Centralized Cooperative Spectrum Sensing Optimization through Maximizing Network Utility and Minimizing Error Probability in Cognitive Radio

Tarangini Shukla, Mr. Pradeep Yadav

***Abstract*— Spectrum Sensing is an emerging technology in the field of wireless communication. It is an essential functionality of Cognitive Radio (CR) where it is used to detect whether there are primary users currently using the spectrum. Selection of suitable spectrum sensing technique is an important task, and it depends on accuracy and speed of estimation. Energy Detection technique is the most commonly used method for spectrum sensing. Non-cooperative spectrum sensing i.e. signal detection by single user suffers from several drawbacks. These drawbacks include shadowing/fading and noise uncertainty of wireless channels. Hence, to overcome these disadvantages, a new methodology called Cooperative Spectrum Sensing (CSS) has been suggested in the literature. This thesis deals with the comparison of conventional spectrum sensing techniques and based on the computational complexity, accuracy and speed of the estimation, suitable sensing method i.e. energy detection technique will be selected. Here, we consider the optimization of conventional energy detection based CSS. In CSS, several CR's cooperatively detect the unused frequency slots called spectrum holes/white spaces. Generally, in CSS at the fusion centre, two data combining techniques are used which are soft combining and hard combining. Hard combining technique has gained importance due to its simplicity and it deals with three decision rules which are 'AND rule', 'OR rule' and 'MAJORITY rule'. In hard combining only hypothesis output will be sent to the fusion centre, which decides about the presence of the primary user. For optimization, we have considered the network utility function and error probability. In order to achieve the goal we have proposed that the optimum voting rule is half voting rule also known as majority rule in 'n out of K' rules and obtained optimal number of cognitive radios by applying the hard decision rules. A method of obtaining the optimal detection threshold, numerically, has been presented. The optimal conditions have been verified through simulation results over an AWGN channel and it is concluded that, in proposed optimization scheme 'MAJORITY rule (half voting rule)' out performes the 'AND rule' and 'OR rule'. It has been found that the suitable selection of CR can achieve better utility function with minimum error probability for any wireless environment.**

***Index Terms*— cognitive radio, energy detection, cooperative sensing.**

I. INTRODUCTION

Cognitive radio (CR) is a new way technology to compensate the spectrum shortage problem for wireless environment. The demand of radio spectrum increases proportionally with the increase in number of users, and thus it causes a significant increase in utilization of spectrum. The major hurdle in the current spectrum scarcity is the fixed spectrum assignment. This spectrum shortage problem has a deep impact on research directions in the field of wireless communication. It enables much higher efficiency of spectrum by dynamic spectrum access. It allows unlicensed users to utilize the free portions of licensed spectrum while ensuring that it causes no interference to primary users' transmission. Cognitive radio cycle shows figure 1,

The wireless technology rides on the spectrum that is being allocated by the Federal Communications Commission (FCC) to the service providers with the help of government bodies. The service providers then provide the wireless services to the end users. The allocated spectrum to the service providers is only for the licensed user, and in some cases the spectrum is not utilized to the fullest of its extent. The wireless technology is being adapted by people very fast and there is an increase in the number of its users day by day, this is leading to scarcity of spectrum [1]. Spectrum sharing or reusing the available spectrum band is the only option left. Spectrum sharing initially was without any cost, but due to new regulatory policies "secondary markets" are available in certain countries where service providers benefits finically from sharing the spectrum on static or dynamic basis [2].

