Guest Editorial
Game Theory in Wireless Communications

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I. Introduction

GAME theory provides a powerful framework to study the interaction of decision makers in cooperative or competitive scenarios. The pioneering works of Von Neumann and Nash, among others, have helped establish the foundations of game theory, which has found applications in a wide spectrum of fields, ranging from Economics and Philosophy to Biology and Engineering. Application of game theory in mobile and wireless broadband networks encompasses a variety of problems, for instance load balancing, queue management, and radio resource allocation.

A steady trend of evolution of wireless technologies is shifting the traditionally centralized architecture of such systems towards distributed network topologies. Correspondingly, the process of decision making in wireless networks is migrating towards more distributed approaches. This calls for adoption of novel analytical approaches to capture the new degrees of freedom available for decision making processes in future communication networks, fitting examples of which include femto-base-stations in beyond-3G systems and cognitive radio (CR) networks.

This special issue aims at bringing together the state-of-the-art in the application of game theory in wireless communications with an emphasis on the value of game theory in addressing real life challenges when other analytical tools fail to deliver solutions. The 17 selected papers, out of 52 submitted papers, cover various traditional as well as emerging networking and communications problems in innovative and insightful ways.

II. Overview of Papers

Secure communication techniques are evolving to address the challenges of next generation wireless systems. In their paper Anti-Jamming Games in Multi-Channel Cognitive Radio Networks, Yongle, Wang, Liu and Clancy focus on anti-jamming strategies for CRs within a Colonel Blotto game model. The authors start with a simpler case of CRs with perfect knowledge where they can only hop one channel at a time and extend this scenario to cases of imperfect knowledge by developing learning schemes. Finally randomized power allocation strategies when CRs can access multiple channels simultaneously are investigated. Another paper addressing anti-jamming strategies, Towards Optimal Adaptive UFH-based Anti-jamming Wireless Communication, by Wang et al. proposes online optimization schemes to quantify the performance of uncoordinated frequency hopping (UFH) approaches. They model UFH communications as a non-stochastic multi-armed bandit problem and propose an asymptotically optimal algorithm to solve it. They further reduce the complexity of their proposed algorithm based on the structure of the strategy selection process. Defense against malware is another security concern in future software-based radio networks. The paper Saddle-Point Strategies in Malware Attack, by Khouzani and Sarkar models the confrontation between malware and network as a zero-sum game for which the existence of robust strategies for the network and malware are proved utilizing worm propagation models in wireless networks and an appropriate damage function. The structural results derived in this paper determine a robust two-phase threshold-based defense strategy which takes into account the non-linear dynamics of state evolution and the non-monotonicity of the state functions. Anand, Sengupta, Hong and Chandramouli, in their paper Power Control Game in Multi-Terminal Covert Timing Channels, develop game theoretic power control strategies to maximize the goodput of a multi-terminal covert timing channel. In covert timing communication a transmitter uses overlay communication to hide underlay covert information that is sent to a receiver by delaying packets by certain amounts. The authors analyze the factors of the overlay communication that affect the goodput of the covert timing channel and derive power control strategies that maximize the goodput of the covert timing channels in a multi-terminal scenario.

Resource allocation strategies play a critical role in improving the performance of wireless networks. To implement a fully distributed power control scheme for CRs without the need of sharing information amongst CRs or with the primary user, Zhou, Chang, and Copeland, in their paper Reinforcement Learning for Repeated Power Control Game in Cognitive Radio Networks, propose a repeated game of incomplete information in which CRs use a Bush-Mosteller reinforcement learning procedure. The existence and uniqueness of an equilibrium as well as the convergence rate of the proposed algorithm are thoroughly investigated. Joint channel and power scheduling in CR networks is the focus of Ni and Zarakovitis in their paper Joint Channel and Power Allocation in Cognitive Radio Systems. The authors exploit a Nash bargaining solution (NBS) concept to achieve the maximal system throughput, under a minimal CR rate constraint as well as primary interference protection. Further, two methods for reducing the complexity of the above combinatorial optimization problem are proposed and their performances are studied.

