Chapter 8
Resource Allocation for Device-to-Device Communications in LTE-A Network: A Stackelberg Game Theory Approach

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ABSTRACT
In the Long Term Evolution-Advanced (LTE-A) system, Device-to-device (D2D) communication underlying cellular networks can bring some advantages such as high data rates, low delay, low power consumption by reusing frequency bands with cellular user equipments (UEs). While at the same time, inter-cell and intra-cell interference is inevitable. The D2D users and cellular UEs will compete or cooperate to coordinate interference and share resources which incurs game theory an effective mathematical tool. This chapter proposed a Stackelberg game based algorithm to jointly allocate power and resources when the uplink frequency is shared with LTE-A users. In the game, the evolved NodeB (eNB) and D2D UEs are grouped to form the seller-buyer pair and the eNB sets prices to reduce the interference that it suffers meanwhile maximizes its revenue. For given specified prices, the D2D users compete for the resources to communicate with each other and reach their individual utility maximization. Simulation results prove that satisfying performance can be achieved by using the proposed mechanisms.

INTRODUCTION
With the development of mobile communications, the requirements on data rates are increasing sharply, nevertheless the scarcity of spectrum is becoming increasingly serious. To get higher total capacity, Device-to-device (D2D) communication underlaying the cellular network has brought much attention as a promising component to improve spectral efficiency. Different from the infrastructure based cellular

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network, D2D users do not communicate via the central coordination (base station, NodeB or evolved NodeB) but operate as an underlay and communicate directly with each other. Excluding the unnecessary core network involvement, D2D communication can also provide several advantages such as high bit rates, low delay, low power consumption, low cost, plug-and-play convenience, and flexibility. It has been integrated into the Third Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-A) system as an underlay to a cellular network. The LTE-A system, in which the total bandwidth of the transmitted signal can be as large as 100MHz by aggregating multiple carriers, is of particular interest as it is the major technology approved by the International Telecommunications Union (ITU) as fulfilling the International Mobile Telecommunications-Advanced (IMT-A) requirements. Note that, the D2D communication can flexibly operate in multiple modes, e.g., the non-orthogonal and orthogonal D2D communication sharing modes, the cellular mode, etc. While by reusing the LTE-A cellular resources, D2D communication enhances spectrum utilization and improves cellular coverage. However, its utilizing cellular spectrum poses new challenges because the system must cope with new interference between the cellular and D2D communications. Consequently, intra-cell interference is no longer negligible and how to allocate physical resource blocks (PRBs) between cellular user equipments (UEs) and D2D UEs and control transmission power of all transmitters is a key problem. If there is no interaction among cellular users and D2D users, all of them will not control their transmit power, so that serious interference may lead to an inefficient outcome.

Modern game theory was born in 1928 when John von Neumann published his minimax theorem. As a branch of applied mathematics, game theory plays exceedingly important roles. On the other hand, as an important tool, game theory has pervaded almost all fields of sciences and social sciences (Nie & Zhang, 2008). The games studied in game theory are well-defined mathematical objects. To be fully defined, a game must specify the following elements: the players of the game, the information and actions available to each player at each decision point, and the payoffs for each outcome. A game theorist typically uses these elements, along with a solution concept of their choosing to deduce a set of equilibrium strategies for each player. As a result, when these strategies are employed, no player can profit by unilaterally deviating from their strategy. These equilibrium strategies determine an equilibrium to the game, namely, a stable state in which either one outcome occurs or a set of outcomes occur with known probability. So far, the game theory has been applied for the cognitive radio networks, heterogeneous network, small cell, and so on.

As D2D communication is an underlay to the cellular networks, the concept of the game is well suited for the cell system to decrease the interference. In this chapter, a Stackelberg game based scheme will be described to coordinate the intra-cell and inter-cell interference in the hybrid network. In the Stackelberg game based work, the eNB and D2D UE make up a seller-to-buyer pair to improve the sum throughput, where the eNB is viewed as the seller and D2D UE is the buyer. The seller acts first, then the buyer observes the seller’s behavior and decides its strategy. In detail, the seller charges some fees to increase its performance of every link, whereas the buyer improves its rates by paying for some fees. Finally, the game will lead to equilibrium, making the cellular link and D2D link communicate reliably. By comparing with traditional methods, simulations prove the effectiveness and efficiency of our proposed scheme.

BACKGROUND

In this section, we first give a brief overview of D2D communications and Stackelberg game and then give the main idea of the proposed Stackelberg game based scheme.
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