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A cooperative sensing technique with weighting based on distance between radio stations

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Abstract- **Cognitive radio, which is expected to yield high frequency utilization, requires a highly reliable sensing technique. Cooperative sensing techniques have been studied to meet this demand. However, conventional techniques have high false alarm rates. To solve this problem, we propose a new cooperative sensing technique in which the received power levels at several radio stations are multiplied by different weights and added. Whether or not radio waves are present is determined from this total power level. A computer simulation demonstrates that the proposed technique offers a lower false alarm rate than conventional techniques while satisfying the misdetection rate.**

Keywords: Cognitive radio, Sensing, Cooperation

I. INTRODUCTION

Cognitive radio is very attractive because of its high frequency utilization [1][2]. The concept of cognitive radio is to be aware of the channel environment and to utilize vacant frequency bands. FCC issued a Notice of Proposed Rule Making and Order [3][4] and has encouraged research on cognitive radio. IEEE 802.22 has argued for a Wireless Regional Area Network (WRAN) with cognitive radio technique for TV band application [5][6]. E^2R projects express an interest in cognitive radio for spectrum sharing with a distributed control and management solution [7].

The cognitive radio systems should have a sensing function that detects the presence of radio waves transmitted by other radio stations. The methods used to implement this sensing function are classified into the energy detector, matched filter, and cyclostationary feature detection methods [8]. The energy detector method is the simplest of these because all that is needed is observation of the received power to detect the presence of radio waves. This method is similar to carrier sense in IEEE 802.11[9].

The energy detector is, however, too sensitive to unpredictable fluctuations in received power level due to shadowing, fading, etc. Such fluctuations may cause misjudgment. There are two types of misjudgment. If the detector detects no radio waves even though there radio waves are present (misdetection), the cognitive radio system may cause severe interference with other radio stations. If the detector detects some radio waves even though none are present (false alarm), the detector may miss an opportunity to utilize a vacant frequency band.

To tackle the problem of misjudgment, the cooperative sensing technique was proposed [8][10][11]. Ghasemi and Sousa proposed a cooperative sensing technique that makes a judgment from individual judgments at different radio stations [12]. This technique can decrease the misdetection rate because judgment is made on the basis of several judgments at different radio stations. However, there is a problem; the technique has a high false alarm rate.

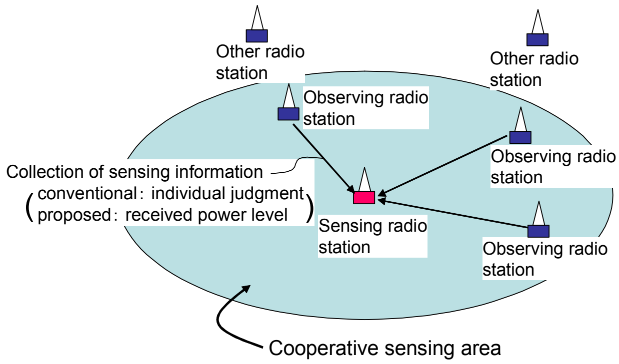

Figure 1. System model of the cooperative sensing technique.

Our solution is a new cooperative sensing technique in which several radio stations observe the received power and then all observed power levels are appropriately weighted and added. The presence of radio waves is detected by comparing the added power level against a threshold.

This paper is organized as follows. Section II describes the conventional and proposed cooperative sensing techniques. Section III discusses the results of our computer simulation of the proposed technique, which demonstrate the superiority of the proposed technique over the conventional technique. We conclude in Section IV.

II. PROPOSED COOPERATIVE SENSING SCHEME

Fig. 1 is a system model of the conventional cooperative sensing technique. The sensing radio station that is trying to judge whether radio waves are present or not and the observing radio stations, which are located within a constant distance from the sensing radio station, cooperate to accurately detect the presence of radio waves. The sensing and observing radio stations individually monitor received power level and judge whether radio waves are present or not by comparing the received power level to a threshold level. The sensing radio station collects all the individual judgments and makes an overall judgment: if any of the radio stations judge that radio waves are present, the overall judgment is also that radio waves are present. Though this technique decreases the misdetection rate, it also increases the false alarm rate

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because the overall judgment is false if even one of the radio stations reports a false alarm.

