Comparison of Different Local Spectrum Sensing Techniques in Cognitive Radios

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***Abstract*—Cognitive Radio (CR) is a self-monitoring wireless communication system. It can utilize the radio frequency spectrum efficiently. The CR user can opportunistically use those idle spectrum bands without causing harmful interference to the licensed/primary user. There are several spectrum sensing techniques which can serve the purpose. In this paper, non-cooperative spectrum sensing is performed by energy detection spectrum sensing and cyclostationary (both one-order and two-order) feature detection technique these are the local spectrum sensing techniques. Using the results obtained the energy efficient and time efficient techniques are determined.**

***Index Terms*— Cognitive Radio** (CR)**, Spectrum sensing, Energy detection, Cyclostationary feature detection.**

I. INTRODUCTION

Wireless communication is everywhere today. Emerging demands such as high-definition high-quality video streaming and fast downloading over wireless channels keep rising. The needs for higher data rates and long-distance wireless communications never end. As a result, more and more radio frequency (RF) spectrum bands are desired. However, the physical resource of usable RF spectrum band is limited. Radio frequency spectrum is a valuable resource. In recent years, the need for wireless communication services has increased drastically. This resulted in severe shortage of radio spectrum. The radio spectrum usage is regulated by government. The conventional fixed radio spectrum allocation resulted in lower utilization of radio spectrum. Actual measurements in [1] reveal that the allocated spectrum is mostly underutilized. This radio spectrum utilization varied from 15% to 85% in the frequency bands below 3GHz [1]. Studies by the FCC (Federal Communications Commission) show that, in certain locations, the average spectrum occupancy is only 5.2% with a maximum occupancy of 13.1% at any point in time. At frequencies above 3GHz, the actual spectral utilization is significantly lower. This inefficient spectrum utilization by the primary users (The users who have legacy rights on the usage of a specific bandwidth of the spectrum), lead the spectrum regulatory policy revised. The FCC released a statement in November 2002 that is produced by the Spectrum-Policy Task Force. In this report reveals that, “In many radio frequency bands, physical scarcity of spectrum is a less significant problem than spectrum access”. The Federal communications commission then granted the permission that these unoccupied bands can be utilized by the secondary users (They are the users with lower priority to utilize the spectrum). This revised policy lead to the concept of Cognitive Radio which can dynamically access the radio frequency spectrum [3]. Therefore, the apparent lack of radio resources can be worked around, if the empty frequency bands can be detected and opportunistically used through a suitable mechanism.In this paper we are analysing different local spectrum techniques and comparing their performance on basis of probability of detection. We are performing a non-cooperative spectrum sensing by energy detection spectrum sensing and cyclostationary (both one-order and two-order). The remaining contents of this paper are as follows:

Section II gives the brief introduction of cognitive radios, its functions and spectrum sensing and its types, section III describes the implementation of spectrum sensing and types of spectrum sensing techniques, section IV shows the simulation results and in last, section V contains the conclusion and future scope of this paper.

II. METHODOLOGY

A. *Cognitive Radio:*-Cognitive Radio (CR) is an intelligent wireless communication system. It will sense the channel availability and uses the ideal channels without any harmful interference with the licensed users. It is capable of changing its operating parameters in accordance with the behaviour of the network and its users. This will improve the efficiency of radio frequency spectrum utilization [2]. The name “cognitive radio” is coined by Joseph Mitola in the year 1999. He illustrated how the flexibility of personal wireless services could be enhanced through cognitive radio [8]. CR is still at a conceptually developing phase. However, it has a great potential in bringing up an important change to the way in which the radio spectrum can utilized. A trustworthy communication services must be provided by a CR whenever needed [6]. CR works on the principle, “learning by understanding”. This principle’s application on radio spectrum utilization gives the new description for CR. It can study various parameters (like transmit-power, transmitted frequency, kind of modulation involved etc.) of its surrounding wireless network [2]. Re-configurability is another feature of CR. For a successful communication, CR wireless transmitter must be properly synchronized with the receiver module. The feedback channel connects both the receiver and transmitter modules [2]. However, quality of service is a paramount for any system like Cognitive Radio which got several challenges to face. [6].

