Adaptive spectrum sensing algorithm based on SNR estimation

Wei Rui

***Abstract*—Considering of the traditional energy detection cannot accurately perceive the signal under the condition of low signal to noise ratio (SNR) . It can easily lead to misjudgment. In order to improve the performance of spectrum sensing in low SNR conditions and shorten the sensing time, combined the cyclic feature detection has high detection performance and robustness but with high computational complexity. This paper developed an adaptive spectrum sensing algorithm based on SNR estimation.It calculated the pre estimation ratio of detection signal to noise signal. When the SNR is higher than the threshold value, the improved adaptive energy detection was performed to reduce the computational complexity, otherwise selected cyclic feature detection to ensure good accuracy. It could according to the requirements of the detection accuracy and efficiency of the sensing system adjusted the size of the selection threshold adaptively. Simulation experiments show that proposed algorithm can effectively improve the accuracy of spectrum sensing under low SNR and shorten the average detection time.**

I. Introduction

THIS paper proposes an adaptive local spectrum sensing scheme. Cognitive radios have emerged as a promising solution to improving spectrum utilization. It has been widely recognized that while there is a perceived scarcity of radio spectrum, large portions of licensed spectrum remain underutilized.Two sensing techniques that have been commonly considered in cognitive radios are energy detection and cyclostationary detection. While energy detection is a simple detection technique,its performance is not robust to noise and is known to be poor at low SNRs. Cyclostationary detection on the other hand provides better detection but is computationally more complex and needs a much higher sensing time. two-stage sensing approach is based on energy detection and cyclostationary detection.For a given channel, in the first stage, energy detection is performed. If the decision metric in this stage exceeds a certain threshold γ, the channel is declared to be occupied. Else, it is declared to be empty and available for secondary use. Although this approach increase the accuracy of sensing,but it needs two sensing process so that increase the sensing time,so it is no better.So, we combine the two methods' strength.As it is already discussed in the introductionsection, the energy detector performs very poor under low SNRs. We defined SNR threshold γ, below which the energy detector is unable to detect channels accurately, and we will perform the cyclostationary detection to sense the channels. Cognitive Radio (CR) is a key technology that can help mitigate scarcity of spectrum.The most essential task of CR is to detect licensed user/Primary User (PU); if PU is absent, then spectrum is available for cognitive radio user/Secondary User (SU) and is called spectrum hole/white space. The process of detection of PU is achieved by sensing radio environment and is called spectrum sensing. The prime concerns of spectrum sensing are about two things: first, the primary system should not be disturbed by SU communication and secondly, spectrum holes should be detected efficiently for required throughput and quality of service (QoS) . For effective spectrum sensing, increasing reliability of PU detection and minimizing sensing time are two primary concerns in CR networks. In view of the fact that spectral efficiency is reduced by false alarms and interference with PU is caused by miss detection, and generally it is vital for optimal detection performance that the maximum probability of detection is achieved subject to the minimum probability of false alarm. In the draft of IEEE 802.22 standard, PUs should be detected within two seconds and the probability of false alarm and miss detection should be less than or equal to 0.1. Simultaneous transmission and sensing of licensed band is not possible. Therefore, for efficient utilization of spectrum holes, SU has to periodically sense the band every Tp seconds known as a sensing period. PU transmission may be obstructed because SU is unaware of its activity during the sensing period, i.e., until the next sensing moment. Therefore, PUs performance is highly dependent on the sensing period. Maximizing sensing period may increase throughput of SU but may make PU obstructed because PU is not often sensed. From a CR network perspective, SU desires to maximize the sensing period and minimize sensing time. The SU has to properly schedule the sensing period to coexist with the licensed band. By reducing sensing time, the SU can achieve higher throughput and less interference with PUs without sacrificing sensing reliability.

