Highly Efficient Sensing Methods of Primary Radio Transmission Systems toward Dynamic Spectrum Sharing-Based 5G Systems

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SUMMARY The Dynamic Spectrum Sharing (DSS) system, which uses the frequency band allocated to incumbent systems (i.e., primary users) has attracted attention to expand the available bandwidth of the fifthgeneration mobile communication (5G) systems in the sub-6 GHz band. In Japan, a DSS system in the 2.3 GHz band, in which the ARIB STD-B57based Field Pickup Unit (FPU) is assigned as an incumbent system, has been studied for the secondary use of 5G systems. In this case, the incumbent FPU is a mobile system, and thus, the DSS system needs to use not only a spectrum sharing database but also radio sensors to detect primary signals with high accuracy, protect the primary system from interference, and achieve more secure spectrum sharing. This paper proposes highly efficient sensing methods for detecting the ARIB STD-B57-based FPU signals in the 2.3 GHz band. The proposed methods can be applied to two types of the FPU signal; those that apply the Continuous Pilot (CP) mode pilot and the Scattered Pilot (SP) mode pilot. Moreover, we apply a sample addition method and a symbol addition method for improving the detection performance. Even in the 3GPP EVA channel environment, the proposed method can, with a probability of more than 99%, detect the FPU signal with an SNR of -10 dB. In addition, we propose a quantized reference signal for reducing the implementation complexity of the complex crosscorrelation circuit. The proposed reference signal can reduce the number of quantization bits of the reference signal to 2 bits for in-phase and 3 bits for orthogonal components.

key words: spectrum sharing, OFDM, signal detection, field pickup unit (FPU), 5G

1. Introduction

The expansion of the fourth-generation mobile communication (4G) systems (i.e., Long-Term Evolution (LTE) and LTE-Advanced) and the increasing sophistication and affordability of smartphones have led to a rapid increase in the number of service subscriptions and a corresponding surge in mobile communication traffic. Developed countries are driving the deployment of the fifth-generation mobile communication (5G) system with more advanced features and allocate some frequency bands to the 5G system [1].

In Japan, 3.7 GHz, 4.5 GHz, and 28 GHz bands have already been allocated to the 5G systems. Totally, 500 or 600 MHz bandwidth has been allocated to each operator; 400 MHz bandwidth in the 28 GHz band, and only 100 or 200 MHz bandwidth in sub-6 GHz bands [2]. The sub-6 GHz bands can be used for macro-cells because radio waves in lower frequency bands have excellent propa-

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gation characteristics. Although the sub-6 GHz bandwidth available for the 5G systems is not sufficient, and further spectrum allocation is desired, the sub-6 GHz band has already been used in various radio systems, and no exclusive bandwidth remains to be allocated. Therefore, a Dynamic Spectrum Sharing (DSS) system, which uses the frequency band allocated to incumbent systems (i.e., primary users) has attracted attention to expand the available bandwidth of the 5G systems in the sub-6 GHz band [3]–[7].

In a spectrum band allocated to primary users, the DSS system identifies or detects the locations where or when the primary users are not operating and allows other systems to have secondary use of the band unless the secondary user interfere with nearby primary users. These spectrum resources available to the secondary users are called white spaces, and research and development to detect and utilize the white spaces have been studied worldwide [8], [9]. Especially in Europe, institutionalization and introduction of the Licensed Shared Access (LSA) is underway. The LSA allows cellular phone systems to have the opportunity to make secondary use in the 2.3-2.4 GHz band allocated to the transmission systems for television program contributions (e.g., wireless cameras, wireless video links) [10]. In the LSA, the primary user registers the spectrum usage plan (i.e., frequencies, areas, dates, and time periods) in advance in the spectrum sharing database (i.e., LSA Repository: LR). The cellular phone system is equipped with an LSA Controller (LC), and the LC allows the cellular phone system to communicate with the LR to verify the available spectrum resources. The base station is then operated by controlling the output power [10].

