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Performance Analysis of Two Stage Spectrum Sensing Scheme for Cognitive Radio

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ABSTRACT: The operation of cognitive radio depends mostly on spectrum sensing. In cognitive radio systems, the main requirement of cognitive radio architectures is the ability to detect the presence of the primary user with fast speed and precise accuracy. The two-stage spectrum sensing scheme for cognitive radios has two stages as the name suggests. The first stage is known as coarse sensing and the second stage is known as fine sensing. The two sensing stages maximizes the probability of detection, given constraints on the probability of false alarm. In this paper, we illustrate the performance comparison between energy detection, cyclostationary detection and two stage spectrum sensing on the basis of probability of detection and mean time detection.

KEYWORDS: Two stage spectrum sensing; energy detection; cognitive radios; cyclostationary detection; matched filter detection; SNR

I. INTRODUCTION

A cognitive radio is a transceiver which automatically detects available channels in wireless spectrum and accordingly changes its transmission or reception parameters so more wireless communications may run concurrently in a given spectrum band at a place.Today's wireless networks are characterized by a fixed spectrum assignment policy. The need of spectrum resources is increasing day by day. To get over this problem, cognitive radio is being recognized as an intelligent technology due to its ability to rapidly and autonomously adapt operating parameters to changing environment. It is extremely useful as a huge portion of the licensed spectrum remains underutilized. In particular, spectrum sensing has to relies on the presence or absence of primary user and sensing of multiple radio channel has to be done as fast as possible. The spectrum sensing schemes can be roughly divided into three types namely, energy detection, cyclostationary detection and matched filter detection[1].

Any of the above techniques can be used in the two stage spectrum sensing process. We plan to use the energy detection as the stage one and cyclostationary spectrum sensing in the stage two. While energy detection is a simple detection technique, its performance is not robust to noise and is known to be poor at low SNRs. Cyclostationary detection on the other hand provides better detection but its computational complexity is more and thus this increases the mean detection time as well as the cost.

II. RELATED WORK

Cognitive radios have emerged as a promising solution to improving spectrum utilization. It has been widely recognized that while there is a perceived scarcity of radio spectrum, large portions of licensed spectrum remain under-utilized. Cognitive radios determine empty portions of licensed spectrum, and utilize such portions for secondary use in order to meet regulatory constraints of limiting harmful interference to licensed wireless systems. The determination of empty spectrum is typically done by spectrum sensing and is a critical challenge in cognitive radios. In particular, spectrum sensing has to reliably determine the presence or absence of on-going licensed transmissions, and sensing of multiple radio channels (possibly spanning several hundreds of MHz) has to be done as fast as possible. Two sensing techniques that have been commonly considered in cognitive radios are energy detection and cyclostationary detection .We consider a two-stage sensing scheme for cognitive radios where coarse sensing based on energy detection is performed in the first stage and, if required, fine sensing based on cyclostationary detection in the second stage. We design the detection threshold parameters in the two sensing stages so as to maximize the probability of detection,

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given constraints on the probability of false alarm. We compare this scheme with ones where only energy detection or cyclostationary detection is performed. The performance comparison is made based on the probability of detection, probability of false alarm and mean detection time.

III. BACKGROUND

Detecting unused spectrum and sharing it, without harmful interference to other users is an important requirement of the cognitive-radio network. Detecting primary users is the most efficient way to detect empty spectrum. As stated earlier, there are a number of commonly used spectrum sensing techniques. We will be using the Energy detection for the coarse sensing and the cyclostationary detection for fine sensing. The both techniques combined will be known as two stage spectrum sensing.

Associated with spectrum sensing are twoparameters: probability of detection and probability of false alarm. The higher the detection probability, the better the primary users can be protected. However, from the secondary users perspective, the lower the false alarm probability, the more chances the channel can be reused when it is available, thus the higher the achievable throughput for the secondary users. Thus there could exist a fundamental tradeoff between sensing capability and achievable throughput for the secondary network[9].

Another parameter associated with the performance of the spectrum sensing schemes is mean detection time. Lesser the mean detection with a fairly accurate result is important for all the spectrum sensing schemes. Based on the probability of detection and mean detection time , the performance of the spectrum sensing schemes can be evaluated.

IV. SPECTRUM SENSING TECHNIQUES

The spectrum sensing schemes used in this paper are energy detection scheme , cyclostationary detection scheme and two stage spectrum sensing. The two stage spectrum sensing uses both energy detection algorithm as well as the cyclostationary algorithm in coarse and fine sensing stages respectively.

