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Performance Analysis of Different Spectrum Sensing Techniques in Cognitive Radio under Different Fading Channels

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Abstract: Radio frequency spectrum is a very valuable resource in wireless communication. Its usage is increasing day by day at a tremendous rate. Since the available spectrum is limited, there is a need to find a way, to efficiently utilize this scarce spectrum. Cognitive radio is a huge step towards this. Cognitive radio helps the secondary users to use the unused licensed spectrum and drop out it when primary users are active. Spectrum sensing is a major function of cognitive radio. Commonly used spectrum sensing techniques are energy based spectrum sensing, matched filter spectrum sensing and cyclo stationary based spectrum sensing. In this paper, Energy detection, Cyclostationary detection and Adaptive double Threshold Energy Detection (ED_ADT) schemes were compared under different channels like AWGN, Rayleigh, and Rician. Results show that ED_ADT is optimal for signal detection having low SNR.

Keywords: Adaptive Double Threshold Energy Detector, Cognitive Radio, Cyclostationary Detector, Energy Detector, Probability of Detection.

I. INTRODUCTION

Currently users are being engaged by the services of large number of available wireless system. So the frequency spectrum is scarce. The radio frequency spectrum involves electromagnetic radiation with frequencies between 3000 Hz and 300 GHz [1]. The utilization of this spectrum is licensed by Governments for wireless applications. Spectrum scarcity is becoming one of the main and most challenging obstacles to the development of latest wireless communication technologies. Studies show that the licensed spectrum is relatively unused across many time and frequency slots. Federal Communication Commission (FCC) showed that, up to 70% of the authorized spectrums are not used. This prompted the thinking on how to utilize the available spectrum as best, so a lot of users can be accommodated within the same band without causing any harm to the licensed user. Cognitive radio (CR) is one of the solution for this problem. Cognitive radio helps to increase the spectrum efficiency. In CR, primary users are licensed users and secondary users are unlicensed users. Primary users have high priority on the usage of spectrum. Cognitive radio helps the secondary users to measure the radio environment and make use of the unused spectrum and drop out the spectrum, when the primary users are active. It works on a Software Defined Radio platform. The term, cognitive radio, can formally be defined as follows (FCC Report 2002): "Cognitive Radio is a radio for wireless communications in which either a network or a wireless node changes its transmission or reception parameters based on the interaction with the environment to communicate efficiently without interfering with licensed users"[2]. Cognitive Radios are able to sense, monitor, and detect the conditions of environment and dynamically reconfigure their characteristics. They can adjust their transmitting parameters such as frequency, output power and modulation properties. Cognitive Radio can use frequency and find available bandwidth where other radios can only see the static.

Spectrum sensing is one of the major component in the CR functions, which allows the unlicensed users to detect the presence of the primary signal. The basic spectrum sensing techniques are matched filtering, energy detection and cyclostationary detection [2]. Each has its own merits and demerits. The sensing performance of the CR is determined by the factors such as sensing reliability and detection probability. Energy detection is the most popular spectrum sensing method since it is simple to implement and does not need any previous information about the primary signal [2]. However, it does not perform well under low SNR conditions. Cyclostationary detection can detect the signals at low SNR but practically it is more complex and needs more sensing time. In [3], ED scheme with adaptive double threshold (ED_ADT) were proposed to overcome sensing failure problem. In this paper, different spectrum sensing techniques are compared under different channels.

II. SYSTEM DESCRIPTION

Cognitive Radio (CR) utilize unused channel of Primary User (PU) where the spectrum sensing mechanism allows them to determine the presence of a PU [4]. In this method, the locations of the primary users are not known to the CRs as there is no signalling between the PUs and the CRs. To detect the PU signal, following hypothesis for received signal is used [3, 4],

$$H_0: y(n) = w(n) \qquad (1)$$

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$$H_1: y(n)=s(n)h(n)+w(n) \quad (2)$$

Where, y(n) shows received signal at secondary user, s(n) is the PU licensed signal, $w(n) \sim N(0,\sigma^2_w)$ is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2_w, h(n) denotes the Rayleigh fading channel gain of the sensing channel between the PU and the CR user. H_0 is the null hypothesis which indicates that PU is absent and H_1 is the alternative hypothesis which indicates that PU is present.

