A Study on Radio Signal Identification Method for Spectrum Sharing

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***Abstract*—Cognitive radio is one of the most promising wireless technologies to solve the problem of a scarcity of wireless resources. The cognitive radio system needs to recognize the surrounding wireless environment by spectrum sensing or spectrum database, and so on. In this paper, we use an amplitude probability distribution as a parameter of the wireless environment to recognize which systems occupy the wireless resource. We measured the amplitude probability distribution in an anechoic chamber in the two cases: a microwave oven is operating, and a WLAN beacon is operating. The measurement result shows the practicality of our proposed amplitude probability distribution methods for spectrum sensing of the cognitive radio system.**

I. Introduction

Internet of Things (IoT) is a system where every physical objects are connected to the internet. Therefore, in the future, various objects will be connected to the internet even though now there are not connected to the internet. When IoT is popularized, our daily life will become convenient because a machine operation and information can be acquired via the internet. In this case, it is expected that these IoT devices are connected over the air since the number of the IoT node is large [1]. Then, a scarcity of frequency resources is a problem, because more devices are connected to the internet with wireless communication. Therefore, more efficient use of frequencies is being required for comfortable use of wireless communications.

A cognitive radio system is one of formulas to realize the smart communication systems that can use frequency resources efficiently [2], [3]. This technology flexibly uses the frequency resources by recognizing an occupancy condition of a frequency band. It is because the wireless node can choose a vacant frequency band in a temporal and a spatial. The technique is referred to as the spectrum sensing deciding whether the frequency band is occupied by another system or not. Therefore, the cognitive radio system can obtain more chances of communication and improve a channel use efficiency by sharing a spectrum with other systems because of its flexible frequency usage.

On the other hand, the cognitive radio generally uses the spectrum sensing method based on energy detection as the easiest technique implementation to decide whether the frequency is available or not [4], [5]. When a general energy detector is used for sensing the spectrum,the system doesnt consider what the source of detected signal is, that is, whether the signal is originated from a radio communication system or a radio emission from non-communication devices such as microwave oven. In this case, the cognitive system usually avoids to use the frequency band where the high received signal power is observed, regardless what kind of system uses it. Therefore, it is easily expected that the frequency use efficiency is limited.

In this situation, however, if IoT device increases and transmits a lot of packets, the available frequency bands would easily decrease. Therefore, the scarcity of wireless resources occurs nevertheless there are some available frequency bands in a temporal.

This study proposes a simple identification method based on feature amount detection by an Amplitude Probability Distribution (APD) to distinguish an electromagnetic wave of non-communication system. The proposed method can expand the available frequency band as one of valuable wireless resources while the frequency band is avoided using to wireless communications due to an interference wave is observed very frequently.

This study focuses on ISM (Industry Science Medical) band of 2.4GHz as one of the typical frequency bands in spectrum sharing. For this reason, many kinds of system exist over the band, for example communication systems such as WLAN and Bluetooth, and non-communication systems such as a microwave oven and a medical heater.

In order to confirm the efficiency of the proposed method, our study conducts experiments measuring the APD of WLAN and microwave oven as typical systems operating in 2.4 GHz ISM band.

II. Amplitude Probability Distribution (APD) [6]

Amplitude Probability Distribution (APD) means time probability that the envelope of the received signal exceeds a threshold. The APD according to the k-th threshold, x_k, is expressed by the following equation:

$$APD(x_k) = \sum_{i=1}^{n(x_k)} \frac{W_i(x_k)}{T_0} \tag{1}$$

where $W_i(x_k)$ and $n(x_k)$ indicate a length of time and the number of times when the envelope of the received signal, $x(t)$, exceeds the threshold, x_k, respectively. T_0 is measurement period. Figure 1 shows an image of the envelop of the received power. In Fig. 1, the vertical axis is the received power level, the horizontal axis is time, and the solid line is an envelope of received signal, $x(t)$. Finally, APD performances are described where the vertical axis is the APD exceeding

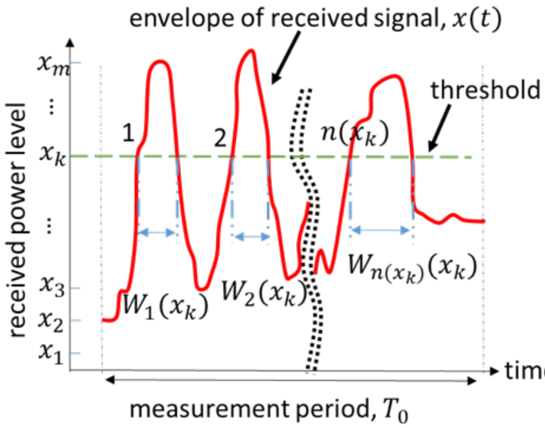

Fig. 1. Image of envelop of received power.

the threshold and the horizontal axis is the threshold. Here, the APD performance monotonically decreases.

III. Identification Method Based on APD

This section explains the procedure of our proposed identification method based on APD for the spectrum sensing. Figure 2 shows an image of our proposed method where the APD is derived as the followings.

