Preface

Mobile wireless communication has experienced explosive growth over the past decade, which is fueled by the popularity of smart phones and various spectrum hungry services. The wireless industry has taken the challenge of cost-effectively supporting a 1000-fold increase in traffic demand over the next decade. Recently, to enhance the network capacity and improve the quality of user experience, various emerging wireless communication network architectures and technologies have been extensively researched, for instance, heterogeneous and small cell networks, device-to-device communication, self-organizing networks, green communication, spectrum aggregation, massive MIMO and COMP, and so on. Additionally, the techniques including interference mitigation, resource management, hybrid access decision, revenue maximization should be poured more research attention with novel modeling, analyzing, and designing methodologies.

Game theory can well characterize the emerging typical features of the mobile wireless networks, including the selfish behaviors, cross-tier cooperation, multiple dimensions of resource and fairness requirements. It can be used to model, analyze and design various issues, for instance, resource allocation, interference management, and energy saving, and so on. Therefore, game theory has been widely recognized as a useful mathematical tool. In the past decade, we have witnessed a huge explosion of interests that intersect wireless networks with game theory. Researchers are still working hard on employing game theory to much wider applications. Therefore, it is necessary to call for them to propose their novel ideas with advanced game theory to study wireless communication network and techniques. It will help to further develop the powerful mathematical tool for future challenges in wireless industry.

As we known, game theory itself is an evergreen evolving discipline. More advanced game models, effective equilibrium concepts, and differential games and mean field games, learning mechanisms in games and so on should be explored and exploited for better understanding and design wireless networks. This book looks to discuss and address the applications, mechanism designs, and challenges that the advanced game theoretic framework for the emerging wireless communication networks techniques. This book is therefore both timely and apposite.

This comprehensive and timely publication aims to be an essential reference source, built on the available literature in the field of game-theoretic framework for wireless communication networks, in particular, the advanced game model, equilibrium, and mechanism for the emerging network architectures and technologies. The book will provide the novel and potential way to solve the encountered problems for wireless network researcher and engineer. It also will help various kinds of networking engineers for understanding and designing the suitable wireless networks.
Preface

Researchers, advanced-level students, technology developers, and engineers will find this text useful in furthering their research on game theory for networks. This text will assist both economics and wireless engineers in furthering their own research efforts and interests in developing game theory for wireless communication and networks. Economics researchers who are interested in the engineering field; wireless engineers who are using game theory.

After careful and rigorous review, finally we accept 16 chapters according to the review results, and content, concentration, and objective of this book; and then we divide them into three sections according to their internal logic:

SECTION 1: ADVANCED GAME THEORY FOR WIRELESS COMMUNICATIONS

In Section 1, various advanced game theoretic models are surveyed in the wireless communications and networks including complete information-supported games of non-cooperative potential games (Chapter 1) and cooperative coalition games (Chapter 2), and games with incomplete information (Chapter 3). In detail, authors in chapter 1 first introduce the concept of potential games and give definitions of different types of potential games. Then, they provide some important results and properties of potential games. After that, the authors introduce three algorithms to achieve Nash equilibrium of a potential game. Next, chapter 1 will show how to apply potential game theory to design efficient algorithms for wireless network optimization. One application of potential game theory is to study the power control problem in wireless networks. Another example is the multimode precoding design in multi-input multi-output multiple access channels. Chapter 1 also shows how to apply potential games for joint resource allocation in a relay network where multiple users can conduct bidirectional communications through a relay node over multiple available channels. As it is known that with the emergence of cooperation as a new communication paradigm, and there needs for self-organizing, distributed networks. Therefore, it is necessary to seek suitable game theoretical tools that allow to analyze and study the behavior and interactions of the nodes in future communication networks. In this context, chapter 2 introduces the coalition formation game theory, and its potential applications in communication and wireless networks. Specifically, it presents the fundamental components, the key properties, the mathematical techniques, the solution concepts, and describes the methodologies for applying these games in several applications drawn from the state-of-the-art research in communications. Furthermore, chapter 3 bridges game theory and practical wireless applications, by focusing on the incomplete, dynamic and uncertain information constraints. Four kinds of distributed learning algorithms including stochastic learning automata, payoff-based log-linear learning, learning by trial and error, and no-regret learning are discussed. The learning procedures and basic theoretical results are presented, and their applications in wireless networks are reviewed. Contrastive analysis on environment dynamics, solution concepts, synchrony, convergence, and convergent results is discussed, and some future research directions are given.