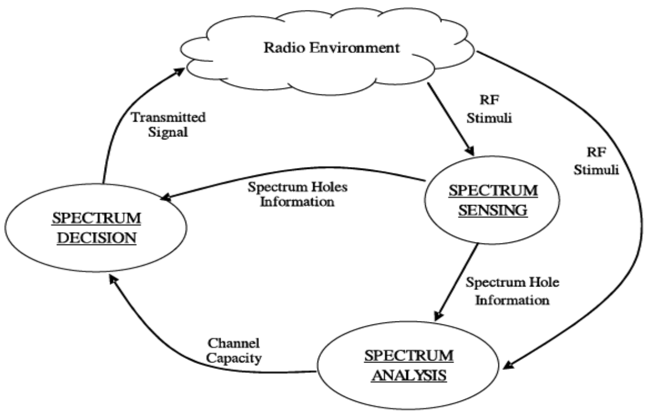

Figure 1 The Cognitive Cycle [2]

II. SPECTRUM SENSING

Spectrum sensing (SS) is the procedure that a cognitive radio user monitors the available spectrum bands, captures their information, reliably detects the spectrum holes and then shares the spectrum without harmful interference with other users. It still can be seen as a kind of receiving signal process, because spectrum sensing detects spectrum holes actually by local measurement of input signal spectrum which is referred

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to as local spectrum sensing. The cognitive users in the network don't have any kind of cooperation. Each CR user will independently detect the channel through continues spectrum sensing, and if a CR user detects the primary user it would vacate the channel without informing the other CR users.

The goal of spectrum sensing is to decide between the following two hypotheses:

H_0: Primary user is absent

H_1: Primary user is present in order to avoid the harmful interference to the primary system.

A typical way to detect the primary user is to look for primary transmissions by using a signal detector. Three different signal processing techniques that are used in the systems are matched filter, energy detector and feature detection. In the next subsections we discuss advantages and disadvantages about them

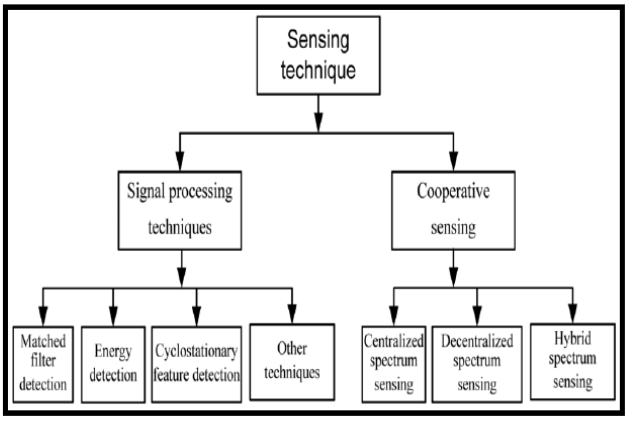

Figure 2 Classification of Spectrum Sensing Techniques

Matched filter [26] is an optimal way for any signal. It is a linear filter which maximizes the received signal-to-noise ratio in the presence of additive stochastic noise. However, a matched filter effectively requires demodulation of a primary user signal.

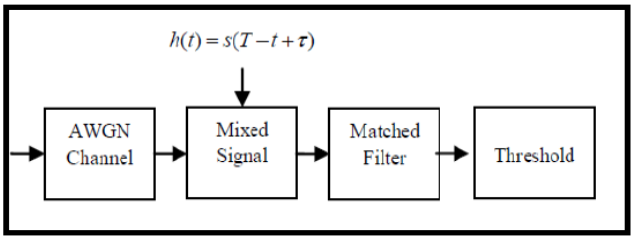

Figure3 Block Diagram of Matched filter detection

If X[n] is completely known to the receiver then the optimal detector is:

$$T(Y) = \sum_{n=0}^{N-1} Y[n]X[n] \gtrless_{>H_0}^{<H_1} \gamma$$

Here γ is the detection threshold, and then the number of samples required for optimal detection is:

$$N = [Q^{-1}(P_D) - Q^{-1}(P_{FD})]^2 (SNR)^{-1} = O(SNR^{-1})$$

Matched filter approach is to perform non-coherent detection through energy detection [26]. The structure of an energy detector is shown in Figure 4.

