A Novel Energy Detection Technique for Cooperative Spectrum Sensing in Cognitive Radio

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Abstract

Co-operative spectrum sensing is used as a promising solution to detect the primary user effectively in a highly noisy environment, where the multiple secondary users make a global decision in relation to the primary user. The Bayesian Estimation Energy Detection (BEED) technique is one of the elegant spectrum sensing techniques available in a non-cooperative environment. So an attempt was made in this paper by incorporating the BEED in a cooperative environment, which yields the detection of primary user effectively up to a Signal to Noise Ratio (SNR) of –19 dB, when the Rayleigh fading effects are considered.

Keywords: cognitive radio, BEED, cooperative spectrum sensing.

1 Introduction

With the rapid growth of wireless applications in the recent decade, more and more spectrum resources are needed to support the numerous emerging wireless services. The radio spectrum is a limited resource and is regulated by authorized agencies such as the Federal Communication Commission

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(FCC) [1]. Cognitive radio (CR) technology has been recently proposed as a solution to solve the conflicts between spectrum scarcity and spectrum under-utilization. This is done by allowing secondary unlicensed network to utilize the unused radio spectrum from primary licensed network. In CR terminology the licensed user is the primary user (PU) and the unlicensed user is the secondary user (SU). By sensing and adapting to the environment, a cognitive radio is able to fill in the spectrum holes [2] and serve its users without causing harmful interference to the licensed user. One of the great challenges of implementing spectrum sensing is the hidden terminal problem, which occurs when the cognitive radio is shadowed in severe multipath fading or inside buildings with high penetration loss, while a PU is operating in the vicinity [3]. Due to the hidden terminal problem, a SU may fail to notice the presence of the PU and then will access the licensed channel and cause interference to the licensed system. In order to deal with the hidden terminal problem in cognitive radio networks, multiple cognitive users can cooperate to conduct spectrum sensing. Such that the spectrum sensing performance can be greatly improved with an increase of the number of cooperative partners [4].

In general the performance of a cognitive radio can be evaluated at the link level, node level and application level. In this paper the work was restricted, since the spectrum sensing is performed at link level only. The performance metrics associated at this level are briefly discussed in [5].

The rest of this paper is organized as follows. In Section 2 cooperative spectrum sensing is briefly discussed. Results and analysis are discussed in Section 3 and finally Section 4 concludes the paper.

2 Cooperative Spectrum Sensing

Cooperation spectrum sensing (CSS) is a solution to problems that arise in spectrum sensing due to noise uncertainty, fading and shadowing. CSS functioning is classified in to two parts as mentioned in Figure 1 one is local decision part (local sensing) and the other is global decision part.

The local sensing will be performed by spectrum sensing and the global decisions are made by the fusion center (FC). Initially the FC intimates SUs the frequency band of PU that they has to sense through sensing channel and the sensed results will be reported to the FC through reporting channel. Finally, the global decision will be made by the FC and the decision is fed back to the SUs through reporting channel. In practical scenario, both the channels will be affected by fading [4, 9]. The local sensing is performed

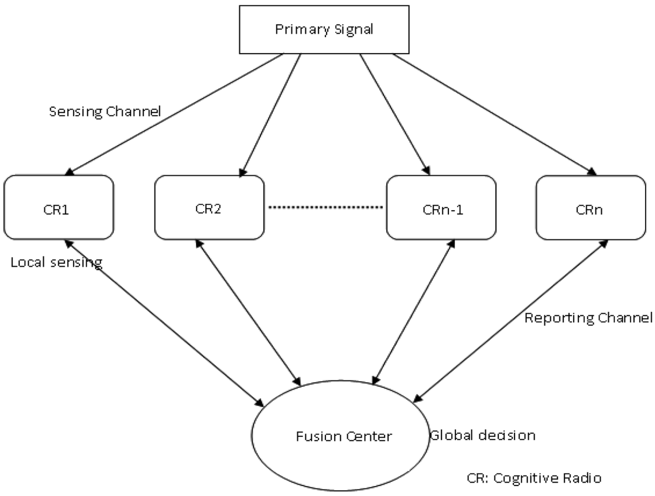

Figure 1 Cooperative spectrum sensing.

with the Spectrum sensing. Spectrum sensing is the mechanism of finding out the existence of PUs in a geographical area. Spectrum sensing is viewed as a binary hypothesis problem in which H_0 is a null hypothesis, which states that there is no licensed user signal in certain spectrum band, i.e. absence of PU, on the other hand, H_1 is an alternative hypothesis, which indicates that there exist some licensed user signal, i.e. presence of PU. The CR spectrum sensing is to decide between the following two hypotheses [6]:

$$x(t) = \left\{ \begin{array}{ll} n(t) & H_0 \\ s(t) + n(t) & H_1 \end{array} \right\}, \tag{1}$$

where $x(t)$ is the signal received by the CR, $s(t)$ is the transmitted signal of the primary user, $n(t)$ is the additive white Gaussian noise.

The performance of spectrum sensing can be characterized by the probability of detection P_d and the probability of false alarm P_f. The probabilities of correct detection given by Prob{Decision $= H_1 \mid H_1$} and Prob{Decision $=$ $H_0 \mid H_0$}, the false alarm probability given by Prob{Decision $= H_0 \mid H_1$}. The spectrum sensing is carried out by spectrum sensing algorithms and the advantages and disadvantages associated with it are briefly discussed in [6].

