International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.1., 2016
(Jan-Feb)

RESEARCH ARTICLE

ISSN: 2321-7758

ENERGY AND AUTOCORRELATION BASED SPECTRUM SENSING FOR COGNITIVE RADIOS

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ABSTRACT
Cognitive radio networks use spectrum sensing technology to detect the presence of the primary user. This paper proposes the importance both energy and autocorrelation method based spectrum sensing algorithm. The detection algorithm is based on the assumption that primary user's signal is not white and compares the performance of the proposed detector and the energy detector in additive white noise channel which is a Gaussian as well as having multipath fading environments, simulation shows that the sensing performance is improved when both detector is adopted.

I. Introduction

Cognitive Radio (CR) is a wireless communication system which can sense and get information from surrounding environment. The cognitive radio technology has recently researched with the ability to adapt the wireless environment by changing its operating parameters. A standard for wireless regional area networks (WRANS) has been proposed by the IEEE 802.22 working group, *which uses the CR technology.* Spectrum sensing is the key technology for cognitive radio, which have the knowledge about both spectrum usage and the presence of the primary users and if the spectrum band is unoccupied by the primary users, it is known to be the spectrum hole and the secondary users can use the spectrum hole. The secondary users need to detect the presence of primary user, if primary user appears, the secondary users can change to another free channel in order to minimize the interference with the primary user.

The cognitive radio system divides the working period into sensing period (quick time) and transmission period. The secondary users will stop transmitting in the sensing period. The challenge for cognitive radio design is to minimize the sensing time to improve the efficiency of spectrum. Frequency bands used by WRANS are licensed for both analog and digital TV broadcasting and microphones which are wireless. The standard demands for the sensing period is less than 2s, probability of detection is 0.9 and probability of false alarm is 0.1. A number of methods for spectrum sensing are used for identifying the presence of the primary users signal. We classify these methods as energy detection sensing method, matched filtering based sensing method, cyclostationary and autocorrelation based sensing method. The energy detection method does not need any prior knowledge about the primary user signal. The computational load is low and is robust to multipath fading. The matched filtering based sensing method is known as optimum method for detection of primary users when transmitted signals are considered to be known. The advantage of matched filtering is its short time to achieve certain probability of false alarm &miss detection.

Cyclostationary feature detection is a method to detect primary user's transmission by exploiting cyclostationary characteristics of the received signal. The cyclostationary based detection algorithms can be used to differentiate noise from primary users' signal. This can be the result of fact that noise is wide-sense stationary having no correlation while modulated signals are cyclostationary. The matched filter based detection and cyclostationary detection methods required a lot of prior knowledge about primary users, which are hard to obtain in the real environment.

The autocorrelation based sensing methods are proposed in this paper. The noise variance does not need to estimate because of the "self-normalizing" feature of narrow band signals. These detectors can detect primary user signal presence based on the fact that most of narrow band signals' autocorrelation matrices are not diagonal. In the paper, a new spectrum sensing algorithm is proposed based on the assumption that primary user's signal is not white. We noticed that correlation feature of the received signal is not considered by the conventional energy detector. Thus when variance of noise is detected by the sensors, if we consider the power and autocorrelation of signal jointly, the sensing performance will improve.

II. SYSTEM MODEL

Let f_s be sampling rate, Ts = 1/fs be sampling period. s(t) is primary user's signal and w(t) is white noise. The sensing period is in the interval [0, T]. Assume noise w(t) is stationary with zero mean and variance σ_w^2. σ_w^2 is detected by the sensors. The primary user signal suffers multipath fading and is uncorrelated with the noise. L length channel vector h is given by $h = [h(0), \ldots, h(L-1]T$. Then received signal is given by

$$x(t) = \eta \sum_{l=0}^{L-1} h(l)s(t-l) + w(t), 0 \le t \le T \quad (1)$$

where the value η ∈ {0, 1} denotes the presence or absence of primary user. If η = 1, primary user appears, otherwise, there is only noise in spectrum. The sample number is N = [T/Ts]. Define x(n) = x(nTs), s(n) =s(nTs) and w(n) =w(nTs).

Let u(n) $=\sum_{l=0}^{L-1} h(l)s(n-l)$. The variance of u(n) is σ_u^2.

