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RESEARCH ARTICLE

Excluded Channel Selection Scheme for Dynamic Spectrum Sharing in Various Interference Environments

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ABSTRACT Dynamic spectrum sharing (DSS), in which multiple wireless systems share the same radio resource, has been considered to improve frequency utilization efficiency. In DSS, the observer measures the channel occupancy rate (COR) and the number of radio resources, such as frequencies used by other wireless systems, and dynamically selects the channel with the lowest COR for communication. As the number of channels increases, the observation time becomes longer, resulting in increased latency and reduced throughput. In addition, many existing studies have been conducted with limited interference patterns. This paper proposes an excluded channel selection scheme to shorten the observation time. In the initial observation, all channels are measured, and channels with high COR are excluded. After exclusion, only the survival channels are measured to shorten the observation time and improve the throughput and latency. Computer simulation results were evaluated to improve the throughput with the observation time rate to 0.2 and the number of excluded channels to five, and the observation time can be cut in half. Even if there is little degradation in throughput by selecting the channel with the second smallest COR, throughput is expected to be improved by reducing the observation time. The throughput characteristics were also evaluated with three types of interference patterns. It is necessary to select the number of excluded channels from the distribution so that the overlapping distribution of each COR is less than 0.03.

INDEX TERMS Dynamic spectrum sharing (DSS), channel observation, channel selection, radio interference.

I. INTRODUCTION

The fifth generation mobile communication system (5G) service has been launched, and now the next generation mobile communication system (6G) is under consideration. In 5G, technological development is being promoted, focusing on high-speed, large-capacity communications, multi-terminal connectivity, and highly reliable, low-latency communications [1], [2], [3]. In addition to communication with devices such as smartphones, communication with various devices such as factory automation, Automated Guided Vehicles (AGVs) in warehouses, sensors, etc., is envisioned. For example, in factories, it is necessary to change the arrangement of manufacturing machines according to the production line. The communication environment changes depending on the arrangement of manufacturing machines. To realize high-speed and large-capacity communications, millimeter waves above 60 GHz are being considered in addition to quasi-millimeter wave bands such as the 28 GHz band [4], [5]. When the communication environment changes, millimeter waves cannot ensure sufficient coverage.

From the coverage viewpoint, it is desirable to use the microwave band. 5G allocates new bands, such as the 3.7 GHz and 4.5 GHz bands [6], [7]. Microwaves are more suitable for use in factories and other areas because they are

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more circumferential than millimeter waves. However, in the microwave band, there are no available frequencies to be allocated to new wireless systems, and bandwidth is secured by coordinating use among existing wireless systems. In other words, developing technologies to improve the frequency utilization efficiency of the microwave band is required to realize the sustainable evolution of wireless communications.

Dynamic Spectrum Sharing (DSS), in which multiple wireless systems share the same radio resource, is considered one of the technologies to improve the frequency utilization efficiency [8], [9], [10]. Wireless systems use radio resources such as allocated time/frequency/space in response to communication requests, but these resources are rarely used all the time. In other words, the allocated radio resources may not be used for a short period or at a specific location. Therefore, DSS can operate multiple wireless systems with limited radio resources by making secondary use of these temporarily available radio resources by other wireless systems. In many factories, multiple wireless systems are in operation. If these systems can effectively use the same radio resources, DSS can solve the problem of radio resource depletion.

On the other hand, when multiple wireless systems use the same radio resource, the degradation of communication quality due to radio interference between the systems becomes a problem [11], [12]. If the wireless systems can cooperate, they can share the usage status of the radio resources by using control signals, etc., and each wireless system can use the radio resources appropriately to reduce interference. In [13] and [14], a management system in DSS manages and allocates the radio resources each wireless system uses. However, centralized management by a management system is challenging to add a new system freely. Spectrum-sharing technology based on blockchain technology is also considered a scheme without the management system [15], [16]. Blockchain technology maintains a blockchain ledger for each system that describes spectrum usage and uses this information to determine which wireless resources to use autonomously and decentralized. The information in the blockchain ledger needs to be shared between systems are required. Unfortunately, not all wireless systems can send and receive control signals when old and new wireless systems exist in the factories. Another problem is that the number of control signals increases as the number of wireless systems increases. Therefore, to realize the DSS that any wireless system can share, an autonomous control type technology that does not use control signals or a management system is required.

As an autonomous control type technology, a technology that measures the usage of radio resources used by other wireless systems and determines the radio resources to be used by each radio system based on the observation results is being considered [17], [18], [19]. Here, among the radio resources that multiple wireless systems can use, a frequency is defined as a channel. The channel occupancy rate (COR) is the percentage of time other wireless systems use the channel. When wireless systems communicate, the overall communication quality is considered higher if they do not cause interference with each other. Therefore, the COR of all available channels is measured, and the channel with the lowest COR is selected for communication.

Due to the limited number of RF circuits, it is only possible to measure some channels simultaneously [20]. When observing channels in sequence using a single observer, the observation time increases when the number of available channels is large, and the time available for communication decreases [21]. In addition, since there is a waiting period between observation and communication, the transmission delay also increases. Since COR is proportional to the amount of communication by the user, it varies depending on the user's activity [22], [23]. In a long-time observation, the COR may change between observation and channel selection in a time-varying environment. On the other hand, the shorter the observation time per channel, the larger the observation error becomes. On the other hand, the shorter the observation time per channel, the larger the observation error. To reduce the observation error, optimization of the observation order of channels and prediction of user demands have been discussed [24], [25]. Sensing schemes with multiple antennas [25] and using the distribution of interfering systems [27] have also been considered to reduce the observation error due to noise. However, previous studies were conducted with limited interference patterns and in simplified environments [24], [25], [26], [27].

