한국ITS학회논문지
제9권, 제1호 (2010년 2월)
pp. 19~26

# Simple Energy Detection Algorithm for Spectrum Sensing in Cognitive Radio

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## Abstract

In this paper, we propose an efficient decision rule in order to get better chance to detect the unused spectrum assigned to a licensed user and improve reliability of spectrum sensing performance. Each secondary user receives the signals from the licensed user. And the resulting signals input to an energy detector. Then, each sensing result is combined and used to make a decision whether the primary user is present at the licensed spectrum band or not. In order to make the reliable decision, we apply an efficient decision rule that is called as a majority rule in this paper. The simulation results show that spectrum sensing performance with the proposed decision rule is more reasonable and efficient than that with conventional decision rules.

**Key words:** Cognitive radio (CR), cooperative spectrum sensing, energy detection, majority decision rule, spectrum sensing

## Ⅰ. Introduction

According to the rapid development of wireless technologies, more spectrum resources are needed to support considerable and various wireless services. However, limited spectrum resources are regulatory assigned to licensed user and any interference cannot allow to licensed user. Also, a recent survey of the spectrum utilization made by Federal Communications Commission (FCC) has indicated that the actual licensed spectrum is largely unutilized in vast temporal and geographic dimensions [1] .In order to relieve the spectrum scarcity and inefficient spectrum utilization, cognitive radio was recently proposed [2,3].

Cognitive radio (CR), proposed by Mitola in 1999 [2], is a promising approach to achieve open spectrum sharing flexibly and efficiently [1-4]. CR is an intelligent wireless communication system that is aware of the radio environment and is capable of adapting its operation to the statistical variations of incoming radio frequency stimuli [3]. This is a very important feature of an CR system, so FCC is reviewing its policies regarding the usage of licensed bands by unlicensed users [5]. If we employ CR techniques as new frequency policies, unlicensed users, called secondary users, can opportunistically use the licensed bands, if

† "본 연구는 지식경제부 및 정보통신산업진흥원의 대학 IT연구센터 지원사업의 연구결과로 수행되었음" (NIPA-2009-(C1090-0902-0005))
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† 논문접수일 : 2009년 9월 22일
† 논문심사일 : 2009년 1월 25일
† 게재확정일 : 2010년 2월 1일

licensed users, called primary user, are not using the frequency. Therefore, secondary users temporarily utilize the licensed bands legally without a license. That means secondary users need to monitor presence or absence of primary users because secondary users must use the licensed spectrum without interference. This technique is called spectrum sensing that is one of the most important technique of CR.

Spectrum sensing requires the detection of possibly weak signal of unknown types with high reliability [6]. However, since users experience multipath fading and shadowing, the performance of spectrum sensing grows worse. In order to overcome this problem and improve the reliability of spectrum sensing, co-operation among secondary users has been proposed [3,6]. In cooperative sensing, the secondary users share sensing information with each other, and as a result, secondary users have better chances of detecting the primary user and reducing effects of multipath fading and shadowing.

Cooperative sensing makes a local sensing result at each secondary user and then sensing results are independently transmitted to the fusion center. In the fusion center, sensing results are combined and then used to make a final decision whether the primary user is present or not. Existing decision rules are AND and OR rules. Those are simple technique for making final decision with arithmetic mean of local sensing results. However, with these rules, we can detect the primary user very strictly or coarsely. As a result, the detection probability is very low or very high.

In order to improve the reliability of the detection probability, we propose the majority decision rule. This rule makes a final decision adopting majority of local sensing results. Simulation results shows that the proposed decision rule is more reliable than the existing decision rules.

This paper is organized as follows. In Section II, we describe the system model. In Section III, we introduce majority decision rule in cooperative sensing. In Section IV, we analyze the spectrum sensing performance of the proposed system. Simulation results illustrating the reliability of the proposed method are given in Section V. Finally, concluding remarks are shown in Section VI.

