

Special Articles on 5G Technologies toward 2020 Deployment

5G Radio Access Technology

In parallel with the proliferation of smartphones, LTE services that can provide data transmission at even higher bit rates with low latency and high efficiency have been spreading rapidly, and the worldwide rollout of LTE-Advanced as an evolved form of LTE has already begun. Nevertheless, the need for further improvements in user QoE and system performance will surely increase going forward, and in anticipation of this need, studies on the next-generation mobile communications system (5G) have begun. This article describes the direction of technology development and promising component technologies for 5G RAT.

5G Laboratory, Research Laboratories

Anass Benjebbour**Keisuke Saito****Yuya Saito****Yoshihisa Kishiyama**

1. Introduction

Radio communications systems in mobile communications have undergone major changes about every ten years starting with the first generation (1G) deployed in the 1980s and evolving into the current fourth generation (4G) in the form of LTE/LTE-Advanced (**Figure 1**). There are key technologies for each of these generations, such as Code Division

Multiple Access (CDMA)*¹ for 3G and Orthogonal Frequency Division Multiple Access (OFDMA)*² and Multiple Input Multiple Output (MIMO)*³ for 4G. The fifth generation (5G), however, will differ from previous generations in that priority will be placed on meeting specific requirements, namely, ultra-high data rate, ultra-high system capacity, ultra-low latency, massive device connectivity, and low power consumption,

rather than on implementing completely new, pioneering technology. Here, the key issue will be how to combine a variety of component technologies in the best way to meet these requirements as Radio Access Technology (RAT)*⁴ matures. In this article, we survey the evolution of RAT toward 5G and describe key technologies from a 5G radio access perspective toward enhanced Mobile Broad Band (MBB) and the Internet of

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*1 **CDMA**: The transmission of multiple user signals over the same radio access channel by assigning each signal a different spreading code.

*2 **OFDMA**: A radio access scheme that uses OFDM. OFDM uses multiple low data rate single carrier signals for the parallel transmission of wideband data with a high data rate, thereby implementing high-quality transmission that is highly robust to multipath interference.

