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Spectrum Sensing Based on Monostable Stochastic Resonance in Cognitive Radio Networks

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Abstract

The cognitive radio technology can provide dynamic spectrum access and improve the efficiency of spectrum utilization. Spectrum sensing is one of the key technologies of cognitive radio networks. The spectrum sensing performance of cognitive radio networks will be greatly reduced in the low SNR environment, especially when using energy detection. Due to the monostable stochastic resonance system can improve the energy detection system output SNR, a monostable stochastic resonanceis applied to spectrum sensing based on the energy detection method of cognitive radio networks in this paper. The simulation results show that in the low SNR environment, when the false alarm probability is constant, the proposed spectrum sensing based on monostable stochastic resonance has better performance than traditional energy detection.

Keywords: *Monostable Stochastic Resonance, Cognitive Radio, Spectrum Sensing, Energy Detection*

1. Introduction

Cognitive radio (CR) can effectively alleviate the contradiction between the spectrum shortage and the needs of the rapid development of wireless communication [1]. Spectrum sensing (SS) is one of the key technologies of CR [2],[3]. The main function of spectrum sensing is to detect spectrum holes. So the secondary users (SU) can access to the unused channel under the condition that do not cause interference to primary users (PU). At the same time the SU monitor the primary users so as to be able to quickly exit when the PU reuses the band.One of the biggest challenges for SS is detecting the weak PU signalin low Signal to Noise Ratio (SNR) environment. In low SNR environment, the performance of spectrum sensing will be greatly reduced [1]. In recent years, some researchers have proposed the application of stochastic resonance (SR) to spectrum sensing in order to solve the problem of detecting weak signal of the PU.

In [4], the bistable SR system is applied to the energy detection in CR, in order to improve SNR. In subsequent studies, He di has also discussed how to add an optimal SR noiseso that it can improve SNR maximally [5]. They also studied the spectrum sensing of CR based on Chaotic Stochastic Resonance [6]. They also confirmed that the SR in the colored noise environment is equally applicable [7]. K.Zheng has proposedBlock Spectrum Sensingand Sequential Spectrum Sensing schemes of SR forspectrum sensing in the low SNR regime [8]. Lin Yingpei has proposed a spectrum sensing schemein CRthat combined the cyclostationary feature detection (CFD) and SR [9]. Chen Wei in order to maximizing detection performance, has proposed a generalized SR method in the local sensing and cooperative sensing [10]-[11]. In addition, the covariance matrix [12],cyclostationary [9] and cooperative spectrum sensing [13]-[14] based on the SR have been confirmed that can improve spectrum sensing performancein a low SNR environment.

The presentresearches on spectrum sensing based on SR are all based on traditionalbistable SR, and the monostable stochastic resonance is not involved. Due to the monostable SR system can improve the output SNR, it is applied to spectrum sensingbased on

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the energy detection method of CR system in order to improve the performance under low SNRin this paper.

2. The Energy Detection Model of Cognitive RadioBased on Stochastic Resonance

Because the energy detection has the following advantages: need not to know any prior knowledgeof the PU, low computational complexity and easy implementation, thus it is widely used in the CR spectrum sensing. According to the Neyman-Pearson criteria, spectrum sensing problem can be formulated as the following two assumptions:

$$\begin{aligned} H_0 &: r(t) = n(t), \qquad (t = 0, 1, ..., N-1) \\ H_1 &: r(t) = s(t) + n(t), (t = 0, 1, ..., N-1) \end{aligned} \tag{1}$$

Where H_1 indicates that the PU exists while H_0 shows that the PU does not exist. $r(t)$ is the received signal of the SU. $s(t)$ is the PU signal and is assumedwith zero mean and variance $\sigma_n^{\ 2}$. $n(t)$ denotes the Gaussian noise and is assumed to be an i.i.dGaussian random process with zero mean and variance $\sigma_n^{\ 2}$.The signal $s(t)$ and the noise $n(t)$ are assumedindependent of each other.

Stochastic resonance refers to the noise energy will be transferred to the signal energy when the input signal and the noise have a match in the non-linear system. At this time, the SNR of the input signal will not be lowered, but will increase. Therefore stochastic resonance is ideal for weak signal detection problem [15].SR system consists of three elements: amonostable or bistable or multistablenonlinear system, input signal and noise. Traditional bistable SR system model is most widely usedin the study. It is described by a Langevin equation [15]:

$$\dot{x}(t) = -V'(x) + A\cos(2\pi ft + \phi) + n(t) = ax(t) - bx(t)^3 + A\cos(2\pi ft + \phi) + n(t) \tag{2}$$

Where $A\cos(2\pi ft + \phi)$ is the input signal, A is the signal amplitude, $n(t)$ is the stochastic resonance noisewith the mean of 0 and variance σ_n^2 SR noise, satisfies the equation $E[n(t)n(t+\tau)] = 2D\delta(t-\tau)$,in which D is the noise intensity. $V(x) = -\frac{a}{2}x^2 + \frac{b}{4}x^4$ is a reflection of the symmetric square potential. a and b are the non-linear system unknown parameters and satisfy $a > 0, b > 0$.

