# 협력 인지 통신 네트워크에서 새로운 증분형 스펙트럼 검출

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# A Novel Incremental Spectrum Sensing in Cooperative Cognitive Radio Networks

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## 요 약

본 논문에서는 새로운 스펙트럼 검출 시스템을 제안한다. 먼저 융합 센터(Fusion Center : FC)에서 1차 사용자의 신호를 수신하고, 이를 이용하여 1차 사용자의 유무를 판단한다. 그러나 이 과정에서 최종 1차 사용자의 유무를 판단하지 못한다면, 각 2차 사용자들의 Local observation 결과를 필요로 한다. 이때 융합 센터(Fusion Center : FC)는 각 2차 사용자의 신호 중 에너지가 가장 큰 2차 사용자의 Local observation의 결과만을 수신하며, 수신한 FC는 최종 결정값을 각 2차 사용자에게 송신한다. 본 논문을 통해 제안하는 기법은 단 하나의 2차 사용자가 스펙트럼 검출에 참여하기 때문에 불필요한 스펙트럼 검출로 인한 비트수를 줄일 수 있다. 그러므로 1차 사용자의 유무를 판단하는 과정에서의 2차 사용자의 전력과 불필요한 Local observation전송으로 인한 대역폭의 소모를 줄일 수 있다. Monte-Carlo 시뮬레이션을 통해 본 논문에서 제안하는 기법의 검출 확률, 오 경보 확률 등을 구함으로서 기존의 기법보다 우수한 성능을 보이는 것을 증명한다.

**Key Words :** Incremental Spectrum Sensing, Cognitive Radio, Cooperative Spectrum Sensing, Energy Detection, Rayleigh Fading Channel

## ABSTRACT

In this paper, we consider a novel spectrum sensing system in which firstly, the fusion center (FC) senses and makes the own decision then if its sensing result is not useful for achieving the final decision, the local observations from the cognitive users (CUs) will be required. Moreover, in case that FC needs the results from CUs, we will choose only CU having the highest collected energy to send its local decision to FC. Based on this selecting method, the number of sensing bits can be reduced; hence, we can save the power and the bandwidth for reporting stage in the cognitive radio network (CRN). The mathematical analysis of the key metrics of the sensing schemes (probability of detection, false alarm, e.g.) will be investigated and confirmed by the Monte-Carlo simulation results to show the performance enhancement of the proposed schemes.

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## Ⅰ. Introduction

Recently, the cognitive radio has gained much consideration to deal with the conflict between the steady spectrum demand of the unlicensed users and the inefficient spectrum utilization of the licensed users (primary user – PU) [1-2]. In CRN, the spectrum sensing techniques receive a lot of attentions and are employed in the IEEE 802.22 standard [3]. Furthermore, to beat the fading and shadowing problems, the cooperative spectrum sensing has been proposed to exploit multiuser diversity in sensing process[4-9].

By far, in some previous works focusing on the perfect channels between CUs and FC, the sensing performances have increased greatly [4-5]. However, when the imperfect reporting channels are considered as in [6-9], the performance is bound by the probability of the reporting error. In [7], Wei et al. proposed the cluster-based method where the CUs are grouped into some clusters; and then in each cluster, the most potential CU with the highest reporting channel gain is chosen to collect the sensing results from the others and forward them to FC. In [6], the authors also suggested to apply to space-time coding and space-frequency coding methods to better the quality of the transmission from CUS to FC by considering CUs as virtual antenna arrays. These methods can reduce the reporting errors; however, accumulating all observations of the users at FC or the cluster head is not a good way since it spends too much time slots for all users. Moreover, FC locates in CRN, so it can also sense PU's signal and make the local observation for itself.

