IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received December 1, 2021, accepted December 18, 2021, date of publication December 21, 2021, date of current version December 29, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3137303

Efficient Immediate-Transmission Scheme for Emergency Packets in Closed Area Wireless Access Networks

HIDEYA SO[1], (Member, IEEE), AND DAISUKE MURAYAMA[2], (Member, IEEE)
[1]Department of Electrical and Electronics Engineering, Shonan Institute of Technology, Fujisawa, Kanagawa 251-8511, Japan
[2]NTT Access Network Systems Laboratories, NTT Corporation, Yokosuka, Kanagawa 239-0847, Japan

Corresponding author: Hideya So (so.hideya@m.ieice.org)

ABSTRACT This paper proposes an efficient immediate-transmission scheme for highly reliable and low-latency wireless communication without waiting for radio resource allocation. In the conventional, basic radio resource allocation scheme, a base station (BS) cannot transmit an emergency packet immediately without waiting until the next transmission allocation period. A technique to shorten the allocation period has been investigated, but the increased control overhead degrades the system throughput. The proposed efficient immediate-transmission scheme takes a different approach. When an emergency packet is input to a BS, it interrupts non-emergency packet transmission. The BS transmits the emergency packet multiple times with shifted subcarriers and orthogonal frequency division multiplexing (OFDM) symbols. The receiver then calculates the correlation between the applicable signals and detects the emergency packet when it exceeds a threshold. Computer simulations derived the appropriate parameters for the transmission of the emergency packet, namely, the number of subcarriers, the number of OFDM symbols, and the detection threshold. The proposed efficient immediate-transmission scheme could improve the system throughput as the generation ratio of emergency packets increases.

INDEX TERMS Wireless communication, highly-reliable and low-latency communication, emergency packet, OFDM.

I. INTRODUCTION

Recently, internet of things (IoT) services have attracted much attention and been thoroughly investigated in terms of many aspects, such as sensing, communication, and applications [1]. For the fifth-generation mobile communication system (5G), standardization to provide IoT services has been discussed [2], [3]. This system has various requirements for multiple terminal connectivity, low power, low latency, and/or high reliability [4], [5]. In 5G, wireless communication requiring low latency and high reliability is specifically defined as ultra-reliability and low-latency communication (URLLC).

Controlling autonomous guided vehicles (AGVs) and production-line robots in a closed area such as a factory or a warehouse is a typical use case of URLLC [6], [7]. These use cases include the situation in which one AGV or robot needs to stop immediately to avoid an accident. This situation requires the lowest latency and highest reliability for emergency stop commands. Hence, these applications and services require a wireless system that can improve the latency and reliability of communication. We define an emergency packet as a packet that sends a command immediately to stop the AGV or robot remotely to prevent an accident. On the other hand, other usual data that is transmitted continuously is defined as non-emergency packets.

To reduce the latency of the downlink transmission, a flexible frame structure and scheduling schemes have been investigated [8]. The flexible frame structure technique introduces a short symbol period or shortens the transmission time interval (TTI). In the band above 6 GHz, a short symbol period by controlling the subcarrier spacing can reduce the latency [9]. In the TTI shortening techniques [10], [11], a base station (BS) allocates a shorter period than the ordinary period. When an emergency packet is input to

The associate editor coordinating the review of this manuscript and approving it for publication was M. Shamim Kaiser.

BS, the transmitter can transmit it with a shorter waiting time. Although the transmission frame length can be shortened, the ratio of control overhead increases, resulting in a decrease in the system throughput.

The reservation of the radio resources and immediate-transmission scheme have been investigated as the scheduling scheme. In this approach, portions of the radio resources such as a frequency and time are reserved to transmit emergency packets with keeping empty in ordinary times [13], [14]. When an emergency packet is input to BS, the BS immediately transmits the emergency packet using the reserved radio resources without waiting next allocation. However, the reservation of the radio resources degrades the system throughput because it wastes the radio resources during the ordinary time when the emergency packets are not input.

On the other hand, in immediate-transmission scheme, the BS interrupts the transmission of non-emergency packets and transmits the emergency packet immediately [15], [16]. However, the immediate-transmission scheme degrades the performance of non-emergency packets because some of them are discarded. In [17], information indicating the location of packets discarded by the immediate-transmission scheme is retransmitted in subsequent packets. In [18], the BS retransmits the discarded parts of the non-emergency packets. These schemes have the problem that they require to transmit the additional information about the packets discarded by the immediate- transmission scheme, which degrades the radio resource usage efficiency.

Overall, these techniques have a tradeoff between the latency and the system throughputs. Moreover, for a use case in which the emergency packets occur frequently, the efficiency of the radio resource usage needs to be improved. Therefore, this paper proposes an efficient immediate-transmission approach without any indication or retransmission of missing parts of the non-emergency packets. To detect the emergency packet easily, the BS transmit known signals that are the orthogonal sequence for the emergency packet. In that case, the receiver can recognize the emergency packet arrival, but it cannot get the additional information about the accident.

Hence, this paper proposes that the BS can transmit any information in the emergency packet. The proposed scheme has two features: 1) the BS repeatedly transmits emergency packets without additional control information, 2) the emergency packet is detected by calculating the correlation between neighboring packets. When an emergency packet is transmitted, the result of the correlation has a peak so that the receiver can detect the existence of the emergency packet. When an emergency packet is detected, combining repeated emergency packets can improve the reception performance of the emergency packet. In contrast to TTI shortening, the proposed scheme does not increase the control overhead because the TTI of the proposed scheme is the same length as that of the conventional. As described above, the proposed scheme without additional control information can achieve low latency of emergency packets and radio resource usage efficiency.

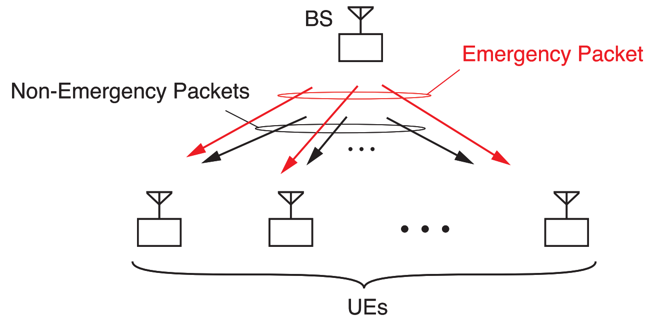

FIGURE 1. System model.

