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A Comprehensive Study on Energy Detection and Cyclostationary Feature based Spectrum Sensing

Meenakshi Sansoy
ECE Department
Punjab Institute of Technology
Kapurthala, India

Avtar Singh Buttar
ECE Department
Punjab Institute of Technology
Kapurthala, India

Abstract: Cognitive Radio plays an important role in the efficient utilization of limited spectra. Spectrum sensing can be d one with a number of techniques available like Energy Detection, Match Filter, Cyclostationary Detection, Wavelet Packet detection, etc. This paper includes the analysis of two basic techniques i.e., Energy Detection (ED) and Cyclostationary Feature Detection (CFD). The study focuses on the theoretical aspect of both the techniques supported by their simulation results. Results show the better performance of Cyclostationary Feature Detection in low SNR regime.

Keywords: Cognitive Radio; Spectrum Sensing; Energy Detection; Cyclostationary Feature Detection; Power Spectral Density

I. INTRODUCTION

With the growth and advancement in the wireless communication, a number of wireless applications have been developed which require large amount of bandwidth to operate to satisfy the customers with higher data rates. These requirements can be fulfilled by efficient utilization of the limited spectra. Most of the bandwidth is allocated to the Primary Users (PUs) or the licensed users. But, they don't fully utilize the bandwidth. According to the FCC report, only 15-85 % of the available spectrum is utilized [1]. This unused spectrum/ holes/ vacant/ white spaces can be allocated to the Secondary Users (SUs) when PUs are not using the their allotted spectrum through the implementation of Cognitive Radio [2, 3].

Cognitive Radio performs spectrum sensing, spectrum sharing, spectrum mobility and spectrum management. Spectrum sensing plays an important role in the identification of the free available band. *Spectrum Sensing:* The main challenge is to sense the hole in the primary band and quickly vacate the hole when needed by PU. A number of techniques are available to detect the free band without hindering the operation of PUs. Energy Detection is a simplest technique to work with but the performance degrades with decrease in Signal-to-Noise-Ratio (SNR). Matched Filter Detection based on the prior knowledge of the Primary User, senses the signal even at lower SNR. Cyclostationary Feature based Detection senses the holes by exploiting the property of periodicity in the signal or its statistics like autocorrelation and mean. *Spectrum sharing:* It assigns the vacant spectrum hole to the SU as long as PU does not require it along with the power allocations. *Spectrum mobility:* If the band acquired by SU is demanded by PU, then it has to vacate that band and allotted a new band without any delay. *Spectrum management:* Once the vacant spaces in the spectrum are found, decision regarding the allotment to the SUs is made based on their requirements.

In this paper, Spectrum sensing techniques, i.e., Energy Detection and Cyclostationary Feature based Detection are discussed. Section II, Section III compares the two techniques and Section IV concludes the paper.

II. SPECTRUM SENSING

Spectrum sensing is the first step to determine the presence of primary signal on a band. Its motive is to find out the spectrum status and activity by periodically monitoring the target frequency band. Sensing can be centralized or distributed. In centralized spectrum sensing, a controller node does the work of sensing the target frequency while in distributed sensing all the nodes in a network perform the task of sensing.

System Model: Let the primary transmitter transmits the signal $x(k)$. If the secondary user is within its range, it can detect the PU signal. We assume two hypotheses to decide the presence of PU, which are

$$H_0: y(k) = w(k) \quad (1)$$

$$H_1: y(k) = h.x(k) + w(k) \quad (2)$$

where $y(k)$ is the received signal by CR user, $x(k)$ is the transmitted signal by, $w(k)$ is the AWGN and h is the channel gain. H_0 is a null hypothesis which represents no primary or licensed user signal. H_1 is an alternative hypothesis which represents the presence of primary user signal. If SU detects a PU signal when it is actually not present or vice-versa, a probability of false alarm (P_f) is calculated to estimate the performance of signal detection. Another performance criterion is to calculate the probability of detection (P_d) which is the ratio of the total number of correct detection to the total number of trials.

