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Research Paper

SPECTRUM SENSING FOR GREEN COGNITIVE RADIO COMMUNICATIONS: A SURVEY

P Dhana Lakshmi[1]* and N Venkateswara Rao[2]

Corresponding Author: **P Dhana Lakshmi, ✉ dhanalakshmimails@gmail.com*

Starting with the evolution of cellular communications in the early '80s, the demand for two-way mobile communication services has increased tremendously. Hence, spectrum scarcity is of severe concern, which obstructs the deployment of new advanced communication services. One solution to this problem is to develop opportunistic channel access, namely, spectrum sensing using a cognitive radio. Spectrum sensing is a process of monitoring the channel in a given (available) bandwidth. Spectrum sensing approaches can be blind or non-blind. Inthispaper,various available approaches to blind spectrum sensing, are discussed. Further, a comparative study between eigenvalue based spectrum sensing approaches are illustrated.

Keywords: Cognitive radio, Signal correlation, Blind spectrum sensing, Eigenvalue based sensing

INTRODUCTION

The term *cognitive radio* refers to a programmable radio that can be dynamically configured to be able to use the best available wireless channel in the spectrum, by adapting to the environment.The increasing demand of wireless applications has put a lot of limitations on the use of available radio spectrum. Survey of spectrum utilization shows that entire spectrum is not used at all the times, so that most of the radio spectrum is unutilized. Some of the frequency bands in the spectrum are unoccupied, some of the frequency bands are less occupied and few bands are over utilized. Cognitive radio system is a technique which overcomes the problem of spectrum underutilization. The important features of the cognitive radio are the ability to acquire, measure, sense, learn and be aware of the radio's operating environment in order to recognize spectrum space opportunities and efficiently use them for adaptive transmission.

Particularly, cognitive radio employs a technique called spectrum sensing, where

[1] Reasearch Scholar, Department of ECE, Acharya Nagarjuna University, Guntur.

[2] Professor, Department of ECE, Bapatla Engineering College, Bapatla.

secondary user continuously senses the communication channel, for the availability of a free band implying the absence of primary user.It should be noted that goal of spectrum sensing is not to select a free channel for transmission, but to select a free channel without causing harmful interferences to other licensed users.

Spectrum sensing techniques can be blind or non-blind. In blind techniques, the computational complexity of the sensing technique is more than that in non-blind techniques. Non-blind techniques require prior knowledge of primary user signal. To sense the spectrum without prior knowledge of the primary signal, eigenvalue-based or the covariance-based blind detectors can be employed.

Various non-blind spectrum sensing techniques are available in the literature that sense the unused spectrum bands. An optimal technique is based on Energy Detection (ED), provided the secondary user knows a prior, the noise power (Urkowitz, 1967). Another technique is matched-filtering detection, which is considered as coherent detection that is suitable primary user's signal pattern is known to the secondary user (Juang *et al*., 2009). Another technique known as feature detection method (cyclo-stationary detection) exploits the modulation scheme periodicity of the primary user signal (Dandawate and Giannakis, 1994), and is usually complicated.

The basic drawback with energy detection is optimal for independent and identically distributed signals, but not for correlated signals. Matched filter should know about the knowledge of the signals and different matches filters are required for different signals (Zeng *et al*., 2010) . Cyclostationary detection has much higher complexity and requires knowledge of the cyclic frequencies

Blind spectrum sensing algorithms employ the usage of eigenvalues of sample covariance matrix and do not require prior information about the primary signal. Many such sensing methods are available in the literature, which are discussed and compared in this paper. The techniques with low computational complexity are preferred for green cognitive radio communications.

The rest of the paper is organized as follows. Section II introduces the structure of a spectrum sensing problem. Section III deals with techniques for blind spectrum sensing. Section IV provides a comparison of the techniques explored in section III. Finally the paper is concluded in section V.

