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# Two-Step Channel Observation Scheme Considering Spread of Observation Results in Dynamic Spectrum Sharing

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**ABSTRACT** Dynamic Spectrum Sharing (DSS), in which multiple wireless systems share the same radio resource, has been studied to improve frequency utilization efficiency. In DSS, the channel occupation ratio (COR), the usage of radio resources (channels) used by other wireless systems, is measured. The wireless system dynamically selects the channel with the lowest COR for communication. A long observation time is required to measure the COR with high accuracy. However, as the number of observed channels increases, the observation time per channel becomes shorter. Since the shorter observation time, the degradation of the accuracy of observed COR is a problem. This paper proposes a two-step channel observation scheme considering the spread of observed results. In the first observation, the proposed scheme measures all channels and excludes channels with high COR, considering the spread due to the error in the observed results. Only remaining channels are observed in the second observation, so the observation time can be relatively long. Computer simulation results show that the proposed scheme with 200 ms or more of first observation can improve communication reliability compared to the conventional scheme.

**INDEX TERMS** Dynamic spectrum sharing (DSS), spectrum sensing, channel observation, channel occupation ratio (COR).

## I. INTRODUCTION

Mobile communication services have seen remarkable development with the advent of smartphones [1]. The fifth-generation mobile communication system (5G) has started its service, and the next-generation mobile communication system (6G) has also been discussed [2], [3]. In 5G, various use cases such as enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC), and Ultra-Reliable and Low Latency Communications (URLLC) have been studied [4], [5]. The technical requirements for wireless systems differ for each use case, and the wireless technologies needed for each use case are discussed [6].

To realize high-speed and large capacity communication, millimeter-wave bands for eMBB have been considered [7]. On the other hand, the electromagnetic waves at the microwave bands are suitable for mMTC and URLLC from the coverage viewpoint [8]. Since various wireless systems use electromagnetic waves at the microwave band, it is difficult to provide new radio resources for these communication systems because the radio resources are not vacant. In the future, it is assumed that the number of the variety of wireless systems will increase. The efficient usage of the radio resources in the microwave band is required.

Dynamic Spectrum Sharing (DSS), in which multiple wireless systems share the same radio resource, has been investigated for improvement of frequency utilization efficiency [9]–[11]. Wireless systems rarely use radio resources such as time/frequency/space all the time, and in a short period, radio resources are vacant. Therefore, another wireless system can use temporarily vacant radio resources and communicate. On the other hand, since multiple wireless systems use the same radio resource in DSS, interference from other systems is a problem.

To avoid interference, it is necessary to know the usage of radio resources that other systems use. Based on the radio resource usage, each system uses the radio resources appropriately to reduce each system's interference with each other [12]. If cooperation between wireless systems is possible, each system can accurately know the radio resource usage using control signals. In [13], the management system that manages and allocates the radio resources used by each wireless system can realize DSS. However, assuming that a variety of wireless systems will be introduced in the future, not all wireless systems can transmit and receive control signals. Backward compatibility is also an issue because the management system should manage radio resources, including legacy systems. Technology that does not rely on control signals or management systems is required to realize a highly flexible DSS.

To overcome this issue, the techniques, which are observation of the radio resource usage and channel selection, have been studied as the scheme without using control signals [14], [15]. Here, let the radio resource usage denote the channel occupancy ratio (COR). COR is calculated by the ratio of the observed time that other systems use the channel to the observation time. Each system measures the COR of all available channels and selects the channel with the lowest COR autonomously based on the observed results for communication.

To observe all channels simultaneously, a wide-band observer or multiple observers are required. However, the problems are the RF hardware limitations [16] and the cost increase of multiple observers. On the other hand, when measuring each channel in turn with a single observer, the observation time allocated per channel becomes shorter as the number of channels increases. Longer observation times can measure COR with high accuracy, but frequency utilization efficiency is reduced because of decreasing the communication time [17]. Furthermore, as the overall observation time increases, the COR may change between the duration of observation and communication in a time-varying environment [18]. There is a trade-off between observation time and COR observation accuracy in channel observations. To reduce the observation time, a sensing scheme based on compressed sampling has been studied [19]. When the number of wireless systems in use is small compared to the number of channels, this scheme detects the existence of other systems in binary for each channel. This scheme is effective in sparse environments where the number of wireless systems in use is small compared t the number of channels, but as the number of wireless systems increases in the future, the environment will become congested where every channel has any wireless systems, and this scheme cannot be used in the future environment.

This paper proposes a two-step channel observation scheme considering the spread of the observed COR. The proposed scheme measures channels two times to improve the observed COR accuracy. The proposed scheme excludes channels with higher COR based on the first observation results from the channel candidate. It allocates the observation time to other channels in the second observation to increase the relative observation time. The authors have also previously clarified the spread of observed COR by focusing on the signal time length of the interfering system [20]. To avoid excluding channels with lower COR from the channel candidate, the proposed scheme selects channel candidate by considering the spread of observed COR.

