2-2 Radio Access Technologies for Massive Machine-Type Communications

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In the IoT era, a radio access technology collects small-size messages sending from user equipment (UE) to base station (BS) is crucial in frequency efficiency viewpoint, especially in massive machine-type communications (mMTC). Some part of mMTC application fields like connected cars or drones needs a radio access technology that provides low latency. We have been engaging to develop a radio access technology that covers the requirements on both efficiency in frequency usage and low latency, by introducing a radio frame structure with resource blocks (RBs) shared by multiple UEs without grant from BS. We have conducted performance evaluation through link level simulations towards realizing a radio access technology that RBs are shared by 5 UEs per one BS antenna with latency of less than 5 ms.

1 Introduction

For the fifth generation mobile communication system (5G), system requirements include enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC), and massive machine-type communications (mMTC), and R&D for realizing 5G has been promoted in countries all around the world. Especially, as a point of difference with conventional mobile communication systems, there are expectations that 5G will cover IoT services, and in addition to massive numbers of IoT devices as user equipment (UE) being connected to base stations (BS), it is projected that a wide range of diverse services will be on offer [1].

Along with massive connections, there are also expectations over the provision of services that require low latency, such as autonomous driving, and there will be a need for technology that can realize low latency while concurrently realizing an increase in the number of UE that can be connected to a BS on the same time and frequency resource. In the IoT environment, which has vast numbers of devices such as sensors connected to it, radio access technologies without iterative procedures such as radio resource scheduling requests (SR) and the corresponding grants will make multiple connections and low latency possible; but, because signal collision probability increases as the number of connected UE increases, the efficient detection of signal collision during times of multiple connections becomes an issue.

In order to solve this issue, we are involved in R&D related to radio access technologies that are equipped with (1) technology that identifies transmitting terminals and establishes both multiple connections and low latency and (2) technology that suppresses or eliminates interference. With existing radio access technologies, only one terminal can be connected at the same time on the same frequency to each individual antenna of a BS or access point. In contrast to this, simultaneous connection with multiple terminals can be realized with this radio access technology.

2 Development of the Radio Access Technology

Figure 1 shows an outline of radio access technology that realizes simultaneous connectivity and low latency. With this radio access technology, frequency usage efficiency is improved by having multiple UEs share the same frequency at the same time, and latency is reduced by employing data transmission without grant, which minimizes the scheduling requests before data transmission when UE has data to be sent to BS.

In order to realize this radio access technology, because multiple UEs will be sharing the same frequency at the same time, there will be a need for (1) technology that can identify the UEs that are connected at the same time and (2) technology that suppresses or eliminates interference

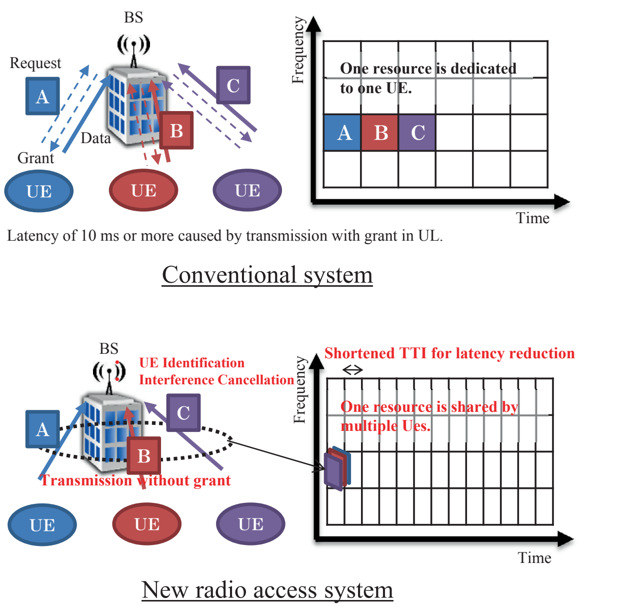


Fig. 1 Outline of radio access technology that realizes simultaneous connectivity and low latency

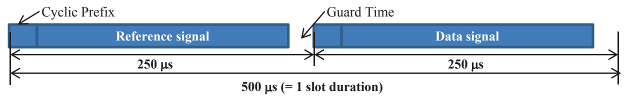


Fig. 2 Basic structure of the radio frame [3]

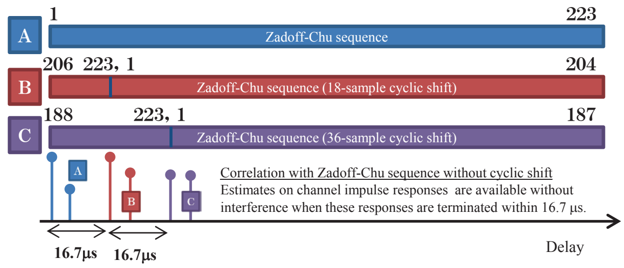


Fig. 3 Reference signal structure example

between UE signals. Those technologies will be explained below. Further, in the designing of this radio access technology, based on a scenario [2] premised on its use with IoT devices, the channel bandwidth will be set at 1.08 MHz.