Then the received signals have two hypotheses

H0 : x(n) = w(n) (2)

H1 : x(n) = u(n) + w(n) (3)

where H0 means there exists primary user in the frequency band and H1 means the primary user is absent

III. DESIGN OF SPECTRUM DETECTOR

A. *Energy Detector*

The energy detector is the basic spectrum sensing method; it doesn't need any information of signal to be detected which is robust to unknown multipath fading. It has very low computational and implementation complexity. The power of received signal is

$$z=\frac{1}{N} \sum_{n=0}^{N-1} x^2(n) \quad (4)$$

Under the hypothesis H0, there is only noise in received signal, thus z is a chi-square distributed with N degrees of freedom. When the value of N is large, z is taken as a gaussian distributed random variable with mean σ_w^2 and variance $2\,\sigma_W^4/N$. The probability of false alarm can be derived as

$$P_{f,ED} = \frac{1}{2\sigma_W^2\sqrt{\pi/N}} \int_\gamma^\infty e^{\frac{Z-\sigma_W^2}{2\sigma_W^4/N}}\, dx \quad (5)$$

For a given probability of false alarm $P_{f,ED}$ the threshold λ of an energy detector can be derived as

$$\lambda = \sigma_W^2 \left(1 + \sqrt{2/N}\, Q^{-1}(P_{f,ED})\right) \quad (6)$$

where Q(x) = (1/√2π)$\int_x^\infty e^{-t^2/2}$ is the normal Q function.

The test statistic of energy detector is

$$T_{ED}=\sum_{n=0}^{N-1} x^2(n) \quad (7)$$

When σ_u^2 is known by detector, probability of detection with given threshold λ is determined as

$$P_{d,ED}=Q\left(\frac{\lambda/\sigma_W^2}{\sigma_u^2/\sigma_W^2+1}\right) \quad (8)$$

B. *Joint Energy method and Autocorrelation method Based Spectrum Sensing Algorithm*

In the paper, we assume that the signal samples are correlated when the primary user signal is present. The assumption is reasonable because lots of original signal are correlated, primary user's signal suffers a multipath fading, and when most of the signal are narrow band, the received signal is when over sampled, it will be highly correlated. So we get the conclusion that the autocorrelation matrix of primary user's signal is not diagonal.

Define

R(τ)= E{x(n)x(n+τ)= $\lim_{N\to\infty}\sum_{n=0}^{N-\tau-1} x(n)x(n+\tau)$ (9)

is the autocorrelation function of x(n). Because the samples number is finite in the real environment, true value of R(τ) cannot be obtained. Thus, we use $R^{\wedge}(\tau)$ as the estimation value of R(τ), which is defined as follows

$$R^{\wedge}(\tau) = \frac{1}{N-\tau}\sum_{n=0}^{N-\tau-1} x(n)x(n+\tau) \qquad (10)$$

Theorem for the estimation value of autocorrelation function has been stated as

Theorem: Under H0 hypotheses, $R^{\wedge}(\tau)$ is a Gaussian distributed variable with mean zero and variance

$\sigma_w^4/(N-\tau)$ when $\tau \neq 0$

Proof: Let x and y be two independent normally distributed variables having mean zero and variances σ_x^2 and σ_y^2. v is the product of x and y. Then the probability density function of v is given by

$$\text{Pxy(v)}=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{e^{-x^2/2\sigma_x^2}}{\sigma_x\sqrt{2\pi}}\frac{e^{-y^2/2\sigma_y^2}}{\sigma_y\sqrt{2\pi}}\partial(xy-v)dx\,dy$$

$$=\frac{K_0\left(\frac{|v|}{\sigma_x\sigma_y}\right)}{\pi\sigma_x\sigma_y} \qquad (11)$$

where δ(·) is the delta function and Kn(·) is a modified Bessel function . The mean of v is 0, and variance of v is $\sigma_x^2\sigma_y^2$

Let a, b, c be independent normally distributed variables with mean zero and variances σ^2, then the variables ab and bc are with zero means and the variances σ^4. The covariance of both ab and bc is

cov{(ab)(bc)}=E{(ab−E{ab})(bc−E{bc})}=E{(ab)(bc)}=E{ab^2c}=E{a}E{b^2}E{c} = 0 (12)

thus, ab is uncorrelated with bc.

IV. SIMULATION RESULTS

In the section, simulations are used to evaluate the performance of energy detector and joint correlation method. We take the sample N=1000,Pf=0.02 to 0.1.Threshold is determined by given equation.

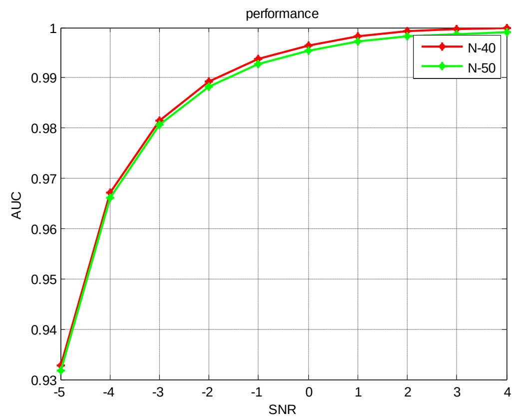

Fig 1 : SNR vs Average user capacity

It shows the performance between signal to noise ratio and average user capacity at different values of N.When SNR increases,user capacity also increases.