Therefore, in this paper we introduce a novel spectrum sensing method named incremental spectrum sensing in which the fusion center senses and makes the local decision first. Based on this result, it can make the final decision immediately, or it will require the reports from the cognitive users if its local result is not useful. In our proposed protocol, when the local observations from CUs are obliged, the timers will be applied at each user due to the energy of sensed signal; so that the energies of all CUs can be compared together indirectly. Afterward, only user having the highest energy will be chosen as a reporting user when the FC needs it. By making use of the spectrum sensing at FC and also limiting the report from all CUs, proposed scheme gets the better sensing performance and also save the bandwidth and power for CRN. Therefore, it shows a good ability to become a potential spectrum sensing scenario in CRN. To investigate this scheme, the main metrics of sensing problem (e.g., detection probability, missing probability and false alarm probability) will be calculated using the total probability theorem. Finally, Monte-Carlo simulations will be given to confirm the analytical results and show the benefits of our proposed scenario.

The rest of the paper is organized as follows. In Section 2, the system model and the novel spectrum sensing approach will be introduced. In Section 3, the proposed scheme's performances are investigated. Next, simulation results are shown and discussed and finally, we make the conclusions in Section 5.

## Ⅱ. System models

In cognitive radio system, cooperative spectrum sensing has been widely used to detect PU with a high agility and accuracy. In some particular works, each CU conducts its individual spectrum sensing using energy detection method and the reports a binary local observation to FC. Usually, FC just collects the reports from all CUs and then makes a final decision according to the fusion function such as the OR rule, the AND rule or the half-voting rule. In order to prevent the interference to the primary user, the spectrum is assumed to be available only when all the sensing users' decision is 0. Thus, in this paper, we will focus on using the OR rule at FC. Moreover, FC is installed on the secondary network and also can "heard" the signal from PU but it just makes the final decision by getting the reports from CUs. That is not a well saving the network component. Hence, we would like to introduce a novel spectrum sensing method in which FC participates in the spectrum sensing approach by sensing the present of PU by itself directly.

In this paper, we investigate the spectrum performance of a cognitive radio network as shown in Fig. 1 with one Fusion Center and N secondary users which help FC to sense the presence or absence of PU. All the links in this scheme are independent and identically Rayleigh faded in which the average SNRs from PU to CUs and FC and from CUs to FC are $\rho$ and $\gamma$, respectively. The new sensing approach for this scheme, named incremental spectrum sensing, is proposed as shown in the flow chart in Fig. 2.

Step 1:The FC collects the signal within the time internal T and gets the energy of that signal. Then, it compares that energy with a pre-determined threshold to make the binary local decision (energy detection method) where "1" delegates for the appearance of the PU and vice versa for "0".

Step 2:Because the OR is used, if the local decision at the FC is "1", it will make the final decision is "1", finish this period sensing and go to the next one which started by the step 1. In the other hand, if it is "0", it will require the reports from the CUs and we next to the step 3 and step 4.

Step 3: Every user collects the energy of the received signal within the time interval T, and then the CU which has the highest received energy will make the local binary decision as the BPSK modulation and send it to FC. The problem "how to determine the best CU" will be introduced in to next section.

Step 4: FC receives the information from the highest energy user and decodes this report to make the final decision.