## Ⅱ. System Model

In this section, we illustrate the system model of cooperative spectrum sensing. The cooperative sensing has the two hypotheses as follows.

$$H_0 : y[k] = v[k], \tag{1}$$

$$H_1 : y[k] = hs[k] + v[k], \tag{2}$$

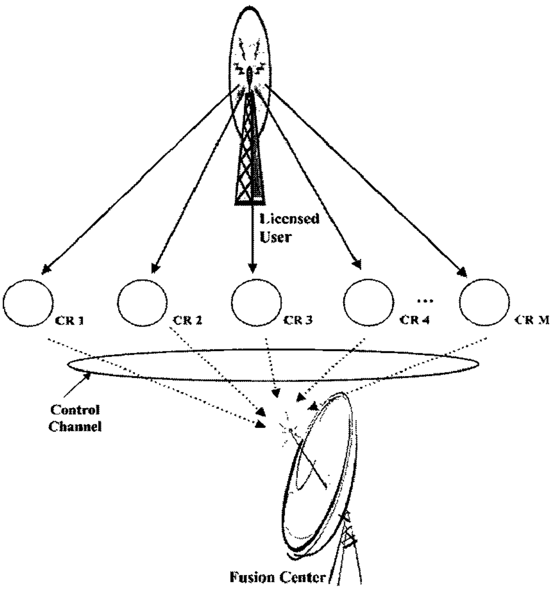
where $h$ is the fading coefficient, $s[k]$ is the transmitted signal by primary user and $k$ is the generated bits from the primary user. The additive white Gaussian noise (AWGN) $v[k]$ is modeled as independent Gaussian random variable. $v[k]$ has normal distribution $N(0, \sigma_v^2)$. $H_0$ indicates that the primary user is absent. $H_1$ indicates that the primary user is present and is located closed to the secondary user.

### 1. Cooperative Sensing Scheme

In this paper, as illustrated Fig. 1, we assume that the cooperative system is composed of a primary user, $M$ secondary users and a fusion center. And the control channel is assumed to be the perfect channel.

In cooperative sensing, each secondary user judges whether primary user is present or not using the energy detector. In other words, the energy of $i^{th}$ secondary user is used for detecting the primary user. The energy of the $i^{th}$ secondary user is shown as

$$E_i[k] = |y_i(k)|^2. \tag{3}$$




<Fig. 1> System model of cooperative spectrum sensing.

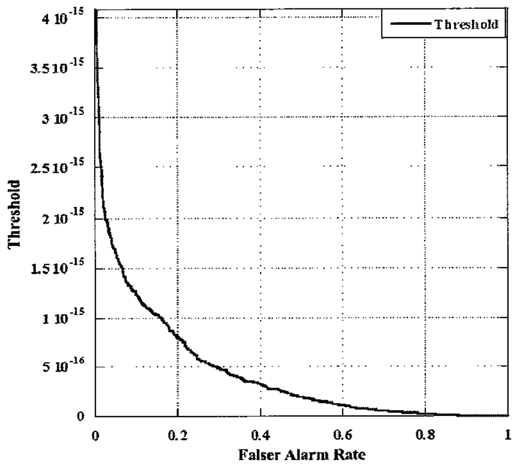
If the primary user is existed, the energy signal is compared with predetermined threshold ($\gamma_i$). Local sensing result of each secondary user can be expressed as

$$D_i[k] = H(E_i[k] - \gamma_i), \tag{4}$$

where $H(\cdot)$ means the Heaviside step function. In other words, if $E_i[k]$ is more than or equal to $\gamma_i$, local sensing result is $D_i[k]=1$ and if $E_i[k]$ is less than $\gamma_i$, local sensing result is $D_i[k]=0$.

$\gamma_i$ is determined in accordance with the constant false alarm rate (CFAR) algorithm [7]. Fig. 2 shows the threshold value versus false alarm rate performance in the cooperative spectrum sensing system.

Local sensing results ($D_i[k]$) are independently transmitted to the fusion center. In the fusion center, each local sensing result is combined and then the result is compared with predetermined threshold ($\gamma$) that is determined according to decision rules. In accordance with this process, final decision about the presence of primary user is made. Final decision result in fusion center is calculated as




<Fig. 2> The measured threshold value versus false alarm rate.

$$D[k] = H\left(\frac{1}{M}\sum_{i=1}^{M} D_i - \gamma\right). \tag{5}$$

In the fusion center, if $D[k]=1$, the primary user is present so secondary users cannot use the spectrum. But if $D[k]=0$, the primary user is absent so secondary users have right to use the spectrum. $\gamma$ is determined in accordance with the decision rule.

