

# Analytical and Simulative Investigation of Cognitive Radio by Implementation of Energy Detection Technique

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**Abstract**— Bandwidth is the back bone of all the wireless systems. To enhance the efficiency of bandwidth usage, the concept of cognitive radio has emerged as a new design paradigm. Cognitive radios have the ability to monitor, sense, and detect the conditions of their operating environment, and dynamically reconfigure their own characteristics to best match those conditions.

In this paper, the basic tool used by the author is MATLAB to simulate the received signals from the cognitive radio networks and an energy detector to detect whether the spectrum is being used or not. The report also compares the theoretical value and the simulated result and then describes the relationship between the signal to noise ratio (SNR) and the detections. Welch method is employed for reducing the noise up to some extent. At last, energy detection, simulation and results are discussed.

**Keywords**-bandwidth;cognitive radio ; welch estimation; IEEE 802.22.; spectrum sensing

## I. INTRODUCTION

Cognitive Radio (CR) is a system/model for wireless communication which is an emerging technical platform. The limited availability of spectrum and the non-efficient use of existing RF resources necessitate a new communication paradigm to exploit wireless spectrum opportunistically. Each of the essential steps indicates a unique feature of the cognitive radio like Continuous Awareness, Dynamic Frequency Selection, and Frequency Negotiation. The steps are shown in the figure1.

Thus two main characteristics of the cognitive radio are stated as:-

**Cognitive Capability**- The ability of the cognitive radio to sense the channels used for transmission. It has all the basic functions of the cognitive radio like spectrum sensing,

spectrum analysis and spectrum allocation & finding the white spaces.

**Reconfigurability**- Cognitive radio is a software based radio without making any changes to its hardware section. Thus it has the capability to switch between different wireless protocols.

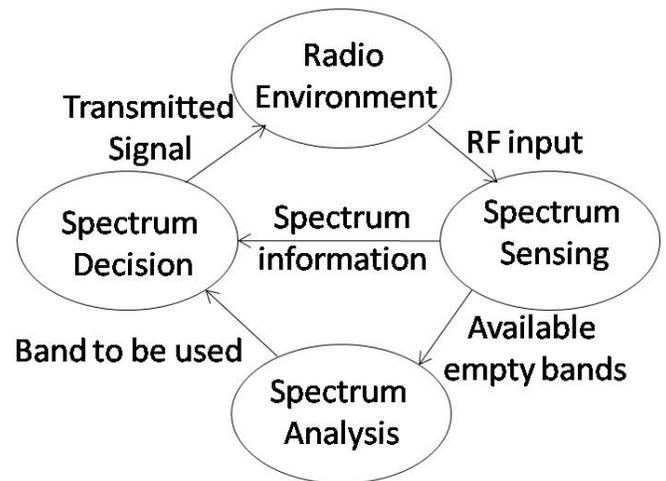


Figure 1 Cognitive Radio Cycle

## II. SPECTRUM SENSING

Spectrum sensing is the most important task of cognitive radio as all the remaining operations depend on it. Spectrum Sensing is the foremost step in cognitive radio network. The sensing equipment has to just decide between one of the two hypotheses:-

$$A1: x(n) = s(n) + w(n) \quad (1)$$

$$A0: x(n) = w(n) \quad (2)$$

Where 'x (n)' is the signal received by the secondary users.

's (n)' is the signal transmitted by the primary users.

'w (n)' is the additive white Gaussian noise. Hypothesis 'A0' indicates absence of primary user and 'A1' points towards presence of primary user.

Modern digital communication signals do not insert carriers or pilot signals that the receiver could access to aid in the demodulation process. They are not included in the modulation process for reasons of power efficiency (battery life and heating load). These systems rely on the ability of the receiver to reconstruct carrier and symbol timing clocks from secondary attributes of the modulated signal. These attributes are related to the excess bandwidth of the signal and statistics such as the absolute value of the mean, variance and autocorrelation of the underlying modulated waveform. Observables related to information is used with a pair of phase locked loops (PLLs) to control the frequency and phase of their associated local oscillators and thus form estimates of the desired carrier and timing clock. As the wireless communication has become the standard for our growing and diverse demands, its spectrum urgency to accommodate future innovations. Thus it is important to analyze spectrum carefully & efficiently. Cognitive radio provides a unique solution to the spectrum utilization problem in terms of spectrum sensing techniques. Spectrum sensing has a twofold approach. Firstly available spectrum is sensed then it is assigned to the non-serviced users for efficient utilization. The underutilized frequency sub-bands are commonly known as "spectrum holes" or "white spaces". The spectrum hole can be defined as a band of frequencies not utilized by a serviced user at a particular time and specific geographical location. Cognitive radio can be used to utilize bandwidth & improve the sensing accuracy to avoid the interference as far as possible. The paper presents the implementation of spectrum sensing through energy detection technique using Welch method using power spectral density & probabilities of detection and probabilities of false alarm. The relation between SNR & detections has been investigated by changing the SNR values. With variation of signal to noise ratio, effect of probability of false alarm and detection will be analyzed & simulated. Both the techniques will be compared theoretically as well as with the help of simulations. Also, the uses of the proposed techniques result in the need of a low complexity in the network. The performance of a Cognitive radio system can be greatly improved by using these spectrum sensing techniques by avoiding interference & improving gain & SNR. As day by day requirement of the communication channels are increasing, so bandwidth utilization is must, thus there is a scope for development of cognitive radio using these spectrum sensing techniques.