In this paper, a DSS system between a transmission system for television program contribution (i.e., ARIB STD-B57-based Field Pickup Unit (FPU) [11]) and a 5G system in the 2.3 GHz band is considered for expanding the available spectrum of the 5G system in Japan as well as the LSA concept [12], [13]. The difference between the European LSA and the DSS system with the Japanese FPU is the mobility of the primary user. In the LSA the primary user is a fixed station and can be operated safely based on the spectrum sharing database. On the other hand, the ARIB STD-B57-based FPU is used as a portable radio relay transmission system. In other words, the primary user is a mobile station. Therefore, the DSS system needs to use not only the spectrum sharing database but also radio sensors to detect the FPU signals with high accuracy for more secure spec-

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trum sharing [13]. When the radio sensor detects an FPU signal, its alert is reported to the spectrum sharing-based 5G system, and its transmission is promptly stopped to avoid interference to the FPU.

This paper proposes high efficiency sensing methods for detecting the ARIB STD-B57-based FPU signals in the 2.3 GHz band for DSS systems. Although radio sensors detecting the ISDB-T-based digital terrestrial broadcast signal [14]–[16] have been studied for television (TV) white space systems, to the best of our knowledge, no report has yet been presented on investigating radio sensors to detect the ARIB STD-B57-based FPU signals for the purpose of DSS systems. The target detection level in this paper is set to 10 dB lower than the noise power (i.e., signal-to-noise power ratio (SNR) is $-10 \, \text{dB}$) as well as the requirement for radio sensors in the TV white space systems [17]. Most of the studies on radio sensors for TV white spaces set the target detection rate to 90% [15], [16], [18]. In this paper, we set a stricter target detection rate of 99% to achieve safer spectrum sharing because the FPU is a mobile system. The proposed method is capable of detecting the FPU signals at $SNR = -10 \, dB$ even in a multi-path fading environment by applying complex cross-correlation and noise reducing circuit. Furthermore, we propose a quantized reference signal of the complex cross-correlation circuit to simplify the circuit scale of the proposed method. The proposed methods are quantitatively evaluated by computer simulation using the 3GPP-defined multi-path channel model to demonstrate the usefulness of the proposed method.

The main contributions of this study are as follows:

- The radio sensor architectures using complex crosscorrelation and noise reduction circuit are proposed for detecting the ARIB STD-B57-based FPU signals [13].
- The quantized reference signal of the complex crosscorrelation circuit is proposed to reduce the radio sensor implementation complexity [13].
- The proposed methods are evaluated by computer simulations for detecting the Continuous Pilot (CP) mode FPU signals [13] and the Scattered Pilot (SP) mode FPU signals.

The remainder of this paper is organized as follows. Section 2 describes an overview of the FPU system based on ARIB STD-B57. Section 3 presents the proposed high efficiency sensing methods to detect low-level FPU signals. Section 4 evaluates the performance of the proposed sensing methods by computer simulation, and finally, Sect. 5 concludes this paper.

2. ARIB STD-B57-Based FPU System

This section describes the detection target system, the ARIB STD-B57-based FPU system, operating in the 1.2 GHz and 2.3 GHz bands [11].

2.1 Transmission Parameters

ARIB STD-B57 is a one-way transmission system for television program contribution using an Orthogonal Frequency Division Multiplexing (OFDM). Single-Input Single-Output (SISO) and 2-by-2 Multiple-Input Multiple-Output (MIMO) are defined as a spatial multiplexing mode. This standard supports various modulation schemes of 64QAM, 32QAM, 16QAM, 8PSK, QPSK, DQPSK, BPSK, and DBPSK with multiple Guard Interval (GI) lengths of 1/8, 1/4, and 3/16.

Two modes are defined in terms of the number of subcarriers to be used: full-mode and half-mode. In the fullmode, all subcarriers are used for transmission, while only half of the subcarriers are used for transmission in the halfmode. Since no signals are assigned to the other half of the subcarriers, the half mode bandwidth is about half that of the full mode bandwidth. In addition, two pilot types of the Continuous Pilot (CP) mode and the Scattered Pilot (SP) mode can be selected.

Besides, two modes of Inversed Fast Fourier Transform (IFFT) can be selected: 2K and 1K modes. In the 2K mode, a 2,048-sized IFFT is applied with a 17.19 MHz bandwidth when the full-mode is selected (i.e., 2K-full-mode), and with a 8.40 MHz bandwidth when the half-mode is selected (i.e., 2K-half-mode). On the other hand, in the 1K mode, a 1,024-sized IFFT is applied with a 17.12 MHz bandwidth when the full-mode is selected (i.e., 1K-full-mode) and with a 8.49 MHz bandwidth when the half-mode is selected (i.e., 1K-full-mode).

