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A Cooperative Weighted Discriminator Energy Detector Technique in Fading Environment

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Abstract—The need in cognitive radio system for a simple, fast, and independent technique to sense the spectrum occupancy has led to the energy detection approach. Energy detector is known by its dependency on noise variation in the system which is one of its major drawbacks. In this paper, we are aiming to improve its performance by utilizing a weighted collaborative spectrum sensing, it is similar to the collaborative spectrum sensing methods introduced previously in the literature. These weighting methods give more improvement for collaborative spectrum sensing as compared to no weighting case. There is two method proposed in this paper: the first one depends on the channel status between each sensor and the primary user while the second depends on the value of the energy measured in each sensor.

Keywords—Cognitive radio; Spectrum sensing; Collaborative sensors; Weighted Decisions.

I. Introduction

NOW days, most of the licensed spectrum bands suffer from the inefficient utilization by the licensed users. This result has come from the surveys that have been done in different countries worldwide over certain spectrum bands. One of these surveys is the federal communication commission (FCC) report that has been published in 2002 [1]; this report gave high attention to the way in which the spectrum should be exploited. Another work have been done in three different suburban locations in Europe [2], in this work the results came to tell about an inefficient utilization for the spectrum band from 400 MHz to 3GHz and also, to encourage the deployment of a new techniques to increase the efficiency of spectrum exploiting. So, from the above mentioned results and based on the vision of J. Mitola [3] about radio knowledge representation language (RKRL), cognitive radio, which is also a term present by Mitola, represents a good and promising solution that could improves the spectrum utilization and increase the abilities given for the communicating parties in a certain network.

There is no general definition for cognitive radio system, but here the adopted definition is the one presented in [4] which state that: *Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and uses the methodology of understanding-by-building to learn from the environment and adopt its internal status to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g. transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:*

It is obvious from the above definition that cognitive radio users have the ability to operate in spectrum bands that are licensed to certain users, called primary user, by detecting their presence or absence. This detection process, called spectrum sensing (SS), represents the first stage for cognitive radio users and could be achieved generally using two techniques [5]: feature detection and energy detection. The second technique has the advantage of simple implementation and its independency from networks standards but it is highly affected by noise variation which is not the case in the first technique. Because of this major drawback the performance of the energy detector need to be improved in order to use it in spectrum sensing. Many researches have been presented in the literature which aimed to improve the performance of the energy detector for spectrum sensing. Some examples of these researches are: using detection scheme to get some of the advantages of both energy and feature detection [6, CR techniques],introducing diversity in each cognitive unit to overcome the fading effect [6][7], collaborative spectrum sensing (CSS) that makes different cognitive users share their decisions to increase the reliability in communication and improve the performance in certain spectrum band [7][8], and parallel collaborative spectrum sensing to sense more than one ban in the same time[9].

II. Problem Formulation

Energy detection is the simplest method in spectrum sensing. No prior knowledge regarding the transmitted signal structure is needed. Energy detector has the advantage of simplicity in implementation where it consists of pre-filter which is a band-pass filter to determine the center frequency and the band of interest, square device to measure the received energy, integrator to determine the observation interval, and a decision device with threshold to compare the output of the integrator, called decision statistic, with the threshold and decide if wither primary user is present or not.

On the other hand, the energy detector suffers from its dependency on the noise variance to determine its threshold. This makes the performance of the energy detector poor compared to other methods of detection [5].

