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Advanced Technique for Cooperative Spectrum Sensing Optimization in Cognitive Radio Network

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Abstract— **Cognitive radio (CR) is an emerging technology that enables the flexible development and deployment of highly adaptive radios that are built upon software defined radio technology. These types of networks have applications in dynamic spectrum access, co-existence of different wireless network, interference management, etc. They are touted to drive the next generation of devices, protocol and applications. The cognitive radio network paradigm poses many new technical challenges in protocol design, power efficiency, spectrum management, spectrum detection and distributed spectrum managements. The optimal rule for any detector applied to cooperative spectrum sensing.**

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].

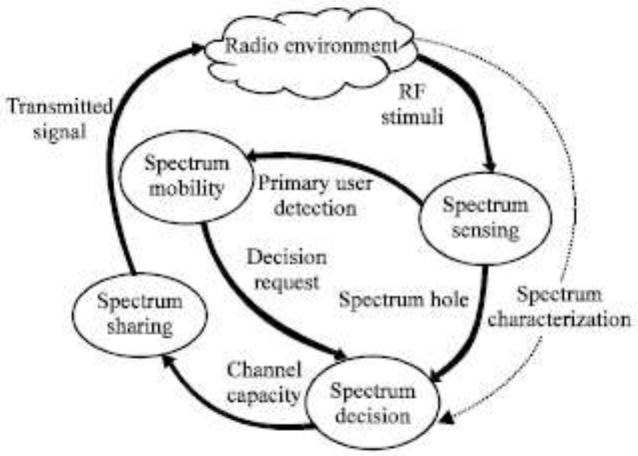

Figure 1 The Cognitive Phase [2]

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 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:

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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

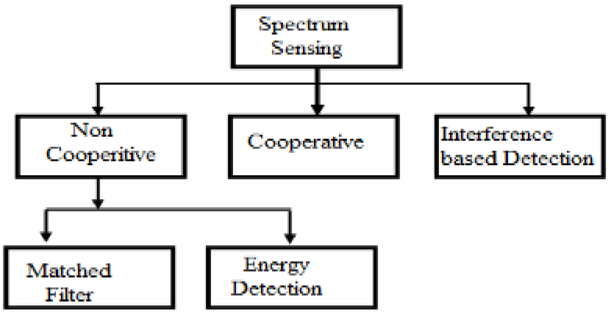

Figure 2 Classification of Spectrum Sensing Techniques

A. *Energy Detection*

The aim of the spectrum sensing is to decide between two hypotheses which are

$$x(t) = w(t), H_0 \qquad \text{(Primary User absent)}$$

$$x(t) = h * n(t) + w(t), H_1 \qquad \text{(Primary User present)}$$

Where x(t) is the signal received by the CR user, n(t) is the transmitted signal of the primary user , w(t) is the AWGN band, h is the amplitude gain of the channel. H0 is a null hypothesis, which states that there is no licensed user signal.
Energy Detection is a simple detection method. The energy detection is said to be a blind signal detector in light of the fact that it overlooks the structure of the signal. Energy detection is based on the rule that, at the receiving end, the energy of the signal to be detected is computed. It estimates the presence of a signal by comparing the energy received and a known threshold λ derived from the statistics of the noise.

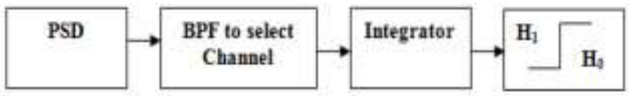

Figure 3: Energy Detector Block Diagram

B. *Matched Filter Detection*

The best sensing technique in AWGN environment without ant prior information about the signal is ED technique. If we considered the signal structure, then we can get best performance by using matched filter method.
Matched filter is a linear filter which used to maximize signal to noise ratio in presence of additive noise. It provides coherent detection. A coherent detector uses the knowledge of the phase of the carrier wave to demodulate the signal.

