Chapter 9
Game–Theoretic Approaches in Heterogeneous Networks

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ABSTRACT

Improving capacity and coverage is one of the main issues in next-generation wireless communication. Heterogeneous networks (HetNets), which is currently investigated in LTE-Advanced standard, is a promising solution to enhance capacity and eliminate coverage holes in a cost-efficient manner. A HetNet is composed of existing macrocells and various types of small cells. By deploying small cells into the existing network, operators enhance the users' quality of service which are suffering from severe signal degradation at cell edges or coverage holes. Nevertheless, there are numerous challenges in integrating small cells into the existing cellular network due to the characteristics: unplanned deployment, intercell interference, economic potential, etc. Recently, game theory has been shown to be a powerful tool for investigating the challenges in HetNets. Several game-theoretic approaches have been proposed to model the distributed deployment and self-organization feature of HetNets. In this chapter, the authors first give an overview of the challenges in HetNets. Subsequently, the authors illustrate how game theory can be applied to solve issues related to HetNets.

INTRODUCTION

High system capacity is one of the fundamental requirements to access current wireless communication. While most advanced signal and transmission techniques potentially enhance the performance of wireless systems (Parkvall, Furuskar, & Dahlman, 2011), they eventually reach the theoretical limitation due to the physical laws: the signal quality. Most of next generation wireless networks are planned to operate in high frequency spectrum. In such spectrum, the signals will degrade significantly in long distance

and indoor environments. This suggests that more areas will experience weak signal receptions unless the network deployment is densified.

In order to boost network capacity in a flexible and cost-efficient manner, the concept of Heterogeneous Networks (HetNets) has been introduced in LTE-A standard (Lopez-Perez et al., 2011). A heterogeneous network consists of macrocells, which are deployed for serving large coverage areas, and low-power and low-cost nodes such as picocells, femtocells, relay nodes, or remote radio heads (RRHs), which provide services in areas with dedicated capacity. The wireless signal quality can be greatly enhanced through the assistance from the low-power nodes when they are properly deployed in the coverage holes in the macrocells. Additionally, these newly deployed small cells can be served for offloading purposes for help reducing the heavy loading in macrocells. The extra capacity offered by these cells can be used to handle more demands in the cellular network, or even redirect them directly to home and company's intranet or the Internet. Lastly, these low-cost nodes are more economically attractive as they usually require lower-cost infrastructure (pico and relay nodes) and lower requirements in terms of backhaul connections (femtocell).

The deployment of HetNets, however, is a serious challenge to the service operators. The deployment scheme depends on the purpose of the service provider. In case of traffic offloading, the deployment should be directly handled by the service provider according to the statistic or predicted demands in certain areas. In such a case, the problem is similar to the traditional cell planning except that the small cell deployment could be dynamic according to the current demands.

On the other hand, when it comes to the cell quality enhancement, the traditional cell planning and deployment solution is impractical to HetNets, especially for the femtocells. This is due to the significant larger number of cell sites and uncertainty in coverage holes. Additionally, the coverage holes are also difficult to be found without the assistance and demands from end-users. This poses a strong link between the deployment of femtocells and the demands from users. These users, who should be considered rational, determine the deployment of femtocells by either sending requests to the service provider or installing low-power nodes by themselves. Unlike the service provider, who concerns the overall system performance, these rational users care about their own benefits only. Additionally, heterogeneous components (pico/femtocells, macrocells, UEs) in HetNet may have different objectives (Khan, Tembine, & Vasilakos, 2012) and preferences on the network configurations. This increases the difficulty to have a proper organization among all these components. The conflict of interests between the service provider and end users may lead to inefficient deployment of HetNets if not carefully addressed. Therefore, it is important to understand how these rational users interact with the service provider in the deployment and configuration of HetNets. Game theory, a powerful tool for analyzing a distributed system with rational users, is a natural choice for studying above scenarios in HetNets.

BACKGROUND

Game theory is a study on the mathematical models of the strategic interactions between individual players in a game. The outcome of the game depends on the interactions among participated players. The players are considered rational and have certain valuations on the outcome of the game. Since the game outcome depends on the interaction, a player will be aware of the (expected) actions of other player and will make her decisions accordingly in order to reach her most desired outcome. Most researchers are interested in predicting the final outcome of a game, in which various types of equilibrium concept, such

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