Examination of efficient aggregation method of sensor information by wireless sensor network for event detection in frequency sharing

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***Abstract*—In recent years, dynamic frequency sharing using radio sensors to observe radio wave usage has been attracting attention in response to the shortage of frequency resources. In this paper, we propose an event-driven access control system that notifies the user when the Received Signal Strength Indicator (RSSI) exceeds a certain level, in order to detect the radio wave usage of the existing system. In this paper, we propose a new method of access control based on cluster partitioning. In this paper, we studied an exploratory data aggregation method for each sensor group using cluster division. In this paper, we propose an exploratory data aggregation method for each sensor group using cluster division.**

***Keywords*—Cognitive Radio, Interference, Multi Sensors, Frequency Sharing, Packet Collision**

I. Introduction

The demand for wireless communications is increasing with the launch of 5G services and the subsequent development toward 6G. The use of microwave frequencies is concentrated due to the ease of antenna miniaturization and the advantage of wide area communication, and the depletion of frequency resources is becoming more serious. Cognitive radio is attracting attention as a way to overcome the depletion of frequency resources, in which another system uses the free frequency resources in space and time[1]. While various forms of cognitive radio have been investigated, dynamic frequency sharing has been widely studied to improve frequency utilization efficiency by actively utilizing fragmented frequency resources while switching the specification bandwidth of the system in the dynamic spectrum access (DSA) type. In recent years, CBRS[2] in the U.S. and LSA[3] in Europe have been verified for social implementation.

One method of detecting spatially free frequencies in DSAs is to determine the spatial range of frequencies that can be used simultaneously by other systems, taking into account the effect of radio wave shielding that takes into account buildings and undulations in the terrain, and the spatial separation distance that does not cause serious interference to existing systems. This is called white space (WS) [4]. WS has been studied for the case where the transmission source of the existing system is fixed, such as IEEE802.22[5]as a shared method in the TV frequency band. In defining WS, multiple sensors are installed in a grid pattern, and the sensing results, RSSI, are aggregated in a spectrum database (DB) [6]. The DB estimates the propagation loss and shadowing by collecting the RSSI obtained from the sensors, and calculates the co-channel interference to the PS, which enables the design of the WS. The sensor deployed in the plane simultaneously detects the RSSI of the signal emitted by the existing system, which results in a wireless sensor network environment where many sensors simultaneously notify the aggregation station.

Until now, information aggregation by autonomous competitive access such as ALOHA and CSMA has been considered as a method of information collection in wireless sensor networks [7]. However, when the sudden appearance of an existing system is used as a trigger for sending packets, there is a risk of packet collision due to simultaneous access by many sensors. In addition, aggregation [8][9] via a representative sensor in a cluster has been considered, but it has the disadvantage that it takes time to aggregate information when the number of radio sensors increases. In [10], a method of aggregating radio sensors in clusters has been proposed, but it cannot simultaneously satisfy packet collision avoidance and low latency aggregation.

In this study, we propose an event-triggered information aggregation method for multiple radio sensor operations. In the proposed method, an autonomous access protocol (DCF: Distributed Coordinate Function) using RSSI detected by sensors as a threshold evaluation is used for access decision, and a PCF (Point Coordinate Function) in which an aggregation station specifies sensors for aggregation is used: In the first stage, the DCF is used to determine the access point. In the first stage, the threshold is set high for DCF to limit the number of sensors to be called by packets. Then, in the second stage, the location of the radio source is estimated based on the RSSI value called in the first stage, and based on a database created from past RSSI aggregation results, a group of radio sensors (cluster) with a strong RSSI is specified, and information is collected by PCF. Then, in the third stage, radio wave sensors above the noise level that could not be aggregated in the second stage are aggregated by competitive access. The proposed three-step aggregation method is based on the idea that the number of simultaneously accessed sensors at the time of an event can be reduced and the aggregation can be performed with a high degree of certainty. The proposed three-step aggregation method has the following advantages.