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Medium access control (MAC) and scheduling techniques have been extensively studied in the literature. The problem of medium access control in a channel sense multiple access (CSMA) regime for CR networks is studied by Leshem, Zehavi and Yaffe in their paper Multichannel Opportunistic Carrier Sensing for Stable Channel Access Control in Cognitive Radio Systems. The authors evaluate lower and upper bounds for optimal as well as stable spectrum allocations based on the Gale-Shapley stable marriage theorem. Practical implementation considerations are also addressed in this paper, and two low-complexity variants of the proposed solution are presented. Mertikopoulos, Belmega, Moustakas and Lasaulce explore the convergence of non-cooperative potential games to their equilibria in the paper Distributed Learning Policies for Power Allocation in Multiple Access Channels. Power allocation of users over orthogonal static and stochastically fluctuating channels is addressed. In the former case the convergence rate is exponential when users follow distributed learning scheme based on the replicator dynamics of evolutionary game theory. In the latter scenario the game still admits a uniqueequilibrium, however, the learning process is not deterministic. The paper A Game-Theoretic Perspective on Code Synchronization for CDMA Wireless Systems by Bacci and Luise discusses the problem of initial code synchronization in an infrastructure code-division multiple-access (CDMA) network. A non-cooperative game model to capture the trade-off between probability of code alignment detection and the transmitted energy between a transmitter-receiver pair is proposed. Considering the coexistence of different Quality of Service (QoS) requirements as well as different types of synchronizers, the authors derive closed-form Nash solutions for this game model and conduct a comparative simulation study. Another interesting practical problem is channel assignment (CA) in mesh networks. While most studies in the literature rely upon orthogonal CA strategies to avoid interference, Duarte, Fadlullah, Vasilakos and Kato propose a partially overlapped CA strategy to resolve an orthogonality constraint in their paper On the Partially Overlapped Channel Assignment on Wireless Mesh Network Backbone: A Game Theoretic Approach. Their analysis verifies that the proposed scheme is near-optimal. To determine the performance of the partially overlapped CA approach, the authors derive an upper bound on the Price of Anarchy for a multi-radio multi-channel scenario. Jin and Kesidis, in their paper A Channel Aware MAC Protocol in an ALOHA Network with Selfish Users, study ALOHA channel access performance around symmetric Nash equilibrium (NE) when the channel state information of each user is considered in the medium access process. More specifically each user sets a packet transmission threshold on its channel gain so as to maximize its utility minus transmit power cost. The presented results indicate an increase in total throughput as the number of users increases in a fading channel scenario, as compared to classical slotted ALOHA schemes. Studying equilibrium strategies in multi-packet reception is the subject of the next featured paper, titled Selfish Random Access over Wireless Channels with Multipacket Reception. The authors, Inaltekin, Chiang, Poor and Wicker, determine necessary and sufficient conditions for a strategy to be an NE and apply these conditions to predict selfishness of users. For the case in which the number of users grows, the authors determine the collective equilibrium behavior as well as the approximate total packet arrival. Furthermore, equilibrium strategies and their uniqueness in imperfect information structures are investigated.

Spectrum sharing can generate excess revenue for the primary networks in CR networks. Kasebkar and Sarkar in their paper titled Spectrum Pricing Games with Spatial Reuse in Cognitive Radio Networks prove the existence of an NE when several primaries engage in a spectrum pricing competition. They identify a class of conflict graphs suitable for various network topologies, referred to as mean valid graphs, for which they prove the uniqueness of the NE. Increasing the efficiency of spectrum sharing, measured as the payoff to the spectrum manager is the subject of the paper The Theory of Intervention Games for Resource Sharing in Wireless Communications, by Park and van der Schaar. These authors postulate that if the spectrum manager can implement a class of incentive schemes for a non-cooperative game of resource sharing, it can improve upon the suboptimal performance of a non-cooperative equilibrium.

A number of other papers in this special issue also discuss practical considerations that can be addressed in a game theoretic framework. In The Impact of Incomplete Information on Games in Parallel Relay Networks, Xiao and Yeh model bargaining between a source node and multiple relay nodes when the channel gain of a given relay is not observable by the source or other relay nodes. Assuming strategic and selfish relay nodes, the authors propose a framework to measure the efficiency loss due to incomplete information. Network-level analysis of Channel State Information (CSI) feedback rate control is the subject of Non-cooperative Feedback-Rate Control Game for Channel State Information in Wireless Networks, coauthored by Song, Han, Zhang and Jiao. The authors assume that the base station and multiple co-channel mobile stations use a linear precoder. A distributed feedback rate control game is first investigated in which each mobile station attempts to maximize its performance. By introducing pricing, the social welfare of the above non-cooperative feedback rate control game is improved to close to optimal (centralized) performance. Finally, learning behavior of users in a heterogeneous 4G system is investigated by Kahn, Tembine and Vasilakos, in their paper Game Dynamics and Cost of Learning in Heterogeneous 4G Networks. Realizing that users can switch between networks and technologies in a heterogeneous setting, and exploiting the difference in learning strategies in each setting, the authors propose a heterogeneous learning paradigm in the context of general-sum stochastic dynamic games with incomplete information. Moreover the cost of switching from one action to another is captured via a cost of learning model.

Acknowledgment

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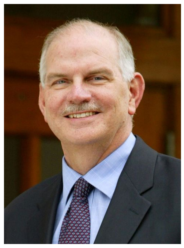
Mérouane Debbah (SM'08) was born in Madrid, Spain. He entered the Ecole Normale Supèrieure de Cachan (France) where he received his M.Sc and Ph.D. degrees respectively. He worked for Motorola Labs (Saclay, France) from 1999-2002 and the Vienna Research Center for Telecommunications (Vienna, Austria) from 2002-2003. He then joined the Mobile Communications department of the Institut Eurecom (Sophia Antipolis, France) as an Assistant Professor. Since 2007, he is a Full Professor at Supelec (Gif-sur-Yvette, France), holder of the Alcatel-Lucent Chair on Flexible Radio. His research interests are in information theory, signal processing and wireless communications. He is an Associate Editor for IEEE Transactions on Signal Processing. Mérouane Debbah is the recipient of the"Mario Boella" prize award in 2005, the 2007 General Symposium IEEE GLOBECOM best paper award, the Wi-Opt 2009 best paper award, the 2010 Newcom++ best paper award as well as the Valuetools 2007, Valuetools 2008 and CrownCom2009 best student paper awards. He is a WWRF fellow.



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