PERFORMANCE EVALUATION OF A COOPERATIVE SENSING METHOD FOR COGNITIVE RADIO

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ABSTRACT

The increase in the number of wireless systems is creating a serious shortage of space in the radio spectrum. Cognitive radio technology is receiving particular attention as a technology that solves this problem. A cognitive radio system dynamically uses vacant spectrum and works adaptively by sensing channel environments and their availability. Spectrum sensing technology is an important elemental technology for recognizing channel environments. Energy detection, cyclostationary detection and cooperative sensing methods have been studied as spectrum sensing technology. Cooperative sensing methods can decrease the miss detection rate of a primary system (PS) in a secondary system (SS) because it determines whether a PS is present or not based on the detection results of multiple terminals. The problem is that the performance of cooperative sensing is affected by the method used to determine whether the PS is present and the information used to make that decision. We have developed a cooperative sensing method that takes into account the reliability of information gathered from each terminal. We evaluated the method's performance by computer simulation. Moreover, we demonstrated that our proposed method is effective on a laboratory test bed consisting of a cognitive radio system.

1. INTRODUCTION

The number of wireless systems, such as wireless LANs, 3G cellular phones, satellite communication, and sensor networks, currently in operation is increasing. This increase is creating a serious shortage of space in the radio spectrum. Cognitive radio technology, which uses the radio spectrum more efficiently than conventional wireless technology, is being developed to alleviate this shortage. A lot of research related to cognitive radio technology has been reported [1][2]. Furthermore, IEEE 802.22 and IEEE SCC41 contain standards for the technology related to cognitive radio technology [3][4]. A cognitive radio system dynamically uses vacant spectrum and works adaptively by sensing channel environments and their availability. Spectrum sensing techniques, such as energy detection, cyclostationary detection, and cooperative sensing are important enabling components of cognitive radio systems [5][6]. When cooperative sensing is used, information is gathered from multiple terminals in order to determine whether a primary system (PS) is present or not. This offers better sensing performance than using information from a single terminal. However, there are many kinds of sensing methods for detecting a PS and the accuracy of the detection depends on the sensing method used. During the detection process, the performance of the device used by a user terminal to detect the PS also influences the reliability of the sensing information. Furthermore, as the signal strength of radio channels fluctuate with time, the positions of terminals and the sensing period and position also affect the accuracy of the sensing result. This means that, because the accuracy with which a PS is detected using a cooperative sensing method greatly depends on the sensing method used by each user and the information used for making an overall determination, the handling of detected information becomes important. To solve this problem, we looked at the reliability of the sensing information gathered by each terminal and proposed using a cooperative sensing method that puts weight on sensing information based on the actual reliability of the information itself.

Section 2 in this paper describes our proposed corporative sensing method, which puts weight on detected information based on the reliability of the information itself. The section also describes the evaluation of the method's performance by computer simulation. Section 3 contains an overview of the laboratory test bed consisting of a cognitive radio system. The system incorporates a high-accuracy interference detection method and interference avoidance. The section also contains a description of how the performance of our proposed method was evaluated on the test bed. Finally, section 4 briefly concludes the paper.

2. CORPORATIVE SENSING METHOD BASED ON RELIABILITY OF INFORMATION

2.1 Proposed corporative sensing method

The procedure of our proposed corporative sensing method is as follows. First of all, a master station collects information from terminals and then uses this information to determine whether a PS exists or not. The information, which is gathered in advance, is on the SS terminals' sensing methods, hardware specifications, and positions. Note that a base station in the SS sometimes works as a master station. The master station then, based on the above information, sets the reliability of information sensed by each terminal. The master station stores gathered information in a terminal management table, as shown in Table 1.

Table 1 Example of terminal management table held by master station

	User terminal position	Sensing method	Specification	Reliability
User terminal 1	X1,Y1	Method 1	Measurement period, Measurement interval, Resolution, etc	R_1^1
User terminal 2	X2,Y2	Method 1	Measurement period Measurement interval, Resolution, etc	R_2^1
		Method 2	Measurement time, Measurement interval, Resolution, etc	R_2^2

Next, if the master station receives a message indicating the detection of a PS from a SS terminal when a SS is working, the master station orders each terminal to execute spectrum sensing. After the execution, each terminal transmits the information it has acquired to the master station. Because the information types are various, the master station dictates the type of information required from each terminal based on the terminal information that was gathered from the terminal in advance. The master station makes an overall determination using expression (1) on information transmitted from each terminal and the relevant information contained in Table 1. The master station determines the presence of a PS by comparing the overall determination result S with the determination threshold. The proposed cooperative sensing method is executed in this way,

$$S = \sum_{i=1}^{n} \sum_{j=1}^{m} R_i^j * I_i^j \qquad (1),$$

Where I_i^j is the information detected in teriminal "j" by the sensing method "i", and R_i^j is the reliability of the sensing method "i" of terminal "j".