II. Theory

Denoting H1 and H0 as the respective probabilities of primary user presence and absence,the problem of signal perception can be discribed by the Binary hypothesis testing model like this:

$$y(n) = \begin{cases} w(n) & H_0 \\ hs(n) + w(n) & H_1 \end{cases} \tag{1}$$

with the primary users signal and receiver noise denoted by s(n) and w(n), respectively. The noise is assumed to be an i.i.d. random Gaussian process with zero mean and variance σ_w^2, while y(n) is the detected signal recieved by the secondary user.h and N denote channel gain and number of sample points respectively.

According to the ratio of desired signal and assumed noise and through setting different SNR to choose a threshold γ and select perception strategy.

III. Procedures

1.framework

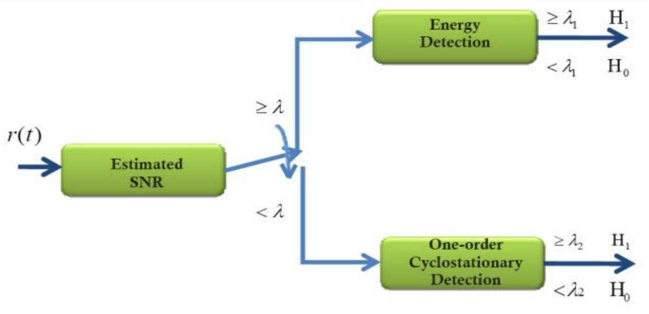

Figure 1. Adaptive spectrum sensing scheme

$$DetectionTechnique = \begin{cases} ED, & SNR \geq \gamma \\ CD, & SNR < \gamma \end{cases} \quad (2)$$

where ED means energy detection,CD means cyclostationary deection.

2.energy detection

Sample the received signal to get y[n] and compute the detection statistics $X = \frac{1}{N}\sum_1^N |y[n]|^2$,then compare with threshold,where X admit chi square distribution.

$$X \sim \begin{cases} \chi_N^2, & H_0 \\ \chi_N^2(2\gamma), & H_1 \end{cases} \quad (3)$$

where γ is the real SNR,according to the central limit theorem,X approximately admit Gaussian distribution when sampling point N much larger than 1.

$$X \sim \begin{cases} N(\sigma_w^2, \frac{2}{N}\sigma_w^4), & H_0 \\ N(\sigma_w^2 + \sigma_x^2, \frac{2}{N}(\sigma_w^2 + \sigma_x^2)^2), & H_1 \end{cases} \quad (4)$$

where σ_x^2 is the signal power, $Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi e^{-\frac{1}{t^2}}}} dt$.

So we get the false alarm probability P_f^E and detection probability in energy detection

$$P_f^E = P(X > \lambda | H_0) = Q(\frac{\lambda - N\sigma_w^2}{\sqrt{2N\sigma_w^4}})$$

$$P_d^E = P(X > \lambda | H_1) = Q(\frac{\lambda - N(\sigma_w^2 + \sigma_x^2)}{\sqrt{2N(\sigma_w^2 + \sigma_x^2)^2}})$$

Because the uncertainty of noise in channel,fixed threshold probably caused misjudgement,it is need to dynamic adjust the threshold,we use $\lambda_e = \lambda_{CF} + \beta\lambda_{CD}$ to change the threshold,where $\beta = E_{SNR}$ is the adaptive adjust factor, λ_{CF} is the threshold when expected false alarm probability is 0.1,$\lambda_{CD}$is the threshold when expected detection probability is 0.9,so

$$\lambda_{CF} = Q^{-1}(0.1) * \sqrt{(2\pi\sigma_w^2)} + N\sigma_w^2$$

$$\lambda_{CD} = Q^{-1}(0.9) * \sqrt{(2\pi\sigma_x^2\sigma_w^2)} + N(\sigma_x^2 + \sigma_w^2)$$

3.cyclostationary detection

Commonly, the primary modulated waveforms are coupled with patterns characterized as cyclostationary features like sine wave carriers, pulse trains, repeating spreading, hoping sequences or cyclic prefixes inducing periodicity,but the noise does not have this cyclostationary charateristic. First,we compute the cyclic autocorrelation function (CAF)