The authors have proposed a channel observation scheme to improve observation accuracy [28]. In this observation scheme, all channels are observed in the first observation, and the channels with low COR are selected based on specific criteria. Only the selected channels are observed in the second observation, which increases the observation time and improves the observation accuracy. However, since all observation times were constant in one period, there was no improvement in the latency viewpoint. Furthermore, the throughput characteristics of the proposed observation scheme still need to be clarified.

This paper proposes the channel selection scheme to shorten the observation time and clarify its characteristics. The proposed scheme shortens the observation time by initially observing all channels and excluding channels with high COR. This is expected to improve throughput and latency. This study conducts a generalized evaluation using multiple interference patterns in an environment where autonomous control systems using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) are mixed. Three types of environments were used: high interference, low interference, and severe conditions.

The rest of the paper is organized as follows. Section II presents the system model and COR for channel observation. Section III describes the proposed excluded channel selection schemes. In Section IV, computer simulation results are detailed in the various interference environment. Finally, Section V concludes the paper.

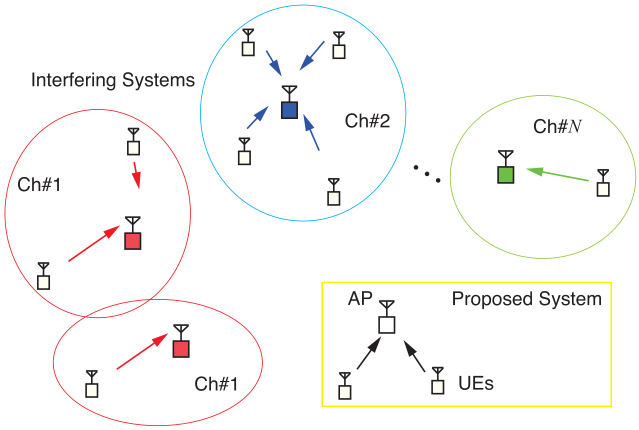
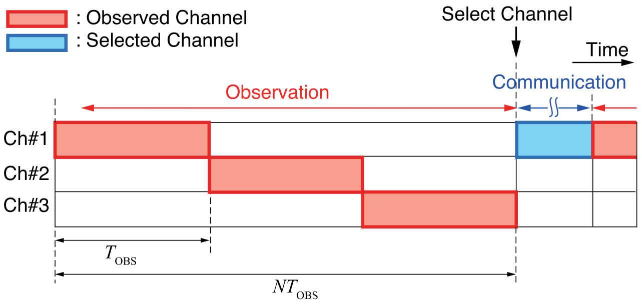
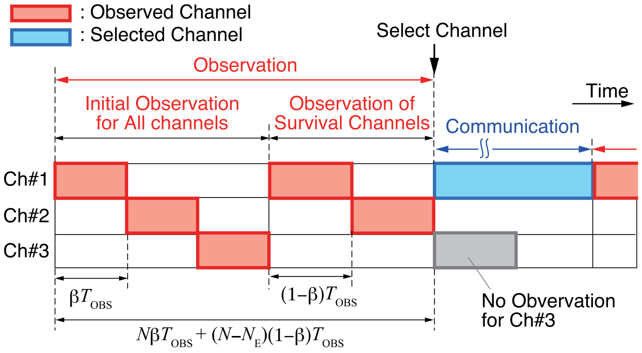


FIGURE 1. System model.



(a) Conventional channel selection scheme



(b) Proposed excluded channel selection scheme

FIGURE 2. Time chart example.

II. CHANNEL SELECTION SCHEME

A. SYSTEM MODEL

Fig. 1 shows the system model assumed in this paper. There are multiple interfering systems and the proposed system nearby. These systems select one of N channels for communication. Each of the N channels is assumed to be uncorrelated, and there are no overlapped. Each system decides the channel selection independently, and the decision criteria and control signals are not shared among the systems. This is because each system is assumed to be a heterogeneous wireless system.

The proposed system has channel observers at an access point (AP), observes the usage of each channel, and selects the channel to use based on the observation results. The proposed system assumes that time is divided into two sections, an observation period and a communication period and that the two sections are switched alternately. Fig. 2 (a) shows an example of a time chart of a channel observation. The observers measure the channel usage in turn. After observing all the channels, select the channel that is judged to be the least used. In this case, the AP selects Channel #1 of the three channels. The AP in the proposed system uses the selected channel to communicate with the User Equipments (UEs). After selecting the channel, the communication is assumed to be performed by random access using CSMA/CA. The AP and UEs are assumed to be perfectly synchronized times. Detailed observation is described in the next section.

The interfering systems also select one channel from N channels for communication. The interfering systems communicate on a fixed channel and do not change the selected channel once it has been selected. The interfering systems are assumed to operate independently, and the number of UEs and traffic is considered to differ. The interfering also transmits using CSMA/CA. Note that after channel selection, the proposed system only occupies the channel when communicating but shares the channel with other systems. Therefore, communication over a channel with many interfering systems will cause packet collisions, degrading the communication quality. To reduce packet collisions and interruptions with interfering systems, this paper proposes the scheme that selects a channel with lower usage.

B. CHANNEL OCCUPATION RATE

Let us explain the evaluation indices used for channel observations. During the observation period, the channel observer measures the sum of the times the received signal power is above the threshold value for each channel. When T_{OBS} is the observation time per channel and $T_{\text{E}}(n)$ is the sum of the times when the threshold is exceeded in the n-th channel, the observed Channel Occupation Rate (COR) in the n-th channel, $\hat{\rho}(n)$, is expressed as

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

This means that multiple interference systems can be used on the same channel. Note that even if there are multiple interfering systems on the same channel, COR does not distinguish between them. In other words, only the time occupancy of the channel is considered. The observation threshold is set to the carrier sense level, e.g., -82 dBm. When the set of observed channels is $\mathcal{N}$, channel n_d is selected by the following norm:

$$n_d = \arg\min_{n\in\mathcal{N}} \hat{\rho}(n). \tag{2}$$

It is assumed that the usage of the interfering system is still the same between the observation and communication segments.