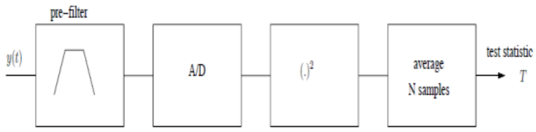

Figure 4 Block diagram of an Energy Detector. [26]

In this case we have:

$$T(Y) = \sum_{n=0}^{N-1} Y^2[n] \gtrless_{>H_0}^{<H_1} \gamma$$

$$N = 2[Q^{-1}(P_{FA}) - Q^{-1}(P_D)]^2 = O(SNR^{-2})$$

These features are detected by analyzing a spectral correlation function SCF. The main advantage of this function is that it differentiates the noise from the modulated signal energy. This is due to the fact that noise is a wide-sense stationary signal with no correlation however modulated signals are cyclo-stationary due to embedded redundancy of signal periodicity. Analogous to autocorrelation function spectral correlation function (SCF) can be defined as:

$$S_x^{\alpha}(f) = lim_{T\to\infty} lim_{\Delta t\to\infty} \int_{-\Delta t/2}^{+\Delta t/2} \frac{1}{T} X_T\left(t, f+\frac{\alpha}{2}\right) X_T^*\left(t, f-\frac{\alpha}{2}\right) dt,$$

Where the finite time Fourier transforms is given by:

$$X_T(t,\nu) = \int_{t-T/2}^{t+T/2} x(u)e^{-j2\pi\nu u}\, du.$$

Spectral correlation function (SCF) is also known as cyclic spectrum. While power spectral density (PSD) is a real valued one dimensional transform, SCF is a complex valued two dimensional transform. The parameter α is called the cycle frequency. If $\alpha = 0$ then SCF gives the PSD of the signal.

III. SYSTEM DESCRIPTION

The CR network, which shares the same spectrum band with a license system, utilizes a cluster-based CSS scheme as shown in Figure 5.

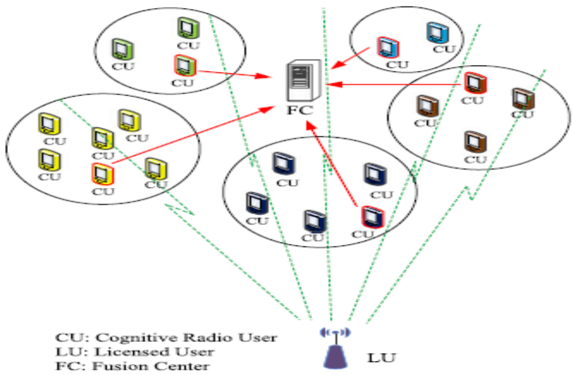

Figure 5 System Model

This identical SNR assumption can be practical when the clusters are divided according to geographical position, i.e., adjacent CUs in a small area are gathered into a cluster. The header in each cluster is not fixed but dynamically selected for each sensing interval based on the quality of the sensing data at each CU. In detail, the node with the most reliable sensing result will take on the cluster header's roles which include making and reporting the cluster's decision to the FC.

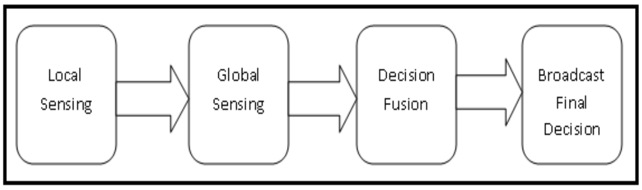

Figure 6 System model depicting the flow from sensing to final decision

In order to reduce the reporting time and bandwidth, only the sensing data of the cluster header, which is the most reliable sensing data, is utilized to make the cluster decision. This method means that the decision of a cluster is made according to the selective combination method. The FC will combine all cluster decisions to make a final decision and broadcast the final sensing decision to the whole network.

The fusion rule in the FC can be any kind of hard decision fusion rules such as an OR rule, AND rule, 'K out of N' rule, or Chair-Varshney rule. Without loss of generality, we propose the utilization of the optimal Chair-Varshney rule at the FC since the SNR value of the received primary signal at the CU is available in this proposed scheme. However, there are three issues with the proposed scheme that need to be considered next step.