A. *Energy Detection Scheme:*

Energy detection is a simple detection technique. It is low cost but is not robust at low SNRs.An energy detector serially searches every channel within the band. The energy detector accumulates the energy of samples and then compares it with a fixed threshold to decide whether the primary user is present or not.The decision rule used in case of the energy detector is as given below.

Let us consider two probabilities, H_1 and H_0 respectively.H_1 is the probability if the primary user is present,Whereas , H_0 is the probability if the primary user is absent.

$$D^c = \sum x^2_k >^{H1} \lambda$$
$$D^c = \sum x^2_k <_{H0} \lambda \qquad (1)$$

Also,the probability of detection can be calculated from the formulas as given below[1].

$$P_d = Q\left(\frac{\lambda - M^c(\sigma^2_n + \sigma^2_s)}{(\sqrt{2}\, M^c (\sigma^2_n + \sigma^2_s)^2)}\right) \qquad (2)$$

The terms in the above formulas are given below,
Where, Q is the Q-function.

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M^c is the no of samples
$\lambda$is the threshold value
σ^2_n is the variance of the noise
σ^2_s is the variance of the signal

In order to compare the agility of the scheme with other schemes, we need to compare their mean detection time as well. The mean detection time is the time taken by the sensing technique for the detection of the signal in the band.
The mean time detection for the energy detection can be given as below[1]:

$$T_{c=} \ L * T_1 \quad (3)$$

$$T_{1=} \ M_c / 2W \quad (4)$$

Where, $M_c$is the no of samples
Wis the threshold value
Lis the number of channels
T_c is the time taken for coarse sensing

B. *Cyclostationary Detection Scheme:*

A cyclostationary process is a signal having statistical properties that vary cyclically with time. Cyclostationary processes are random processes for which the statistical properties such as the mean and autocorrelation change periodically as a function of time. A cyclostationary detector , has better performance than the energy detector, particularly for low SNR.Primary user signals which have periodicities can be easily detected by their correlation which tends to enhance their similarity. Fourier transform of the correlated signal results in peaks at frequencies which are specific to a signal and searching for these peaks helps in determining the presence of the primary user. Noise is random in nature and as such there are no such periodicities in it and thus it doesn't get highlighted on taking the correlation.According to the cyclostationary signal processing theory, most modulated signals are characterized as cyclostationarity since their mean and autocorrelation exhibit periodicity.The formulas we will be considering for the Cyclostationary detection are as below. We will be calculating the probability of detection from the formula below[1],

$$Pd = \frac{Q(\gamma - Mf\ Rx)}{(\sqrt{4MfRx})} \quad (5)$$

In the above formulas, Q is the Q function

In order to compare the agility of the scheme with other schemes, we need to compare
their mean detection time as well. The mean detection time is the time taken by the sensing technique for the detection of the signal in the band.

The mean time detection for the energy detection can be given as below[1]:

$$T_{f=} \ MC * T_1 \quad (6)$$

$$T_{1=} \ M_f / 2W \quad (7)$$

Where, M_f is the no of samples
Wis the threshold value
MC is the meannumber of channels
T_f is the time taken for fine sensing

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C. *Two Stage Spectrum Sensing Detection Scheme:*

Two sensing techniques that have been commonly considered in the two stage spectrum sensing in cognitive radios are energy detection and cyclostationary detection. Firstly, the coarse then fine sensing is performed for the selected channel for identifying the type of incoming signal. More specifically, a fast spectrum sensing algorithm based on the energy detection is introduced focusing on the coarse detection. A complementary fine spectrum sensing algorithm adopts one order cyclostationary properties of primary user's signals in time domain.The coarse detection based on energy detection is performed by searching the whole detected bandwidth. It selects the unoccupied candidate channels by sorting the channels in the ascending order based on the power of each channel, and it is rational due to the fact that the channel with low power has high probability to be an unoccupied channel. Then the channel with lowest power is examined by one-order feature sensing to detect weak signals at the fine stage. A two-stage spectrum sensing technique is proposed to meet the requirements to speed and accuracy in cognitive radio systems.

