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A Two Stage Approach to Spectrum Sensing in Cognitive Radio

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Abstract

Cognitive Radio is one of the recent trends for increasing the usage of spectrum effectively. Sensing is one of the major tasks of cognitive radio where the availability of vacant channels in licensed bands should be detected and utilized by a secondary or cognitive user in the radio spectrum. Two stages of sensing based on Energy Detection (ED) and Singular Value Decomposition (SVD) are considered for detecting the unused frequencies. Combining the advantages of both the technique to increase the probability of detection with no knowledge about the received signal is the goal of two stage sensing. The limitation of energy detection to perform in high noise is overcome by SVD, so that the overall performance for sensing is increased. Simulation results also indicate the increase in detection probability with respect to signal to noise ratio than single stages of sensing.

Keywords– Cognitive Radio, Two Stage Sensing, Energy Detection, SVD

I. INTRODUCTION

Cognitive Radio (CR) is an intelligent radio that identifies and uses the available spectrum holes and the scarcity in the usage of radio spectrum leads to the idea of CR. The unoccupied bands of the licensed or primary users are referred as the holes. The main functions of CR are sensing, sharing, mobility and management among which sensing is considered. Sharing and mobility is the process in which CR allows its user to utilize the licensed bands and changes the frequency of operation. Based on the user requirement capturing the suitable spectrum is referred as management.

Spectrum sensing in cognitive radio is a process in which the unused frequency bands of the allocated users is sensed and utilized by a secondary user without causing any interference to them. This is done due to the scarcity of spectrum resources and to effectively improve the utilization. The primary goal of sensing is to maximize the detection probability with less probability of false alarm while reducing the complexity and time to detect the radio. Sensing is further classified into three types as [1] cooperative, non-cooperative and interference based detection. Information from different CR users is collected and the decision is made to obtain more efficiently the vacant spectrum in cooperative based sensing.

In interference based sensing the secondary user should transmit with less power than the primary to avoid interference caused to them. The non-cooperative or transmitter based detection is a form of blind sensing where no information about the primary signal is available to detect and CR users determine the signal strength. Some of the methods to implement this type are energy detection(ED), matched filter, cyclostationary feature based detection of which ED is the simplest. There are also other techniques like Eigen decomposition, wavelet based, correlation based approach etc. Every method has its own advantages and limitations for sensing the user signal, so two of them can be combined to improve the performance further.

The principal objective of this study is two stages of sensing where the first stage is energy detection and the second is singular value decomposition. The section II discuss about the system model for energy detection. SVD, two stage sensing algorithm and simulation results are discussed in the section III and IV. Finally conclusions are drawn in the last section.

II. ENERGY DETECTION

Spectrum sensing is done based on a binary hypothesis testing [2] which is given by,

H0: y[n] = w[n] (primary user absent)

H1: y[n] = s[n] + w[n] (primary user present)

where y[n] is the received signal, s[n] is the transmitted signal of the user and w[n] is the noise which is considered to be additive white Gaussian[3][4]. Energy of the band of signals selected by the band pass filter is measured and compared with a threshold obtained from the estimation of noise variance. If the energy exceeds the threshold it specifies the occupation of the band by the primary user else the user is absent. The secondary or cognitive user uses the band for transmission or reception when the primary user is absent. Energy [5][6] is measured using the decision statistic (T) as shown,

$$\mathrm{T} = \sum_{n=1}^{N} (\mathrm{Y}[\mathrm{n}])^2 \qquad (1)$$

Neyman-Pearson hypothesis [7] is used for detection which consists of two types of errors such as probability of misdetection and false alarm. When the condition that energy greater than threshold is true, it is considered as probability of detection and if false it is called probability of false alarm. PF should be kept as a constant to improve the detection in NP hypothesis.

$$PF = Q\left(\frac{\gamma - N\sigma_w^2}{\sqrt{2N\sigma_w^4}}\right) \quad (2)$$

$$PD = Q\left(\frac{\gamma - N(\sigma_s^2 + \sigma_w^2)}{\sqrt{2N(\sigma_s^2 + \sigma_w^2)^2}}\right) \quad (3)$$