2.2 Performance evaluation

We evaluated our proposed method by computer simulation. Figure 1 shows the simulation model and Table 2 shows the simulation conditions. The radius of the area of a PS is defined as r1. The radius of the area of a SS is defined as r2. The distance between a PS base station and a SS base station is defined as D. When (r1+r2) is larger than D, interference is generated between the PS and SS because the area of the PS overlaps with the area of the SS. When both areas overlap, a miss detection is defined as the case when the SS incorrectly determines that the PS does not exist, i.e., the PS does actually exist but the SS determines that it does not. When (r1+r2) is smaller than D, interference is not generated between a PS and a SS because the area of the PS does not overlap with the area of the SS. When both areas do not overlap, a false alarm is defined as the case when an SS incorrectly determines that a PS exists though the PS actually does not.

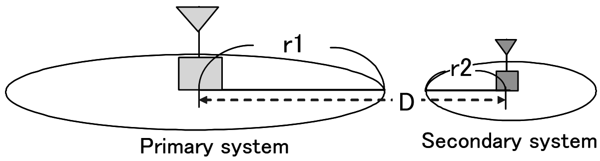

Fig. 1 Simulation model

Table 2 Simulation conditions

Frequency	5 GHz
Modulation	OFDM,QPSK
Transmission power	100 mW
Propagation model	Free space propagation
Channel model	16 – Rayleigh fading (Trms= 80 [ns])
Coverage area	PS: r1= 30, SS: r2= 15 m
Number SS terminals	100, Uniform distribution
Sensing period	476 us
Sensing method used by terminals	Energy detection

First of all, before we evaluated our proposed method, we determined the value of the reliability, which is represented by the variable R in equation (1). In this evaluation model, all SS terminals had the same hardware performance and detected a PS by using energy detection. However, because the SS terminals were uniformly distributed over the SS, the reliability of the sensing information only depended on the position of each terminal. Therefore, we decided that the reliability of a given SS terminal's information depended on the distance between the PS base station and said given SS terminal.

Reliability was assumed to be $R = (1/d)^n$, and R was optimized in this model. "d" stands for the distance between a SS terminal and the PS base station. Figure 2 shows the results of simulating the use of our proposed method in an environment in which the PS and SS were adjacent. That is when D= r1+r2= 45. The graph shows the relationship between the false alarm rate and variable n of R. The effect of the distance on reliability grows as n grows. Figure 2 shows that the false alarm rate is minimized when n= 5; therefore, we set reliability R to be $R = (1/d)^5$ when we evaluated our proposed method.

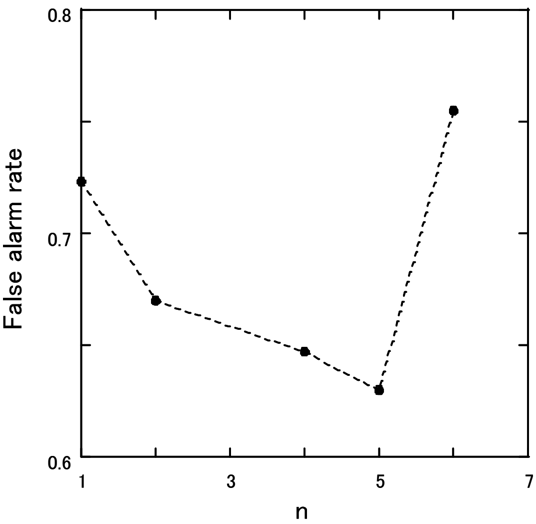

Fig. 2 Variable n vs. False alarm rate

Figure 3 shows the relation between the normalized distance D' and the false alarm rate. The normalized distance D' is D/(r1+r2). Therefore, the PS and SS are adjacent at D'=1. When using either our proposed method or the conventional method, it is necessary to set a threshold such that the miss detection rate is 10% or less at D'< 1. In the conventional method, a cooperative sensing method without weighting based on reliability is used. In our proposed method, the false alarm rate can be reduced by 12% or less compared with the conventional method at D > 1 where PS and SS do not overlap. Because our proposed method enables a more accurate detection of whether a PS is presence or not, our proposed method can increase the opportunity for communication in the SS; therefore, more efficient use of the systems' frequencies become possible.

