

## Chapter 2

# Spectrum Sensing in Cognitive Radio: Aspects of Fading and Cooperation

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### **ABSTRACT**

*The cognitive radio has been widely investigated to support modern wireless applications. To exploit the spectrum vacancies in cognitive radios, the chapter considers the collaborative spectrum sensing by multiple sensor nodes in the likelihood ratio test (LRT) frameworks. In this chapter, the functions of sensors can be served through the cooperative regular nodes in the cognitive radio, or the specifically deployed sensor nodes for spectrum sensing. In the LRT, the sensors make individual decisions. These individual decisions are then transmitted to the fusion center to make the final decision, which provides better detection accuracy than the individual sensor decisions. The author provides the lowered-bounded probability of detection (LBPDP) criterion as an alternative criterion to the conventional Neyman-Pearson (NP) criterion. In the LBPDP criterion, the detector pursues the minimization of the probability of false alarm while maintaining the probability of detection above the pre-defined value. In cognitive radios, the LBPDP criterion limits the probabilities of channel conflicts to the primary users. Under the NP and LBPDP criteria, the chapter provides explicit algorithms to solve the LRT fusion rules, the probability of false alarm, and the probability of detection for the fusion center. The fusion rules generated by the algorithms are optimal under the specified criteria. In the spectrum sensing, the fading channels influence the detection accuracies. The chapter investigates the single-sensor detection and collaborative detections of multiple sensors under various fading channels and derives testing statistics of the LRT with known fading statistics.*

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## 2.1 INTRODUCTION

The cognitive radio can facilitate the increased utilization of the spectra. In conventional spectrum allocation schemes, the spectra are licensed to a certain group of users or systems, preventing other users from using the spectra. These conventional spectrum allocation schemes lead to low utilization of the spectra. To increase the utilization of the spectra, the concept of the cognitive radio is to allow the secondary users to use the spectra when the channel is not occupied by the primary (i.e., licensed) users.

In the cognitive radio system, the secondary users must seek spectrum vacancies, i.e., the spectrum not occupied, by using spectrum sensing techniques. The accuracies of the spectrum sensing techniques play a crucial role in the cognitive radio scheme. An accurate spectrum sensing facilitates the efficient utilization of the spectrum vacancy by the secondary users, and reduces the potential interferences and channel conflicts to the primary users. Several techniques (Cabric, 2004; Cabric 2006; Visotsky, 2005) have been used for spectrum sensing, such as energy detection (Kostylev, 2002; Digham, 2003), matched filter detection, and feature detection. These techniques are employed on the single-user detection scenario.

One approach to increase the sensing accuracies is to adopt cooperative spectrum sensing (Cabric, 2006; Visotsky, 2005), where the distributed secondary users form the sensor network and make independent detections (e.g., binary hypothesis tests), and then transmit their decisions to the fusion center (FC). The fusion center makes the final decision based on the decisions from the secondary users. The goal of the cooperative spectrum sensing is to make the decisions, whether to use the intended channel or not, for the secondary users based on the final decision of the fusion center. Thus, the fusion rule at the fusion center must be well designed (Mishra, 2006; Ghasemi, 2005; Lin, 2005; Chen, 2004), such that the probability of false alarm and

the probability of detection of its final decision achieve the performance criteria. The cooperative sensing techniques in the cognitive radio belong to the category of the distributed detections (Viswanathan, 1997; Elias-Fuste, 1992; Chair, 1986; Barkat, 1989). We suggest the lowered-bounded probability of detection (LBPD) criterion to be more suitable than the Neyman-Pearson (NP) criterion for the cognitive radio problem. The algorithms are provided to explicitly compute the optimal decision fusion rules for the two criteria.

Since the fading channels are ubiquitous in wireless communications, we investigate the single-sensor detection and collaborative-detection under the influences of the fading channels. We formulate the pdfs of the fading channel gains into the fusion rules. Our approaches, called the likelihood ratio test with fading statistics (LRFS), incorporate the fading statistics into the likelihood ratio test framework. The receiver operating curves (ROCs) are evaluated. The ROCs show performance improvements when the fading statistics are incorporated in the detection frameworks.

## 2.2 COLLABORATIVE DECISION FUSION FOR SPECTRUM SENSING

The spectrum sensing scenario in the sensor networks is described as follows. A cognitive radio network with  $N$  secondary users is deployed. The  $N$  secondary users form a sensor network to detect the spectrum vacancies. Each secondary user conducts local detections using energy detection, matched filter detection, or feature detection. Each secondary user decides either  $H_0$  (channel vacant) or  $H_1$  (channel occupied). The probabilities of the local false alarm are denoted as  $\{P_{FAi} \mid i = 1, 2, \dots, N\}$ , where  $P_{FAi}$  represents the probability of false alarm of the  $i$ -th user. The probabilities of detection are denoted as  $\{P_{Di} \mid i = 1, 2, \dots, N\}$ , where  $P_{Di}$  represents the probability of detection of the  $i$ -th user. The local

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