Our proposal is a cooperative sensing technique that overcomes the problem of the conventional cooperative sensing technique. The system model of the proposed cooperative sensing technique is the same as that of the conventional cooperative sensing technique shown in Fig. 1. The sensing and observing radio stations observe the received power. Next, the sensing radio station collects information about the received power level from the observing radio stations. The collected power levels are multiplied by weights according to the distance between the sensing radio station and each observing radio station. This approach ensures that the power level observed at an observing radio station that is closer to the sensing radio station is multiplied by a larger weight. In this paper, we consider the weights are the reciprocal of the squared distance between the sensing radio station and the observing radio station. This is free space loss propagation. All power levels are added, and then a judgment is made as to whether radio waves are present or not by comparing the added power level to the threshold level. Equation 1 shows the added power level at the sensing radio station.

$$SP_m = w \cdot P_m + (1-w) \cdot \left(\sum_{\substack{k=1 \\ m \notin k}}^{N+1} 1/d_{mk}^2 \cdot P_k \Bigg/ \sum_{\substack{k=1 \\ m \notin k}}^{N+1} 1/d_{mk}^2 \right) \quad \ldots(1)$$

where N is the number of observing radio stations, k ($1 \le k \le N+1$) is the index of radio stations, P_m is the received power level (real value) at the sensing radio station, P_k is the received power level (real value) at observing radio station k, d_{mk} is the distance between sensing radio station and observing radio station k, and w is the weight of the received power level at the sensing radio station. If the SP_m is smaller than the threshold level, the sensing radio station judges that radio waves are not present. If SP_m is larger, the sensing radio station judges that radio waves are present.

III. Performance Evaluation

A. Simulation model

We evaluated the proposed cooperative sensing technique by computer simulation. Fig. 2 shows the simulation model. The other radio communication system's transmitter was located at (0, 0). The transmitter continuously sent signals to other radio communication system's terminals. The sensing radio station was located at (D, 0) and the observing radio stations were uniformly distributed within a constant distance, r [km], from the sensing radio station.

The simulation parameters are shown in Table I. The parameters are set based on IEEE 802.22 [5]. We set $r = 3$ [km]. The propagation loss model was based on the Okumura-Hata model. Equation 2 shows propagation loss L_p.

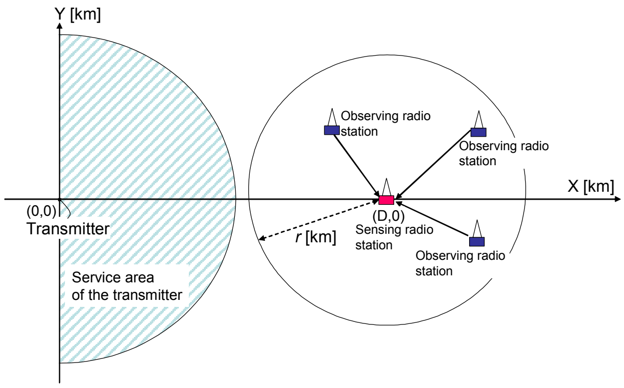

Figure 2. Simulation model.

TABLE I
Simulation Parameters

Center frequency f_c	615 [MHz]
Transmitted power of transmitter P_t	30 [dBm]
Height of transmitter antenna h_t	200 [m]
Height of radio station antenna h_r	10 [m]
Minimum required received power for transmitter's service P_{req}	-92 [dBm]
Log normal shadowing standard deviation σ	5.5 [dB]

$$L_p = 69.55 + 26.16 \cdot \log_{10} f_c - 13.82 \cdot \log_{10} h_t - a(h_r) + (44.9 - 6.55 \cdot \log_{10} h_t) \cdot \log_{10} D \quad \ldots(2)$$

where $a(h_r) = (1.1 \cdot \log_{10} f_c - 0.7) \cdot h_r - (1.56 \cdot \log_{10} f_c - 0.8)$, f_c is the central frequency, h_t is the height of transmitter's antenna, and h_r is the height of receiver's antenna (sensing and observing radio stations). The computer simulation assumed only lognormal shadowing. Fading and noise were not considered.