III. EXCLUDED CHANNEL SELECTION SCHEME

If the observation time, T_{OBS}, is long enough, the channel observer can accurately determine the channel usage of all systems using the channel. However, when the number of observed channels is large, the longer T_{OBS} is, the shorter the communication period, resulting in lower system throughput. In addition, the time between observation and communication periods is also longer, resulting in higher latency. On the other hand, when T_{OBS} becomes shorter, the observation error increases, and the probability of selecting a channel with higher COR increases, resulting in lower system throughput. Excluding the channel with a high COR from observation can reduce the probability of selecting a channel with a higher COR. Furthermore, it can improve the throughput by allocating the observation time to communication time.

For efficient channel observation, we have proposed a two-step channel observation scheme that divides the observation period into two parts and narrows the observed channels from the first observation result [28]. In [28], the channels with higher COR are excluded from the candidate channels for the second observation, focusing on the spread of observation error in the first observation. The observation time for the excluded channels was allocated to the observation time of the remaining channels, thereby increasing the relative observation time and improving the observation accuracy. However, since the length of the observation period stayed the same in this scheme, there was no improvement in transmission latency when the number of channels was large. Therefore, this paper aims to reduce the latency and improve the system throughput by eliminating the observation time for the excluded channel in the second observation instead of allocating the observation time to the other channel.

Fig. 2 (b) shows an example time chart of the proposed excluded channel selection scheme. In the initial observation, the channel observer measures at βT_{OBS} observation time where β is the ratio of the first observation time ($0 \leq \beta \leq 1$). Let $\hat{\rho}^{(1)}(n)$ be the COR of the n-th channel in the initial observation, and is expressed as

$$\hat{\rho}^{(1)}(n) = \frac{T_{\mathrm{E}}^{(1)}(n)}{\beta T_{\mathrm{OBS}}}, \tag{3}$$

where $T_{\mathrm{E}}^{(1)}(n)$ is the sum of the observed time in the initial observation at n-th channel. The channel observer sorts the N observed $\hat{\rho}^{(1)}(n)$ in ascending order. Among the sorted $\hat{\rho}^{(1)}(n)$, exclude N_{E} channels from the bottom. Here, let $\mathcal{N}'$ denote the survival channel set after exclusion. In the case of Fig. 2 (b), Channel #1 and #2 are the surviving channels. The channel observer measures $\mathcal{N}'$ with $(1-\beta)T_{\mathrm{OBS}}$ observation time. After the observation, the COR is calculated by combining the results of the two observations. Let $\hat{\rho}^{(2)}(n)$ denote the combined COR and express as

$$\hat{\rho}^{(2)}(n) = \frac{T_{\mathrm{E}}^{(1)}(n) + T_{\mathrm{E}}^{(2)}(n)}{T_{\mathrm{OBS}}}, \tag{4}$$

where $T_{\mathrm{E}}^{(2)}(n)$ is the sum of the observed time in the survival channel observation at n-th channel. The proposed scheme selects the channel with the lowest $\hat{\rho}^{(2)}(n)$.

TABLE 1. Simulation conditions.

Number of channels, N	8
Access scheme	CSMA/CA (Uplink)
Hidden terminal	None
Time length that interference system transmits	266 μs
Proposed system	
Payload length	1500 Bytes
Transmission rate	39 Mbps
Signal generation	Poisson distribution (λ = 100/sec/UE)
Number of APs	1
Number of UEs	10
Communication period, T_{COM}	1000 ms

TABLE 2. Interference patterns.

Pattern	True COR
Interference pattern #1	[0.31, 0.35, 0.39, 0.43, 0.47, 0.54, 0.62, 0.62]
Interference pattern #2	[0.31, 0.33, 0.35, 0.37, 0.39, 0.41, 0.43, 0.45]
Interference pattern #3	[0.22, 0.25, 0.28, 0.31, 0.35, 0.39, 0.42, 0.47]

Thus, by excluding N_{E} channels from the initial observation, the whole observation time can be reduced by $N_{\mathrm{E}}(1-\beta)T_{\mathrm{OBS}}$. So the whole observation time, T_{O} is expressed as

$$T_{\mathrm{O}} = N\beta T_{\mathrm{OBS}} + (N - N_{\mathrm{E}})(1-\beta)T_{\mathrm{OBS}}. \tag{5}$$

In Fig. 2 (b), it can be reduced by $(1-\beta)T_{\mathrm{OBS}}$, the observation time of channel #3. When β is small, the possibility of excluding the channel with the smallest COR increases, but the time which is excluded increases. Therefore, the improvement of the characteristics can be expected. Note that the complexity of the proposed scheme is almost the same as that of the conventional scheme. The only difference between the proposed and the conventional scheme is excluding the process after the all-channel observation. The complexities do not increase because the comparison of observed CORs is a few processes. Hence, the proposed channel selection can be achieved without complicated processing.

If all channels have high COR, the throughput characteristics would be identical regardless of the selected channel. However, since the observer cannot know the true value of COR as a priori information, the observation is performed similarly, even if all channels have a high COR. It has also been revealed that communication reliability can be improved by using redundant communication, in which multiple channels are used simultaneously, even for channels with high COR [29]. It is necessary to control whether to use single or multiple channels for redundant communication depending on the communication type. Switching between these two options will be considered in the future.

