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Energy-efficient design of channel sensing in cognitive radio networks ☆

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ABSTRACT

In cognitive radio (CR) networks, cooperation can greatly improve the spectrum sensing performance. However, more energies are required in the local spectrum sensing and sensing results reporting process. When the energies of the secondary users (SUs) are constrained, using their energies efficiently is a crucial problem, which must be considered. In this paper, the energy efficiency is defined as the ratio of the average channel throughput and the average energy consumption. We focus on the optimization of the final decision threshold to maximize the energy efficiency for additive white Gaussian noise (AWGN) channels, Nakagami fading channels and Rayleigh fading channels. An energy efficient optimization strategy (EEOS) is proposed to calculate the optimal solutions. Computer simulations show that fundamental improvement of the energy efficiency can be obtained by using our proposed EEOS, and there is an optimal number of cooperating SUs that can maximize the energy efficiency.

1. Introduction

The explosive development of wireless services makes the spectrum a scarce resource. The actual spectrum utilization is not quite efficient even though it is almost fully assigned to various licensed wireless users [1]. Cognitive radio has been proposed as a promising technology to alleviate the spectrum scarcity issue by allowing access of unlicensed users (a.k.a. secondary users) to the spectrum bands that are allocated to licensed users (a.k.a. primary users (PUs)), in a way that does not affect the Quality of Service (QoS) of the licensed networks [2]. To realize this, the first step is to find spectrum opportunities in the PUs' spectrum usage, that is, the so-termed spectrum sensing. By sensing the wireless spectrum environment, once an idle channel is sensed, a SU is able to access this channel. Since additional energy consumption is required for spectrum sensing compared with other traditional communication systems, when the energies of the secondary users are constrained, increasing energy efficiency becomes an important issue which must be considered.

To make use of the idle spectrum efficiently and effectively as well as to avoid interference to PUs, a SU needs to carry out spectrum sensing accurately and quickly. Existing spectrum sensing techniques can be broadly divided into three categories: energy detection, cyclostationary feature detection (exploitation of the inherent periodicity of primary signals) and matched filter detection (coherent detection through maximization of the signal-to-noise ratio (SNR)) [3]. The energy detector is the

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simplest technique to perform spectrum sensing in CR networks. It works well when the SNR is high. However, in wireless channels, the received signal would be severely degraded due to the detrimental effects of fading and shadowing as well as the uncertain noise, which may lead to a very low SNR. In this case, reliable spectrum sensing is not always guaranteed. To overcome this problem, cooperative spectrum sensing (CSS) by multiple SUs can significantly improve the sensing performance. Thus, this has become the focus of most ongoing research [4].

The main idea of cooperative spectrum sensing is that a fusion center (FC) collects multiple sensing results from secondary users at different locations to benefit from space diversity. In CSS, each secondary user acts as a sensing terminal that conducts local spectrum sensing [5]. The sensing results are sent to the FC via a common control channel (CCC). Then, the fusion center executes data fusion and makes a final decision to indicate that the channel is idle or occupied. Although cooperation can help to improve the performance of spectrum sensing, more energies are required in the local spectrum sensing and sensing results reporting process. When the energies of the secondary users are constrained, finding a way to improve the energy efficiency is a crucial problem which must be considered.

Based on cooperative spectrum sensing, authors in [6] proposed a distributed greedy algorithm to improve the average SU throughput and reduce the probability of collision. Using the Markovian approach, authors in [7] showed that the best-fit channel selection (BFC) can enhance the CR network performance. In multi-hop CR networks, an intelligent and distributed channel selection strategy SURF is proposed, which can classify the available channels and use them efficiently to increase the data dissemination reliability [8,9]. In [10], the proposed optimal cooperative sensing method with entropy and cyclic features can greatly enhance the performance of spectrum sensing, and it is less severe to noise uncertainties compared with the conventional methods. For CR networks with few suspicious CR users, significant improvement in cooperative sensing performance can be obtained by elimination of multiple suspicious CR users [11]. Authors in [12] proposed a novel CSS frame structure, in which the CR users can conduct spectrum sensing and data transmission concurrently over two different parts of the primary user spectrum band. The throughput of CR network is maximized via joint optimization of the sensing bandwidth and the final decision threshold in FC.

Some previous works focused on minimizing the energy consumed in cooperative spectrum sensing. When the secondary users are farther away from the FC, they require more energies to send the local sensing results to the FC. The authors in [13,14] employed a censoring method that only the SUs with reliable information are allowed to send their local sensing results to the FC while the others will not make any decision during the reporting stage. The authors in [15] reduced sensing energy consumption by dividing the SUs into several subsets and activating one subset at a certain period. A partial spectrum sensing algorithm with decision result prediction and modification techniques [16] was proposed to reduce the CSS energy. In [17], the authors proposed two TSEEOB-CSS algorithms to significantly decrease the sensing time and energy consumption of the CR system. The above methods focused on reducing the CSS energy consumption.

For energy efficient CR systems, authors in [18] studied joint design of the sensing-access strategies and the channel sensing order to maximize the energy efficiency. In [19], the authors studied energy-efficient CR systems by jointly determining the sensing and transmission durations. An energy-efficient multichannel cooperative sensing scheduling with heterogeneous channel conditions was analyzed in [20].

In this paper, we define the energy efficiency as the ratio of the average channel throughput and the average energy consumption. The average channel throughput is the sum of the throughput of primary system and the throughput of the secondary system, and the average energy consumption consists of the energy consumed by spectrum sensing, sensing results reporting, PU data transmission and SU data transmission. We focus on designing the sensing parameters by using some efficient algorithms to enhance the energy efficiency.

In cooperative spectrum sensing, we employ the counting rule as the fusion rule at the fusion center since it requires the least communication overhead and is easy to implement. Similar to [21], we assume that the energy detection is employed as the local sensing. When the energy of the CR network is limited, maximizing the energy efficiency is one of the most practical interests. Our object is to find the optimal final decision threshold in the FC to maximize the energy efficiency for AWGN, Nakagami fading channels and Rayleigh fading channels. To achieve that, we propose an energy efficient optimization strategy (EEOS) that will obtain the optimal threshold in the FC and the maximum energy efficiency. It has been shown that the optimal final decision threshold obtained by EEOS is the same as using an exhaustive search. Simulation results show that EEOS will further increase the energy efficiency as compared to that using conventional Majority rule.

In cooperative spectrum sensing, from a spectrum efficiency standpoint, one should use more SUs in cooperative sensing to achieve better sensing performance. From an energy efficiency standpoint, increasing the number of cooperating SUs will also increase the energy consumed by spectrum sensing and sensing results reporting. Hence, there are tradeoffs among the sensing performance and the energy consumption when designing the sensing parameters. Computer simulations show that, when the EEOS is employed in the fusion rule, there is an optimal number of cooperating SUs that maximizes the energy efficiency, and the optimal number decreases as the energy consumed by spectrum sensing becomes higher.

The rest of this paper is organized as follows. In Section 2, the system model and cooperative spectrum sensing are introduced. Section 3 is devoted to the analysis of energy efficiency. Our proposed EEOS to find the optimal final decision threshold is presented in Section 4. Simulation results are provided in Section 5, followed by concluding remarks in Section 6.