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# 스펙트럼 센싱 성능 향상을 위한 선택적 결합 사용 방법

# A Method Using Selection-Combining To Enhance Spectrum Sensing Performance

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**요 약** 본 논문에선, 스펙트럼 센싱 과정에서 서로 협력적으로 선택되고, 보고된(reporting) 채널과 감지된 채널에서 최상의 SNR을 가진 두 사용자의 협력적 스펙트럼 센싱에 대한 2차 사용자의 선택 방법에 대한 연구를 한다. 감지 결과 두 사용자는 첫 번째 사용자 신호의 동작을 검출하기 위해 결합되며, 사용자는 최상의 SNR 채널을 감지해서 기존의 선택 기법과 제안된 방식을 비교한다. 감지 채널들을 I.I.D 레일리 페이딩 채널, 보고된(reporting) 채널은 invariant, non-identical로 가정한다. 시뮬레이션을 통해 제안한 내용을 검증한다.

**Abstract** This paper considers an approach of secondary user selection method in cooperative spectrum sensing, which two users with the best SNR in sensing channel and in reporting channel, respectively, are selected to cooperate with each other in the spectrum sensing. The sensing results reported by two users are then combined to detect PU signal operation. A comparison between this proposed method with conventional selection technique in which only the user having the best sensing channel SNR is selected shows that the proposed method outperforms. We make an assumption that sensing channels experience identical, independent distributed (i.i.d) Rayleigh fading and the reporting channels are invariant and non-identical. Simulation results are derived for demonstration.

**Key Words :** cognitive radio, cooperative spectrum sensing, Rayleigh fading.

## Ⅰ. 서 론

Cognitive Radio (CR) has been seen as a technology to allow for the opportunistic spectrum sharing since it is able to be aware of the available spectrum holes and adapt their usage with the existing spectrum. In this paradigm, a secondary (unlicensed) user monitors the primary spectrum band which is licensed for the primary user (PU) system for a given time, and it opportunistically transmits its signal if it does not detect any ongoing operations of the primary user [1]. However, this can degrade the PU system because of the unreliability in the spectrum sensing [2]. Affected by wireless environment, a secondary user (SU) experiences the unwanted multipath, severe shadowing in both of sensing and reporting channels. This possibly leads to that the incorrect detection is taken and interferences occur at PU system as a result.

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To cope with possible losses rendered by multipath, shadowing and building penetration, it is necessary for SU to be more sensitive in detection than the primary receiver. Multiple radios can operate as a proxy and hence, it is able to help to eliminate the effects of multipath which fades the channels. In the spectrum sensing with multiple CRs, the probability that all users simultaneously experience deep fading is extremely low. Thus, the cooperative model allow for the robust detection without any strict requirements on each radio [2]. It has been shown that the spectrum sensing performance can be greatly improved by increasing the number of cooperative partners. In [3], linear combining technique is the popular method in cooperative spectrum sensing, where the received signals at the fusion center are assigned different weights for global fusion and convex optimization is formulated to solve the linear weights. [4] has investigated on the case that selects only one sensor to perform spectrum sensing. This selection aims to reduce the power consumption of distributed sensors. Aiming to reduce power consumption, [4] studies a case that only sensor having the best sensing channel SNR is selected to perform spectrum sensing.

For reducing energy of transmission for reporting, in this paper, we render a method which combines two SUs having the maximum SNR sensing channel and maximum gain reporting channel accordingly. Then, we make a comparison with conventional selection method where only SU having the best sensing channel is selected. We make an assumption that the reporting channels are AWGN channel with channel gain being invariant and non-identical in respect to different users. Sensing channels experience i.i.d slow Rayleigh fading channel. The next parts of the paper consist of: (II) System Model, (III) Analytical Analysis, (IV) Numerical result, (V) Conclusion.

## II. 시스템 모델

Fig.1 demonstrates the system model in which there are N SUs with a common fusion and a PU source. We denote $h_{si}, h_{ri}$ as the sensing and reporting channel coefficients of the i-th SU, where $i = 1, \ldots, N$ and N is the number of SUs in the group. Energy signal calculated by the i-th SU is denoted as $x_i(\mathrm{t})$. In this model, we employ the amplify-and-forwarding (AF) protocol for the cooperative spectrum sensing. The observation signal $x_i(\mathrm{t})$ is then reported to fusion for global detection. In this scheme, we make an assumption that the fusion center has the knowledge of SNR in sensing channels and reporting channel gains, which sensing channels experience the i.i.d Rayleigh fading and reporting channel gain is invariant. It is thus that the fusion is able to choose SU which has property of best SNR of sensing link and the best reporting channel.