We can see that these surveyed game models of chapter 1, 2, and 3 in Section 1 are relatively novel and with typical characteristics. Therefore, this book covers all types of games and their applications appearing in the game theory, which will provide a full understanding of game theory for wireless communications. Section 1 will help understand the following chapters since their further application of the survey games.
SECTION 2: GAME THEORY IN EMERGING HETEROGENEOUS SMALL CELL NETWORKS

Section 2 is the main part of this book, where we focus on the heterogeneous small cell networks since they can be recognized as the most powerful technology to provide exponential capacity growth for data traffic. Basics for interference mitigation, resource management, hybrid access decision, revenue maximization challenges of heterogeneous small cell networks, and applications of various game theoretic models in them including strategic game approach, potential game, Bayesian game, Stackelberg game, and mechanism design, and future research directions are provided in Chapter 4. In detail, improving capacity and coverage is one of the main issues in next-generation wireless communication. Chapter 4 concentrates on heterogeneous networks (HetNets), which is currently investigated in LTE-Advanced standard, and 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 chapter 4, 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.

Similarly, in order to solve interference problems, chapter 5 focuses on Game Theory based uplink power control and downlink power allocation strategies for the interference mitigation of the heterogeneous Small Cell Network (SCN). For the uplink scenario, chapter 5 proposes the non-cooperative game model based power control algorithm, which can optimize the initial transmission power of both Macro Cell and Small Cell users through the Nash Equilibrium solution. For the downlink scenario with multiple service types in the SCN, the non-cooperative game model based scheme is proposed to optimize the transmission power allocation with constraints of different Quality of Service (QoS) requirements. The simulation results show the merits of the proposed strategies over current works.

To optimize radio resource allocation, the game theory is utilized as a powerful tool because its characteristic can be adaptive to the distribution characteristics of in heterogeneous small cell networks (HSCNs). Chapter 6 summarizes the recent achievements for the game theory based radio resource allocation in HSCNs, where macro base stations (MBSs) and dense small cell base stations (SBSs) share the same frequency spectrum and interfere with each other. Two kinds of game models are introduced to optimize the radio resource allocation, namely the non-cooperative Stackelberg and the cooperative coalition. System models, optimization problem formulation, problem solution, and simulation results for these two kinds of game models are presented. Particularly, the Stackelberg models for HSCNs are presented with the Stackelberg equilibrium and the closed-form expressions. The coalition formations for traditional HCSNs, cloud small cell networks, and heterogeneous cloud small cell networks are introduced. Simulation results are shown to demonstrate the proposed game theory based radio resource optimization strategies converged and efficient.

Chapter 7 focuses on the coverage optimization of small cell networks (SCN), and starts with a detailed analysis on various coverage problems, based on which the coverage optimization problem is formulated. Then centralized and distributed coverage optimization methods based on game theory are
Preface

-described. Firstly, considering the coverage optimization with a control center, a modified particle swarm optimization (MPSO) is presented for the self-optimization of SCN, which employs a heuristic power control scheme to search for the global optimum solution. Secondly, distributed optimization using game theory (DGT) without a control center is concerned. Considering both throughput and interference, a utility function is formulated. Then a power control scheme is proposed to find the Nash Equilibrium (NE). Simulation results show that MPSO and DGT significantly outperform conventional schemes. Moreover, compared with MPSO, DGT uses much less overhead. Finally, further research directions are discussed and conclusions are drawn.

In the Long Term Evolution-Advanced (LTE-A) system, Device-to-Device (D2D) communication underling cellular networks can bring some advantages such as high data rates, low delays, low power consumption by reusing frequency band with the 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. Chapter 8 proposed a Stackelberg game based algorithm to jointly allocate power and resources when uplink frequency is shared with LTE-A users. In the game, the evolved NodeB (eNB) and D2D UE 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.