IV. COMPUTER SIMULATION

A. SIMULATION CONDITIONS

Computer simulation evaluates the transmission characteristics of the proposed scheme. Table 1 lists the simulation conditions. The total number of available channels was set to

$N = 8$. The time length per transmission that the interfering system transmits signals was set to 266 μs. The number of APs in the proposed system is assumed to be one, and ten UEs are connected under the AP. The communication period after the observation period is set to $T_{\mathrm{COM}} = 1000$ ms, during which the proposed system transmits packets by CSMA/CA with the selected channel. Assuming an uplink, a signal with a payload length of 1500 Bytes is transmitted at a transmission data rate of 39 Mbps. The signal generation per UE is assumed to follow Poisson generation, and $\boldsymbol{\lambda}$ was set to 100 (1/sec/UE). Thus, the average UE throughput transmitted during T_{COM} without considering the observation time overhead is 12 Mbps. Only data and ACK packets are used in this simulation, and other control signals are not considered. All radio technologies (RATs) were assumed capable of receiving all signals within range. So there are no hidden terminals. Packet errors were assumed to be due to packet collisions between UEs or with interfering signals, and no transmission errors by propagation loss were considered.

Three interference patterns were considered as listed in Table 2. These values are true CORs when the proposed system does not transmit. The computer simulations were conducted within the range where there is an effect of communication due to interference. When the COR is less than 0.2, there is little interference, so there is almost no effect of interference, and the throughput characteristics are the same. Since control overheads such as Short Inter Frame Space (SIFS), Distributed coordination function IFS (DIFS), and random backoff are no-signal periods and are not included in the COR observation, the maximum value of the COR is 0.62. Hence, this study set interference patterns in the range of 0.22–0.62. This paper set the three interference patterns: Interference pattern #1 includes the highest COR, the minimum COR was set to 0.31, and the minimum difference between CORs was about 0.04 intervals. Interference pattern #2 had the same minimum COR as interference pattern #1, but the minimum difference between the CORs was set to about 0.02. Interference pattern #2 is a severe condition with high observation error due to narrow channel spacing. Interference pattern #3 includes the minimum COR of 0.22, and the minimum difference between CORs was about 0.03 intervals. Interference pattern #3 is the least interfering pattern among the three. These channels do not overlap in frequency and are assumed the interfering systems operate independently. Note that there are two maximum values of 0.62 in interference pattern #1, but this is since CSMA/CA is used, so it cannot occupy more than this.

The throughput of the i-th UE is calculated by

$$R(i) = \frac{T_{\mathrm{COM}}}{T_{\mathrm{COM}} + N\beta T_{\mathrm{OBS}} + (N - N_{\mathrm{E}})(1 - \beta)T_{\mathrm{OBS}}} B(i), \tag{6}$$

where $B(i)$ is the amount of transmission between T_{COM} of the i-th UE. The overhead of the observation time is taken into account. If there are no excluded channels ($N_{\mathrm{E}} = 0$), the throughput is expressed by

$$R(i) = \frac{T_{\mathrm{COM}}}{T_{\mathrm{COM}} + NT_{\mathrm{OBS}}} B(i). \tag{7}$$

(7) is the throughput in the conventional scheme.

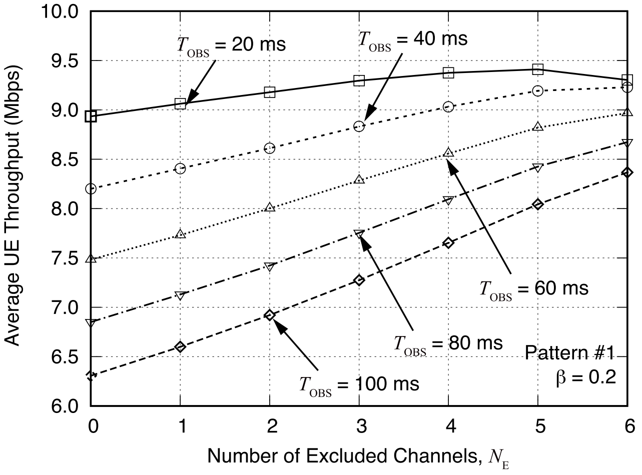


FIGURE 3. Average UE throughput characteristics as a function of number of excluded channels, N_{E}.

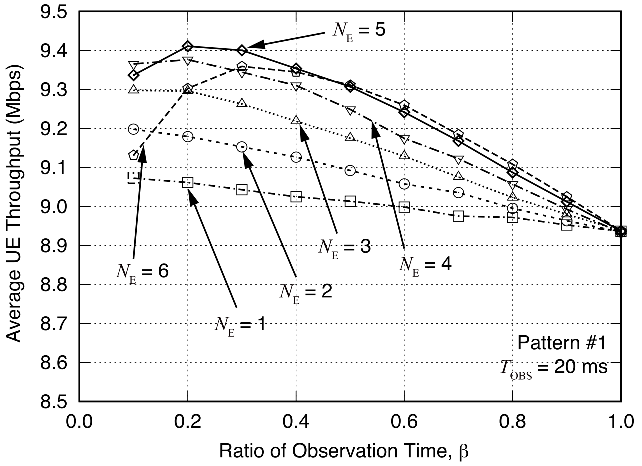


FIGURE 4. Average UE throughput characteristics as a function of observation ratio, β.