In this paper, we assume the SISO-2K-half-mode FPU signal with 1/8 GI applying the CP mode pilot and the SP mode pilot as a target system for signal detection, because the 2K mode with 1/8 GI is a commonly-used mode in actual operations. Furthermore, the half-mode is as the more challenging mode for the signal detection compared to the full-mode because the half-mode has fewer number of subcarriers of the full-mode. Therefore, we select the half-mode as the target of this evaluation. Moreover, the CP's configuration for signal detection in SISO and MIMO is basically the same. In MIMO, space-time coding is performed to the CP, and the signal is transmitted from multiple antennas. In this paper, the SISO configuration is evaluated in order to evaluate the fundamental detection characteristics.

2.2 Frame Configuration

Figure 1 shows the OFDM frame structure of the SISO-2K-half-mode applying the CP mode pilot. The OFDM frame consists of the CP, Transmission and Multiplexing Configuration Control (TMCC), the Auxiliary Channel (AC), data, and null subcarriers. Here, 106 CP carriers are assigned at 8-subcarrier intervals from carrier index 0 to 840 [11].

Figure 2 shows the OFDM frame structure of the SISO-2K-half-mode applying the SP mode pilot. The OFDM frame consists of the SP, CP, TMCC, AC, data, and null subcarriers. In each symbol, 105 SP carriers and one CP carrier



Fig. 1 ARIB STD-B57-based OFDM frame structure of the SISO-2K-half-mode applying the CP mode pilot.



Fig.2 ARIB STD-B57-based OFDM frame structure of the SISO-2K-half-mode applying the SP mode pilot.

are assigned at 8-subcarrier intervals from carrier index 0 to 840, while the first position of the SP carrier index is shifted from 0 to 2, 4, and 6 in a 4-symbol period. When using the SP mode pilot, the CP carrier is assigned to the last carrier of the transmitted signal [11]. Therefore, the transmission signal with the SP mode pilot of the symbol index 4(m - 1), where *m* is a nonnegative integer, is the same as the transmission signal with the CP mode pilot.

3. Proposed High Efficiency Sensing Method of FPU

In this section, we propose high efficiency sensing methods for detecting the ARIB STD-B57-based FPU signal.

3.1 Configuration of Proposed Signal Detector

Figure 3 depicts the configuration of a proposed signal detector consisting of a complex cross-correlation circuit and a signal detection circuit. First, received signals containing the target signals are input to the complex cross-correlation circuit. In this circuit, the primary detection of the target signal is performed. Then, the output of the complex crosscorrelation is fed into the signal detection circuit to reduce the noise effect and improve the signal detection performance. Details of these two circuits are explained in the following subsections.



Result of signal detection

Fig. 3 Configuration of the proposed FPU signal detector.

3.2 Complex Cross-Correlation Circuit

The complex cross-correlation circuit calculates the similarity between two complex signals. The purpose of this circuit is to obtain peak values required for signal detection. In this paper, we consider a complex value calculation. The complex cross-correlation z(t) between two complex timedomain signals h(t) and x(t) is calculated as follows:

$$z(t) = \frac{1}{H} \sum_{i=0}^{H-1} h(i)\bar{x}(t+i-H),$$
(1)

where x(t) is the received signal containing the target signal, h(t) is the reference signal, and H denotes a length of h(t), and $\bar{x}(t)$ represents a conjugate of x(t).

If the components of h(t) are included in x(t), the peak values can be obtained as a result of the complex cross-correlation. The number of peaks and its level depend on the features of the target signal and reference signal. In general, known signals at the receiver (e.g., pilot signals for channel estimation) are used as the reference signal [18]–[20].

3.3 Proposed Reference Signal

This paper proposes two reference signals: a *Full-CP carrier (FC) reference signal* and a *quantized Partial-CP carrier (PC) reference signal*. These proposed reference signals can be selected according to the purpose. The primary purpose of the FC reference signal is to maximize the signal detection performance, while the scale of the correlation circuit required for the signal detection will increase. Conversely, the primary purpose of the PC reference signal is to downsize the detection circuit by reducing the number of quantization bits of the reference signal. Although the detection accuracy of a single radio sensor is degraded, the target detection rate is achieved by receiving diversity with multiple radio sensors. The details of each proposed method are described in the next sections.

