Cooperative Spectrum Sensing Using Hard Decision Fusion Scheme

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Abstract—Cooperative spectrum sensing using energy detection is the efficient method of detecting the spectrum holes in a particular band of interest or channel by combining the information gathered by multiple CR users. In this paper, we study the hard decision fusion scheme using Logical 'AND' and the Logical 'OR' rule and a brief introduction of Soft and Quantized fusion scheme. Simulation compares ROC (Receiver Operating Characteristics) curves for the above mentioned scheme. And it shows that the Logical 'OR' has better performance than the Logical 'AND' rule.

Keywords - Cognitive radio(CR), Energy detection, cooperative spectrum sensing, Fusion scheme, hard decision fusion rule, Centralized sensing, AWGN channel etc.

INTRODUCTION

The demand for ubiquitous wireless service is growing with the proliferation of mobile multimedia communication devices. As a result, vast majority of the available spectrums are already been licensed. It thus appears that there is little or no room to add any new services. On the other hand, studies have shown that most of the licensed spectrum is largely under-utilized. [1]

Therefore a radio which can identify and sense radio spectrum situations, to recognize temporarily vacant spectrums and make use of it, has the potential to present higher bandwidth services, enhance spectrum competence and lessen the need for centralized spectrum organization. This might be achieved through a radio which can formulate autonomous decisions regarding how it accesses spectrum. Cognitive radios comprise the potential to carry out this. Cognitive radios have the potential to jump in and out of unused spectrum gaps to enlarge spectrum competence and make available wideband services.

They can advance the spectral competence by sensing the environment and, in order to provide the quality of service to the primary user, filling the discovered gaps of unused licensed spectrum with their own transmissions. Precise spectrum awareness is the main concern for the cognitive radio system (secondary user). In this regard it is a proposal that adaptive transmission in unused spectral bands without causing interference to the primary user. The transmissions of licensed users have to be detected without failure and the main goal for adaptive transmission is the detection of vacant frequency bands. A scheme is propose to formulate a cognitive radio that is intelligent to detect vacant frequency bands professionally, to get maximum throughput without causing any detrimental harm to the primary user's quality of service. Therefore, a reliable spectrum sensing technique is needed. Energy detection exhibits simplicity and serves as a practical spectrum sensing scheme.

As a key technique to improve the spectrum sensing for Cognitive Radio Network (CRN), cooperative sensing is proposed to combat some sensing problems such as fading, shadowing, and receiver uncertainty problems. The idea of cooperative spectrum sensing in a RF sensor network is the collaboration of nodes on deciding the spectrum band used by the transmitters emitting the signal of interest. Nodes send either their test statistics or local decisions about the presence of the signal of interest to a decision maker, which can be another node.

The centralized cooperating spectrum sensing (as shown in Fig 1.) can be understood as follows:

- All cooperating CRs perform local spectrum sensing of the channel or frequency individually and give the information to the Fusion Centre FC through reporting channels.

- Then the FC fuses (either hard or soft decision techniques) the sensing information to decide vacancy of spectrum.
- And then FC passes the information to the CRs.

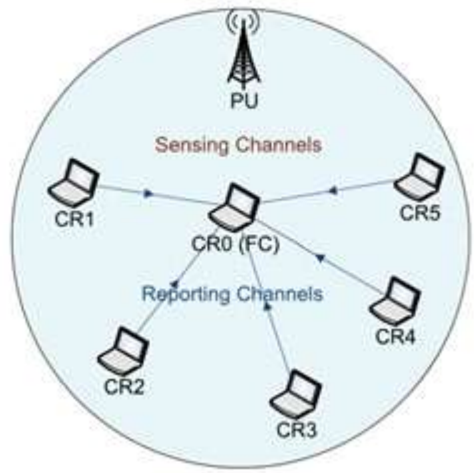

Fig 1. Centralized cooperative spectrum sensing.

In this paper we studied and implemented the logical AND and OR hard fusion technique. Energy detection method based on Neyman-pearson criterion [2] is used for local spectrum sensing. And finally the hard fusion technique is used for the detection of primary user PU.

