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Implementation of Spectrum Sensing Algorithms in Cognitive Radio

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***Abstract**—The Cognitive radio is one of the recent revolutionary advancement that promises to govern the future wireless world. The ultimate objective of cognitive radio is to use available spectrum efficiently in fair-minded and cost-effective manner and provide highly reliable communication for all users of the network, wherever and whenever needed. In this paper various non-cooperative spectrum sensing techniques are discussed and their algorithm implementation is compared.*

***Keywords**— Cognitive Radio, Spectrum Sensing, Energy Detection, Matched filter detection, Cyclostationary detection, AWGN Noise, Power spectrum Density, Probability of detection*

I. INTRODUCTION

With the growth of communication applications the spectrum becomes more congested even though Federal Communications Commission (FCC) has expanded some unlicensed spectrum bands. However, radio spectrum is a limited resource, and the spectrum for each service has been allocated mostly through fixed spectrum assignment. Hence, spectrum scarcity is imminent. On the other hand, recent studies reveal that some frequencies allocated for some radio access technologies (RATs) are underutilized.[3]

Cognitive radio is one of the recent revolutionary advancement that promises to govern the future wireless world. The ultimate objective of cognitive radio is to use available spectrum efficiently in fair-minded and cost-effective manner and provide highly reliable communication for all users of the network, wherever and whenever needed;[1]

A. What is & Why CR?

The motivation for Cognitive radio is a concept of reusing licensed spectrum in an unlicensed manner without causing interference. Spectrum sensing is an important part for efficient utilization of spectrum. Primary user can use the spectrum at any time. Secondary users must sense the spectrum to detect whether itis available or not. Secondary users must be able to detect very weak primary user signals.

CR Consists Four important Steps [9];

1. Spectrum sensing
2. Spectrum decision
3. Spectrum sharing
4. Spectrum mobility

Spectrum sensing is the process of a cognitive radio sensing the channel and determining if a primary user is present, detecting the spectrum holes. Spectrum management is selecting the best available channel (for a cognitive user) over the available channels. Spectrum sharing is the allocation of available frequencies between the cognitive users. Spectrum mobility is the case when a secondary user rapidly allocates the channel to the primary user when a primary user wants to retransmit again

B. Spectrum Sensing

Spectrum sensing, defined as the task of finding spectrum holes by sensing the radio spectrum in the local neighbourhood of the cognitive radio receiver. The term spectrum holes stands for those frequency bands of the radio spectrum that are underutilized. The spectrum sensing function enables the cognitive radio to adapt to its environment by detecting spectrum holes.

In many scenarios involving CR, a communication device needs to capture the current usage of the spectrum before establishing its own communication. This behaviour is referred to as detecting free bands, which means identifying frequency bands that are free of already established communications. Band Frequency band can be considered free if the signal received in this band BL is only made of noise. On the other hand, if signals are detected in the presence of noise, the band is declared occupied. Thus, the function the detector has to perform is that of detecting signals in the presence of noise, which can be stated as the following hypothesis:

Basic hypothesis model for transmitter detection can be defined as follows [2];

$$x(t) = \begin{cases} n(t) & 0 < t < T \quad \text{under } H_o \\ s(t) + n(t) & 0 < t < T \quad \text{under } H_1 \end{cases}$$

x(t) – Received signal from CR
n(t) - Additive white Gaussian noise (AWGN)
s(t) – Transmitted signal from Primary user.
H_o – Spectrum is not occupied by Primary User
H_1 – Spectrum is occupied by Primary User

Here x(t) is the signal received at the receiver. s(t) is the transmitted signal of the primary user, n(t) is the Additive white Gaussian noise (AWGN)and h is the amplitude gain of the channel.H0 is a null hypothesis, which states that there is no licensed user signal in a certain spectrum band. On the other hand, H1 is an alternative hypothesis, which indicates that there exists some licensed user signal. Three methods are generally used for the non-cooperative detection according to the hypothesis model.

The most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range. In reality, however, it is difficult for a cognitive radio to have a direct measurement of a channel between a primary receiver and a transmitter. Thus, the most recent work focuses on primary transmitter detection.
Generally, the spectrum sensing techniques can classified as [3];

Non- cooperative detection:-This form of spectrum sensing ,occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is preloaded.

Cooperative detection:- Within a cooperative cognitive radio spectrum sensing systems ,sensing will be undertaken by a number of different radios within a cognitive radio network. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit.