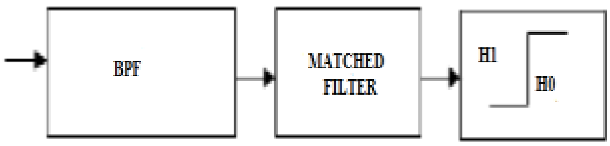

Figure 4: Matched filter Block diagram

III. Classification Model

System being designed should provide an efficient spectrum trading mechanism with the desired properties such as power efficiency, allocation fairness, incentive compatibility, Pareto efficiency, and so on. The proposed cognitive radio system operates as follows. In the beginning, an initial spectrum sensing is performed, in order to determine the status (active/idle) of the frequency band. When the frequency band is detected to be idle, the secondary transmitter accesses it for the duration of a frame by transmitting information to the secondary receiver transmitting information to the secondary receiver.

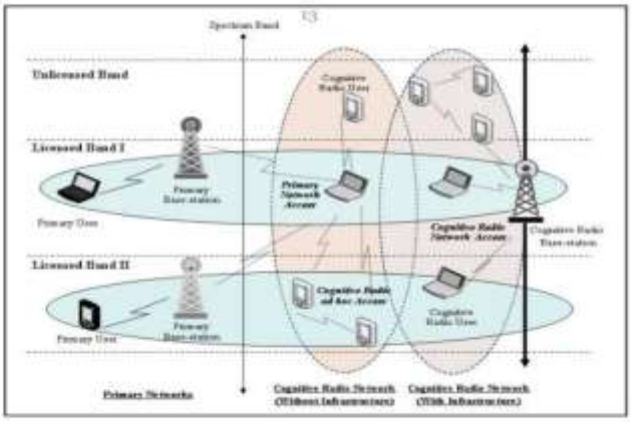

Figure 5: cognitive radio structural design

The cognitive radio platform abides by the policies defined by government agencies like the *Federal Communications Commission* (*FCC*) in USA and Department of telecommunications *(DoT)* in India to use the unused spectrum available, sometimes termed as white space, efficiently so that all the secondary users can share these spectrum bands for communication. The project focuses on spectrum sensing and spectrum management and also provides an efficient path which corresponds to highest throughput providing services to the users thus making maximum use of the available spectrum.
The latter decodes the signal from the secondary transmitter, strips it away from the received signal, and uses the remaining signal for spectrum sensing, in order to determine the action of the cognitive radio system in the next frame. At the end of the frame, if the presence of primary users is detected, namely if the primary users started transmission after the initial spectrum sensing was performed, data transmission will be ceased, in order to protect the primary users from harmful interference. In the opposite case, the secondary users will access the frequency band again in the next frame. Finally, the process is repeated.
In order to solve the conflicts between spectrum scarcity and spectrum under-utilization, cognitive radio (CR) technology has been recently proposed. It can improve the spectrum utilization by allowing secondary networks (users) to borrow unused radio spectrum from primary licensed networks (users) or to share the spectrum with the primary networks (users)[2]. As an intelligent wireless communication system, a cognitive radio is aware of radio frequency environment. It will going to select the communication parameters (such as carrier frequency, bandwidth, and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly.

Optimal voting rule for any detector applied to cooperative spectrum sensing and also optimize the detection threshold when energy detection is employed. Finally a fast spectrum sensing algorithm for a large network which requires fewer than the total number of cognitive radios in cooperative spectrum sensing while satisfying a given error bound is proposed. 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. Model of CR

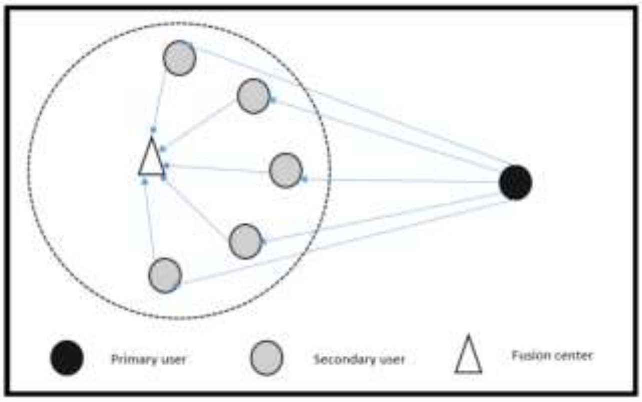

Figure 7 System Model of CR Network

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]:

$$y_i(t) = u_i(t) \qquad\qquad H0$$
$$y_i(t) = h_i(t)\, s_i(t) + u_i(t) \qquad H1$$

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.