2.1 BEED Technique

The disadvantage associated with the general energy detection technique is the noise level estimation which is inaccurate in practical situations [6]. So the BEED technique almost eliminates the noise uncertainty by sensing the primary channels and making decisions one by one. With the help of BEED the number of occupied channels of the primary user can be known such that unoccupied channels can be utilized by the secondary users or cognitive users. The general procedure or algorithm followed by BEED is given in [7].

The two quantities used to assess the sensing channel performance are detection probability and the probability of false alarm. Hence, the appropriate expressions for the probability of false alarm and the probability of detection are given by

$$P_f = Q\left(\frac{\gamma_i - \sigma^2}{\frac{\sigma^2}{\sqrt{N}}}\right) \tag{2}$$

$$P_d = Q\left(\frac{\gamma_i - \sigma^2}{\frac{\sigma_i^2}{\sqrt{N}}}\right) \tag{3}$$

where $Q(x)$ is the complementary cumulative distribution function, γ_i is the threshold based on the noise power, σ^2 is the noise variance of the complex AWGN channel, σ_i^2 is the sample power of the ith channel when a primary signal exists.

2.2 Global Decision

The global decision will be made by the FC depending on the decision rules. The decision rules are mainly classified in to two categories one is soft combination decisions and the hard combination decisions. In this paper the hard combination decisions are taken into account. The commonly used hard combination decision fusion rules are AND, OR, and MAJORITY Rules. These simple fusion rules can be generalized to the k out of the N rule. Under this rule, the FC declares $H_1(H_1)$ if k out of N CR users report "1". The false alarm and detection probabilities for cooperative sensing under this rule for data fusion are given by [4]

$$Q_f = \text{prob}\{H_1/H_0\} = \sum_{l=k}^{N} \begin{pmatrix} N \\ l \end{pmatrix} p_f(1 - p_f)^{N-1} \tag{4}$$

Table 1 Simulation parameters.

Number of primary channels	25
Bandwidth of primary user	30 MHz
Sensing time	10 μs
Number of cognitive radios	5
Probability of false alarm	0.0001

Table 2 Sensing time versus SNR.

Sensing time	SNR (dB)		
(sec)	Non-cooperation	OR rule	Majority rule
1e-5	–3 dB	–15 dB	–17 dB
1e-4	–9 dB	–10 dB	–12 dB
1e-3	–14 dB	–6 dB	–7 dB
1e-2	–19 dB	–2 dB	–1 dB

$$Q_d = \text{prob}\{H_1/H_1\} = \sum_{l=k}^{N} \left(\begin{array}{c} N \\ l \end{array} \right) p_d (1 - p_d)^{N-1} \tag{5}$$

When the value of k is taken as 1 and N, the k out of N rule becomes the OR and AND rules, respectively. The majority rule can be obtained from the k out of N rule under the condition when $k \leq N/2$.

3 Results and Analysis

This section describes the simulations carried out by considering the BEED technique as Spectrum sensing technique and hard decisions as global decisions.

Simulation parameters are mentioned in Table 1. The probability of detection by varying SNR values is evaluated. The optimized sensing time is chosen with the help of Table 2. The sensing time becomes a major parameter because if the sensing time is not properly chosen the cooperation environment becomes worse than the non-cooperation environment.

From Figure 2 it is observed that the maximum probability of detection or the accurate detection of primary is possible up to a SNR of –19 dB for OR rule and –19 dB for MAJORITY rule.

Table 3 shows that up to what value of SNR a BEED spectrum sensing technique can effectively detect the PU when compared with other spectrum sensing techniques. It is clear that the BEED effectively identifies the PU with that of other spectrum sensing algorithms.

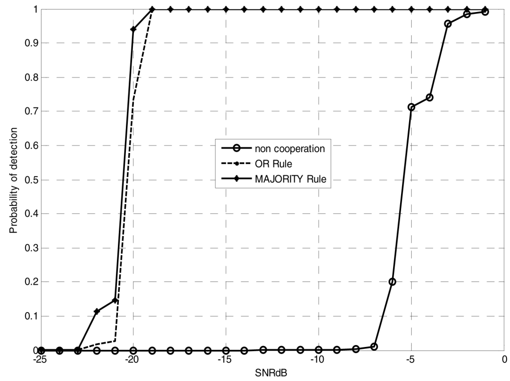

Figure 2 Probability of detection for varying SNR under Rayleigh fading.

Table 3 Comparison of different spectrum sensing techniques in cooperative environments.

(Maximum Probability of Detection) Spectrum Sensing Technique	SNR (dB)
Energy Detection (Existing) [3]	–14 dB
Cyclostationary Detection (Existing) [8]	–10 dB
BEED (Proposed)	–19 dB

4 Conclusions

In this paper, the sensing of primary user in a cooperative spectrum sensing model under Rayleigh fading was investigated by implementing the local spectrum sensing with the BEED technique which effectively detects the primary user with a minimum of –5 to –9 dB variation in SNR when compared to that of other spectrum sensing techniques. The above analysis was considered in an ideal cooperative spectrum sensing system.

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Biographies

Venkatapathy Prithiviraj is the Principal of Pondicherry Engineering College. He completed his Bachelor of Engineering (Electronics and Communication Engineering) in 1972 from the College of Engineering, Guindy Madras University, his M.S. by research in 1982 from IIT, Madras, and his Ph.D in 1999 from IIT, Kharagpur (research area – Signal Processing Techniques in Array Antennas Systems).

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He has also held the position of Director, IT for Government of Pondicherry (2002–2005). Currently, he is a Member of Expert Committee for monitoring International Indo-French projects in the field of Information Technology as well as Regional Committee of AICTE for Tamil Nadu and Pondicherry.

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