The block diagram for two stage spectrum sensing is as below,

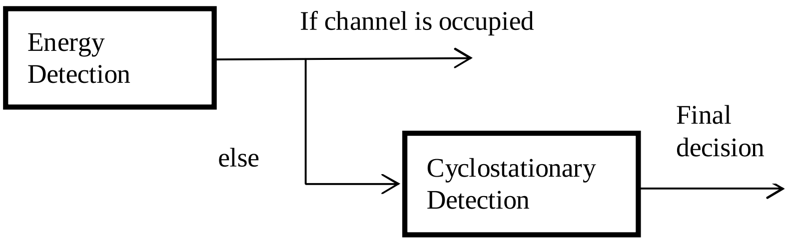

Fig.1. Two Stage Spectrum Sensing Scheme Block Diagram

As shown in the figure above ,firstly, in the coarse sensing stage which is the, the channel is sensed using energy detection. If the decision metric is greater than a threshold, the channel is declared to be occupied. Else, the received signal is analyzed by fine sensing consisting of cyclostationary detection.
The mean time detection for the energy detection can be given as below:

$$M_{T} = T_c + T_f \qquad (8)$$

V. SIMULATION RESULTS

A. *Energy Detection:*

As stated earlier, the energy detection is a simple process with low complexity. But it is not robust at low SNR. This can be shown from the simulations below. We took a number of samples and plotted a graph of Probability of detection against the SNR. The graphs are simulated for ten readings so that the comparison can be made clearly.

From the below simulation in Fig 2. , it is clear that the Probability of detection is almost zero at a lower SNR. As the SNR increases, the probability of detection increases. Also , as seen from the graph in Fig 3., the mean detection time for the energy detection is lower as compared to the cyclostationary detection.

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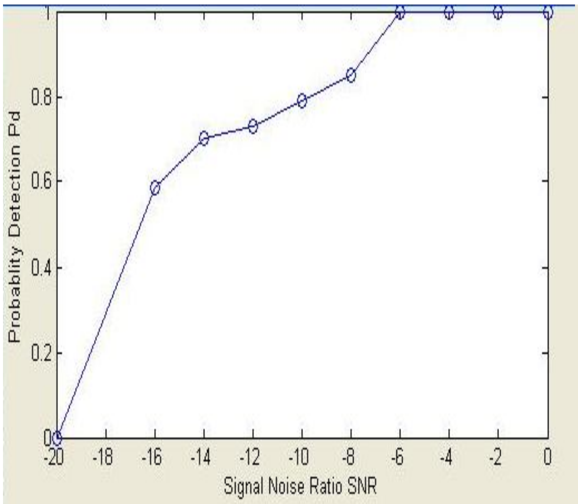


Fig.2.Probability of Detection of Energy Detection w.r.t SNR

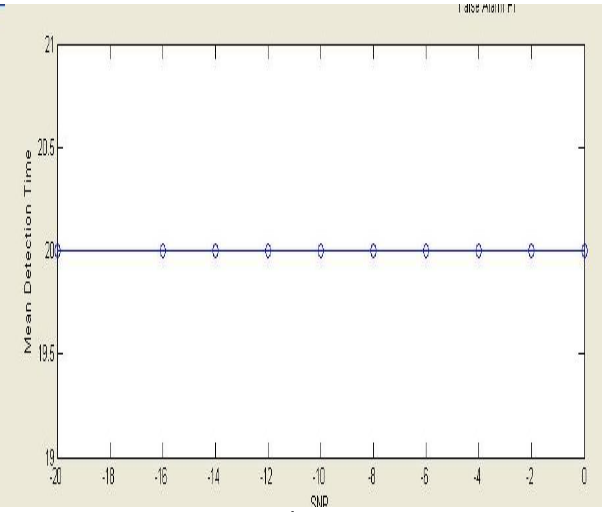
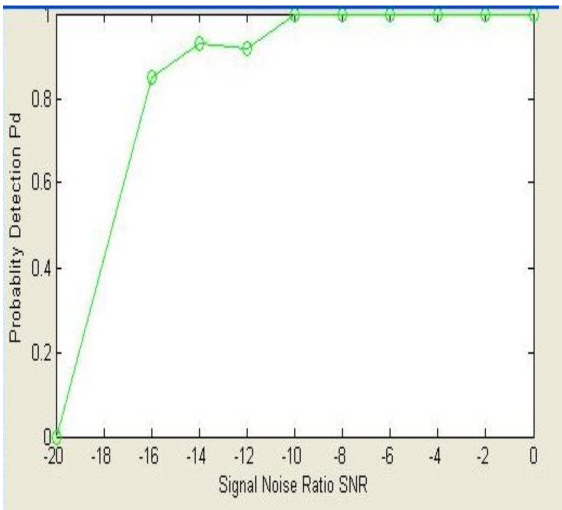


Fig.3.Mean Detection Time of Energy Detection w.r.t SNR

The probability of detection is very good for a good SNR but it reduces as the SNR value decreases.The mean time detection is less for the energy detection scheme as seen in Fig. 3 across all SNR values.