We assumed that the sensing radio station knew the exact locations of the observing radio stations. Therefore, the exact distance between the sensing radio station and the observing radio stations was used in Eq. (1).

The sensing station judges whether it is in the service area (of the transmitter) or not. We used misdetection rate (R_{md}) and false alarm rate (R_{fa}) as evaluation metrics. We defined R_{md} and R_{fa} as follows: R_{md} is the rate at which the sensing radio station misjudges that the sensing radio station is not located in the service area of the transmitter even though it is in the service area. R_{fa} is the rate at which the sensing radio station misjudges that the sensing radio station is located in the service area of the transmitter even though it is not. We evaluated R_{md} when $D \le 11$ [km] and R_{fa} when $D \ge 12$ [km] because the service area of the transmitter is 11 [km], as calculated from Table I and Eq. (2).

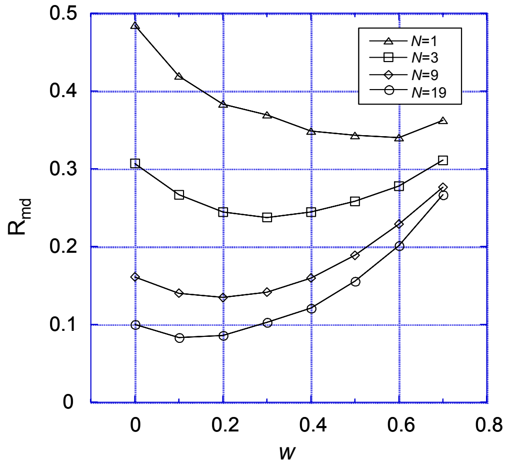

Figure 3. R_{md} versus *w*.

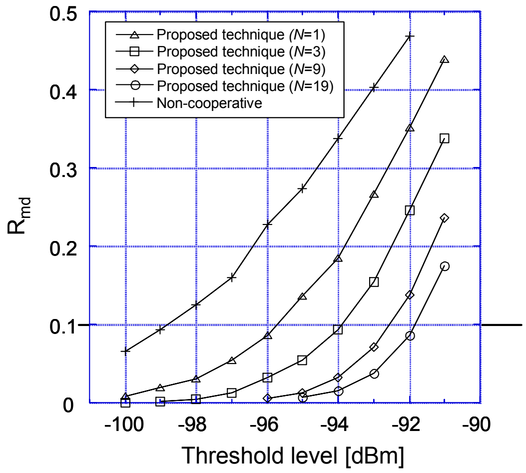

Figure 4. R_{md} versus threshold level.

B. Simulation results

1) Basic performances of the proposed cooperative sensing technique

To clarify the optimum value of *w* in Eq. (1), we evaluated the value of *w*. Given that the sensing station should interfere as little as possible with the transmitter's service, we defined the optimum value of *w* as the value at which R_{md} is minimum when D=11 [km], which is the limit of the transmitter's service area. The threshold was –92 [dBm], which is the same as P_{req}. Fig. 3 shows plots of R_{md} versus *w*. We evaluated R_{md} with *N*=1, 3, 9 and 19. The performances of R_{md} improved with larger *N*. The optimum value of *w* falls as *N* increases.

Then, we evaluated the threshold level to satisfy the required condition that we set $R_{md} \leq 0.1$, as per parameters in IEEE 802.22 [5]. Fig. 4 shows R_{md} versus threshold level at D=11 [km] with *N*=1, 3, 9 and 19. The optimum values of *w* were set to 0.6, 0.3, 0.2 and 0.1, respectively, as shown in Fig. 3. The maximum threshold levels are -96, -94 -93 and -92 [dBm] for the cases of *N*=1, 3, 9 and 19, respectively.

Fig. 5 shows plots of R_{fa} versus D [km] with *N* = 1, 3, 9 and 19. The optimum values of *w* and threshold level, which were derived from Fig. 3 and Fig. 4, were set. R_{fa} performance improved with *N* while achieving the required condition, $R_{md} \leq 0.1$.