The energy detection model based on SRis shown in Figure 1 [5].

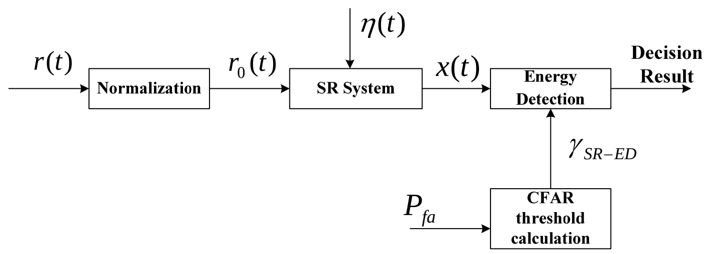

Figure 1. The energy detection model based on SR

3. Spectrum Sensing Based on Evstigneev Type Monostable Stochastic Resonance

3.1. Monostable SR systems

Evstigneev M has studied a new single-stable SR system- Evstigneev(E) type SR [16]. Pin W etc. have studied the SNR gain of the Evstigneev type monostable SR, and concluded that the SNR gain can be greater than 1 in a certain region through adjusting the parameters

[17]. The SNR gain greater than 1 means that the output SNR greater than the input SNR after the signal through the Evstigneev type SR system. Therefore, for the energy detector, detection performance can be improved by certain E type monostable SR system.

In the case of neglecting the inertial effect, Langevin equation of monostable model proposed by [14] is:

$$\dot{x}(t) = -V'(x) + A\cos(2\pi ft + \phi) + n(t) \tag{3}$$

$$V(x) = a|x|^{\alpha} + b|x|^{\beta} \quad a,\ b > 0,\quad 0 < \alpha < \beta \tag{4}$$

Where $V(x)$ is the system potential function, $A\cos(2\pi ft + \phi)$ is the drive signal, when applied in the spectrum sensing it is the PU signal. $n(t)$ is additive white Gaussian noise with mean 0 and variance 1, and satisfies the formula $E[n(t)n(t+\tau)] = 2D\delta(t-\tau)$, Where D is the noise intensity.

When $a = b = 1$, $\alpha = 3/2$, $\beta = 4$, the potential function in (4) does not exist any barrier, also does not exist the inflection point, Evstigneev M thinks this is a kind of SR model.

In [15], the monostable potential function is:

$$V(x) = \frac{2}{3}a|x|^{3/2} + \frac{1}{4}b|x|^{4} \quad a,\ b > 0 \tag{5}$$

Equation (5) is d in equation (3):

$$\dot{x}(t) = -a|x|^{1/2} sign(x) \text{-} b|x|^{3} + A\cos(2\pi ft + \phi) + n(t) \tag{6}$$

Where $sign(x)$ is the sign function:

$$sign(x)\begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases} \tag{7}$$

Ref. [17] points out that when $a = 0.5$, $b = 1$, and in the appropriate frequency range, Etype monostable SR can make the system SNR gain greater than 1.

3.2.Energy Detection Based on Monostable SR

3.2.1. Experimental Procedure

Detection performance is discussed in the situation that under different false alarm probabilities condition while same SNR, and in the situation that under different SNR while same false alarmprobability. The Monte Carlo method is used, specific steps are as follows:

1. Different false alarm probabilities while same SNR

(1) According to binary hypothesis, the received signal is divided into two cases: H_0 and H_1. The received signal is performed *N*-point sampling, and then processed by stochastic resonance system.

(2) According to the energy detection principle, received signalenergy values E_0 and E_1 in two hypothetical scenarioswere calculated,then the *n* cyclescalculations are carried out.

(3) After *n* cycles of calculations, the resulting E_0 and E_1 will bestored in the array $a[E_{01}, E_{02}, E_{03}, \ldots, E_{0n}]$ and $b[E_{11}, E_{12}, E_{13}, \ldots, E_{1n}]$.Then array $a[E_{01}, E_{02}, E_{03}, \ldots, E_{0n}]$ is arranged in ascending order, and be saved to another array $\gamma[\gamma_1, \gamma_2, \gamma_3, \ldots, \gamma_n]$ as threshold values.

