

Multiobjective Multivariate Optimization of Joint Spectrum Sensing and Power Control in Cognitive Wireless Networks

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ABSTRACT

In this paper, the authors investigate trade-off factors in designing efficient spectrum sensing and optimal power control techniques for a multichannel, multiple-user cognitive wireless network. They introduce the problem of joint spectrum sensing and power control as a maximization of the network throughput and a minimization of the interference to the network. These two optimization objectives can be achieved by a joint determination of sensing and transmission parameters of the secondary users, such as sensing times, decision threshold vectors, and power allocation vectors. There is a conflict between these two objectives, thus a multiobjective optimization problem is introduced. The authors propose an analytical approach based on Newton's methods and nonlinear barrier method to solve this large-scale joint multiobjective optimization problem.

KEYWORDS

Cognitive Radios, Cognitive Wireless Networks, Multiobjective Optimization, Newton's Methods, Nonlinear Barrier Method, Power Control, Spectrum Sensing

1. INTRODUCTION

Cognitive radios have been proposed to be the next generation wireless devices that can share underutilized spectrum (Haykin, 2005; Hossain & Bhagava, 2007; Mitola & Maguire, 1999). Spectrum sensing and dynamic spectrum access are the main principles of cognitive radios. In spectrum sensing, cognitive radio users (*secondary users* - SU) sense the spectrum of licenced users (*primary users* - PU) to detect and utilize spectrum holes within the PUs' spectrum. The cognitive radio networks adopt a hierarchical access structure by considering the PUs as the legacy spectrum holders, as well as the SUs as the unlicensed users.

The challenge for a reliable sensing algorithm is to identify suitable transmission opportunities without compromising the integrity of the PUs (Almalfouh & Stuber, 2012; Pang & Scutari, 2013). The efficiency of the employed spectrum sensing technique plays a key role in maximizing the cognitive radio network throughput, while protecting the PUs from interference. The popular criterion in designing sensing techniques is to minimize the probability of false alarm as low as possible (Almalfouh & Stuber, 2012; Pang & Scutari, 2013). In addition, in order to limit the probability of interfering with PUs, it is desirable to keep the missed detection probability as low as possible. The sensing time is the tradeoff factor between the quality and the speed of sensing. Increasing the sensing times allows to have both low false alarm and low missed detection probabilities, but reduces the time available for transmissions which results in low throughputs of SUs. Another tradeoff factor between the false alarm and the missed detection probabilities includes the detection thresholds.

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Low detection thresholds result in high false alarm probability and low missed detection probability and vice versa. Thus, to maximize the throughput of SUs, a joint optimization of the sensing and transmission parameters of the SUs is required. The optimization parameters include: sensing times, decision threshold vectors, and power allocation vectors.

The joint spectrum sensing design and power control for a single-channel point-to-point cognitive radio network has been introduced in (Almalfouh & Stuber, 2012). In that work, the authors formulated the joint sensing-duration design and power control problem as a two-stage stochastic program with recourse. Their numerical results show that the method obtains a good throughput for the SUs. However, only the sensing time parameter in the spectrum sensing process is considered as an optimization variable, while the decision threshold is prefixed. Furthermore, the obtained throughput is not optimal because of using a two-stage stochastic programming in which the first stage is for finding the optimal sensing time, and the second stage is for finding the optimal power.

A game theory approach for the joint sensing and power allocation optimization problem of a multiple-channel multiple-SU cognitive radio network has been proposed by Pang and Scutari (Pang & Scutari, 2013). In that work, a novel class of Nash problems has been introduced, where each SU considered as a player competes against other SUs to maximize his/her own opportunistic throughput by choosing jointly the sensing duration, the detection thresholds, and the power allocation vector over multichannel link. Several constraints included interference constraints, probability constraints, and power budget constraints have been used to setup the game. The resulting players' optimization problems are so non-convex that it is very challenging to solve it in the traditional game theory framework. To deal with the non-convexity of the game, the Quasi-Nash Equilibrium is proposed to obtain a reasonable performance. However, using too many constraints makes the joint optimization problem less dynamic to obtain a global optimality.

This joint optimization has a set of optimal solutions instead of only one solution. Depending on the network's context and operational budgets, the best-suited solution is selected along the set of optimal solutions to configure the network. Thus, finding the set of those optimal solutions are essential to make the network cognitive and adaptive to the environment and operational context. Dang and Kinsner (Dang & Kinsner, 2014-2015) have formulated the joint optimization as a multiobjective optimization to maximize the averaged throughput and the averaged transmission gain of the network. A multiobjective evolutionary memetic optimization algorithm was proposed to solve that optimization problem. The method has produced good results; however, this method is of high computational complexity due to the nature of the evolutionary algorithm employed.

In this paper, we model the joint optimization problem between spectrum sensing and power control of a multichannel, multiple-user cognitive radio network as a bi-objective optimization problem. Two conflicting objectives are the throughput of SUs and the interference created by the SUs. We propose an analytical approach based on Newton's method and nonlinear barrier method to search for the optimal sensing times, decision vector, and power allocation vector of each SU to maximize the averaged throughput, while minimizing the averaged interference of the cognitive network. The main contributions of this work are as follows.

- A. A multiobjective joint optimization problem between spectrum sensing and power allocation for a multichannel multiple-SU cognitive radio network is introduced; and
- B. A novel numerical multiobjective optimization method is proposed to solve the multiobjective joint spectrum sensing and power control problem.

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