Technology Reports 5G URLLC Demonstration

Special Articles on Demonstration of New Technologies for 5G

Field Experiments on 5G Ultra-Reliable Low-Latency Communication (URLLC)

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Standardization deliberation and technical demonstrations are progressing toward implementation of 5th Generation mobile communications systems (5G). One usage scenario that is anticipated for 5G is URLLC, which is needed for applications such as autonomous vehicles and remote controls. NTT DOCOMO has conducted field trials toward realization of URLLC. This article gives an overview of URLLC and discusses the field trials done jointly with Huawei Technologies, to demonstrate URLLC over distances up to 1 km, along with the latest test results.

1. Introduction

5th Generation mobile communications systems (5G) are highly anticipated for handling explosive increases in traffic and diversification of services. Organizations such as the 3GPP are deliberating on standards, and major organizations and enterprises throughout the world are conducting demonstrations toward introduction of 5G. NTT DOCOMO has also been actively working toward implementation of 5G since about 2010, proposing technology concepts, conducting experiments, and taking leadership in standardization deliberations.

Typical usage scenarios for 5G include (1) enhanced Mobile Broad Band (eMBB), (2) massive Machine Type Communications (mMTC), which realizes large numbers of simultaneous connections, and (3) Ultra-Reliable and Low-Latency Communications

(URLLC) [1]. URLLC has received particular attention for its potential in new use cases in the future, such as autonomous vehicles, tactile communications, and remote medicine. In collaboration with Huawei Technologies, NTT DOCOMO has conducted the first successful field trials simultaneously achieving both high reliability and low latency, as required for URLLC. This article gives an overview of URLLC and describes these field trials.

2. Overview of URLLC

5G use cases and technical requirements for realizing them have been discussed in industry organizations within and outside of Japan [1]-[3]. For eMBB, requirements have been set to extend speed and capacity, as they were with 4G and earlier.

On the other hand, expectations in industry are growing for the Internet of Things (IoT), so requirements for mMTC and URLLC have been set anticipating integration in industries other than mobile communications, such as automobiles, robots, and sensors.

2.1 URLLC Use Cases

URLLC is targeted mainly for services such as traffic control or remote control, which require both high reliability and low latency. The following use cases are typical examples [3].

1) Control of Autonomous Vehicles and Traffic Control

This use case involves sending warning signals between vehicles and other vehicles, roadways, and even pedestrians to reduce traffic accidents, improve traffic efficiency and support movement of emergency vehicles.

2) Robot Control and 3D Connection with Drones and Other Devices

Automation of manufacturing and logistics using robots at smart factories and other facilities is anticipated, and control of these is a use case for 5G. It is also expected to cover airborne as well as terrestrial applications, so ability to control drones and other devices in the air remotely is also specified.

3) Remote Surgery

Remote surgery can be implemented using optical communications or other fixed networks, but this is difficult to apply in disaster areas or other dangerous situations. Remote surgery in such locations is another use case for 5G.

All of the above use cases require high reliability and low latency, and in most cases, the wireless systems are to be used for sending the control signals. For these cases, there are strict requirements on 5G URLLC regarding reliability, low latency, and mobility rather than high transmission speed or large numbers of connected terminals.

2.2 URLLC Requirements and Issues

End-to-end target values for URLLC, including the core network, have been discussed, but this article describes only the URLLC requirements for the radio access network.

1) URLLC Requirements

There are various URLLC requirements that have been defined by industry organizations such as 3GPP, stating the certainty that an X-byte packet will be received successfully with latency under a set time [4]. Here, latency refers to the time from the start of processing of the service data unit*1 at wireless protocol layer*2 2 (or 3) in the transmitter, to when the packet has been received successfully. This is called the radio segment latency, or user plane*3 latency. The definition of user plane latency is shown in **Figure 1**. User plane latency is the one-way latency for successful reception of a packet, and includes the time for one or more retransmissions if packet reception fails. From the above, URLLC implementations must satisfy a probability that at least a set number of packets are received successfully (reliability), while also satisfying user plane latency below a set value (low latency). Concrete target values have also been proposed. 3GPP has set a target of "user plane latency of 1 ms or less for transmission of a 32-byte packet, with successful reception rates of 99.999% or better."

2) Issues in Meeting Requirements

To meet URLLC requirements for reducing latency requires (1) reducing radio signal transmission time, and (2) reducing time needed for retransmissions, and for increasing reliability, requires (3) improving successful packet reception rates. These requirements are described in detail below.