3.3.1 Full-CP Carrier Reference Signal

First, we describe the FC reference signal to maximize the signal detection performance. The FC reference signal is



Fig. 4 Proposed FC reference signal (9FC and 1FC reference signals).

generated by mapping only the CP carriers for the CP mode pilot to the OFDM symbol or by mapping only the SP carriers and the CP carrier for the SP mode pilot of the symbol index 0 to the OFDM symbol. As explained in Sect. 2.2, the CP carriers are assigned at 8-subcarrier intervals in the frequency-domain. Therefore, eight repetition patterns can be observed in the time-domain OFDM symbol if only CP carriers are mapped. In addition, when the GI length is set to 1/8 of the OFDM symbol, the GI-inserted OFDM symbol has nine repetition patterns with phase rotation as shown in Fig. 4.

The proposed FC reference signal can be categorized into two types: the 9-cycle FC (9FC) reference signal consists of nine repetition patterns (i.e., 2,304 samples), and the 1-cycle FC (1FC) reference signal is one repetition pattern (i.e., 256 samples) to reduce memory length of the complex cross-correlation circuit. If the target signal is the FPU signal applying the CP mode pilot, it is expected that one peak is observed for each OFDM symbol interval when using the 9FC reference signal, and nine peaks are observed for each OFDM symbol interval when using the 1FC reference signal.

On the other hand, if the target signal is the FPU signal applying the SP mode pilot, the same OFDM symbol shown in Fig. 5 is observed at every four OFDM symbol intervals when only SP carriers and a CP carrier are mapped to OFDM symbols. Therefore, peaks are expected to be observed at every four OFDM symbol intervals for the FPU signals applying the CP mode pilot.

3.3.2 Quantized Partial-CP Carrier Reference Signal

Second, we describe the PC reference signal to simplify the implementation of the complex cross-correlation circuit. To reduce the implementation complexity of the complex cross-correlation circuit, the number of quantization bits of the reference signal needs to be reduced. The PC reference signal is generated by limiting the number of applying CP carriers



Fig.5 SISO-2K-half-mode OFDM signal applying the SP mode pilot when only SP carriers and a CP carrier are mapped to each OFDM symbol.

for the FC reference signal and replacing the selected CP carriers with the Walsh functions of that frequency.

The sampling frequency for generating the proposed PC reference signal is set to the frequency of the highest subcarrier (i.e., the 840th subcarrier) of the OFDM signal. Then, the indices of the CP carriers with a cycle length that is an integer multiple of the reciprocal of the sampling frequency (i.e., the $(420 \pm n)$ -th carriers with the condition of $(420 \pm n) \mod 8 = 0$, where *n* is a positive integer from 0 to 420). As a result, only 16 CP carriers are selected. Among them, six carriers (i.e., 280, 360, 400, 440, 480, and 560-th carriers) contribute to the in-phase component, and ten carriers (i.e., 0, 336, 392, 408, 416, 424, 432, 448, 504, and 840-th carriers) contribute to the quadrature component. Since the in-phase component is a cosine function, if the signs of $\pm n$ -th CP carriers are opposite, these CP carriers are canceled in the time-domain. Similarly, since the quadrature component is a sine function, if the signs of $\pm n$ th CP carriers are same, these CP carriers are also canceled in the time-domain.

Finally, the Walsh functions with the frequencies of the selected CP carriers are generated and summed over the time-domain to produce the PC reference signal as shown in Fig. 6. As a result, the quantization resolution of the PC reference signal is only 2 and 3 bits for the in-phase and the quadrature components, respectively.

Similar to the FC reference signal, the PC reference signal can be categorized into two types: the 9-cycle PC (9PC) reference signal consists of the 9 repetition patterns (i.e., 2304 samples), and the 1-cycle PC (1PC) reference signal is 1 repetition pattern (i.e., 256 samples) as shown in Fig. 6.

3.4 Signal Detection Circuit

To improve the performance of the signal detection, noise component in the output of the complex cross-correlation



Fig. 6 Proposed PC reference signal (9PC, 1PC).

circuit is reduced in the signal detection circuit. In this paper, we propose two noise reduction methods of a *sample addition method* and a *symbol addition method*.

