REAL TIME SPECTRUM SENSING BY USING FREQUENCY SHIFTED SENSOR FOR SPECTRUM SHARING COGNITIVE RADIO

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ABSTRACT

In this paper, we propose a real-time spectrum sensing method by utilizing the characteristic of different bandwidth between the secondary user (SU) and the primary user (PU). In general, it is difficult to detect the PU signal when the SU transmits the data signal during sensing period. Therefore, some dedicated period for sensing like a quiet period is required before SU transmission. However, if we consider TV white space or broadband PU, the SU occupies narrower bandwidth compared with wide band PU channel. The proposed sensing function utilizes the different frequency for PU sensing from the frequency of SU data communication. Here, SU is equipped with a dedicated radio receiver for sensing with different antenna from data communication and the frequency for SU transmission is allocated to the same band of PU. This configuration degrades the PU sensing performance due to the influence of the signal from its own SU transmitted at near frequency. In this research, we implement this configuration to USRP N210 to evaluate the sensing performance experimentally for confirming the effect of the SU signals transmitted at near frequency. From the experimental results, we can confirm that the proposed method can achieve a real-time sensing if we can reduce the very large signals inputting to the sensing device by separating the antenna distance from the SU transmitter and the sensing receiver.

1. INTRODUCTION

Cognitive radio has attracted attention in these days for one of the solutions for spectrum shortage due to increasing demands of wireless communications. The current spectrum management policy exclusively allocates the spectrum to the unified licensed service for protecting the quality of communication or TV as primary users (PU). However, the ratio of the spectrum effectively used in time domain or spatial domain is 15 to 18 % according to the report of FCC (Federal Communications Commission) [1]. In order to improve the spectrum efficiency, spectrum sharing techniques by using cognitive radio technologies have been considered as promising techniques [2]. In the spectrum sharing system, the cognitive radio users called secondary users (SU) adaptively select the spectrum of PU without giving interference toward PU and share the spectrum. Therefore, the spectrum allocated to PU can be reused by SU when the PU is not active or spectrally apart from PU.

In a spectrum sharing type cognitive radio, spectrum sensing technologies have been considered as one of methods for protecting communications of PU from the interference of SU. Energy detection techniques are well known spectrum sensing methods [3][4], which detect PU existence by comparing the power of the received signal with a threshold. However, if the SU is active in the same frequency band, since an energy detector cannot distinguish the PU and the SU signals, it is difficult to detect the PU activity. Therefore, when PU with priority starts to send the signal while SU is active, SU cannot detect the PU existence and it is difficult to smoothly release the spectrum to PU.

There are various types of PU whose spectrum is utilized for spectrum sharing with SU. In this paper, we consider that a PU occupies wide band spectrum such as television broadcasting and wireless broadband. We assume spectrum sharing system in which SU can share the same spectrum when PU is not operated temporally or spatially in the same spectrum. If the wide band PU signals are received at the SU shifting the measured frequency to non SU transmission frequency with the dedicated sensing receiver, the SU may sense the PU signal even if SU is active. In the shifted frequency, while SU signal is not transmitted, PU signal can be received because the bandwidth of PU signal is wider.

In this paper, we consider the energy detection method for sensing by using the shifted frequency from the frequency of SU transmission. If the amount of frequency shift is small, the leakage signal from the SU transmitted signal may influence to the sensing performance. In this paper, in order to avoid the influence of own transmitted SU signal, we consider antenna separation between SU transmitter and SU sensing device. The antenna separation between sensing and data communication can reduce the impact of the SU transmitted signal toward the energy detection of PU signal. By using the dedicated radio for sensing, the SU can continuously operate the sensing function during SU transmission. If we consider the small terminal like mobile terminals, it is difficult to separate the antenna distance. In this paper, we consider an application of SU as a vehicle to vehicle communication system because if we set up these antennas on the vehicles, we can separate the antenna distance to be a few meter for reducing the influence of SU.