A. *Energy Detection*

It is a non-coherent and the most suitable technique where the Cognitive Radio finds hard to get adequate information from the licensed user's signal. The basic theory behind this technique is the power estimation of PU signal [4,7].

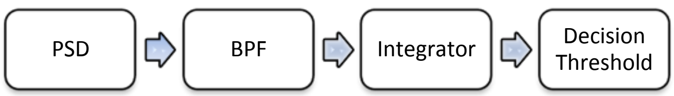

Fig.1. Block Diagram of Energy Detection

Figure 1. shows the block diagram of energy detection method where the received signal is transformed from time domain to frequency domain by Fast Fourier Transform (FFT) and power in each frequency is determined resulting which is known as PSD (Power Spectral Density), then passed through band pass filter of bandwidth W to select the channel and integrated over some time interval T.

$$E = \sum_{n=1}^{N} |x(n)|^2 \qquad (3)$$

The output is then compared with the pre-defined threshold (λ) to make a decision regarding the presence of free hole. If the energy is below the threshold then PU signal is not present i.e. band is vacant else band is occupied by PU.[8, 9]

Probability of Detection (P_d) and Probability of False Alarm (P_f) for Energy Detection can be calculated by following:

$$P_d = P[E > \lambda / H_1] \qquad (4)$$

$$P_f = P[E > \lambda / H_0] \qquad (5)$$

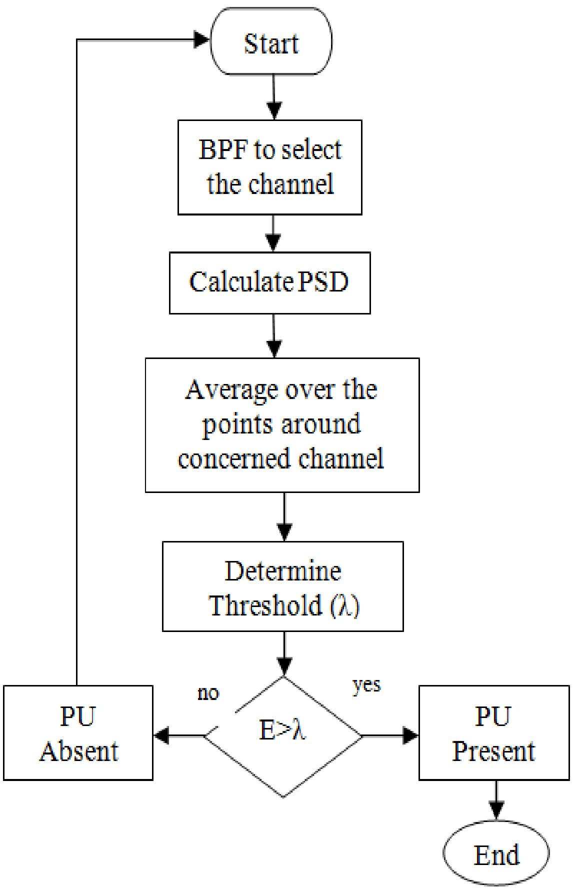

Fig. 2. Flowchart of Energy Detection

B. Cyclostationary Feature based Detection

This technique is grounded on the feature called periodicity or cyclic redundancy. The transmitted signals show cyclostationary features based on carrier frequency, modulation type and data rates, thus, identifying this unique feature of a particular PU signal can be used to detect the hole in the band.[5,6]

