An Energy Detection Based on Coefficient of Variation for Spectrum Sensing in Cognitive Radio

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Abstract. In the Cognitive Radio system, cognitive users require perceiving the real-time using of the spectrum accurately. At the same time, the cognitive user stations are usually in severe fading or interference. Energy detection is used widely due to the low computation complexity and an effective method under the high SNR, but it is impressionable by the noise. According to these facts, we propose to use the coefficient of variation (CV) of the sampled signals to amend the judgment result and get the blending final result. After the energy detection, if the test statistic of the signal energy is within a specified range and the signal CV is less than a threshold value, it concludes that the spectrum bands are occupied by another user. The simulation results prove that the rectification method can greatly improve the cognitive user's accurate detection performance of spectrum usage in real-time while ensuring the computation complexity.

Keywords: Spectrum sensing · Energy detection · Coefficient of variation

1 Introduction

Today, as the rapid progress and development of modern wireless communications technology, the radio frequency spectrum resources have become more and more strained. Cognitive Radio (CR) technology can raise the utilization and reduce the tension situation of spectrum resources [1]. In CR networks, the Secondary User (SU) is allowed to use the licensed spectrum when the Primary User (PU) don't occupy the bandwidths. With the guaranty of PU in a certain band, the SU needs to continually detect the presence of the PU. Spectrum sensing is the foundation and precondition for the implementation of Cognitive Radio, which also is one of the key techniques in CR [2].

Among the common spectrum sensing methods, energy detection has been used widely because of its simplicity [3]. It is the simplest method to detect the presence of PU, which doesn't require prior information of the PU. The traditional energy detection based schemes typically compare the received energy with the fixed threshold to decide

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whether the PU is active or not. But the energy threshold is related to the channel noise and is easy to be affected by the noise power fluctuation. The traditional dual-threshold energy detection algorithm has two thresholds to make the decision, the detected energy values are divided into three areas. But there is a problem of "Confused Region" that is between upper bounds and lower bounds. Once the detected energy value falls into the region, the result of the spectrum sensing would be failing.

The correlation coefficient is used to measure the linear correlation between quantitative variables. Based on the analysis of eigenvalue detection theory, the correlation between PU signal and additive white Gaussian noise (AGWN) is different, and the correlation of PU signal is higher than AGWN [4]. But it is not always a good criterion of the signals' volatility. Considering traditional energy detection algorithm's shortages and the influence of the noise uncertainty on system performance, this paper proposes a new method of double-threshold energy detection algorithm which is based on the received signal coefficient of variation (SCVED). This method is applied for the SU between the two thresholds. The advantage of using SCVED instead of energy detection is two-fold: improved the detection probability; reduced the influence of the noise.

The remainder of the paper is organized as follows: the conventional signal energy detection method is briefly reviewed in Sect. 2. Then, we focus on the technical aspects of SCVED in Sect. 3. In Sect. 4, its performance is evaluated by experiments. Finally, we summarize the paper in the last section.

2 The Conventional Signal Energy Detection Method

Energy detection collects and calculates the signal energy in a given time period, compares the result with a pre-set threshold to judge whether PU is present or not. In addition, suppose that there is no signal between the PU and the SU. That is, the SU is completely independent of the PU. A binary hypothesis testing model is shown, which spectrum sensing can be modeled as:

$$y(t) = \begin{cases} n(t), & \mathrm{H}_0 \\ n(t) + h \cdot x(t), & \mathrm{H}_1 \end{cases} \qquad t = 1, 2, \cdots, N. \tag{1}$$

In the testing, N denotes the sampling number during a sampling period, $y(t)$ shows the sample of the received signal by the SU, $n(t) \sim N\left(0, \sigma_{\omega}^{2}\right)$ is the AWGN, $x(t)$ is the PU signal sample, h indicates the channel gain. In the channel, hypothesis H_0 sates that the PU is absent, and hypothesis H_1 sates that the PU is present.

For the detection of unknown signals disturbed by AWGN, a conventional energy detector is derived in [5]. This is easily implemented detector for detection of unknown signals in spectrum sensing. Collect the test statistic and compare it to a threshold λ to decide whether the PU exists.

