Analysis of Spectrum Sensing Algorithm based on Energy Detection

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Abstract: On the basis of analyzing the principle and performance of the energy detection algorithm, the algorithm is simulated and analyzed by MATLAB. The relationship between detection probability and signal-to-noise ratio under CFAR probability is studied, and the detection performance is analyzed. The simulation results show that the energy detection algorithm does not need to know the prior knowledge of the signal, and it is simple to implement and has low computational complexity. It can be applied to the spectrum sensing of cognitive radio as a preliminary coarse detection to improve the detection efficiency.

1. Introduction

Wireless communication carries and transmits information through electromagnetic waves [1]. The current spectrum allocation policy is fixed spectrum allocation. That is to say, the planning and use of wireless spectrum resources are formulated by the international spectrum regulatory agencies and the radio regulatory departments of various countries. The use of wireless spectrum resources by transceivers needs the permission of the government [2]. Fixed spectrum allocation divides the RF spectrum into two types: authorized and unauthorized bands. Due to the rapid development of communication industry, the problem of spectrum resource scarcity is becoming more and more serious [3]. It is found that the spectrum utilization of authorized bands used globally, especially the hundreds of MHz to 3GHz bands with very tight frequency requirements, is very low [4]. The US Federal Communications Commission study shows that the vast majority of spectrum allocations currently allocated are between 15% and 85%, and the main reason for the low spectrum utilization is the current fixed spectrum allocation method [5]. In this way of distribution. Even if the authorized user (primary user, PU) does not use its licensed frequency band at a certain time and place, other non-authorized users, ie secondary users (SU), cannot use the frequency band, resulting in spectrum resources. Waste in time and space [6].

Considering that the use of spectrum is dynamic and varies with frequency, time and space, studying a dynamic spectrum access is an effective technique to solve the current inefficient use of spectrum. The concept of Cognitive Radio (CR) was first proposed by Mitola in 1999 [7]. By sensing the spectrum environment, it distributes the free spectrum to unauthorized users in a specific time and space to improve the spectrum utilization. This dynamic spectrum sharing method can greatly improve the spectrum utilization [8].

Spectrum sensing is one of the key technologies in CR technology. CR users must monitor spectrum changes in real time in order to avoid collision with primary users [9]. In order to avoid interference to primary users, secondary users need to continuously detect the bands of interest before accessing the authorized spectrum to detect the free spectrum that is not occupied by PU for its use [10]. At present, there are many classical detection methods for spectrum sensing, among which the spectrum sensing methods based on transmitter mainly include matched filter sensing, energy detection sensing, cyclostationary feature sensing and so on. These classical spectrum sensing methods have their own advantages and disadvantages. Energy detection method is a traditional detection method, which belongs to the incoherent detection of signals. The greatest advantage of energy detection method is that it does not need to know the prior knowledge of signals. It is simple to implement and has low computational complexity. It is a commonly used signal detection method. Applying the energy detection method to cognitive radio can be used as a preliminary coarse detection to improve detection efficiency. This paper mainly studies the

performance of energy detection method and verifies its effectiveness through simulation.

2. Energy detection system model and detection principle

Spectrum sensing technology can be summarized into single point perception, collaborative sensing and blind sensing. Single point awareness mainly includes transmitter-based sensing and receiver-based sensing. The transmitter spectrum sensing means that the cognitive user judges the working state of the main user transmitter by analyzing whether the main user signal exists in the signal detected. Then, it can judge whether the spectrum of interest is occupied or idle. It is a kind of perception assuming that the location of the main user's receiver is unknown. The binary hypothesis model of transmitter perception can be described by the following formula:

$$y(n) = \begin{cases} w(n) & n = 0,1,...N-1 \quad H_0 \\ hs(n) + w(n) & n = 0,1,...N-1 \quad H_1 \end{cases}$$
(1)

Among them, y(n) is the signal received by cognitive users; S(n) is the primary user transmission signal. N is the number of samples (detection time); h is the channel gain. H0 is not occupied, indicating that there is no primary user signal in a certain frequency band at present; H1 indicates that the channel is occupied, indicating that there is a primary user in this frequency band at present.

There are three main indicators to measure perception performance: detection probability P(d), false alarm probability P(f) and missed detection probability P(m), which are expressed as follows:

$$\begin{cases} P_d = P(H_1 \mid H_1) \\ P_f = P(H_1 \mid H_0) \\ P_m = P(H_0 \mid H_1) \end{cases}$$
(2)

Where P(d) represents the presence of the primary user, the cognitive user detects the probability of the existence of the primary user. P(f) denotes the probability that cognitive users detect the presence of primary users in the absence of primary users. P(m) denotes the probability that cognitive users will detect the absence of primary users in the presence of primary users.