STRUCTURE OF SPECTRUM SENSING PROBLEM

The primary task of a spectrum sensing technique is to sense if the channel is free or occupied. This implies a sensing technique can be treated as a solution to signal detection problem. Signal detection problem is in general posed as a Hypothesis Testing Problem (HTP). The null hypothesis H_0, is noise alone case and the alternate hypothesis H_1, is the signal plus noise case. The HTP frame work used in this paper is

$$\begin{aligned} H_0 &: \quad x(nT_S) = w(nT_S) \\ H_1 &: \quad x(nT_S) = s(nT_S) + w(nT_S) \end{aligned} \qquad \text{...(1)}$$

$$w(nT_S) = CN\left(0, \sigma_v^2\right)$$

where,

is the complex normal distributed noise and T_s is the sampling time period. For detection of signal, the corresponding test criterion or the decision metric is defined as

$$\begin{aligned} T &< R \quad \Rightarrow H_0 \\ T &> R \quad \Rightarrow H_1 \end{aligned} \quad ...(2)$$

where T is the test criterion and R is the threshold. Based on the algorithm procedure at hand, T and R change. The performance of the sensing algorithm is evaluated using one or more measures. The prominent measure is to test the detection probability as a function of received signal to noise ratio (SNR). Further, an ROC plot can also be obtained which is the plot of probability of detection (P_d) versus probability of false alarm (P_{fa}). However, in some sensing techniques, the threshold or the test criterion are framed for a given P_{fa}. In such cases the $P_d$versus SNR plot can be used to measure the performance of the algorithm.

TECHNIQUES FOR BLIND SPECTRUM SENSING

Blind techniques for spectrum sensing employ a threshold that is a function of eigen values of sample covariance matrix. These techniques utilize the following fact that correlation between signal samples due to oversampling, multipath or multiple receivers gets reflected on the eigenvalues of the covariance matrix. As a matter of fact, it has been observed that different combinations of eigenvalues are used as test statistics and distribution of eigenvalues and expression of probability of detection are based on Random matrix theory (RMT) (Shree Krishna Sharma *et al*., 2014). Some of the eigenvalue based detectors that are studied in this paper are listed below:

1. Maximum-minimum eigenvalue detection (MME)
2. Maximum minus minimum eigenvalue detection (MMME)
3. Difference of means of eigenvaluedetection (DME)
4. Maximum eigenvalue based detection (MED)
5. Minimum eigenvalue detection (ME)

Two stage spectrum sensing detections are also possible. For example ED and MMMEare employed for detection in (Naresh Gunichetty *et al*., 2015).Energy and eigenvalue-based combined fully-blind self-adapted detection is studied in (Mohamed Hamid *et al.,* xxxx).

Some variants of eigen value based detectors are also popular. The first type are covariance-based blind detectors like covariance absolute value (CAV) and the covariance Frobenius norm (CFN) detectors, exploit the difference between the covariance matrices of primary signals and noise. The second type are information theoretic criterion (ITC) based detectors, which calculate any ITC criterion like Akaike information criterion (AIC) or minimum description length (MDL) using eigenvalues and then using monotonic nature of the criterion under only noise case, the signal can be detected.

A. MME Detection: *MME detection compares the threshold with the ratio of maximum eigenvalue to minimum eigenvalue. The decision criterion is* (Boillig and Rudolf Mahtar, 2013),

$$T_{MME} = \frac{\lambda_{\max}}{\lambda_{\min}} \underset{H_0}{\overset{H_1}{\geq}} \Upsilon_{MMME}$$

Unlike ED, here the threshold (Υ_{MMME}) is not based on noise power. In these algorithms, the threshold is estimated by using number of samples, smoothing factor and false alarm probability.

B. MMME Detection*: For higher noise, MME performance gets affected by SNR. To tackle this issue, MME can be modified as MMME. In MMME detection, maximum minus minimum eigenvalue is compared with the threshold.*

The decision criterion is

$$T_{MMME} = \ln \frac{e\lambda_{\max}}{e\lambda_{\min}} = \lambda_{\max} - \lambda_{\min} \underset{H_0}{\overset{H_1}{\geq}} \Upsilon_{MMME}$$

This technique was published in IEEE,2013, based on the MMEdetector,the MMME detector improves upon theperformance of itsOrigin[8].

C. DME detection :*A typical phenomenon to decrease noise is to average over multiple values. MMME does not exploit this phenomenon. Therefore, MMME can be further modified as DME detection[8] .In DME detection, difference of means of eigenvalue is compared with the threshold.*

The decision criterion is

$$T_{DME}(N_1) = \frac{1}{N_1}\sum_{i=1}^{N_1}\lambda_i - \frac{1}{ML-N_1}\sum_{i=N_1+1}^{ML}\lambda_i \underset{H_0}{\overset{H_1}{\geq}} \Upsilon_{DME}$$

where, M is number of receivers, N is the order of the channel, L is smoothing factor.