3.4.1 Sample Addition Method

First, the sample addition method is proposed for the systems applying the 1FC and 1PC reference signals. As shown in Figs. 4 and 6, one OFDM symbol with the GI of the target signal has nine repetition patterns. Therefore, we can observe nine peaks in the output of the complex cross-correlation circuit z(t) when the 1FC or the 1PC reference signal is applied. In this method, these nine peaks are summed to average out the noise effect and improve SNR. Figure 7 shows the signal detection circuit of the proposed sample addition method. The sample delay *M* is set to 256.

The threshold to detect signal is calculated by the power of $z'_N(t)$ by turning on the switch 1 (SW1) and off the switch 2 (SW2), and only noise is fed into the complex cross-correlation circuit. Then, the maximum value of the input signal into the threshold decision circuit is set as the threshold for minimizing the false alarm.

3.4.2 Symbol Addition Method

Second, the symbol addition method is proposed for the systems applying 1FC, 9FC, 1PC, and 9PC reference signals. Since the features of the reference signal are included for each OFDM symbol of the target signal, we can observe the peaks at every OFDM symbol period in the output of the complex cross-correlation circuit z(t). In the symbol addition method, these peaks are summed to average out the effect of noise and improve SNR. Figure 8 shows the signal detection circuit of the proposed symbol addition method. Here, N is set to the number of peaks to be added, and the sample delay L is set to 2,304 and 9,216 when the target signal includes the CP mode pilot and the SP mode pilot, respectively. Incidentally, it is also possible to apply the



Fig. 7 Proposed signal detector by sample addition.



Fig. 8 Proposed signal detector by symbol addition.

symbol addition method after applying the sample addition method. In this case, the power of $z'_N(t)$ is calculated only in the symbol addition method.

The threshold to detect signal is calculated by the power of $z'_N(t)$ by turning on the switch 3 (SW3) and off the switch 4 (SW4), and only noise is fed into the complex cross-correlation circuit. Then, the maximum value of the input signal into the threshold decision circuit is set as the threshold for minimizing the false alarm.

3.5 Receiver Diversity

A receiver diversity is one of the effective means to further improve the detection performance in a multi-path fading environment. By distributing *S* radio sensors and using all detection results cooperatively (i.e., by applying a sensor selecting diversity), the signal detection rate P_d can be improved as follows:

$$P_{\rm d} = 1 - (1 - p_{\rm d})^S, \tag{2}$$

where p_d is the signal detection rate by one radio sensor. We assume that each propagation path between the FPU and sensors are independent.

4. Computer Simulation

In this section, the signal detection performance of the proposed methods was evaluated by computer simulation with the parameters shown in Table 1. The AC carriers of the transmission signal were assumed to be random data. As the channel model, the Additive White Gaussian Noise (AWGN) and the 3GPP Extended Vehicular A (EVA) channel model [21] were used. Since one of the typical use cases of the FPU is a TV broadcast in a marathon event, the Doppler frequency was set to 42.6 Hz assuming a moving speed of 20 km/h. When the 1FC and 1PC were used, the symbol addition method was applied to all cases with the sample addition method. We set a target as the detection rate of 99% at SNR $\leq -10 \, \text{dB}$.

4.1 Determination of Signal Detection Threshold

The threshold for each reference signal with each signal detection parameter was calculated. As explained in Sect. 3.4, the threshold to detect signal was set as the maximum value of the power of $z'_N(t)$. Here, the power of the Gaussian noise was normalized to 1. The calculated threshold is listed in Table 2. As the number of symbol additions N is increased, the threshold becomes lower because the average value of the noise power approaches zero by the central limit theorem.

4.2 Detection Performance of FC Reference Signals for FPU Signals Applying CP Mode Pilot

First, we evaluated the proposed methods using FC reference signal for detecting the FPU signals applying the CP mode pilot. The difference between this paper and [13] is the AC carriers in the evaluation. Figure 9 shows the signal detection rates achieved by using the 9FC and 1FC reference signals in an AWGN environment. The two methods indicated almost the same performances when N = 1. When N = 10 and 20, the detection performance of the 1FC reference signal is slightly better than that of the 9FC reference signal. The target signal can be detected at lower SNR as the number of symbol addition N increased. Even in the absence of symbol addition (i.e., N = 1), the 9FC and 1FC reference signals can achieve a 99% detection rate under the condition of SNR = $-10 \, \text{dB}$.