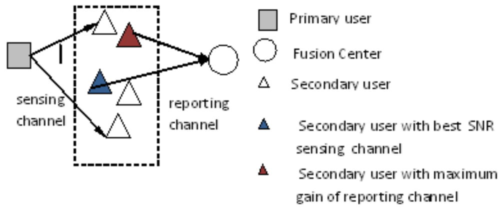


그림 1. 시스템 모델
Fig. 1. System model

## III. 성능 평가

### 1. Local Energy Sensing

The hypothesis tests for received signal at the i-th SU are :

$$\begin{cases} H_0 : r_i(t) = n_s(t) \\ H_1 : r_i(t) = h_{si} s(t) + n_s(t) \end{cases} \qquad (1)$$

where $s(t)$ is the signal of primary user when it is operating. The s(t) is assumed as the Gaussian signal with zero mean and variance $\sigma_s^2$ . The noise follows the AWGN noise with $\mathrm{n_s(t)} \sim \mathrm{N}(0, \sigma_{\mathrm{ns}}^2)$. As assuming that the fading is slow, $h_{si}$ is invariant during each cooperative sensing period. The local SNR at each SU is defined as $\gamma_{si} = \sigma_s^2 h_{si}^2 / \sigma_{ns}^2$ . The local energy $x_i$ is computed as follows,

$$x_i = \frac{1}{K}\sum_{k=1}^{K}\left|r_i(k)\right|^2 \quad (2)$$

where K is the number of samples in the sensing time. When K is sufficiently large, the local statistics of $x_i$ can be approximated as Gaussian random variable [3, 5] as follows,

$$\begin{cases} H_0 : x_i(t) \sim \mathcal{N}\left(\sigma_{ns}^2, \frac{\sigma_{ns}^4}{K}\right) \\ H_1 : x_i(t) \sim \mathcal{N}\left((\gamma_{si}+1)\sigma_{ns}^2, \frac{(2\gamma_{si}+1)\sigma_{ns}^4}{K}\right) \end{cases} \quad (3)$$

### 2. Global Detection

This energy signal $x_i$ is then forwarded by the SU to fusion center for global decision for the PU operation. Each arrived signal at data fusion is expressed by:

$$y_i = h_{ri}x_i + n_r \quad (4)$$

where $n_r$ follows as real AWGN noise with zero mean, and variance $\sigma_{nr}^2$ . Combining (3) and (4), the statistics of $y_i$ under the two hypotheses are as follows,

$$\begin{cases} H_0 : y_i \sim \mathcal{N}\left(h_{ri}\sigma_{ns}^2, \frac{h_{ri}^2\sigma_{ns}^4}{K} + \sigma_{nr}^2\right) \\ H_1 : y_i \sim \mathcal{N}\left((\gamma_{si}+1)h_{ri}\sigma_{ns}^2, \frac{(2\gamma_{si}+1)h_{ri}^2\sigma_{ns}^4}{K} + \sigma_{nr}^2\right) \end{cases} \quad (5)$$

For reducing energy of reporting transmission, this paper combines two SUs which have either the maximum gain of reporting channel or best SNR of sensing channel. At first, fusion center makes a priority to select SU having maximum reporting channel gain. Then, among the rest of unselected SUs, fusion choose the SU having best SNR sensing channel. We select two users for the cooperative spectrum sensing. The first selected SU is the SU which has the maximum reporting channel gain:

$$i = \arg\ \max\left\{h_{ri}\right\}_{i=1}^{N},\ i = 1,..,N \quad (6)$$

The second selected SU is the SU which has the best SNR sensing channel:

$$\hat{i} = \arg\ \max\left\{\gamma_{si}\right\}_{\substack{i=1 \\ i\neq\tilde{i}}}^{N},\ i = 1,..,N \quad (7)$$