(1) Reducing radio signal transmission time

The longer the slot length, which is the unit of signal transmission, the longer the wireless signal transmission time will be. For example, with LTE-Advanced, which is a 4th generation mobile communications system (4G), the user plane latency to transmit just the wireless signal was over 1 ms. As described earlier, the user plane latency includes signal processing latency for both transmission and reception, so reducing the slot length is desirable.

(2) Reducing time needed for retransmissions

Successful packet reception rates can be increased through signal retransmission, but the retransmission procedure requires signaling on the uplink and downlink, which introduces delay. For example, if the mobile terminal does not receive a signal correctly on the downlink, or if the downlink signal is not received within a fixed time, a Negative ACKnowledgement (NACK)*4 signal is fed back on the uplink channel. When the base station receives the NACK signal, it sends a

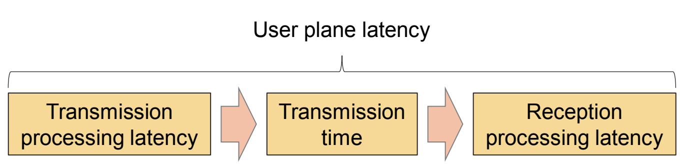

Figure 1 User plane latency definition

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*1 Service data unit: The data without added headers, etc.

*2 Protocol layer: A communications protocol layer defined in the OSI reference model, which is a design guideline for network architectures. Protocol layer 2 refers to the data link layer, and protocol layer 3 refers to the network layer.

*3 User plane: The part of the signal sent and received in communication, which contains the data sent and received by the user.

*4 NACK: A signal sent to notify the sending party that the data was not received correctly. Note that a signal called an ACK is sent to indicate that the data was received correctly.

retransmission signal on the downlink channel. This improves the packet reception success rate, but the user plane latency increases due to the retransmission procedure. Thus, it is important to reduce the time required for retransmission in order to achieve both high reliability and low latency.

(3) Improving successful packet reception rates

To increase successful packet reception rates with low latency, it is desirable to receive packets successfully with one transmission, and avoid retransmissions to the extent possible. Packet reception success rates tend to drop particularly in multipath environments*5, where the radio channel tends to degrade due to fading*6. High successful packet reception rates must be maintained even in such environments.

3. Technologies for Realizing URLLC

New air interfaces have been discussed for high reliability and low latency, including new radio frame structures, retransmission schemes, and grant free access*7. Below, we describe technologies for realizing URLLC, focusing on the technologies used in our field trials. Note that the trials assumed a Time Division Duplex (TDD)*8 format.

3.1 Radio Frame Structure for Reducing Transmission Time

1) Radio Frame Structures Studied for NR

A New Radio (NR), which is not backward compatible with LTE-Advanced, is being studied in 5G deliberation at 3GPP. To meet various requirements such as supporting high-frequency bands, NR uses multiple different Orthogonal Frequency Division Multiplexing (OFDM)*9 subcarrier*10 intervals (15, 30, 60, and 120 kHz) [5]. Using wide OFDM subcarrier intervals like 120 kHz provides wider bandwidth per subcarrier, so that the same amount of information can be transmitted in a shorter time. This enables the transmission time for the radio signal to be shortened, reducing latency. However, it also reduces the number of subcarriers, so ignoring overhead, the amount of information that can be sent in a set period of time is the same.

An approach that introduces the mini-slot*11, with the conventional 15 kHz OFDM subcarrier interval, has also been proposed [6]. The time required for retransmissions can also be reduced by designing a radio frame that allows rapid switching of transmission between the uplink and the downlink. The trials described here use an approach with a wide OFDM subcarrier interval and a new radio frame design to reduce latency.

2) Radio Frame Structure Used in Trials

The radio frame structure used in testing is shown in **Figure 2**. This frame structure has a 60 kHz subcarrier interval, an OFDM symbol*12 length of 16.67 μs defined by the inverse of the subcarrier interval, and an added Cyclic Prefix (CP)*13 of length 1.56 μs. This frame structure is composed of special slots and normal slots. A normal slot has six-OFDM symbols for downlink or uplink data transmission and two-OFDM symbols for guard time*14. This results in 0.125 ms each on up and down links, for a total slot length of 0.25 ms. This enables the transmission time to be reduced. Note that a special slot requires more control signals and has twice the

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*5 Multipath environment: An environment in which the signal from the transmitter arrives directly, superimposed with signals reflected from buildings and other features in the environment.

*6 Fading: The phenomenon in which the level of the received signal fluctuates with movement of the mobile station and the passage of time.

*7 Grant free access: A format in which the mobile station can transmit without first receiving permission to transmit (grant) from the base station.

*8 TDD: A format in which downlink and uplink communication is segmented in time, with transmission and reception alternating.