Energy detection algorithm is a blind detection algorithm. It simply regards the main signal as noise, and determines whether the main signal exists or not according to the energy of the observed signal. It belongs to the incoherent detection method of the signal in principle. This detection method does not need to acquire any prior knowledge of authorized user signals in advance, and has relatively low computational complexity and simple implementation. It is the most commonly used detection method, especially suitable for broadband spectrum sensing in practice.

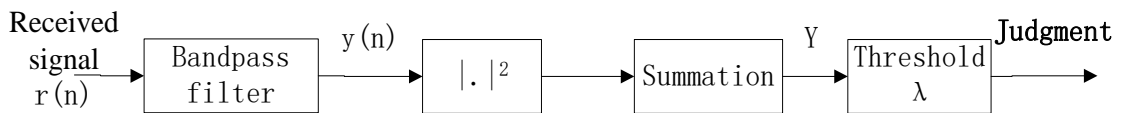The detection principle is shown in Figure 1 below.

Fig.1. Schematic diagram of energy detection algorithm

The received signal is first obtained by a band-pass filter to remove the out-of-band noise. By squaring the amplitude, the energy Y of the received signal, i.e. the test statistic Y of energy detection, can be obtained after summation. The decision is made by comparing it with the preset threshold. The rules of judgment are as follows:

$$\begin{cases} Y < \lambda & H_0 \\ Y \geq \lambda & H_1 \end{cases}$$
(3)

If Y >λ, the primary user is judged to exist, and the secondary user cannot access the frequency

band; otherwise, if Y <λ, the primary user does not exist in the frequency band, and the secondary user can access the frequency band.

It is assumed that s(n) is a Gaussian process with 0 mean and σ_s^2 variance, and w(n) is an additive white Gaussian noise (AWGN) with zero mean and σ_w^2 variance, which are independent of each other.

Under H0 assumption, Y obeys the central chi-square distribution with degree of freedom of 2N; under H1 assumption, Y obeys the non-central chi-square distribution with degree of freedom of 2N, non-central parameter of Mu and $\mu = \dfrac{\sigma_s^2}{\sigma_w^2}$ are the signal-to-noise ratio of the signal.

Under the background of non-fading white Gaussian noise, the expressions of detection probability and false alarm probability are obtained as follows:

$$P_f = \frac{\Gamma(N, \lambda/2)}{\Gamma(N)} \tag{4}$$

$$\begin{aligned} P_d &= P(Y > \lambda \mid H_1) \\ &= Q_N(\sqrt{2\mu}, \sqrt{\lambda}) \end{aligned} \tag{5}$$

$Q_N(\sqrt{.}.\sqrt{.})$ is N-order Marcum Q function and $\Gamma(.,.)$ is incomplete Gamma function.

The task of spectrum sensing is to distinguish the two different assumptions under the Neyman-Pearson criterion, so as to determine whether there is a primary user in the communication at that time and in the band range. In general, constant false alarm (CFAR) method is adopted. Firstly, the probability of false alarm Pf is determined, and then the detection probability under different SNR is calculated to measure the detection performance. The larger the detection probability under the same SNR, the better the detection probability, indicating that the interference to the primary user is smaller.