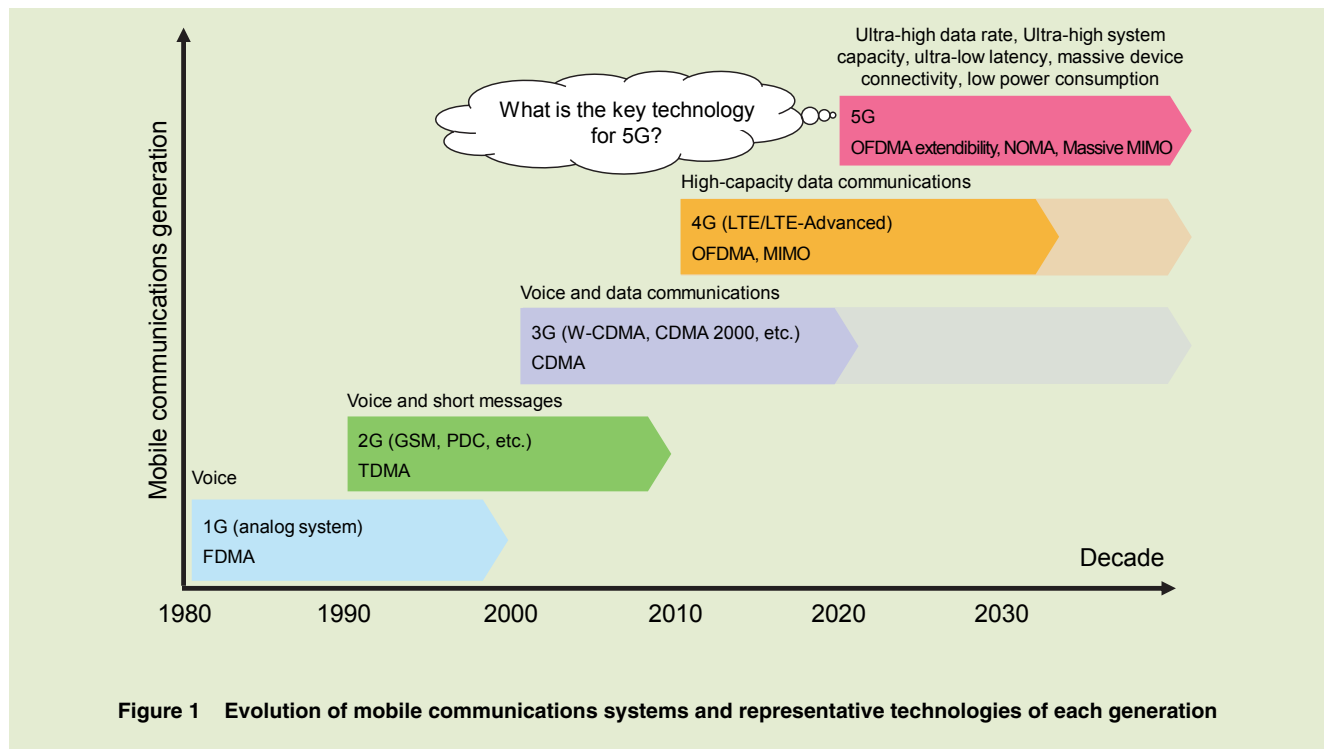


Figure 1 Evolution of mobile communications systems and representative technologies of each generation

Things (IoT)^{*5} era.

2. Evolution of RAT toward 5G

2.1 Ultra-high Data Rate, Ultra-high System Capacity Approach

The 5G system must achieve a dramatic leap in performance. Specifically, it must provide ultra-high data rate and ultra-high system capacity 100 times and 1,000 times, respectively, that of 2010, the first year of LTE services [1]. Here, we can consider the approach shown in **Figure 2** as a solution to increasing capacity. This approach combines technology for improving spectrum efficiency^{*6} (Fig. 2 (1)), technology

for effectively using wider bandwidths in a variety of frequency bands (Fig. 2 (2)), and technology for operating small cells in dense deployments (Fig. 2 (3)). If, by this approach, spectrum efficiency per cell (bps/Hz/cell), frequency bandwidth (Hz), and number of cells per unit area (cell/km²) in Fig. 2 (1), (2), and (3), respectively, can each be improved by ten times, a calculation of radio communications capacity per unit area (bps/km²) will give a value of 1,000 times existing capacity (corresponding to the volume of the cube appearing in the figure). In addition, applying technologies such as high-efficiency offloading of traffic to wireless LAN is likewise an effective approach

to increasing capacity that can be introduced in a mutually complementary manner (Fig. 2 (4)).

At the same time, extending and making effective use of frequency bandwidth in the next-generation mobile communications system will require the exploitation of higher frequency bands in addition to existing frequency bands used by 3G and 4G, and increasing the number of cells will invite higher network costs and increased power consumption. More efficient construction and operation methods are therefore needed. Further improvements in spectrum efficiency are also necessary as described above. In 5G, the above objectives must be achieved through novel

^{*3} **MIMO:** A signal transmission technology that improves communications quality and spectrum efficiency (see ^{*6}) by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

^{*4} **RAT:** Radio access technology such as LTE, 3G, and GSM.

^{*5} **IoT:** General term used to refer to control and information communications with the goal to connect all sorts of "things" to the Internet

and cloud.

^{*6} **Spectrum efficiency:** Maximum amount of information that can be transmitted per unit frequency (bps/Hz).

designs and effective technical solutions.