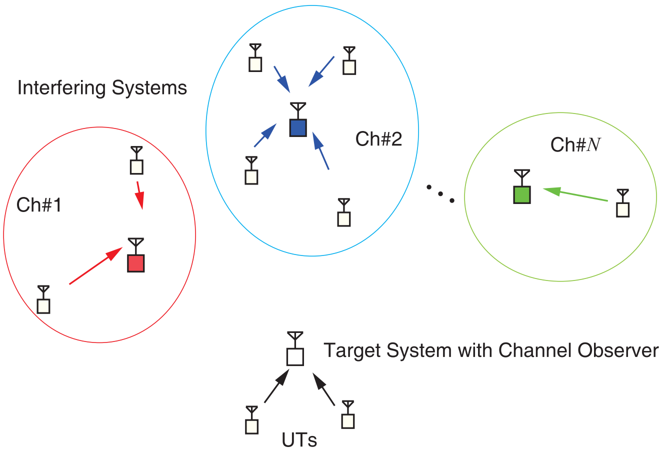



**FIGURE 1.** System model.

The rest of the paper is organized as follows. Section II presents the system model and discusses the problem of the short observation time. Section III describes the conventional and proposed channel observation schemes. In Section IV, computer simulation results are detailed. Finally, Section V concludes the paper.

## II. SYSTEM MODEL AND PROBLEM OF CHANNEL OBSERVATION

### A. SYSTEM MODEL

Let us consider a system model shown in Fig. 1, which includes the target (proposed) and multiple interfering wireless systems. These systems are assumed to use $N$ independent channels with the same bandwidth. It is also assumed that the Access Point (AP) of the target system selects one channel from $N$ channels to communicate with its User Terminals (UTs). The AP is equipped with a channel observer that monitors the usage of each channel. The target system can receive all signals, including control information from the interfering system. Still, it is incapable of decoding because it is assumed to be a heterogeneous wireless system.

In this paper, the whole time can be divided into two periods; the observation and communication periods and observation and communication are performed alternately. During the observation period, the channel observer in the AP measures the channel usage time for each channel during the observation time, $T_{\mathrm{OBS}}$. The COR is defined as the ratio of the channel usage time to observation time, and $\rho(n)$ denotes the true value of the COR at the $n$-th channel. $T_{\mathrm{E}}(n)$ is the channel usage time at the $n$-th channel when the received signal power is above the carrier sense level during $T_{\mathrm{OBS}}$. Let $\hat{\rho}(n)$ denote the observed COR at the $n$-th $(1 \leq n \leq N)$ channel and $\hat{\rho}(n)$ is given by

$$\hat{\rho}(n) = \frac{T_{\mathrm{E}}(n)}{T_{\mathrm{OBS}}}. \tag{1}$$

The COR fluctuation is determined by the user behavior, such as how many users are staying in the communication area [21]. Here, this paper assumes that the time between observation and communication periods is short and that the number of users in the area does not fluctuate. So the COR estimation is assumed to be unbiased, which means that the ensemble average of $\hat{\rho}(n)$ is equal to the true value. After measuring the COR of all the channels, the AP selects the corresponding channel to the minimum COR.

Another problem is that the channel observer of the AP cannot receive signals from hidden terminals. Since the observer and the user terminals (UTs) are in different locations, the COR at each may differ depending on geographical location and other factors. UTs perform distributed sensing and send sensing results to AP to solve this problem, as proposed in [22]. The proposed scheme can be combined with the above-distributed sensing techniques. This paper does not consider the hidden terminal for simplifying.

### B. PROBLEM OF CHANNEL OBSERVATION FOR SPECTRUM SENSING

Let us discuss the relationship between the observation time and the error of the observed COR. To select the channel with the minimum COR, it is necessary to observe it accurately. Increasing the observation time can improve the accuracy of observation results. However, as the number of channels increases, the observation time becomes longer, resulting in a relatively shorter communication period and lower system throughput. On the other hand, it is a problem that shortening the observation time reduces the accuracy of the observation results.

In [20], the probability density function for the observed COR is given by

$$p\left(\rho(n), \hat{\rho}(n)\right) = \frac{1}{\sqrt{2\pi\sigma^2(n)}} \exp\left(-\frac{(\hat{\rho}(n) - \rho(n))^2}{2\sigma^2(n)}\right), \tag{2}$$

where $\sigma(n)$ denotes the standard deviation of $\hat{\rho}(n)$ at the $n$-th channel. $\sigma(n)$ is determined by $\rho(n)$, so it is different for each channel, and can be obtained from the reference [23] as follows:

$$\sigma(n) = \sqrt{\frac{\rho(n)(1-\rho(n))}{T_{\mathrm{OBS}}}}. \tag{3}$$

$\sigma(n)$ is inversely proportional to the observation time $T_{\mathrm{OBS}}$. Therefore, the shorter observation time has a spread in the observed results.