Rest of the paper is organized as follows: Section II presents concept of two hypotheses (Analytic Model), spectrum sensing through energy detection for single node and cooperative spectrum sensing. Section III presents simulation results followed by conclusion in Section IV.

SYSTEM MODEL

Concept of two hypothesis

Spectrum Sensing is a key element in cognitive radio network. In fact it is the foremost step that needs to be performed for communication to take place. Spectrum sensing can be simply reduced to an identification problem, modelled as a hypothesis test [3]. The sensing equipment has to just decide between for one of the two hypotheses:-

$$H1: x(n) = s(n) + w(n) \quad (2.1)$$

$$H0: x(n) = w(n) \quad (2.2)$$

Where ‘s(n)’ is the signal transmitted by the primary users.
‘x(n)’ being the signal received by the secondary users.
‘w(n)’ is the additive white Gaussian noise with variances .

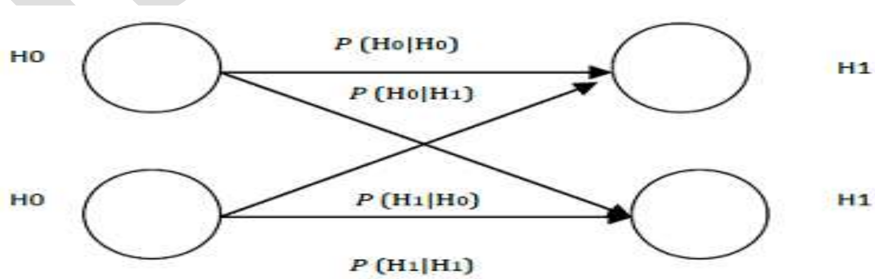

Fig 2.1 Hypothesis problem model

As shown in fig 2.1 above Hypothesis 'H0' indicates absence of primary user and that the frequency band of interest only has noise whereas 'H1' points towards presence of primary user.
Thus for the two state hypotheses numbers of important cases are:-

- H1 turns out to be TRUE in case of presence of primary user i.e. P(H1/H1) is known as **Probability of Detection (Pd).**
- H0 turns out to be TRUE in case of presence of primary user i.e. P(H0/H1) is known as **Probability of Miss-Detection (Pm).**
- H1 turns out to be TRUE in case of absence of primary user i.e. P(H1/H0) is known as **Probability of False Alarm (Pf).**

The probability of detection is of main concern as it gives the probability of correctly sensing for the presence of primary users in the frequency band. Probability of miss-detection is just the complement of detection probability. The goal of the sensing schemes is to maximize the detection probability for a low probability of false alarm.

Energy Detection

If the secondary user cannot gather sufficient information about the PU signal, the optimal detector (due to fewer complexities) is an energy detector, also called as a radiometer [4]. It is common method for detection of unknown signals. The block diagram of the energy detector is as shown in Fig 2.2

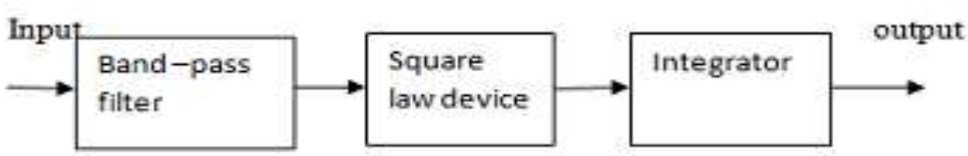

Fig 2.2 Energy Detection block diagram

First, the input signal y(t) is filtered with a band pass filter (BPF) in order to limit the noise and to select the bandwidth of interest. The noise in the output of the filter has a band-limited, flat spectral density. Next, in the figure there is the energy detector consisting of a squaring device and a finite time integrator.

