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Energy efficient power allocation in cognitive radio network using coevolution chaotic particle swarm optimization

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ABSTRACT

In this paper, the trade-off between utility and energy consumption in orthogonal frequency division multiplexing (OFDM)-based cognitive radio (CR) network is investigated. Energy efficiency problem is very important in the field of CR network, where the utility is maximized and the energy consumption is minimized in such a CR network. Since the trade-off between them has been paying more attentions in literature, this study summarizes the power allocation as an optimization problem that maximizes the energy efficiency via a new energy efficiency metric defined by this paper. The formulated problem is a large-scale nonconvex problem, which is very difficult to solve. In this paper, we present an improved particle swarm optimization (PSO) algorithm to solve the difficult large-scale optimization problem directly. Given the weak convergence of the original PSO around local optima, an improved version that combines the chaos theory is proposed in this study, where chaos theory can help PSO search for solutions around the personal and global bests. In addition, for the purpose of accelerating the convergence process when facing with such a large-scale optimization, the original problem is decomposed into a number of small ones by employing the coevolutionary methodology, and then divide-and-conquer strategy is used to avoid producing infeasible solutions. Simulations demonstrate that the proposed coevolution chaotic PSO needs a smaller number of iterations and can achieve more energy efficiency than the other algorithms.

1. Introduction

Nowadays almost all wireless spectrum has been licensed to existing wireless communications applications. With the increasing demand for wireless data service, spectrum scarcity will become a big problem in future development of wireless communications networks. One promising solution to overcome the spectrum scarcity problem is to use opportunistic spectrum access techniques such as cognitive radio [1], which lets unlicensed users (called secondary users or cognitive users) temporarily utilize a licensed spectrum band, if the licensed users (called primary users) are idle or the interference received at primary users from secondary transmissions is tolerable (in other words, secondary transmissions do not affect the transmission quality of primary users). Due to its potential to largely improve the spectrum utilization efficiency, CR has received much attention from academia, industry, and spectrum regulation agencies [2].

In a cognitive radio (CR) network, primary users have the highest priority to use the spectrum. Secondary users are aware of the transmission environments, and can adapt their transmission/reception patterns to the varying spectrum environments. As an example, consider that a secondary user uses a licensed spectrum band. If the corresponding primary user is back (i.e., the primary user needs to use the spectrum band), the secondary user needs to stop using the spectrum band, and try to find

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other idle spectrum bands to continue its wireless access service. Dynamic spectrum allocation is a main challenge in the design of cognitive radio networks, which enables wireless devices to opportunistically access portions of the spectrum as they become available.

In this paper, we consider an orthogonal frequency division multiplexing (OFDM)-based CR network, and we focus on the network utility (to be defined in Section 3). We define “utility per Joule” as the energy efficiency metric, which can effectively characterize the trade-off between utility and energy. A power allocation problem is formulated, which maximizes the energy efficiency. Since there are base stations (BSs) in the system, the optimization problem is centralized and nonconvex, and is hard to be transformed to a convex problem. So in this paper, we adopt PSO (particle swarm optimization) algorithm , which can solve the nonconvex optimization efficiently. PSO algorithms are modern heuristic algorithms based on bird flocking, there is no theory proof for PSO to get the global optimum, but they have demonstrated their potential in solving complicated optimization problems [3–6] and network optimization problems [7–9]. The advantages of PSO algorithms include: they have simple theoretical structure with good convergence properties; they are easy to implement; they do not require the objective functions to be continuous. PSO methods have been popularly used in wireless networks. For example, Zhao et al. [7] uses PSO to optimize CR parameters based on the spectrum environments and user needs; a PSO-based distributed resource allocation algorithm in wireless mesh networks is proposed in Ref. [8]; and Lin [9] applies PSO to deal with router node placement problem in a dynamic wireless mesh network such that the network connectivity and client coverage are maximized.