Fig. 2 shows the distribution of observed COR calculated from (2). This is an example when the true COR is set to $\rho(n) = 0.22$ when the observation time is $T_{\mathrm{OBS}} =$ 50, 100, 500, 1000 ms. It can be seen from Fig. 2 that the probability that $\hat{\rho}(n) = 0.1$ is almost zero at $T_{\mathrm{OBS}} = 500$ ms, but is about 0.01 at $T_{\mathrm{OBS}} = 50$ ms. A shorter observation time increases the probability of observed COR that differs from the true COR by two times. Thus, shortening the observation time increases the observation error and the probability of selecting a channel with a high COR, thereby reducing communication reliability.

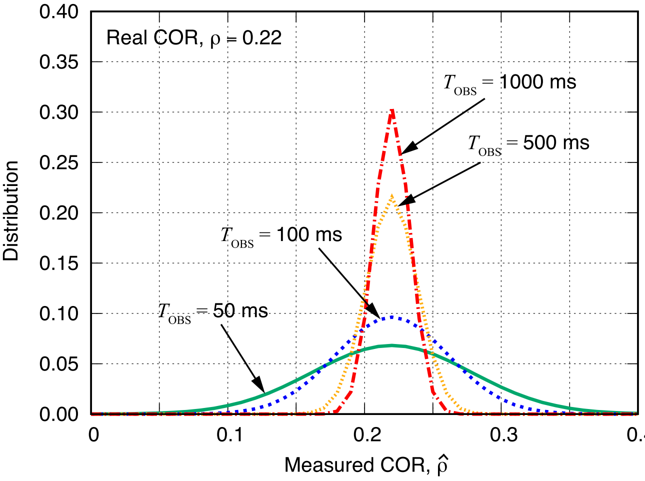



**FIGURE 2.** Distribution of observed COR.

## III. CHANNEL OBSERVATION SCHEME

This section discusses how to measure the COR. For comparison, the conventional scheme, the equal interval observation, is explained first. Next, the proposed two-step observation scheme is detailed to improve the observation accuracy of COR.

### A. EQUAL INTERVAL CHANNEL OBSERVATION SCHEME (CONVENTIONAL)

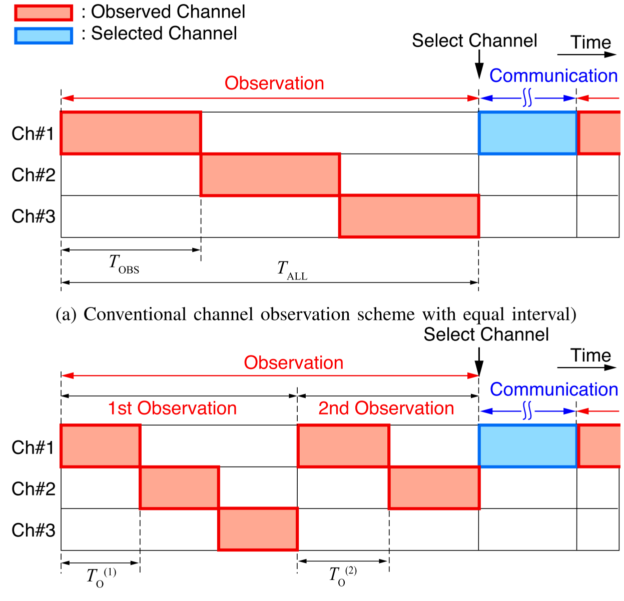
Fig. 3(a) shows a time chart example of the conventional channel observation scheme. For simplicity, let us explain the example with the number of channels $N = 3$. In an observation period, the observation time is divided into $N$, and $N$ channels are observed in turn. Let the total time of the observation interval denote $T_{\mathrm{ALL}}$, and the observation time per channel $T_{\mathrm{OBS\_C}}$ for the conventional scheme is given by

$$T_{\mathrm{OBS\_C}} = \frac{T_{\mathrm{ALL}}}{N}. \tag{4}$$

As $N$ increases, $T_{\mathrm{OBS\_C}}$ becomes shorter, so the observation error increases as shown in Fig. 2.

### B. PROPOSED TWO-STEP CHANNEL OBSERVATION SCHEME

To improve the observation accuracy of COR, we propose a two-step channel observation scheme in which the observation period is divided into two parts, and the observation channels are chosen. Fig. 3(b) shows a time chart of the proposed



(a) Conventional channel observation scheme with equal interval)

(b) Proposed two-step channel observation scheme

**FIGURE 3. Time chart example when $N = 3$.**

scheme. In the first observation, the proposed scheme measures the COR of all channels. Based on the results of the first observation, channels with high COR are excluded from the channel candidate. In the second observation, the observation time of the excluded channel is allocated to another channel to increase the observation time. More than three-step observations may improve the accuracy of the COR. However, for the following reasons, this paper uses two-step observations: 1) The system throughput is degraded because the total observation period becomes longer as the number of steps increases. 2) The short observation time per step makes the observation error due to the larger standard deviation. Hence, the observation time per step is required for a sufficient period. This paper used two-step observation to ensure sufficient observation time per step.

In the following, we explain how to select the channels for the second observation and describe the observation flow of the proposed scheme.