Theoretical evaluation of the influence by SU signal leakage toward the proposed sensing function is difficult because the performance depends on the hardware device. Therefore, in this paper we derive the sensing performance with experiment in a lab and a field. Here, we implemented the proposed sensing function into a general-purpose software-defined radio platform USRP N210 with WBX daughterboard. Here, we evaluate the sensing performance under the existence of the different power level SU signal at 500 KHz to 3 MHz away from the SU communication channel by using the radio with spectrum sensing function. We experimentally evaluate the probability of false alarm when changing the input power and the frequency separation of SU signal,

In Section 2, the energy detection spectrum sensing is explained as the basis of this study. In Section 3, the proposed frequency shifted sensing method is explained, and the experimental configuration is figured out in Section 4. Then experimental results are shown in Section 5. Finally, we conclude this paper in Section 6.

2. ENERGY DETECTION SPECTRUM SENSING

In order to realize spectrum sharing between PU and SU, SU has to avoid the interference toward PU by recognizing PU status. A spectrum sensing is known as one of the interference avoidance techniques by detecting the signal transmitted from PU at the SU device. If SU device detects the primary signal by the results of sensing process, the PU changes the utilized spectrum or terminates the signal transmission immediately. Several types of spectrum sensing have been proposed like energy detection, cyclic feature detection, matched filtering detection and so on [5]. The performance and the complexity of each sensing method are different. In this paper, we select an energy detection spectrum sensing because the computational cost is low and it is easy to implement to the USRP N210 for experimental tests. The energy detection method detects the PU signal by observing the energy of the sampling signals of the received signals at SU device.

During the sensing period, the received signal $y(t)$ is denoted by two hypotheses $\mathcal{H}_0, \mathcal{H}_1$. In case of $\mathcal{H}_0$, PU is idle and the received signal is composed by only noise. In $\mathcal{H}_1$, PU is active and the received signal is composed by PU transmitted signal and the receiver noise. Therefore, SU has to estimate the PU state by distinguishing the following hypothesis test,

$$\begin{cases} \mathcal{H}_0 : y(t) = w(t) \\ \mathcal{H}_1 : y(t) = s(t) + w(t) \end{cases}, \tag{1}$$

where $w(t)$ is AWGN (Additive White Gaussian Noise) and $s(t)$ is PU signal. In order to distinguish the status of $\mathcal{H}_0$ and $\mathcal{H}_1$, the power of received signals are used in the energy detection. The test statistic of the energy detection can be shown as

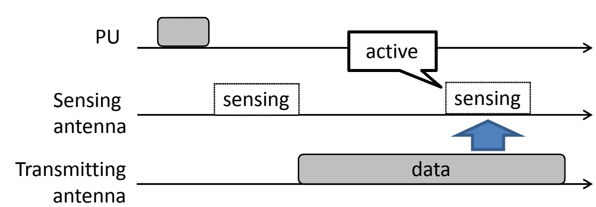
$$T_S = \frac{1}{N}\sum_{n=1}^{N}|y(n)|^2 , \tag{2}$$

where N is the number of averaging samples, n is the sampling index. Here, we set a pre-defined threshold γ and the test statistic is compared with γ for distinguishing the PU is active or not according to the following hypothesis test,

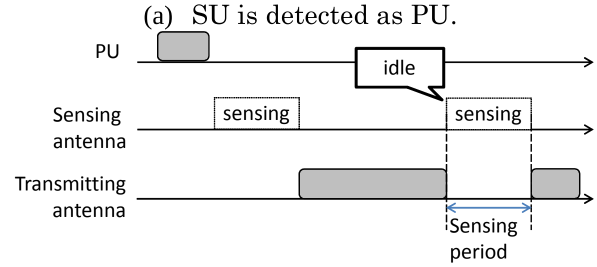
$$T_s \begin{cases} < \gamma : \mathcal{H}_0 \\ \geq \gamma : \mathcal{H}_1 \end{cases} . \tag{3}$$

Then we can understand the PU status.

As shown in Eq. (3), since the energy detection method compares the average energy of the received signal with the threshold, the different signals received at the sensing device affect to the results of spectrum sensing. In particular, during the communication of SUs, the signal transmitted from own SU gives large influence to the signal detection at the SU as shown in Fig. 1 (a). In general, the SUs terminate the signal transmission during the sensing period as shown in Fig. 1 (b). Therefore the influence of surrounding SUs toward PU signal sensing can be avoided. However, the sensing period degrades the time efficiency of SUs because periodical quiet period has to be prepared. Moreover, if the PU becomes active just after the SU sensing, the SU may give the interference toward the PU.