A. AWGN channel

For an AWGN channel, the received signal r (t) takes the form:

$$r(t) = hs(t) + n(t) \tag{1}$$

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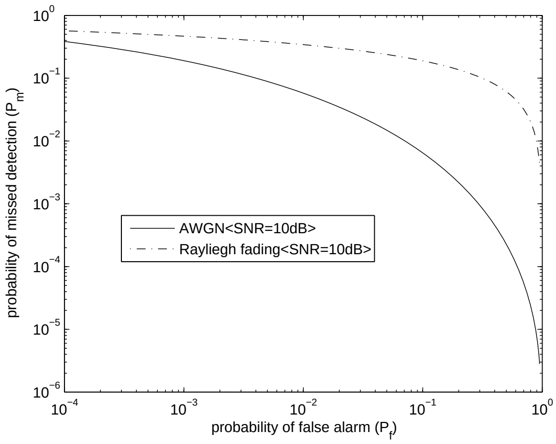

Fig. 1. CROC curves in AWGN and Rayleigh channel

Where h= 0 or 1 under hypotheses H_0 (No signal) or H_1 (signal present), respectively. This signal forms the input to the energy detector. The output from the integrator Y will be the test statistic to test the two hypotheses H_0 and H_1 [7]. And Table.1 shows the different possible events.

In order to measure the performance of the energy detector, probability of false alarm (P_f) and the probability of detection (P_d) will be used [8]:

$$P_f = P_r(Y > \lambda|H_o) = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \quad (2)$$

$$P_d = P_r(Y > \lambda|H_1) = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (3)$$

Where (u) is the time-bandwidth product, (λ) is the threshold value, and (γ) is signal-to-noise ratio.

It is obvious from these two equations that the probability of false alarm doesn't depend on the signal to noise ratio (SNR) but in contrast it depends on the number of samples taken in the observation interval and the threshold of the decision device. This observation makes P_f take the same expression in any other kind of channel

B. Rayleigh Fading Channel

In a more realistic channel where a multipath faded components of the received signal are present. The distribution of the probability density function of the received signal amplitude will follow a Rayleigh distribution of the form [7]:

$$f_\gamma(\gamma) = \frac{1}{\bar{\gamma}} \exp(-\frac{\gamma}{\bar{\gamma}}) \quad (4)$$

Where $\bar{\gamma}$ is the average signal-to-noise ratio. the average probability of detection in the Rayleigh channel is given as [7]:

$$\bar{P_d} = e^{\frac{-\lambda}{2}} \sum_{n=0}^{u-1} (\frac{1}{n!})(\frac{\lambda}{2})^n + (\frac{1+\bar{\gamma}}{\bar{\gamma}})^{u-1}[e^{-\frac{\lambda}{2(1+\lambda)}} - e^{-\frac{\lambda}{2}} \sum_{n=0}^{u-2} (\frac{1}{n!})(\frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})})^n] \quad (5)$$

Figure 1 shows the performance of the energy detector over both, AWGN and Rayleigh, channels for one sensor with $SNR = 10dB$ and $u = 1$.

III. COLLABORATIVE SPECTRUM SENSING

In order to improve the performance of energy detector for spectrum sensing, cooperation between different cognitive users, sensors, have to be implemented. Each sensor will send its final decision to a network center, fusion center, where the final decision will be made according to certain rule. In [8] [9], OR-rule in fusion center was presented and a good improvement in the performance was achieved. The expressions of probabilities of detection and false alarm have been given as following:

$$Q_m = \prod_{i=1}^{n} (1 - P_d) \quad (6)$$

$$Q_d = 1 - Q_m \quad (7)$$

and

$$Q_f = 1 - \prod_{i=1}^{n} (1 - P_f) \quad (8)$$

Here the same rule will be used but there will be a modification in the sense of making the contribution of each sensor differs according to different considerations. This process called: "decision weighting" and will be presented in the following subsections:

A. Weighting According to channel Preference

In real cognitive radio system each sensor experience different channel status with the primary user. This difference makes some of the sensor more reliable in deciding the presence or absence of the primary user than other sensors. So, assuming that each sensor experience independent but not identically distributed channel and assuming also that the fusion center knows each channel status, it will be very helpful to weight their decision following certain weighting algorithm. Assuming that we can generate a decision that is equivalent to the decision of the best channel status sensor then replace it with the decision of the worse channel status sensor. This generation and replacement operation has to be done in a way to hold two important conditions: the total number of sensors must not be changed and the decision independency is maintained. Now, If we expand the expression of Q_d, given in (7), we will have:

$$Q_d = 1 - \{(1 - P_d^1)(1 - P_d^2)...(1 - P_d^n)\} \quad (9)$$

For the case in which there is one sensor, called s1, out of (n) number of sensors experience better channel with the primary user, say AWGN channel, and other sensor experience same worst channel, say Rayleigh fading channel. The decision of (s1) may be considered as the decision of two sensors instead of one and other decisions of the $(n - 1)$ sensors will be considered as $(n - 2)$ sensors decisions. This can be done simply by multiplying the power of the parentheses