2.1 Structure of radio frame

Here we discuss the structure of the radio frame for uplink data transmission from UE to BS. Figure 2 shows the basic structure of the radio frame. The time slot has a total length of 500 µs and is composed of a 250 µs reference signal and a 250 µs data signal. The reference signal is used for the purposes of identifying the UE terminals and estimating the channel impulse response between the UE and BS. The data signal is used to transfer data sent from UE. Transmission delay is minimized by sending a reference signal and a data signal without intermission.

Here we discuss the structure of the reference signal. By using orthogonal sequences for the reference signal, even when signals are being sent by multiple UE terminals on the same time and frequency resource—in addition to identifying the sending UE—estimation of the channel impulse response necessary for the data demodulation and decoding is conducted. In the current R&D at hand, we employ the Zadoff-Chu sequence for the orthogonal sequence, which is also used in LTE-A. When using this sequence, in order to estimate the channel impulse response without interference between signals from UE terminals, it is necessary to assign each UE terminal with a Zadoff-Chu sequence having a cyclic shift time equal to or longer than the maximum propagation delay time of valid multi-paths. Among the channel models [4] for developing the technical specifications of the 5G radio access, the TDL-A channel model includes the longest delayed path in a non-line of sight environment, and the maximum delay time is approximately 3.5 µs. Further, assuming the BS-UE distance of 1,153 m and urban macro cell environment, propagation delay time from UE to BS is 3.8 µs. Considering the above, it would be necessary for the orthogonal sequence cyclic shift time in the reference signal to be equal to or larger than 7.3 µs, and also considering the synchronization error between BS and UE, 18 samples equivalent to 16.7 µs are set as the cyclic shift of the orthogonal sequence. In order to accommodate simultaneous connection of 12 UEs, it would be necessary for the sequence length to be 216 or more, and in the current R&D the Zadoff-Chu sequence length is set at 223. As was shown in Fig. 2, a 20-length sample (equivalent to 18.5 µs) cyclic prefix (CP) is added to a sequence that has been cyclically expanded to a length of 225. Figure 3 shows an example of the structure of the reference signal when cyclic shift has been applied. By assigning different cyclic shift numbers for each UE terminal, it becomes possible to identify the UE even when the BS simultaneously receives reference signals from multiple UEs. In the grant-free transmission scheme, a UE-specific cyclic shift number is assigned to each UE.

Next, we discuss the structure of the data signal. Figure 4 shows the processing of information bits for the data signal in each UE terminal. After the information bits are scrambled, 8 bit cyclic redundancy check (CRC) encoding is performed. Following this, turbo encoding (coding rate: 1/2 or 1/3; constraint length: 4) is performed. After QPSK or 16-QAM modulation, CP is inserted and the transmission signal is generated. As was shown in Fig. 2, in the structure of the radio frame under this radio access method, guard time is set in order to avoid interference from the following time slots. Through a combination of the coding rate and modulation scheme, transmittable information bit numbers (message size) in the unit data signal section can be changed to between 17–54 bytes. Because a 20 byte message size is assumed in the usage scenario for mMTC [2], the design is made in accordance with this scenario.

2.2 Interference suppression/cancellation technology

Here we discuss technology that suppresses or cancels interference in data signals. In transmission without grant, because a UE-specific cyclic shift number is given in orthogonal sequence for reference signals, signal separation is possible. However, because data signals are not in orthogonal sequence there needs to be suppression or cancellation of interference between UE terminals. All UEs sharing the same frequency at the same time are assumed as using the same coding rate and modulation scheme, and, using the channel impulse response estimated from the reference signal, interference among UE data signals is suppressed or cancelled. Regarding the method, we evaluate the two shown in Fig. 5 (successive interference cancellation (SIC) and parallel interference cancellation (PIC)).

With SIC, demodulation and decoding is carried out in order of the highest strength incoming signal, and when it is determined from the result of the CRC decision there is no bit error, a signal replica is created and interference is removed by subtracting this from the received signal wave form. However, in order for the demodulation and decoding to succeed, as a condition, some signal-to-interference ratio (SIR) must be required. On the other hand, because the computational cost will increase in a linear fashion in accordance with an increase in the number of connected UEs, processing can be completed with less latency compared with the PIC method, which is discussed below.