II. NON-COOPERATIVE DETECTION METHODS

Basically, non-cooperative detection approach is based on the detection of the signal from a primary user. In the following we will present main three methods of non-cooperative detection. for efficient utilization of spectrum for cognitive radio, that have been of great interest in recent research. We will highlight some fundamental problems and present techniques for signal detection.[1,2]

1. Energy Detection Technique
2. Matched Filter Detection Technique
3. Cyclostationary Detection Technique

In this paper, we focus attention on the particular task on which the very essence of cognitive radio rests:
The probability of detection is of main concern as it gives the probability of correctly sensing for the presence of primary users in the frequency band. Probability of miss-detection is just the complement of detection probability.

A. Energy Detection Technique

Energy detector is well known spectrum sensing technique. It is based on the principle that the energy of the received signal to be detected is always higher than the energy of noise. Energy detector is said to be blind signal detector because it ignores the structure of received signal with known threshold. Threshold value can be fixed according to channel condition.

Energy Detection over AWGN Channels has analysed in which ten carrier frequencies were used.[6]

Algorithm for energy detection is designed as follows.

1. First we have transmitted signals of primary user.
2. At the receiver, received signal 'y' is calculated by adding all received signals.

3.Then we have estimated power spectrum density of signal 'y' by using periodogram function in MATLAB. The integral of the PSD over a given frequency band computes the average power in the signal over that frequency band.
4. The signal power. is then compared with a threshold and if it is above the threshold, then the result of the detector is that a primary user is present.
5. Plot the probability of detection by using Marcumq function.

B. Matched filter detection

We have seen previously in section --- that the best sensing technique in an AWGN environment, and without knowledge of the signal structure is the energy detector. If we do some knowledge of the signal structure then we can achieve a better performance by using Matched filter detection. Matched filter detection achieves the optimal detection performance in AWGN channel, since it maximize the SNR[9].

Matched filter has the interesting property that no matter what the shape, time duration or bandwidth of the input waveform maximize the SNR ratio is simply twice the energy E contained in transmitted signal divided by number of the matched filter prior knowledge of primary user waveform is required.

Algorithm for Matched filter detection is designed as follows.
First we have transmitted signals of primary user.

1. At the receiver, received signal y(t)s calculated by adding all received signals.
2. Add AWGN in received signal.

   $$Yr(t)=y(t)+n(t)$$

3. Convolute the Yr(t) with impulse response h(t) of Matched filter .

   Here h(t) is taken as the received signal of each primary user. For example if received signal $y_1(t)$ from first primary user then convolution becomes

   $$Yr(t)*h(t) = \int_0^t Yr(T)\, h(t-T)\, dT$$

   where h(t)=y1(t). Similarly it is done for all primary users.

4. By using convolution, matched filter will match the received signal with primary user signals If it is matched it will show peak value at that particular carrier frequency of PU.
5. Draw the frequency spectrum of Yr(t) using FFT.
6. Peak values which are present in the frequency spectrum are then compared with a threshold and if it is above the threshold, then the result of the detector is that a primary user is present.

This method is optimal in the sense that it maximize the SNR, minimizing the decision errors.
However this method is not practical since it require the cognitive user to know the primary user's signalling type.

C. Cyclostationary detection

Cyclostationary detection is a method for detecting primary user transmissions by exploiting the Cyclostationary features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing. Instead of power spectral density (PSD), cyclic correlation function is used for detecting signals present in a given spectrum. The Cyclostationary based detection algorithms can differentiate noise from primary users signals. This is a result of the fact that noise is wide-sense stationary (WSS) with no correlation while modulated signals are Cyclostationary with spectral correlation due to the redundancy of signal periodicities.

Algorithm for Cyclostationary detection is designed as follows;

1. First we have transmitted signals of primary user.
2. At the receiver, received signal y(t)s calculated by adding all received signals.
3. Add AWGN in received signal.

   $$Yr(t) = y(t) + n(t)$$

4. Multiply the signal Yr(t) by Hamming window.
5. Then multiply by positive and negative exponential function and calculate x1 and x2 respectively.
6. Calculate cyclic autocorrelation of x1 and x2 in frequency domain.
7. Estimate the cyclic spectral density (CSD) function.
8. The channel is considered to be busy if the cyclic autocorrelation of the signals received by the SU at the cyclic frequency is nonzero; otherwise, the channel is vacant.

III. RESULTS AND ANALYSIS

A. *System Model:*

Following parameters are considered for implementation of above methods in **MATLAB**.