Game theoretical approaches have been used to develop distributed resource allocation technologies for cognitive heterogeneous networks. In chapter 9, the authors present a novel distributed resource allocation strategy for cognitive small cell networks based on orthogonal frequency-division multiple access. In particular, the authors consider a heterogeneous network consisting of macrocell networks overlaid with cognitive small cells that opportunistically access the available spectrum. A regret-matching game approach is proposed, aiming at maximizing the total throughput of the small cell network subject to cross-tier interference and quality of service (QoS) constraints. The regret-matching game approach exploits a regret procedure to learn the optimal resource allocation strategy from the regrets of the actions of cognitive users. Furthermore, the regret-matching game approach is extended to the joint resource allocation and user admission control problem. Numerical results are presented to demonstrate the effectiveness of the proposed regret-matching approaches.

Dynamic spectrum access is envisioned as a promising paradigm for addressing the spectrum under-utilization problem. According to the recent ruling of Federal Communications Commission (FCC) for white-space spectrum access, white-space devices are required to query a geo-location database to determine the spectrum availability. Chapter 10 adopts a game theoretic approach for the self-organizing white-space spectrum access network design. Chapter 10 first models the distributed channel selection problem among the devices as a distributed spectrum access game, and show that the game is a potential game. Chapter 10 then designs a self-organizing spectrum access algorithm which can achieve a Nash equilibrium of the game without any information exchange among the devices. Numerical results demonstrate that the proposed algorithm is efficient and can adapt to the dynamical network context changing.

Chapter 11 addresses the complex scenario of multi cell OFDMA network resource allocation and interference control by auction theory. An auction framework that meets the properties of efficiency and incentive compatibility is proposed. We consider a multi-cell OFDMA network with Fractional Frequency Reuse (FFR) implementation. An auction is presented to allocate subcarriers. According to the proposed auction framework, users will avoid bidding for the subcarriers where they have a relatively low chance
of winning. Optimal bidding strategy based on Bayesian Nash Equilibrium (BNE) is obtained in which users are maximizing their net profit. A focal distance which classifies the users into cell-center and cell-edge users is characterized. The proposed approach maximizes the total auctioneer revenue, while balancing a tradeoff between system performance in terms of total system throughput and quality of service provisioning for cell-edge users.

In summary, in section 2 game theory based uplink power control and downlink power allocation strategies for the interference mitigation are investigated in Chapter 5. Two kinds of game models are introduced in Chapter 6 to optimize the radio resource allocation, namely the non-cooperative Stackelberg and the cooperative coalition. The centralized and distributed coverage optimization methods based on game theory are described in Chapter 7. Chapter 8 proposed a Stackelberg game based algorithm to jointly allocate power and resources when the uplink frequency is shared with LTE-A users. A heterogeneous network consisting of macrocell networks overlaid with cognitive small cells that opportunistically access the available spectrum is considered in Chapter 9. Further, the regret-matching procedure in game theory is exploited to solve a competition problem. Chapter 10 adopts a game theoretic approach for the self-organizing white-space spectrum access network design. Optimal bidding strategy based on Bayesian Nash Equilibrium (BNE) is obtained in Chapter 11 in which users are maximizing their net profit.

SECTION 3: ADVANCED GAME THEORY FOR PROMISING WIRELESS TECHNIQUES AND SERVICES

In Section 3, we summarize advanced game theory for the promising wireless techniques including physical layer security (Chapter 12), infrastructure sharing (Chapter 13) and renewable energy (Chapter 14) for green communications, and then concentrate on the challenges and application of game theory for promising wireless services including multimedia and social interactions (Chapter 15) and cooperative video transmission by broadcasting (Chapter 16).

Chapter 12 provides a comprehensive review of the domain of game theory based physical layer security in wireless communications. By exploiting the wireless channel characteristic and secure cooperation of nodes, physical layer security is to enable the exchange of confidential messages over a wireless medium in the presence of unauthorized eavesdroppers, without relying on higher-layer encryption. However, the selfishness of nodes seriously affects the secure cooperation; game theory can model the influence of the selfishness on physical layer security. Chapter 12 firstly describes the physical layer security issues in the wireless networks and the role of game theory in the research on physical layer security. And then the typical applications of game theory in physical layer security are subsequently covered, including zero-sum game, Stackelberg game, auction theory, coalition game. Finally, Chapter 12 concludes with observations on potential research directions in this area.