### III. PROPOSED ALGORITHM

Detection probability ( $P_d$ ), false alarm probability ( $P_{fa}$ ) and missed detection probability ( $P_{md}$ ) are the key measurement metrics that are used to analyze the performance of spectrum sensing techniques. The performance of energy detector spectrum sensing technique is illustrated by using ROC (Receiver operating characteristics) curves which is a plot of  $P_d$  versus  $P_{fa}$  or  $P_{md}$  versus  $P_{fa}$ . The simulation was done on

MATLAB version R2013a (8.1.0.604) through which the capability of an energy detector is evaluated. MATLAB is a fourth generation programming language tool for numerical computation, data visualization and serves as an easy laboratory.

Where,

$P_{md}$  = probability of missed detection

$P_d$  = probability of detection

$P_{fa}$  = probability of false alarm

Welch method of estimation is used for simulation. Welch's technique reduces the variance of the periodogram and breaks the time series into segments, usually overlapping. Welch's method computes a modified periodogram for each segment and then averages these estimates to produce the estimate of the power spectral density. The modified periodograms represent approximately uncorrelated estimates of the true PSD and averaging reduces the variability. The segments are typically multiplied by a window function, such as a Hamming window, so that Welch's method amounts to averaging modified periodograms. The plot of Probability of false alarm versus Probability of detection for different values of signal to noise ratio is illustrated in figure 2 and Detection probability ( $P_d$ ), False alarm probability ( $P_{fa}$ ) and missed detection probability  $P_{md} = (1 - P_d)$  are the key measurement metrics that are used to analyze the performance of spectrum sensing techniques. It is clearly seen that, for very less probability of false alarm values, probability of missed detection is very high.

### IV. RESULT DISCUSSION

As  $P_{fa}$  increases,  $P_{md}$  values are going to decrease drastically which improves performance of energy detector at low SNR values. The table 1 and table 2 show the values of probability of detection probability of false alarm increases; there is a drastic decrease in the probability of missed detection. Similarly, as values of SNR are decreasing, detection probability decreases and increase in values of probability of missed detection. One feature of the rocsnr function is to calculate the ROC curve based on SNR values and probabilities of detection and missed alarm for each of the SNR values. Instead of individually calculating  $P_d$  and  $P_{fa}$  values for a given SNR, the results are shown in a plot of ROC curves. The rocsnr function plots the ROC curves by default if no output arguments are specified. Calling the rocsnr function with an input vector of four SNR values and no output arguments produces a plot of the ROC curves.

In order to simulate the proposed system a cognitive radio system a signal is supposed at the range of 0-6 kHz frequency with an interval of 1 kHz and applied to the energy detector. This is considered as primary user signal and the detector is used to find the peaks at specific frequency points  $F_{c1}=1$  kHz,  $F_{c2}=2$  kHz,  $F_{c3}=3$  kHz,  $F_{c4}=4$  kHz,  $F_{c5}=5$  kHz and where as sampling frequency is taken as  $F_s=12$  kHz. As shown in figure

2 the display of channels at frequencies from 1-5 kHz in time domain and their individual spectra without noise. In case when odd slots are filled the simulation and results remained unchanged as any slot can be allotted at any time and an algorithm has been developed to empty the slots.