*9 OFDM: A multi-carrier transmission scheme that uses orthogonal narrow-band carriers. Many wireless communication systems such as LTE-Advanced and Wi-Fi® use OFDM. Wi-Fi is a registered trademark of the Wi-Fi Alliance.

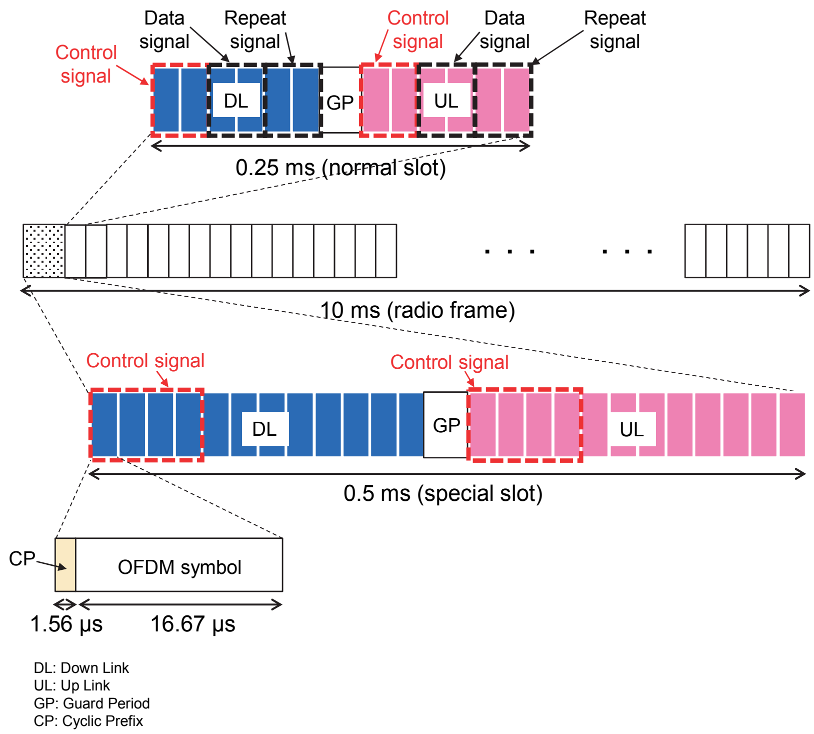

Figure 2 Radio frame structure used in trials

number of OFDM symbols for data and repeat signals of a normal slot, so the total slot length for up and down links is 0.5 ms. A radio frame contains one special slot.

This radio frame structure uses a TDD format. Since it switches between downlink and uplink every 0.125 ms, feedback signals such as ACK and NACK can be sent quickly, reducing the time required for retransmissions. With the LTE-Advanced TDD format, 10 to 11 ms was needed from signal transmission to retransmission, but this can be reduced to approximately 0.75 to 1 ms with this radio frame structure.

3.2 Transmission of Repeated Signals

As described earlier, packet success probability can be improved using retransmission, but it increases user plane latency. Packet success probability can also be improved by repeating transmission of signals even before feedback signals such as NACK are sent. Sending the same signal multiple times reduces transmission efficiency, but it is able

*10 Subcarrier: Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*11 Mini-slot: A slot defined with a shorter than normal slot length.

*12 OFDM symbol: A unit of transmission data consisting of multiple subcarriers. A CP (see *13) is inserted at the front of each symbol.

*13 CP: The guard interval added to the beginning of an OFDM symbol. It reduces the effects of inter-symbol interference due to the previous OFDM symbol in delayed signals and loss of orthogonality among subcarriers.

*14 Guard time: An interval established when using a TDD format. Prevents collision of uplink and downlink signals due to transmission delay.

to improve packet success probability without increasing user plane latency. In the radio frame structure used in these trials, the first two OFDM symbols on the downlink or uplink are used as control signals, the next two OFDM symbols as data signals. Then, the two OFDM symbols after the data signal are used to send a repeat signal.

3.3 Multi-antenna Diversity Technology

Another approach of improving packet success probability is to use diversity technology[*15] with multiple antennas. Diversity technology can be used to prevent a drop in packet success probability in multipath environments. Our trials adopted transmission antenna diversity technology with eight antennas on the base station and two antennas on the mobile terminal. The transmit antenna diversity technology used was a format called Space Frequency Block Coding (SFBC)[*16], with two antennas [7]. Note that the two signals output with SFBC at the base station were each transmitted from four antennas, so a total of eight antennas were used.

4. URLLC Field Trials

URLLC field trials were conducted at NTT DOCOMO in collaboration with Huawei Technologies. An overview of the trials and results is given below.