TABLE I
DIFFERENT POSSIBLE EVENTS

Probability	Sensor Decision	Network Condition	Conclusion	Remarks
$Pr(Y > \lambda \mid H_1)$	Primary signal is present	Spectrum is occupied	Correct detection of PU present. CU is not allowed to use the spectrum	Probability of detecting PU correctly
$Pr(Y > \lambda \mid H_0)$	Primary signal present	Spectrum is vacant	Wrong detection of PU present. Therefore, Spectrum is wasted	Probability of false alarm
$Pr(Y > \lambda \mid H_1)$	Primary signal absent	Spectrum is occupied	Wrong detection of PU present. CU will allowed using the spectrum wrongfully	Probability of collision between PU and CU
$Pr(Y > \lambda \mid H_0)$	Primary signal absent	Spectrum is vacant	Correct detection of PU absent. CU is allowed to use the spectrum	Probability of capacity

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that represents the probability of missing for (s1) by a factor $(k = 2)$ and combining other sensors probabilities in one parentheses with power $(n-1)$ then multiplying this power with the factor $(\frac{n-k}{n-1} = \frac{n-2}{n-1})$ as following:

$$Q_d = 1 - \{(1-P_d^1)^2 (1-P_d)^{(\frac{n-2}{n-1})*n-1}\} \qquad (10)$$

Figure 2 shows the CROC curves for collaborative 4-sensors in different channel status with and without weighting, in this figure the SNR assumed to be 10dB and $u = 1$. Finally, it is worth to mention that, in this weighting method if there is wrong channel estimation and one sensor have been considered having better channel than others where in fact this is wrong, the performance of the collaborative sensors will not degraded very much but instead it will be equivalent to the performance of collaborative sensors that have the same worst channel which in turn better than the performance of individual spectrum sensing

B. Weighting According to the Value of Decision Statistic:

Different sensors in cognitive radio system may have the same decision about the absence or presence of primary user. But this doesn't mean they have the same value of decision statistic some of sensors have a high decision statistic value and others doesn't [10]. Because of this difference, the reliability on the decisions of different sensors should be different and the final decision should reflect this preference of some sensors over others.

Let us defined reliability factor (Rf) to be the difference between the value of the decision statistic (Y) in one sensor and the threshold value, assuming all sensors have same threshold value, reliability factor is given as:

$$R_f = Y - \lambda \qquad (11)$$

In order to calculate probability of detection and false alarm using this weighting method, reliability factor should be included in the expression. Noticing that (6) consist of multiplied parentheses that represent probability of missing for each sensor, the reliability factor for certain sensor's decision statistic will be introduced in complement form and multiplied with the probability of missing of that sensor, e.g. for a network consist of 4-sensors and one of the sensors, say sensor number one (s1), is obtaining a value of (Y) that equals (1.6λ) and other sensors have the same value of (Y) which equals (1.2λ) then the reliability factor for this simple network will be evaluated from the value of the decision statistic obtained from (s1) to give: $R_f = 0.6$. The complement of this factor will be multiplied with probability of missing of this sensor, (s1), then taking the complement of this expression gives probability of detection as in (7):

$$Q_d = 1 - [\{R_f * P_{m1}\} P_{m2} ... P_{mn}] \qquad (12)$$

For (SNR) value equals 10 dB and time-bandwidth product (u) equals 5, figure 3 shows the CROC curves of such collaborative sensors. In this figure the thick three lines represent 4-sensors experiencing Rayleigh fading channel and other lines are for AWGN channel.