For Gaussian distribution, the probability of false alarm (PF) and detection (PD) is given by (2) and (3) where Q is the Gaussian function, N is the number of samples, γ is the threshold, σ_w and σ_s are the noise and signal power. Threshold can be obtained from (2) as,

$$\gamma = \sigma_w^2(Q^{-1}(PF)\sqrt{2N} + N) \quad (4)$$

The probability of misdetection (MD) can be obtained from detection as,

$$MD = 1 - PD \quad (5)$$

Modulated signals such as BPSK, QPSK and 16-QAM are used to test the probability of detection of this technique as shown in fig.1. Since the data rate of QAM is higher than the phase shift keying techniques, it can occupy more number of users.

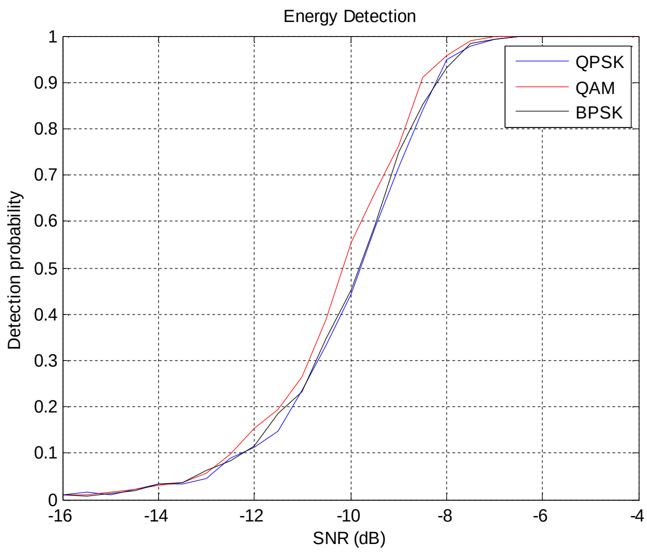

Fig.1. Probability of detection for modulated signals

The comparison is done for 1000 samples and PF=0.01 over a bandwidth of 5MHz. One of the limitations of energy detection technique is that, it is difficult to distinguish between the user signals and noise if the signal to noise ratio is low. Also knowledge of noise variance is an important criterion to determine the threshold.

III. SINGULAR VALUE DECOMPOSITION

The efficient and accurate algorithm for computation makes SVD useful in many applications like signal processing and statistics. The basic algorithm is first considered for a time series y (n) with n=1,2,….,N in which N is the number of samples. A Hankel matrix is constructed with M rows where M=N-L+1 and L columns as follows:

$$R = \begin{bmatrix} y(1) & y(2) & \cdots & y(L) \\ y(2) & y(3) & \cdots & y(L+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(N-L+1) & y(N-L+2) & \cdots & y(N) \end{bmatrix} \tag{6}$$

The matrix R can be factorized using SVD as $R = U\epsilon V$ where U and V unitary matrices. ϵ is a diagonal matrix whose values are the square roots of the positive Eigen values of matrix R and are called the singular values. The signal can be detected by the presence of dominant singular values. When there is no signal present, the received signal consist only additive white Gaussian noise and all the singular values are same and close to zero. Threshold for the detection process can be calculated based on the results of the theorem [8] and [9] as

$$\gamma = \frac{\left(\sqrt{N}+\sqrt{L}\right)^2}{\left(\sqrt{N}-\sqrt{L}\right)^2} \times \left(1 + \frac{\left(\sqrt{N}+\sqrt{L}\right)^{\frac{-2}{3}}}{(NL)^{\frac{1}{6}}} . F_1^{-1}(1-PF)\right) \tag{7}$$

where F_1 is the cumulative distribution function of the Tracy-Widom distribution of order 1. This method is fast and the presence of other signals can be detected with the help of dominant singular values obtained from the matrix. SVD based signal detector method by Zeng and Liang is considered [9] [10].

