Outdoor Experimental Evaluation of Asynchronous Successive Interference Cancellation for 5G in Shared Spectrum with Different Radio Systems

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Abstract: This paper demonstrates the feasibility of interference cancellation for 5G receivers applicable for spectrum sharing with different radio systems through field experiments. In the demonstration system, the receiver cancels the signals of the existing primary radio system that are received asynchronously with respect to the 5G signal by implementing real-time signal processing on the field-programmable gate array. Through experiments, we confirm that the proposed asynchronous successive interference cancellation method can reduce interference and improve the block error rate performance significantly in the region where the received power level of the interference signal is high.

Keywords: Spectrum Sharing, Successive Interference Cancellation, Asynchronous Reception, 5G

Classification: Wireless communication technologies

References

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1 Introduction

Mobile communication traffic is increasing yearly due to the spread of mobile broadband services, and the demand will increase even further after 5G service begins. However, in Japan, most frequency bands being considered for use in 5G are already allocated to other existing radio systems. Hence, spectrum-sharing with other existing radio systems will be highly important for mobile communication systems, including 5G and beyond. Conventionally, in spectrum sharing, the secondary system that shares the spectrum must not interfere with the existing primary radio system. Hence, a transmitter of the secondary system should have a sufficiently large separation distance with respect to the primary system so as to avoid severe interference. However, when the separation distance is excessively great, the area in which the secondary system can share the spectrum shrinks.

Conventionally, successive interference cancellation (SIC) has been one of a promising techniques to cancel the interference at the receiver and has been widely researched for various wireless transmission and multiplexing schemes. However, most of the research aimed to enhance the spectrum efficiency of a single radio system by canceling the interference. Therefore, it can only be used in the waveform parameters such as the sampling rate are common for both the desired signal and interference signal and that both are synchronously received. In this paper, interference cancellation within the same system is defined as synchronous SIC, and interference cancellation between multiple systems with different parameters, etc., is defined as asynchronous SIC. Asynchronous SICs for spectrum sharing systems have been the subject of theoretical calculations and simulation evaluations under the assumption that there are complex receivers capable of decoding the signals of each system [1,2]. To the best of the authors’ knowledge, there are few papers that consider suitable receiver design based on the realistic assumption that the signals of both systems are transmitted with different parameters such as the sampling rate, and the signals are asynchronously received. [3] reports an interference suppression method for Wi-Fi and LTE spectrum sharing. The propagation channel is estimated from the reference signal points that do not interfere due to differences in guard bandwidths. Then, interference is suppressed by array signal processing using the estimated propagation channel. Here, receivers are prepared for each system, and the implementation scale is not
taken into consideration. Therefore, we have proposed a single 5G receiver design with asynchronous SIC that cancels the signal from the primary system, and we have illustrated its effectiveness through computer simulation [4]. Moreover, the characteristics of the proposed method are confirmed by a simulation and an offline analysis of the data acquired in an anechoic chamber [5]. In this paper, we report the basic characteristics of the proposed method with online digital signal processing in an outdoor environment based on the results of experiments conducted on an outdoor sports field to demonstrate the feasibility of the proposed asynchronous SIC method.

2 Target scenario and proposed receiver

2.1 Target scenario

We consider a scenario where 5G is operated as the secondary system and shares a spectrum with an existing primary radio system with the systems deployed in fairly close proximity, as shown in the upper part of Fig. 1. The scenario assumes that the transmission power of the 5G is set to a lower level so that the corresponding received power at the receiver of the primary system is under a certain level, which is lower than the noise floor, to protect the primary system. In addition, the scenario also assumes that the primary system operates without attenuating the transmission power to protect the 5G, and the receiver of the 5G receives comparatively high-level interference from the primary system. Therefore, the effect of intersystem interference at the receiver of the 5G appears more prominent in such scenarios with shorter separation distances. Here, the 5G and primary systems operate independently. In addition, since the symbol length and sampling rate differ depending on the system, the appropriate FFT timing also differs between the systems.

2.2 Proposed receiver design

This section briefly describes the 5G receiver with asynchronous SIC that we proposed in [4] and implemented on the field-programmable gate array (FPGA). Fig. 1 shows the target scenario and proposed receiver block diagram.