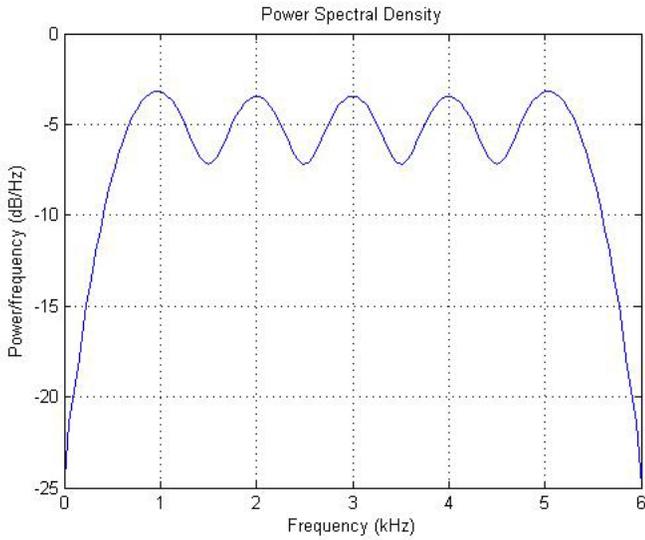


Figure 2 Composite time signal and its spectra without noise

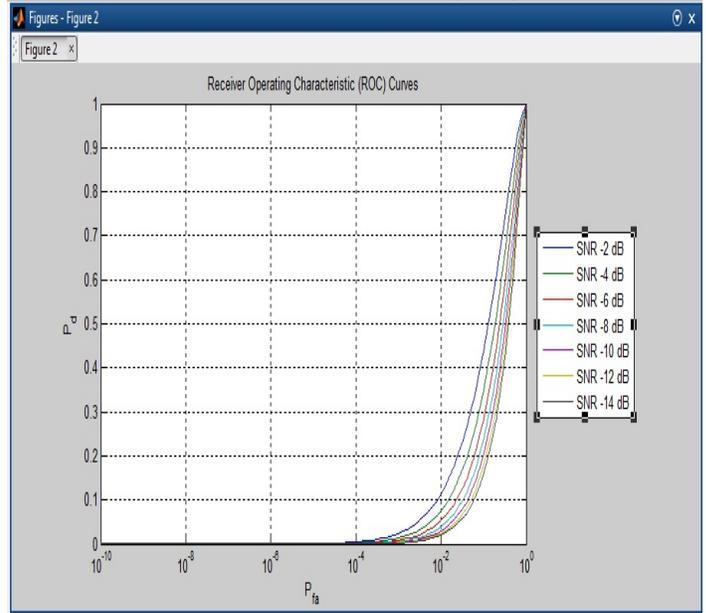


Figure 4 Receiver Operating Characteristics (ROC) Curves

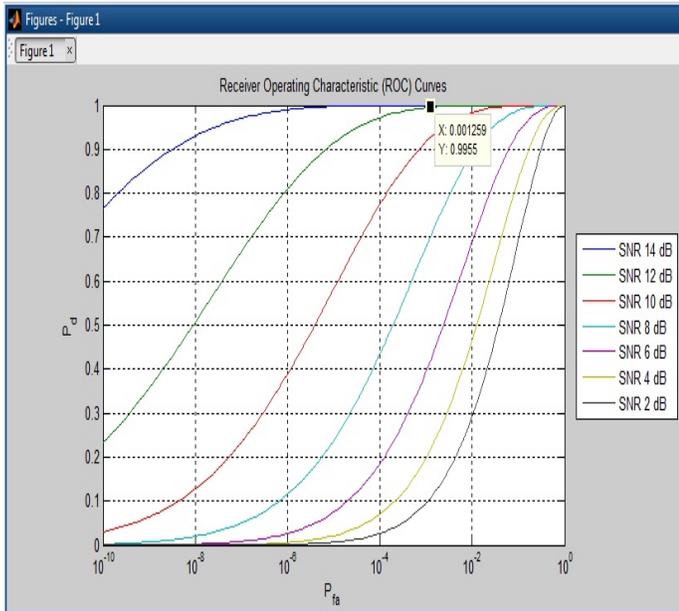


Figure 3 Receiver Operating Characteristics (ROC) Curves

The characteristics between probabilities of detection and false alarm are shown in figure 3 with positive values of signal to noise ratio and figure 4 with negative values of signal to noise ratio. It can also be analyzed from the receiver operating characteristics that as the SNR is more positive the probability of detection increases whereas, if the SNR decreases it becomes very near to probability of false alarm and also affect the probability of detection .