IV. Cognitive Radio Model

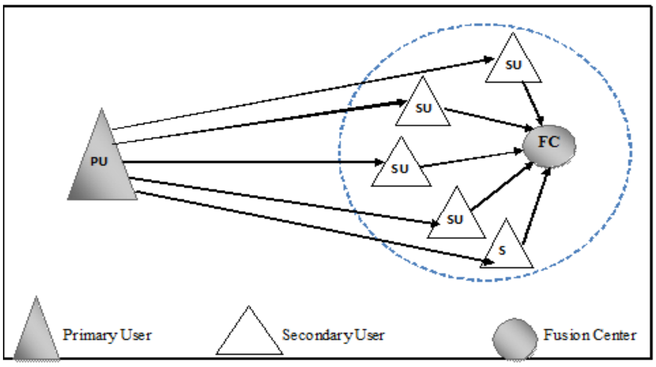

Figure 7 System Model of CR Network

We consider a CR system, which consists of N (network size) number of CR's, K No.of CR's in cooperation and a common receiver (Fusion Center). Fusion Centre functions as a Base Station (BS) in a cellular network and as an Access Point (AP) in WLAN (Wireless Local Area Network). We assume that each CR senses the spectrum independently using the conventional energy detector and sends the local decisions (either binary 1 or 0) to the FC. Fusion Centre performs hard decision fusion then decides the absence or presence of PU. The local spectrum detection is used to decide between two binary hypothesis testing problems. PU is absent will be considered under hypothesis H0, and PU is present under hypothesis H1.

In the above structure, i number of CRs are present. We consider spectrum sensing at the i^{th} CR only. The signal received by the i^{th} CR is given as [16]:

$$y_i(t) = u_i(t) \qquad \text{H0}$$

$$y_i(t) = h_i(t)s_i(t) + u_i(t) \qquad \text{H1}$$

Where $u_i(t)$ is the Gaussian noise signal, $h_i(t)$ is the sensing channel gain and $s_i(t)$ is the transmitted signal by the PU.

The primary objective of cooperative spectrum sensing is to decrease the probability of misdetection, false alarm, sensing time and to increase the detection probability. Cooperative sensing is usually implemented in two stages i.e. detecting and reporting. Cooperative sensing deals with the two channels, one is sensing the channel and another one is reporting channel and uses the control channel to share spectrum sensing result. In the CSS, fusion center plays a significant role. It handles the decisions either 1 or 0. If the primary user is present, then it sends the binary decision 1 or else 0. Based on the decision secondary user occupies the frequency band.

In centralized sensing, a common receiver plays a significant role. The primary task is to collect the data from secondary users and detects the spectrum availability.

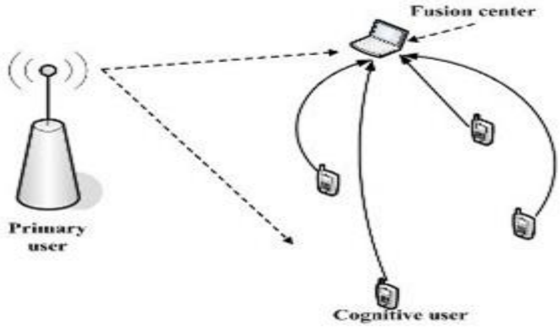

Figure 8 Centralized Cooperative Spectrum Sensing

Decentralized sensing, all the cognitive radios share the data among each other, and the will take their decision as per their used radio spectrum. In decentralized technique, cognitive radios share only final information or final decision to reduce the network overhead due to collaboration.