1) Since sensors with high RSSI in the first report are given

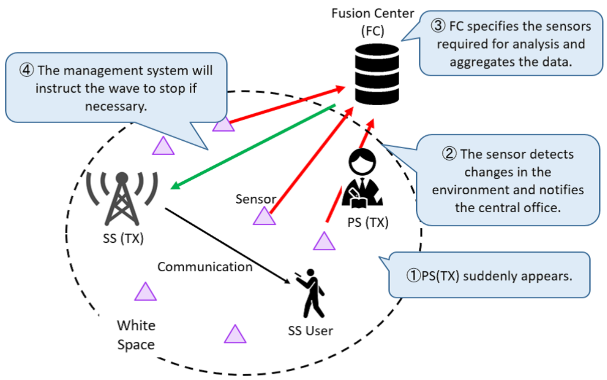


Fig. 1. Flow of monitoring propagation path conditions using radio wave sensors

priority in the collection of information, the presence of radio calls in the existing system can be detected with a high degree of certainty.

2) By using the estimation result of the first report to estimate the location of the radio call decrease, we can select clusters to which sensors with RSSI above the noise level belong, and thus avoid aggregating information from sensors with RSSI below the noise level by PCF.
3) As a result of the aggregation in the second report, information collection can be completed from sensors with RSSI above the noise level. Therefore, even if the evaluation threshold of RSSI is set to the noise level in the third method, simultaneous access from notified sensors can be avoided in the DCF in an environment where the number of simultaneously accessed sensors is reduced.

The effectiveness of the proposed method is evaluated by computer simulation, and the results show that the proposed method can significantly improve the aggregation time compared to the conventional aggregation method without pretraining.

In Section II, we described the system model assumed in this paper. In Section III, the details of the proposed method are described. Section IV describes the simulation parameters, and Section 5 discusses the simulation results. Finally, Section VI summarizes the contents of this paper.

II. System Model

The system model assumed in this paper is shown in Fig. 1, where the PS and the Secondary System (SS) share the same frequency band. Fig. 1 shows the PS transmitter (PS(TX)) and the SS transmitter (SS(TX)).

SS(TX) is assumed to be a fixed base station such as a cellular system, and PS(TX) is assumed to be a temporary use radio station such as a mobile relay station. The SS(TX) is connected to the frequency sharing DB via the Internet to determine the spatial range of the available frequency, WS, and to determine the transmission power and timing of the signal. In order to ensure the protection of the PS(TX), radio sensors that monitor the RSSI are installed at equal intervals, and when an RSSI exceeding a certain level is detected, the RSSI is notified to the information aggregation station. For notification, wide area and low rate communication such as LPWA (Low Power Wide Area) is assumed. The information aggregation station evaluates the difference in the propagation model calculated by the database from the aggregated RSSI values. When the difference is judged to be more than a certain level, the aggregation station notifies the database that the SS (TX) will be stopped.

III. Proposed access method

A. Overview of the Proposed access method

In the proposed method, two access control schemes, PCF and DCF, are used. In PCF, the information aggregation station specifies the radio sensor and notifies the RSSI, while in DCF, the radio sensor accesses the station when it detects the power exceeding the threshold. In DCF, access is controlled by random backoff to avoid simultaneous access. In DCF, two threshold values $th_1, th_2 (th_1 > th_2)$ are set, and the threshold value can be switched by a command from the information aggregation station.

B. flowchart

The flow of the proposed access method is as follows.

1) A radio sensor that detects RSSI exceeding the threshold th_1 notifies data to the information aggregation station via DCF.
2) Determine the location of PS(TX) from the notification in Step 1, and estimate the area of appearance.
3) Add the cluster to which the radio sensor notified in Step 1 belongs to the aggregation target..
4) We aggregate the target clusters with PCF.
5) Determine whether to continue search aggregation from that cluster according to the aggregation continuation factor p.
6) Determine the aggregation direction according to the neighbor aggregation coefficient q, based on the accumulated data. Add the selected neighboring clusters to the aggregation target.
7) Repeat step 4 to step 6 until there are no more clusters to aggregate.
8) Command notification to update threshold value to $th_1 \rightarrow th_2 (th_2 < th_1)$..
9) When a radio sensor detects RSSI exceeding th_2, it notifies the information aggregation station by DCF. However, sensors that have already been notified are not accessed.

Hereafter, step 1 will be referred to as the first report, step 4 through 7 as the second report, and step 9 as the third report.