### 1) SELECTION OF OBSERVATION CHANNELS CONSIDERING SPREAD OF OBSERVED CORS

The observed COR, $\hat{\rho}(n)$, is measured by including $\pm\varepsilon(n)$ error in true COR, $\rho(n)$. Let us consider the case where there are two channels such that $\rho(1) < \rho(2)$. When the observation result is $\hat{\rho}(1) > \hat{\rho}(2)$, the true and observed CORs are reversed, and the channel with the higher COR is selected for communication. By increasing the observation time to reduce the observation error, the situation where $\hat{\rho}(1) > \hat{\rho}(2)$ can be reduced. However, the many channel candidate makes it difficult to ensure a sufficiently long observation time. We consider reducing the miss-selection of CORs by using the estimated error range.

Since the distribution of the observed COR concerning the observation time is obtained from(2), the observed COR determines the range where the true COR exists. When $\hat{\rho}(n)$ is measured, the probability density function for $\rho(n)$ is given by

$$p\left(\hat{\rho}(n), \rho(n)\right) = \frac{1}{\sqrt{2\pi\sigma^2(n)}} \exp\left(-\frac{(\rho(n)-\hat{\rho}(n))^2}{2\sigma^2(n)}\right), \quad (5)$$

calculated from (2).

Here, when the observer measures the channel 1 as $\hat{\rho}(1)$, the probability $P_L(\rho_{\text{th}}, \rho(1))$ that true COR for that channel is less than $\rho_{\text{th}}$ is

$$P_L(\rho_{\text{th}}, \rho(1)) = \int_{-\infty}^{\rho_{\text{th}}} p\left(\hat{\rho}(1), \rho(1)\right) d\hat{\rho}(1), \quad (6)$$

where $\rho_{\text{th}}$ the threshold of observed COR to exclude the channel candidate. $\rho_{\text{th}}$ is used for all channels, and its value is the same. For example, if $P_L(\rho_{\text{th}}, \rho(1)) = 0.99$, then the probability that $\rho(1)$ is greater than $\rho_{\text{th}}$ is 0.01. In other words, $P_L(\rho_{\text{th}}, \rho(1)) = 0.99$, and if the observed COR of all channels except channel 1 is $\rho_{\text{th}} < \hat{\rho}(n)$, then the COR of channel 1 is the minimum with a probability of 0.99.

On the other hand, since the observation results of other channels also include observed errors, these ranges are also taken into account. When the observer measures the channel 2 as $\hat{\rho}(2)$, the probability that the true COR for that channel is greater than or equal to $\rho_{\text{th}}$ is

$$P_H(\rho_{\text{th}}, \rho(2)) = \int_{\rho_{\text{th}}}^{\infty} p\left(\hat{\rho}(2), \rho(2)\right) d\hat{\rho}(2). \quad (7)$$

When (6) and (7) are equal and the probability is high, the probability that $\hat{\rho}(1) > \hat{\rho}(2)$ is low. Therefore, let the threshold, $\rho_{\text{th}}$, calculate when the following equation is obtained:

$$P_L(\rho_{\text{th}}, \rho(1)) = P_H(\rho_{\text{th}}, \rho(2)). \quad (8)$$

Since channels with $\rho_{\text{th}} < \hat{\rho}(n)$ are assumed to be with high COR, and the number of observed channels can be selected.

### 2) APPROXIMATION OF SELECTION THRESHOLDS

Calculating $\rho_{\text{th}}$ from (8) for each observation period increases the amount of operations. So, let us consider simplifying the operations involved in channel selection.

It is known that the normal distribution contains approximately 95% of elements within a range of four times the standard deviation centered on the mean. By using the value of the standard deviation, approximate (6) and (7) as follows:

$$P_L(\rho_{\text{th}}, \rho(1)) \simeq \hat{\rho}(1) + 2\sigma(1), \quad (9)$$

$$P_H(\rho_{\text{th}}, \rho(2)) \simeq \hat{\rho}(2) - 2\sigma(2). \quad (10)$$

Note that $\sigma(1)$ and $\sigma(2)$ are different normal distributions for each channel.

Here, the estimation of the standard deviation that can be accurately estimated by using the time length of the observed signal has been proposed [20]. As the average time length of the observed signal denotes $T_{\mathrm{P}}(n)$, the estimated standard deviation $\hat{\sigma}(n, T_{\mathrm{OBS}})$ for the observation time, $T_{\mathrm{OBS}}$, is given by

$$\hat{\sigma}(n, T_{\mathrm{OBS}}) = \sqrt{\frac{\hat{\rho}(n)T_{\mathrm{P}}(n)}{T_{\mathrm{OBS}}}}. \tag{11}$$

Using this estimation of the standard deviation can be simplified the computation.

