SNR Based Adaptive Spectrum Sensing in Cognitive Radio Networks

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***Abstract* - A Cognitive Radio(CR) is an evolved Software Defined Radio (SDR) that, in addition to the re-configuration capability, also has the ability to analyze its surrounding radio environment and decide how best to re-configure itself. The CR has the ability to identify any opportunities that exist in the spectrum band of interest and utilize them without causing any interference to the Primary users (PU). The process by which the CR identifies the existence of spectrum holes is termed as spectrum sensing and is the key challenge for implementation of a CR. The methods of spectrum sensing for cognitive radio are based on matched filter method, energy detection method, and cyclostationary feature detection method. Energy detection is the simplest detection method and most commonly used method. Energy detection has a hidden terminal problem in real time communication, because the secondary user can be affected by fading and shadowing. Cooperative spectrum sensing can be solving this problem using spatial diversity. So, the proposed system model using adaptive spectrum sensing algorithm is simulated. Adaptive spectrum sensing algorithm method consider both single energy sensing and cooperative energy sensing according to the received Signal to Noise Ratio (SNR) from Primary User (PU). The simulation results show that adaptive spectrum sensing has an efficiency and improvement in CR.**

Index Terms --- Cognitive Radio (CR), Software Defined Radio (SDR), Energy Detection, Adaptive Spectrum Sensing, Cooperative Sensing.

I. INTRODUCTION

Traditional spectrum allocation policies are facing scarce radio frequency resources due to the proliferation of wireless service. With the increases of customers in wireless network services, the demand for radio spectrum is also increasing significantly. The trends of new wireless devices and applications are expected to continue in coming years which will increase the demand for spectrum. The radio spectrum is limited resource and is regulated by authorized agencies such as the Federal Communication Commission (FCC) [1]. Cognitive Radio (CR) technology has been recently proposed as a solution to solve the conflicts between spectrum scarcity and spectrum under utilization. This is done by allowing secondary user to utilize the unused radio spectrum from primary user network. By sensing and adapting to the environment, a cognitive radio to fill in spectrum holes and serve its users without causing harmful interference to the licensed user. A number of different techniques have been proposed for identify the presence of the primary user signal transmission. The existing spectrum sensing techniques can be broadly divided into three categories: cyclostationary detection, matched filter detection and energy detection techniques are widely used as detection techniques. Energy detection has been widely used because it does not require any priori knowledge of the primary signals and has much lower complexity than others two techniques. Energy detection does not need any priori knowledge about the primary signals. So, it has been studied both local spectrum sensing. To deal with the hidden terminal problem in cognitive radio networks, more cognitive users can cooperate to conduct spectrum sensing. The spectrum sensing performance can be greatly improved with an increase the number of cooperative users. To improve the throughput for the CR users adaptively using time varying channels and Channel State information CSI. In cognitive radio systems, secondary users can be coordinated to perform cooperative spectrum sensing so as to detect the primary user more correctly.

The detection performance can be primarily determined on the basis of two matrices: probability of false alarm and probability of detection. The Probability of false alarm denotes the probability of a cognitive radio user declaring that a primary user is present and the spectrum is actually free. The Probability of detection denotes the probability of a cognitive radio user declaring that a primary user is present and the spectrum is occupied by the primary user. Cognitive Radio implementations many technical challenges including spectrum sensing, dynamic frequency selection, adaptive modulation and wideband frequency-agile RF front-end circuitry. That means CR users need to detect the primary users present or absent because CR users need to use unlicensed band without interference to the primary users. In cooperative spectrum sensing, cognitive radio users share the sensing information to the other cognitive radio users. Cooperative spectrum sensing can be classified into: centralized, distributed and relay assisted. As a simulation, CR users have a better chance to detect the primary user and reducing the problem such as frequency fading, multipath fading and shadowing. We proposed adaptive spectrum sensing between single energy sensing and cooperative energy sensing.

The rest of this paper is organized as follows. Section II Describes the system model and Section III describes performance of the system and simulation results are presented. Finally, conclusions are given in Section IV.