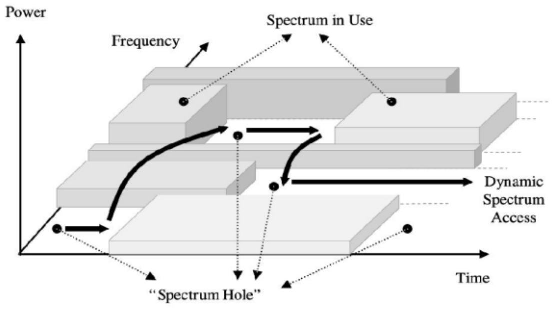

Fig.1 The white spaces in fixed spectrum allocation [2]

Function of Cognitive Radio technology:-

1) Determine which portion of spectrum are available and detect the presence of a licensed user when a user operates in licensed band (spectrum sensing).
2) Select the best available channel (spectrum management).
3) Coordinate access with other user (spectrum sharing).
4) Vacate the band when the primary user is detected (spectrum mobility).

B. Spectrum Sensing:-

Spectrum sensing is a key element in CR communication as it should be performed before allowing unlicensed user to access a vacant licensed channel. The most efficient way to detect spectrum holes is to sense the primary users that are receiving data within the communication range of a cognitive user.

In reality, however, it is difficult for a CR to have a direct measurement of a channel between a primary receiver and a transmitter. Thus, most recent work focuses primary transmitters detection based on local observation of cognitive user.

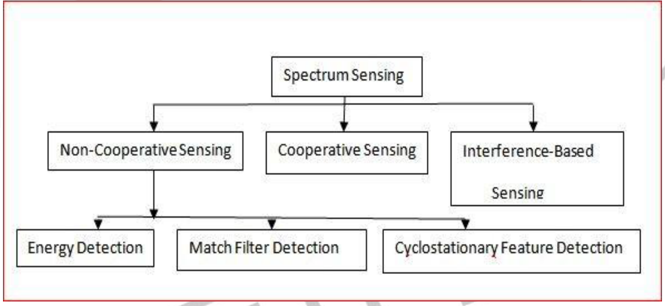

Fig.2 Different types of spectrum sensing techniques

C. Non-cooperative transmitter sensing:-

Non-cooperative spectrum sensing is used by an unlicensed user to detect the transmitted signal from a licensed user by using local measurements and local observations. The model for signal detection at time *t* can be described as [6]

$$r(t)= n(t) \quad (1)$$
$$r(t)=h\, s(t) + n(t) \quad (2)$$

where r(t) is the received signal of an unlicensed user, s(t) is the transmitted signal of the licensed user, n(t) is additive white Gaussian noise (AWGN) , and h is the channel gain. Here, and are defined as the hypothesis of not having and having a signal from a licensed user in the target frequency band, respectively. The performance of a spectrum sensing technique is generally measured in terms of the probability of detection (P_d) probability of false alarm (P_f) and probability of miss detection(P_m) which are define as

$$P_d= P_r\ (H_1 / H_1) \quad (3)$$
$$P_f = P_r\ (H_1 / H_0) \quad (4)$$
$$P_m= P_r\ (H_0 / H_1) \quad (5)$$

The probability of detection can be written in terms of probability of miss detection as

$$P_d= 1- P_m \quad (6)$$

The three different methods in non-cooperative sensing are as follows:-

D. Matched filter detection or coherent detection:

Matched filter detection [5] is generally used to detect a signal by comparing a known signal (i.e. a template) with the input signal. A matched filter will maximize the received SNR for the received signal. Therefore, if the information of the received signal from a licensed user is known (e.g. modulation and packet format), a matched filter is an optimal detector in stationary Gaussian noise. Since a template is used for signal detection, a matched filter requires only a small amount of time to operate. However, if this template is not available or is incorrect, the performance of spectrum sensing degrades significantly. Matched filter detection is suitable when the transmission of a licensed user has pilot, preambles, synchronization word, which can be used to construct the template for spectrum sensing.