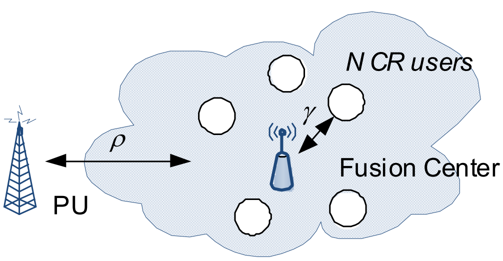


그림 1. 인지 통신 시스템
Fig 1. The cognitive radio system

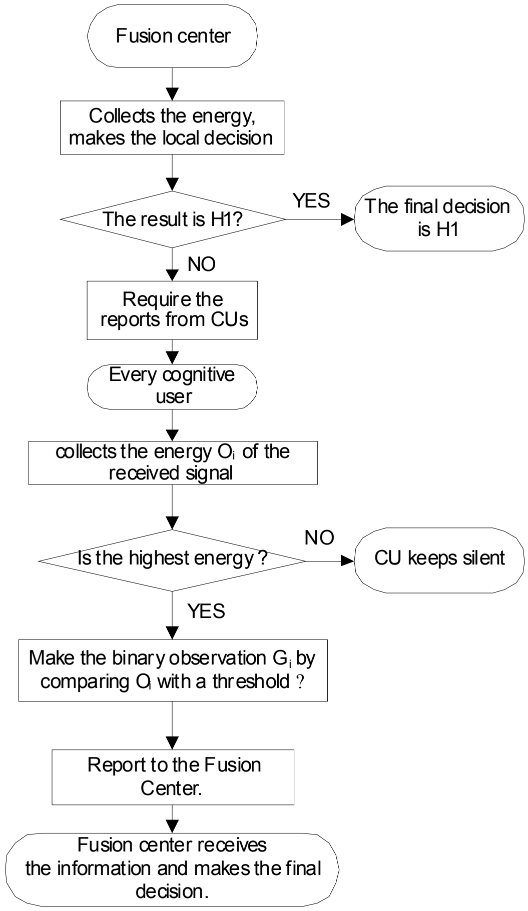


그림 2. 증분형 스펙트럼 검출 단계의 순서도
Fig 2. The flow chart of the incremental spectrum sensing strategy

## Ⅲ. Performance analysis

In this section, firstly, we introduce the timer method to determine the user having the highest received power. Then, the local spectrum sensing is shown briefly. Next, the main part - performance of incremental spectrum sensing - will be investigated.

### 3.1 Compare the energy by setting timers

In order to choose the best CU, the indirect comparison among the received signal's powers of all CUs are processed by applying the timer at each CU as follows. In the secondary network, after collecting the energy of the received signal $O_i$, each

CU set a timer for itself as

$$T_i = A/O_i \quad (1)$$

where A is a constant. Here, for a fair comparison, the perfect synchronization between all CUs is assumed. In the practical systems, this assumption can be achieved by applying a beacon from FC. The sensing process can be started when FC broadcasts a signal to all CUs. Hence, all nodes can receive the beacon at the same time, then collect the signal in the same interval time T, calculate the energy and start the timers at the same time. Finally, the node which has the highest sensed energy will have the shortest timer and its timer expires first. Thus, this user will be chosen to make and report the local decision to FC if FC requires.

Here, we note that the report for timer expiration is no need at the chosen CU. Because, when the chosen user's timer stops, that of the others are still running; hence, the highest energy CU is the first users which can broadcast it local observation to FC and the other CUs. Then, the others receive the signal from the best one, finish their timers and keep silent. At the same time, FC also gets that signal, decodes and makes the final decision. Finally, by broadcasting the local decision, CU having highest energy can inform itself as the best one to all the members in secondary network.

### 3.2 Local spectrum sensing

#### 3.2.1 At the normal CUs (include FC).

Each CU and FC conducts a spectrum sensing process, which is called local spectrum sensing in distributed scenario for detecting PU's signal. Local spectrum sensing is essentially a binary hypotheses testing problem:

$$\begin{cases} H_0 : x(t) = n(t) \\ H_1 : x(t) = h(t)x(t) + n(t) \end{cases} \quad (2)$$

where $H_0$ and $H_1$ are respectively correspondent to hypotheses of absence and presence of PU's signal. $x(t)$ represents received data at CU, $h(t)$ denotes the amplitude gain of the channel. $s(t)$ is the signal transmitted from PU and $n(t)$ is the additive white Gaussian noise.