B. CHARACTERISTICS OF PROPOSED SCHEME

First, to clarify the characteristics of the proposed scheme when the number of excluded channels N_{E} is varied, computer simulation results are evaluated using interference pattern #1. Fig. 3 shows the average UE throughput characteristics with T_{OBS} being a parameter when N_{E} is varied. β was set to 0.2. As N_{E} increases, the average UE throughput increases because the observation time decreases. The larger T_{OBS} per channel, the more significant the effect of increasing N_{E}. On the other hand, for the highest throughput with $T_{\mathrm{OBS}} = 20$ ms and $N_{\mathrm{E}} = 5$ is the maximum value.

Fig. 4 shows the average UE throughput characteristics for $T_{\mathrm{OBS}} = 20$ ms with β being a parameter. As β is set

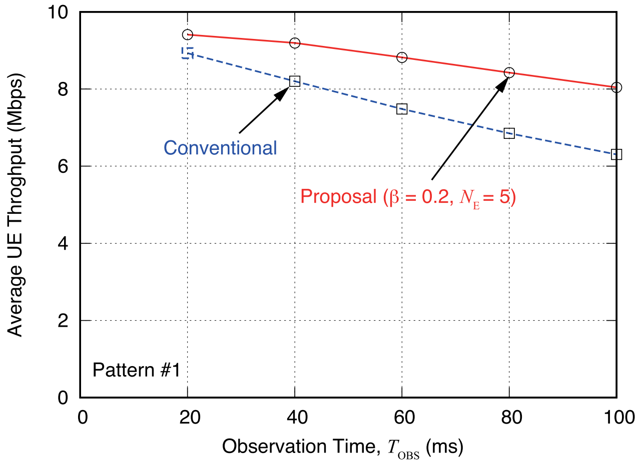


FIGURE 5. Average UE throughput characteristics as a function of the observation time.

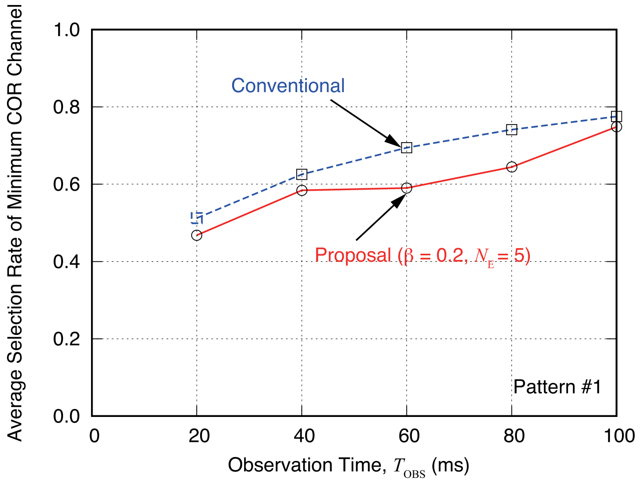


FIGURE 6. Selection probability of channel that is minimum COR.

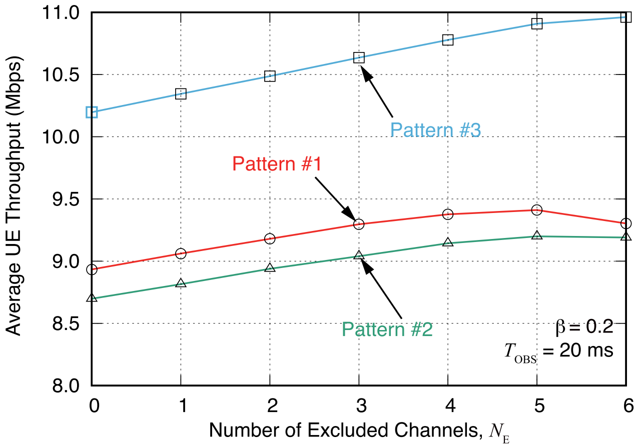


FIGURE 7. Characteristic differences by the number of excluded channels in multiple interference patterns.

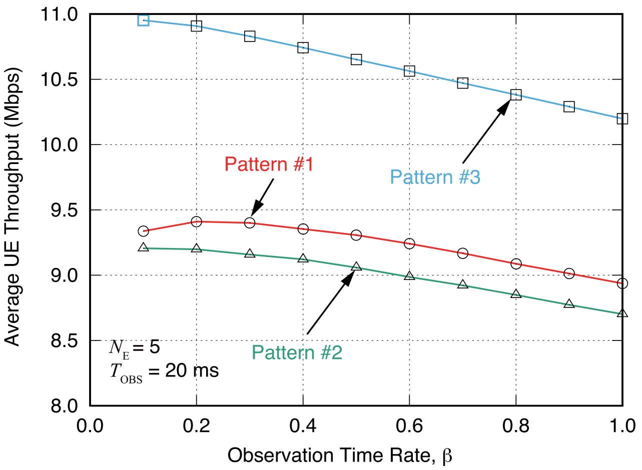


FIGURE 8. Characteristic difference by observation time ratio β in multiple interference patterns.

closer to 0.1, the average UE throughput improves because the observation time for survival channels becomes longer. On the other hand, the average UE throughput reaches its maximum value at $\beta = 0.2$ for $N_{\mathrm{E}} = 5$ and $\beta = 0.3$ for $N_{\mathrm{E}} = 6$. As N_{E} increases, the probability of excluding the channel with the smallest COR increases due to the effect of the observation error in the initial observation results. From the above, from the viewpoint of average UE throughput, $\beta = 0.2$ and $N_{\mathrm{E}} = 5$ can maximize the UE throughput.