C. advance preparation

Before running the proposed access method, as a preliminary preparation, we aggregate the expected value E_q of the average number of sensors whose RSSI exceeds th_2 in the

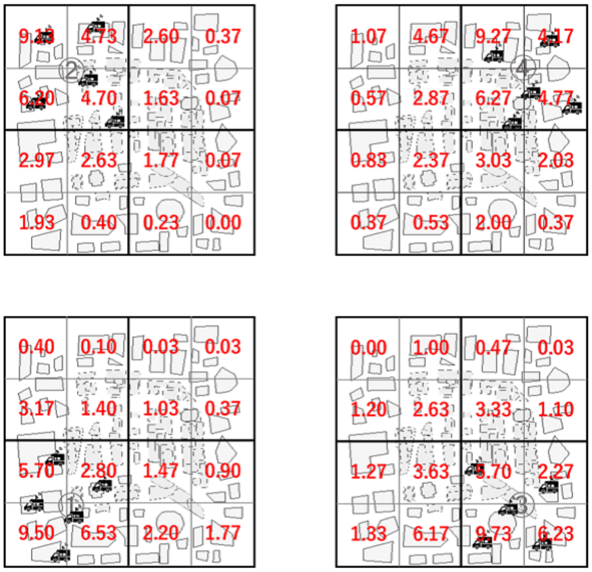


Fig. 2. Number of expected aggregate sensors E_q when PS(TX) appeared in each area in the past

cluster when PS(TX) appeared in an area in the past, as shown in Fig. 2.

D. Location estimation method for PS(TX) [11]

In this paper, we use the power weighted average position method. In the following, the number of simultaneous occurrences of PS(TX) is assumed to be 1. Assuming that N radio sensors are notified in the first report, and the position and received power acquired by sensor n are $(x_n, y_n), P_n$, the estimated position $G(x_G, y_G)$ is calculated by the following equation.

$$x_G = \frac{\Sigma_{n=1}^{N} P_n x_n}{\Sigma_{n=1}^{N} P_n}, y_G = \frac{\Sigma_{n=1}^{N} P_n y_n}{\Sigma_{n=1}^{N} P_n} \quad (1)$$

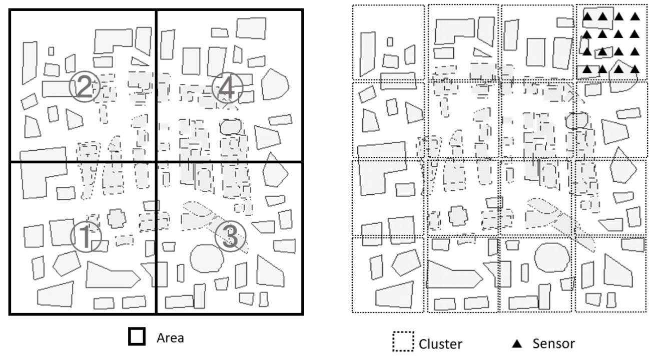
E. Defining Areas and Clusters

The area enclosed by the solid line in Fig. 3(a) is called the area, and the area enclosed by the dotted line in Fig. 3(b) is called the cluster. In the example shown in the figure, the area is divided into 4 areas and 16 clusters. In the example, there are 4 areas and 16 clusters. The entire space is covered with a mesh of radio sensors, and each cluster contains several sensor groups. The cluster and area boundaries do not necessarily have to coincide, but the area must be a cluster < area.

F. The aggregation continuation factor p

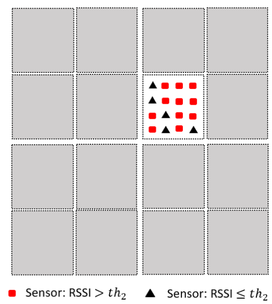
The aggregation continuation factor determines whether to continue the search according to the number of sensors p_t whose RSSI is greater than th_2 in the aggregated cluster. If $p \leq p_t$, the search is continued. If $p > p_t$, the search is terminated.

Consider the case where $p = 5$. Fig. 4(a) shows an example where 11 radio sensors ($p_t = 11$) have RSSI greater than th_2

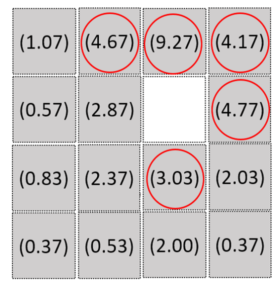


(a)Defining Areas (b)Difining Clusters and Sensors

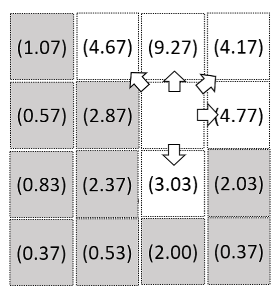
Fig. 3. Defining Areas and Clusters



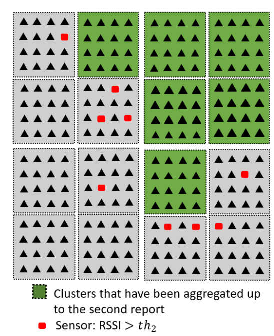
(a)RSSI of the cluster that received the first report