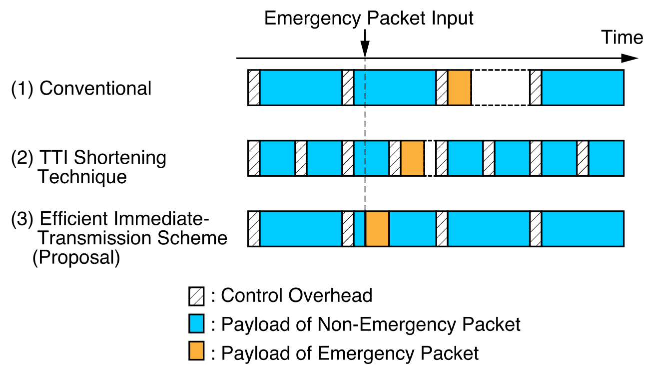

FIGURE 2. Time chart example showing each technique.

The rest of the paper is organized as follows. Section 2 presents the system model and problems of the emergency packet input. Section 3 describes the proposed efficient immediate-transmission scheme. In section 4, computer simulation results show the performance of the proposed scheme. Finally, section 5 concludes the paper.

II. SYSTEM MODEL AND PROBLEMS OF EMERGENCY PACKET INPUT

We consider the system model shown in Fig. 1, in which user equipment (UE) communicates with one base station (BS). The use case is assumed the local area communications in the closed area of the building such as factories or warehouses. The interference from the other system, which uses the same radio resources, is not considered. We focus on downlink transmission in which the BS transmits and the UEs receive signals. This downlink transmission uses orthogonal frequency division multiplexing (OFDM). The radio resource unit that the BS and UEs use for transmission is called a resource block (RB) and consists of multiple subcarriers and OFDM symbols. Thus, the BS transmits downlink data to a UE by using RBs that the BS allocates preliminarily to the UE. These are the same conditions as in 5G New Radio (NR).

Downlink packets addressed to connected UEs from the host network are input to the BS. In ordinary times, the BS transmits non-emergency packets to UEs by using

RBs. On the other hand, in emergency times, the BS transmits an emergency packet immediately to avoid an accident for AGVs or production-line robots. This emergency information is shared within the system for safety. As BS transmits the emergency packet in a broadcast manner without any downlink control information, all UEs can detect the emergency packet and can recognize the emergency condition in the neighborhood. To avoid the crisis for a specific UE or UE group, the payload of the emergency packet can include the command which has UE's ID number and information about the exact emergency condition. The UE's ID number may set a number unlike UE_ID beforehand because UE exists in the closed area.

When an emergency packet to UEs is input to a BS, the BS is required to transmit it as soon as possible to avoid an accident or other danger. This packet has the highest priority, but in a conventional system, the BS transmits it in the next allocation period. Since the BS in the conventional system waits for the next allocation period, the BS cannot transmit the emergency packet immediately. Additionally, the length of the emergency packet is assumed shorter than that of a non-emergency packet. In such systems, redundant radio resources remain because of the length difference between a pre-scheduled non-emergency packet and the interposed emergency packet, as shown in row (1) of Fig. 2.

To reduce the amount of redundant radio resources and the waiting time for transmission, a TTI shortening technique has been proposed. In that technique, the TTI might be reduced to half the conventional interval, for example, as shown in row (2) of Fig. 2. This shortens the waiting time from packet input to the transmission and reduces the amount of unallocated radio resources. It is necessary, however, to include the control overhead in every frame, causing a problem of system capacity degradation by increasing the control overhead.

To solve these problems, this paper proposes a technique for immediate interposed transmission while maintaining high resource usage efficiency. Row (3) of Fig. 2 shows a time chart example for this technique. The TTI for transmission of non-emergency packets is the same as in the conventional technique. In the ordinary time, when no emergency packet is input, non-emergency packets are transmitted in the conventional way. In the proposed scheme, the control overhead is the same as in the conventional one. Specifically, the control overhead indicates only the information of the allocated RB for UEs receiving non-emergency packets. Then, when an emergency packet is input, the BS interrupts the transmission of non-emergency packets and transmits the emergency packet immediately. To do so, it uses a portion of the radio resources intended for non-emergency packets. Note that the radio resources and the transmission power are the same as in the conventional scheme. After transmitting the emergency packet, the BS resumes transmitting non-emergency packets. It discards part of a non-emergency packet while transmitting the emergency packet. As a result, the proposed scheme can reduce the waste of radio resources during emergency packet transmission

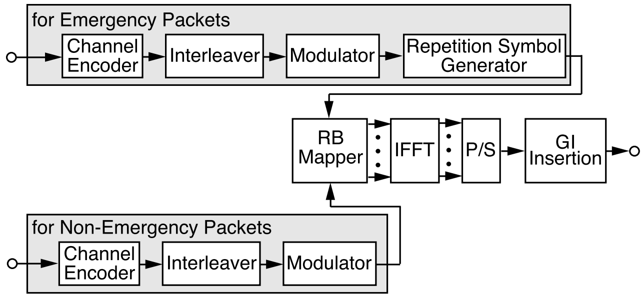

FIGURE 3. Block diagram of the transmitter for emergency and non-emergency packets.

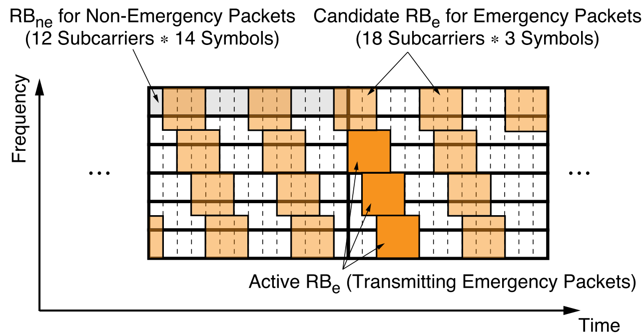

FIGURE 4. Example of the frames for emergency and non-emergency packets.

while meeting the emergency packet's latency requirement. The details are discussed below.