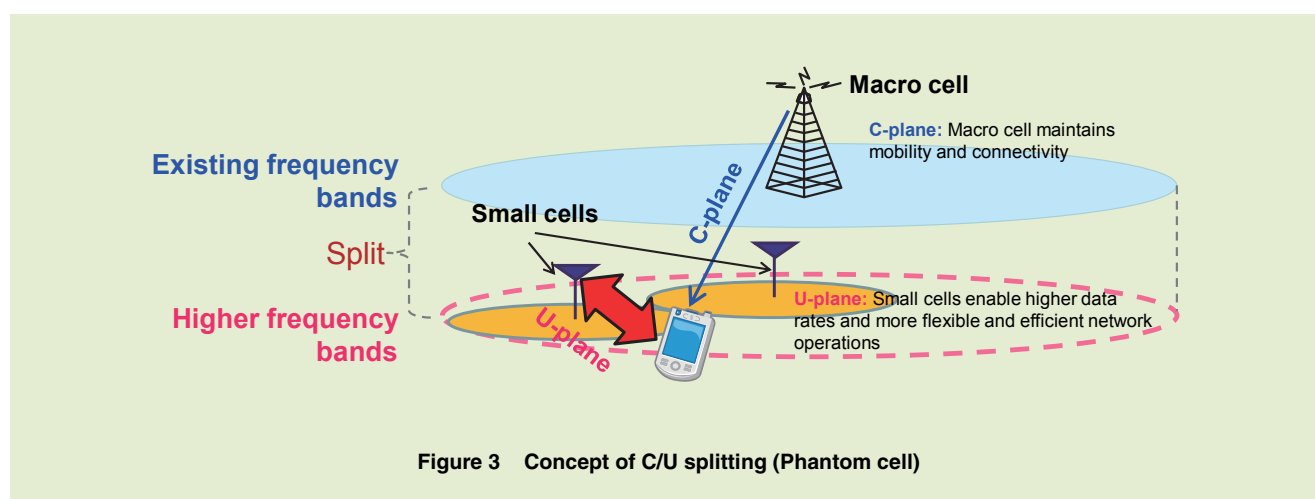
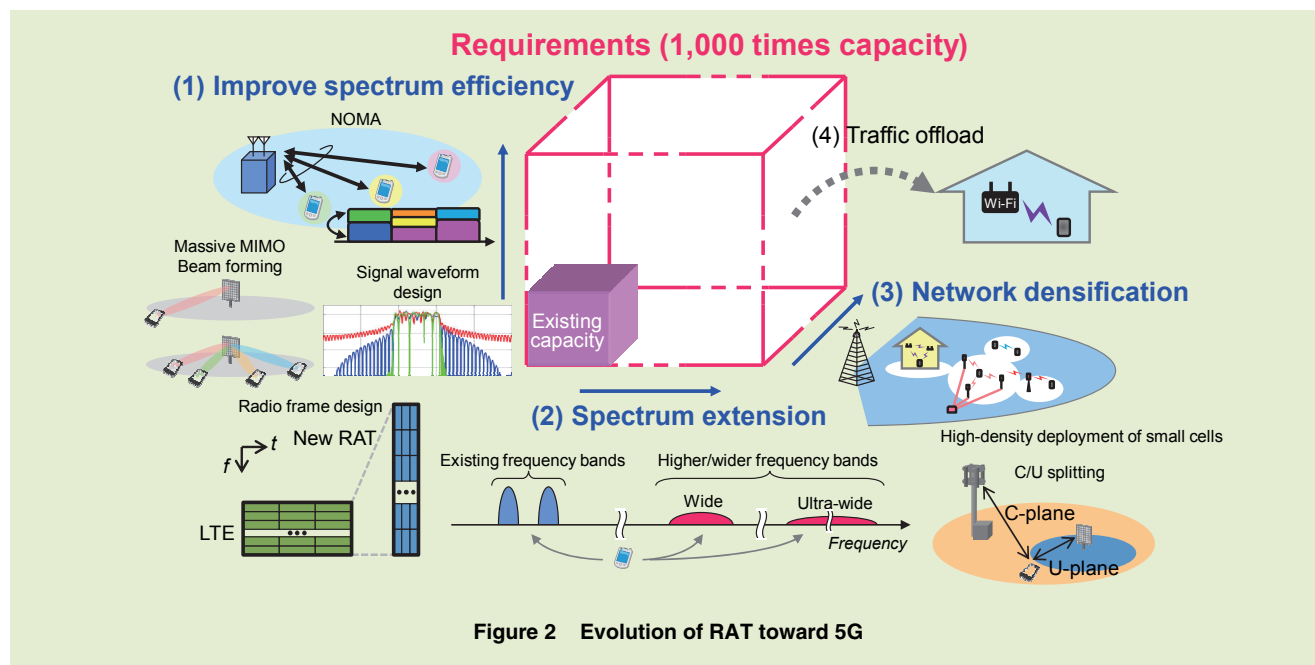
2.2 C/U Splitting (Phantom Cell)

NTT DOCOMO has proposed the Phantom cell concept as a means of linking different frequency bands and different RATs [2]. As shown in **Figure 3**, this refers to a network configuration

that uses C/U splitting in which the Control Plane (C-plane)^{*7} and User Plane (U-plane)^{*8} are split between a macro cell^{*9} and multiple instances of a small cell^{*10}.