## Ⅲ. Majority Decision Rule

### 1. Conventional Decision Rule

In the fusion center, simple decision rules are known as AND and OR rule [8]. These rules are distinguished by threshold value. In (4), if threshold is set at $\gamma = 1/M$, this way is called as AND rule and if threshold is set to be $\gamma = 1$, this way is called OR rule. AND logic is that if one of local sensing result is "0", the fusion center judges primary user is absent. AND logic is that if one of sensing result of local sensing result ($D_i[k]$) is "1", the fusion center judges primary user is present.

## 2. Proposed Decision Rule

In this paper, we propose majority decision rule. Existing decision rules judge very strict or very coarse. Therefore, the detection probability is very low or very high. majority rule is that final decision will be made as majority of local spectrum sensing result and threshold ($\gamma$) set $\gamma = M/2$. In other words, if the majority of local sensing result is "1", final decision ($D[k]$) calculated "1" or if the majority of local sensing result is "0", final decision ($D[k]$) calculated "0". This method is reasonable for making a final decision compared with AND / OR rule and reliable than other decision rules.

# Ⅳ. Performance Analysis

In this section, we analyze the proposed system performance. If a $H_1$ cell is being tested, the probability density function (PDF) of the received signal $y_i(k)$ at the $i^{th}$ secondary user can be expressed as

$$f_{Y_i}(y|H_1) = \frac{1}{\sqrt{2\pi\sigma_v^2}} e^{-\frac{(y-\overline{S})^2}{2\sigma_v^2}}, \tag{6}$$

where $\overline{S}$ is the mean magnitude value of the transmitted signal at the primary user. And if a $H_0$ cell is being tested, then the PDF of $y_i(k)$ can be expressed as

$$f_{Y_i}(y|H_0) = \frac{1}{\sqrt{2\pi\sigma_v^2}} e^{-\frac{y^2}{2\sigma_v^2}}. \tag{7}$$

After each secondary user determines whether there is the primary user or not, the results are retransmitted to the fusion center over wireless channel. Then, the fusion center makes the final decision by combining the received signals from $M$ secondary users.

$$y_F(k) = \sum_{i=1}^{M} y_i(k). \tag{8}$$

When the $H_1$ and $H_0$ cells are being tested, the PDFs of the combined result $y_F(k)$ at the fusion center are expressed as

$$f_{Y_F}(y|H_1) = \frac{1}{\sqrt{2\pi M\sigma_v^2}} e^{-\frac{(y-\overline{S_F})^2}{2M\sigma_v^2}}, \tag{9}$$

$$f_{Y_F}(y|H_0) = \frac{1}{\sqrt{2\pi M\sigma_v^2}} e^{-\frac{y^2}{2M\sigma_v^2}}, \tag{10}$$

where $\overline{S_F} = \sum_{i=1}^{M} \overline{S_i}$ and $\overline{S_i}$ is the mean value of the transmitted signal from the $i^{th}$ secondary user. The detection probability for a given value of the decision threshold is defined as the probability of the event that the output decision variable corresponding to the $H_1$ cell exceeds the decision threshold, which can be obtained by

$$\begin{aligned} P_D &= \int_{\gamma}^{\infty} f_{Y_F}(y|H_1)\,dy \\ &= \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi M\sigma_v^2}} e^{-\frac{(y-\overline{S_F})^2}{2M\sigma_v^2}} dy \end{aligned}, \tag{11}$$

where $P_D$ represents the detection probability of the $H_1$ cell. Also, the false alarm probability for a given value of the decision threshold is defined as the probability of the event that the output decision variable corresponding to the $H_0$ cell exceeds the decision threshold, which can be obtained by

$$\begin{aligned} P_{fa} &= \int_{\gamma}^{\infty} f_{Y_F}(y|H_0)\,dy \\ &= \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi M\sigma_v^2}} e^{-\frac{y^2}{2M\sigma_v^2}} dy \end{aligned}, \tag{12}$$

where $P_{fa}$ represents the detection probability of the $H_0$ cell. Let $z = \frac{y - \overline{s_F}}{M\sigma_v^2}$, then the detection probability can be expressed as

$$P_D = \int_{\frac{\gamma - s_F}{M\sigma_v^2}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz = Q\left(\frac{\gamma - s_F}{M\sigma_v^2}\right), \quad (13)$$