Principle of CFD: A random process $x(t)$ is called as a wide sense cyclostationary process if its mean and autocorrelation are periodic with some period T, and are given as

$$E_x = E_x(t + kT) = E[x(t)] \qquad (6)$$

and

$$R_x(t,\tau) = R_x(t + kT, \tau) = E[x(t)\tilde{x}(t+\tau)] \qquad (7)$$

where T is the time period, τ represents time lag associated with the autocorrelation function, $\tilde{x}(t)$ is the complex conjugate of $x(t)$ and k is an integer. Autocorrelation in terms of Fourier series can be expressed as

$$R_x(t,\tau) = \sum_{\alpha=-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(j2\pi\alpha t) \qquad (8)$$

where,

$$R_x^{\alpha}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x\left(t+\frac{\tau}{2}\right) \tilde{x}\left(t-\frac{\tau}{2}\right) \exp(-j2\pi\alpha t)\,dt \qquad (9)$$

Eq. (9) is called as *cyclic autocorrelation* with cyclic frequency $\alpha = n/T$. The Cyclic Spectral Density (CSD) or Spectral Correlation Function (SCF) represents the time averaged correlation between two spectral components of a process which are separated in frequencies by 'α' is given as

$$S_x^{\alpha}(f) = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(-j2\pi f\tau)\,d\tau \qquad (10)$$

CSD represents the density of correlation between two spectral components.

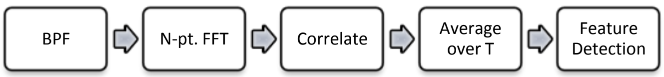

Fig. 3. Block Diagram of Cyclostationary Detection

1. The received signal $r(t)$ is fourier transformed after band pass filtering.

$$R = fft(r) \qquad (11)$$

2. Multiply r with complex exponential function

$$AT = r.* \exp(j * 2 * pi * shftT) \qquad (12)$$

3. Then correlate this signal with the received signal

$$AB = xcorr(AT, R) \qquad (13)$$

4. And after averaging over time T compare with the threshold to decide whether the primary user is present or not.

$$P = fft(AB).* conj(fft(AB)) \qquad (14)$$

$$P > \lambda, P < \lambda \qquad (15)$$

This technique is robust to noise discrimination and performs well than energy detector and is optimal in low SNR regime. But, the disadvantage is its highly complex computations and long observation time [10, 11].

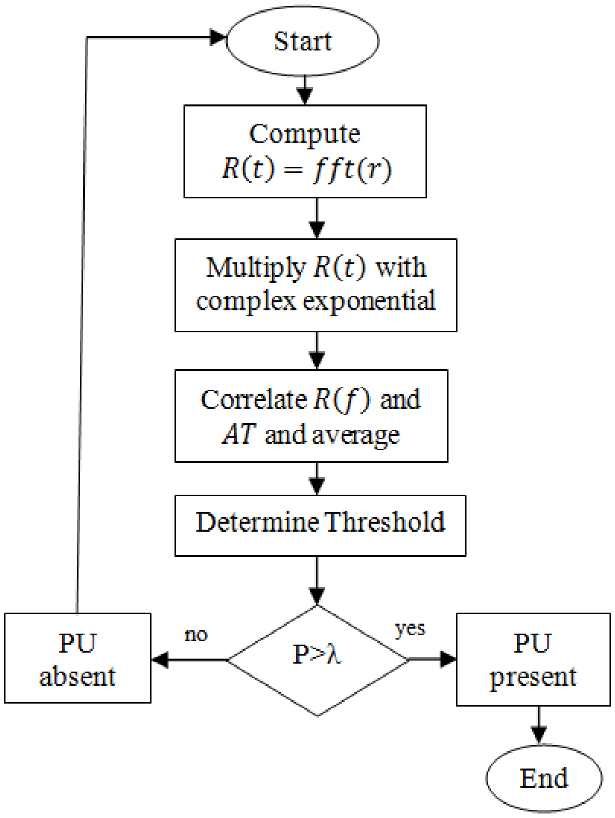

Fig. 4. Flowchart of Cyclostationary Feature based Detection

III. COMPARISON

Energy Detection technique is prone to false alarm as it measures only the signal power. It is impossible to distinguish between two primary signals because it is not able to differentiate between the two received energy sources. It does not give best performance under the low SNR conditions. It takes long time to collect data to detect the signal reliably.