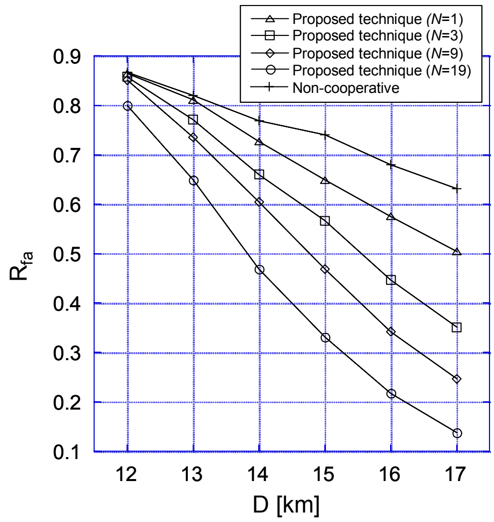

Figure 5. R_{fa} versus D.

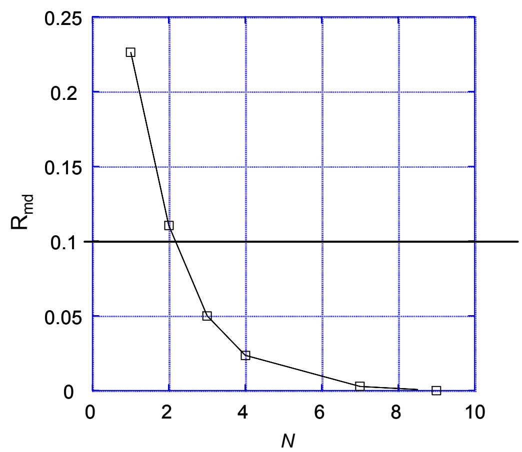

Figure 6. R_{md} versus *N* in the conventional cooperative sensing technique.

2) Comparison between proposed cooperative sensing technique and conventional cooperative sensing technique

We compared the proposed cooperative sensing technique with the conventional cooperative sensing technique. We set the required condition to $R_{md} \leq 0.1$. The threshold level for individual judgment in the conventional technique was set to -92 [dBm], the same as P_{req}.

We clarified the value of *N* needed to achieve the required condition in the conventional cooperative sensing technique. Fig. 6 shows plots of R_{md} versus *N*. These results show that the conventional technique needs *N*=3 to achieve the required condition, $R_{md} \leq 0.1$. Therefore, we set *N*=3 in the proposed and conventional technique to simplify the comparison.

In the proposed technique, the value of *w* was 0.3 and the maximum threshold level was -94 [dBm] to achieve the required condition, as shown in Fig. 3 and Fig. 4.

Fig. 7 shows plots of R_{fa} versus D [km]. The proposed technique was superior to the conventional technique in R_{fa} outside the service area (D≥12 [km]) while achieving the required condition, $R_{md} \leq 0.1$.

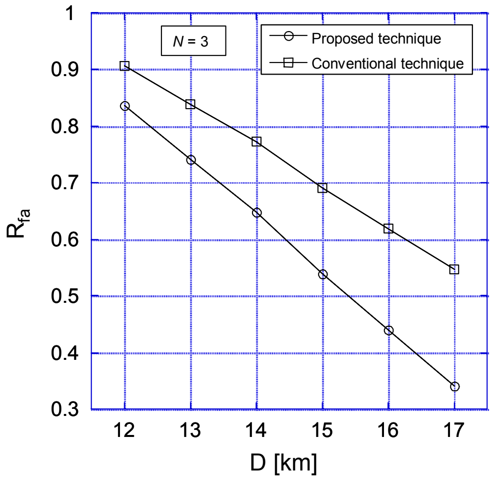

Figure 7. R_{fa} versus D.

IV. Conclusions

We proposed a new cooperative sensing technique for cognitive radio to accurately detect the presence of radio waves. In the proposed technique, the sensing radio station and the observing radio stations observe the received power. Each received power level is multiplied by a weight according to the distance between the sensing radio station and the observing radio station. All power levels are added, and a judgment of whether radio waves are present or not is made based on the added power level. We showed that the proposed technique achieved lower R_{fa} while still achieving the required condition, $R_{md} \leq 0.1$.

The results show that the proposed technique reduces R_{fa}; moreover, it misses fewer opportunities to utilize vacant frequency bands. Therefore, the proposed technique contributes to high frequency utilization.

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