Performance Analysis of Energy Detection Algorithm in Cognitive Radio

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ABSTRACT

In cognitive radio systems, secondary users should determine correctly whether the primary user is absent or not in a certain spectrum within a short detection period. Spectrum detection schemes based on fixed threshold are sensitive to noise uncertainty; the energy detection based on dynamic threshold can improve the antagonism of noise uncertainty; get a good performance of detection while without increasing the computer complexity uncertainty and improves detection performance for schemes are sensitive to noise uncertainty in lower signal-to-noise and large noise uncertainty environments. In this paper we analyze the performance of energy detector spectrum sensing algorithm in cognitive radio. By increasing the some parameters, the performance can be improved as shown in the simulation results.

Keywords - cognitive radio, detection threshold, dynamic threshold detection, noise uncertainty

1. INTRODUCTION

With the development of a host of new and ever expanding wireless applications and services, spectrum resources are facing huge demands. Currently, spectrum allotment is done by providing each new service with its own fixed frequency block. As more and more technologies are moving towards fully wireless, demand for spectrum is enhancing. In particular, if we were to scan the radio spectrum, including the revenue-rich urban areas, we find that some frequency bands in the spectrum are unoccupied for some of the time, and many frequency bands are only partially occupied, whereas the remaining frequency bands are heavily used [1]. It indicates that the actual licensed spectrum is largely under-utilized in vast temporal and geographic dimensions [2].A remedy to spectrum scarcity is to improve spectrum utilization by allowing secondary users to access under-utilized licensed bands dynamically when/where licensed users are absent.

Cognitive radio is a novel technology which improves the spectrum utilization by allowing secondary users to borrow unused radio spectrum from primary licensed users or to share the spectrum with the primary users. A cognitive

radio is able to able to fill in the spectrum holes and serve its users without causing harmful interference to the licensed user. To do so, the cognitive radio must continuously sense the spectrum it is using in order to detect the re-appearance of the primary user [3]. Once the primary user is detected, the cognitive radio should withdraw from the spectrum instantly so as to minimize the interference. This is very difficult task as the various primary users will be employing different modulation schemes, data rates and transmission powers in the presence of variable propagation environments and interference generated by other secondary users [1].

The paper is organized as follows. Section 2 discuss the spectrum sensing problem, overview of spectrum sensing methods and the performance of energy detector spectrum sensing algorithm in cognitive radio. Section 3 discusses the performance of dynamic threshold based spectrum detection in cognitive radio systems. Section 4 discusses the conclusion and future in this field of study.

2. SPECTRUM SENSING PROBLEM

2.1 ENERGY DETECTION

Spectrum sensing is a key element in cognitive radio communications as it must be performed before allowing unlicensed users to access a vacant licensed band. The essence of spectrum sensing is a binary hypothesis-testing problem

$$H_0: X(N) = W(N)$$
$$H_1: X(N) = S(N) + W(N) \quad (1)$$

Where N is the number of samples, N=2TW, T is duration interval ,W is bandwidth, S (N) is the primary user's signal, W (N) is the noise and X (N) is the received signal. H_0 and H_1 denote that the licensed user is present or not, respectively. The noise is assumed to be additive white Gaussian noise (AWGN) with zero mean and is a random process. The signal to noise ratio is defined as the ratio of signal power to noise power

Under the assumption of absolutely no deterministic knowledge about the signal X (n), i.e., we assume that we know only the average power in the signal. In this case the optimal detector is energy detector or radiometer can be represented as [23]

$$D(Y)=\frac{1}{N}\sum_{n=0}^{N-1}Y(n)X(n)>\gamma \quad H_1$$

$$<\gamma \quad H_0 \qquad (2)$$

Where D(Y) is the decision variable and is the decision threshold, N is the number of samples. If the noise variance is completely known, then from the central limit theorem the following approximations can be made [24]

$$D(Y|H_0)\sim N(\sigma_n^2, 2\sigma_n^4/N)$$

$$D(Y|H_1)\sim N(P+\sigma_n^2, 2(P+\sigma_n^2)^2/N) \qquad (3)$$

Where P is the average signal power and σ_n^2 is the noise variance. Using these approximations
The probability expressions are

$$P_{FA}=P_r(D(Y)>\gamma|H_0)=Q\left(\frac{\gamma-\sigma_n^2}{\sqrt{2\sigma_n^4/N}}\right) \qquad (4)$$

$$P_D=P_r(D(Y)>\gamma|H_1)=Q\left(\frac{\gamma-(P+\sigma_n^2)}{\sqrt{2(P+\sigma_n^2)^2/N}}\right) \qquad (5)$$

$$P_{Md}=1-P_D=1-Q\left(\frac{\gamma-(P+\sigma_n^2)}{\sqrt{2(P+\sigma_n^2)^2/N}}\right) \qquad (6)$$

Where $Q(\cdot)$ is the standard Gaussian complementary cumulative distribution function (*CDF*). P_D, PF_A and P_{Md} represent detection probability, false alarm probability and missing probability respectively.
From (4) and (5) eliminating threshold γ

$$N=2\left[Q^{-1}(P_{FA})-Q^{-1}(P_D)\right]^2(SNR)^{-2} \qquad (7)$$

Where $SNR=\frac{P}{\sigma_n^2}$, σ_n^2 is the normalized noise power.