The test statistic is calculated by:

$$Y = \sum_{t=1}^{N} [y(t)]^2. \tag{2}$$

The 2-gram model of energy detection can be expressed as:

$$\begin{cases} Y < \lambda, & \mathrm{H}_0 \\ Y \geq \lambda, & \mathrm{H}_1 \end{cases} \tag{3}$$

In AWGN channel, the distribution of the test statistic Y under two hypotheses is [6]:

$$Y \sim \begin{cases} \chi^2_{2u}, & \mathrm{H}_0 \\ \chi^2_{2u}(2\gamma), & \mathrm{H}_1 \end{cases} \tag{4}$$

Y follows a central (under H_0) and non-central (under H_1) chi-square distribution with 2μ degrees of freedom. μ shows the time-bandwidth product, γ shows the signal-to-noise ratio of the channel. When N is large enough, the central limit theorem can be employed to approximate the Y as Gaussian.

$$Y \sim \begin{cases} \mathrm{N}\left(N\sigma_n^2, 2N\sigma_n^4\right), & \mathrm{H}_0 \\ \mathrm{N}\left(N\left(P+\sigma_n^2\right), 2N\left(P+\sigma_n^2\right)\right), & \mathrm{H}_1 \end{cases} \tag{5}$$

where P is the average power of PU signal, then the target probability of false alarm P_{fd} and the probability of detection P_d can be given as [8]:

$$P_{fd} = P_r(P > \lambda | H_0) = Q\left(\frac{\lambda - N\sigma_n^2}{\sqrt{2N}\sigma_n^2}\right) \tag{6}$$

$$P_d = P_r(P > \lambda | H_1) = Q\left(\frac{\lambda - N\left(P+\sigma_n^2\right)}{\sqrt{2N}\left(P+\sigma_n^2\right)}\right) \tag{7}$$

where $Q(\bullet)$ is the standard Gaussian complementary cumulative distribution function. Based on the Constant False Alarm Rate (CFAR) approach, the threshold λ is set to meet a certain P_{fd} for CR system. Here, λ is got as follows:

$$\lambda = \sigma_n^2\left(Q^{-1}\left(P_{fd}\right)\sqrt{2N} + \sqrt{N}\right) \tag{8}$$

The formula (8) indicates that λ is not only affected by P_{fd}, but also the noise variance σ_n^2.

3 The Energy Detection Algorithm Based on the Signal CV

3.1 Coefficient of Variation

In probability theory and statistics, the coefficient of variation (CV), also called relative standard deviation, is a standardized measure of dispersion of a probability distribution or frequency distribution. CV can eliminate the effect of dimension and quantity of data. It is usually measured the non-stationary properties of a variable in statistical models. During spectrum sensing, the fluctuation of received signals is very different under two conditions (H_0 and H_1). Thus, this paper introduces CV to the analyses of the spectrum sensing and compared it with the conventional energy detection. In order to make CV > 0, it is defined as the ratio of the standard deviation σ_y to the mean μ_y and computed in this thesis as follows [6]:

$$\mu_y = \left| \frac{1}{N} \sum_{t=1}^{N} y(t) \right| \quad (9-1)$$

$$\sigma_y = \sqrt{\frac{1}{N} \sum_{t=1}^{N} \left(y(t) - \mu_y \right)^2} \quad (9-2)$$

$$CV = \frac{\sigma_y}{\mu_y} \quad (9-3)$$

In order to observe the different degree of received signal CV, the experiments use BPSK signal in AWGN to simulate the actual communication channel [7]. The simulation shows the value of received signals' CV is smaller when PU is the presence. When PU is absent, the values of certain CV are especially high. To better observe the subtle difference between H_0 and H_1, the CV's maximum value is set to 30. In other words, the value is equivalent to 30 when CV > 30. The result of the simulation turns into Fig. 1.

Figure 1 shows the received signals' CV versus times of calculations in SNR = 8 dB when the CV's maximum value is set to 30. In SNR = 8 dB, the values of the CV are higher when PU is absent than present, the CV's maximum value is 0.4996 under H_1, the CV's minimum value is 3.5069 under H_0, and all the values of CV under H_0 are greater than it under H_1.

To better observe the relationship of the SNR and CV, in SNR = 8 dB, we do the same experiments under same conditions. The result of the simulation turns into Fig. 2.

Figure 2 shows the received signals' CV versus times of calculations in SNR = −8 dB when the CV's maximum value is set to 30. In SNR = −8 dB, most of the CVs' values are higher when PU is absent than present, the CV's maximum value is 6.6564 under H_1, and the CV's minimum value is 3.6141 under H_0. Compared Fig. 1 with Fig. 2, a conclusion can be got that the volatility of the received signals slightly increase as the increase of the SNR. Whether SNR = −8 dB or SNR = 8 dB, PU is judged to be present if cv < 3.6. Set $\gamma = 3.0$, if $cv \leq \gamma$, PU is judged to be present. The 2-gram model of SCVED can be expressed as:

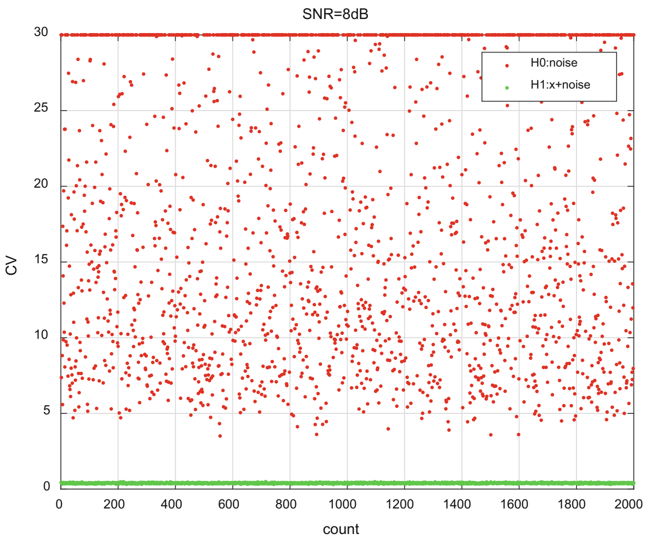

Fig. 1. The signals' CV versus times of calculations in SNR = 8 dB

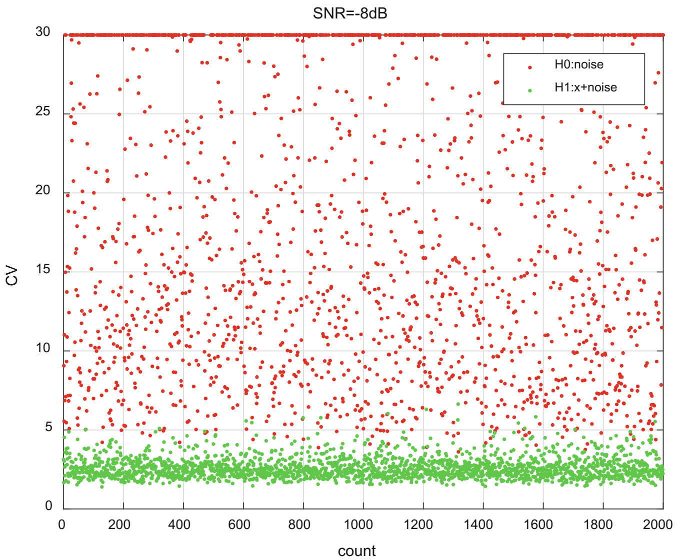

Fig. 2. The signals' CV versus times of calculations in SNR = −8 dB

$$\begin{cases} cv > \gamma, & H_0 \\ cv \leq \gamma, & H_1 \end{cases} \tag{10}$$

3.2 Overview Proposed Algorithm

In the proposed algorithm, the result of energy detection is revised by the signal CV, there is a joint detection of the energy detection and SCVED, and the SCVED is applied for the SU between the two thresholds.

The test statistic of the signal energy Y is collected in a given period of time and calculated by (2), which is compared to the threshold (λ). If $Y \geq \lambda$, it is the case H_1, which means PU is present; If $Y < \lambda/2$, it is the case H_0, which means PU is absent; if $\lambda/2 \leq Y < \lambda$, SCVED is conducted. The signals' CV is calculated according to the formula (9-1). If $cv \leq \gamma$, it is the case H_1. Otherwise, PU is absent.

The procedures of the improved algorithms are as follows (Fig. 3):

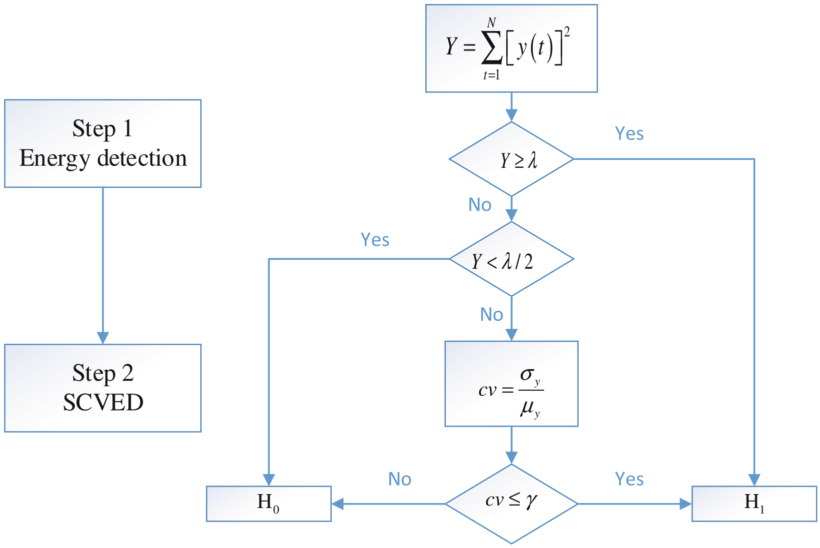

Fig. 3. Proposed algorithm flowchart.