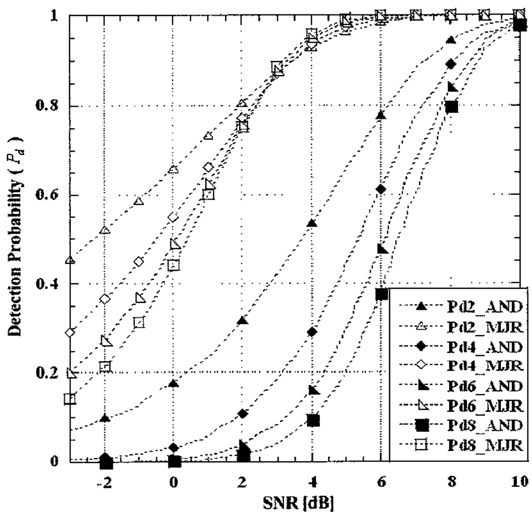
where $Q(\cdot)$ is the Q function. And let $z = \frac{y}{M\sigma_v^2}$, then the false alarm probability can be expressed as

$$P_{fa} = \int_{\frac{\gamma}{M\sigma_v^2}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz = Q\left(\frac{\gamma}{M\sigma_v^2}\right). \quad (14)$$

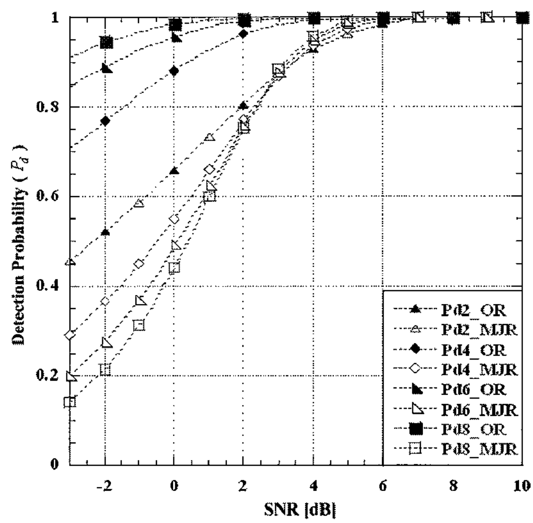
## V. Simulation Results

In this section, we present simulation results in order to illustrate the performance of the proposed decision rule. For simulations, binary phase shift keying (BPSK) signal is used for the primary user's signal. And the energy detection scheme is employed for sensing the spectrum of the primary user.

The detection probability versus signal to noise ratio (SNR) performance in accordance with the AND and majority rules is presented in Fig. 3 and Fig. 4 presents the detection probability versus SNR performance in accordance with the OR and majority rules. When the $H_1$ cell is being tested, we can show that the detection probability employing AND rule is less than that with majority rule. Also, the detection probability employing AND rule decreases as the number of secondary users increases. In other words, AND rule judges whether there is primary user or not very strictly. In Fig. 4, we can see that the detection probability employing OR rule is higher than that with majority rule. Also, both in Fig. 3 and in Fig. 4, we can see that the rate of increase is similar to each case when SNR is more than about 3 dB.



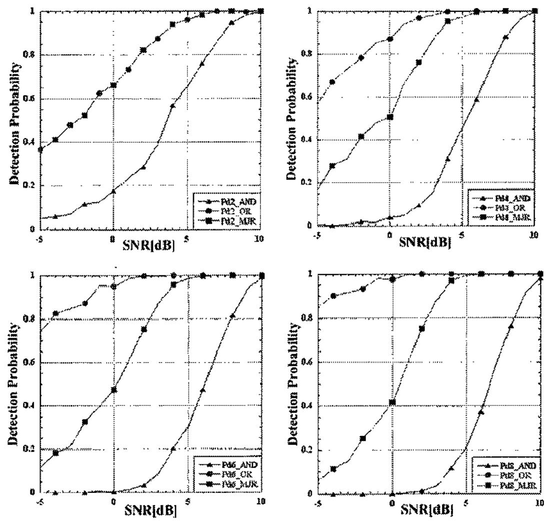

<Fig. 3> The detection probability versus signal to noise ratio (SNR) performance in accordance with the decision rules (AND rule and majority rule).