In order to sense whether PUs are present or absent, some spectrum sensing techniques have been proposed in [10]. The energy detection is performed by measuring the energy of the received signal $x(t)$ in a fixed bandwidth $W$ over an observation time $T$. The energy collected in the circular time $T$ is denoted by $O$ which can be achieved by eqn. (2) in [9]. By comparing the energy $O$ with a certain threshold $\lambda$, the local observation $G$ is made as 1 or 0 if the energy is over the threshold or not, respectively.

$$G = \begin{cases} 1 & O > \lambda \quad (H_1) \\ 0 & otherwise \quad (H_0) \end{cases} \quad (3)$$

Under the Rayleigh fading channels, the average value of the false alarm probability, the probabilities of detection and the missed detection[9] are given respectively as [11]

$$\begin{aligned} P_f(\lambda) &= E[\Pr\{\mathrm{H_1}|\mathrm{H_0}\}] = \mathrm{E}[\Pr\{\mathrm{O} > \lambda|\mathrm{H_0}\}] \\ &= \Gamma(u, \lambda/2)/\Gamma(u) \end{aligned} \quad (4)$$

$$\begin{aligned} P_d(\rho,\lambda) &= E[\Pr\{H_1|H_1\}] = E[\Pr\{O > \lambda|H_1\}] \\ &= e^{-\lambda/2}\sum_{n=0}^{u-2}(\lambda/2)^n/n! + [(1+\rho)/\rho]^{u-1} \\ &\times\left\{e^{-\lambda/2(1+\rho)} - e^{-\lambda/2}\sum_{n=0}^{u-2}[\lambda\rho/2(1+\rho)]^n/n!\right\} \end{aligned} \quad (5)$$

and

$$P_m = 1 - P_d \quad (6)$$

where $E[*]$ represents the expectation, $\Pr\{*\}$ stands for the probability, $\Gamma(*)$ and $\Gamma(*,*)$ are the complete and incomplete gamma function [12], $\lambda$ is the threshold of the energy detector and $u=WT$ is the time bandwidth product.

#### 3.2.2 At CU having the highest collected energy

After calculating the energy $O_i$, each user starts a timer by itself based on the value of $O_i$ as the timer process in the section 3.1. Afterward, the user whose timer expires first is the best one which has the highest energy. Then, the best one immediately makes the local observation and broadcasts the result to all the members in the network. Due to this report, it can inform itself as the best one to every node and also send its observation to FC. The decision of the reporting user can be given as

$$G_{\max} = \begin{cases} 1 & , O_{\max} \geq \lambda \\ 0 & , otherwise \end{cases} \tag{7}$$

where $O_{\max} = \max\{O_1, O_2, ..., O_N\}$. Thus, the false alarm probability $P_f^{\max}$ and the detection probability $P_d^{\max}$ can be expressed as

$$\begin{aligned} P_f^{\max}(\lambda) &= \Pr(O_{\max} > \lambda | H_0) \\ &= 1 - \Pr(O_{\max} < \lambda | H_0) \\ &= 1 - \Pr(\max\{O_1, O_2, ..., O_N\} < \lambda | H_0) \\ &= 1 - \prod_{i=1}^{N} \Pr(O_i < \lambda | H_0) = 1 - \prod_{i-1}^{N} (1 - P_{f,i}) \end{aligned} \tag{8}$$

$$\begin{aligned} P_d^{\max}(\rho, \lambda) &= \Pr(O_{\max} \geq \lambda | H_1) \\ &= 1 - \Pr(\max\{O_1, O_2, ..., O_N\} < \lambda | H_1) \\ &= 1 - \prod_{i=1}^{N} \Pr(O_i < \lambda | H_1) = 1 - \prod_{i-1}^{N} P_{m,i} \end{aligned} \tag{9}$$

Hence, by choosing the user having the highest sensing power, we can get the local decision which can present for all CUs in the network.

### 3.3 The incremental spectrum sensing

In order to investigate the performance of the incremental spectrum sensing method, we analysis the key metrics of the spectrum sensing problem that is the probability of detection and the probability of false alarm in two cases, i.e., the local decision at FC is $H_1$ or $H_0$.

