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Overcoming sensing failure problem in double threshold based cooperative spectrum sensing

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ABSTRACT

Energy detection is widely used spectrum sensing algorithm in cognitive radio networks because of the reason it is simple and easy to implement and does not require the prior information about the Primary user (PU). However, performance of conventional energy detector falls in low signal to noise ratio (SNR) region. Cooperative spectrum sensing (CSS) in which each Cognitive radio (CR) employs double threshold was introduced to increase the reliability of decision especially in low SNR region but suffers from sensing failure problem. In this paper, we are proposing a method for overcoming sensing failure problem in double threshold CSS. In this method, each CR either sends one bit decision when observed energy lies out of the confused region or sends two bit decision based on quantization when energy lies within the confused region. Final decision about the presence or absence is taken at fusion center after processing the received decisions. We have carried out MATLAB simulations to prove the superiority of the algorithm in achieving a tradeoff between traffic overhead and detection performance.

1. Introduction

With the increase in the number of wireless services and applications, the demand of wireless spectrum is increasing day by day. Currently used fixed spectrum allocation policy is finding it difficult to accommodate the growing demand due to the shortage of spectrum. However it has been reported by Federal Communication Commission (FCC) that it is not the shortage of spectrum but the inefficient utilization of the spectrum [1]. It has been shown that large part of the spectrum is unused by the PUs or licensed users independent of time and space.

Cognitive radio is identified as a new paradigm in wireless communication to solve the problem of spectrum underutilization [2–4]. In cognitive radio networks, unlicensed users or Secondary Users (SUs) are allowed to use the licensed band opportunistically when PUs are not using the same. Spectrum sensing is one of the primary function of CR (or SU) to enable the opportunistic spectrum access. Many spectrum sensing algorithms are available in the literature to locate the vacant spectrum holes. Among all, energy detection method is commonly used due to its low complexity and simple implementation. Here in this paper, we have considered that each CR is using energy detection method for spectrum sensing.

Concept of CSS in CR network was introduced to tackle with the hidden node problem and improve the spectrum sensing performance [5]. CSS takes the advantage of spatial diversity for improving the sensing performance. In CSS, there are three steps: first in which each CR sense the spectrum independently, second in which every CR reports sensing results to Fusion Center (FC) and third in which the FC combines the results from every CR to make a global decision and reports back the global decision to every CR. In second step of CSS, reporting of the results can be done in one of the two ways: one is soft decision reporting in which each CR forwards the absolute value of observed energy to the FC and decision is made by combining these absolute energy values but this method requires a larger control channel bandwidth [6]. Another method of reporting the decisions is hard decision reporting in which each CR makes a local decision about the presence of absence of PU and sends only one bit decision i.e. bit '0' for PU absent and bit '1' for PU present. Then results from different CRs are combined at FC by one of the logical fusion rule i.e. by OR rule or AND rule or MAJORITY rule. The main advantage of this hard decision method is that it requires less bandwidth of the control channel [6]. Encouraged by the performance of soft fusion schemes and keeping in view the bandwidth constraint of control channel, authors further proposed softened two-bit hard combination scheme in which whole range of observed energy is divided into four regions with same width and

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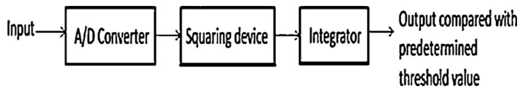

Fig. 1. Conventional energy detector [9].

each region is allotted two bits i.e. 00, 01, 10 and 11. The scheme achieves performance in between hard and soft fusion schemes. CSS in which each CR employs double threshold energy detection method was discussed in [7] to increase the reliability of decision especially in low SNR region. A censoring method was proposed to reduce the communication traffic between CRs and FC but at the cost of some sensing information lost (No decision was taken when energy lies in the confused region). If incase observed energy of all the CRs lie in the confused region, FC will not receive any decision which causes sensing failure problem. In [8,9], one bit decision is sent to the FC when CR is able to make a clear decision and absolute energy value is sent when observed energy lies in confused region. This will improve the sensing performance by addressing the sensing failure problem when compared to censoring method but again at the cost of more bandwidth requirement as absolute value of energy is required to be sent when in confused region.