III. EFFICIENT IMMEDIATE-TRANSMISSION SCHEME

A. IMMEDIATE-TRANSMISSION SCHEME

Fig. 3 shows a block diagram of the transmitter in the proposed scheme. Two kinds of packets of different priority are input, i.e., emergency packets (higher priority) and non-emergency packets (lower priority). In general, the information bit sequence of either a non-emergency packet or an emergency packet enters a channel encoder for convolutional channel coding. Then, the encoded bit sequence is fed into an interleaver. Next, the outputs are mapped to complex symbols for M-quadrature ($M \geq 2$) amplitude modulation (QAM). The output complex symbols are then mapped to RBs. We denote RBs for non-emergency and emergency packets as an RB_{ne} and RB_{e}, respectively. Both RBs consist of mutual subcarriers and symbols, and Fig. 4 shows an example of RB mapping. An RB_{e} is mapped to overlap an RB_{ne}. The assigned complex symbols are fed into an N-point ($N \geq 2$) inverse fast Fourier transform (IFFT) processor. A guard interval (GI) with a length of Δ_G samples is added to the IFFT outputs in the time domain, which yields OFDM signals. Finally, the OFDM signals are up-converted to a radio frequency (RF) and transmitted by an antenna.

Next, we explain the transmission process for an emergency packet. When an emergency packet is input to the transmitter, it modulates the packet and stores the complex symbols in another line with the same processes as non-emergency packets. The repetition symbol generator copies

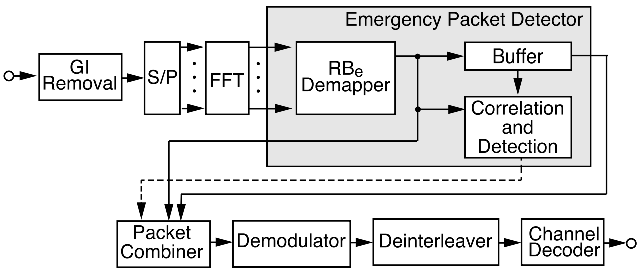

FIGURE 5. Block diagram of the receiver for emergency packets.

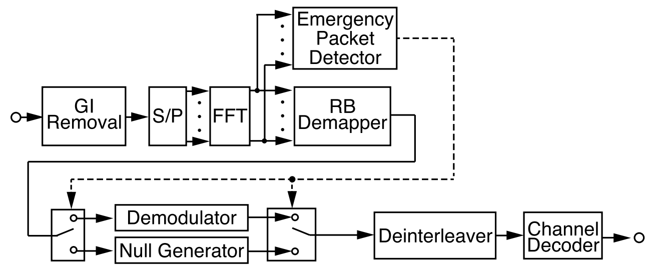

FIGURE 6. Block diagram of the receiver for non-emergency packets.

the emergency packet's complex symbols to detect the emergency packet without additional control overhead. The transmitter assigns them to the next RB_e, which shifts the time and frequency from the previous RB_e, as shown in Fig. 4. The proposed scheme can thus reduce the effect on the RB_{ne} and the transmission delay time by shifting the time and frequency without transmitting the same subcarrier in succession. To transmit the emergency packet at any timing, the candidate of RB_e for each one OFDM symbol is set. The subcarrier position for RB_e is fixed, but UEs can know it without the additional control overhead, which indicates RB_e position. The repetition symbol generator assigns the copied complex symbols of the emergency packet Q_{ep} times in succession. When the transmitter assigns the emergency packet's complex symbols to the RB_e, it discards those of the non-emergency packet overlapping the RB_e.

B. DETECTION FOR EMERGENCY PACKETS

Fig. 5 shows a block diagram of the receiver for emergency packets. The OFDM signals are propagated over multipath fading channels and received by an antenna. After down-conversion and GI removal, the received signals are fed to a fast Fourier transform (FFT) processor, which outputs the subcarrier signals in the frequency domain. It is assumed that the transmission time offset plus the maximum delay time of the propagation paths does not exceed the GI length.

Next, the emergency packet detector extracts the subcarrier signals of the corresponding RB_e from the received signals and calculates the correlation between adjacent RB_e. The n-th subcarrier signal for the i-th OFDM symbol, $r(n, i)$, can be expressed as

$$r(n, i) = h(n)s(n, i) + N(n, i), \tag{1}$$

where $N(n, i)$ is fast-Fourier-transformed white Gaussian noise for the n-th subcarrier and i-th OFDM symbol. Here, we denote a subcarrier set on the t-th RB_e as $\phi_{ep}(t)$. Then, $\boldsymbol{r}_{ep}(t)$, which has the subcarrier elements of $\phi_{ep}(t)$, is an N_{ep}-by-1 subcarrier signal vector for the t-th RB_e:

$$\left\langle \left(\boldsymbol{r}_{ep}(t-1)\right)^{T} \boldsymbol{r}_{ep}(t) \right\rangle > \beta_{TH}, \tag{2}$$

where $\langle\cdot\rangle$ denotes the ensemble mean, and β_{TH} is a threshold for emergency packet detection. For the case of an emergency packet, the transmitter transmits the same emergency packets by using neighboring RB_e. If BS transmits emergency packets, the correlation between the signals of neighboring RB_e exceeds the threshold and receiver can detect the emergency packet. The detection performance for the emergency packet depends on β_{TH} and the noise power. Changing β_{TH} according to the reception condition(s) of actual target UE(s) can adjust the detection performance.

C. DEMODULATION FOR EMERGENCY PACKETS

Let us explain how to demodulate emergency packets. When the correlation between the signals of neighboring RB_e exceeds β_{TH}, the receiver recognizes the emergency packet arrival. In that case, the receiver detects the same two emergency packets. To improve the demodulation performance for the emergency packet, the detected RB_e are combined by maximum likelihood detection (MLD) [19]. The channel decoder decodes the information bit sequences by using the combined signals.

The number of repetitions is determined by BS based on β_{TH} in advance according to the distance between BS and each UE. To command details for the UE at the cell edge, BS transmits the emergency packet three times or more. On the other hand, for the UE near BS, BS transmits it two times. In this case, the command for UEs near BS may not be demodulated by UEs at the cell edges. Since the information is not addressed to the UE at the cell edge, UE doesn't need to demodulate it.