E. Transmitter energy detection:

Energy detection is the optimal method for spectrum sensing when then information from a licensed user is unavailable. In this approach, the radio frequency signal energy or receiver signal strength indicator is determine and based on that, channel status is decided. The output of the signal is filtered with a band pass filter to select the bandwidth of interest. The output is then squared and integrated over the observation time. Lastly, the output is compared against a predetermined threshold to infer the presence or absence of primary user.

Although the energy detector can be implemented without any prior knowledge, it still has some drawbacks. The first problem is that it has a very poor performance at low values of SNR. This is due to uncertainty of noise at low SNR. Secondly, its inability to differentiate the interference from other secondary user sharing the same channel.

F. Cyclostationary feature detection:

The transmitted signal from a licensed user generally has a periodic pattern. This periodic pattern is referred to as cyclostationary, and can be used to detect the presence of a licensed user [8]. A signal is cyclostationary if the autocorrelation is a periodic function. With this periodic pattern, the transmitted signal from a licensed user can be distinguished from noise, which is a wide-sense stationary signal without correlation. In general, cyclostationary detection can provide a more accurate sensing result and it is robust to variations in noise power. However, the detection is complex and requires long observation periods to obtain the sensing results.

III. IMPLIMENTATION OF SPECTRUM SENSING

The goal of spectrum sensing is to determine if a licensed band is not currently being used by its primary owner. Therefore, spectrum sensing for opportunistic access may be
Formulated as a binary hypotheses test between two following hypothesis,

$r(t)= n(t)$ $\quad$ (H_0) $\quad$ (white space)
$r(t) = s(t) + n(t)$ $\quad$ (H_1) $\quad$ (occupied)

Where r(t) is the signal observed by the secondary user, s(t) is the signal transmitted by primary user, n(t) is the AWGN noise.

The probability distribution functions (pdfs) of the received signals at a secondary user are shown in Fig.3.1. If the primary user is absent, the pdf is a noise-only distribution. If the primary user's signal is being transmitted, the pdf is signal plus noise distribution. According to a certain criterion (or threshold), the secondary users determine if the primary user is present or not. Depending on whether or not the primary user is present and on the secondary user's decision, there are four possibilities as shown in Table 3.1.

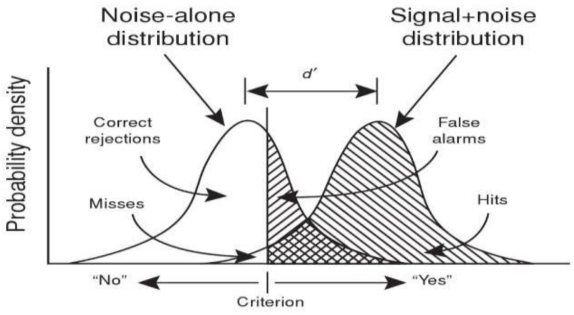

Fig 3. Received signal strength [6]

With the transmission of a primary user, if the secondary user detects the transmission, it is called a "hit", otherwise, it is called a "miss". In the absence of a primary user, if the secondary user says the primary is "on", the case is called a "false alarm", otherwise it is the correct "correct rejection". It is evident that the probabilities of all four cases highly depend on the threshold.

Table 3.1 Conditions for decision possibilities

	Secondary user response yes	Secondary user response no
Primary user on	Hit	Miss
Primary user off	False alarm	Correct rejection

The performance of a spectrum sensing technique is generally measured in terms of the probability of detection(Pd) probability of false alarm(Pf) and probability of miss detection (Pm) which are define as

$$P_d = P_r\ (H_1 / H_1) \tag{7}$$

$$P_f = P_r\ (H_1 / H_0) \tag{8}$$

$$P_m = P_r\ (H_0 / H_1) \tag{9}$$

The probability of detection can be written in terms of probability of miss detection as

$$P_d = 1 - P_m \tag{10}$$

A. Implementation of Energy detection technique:

A simple and low cost spectrum sensing scheme is the energy detection, which is a common technique for detection of unknown signals in noise. Fig. 3.2 depicts the block diagram of an energy detector. The input band-pass filter selects the centre frequency and is followed by a squaring device to measure the received energy and an integrator which determines the observation interval. Finally the normalized output of the integrator, Y, is compared with a threshold, to decide whether the signal is present.