Much like Advanced Centralized Radio Access Network (C-RAN)^{*11} [3] architecture based on LTE-Advanced

Carrier Aggregation (CA)^{*12} technology, this Phantom cell makes it easy to expand a cell to higher frequency bands without complicating mobility management and control as in handover^{*13} or other processes. Furthermore, as a feature not provided by Advanced C-RAN, the Phantom cell represents technology



^{*7} **C-plane:** Plane that handles control signals.

^{*8} **U-plane:** Plane that handles user data.

^{*9} **Macro cell:** A cellular communication area with a radius of from several hundred meters to several tens of kilometers used mainly to provide outdoor communications. Macro cell antennas are usually installed on towers or roofs of buildings.

^{*10} **Small cell:** General term for a cell covering a small area compared with a macro cell and having low transmission power.

^{*11} **Advanced C-RAN:** Technology for achieving

close coordination between a macro cell and small cells and increasing spectrum efficiency.

^{*12} **CA:** A technology for increasing bandwidth while maintaining backward compatibility by simultaneously transmitting and receiving multiple component carriers.

^{*13} **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal moves from the coverage area of a base station to another.

that can achieve C/U splitting even in a distributed base station configuration. In other words, it enables CA technology to be applied even among different base stations with separate baseband units.

Phantom cell technology also negates the need for a physical cell ID^{*14} in small cells using higher frequency bands, and compared with existing LTE/LTE-Advanced, it can accommodate advanced functional extensions such as virtualization technology for virtualizing cell IDs and technology enabling terminals to efficiently discover small cells [4]. One component technology related to Phantom cells is Dual Connectivity (DC), whose specifications have already been completed at the 3rd Generation Partnership Project (3GPP) as small-cell enhancement technology in LTE-Advanced. The Phantom cell is also basic to the 5G radio access concept of supporting both low and high frequency bands by combining enhanced LTE (eLTE) and New RAT.

2.3 New RAT Design

1) Support of Flexible Radio Parameters

In 5G, the introduction of New RAT, while allowing for non-backward compatibility with LTE, must mean a significant increase in performance. Specifically, to achieve bit rates of 10 Gbps and greater, New RAT must support higher frequency bands in addition to wider bandwidths from several hundred MHz to 1 GHz and higher. However, the effects of phase noise^{*15} can be large in high frequency bands, so there is a need here to improve resistance to phase noise such as by optimizing radio parameters. For example, LTE applies Orthogonal Frequency Division Multiplexing (OFDM) with a subcarrier^{*16} interval of 15 kHz as a signal format. However, as shown in **Figure 4**, widening the subcarrier interval (shortening the OFDM symbol^{*17} length) in high frequency bands can reduce the effects of interference between subcarriers and improve resistance to phase noise.

Here, a design that enables LTE ra-

dio parameters to be changed in a scalable manner according to the frequency band in use is an effective method for achieving radio parameters ideal for high frequency bands. An advantage of such a design is that terminals supporting both LTE and New RAT (dual mode) and terminals that can simultaneously connect to both low and high frequency bands (DC) would be relatively easy to implement. Furthermore, since the packet Transmission Time Interval (TTI)^{*18} can be simultaneously shortened by the shortening of the OFDM symbol length (lower left in Fig. 2), latency in the radio access interval can also be reduced.

2) High-efficiency Radio Frame Configuration

In New RAT, a high-efficiency radio frame configuration is deemed necessary. For example, LTE features a Cell-specific Reference Signal (CRS) that is mapped and widely dispersed along the time and frequency axes for use in data demodulation and mobility measurement (**Figure 5**). However, a base sta-

