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Energy Detector using Adaptive-Fixed Thresholds in Cognitive Radio Systems

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***Abstract-* Cognitive Radio systems offer the opportunity to improve spectrum utilization by detecting unused spectrum bands while avoiding the interference to primary users. In this paper, we propose a new algorithm for spectrum sensing, which is energy detector using both adaptive and fixed threshold, in order to compensate the weak points of the existing energy detector in the distorted communication channel environment. The simulation results show that the performance of the proposed scheme is much better than the existing scheme. Additionally, the performance is described in terms of the complementary ROC curve. It is shown that the proposed algorithm makes the detector highly robust against fading, shadowing, and interference by simulation results.**

Keywords: Cognitive radio, primary user, secondary user, energy detector, fixed threshold, adaptive threshold

I. INTRODUCTION

Wireless applications service shows a tendency to require more bandwidth and higher bits rate. Thus, the wide bandwidth is needed in order to meet such large demand of the usage. However because of limited frequency resource and inefficiently utilized spectrum, it is necessary to more efficiently use frequency band. According to the FCC's (Federal Communications Commission) spectrum policy task force report, the usage of allocated spectrum varied depending on temporal and geographic situation [1].

Cognitive radio (CR) technique has been proposed as a possible solution to much more efficiently utilize the spectrum with the concept of dynamic spectrum management [2]. The CR technique is aiming at using unoccupied spectrum, while guaranteeing the right of privileged primary users. In IEEE 802.22, CR technique is introduced for the standardization of wireless regional area network (WRAN). To employ the CR properly, it is very important to reliably search and use the empty frequency band on the condition that the impact of interference should be small enough in frequency where primary users exist [3]. Therefore, a secondary user has to monitor licensed bands, and opportunistically transmit whenever no primary signal is detected.

For the spectrum sensing, there are three methods such as energy detection, matched filter detection and feature detection. Energy detection decides the existence of energy of primary user's signal. Both energy detection and feature detection should have information about characteristic of received signal in advance [4]. Thus, matched filter detection and feature detection must have a precondition which is constraint that they should have information about received signal sufficiently.

In practice, CR system has lack of knowledge about received primary signal's structure and information. So we select energy detector that only needs the energy of received primary signals. However, the performance of the energy detection is largely dependent on channel environment such as noise, interference, shadowing and multipath fading. Therefore, we intend to enhance the reliability of energy detection and thus improve the performance.

In this paper, we propose a new algorithm for energy detector, which uses adaptive and fixed thresholds. This algorithm makes use of advantages in both the adaptive and the fixed thresholds. The performance is investigated by simulation and compared to that of the conventional energy detector.

This paper is organized as follows: Section II briefly reviews the methods of energy detector, In Section III, we describe the proposed sensing algorithm. In Section IV, the simulation results are analyzed. Finally discussion and conclusion are in Section V.

II. ENERGY DETECTORS

A. General energy detector with fixed threshold

The Cognitive Radio system is usually in the shortage of knowledge about the structure and information of primary signal. Thus, we select energy detection method because it could detect primary signal even if the feature is unknown. Moreover, its implementation is quite easy. Figure 1 shows the block diagram of the energy detector; the received signal passing the desiring band-pass filter (BPF) and multiplying by itself and integrating as required time and comparing with fixed threshold.

The goal of energy detector is to distinguish between the following hypotheses.

$$\begin{aligned} &H_0 : r[i] = n[i] \\ &H_1 : r[i] = h[i] \cdot s[i] + n[i], \quad i = 1, \ldots, N \end{aligned} \tag{1}$$

where N is a maximum sensing interval. $r[i]$ is the signal received by secondary user and $h[i]$ is the fading channel, $s[i]$ is the primary user's signal, $n[i]$ is the Additive White Gaussian Noise(AWGN). In a non-fading environment where $h[i]$ is 1 in all interval, the probability of miss detection and false alarm are defined by the following equations [5].

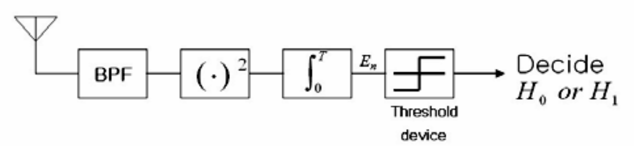

Figure 1. The Block Diagram of Energy Detector

$$P_{md} = P\{r<\lambda|H_1\}=1-Q_m(\sqrt{2\gamma},\sqrt{\lambda}) \quad (2)$$

$$P_{fa} = P\{r>\lambda|H_0\} = \frac{\Gamma(m,\lambda/2)}{\Gamma(m)} \quad (3)$$

where $\Gamma(\cdot)$ and $\Gamma(\cdot,\cdot)$ are complete and incomplete gamma functions respectively and $Q_m(\cdot,\cdot)$ is the generalized Marcum Q-function, γ is the signal to noise ratio(SNR), λ is the thresholds, and m is an the time-bandwidth product.