II. SYSTEM MODEL

In our system model, cognitive radio system must be secured maximal spectrum holes through the spectrum sensing quickly and accurately. Spectrum sensing method senses the unused spectrum range. One of the techniques widely used such as energy detection because it has the simplest method by detecting without primary user information. Secondary user can be affected by fading and shadowing in real communication environments. Cooperative spectrum sensing is proposed to solve hidden terminal problem. Cooperative spectrum sensing has good performance the more cooperative secondary users. But cooperative spectrum sensing has additional problems of the traffic overhead. So we proposed adaptive spectrum sensing method according to secondary users estimated SNR status by selecting single sensing and cooperative sensing adaptively. If the secondary user has sufficient SNR to detect reliable so we proceed with a single energy sensing otherwise cooperative energy sensing.

$$\text{Detection techniques}=\begin{cases}\text{Single Energy Sensing} & \text{if SNR} > k \\ \text{Cooperative Energy Sensing} & \text{if SNR} < k\end{cases}$$

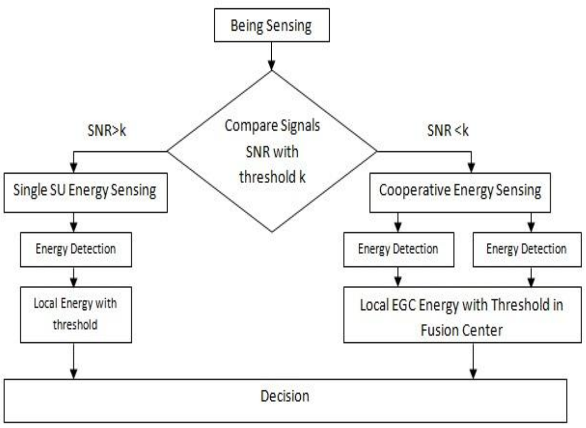

Figure-1: Adaptive Spectrum Sensing Model.

A. Energy Detector

At the energy detector, the received signal r(k) can be formulated as hypothesis test with H_0 (signal is not present) or H_1 (signal is present)

$$H_0: y(k) = v(k),$$
$$H_1: y(k) = h(k)s(k)+v(k), \quad (1)$$

Where k denotes the sample index, h(k) denotes impulse response of the channel between the primary user and secondary users, s(k) is the signal from primary user with zero mean and unit variance $E\{|s(k)|^2\} = 1$, v(k) denotes Additive White Gaussian Noise(AWGN) and H_0,H_1 represent hypothesis corresponding to the absence and presence of the primary users signal. We assume that the channel h(k) is unchanged during the sensing process, say $h(k) = h_0$.

We consider the use of energy detection for the spectrum sensing. The energy detector can be represented as

$$T_N(y) = \frac{1}{N}\sum_{n=1}^{N}|y(k)|^2 \quad (2)$$

Where N is the number of samples and k is the threshold level to be determined.

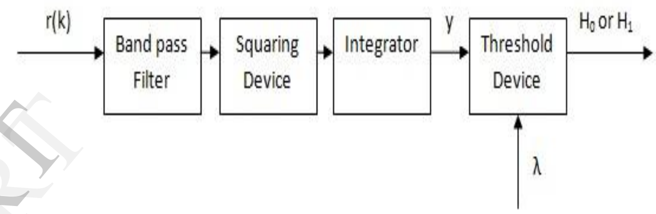

Figure-2: Energy Detector

Single SU Energy Sensing input signal consider only the Signal to Noise Ratio greater than threshold value. The received signal at an energy detector will be filtered by an ideal bandpass filter with bandwidth W. Then using a magnitude squaring device, the received energy, Y is measured over an observation time of T and compared with a predetermined threshold λ to decided whether the signal is present or not.