(4) Calculate the numbers that the elements in the array $a[E_{01}, E_{02}, E_{03}, \ldots, E_{0n}]$ greater than the threshold value $\gamma_1, \gamma_2, \gamma_3, \ldots, \gamma_n$ respectively, then obtained $L[L_1, L_2, L_3, \ldots, L_n]$. $[L_1/n, L_2/n, L_3/n, \ldots, L_n/n]$ represents a set of false alarm probability $P_{fa}[P_{fa1}, P_{fa2}, P_{fa3}, \ldots, P_{fan}]$,where $P_{fa} \in [0,1]$.

(5) Calculate the numbers that the elements in the array $b[E_{11}, E_{12}, E_{13}, \ldots, E_{1n}]$ greater than the threshold value $\gamma_1, \gamma_2, \gamma_3, \ldots, \gamma_n$ respectively, then obtained $M[M_1, M_2, M_3, \ldots, M_n]$. $[M_1/n, M_2/n, M_3/n, \ldots, M_n/n]$ represents a set of detection probability $P_d[P_{d1}, P_{d2}, P_{d3}, \ldots, P_{dn}]$. $P_{d1}, P_{d2}, P_{d3}, \ldots, P_{dn}$ represent the detection performance when false alarm probabilities are $P_{fa1}, P_{fa2}, P_{fa3}, \ldots, P_{fan}$ under the same SNR environment.

2 .Constant false alarm probability under different SNR environment

Steps (1), (2), (3) and (4) are same as above.

(5) Under the condition of constant false-alarm probability, the subscript of γ in the array $\gamma[\gamma_1, \gamma_2, \gamma_3, \ldots, \gamma_n]$ is represented by. γ_u is the corresponding energy detection threshold in a given false-alarm probability. After n times calculations, the resulting energy values E_1 are saved to array $b[E_{11}, E_{12}, E_{13}, \ldots, E_{1n}]$ .Then the number M that the elements of $b[E_{11}, E_{12}, E_{13}, \ldots, E_{1n}]$ greater than γ_u is calculated. M/n is the detection probability P_d .

(6) Repeat steps (1) to (5) different SNR environments, the detection probabilities can be obtained under the environments with constant false alarm probability and different SNR.

3.2.2. Simulation results

Using MATLAB7.1 establish the simulation environment. Channel interference and fading effect is not taken into account in this paper. Assume that the signal of the PU is $A\cos(2\pi ft + \phi)$, Gaussian white noise is $\eta(t)$. Where $\phi = \frac{\pi}{4}$, $A = 2\sigma_n^2 \cdot SNR_i$, the noise variance $\sigma_n^2 = 1$, f are 0.01Hz, 0.05Hz, 0.2Hz respectively. Sampling frequency $f_s = 128f$ .Sampling point $N = 256$. The number of Monte Carlo simulations is 1000. Compare the traditional energy detection method and energy detection method based on E type monostable SR performance under two conditions that at the same SNR different false alarm probability environment and constant false alarm probabilitydifferent SNR environment. The results are shown in Figure 2,3,4,5 respectively.

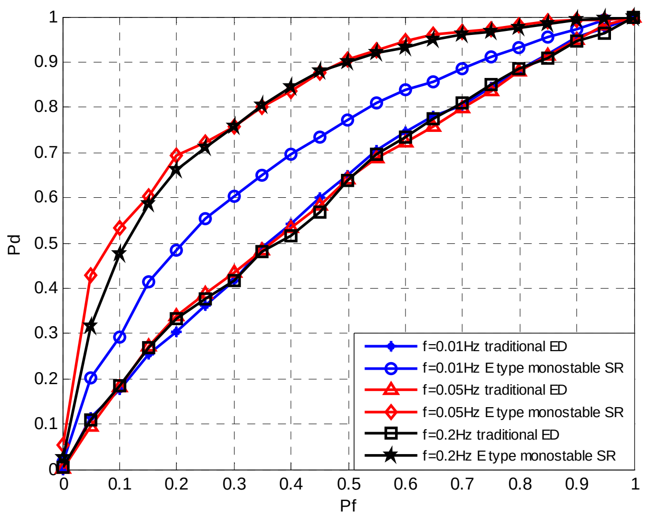

Figure 2. ROC curves of two methods under different frequencies while SNR=-15dB

As can be seen from the Figure 2, 3, in the condition of SNR=-15dB and SNR=-20dB, the performance of the traditional energy detection is almost the same when the signal frequency f are 0.01Hz, 0.05Hz, and 0.2Hz. This is because the traditional energy detection is frequency independence. The performanceof energy detection based on E type monostable SR changes when the frequency changes and this performanceare higher than the traditional energy detection methods. The detection performance is the lowestwhen $f = 0.01Hz$ andthe detection performance is the highest when $f = 0.05Hz$. This shows that thesignal frequency has a certain effect on the energy detection based on E type monostable SR.