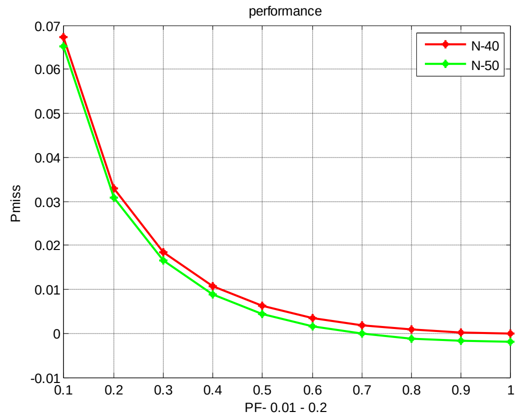

Fig 2:Performance comparison between Pmiss and P_f

when P_f increases,Pmiss decreases

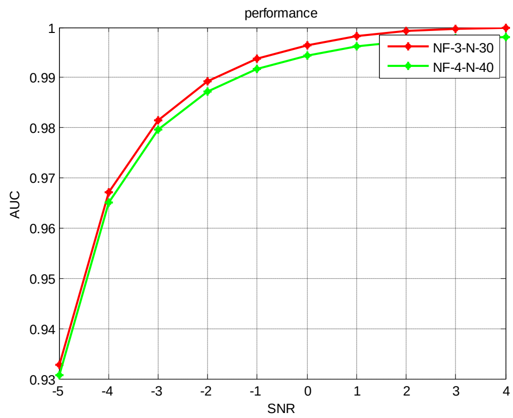

Fig 3:Performance comparison between AUC and SNR

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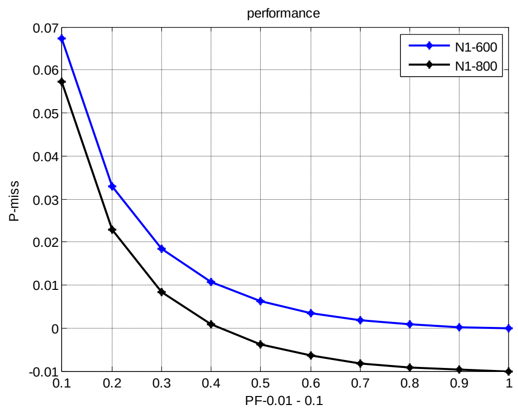

Fig 4: Performance comparison of Pmiss vs Pf

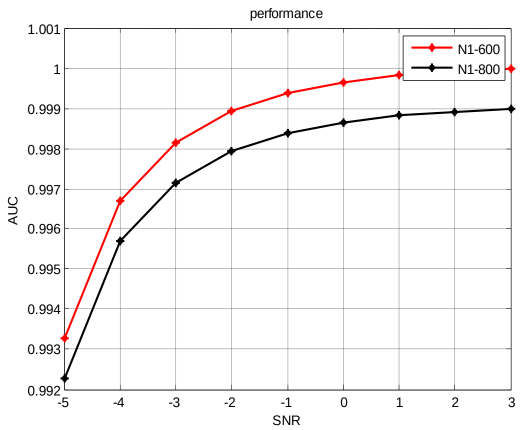

Fig 5: Performance between Average user capacity and SNR

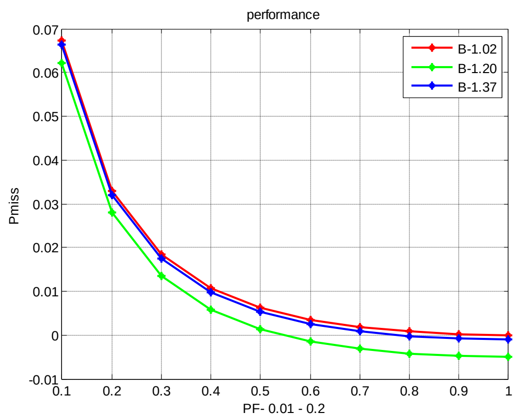

Fig 6. Performance between Pmiss and Pf

When Pf increases ,Pmiss decreases for different values of noise variance.

V. Conclusion

This paper proposes a joint energy and autocorrelation method spectrum sensing algorithm. This proposed detection algorithm can be used in fading condition also .Using both method will improve the detection performance at low SNR condition. Studied the performance between SNR and average user capacity in joint and energy detection method for spectrum sensing. Its Future work consist of deriving the closed-form expressions for both probability of false alarm and detection probability of the proposed method in the AWGN and multipath fading channel.

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