B. *Cyclostationary Detection:*

The cyclostationary detection is much more accurate at the low SNR. But its computational complexity is very high as compared to the energy detection. Thus, the mean detection time for the cyclostationary detection is much higher as compared to the energy detection. We took a number of samples and plotted a graph of Probability of detection against the SNR.



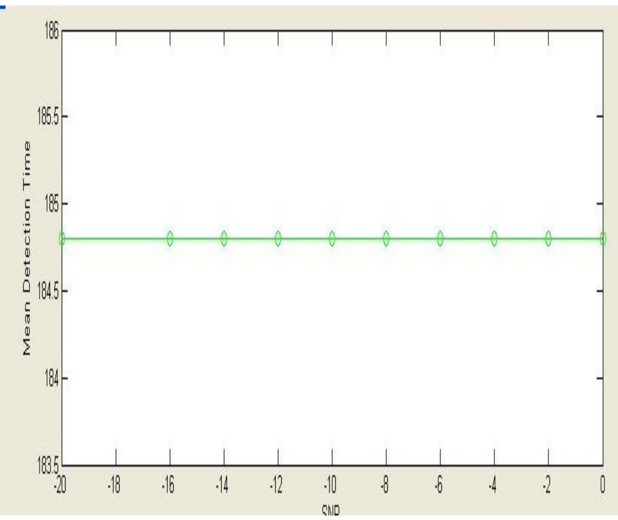


Fig.4. Probability of Detection of Cyclostationary Detection w.r.t SNR

Fig.5. Probability of Detection of Cyclostationary Detection w.r.t SNR

From the above simulation in Fig 4., it is clear that the Probability of detection is good at a lower SNR. As the SNR increases, the probability of detection increases. As seen in the Fig 5. above, the mean detection time for the cyclostationary detection is much higher as compared to the energy detection.

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C. *Two Stage Spectrum Sensing Detection:*

The two-stage spectrum sensing that we propose is shown in the figure below. Assume that there are L channels to be sensed and that channels are sensed serially. In the coarse sensing stage, the channel is sensed using energy detection. If the decision metric is greater than a threshold, the channel is declared to be occupied. Else, the received signal is analysed by fine sensing consisting of cyclostationary detection. If the constituent detection metric is greater than a threshold, the channel is declared occupied, else it is declared to be empty. The graphs for two stage spectrum sensing are as below.