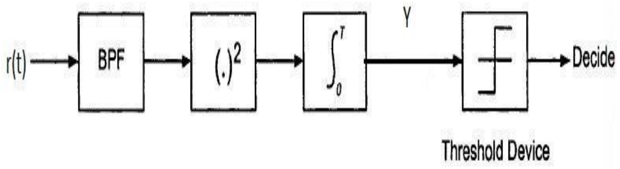

Fig. 4 block diagram of energy detector

For simplicity we assume that the time-bandwidth product, TW, is an integer number which we denote by u. Following the work of Urkowitz [13], Y may be shown to have the following distribution,

$$Y \approx \begin{cases} \chi_{2u}^2 & H_0 \\ \chi_{2u}^2(2\gamma) & H_1 \end{cases} \tag{11}$$

Where χ_{2u}^2 and $\chi_{2u}^2(2\gamma)$ denote the central and non-central chi-square distributions, respectively, each with 2u degrees of freedom and a non-centrality parameter of for the latter distribution. Therefore, the PDF of Y under two hypotheses may be written as [7],

$$f_{Y/H_0}(y) = \frac{y^{u-1} e^{\frac{-y}{2}}}{\Gamma(u) 2^u} \tag{12}$$

$$f_{Y}/H_1(y) = \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{-(2\gamma+y)}{2}} I_{U-1}\sqrt{2y\gamma} \tag{13}$$

Where $\Gamma(.)$ is the gamma function and $I_v(.)$ is the v-th order modified Bessel function of the first kind. Where γ is the instantaneous signal to noise ratio of the received signal?

- *.False alarm probability and Detection probability*

In a non-fading environment, the false alarm probabilities and detection probabilities as defined by eqn. (14) and (15) respectively for the hypotheses test of (3.1) are given by following [8]

$$p_f = \frac{\Gamma(u, \frac{\lambda}{2})}{\Gamma} \tag{14}$$

$$P_d = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{15}$$

Where $Q_u(a,b)$ represent the Marcum Q-function here $\Gamma(.)$ is the incomplete gamma function.

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B. Cyclostationary feature detection based spectrum sensing:

A signal is said to be cyclostationary if it obeys the property periodicity. If a signal is periodic in a time interval T, it can be detected in the presence of noise using cyclostationary feature detection technique. This technique is more advantageous because if the signal has lower signal to noise ratio [11]. In this sensing technique, there are two different approaches to detect the signal. The two cyclostationary detection techniques
are one-order cyclostationary detection and two-order cyclostationary detection. The two order cyclostationary detection technique is more robust to noise and is more efficient than the one-order cyclostationay detection. Both these techniques are more efficient than the energy detection technique when detecting the signals with lower signal to noise ratio. The following sections, explains each of these cyclostationary detection techniques in detail.

- *One-Order Cyclostationay Feature Detector:*

In cyclostationary feature detection, the modulated signals are exhibits periodicity since their mean and autocorrelations exhibits cyclostationary. We deal with the cyclostationary detection technique in time domain. Consider a deterministic sine signal s(t) such that

$$s(t) = A\sin(2\pi f_o t + \theta) \tag{16 }$$

Where A is the envelope, f_0 is the periodic frequency and θ is the phase of signal. In the transmission of s(t) through an AWGN channel

$$x(t) = s(t) + n(t). \tag{17}$$

If the signal is travelled through AWGN channel then we can observe that the mean of the signal is time varying. When it is sampled for any instant of time t and any value of integer P, we can calculate mean as

$$Y = M_x(t)_T = \frac{1}{2N+1 \sum_{P=-N}^{N} X(t+PT_0)} \tag{18}$$

The mechanism of this sensing technique can be explained through a block diagram as shown in Fig.5