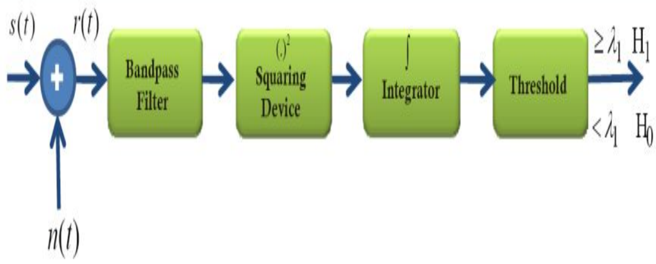

Figure 2. Block diagram of energy detection

$$R_y^a(k) = \lim_{N \longrightarrow \infty} \frac{1}{2N+1} \sum_{-N}^{N} [y(n+k)e^{-j\pi\alpha(n+k)}] * [y(n)e^{-j\pi\alpha n}]$$

where α is introduced cyclic frequency(CF),after fast Fourier transform(FFT),we get spectral correlation function(SCF)

$$S_y^a(f) = \sum_{k=-\infty}^{\infty} R_y^a(k)e^{-j2\pi fk}$$

$S_y^\alpha(f)$ also can be called cyclostationary spectrum density (CSD). Because noise does not have the cyclostationary charateristic,maybe signal and noise is coincident in power spectrum,but noise is discrete in cyclostationary spectrum.The energy of noise is concentrate in zero cyclostationary spectrum.So we can search the peak of detected signal cyclostationary spectrum to judge whether the signal exist,after analyzed,we get the following judge rule

$$S_y^\alpha(f) = \begin{cases} S_s^\alpha(f), & H_0 \\ 0, & H_1 \end{cases} \quad (5)$$

where $\alpha \neq 0$

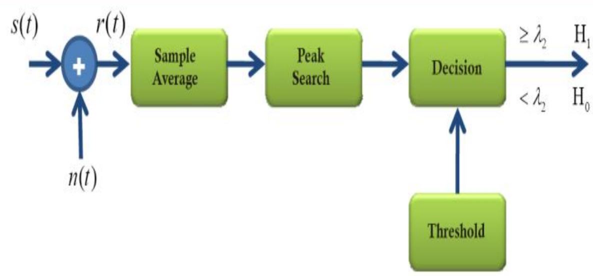

Figure 3. Block diagram of one-order cyclostationary detection [14]

IV. Analysis

First,estimate the real SNR and compare with γif $S \geq \gamma$ then choose energy detection,else choose cyclostationary detection;

Second,using $P_d = P(S \geq \gamma)P_d^E + P(S < \gamma)P_d^C$ to compute real detection probability, where P_d^E and P_d^C is the detection probability when use energy detection and cyclostationaary detection respectively,$P(S \geq \gamma)$ is the probability to using the energy detection,$P(S < \gamma)$ is the probability to using cyclostationary detection,their summation is 1;

Third,using $\gamma_i = \gamma_{i-1} + \kappa(\bar{P}_d - P_d)$ to adjust the SNR threshold, if $P_d < \bar{P}_d$,increase this threshold,otherwise decrease the threshold. where $\bar{P}_d$ is the expected detection probability, P_d is real detection probability. When $P_d = \bar{P}_d$,it's no need to adjust the threshold,then end this loop.

V. Simulation

In the reference [1],they compare this approach of spectrum sensing with the adaptive energy detection and two-stage detection.But I didn't simulate this approach sucessful.

In my opinion,this strategy combines the energy detection and cyclostationary detection.So first I simulate them respecively. In energy detection,Monte Carlo simulation is used for experimentation under the following system settings: there is simple-frequency signal in AWGN channel and The sensing performance is quantified by the complementary receiver operating characteristic (ROC), i.e., Pf versus Pm.I simulate this approach with SNR=-3,5,7,with each SNR,I compare the simulation value with the theoretical value ,so the following figure is the simulation result.