#### 3.3.1 The probability of detection:

In this metric, the true hypothesis of the PU is $H_1$. By applying the total probability theorem, the final probability of detection can be given as

$$\begin{aligned} Q_d = & P_d(G_{FC} = 1) \Pr(G_{FC} = 1 | H_1) \\ & + P_d(G_{FC} = 0) \Pr(G_{FC} = 0 | H_1) \end{aligned} \tag{10}$$

In the eqn. (10), $P_d(G_{FC} = 1) \Pr(G_{FC} = 1 | H_1)$ presents for the probability that the final decision is $H_1$ when the FC has the local decision is $H_1$. Therefore, it's easy to see that probability for this case is that of the local detection at FC which can be achieve follow the eqn. (5), hence, we have

$$P_d(G_{FC} = 1) \Pr(G_{FC} = 1 | H_1) = P_d^{FC}(\rho, \lambda) \tag{11}$$

Inversely, $P_d(G_{FC} = 0) \Pr(G_{FC} = 0 | H_1)$ denotes the probability that the final decision is $H_1$ when the FC has the local decision is $H_0$. Here, $\Pr(G_{FC} = 0 | H_1)$ is exactly the local missed detection probability of the FC which can be achieved from the eqn. (5) and (6). And, $P_d(G_{FC} = 0)$ is the probability that the FC receives the bit 1 from the chosen CU which has the highest collected energy.

There are two cases that FC receives the $H_1$ report. First, the local decision at the chosen user is $H_1$ (right detection) and the transmission to FC is good (without error). Second, the local decision at the chosen user is $H_0$ (missed detection) and the transmission from it to FC is bad (with the error, $H_0$ is changed to $H_1$). Thus, the probability that FC receives the bit 1 with the true hypothesis $H_1$ at PU is

$$\begin{aligned} P_d(G_{FC} = 0) = & P_d^{\max}(\rho, \lambda)(1 - P_e(\gamma)) \\ & + (1 - P_d^{\max}(\rho, \lambda)) P_{e(\gamma)} \end{aligned} \tag{12}$$

where $P_d^{\max}(\rho, \lambda)$ performs as in eqn. (9) and $P_e(\gamma)$ denotes the reporting error probability of the direct transmission from the chosen user to the FC with the channel gain mean is $\gamma$. By averaging the Q-function over the instantaneous SNR between the chosen user and the FC, the error probability can be given as [13]

$$P_e(\gamma) = \int_0^\infty Q(\sqrt{2\gamma_{\max}}) f_{\gamma_{\max}}(\gamma_{\max}) d\gamma_{\max} = \left[1 - \sqrt{\gamma/(1+\gamma)}\right]/2 \tag{13}$$

where $\gamma_{\max}$ is the instantaneous SNR of the signal transmitted from the chosen user to the FC and the probability density function of $\gamma_{\max}$ is $f_{\gamma_{\max}} = (1/\gamma)\exp(-\gamma_{\max}/\gamma)$ due to the Rayleigh fading. Hence, the total probability of detection can be given as

$$Q_d = P_d^{FC}(\rho,\lambda) + \left[P_d^{\max}(\rho,\lambda)(1-P_e(\gamma)) + (1-P_d^{\max}(\rho,\lambda))P_e(\gamma)\right]P_m^{FC}(\rho,\lambda) \tag{14}$$

From the probability detection probability we can get the missing probability as

$$Q_m = 1 - Q_d \tag{15}$$

#### 3.3.2 The false alarm probability:

For this metric, the true hypothesis of PU is $H_0$. Analyzing similarly to the previous, the total false alarm probability can be given as

$$Q_f = P_f(G_{FC}=1)\Pr(G_{FC}=1|H_0) + P_f(G_{FC}=0)\Pr(G_{FC}=0|H_0) \tag{16}$$

where $P_f(G_{FC}=1)\Pr(G_{FC}=1|H_0) = P_f^{FC}(\lambda)$ is the local false alarm probability at the FC and $\Pr(G_{FC}=0|H_0) = 1 - P_f^{FC}(\lambda)$ is the probability the FC get the local decision is $H_0$. Moreover, $P_f(G_{FC}=0)$ is the probability that the FC receives the bit 1 from the chosen CU having the highest collected energy. Likewise as the previous section, we have

$$P_f(G_{FC}=0) = P_f^{\max}(\rho,\lambda)(1-P_e(\gamma)) + (1-P_f^{\max}(\rho,\lambda))P_{e(\gamma)} \tag{17}$$