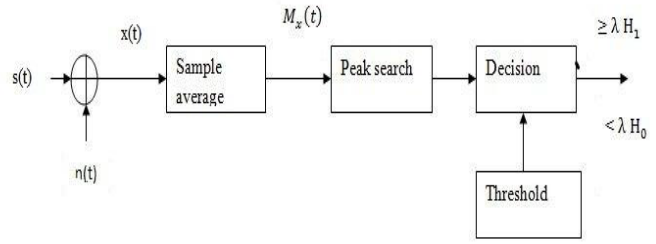


Fig.5 One-order Cyclostationary feature detection

The mean of the signal is then compared with a predetermined threshold value to obtain the test statistics. The test statistic will have two hypotheses and where corresponds to the hypotheses with no signal transmitted and corresponds to the Hypotheses with signal transmitted. The probability of detection and probability of false alarm are approximated over Gaussian channel [09]. Theoretically the threshold value can be computed from the equation:

$$p_{f(ofd)} = \exp(\frac{-\lambda}{2\delta_A^2}) \qquad (19)$$

$$P_{d(tfd)} = Q_1\left(\frac{\sqrt{2\gamma}}{\delta}, \frac{\lambda}{\delta^2{}_A}\right) \qquad (20)$$

Where λ is the threshold and δ_A^2 is the variance with the non-centrality parameter A. If we assume the value for A and variance then we can get the value of the threshold .Then
we can calculate the probability of detection [09] from the formula.
Where is Q(..) the generalized Marcum Q-function and γ is the instantaneous signal to noise ratio.

- *Two-order Cyclostationary detection technique :*

The extent of similarity between two signals can be determined through correlation process. Correlation between same waveforms can attain the maximum correlation value.
Let x(t) be an input signal which was propagated through the additive white Gaussian channel. In two-order cyclostationary detection technique in Fig.6, the input signal is time shifted with a period .The time shifted signal is auto correlated using the equation :

$$\gamma_{tfd} = \frac{1}{2N+1} - N^{x(t+gT_o)} * x^*(t+(g-1)T_0 \qquad (21)$$

Where N is number of samples, T_0 the pre-determined delay and g is an integer which takes value from -N to N.

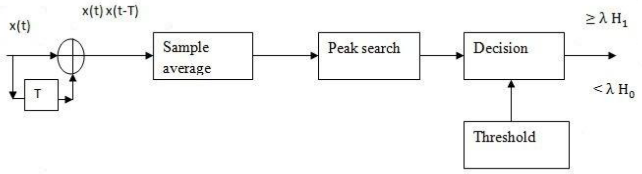


Fig 6 Two order Cyclostationary detection technique

The mean of correlated signal is calculated and is compare with a predetermined threshold value threshold value the threshold value for two order cyclostationary detection can be obtained

$$P_{f(tfd)} = \exp\left[\frac{-(2N+1)\lambda^2}{2\delta^4}\right] \qquad (22)$$

Where N is the number of samples, λ is the threshold and δ is the variance of the input signal. In the above equation, if we assume the value for probability of false alarm and variance, then we can obtain the values for the threshold. Therefore, value for two order cyclostationary probability of detection can then be calculated [09] using the equation

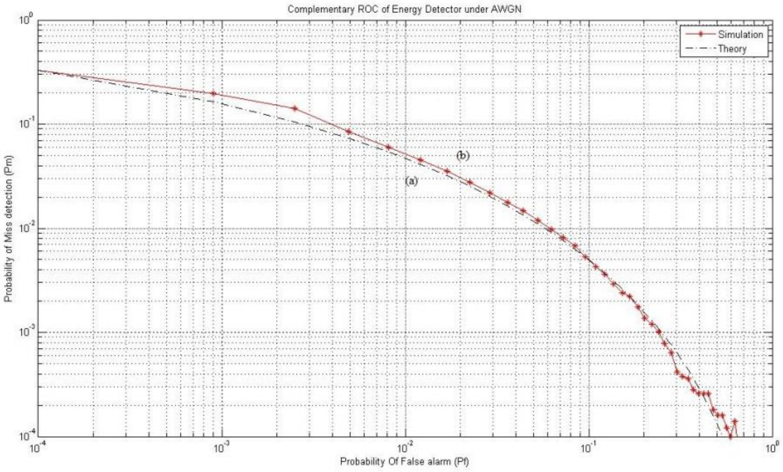
$$P_{d(tfd)} = Q_1\left(\frac{\sqrt{2\gamma}}{\delta}, \frac{\lambda}{\delta_B}\right) \qquad (23)$$

Where γ is the instantaneous signal to noise ratio of the received signal, and the value of can be calculated from the equation

$$\delta^2{}_B = \left(\frac{2\gamma+1)\delta^4}{2N+1}\right) \qquad (24)$$

The interrelation between x(t) original input signal and x(t-T) the corresponding delayed signal is given by the product of two signal. Correlated value is integrated and compared with threshold to determine the presence of primary user.