4.1 Test Overview

The trials were conducted in the Yokohama Minato-Mirai 21 district.

Photographs of the test equipment are shown in **Figure 3**. The Radio Frequency (RF)[*17] and Intermediate Frequency (IF)[*18] units of the base station were located on the roof of the building, and the height of the antennas was approximately 108 m. The baseband[*19] unit of the base station and other equipment were located inside the building and were connected to the IF unit by optical fiber. The mobile station antennas were mounted on top

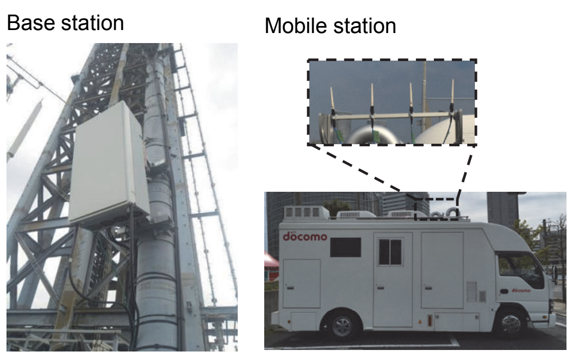

Figure 3 External view of test equipment

*15 **Diversity technology:** A technology that reduces drops in received-signal level due to fading by selecting among or synthesis from multiple received signals that have low correlation.

*16 **SFBC:** A type of transmit diversity technology in which Alamouti coding is used between adjacent subcarriers on two transmit antennas, and by coding between frequencies and antennas, diversity gain equivalent to maximal ratio combining can be obtained.

*17 **RF:** A signal or radio wave of frequency used as a carrier for radio communications.

*18 **IF:** An intermediate frequency used in transmitters and receivers when converting to the carrier signal frequency.

*19 **Baseband:** The signal band before modulation and after demodulation on the carrier wave of a radio signal.

of a test vehicle, at a height of 3.2 m. Other mobile station equipment was installed inside the vehicle.

Test equipment specifications are shown in **Table 1**. Tests were done using a 20 MHz bandwidth in the 4.5 GHz band, and measurements were taken using different Modulation and Coding Schemes (MCS)*20, depending on packet size. The packet sizes used in the trials were 32, 50, 100, and 200 bytes.

The test environment as seen from the base station is shown in **Figure 4**. Trials were done with the test vehicle both stationary and moving. Stationary tests were done at points A, B, and C with different transmission distances from the base station, as shown in Fig. 4, and at point D, which was not in the line-of-sight of the base station. The moving tests were done along the running course shown in Fig. 4. A driving speed was 25 km/h during the tests.

Table 1　Test equipment specifications

Main specifications	Base station	Mobile station
Central frequency	4.66 GHz	
System bandwidth	20 MHz	
Signal waveform	Filtered-OFDM	
OFDM subcarrier interval	60 kHz	
OFDM symbol length	16.67 μs	
Slot length	0.125 ms	
Guard time	31.25 μs	
CP length	1.56 μs	
Channel encoding	Polar coding	
MIMO mode	SFBC	
No. of MIMO streams	1	
No. of antenna elements	8	2
Antenna tilt angle	16.4°	0°
Antenna height	108 m	3.2 m
Max. transmission power	46 dBm	23 dBm
Traffic model	Transmitting packets of the same size at fixed intervals	
Packet size	32, 50, 100, or 200 bytes	

Polar coding: A communications coding method that uses polarization that occurs when repetitive operations are applied on the communication path.

*20 MCS: A combination of modulation scheme and coding rate determined beforehand when performing adaptive modulation.