D. DEMODULATION FOR NON-EMERGENCY PACKETS

Fig. 6 shows a block diagram of the receiver for non-emergency packets. The receiver of the non-emergency packet also has the emergency packet detector. When the receiver does not detect an emergency packet, it picks up allocated RBs and demodulates them. A channel decoder decodes the demodulated signals into information bit sequences, fed to a cyclic redundancy check (CRC) to detect bit errors. On the other hand, when the receiver detects an emergency packet, it replaces the overlapped subcarrier signals of non-emergency packets with null signals [16].

IV. COMPUTER SIMULATION

A. SIMULATION CONDITIONS

Computer simulations were conducted to verify the performance of the proposed scheme. It is assumed that the system

TABLE 1. Simulation conditions.

Transmission scheme	OFDM in downlink
Number of FFT points, N	128
Number of available subcarriers	72
Subcarrier spacing	15 kHz
Bandwidth	1.4 MHz
Modulation	QPSK
Channel encoding	Convolutional coding (constraint length: 7)
Coding rate	1/2
Number of Tx antennas	1
Number of Rx antennas	1
Size of RB_{ne} (non-emergency packet)	$N_{nep} = 12$, $I_{nep} = 14$
Size of RB_e (emergency packet)	$N_{ep} = \{18, 24, 36, 72\}$, $I_{ep} = \{1, 2, 3, 4, 5\}$
Number of repeat transmissions, Q_{ep}	1 – 5
Power ratio between non-emergency and emergency packets	0 dB
Channel model	6-path Rayleigh fading with exponential decay
Maximum Doppler frequency	0 Hz
r.m.s. delay spread	500 ns
Channel estimation	Ideal

will be used in closed spaces such as factories or warehouses. And there is no interference from other systems. Table 1 lists the simulation parameters. We considered OFDM for the downlink transmission scheme. The numbers of Tx and Rx antennas were set to both one for simplicity. To clarify the principle of the proposed method, the bandwidth was set to 1.4 MHz, the minimum bandwidth of LTE, and the number of available subcarriers was set to 72. The BS could simultaneously use six RBs to transmit non-emergency packets. In other words, the number of subcarriers for one RB_{ne} was $N_{nep} = 12$. Since the number of symbols for one RB_{ne} was set to $I_{nep} = 14$, non-emergency packets were transmitted using 12×14 subcarriers. The candidate numbers of subcarriers and symbols for emergency packets were $N_{ep} = \{18, 24, 36, 72\}$ and $I_{ep} = \{1, 2, 3, 4, 5\}$, respectively. The emergency packets were transmitted using RB_e arranged in advance, and the total number of subcarriers for RBe was $N_{ep}I_{ep}$. The transmission power was the same between emergency and non-emergency packets; the power ratio was 0 dB. The channel impulse responses were assumed to follow multipath Rayleigh and block fading. They were also assumed to be statistically independent of each other and time-invariant so that the maximum Doppler frequency equaled 0 Hz.

B. IMPACT ON NON-EMERGENCY PACKET TRANSMISSION PERFORMANCE

First, we evaluated the performance impact on non-emergency packet transmission when an emergency packet was inserted. The effect of the emergency packet size on the block error rate (BLER) as the performance of the non-emergency packets is clarified. We assumed that the UEs knew the position of emergency packets exactly in Section IV-B. Since the emergency packet was inserted in every non-emergency

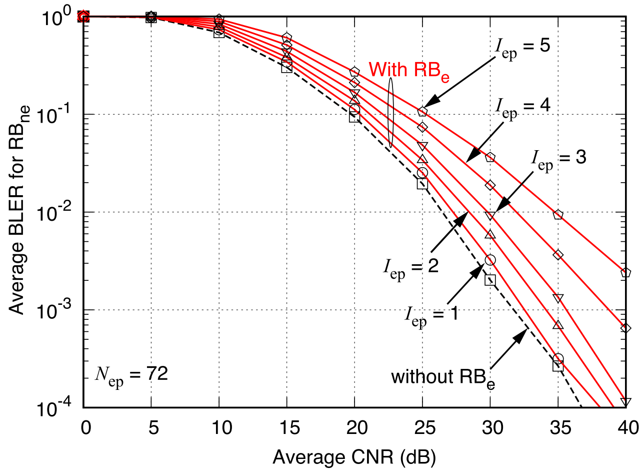

FIGURE 7. Average BLER for the non-emergency packet RB_{ne} for comparison with average BLER without the emergency packet. I_{ep} is a parameter, and N_{ep} was set to 72 that the emergency packet uses all subcarriers.

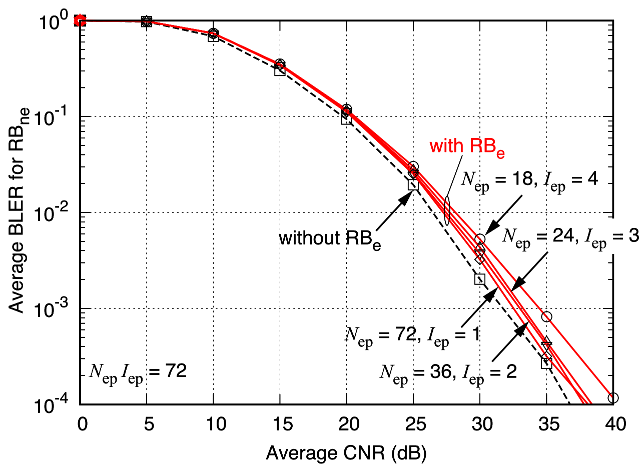

FIGURE 8. Average BLER for the non-emergency packet with N_{ep} and I_{ep} being parameters. The number of total subcarriers for RB_e was constant and set to 72.

packet one by one, the number of emergency packet transmissions was $Q_{ep} = 1$.

Fig. 7 shows the average BLER for non-emergency packets as a function of the average carrier-to-noise ratio (CNR). N_{ep} was set to 72. Since the emergency packet uses all subcarriers, it degrades the BLER performance for all the RB_{ne}s. The number of OFDM symbols for emergency packets is a variable parameter. For comparison, the figure also shows the average BLER for non-emergency packets when the BS does not transmit emergency packets. As the length of the emergency packet becomes long, the BLER performance for the non-emergency packet deteriorates. When the average BLER $= 10^{-3}$, the degradation is approximately 1 dB at $I_{ep} = 1$.