(a) SU is detected as PU.



(b) Quiet period for sensing.

Fig. 1 Sensing under SU signal.

Then, in the following sections, we propose a novel sensing method in which the PU signal can be detected during the SU signal is active by sensing frequency is shifted not to receive the influence of SU signal for PU detection.

3. FREQUENCY SHIFTED SENSING

In this paper, we consider a novel spectrum sensing method by shifting the sensing frequency for detecting PU signal during SU transmission. The proposed frequency shifted sensing can be utilized at the narrow band SU transmission on the wide band PU spectrum. The channel plan of the proposed frequency shifted sensing spectrum is shown in Fig. 2. As shown in this figure, the spectrum of PU is wider than that of SU and multiple SU channels can be allocated to one PU spectrum. Here, if we set the channel of SU on the edge of PU spectrum, the other frequency on the same PU is not occupied by SU and the frequency can be used for sensing. If the same channel is shared between SU transmission and PU detection, it is difficult to detect the PU signal during SU transmission because the large SU transmitted signal affects to the adjacent frequency. In this paper, we consider an application of wireless vehicular networks and the antennas are set on the vehicle. Then the different transceivers between SU transmission and PU transmission are prepared and the antenna of each transceiver is separately set on the vehicle. Therefore, the received signals power of SU at each PU receiver can be mitigated to reduce the effect of out band emission signals of SU transmitter. The structure of the SU and PU detector on the vehicle is shown in Fig. 3. The antenna of the sensing detector is separated from the SU transmitting antenna.

In the proposed sensing method, the energy detection sensing shown in the previous section is utilized in the shifted frequency from SU transmission. Here, the different frequency within the same PU occupation spectrum is sensed by energy detection technique. As a result, the spectrum sensing during SU transmission can be realized. Therefore, it is not required to prepare a special quiet sensing period at SUs. In this paper, the performance of the proposed energy detection sensing on the shifted frequency is evaluated by using experiment because it is difficult to theoretically evaluate the effect of spectrum leakage of SU. Here, we implement the proposed frequency shifted sensing on USRP N210 with WBX daughterboard and the sensing performance is evaluated on the sensor setting on the vehicle. The detail experimental configurations are presented in the next section.

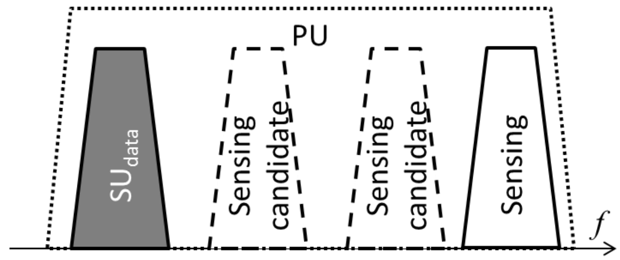


Fig. 2 Channel plan for proposed spectrum shifted sensing.

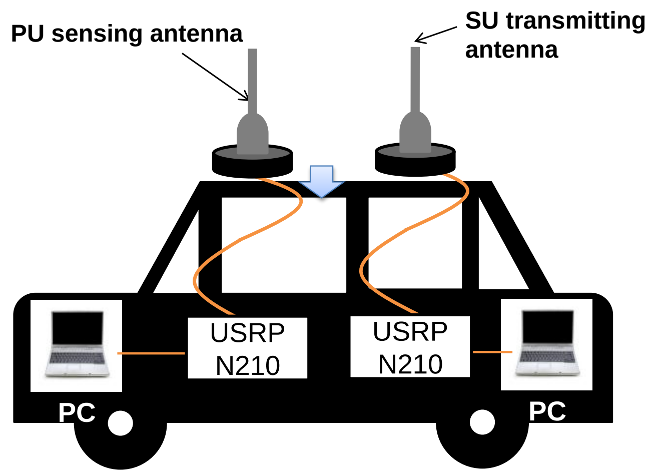


Fig. 3 Structure of the SU and PU detector.