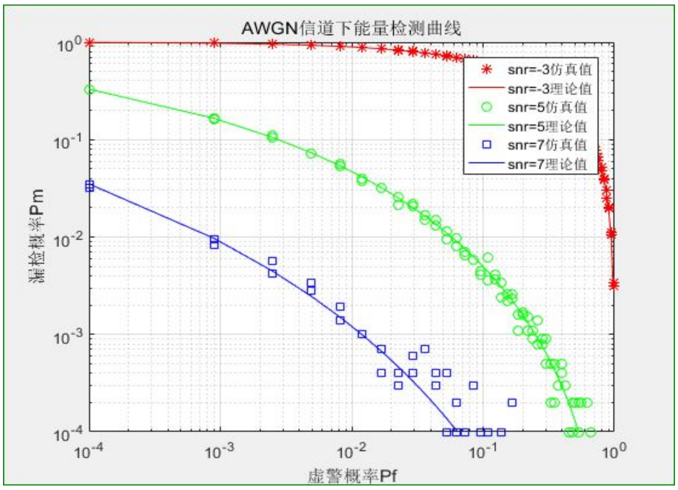

Fig. 1. Energy Detection

Also,in the cyclostationaary detection,the system setting is :there is BPSK signal in AWGN channel and The sensing performance is quantified by detection performance versus SNR.

Parameter specification:the SNR inteval is[-20,5]dB,Monte Carlo simulation time is 10(I changed it to be 1000,but it runs slow so I gave up),false alarm probabilty is 0.05,sample frequency f_s is 0.2MHz,carrier frequency f_c is 90KHz,symbol rate f_0 is 1000bps,cyclic frequency is $\alpha = 2f_0$.

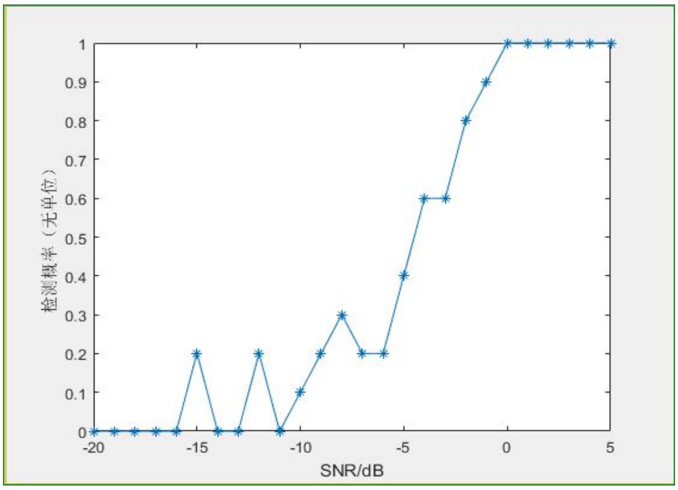

Fig. 2. Cyclostationary Detection

In the reference[1],they also compared the two-stage spetrum sensing with this proposed method.The two-stage spectrum sensing is shown in following figure.We assume that there are L channels to be sensed and that channels are sensed serially. In the coarse sensing stage, the channel is sensed using energy detection. If the decision metric is greater than a threshold λ, the channel is declared to be occupied. Else, the received signal is analyzed by fine sensing consisting of cyclostationary detection. If the constituent detection metric is greater than a threshold γ, the channel is declared occupied, else it is declared to be empty. It includes coarse sensing which adopts energy detection and fine sensing which adopts cyclostationary detection.

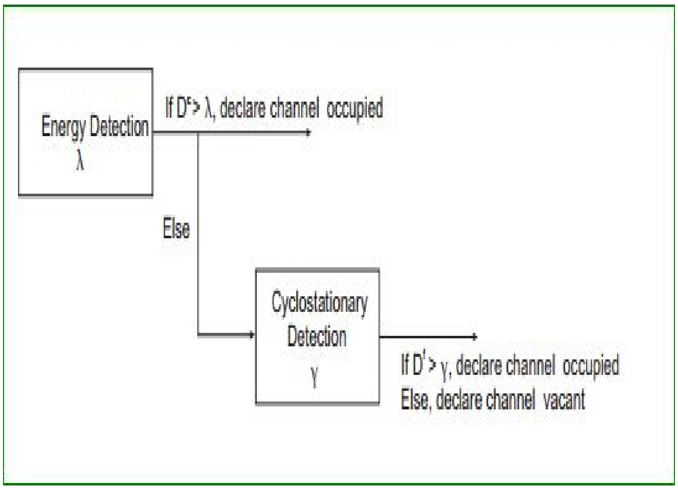

Fig. 3. Two-stage spetrum sensing scheme

VI. Problems

1.I run the energy detection and cyclostationary feature detection respectively,but the way to generate BPSK signal is different.if use the SNR to create it,when I run the codes,the λ_e is changing,but I need it changes after one loop.