The steps to detect the presence and absence of signals are shown in fig.2. It follows selecting the number of columns (L) for the covariance matrix and then factorizing the matrix by using the singular value decomposition. Based on this method the maximum and minimum Eigen values are obtained and their ratio is considered as the test statistic. Threshold value is computed based on the equation and compared with the ratio of Eigen values.

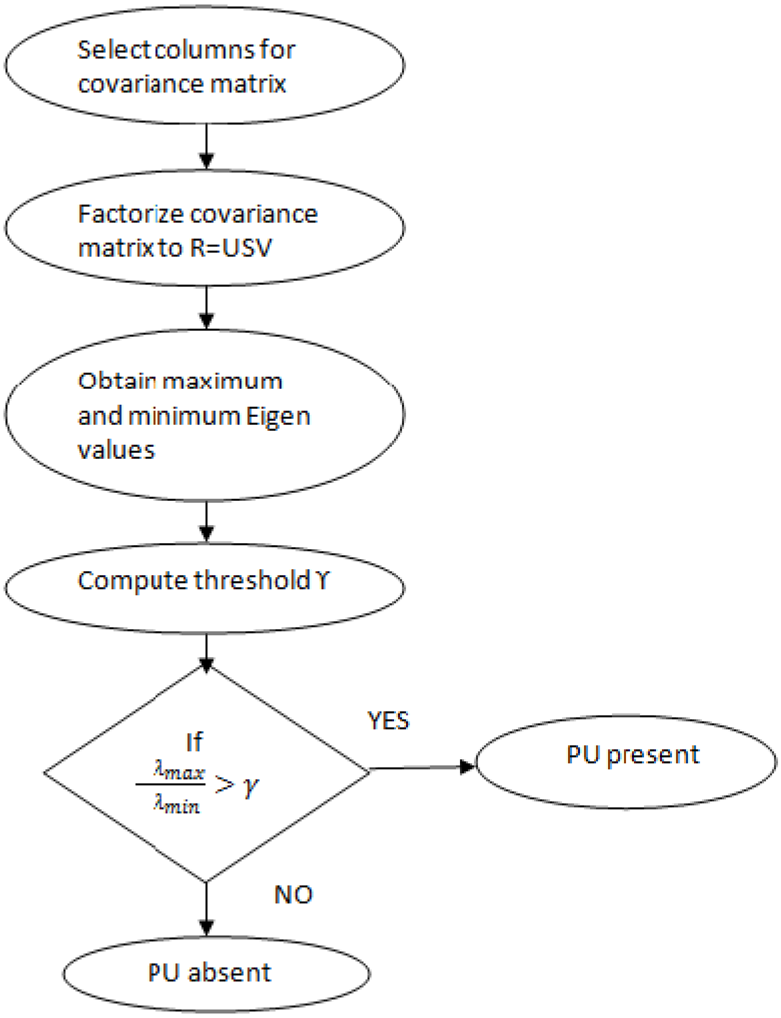

Fig.2. Flow diagram for SVD

If the test statistic is greater than the threshold, it signifies the presence of user signal else the user is absent. The table I shows the values of the distribution function and the inverse of it can be obtained from them for the calculations of threshold.

Table I. Numerical table for Tracy-Widom distribution of order 1

T	-3.90	-2.78	-1.91	-1.27	-0.59	0.45	2.02
$F_1(t)$	0.01	0.10	0.30	0.50	0.70	0.90	0.99

IV. TWO STAGE SENSING ALGORITHM AND SIMULATION RESULTS

To overcome the limitations of single stage sensing, two stages is considered where the

first stage is chosen as energy detection technique. ED performs better in high SNR and is chosen for its simplicity and low computational complexity. The second stage can be selected from any of the methods like cyclostationary feature detector (CFD), Eigen value decomposition (EVD), covariance based detection etc, whereas Singular Value Decomposition is considered in this paper. Like energy detection, SVD also does not require prior information on the user signal to detect them. The steps involved in two stage sensing are as follows:
Step 1: Using ED, energy E_1 and the threshold γ_1 are calculated.
Step 2: If $E_1 > \gamma_1$, user is present else second stage is activated.
Step 3: In the second stage, SVD then calculates the test statistic E_2 and the corresponding threshold γ_2.
Step 4: If $E_2 < \gamma_2$, then the user is confirmed to be absent.