The output signal V from the integrator is

$$V=1/T\int_{t-T}^{t} |y(r)|^2\, dr \quad (2.3)$$

Finally, this output signal V is compared to the threshold given by Digham [5] y in order to decide whether a signal is present or not. The threshold is set according to statistical properties of the output V when only noise is present. The probability of detection Pd and false alarm Pf [6] are given as follows.

$$Pd = P\{y > X\backslash H1\} \quad (2.4)$$

$$Pf = P\{y > X\backslash Ho\} \quad (2.5)$$

From the above functions, while a low Pd would result in missing the presence of the primary user with high probability which in turn increases the interference to the primary user, a high Pf would result in low spectrum utilization since false alarm increase the number of missed opportunities. Since it is easy to implement, the recent work on detection of the primary user has generally adopted the energy detector. However, the performance of energy detector [7] is susceptible to uncertainty in noise power. In order to solve this problem, a pilot tone from the primary transmitter is used to help improve the accuracy of the energy detector. The energy detector is prone to the false detection triggered by the unintended signals.

Cooperative spectrum sensing

Under fading or shadowing, received signal strength can be very low and this can prevent a node from sensing the signal of interest. Noise can also be a challenge when energy detection is used for spectrum sensing, although there are spectrum sensing techniques that are robust in the presence of noise, such as feature detection approaches [8]. Due to a low signal-to-noise ratio (SNR) value, the signal of interest may not be detected.

The idea of cooperative spectrum sensing in a RF sensor network is the collaboration of nodes on deciding the spectrum band used by the transmitters emitting the signal of interest. Nodes send either their test statistics or local decisions about the presence of the signal of interest to a decision maker, which can be another node. Through this cooperation, the unwanted effects of fading, shadowing and noise can be minimized [8]. This is because a signal that is not detected by one node may be detected by another. As illustrated in Fig. 1 the cooperation of nodes in the detection of a signal of interest under shadowing and fading conditions. As the number of collaborating nodes increases, the probability of missed detection for all nodes decreases [9].

Cooperation in spectrum sensing also improves the overall detection sensitivity of a RF sensor network without the requirement for individual nodes to have high detection sensitivity [8]. Less sensitive detectors on nodes means reduced hardware and complexity [8]. The trade-off for cooperation is more communication overhead [8]. Since the local sensing results of nodes should be collected at a decision maker, where the decision is made, a control channel is required between the decision maker and the other nodes [8].

There are three forms of cooperation in spectrum sensing: hard decision (also known as decision fusion), soft decision also known as data fusion) and quantized decision. The difference between these forms is the type of information sent to the decision maker.

The following subsections give a detailed introduction of hard decision fusion and a brief introduction of soft decision fusion and quantized decision fusion schemes.

1. Hard Decision

In the hard decision fusion scheme, local decisions of the nodes are sent to the decision maker. The main advantage of this method is the fact that it needs limited bandwidth [10]. The algorithm for this scheme is as follows [9]. Every node first performs local spectrum sensing and makes a binary decision on whether a signal of interest is present or not by comparing the sensed energy with a threshold. All nodes send their one-bit decision result to the decision maker. Then, a final decision on the presence of the signal of interest is made by the decision maker.

The detection probability P_d, miss detection probability p_m and false alarm probability P_f over AWGN channels can be expressed in following way [4]

$$\mathbf{P_{d,k} = Q_m(\sqrt{2y}, \sqrt{\lambda})} \qquad (2.6)$$

$$\mathbf{P_{m,k}=1-P_{d,k}} \qquad (2.7)$$

$$\mathbf{P_{f,k}} = \frac{\Gamma(m, \lambda/2)}{\Gamma(\mathbf{m})} \qquad (2.8)$$

Where **y** is the signal to noise ratio (SNR), m=TW is the time bandwidth product, $Q_m(-,-)$ is the generalized Marcum Q-function, **Γ** (.) and **Γ** (.,.) are complete and incomplete gamma functions respectively.

