

# Effective Combining Scheme for Channel Sensing in Multiuser Cognitive Radio Systems

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## Introduction

In cognitive radio (CR) systems, channel sensing should be performed very accurately in order to protect primary user (PU) and to achieve high spectral efficiency. Recently, there are some efforts to improve the accuracy of the channel sensing in the CR systems. In particular, it is shown that the correctness of channel sensing can be improved by combining the multiple sensing results from CR nodes [1]. However, previous works do not consider the fact that CR nodes receive very dissimilar energy from PU with respect to each other, according to their distances from the PU. For example, if a node is close to a PU, it can receive large amount energy from the PU. On the other hand, a node located far away from the PU receives weaker energy from the PU. In this situation, without considering the dissimilarity of received energy among CR nodes, optimal combining for the sensing information cannot be achieved.

In this paper, we propose an effective combining scheme for the multiuser CR systems. In contrast to the previous works, the proposed scheme combines multiple sensing results reported from CR nodes, considering the heterogeneity of their received energy caused by the diversity of their distances from the PU. To accomplish this, the proposed scheme investigates the probability distribution of statistics from the energy detector by using the virtual grid.

## Proposed Scheme

We consider the CR system which contains  $N$  CR nodes. Each CR node is equipped with an energy detector. During the normal operation, all CR nodes carry out the channel sensing (by using the energy detector) and exchange the measurement results. Using the collected information, CR system determines whether there is a PU signal or not. In this paper, we assume that the transmission power of a PU is known to the CR system. It is also assumed that each CR node knows its geographical location.

On the other hand, the objective of energy detection is to distinguish between PU absent hypothesis  $H_0$  and PU present hypothesis  $H_1$  [2]. If we assume the additive white Gaussian noise, measured energy  $X$  (called “decision statistic” in this paper) under each hypothesis for a CR node can be modeled as a Gaussian random variable with following pdf (probability density function):

$$g(x) \sim \mathcal{N}\{2BT_s N_0, 4BT_s N_0^2\}, H_0, \quad (1)$$

$$f(x) \sim \mathcal{N}\{2BT_s N_0 + E, 4BT_s N_0^2 + 4EN_0\}, H_1, \quad (2)$$

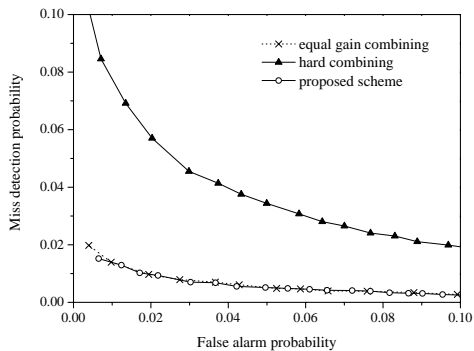
where  $\mathcal{N}\{\mu, \sigma^2\}$  is a Gaussian distribution with mean of  $\mu$  and variance of  $\sigma^2$ ,  $B$  is bandwidth of CR system,  $N_0$  is noise density,  $E$  is the received energy from a PU signal, and “ $\sim$ ” denotes “is pdf of”.

The proposed scheme aims at improving the channel sensing performance by exploiting the fact that distance between primary and each CR node can be different according to their geographical location. However, to obtain the information about distance can generally be difficult, especially when CR nodes have mobility. Thus, in order to exploit the geographical property with a minimum prior information, CR system (virtually) organizes a grid. The grid contains total  $M \times M$  squares and the side length of each square is  $D$  meters. A square is indexed by  $m$  ( $1 \leq m \leq M^2$ ). Then, we can calculate the distance between the PU located at the center of each square and each CR node. Let  $d_{n,m}$  denote the distance between the PU and the CR node  $n$  if the PU is activated at the center of square  $m$ . Considering the simplified path-loss model, estimated signal energy from PU located at square  $m$  to CR node  $n$  can be represented as  $E_{n,m} = T_s \cdot P_t \cdot y(d_{n,m})$ , where  $T_s$  is sensing time,  $P_t$  is transmission power of PU, and  $y(\cdot)$  is a function for path-loss gain.