B. Cooperative Spectrum Sensing

Cooperative spectrum sensing scheme is used as a promising solution to detect the primary user effectively in highly noisy environment, where the multiple secondary users make a global decision in relation to the primary user. Cooperation spectrum sensing (CSS) is a solution to problems that arise in spectrum sensing due to noise uncertainty, fading and shadowing. CSS function is classified in to two parts such as local sensing and global decision part. The local sensing has been performed by spectrum sensing and the global decisions are performed by fusion center (FC).

The performance of the spectrum sensing can be characterized by the probability of missed detection P_{md} and the probability of false alarm P_f.The probabilities of correct detection are given by Prob$\{Decision = H_1|H_1\}$, Prob$\{Decision = H_0|H_0\}$, and the false alarm probability given by Prob$\{Decision = H_0|H_1\}$.

C. Probability Of Detection And Probability Of False Alarm

The following of the two schemes have the two hypotheses in common for spectrum sensing at the k^{th} time instant as follows

From the above equation (1), consider H_0 is the primary user is absent and H_1 is a primary user is present. The fading coefficient is h, s(k) is the transmitted signal by the primary user and v(k) is the additive white Gaussian noise(AWGN). If the H_1 cell is tested, the probability density function (PDF) of the received signal $y^i_c(k)$ at the i^{th} CR user can be expressed as

$$f_{y_c^i}(y\,|\,H_1)=\frac{1}{\sqrt{2\pi\sigma_Y^2}}e^{-\frac{(y-\overline{Sc})^2}{2}} \quad (3)$$

Where $\overline{Sc}$ is the mean value of the transmitted signal at the primary user. If a H_0 cell is being tested, then the PDF of y_c^i can be expressed as

$$f_{y_c^i}(y\,|\,H_0)=\frac{1}{\sqrt{2\pi\sigma_Y^2}}e^{-\frac{y^2}{2}} \quad (4)$$

After each CR user determines whether there is the primary user are present or not. If the primary user is present, secondary users not use the spectrum range. If primary user is not present, CR user or Secondary user using the spectrum ranges.

$$f_{Y_F}(y\,|\,H_1)=\frac{1}{\sqrt{2\pi M\sigma_Y^2}}e^{-\frac{(y-\overline{Sf})^2}{2}} \quad (5)$$

$$f_{Y_F}(y\,|\,H_1)=\frac{1}{\sqrt{2\pi M\sigma_Y^2}}e^{-\frac{y^2}{2}} \quad (6)$$

Where $\overline{S_F} = \sum_{i=1}^{M}\overline{S_F^i}$ and $\overline{S_F^i}$ is the mean value of the transmitted signal from i^{th} CR user. The detection probability for a given value of the decision threshold is defined as the probability of the event that the output decision variable corresponding value to the H_1 cell exceeds the decision threshold, which can be obtained by

$$P_D = \int_\gamma^\infty f_{Y_F}((y|H_1))\,dy, \quad (7)$$

$$P_D = \int_\gamma^\infty \frac{1}{\sqrt{2\pi M\sigma_F^2}}e^{-\frac{(y-\overline{S_F})^2}{2}}dy, \quad (8)$$

Where P_D is the detection probability of the H_1 cell. Let $z = \frac{y-\overline{S_F}}{M\sigma_F^2}$, then the detection probability can be expressed as

$$P_D = \int_z^\infty \frac{1}{\sqrt{2\pi}}e^{-\frac{z^2}{2}dz}, \quad (9)$$

$$P_D = Q\left(\frac{\gamma-\overline{S_F}}{M\sigma_F^2}\right). \quad (10)$$

Where Q(.) is the Q function.