To realize the SIC of different radio systems, the receiver requires received signals sampled at the sampling rates of each system for demodulation. However, it is not realistic to prepare radio frequency (RF) devices and analog to digital converters (ADCs) for each system independently on the 5G receiver because the implementation scale would become large. Therefore, in the proposed receiver design, the signals received using one RF device and one ADC are converted to their respective sampling rates, and processing steps such as demodulation and interference cancellation are then performed. As Fig. 1 shows, when SIC is applied in a 5G receiver, it first converts the sampling rate from the received sampling rate to the sampling rate of the primary system, then estimates the channel response among the receiver and transmitter of the primary system based on the reference signal of the primary system, demodulates the transmitted symbol and decodes it. Next, a replica signal of the primary system is generated based on the estimated channel response and re-modulated symbols yielded by the decoded transmitted...
bits, and that replica signal is converted to the 5G sampling rate. Then, the replica signal of the primary system is subtracted from the received signal, which is converted to a 5G sampling rate. Finally, the 5G information bits are decoded after the channel estimation based on the 5G reference signal and demodulation. It is assumed that for the receiver, all system information is known, including the modulation type, sampling rate, and reference signals for both systems. The assumption is realistic if there are standard specifications of the primary systems.

3 Outdoor experimental evaluation results

3.1 Experimental environment and specifications

Fig. 1. shows the experimental environment and specifications. As shown in Fig. 2 (a), this experiment was conducted on an outdoor sports field on the Tagajo campus of Tohoku Gakuin University as a typical open space environment to measure basic performance. The parameters used in the experiment, such as the center frequency, are shown in Fig. 2 (b). Normally, if a signal with a different sampling rate from appropriate rate of each system, specified with number of FFT points and subcarrier interval of OFDM signal, is received, then that signal cannot be demodulated correctly. Therefore, the conventional synchronous SIC cannot be directly applied to a receiver for spectrum sharing with a different radio system that utilizes different waveform parameters. In this evaluation, the proposed interference cancellation technique is implemented on the FPGA at the receiver, and SIC is performed by online processing. The combinations of the 5G modulation order and coding rate that vary according to the modulation and coding.
3.2 Experimental results

Fig. 3 shows the results of the experiment. Figs. 3 (a) and (b) show the desired to undesired signal ratio (DUR) versus the block error rate (BLER) characteristics for 5G MCS index = 4 and 11. As Figs. 3 (a) and (b) show, the proposed method is effective in the region where the received power level of the interference signal is high, which is DUR = −18 to −6 dB for MCS index = 4 and DUR = −8 dB for MCS index = 11. However, when SIC is applied at DUR = −4 to 4 dB for MCS index = 4 and DUR = −6 dB or more for MCS index = 11, and the BLER may be lower than those without SIC. Since the received power of the primary system is lower than that of 5G and the replica signal generation accuracy of the primary system is reduced, it is considered that the signal components other than interference are also removed when SIC is applied, resulting in degradation of the BLER characteristics. In addition, degradation of the BLER characteristics can be observed in the region with a low DUR, which is DUR = −20 dB for MCS index = 4 and DUR = −10 dB or less for MCS index = 11, although the point of change varies depending on the MCS index. The received power of the primary system is higher than the 5G received power, and the replica generation accuracy of the primary system is high. However, since the ratio of the 5G received power to the received power before applying SIC is small, the replica generation error effect of the primary system increases, and the effect of applying SIC is considered to decrease. As an example of the effect of applying interference cancellation, the constellations before and after applying SIC are shown in Figs. 3 (c) ~ (f) for the case where MCS index = 4 and 11, respectively. As Figs. 3 (c) and (d) show, the constellation, which was scattered by the interference from the primary system before applying SIC, converges to 4 points of QPSK. At this time, the constellation spread was at a level that could be corrected by the forward error correction (FEC), and the BLER was
0. In the case of MCS index = 11, the constellation converges to the center after applying SIC. Furthermore, the constellation could be decoded by FEC with BLER = 0.001, whereas its Euclidian distances of the demodulating symbols appear to be insufficient for demodulating 16QAM.

![BLER characteristics and example of constellations](image)

**Fig. 3.** BLER characteristics and example of constellations

### 4 Conclusion

In this paper, we have demonstrated the feasibility of the asynchronous interference cancellation for 5G receivers applicable to spectrum sharing systems and have clarified its basic characteristics with online digital signal processing through a field experiment in an outdoor environment. We have confirmed that the proposed method is effective in the region where the received power level of the interference signal is high. However, we have clarified that the improvement in the proposed method decreases when the DUR is below a certain level, although the value depends on the MCS index. In future works, we will conduct evaluations in more multipath-rich environments, such as densely built-up environments.

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