3. Simulation results and analysis

1) Experimental environment
All the simulation of the energy detection algorithm is carried out under matlab, and the version used is R2014a.
2) Experimental Data Set
The specific simulation model of the energy detection algorithm is:
The first step: the BPSK signal is used in the experiment to simulate the primary user PU signal of the cognitive radio.
The second step: the background noise is Gaussian white noise, and the variance of the Gaussian white noise is set to 1, that is, $\sigma_w^2 = 1$.
Step 3: The IEEE802.22 system requires the detector to receive the signal-to-noise ratio of the primary user signal below 10 dB and provide Pd=90%--95% while maintaining the false alarm probability Pf=1%-10%. Detection probability.
The curve between the detection probability and the signal-to-noise ratio is simulated under the constant false alarm probability to reflect the detection performance. In this simulation, Pf=0.001, and the estimation threshold of the decision threshold is used to calculate the decision threshold based on Pf.
The fourth step: the simulation uses the Monte-Carlo method to obtain the final statistical result by independent simulation 10,000 times to draw a graph.
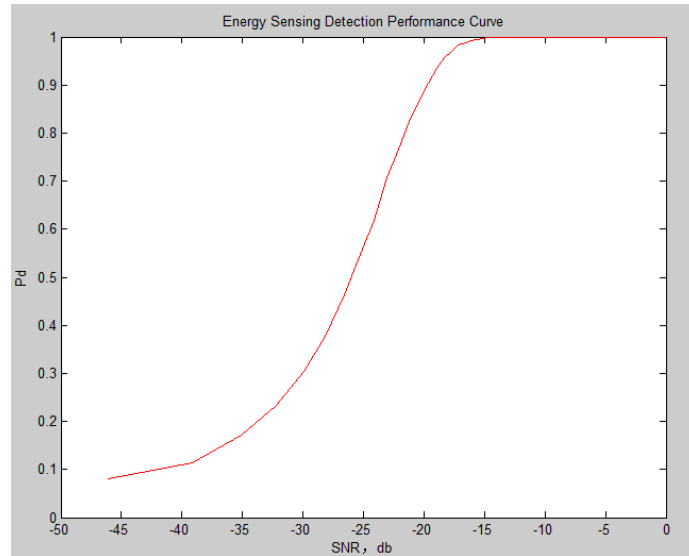
Fig.2. Relationship between detection probability and SNR

Energy Sensing Detection Performance Curve Under the premise that the local false alarm probability is certain, the greater the received signal-to-noise ratio of the cognitive user, the greater the local detection probability, that is, the smaller the local miss detection probability. That is to say, the size of the received signal to noise ratio of the cognitive user plays a key role in its detection performance. However, each cognitive user wants to be able to both increase its local detection probability and reduce its local false alarm probability. Because these two probabilities are contradictory parameters, they can not achieve the above expected results, so it is important to find an appropriate compromise between them. For the energy perception method, the process of finding the compromise is the process of finding the optimal threshold.
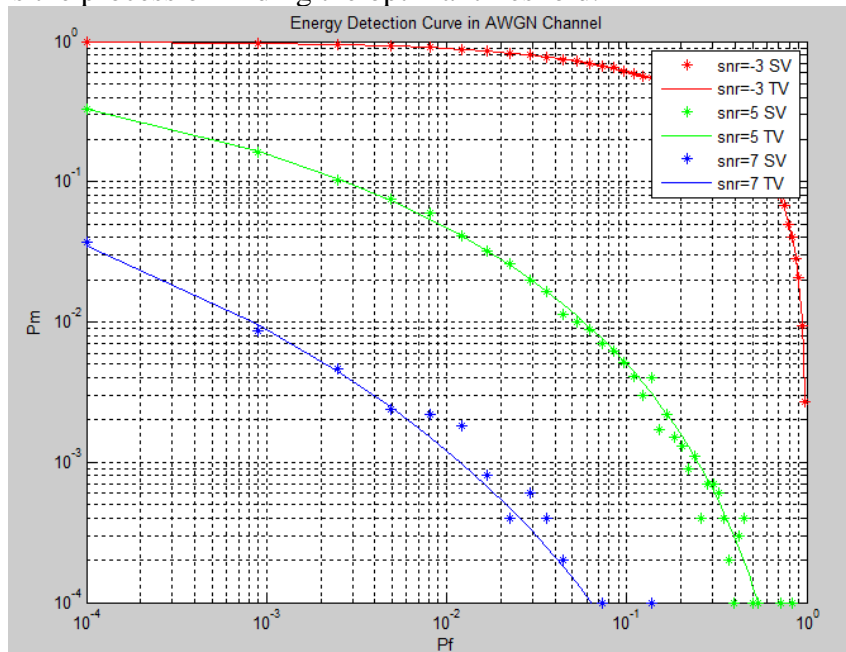

Fig.3. Transformation curves of detection probability and false alarm probability at different SNRV

In addition, under different SNR and different false alarm probability, the receiver performance is analyzed. In Figure 3, SV (Simulation Value) refers to the simulation value; TV (Theoretical Value) refers to the theoretical value. From the above figure, we can see that the probability of missed detection decreases with the increase of false alarm probability, and the detection probability is improved in the side, and the detection performance is satisfactory. In addition, under the same false alarm probability, the higher the signal-to-noise ratio, the lower the probability of missed detection.

4. Conclusion

Energy detection algorithm is a commonly used spectrum sensing method. This paper introduces the algorithm model and detection principle of classical energy detection algorithm, and focuses on the analysis of detection performance. From the simulation results, the energy detection algorithm is simple and does not require prior knowledge, but the decision threshold is more difficult to set, and the optimal threshold should be found in the detection process.

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