The second stage is activated only when there is no primary user detected in the first stage of detection. The signal considered here is BPSK with 50,000 samples for testing the performance of both the techniques. Fig.3 shows the single stage of sensing by energy detection and singular value decomposition where the performance of SVD is higher even in high noise than energy detection and also the complexity is medium.

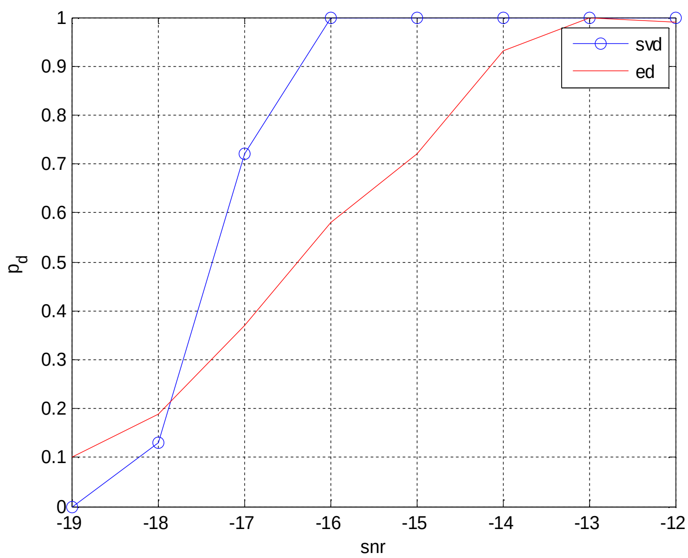

Fig.3. sensing by ED and SVD

The probability of detection (P_d) increases further in the case of double stages as shown in fig.4, where signals in low signal to noise ratio are also considered with the help of SVD. The probability of false alarm is kept at a constant of 0.01 and the number of columns for the matrix is taken as L=16.

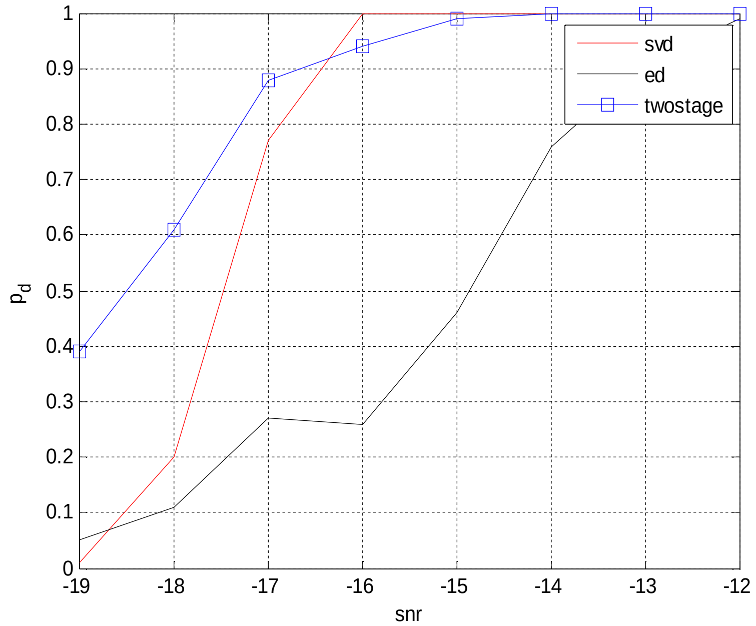

Fig.4. Two stage sensing performance

V. CONCLUSION

In this paper, a two stage approach has been performed for sensing the spectrum which shows better detection capability by using singular value decomposition as the second stage. Also energy detector performance for different modulated signals is presented with respect to various signal to noise ratios. For effective usage of spectrum, the number of detections in the sensing process is important. Hence simulation results also highlight the increase in performance of probability of detection for low and high noise scenarios.

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