When observed COR is less than $\rho_{\mathrm{th}}$, the probabilities are $P_L(\rho_{\mathrm{th}}, \rho(1)) < P_H(\rho_{\mathrm{th}}, \rho(2))$. The following conditions are obtained from (9)–(11):

$$\hat{\rho}\left(n_{\mathrm{min}}^{(1)}\right) + 2\hat{\sigma}\left(n_{\mathrm{min}}^{(1)}, T_{\mathrm{O}}^{(1)}\right) < \hat{\rho}(n) - 2\hat{\sigma}\left(n, T_{\mathrm{O}}^{(1)}\right), \tag{12}$$

$$\hat{\rho}\left(n_{\mathrm{min}}^{(1)}\right) + 2\sqrt{\frac{\hat{\rho}\left(n_{\mathrm{min}}^{(1)}\right)T_{\mathrm{P}}\left(n_{\mathrm{min}}^{(1)}\right)}{T_{\mathrm{O}}^{(1)}}} < \hat{\rho}(n) - 2\sqrt{\frac{\hat{\rho}(n)T_{\mathrm{P}}(n)}{T_{\mathrm{O}}^{(1)}}}, \tag{13}$$

where $n_{\mathrm{min}}^{(1)}$ and $T_{\mathrm{O}}^{(1)}$ denote the channel with the minimum COR in the first observation and the observation time at the first observation, respectively. Channel selection can be simplified by finding the range of channels from the observed $\hat{\rho}(n)$ and $T_{\mathrm{P}}(n)$.

#### 3) OBSERVATION FLOW OF PROPOSED SCHEME

First, in the first observation, all channels are measured with the observation time $T_{\mathrm{O}}^{(1)}$, and the channel with the minimum COR is found. When the sum of the occupied time at the $n$-th channel in the first observation, $T_{\mathrm{E}}^{(1)}(n)$, is measured, the observed COR $\hat{\rho}^{(1)}(n)$ is calculated by (1) and expressed as

$$\hat{\rho}^{(1)}(n) = \frac{T_{\mathrm{E}}^{(1)}(n)}{T_{\mathrm{O}}^{(1)}}. \tag{14}$$

The channel $n_{\mathrm{min}}^{(1)}$ with the minimum COR in the first observation is given by

$$n_{\mathrm{min}}^{(1)} = \arg\min_{n\in\mathcal{N}} \hat{\rho}^{(1)}(n), \tag{15}$$

where $\mathcal{N}$ denotes the set of all channels. The channels that satisfied (13) using $n_{\mathrm{min}}^{(1)}$ and $\hat{\rho}^{(1)}(n)$ are selected. Let $\mathcal{N}'$ denote the set of selected channels. If there is only one channel in $\mathcal{N}'$, the channel is selected for communication without the second observation. In this case, the observation period is reduced, which improves system throughput. For channel set $\mathcal{N}'$, a second observation is performed with the observation time of $T_{\mathrm{O}}^{(2)}$. $T_{\mathrm{O}}^{(2)}$ is given by

$$T_{\mathrm{O}}^{(2)} = \frac{T_{\mathrm{ALL}} - NT_{\mathrm{O}}^{(1)}}{N'}, \tag{16}$$

where the number of selected channels is $N'$. Since the observation time for the selected channels is the sum of the first and second observation time, the observation time for the proposed scheme, $T_{\mathrm{OBS\_P}}$, is given by

$$T_{\mathrm{OBS\_P}} = T_{\mathrm{O}}^{(1)} + T_{\mathrm{O}}^{(2)} = \frac{T_{\mathrm{ALL}} - \left(N - N'\right)T_{\mathrm{O}}^{(1)}}{N'}. \tag{17}$$

If even one channel is excluded by channel selection ($N > N'$), the observation time is longer than that of the conventional scheme of (4).

The observed COR for the channel with the second observation is the sum of the results of the first and second observations, and is calculated as

$$\hat{\rho}^{(2)}(n) = \frac{T_{\mathrm{E}}^{(1)}(n) + T_{\mathrm{E}}^{(2)}(n)}{T_{\mathrm{O}}^{(1)} + T_{\mathrm{O}}^{(2)}}, \tag{18}$$

where $T_{\mathrm{E}}^{(2)}(n)$ is the sum of the second observed signal times at the $n$-th channel. From $\hat{\rho}^{(2)}(n)$, the channel with the smallest COR is given by

$$n_{\mathrm{min}}^{(2)} = \arg\min_{n\in\mathcal{N}'} \hat{\rho}^{(2)}(n), \tag{19}$$

and communicate using channel $n_{\mathrm{min}}^{(2)}$.