Figure 1 shows the numerical results of (7) for given P_{FA} (0.0.9), sample number N=500, with different SNR values with that the performance is improved by increasing SNR value

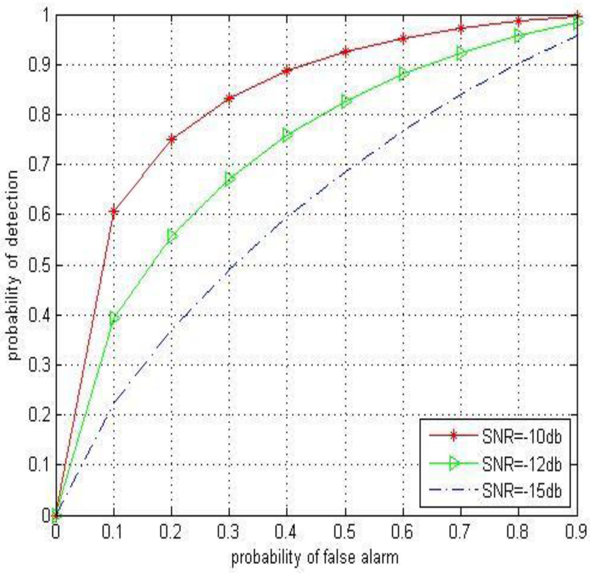

Figure 1 ROC curves of energy detection scheme with different SNR

Figure 2 is the numerical results of (7) for given P_{FA} (0.0.9), SNR=-15dB. It shows that the performance is improved by increasing N, and probability of detection can be improved by increasing N value even if the SNR is much lower, as long as N is large enough without noise uncertainty.

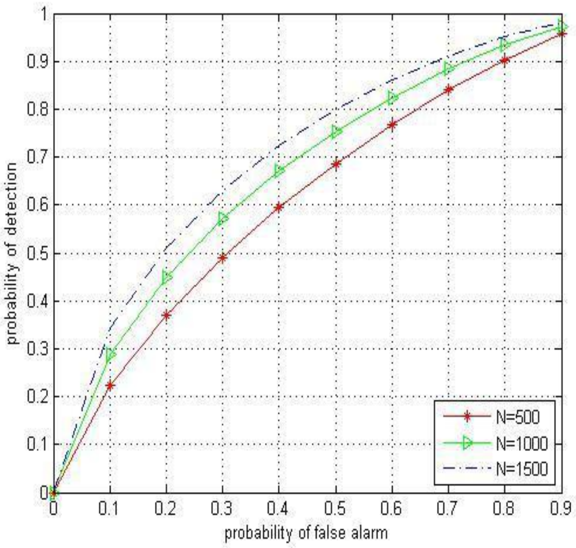

Figure 2 ROC curves of energy detection scheme with different N

2.2 NOISE UNCERTAINTY

Now, considering the case with uncertainty in the noise model [20], the distributional uncertainty of noise can be represented as

$$\sigma^2 \in [\sigma_n^2 / \rho, \rho\sigma_n^2]$$

ρ is the noise uncertainty coefficient and $\rho > 1$

Now

$$P_{FA} = Q\left(\frac{\gamma - \sigma_n^2}{\rho\sigma_n^2\sqrt{2/N}}\right) \quad (8)$$

$$P_D = Q\left(\frac{\gamma - (P + \sigma_n^2 / N)}{(P + \sigma_n^2 / \rho)\sqrt{2/N}}\right) \quad (9)$$

eliminating threshold γ and equating both equations we have

$$N = 2\left[\rho Q^{-1}(P_{FA}) - (1/\rho + SNR)Q^{-1}(P_D)\right]^2 (SNR - (\rho - 1/\rho))^{-2} \quad (10)$$

Comparing (10) with (7), there is almost no contribution to the whole expression results if there is a tiny change of ρ; however, SNR^{-2} and $(SNR - (\rho - 1/\rho))^{-2}$ should be mainly discussed and compared. When $\rho \approx 1$, then $SNR{-2} \approx (SNR - (\rho - 1/\rho))^{-2}$, the numerical value of (10) and (7) are almost the same; When ρ is larger and suppose $\rho = 1.05$, then $(\rho - 1/\rho) = 0.0976 \approx 0.1$, if $SNR = 0.1$, well then $(SNR - (\rho - 1/\rho))^{-2} \approx 0$, substituting into equation (10) to be $N \rightarrow \infty$. In other words, only infinite detection duration can complete detection, which is impracticable. A tiny fluctuation of average noise power causes performance drop seriously, especially with a lower *SNR*.