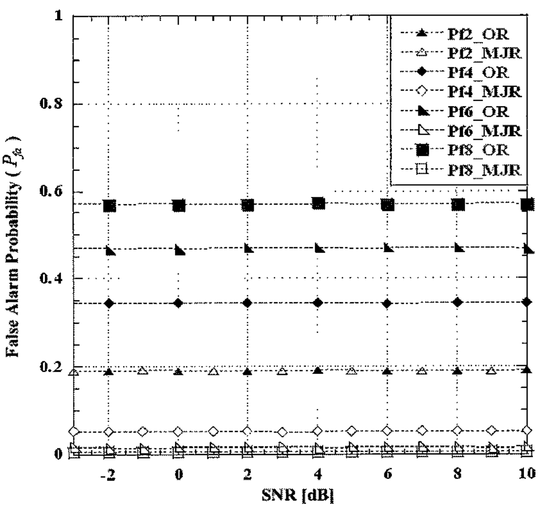

<Fig. 4> The detection probability versus SNR performance in accordance with the decision rules (OR rule and majority rule).

Fig. 5 shows that detection probability employing the conventional rules is very higher or lower than that with majority rule. In Fig. 6, the false alarm probability versus SNR performance in accordance with the OR and majority rules is presented.

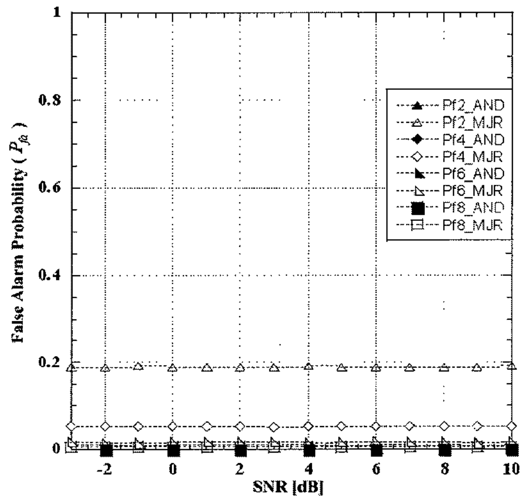
When the $H_0$ cell is being tested, we can show that the false alarm probability employing OR rule is higher than that using majority rule. Also, the false alarm probability employing OR rule increases as the number of secondary users increases. In other words, the




<Fig. 5> The detection probability versus SNR performance in accordance with the decision rules and the number of uses.




<Fig. 6> The false alarm probability versus SNR performance in accordance with the decision rules (OR rule and majority rule).




<Fig. 7> The false alarm probability versus SNR performance in accordance with the decision rules (OR rule and majority rule).

spectrum sensing performance better than that with OR rule.

In Fig. 7, the false alarm probability versus SNR performance in accordance with the AND and majority rules is presented. When the $H_0$ cell is being tested, we can show that the false alarm probability employing AND rule and majority rule is almost similar.

Hence, the false alarm probability increases in spite of increasing the number of secondary users. According to this result, the sensing result employing majority rule is more reliable than OR rule. Because the $H_0$ cell is being tested, secondary users are not received any signals from the primary user. In order to decrease the false alarm rate, we propose the majority rule.

## Ⅵ. Conclusions

In the cooperative sensing scheme, the result is decided by the combination of local sensing outputs. Therefore, in order to decide the sensing outputs precisely, effective decision rule is required.

In this paper, we proposed efficient decision rule that was more reliable than conventional decision rules known as AND and OR rules. And the spectrum sensing performance was analyzed and simulated with the cooperative sensing scheme. In this paper, it was called as majority rule. In the case of $H_1$ cell, the proposed rule had higher detection probability than AND rule did. Besides, the proposed rule showed lower false alarm rate when the $H_0$ cell was tested. Therefore, it was confirmed that the majority rule was more creditable than any other rules.

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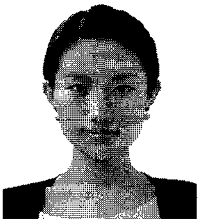
## 저자소개



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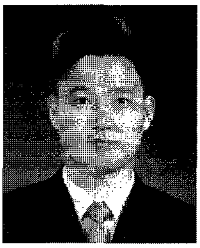

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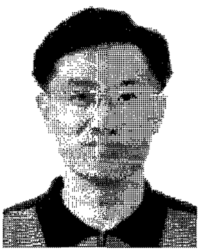

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