1) IoT node observes the envelope of the received signal for a total observation time, T.
2) At first, the first APD, $APD_1(x_k)$, is calculated by using the measured results for a certain derivation period (DP), DP_1. Then Eq. (1) can be rewrote by:

$$APD_1(x_k) = \sum_{i=1}^{n(x_k)} \frac{W_i(x_k)}{DP_1} \tag{2}$$

3) After the l-th APD is calculated, a derivation period, DP_l $(l = 1, \cdots, L)$, is shifted by a certain shift amount, s, for $s < DP$. That is, the l-th APD, $APD_l(x_k)$, is given by:

$$APD_l(x_k) = \sum_{i=1}^{n(x_k)} \frac{W_i(x_k)}{DP_l}. \tag{3}$$

4) The calculation of APD is repeated until the measured results are exhausted.
5) The calculated APD values shows a time variation characteristic of the received signal in its wireless environment. Then, the derived APD time variation is the feature quantity of an observed system.
6) Finally, the IoT node identifies the system which occupies the frequency band by using the time variation characteristic of derived APD.

The reason for shifting derivation period by s is to confirm the time variation characteristic of APD. It should be noted that the IoT node knows a time variation characteristic of APD

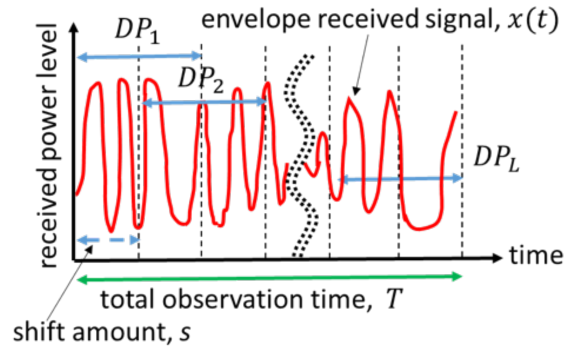

Fig. 2. APD derivation period.

TABLE I
Comparison of the Proposed Method and the Conventional Method for Energy Detection

	Proposed Method	Conventional Method
Basic Technique	APD	FFT
Amount of Calculation	Easy (addition order)	Hard (multiplication order)
Implementation	Simple	Complex
Power Consumption	Low	High

of coexisting system by using past observation results or a database.

An energy detection method is well known as one of the spectrum sensing methods to decide whether a frequency band is idle or not. This method is easily implemented because the vacant radio resources can be detected by comparing the received power to a threshold with the energy detector. Moreover, there is a method based on a fast Fourier transfer (FFT) [7] - [10]. FFT is used for dividing the received power into frequency components. Then a power value at each frequency component is calculated to conduct the energy detection for the spectrum sensing. However, a calculation amount of FFT is large because of an order of multiplication. In contrast, APD is calculated with addition order.

Table 1 shows characteristics of the two cases: the energy detection with FFT, which is conventional method, and our proposed method, which is based on APD. It is desired for IoT equipment that its power consumption is low because of a battery-driven device. From these points, the proposed identification method using APD is good for IoT system in comparing to the convention method using FFT.

IV. Experimental Environment and Results

This paper considers coexistence environment between a wireless communication system and a non-communication system. Therefore, we focus on 2.4 GHz ISM band. Over the 2.4 GHz ISM band, an interference from microwave oven toward WLAN system is a serious problem because both the systems use the same band. However, while WLAN system uses the band for communication over the air, the microwave oven is used not for communication but for heating

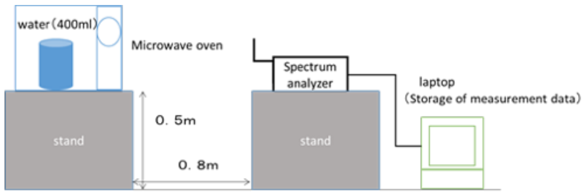

Fig. 3. Measurement system of microwave oven.

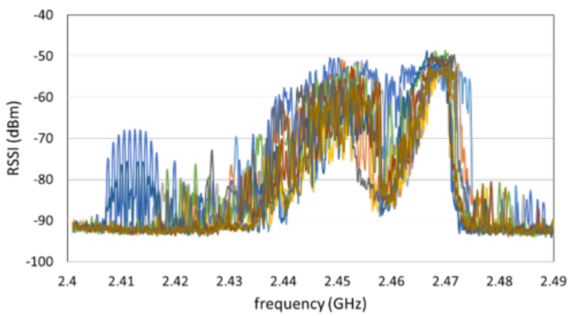

Fig. 4. Spectrum result of microwave oven 10 times.

up. Therefore, in order to distinguish the electromagnetic wave of WLAN system from that of the microwave oven, we measured a received power of each radio waves to derive APD characteristic by measurement experiment.

At first, in order to conduct a simple experiment for deciding an observation frequency, we built an experimental system in an anechoic chamber as shown in Fig. 3. Then we measured the received power by using a real-time spectrum analyzer, because it is desirable to observe the frequency which has the most distinctive characteristic. The microwave oven is operated with 730 W. In this experiment, we measured an RSSI level 10 times with MAXhold mode of spectrum analyzer by running a microwave oven. In Fig. 4, the measurement results are drawn 10 times, and then indicate that the observation frequency having the most distinctive feature which is observed the largest spectrum of microwave oven is 2.4655 GHz. Therefore, in this paper, APD measurements are conducted with 2.4655 GHz.

