



A multi-objective genetic optimization for spectrum sensing in cognitive radio



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ABSTRACT

Cognitive radio (CR) has emerged as a promising solution to the problem of spectrum underutilization. In CR, spectrum sensing is a key feature. It enables the cognitive user or secondary user (SU) to detect spectrum holes and ensure non-interference to primary communication. Spectrum sensing has its own challenges, such as discovery of opportunities for transmission and sensing overhead. High sensing overhead may impair spectral efficiency as the radio is mostly used for detecting primary users (PUs), rather than transmitting data. On the other hand, a less frequent sensing may result in interference to PU, due to the delay in the detection of the PUs reappearance and can lead to loss of transmission opportunities. Thus, it is of paramount importance to optimize the sensing periods for each primary channel in order to maximize the number of transmission opportunities and reduce the sensing overhead incurred. This paper extends our previous letter (Balieiro, Yoshioka, Dias, Cavalcanti, & Cordeiro, 2013) and presents a detailed description of our adaptive sensing optimization scheme for CR Networks based on a multi-objective genetic algorithm (GA) formulation. Our scheme aims at maximizing the spectrum opportunities as well as keeping the sensing overhead always within a user-defined maximum value. The simulation results show that the proposed scheme outperforms the schemes described in the literature, while keeping the sensing overhead within a target value. In addition, it provides different levels of protection to PU communication through the configuration of threshold for sensing overhead.

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1. Introduction

Nowadays, the number of developed systems based on wireless communications has increased in the world. For deployment of these systems, it is necessary the availability of a scarce resource, the electromagnetic spectrum.

The current static allocation policy for spectrum regulation allocates a given spectrum band to each licensed service/primary user (PU) to ensure that the primary users cause each other minimal interference. However, studies have shown that this system of regulation does not provide an efficient usage of spectral resources, since some licensed spectrum bands are not fully used (Akyildiz, Lee, Vuran, & Mohanty, 2006; Federal Communications Commission, 2002).

Thus, cognitive radio (CR) technology has emerged to enable new wireless services to be employed, and as a result, improve the spectral efficiency, and ensure non-interference to primary user communication. Cognitive radio is a radio that can change its transmitter

parameters based on interactions with the environment in which it operates and user requirements. It provides dynamic spectrum access, which can be performed in two main ways, spectrum underlay and spectrum overlay (Akyildiz et al., 2006).

In the first way, the cognitive radio uses spread spectrum techniques to perform its communication simultaneously with the primary user, such that its transmit power at the shared spectrum does not exceed a predefined threshold, so its signal is considered as noisy by the primary communication. In the last one, the cognitive or secondary users (SU) access the spectrum in an opportunistic way, i.e. while the primary users are not using it. To allow this, the CR senses the surrounding spectral environment to identify spectrum opportunities, i.e. available frequency bands (or channels) for its operation, and then dynamically reconfigure its transmission parameters, such as transmission power, encoding scheme, frequency carrier, and so on, so that it can act on the target channel. Cognitive radio networks (CRNs) are composed of a combination of nodes with cognitive radio capabilities.

Spectrum sensing (Yucek & Arslan, 2009) is an essential capability for CRNs using spectrum overlay approach for dynamic spectrum access, because the SU must discover available bands for its transmission and be able to detect the presence of the PU. The

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discovery of spectrum opportunities can be carried out through centralized spectrum databases, which keep track of the PUs and corresponding channel availability within certain areas. For example, incumbent databases are being developed to provide access to TV White Spaces (TVWS) in the US, as required by FCC regulations (Spectrum Bridge's White Space Database, 2012; Telcordia's TV Bands White Space Database, 2012). The database system requires a central trustworthy entity to store the information. However, it is not the most efficient method for dynamic environments with mobile secondary users and low power incumbents (such as wireless microphones in the US). The discovery of spectrum opportunities can also be achieved through distributed spectrum sensing by secondary users, which is a more scalable and efficient solution for highly dynamic environments. Spectrum sensing has its own challenges, including the problem of sensing reliability and overhead, which is the main focus of this work. Sensing overhead corresponds to the time spent by the SU when it has to stop data transmissions to measure the availability of the communication channel in order to obtain a reliable measurement. High sensing overhead may impair the spectral efficiency as the radio is mostly used for detecting PUs, rather than transmitting data.