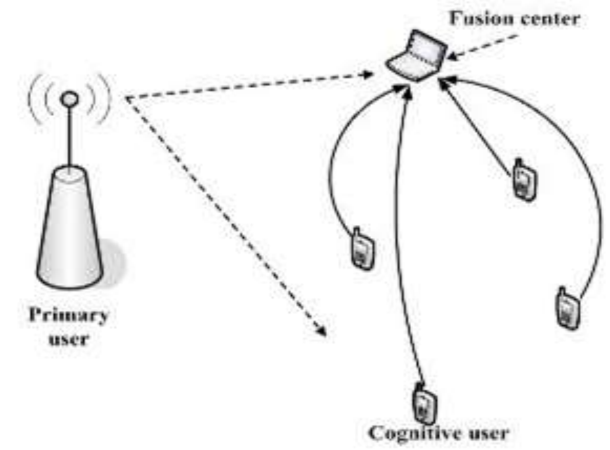

Figure 8 Centralized Cooperative Spectrum Sensing

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.

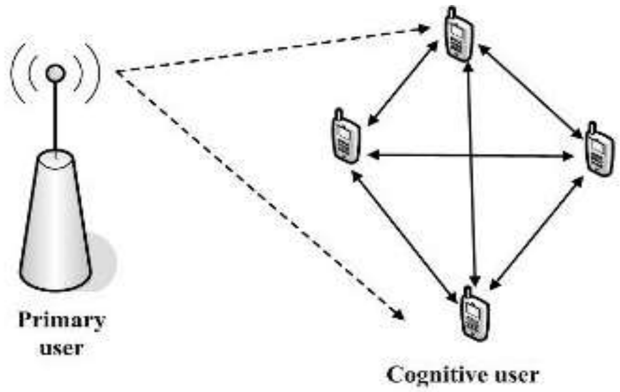

Figure 9 Decentralized Cooperative Spectrum Sensing

V. 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]:

$$Q_f(K) = \sum_{j=n}^{K} \left(\frac{K}{j}\right) P_f^j \,(1-P_f)(1-P_f)^{k-j}$$

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

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

OR 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 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:

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 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:

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

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

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

VI. Results

When plotted the Receiver Operating Characteristic (ROC) curve under the AWGN non fading and Rayleigh fading channel plot as shown in Figure 10 and table 1 show AWGN Versus Rayleigh Fading Channel for Energy Detector.

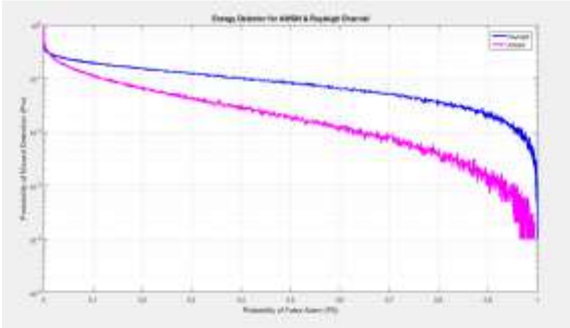

Figure 10: ROC for Energy detector plotted for PF versus PM

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 11 shows the Centralized Cooperative sensing implemented using AND rule, OR rule, MAJORITY rule for N=10 and SNR=10dB. In table 2 show AND, OR, MAJORITY implementation with different threshold value.