With PIC, from the received wave form and the estimated channel impulse response of each UE, the likelihoods are calculated for all possible combinations of transmission signals from each UE terminal, and from that result, log likelihood ratio (LLR) of the codeword bit sent from the UE is calculated. After that, decoding is carried out in a turbo decoder, and the obtained external information is fed back and used to update the LLR and the transmitted data from each UE is estimated. Although there are no restrictions on the SIR condition among UE signals in the PIC method, because all combinations of transmission signals need to be taken into account, the computational cost in-

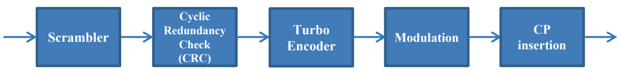
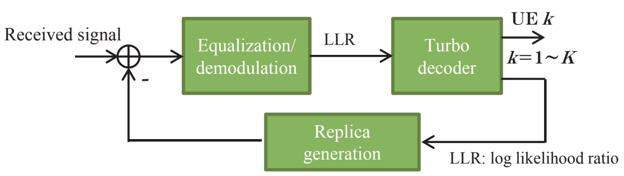
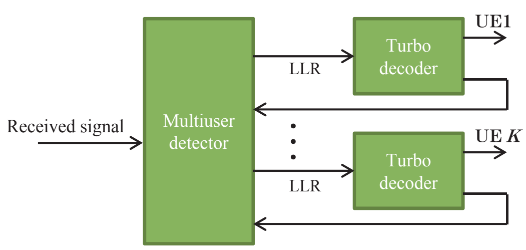


Fig. 4 Data signal generation block diagram



(a) Successive Interference Cancellation (SIC) [3][5]–[8]



(b) Parallel Interference Cancellation (PIC) [6][9][10]

Fig. 5 Outline of interference suppression/cancellation techniques

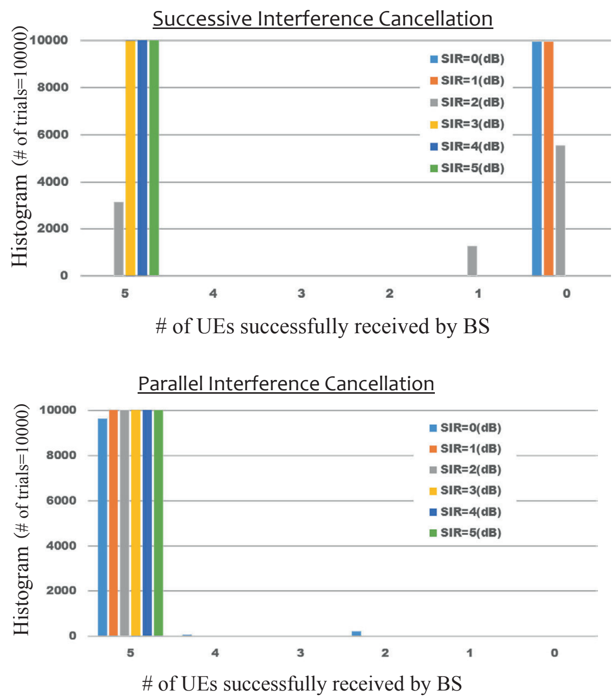


Fig. 6 Performance evaluation results for interference suppression/ cancellation technologies

creases exponentially with the increase in number of connected terminals.

The performance evaluation results for the two methods are shown in Fig. 6. A histogram shows the number of terminals with successfully separated signals when the interference power ratio of the signal is changed. With the simultaneously connected number of UE terminals at five, the horizontal axis shows the number of terminals for which separation was successful. We conducted 10,000 trials with the modulation method as QPSK and the coding rate of the turbo encoder at 1/3. In regard to the reference signal, a different cyclic shift number was given to each UE terminal, and in interference suppression/cancellation processing we used the channel impulse response estimated from the received reference signal. From the performance evaluation results, it is shown that in order to obtain a successful separation rate of 90% or more, SIR needs to be set at 3 dB or higher in SIC. On the other hand, in PIC, even if SIR is 0 dB, it can be seen that a successful signal separation rate of 90% or more is possible.

In regard to these interference suppression/cancellation, hardware demonstration using FPGA has been reported in terms of achievable latency [11] [12]. Further, in regard to the number of accommodated UE terminals, we are also carrying out evaluations when using transmission without grant, which minimizes scheduling requests before data transmission [13]. In order to fulfill the objective of this R&D, which is to realize a 5 ms or less latency even in a field environment, we are working to improve algorithms for interference suppression/cancellation.

3 Future prospects

In this paper, we showed our R&D directed toward realizing radio access technologies that accommodate small-size data derived from massive numbers of IoT devices within the network with high efficiency and low latency. In order to improve frequency usage efficiency, we are pursuing R&D on radio access technologies that use transmission without grant, which does not require transmission scheduling requests, to decrease the latency by making it possible for multiple UE terminals to share the same frequency at the same time. In the future, we plan to conduct performance evaluations in the field considering mMTC usage scenarios.

Acknowledgments

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