4. EXPERIMENTAL CONFIGURATION

In this experiment, we use a general purpose software defined radio USRP N210 with WBX daughterboard in which the energy detection sensing method is implemented as a sensing device. In Section 4.1, we explain the system configuration of the sensing based on the energy detection. In Section 4.2, we introduce an indoor laboratory experiment to evaluate the performance of sensing ability of USRP N210. In Section 4.3, we show the configuration of the field experiment which observes the performance in UHF band operated in an actual environment.

4.1. System Configuration of Experiment

In this experiment, in order to use USRP as the proposed frequency shifted sensing device, the spectrum sensing function based on the energy detection was implemented. Here, we assume TV white space based on Japanese TV broadcasting as a PU and the bandwidth of the PU is 6 MHz band. Then the narrow band SU channel is allocated within the bandwidth of PU. The center frequency of the sensing device is shifted within PU bandwidth from the SU center frequency to detect the PU even if the SU is active.

An energy detection device detects the presence or absence of the primary signal by comparing the mean square of the received signal power and the predetermined threshold. In this experiment, we decide the sampling rate is 200 kHz and the number of samples is 2048 by considering enough sensing performance with the limited number of samples. Then the detection hypothesis test is shown as,

$$\frac{1}{2048}\sum_{n=1}^{2048}|y(n)|^2 \underset{\geq}{<} \gamma \begin{array}{c} PU\ is\ OFF \\ PU\ is\ ON \end{array}, \quad (4)$$

where γ is the predetermined threshold. In this experiment, threshold γ is defined $P_{fa} = 0.1$ at no signal. To determine the threshold, we iterate the measurement 10000 times by USRP N210.We have an experiment radio license of 1MHz bandwidth on 413MHz band. Therefore, we evaluate the sensing performance in indoor laboratory environment and outdoor field environment using 413 MHz band.

4.2. Indoor Laboratory Experiment

First, in order to check the sensing performance under statistic environment, we observe the data by connecting the USRP N210 with WBX board installing the energy detection function with a signal generator (SG) by wire. The system configuration is shown in Fig. 4, and the transmitted signal of SU is inputted from the other USRP N210. The SG signals and USRP N210 signals are combined through a combiner. Then the combined signals are inputted to USRP N210 for checking the performance. Here, PU and SU are transmitted on the different center frequency for avoiding the inter-system interference. The influence of large SU power at the USRP N210 receiver is evaluated in Section 5.

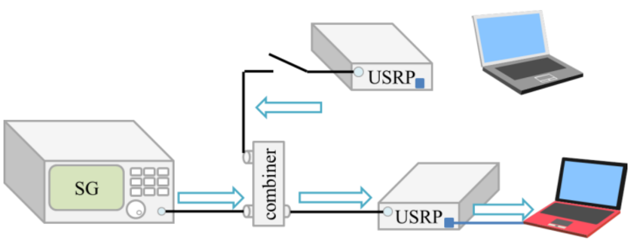


Fig. 4 Configuration of indoor laboratory experiment.

4.3 Outdoor Field Experiment

In order to evaluate the influence of multi-path environment, we derive the sensing performance on the field. We prepare a vehicle with two transceivers based on USRP N210. One is used for the sensing based on energy detection and the other one is used for transmitting SU signal based on GMSK. Monopole antennas of transceivers are set on the roof of the vehicles as shown in Fig. 5. These antennas are placed in the front and rear of the car's roof. The distance between antennas is placed in the most separated place of the roof as 1.5m. The vehicles are parked on the large parking lot and the location of the vehicles is shown in Fig. 6.

distance of antenna to antenna :1.5m

Fig. 5 Monopole antennas on the roof

Fig. 6 Experimental site of an outdoor experiment.

The spectrum plan for evaluating the sensing performance is shown in Fig. 7. SU transmits the data signal on the channel with its center frequency is f_c [Hz]. In this experiment, we set 412.5 MHz for the center frequency of SU transmission. Then the sensing devise sensed frequency is shifted by 500 kHz, 1 MHz, 2 MHz, and 3 MHz. Then the sensing performance with different shifted frequency can be derived by varying P_{fa}.

