Research of Double Threshold Collaborative Spectrum Sensing based on OFDM

Ruilian TAN[1,2]
[1] Armed Police Engineering University Electronic Technology Laboratory of Information Engineering Department, Xi'an 710086, China
[2] College of Equipment Management and Safety Project, Air Force Engineering University, Xi'an 710051,China
madamtan@126.com

Abstract. In view of the shortage of the single threshold energy detection in spectrum sensing, the double threshold energy detection is studied. Combined with the characteristics of OFDM spectrum efficiency, the double threshold energy detection and OFDM system are combined. The method is on the basis of OFDM with the sub-channel as the user to be perceived. According to the available subcarrier number, the actual number of user to be perceived is determined, and the double threshold energy detection is conducted in sub-channels. The data fusion center makes decisions by means of "or" criterion. The simulation results show that the method can well identify the main users, thus controlling the data transmission of OFDM .

Key Words. Cognitive Radio; Collaborative Spectrum Sensing; Double Threshold Energy Detection; OFDM

1 Introduction

As the growth of the wireless communication business, spectrum resources increasingly tense, the FCC spectrum strategy task group pointed out that in the literature, the existing spectrum demand more nervous several hundred MHz to 3GHz wireless spectrum available resources are assigned to complete almost [1]. In view of the allocated spectrum resource utilization problem of low, Joseph Mitola put forward the Cognitive Radio (CR)) technology in 1999 [2], the concept of it to study the environmental awareness, and real-time adjust the transmission parameters to adapt to the change of external environment, which use has not been authorized band [3]. Spectrum sensing is the premise of cognitive radio, only spectrum hole, measured by the frequency spectrum can be achieved to dynamic spectrum access, it is in the normal communication does not interfere with the primary user of the key technology to improve spectrum efficiency under the premise of [4]. At present, the idle spectrum detection method mainly includes the matched filtering detection, cyclic stationary feature detection and energy detection. The filter detection needs to know the main users of a priori information, such as modulation method, and the prior information in

F. Xhafa et al. (eds.), *Advances on P2P, Parallel, Grid, Cloud and Internet Computing*, Lecture Notes on Data Engineering and Communications Technologies 1, DOI 10.1007/978-3-319-49109-7_2

the actual process of communication is difficult to get [5]; complicated cycle stationary feature detection algorithm and the difficulties [6]. Literature points out that the energy detection is don't need any priori information of spectrum detection method[7], the starting point is the energy of the signal and noise is greater than the energy of the noise, belong to the blind detection algorithm, the algorithm is relatively simple, usually adopt single threshold energy, however, in actual communication performance is often in the multipath fading and shadow effect factors such as constraints, greatly decline the performance of the single threshold energy detection, aiming at this problem, can the method of using double threshold energy of collaborative detection [8].

In wireless communication, orthogonal frequency division multiplexing (OFDM) modulation technology has high spectrum efficiency, on the resistance to multipath fading, resist narrow-band interference obvious advantages, can improve the system's ability to non-line-of-sight propagation [9], and therefore OFDM transmission system is suitable for digital signal transmission, is widely used. This paper mainly studies the double threshold energy detection in cognitive radio spectrum perception, combined with the characteristics of OFDM spectrum utilization rate is higher, and puts forward the energies of the double threshold detection method combined with OFDM system. The method on the basis of OFDM system, the system as sub-channels to perception of users, according to the energy statistics to determine the available subcarrier number as the actual perception of users, in sub-channels, double threshold energy detection, data fusion center by means of "or" criterion. Simulation results show that the method can well identify the main users, in the main user when idle, OFDM system can be normal for data transmission, with the increase of the subcarrier number available, you can get a better recognition performance.

2 Double threshold detection energy model

2.1 Energy detection model

Energy spectrum detection is the most basic method, its judgment method is to preset a threshold method, through the energy detector and set threshold comparison, more than decision threshold method, the main users determine the spectrum exist, otherwise the frequencies in the idle state. Our energy detection can be defined as a binary hypothesis problem:

$$\begin{cases} H_0: y(k)=\omega(k) & H_0 \\ H_1: y(k)=s(k)+\omega(k) & H_1 \end{cases} \tag{1}$$

$y(k)$ is the signal received by the users, $s(k)$ is the detected signal, namely the main signal, $\omega(k)$ is additive white Gaussian noise, k = 1, 2..., n; n is the expressed received signals, H_0 is the idle stats, and the main user does not exist, H_1 is the occupation state, namely the primary user. When users are out of the frequency, $s(k)$ is zero, the detection is in H_0, the energy detector can be written as P [9]:

N is the vector dimension sampling sequence. Because of take up channel signal energy must be greater than the energy of the idle state, this time can determine whether the main user exists by P compared with preset threshold λ_E, λ_E is the primary user occupancy state; otherwise it is idle, and it can be used access the idle spectrum.