2.If the variance of noise is invariant and with the SNR is setting, the signal's power is certain,then $\lambda_e = \lambda_{CF} + \beta\lambda_{CD}$ is easy.But if not,the value is changing,P_d^E is difficult to compute and it's no need to estimate SNR.

3.I don't know how to compute $P(S \geq \gamma)$,so can't get the real P_d.I think it should compute N-simu(Monte Carlo) times for each signal sample in order to get detection probability and the probability that choose energy detection.

4.The adaptive spectrum sensing scheme was proposed in this paper to meet the accuracy and the minimum sensing time required in CR networks. The proposed scheme chooses either the energy detection or the cyclostationary detection based on the estimated SNR. We observed that at low SNRs where energy detector is not reliable, the proposed scheme provides improved detection at the cost of mean detection time. At high SNRs, the proposed scheme provides fast detection using the energy detector.

Although I didn't have a good simulation,just run the two strategy respectively,I find the cyclostationary feature detection indeed is complex in computation that we can compare the Monte Carlo simulation time.In energy detection,it is 1000,but in cyclostationary detection it is just 10,when I change it to 1000,I found the run time is long,so I gave up.

REFERENCES

[1] Ni Shuiping,Chang Huigang,Xu Yuping. Adaptive spectrum sensing algorithm based on SNR estimation. *Application Research of Computers*, 2018(09):1-2[2018-01-17]. http://kns.cnki.net/kcms/detail/51.1196.TP.20170828.1023.044.html

[2] Ejaz W, Hasan N U, Kim H S. SNR-based adaptive spectrum sensing for cognitive radio networks. *International Journal of Innovative Computing Information and Control*, 2012, 8 (9): 6095-6105.

[3] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran and S. Mohanty.Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey *Computer Networks*. vol.50, no.13, pp.2127-2159,2006.

[4] J. Ma, G. Li and B. H. Juang. Signal processing in cognitive radio*Proc. of the IEEE* ,vol.97, no.5,pp.805-823, 2009.

[5] T. Yucek and H. Arslan. A survey of spectrum sensing algorithms for cognitive radio applications. *IEEE Communications Surveys Tutorials*, vol.11, no.1, pp.116-130, 2009.

[6] S. Haykin.Cognitive radio: Brain-empowered wireless communications*IEEE Journal on Selected Areas in Communications*, vol.23, no.2, pp.201-220, 2005.

[7] D. Cabric, S. M. Mishra and R. W. Brodersen. Implementation issues in spectrum sensing for cognitive radios. *Proc. of the 38th Asilomar Conference on Signals, Systems and Computers*, pp.772-776, 2004. bibitemMJH06 I. F. Akildiz, B. F. Lo and R. Balakrishan. Cooperative spectrum sensing in cognitive radio networks:A survey. *Physical Communication*, vol.4, pp.40-62, 2011. bibitemMJH06 I. F. Akildiz, B. F. Lo and R. Balakrishan. Cooperative spectrum sensing in cognitive radio networks:A survey. *Physical Communication*, vol.4, pp.40-62, 2011.

[8] I. W. G. on Wireless Regional Area Networks (WRANs). http://www.ieee802.org/22/ bibitemMJH06 C. R. Stevenson, C. Cordeiro, E. Sofer and G. Chouinard. Functional requirements for the 802.22 WRAN standard*IEEE 802.22 Draft*, 2005.

[9] A. Ghasemi and E. S. Sousa.Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs*IEEE Communication Magazine*, pp.32-39, 2008.