Figure 3 shows the numerical result of (10) probability of false alarm on X-axis and probability of detection on Y-axis for an SNR=-15dB, $P_{FA} = (0, 0.9)$, N=500 and varying the noise uncertainty value.

From the Figure it is seen that the performance gradually drops as the noise factor increasing. This indicates that Energy detector is very sensitive to noise uncertainty. It means that cognitive users predict the spectrum to be idle no matter whether there are primary users present or absent. Consequently, cognitive users are harmful to licensed users when primary users are present. This situation often occurs in cognitive radio systems, particularly in lower signal-to-noise ratio environments. In order to guarantee a good performance, choosing a suitable threshold is very important. Traditional energy detection algorithms are based on fixed threshold and we have verified that performance decreased under noise uncertainty environments. This indicates that the choice of a fixed threshold is no longer valid under noise uncertainty and threshold should be chosen flexible based on the necessities.

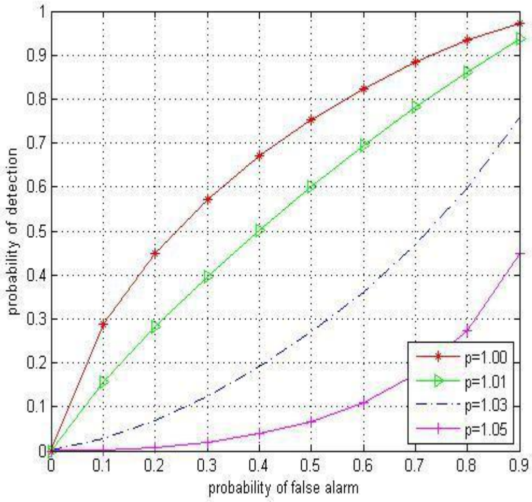

Figure 3 ROC curves of energy detection scheme with different ρ

3. DYNAMIC THRESHOLD

Performance of cognitive radio declined sharply due to noise uncertainty and cognitive users' accessing will be serious interference to licensed users. This should be avoided in dynamic spectrum access technology. For this reason, a new algorithm combating the noise uncertainty is presented [21][20].

Assume that the dynamic threshold factor ρ and $\rho' > 1$ the distributional of dynamic threshold in the interval $\gamma' \in [\gamma' / \rho, \gamma' \rho]$

Then the probability relationships are represented as

$$P_{FA} = \left(\frac{\rho'\gamma - \sigma_n^2}{\sigma_n^2\sqrt{2/N}}\right) \quad (11)$$

$$P_D = \left(\frac{\gamma - \left(P + \sigma_n^2\right)}{\left(P + \sigma_n^2\right)\sqrt{\frac{2}{N}}}\right) \quad (12)$$

After simplifying (11) and (12) we get the relationship for SNR, N, P_{FA}, P_D and ρ'

$$N = 2\left[Q^{-1}(P_{FA}) - \rho'^2(1 + SNR)Q^{-1}(P_D)\right]^2 \times \left(\rho'^2 SNR + \left(\rho'^2 - 1\right)\right)^{-2} \quad (13)$$

Figure 4 shows the performance of energy detection scheme, probability of false alarm on X-axis and probability of detection on Y-axis.

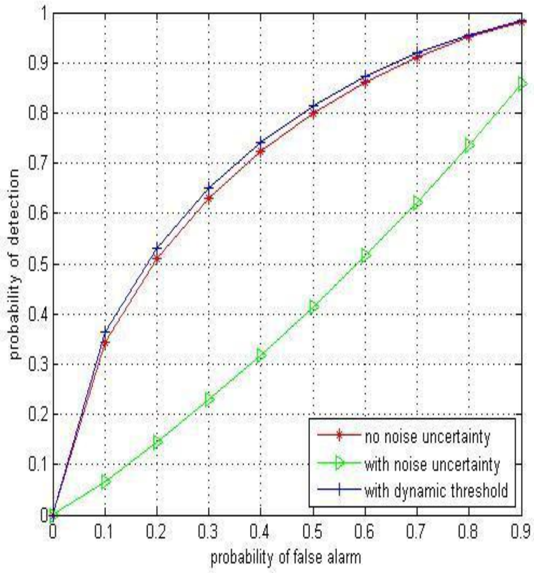

Figure 4 ROC curves of energy detection scheme with no noise uncertainty, with noise uncertainty, and with dynamic threshold

Here we have taken a SNR=-15dB, $P_{FA} \in (0,0.09)$, N=1500, noise uncertainty1.02 and dynamic threshold1.001.It is observed that the performance is improved by using a dynamic threshold