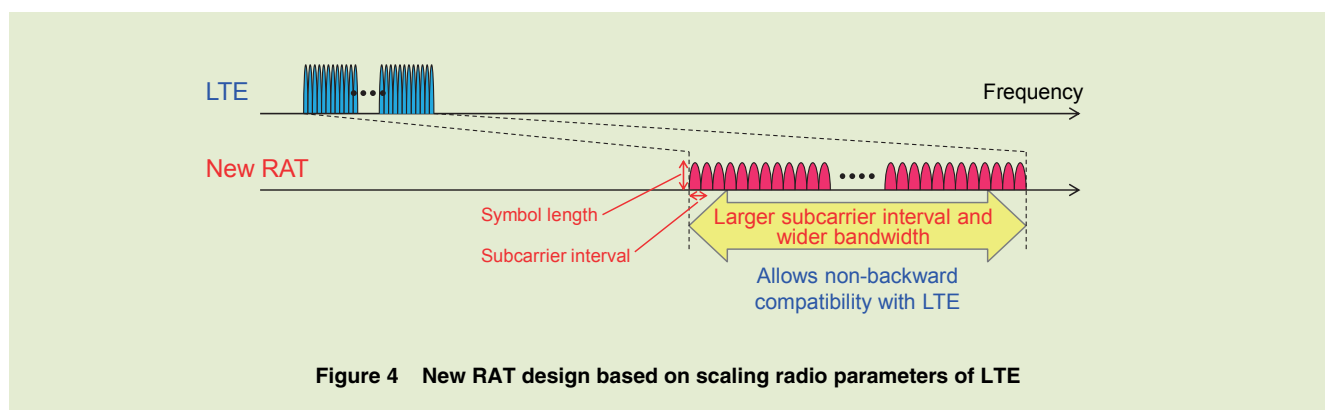


Figure 4 New RAT design based on scaling radio parameters of LTE

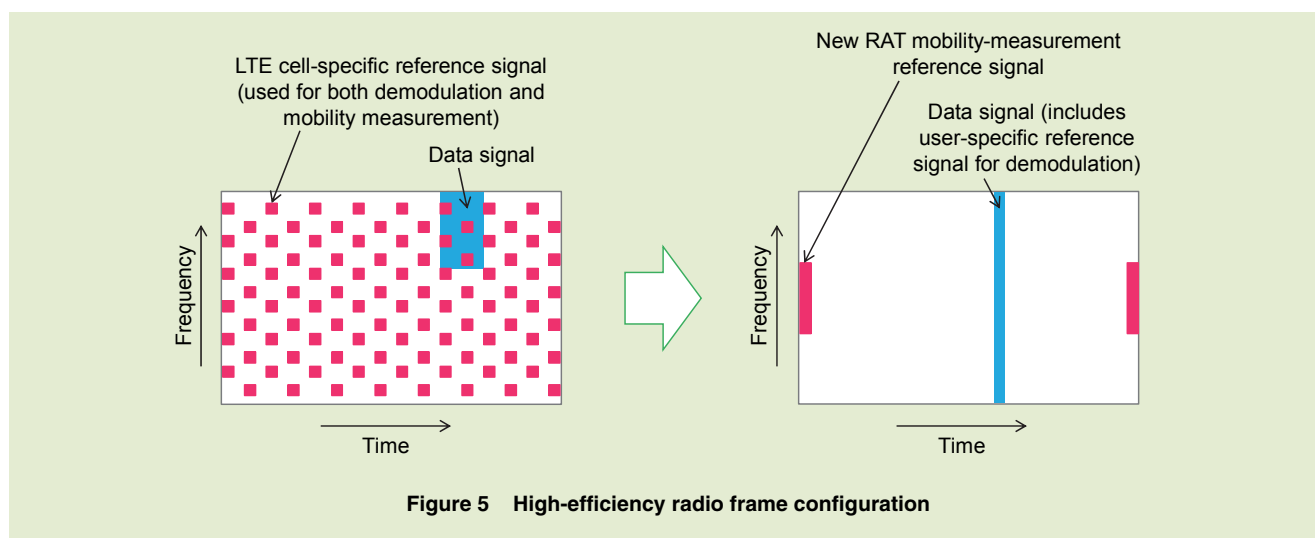
^{*14} **Cell ID:** Identifying information assigned to each cell.

^{*15} **Phase noise:** Phase fluctuation that occurs due to frequency components other than those of the carrier frequency in a local oscillator signal.

^{*16} **Subcarrier:** An individual carrier for transmitting a signal in multi-carrier transmission schemes such as OFDM.