We clarified the performance when the number of subcarriers used by the emergency packet changes. Fig. 8 shows the average BLER with N_{ep} and I_{ep} as parameters. The number of total subcarriers for the emergency packet was constant and

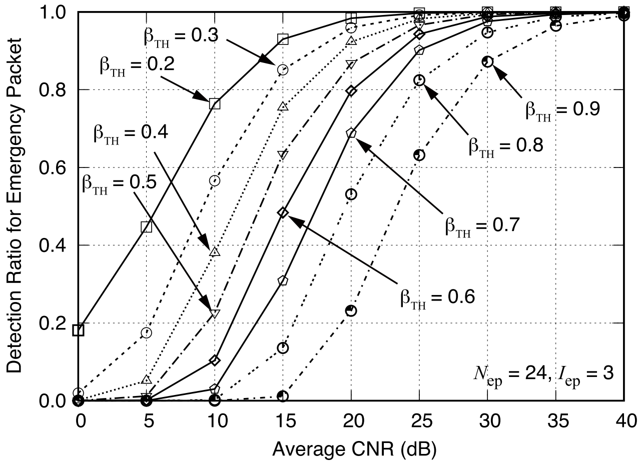

FIGURE 9. Detection ratio for the emergency packet with detection threshold, β_{TH}, is a parameter. The size of the emergency packet was set to $(N_{ep}, I_{ep}) = (24, 3)$.

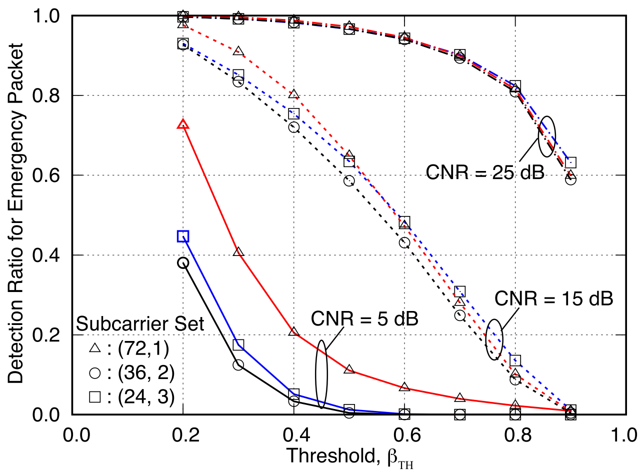

FIGURE 10. Detection ratio for the emergency packet as a function of β_{TH}. For comparison, there is three noise conditions: CNR = 5, 15, 25 dB.

set to $N_{ep}I_{ep} = 72$. It can be seen that the average BLER decreases with smaller N_{ep}. As N_{ep} becomes smaller, I_{ep} becomes larger because total subcarriers are constant. As can be seen from the results in Fig. 7, the BLER degrades as the number of overlapping symbols increases. We can see that the degradation for the non-emergency packet is less than 2 dB when $I_{ep} < 4$, so it is preferable to set $I_{ep} < 4$.

C. EMERGENCY PACKET DETECTION PERFORMANCE

Next, to clarify the detection capability of emergency packet, we evaluated the detection performance for emergency packets in terms of the detection and false-alarm ratios. The detection ratio for the emergency packet was defined as the correct detection ratio when BS transmits the emergency packet. The false-alarm ratio was defined as the misdetection ratio when UEs detect the emergency packet, but BS does not transmit it. The number of total subcarriers for the emergency packet was again set to $N_{ep}I_{ep} = 72$. The number of times repeatedly transmitting the emergency packet, Q_{ep}, was set to two.

TABLE 2. Summary of detection parameter.

Parameters	
N_{ep}	Not using all subcarriers
I_{ep}	Short length is better
β_{TH}	0.4

Fig. 9 shows the detection ratio for the emergency packet with the threshold β_{TH} being a parameter. The subcarrier set of the emergency packet was set to $(N_{ep}, I_{ep}) = (24, 3)$. As the average CNR increases, the detection ratio improves. As the threshold, β_{TH}, increases, the detection ratio increases even at low CNR. Fig. 10 shows the detection performance with the subcarrier set being a parameter at each CNR. The subcarrier set of the emergency packet, (N_{ep}, I_{ep}), was set to (24, 3), (36, 2), and (72, 1). It can be seen that a smaller β_{TH} improves the detection ratio in the lower-CNR region, especially when the number of subcarriers is $N_{ep} = 72$. This is because the frequency diversity effect improves the detection ratio as RB_e uses all subcarriers.

Fig. 11 shows the false-alarm ratio for the emergency packet with various detection thresholds being a parameter. The subcarrier set of the emergency packet, (N_{ep}, I_{ep}), was also set to (24, 3), (36, 2), and (72, 1). For the conditions of $(N_{ep}, I_{ep}) = (24, 3)$ and (36, 2) in Fig. 11 (a) and (b), it can be seen that the false alarm does not occur when $\beta_{TH} > 0.4$ and CNR > 25 dB. It is difficult to recognize between emergency packets and noise when β_{TH} is less than 0.4. On the other hand, there are false alarms for most β_{TH} in the high CNR region in $(N_{ep}, I_{ep}) = (72, 1)$. In this case, the correlation result is very high because all subcarriers of one RB_e are the same as that of the neighboring RB_e. Therefore, even if there is no emergency packet, the UE detects the presence of the emergency packet, resulting in a false alarm. In other words, it is better for the RB_e not to use all subcarriers According to these results, the parameters for the detection of the emergency packet should be the following: (1) do not use all subcarriers, (2) I_{ep} should be short, and (3) set the threshold to 0.4. These are summarized in Table 2.

In this paper, emergency packets are detected by calculating the correlation between neighboring RB_es. The proposed scheme is a basic technique, and other techniques to improve the detection rate and false-alarm ratio have been investigated [20]. For example, noise level normalization and a constant false-alarm rate method have been proposed. By combining these techniques with the proposed scheme, the detection rate and false-alarm ratio can be improved.