Next, the proposed scheme is compared with the conventional scheme that is equally channel observations. The conventional scheme measures at observation time T_{OBS} and does not exclude channels. Fig. 5 shows the average UE throughput characteristics with T_{OBS} being a parameter. The observation time rate of the proposed scheme and the number of excluded channels were set to $\beta = 0.2$ and $N_{\mathrm{E}} = 5$, respectively. At all observation times, the throughput of the proposed scheme is improved compared to the conventional scheme. The proposed scheme achieves 1.28 times higher UE throughput than the conventional scheme at $T_{\mathrm{OBS}} = 100$ ms. Furthermore, the time from observation to the start of communication is reduced by 400 ms at $T_{\mathrm{OBS}} = 100$ ms. This means that the whole observation period is halved, and the transmission delay time is reduced by this amount. Since the observation time reduction ratio is the same regardless of the absolute amount of T_{OBS}, the observation time can be halved for all T_{OBS} when $\beta = 0.2$ and $N_{\mathrm{E}} = 5$.

The selection probability of the channel with the minimum COR is shown in Fig. 6. The conventional scheme has a higher probability of selecting the channel with the minimum COR because the observation time of each channel is longer than that of the proposed scheme. On the other hand, the proposed scheme has a lower selection probability for the channel with the lowest COR, but it can improve the throughput by eliminating the observation time. In other words, there is no operational problem even if the channel selection probability is reduced.

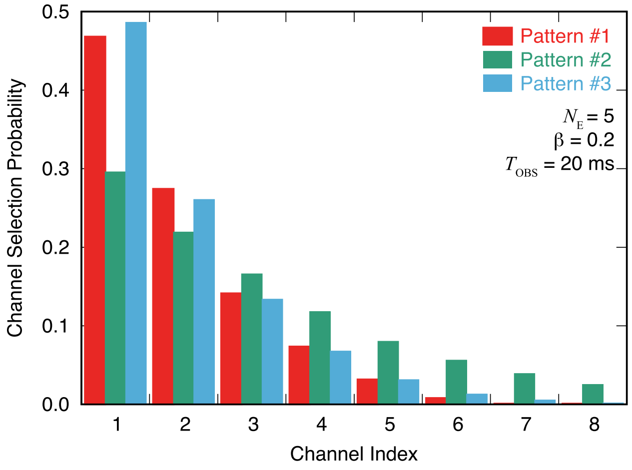


FIGURE 9. Channel selection probability when $\beta = 0.2$ and $N_E = 5$.

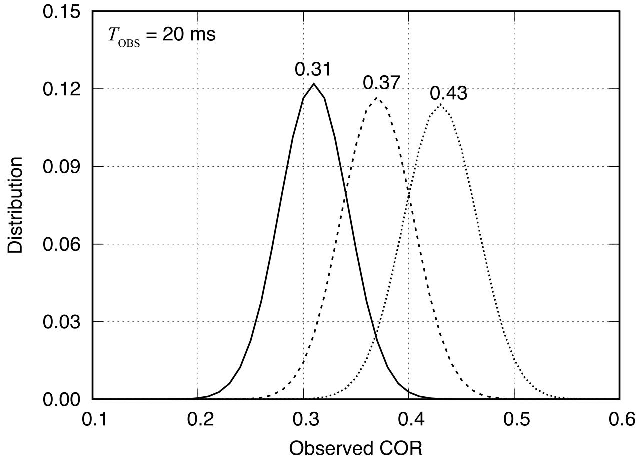


FIGURE 10. Distribution of observed COR.

C. CHARACTERISTICS IN DIFFERENT INTERFERENCE ENVIRONMENTS

To confirm the generality of the proposed scheme, this paper clarifies the characteristics of the proposed scheme when the interference patterns are varied. Fig. 7 shows each interference pattern's average UE throughput characteristics with N_E being a parameter. The three patterns in Table 2 were used. T_{OBS} and β were set to 20 ms and 0.2, respectively. The average UE throughput increases with increasing N_E for all interference patterns. Interference pattern #3 has higher UE throughput than the other interference patterns, and throughput is highest at $N_E = 6$. This is because the minimum COR of interference pattern #3 is 0.22, and the effect of interference on communication is smaller than that of the other interference patterns. On the other hand, interference pattern #2 decreases throughput by about 0.3 Mbps compared to interference pattern #1. In the interference pattern #2, the difference in the true value of COR for each channel is small, so the channel with the lowest COR is not selected. Fig. 8 shows the average UE throughput characteristics at $T_{OBS} = 20$ ms and $N_E = 5$. The trend is similar to the previous section's results. Note that since the interference patterns such as true value of COR cannot be known in advance, the number of excluded channels must be controlled adaptively by observing the observation results.

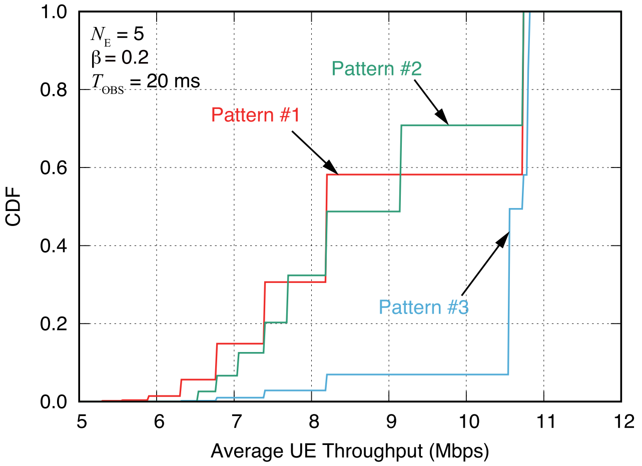


FIGURE 11. CDF characteristics of UE throughput for each interference pattern.