^{*17} **OFDM symbol:** A unit of transmission data consisting of multiple subcarriers. A Cyclic Prefix (CP) is inserted at the front of each symbol.

^{*18} **TTI:** Transmission time per data item transmitted via a transport channel.



tion will regularly transmit CRS even during periods of no data traffic. These signals can therefore be a waste of energy while also interfering with other cells in environments having a dense deployment of cells as in urban areas.

Thus, for New RAT, studies are being performed on a high-efficiency radio frame configuration featuring a transmission gap at times of no data traffic. This is accomplished by transmitting the least number of reference signals needed for mobility measurement at relatively long intervals and in a local manner. In this case, reference signals for demodulation will be multiplexed with user-specific data signals. In addition, shortening of the TTI length means that data signals can be transmitted in even shorter time periods, which means that a reduction in power consumption can be expected.

Furthermore, considering the need

for supporting a variety of scenarios (such as Device-to-Device (D2D)^{*19}, radio backhaul^{*20}, and multi-hop communications^{*21}) that will be using New RAT in the future, a radio frame configuration with high symmetry between the uplink and downlink would be desirable.

3. Component Technologies for 5G Radio Access

The following describes key component technologies for 5G radio access. We omit description about Massive MIMO^{*22} technology here since it is introduced in another special article in this issue.

3.1 Waveform Design

From the point of view of signal waveform, MBB/IoT-related scenarios in the 5G system are targets of consid-

eration (Figure 6). For MBB, coverage extendibility and propagation delay must be dealt with, extendibility to high frequency bands should be provided, and robustness to changing propagation channels in a high-speed mobile environment should be achieved. In the case of IoT, support for short packet transmission and asynchronous access in Machine Type Communications (MTC)^{*23} should be provided.

As shown in Figure 7, an effective approach here in 5G is to apply different radio parameters and waveform designs according to the frequency band and frequency bandwidth to be used and the application environment as well. For example, in 5G, we can consider that OFDM-based multi-carrier transmission^{*24} would be an effective candidate for signal waveforms and that a wide variety of frequency bands could be supported by applying variable radio

^{*19} **D2D**: A communication method that enables direct exchange of data between two terminals without a base station as an intermediary.

^{*20} **Radio backhaul**: Achieving communications between base stations by a radio link.

