Optik 127 (2016) 5968–5975

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Eigenvalue based double threshold spectrum sensing under noise uncertainty for cognitive radio

Chhagan Charan*, Rajoo Pandey

National Institute of Technology, Kuruksheta, India

ARTICLE INFO

Article history:
Received 14 February 2016
Accepted 13 April 2016

Keywords:
Cognitive radio
Covariance matrix
Noise uncertainty
Eigenvalues
Double threshold
Spectrum sensing

ABSTRACT

Spectrum sensing is a fundamental problem in cognitive radio. The conventional energy based channel sensing method is highly vulnerable under low SNR and noise uncertainty conditions. The use of double threshold usually improves the detection performance, however, under noise uncertainty its performance deteriorates. Another method based on eigenvalues of sample covariance matrix has been studied in literature with single threshold. In this paper an eigenvalue based spectrum sensing technique with double threshold is proposed. The random matrix theory (RMT) is used to quantify the ratio of eigenvalues and derives the expression for the two thresholds required for reliable spectrum sensing. The proposed scheme overcomes the noise uncertainty and low SNR problems and out performs the conventional energy based detection method. The simulation results show that the proposed double threshold method based on eigenvalues exhibits better detection performance compared to conventional energy detection methods in terms of detection probability and number of samples required for reliable sensing.

1. Introduction

The studies carried out by FCC have revealed that most of the spectrum is underutilized, due to conventional fixed spectrum allocation policies [1,2]. Therefore, to better utilize the unused spectrum in "Cognitive radio", secondary user borrows the spectrum band from licensed primary user when the primary user is inactive [3–5]. The cognitive radio has the ability to sense the huge swath of spectrum in external environment and adopts itself by changing its internal states accordingly. Thus, the secondary user (SU) has to detect the presence of primary user (PU) dynamically to insure the maximum protection to licensed user.

In view of above, spectrum sensing is an important component in cognitive radio. There are several methods available in the literature to detect the status (active/idle) of the frequency band, such as energy detection (ED) [8–11], cyclostationary feature detection [13,14], matched filter detection (MF) [12,19], covariance based method [15], maximum eigenvalue detection method [16,17] and others [18]. Among these methods, the energy detection based spectrum sensing scheme has gained a lot of attention over the years as it does not require any prior information of the PUs and is easy to implement. In order to improve the performance of conventional energy based spectrum sensing method under low SNR (signal to noise ratio), double threshold based spectrum sensing technique employed [20,21]. However, as shown by several studies [6,7,22]

* Corresponding author.
E-mail addresses: chhagan.charan@nitkkr.ac.in, er.chhagan@gmail.com (C. Charan), rajoo_pandey@nitkkr.ac.in (R. Pandey).

http://dx.doi.org/10.1016/j.ijleo.2016.04.049
0030-4026/

these techniques are vulnerable to noise uncertainty and performance significantly degrades. As these methods depend upon accurate value of noise power. In practical scenario, it is very challenging to obtain accurate noise power and energy based double threshold spectrum sensing method requires longtime for re-sensing in confusion region under noise uncertainty conditions. Cyclostationary feature detection needs more processing time and prior knowledge of the signal characteristics of the PUs and is more complex to implement. Matched filter detection can perform well even in a low signal to noise ratio (SNR) environment but requires prior information of the PU. Covariance based detection methods use the statistical covariance of signal and noise, which are usually different. This property is exploited to decide whether PU is active or not [15]. This method is implemented by computing the thresholds based on the radio of maximum and minimum eigenvalues of the covariance matrix.

In this paper, we propose a new scheme which implies two thresholds based on eigenvalues statistical covariance of the received signal. The ratio of maximum eigenvalue to minimum eigenvalue is used as a test statistic to decide whether primary user is active or not. The random matrix theory (RMT) is used to quantify the ratio of eigenvalues and derives the expression for the two thresholds required for reliable spectrum sensing. The proposed method exploits the correlation among signal samples to distinguish the correlated PU's signal from noise. Furthermore, as in case of energy detection method, the present method also does not require prior information of channel, signal and synchronization. As this method does not require explicit knowledge of noise variance, it is betterly suited to address the noise uncertainty problem in comparison with energy detection method.

The organization of this paper is as follows. First the conventional spectrum sensing methods are introduced in Section 2. The proposed eigenvalue based double threshold sensing method is described in Section 3. Section 4 presents simulation results and a comparison with existing approaches. Finally, Section 5 concludes the overall findings of this study.

2. Conventional spectrum sensing method

In this section a brief review of commonly used sensing model and energy detection based spectrum sensing method is presented.

2.1. Spectrum sensing model

Suppose the frequency band with central frequency of f_c and bandwidth is required to be sensed by the secondary user. The received signal can be expressed as the hypotheses as following [8,10,17]:

$$H_0 : x(n) = \eta(n) \tag{1}$$

$$H_1 : x(n) = s(n) + \eta(n) \tag{2}$$

where $x(n)$ is denotes the sample of signal received by secondary user, $s(n)$ is the sample of primary users' transmitted signal with mean 0 and variance σ_s^2; $\eta(n)$ is additive white Gaussian noise (AWGN). The noise samples are assumed to be independent and identically distributed (IID) with zero mean and variance σ_η^2.

The hypothesis H_0 represents that the PU is absent and frequency band is vacant. Whereas hypothesis H_1 indicates that the PU is present and frequency band is busy. Following probabilities are of interest in spectrum sensing: probability of detection (P_d), it is under hypothesis H_1, probability of detecting the presence of primary user under hypothesis H_1 i.e. a busy band is detected to be busy. Probability of false alarm (P_f), it is the probability that an idle band is detected to be busy, that is probability of detecting the presence of primary user under hypothesis H_0. Probability of miss detection (P_m), which means a busy band is detected to be idle, probability of detecting the absence of primary user under hypothesis H_1. To achieve the maximum protection to PU, P_m should be low while P_{fa} should be as small as possible to attain the higher throughput of the SUs [23].

2.2. Energy based spectrum sensing

The test statistic using for energy based detection is given as

$$T(x) = \frac{1}{M}\sum_{n=1}^{M}|x(n)|^2 \tag{3}$$

where M is number of samples.

In general $T(x)$ follows chi-square distribution. However, using central limit theorem, when M is a large number, $T(x)$ will be approximately Gaussian distributed.

In single threshold based energy detection, false alarm probability with given certain threshold λ, can be obtained as follows [23]:

$$P_f = P(T > \lambda/H_0) = Q\left(\left(\frac{\lambda}{{\sigma_\eta}^2} - 1\right)\sqrt{\frac{M}{2}}\right) \tag{4}$$