Using the estimate of received energy from the PU located at each square derived above, pdf of decision statistic under hypothesis  $H_1$  for node  $n$  and PU at square  $m$  can be modified as  $f_{n,m}(x) \sim \mathcal{N}\{2BT_s N_0 + E_{n,m}, 4BT_s N_0^2 + 4E_{n,m} N_0\}$ . Now, using the pdf of decision statistic, the CR system can determine whether the spectrum band is occupied by the PU or not. Since

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This work was supported in part by MIC & IITA through IT Leading R&D Support Project



**Figure 1. Detection performance when  $D = 7$  km and  $P_t = 70$  dBm/Hz.**

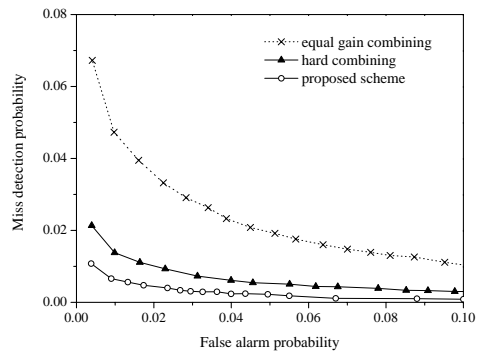
the Neyman-Pearson criterion has been known as the optimal decision rule, we apply it for the decision making. Let  $p_m$  denote the probability that a PU is activated at the square  $m$  and let  $\mathbf{x} := (x_1, x_2, \dots, x_N)$ , where  $x_n$  is the measured value of decision statistic at node  $n$ . Then, the likelihood ratio is defined as  $\mathbf{L}(\mathbf{x}) := (\sum_{m=1}^{M^2} p_m \prod_{n=1}^N f_{n,m}(x_n)) / (\prod_{n=1}^N g(x_n))$ . With a predetermined threshold value  $\epsilon$ , the CR system regards that the spectrum band is occupied if  $\mathbf{L}(\mathbf{x}) \geq \epsilon$ .

## Numerical Results

In simulation,  $N = 9$  and  $M = 10$ . Thus, the grid consists of total 100 squares. The square in which the PU is activated is selected randomly with the equal probability. Accordingly, for the proposed scheme,  $p_m = 0.01$  for all  $m$ . In order to calculate the path-loss gain, we use the equation  $y(d) = 10^{-12.81 - 3.76 \log_{10} d}$ , where  $d$  is the distance between two nodes. The noise density is set to  $-163$  dBm/Hz and energy detection length is  $100 \mu\text{sec}$ . The system bandwidth is 1 MHz. For a comparison purpose, we also evaluate the performance of the hard combining with OR rule and the equal gain combining.

First, we consider the case that the transmission power of the PU is strong so that it covers the entire area of the CR system. In this situation, all CR nodes can receive enough energy from the PU to detect its presence. For the simulation, we use  $D = 7$  km and the transmission power of the PU is set to 70 dBm/Hz. From Fig. 1, we can see that the equal gain combining achieves much better performance than the hard combining. This results from the fact that the combining with equal gain is very effective in this case since all CR users receive similar amount energy from the PU. The figure indicates that the performance of proposed combining is the same as that of equal gain combining.

Next, we consider the situation that only a part of CR



**Figure 2. Detection performance when  $D = 250$  meters and  $P_t = 5$  dBm/Hz.**

nodes can receive enough energy from the PU since the transmission power of the PU is very weak. For the simulation, we use  $D = 250$  meters and the transmission power of the PU is set to 5 dBm/Hz. According to the results in Fig. 2, we can see that the performance of the equal gain combining is very poor in comparison with that of the hard combining. This is because although the sensing result at a node close to the PU is more accurate than that at nodes far from the PU, the equal gain combining assigns the same weighting value to the results from all nodes. On the other hand, the proposed scheme can outperform the hard combining even in this case since it can combine the sensing results from multiple nodes by considering the diversity of received energy among them.

## Conclusion

We have investigated the effective combining method for the multiuser CR systems in this paper. In contrast to the previous works, the proposed scheme considers the fact that the received energy from the PU can be very dissimilar among CR nodes according to their geographical location. The numerical results show that the proposed scheme improves the detection performance significantly in comparison with other traditional schemes.

## References

- [1] S. M. Mishra, A. Shahi, and R. W. Brodersen, "Co-operative sensing among cognitive radios," in *Proc. IEEE ICC 2006*, Istanbul, Turkey, June 2006.
- [2] H. Urkowitz, "Energy detection of unknown deterministic signals," *Proc. IEEE.*, vol. 55, no. 4, pp. 523–531, Apr. 1967.