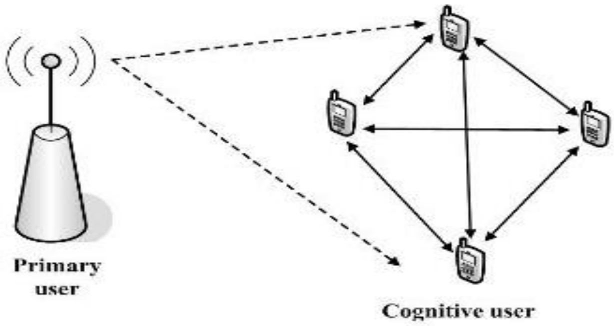

Figure 9 Decentralized Cooperative Spectrum Sensing

V. Data Fusion Rule

CSS deals with the hard decision and soft decision combining techniques. Totally there are six fusion rules are presented in the literature they are soft Optimal Linear mixing, Likelihood Ratio combining, soft Equal Weight combining, and hard decision combined with the AND, OR, and the MAJORITY counting rules. Because of simplicity most famous combining technique is hard decision combining contains OR, AND, and the Majority counting rules. In the implementation of hard decision rules, the fusion centre or central unit produce an n out of M rule that decides on the hypothesis testing at the secondary user. Whenever one secondary user sends output as one i.e., H1, then it comes under OR logic rule similarly if all the secondary users send output as one then it comes under AND logic rule. If majority secondary users send the decision as one then it comes under MAJORITY rule. Assuming uncorrelated decisions, the probability of detection, probability of false alarm and probability of miss detection at the fusion centre are given by [16]:

$$Q_f(K) = \sum_{j=n}^{K} \binom{K}{j} P_f^{\,j} (1-P_f)^{K-j}$$

$$Q_m(K) = 1 - \sum_{j=n}^{K} \binom{K}{j} P_d^{\,j} (1-P_d)^{K-j}$$

$$Q_d(K) = 1 - Q_m(K)$$

There are three rules under hard fusion combining AND rule, OR rule and MAJORITY rule.

OR Rule:

AND rule is implemented when the sensing threshold is low, and at that time all the cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule can be calculated by putting n=1 in the above Equations:

$$Q_d(K) = 1 - \prod_{i=1}^{K}(1-P_{d,i})$$

$$Q_f(K) = 1 - \prod_{i=1}^{K}(1-P_{f,i})$$

$$Q_m(K) = 1 - Q_d(K)$$

AND Rule:

OR rule is implemented when the sensing threshold is high and thus only one or very few cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule will be calculated by putting n=N in the above equations:

$$Q_d(K) = P_{d,i}{}^{K}$$

$$Q_f(K) = P_{f,i}{}^{K}$$

$$Q_m(K) = 1 - Q_d(K)$$

MAJORITY Rule:

The MAJORITY rule is implemented when more than half of the cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule can be calculated by putting n= $\lfloor N/2 \rfloor$ in the above equations

$$Q_{f,maj} = \sum_{\lfloor \frac{N}{2} \rfloor}^{N} \binom{N}{k} P_f^{\,j} (1-P_f)^{K-j}$$

$$Q_{d,maj} = \sum_{\lfloor \frac{N}{2} \rfloor}^{N} \binom{N}{k} P_d^{\,j} (1-P_d)^{K-j}$$

$$Q_m(K) = 1 - Q_d(K)$$

VI. RESULTS

When plotted the Receiver Operating Characteristic (ROC) curve under the AWGN non fading and Rayleigh fading channel we the plot as shown in Figure 10. It can be seen that the