Fig. 9 shows the channel selection probabilities for each interference pattern. The parameters were set to $N_E = 5$, $\beta = 0.2$, and $T_{OBS} = 20$ ms, respectively. The channel indices correspond to the decreasing order of the COR true values, same as Table 2 order. For interference patterns #1 and #3, the selection probability of each channel is almost the same. If the minimum difference between CORs is about 0.04, as in interference pattern #1, channel index 1, which has the minimum COR, can be selected with a probability of 0.45 to 0.5. On the other hand, for interference pattern #2, the probability of selecting the channel index 1, which is the smallest COR, is 0.3, which is smaller than the other patterns. This is due to the small difference in the respective CORs. In an environment where the minimum difference between CORs is small, the probability of failing to select the minimum COR should be reduced by increasing the initial observation time or reducing the number of excluded channels. Fig. 10 shows the distribution of observed COR obtained from the theoretical values. The theoretical values were obtained as follows [30]:

$$\sigma(n) = \sqrt{\frac{\rho(n)(1-\rho(n))}{T_{OBS}}}. \tag{8}$$

$\sigma(n)$ is inversely proportional to the observation time T_{OBS}. Fig. 10 shows that the true values were 0.31, 0.37, and 0.43, respectively. These are channels index 1 and 4 (assuming $N_E = 5$) in patterns #1 and #2. The point where the two distributions, $\rho = 0.31$ and 0.43, the overlap is 0.03, but that with $\rho = 0.31$ and 0.37 is 0.75. It is also necessary to select the number of excluded channels from the distribution so that the overlapping distribution is less than 0.03.

Fig. 11 shows the Cumulative Distribution Function (CDF) of the UE throughput for each interference pattern.

The characteristics are staircase-like for each selected channel. Note that the true values of each COR are discrete. It can be seen that interference pattern #3 achieves a throughput of more than 10 Mbps even when the second smallest COR is selected. This results in higher throughput than the other interference patterns. Patterns with many low CORs do not necessarily require the selection of the channel with the lowest COR. In other words, further improvement in UE throughput can be expected by shortening the observation time or increasing the number of excluded channels. It can also be seen that the CDF characteristics of interference pattern #2 are degraded compared to interference pattern #1 due to the low selection probability of the channel with the smallest COR.

V. CONCLUSION

In dynamic spectrum sharing, where multiple wireless systems share the same radio resource, this paper has proposed an excluded channel selection scheme to improve throughput and latency. Based on the results of the initial observation, channels with high COR are excluded from shortening the observation time, thereby improving throughput and reducing transmission delay time. Computer simulation results have evaluated that when the total number of channels is eight, the UE throughput is improved by setting the observation time ratio to $\beta = 0.2$ and the number of excluded channels to $N_{\mathrm{E}} = 5$. The whole observation period can be cut in half for all T_{OBS} when $\beta = 0.2$ and $N_{\mathrm{E}} = 5$. The throughput characteristics were also evaluated using three types of interference patterns. The UE throughput is higher when the minimum COR in the interference pattern is smaller than the other patterns. Even if there is little degradation in UE throughput by selecting the channel with the second smallest COR, throughput is expected to be improved by reducing the observation time. When the minimum CORs are the same, UE throughput is degraded because the probability of selecting the channel with the smaller difference between the CORs decreases. Increasing the initial observation time or decreasing the number of excluded channels can improve the characteristics in this case.

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REFERENCES

[1] T. Nakamura, "5G evolution and 6G," in *Proc. Int. Symp. VLSI Design, Autom. Test (VLSI-DAT)*, Aug. 2020, pp. 1–5.

[2] *Ever-Present Intelligent Communication*, Ericsson, Stockholm, Sweden, Nov. 2020.

[3] J. Kaur and M. A. Khan, "Sixth generation (6G) wireless technology: An overview, vision, challenges and use cases," in *Proc. TENSYMP*, Jul. 2022, pp. 1–6.

[4] A. Osseiran, F. Boccardi, V. Braun, K. Kusume, P. Marsch, M. Maternia, O. Queseth, M. Schellmann, H. Schotten, H. Taoka, H. Tullberg, M. A. Uusitalo, B. Timus, and M. Fallgren, "Scenarios for 5G mobile and wireless communications: The vision of the METIS project," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 26–35, May 2014.

[5] *5GMF White Paper: 5G Mobile Communications Systems for 2020 and Beyond Ver. 1.1*, Fifth Gener. Mobile Commun. Promotion Forum, Japan, Sep. 2017.

[6] *NR User Equipment (UE) Radio Transmission and Reception—Part 1 Range 1 Standalone*, document TS 38.101-1, V17.1.0, 3GPP, Mar. 2021.

[7] *NR User Equipment (UE) Radio Transmission and Reception—Part 2 Range 2 Standalone*, document TS 38.101-2, V17.1.0, 3GPP, Apr. 2021.

[8] R. Etkin, A. Parekh, and D. Tse, "Spectrum sharing for unlicensed bands," in *Proc. IEEE 1st Int. Symp. New Frontiers Dyn. Spectr. Access Netw. (DySPAN)*, Baltimore, MD, USA, Nov. 2005, pp. 251–258.

[9] S. Bhattarai, J. J. Park, B. Gao, K. Bian, and W. Lehr, "An overview of dynamic spectrum sharing: Ongoing initiatives, challenges, and a roadmap for future research," *IEEE Trans. Cognit. Commun. Netw.*, vol. 2, no. 2, pp. 110–128, Jun. 2016.

[10] *Dynamic Spectrum Sharing in Rel-17*, document TSG RAN Meeting #84 RP-191052, 3GPP, Newport Beach, CA, USA, June 3–17 2019.

[11] F. P. A. Teixeira, L. C. Freitas, and J. C. W. A. Costa, "Spectrum sharing between 5G networks and fixed services operating in millimeter-waves," in *IEEE MTT-S Int. Microw. Symp. Dig.*, Nov. 2019, pp. 1–3.

