Chapter 4
Perturbation Analysis for Spectrum Sharing

Hengameh Keshavarz
University of Sistan and Baluchestan, Iran

ABSTRACT

The main challenge in operating cognitive ad-hoc networks is the lack of a centralized controller performing resource allocation for different users in the network. In this chapter, a distributed power allocation scheme is considered for secondary users and its performance is analyzed when time average channel gains are substituted for instantaneous channel gains. In this way, it is not necessary to exchange channel information; however, users’ allocated power will be perturbed. It is of interest to analyze mathematically this perturbation and to show how it affects the network performance. In particular, an upper bound on perturbation of each user’s allocated power is obtained. Then, it is shown that how this perturbation affects throughput and the interference constraint for the secondary network.

INTRODUCTION

Cognitive radio is a promising technology to solve the problem of the over-crowded spectrum. Federal Communications Commission’s (FCC’s) frequency allocation chart shows a heavily crowded spectrum with most frequency bands already assigned for some applications. However, measurements show that most of the time, many frequencies are unused. This fact inspired scientists to propose the notion of cognitive radio or using these temporary unused frequency bands referred to as spectrum holes to accommodate secondary (i.e., unlicensed) wireless devices for opportunistic communications.

In cognitive networks, it is always important to ensure the quality of service (QoS) for the primary users. Hence, secondary (i.e., cognitive) users are conditioned not to make unacceptable interference for the primary network. The problem of resource allocation for cognitive radio networks has been studied in the literature based on the network architecture. Power allocation problem can be approached in a centralized or a distributed manner. With centralized power allocation, the nodes firstly inform the network controller about the quality of their channels to the destination and to other nodes. Then, the network controller calculates optimum transmit power for each link. Finally, the network controller conveys the results to the various nodes, which will then adjust their transmit power accordingly. One of the main objectives of the distributed power allocation approach is to reduce the computational burden at the network controller. Furthermore, in some scenarios, for example in sensor networks, a
network controller might not be available, in which case a centralized approach might be infeasible. In the distributed approach, each node determines its own transmit power only, this is in contrast to the centralized approach where the network controller is responsible for calculating transmit power of all nodes (Adeane, 2005).

Extensive research has already been focused on joint power/rate/channel allocation in cognitive networks with centralized controllers. For example, in Digham (2008), a near-optimal yet simple algorithm was derived with linear complexity targeting capacity maximization of a cognitive radio network while jointly optimizing power and channel allocation among secondary users and respecting total power constraints per individual users.

In Wu (2008), the distributed multi-channel power allocation problem was studied for the spectrum sharing cognitive radio networks, where secondary transceiver pairs share the same spectrum with the primary system. The problem is formulated as a non-cooperative game with coupled constraints to address the interference temperature restrictions imposed by the primary system. Existence and uniqueness of the Nash Equilibrium for this power allocation game were investigated.

In Kim (2008), a framework to perform joint admission control and rate/power allocation was developed in a dynamic spectrum sharing environment. In Kim (2008), instead of instantaneous channel gains, mean channel gains averaged over short-term fading were assumed to be available for resource allocation.

In Le (2008), a resource allocation framework was presented for spectrum underlay in cognitive wireless networks. Both interference constraints for primary users and QoS constraints for secondary users were considered. Admission control algorithms, which are performed jointly with power control, were proposed so that QoS requirements of all admitted secondary users are satisfied while keeping interference to primary users below the tolerable limit.

Less research has been focused on resource allocation in ad-hoc networks because of non-convexity of sum-rate maximization problems in interference channels. Moreover, in cognitive ad-hoc networks, due to the lack of a centralized controller, distributed spectrum sharing methods are desirable. In Wang (2008), a novel joint power/channel allocation scheme was presented that uses a distributed pricing strategy to improve network performance. According to this scheme, the spectrum allocation problem is modeled as a non-cooperative game. A price-based iterative water-filling (PIWF) algorithm was proposed, which allows users to converge to the Nash Equilibrium (NE). This PIWF algorithm can be implemented distributively, with secondary users repeatedly negotiating their best transmission power and spectrum.

In this chapter, a primary ad-hoc network working in parallel with a secondary ad-hoc network is considered. As also shown (Wang, 2008), controlling the interference caused by the secondary network to the primary users needs the knowledge of cross channel gains between the secondary and the primary network. To obtain this knowledge, channel information needs to be exchanged between primary and secondary nodes which is not favorable and wastes system resources. Therefore, a distributed power allocation scheme is presented here for secondary users and its performance is analyzed when time average channel gains are substituted for instantaneous channel gains. In this way, it is not necessary to exchange channel information; however, users’ allocated power will be perturbed. It is of interest to analyze mathematically this perturbation and to provide an upper bound on it as a function of the number of secondary transmitters.
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