Cyclostationary Feature based Detection technique is more robust under noisy environment and give better performance in low SNR regions but suffers from long computational time and high complexity.

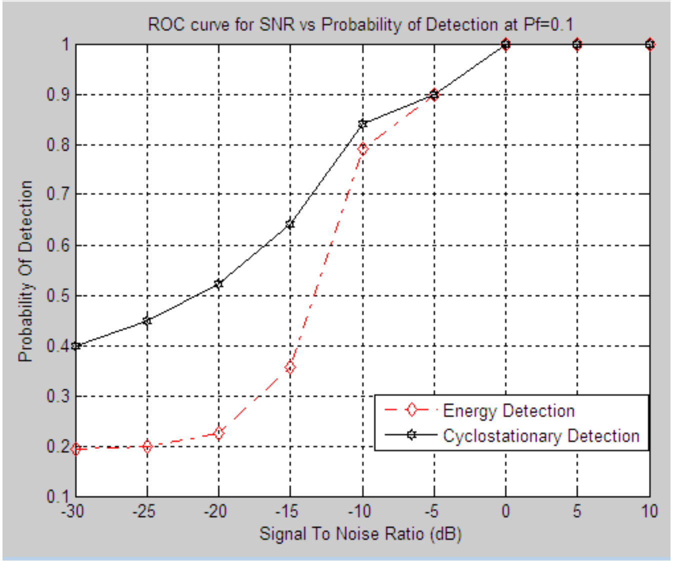

Fig. 5. Probability of Detection vs SNR

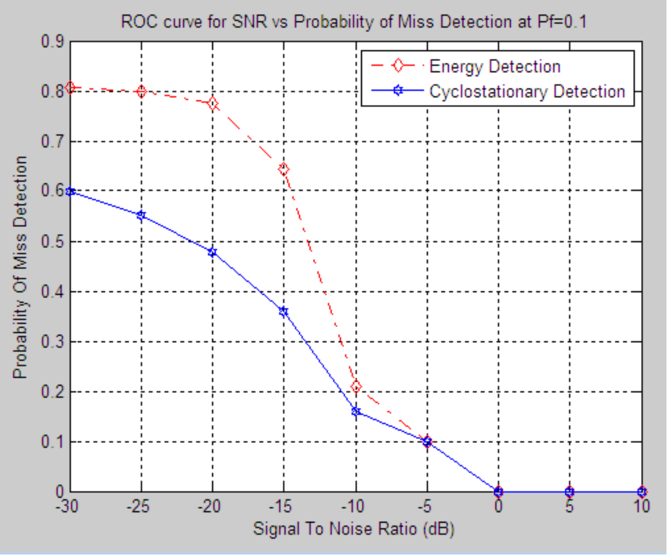

Fig. 6. Probability of Miss Detection vs SNR

TABLE 1. COMPARISON BETWEEN ENERGY DETECTION AND CYCLOSTATIONARY DETECTION

S.No	Parameter	Energy Detection	Cyclostationary Detection
1.	Ease of Implementation	Simple	Complex
2.	Sensing Period	Less	More
3.	Low SNR Performance	Poor	Good
4.	Prior Knowledge of PU Required	No	No

IV. CONCLUSION

Cognitive Radios play an important role in efficient utilization of the spectrum holes. For accurate sensing of the vacant spectrum holes, a sensing technique used for sensing the environment must be optimal as per the given conditions. In this paper, two commonly used spectrum sensing techniques have been discussed and compared. These two techniques namely, Energy Detection and Cyclostationary Feature based Detection are transmitter detection techniques. Both have their own significance under different conditions. ED is considered optimal because of its simple implementation, low cost and when there is no information about the primary user's waveform. CFD is a good choice when the detection is to be done in a low SNR environment and there is no prior knowledge of the primary user signal, but suffers from the drawback of high computational complexity and long observation time. Further improvements in the sensing process can be made by hybridization of the techniques.

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