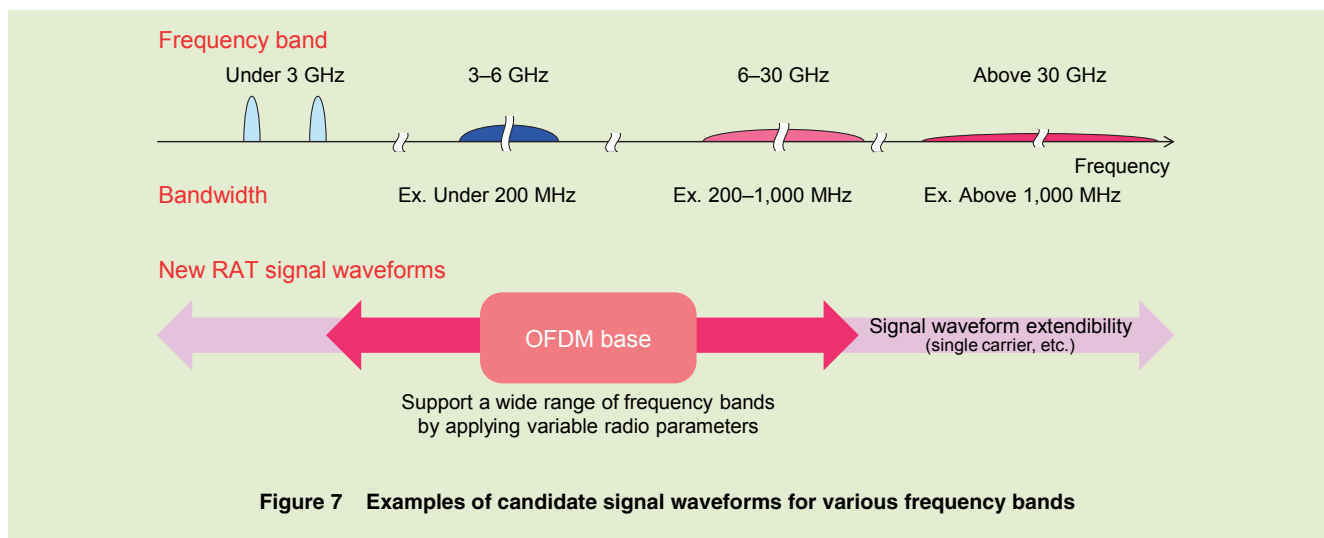
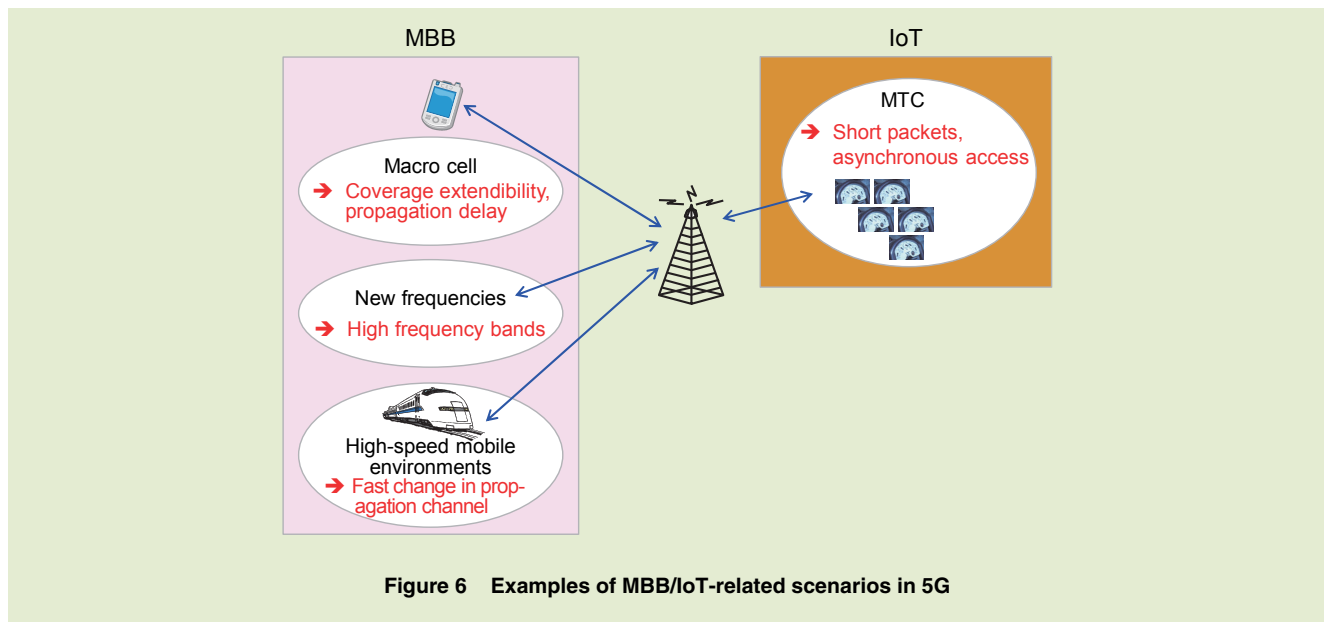
^{*21} **Multi-hop communications**: A method that enables two terminals that cannot directly communicate with each other to communicate by having other terminals function as relays.

^{*22} **Massive MIMO**: Large-scale MIMO using a very large number of antenna elements. Since antenna elements can be miniaturized in the case of high frequency bands, Massive MIMO is ex-

pected to be useful in 5G.

^{*23} **MTC**: General term in 3GPP for machine-based communications using no intermediate human operations.