[12] A. Lackpour, C. Hamilton, M. Jacovic, I. Rasheed, X. R. Rey, and K. R. Dandekar, "Enhanced 5G spectrum sharing using a new adaptive NC-OFDM waveform with reconfigurable antennas," in *Proc. IEEE Int. Symp. Dyn. Spectr. Access Netw. (DySPAN)*, Mar. 2017, pp. 1–2.

[13] A. Ikami, T. Hayashi, and Y. Amano, "Interoperator channel management for dynamic spectrum allocation between different radio systems," *IEICE Commun. Exp.*, vol. 9, no. 10, pp. 512–518, Oct. 2020.

[14] S. Shi, Y. Xiao, W. Lou, C. Wang, X. Li, Y. T. Hou, and J. H. Reed, "Challenges and new directions in securing spectrum access systems," *IEEE Internet Things J.*, vol. 8, no. 8, pp. 6498–6518, Apr. 2021.

[15] R. Zhu, H. Liu, L. Liu, X. Liu, W. Hu, and B. Yuan, "A blockchain-based two-stage secure spectrum intelligent sensing and sharing auction mechanism," *IEEE Trans. Ind. Informat.*, vol. 18, no. 4, pp. 2773–2783, Apr. 2022.

[16] K. Zhu, L. Huang, J. Nie, Y. Zhang, Z. Xiong, H.-N. Dai, and J. Jin, "Privacy-aware double auction with time-dependent valuation for blockchain-based dynamic spectrum sharing in IoT systems," *IEEE Internet Things J.*, vol. 10, no. 8, pp. 6756–6768, Apr. 2023.

[17] S. Haykin, D. J. Thomson, and J. H. Reed, "Spectrum sensing for cognitive radio," *Proc. IEEE*, vol. 97, no. 5, pp. 849–877, May 2009.

[18] S. C. Horng and S. S. Lin, "Dynamic channel selection and reassignment for cellular mobile system," in *Proc. Int. Symp. Comput., Consum. Control*, Jun. 2014, pp. 1006–1009.

[19] S. Takeuchi, M. Hasegawa, K. Kanno, A. Uchida, N. Chauvet, and M. Naruse, "Dynamic channel selection in wireless communications via a multi-armed bandit algorithm using laser chaos time series," *Sci. Rep.*, vol. 10, no. 1, p. 1574, Jan. 2020.

[20] T. Xiong, Y. Yao, Y. Ren, and Z. Li, "Multiband spectrum sensing in cognitive radio networks with secondary user hardware limitation: Random and adaptive spectrum sensing strategies," *IEEE Trans. Wireless Commun.*, vol. 17, no. 5, pp. 3018–3029, May 2018.

[21] G. Umashankar and A. P. Kannu, "Throughput optimal multi-slot sensing procedure for a cognitive radio," *IEEE Commun. Lett.*, vol. 17, no. 12, pp. 2292–2295, Dec. 2013.

[22] F. Xu, Y. Li, H. Wang, P. Zhang, and D. Jin, "Understanding mobile traffic patterns of large scale cellular towers in urban environment," *IEEE/ACM Trans. Netw.*, vol. 25, no. 2, pp. 1147–1161, Apr. 2017.

[23] M. Z. Shafiq, L. Ji, A. X. Liu, J. Pang, and J. Wang, "A first look at cellular machine-to-machine traffic: Large scale measurement and characterization," in *Proc. 12th ACM SIGMETRICS/PERFORMANCE Joint Int. Conf. Meas. Model. Comput. Syst.*, Jun. 2012, pp. 65–76.

[24] N. Dao, W. Na, A. Tran, D. N. Nguyen, and S. Cho, "Energy-efficient spectrum sensing for IoT devices," *IEEE Syst. J.*, vol. 15, no. 1, pp. 1077–1085, Mar. 2021.

[25] T. Stahlbuhk, B. Shrader, and E. Modiano, "Throughput maximization in uncooperative spectrum sharing networks," *IEEE/ACM Trans. Netw.*, vol. 28, no. 6, pp. 2517–2530, Dec. 2020.

[26] S. Lee, S. R. Park, Y. H. Kim, and I. Song, "Spectrum sensing for cognitive radio network with multiple receive antennas under impulsive noise environments," *J. Commun. Netw.*, vol. 23, no. 3, pp. 171–179, Jun. 2021.

[27] W. Li, G. Shentu, and X. Gao, "Estimation of distribution of primary channel periods based on imperfect spectrum sensing in cognitive radio," *IEEE Access*, vol. 10, pp. 82025–82035, 2022.

[28] H. So and H. Soya, ''Two-step channel observation scheme considering spread of observation results in dynamic spectrum sharing,'' *IEEE Open J. Veh. Technol.*, vol. 3, pp. 367–374, 2022.

[29] H. So, T. Fujita, K. Yoshizawa, M. Naya, and T. Shimizu, ''Highly reliable radio access scheme by duplicate transmissions via multiple frequency channels and suppressed useless transmission under interference from other systems,'' *IEICE Trans. Commun.*, vol. 104, no. 6, pp. 696–704, Jun. 2021.

[30] H. So, H. Soya, and K. Fukawa, ''Spectrum sensing scheme measuring packet lengths of interfering systems for dynamic spectrum sharing,'' *IEEE Access*, vol. 9, pp. 135160–135166, 2021.

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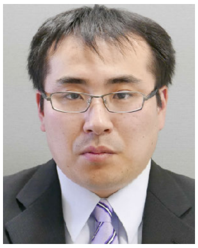

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