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Throughput maximization by alternative use of single and double thresholds based energy detection method

Pankaj Verma*, Brahmjit Singh

Electronics and Communication Engineering Department, National Institute of Technology, Kurukshetra, India

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ABSTRACT

Cognitive radio (CR) offers solution to the problem of spectrum underutilization by opportunistic spectrum access. Spectrum sensing is one of the important functions of CR as it affects both Primary Users (PUs) protection and Secondary Users (SUs) achievable throughput. In this paper, we are introducing a spectrum sensing scheme which selects either single threshold or double threshold energy detection method based on the estimated Signal to Noise Ratio (SNR) value of the channel. This scheme achieves a better tradeoff between sensing performance and achievable throughput as compared to conventional methods that works purely on single threshold or double threshold energy detection method.

1. Introduction

The widespread increase in demand of wireless services and applications has triggered a huge demand of the spectrum but almost all the available spectrum is already allocated to the licensed or Primary Users (PUs). On the other side, recent studies conducted by Federal Communication Commission (FCC) has exposed underutilization of the allocated spectrum [1]. The term "Cognitive Radio" first coined by Joseph Mitola in his PhD thesis [2,3]. This technology enables SUs to opportunistically exploit the underutilized spectrum in a way that does not affect the quality of service of PUs. Therefore, FCC issued a notice in 2003 where CR is identified as a potential candidate to address the problem of spectrum underutilization [4].

Spectrum sensing plays a very important role in opportunistic spectrum access. There are many spectrum sensing algorithms available in the literature which include energy detection, cyclostationary feature detection and matched filter detection. Sensing performance of every algorithm can be measured in terms of probability of detection (P_d) and probability of false alarm (P_f). Higher probability of detection protects PUs and lower probability of false alarm increases the chances of effective spectrum utilization, so we need a tradeoff between the two. Owing to own set of advantages and disadvantages of different algorithms, energy detection technique is widely used because of its simple implementation. However performance of energy detection scheme gets deteriorated in low SNR environment because of the noise uncertainty. Double threshold energy detection method was proposed to increase the reliability of decision especially in low SNR regions and to address the bandwidth constraint problem of control channel [5]. In double threshold energy detection, CR uses two thresholds instead of a single threshold as used in conventional energy detection method. PU is considered as present if observed energy lies above the upper threshold and absent when it lies below the lower threshold. The region between the two thresholds is considered as uncertainty region and CR does not conclude any decision in this region and goes for the sensing again if it is operating in non-cooperative environment. Therefore, double threshold energy detection method increases the reliability of decision but at the cost of increased number of sensing repetitions.

In this paper, we proposed a scheme which first estimates the SNR of the channel and then based on the estimated SNR, CR selects either single or double threshold energy detection. To prove the superiority of the scheme, we have developed a model to study the tradeoff between sensing performance and throughput of the secondary network. Rest of the paper is organized as follows: Section 2 covers the preliminaries about single and double threshold energy detection. Frame structure used in cognitive radio networks is also discussed in this section. Section 3 covers the proposed scheme. Section 4 shows the simulation results and analysis and Section 5 concludes the paper.

* Corresponding author. Tel.: +91 8295577722.
E-mail addresses: pankaj@nitkkr.ac.in (P. Verma), brahmjit@nitkkr.ac.in (B. Singh).

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2. Preliminaries

2.1. Energy detection

Energy detection is the most widely used spectrum sensing technique as it does not require the prior information about the PUs. Working of energy detector can be explained with the help of Fig. 1 [6].

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

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

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

Symbol $y(n)$ represents the received signal, $u(n)$ is Gaussian noise which is assumed to be independent, identically distributed (i.i.d.) with zero mean and variance σ_w^2. $s(n)$ represents the signal from PU signal also assumed to be i.i.d. with zero mean and variance σ_s^2. Test statistics for energy detector to decide between two hypotheses can be calculated as

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

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 to decide between the two hypotheses. Expressions for probability of detection and probability of false alarm can be given as in [7].