**TABLE 1** **Simulation Conditions**

| | |
|---|---|
| Channel conditions | |
| No. of all channels, $N$ | 8 |
| True COR, $\rho(n)$ | 0.22, 0.26, 0.30, 0.34, 0.38, 0.44, 0.48, 0.54 |
| Average signal length, $T_{\mathrm{P}}(n)$ | 266 $\mu$s |
| Target system conditions | |
| Access scheme | CSMA/CA |
| Data rate | 39 Mbps |
| Payload length | 64 Bytes |
| Packet generation rate, $\lambda$ | Poisson, 100 (1/sec/UT) |
| No. of UTs | 10 |

## IV. COMPUTER SIMULATIONS

### A. SIMULATION CONDITIONS

The computer simulations were conducted to verify the effectiveness of the proposed channel observation scheme. Table 1 lists the simulation conditions. The total number of observation channels was set to $N = 8$. It was assumed that there is an interfering system on each channel, and each channel transmits its signal independently. The true COR was set to $\rho(n) = \{0.22, 0.26, 0.30, 0.34, 0.38, 0.44, 0.48, 0.54\}$ and $\rho(n)$ was assumed to remain unchanged between the observation and communication periods. Since the finite buffer model was employed, the signal generation of the interfering system was assumed to follow the Poisson distribution. Interference systems are equipped with adaptive modulation and coding (AMC) scheme. So the time lengths of packets are variable. The average time length of packets was set to $T_{\mathrm{P}}(n) = 266\mu$s. It was assumed that the channel observer could receive all signals from the interfering systems. To evaluate the feasibility of the proposed scheme, this paper does not consider the hidden terminals.The target system selects only one channel from $N$ channels based on the channel observation results and

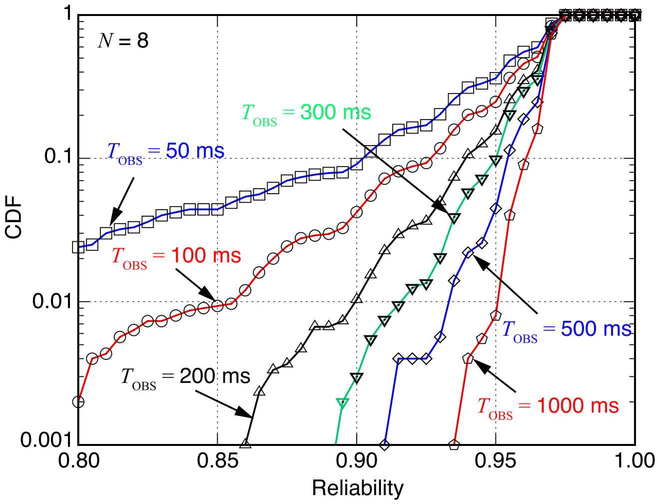
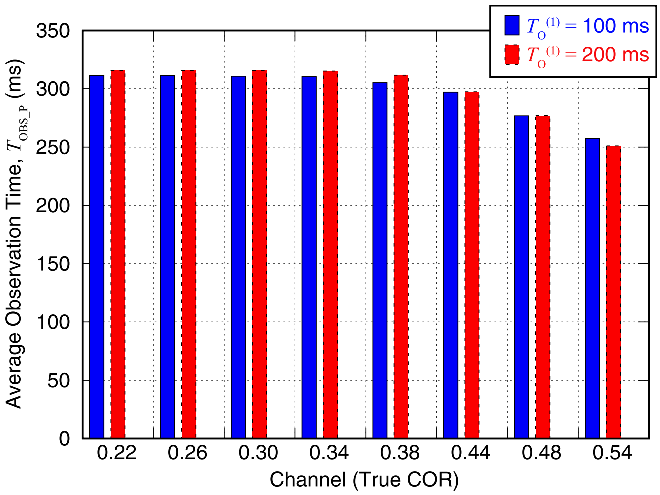
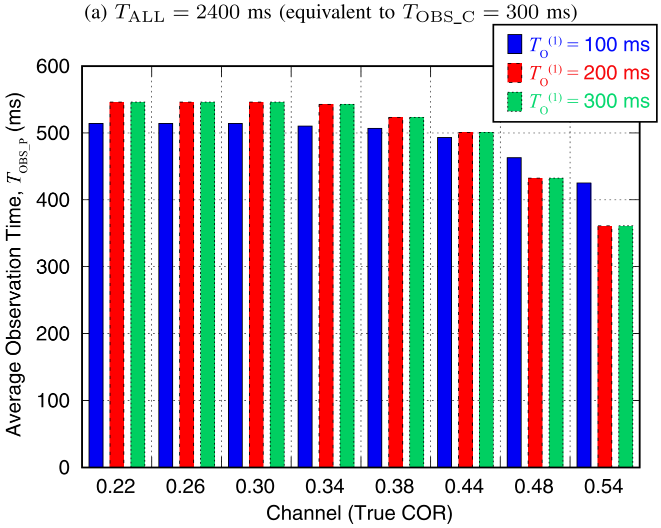



**FIGURE 4.** CDF characteristics of reliability in conventional scheme.




(a) $T_{\mathrm{ALL}} = 2400$ ms (equivalent to $T_{\mathrm{OBS\_C}} = 300$ ms)




(b) $T_{\mathrm{ALL}} = 4000$ ms (equivalent to $T_{\mathrm{OBS\_C}} = 500$ ms)

**FIGURE 5.** Average observation time of the proposed scheme for each channel.

communicates using this selected channel. The target system transmits packets with a payload length of 64 bytes at the data rate of 39 Mbps using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The packet generation was assumed to be Poisson ($\lambda = 100$/sec/UT). The AP includes ten UTs. We define the reliability $R$ as the probability that a packet is successfully received within 2 ms of its occurrence, including the retransmissions [24].