Spectrum detection performance by two probability measure [2]: detection probability P_d and false alarm probability P_f. P_f is the occupied channel frequency when the channel is idle, the increase of P_f will make cognitive users lose the opportunity to access the idle spectrum. It can be expressed as:

$$P_d = probability(P > \lambda_E | H_1) \quad (3)$$

$$P_f = probability(P > \lambda_E | H_0) \quad (4)$$

P adheres to the chi square distribution with the degree of freedom 2υ:

$$P \sim \begin{cases} \chi^2_{2\upsilon} & H_0 \\ \chi^2_{2\upsilon}(2\eta) & H_1 \end{cases} \quad (5)$$

υ= TW, T is the observation time, W is the observation bandwidth, and η is the signal-noise ratio.

The probability distribution function of P is:

$$f_P(m) = \begin{cases} \frac{1}{2^{\upsilon}\Gamma(u)} m^{\upsilon\text{-}1} e^{-\frac{m}{2}} & H_0 \\ \frac{1}{2}\left(\frac{m}{2\eta}\right)^{\frac{\upsilon\text{-}1}{2}} e^{-\frac{2\eta+m}{2}} I_{\upsilon\text{-}1}\left(\sqrt{2\eta m}\right) & H_1 \end{cases} \quad (6)$$

$\Gamma(\bullet)$ is the gamma function, $I_{\upsilon}(\bullet)$ is the υ-order first kind of deformation Beisaier function.

Assumes that the cognitive radio network for the decline, the detection probability P_d and false alarm probability P_f can be obtained under additive white Gaussian noise:

$$P_d = probability(P > \lambda_E | H_1) = Q_{\upsilon}\left(\sqrt{2\eta}, \sqrt{\lambda_E}\right) \quad (7)$$

$$P_f = probability(P > \lambda_E | H_0) = \frac{\Gamma(\upsilon, \lambda_E / 2)}{\Gamma(\upsilon)} \quad (8)$$

Among them, $Q_{\upsilon}(a,x)$ is the general Marcum Q function.

In accordance with the above assumptions, the energy detector flow chart shown in figure 1, cognitive users the received signal y (t) first by band-pass filter to select the corresponding bandwidth and center frequency, and then through the square law to calculate the energy of the signal device, and through the integrator to implement energy accumulated over a period of time, the resulting energy detector statistics P, P into the judgment and decision of preset threshold λ_E for comparison; more than λ_E is the primary user occupancy state; otherwise, it is idle, used to access the idle spectrum.

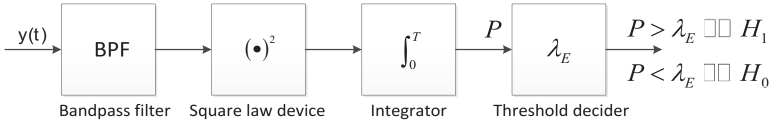

Fig 1 The flow chart of energy detector

2.2 Double threshold energy detection

Through the above analysis, we know, the traditional energy detection is based on the single threshold; the threshold is only one decision threshold. When the primary user signal power and noise is small, single threshold energy detection is a good way to work, namely under the condition of low SNR, there may not be able to identify primary user signal, single threshold energy detection may make a wrong decision, so as to make the false alarm rate increases, weaken in idle spectrum. In view of this, the literature [10] [11] based on the shortage of the single threshold energy detection, put forward the double threshold detection together, and through the computer simulation proves the feasibility of this method. The test set up two decision threshold λ_0 and λ_1, when the signal energy statistic value is greater than λ_1, the ruling Lord user exists, send data fusion center local decision 1; if signal energy statistic value is less than λ_0, it means that the main user does not exist, the data fusion center send local decision 0; if signal between λ_0 and λ_1, it needs to send signal energy statistics to the data fusion center again.