TABLE 1: PARAMETERS USED IN MATLAB PROGRAM

Sr. No.	Parameters	Description
01	No. of Primary Users	06
02	No. of Secondary Users	01
03	Threshold Value V_T	30 dB
04	No. of Carrier Frequencies Fc	10
05	Value of Fc in KHz	2,4,5,6,8,10,12,17,24,25
06	Sampling Frequency Fs	54 KHz
07	Transmitted signal X(t)	Cos (2 ∏* 1000 t)
08	Received Signal Y(t)	$Y(t)=Y_1+Y_2+Y_3+Y_4+Y_5+Y_6+Y_7+Y_8+Y_9+Y_{10}$ (Transmitted signals of Primary Users)
09	Noise signal n(t)	AWGN

The performance of the detection algorithm can be summarized with two probabilities [8]:

a. probability of detection Pd and
b. probability of missed detection..

Pd is the probability of detecting a signal on the considered frequency when it truly is present. Thus, a large detection probability is desired. Probability of detection can be obtained by averaging the MarcumQ- function over the probability distribution function of SNR.

Pd =MarcumQ(√2γ, √ λ)   [5]

Where γ in (5) corresponds to the SNR of received signal and λ is mean value of received signal Y(t).

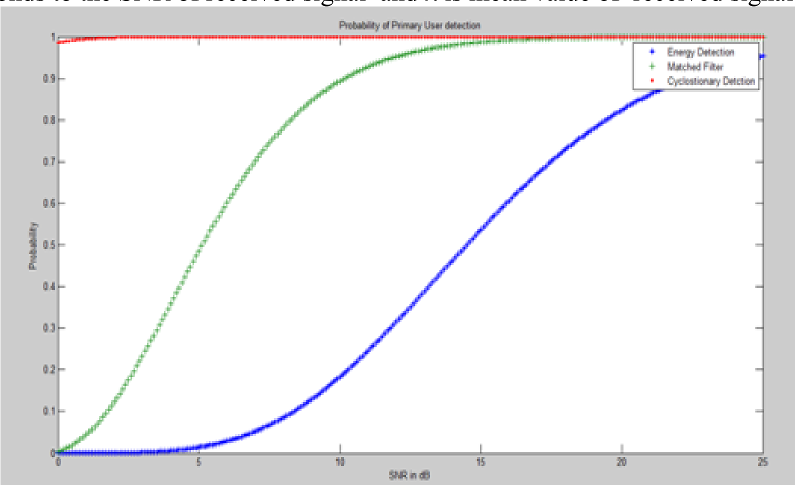

Figure 1: Probability of User Detection

Figure 1—shows the probability of detection as a function of SNR for the three cases.

i. Energy Detection
ii. Matched filter Detection
iii. Cyclostationary Detection.
iv.

It is observed that for Energy Detection and Matched filter Detection much higher SNR is required to obtain a detection. It is observed that for en Σ

Probability of missed detection means not detecting signal in presence of primary user.
Figure 2—shows the probability of Missed detection as a function of SNR for the three cases.

i. Energy Detection
ii. Matched filter Detection
iii. Cyclostationary Detection.

IV. CONCLUSION

Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades. Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of cognitive radio is sensing the available spectrum opportunities. In this paper, all three spectrum sensing methods have been implemented using MATLAB and depending upon the SNR value we can easily decide the method to adopt. Energy detection method is very simple but SNR should be low Vs. Cyclostationary detection method is quite complex but gives the best result even if considerable SNR conditions..

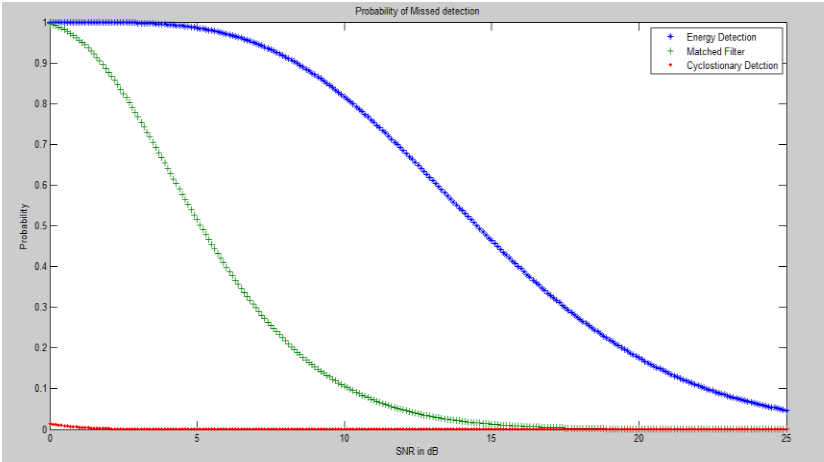

Figure 2: Probability of Missed Detection

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