Because diversity has a powerful effect in improving the performance in Rayleigh fading channel [8], this solution has been introduced in the 4-sensor network and a better result have been found, figure 4 illustrates this case with same (SNR) and (u) values indicated before.

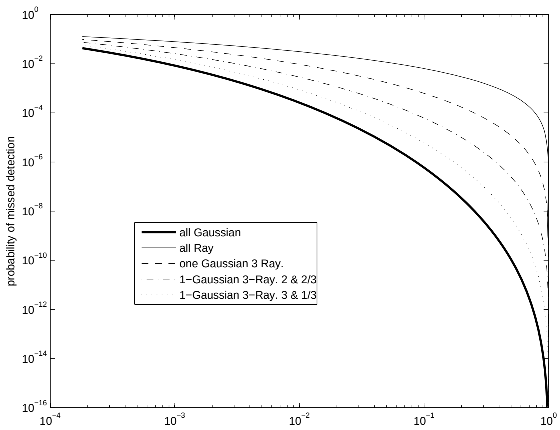

Fig. 2. CROC curves in AWGN and Rayleigh channel

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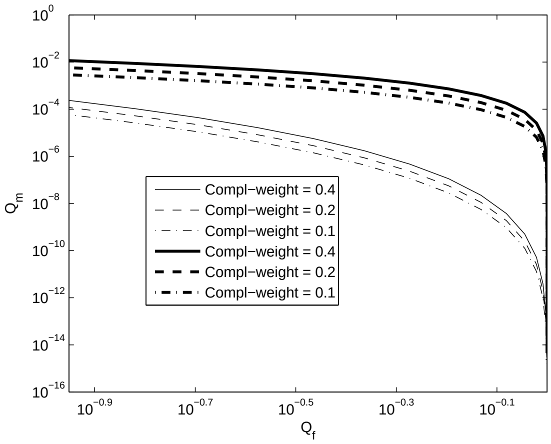

Fig. 3. CROC curves for 4-collaborative sensors using decision statistic weighting method. the three thick lines for Rayleigh fading channel and others for AWGN channel.

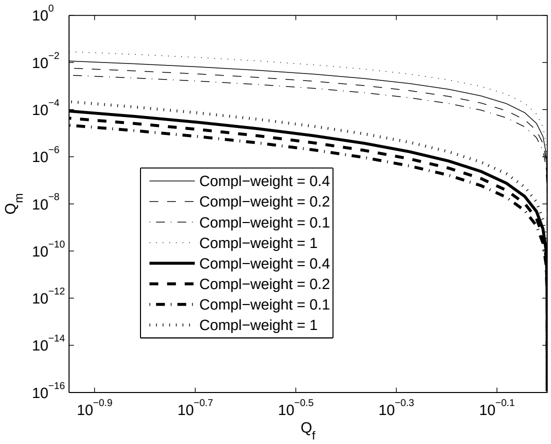

Fig. 4. CROC curves that reflects diversity effect in improving the performance in Rayleigh fading channel.

IV. Conclusion

In order to improve the performance of energy detector in sensing the spectrum occupancy, weighted collaborative spectrum sensing has been introduced. This technique used OR-rule in the fusion center to determine the final decision but the difference here is in the way the individual decisions of each sensor are manipulated in the fusion center before making the final decision. Two approaches have been discussed here; the first one is weighting according to channel preference by duplicating the decision of certain sensor, that is known to have a better channel status than others, (k) number of times while decreasing other sensors, that have wrest channel status, participation by a factor of $(\frac{n-k}{n-1})$. The second approach uses the higher difference between decision statistic value and threshold value, called reliability factor, to determine which one of the sensors is discovering the presence of the primary user more accurately. This difference has been introduced in probability of detection expression as the complement to the reliability factor because the expression uses probability of missing to calculate collaborative probability of detection. Good results were found and also more improvement has been achieved using diversity solution.

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