D. TRANSMISSION PERFORMANCE IMPROVEMENT FOR EMERGENCY PACKETS WITH REPETITION

Finally, we evaluated the emergency packet transmission performance. The BLER for the emergency packets considering the detection ratio was clarified the performance of the emergency packet. In addition, the overall system performance

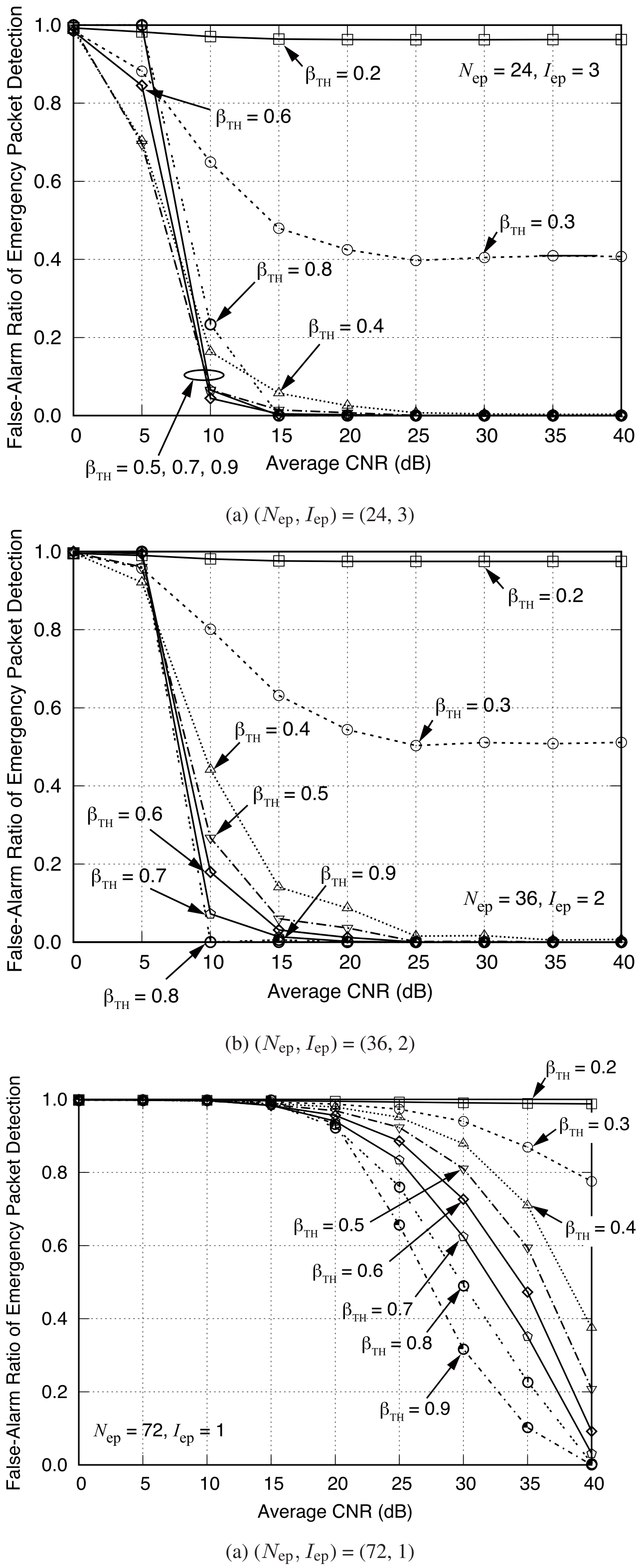

FIGURE 11. **False-alarm ratio for the emergency packet with detection threshold, β_{TH}, is a parameter. The number of a total subcarrier for all results is the same and set to 72.**

was evaluated by the system throughput. According to the results described above, the size of the emergency packet was set to (N_{ep}, I_{ep}) = (24, 3), and β_{TH} was set to 0.4. Fig. 12

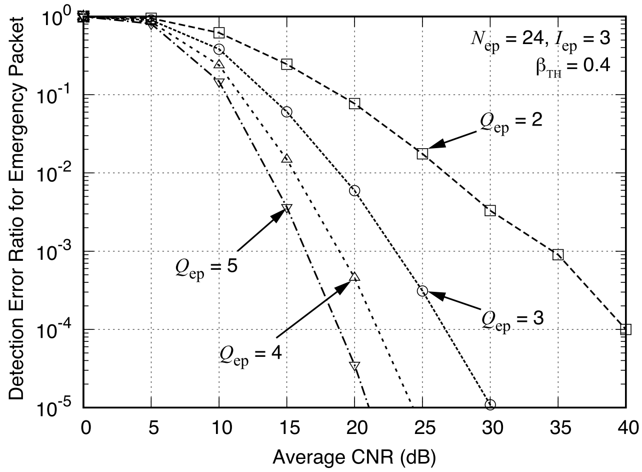

FIGURE 12. **Detection error ratio for the emergency packet with the number of repeat transmissions, Q_{ep}, is a parameter. The subcarrier of the emergency packet is (N_{ep}, I_{ep}) = (24, 3), and the detection threshold is 0.4.**

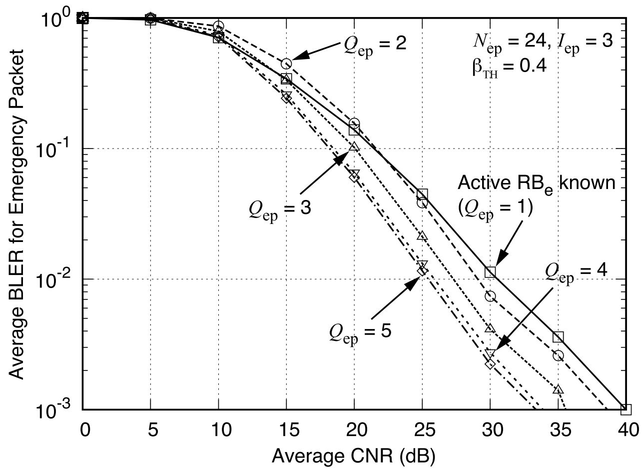

FIGURE 13. **BLER characteristics for the emergency packet with the number of repeat transmissions, Q_{ep}, is a parameter for comparison with the result with the position of RB_e known. The subcarrier of the emergency packet is (N_{ep}, I_{ep}) = (24, 3), and the detection threshold is 0.4.**

shows the detection error ratio for the emergency packet with the number of repeat transmissions, Q_{ep}, as a parameter. It can be seen that the detection error ratio decreases as the number of repeat transmissions increases. The proposed scheme achieves an emergency packet detection ratio of 99.999% ($= 1 - 10^{-5}$) at CNR >21 dB when the number of repeat transmissions is $Q_{ep} = 5$. For CNR > 21 dB, the UE can thus recognize almost every emergency packet arrival and provide instructions to stop a device.