A. Basic Energy Detector

Energy detector does not require prior knowledge about the primary user signal, only the value of white Gaussian noise is to be known. It collects the test statistic and compares it with a threshold to decide whether the PU signal is present or absent. Energy detection is optimal for detecting independent and identically distributed signal in high SNR conditions, but not optimal for detecting correlated signals. The test statistic is given by,

$$X = \frac{1}{N}\sum_{n=1}^{N}\left|y(n)\right|^2 \quad (3)$$

Where, y(n) is received input signal, N is the number of observations, X denotes the energy of received input signal which is compared with threshold to make the final decision. Threshold value is set to meet the target probability of false alarm P_f according to the noise power. The probability of detection Pd can be also identified. The expression for P_f and P_d are given by,

$$P_f = Q\left(\frac{T - N\sigma^2{}_w}{\sqrt{2N\left(\sigma^4{}_w\right)}}\right) \quad (4)$$

$$P_d = Q\left(\frac{T - N(\sigma_s{}^2 + \sigma^2{}_w)}{\sqrt{2N\left(\sigma^2{}_s + \sigma^2{}_w\right)^2}}\right) \quad (5)$$

Where, σ^2_w and σ^2_s are the noise variance and signal variance, respectively. Q() denotes the Gaussian tail probability Q-function and T denotes the threshold used in the energy detector. Threshold used in energy detector depends upon noise variance. So a small variation in noise variance estimation causes performance degradation. In conventional Energy detector, threshold can be determined as,

$$T = Q^{-1}\left(P_f\right)\sqrt{2N\sigma_w^4} + N\sigma_w^2 \quad (6)$$

Where Q^{-1} denotes the inverse Gaussian tail probability Q function.If the threshold is exceeded, it is decided that signal is present otherwise it is absent. Energy detection can be implemented both in time and frequency domain using Fast Fourier Transform (FFT). Energy Detector simply needs a band-pass filter, square law device and an Integrator. First the input signal's bandwidth is limited to a band of interest. Then the filtered signal is squared and integrated. Finally the output of the Integrator is compared with a threshold to decide whether a primary signal exists or not. The threshold value of energy detection can be fixed or variable based on the channel conditions and threshold value depends on SNR ratio. The energy detection is also called as blind signal detector because it ignores the structure of the signal and properties of the signal.

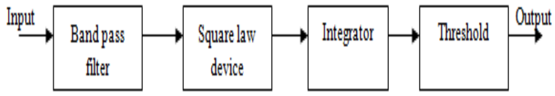

Fig. 1 Block diagram of Energy detector

B. Cyclostationary Detection

Most of the communication signals such as BPSK, QPSK, and AM exhibit cyclostationary behaviour. These cyclostationary features are caused by the periodicity in the signal or statistics like mean and autocorrelation. Cyclostationary feature detection is a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals [5]. Cyclostationary feature detection doesn't need any transmitter information at CR network. Such a scheme can distinguish between noise and user signal by evaluating its periodicity. During this technique, modulated signals are coupled with sine wave carrier, spreading codes, or cyclic prefixes, are built in periodicity, and their mean and autocorrelation exhibit periodicity [6]. The cyclostationary detection has higher performance than the energy detection under low SNRs, however its complexity and sensing time is more. This is because noise is completely random and does not exhibit any periodic behaviour. When there is no previous knowledge about primary user, best technique is cyclostationary feature detection.

(4)

Noise is a wide sense stationary signal with no correlation. Using Spectral Correlation Function (SCF), it is very easy to differentiate signal energy and noise energy and thereby detect the primary user signal. Received signal cyclic spectral density function or Cyclic Autocorrelation Function (CAF) is written as,

$$R_y^{\alpha}(\tau) = E\left[y(n+\tau)y^*(n-\tau)e^{j2\pi\alpha n}\right] \quad (7)$$

where, α is the cyclic frequency. The cyclic frequencies are multiples of the reciprocal of period of cyclostationarity. Cyclostationarity detection is based on cyclic spectral density (CSD) and is able to separate the primary user signal from noise due to the fact that white noise has little correlation hence its cyclic spectral density is weak. The cyclic spectrum density (CSD) which is obtained by taking the Fourier transform of the cyclic auto-correlation function (CAF) represents the density of the correlation between two spectral components that are separated by a quantity equal to the cyclic frequency. The spectral correlation function is,

$$S(f,\alpha) = \sum_{\tau=-\infty}^{\infty} R_y^{\alpha} e^{-2\pi f\tau} \quad (8)$$

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For detecting the primary signal, cyclostationary detector computes the SCF of the received signal and compares it with the predetermined threshold.