Under the hypothesis H_0, the false alarm probability can be represented as

$$P_f(\lambda) = P_r(T_N(y) > y|H_0) \quad (11)$$

$$= Q\left(\left(\frac{\lambda}{\sigma_u^2}-1\right)\sqrt{N}\right) \quad (12)$$

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty exp\left(-\frac{z^2}{2}\right)dz \quad (13)$$

Similar for H_1 hypothesis, the detection probability can be represented as

$$P_d(\lambda) = P_r(T_N(y) > y|H_1) \quad (14)$$

$$P_d(\lambda) = Q\left(\left(\frac{\lambda}{\sigma_u^2}-\gamma-1\right)\sqrt{\frac{N}{2\gamma+1}}\right) \quad (15)$$

Thus, the miss detection probability can be represented as

$$P_m(\lambda) = 1 - P_d(\lambda) \quad (13)$$

From the equation () and (), for a target miss detection probability $\bar{P}_m$, the relation between false alarm and miss detection probabilities can be represented as

$$P_f(\lambda) = Q\{\sqrt{2\gamma+1}Q^{-1}(1-\bar{P}_m) - \gamma\sqrt{N}\} \quad (14)$$

For a given pair of target probabilities$(\bar{P}_f, \bar{P}_m)$, the minimum number of required samples to achieve these targets can be determined by

$$N_{min} = \left[\frac{1}{\gamma^2}Q^{-2}\{\bar{P}_f - (1-\bar{P}_m)\sqrt{2\gamma+1}\}^2\right] \quad (15)$$

The false alarm probability are lower, the capacity of the secondary user are larger, so to access the vacant spectrum for more secondary users. Otherwise, the lower miss detection probability, the large the capacity of the primary user due to high protection level about ongoing transmission.

D. Equal Gain Combining Diversity And Decision Combining Scheme

We present Equal Gain Combining (EGC) and Decision combining scheme for the spectrum sensing decision. Here the transmitted signals of the primary user is a random signal, we use energy detector is a spectrum sensing. EGC is similar to Maximum Ratio Combining (MRC) scheme but in this technique the received signal over diversity branches are co phased and combined but without the weighting. After Co phasing and combining, the envelop of the composite signal (h_{EGC}) can be written as

$$h_{EGC} = \sum_{i=1}^{L} h_i \qquad (16)$$

The sum of branch noise power is LN_{01} and the resulting SNR is defined by

$$\gamma_{EGC} = \frac{h_{EGC}^2 E_s}{LN_{01}} \qquad (17)$$

The performance of an EGC combiner is very close to the best performing MRC combiner. The EGC combiner is relatively simple compared to the MRC combiner as the channel amplitude is not necessary for the EGC operation. Further, the performance of the EGC detector is well above the SC, SSC, SLC and SLS combiners. However, the performance of an energy detector which utilizes EGC is not solved in any of the available literature. Each local sensing result is combining employing EGC. The combined decision variable from local EGC energy and local energy are defined as

$$Y_C = \sum_{i=1}^{N} w_i Y_i \qquad (18)$$

Where w_i and Y_i are weight and decision variable of i^{th} indexed user and N number of cooperative cognitive users. Base on Y_c, the final decision is made.

III-SIMULATION RESULT

In this section, we present simulation result in order to confirm performance improvement of the proposed system model.Table.1 is simulation parameter. Quadrature Phase Shift Keying (QPSK) signals is used for the primary users signal. Detection method used for energy detection scheme. Combining scheme is used for EGC (Equal Gain Combining) for processing data of cooperative spectrum sensing in fusion center. FA (False Alarm Probability) is applied for detection threshold and in order to get detection probability in fusion center. Channel model used for Additive White Gaussian Noise (AWGN).

Table 1.Simulation Parameter.

Parameter	Single Sensing	Cooperative Sensing
Noise Model	AWGN	AWGN
Detection Method	Energy Sensing	Energy Sensing
Modulation Scheme	QPSK	QPSK
Combining Method	-	EGC

From the below graphs Figure-3, the simulation results show the performance of missed detection probability when the probability of false alarm rate increase the probability missed detection rate decrease because CR users ranges increases. Cooperative Spectrum has Detection probability greater than single sensing.