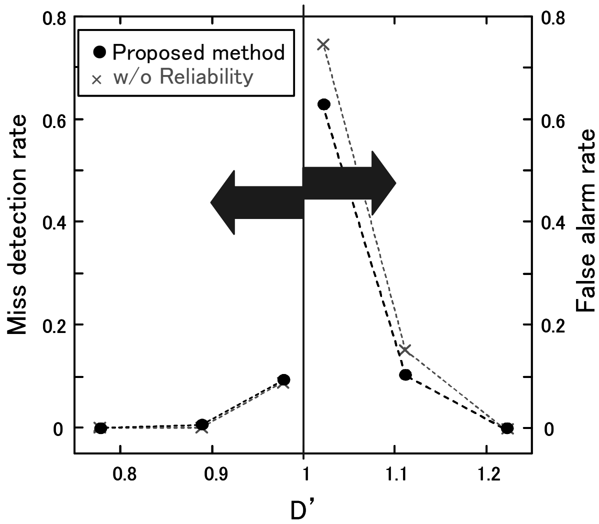

Fig. 3 D' vs. False alarm rate

3. PERFORMANCE EVALUATION USING COGNITIVE RADIO PROTOTYPE SYSTEM

3.1 Cognitive radio prototype system

We developed a cognitive radio prototype system on which we mounted the proposed cooperative sensing method [7]. The cognitive radio prototype system is composed of a PS and a SS. To execute highly accurate interference detection and interference avoidance, the cognitive radio prototype system has a channel control function and an alert transmission function in addition to a cooperative sensing function. Figure 4 shows an overview of the cognitive radio prototype system.

Figure 5 shows the configuration of the system. Figure 5 shows that the PS and the SS are interconnected. It is assumed that there is a priority in the use of the channels used by the wireless LAN and that the priority differs in the PS and SS. The PS is composed of an access point, a terminal for the wireless LAN, and an alert transmission server, which gives an interference avoidance indication to the SS. The SS is composed of a base station, a terminal, a channel control server, and a channel sensing server. When the cooperative sensing method is being used, the channel sensing server is the master station. The terminal management table shown in Table 1 is held by the channel sensing server. The SS base station and the SS terminals represent the wireless LAN and PHS, respectively. User data is communicated by using the wireless LAN. The control data for the cognitive radio system, consisting of sensing information etc., is communicated by using the PHS in the SS.

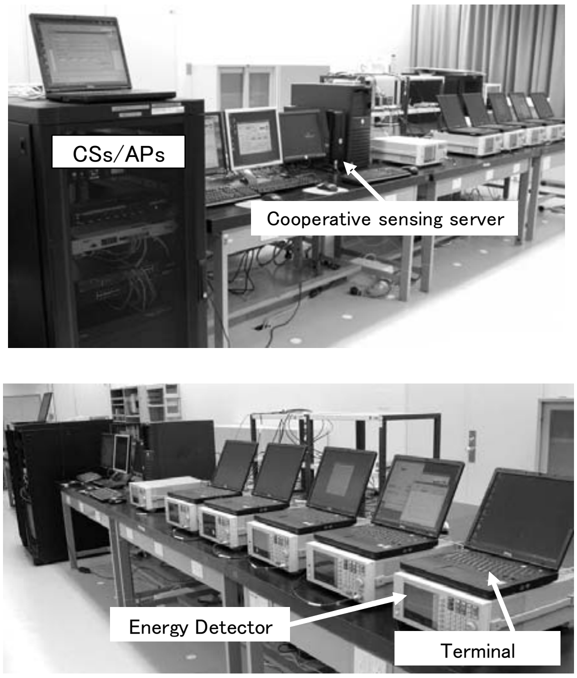

Fig. 4 Cognitive radio prototype system overview

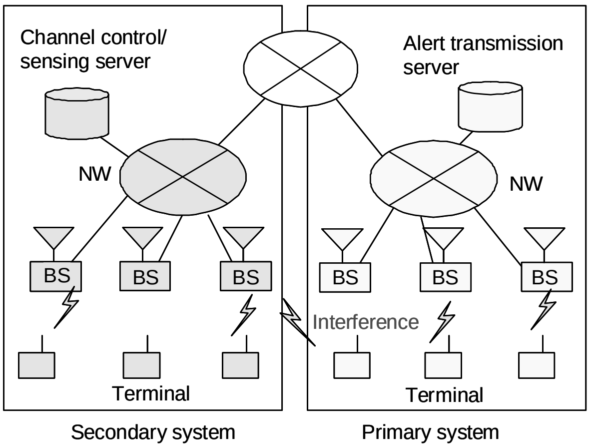

Fig. 5 System configuration

3.2 Evaluation model

Figure 6 shows the configuration used in our experiment. The conditions are summarized in Table 3. The PS and SS were connected by cable. There were five terminals in the SS. The master station contained a channel sensing server that executed cooperative sensing by using the information gathered from the SS terminals. The PS transmitted the signal with a transmission power of 15 dBm. The decay of cables and dividers between the PS and the SS was 32 dB. ATT was set to evaluate the performance of proposed method based on a distance between the PS and the SS. The distance decay between systems was expressed as the sum of the decay of cables and dividers and an attenuation value of ATT which was set from 0 to 10 dB. The SS terminals were normally distributed over the area of the SS. The value of SS_ATT_i connected to the SS terminal i was set from 0 dB to 50 dB based on the position of each SS terminal. In this experiment "i" is an integer from 1 to 5. The received power of the PS signal in the SS terminal i is expressed by the following equation (2).

$$Pr_i = Pt - ATT - SS\_ATT_i - Loss \qquad (2),$$

Where Pr_i and Pt represent the received power and the transmission power, respectively. *Loss* also stands for the decay of cables and dividers.