The fusion then equally combines two reporting signals from the i˜-th and iˆ-th signal

$$z = y_{\hat{i}} + y_{\tilde{i}} \quad (8)$$

Based on [3], we can derive the distribution of global sensing signal and its probability of detection as showed in the (9) and (10) as follows,

$$z = y_{\hat{i}} + y_{\tilde{i}} \sim \begin{cases} N\left(\sum_{i=\hat{i},\tilde{i}} h_{ri}\sigma_{ns}^2, \sum_{i=\hat{i},\tilde{i}} \frac{h_{ri}^2\sigma_{ns}^4}{K} + \sigma_{nr}^2\right) & : H_0 \\ N\left(\sum_{i=\hat{i},\tilde{i}} (2\gamma_{si}+1)h_{ri}\sigma_{ns}^2, \sum_{i=\hat{i},\tilde{i}} \frac{(2\gamma_{si}+1)h_{ri}^2\sigma_{ns}^4}{K} + \sigma_{nr}^2\right) & : H_1 \end{cases} \quad (9)$$

$$P_d^I = Q\left(Q^{-1}(\alpha) - \frac{\sum_{i=\hat{i},\tilde{i}} h_{ri}\gamma_{si}}{\sqrt{\sum_{i=\hat{i},\tilde{i}} \frac{h_{ri}^2}{K} + \sigma_{nr}^2/\sigma_{ns}^4}}\right) \quad (10)$$

where $\alpha$ is probability of false alarm, and Q(x) is defined as

$$Q(x) = \frac{1}{2\pi}\int_{x}^{+\infty} exp\left(-t^2/2\right)dt \quad (11)$$

### 3. Probability density of the methods

The PDF of the SNR of the sensing channel is,

$$f_{\gamma_{si}}(\gamma) = \frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \quad (12)$$

We derive the PDF of the sensing channel SNR selected by (6) & (7). Firstly, the PDF of the SNR of the sensing channel of SU selected by maximum reporting gain (6) has the same distribution with (12), hence:

$$f_{\gamma_{s\breve{i}}}(\gamma)=\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \tag{13}$$

In the next step, best sensing channel is selected among the remaining users. Hence, PDF of this selection in which the i-th SU is selected can be described as shown below:

$$\begin{aligned} f_{\gamma_{\hat{i}}}(\gamma) &= P\left(\gamma_{\hat{i}}=\gamma,\gamma_1\le\gamma,..,\gamma_{j,j\ne\hat{i},j\ne\breve{i}}\le\gamma,\gamma_N\le\gamma\right) \\ &= f_{\gamma_{si}}(\gamma)\prod_{\substack{j=1\\ j\ne\hat{i},\breve{i}}}^{N}F_{\gamma_{sj}}(\gamma) \\ &= \frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\left[1-\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right]^{N-2} \end{aligned} \tag{14}$$

$h_s=[h_{s1},h_{s2},..,h_{sN}]$ describes the vector of the sensing channels and $h_r=[h_{r1},h_{r2},..,h_{rN}]$ is the vector of the reporting channel with $h_{ri}\ne h_{rj}$ when $i\ne j$ . In this method, we have selected two pairs of channels $(h_{s\hat{i}},h_{r\hat{i}})$ and $(h_{s\tilde{i}},h_{r\tilde{i}})$. Because the Rayleigh fading is i.i.d, the average probability of detection depends on both random variables of $\gamma_{s\hat{i}}$ and $\gamma_{s\tilde{i}}$ by combining (10), (13) and (14).

$$\bar{P}_d^{I}= \int_0^{+\infty}\left(\sum_{\substack{i=1\\ i\ne\breve{i}}}^{N}\int_0^{+\infty}Q\left(Q^{-1}(\alpha)-\frac{h_{r\hat{i}}\gamma_{\hat{i}}+h_{r\breve{i}}\gamma_{s\breve{i}}}{\sqrt{\sum_{i=\hat{i},\breve{i}}\frac{h_{ri}^2}{K}+\sigma_{nr}^2/\sigma_{ns}^4}}\right)f_{\gamma_{\hat{i}}}\left(\gamma_{\hat{i}}\right)d\gamma_{\hat{i}}\right) \times f_{\gamma_{s\breve{i}}}\left(\gamma_{s\breve{i}}\right)d\gamma_{s\breve{i}} \tag{15}$$

For case that only sensing channel having the best SNR of sensing channel is selected by (18), we can easily obtain average detection propability:

$$\bar{P}_d^{II}=\int_0^{+\infty}Q\left(Q^{-1}(\alpha)-\frac{h_{r\breve{i}}\gamma_{s\breve{i}}}{\sqrt{\frac{h_{r\breve{i}}^2}{K}+\sigma_{nr}^2/\sigma_{ns}^4}}\right) \times f_{\gamma_{s\breve{i}}}\left(\gamma_{s\breve{i}}\right)d\gamma_{s\breve{i}} \tag{16}$$

with:

$$\begin{aligned} f_{\gamma_{s\breve{i}}}(\gamma) &= f_{\gamma_{s\breve{i}}}(\gamma)\prod_{\substack{j=1\\ j\ne\breve{i}}}^{N}F_{\gamma_{sj}}(\gamma) \\ &= \frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\left[1-\exp\left(-\frac{\gamma}{\bar{\gamma}}\right)\right]^{N-1} \end{aligned} \tag{17}$$

and

$$\breve{i}=\arg\ \max\left\{\gamma_{si}\right\}_{i=1}^{N},\ i=1,..,N \tag{18}$$

## IV. 시뮬레이션

In our simulation, we consider performance of two techniques with these settings: number of users N = 4, noise variances of sensing and reporting channels are 1, reporting channel gain of each user is alternatively [5,7,10,12] dB, average SNR of sensing channels are [-10,-13,-16,-19] dB, $\sigma_{ns}^2=\sigma_{nr}^2=1$ , K=100.

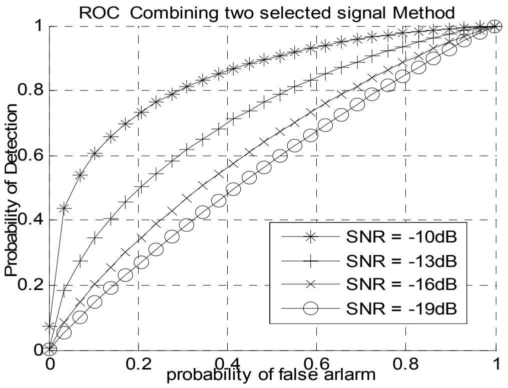


그림 2. i.i.d 레일리 페이딩에서 선택된 신호 결합 방법에서 감지 성능

Fig. 2. Detection performance in the method which combines two selected signals in i.i.d Rayleigh Fading

Fig. 2 and 3 describe the change in the average probability of detection in the two cases: the combining two selected signal and the best selection techniques. When SNR increases, performance of detection grows respectively. We can see that the theoretic analysis is well matched with the simulation results.

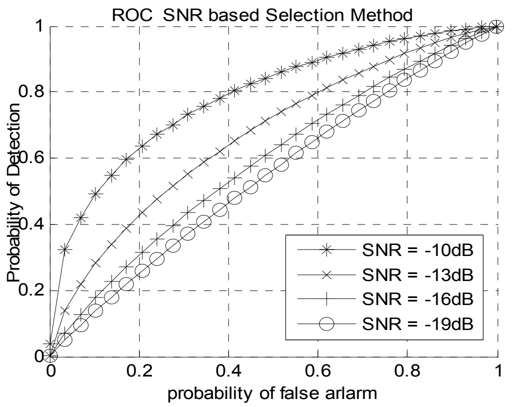


그림 3. 기존의 i.i.d 레일리 페이딩 채널에서 최상의 SNR 검출 채널을 기반으로 선택된 하나의 2차 사용자에 대한 선택 기법의 성능

Fig. 3. Performance of conventional selection method which use only one SU selected based on best SNR sensing channel in i.i.d Rayleigh Fading

Fig.4. compares performance of the both methods in scenarios of different SNR. This plot also shows that the proposed method which combining the sensing results of two best selection users is better than the method which uses only the result from the best users in the sensing channel.

## V. 결 론

To save resources consumption, the paper has presented the cooperation scheme in which the SU having the maximum reporting gain is firstly selected, and the SU having the best sensing channel SNR is selected. We then combine the sensing results of these two users. The analysis of this method is well matched with simulation result. In addition, the evaluation has shown that this method outperform the method which selecting only one best user in the sensing channel.

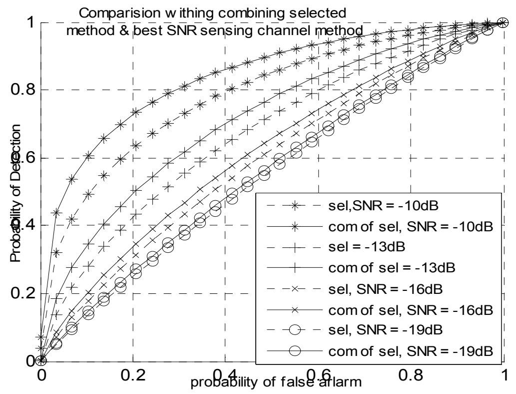


그림 4. N = 4인 i.i.d 레일리 페이딩 채널에서 동작할 때, 두 방법 성능 비교

Fig. 4. Performance comparison of two methods when operates in i.i.d Rayleigh Fading, N = 4.

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