Step 1 Energy detection: Generate a BPSK signal plus white noise or noise in a continuous time and calculate the test statistic Y according to the formula (2). Compare Y with the threshold λ, if $Y \geq \lambda$, PU is present. If $Y < \lambda/2$, PU is absent.

Step 2 SCVED: Calculate the signal CV according to the formula (9-1), if $cv \leq \gamma$, PU is present. Otherwise, PU is absent.

4 Simulation Analysis

The simulation platform uses BPSK signal in AWGN to simulate the actual communication environment [8, 9]. Besides, we very SNR from −15 dB to 15 dB with a step of 1 dB in order to evaluate the proposed algorithm in different channel environment. And, the probability of false detection is set as 0.1 and 0.01 respectively. The result of the simulation turns into Figs. 4 and 5.

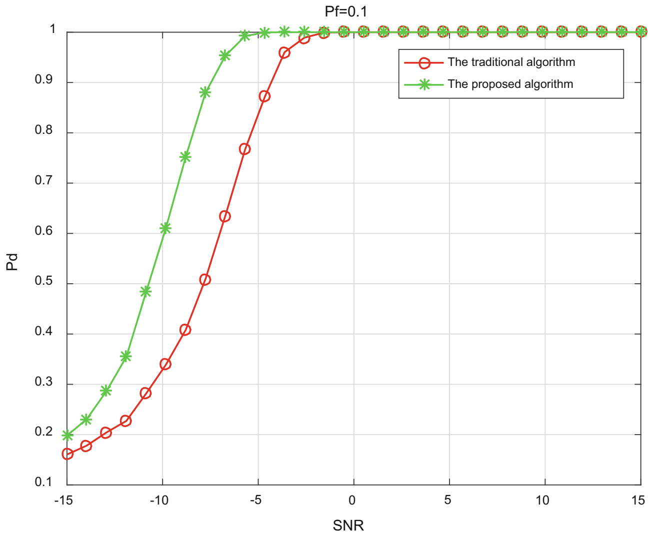

Fig. 4. The detection probability versus SNR at $P_{fd} = 0.1$.

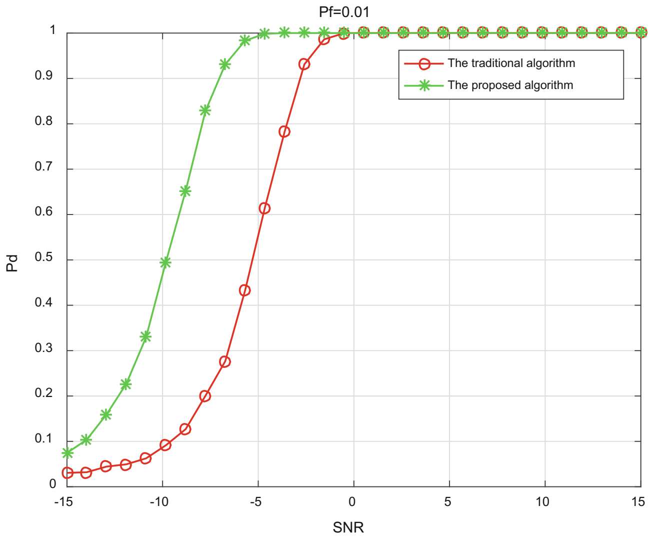

Fig. 5. The detection probability versus SNR at $P_{fd} = 0.01$.

Figure 4 shows the graph of detection probability versus SNR with N = 128 at $P_{fd} = 0.1$. The proposed algorithm performs better than the traditional algorithm. In detection performance, SCVED scheme shows 29% of improvement than the traditional under SNR = −10 dB.

Figure 5 shows the graph of detection probability versus SNR with N = 128 at $P_{fd} = 0.01$. The proposed algorithm performs remarkably better than the traditional algorithm. In detection performance, SCVED scheme shows 42% of improvement than the traditional under SNR = −10 dB. In the figures, we can see that the proposed algorithm has a greater improvement at low P_{fd}.

5 Conclusions

This paper proposes a new energy detection algorithm based on the variation coefficient of the received signals in the CR system. Based on the signal CV, the SCVED judges the status of PU on special frequencies and perfects the final result. Simulation results show that the joint algorithm can improve the detection probability, and reduce the influence of the noise and SNR. The threshold of step 2 is set based on abundant experiments and has not been proved through the formula. The next work is to investigate the accurate formula of the threshold.

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