Each terminal detected a PS signal by using the energy detection method and transmitted the detection result to the master station. The master station determined the presence of PS by using equation (1). In this experiment, all terminals had the same hardware specifications and used the same sensing method. The reliability of the information was based on the distance between the PS and the SS terminal, as explained in section 2.

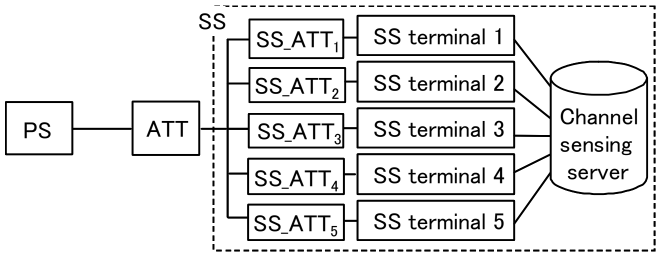

Fig. 6 Configuration used in experiment

Table 3 Experimental conditions

Transmission power of PS	15 dBm
Number of SS terminals	5
Number of terminals used in cooperative sensing	5
Distribution of terminals	Normally distribution (SS_ATT_1–SS_ATT_5: 0–50 dB)
Sensing method of terminals	Energy detection
Reliability	$(1/d)^5$

3.3 Evaluation result

To demonstrate the effectiveness of our proposed method, we evaluated the PS detection rate. Figure 7 shows the relationship between Attenuation of ATT and the detection rate. Using the proposed method substantially improved the PS detection rate compared with that of using a conventional method. Moreover, the detection rate when our method was used on the test bed agreed with the detection rate when the use of our method was simulated on a computer. These results demonstrated that our method performed as designed. Figure 7 shows that, when the attenuation is increased, the detection rate using our proposed method diverges from the detection rate obtained when our proposed method was simulated on a computer. However, this divergence was due to not enough individual measurements being made at each attenuation level. If we take more measurements at each attenuation level, we do not expect there to be such divergence. The divergence does not indicate that using our method has a worse detection rate than using a conventional method.

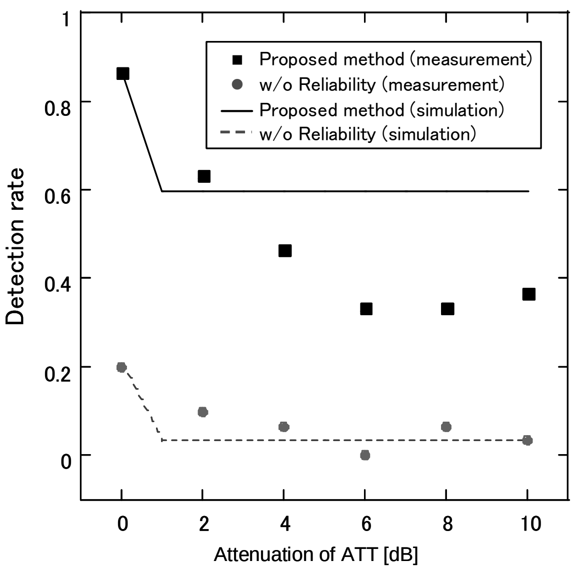

Fig. 7 Attenuation of ATT vs. the detection rate

4. CONCLUSION

We looked at the reliability of information acquired by SS terminals and proposed using a cooperative sensing method in which the information acquired by the terminal is weighted based on the reliability of the information. We evaluated the performance of our proposed method by computer simulation. The result demonstrated that our proposed method was able to reduce the false alarm rate compared with using a conventional system by appropriately determining the reliability of the information used to determine if a PS existed or not. Moreover, we confirmed that our proposed method operated as it was designed and demonstrated that the proposed method operated effectively by running it on a prototype.

Our proposed method increases the traffic of a network by communicating the information of terminal management table, sensing information and control data between a master station and SS terminals. Frame format of information and a transmission interval of sensing information will be subjects of a study to decrease traffic of a network. The location of a master station will be also an important subject because traffic flow will change. We will study these subjects by considering the detection rate of the proposed method as future works.

ACKNOWLEDGMENTS

This work was based on the Research and Development Program of the Ubiquitous Network Authentication and Agent 2007, of the Ministry of Internal Affairs and Communications, Japan.

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