issue of the physical layer due to the potentially significant performance gains achieved when nodes limit their power level. In wireless communication systems, mobile terminals respond to the time varying nature of the channel by regulating their transmitter powers. Specifically, in a CDMA system, where signals of other terminals can be modeled as interfering noise signals, the major goal of this regulation is to achieve a certain signal to interference (SIR) ratio regardless of the channel conditions while minimizing the interference due to terminal transmit power level. Hence, there are two major reasons for a terminal to perform power control; the first one is the limit on the energy available to the mobile node, and the second reason is the increase in quality of service (QoS) by minimizing the interference (Mehta, & Kwak, 2009).

Distributed power control, which is adopted by a node, can be performed, that means, not only can the node adjust its power according to its own status, but also the distributed networking function can determine the proper power limit to optimize the performance of the whole network. From a physical layer perspective, performance is generally a function of the effective signal-to-interference-plus-noise ratio (SINR). When the nodes in a wireless network respond to changes in perceived SINR by adapting their signal, a physical layer interactive decision making process occurs. This signal adaptation can occur in the transmit power level.

Based on the game theory, several distributed power control models have been implemented in wireless networks (Srivastava, 2005). In the context of game theory, each node pursues a strategy that aims to maximize the utility by adjusting its transmitter power. In doing so, the action of one node influences the utilities of other nodes and causes them to adjust their powers. The distributed power control models are referred to as non-cooperative games because each node pursues a strategy based on locally available information. By contrast, a centralized power control model uses information about the state of all nodes to determine all the power levels. A centralized model corresponds to a cooperative game. The convergence of the distributed power control model corresponds to the existence of a

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