However, it is very likely that traditional PSO algorithms may be trapped into local optimal solutions (which are not global optimal). Therefore, in the literature, chaos, which has the features of randomness, ergodicity and regularity, has been used in PSO algorithms recently [10–14]. Chaotic PSO algorithms can maintain the population diversity, which is a nice property. Liu et al. [10] applies chaotic dynamic in PSO algorithms, using the chaotic local searching behavior. Coelho and Herrera [11] considers fuzzy identification, which enhances PSO algorithms with chaotic Zaslavskii map sequences and efficient Gustafson–Kessel clustering. The chaotic PSO algorithm is shown to be effective in building a good TS fuzzy model. In [12], the authors consider prediction of silicon content in hot metal, in which PSO algorithms are enhanced with chaotic under the logistic equation. A binary PSO is used in [13] to predict operon in bacterial genomes, and chaotic sequence is introduced when updating inertia weight. In [14], the authors apply a PSO algorithm to estimate the unknown parameters for a hybrid-forecasting model, in which initial values of unknown constants in particle velocity and position equations are generated by chaotic mapping. Due to the nice features of chaos theory in PSO algorithms, we adopt a chaotic PSO algorithm in this paper.

Besides the chaos, we also apply the cooperative coevolution theory, since cooperative coevolution theory is very suitable for large scale optimization problems. An application of cooperative coevolution theory in PSO can be found in [15], in which PSO position update rule relies on Cauchy and Gaussian distributions. And in our recent paper [16], chaos theory is combined into cooperative coevolving PSO, as chaos theory can help PSO search for solutions around the personal and global bests, thus avoiding being trapped into local optimal points. And a belief space is used to store the experiences for individuals to learn from each other indirectly. In this paper for CR networks, coevolution and chaos theory are all combined with PSO, referred to as CCPSO. But there is no need to set a belief space. Two populations of PSO are included in the CCPSO, and the problem is solved by using max–min approach.

The rest of the paper is organized as follows. Related work is given in Section 2. The system model and problem description are presented in Section 3 The proposed CCPSO algorithm is given in Section 4. Numerical results are provided in Section 5, followed by conclusions in Section 6.

2. Related work

The utility maximization in a multi-cell CR network under a total transmit power constraint is considered in [17]. A cooperative secure resource allocation in CR Networks was considered in [18], since the problem is NP hard, the problem is transformed into a generalized geometric programing model. Since secondary users are usually powered by battery, energy consumption in their wireless transmissions is an important issue. Further, large energy consumption is often due to large transmission power, which actually generates large interference to users in the vicinity and degrades service of those users. Accordingly, in this paper, we consider energy efficient CR networks that employ orthogonal frequency division multiplexing (OFDM) technology [19]. The reason we consider OFDM is that OFDM is very suitable for high speed broadband wireless access due to its immunity to inter-symbol-interference (ISI).

Energy efficiency has been well-investigated in traditional wireless networks [20,21]. Code division multiple access (CDMA) networks are considered in [22], which develops a cross-layer algorithm for energy efficiency. It is proved that the algorithm is Pareto-optimal under certain conditions. Meshkati et al. [23] also considers a CDMA network, which studies the trade-off between energy efficiency and delay. A game theoretical approach is presented to maximize the utility by selecting the transmit power under a delay requirement.

Due to the popularity of CR research, energy efficiency in CR has also received a lot of attention. Buzzi and Saturnino [24] consider a cognitive CDMA wireless network, and presents a game-theoretic algorithm to achieve energy efficiency in a one-shot fashion. Wu and Tsang [25] investigates the sensing and transmission durations of secondary users. A nonconvex optimization problem is formulated to achieve energy-efficient power allocation, which is solved by analyzing three special cases. In [26], the authors develop an energy efficient power control algorithm for OFDM-based CR networks. The objective function is based on the “throughput per Joule” metric. The formulated optimization problem, which is nonconvex, is transformed