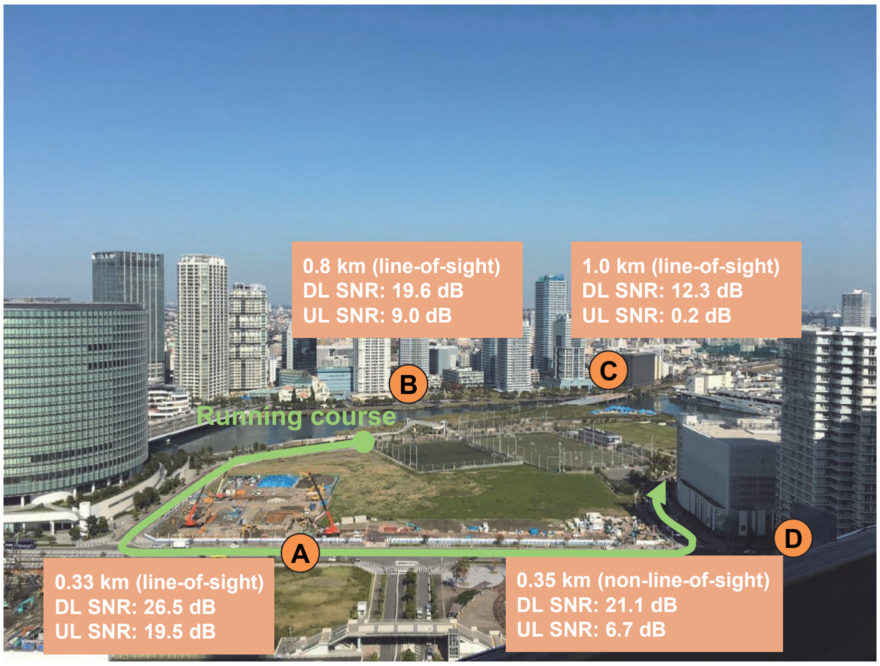

Figure 4 Test environment

4.2 Test Results

In these trials, we evaluated the maximum packet size for which the 3GPP URLLC requirements could be achieved. The test results are summarized in **Table 2**.

1) Stationary Trials (within Line-of-sight)

In stationary testing, 200-byte packets were transmitted on both uplink and downlink over distances of approximately 0.33 km to point A and 0.8 km to point B, satisfying latency of 1 ms or less, and a packet success probability of 99.999% or better. The same URLLC conditions were also met over the distance of approximately 1.0 km to point C with 100-byte packets. This verifies that URLLC can be realized over this range of distances.

The conditions were not met for point C with 200-byte packets because adequate Signal-to-Noise Ratio (SNR)*21 could not be obtained. With the radio frame structure, user plane latency of 1 ms or less cannot be achieved unless one packet is transmitted per slot. However, the SNR was insufficient when using the MCS needed to transmit a 200-byte packet in one slot for point C, and the packet success probability dropped. Conversely, when using an MCS able to maintain the packet success probability, multiple slots were required to send a 200-byte packet, resulting in user plane latency over 1 ms. In this way, the MCS must be selected in

*21 SNR: The ratio of the desired signal power to the noise power.

Table 2 Test results

Terminal conditions	Distance from base station	Transmitted packet data (max)	Radio segment delay	Transmission success rates
Stationary (line-of-sight)	Approx. 0.33 km	200 bytes	0.5 to 0.7 ms	99.999 to 100%
	Approx. 0.8 km	200 bytes		
	Approx. 1.0 km	100 bytes		
Stationary (non-line-of-sight)	Approx. 0.35 km	Downlink: 200 bytes Uplink: 100 bytes		
Moving (speed: 25 km/h)	Approx. 0.3 to 0.6 km	100 bytes		

consideration of the packet size and SNR for URLLC. Link adaptation technology*22, which switches MCS adaptively according to SNR, is used in many wireless systems. However, to switch MCS adaptively for URLLC, it must be done with consideration for both packet size and SNR, instead of just SNR as in earlier systems. Thus, to improve the characteristics of URLLC, improvements must be made to the MCS selection algorithm and the radio frame structure.

2) Stationary Trials (Non-line-of-sight)

URLLC requirements were also achieved for point D, in a non-line-of-sight environment where multipath effects were observed, while transmitting 200-byte packets on the downlink and 100-byte packets on the uplink. Reasons that the URLLC requirements were not achieved for 200-byte packets on the uplink, could be that the transmission power is less than on the downlink, or fluctuations in SNR due to multipath effects. This shows that the amount of data that can be transmitted as URLLC is limited by the radio environment. Assuming that URLLC services will be expanded widely in the future, it will be important to clarify coverage and upper limits on the amount of information that can be transmitted when providing services.

3) Mobile Trials

In mobile trials, the URLLC requirements were met with 100-byte packets on both downlink and uplink, in spite of screening by trees and other objects, and changes in direction of movement. These trials demonstrate that URLLC can be realized even when moving by car or other vehicle in urban areas, and show the potential for applications such as autonomous cars.

5. Conclusion

This article has given an overview of URLLC as a 5G use case and described field trials conducted by NTT DOCOMO. The trials have demonstrated that the URLLC requirements of high reliability and low latency can be met at the same time. However, to provide stable URLLC, further improvements

*22 Link adaptation technology: The function that selects MCS according to the radio environment. An MCS with high transmission rate is selected when conditions are favorable with a low transmission rate when they are poor.

to the radio frame structure and control algorithms are needed.

To support future services with flexibility, it is also desirable to increase the volumes of data that can be transmitted while satisfying the requirements of URLLC. It will also be necessary to clarify the transmission coverage that is possible. We will continue work toward resolving the issues identified in the field trials and creating new services using URLLC.

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