Three of the rules used by the decision maker for a final decision are now discussed.

a. Logical-OR Rule

In this rule, if any one of the local decisions sent to the decision maker is a logical one (i.e., any one of the nodes decides that the signal of interest is present), the final decision made by the decision maker is one (i.e. decision maker decides that the signal of interest is present) [11]. Cooperative detection probability Q_d, cooperative false alarm probability Q_f and Cooperative miss detection probability Q_{md} are defined as:

$$\mathbf{Q_{d,or}} = 1-\prod_{k=1}^{k}(1-\mathrm{Pd,k}) \qquad (2.9)$$

$$\mathbf{Q_{f,or}} = 1-\prod_{k=1}^{k}(1-\mathrm{Pf,k}) \qquad (2.10)$$

$$\mathbf{Q_{md,or}} = 1-Q_{d,or} \qquad (2.11)$$

b. Logical-AND Rule

In this rule, if all of the local decisions sent to the decision maker are one (i.e., all of the nodes decide that the signal of interest is present), the final decision made by the decision maker is one (i.e., decision maker decides that the signal of interest is present) [11].

$$Q_{d,and} = \prod_{k=1}^{k} \mathrm{Pd,k} \qquad (2.12)$$

$$Q_{f,and} = \prod_{k=1}^{k} \mathrm{Pf,k} \qquad (2.13)$$

$$Q_{md,and} = 1-Q_{d,and} \qquad (2.14)$$

c. Majority Rule

In this rule, if half or more of the local decisions sent to the decision maker are one (i.e., half or more of the nodes decide that the signal of interest is present), the final decision made by the decision maker is one (i.e., decision maker decides that the signal of interest is present) [11].

2. Soft Combination

In the soft combination scheme, nodes send their sensing information directly to the decision maker without making any decisions [12]. The decision is made at the decision maker by the use of this information [12]. Soft combination provides better performance than hard combination, but it requires a wider bandwidth for the control channel [13]. It also requires more overhead than the hard combination scheme [12].

3. Quantized Fusion

Instead of sending the received signal energy values as in conventional schemes, the CRs quantize their observations according to their received signal energy and the quantization boundaries. Then, the quantized level is forwarded to the fusion centre, which sums up the entire received quantum it re-creates and compares to the fusion threshold [14]. First the optimization for both uniform and non-uniform quantization for cooperative spectrum sensing is considered. Then, the low complexity quantized approach using an approximated CDF on Hi is investigated. In these schemes, the optimization is based only on Hi in order to minimize the quantization uncertainty for the PU's signal, and hence improve the detection probability.

SIMULATIONS AND RESULTS

In this section we study the detection performance of our scheme through simulations using complementary Roc curves. First, we present the performance of the energy detection for single node i.e. without cooperation. Secondly, we will present the performance of hard decision rule using logical 'AND' and the performance comparison of logical 'OR' rule simulation with the theoretical logical 'AND'rule.

For the energy detection for single node i.e. without cooperation, we present in Fig 3.1 the complementary ROC curve between the probability of false alarm and the probability of miss detection. For the simulation, we use SNR of -10db under the AWGN channel considered over the 1000 samples.

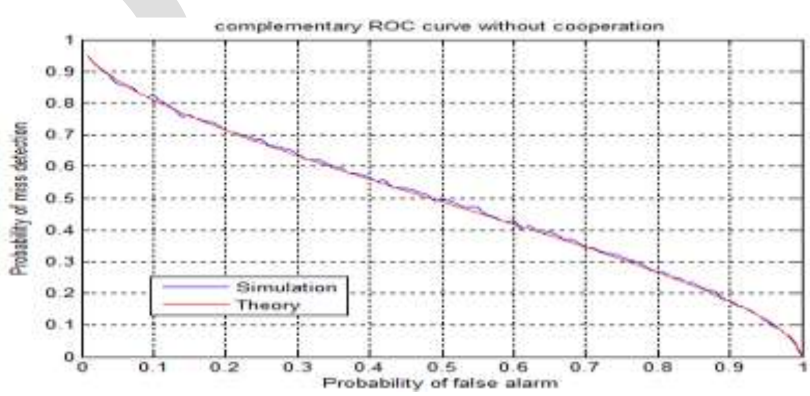

Fig 3.1 Complementary ROC curve under AWGN channel for single node (i.e. without cooperation).

For the hard decision scheme using Logical 'AND' rule, Fig 3.2 shows the complementary ROC curve as discussed in the section II.C.1.a under AWGN channel. For simulation, we plotted the miss detection probability using Monte Carlo technique of 1000 iterations. The numbers of CR users are 10 for simulation; each user has a SNR of -10db, whereas for the theory the no. of CRs chosen are different (5 and 10).