Therefore, the total false alarm probability for this spectrum sensing system can be given as

$$Q_f = P_f^{FC}(\rho,\lambda) + \left[P_f^{\max}(\rho,\lambda)(1-P_e(\gamma)) + (1-P_f^{\max}(\rho,\lambda))P_e(\gamma)\right]\left(1-P_f^{FC}(\rho,\lambda)\right) \tag{18}$$

#### 3.3.3 The average number of reports from the CU

In the conventional works, FC collects all the local observations from all CUs so the average number of the reports always equals the number of CUs. Inversely, in our proposed scheme, the average number of report is reduced strongly by picking up the sensing process at the FC and choosing only one CU to report to the FC. Denote $\Pr(H_1)$ and $\Pr(H_0)$ as the probabilities of the presence and absence of PU, respectively. Because the report from the chosen CU is required when the local decision at FC is $H_0$, the average number of reports from CU can be calculated as

$$\overline{N_r} = \Pr(H_1)P_m^{FC}(\rho,\lambda) + \Pr(H_0)(1-P_f^{FC}(\rho,\lambda)) \tag{19}$$

## Ⅳ. Simulation results and discussion

In this section, the analytical and simulation results will be provided. Note that in all the figures in this section, the numerical results are represented by curves, while simulation results are represented by discrete marks on the curves. We use the Monte-Carlo method for the simulations with the number trials for each point is 10000, the links from PU to CUs and FC and from CUs to FC are independent and identically Rayleigh faded. The value of time bandwidth product $u$ is set to be 4.

The Fig. 3 shows the impact of the average SNR of the links form PU to CUs ($\rho$) on the probability of detection $P_d$ of the single CU scheme, the cooperative spectrums sensing scheme[8-9] and our proposed scheme. In this figure, the average SNR from CUs to FC is set to be 40dB due to the good channel between CUs and FC (i.e., short distances) and the value of $\rho$ varies from -2dB to 20dB, the detection threshold is 10. As in Fig. 2, when the value of $\rho$ is at a small region (e.g., from -2dB to 2dB), the detection probability $P_d$ is nearly 0, it means that the scheme cannot detect PU. When $\rho$

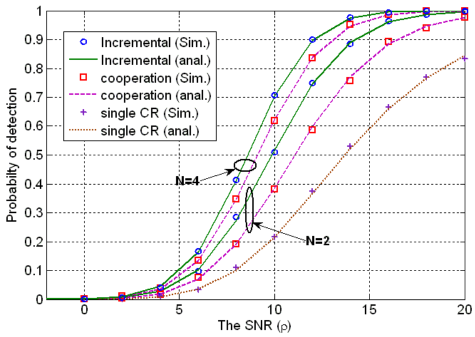


그림. 3. 2차 유저 수에 따른 검출 확률과 SNR값의 관계
Fig. 3. Variation of Pd with ρ for different value of CUs

increases, the detection probabilities also increase. This figure also shows that the probability of our proposed scheme is higher than the other. These results can be explained according to making use of one more sensing process at fusion center. Moreover, the local decision at FC can be used directly without transferring through a non-perfect (with error) wireless channel as reporting from CUs. From Fig. 3, we also see that as the larger number of CUs the performances of our proposal and cooperative schemes get better.