In this paper, we employ a novel method of decision fusion in contrast to the schemes used in [8–10] and addressed the sensing failure problem without increasing the burden on control channel. Here FC receives two types of decision from CRs i.e. one bit decision from CRs which lies out of the confused region or two bit decisions from the CRs which lies within the confused region. If the FC does not receive any single bit decision which is the case of sensing failure than only those received two bit decisions are processed at the FC to estimate the observed average energy and this average energy is then compared to system threshold to reach to a decision. Simulation model is developed in MATLAB to verify the superiority of the proposed method. The rest of the paper is organized as follows: Section 2 covers the preliminaries about the single threshold & double threshold energy detector and double threshold based CSS. Section 3 covers the proposed model that shows how fusion center makes a final decision based on the local decision of the CRs. Section 4 shows simulations results & analysis and Section 5 concludes the paper.

2. Preliminaries

2.1. Single and double threshold energy detection

Energy detection technique can be explained with the help of Fig. 1 [10].

Input signal is passed through analog to digital converter and then squared and integrated over time to get the energy. This energy is then compared with a predetermined threshold to decide among the two hypotheses as given below:

$$\text{PU present,}\quad H_1: \qquad y(n) = h(n)s(n) + u(n) \tag{1}$$

$$\text{PU absent,}\quad H_0: \qquad y(n) = u(n) \tag{2}$$

here $y(n)$ is the received signal, $h(n)$ is the channel gain which is assumed as unity in this case. $u(n)$ is AWGN noise with zero mean and variance σ_w^2. $s(n)$ is the PU signal also assumed to be AWGN with zero mean but with a different variance σ_s^2. Energy can be calculated as below:

$$X = \sum_{n=1}^{N} \left| y(n) \right|^2 \tag{3}$$

where X is the energy of the received signal and N is the number of samples taken for detection. Single threshold and double threshold energy detection can be explained with the help of Fig. 2. In single threshold energy detection as in Fig. 2(a), energy X is compared to a threshold λ_0 to decide among the two hypotheses. Expressions for probability of detection and probability of false alarm can be given as in [11].

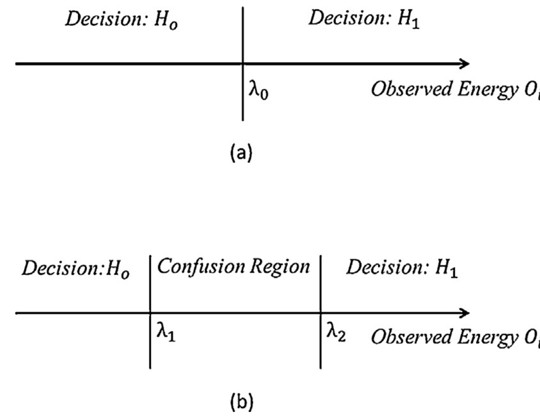

Fig. 2. Single and double threshold energy detection.

$$P_f = P(X > \lambda_0 | H_0) = Q\left(\frac{\lambda_0 - N\sigma_w^2}{\sqrt{2N(\sigma_w)^4}} \right) \tag{4}$$

$$P_d = P(X > \lambda_0 | H_1) = Q\left(\frac{\lambda_0 - N(\sigma_s^2 + \sigma_w^2)}{\sqrt{2N\left(\sigma_s^2 + \sigma_w^2\right)^2}} \right) \tag{5}$$

In double threshold energy detection as in Fig. 2(b), if energy X lies above threshold λ_2 then H_1 is true and if it is below λ_1 then H_0 is true. If X lies between λ_1 and λ_2, then no decision is taken and CR will go into the sensing again.

From Eq. (4) threshold λ_0 can be calculated as

$$\lambda_0 = N\sigma_w^2 + Q^{-1}\left(P_f\right)\sqrt{2N\sigma_w^4} \tag{6}$$

And thresholds λ_1 and λ_2 can be found as [12]:

$$\lambda_1 = (1 - \rho)\lambda \tag{7}$$

$$\lambda_2 = (1 + \rho)\lambda \tag{8}$$

where ρ is the uncertainty parameter. Probability of error in decision making is given as

$$P_e = P(H_0)P_{fa} + P(H_1)(1 - P_d) \tag{9}$$

where $P(H_0)$ and $P(H_1)$ are the priory probabilities of PUs occupancy.

2.2. Double threshold based cooperative spectrum sensing

CSS in which each CR uses double threshold based energy detection scheme can be explained with the help of following steps:

Each SU (i = 1,. . .,M) will make a decision if and only if observed energy X_i lies above λ_2 or below λ_1 which is given by

$$L_i = \begin{cases} 0 & X_i < \lambda_1 \\ 1 & X_i > \lambda_2 \end{cases}$$

FC receive decisions from the different CRs and combine them in accordance with some rule of fusion.

If X lies between λ_1 and λ_2, then SU does not make a decision and will not report anything to the FC. If FC does not receive any decision from any of the CRs, there exists a sensing failure problem.