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Throughput optimization in cognitive wireless network based on clone selection algorithm☆

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ABSTRACT

In cognitive wireless network, throughput scheduling optimization under interference temperature constraints has attracted more attentions in recent years. A lot of works have been investigated on it with different scenarios. However, these solutions have either high computational complexity or relatively poor performance. Throughput scheduling is a constraint optimization problem with NP(Non-deterministic Polynomial) hard features. In this paper, we proposed an immune-clone based suboptimal algorithm to solve the problem. Suitable immune clone operators are designed such as encoding, clone, mutation and selection. The simulation results show that our proposed algorithm obtains near-optimal performance and operates with much lower computational complexity. It is suitable for slowly varying spectral environments.

1. Introduction

The increasing growth in wireless communication demand has intensified the shortage crisis for the radio spectrum, but a significant amount of the licensed spectrums have not been effectively utilized [1], it is far more underutilized rather than naturally scarce. Cognitive wireless network (CWN) is a kind of intelligent communication system, which enables the devices to opportunistically access the licensed spectrum, and thereby it enhances the utilization of the existing spectrum resources [2]. The nodes in a cognitive wireless network can be classified as primary users (PUs) and secondary users (SUs). A PU is a licensed user that has exclusive rights to access spectrum. An SU is an unlicensed user that can utilize the spectrum opportunistically with PUs under interference restrictions.

Throughput optimal scheduling for cognitive wireless network under interference temperature constraints is an open research issue [4]. The throughput scheduling determines how many packets and with which frequency each SU will transmit in each time slot [5]. The goal of it is to maximize the total throughput of the SUs in the cell. The throughput scheduling issue in conventional networks has been widely studied [6]. Nonetheless, cognitive radio paradigm brings new challenges into the issue because of the coexistence of the PUs and the SUs. The throughput scheduling problem considered in this paper can be distinguished from these works by its cognitive radio specific nature. That is, not only the availability of different frequencies but also the maximum allowable transmission rates of the frequency bands are time-varying [5].

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Researchers have done some works on throughput optimization problem with different scenarios. In Ref. [6], a throughput optimization algorithm was proposed which does not enable true coexistence of the PUs and the SUs. The authors in Ref. [7] formulate a distributed heuristic algorithm to determine the channels and time slots for the cognitive nodes. However, they don't consider the interferences to the PUs either in their formulation or in their suboptimal heuristic algorithm. The interference temperature model provides true coexistence of licensed and unlicensed users. The throughput optimization is a binary integer programming problem, so the formulated scheduling methods have high computational complexity [3–7]. In Ref. [3], its optimal solution was obtained by the branch-and-bound algorithm with very high computational complexity. In Ref. [4], the author focused on throughput scheduling optimization under interference temperature constraints and formulated the throughput maximization problems. Then the author proposed suboptimal scheduling models, denoted as MFS (Maximum Frequency Selection) and PFS (Probabilistic Frequency Selection), with low complexity at the expense of poor throughput performances. Hence, it is very meaningful to design a suboptimal scheduling algorithm with better performance and reasonable complexity.

It is known that bio-inspired methods are ideal for such nonlinear optimization problems [8]. Some bio-inspired methods have been used in conventional (non-cognitive) scheduling, such as genetic algorithm [9] and particle swarm optimization [10]. In this paper, an improved immune clone selection algorithm is introduced to solve the throughput optimization problem. The inspiration comes from the fact that clone selection algorithm is ideal for nonlinear optimization problems with a large feasible solution space where a quick suboptimal solution will suffice. Also, to the best of our knowledge, the use of clone selection algorithm for scheduling in cognitive wireless network has not previously been explored. The simulation results show that the proposed algorithm is more suitable for slowly varying spectral environments.

The remainder of the paper is structured as follows. In Section 2, the system model is described and the problem of throughput optimization is formulated. In Section 3, the proposed algorithm is presented. Simulation results are discussed in Section 4. Finally, Section 6 concludes the paper.

2. System model

Considering a time-slotted IEEE 802.22 system in which the SUs are controlled and guided by the CBS(cognitive base station) [4,5]. The scheduling is done at the CBS. We assume that the interference temperature perceived by the PUs is within the interference temperature limits, reliable communication between the CBS and the SUs is achieved, and collisions among the SUs are avoided [4]. U_{nf} is the maximum number of packets that each SU(denoted as n) can transmit for a frequency (denoted as f) in a time slot. The calculation procedure for U_{nf} within the interference temperature limits. The CBS then constitutes a matrix called $\mathbf{U} = [U_{nf}]$.

The throughput optimization problem can be formatted as [3,5]:

$$Q = \max \sum_{n=1}^{N} \sum_{f=1}^{F} \sum_{t=1}^{T} \frac{U_{nf} X_{nft}}{T} \tag{1}$$

$$\text{Subject to} \sum_{f=1}^{F} \sum_{t=1}^{T} X_{nft} \geq 1 \ \forall n \in (1, 2, \ldots N) \tag{1a}$$

$$X_{nft} + X_{n'ft} \leq 1 \ \ \forall n, n' \in (1, 2, \ldots N), n \neq n', \ \ \forall f, \forall t \tag{1b}$$

where N, F, T is the total number of SUs, frequencies, time slots respectively, and $X_{nft}$is a binary variable such that $X_{nft} = 1$ if user n transmits with frequency f in time slot t and 0 otherwise. Here, Eq. (1a) guarantees that at least one time slot is assigned to each SU, whereas Eq. (1b) makes certain that at most one user can transmit in a particular time slot and frequency combination, and consequently preventing collisions among the cognitive nodes. Moreover, the schedule length T is the time period in which the spectral and network environment changes slowly enough so that the X_{nft}values are not affected. For example, the TV bands used by an IEEE 802.22 network constitute a slowly varying spectral environment, and hence enable T to be quite large [4].

3. The proposed algorithm

3.1. Overview of immune clone selection algorithm

Artificial immune system (AIS) is inspired by the human immune system. AIS-based algorithms typically extract ideas from the human immune system, which can learn and solve some complicated problems [10].The most immune-clone-inspired-optimization algorithms are based on clone selection theory. Clone selection is a dynamic process simulation of the immune system against the antigen. Now, the immune clone selection algorithm for optimization has been widely used in engineering-oriented fields, such as spectrum allocation [11], job scheduling [12], and image segmentation [13] and so on. These algorithms get solutions to problems by repeating a cycle of clone, affinity maturation (via mutation) and selection for a candidate population, and remaining good solutions in the population [10–12]. Immune clone selection algorithm is also known as immune algorithm or clone algorithm for short.