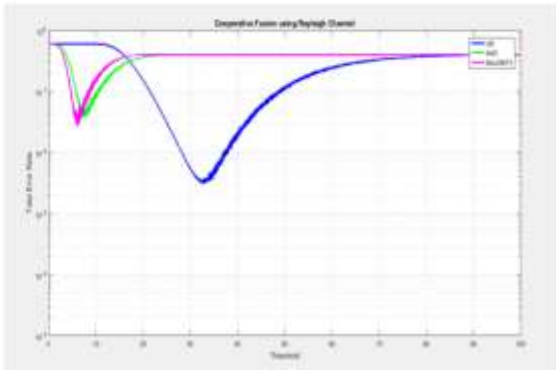

Figure 11: Centralized Cooperative sensing implemented using AND rule, OR rule, MAJORITY rule for N=10 and SNR=10dB

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	0.1950	0.9899

Figure 12 shows Optimization of Threshold value, plotted for Threshold versus Number of Cognitive Radios (CR) for Pf= 0.1, 0.5, 0.8 and table 3 shows Optimization Of Threshold Value For Number Of Radios Versus Probability Of False Alarm (Pf) = 0.8, 0.5, 0.1 with different Number of cognitive Radios.

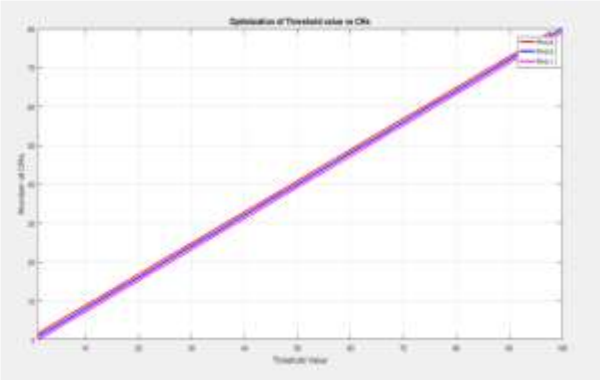

Figure 12: Optimization of Threshold value, plotted for Threshold versus Number of Cognitive Radios (CR) for Pf= 0.1, 0.5, 0.8

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

The comparison of different hard decision rules at the fusion center for showing the network utility versus energy threshold. From Figure 13, we have concluded that half voting rule must be implemented for achieving better network utility with minimum error probability.

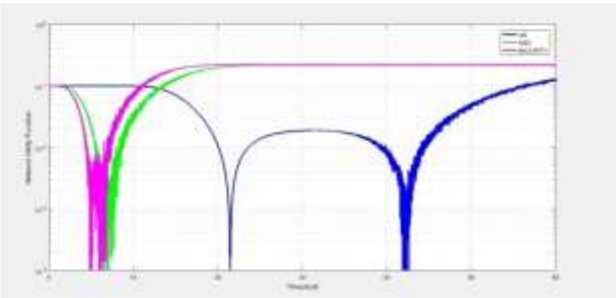

Figure 13: Comparison of fusion rules for different thresholds

The Receiver Operating Characteristic (ROC) curve under the AWGN Non fading and Rayleigh fading channel plot as shown in Figure 14.

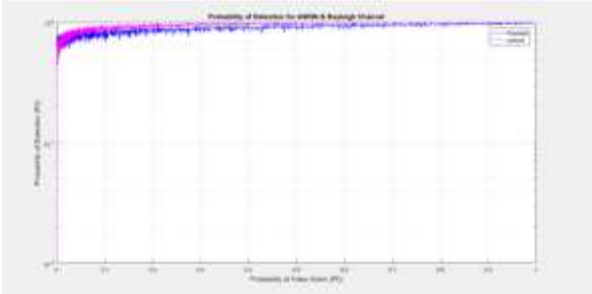

Figure 14: ROC for Energy detector plotted for PF versus PD

VII. Conclusion

The performance of cooperative sensing with energy detection in cognitive radio networks has been found that the optimal decision voting rule to minimize the total error probability is the half-voting rule. A method of numerically obtaining the detection threshold has been presented. Cognitive radio is an immature but rapidly developing technology area. In terms of spectrum regulation, the key benefit of CR is more efficient use of spectrum, because CR will enable new systems to share spectrum with existing legacy devices, with managed degrees of interference.

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