Chapter 7.17
Game Theory for PHY Layer and MAC Sublayer in Wireless Telecommunications

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ABSTRACT

The aim of this chapter is to address the role of a novel concept in wireless telecommunications: Game theory. Game theory is a branch of applied mathematics, which has recently drawn attention as a powerful tool to solve complex problems in wireless environments. To fulfil the intended goal, this chapter introduces the most relevant concepts of game theory such as game, player, and strategy, and give an overview of the applications of game theory in wireless networks.

INTRODUCTION

In telecommunications, state-of-the-art trends are towards very sophisticated services the objective of which is to provide multimedia contents to fixed or mobile users. This implies a strict quality control to guarantee the delivery of these services to the clients, ensuring high quality of service (QoS) and large data rates. To meet such requirements, telecommunications resources are intensively used. Moreover, when providing multimedia services, their quality parameters and the available resources are interrelated, creating dependence relations between them. As one may perceive, the task of a joint management of all these variables with the aim of exploiting the network in an optimized manner requires the utilization of tools capable of tackling such complex situations, and this task frequently becomes highly intricate when layer-by-layer solutions are applied. Then, novel approaches are used to solve complex telecommunications problems. One of these novel approaches is game theory, which can efficiently deal with the aforementioned problem of joint management of resources, service provisioning and network exploitation.

From its beginning in the middle of 20th century game theory has been intensively applied to economics, evolutionary biology and psychology, among others. Its utilization in telecommunications started at the late 1990s for the resolution of problems related to networking (flow and congestion control, routing), but its most interesting applications came relatively recently: its potential utilization for wireless systems.

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The objective of this chapter is to provide an overview of game theory for telecommunications. Once the basic concepts are introduced, most relevant and recent works will be described.

GAME THEORY FOR WIRELESS COMMUNICATIONS

Why may game theory be applied to wireless telecommunications? The answer to this question rests on the very nature of game theory. It formalizes the interaction among autonomous agents (players) with selfish and even opposite objectives, and defines what a solution to the stated problem may be. It is clear then that by means of game theory the design and configuration of wireless networks such as ad hoc, sensor and mesh networks may be addressed in order to cope with limitations as power constraint, decentralized operation, interference mitigation and efficient multi-hop routing.

Game-theoretic concepts have mostly been applied in wireless applications to design network layer, flow control mechanisms and routing algorithms. Game theory has also demonstrated its validity for power allocation problem in wireless networks, where the network (e.g. the base station in centralized configurations) allocates the available resource (power) to the players (transmitters) with different types of constraints, e.g. interference, energy minimization or minimum required bit-rate constraints. In a similar manner, bandwidth allocation problems may be solved for this type of networks considering constraints such as the mutual interference among the transmitters. An alternative approach to obtaining solutions in telecommunication networks, e.g. routing protocols, is the usage of pricing: pricing schemes charge each node or customer locally for the resources he has used. An overview of the most relevant works on these areas is developed in the next section.

PHYSICAL (PHY) LAYER and medium access control (MAC) sublayer problems in wireless networks have not received too much attention up to recent dates in the context of game theory. For instance, in the case of PHY layer, we may consider cooperative diversity (explained in detail in a subsequent section) as a suitable technique to be studied applying game theory given the intrinsic selfish behaviour of the users of the network. With respect to the MAC sublayer, in addition to allocation applications, some game theoretic approaches have attempted to model packet radio protocols (Aloha, Slotted-Aloha) and channel assignment strategies. These applications demonstrate how promising game theory is for PHY and MAC LAYERS design.

Game theory, as we mentioned in the introduction, is a mathematical tool, but it is not very familiar to telecommunications. Hence, we will devote the remaining of this section to introduce the most relevant concepts and elements used in the literature up to now to address wireless systems by means of game theory. Although we consider the overview provided in this section adequate for the comprehension of the rest of this chapter, the reader may find it useful to complement this introduction to game theory with (MacKenzie and DaSilva, 2006).

What is a Game?

Let us start by defining the very concept of game. A game is (Osborne, 2004) "a description of strategic interaction that includes the constraints on the actions that the players can take and the players' interests, but does not specify the actions that the players do take". The ultimate aim of the game formalism is to provide a solution consisting of a set of the different players' outcomes. Those outcomes are the result of jointly maximizing each player's utility, by means of the assignment to each player of a certain quantity of resources (money, power), considered as variables in their benefit functions. Then, it is clear that the goal of the players is to obtain a benefit as high as possible.