(b)E_q of area 4



(c)Search direction



(d)The third report

Fig. 4. Cluster Behavior

in a cluster when a cluster is aggregated. In this case, since $p \leq p_t$, we decide to continue the search from that cluster.

G. The neighbor aggregation factor q

When PS(TX) has appeared in the same area in the past, the expected number of sensors in the cluster whose RSSI exceeds th_2, E_q, is calculated in advance. The neighbor aggregation factor determines whether neighboring clusters can be aggregated or not according to this expected number of aggregated sensors E_q. Fig. 4(b) shows the data of the corresponding area from the database of Fig. 2 prepared in advance.

Consider the case where we set $q = 3$. Fig. 4(b) shows that the number of clusters that exceed $q = 3$ in five directions, starting from the cluster aggregated in Fig. 4(a). Therefore, the search aggregation is performed as shown in Fig. 4(c).

H. The third report

In the third report, we aggregate the sensors that could not be aggregated in the second report even though the RSSI exceeds th_2. The threshold is lowered from th_1 to th_2 and sent from the radio sensor side to the aggregation station by DCF as in the first report. Among the sensors shown in Fig. 4(d), only the sensors whose RSSI exceeds th_2 are aggregated.

IV. Overview of the simulation

The simulation parameters are shown in Table I. In this paper, we compare the conventional method, DCF, in which all sensors over th_2 are notified at once, and PCF, in which all sensors are systematically aggregated.

V. Simulation Result

The simulation results are shown in Fig. 5. When compared to polling with $th_1 = -50[\mathrm{dBm}]$, the proposed method (the first report only) achieves a time reduction of 26.4 seconds (95.7%). This means that the proposed method can significantly shorten the time for "quick notification upon detection of PS(TX) appearance," which is one of the goals of installing a radio sensor, and can minimize the interference to the PS. In addition, when comparing the proposed method with polling and competitive access when including the third bulletin, we were able to reduce the time by more than 6 seconds.

In the case of polling, the aggregation using prior information significantly reduced the number of sensors below the noise level, and in the case of competitive access, the aggregation divided into three stages reduced packet collisions and ensured the aggregation, which led to the time reduction.

VI. Conclusions

In this paper, we studied a method of aggregating radio wave sensor information using PCF and DCF, dividing the information into three stages, and using prior information. In the future, we will study further reduction of aggregation time and optimization of the number of aggregated sensors by utilizing the prior information.

Acknowledgement

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TABLE I
THE SIMULATION PARAMETERS

th_1	-50, -60, -70, -80 [dBm]
th_2	-85 [dBm]
PS and SS usage frequency	2300 [MHz]
PS(TX) output	0.5 [W]
Number of radio wave sensors	240
Radio wave sensor interval	100 [m]
The aggregation continuation factor p	2.0
The neighbor aggregation factor q	2.0

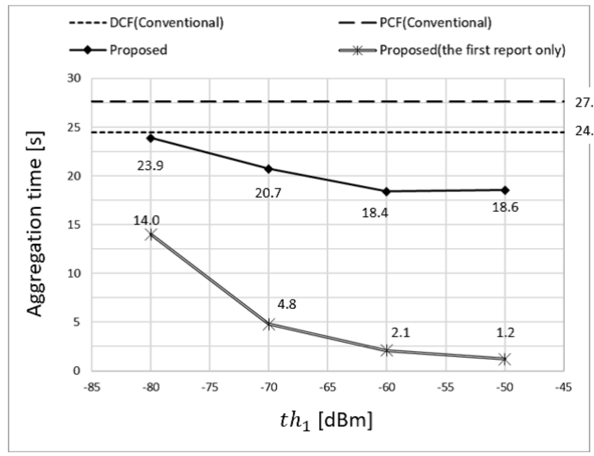

Fig. 5. Aggregation time when th_1 is changed

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