Chapter 13 investigates the interplay between cooperative device-to-device (D2D) communications and green communications in LTE heterogeneous networks (HetNets). Two game theoretic concepts are studied and analyzed in order to perform dynamic HetNet base station (BS) on/off switching. The first approach is a coalition-based method whereas the second is based on the Nash bargaining solution. Afterwards, a method for coupling the BS on/off switching approach with D2D collaborative communications is presented and shown to lead to increased energy efficiency. The savings are additionally increased when a portion of the small cell BSs in a HetNet are powered by renewable energy sources.
Preface

Different utility functions, modeling the game theoretic framework governing the energy consumption balance between the cellular network and the mobile terminals (MTs), are proposed and compared, and their impact on MT quality of service (QoS) is analyzed.

The emerging traffic demand has fueled the rapid densification of cellular networks. The increased number of Base Stations (BSs) leads to augmented energy consumption and expenditures for the Mobile Network Operators (MNOs), especially during low traffic, when many of the BSs remain underutilized. Hence, the MNOs are encouraged to provide “green” and cost effective solutions for their networks. In chapter 14, an innovative algorithm for infrastructure sharing in two-operator environments is proposed, based on BSs switching off during low traffic periods. Motivated by the conflicting interests of the operators, the problem is formulated in a game theoretic framework that enables the MNOs to act individually to estimate the switching off probabilities that reduce their financial cost. The authors in chapter 14 analytically and experimentally estimate the potential energy and cost savings that can be accomplished. The obtained results show a significant reduction in both energy consumption and expenditures, thus giving the operators the necessary incentives for infrastructure sharing.

Chapter 15 provides an overview of game theoretic solutions in a wireless application of particular interest for multimedia and social interactions in modern telecommunication systems. In particular, coalitional games, bargaining solutions and fairness and stability issues will be investigated within wireless cooperative content-sharing. According to this paradigm, users download portions of data of common interest over long-range cellular links while exchanging the downloaded portions over short-range radio links. Expected benefits, which are natural incentives to cooperation, may be in terms of content price, energy consumption, and transfer delay reduction. Significant research activity has been conducted to design strategies that simultaneously exploit the multiple radio interfaces of modern wireless devices and maximize the gain. A valid solution for the cooperative content-sharing application should be based on fairness in the utility distribution among the involved nodes which can be eased by exploiting the game theoretic approaches presented in chapter 15.

Chapter 16 presents a cooperative video transmission mechanism based on game theory for heterogeneous devices during broadcasting. Broadcasting is a multi-point delivery of transmission that sends data from a source to multiple destinations. The terminal is involved in cooperative transmission when the station broadcast video data. To enhance performance, the heterogeneity and forwarding capabilities should be considered. This work studies power control and allocation in a collaborative transmission based on game theory, which provides an effective strategy when network resources are limited. First, a novel power allocation model of the base station (BS) based on non-cooperative game theory and bidding is presented in this study. Additionally, the authors also propose the utility function of Signal-to-Noise Ratios (SNRs) along with Signal-to-Interference Ratio (SIRs).

In summary, in Section 3 the typical applications of game theory in physical layer security are subsequently covered in Chapter 12, including zero-sum game, Stackelberg game, auction theory, coalition game. Two game theoretic concepts are studied and analyzed in Chapter 13 in order to perform dynamic HetNet base station (BS) on/off switching. The first approach is a coalition-based method whereas the second is based on the Nash bargaining solution. Afterwards, a method for coupling the BS on/off switching approach with D2D collaborative communications is presented and shown to lead to the increased energy efficiency. The authors in Chapter 14 analytically and experimentally estimate the potential energy and cost savings that can be accomplished. Chapter 15 provided an overview of game theoretic
solutions in a wireless application of particular interest for multimedia and social interactions in modern telecommunication systems. Chapter 16 presented a cooperative video transmission mechanism based on game theory for heterogeneous devices during broadcasting.

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