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Nonconvex dynamic spectrum allocation for cognitive radio networks via particle swarm optimization and simulated annealing

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ABSTRACT

Dynamic spectrum access is a promising technique designed to meet the challenge of rapidly growing demands for broadband access in cognitive radio networks. By utilizing the allocated spectrum, cognitive radio devices can provide high throughput and low latency communications. This paper introduces an efficient dynamic spectrum allocation algorithm in cognitive radio networks based on the network utility maximization framework. The objective function in this optimization problem is always nonconvex, which makes the problem difficult to solve. Prior works on network resource optimization always transformed the nonconvex optimization problem into a convex one under some strict assumptions, which do not meet the actual networks. We solve the nonconvex optimization problem directly using an improved particle swarm optimization (PSO) method. Simulated annealing (SA), combined with PSO to form the PSOSA algorithm, overcomes the inherent defects and disadvantages of these two individual components. Simulations show that the proposed solution achieves significant throughput compared with existing approaches, and it is efficient in solving the nonconvex optimization problem.

1. Introduction

As wireless communication technology develops, the available spectrum resources become increasingly scarce. Current policies allocate a fixed spectrum, where governmental agencies assign the entire wireless spectra to license holders on a long-term basis for large geographical regions. As the spectrum demand increases, this policy faces spectrum scarcity in particular spectrum bands. One promising solution to overcome the artificial scarcity is dynamic spectrum access. In this case, future wireless devices no longer operate on a statically assigned spectrum, but acquire a spectrum on-demand.

The key enabling technology for dynamic spectrum access techniques is cognitive radio (CR) [1], which provides the capability to share a wireless channel between licensed and unlicensed users opportunistically. CR networks are envisioned to provide high bandwidth to mobile users through heterogeneous wireless architectures and dynamic spectrum access techniques. This goal can be realized only through dynamic and efficient spectrum management techniques. The Federal Government of the United States recently changed its approach to managing the frequency spectrum. A Federal Communications Commission (FCC) technical report [2] explained this paradigm shift which described how cognitive radio can use the frequency spectrum more dynamically and efficiently and proposed rule changes and certification tests for such radios.

In this paper, we focus on spectrum sharing based on the interference temperature (IT) model [3]. The IT is defined as the radio frequency power per unit bandwidth

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measured at a receiving antenna. In [4], auction schemes, especially SINR-auction and power-auctions, were proposed to arbitrate Pareto-optimal power allocation under IT constraints. Xing et al. [5] proposed a centralized tree-pruning algorithm for partially removing secondary links when systems with both QoS and IT constraints cannot support a given set of secondary users (SUs). The problem of optimal power control for SUs under interference constraints for primary users (PUs) was formulated as a concave minimization problem in [6], and thus the authors proposed a branch and bound algorithm to obtain the solution. In [7], the channel allocation problem was formulated using game theory, but primary users were not explicitly protected from interference due to spectrum access by secondary users. In [8], a centralized and distributed protocol were presented for spectrum allocation, and the authors concluded that these protocols were near-optimal in most scenarios. A cross-layer opportunistic spectrum access and dynamic routing algorithm for cognitive radio networks was proposed in [9]; they solved the nonconvex optimization problem by relaxing constraints using the dual theory. In [10], a network-wide radio spectrum resource was minimized for a set of user sessions. They developed a lower bound for the objective by relaxing the integer variables and designed a near-optimal algorithm to solve this optimization problem. A solution for handling the interference constraints for PUs and quality of service constraints for SUs would be switched off by admission in [11], and the nonconvex optimization problem was transformed to a convex form under some assumptions.

Mathematical programming approaches, including nonlinear, quadratic, and linear programming, have been used for network optimization problems where the utilities are assumed to be concave, so many extensive methods and algorithms can be used, such as the Karush–Kuhn–Tucker (KKT) conditions and duality theorem. This paper models and analyzes a spectrum sharing problem in cognitive radio networks and proposes a solution to the dynamic spectrum allocation problem for SUs in cognitive radio networks. As the spectrum sharing optimization problem is nonconvex, the methods mentioned above are not appropriate. Even if these methods can be used, enormous computational efforts and time consumption are usually needed. The nonconvex problem is generally solved under some assumption or through the log transform [9–11]. The subgradient or dual theory was used to solve the nonconvex optimization problem, which was close to the optimal solution and cannot get the expected results when the dual gap was not zero. In this paper, we apply an evolutionary computation technique, the particle swarm optimization (PSO) algorithm [12], to solve the nonconvexity issues directly. The distinct advantages of PSO include the following: it is conceptually simple and can be easily implemented; it does not need to calculate the gradients or form of the objective function; it has comparable or even superior search performance for some hard optimization problems with faster convergence rates than other algorithms; and its ability to handle complicated optimization problems, including reactive power optimization [13], neural network training [14], image segmentation [15], hydroelectric system scheduling [16], data clustering [17] and communication networks[18,19]. In [18], PSO is used to optimize cognitive radio parameters according to the environment and user needs. In [19], a distributed resource allocation algorithm based on PSO was proposed for mesh networks. The traditional PSO often suffers from the problem of being trapped in local optima. To avoid this, an adaptive inertia weight factor (AIWF) and simulated annealing (SA) are combined into PSO to construct an improved PSO (PSOSA), where the parallel population-based evolutionary searching ability of PSO and the convergence of SA to a global optimum are reasonably combined. We apply the PSOSA method to the nonconvex optimization problem.

The key contributions of our work are summarized thus: A utility-based architecture is proposed for cognitive radio networks. Based on the proposed architecture, we derive a decentralized algorithm for controlling power, which maximizes the weighted sum goodput under the constraints. We solve the nonconvex optimization problem directly using PSOSA. Simulations are conducted to quantify the performance of the proposed approach. Results indicate that the proposed approach can solve the nonconvex optimization problem and is more effective than the existing approaches.

The rest of the paper is organized thus: Section 2 describes the system model and formulates the proposed PSOSA algorithm. Section 3 provides numerical results, and Section 4 concludes the paper.

2. Dynamic spectrum optimization algorithm

2.1. System description

We assume a cognitive radio network with N SUs and S PUs, which contains one base station (BS) transmitting to the nodes, as in Fig. 1. The secondary system is assumed to opportunistically access a spectrum licensed to another network, where users are referred to as the PUs and have the highest priority for using the spectrum. To avoid interrupting PUs' communication, every transmitter in the SU system is not allowed to transmit if there is an active PU.

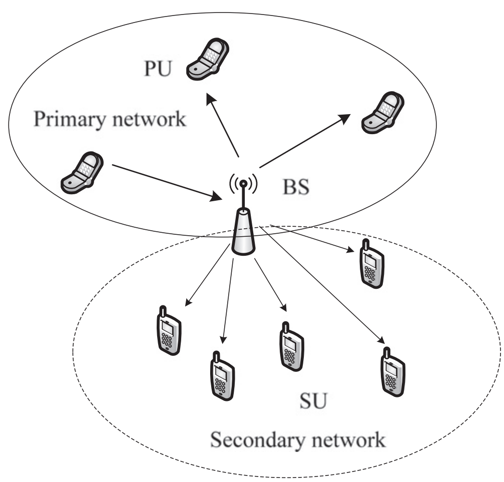

Fig. 1. The scenario studied.