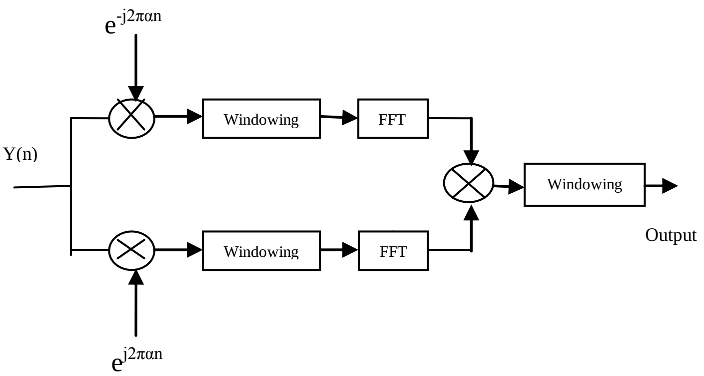

Fig. 2 Block diagram of Cyclostationary detector [5]

C. Adaptive Double Threshold Scheme

Adaptive Double Threshold Scheme is a modified version of basic energy detection. In basic energy detection spectrum sensing [7], noise uncertainty increases the difficulty in setting the optimal threshold for a CR and thus degrades the performance of sensing [8]. In addition, this may not be optimum in low SNR conditions where the performance of fixed single threshold (T) based detector can vary from the targeted performance metrics substantially [8]. ED_ADT overcomes these disadvantages by setting two thresholds T1 and T2. If the detected energy values lies inside or outside the confused region, the scheme decides

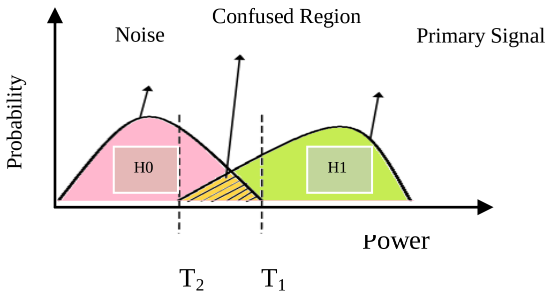

Fig. 3 Energy distribution of PU signal and noise

In Fig. 3, the area between upper bound (T1) and lower bound (T2) is known as confused region. In this region, noise and PU signal detection is difficult using single threshold. In the ADT scheme, the upper bound threshold (T1) is selected according to the maximum noise variance, and the lower bound threshold (T2*)* is selected according to the minimum noise variance. In this, confused region is divided into four equal levels [4]. If the detected energy values (X) fall in the confused region, it will generate its respective decimal values (DVs). This decimal values are compared with threshold (T) to make a decision at a fixed probability of false alarm (Pf), i.e., 0.1. If the values lie outside the confused region, it will generate 0 or 1 depending upon signal.The two bit quantization method divides confused into four equal intervals as T_2A-AB-BC-CT_1 (shown in Fig.4),

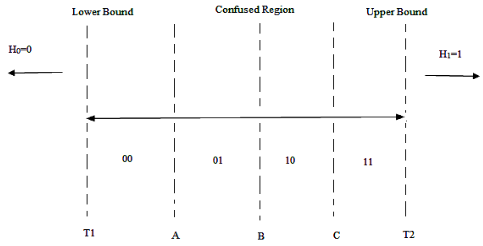

Fig. 4 Confused Region divided into four equal quantization intervals using two bit quantization method

G is the gap between each quantization levels T_2, A, B, C and T_1 are sub thresholds (ST) and the values [3] are,

$$ST = \begin{cases} A = T_2 + G \\ B = A + G \\ C = B + G \\ T_1 = C + G \end{cases} \quad (9)$$

$$G = \frac{\text{(Upper Bound- Lower Bound)}}{\text{No of quantization intervals}} \quad (10)$$

$$M = \begin{cases} 00, \ldots T_2 \angle X \le A \\ 01, \ldots A \angle X \le B \\ 10, \ldots B \angle X \le C \\ 11, \ldots C \angle X \le T_1 \end{cases} \quad (11)$$

Assume that the noise uncertainty in adaptive double threshold energy detector is $[1/\rho\sigma_w^2, \rho\sigma_w^2]$, where $\rho > 1$ is a parameter that indicates the size of uncertainty. In adaptive double threshold, upper threshold is selected according to maximum noise variance and lower threshold is selected according to minimum noise variance [1]. Therefore,

$$T_1 = Q^{-1}(P_f)\sqrt{2N\rho\sigma_w^4} + N\rho\sigma_w^2 \quad (12)$$

$$T_2 = Q^{-1}(P_f)\sqrt{2N/(\rho\sigma_w^4)} + N/(\rho\sigma_w^2) \quad (13)$$

III. RESULTS AND ANALYSIS

An extensive set of simulations have been conducted to analyse the performance of three spectrum sensing techniques. The result is obtained on the basis of probability of detection under different SNR in different channels which are AWGN, Rayleigh and Rician.

