Chapter 17

Throughput-Efficient Spectrum Access in Cognitive Radio Networks: A Coalitional Game Theoretic Approach

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ABSTRACT

Cognitive radio based on dynamic spectrum access has emerged as a promising technology to meet the insatiable demand for radio spectrum by the emerging wireless applications. In this chapter, the authors address the problem of throughput-efficient spectrum access in Cognitive Radio Networks (CRNs) using Coalitional Game-theoretic framework. They model the problem of joint Coalition Formation (CF) and Bandwidth (BW) allocation as a CF game in partition form with non-transferable utility and present a variety of algorithms to dynamically share the available spectrum resources among competing Secondary Users (SUs). First, the authors present a centralized solution to reach a sum-rate maximizing Nash-stable network partition. Next, a distributed CF algorithm is developed through which SUs may join/leave a coalition based on their individual preferences. Performance analysis shows that the CF algorithms with optimal BW allocation provides a substantial gain in the network throughput over existing coalition formation techniques as well as the simple cases of singleton and grand coalition.

INTRODUCTION

Cognitive radio (CR) technology provides a smart solution to spectrum scarcity problem by allowing unlicensed users to access licensed frequency bands under stringent operating constraints. In CR terminology, the users with legacy rights on the usage of specific part of the spectrum are called primary users (PU) while the term secondary users (SU) is reserved for low-priority un-licensed users which are

DOI: 10.4018/978-1-4666-6571-2.ch017
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equipped with a cognitive capability to exploit this spectrum without being noticed by PU. The practical implementation of CRNs is facing many challenges and conflicting requirements such as PU protection and SU rate maximization, as identified by Akyildiz et al. (2006). While the last decade of research activities has focused on enhancing spectrum sensing (SS) performance (Umar and Sheikh, 2012), or more recently on jointly optimizing the spectrum sensing and spectrum access parameters (Khan et al., 2010), (Hao et al., 2012) as a means of improving the secondary network throughput, their scope has proven to be limited after the FCC ruling (FCC, 2010) which obviated the SS requirement in CRNs. As a result, there has been a dire need to explore stand-alone efficient spectrum access schemes in a competitive environment where SUs do not solely rely on SS performance for their throughput improvement.

Hence, this chapter presents an efficient strategy to dynamically share the available spectrum resources among competing SUs under the assumption that available spectrum opportunities are known a priori. The task of obtaining information about the real time spectrum occupancy by the primary users, and ultimately identifying secondary spectrum usage opportunities, is termed as spectrum sensing, and has been extensively discussed in literature (Yucek and Arslan, 2009, Wang and Ray, 2011, Axell et al., 2012, Umar and Sheikh, 2013). The overall performance of a CRN is influenced by the sensitivity and specificity of the underlying sensing mechanism (Yucek and Arslan, 2009, Umar and Sheikh, 2012), such that any error in the spectrum sensing either result in the interference with the primary transmissions or causes a reduced secondary network throughput. The impact of sensing errors on the performance of CRN has been well investigated in the literature (Khan et al., 2010 Hao et al., 2012, Saad et al. 2012), however, how to efficiently share the available spectrum resources among the competing SUs, is comparatively less-explored in analyzing the achievable performance of CRNs. Hence, this chapter primarily focuses on the throughput-efficient spectrum access in CRNs.

In particular, a cooperative game theoretic model for joint coalition formation and bandwidth allocation is presented in this chapter to improve the throughput of a CRN at two levels: First, in the process of choosing best partners to collaborate, and second, in the process of optimally allocating and efficiently accessing the available BW. Both centralized and ad hoc network models are considered, and efficient CF algorithms, that maximize spectrum reuse efficiency subject to interference constraints, are discussed. Coalition formation games are shown to fit well in modeling the throughput-efficient spectrum access problem in CRNs. For centralized CRNs, the sum-rate maximizing network partitioning problem is formulated as a coordinated CF game. On the other hand, for ad hoc CRNs, a fully distributed CF game is designed in which rational distributed CRs self-organize into throughput-efficient disjoint coalitions. A closed-form expression of the optimal BW allocation among the coalition members is obtained and the convergence/stability analysis of different CF rules is carried out.

Detailed analyses of the presented centralized and distributed CF algorithms is performed which shows the effectiveness and the gains of the joint CF and BW allocation approach, in terms of average payoff (rate) per CR, over existing CF techniques.