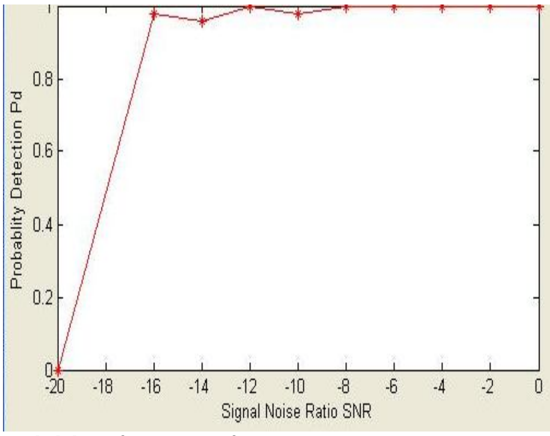

Fig.6. Probability of Detection of Two Stage Spectrum Sensing w.r.t SNR

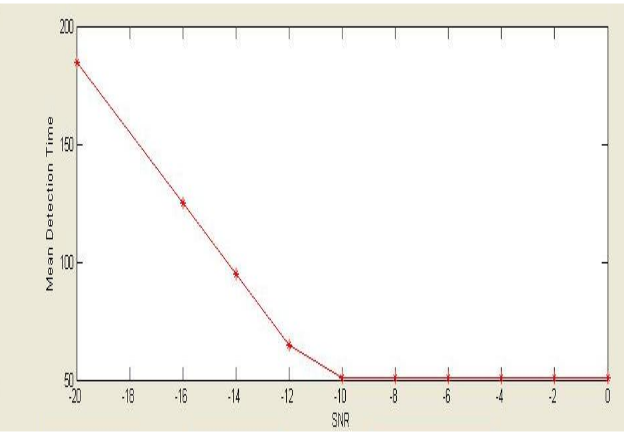

Fig.7. Probability of Detection of Two Stage Spectrum Sensing w.r.t SNR

From the above simulation in Fig 6. it is clear that the Probability of detection is good at very lower SNR. As the SNR increases, the probability of detection increases. It is almost full proof for the detection of the primary user in the channel.
As seen in the Fig.7, the mean detection time for the two stage spectrum sensing detection is a little higher than as compared to the energy detection but it is considerably low as compared to cyclostationary detection. But the accuracy is very high as compared to both ,cyclostationary detection as well as energy detection. The two-stage sensing does not always have a smaller mean detection time than the cyclostationary detector. But is effective mostly.

VI. Comparison Of Spectrum Sensing Schemes

The performance comparison between all the three processes can be easily seen from the Fig.10 and Fig.11. The comparison is based on the probability of detection and mean time detection.
From Fig.8, it is observed that the probability of detection is the highest for two stage spectrum sensing as compared to the other two. Also, the probability of detection is higher to two stage spectrum sensing at the lower SNR as compared to the rest.

From Fig.9, it is observed that the mean time detection for energy detection is the lowest as compared to the other two. But , the probability of detection for the energy detection is much lesser as compared to the two stage spectrum sensing. Also , at a good SNR , the difference between the mean time detection for energy detection and two stage spectrum sensing is less as compared to the difference at very low SNR.

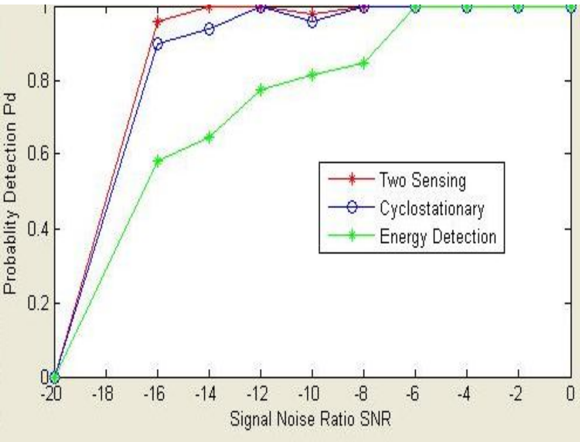

Fig.8.Probability Of Detection Comparison w.r.t SNR

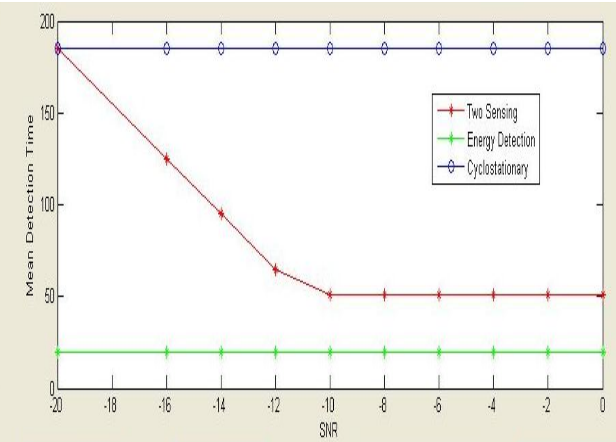

Fig. 9. Mean Detection Time Comparison w.r.t SNR

VII. CONCLUSION AND FUTURE WORK

A two-stage sensing scheme is analyzed in terms of its detection performance and mean detection time. It is observed that at low SNR, where the energy detector is not reliable, the two-stage sensing scheme provides improved detection. Furthermore, it is proved that the mean detection time of the two-stage sensing scheme is much lower than the cyclostationarity detection scheme for most of the SNR range..Cyclostationary detector is accurate at low SNRs but the Energy detection is not full proof at low SNRs. It cannot detect the primary user at a lower SNR. Thus the two stage spectrum sensing emerges as a best approach as compared to the energy detection and cyclostationary detection.The two stage spectrum sensing can be used in various applications such as military applications , WSD , emergency networks , E- Health applications , cognitive mesh network.

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BIOGRAPHY

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