Next, we conducted the measurement experiments to calculate the APD performance with our method. In this measurement experiment, we are set the sampling interval to 10 ms and the total observation time to 13 seconds. In the assumption that the derivation period is 5 seconds. Then, we derived one APD result from the observed data for the first 5 seconds to evaluate the time variation of the observed electromagnetic wave. In addition, we repeatedly derived the APD where the shift amount is 1 sec. In this experiment, because the observation period is 13 seconds, 9 APD results are obtained as shown in Figs. 5 and 6.

Figure 5 shows the APD results in anechoic chamber in the case of microwave oven. This result shows that the received

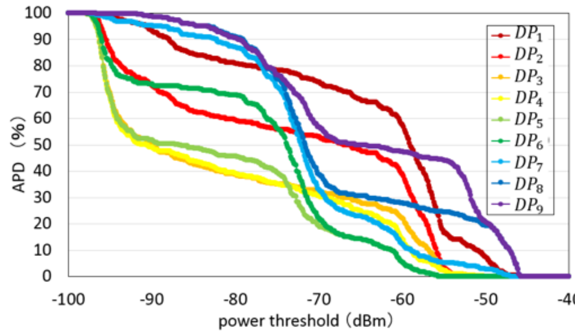

Fig. 5. Measured APD performance of microwave oven.

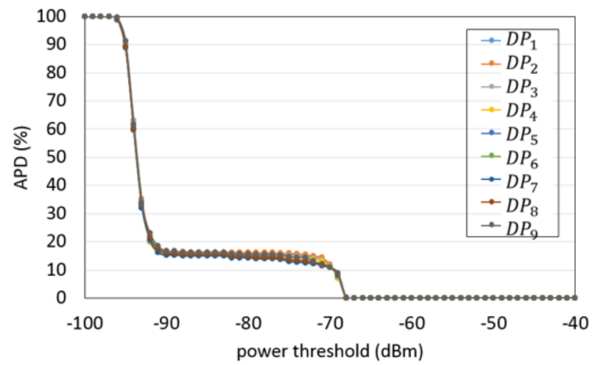

Fig. 6. Measured APD performance of WLAN (time shift).

electromagnetic wave is mixed two kind signals, which are a high power signal and a low power signal according to the observed data, and the ratio of both the signals depends on the timing of the measurement.

We measured the frequency of WLAN which is 2.46 GHz in the case of that the sampling interval is 10 ms and the amount of shift time is 1 sec, which is the same parameters in the case of the microwave oven. In order to understand the time variation of the reception power in the frequency of WLAN, the same measurement experiment as the case of the microwave oven is conducted. The results are shown in Fig. 6. From this result, it is clear that the received electromagnetic wave of WLAN hardly changes. Next, in the case of the beacon-only of the WLAN, the number of measurements is three times and the reception electromagnetic wave measures for 13 seconds and its APD is derived by each measurement, as shown in Fig. 7. The results of beacon-only case of the WLAN show that the reception power is only about -70 dBm, and the APD is about 18% over the whole observation time. In comparing the case of microwave oven and the case of WLAN signal, the performance in two cases totally has different.

As a result, from these experiment results, it confirms that possibility that the electromagnetic wave occupying frequency resources can be identified with simple technique by compar-

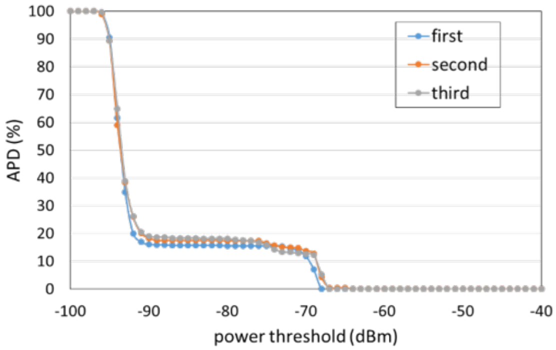

Fig. 7. Measured APD performance of WLANs beacon (three measurements).

ing APD performances.

V. Conclusions

In this paper, because serious problem that is the scarcity of frequency resources occurs as IoT system is popularized, the identification method based on APD for spectrum sharing of the cognitive radio system is proposed. The motivation of our proposed method is to improve a frequency usage efficiency by using frequency resources that interference tends to frequently occur. For this purpose, the identification method is needed to distinguish whether the received power is caused by a wireless communication system or a non-communication system. If the received power is electromagnetic waves from system except wireless communication system, the channel can temporally use possible. Our proposed method identifies these system by measuring the time variation performance of the received electromagnetic waves.

In this paper, in order to make sure the efficiency of the proposed method, APD characteristic of two cases is compared through experiments. One is the electromagnetic waves from microwave oven which is interference wave, and the other is the electromagnetic waves of WLAN.

From experiment results, it confirms that the proposed identification method based on APD is effective in improvement of the rate of frequency utilization, because the feature quantity of system can be defined by using the proposed method.

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