In the threshold device for the energy detector in Figure 1, fixed threshold value is generally considered. With the fixed thresholds, the performance of the energy detector is mainly dependent on the channel environments such as fading, shadowing, and interference. It is difficult to detect primary user's signal when the signal's energy is small by the fading, shadowing and interferences. That is, the secondary user cannot distinguish the unused band from the deep fade [5], where miss detection probability increases. That means it could make serious interference to primary user. In order to make the miss detection probability lower, we need to decrease the threshold level. However, when the threshold keeps too low, false alarm probability increases even though primary user's signal does not exist. That means it could miss out the chance for secondary user to transmit.

B. Adaptive Threshold

Using the adaptive threshold method enhance the reliability of the energy detector and thus improve its performance in terms of the miss detection probability and the false alarm probability. The threshold is adaptively determined depending on the time varying environment.

The adaptive threshold algorithm is described in Figure 2. First, energy of received signal in required time-bandwidth is compared with the present threshold (λ_n). If energy is smaller than threshold, then decide H_0, there are no primary users, and the threshold in next sensing duration is determined to equal with the present threshold $(\lambda_{n+1} = \lambda_n)$. On the other hand, if energy is bigger than threshold, then decide H_1. Thresholds update only in the conditional case H_1 [6]. Because, if there is no primary signal, the only AWGN signal exists. If adaptive threshold algorithm considers the noise uncertainty, amount of noise uncertainty, which is calculated, is remarkably increasing. That cause unnecessarily power consumption during processing. A threshold in the next sensing time is obtained by taking the median value between the proper threshold for received signal power and the present threshold in the present sensing time. But, a threshold in the next sensing time must not be below the lower boundary $(\lambda_{n+1}' < \lambda_{\min})$, if the

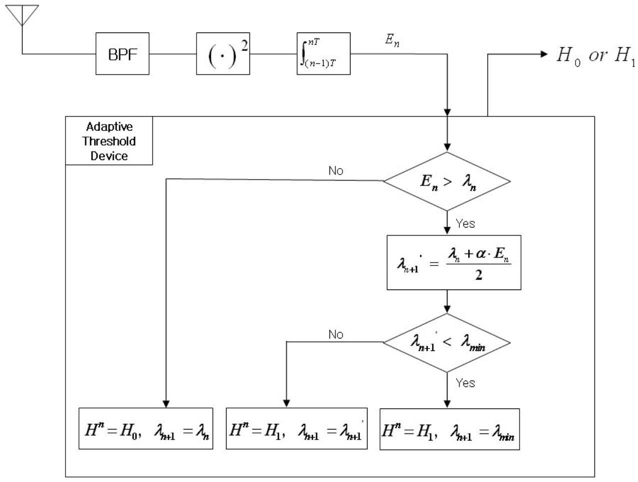

Figure 2. Flow chart of energy detector using adaptive threshold

threshold of that case should have the lower boundary value. We are able to get stable performance of energy detector, if we set the $\lambda_{\min}$ as the value of minimum at adaptive threshold. Because $\lambda_{\min}$ prevent degradation of performance from influence that the severe threshold level depends on channel information.

Especially, an $\alpha(0<\alpha<1)$ in the adaptive threshold device is a key parameter to determine performance in a hardware design of energy detector using adaptive threshold, since the α determines how much reflection of present channel environment. In the large α case, the adaptive thresholds tend to change sensitively because the received signal is effecting highly. The Proper α value is determined by the fixed threshold and the estimated power of received signal.

III. PROPOSED SPECTRUM SENSING ALGORITHM

In this section, we describe a new spectrum sensing algorithm, which is energy detector using both adaptive threshold and fixed threshold. The Figure 3 shows the flow chart of our proposed method that is mixed in adaptive and fixed threshold.