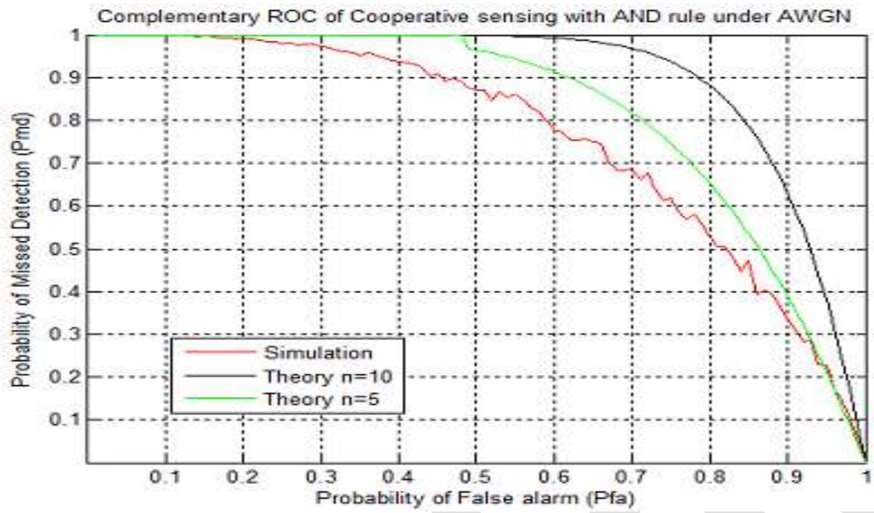

Fig 3.2 Complementary ROC curve for hard decision Logical 'AND' rule under AWGN channel over 1000 samples.

Fig 3.3 compares the complementary curve of hard decision logical 'OR' rule with the theoretical part of hard decision logical 'AND' rule (with no. of CRs 5,10) with each user having a SNR of -10db,and simulated over 1000 Monte Carlo iterations.

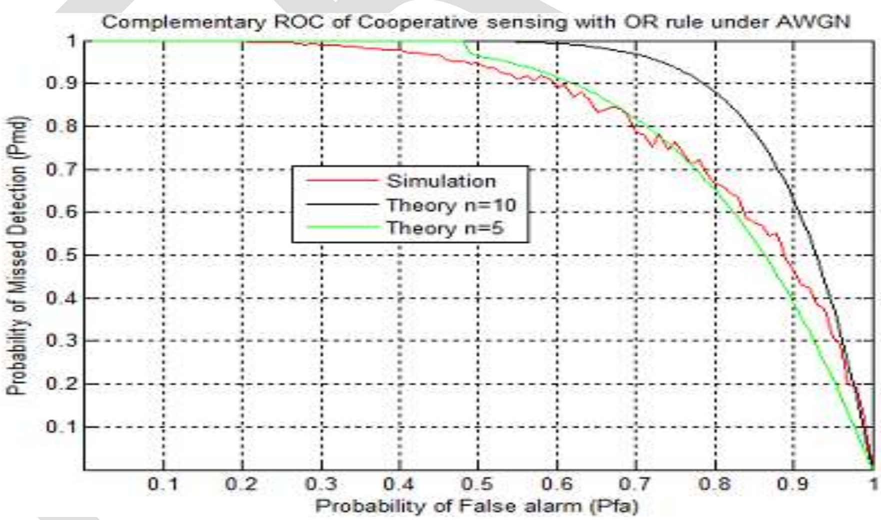

Fig 3.3 Complementary ROC curve for comparison of Logical OR rule with Logical And rule of hard decision scheme.

Conclusions

In this paper we have studied and implemented the cooperative spectrum sensing using hard decision rule using Logical 'AND' and the Logical 'or' rule based on the energy detection. From the simulation it is evident that the performance of the spectrum sensing increases with cooperation. But there is a trade-off between performance and architecture complexity. However the simulation results also shows that the hard decision 'OR' rule has better performance than the hard decision Logical 'AND' rule, which is due to the fact that FC decide in favor of the presence of primary signal when at least one CR detect, however in the Logical 'AND' rule all CR user must detect the primary user.

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