Signal detection rates of FPU signals applying CP mode pilot by Fig. 9 using 9FC and 1FC reference signals in AWGN environment.



Fig. 10 Signal detection rates of FPU signals applying CP mode pilot by using 9FC and 1FC reference signals in 3GPP EVA channel environment.

Figure 10 shows the signal detection rates achieved by using the 9FC and 1FC reference signals in a 3GPP EVA channel environment. These methods also indicated almost the same performances. When N = 10, the 9FC and 1FC reference signals can achieve a 99% detection rate under the conditions of SNR = -13 and -14 dB, respectively. The detection performances of the 9FC and 1FC reference signals were almost the same when N = 1. When N = 10and 20, the detection performance of the 1FC reference signal is slightly better than that of the 9FC reference signal. Furthermore, the 1FC reference signal has the additional advantage of reducing the memory length of the complex cross-correlation circuit by 1/9 compared to the 9FC reference signal.





cross-correlation calculation method with N = 1, 10, and 20.

9FC

-21.4 dB

-31.1 dB

-33.7 dB

FC reference signal

Channel model

1FC

-2.4 dB

-12.5 dB

-15.2 dB

Table 2

N

1

10

20

Parameters of transmitted signal.

AWGN, 3GPP EVA [21]

PC reference signal

9PC

-21.1 dB

-30.8 dB

-34.0 dB

1

Calculated threshold for each reference signal and each complex

1PC

-2.7 dB

-12.1 dB

-15.3 dB



Fig. 11 Signal detection rates of FPU signals applying CP mode pilot by using 9PC and 1PC reference signals in AWGN environment.

4.3 Detection Performance of PC Reference Signals for FPU Signals Applying CP Mode Pilot

Second, we evaluated the proposed methods using PC reference signal for detecting the FPU signals applying the CP mode pilot. Figure 11 shows the signal detection rates by using the 9PC and 1PC reference signals in an AWGN environment. The detection performance of the 1PC reference signal is slightly better than that of the 9PC reference signal. The target signal can be detected at lower SNR as the number of symbol addition *N* increased. Although overall performance was degraded by up to 9 dB compared to the 9FC and 1FC reference signals, the 9PC and 1PC reference signals also can achieve a 99% detection rate under the conditions of SNR = -12 dB when N = 10.

Here, we investigated the factors that caused the 9 dB performance degradation of the 9PC and 1PC reference signals compared to the 9FC and 1FC reference signals. Figure 12 shows the signal detection rates when using the 9PC and 1PC reference signals before the conversion to the Walsh waveform (i.e., the number of CP carriers-limited 9FC and 1FC reference signals). The performances in Figures 11 and 12 show almost the same performance of the PC reference signals was caused by the reduction of the number of CP carriers used for the reference signal.

Figure 13 shows the signal detection rates achieved by the 9PC and 1PC reference signals in a 3GPP EVA channel environment. Even under the condition of N = 20, the 9PC and 1PC reference signals cannot achieve a 99% detection rate. Therefore, the receiver diversity explained in Section 3.5 was applied to improve the detection rate. From Fig. 13, it was found that the detection rates of the 9PC and 1PC reference signals under the condition of N = 20 at SNR = -10 dB were 76.5% and 78.6%, respectively, when only one radio sensor is operated (i.e., S = 1). From Eq. (2), it can be calculated that S = 4 and 3 are required to achieve a 99%



Fig. 12 Signal detection rates of FPU signals applying CP mode pilot by using 9PC and 1PC reference signals before Walsh waveform conversion in AWGN environment.



Fig. 13 Signal detection rate of FPU signals applying CP mode pilot by using 9PC and 1PC reference signals in 3GPP EVA channel environment.

detection rate when the 9PC and 1PC reference signals are used, respectively.

4.4 Detection Performance of FC Reference Signal for FPU Signals Applying SP Mode Pilot

Third, we evaluated the proposed methods using 9FC reference signal for detecting the FPU signals applying the SP mode pilot. Figure 14 shows the signal detection rate in an AWGN environment. Even in the absence of symbol addition, the 9FC reference signals can achieve a 99% detection rate with SNR = -11 dB.