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

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

In double threshold energy detection as in Figs. 2(b) and 3, if energy X lies above threshold λ_2 then H_1 is true and if it is below λ_1 then H_o is true. If X lies between λ_1 and λ_2, then no decision is taken and CR will go for sensing again. By fixing the P_f, threshold λ can be calculated from Eq. (4) as

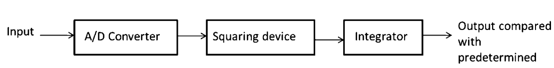

Fig. 1. Conventional energy detector.

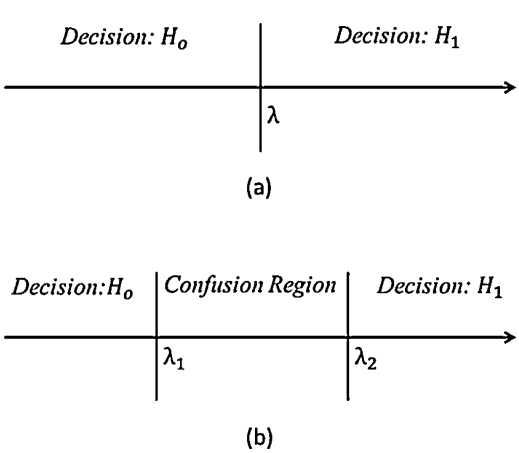

Fig. 2. Single and double threshold energy detection.

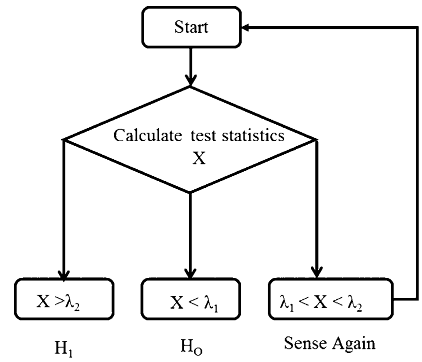

Fig. 3. Double threshold energy detection.

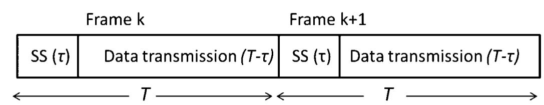

Fig. 4. Frame structure used in cognitive radio networks.

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

And thresholds λ_1 and λ_2 can be calculated as:

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

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

where ρ is the uncertainty parameter used to calculate the two threshold values from system threshold λ.

2.2. Throughput

Frame structure used in cognitive radio networks is explained with the help Fig. 4. In every time frame, τ time is used for sensing the channel and $T - \tau$ time is used for data transmission. Let $P(H_o)$ and $P(H_1)$ are the probabilities that hypothesis H_o and H_1 are true respectively. Let SNR_s represents the signal to noise ratio of secondary point to point link and SNR_p represents the signal to noise ratio of primary user at the secondary receiver. Achievable throughput of the secondary network is given by [8]

$$\varphi = \frac{T - \tau}{T}[C_o(1 - P_f)P(H_0) + C_1(1 - P_d)P(H_1)] \tag{9}$$

where $C_o = \log_2(1 + SNR_s)$ is the capacity of the secondary network in the absence of primary user and $C_1 = \log_2(1 + (SNR_s/(1 + SNR_p)))$ is the capacity of secondary network in the presence of primary user.

3. Proposed model

Flow chart of the proposed scheme for a single CR can be explained with the help of Fig. 5.

a. CR estimates SNR of the channel. Estimation of SNR of the channel has already been discussed in [9–12]. In this paper, we assume that SNR is estimated by anyone of the techniques discussed in these literatures.
b. If $SNR > SNR_{th}$; single threshold energy detection is employed

$$D = \begin{cases} 0 & X < \lambda \\ 1 & X > \lambda \end{cases}$$