Thus, it is of paramount importance to optimize the sensing periods for each channel as a means of maximizing the number of spectrum opportunities (transmission opportunities) and reducing the sensing overhead incurred. In this paper, we extend our previous work (Balieiro, Yoshioka, Dias, Cavalcanti, & Cordeiro, 2013), where we proposed an adaptive sensing period optimization scheme based on a genetic algorithm (GA) formulation (Goldberg, 1989). Our scheme ensures that the sensing overhead is always within a user-defined maximum value. Considering our previous work, this paper presents the following contributions: (1) a comprehensive approach to the sensing period determining problem, considering the sensing overhead versus number of discovered opportunities tradeoff; (2) a detailed description to the sensing period optimization problem based on genetic algorithms and the main differences between our proposal and those ones presents in the literature; (3) we describe the adopted genetic operators, the process carried out for selection of parameters as crossover and mutation probabilities and the flow execution of our scheme; (4) we present the convergence evaluation of our scheme based on GA and new evaluation results obtained in terms of sensing overhead besides those ones presented in Balieiro et al. (2013).

To the best of our knowledge, this is the first GA-based scheme to optimize the scheduling of sensing periods. Although the well-known GA has a large convergence time, a number of solutions to reduce this time have been proposed (Chen, Newnan, Evans, & Wyglinski, 2010). In this work, we assume that the GA can be adopted in the first stage of the cognitive cycle during the initialization phase, before the network becomes fully operational. In addition, depending on the dynamic nature of the spectral environment, the GA can also be used to update the sensing periods during the normal operation, such as a background task. Moreover, processing overhead and energy waste in the wireless device can be avoided by carrying out the GA execution in a remote network server or distributing the processing load amongst cooperating secondary devices.

The remainder of this paper is structured as follows. Section 2 describes the challenges raised by MAC layer sensing and related works. The GA based optimization for the sensing period is presented in Section 3. The simulation and analysis are discussed in Section 4. Section 5 concludes this paper.

2. MAC layer sensing and related works

Spectrum sensing is a dynamic and periodic process of spectral environment monitoring that aims at finding transmission

opportunities and to avoid interference to PU transmission. This process can be realized as a two-layer mechanism, PHY and MAC (Kim & Shin, 2008). The PHY-layer sensing focuses on efficiently detecting the primary user's signals to identify opportunities for spectrum utilization. Energy detection, matched filter, and feature detection are well known candidate methods for PHY-layer sensing (Yucek & Arslan, 2009). At the same time, MAC-layer sensing aims to determine when the SU has to sense the spectrum, i.e. the sensing periodicity of the channels.

One of the fundamental in spectrum sensing is how to define the channel sensing schedules for the SUs. The tradeoff between the number of discovered transmission opportunities and the corresponding sensing overhead has to be taken into account when determining the sensing time and sensing period. The former refers to the time spent by the SU to determine the signal strength for a certain channel, in the light of the desirable false-alarm and detection probabilities. The latter is the time interval between two consecutive sensing instances; this determines how often a particular band is monitored by SU. The sensing time and sensing period concepts are illustrated in Fig. 1.

In this work, as in Kim and Shin (2008), Yang, Cao, and Zheng (2007), we adopt the same ON–OFF model (see Fig. 1) to represent the PU behavior in the context of MAC layer sensing. In this model, the SU can transmit opportunistically while the channel is in the OFF state, i.e. when no PU is currently transmitting; it must stop its transmission when the PU is present in the channel, in the ON state.

If a shorter sensing period is adopted, many transmission opportunities will be discovered and the PU return can be quickly detected by the SU. However, the SU will spend a lot of time sensing instead of transmitting, owing to the increase in the sensing frequency, which has a negative impact on the spectrum utilization. The increase in the sensing frequency can lead to redundant sensing, i.e. the SU performs the spectrum sensing even though no change in the channel state has occurred, as illustrated in Fig. 2.

However, using less frequent sensing may result in interference to the PU, due to the delay in the immediate detection of the PU reappearance. Furthermore, if there is a long sensing period, it can lead to a loss of transmission opportunities (missed opportunities) by the SU, as depicted in Fig. 3. A missed opportunity is the time interval when the channel was in the OFF state, but it was not detected by the SU. In Fig. 3 the PU activity (ON state) was not detected because the sensing period was too long. Hence, despite the smaller sensing overhead, the PU communication can undergo interference from the SU (interference to the PU).

In addition, due to the peculiar usage pattern of each channel, defined by the PU activity, a sensing period may result in a good performance, in terms of its ability to minimize the interference to the PU, reduce overhead sensing and detect effective transmission opportunities in one channel (e.g. Ch1), but not be effective in another one (Ch2), as shown in Fig. 4. Thus, the choice of a single sensing period for all the channels cannot represent a good overall performance.

As can be seen, the definition of the periodicity of the spectrum sensing phase is challenging. In (Choi, 2010) a sensing system was developed to achieve a better spectral utilization by deciding

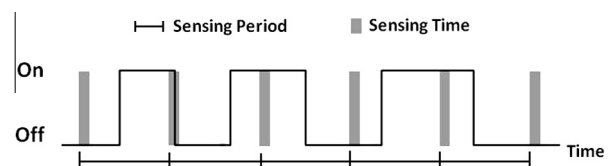


Fig. 1. ON–OFF model and sensig time and sensing period concepts.

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