This performance is almost same as that in Fig. 9 with applying the CP mode pilot. However, since the repetition period of the time-domain signal applying the SP mode pilot is four times that applying the CP mode pilot, the required processing time for the symbol addition method also



Fig. 14 Signal detection rate of FPU signals applying SP mode pilot by using 9FC reference signal in AWGN environment.



Fig. 15 Signal detection rate of FPU signals applying SP mode pilot by using 9FC reference signal in 3GPP EVA channel environment.

becomes four times longer.

Figure 15 shows the signal detection rate achieved by using the 9FC reference signal in a 3GPP EVA channel environment. When N = 10, a 99% detection rate can be achieved under the condition of SNR = -13 dB. This detection performance is slightly better than that in Fig. 10 with applying the CP mode pilot. Since the required observation duration for the FPU signal applying the SP mode pilot is four times longer compared to that applying the CP mode pilot, the symbol addition induces the time diversity effect with the time variation caused by fading.

4.5 Detection Performance of PC Reference Signal for FPU Signals Applying SP Mode Pilot

Finally, we evaluated the proposed methods using the 9PC reference signal for detecting the FPU signals applying the SP mode pilot. Figure 16 shows the signal detection rate in



Fig. 16 Signal detection rate of FPU signals applying SP mode pilot by using 9PC reference signal in AWGN environment.



Fig. 17 Signal detection rate of FPU signals applying SP mode pilot by using 9PC reference signal in 3GPP EVA channel environment.

an AWGN environment. The target signal can be detected at lower SNR as the number of symbol addition *N* increased. When N = 10, the 9PC reference signal can achieve a 99% detection rate with SNR = -12 dB. This detection performance is almost same as that in Fig. 11 with applying the CP mode pilot; however, the required processing time for the symbol addition method becomes four times longer.

Figure 17 shows the signal detection rate achieved by using the 9PC reference signal in a 3GPP EVA channel environment. When N = 20, the detection rate was 33.9% under the condition of SNR = -10 dB. Compared to the performance of the 9PC reference signal for the target signal with the CP mode pilot, the signal detection rate was degraded by about 3 dB. This degradation was caused by the difference in the period of the repetition pattern in the timedomain between the SP mode pilot and the CP mode pilot. In the case of the CP mode pilot, the repetition period of the CP signal is 2,304 samples (i.e., one OFDM symbol period). On the other hand, in the case of the SP mode pilot, the repetition period of the CP signal is 9,216 samples (i.e., four times of the CP mode pilot, in other words, period of four OFDM symbols). Therefore, the adjacent complex cross-correlation peak values are rotated in the complexplane (i.e., the phase of the peaks changes) due to the time variation of the channel caused by fading. As a result, the detection performance of the symbol addition method was degraded.

To achieve a 99% detection rate, the receiver diversity was applied. Since the detection rates of the 9PC reference signal under the condition of N = 20 at SNR = -10 dB was 33.9%, it can be calculated that S = 12 is required to achieve a 99% detection rate by using Eq. (2). In addition, the improvement of complex cross-correlation circuit and reference signal design are the future works. In this paper, only the feature of the 4(m-1) OFDM symbols were used to detect the signal. Therefore, by using the remaining symbols (i.e., the symbol indices 4m - 3, 4m - 2, and 4m - 1) for signal detection as well, the detection performances of the SP mode signals might be improved to the almost same level of the CP mode signals shown in Fig. 13.

5. Conclusion

In this paper, we proposed high efficiency sensing methods to detect the ARIB STD-B57-based FPU signal for the spectrum sharing-based 5G system. We improved the detection performance by the proposing the sample addition method and the symbol addition method. Furthermore, as the reference signals for the complex cross-correlation circuit, the FC and PC reference signals were proposed. The proposed methods were evaluated by computer simulations. The all proposed methods can detect the FPU signal applying the CP mode pilot and the SP mode pilot. Even in a 3GPP EVA channel environment, when N = 20, the 9FC reference signal can detect the FPU signal with the SNR of -10 dB with the probability of more than 99%. In addition, the PC reference signal can reduce the number of quantization bits of the reference signal to 2 bits for in-phase and 3 bits for orthogonal components. Although the PC reference signal offers inferior signal detection performance compared to the FC reference signal, more than 99% detection rate can be achieved with the receiver diversity using multiple radio sensors.

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