IV. SIMULATION RESULT



Fg.7 Complementary Receiver Operating Characteristic (CROC) curve of Energy detection technique over AWGN channel (a) theoretical (b) as obtained through simulation

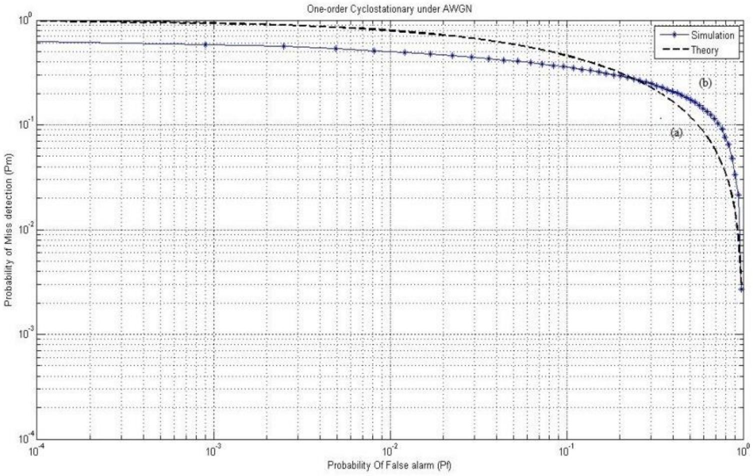


Fig. 8 CROC curves of one-order Cyclostationary detection technique over AWGN channel (a) theoretical (b) as obtained through simulation.

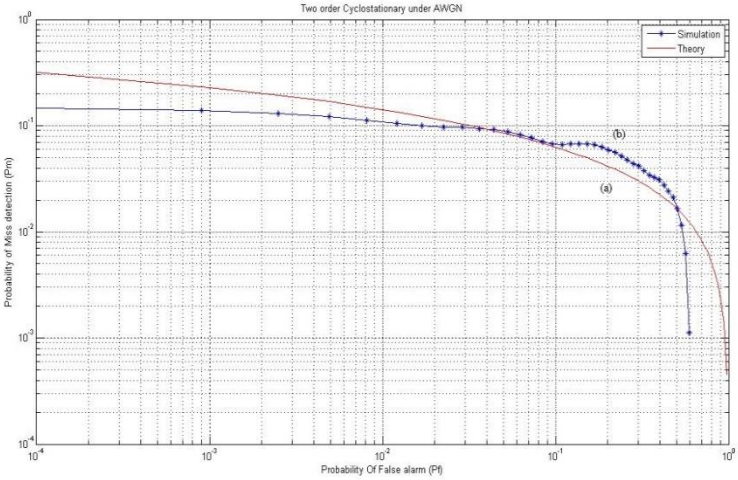


Fig. 9 CROC curves of two-order Cyclostationary detection technique over AWGN channel (a) theoretical (b) as obtained through simulation.

Simulation result in Fig 7,8 &9 shows the various spectrum sensing method , in which graph is plotted in between probability of false alarm and probability of misdetection. Each graph comparing the simulation result with the theoretical results.

IV. CONCLUSION

The complementary receiver operating characteristic curve for the spectrum sensing techniques are plotted. It can be observed that as the probability of false alarm is increasing, the probability of miss detection is decreasing exponentially. For high values of probability of false alarm, value of probability of miss detection is low, which implies that the probability of detection is more. We can also see that the probability of miss detection is significantly lower for two order cyclostationary detection technique than the one-order cyclostationary detection technique. The order of performance of spectrum sensing techniques with respect to increased probability of detection is two-order cyclostationary detection technique, followed by one-order cyclostationary detector and then the energy detection technique. Cyclostationary detector is very complex to build but is very efficient in low SNR regimes.

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