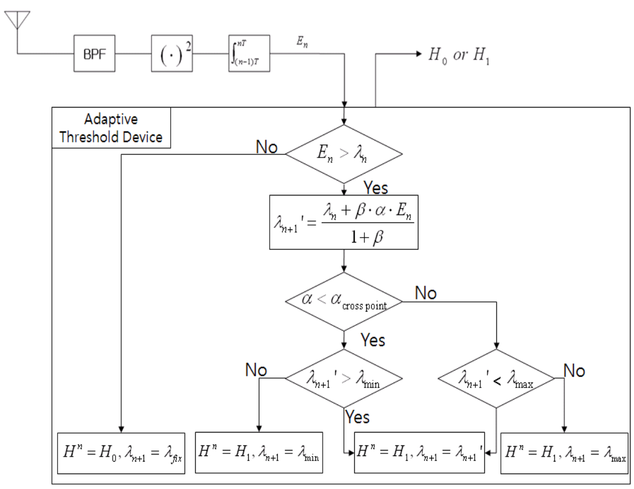

Figure 3. Flow chart of energy detector using adaptive-fixed threshold

As previously stated in session II, in case of using only adaptive threshold method, it has some weak point. If the primary user's signal exists and the channel environment is a good situation, the adaptive thresholds are high level. And then, in case the channel is vacant, the threshold value will keep the high level. As a result of high level threshold, the false alarm probability is lower and the adaptive system has a good performance. If, on the other hand, the primary user's signal does not exists and the channel environment is a bad situation, the adaptive thresholds are low level. And then in case the detected signal is off, the threshold value will keep the low level. As a result of low level threshold, the probability of false alarm is higher. Thus, the performance of adaptive threshold is degraded.

In order to compensate the above weak point, we propose the new algorithm that uses adaptive-fixed threshold. We use the fixed threshold when the energy level of the received signal is lower than the adaptive threshold ($E_n > \lambda_n,\ \lambda_{n+1} = \lambda_{fix}$). In such case, there is no primary signal condition, the performance of energy detector is guarantee of fixed threshold level.

The parameter α is a ratio a ratio of the fixed threshold to the estimated average power of received signal. The parameter β is the weight between the existing level of threshold and the newly updated level of threshold. The value of $\alpha_{\text{cross point}}$ means the value of α which is the cross point between adaptive threshold and fixed threshold in the performance of energy detector [6]. If the value of α is smaller than the value of $\alpha_{\text{cross point}}$, then the minimum value of adaptive threshold set to the $\lambda_{\min}$. And if α is bigger than the value of $\alpha_{\text{cross point}}$, then the maximum value of adaptive threshold determine to the $\lambda_{\max}$. Thus, the adaptive threshold value, λ is contained between the minimum value of $\lambda_{\min}$ and the maximum value of $\lambda_{\max}$. By this reason, the level of adaptive threshold can keep properly.

IV. Simulation Results

In our simulation, the Suzuki channel, which represents multiplying Rayleigh fading and lognormal shadowing [7], was considered by calculating MED (Method of Equal Distance). The simulation related parameters are defined in Table I.

Figure 4 and 5 show simulation results, which may be characterized through the complementary receiver

TABLE I
THE SIMULATION RELATED PARAMETER

Parameter	Value
Carrier frequency	400MHz
Mobile Speed of Secondary User	3km/h, 60km/h
Max. Doppler freq.	1.111Hz
Cutoff freq.	0.0111 Hz
Number of Samples	100000
Sampling Interval	0.33ms
Sensing Time Period	3.3ms

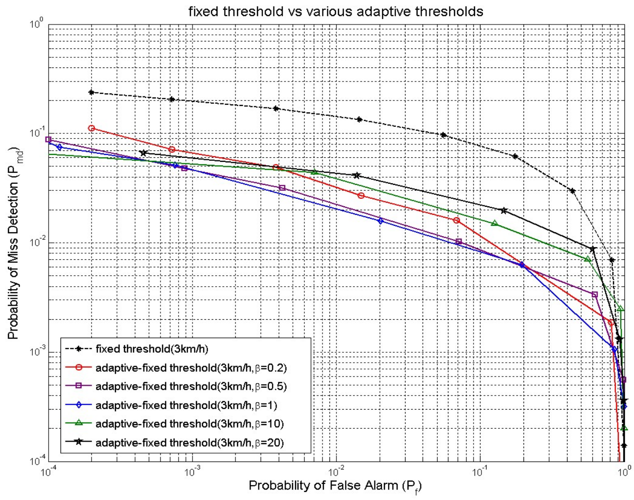

Figure 4. The performance of the energy detector with fixed or adaptive-fixed thresholds (Mobile velocity = 3km/h, β =0.2, 0.5, 1, 10, 20)

cooperating characteristics (ROC) curves (plot of P_{md} vs. P_f). The Primary signal is transmitted by BPSK modulation under Suzuki channel, and we set the SNR to 10dB. Figure 4 shows the performance of proposed sensing algorithm with variable values of β and fixed threshold, when the mobile speed is 3km/h. When β is 1, the best performance of proposed algorithm can be shown. When the mobile velocity is 60km/h, the performance of variable values of β and fixed threshold is shown in Figure 5. In case, β is 10, the most reliable performance can be shown. As compare Figure 4 with Figure 5, When mobile speed is fast, we found that the performance of adaptive-fixed threshold is closed to the fixed threshold. On the other hand, when the mobile speed is slow, we found that the performance of adaptive-fixed threshold is closed to the adaptive threshold. Thus, proposed scheme takes advantage of combining adaptive threshold with fixed threshold according to channel variation.