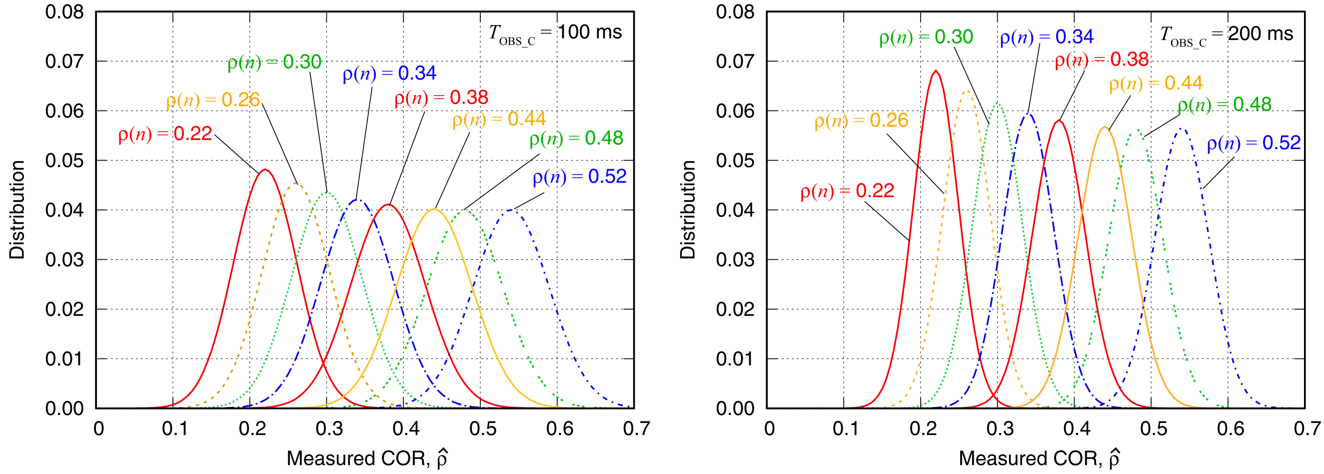
### B. CHARACTERISTICS OF CONVENTIONAL SCHEME

First, we clarify the reliability performance of the communication concerning the observation time when using the conventional scheme. The Cumulative Distribution Function (CDF) of the reliability $R$ when the target system transmits packets is used for evaluation. Fig. 4 shows how the ovservation time affects the CDF of reliability when $T_{\mathrm{OBS\_C}}$ is varied from 50 to 1000 ms. Here, the time $T_{\mathrm{ALL}}$ of the observed period is assumed to keep the (4) relationship so that as $T_{\mathrm{OBS\_C}}$ increases, $T_{\mathrm{ALL}}$ also increases. The reliability improves with increasing $T_{\mathrm{OBS\_C}}$. The conventional scheme with $T_{\mathrm{OBS\_C}} = 1000$ ms improves reliability by about 0.1 compared to that with $T_{\mathrm{OBS\_C}} = 100$ ms when CDF $= 0.01$. It can be seen that all the results are stair-stepped, and the reliability of these steps is approximately equal. The true COR is approximately every 0.04, so the conventional scheme can select the channel with the lower COR. The above results indicate that if the observation period can be made longer, the probability of selecting the channel with the smallest COR can be increased, thus improving the reliability.