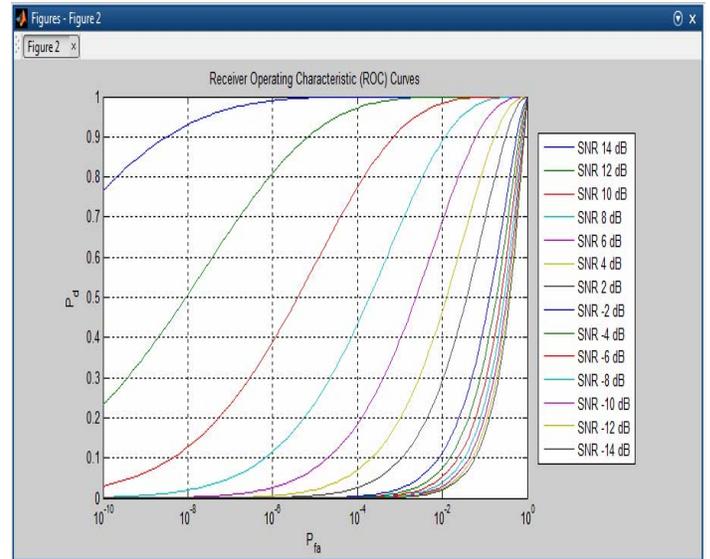


Figure 5 Receiver Operating Characteristics (ROC) Curves

The compilation of the results for the entire signal to noise ratios has been shown in figure 5. The table 1 and table 2 show that simulation and theoretical values of probability of detection for different values of SNR curves. Here probability of false alarm is taken as 0.01 and 0.1 from the receiver operating characteristics curve it is observed that detection performance of the receiver is better at higher SNR values and the simulation and theoretical values matches at higher SNR values.

In this part simulation was run several times to compare the observations with the expected parameters. At SNR = +14 dB, which can let the energy detector performs best, the false alarm probability = 0.01, probability of missed detection = 0,

then as the probability of false alarm has been increased from 0.01 to 0.1 which defines a threshold in case of energy detector, the improvement has been observed at SNR = +12 dB, as shown in ROC curve the probability of detection increases with increase in signal to noise ratio with an increase in threshold value i.e. probability of false alarm. In a nutshell with the decrease in the SNR value the clutter in the background increases and thus causes detection issues.

V. CONCLUSION

Cognitive Radio techniques can improve utilization of the spectrum holes of the licensed bands efficiently. It intelligently detects the Spectrum holes. In this paper different Spectrum Sensing techniques and their advantages and disadvantages are discussed. In terms of performance, the Energy detector is the easiest to implement, however its threshold is highly susceptible to inband and outband noises. It can be easily concluded as the number of users increases the detection probability is higher for low values of SNR and for higher SNR values there is hardly a huge difference. For low probability of false alarm the minimum number of users required is more as the threshold is less whereas for higher false alarm probability one requires fewer users as threshold is more. Further noise issues were discussed which occurred as a major problem in Cognitive Radio networks. To address this issue improved periodogram technique was discussed. Also the proposed technique has been implemented in simulation and found improvement in the performance efficiency of Energy detector. In order to find the receiver operating characteristics (ROC) analysis, suppose a signal at arbitrary frequency is taken and applied to the energy detector. This is considered as primary user’s signal and the detector is used to find the peaks at specific frequency points. A particular secondary user is allowed to test for the signal for a number of times and the probability of correctly identifying the primary users gives the probability of detection whereas the threshold for detection is decided by the probability of false alarm. Figure 3 and figure 4 shows the ROC curves for different SNR values for a total of 5 channel model including primary and secondary users also for optimal number of users. It has been observed that probability of detection is higher for higher SNR values as compared to other techniques with Pfa=0.1. The probability of detection has been improved with the proposed technique. Therefore the results are satisfactory and the energy detector performs efficiently in the simulation.

VI. FUTURE SCOPE

To optimally utilize the spectrum an intelligent radio technique has been discussed which is known as energy detection and one of the cognitive radio techniques. Further researches in the study of cognitive radio techniques using the energy detection method may consider fading channels with the proposed technique with regard to the SNR. In this regard experiments need to be conducted in real world scenario. By increasing weightage to the user detection can be further improved with reference to event of miss detections. The

proposed method can be applied to other spectrum sensing techniques also. It becomes more complex to go beyond the simulation and coding although a hardware implementation of the proposed technique can be put to real time sensing.

SNR	P <sub>d</sub>	P <sub>fa</sub>	P <sub>md</sub>
+14	1	0.01	0
+12	0.9995	0.01	0.0005
+10	0.9841	0.01	0.0159
+8	0.8899	0.01	0.1101
+6	0.6898	0.01	0.3102
+4	0.4661	0.01	0.5339
+2	0.2925	0.01	0.7075
-2	0.1145	0.01	0.8855
-4	0.0758	0.01	0.9242
-6	0.0529	0.01	0.9471
-8	0.0389	0.01	0.9611
-10	0.0301	0.01	0.9699
-12	0.0244	0.01	0.9756
-14	0.0205	0.01	0.9795

Table: 1

SNR	P <sub>d</sub>	P <sub>fa</sub>	P <sub>md</sub>
+14	1	0.1	0
+12	1	0.1	0
+10	0.9993	0.1	0.0007
+8	0.9884	0.1	0.0116
+6	0.9382	0.1	0.0618
+4	0.8314	0.1	0.1686
+2	0.6911	0.1	0.3089
-2	0.4371	0.1	0.5629
-4	0.3485	0.1	0.6515
-6	0.2834	0.1	0.7166
-8	0.2362	0.1	0.7638
-10	0.2020	0.1	0.798
-12	0.1771	0.1	0.8229
-14	0.1588	0.1	0.8412

Table: 2

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