3 Double threshold collaborative spectrum sensing based on OFDM

In wireless communication, orthogonal frequency division multiplexing (OFDM) modulation technology has high spectrum efficiency, resistance to multipath fading, resist narrow-band interference on obvious advantages. OFDM basic idea is to decompose high-speed data stream into many low speed of data flow, the channel is divided into many sub orthogonal channel, the channel between the carrier of maintain orthogonality, spectrum overlap each other, in the form of parallel transmission in multiple child carrier, as a result of the orthogonal relation between subcarrier so as to eliminate the influence of data between the carrier, due to the spectral overlap each other so as to improve the spectrum utilization. The OFDM technology can be combined with a spectrum sensing technology used.The energy detection can use FFT module and OFDM modulation used when FFT module reuse, so as to reduce the system complexity. At the same time, the spectrum sensing consumed time period can also be guaranteed. In this paper, according to the principle of OFDM combined collaborative spectrum sensing, transmission model and collaborative spectrum sensing model OFDM system is obtained as shown in figure 2 and figure 3.

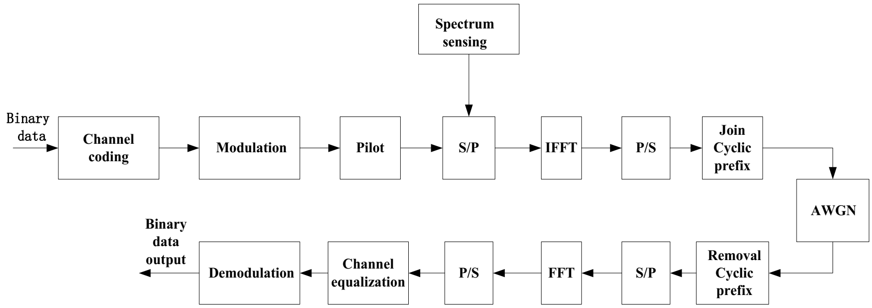

Fig 2 OFDM system transmission model

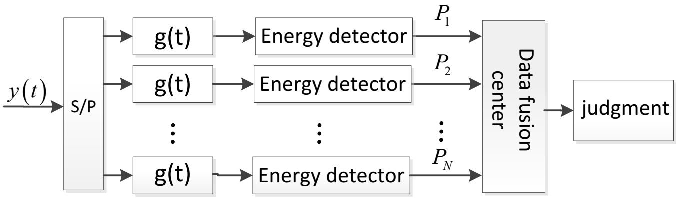

Fig 3 OFDM collaborative spectrum sensing model

The signal enters the OFDM transmission system, after a string of distribution and transform to N road rate lower, sub-channels is due to the rate of sub-channels to 1/N, symbol cycle expanded to N times. Subcarrier can by the channel bandwidth, the number of data throughput and useful symbol duration to decide. Assumption under the given conditions there are N-K carriers, K is carrier at this point, equivalent to N-K users perceived g (t), g (t) in the approach channel, get energy test statistics, various statistical values into the data fusion center, adopt corresponding "or" judgment standard, can be perceived. Feel the result control system is working correctly, to determine if the spectrum idle system normal to send data; to determine if the spectrum, is to stop sending data.

Due to the energy detector with double threshold judgment, the data fusion center at this time will receive the two kinds of data sent by N-K g(t), namely:

$$V_i = \begin{cases} A_i \ , \ \lambda_0 \le A_i \le \lambda_1 \\ B_i \ , \ A_i > \lambda_1 \ \ or \ \ A_i < \lambda_0 \end{cases} \tag{9}$$

According to the maximal-ratio combining principle:

$$D = \begin{cases} 0 \ , \ 0 \le \sum_{i=1}^{N-K} w_i \bullet A_i \le \lambda \\ 1 \ , \ \sum_{i=1}^{N-K} w_i \bullet A_i > \lambda \end{cases} \tag{10}$$

$w_i = \dfrac{\gamma_i}{\sqrt{\sum_{i=1}^{N-K} \gamma_j^{\,2}}}$ is the maximum ratio combining coefficient, and λ is the maximum merger decision threshold.

The decision after data fusion is as follows:

$$D_{final} = \begin{cases} H_0 \ : \ \ D=0 \\ H_1 \ : \ \ D=1 \end{cases} \tag{11}$$