### C. CHARACTERISTICS OF PROPOSED SCHEME

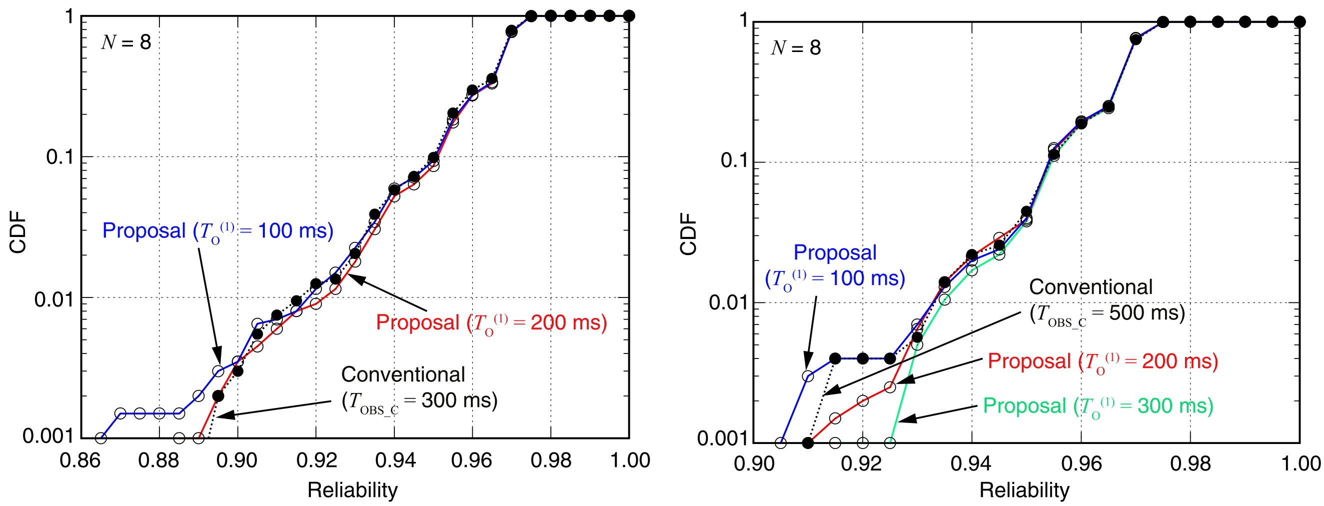
Next, we clarify the characteristics of the proposed scheme. Let us consider the two conditions of observation period: $T_{\mathrm{ALL}} = 2400, 4000$ ms. The number of available channels is $N = 8$, which is equivalent to $T_{\mathrm{OBS\_C}} = 300, 500$ ms observation time per channel in the conventional scheme. Fig. 5 shows the average observation time for each channel using the proposed scheme. Using the proposed scheme, the observation time for channels with true COR between 0.44 and 0.54 becomes shorter than that of the conventional scheme, while the observation time for the other channels becomes longer. Since the observation time for the high COR channel can be shortened, the observation time for the other low COR channels can be made longer. At $T_{\mathrm{ALL}} = 4000$ ms, $T_{\mathrm{O}}^{(1)} = 200, 300$ ms for the first observation time is about 1.1 times longer. In addition, under the computer simulation conditions, there is no case where only one channel was not selected after the first observation because a combination of channels with close CORs was used. So the simulation results do not include the improvement of the system throughput.

Here, Fig. 6 shows the distribution for each channel where the true COR is 0.22 through 0.34. The results with $T_{\mathrm{OBS\_C}} = 100, 200$ ms are shown. Note that these results are only once




(a) $T_{\mathrm{OBS\_C}} = 100$ ms (b) $T_{\mathrm{OBS\_C}} = 200$ ms

**FIGURE 6. Distribution for each observation time.**




(a) $T_{\mathrm{ALL}} = 2400$ ms (equivalent to $T_{\mathrm{OBS\_C}} = 300$ ms) (b) $T_{\mathrm{ALL}} = 4000$ ms (equivalent to $T_{\mathrm{OBS\_C}} = 500$ ms)

**FIGURE 7. CDF characteristics for proposed scheme.**

for observation time, as in the conventional scheme. When $T_{\mathrm{OBS\_C}} = 100$ ms, the spread of observation results is so large that there is more than 99% overlap of $\rho(n)$ from 0.22 to 0.38. On the other hand, when $T_{\mathrm{OBS\_C}} = 200$ ms, compared to 100 ms, the channel with $\rho(n) = 0.38$ is excluded. The standard deviations for observation times $T_{\mathrm{OBS\_C}} = 100, 200, 300$ ms at $\rho(n) = 0.22$ are $\sigma(n) = 0.024, 0.017, 0.014$ calculated by (11), respectively. In the first observation, the spread of the observed COR can be narrowed by increasing the observation time, and the proposed scheme can exclude the channel.

Fig. 7 shows how the first observation time affects the CDF of reliability for the proposed scheme. For comparison, the results of the conventional scheme with the fixed observation time are shown. In both cases, setting $T_{\mathrm{O}}^{(1)}$ to 200 ms or more improves the reliability compared to the conventional scheme. The CDF can be improved for $T_{\mathrm{ALL}} = 4000$ ms by increasing the first observation time to $T_{\mathrm{O}}^{(1)} = 300$ ms. On the other hand, the characteristics with $T_{\mathrm{O}}^{(1)} = 100$ ms, the shorter observation time, are degraded compared to the conventional scheme. The proposed scheme excludes channels with lower COR for which the observed COR in the first observation is reversed. As seen from Fig. 4, $T_{\mathrm{O}}^{(1)} = 100$ ms, there is a large variation in the observed COR, and the probability of selecting a low COR decreases. When $T_{\mathrm{ALL}} = 2400$ ms, the characteristics of the proposed scheme at CDF 0.001 are the same as that of the conventional one. This is because the observation time is not long enough. Therefore, the proposed scheme can improve the reliability with a longer observation time for the first observation.

## V. CONCLUSION

In this paper, the two-step channel observation scheme with two observation periods has been proposed to improve the accuracy of the observed COR in channel observation for dynamic frequency sharing. Based on the first observation results, the proposed scheme excludes the channels with higher COR from the channel candidate. It allocates the observation time to other channels in the second observation, thereby increasing the observation time relatively. Computer simulations have shown how the observation time affects the reliability of communication. It has also demonstrated that the proposed scheme with the first observation time to 200 ms or longer can improve the reliability.

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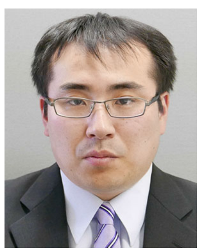

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