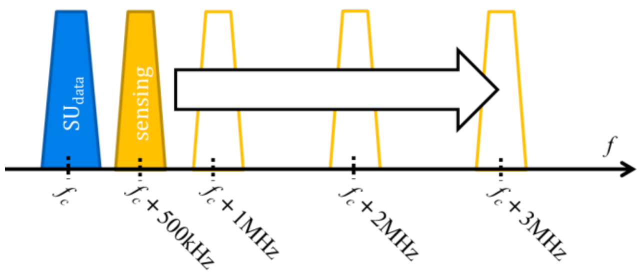


Fig. 7 Channel allocation plan for experiment.

5. EXPERIMENTAL RESULTS

In this section, we show experimental results of the indoor laboratory experiment and the outdoor field experiment. The detail parameters of experiments are shown in Tables 1 to 3. Table 1 shows the parameters of sensing device. The sampling rate is decided as 200 kHz and the FFT size is decided as 2048 samples. Then the energy detection is performed. Table 2 shows the parameters of SU data transmission. Here, we consider 200 kHz band GMSK signal for data communication. Finally, Table 3 shows the parameters of PU signal transmission by SG in the indoor laboratory test. This signal is detected at the sensing device at indoor experiment. In this experiment, the sampling rate is set to 200 kHz which is less than the bandwidth of primary system. This is because to the low sampling rate signal can mitigate the effect of deep fade due to the fading.

Table 1 Sensing parameters.

Parameters	value
Sampling rate	200 kHz
FFT size	2048
Center frequency	413,413.5,414.5,415.5 MHz

Table 2 SU data transmission parameters.

Parameters	value
Modulation	GMSK
Bandwidth	200 kHz
Transmit power at outdoor	10 dBm
Transmit power at indoor	variable

Table 3 PU signal transmission parameters.

Parameters	value
Modulation	GMSK
Bandwidth	200 kHz
Receive power at sensor	-40 dBm

5.1 Results of Indoor laboratory Experiment Results

The results of the probability of false alarm without SU versus the probability of no SU detection under the SU signal when the sensing device senses in different shifted frequency in the indoor laboratory experiment are shown in Fig.8. This experiment SU transmit parameter is 10 dBm and attenuator is inserted so that SU sensing sensor received power set to -40dBm. If the influence of SU is not affected, the performance of no SU detection is the same as 1 - the false alarm rate. From this figure, we can confirm that the shifted frequency of the proposed sensing is 500 KHz cannot suppress the influence of SU leakage and the detection performance degrades. On the other hand, if we set the shifted frequency of the proposed sensing becomes large like 1 MHz to 3 MHz, the performance can be improved because SU leakage signal can be suppressed enough. From this figure, the influence of SU signal can be neglected if SU signal is shifted more than 2 MHz.

Next, we show the detection performance when PU signal was inputted at 467 MHz, SU signal is inputted at 466MHz and the sensing channel is 467MHz on Fig. 9. In this figure, SNR means the received signal to AWGN rate at inputting only PU or PU+SU. After recalculating a threshold, SNR expresses the rate of PU signal to SU signal and AWGN. In this result, if SU is inputted into an adjacent channel, the detection probability is increased due to the large signal of SU. However, if the received power of SU is known in advance, it turns out that the sensing node can demonstrate the conventional sensing performance by setting up the threshold value in consideration of the influence from SU. However, this method has a problem that the SU status has to be known at the SU before starting the sensing. Therefore, we evaluate the influence of SU signal transmitted in the adjacent frequency in the realistic out door environment in the next sub section.

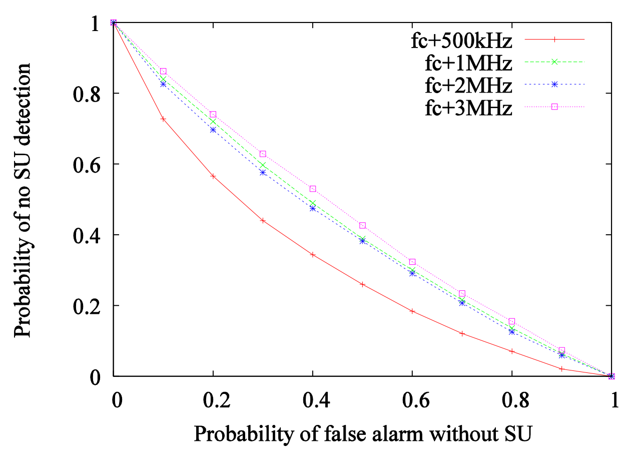


Fig. 8 Detection performance when SU is input in indoor experiment.