The Fig. 4 shows the analytical results and simulation results regarding how the probability of missing detection $P_m$ changes with the false alarm probability $P_f$. For the analytical results, the equation (15) is used for different value of $N$. We can see our proposed scheme gets the better performance in the comparison with the conventional cooperative spectrum sensing scheme in [8-9]. As the number of cognitive users increases, the performance spectrum sensing of both schemes also increases. Furthermore, Fig.4 also presents a well example for the drawback of the cooperative spectrum sensing that the false alarm probability is lower bounded by the error of the transmission as in [9](eqn. 13) and this bound raises due to the increase of N. Hence, we can see that the slope of cooperative-system curve with N = 4 is steep at $Q_f$ is $10^{-2}$ according to the limitation of the reporting error from CUs to FC.

Fig. 5 illustrates the average number of report from CUs to FC versus the different value of ρ for the number of CUs is 2 and the different value of $\Pr(H_1)$. We can see that the average number of reports of our proposed scheme is always less than 1. Hence, we can reduce the bandwidth and the transmitted power for CUs to inform the local decision to FC while getting a better performance than the conventional one[9]. Finally, it is clearly to see that the analytical results match perfectly with their simulation counterparts, confirming the accuracy of the analysis.

Finally, as we know the OR rule is that the final decision is $H_1$ if there is at least one local decision is $H_1$. Hence, based on using this fusion rule, we can take the advantages by just considering the local decisions at FC and the best CU, respectively that will be explained as follow. If the local observation at FC is $H_1$, it is not necessary to care about the results at the others. Inversely, if FC's result is $H_0$,

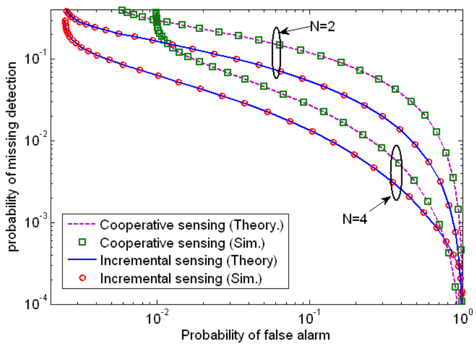


그림. 4. 2차 유저 수에 따른 오경보 확률과 미검출 확률의 관계
Fig. 4. Variation of $P_m$ with $P_f$ for N=2, 4

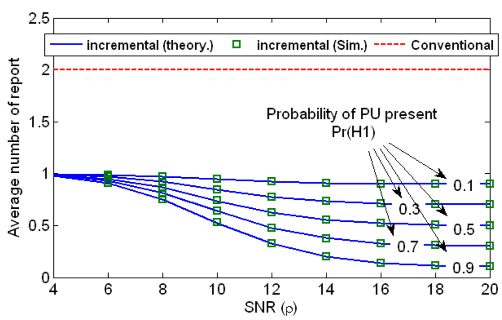


그림. 5. $\Pr(H_1)$에 따른 평균 전송 수와 SNR값의 관계
Fig. 5. Variation of average number of report with ρ for different value of $\Pr(H_1)$

the local decisions at CUs will be required. By selecting the user having the highest sensed energy, we have that if its energy is greater than the threshold, the local decision is $H_1$ and it satisfies the OR rule to make the final decision. However, if this energy is less than the threshold, all energies of all CUs will be less than the threshold; so, using the $H_0$ local observation at the chosen CU can get the same result as collecting all $H_0$ results of CUs due to the OR rule. As a final point, checking the local decisions at FC and the chosen user (presenting for all CUS) with the OR rule, our scheme can outperform the convention cooperative schemes on the views of the sensing performances and saving the power transmission.

## Ⅴ. Conclusion

We developed the protocol to get the better final decision with saving the resource by dropping the number of reports in cognitive networks. Moreover, analysis and simulation results show that with our protocol, we can achieve the lower missing probability and false alarm probability in comparison with the conventional cooperative spectrum sensing. Therefore, this proposed scheme shows a good ability to become a potential spectrum sensing scenario in the cognitive radio network.

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