3.1 NOISE UNCERTAINTY AND DYNAMIC THRESHOLD

We have discussed two cases that existing noise uncertainty and dynamic threshold respectively, this section will give the expressions that considering noise uncertainty and dynamic threshold together, we got expressions of false alarm probability and detection probability

The noise variance in the interval $\sigma \in \left[\sigma_n^2 / \rho , \rho\sigma_n^2 \right]$

Now the probability relations are represented as

$$P_{FA} = Q\left(\frac{\rho'\gamma - \rho\sigma_n^2}{\rho\sigma_n^2 \sqrt{2/N}} \right) \qquad (14)$$

$$P_D = Q\left(\frac{\frac{\gamma}{\rho'} - \left(P + \frac{\sigma_n^2}{\rho} \right)}{\left(P + \frac{\sigma_n^2}{\rho} \right)\sqrt{\frac{2}{N}}} \right) \qquad (15)$$

Eliminating threshold γ

we get the inter relationship for SNR, N, P_{FA} , P_D and ρ'

$$N = 2\left[(\rho/\rho')\left(Q^{-1}(P_{FA})\right) - \rho'\left(\frac{1}{\rho} + SNR \right) Q^{-1}(P_D) \right]^2 \times \left(\rho' SNR + \frac{\rho'}{\rho} - \frac{\rho}{\rho'} \right)^{-2} \qquad (16)$$

In (16), when $\rho' \approx \rho$ and $\rho'\rho \approx \rho/\rho' \approx 1$, $(\rho' SNR + \rho'/\rho - \rho/\rho')^{-2} \approx (SNR)^{-2}$ and ρ' $(1/\rho+SNR) \approx (1+SNR)$. We substitute (16) with the above approximate unequal expressions, and we can get that the numerical value of (16) is almost the same to (7). Therefore, dynamic threshold detection algorithm can overcome the noise uncertainty as long as a suitable dynamic threshold factor is chosen. Comparing (16) with (13), supposing SNR = 0.1 and ρ' and ρ both closer to 1, it is clear that $(\rho' SNR + \rho'/\rho - \rho/\rho')^{-2} >> (SNR - (\rho - 1/\rho))^{-2}$. Consequently, detection duration N has been shortened largely to N= 500 with the same probability parameters P_D and P_{FA} as shown in Figure 5 It can be concluded that as long as the dynamic threshold factor is suitable, even if there is noise uncertainty, we can get a better spectrum performance. To attaining the same performance, the detection time of dynamic threshold energy detection Algorithm is less than the traditional version.

Figure 5 is the numerical results of (7), (13) and (16). With the same parameters as before.

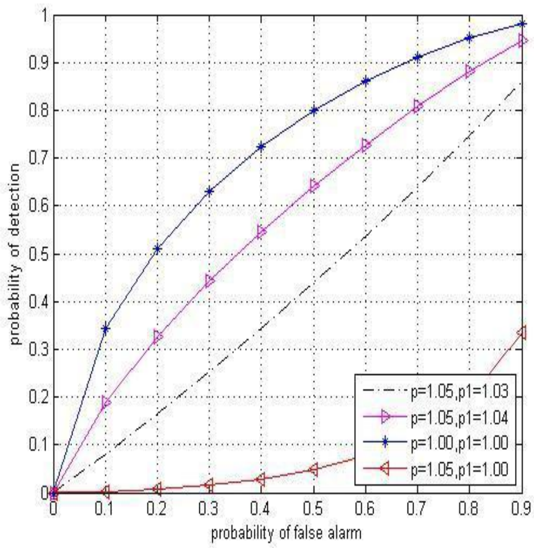

Figure 5 ROC curves of energy detection scheme with N=500, different ρ and ρ'

Where ρ = 1.00 denotes that the average noise power keeps constant (without noise uncertainty); ρ' = 1.00 denotes that the algorithm did not use dynamic threshold (the threshold is fixed); otherwise, it represents cases with noise uncertainty and dynamic threshold. From Figure 5 it indicates that a tiny fluctuation of average noise power causes a sharp decline in detection performance. The dynamic threshold makes the performance improve significantly as the dynamic threshold factor increasing. If a suitable dynamic threshold factor is selected, the falling proportion of performance caused by noise uncertainty can be omitted and the performance may be more accurate.

4. CONCLUSION

Energy detection based on fixed threshold are sensitive to noise uncertainty, a fractional change of average noise power causes decreasing the performance quickly. According to the drawback in Matched filter which not sensitive to noise uncertainty, by using dynamic threshold the performance can be improved as compared with the fixed threshold. The computer simulations of the dynamic threshold based energy detection algorithm in cognitive radio improve the detection performance but in practical how acquire the detection threshold and how to improve the detection performance by other sensing methods.

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