To evaluate the emergency packet transmission performance, Fig. 13 shows the average BLER characteristics for the emergency packet with the number of repeat transmissions as a parameter. This average BLER includes the effect of detection error. For comparison, the figure also shows the average BLER when the subcarrier position for transmission of the emergency packet is known, and the number of transmissions is one (i.e., $Q_{ep} = 1$). The

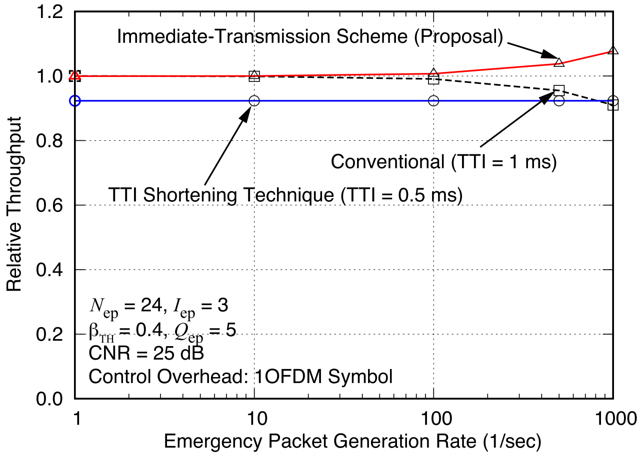

FIGURE 14. System throughput of the immediate-transmission scheme compared with that of the conventional scheme. The packet generation rate for the emergency packet is a parameter. The control overhead for these results are the same and one OFDM symbol.

BLER performance improves as Q_{ep} increases. However, in the lower CNR region, the BLER characteristics at $Q_{ep} = 2$ deteriorate compared to those at $Q_{ep} = 1$ because the proposed scheme has a lower detection ratio and higher false-alarm ratio. The BLER characteristics at $Q_{ep} = 4$ and 5 are the same because of using all the subcarriers for the repeat transmissions. It can be seen that the BLER is 0.05 at CNR = 21 dB when the emergency packet detection ratio is 99.999%. These simulations did not use Hybrid automatic repeat request (ARQ), so introducing Hybrid ARQ would improve the BLER performance [21]. In addition, shortening the round-trip time of HARQ has been proposed, and can be combined with proposed immediate-transmission scheme to expect further reduction of the delay transmission time [22], [23].

Fig. 14 shows the system throughput for overall system performance, and the emergency packet generation rate is a parameter. For simplicity in clarifying the effect of the proposed scheme, adaptive modulation and coding (AMC) and retransmission of each packet (e.g., Hybrid ARQ) were not considered. We defined the system throughput as the throughput relative to that in an ordinary time when no emergency packet was input. In other words, the system throughput performance clarifies how much the proposed scheme can improve the throughput by transmitting additional emergency packets. The CNR was 25 dB, and $Q_{ep} = 5$. The control overhead was set to one OFDM symbol. For comparison, the results of conventional and TTI shortening techniques, as shown in Fig. 2, were also shown. In the conventional scheme, the BS transmitted the emergency packet at the next frame after it was input. For the TTI shortening technique, the TTI was set to 0.5 ms, which is half that of the conventional scheme. The numbers of subcarriers and symbols for TTI shortening were $N_{nep\_short} = 12$ and $I_{nep\_short} = 7$.

As seen in Fig. 14, the proposed scheme maintains the system throughput as the ratio of emergency to non-emergency packets increases. On the other hand, the conventional scheme decreases the system throughput. Since the length of the emergency packet is shorter than that of the non-emergency packet, the number of subcarriers that are not used for transmission increases. Lastly, it can be seen that the TTI shortening technique degrades the relative throughput, and the relative throughput is constant despite the packet generation rate. Since the frame size without the control overhead for TTI shortening is $N_{nep\_short}(I_{nep\_short} - 1) = 72$ subcarriers, the frame size for TTI shortening is the same as that for the emergency packet. On the other hand, the frame size of the conventional scheme without the control overhead is $N_{nep}(I_{nep} - 1) = 156$ subcarriers. The TTI shortening technique can transmit two RBs, however, while the conventional scheme transmits one RB. Therefore, the relative throughput is

$$\frac{N_{nep\_short}(I_{nep\_short} - 1) \times 2}{N_{nep}(I_{nep} - 1)} \simeq 0.92, \tag{3}$$

and this matches the simulation results, which show 8% degradation. Table 3 summarized the relative throughput of each scheme when the emergency packet generation rate is 1000 (1/sec). It can be seen that the proposed scheme can improve the throughput by about 17% compared to the conventional one. As a result, the effectiveness of the proposed immediate-transmission scheme was validated in terms of the throughput performance.

TABLE 3. Summary of system throughput when packet generation rate is 1000 (1/sec).

Conventional	TTI Shortening	Immediate-Transmission
0.91	0.92	1.08

V. CONCLUSION

This paper has proposed an efficient immediate-transmission scheme to achieve highly reliable and low-latency wireless communication in closed areas with non-emergency background traffic. When the emergency packet is input, the BS interrupts the transmission of non-emergency packets and transmits the emergency packet immediately. The TTI is the same as in the conventional scheme in ordinary times. The BS transmits the emergency packet several times, displacing it to shift subcarriers and OFDM symbols, and the receiver of the emergency packet then calculates the correlation between each RB_e. The correlation value exceeding the threshold is considered as the detection of emergency packet. Moreover, the multiple packets are combined to improve the reception performance of the emergency packet. Computer simulation has shown the detection performance of emergency packets and the overall system. When the total number of subcarriers of emergency packets is the same, the degradation of BLER for non-emergency packets can be reduced to less than 2 dB when the number of OFDM symbols is less than 4. For the detection of emergency packets, 1) not using all subcarriers, 2) reducing the number of OFDM symbols for the emergency packet, and 3) setting the threshold to 0.4 can improve the detection ratio and reduce the false-alarm ratio. The detection ratio of emergency packets is achieved 99.999% when CNR > 21 dB and the proposed scheme can improve the system throughput by about 17% compared to the conventional scheme.

REFERENCES

[1] L. Atzori, A. Iera, and G. Morabito, ''The Internet of Things: A survey,'' *Comput. Netw.*, vol. 54, no. 15, pp. 2787–2805, Jun. 2010.