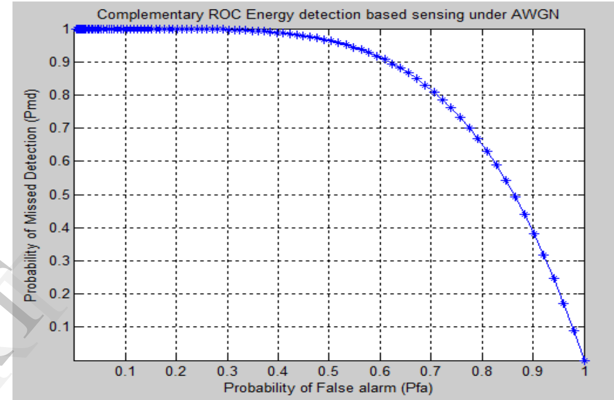

Figure-3: Complementary ROC Energy Detection based sensing under AWGN

From the Fig.2, the simulation results show the performance of detection and false alarm. In Single Energy Sensing condition, the Signal to Noise ratio greater than threshold value, so the probability of detection increases. When the more number of samples increases the probability of detection also increases. In energy detection is high performance whether the signal to noise ratio will be high. Due to the constrain of detection probability, some CR communication opportunities may be missed and the available spectrum resources is wasted, especially when the channels are in good state. To improve the performance, we should reduce the missing transmission probability when channel is in good state and allow a high missing transmission probability when the channels is bad state so that the overall false alarm probability fixed. The false alarm probability also effects on the detection probability. If the false alarm increases, the detection probability increases. We get suitable SNR for the energy detector.

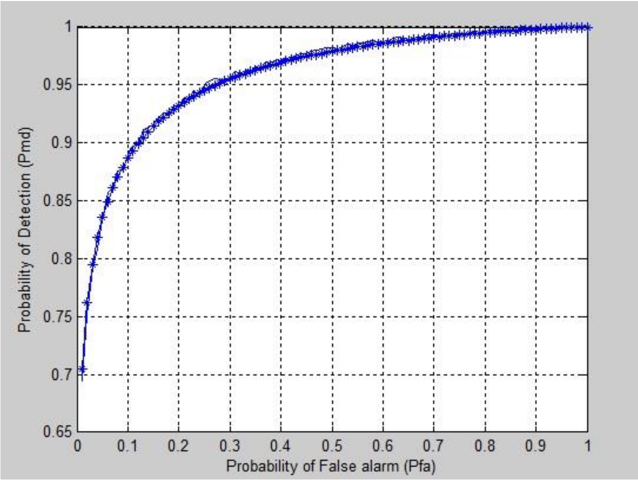

Figure-4: Probability of detection vs. Probability of False alarm

From the Fig.3, the simulation result show that the reporting error comparison for different cognitive radio users. It can be seen that, for the same SNR, with increase of the number of cognitive radio users, the reporting error decreases.

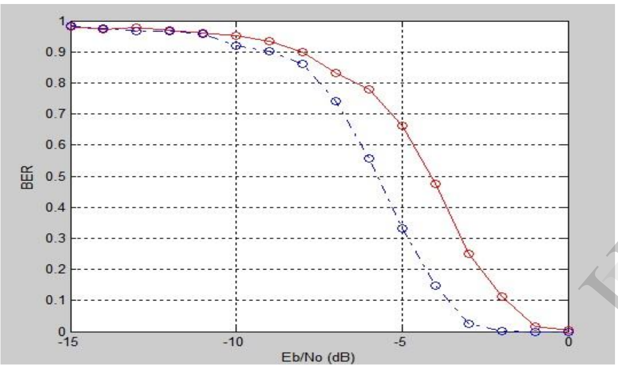

Figure-5: BER vs. $\frac{E_b}{N_0}(dB)$

IV-CONCLUSION

Cooperative sensing solves the hidden terminal problem by using Secondary users with spatial diversity. But, cooperative sensing has problem of reporting delay to fusion center and this problem can reduce overall system performance. In low SNR condition or slow fading channel the bit error rate decreases and increase the performance in low signal to noise condition. Energy detection sense the signal to noise threshold level to EGC(Equal Gain Combining) have equal weight for all the channels at the result the hidden terminal problem reduced. So we propose adaptive spectrum sensing method according to the Secondary users SNR status by selecting both single sensing and cooperative sensing and confirm performance improvement.

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