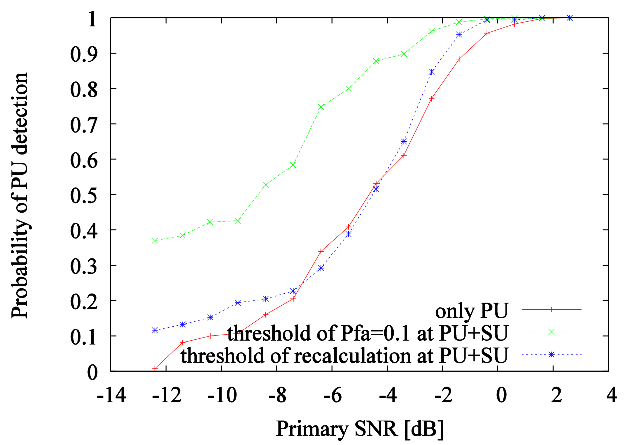


Fig. 9 Probability of PU detection with SU in $f_c + 1$ MHz.

5.2 Results of Outdoor Field Experiment Results

The results of the probability of false alarm without SU versus the probability of no SU detection under the SU signal when sensing device senses in different shifted frequency in the outdoor field experiment are shown in Fig.10. The detail experimental configuration is explained in Section 4.3. Here, the antenna distance between SU transmitter and spectrum sensor is 1.5 m. The received SU signal power at the sensor on the SU transmitted frequency is -41 dBm. If the effect of large SU signal received at the sensing device can be neglected, the vertical value can be calculated by 1- the horizontal value. Therefore, if the effect of SU is not observed, the results of vertical value are 1- the horizontal value. Then we plot the performance by changing the shifted frequency between SU transmission and sensing.

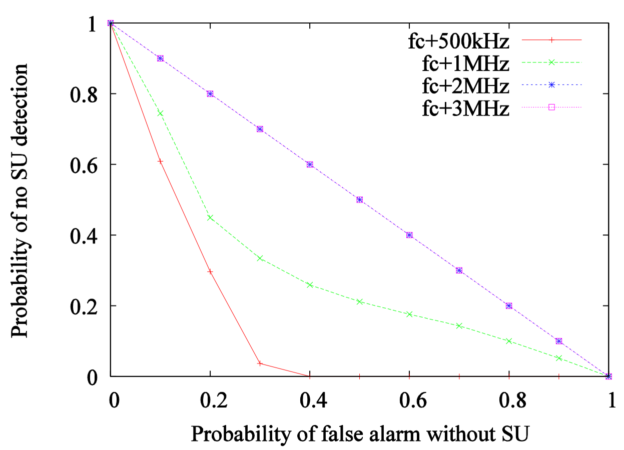


Fig. 10 Detection performance when SU is input in outdoor field experiment.

From, this figure, we can understand that the large influence occurs when the frequency shift is 500 kHz and 1 MHz. On the other hand, if the frequency shift is more than 2 MHz, the performance of sensing achieves almost the same performance without SU transmission. From this figure, the proposed sensing method by shifting the sensing frequency is effective if the frequency shift is more than 2 MHz.

6. CONCLUSION

In this paper, we propose a frequency shifted spectrum sensor for finding the weak primary user (PU) signal when the secondary user (SU) is active. The proposed method utilizes the bandwidth difference between PU and SU and the non SU occupancy spectrum within PU band is used for sensing frequency. Then the effect of SU at the sensing device can be mitigated. We evaluate the performance by the indoor laboratory experiment and the outdoor field experiment. In these experiments, we derive the detection performance when sensing is performed in the frequency shifted channel under active SU. From the result of experiments, we confirm the effectiveness of the proposed frequency shifted sensor for realizing a real time cognitive radio communication.

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