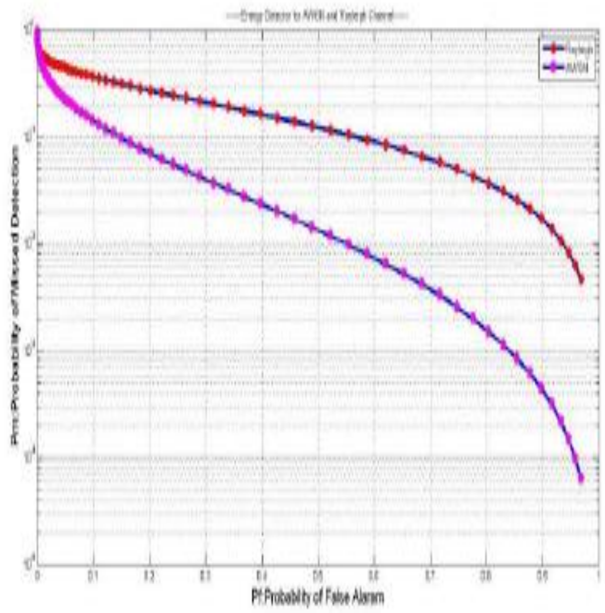

Figure 10 ROC for Energy detector plotted for PF versus PM

TABLE 1: AWGN VERSUS RAYLEIGH FADING CHANNEL FOR ENERGY DETECTOR

Threshold	Rayleigh Channel		AWGN Channel	
	Probability of False Alarm	**Probability of Missed**	**Probability of False Alarm**	**Probability of Missed**
10	**0.0046**	**0.9682**	**6.4E-5**	**0.9682**
30	**0.4042**	**0.0699**	**0.1825**	**0.0699**
50	**0.7571**	**0.0002**	**0.8241**	**0.0002**

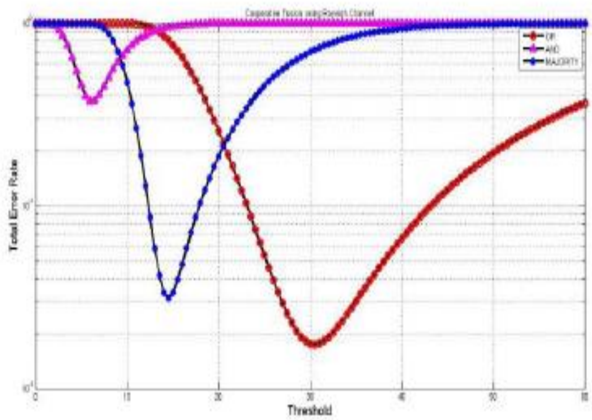

Figure 5.2 Centralized Cooperative sensing implemented using AND rule, OR rule, MAJORITY rule for N=10 and SNR=10dB

TABLE 2: VOTING RULES (AND, OR, MAJORITY) IMPLEMENTATION

Threshold	**Total Error Rate**		
	AND Rule	**OR Rule**	**MAJORITY Rule**
10	0.7111	0.9970	0.4712
30	0.9999	0.0177	0.6958
50	1.000	0.1950	0.9899

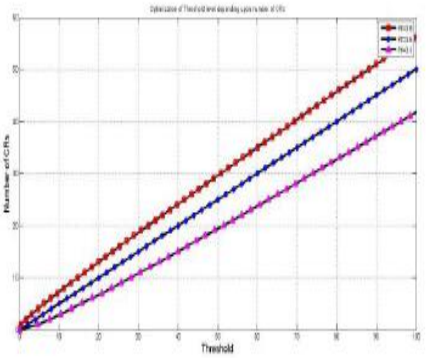

Figure 5.3: Optimization of Threshold value, plotted for Threshold versus Number of Cognitive Radios (CR) for Pf= 0.1, 0.5, 0.8

TABLE 3: OPTIMIZATION OF THRESHOLD VALUE FOR NUMBER OF RADIOS VERSUS PROBABILITY OF FALSE ALARM (PF) = 0.8, 0.5, 0.1

Number of cognitive Radios	Threshold(λ)		
	PF=0.8	PF=0.5	PF=0.1
0	0	0	0
5	6	10	15.73
10	14.68	20	28.10
15	23.48	30	39.92
20	32.47	40	51.46
25	41.58	50	62.82
30	50.78	60	74.04

VII. Conclusion

The wireless spectrum is limited and getting scarce, thus to have maximum utilization we use cognitive radio where we share the available resources in adaptive manner. For spectrum sensing energy detector is used, as easy to implement and does not require synchronization information to monitor.

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