This technique was published in [8]IEEE,2013. It shows that the detection probability is highest for all probabilities of false alarm.

D. MED detection*: Maximum or large eigenvalue based spectrum sensing is evaluated for correlated noise. ME detection compares the ratio of maximum eigenvalue to noise power with the threshold. It is observed that the threshold calculated for uncorrelated scenario when applied to correlated scenarios, the P_{fa} value gets deviated from the targeted P_{fa} value.*

The decision criterion is

$$\frac{\lambda_{\max}(N)}{\sigma^2}\Upsilon$$

Here Υ threshold and σ^2 is noise power. Otherwise decision in favor of noise. This technique was published in IEEE,2014 [5],showed that the probability of false alarm for the considered correlated case increases with the increase inthe correlation level.

E. ME detection *: Minimum eigen value detection algorithm is based on covariance matrix. The ratio of minimum eigen value to noise power is used as the test statistic*

The decision criterion is

$$\frac{\lambda_{\min}(N)}{\sigma^2} > \Upsilon$$

Here Υ threshold and $\sigma^2$is noise power.This method has a higher probability of detection at low SNR compared with maximum eigen value technique. This technique was published in IJECE, 2014 [9] The ratio of the minimum eigenvalue to noise power is used as test statistic the method need only noise power. The proposed method is shown to be better than maximum eigenvalue detection and the energy detection for correlated signals.

F. CAV detection:*This method uses only the received signalsamples. It does not need any prior information of the signal,channel,and noise power and no need of sychronization [10].It just compute the auto correlations functions of the received sample covariance matrix.*

The detection criteria is

$$\frac{T_1(N_s)}{T_2(N_s)} > \Upsilon_1$$

where Υ_1 is threshold, and T_1 and T_2 are autocorrelationfunctions. The validity of this algorithm relies on the assumption that the signal samples are correlated, which is true in all practical conditions, as the signal passes through a fading channel.

G. SPET detection:*In this method only one eigen value is compared with threshold.This method is a simplified method which tests the largest eigenvalue against its own predicted threshold[11]. The decision criteria is:*

$$T_{SPET} = \frac{l_1}{\frac{1}{q}\sum_{i=1}^{q} l_i} \underset{H_0}{\overset{H_1}{\geq}}$$

H. ITC based sensing:*In this a new over-determined channel model constructed by applying multiple antennas in order to make the ITC applicable. a simpliûed ITC sensing algorithm needs to compute and compare only two decision values.*

The decision criteria is

$$T_{ITC-AIC/MDL} = AIC/MDL(0) \underset{H_0}{\overset{H_1}{\geq}} AIC/MDL(1)$$

where *AIC* means Akaike information criterionand *MDL* minimum description length criterion (Rui Wang and Meixia Tao, 2010). This technique was published in IEEE 2010, blind sensing algorithm with AIC criterion achieves higher probability of detection than the eigenvalue-based sensing algorithms (Anupama *et al*., 2015), while having the same probability of false alarm. Meanwhile, the proposed algorithm with MDL criterion achieves the lowest probability of false alarm among all the considered blind sensing methods.

Among all these detection techniques, the maximum and minimum eigenvalue detection techniques are having highest computational complexity and less accuracy . The MME, MMME, and DME techniques are having less number of computational complexity and more accuracy compared to ED, MED and ME detection techniques at both high SNR and at correlated noise environment, leads to the existence of green cognitive radio.When the received signals are more correlated , the CAV detection has better accuracy than ED. ITC sensing algorithm, signiûcantly reduces the computational complexity without losing any performance. ITC sensing algorithms show that they considerably outperform existing blind spectrum sensing methods in certain cases.

CONCLUSION

Spectrum sensing is the heart of any cognitive radio system. Many blind spectrum sensing algorithms are available, which can be employed by the secondary user system to sense the presence or absence of the primary user in a given channel. ED techniques are commonly useful when noise estimation is proper. Else, eigenvalue based detectors are useful. Six such techniques have been briefed and compared in this paper. Further, covariance based detectors and ITC based detectors, which are variants of eigenvalue based detectors have also been briefed and compared in this paper. For a given communication channel and a cognitive radio, performance of the detectors discussed in this paper change. Hence, assuming a given channel environment, and employing a cognitive radio with one or more of these sensing algorithms, the performance of detection for various SNR can be studied and a hybrid sensing algorithm can be devised to overcome the environment specific problems in a given cognitive radio system, which forms the future work of this paper.

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