In the data fusion decision criterion, it usually uses the "or" criterion, "or" criterion refers that as long as there is a cognitive users determine the main existence, you get to the final result, the principle was proved to be the one of the rule of data fusion has a better detection performance. Because each subcarrier in OFDM system is relatively independent, so entering the data fusion center of N-K energy statistics will also be independent identically distributed, the data fusion center by means of "or" criterion for the collaborative detection probability and false alarm probability are:

$$Q_{d.or} = 1 - \prod_{i=1}^{N-K} \left(1 - P_{d.i}\right) \quad (12)$$

$$Q_{f.or} = 1 - \prod_{i=1}^{N-K} \left(1 - P_{f.i}\right) \quad (13)$$

4 Simulation and Result Analysis

4.1 Detection performance analysis under different SNR

In AWGN channel under MATLAB simulation parameters are as follows: the primary user signal is $X = \sqrt{2\eta_i}\sin\left(2 * \pi * T\right)$, adjust the signal amplitude according to the signal to noise ratio η_i; rate L = 300; sampling frequency Fs = 1000 Hz; carrier frequency f_0=fs/20; η=[-20,0]dB, step 0.5. N-K=14; P_{f_1} = 0.01, P_{f_2} =0.1, P_{f_3} =0.2, P_{f_4} =0.3.

As shown in figure 4, after BPSK modulation for output of the signal with noise, figure 5 energy values for after energy detector, it can be seen that the main user is noise and produced distortion, at the same time due to the superposition of the noise energy mix signal energy increases, so it is very important how to detect the primary users.

Figure 6 shows the different SNR performance of the energy detection. From formula (8), we can know when know that under the premise of false-alarm probability can be calculated each user perception detection threshold $\lambda_{E,i}$. The formula (7) shows that when the SNR η_i is determined, the detection probability $P_{d,i}$ can be obtained at this time. Formula (12) and (13) can be the collaborative detection probability and false alarm probability. From the simulation results, it can be seen that when the number of carrier and false alarm probability; when the signal-to-noise ratio at the same time, the greater the false-alarm probability, the greater the probability of detection. Too much means that cognitive users will lose the chance of more access to the spectrum hole, too low will make testing less than primary user, error-prone, so must balance between the detection probability and false alarm probability, selected appropriate threshold method.

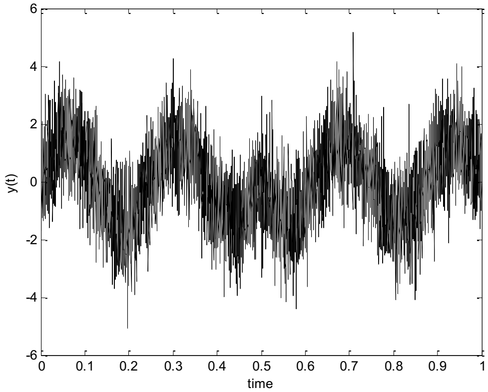

Fig 4 Primary user signal with noise

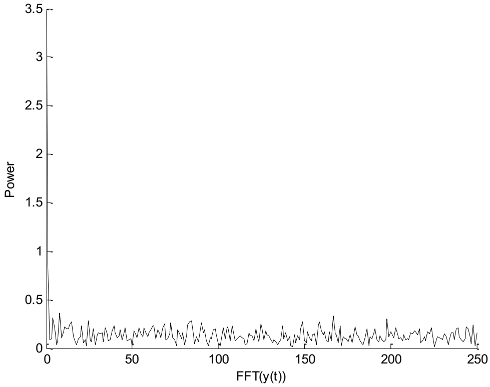

Fig 5 Energy detection

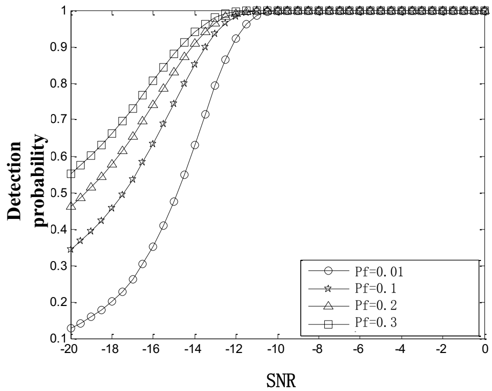

Fig 6 Signal-to-noise ratio and detection probability curve

4.2 Detection performance analysis under "or" fusion criterion

Set the MATLAB simulation parameters under AWGN channel as follows: primary user signal as randn (n, 1); W=5*10^4Hz; Fs = 2*W; SNR η = -10 dB; work subcarrier number N-K = 14; as shown in figure 7, conduct the energy detection performance under the "or" fusion criterion.