[2] *5GMF White Paper: 5G Mobile Communications Systems for 2020 and Beyond Version 1.1*, Fifth Gener. Mobile Commun. Promotion Forum, Japan, Sep. 2017.

[3] 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.

[4] *IMT Vision—Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond*, document ITU-R M.2083-0, Sep. 2015.

[5] S. E. E. Ayoubi, M. Boldi, O. Bulakci, M. Schellmann, P. Marsch, M. Saily, J. F. Monserrat, T. Rosowski, G. Zimmermann, I. Da Silva, M. Tesanovic, M. Shariat, and A. M. Ibrahim, ''Preliminary views and initial considerations on 5G RAN architecture and functional design,'' 5G PPP, METIS II 5G PPP White Paper, Mar. 2016. [Online]. Available: https://metis-ii.5g-ppp.eu/wp-content/uploads/white_papers/5G-RAN-Architecture-and-Functional-Design.pdf

[6] *Study on Scenarios and Requirement for Next Generation Access Technologies (Release 14)*, document 3GPP TR 38.913, Version 14.0.0, Dec. 2016.

[7] K. Hiltunen, Y. Yang, and F. Chernogorov, ''Impact of network densification on the performance of a non-public URLLC factory network,'' in *Proc. PIMRC*, Sep. 2021, pp. 1570–1575.

[8] H. Ji, S. Park, J. Yeo, Y. Kim, J. Lee, and B. Shim, ''Ultra-reliable and low-latency communications in 5G downlink: Physical layer aspects,'' *IEEE Wireless Commun.*, vol. 25, no. 3, pp. 124–130, Jun. 2018.

[9] M. Iwabuchi, A. Benjebbour, Y. Kishiyama, G. Ren, C. Tang, T. Tian, L. Gu, T. Takada, and T. Kashima, ''5G field experimental trials on URLLC using new frame structure,'' in *Proc. GC Wkshps*, Dec. 2017, pp. 1–6.

[10] S. Xiaotong, H. Nan, and Z. Naizheng, ''Study on system latency reduction based on shorten TTI,'' in *Proc. ICSP*, Nov. 2016, pp. 1293–1297.

[11] J. Li, H. Sahlin, and G. Wikström, ''Uplink PHY design with shortened TTI for latency reduction,'' in *Proc. WCNC*, Mar. 2017, pp. 1–5.

[12] *Technical Specification Group Radio Access Network, NR (Release 15)*, document 3GPP TS 38.211, Version 15.0.0, 2017.

[13] Y. Chen, L. Cheng, and L. Wang, ''Prioritized resource reservation for reducing random access delay in 5G URLLC,'' in *Proc. PIMRC*, Oct. 2017, pp. 1–5.

[14] C.-C. Chang, S.-S. Wang, and S.-T. Sheu, ''On beam-based channel reservation for URLLC in unlicensed spectrum,'' in *Proc. VTC-Fall*, Nov. 2020, pp. 1–5.

[15] *5G: Views on Technology and Standardization*, document 3GPP RWS-150012, Qualcomm, Sep. 2015.

[16] K. I. Pedersen, G. Pocovi, J. Steiner, and S. R. Khosravirad, ''Punctured scheduling for critical low latency data on a shared channel with mobile broadband,'' in *Proc. IEEE VTC-Fall*, Toronto, ON, Canada, Sep. 2017, pp. 1–6.

[17] ''DL URLLC/eMBB dynamic multiplexing and indication design,'' 3GPP TSG-RAN WG1 #88 R1-1702639, Qualcomm Incorporated, Athens, Greece, Feb. 2017.

[18] ''On DL multiplexing of URLLC and eMBB transmissions,'' 3GPP TSG RAN WG1 Meeting #88 R1-1701663, Huawei, HiSilicon, Athens, Greece, Feb. 2017.

[19] R. Nagareda, K. Fukawa, and H. Suzuki, ''OFDM mobile packet transmission system with multiuser detection and metric combining ARQ,'' *IEICE Trans. Commun.*, vol. E88-B, no. 1, pp. 106–114, Jan. 2005.

[20] M. M. Sebdani and M. J. Omidi, ''Detection of an LTE signal based on constant false alarm rate methods and constant amplitude zero autocorrelation sequence,'' in *Proc. ICIAS*, 2010, pp. 1–6.

[21] A. M. Cipriano, P. Gagneur, G. Vivier, and S. Sezginer, ''Overview of ARQ and HARQ in beyond 3G systems,'' in *Proc. PIMRC*, Sep. 2010, pp. 424–429.

[22] Y. Shiomitsu, E. Okamoto, M. Mikami, and H. Yoshino, ''Poster: Performance analysis of early HARQ retransmission scheme in highway environments,'' in *Proc. VNC*, Dec. 2020, pp. 1–2.

[23] S. AlMarshed, D. Triantafyllopoulou, and K. Moessner, ''Deep learning-based estimator for fast HARQ feedback in URLLC,'' in *Proc. PIMRC*, Sep. 2021, pp. 642–647.

HIDEYA SO (Member, IEEE) received the B.E. degree from the Tokyo University of Science, Japan, in 2009, and the M.E. and D.Eng. degrees from the Tokyo Institute of Technology, Japan, in 2011 and 2021, respectively. From 2011 to 2021, he was with the NTT Access Network Service Systems Laboratories, NTT Corporation. He involved in has researched on high-reliability radio access, base station antennas, and adaptive arrays for the future wireless access systems. He is currently working with the Shonan Institute of Technology. He is also a member of IEICE. He received the IEICE Radio Communication Systems (RCS) Active Researcher Award in 2011, the IEICE Young Researcher's Award in 2016, and the IEICE Best Paper Award in 2016.

DAISUKE MURAYAMA (Member, IEEE) received the B.E., M.E., and Ph.D. degrees in electrical engineering from Keio University, Yokohama, Kanagawa, Japan, in 2005, 2007, and 2015, respectively. Since 2007, he has been with the NTT Access Network Service Systems Laboratories, NTT Corporation, Atsugi, Kanagawa, where he researches wireless and optical access networks and systems. His current research interests include 5G NR and other unlicensed wireless access networks, passive optical networks, system control, and measurement engineering. He is currently a member of IEICE.