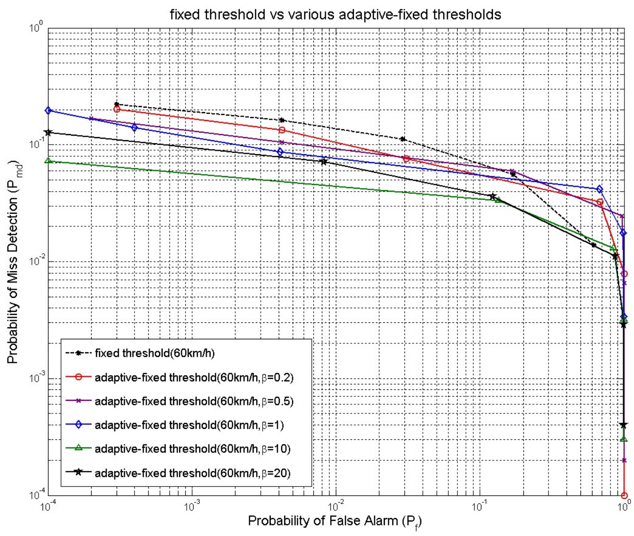

Figure 5. The performance of the energy detector with fixed or adaptive-fixed thresholds (Mobile velocity = 60km/h, β =0.2, 0.5, 1, 10, 20)

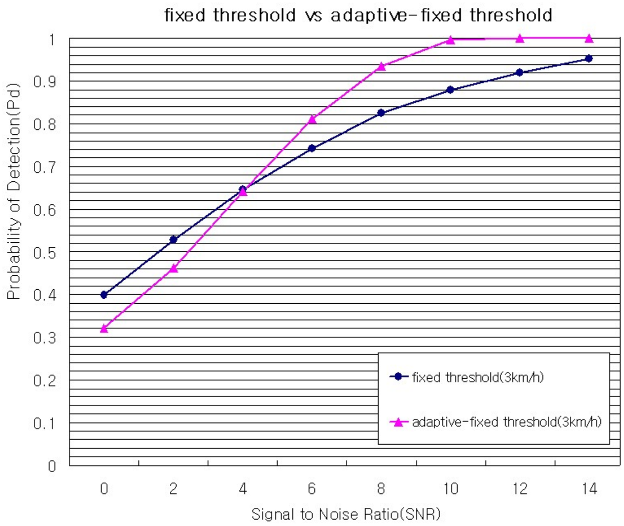

Figure 6. SNR vs. Probability of Detection(Pd) (Mobile speed = 3km/h), P_{fa} = 1%

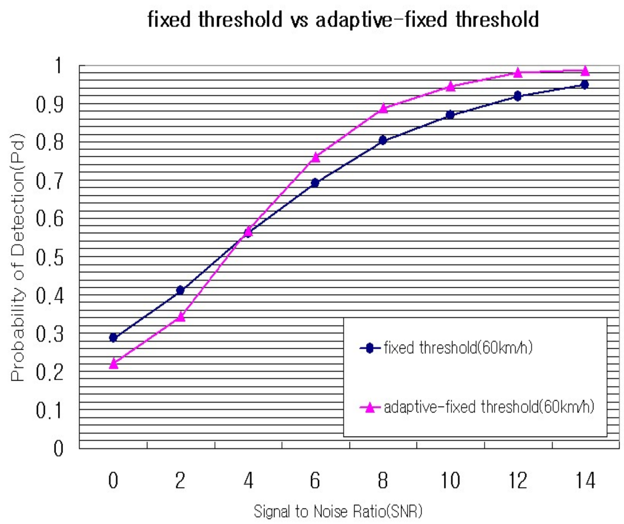

Figure 7. SNR vs. Probability of Detection(Pd) (Mobile speed = 60km/h), P_{fa} = 1%

The simulation results in Figure 6 and Figure 7, which are plotted by SNR versus the probability of detection (Pd), represent that the performance of adaptive-fixed threshold algorithm is much better than the fixed threshold. When the mobile speed is 3km/h and the target probability of detection is 90%, the proposed scheme obtains 3dB gain in comparison with the fixed threshold scheme. And the proposed scheme, when the mobile speed is 60km/h, also obtains 3dB gain in comparison with the fixed threshold scheme.

V. Conclusion

In this paper we proposed a new spectrum sensing scheme that is a key technique in CR system of the energy detector with adaptive-fixed threshold algorithm. The simulation results indicated that the proposed sensing scheme has better performance in terms of the complementary ROC curve under Suzuki channel environments because the proposed scheme takes advantage in both adaptive threshold and fixed threshold.

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