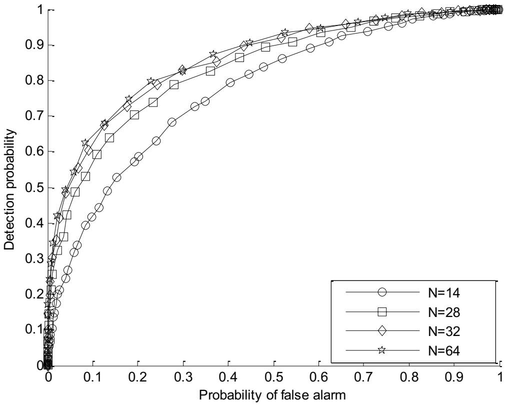

Fig 7 False-alarm probability and detection probability curve under "or" fusion criterion

From figure 7, it can be seen that under the "or" fusion criterion, when the number of carrier is defined, the detection probability will increase with the increase of false-alarm probability. When certain false-alarm probability is defined, with the increase of subcarrier number N - K, the detection probability will also increase. The formula (7) shows that in terms of a single user, the signal-to-noise ratio and false alarm probability are determined. The formula (12) shows that $Q_{d.or} = 1 - \prod_{i=1}^{N-K}\left(1 - P_{d.i}\right)$. The joint detection probability $Q_{d.or}$ is mainly influenced by N-K, the more N-K number is, the greater the simulation results will be consistent with theoretical analysis. Detection probability performance, however, with the increase of the subcarrier number N - K number starts to degrade, when the carrier number is 64, its detection probability will be similar to the 32 subcarriers. With the increase of the false alarm probability, the performance becomes poor, and even in some places than the subcarrier number 32 detection performances, so the appropriate subcarrier number can achieve better detection probability. At the same time, because our main users of radon (n,1) function is randomly generated, the false alarm probability and detection probability curve are not smooth, but determined by the individual test results.

5 Conclusion

This paper studies the application of spectrum sensing algorithm in the cognitive radio, focuses on analyzing the deficiency of the single threshold energy detection and advantage of double threshold energy detection, and proposes the combination of double threshold detection and OFDM system combined with the advantages of high spectrum efficiency of OFDM system. The simulation results prove the feasibility of the proposed method, and the experimental data and theoretical reasoning are consistent. The increasing subcarrier number can improve the performance of system identification, but when it increases to a certain number, the recognition performance will become poor. Therefore, the next step of research is to focus on the subcarrier number suitable for the system.

References

1. First Report and Order, Federal Communication Commission Std. FCC 02-48, Feb.2002.
2. P Qihang,Z Kun,W Jun,et al.A Distributed Spectrum Sensing Scheme Based on Credibility and Evidence Theory in Cognitive Radio Context. Proceedings of 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) ,2006.
3. I F Akyildiz, W Y Lee, M C Vuran, S Mohanty. Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey[J]. Computer Networks Journal(Elsevier),2006,50(13):2127-2159.
4. Cui Tao, Gao Feifei, Nallanathan A. Optimal ofcooperative spectrum sensing in cognitive radio. IEEETransactions on Vehicular Technology ,2011 .
5. Penna F, Garello R, Spirito M A. Cooperative spectrum sensing based on the limiting Eigen value ratio distribution in wishart matrices[J].IEEE Communications Letters. 2009,13(7):507-509.
6. Urkowitz H. Energy detection of unknown deterministic signals[J]. Proceedings of the IEEE.1967,55(4):523-531.
7. Kostylev V I. Energy detection of a signal with random amplitude[J]. ICC, New York, 2002:1606-1610.
8. PanLiang Deng,YuanAn Liu,Gang Xie,XiaoYu Wang,BiHua Tang,JianFeng Sun. Error exponents for two-hop Gaussian multiple source-destination relay channels[J]. Science China Information Sciences, 2012 (2) :388-391.
9. BOMFIN R C D V,GUIMARAES D A,SOUZA R A A D. On the probability of false alarm of the power spectral density split cancellation method. IEEE Wireless Communication Letters . 2016,8 (7):47-55.
10. Li Qunwei,Li Zan,Shen Jian,Gao Rui.A novel spectrum sensing method in cognitive radio based on suprathreshold stochastic resonance. 2012IEEE International Conference on Communications . 2012：2682-2686.
11. G Ganesan and Y Li. Cooperative spectrum sensing for cognitive radios under bandwidth constraints[C]. Proceedings of the Wireless Communications and Networking Conference.Jun.2007:1-5.

Springer

http://www.springer.com/978-3-319-49108-0

Advances on P2P, Parallel, Grid, Cloud and Internet Computing
Proceedings of the 11th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC–2016) November 5–7, 2016, Soonchunhyang University, Asan, Korea
Xhafa, F.; Barolli, L.; Amato, F. (Eds.)
2017, LXI, 976 p. 414 illus., Softcover
ISBN: 978-3-319-49108-0