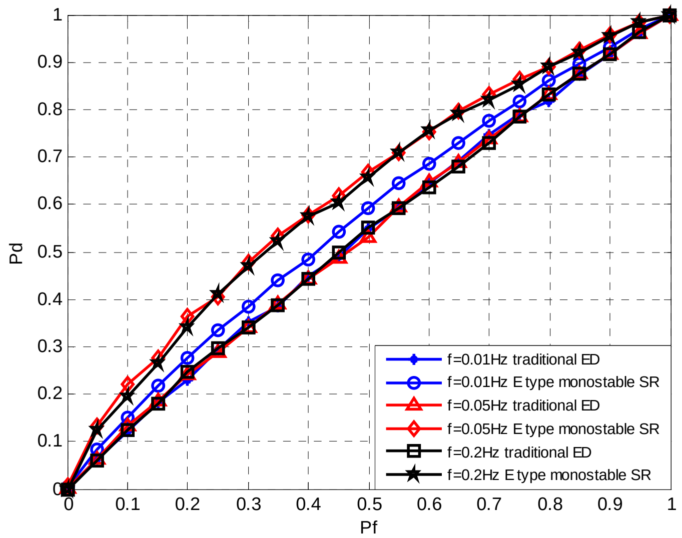

Figure 3. ROC curves of two methods under different frequencies while SNR=-20 dB

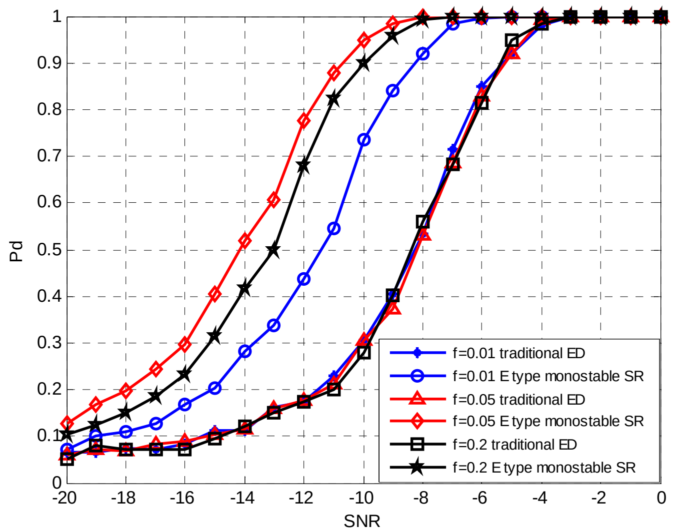

Figure 4. Detection probability versus SNR under different f when $P_{fa} = 0.05$

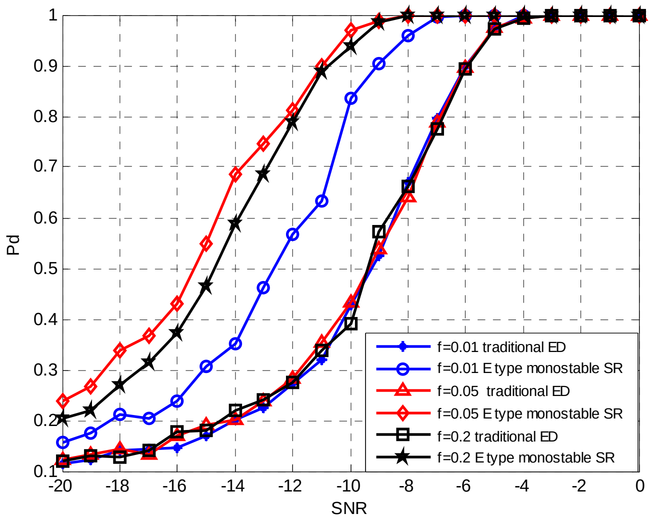

Figure 5.Detection probability versus SNR under differentfrequencies when $P_{fa} = 0.1$

As can be seen from the Figure 4, 5, in the different SNRenvironment, the detection performance ofthe traditional energy detection is almost the same when f changes. It also shows that the traditional energy detection method is signal frequencyindependence again. The performanceof energy detection based on E type monostable SR changes when the frequency changes and this performanceare higher than the conventional energy detection methods. The detection performance is the lowestwhen $f = 0.01Hz$ andthe detection performance is the highest when $f = 0.05Hz$ .When $f = 0.02Hz$ the detection performance is slightly lower than that when $f = 0.05Hz$.

4. Conclusions

In this paper, an Evstigneev-type monostablestochastic resonance system is applied to energy detection of spectrum sensing in order to increase the system output SNR, thereby enhancing the low SNR environment energy detection performance. Simulation results show that in the case of constant false alarm probability, the detection probability of energy detection based on monostable SR is higher than that of the traditional energy detection method, especially in low SNR environment. This research will broaden the scope of application of SR and can increase the detection probability of spectrum sensing under low SNR environment.

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