Assumed the total number of samples (N) as 1000, SNR range varies from -20 to 0dB, Pf=0.1. Fig. 5 shows the comparative performance of ED, Cyclostationary and ED_ADT in Gaussian channel. Results shows that adaptive threshold perform better than cyclostationary and Energy detection. Adaptive double threshold requires less sensing as compared with other technique and increases throughput as well. Probability of detection increases with increase in the value of SNR. At -8dB SNR the probability of detection of ED_ADT is 0.98 and cyclostationary detection is 0.38.

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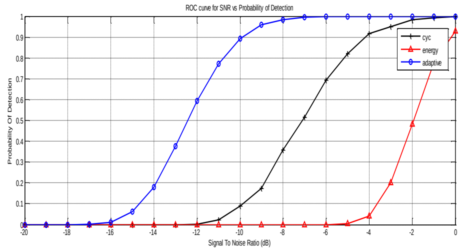

Fig. 5 Probability of detection versus SNR at P_f=0.1 with N=1000 in Gaussian Channel

Fig. 6 shows comparative analysis of spectrum sensing techniques in Rayleigh channel and Fig. 7 shows comparative analysis of spectrum sensing techniques in Rician channel. It is observed that probability of detection in Rician channel is small compared to other channel. In Rician channel at -12dB SNR the probability of detection is zero where as in Gaussian channel is 0.6 for ED_ADT.

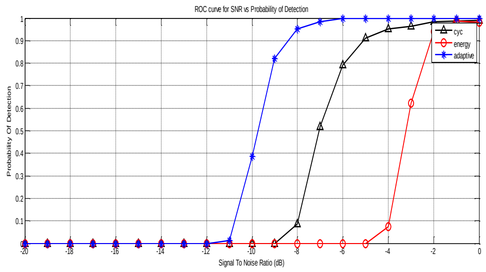

Fig. 6 Probability of detection versus SNR at P_f=0.1 with N=1000 in Rayleigh Channel

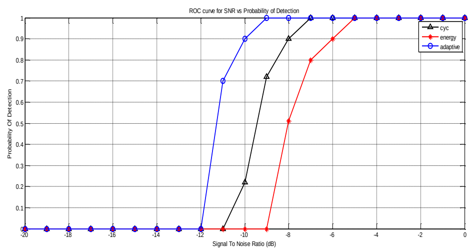

Fig. 7 Probability of detection versus SNR at P_f=0.1 with N=1000 in Rician Channel

Fig. 8 illustrates the probability of detection of ED_ADT for the three channels at different SNR levels. Result shows that probability of detection increases with increases with increase in SNR levels. It is also observed that AWGN channel has maximum detection as compared to other ie., means the probability of false alarm is high for Rayleigh fading channel.

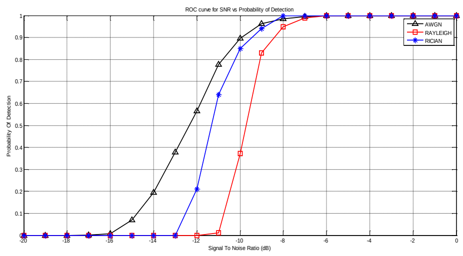

Fig. 8 Probability of detection versus SNR of ED_ADT under different channels

IV. CONCLUSION

Cognitive radio is a solution for the spectrum scarcity problem by providing a means for the use of spectrum holes. Cognitive Radio allows the unlicensed user's to use the spectrum when primary users are not using. In this paper comparative analysis of different spectrum sensing techniques like ED_ADT, Cyclostationary detection and Energy detection were performed. From the simulation and results, it is observed that ED_ADT performs best as compared to other spectrum sensing technique. Probability of detection increases with increase in SNR. It is also observed that AWGN channel has maximum probability of detection as compared to Rayleigh and Rician channel.

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