^{*24} **Multi-carrier transmission**: A method for modulating and transmitting multiple streams of data on multiple carriers. The OFDM method, for example, is used in LTE and LTE-Advanced.



parameters. However, from the viewpoint of supporting ultra-wide bandwidths (of several GHz) in very high frequency bands (above 30 GHz), single-carrier transmission^{*25} also becomes a candidate owing to its superiority in coverage compared to OFDM. Still, OFDM as the baseline transmission waveform

in 5G has good affinity with MIMO and can achieve high spectrum efficiency under multipath^{*26} conditions in wide-bandwidth transmission. OFDM or new signal waveforms based on OFDM should facilitate the support for a wide variety of services. With the above in mind, signal waveforms need to have

“high spectrum efficiency,” “high localization in frequency/time domains (guard-band reduction by suppressing out-of-band in the frequency domain and limited time response by limiting transmission-signal spreading in the time domain),” and “high orthogonality between subcarriers (affinity with channel

^{*25} **Single-carrier transmission:** A method for modulating and transmitting a data signal on one carrier.

^{*26} **Multipath:** A phenomenon that results in a radio signal transmitted by a transmitter reaching the receiver by multiple paths due to propagation phenomenon such as reflection, diffraction, etc.

estimation^{*27} method and other technologies such as MIMO).” To satisfy these requirements, we are studying new signal waveforms that apply a filter to OFDM signals. In the following, we describe Filter Bank MultiCarrier (FBMC), Universal Filtered OFDM (UF-OFDM), and Filtered OFDM (F-OFDM) as new alternative signal waveforms toward 5G. In **Figure 8**, we present the frequency- and time-domain responses for OFDM applying a Cyclic Prefix (CP)^{*28} (CP-OFDM), which has already been introduced in the LTE downlink, and for the above-mentioned new alternative waveforms for 5G.

(1) FBMC

FBMC applies a filter in units of subcarriers. It applies, in particular, a filter with steep frequency characteristics to maintain orthogonality between subcarriers, but out-of-band radiation^{*29} is small compared with the other waveforms. On the other

hand, the signal waveform response has a wide spread in the time domain, which raises concerns about an increase in overhead and an increase in delay time when applying short packets.

(2) UF-OFDM

UF-OFDM applies a filter in sub-band^{*30} units. It prevents inter-symbol interference by inserting a guard interval (no-transmission interval) for each symbol instead of a CP. Compared with FBMC, its out-of-band radiation is large, but its waveform spread in the time domain is small. UF-OFDM is therefore applicable to short packets and asynchronous access and is effective in shortening delay time.

(3) F-OFDM

F-OFDM applies a filter in units of sub-bands while maintaining CPs. The insertion of CPs here makes the use of a guard interval unnecessary,

so a filter with a long filter length can be applied compared with UF-OFDM. However, compared with FBMC, the time spread of the waveform can be made small. Inter-symbol interference will occur since the edge of the filter exceeds the CP interval, but selection of an appropriate filter can minimize that effect. Similar to UF-OFDM, F-OFDM can be applied to short packets and asynchronous access and it is effective for shortening delay time.

With the aim of providing 5G services in 2020, NTT DOCOMO is collaborating with 13 leading international vendors to accelerate standardization and commercial development and is vigorously promoting 5G studies [5]. In terms of new signal waveforms, we are conducting experimental trials on FBMC and UF-OFDM with Alcatel-Lucent and on F-OFDM with Huawei. We are also

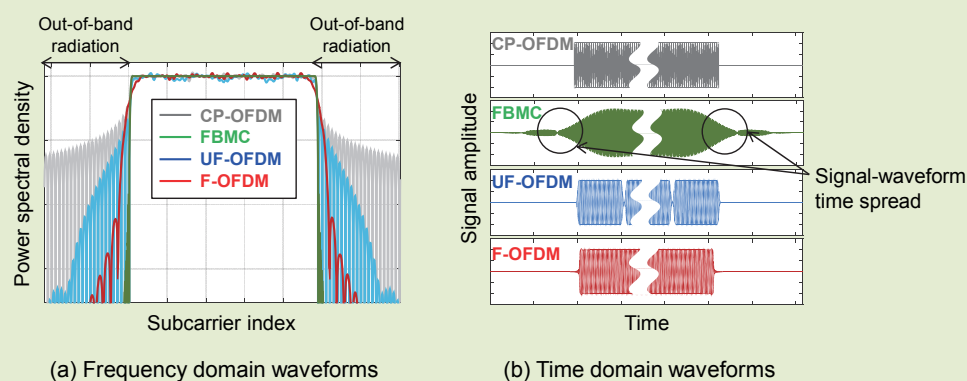


Figure 8 Response of various signal waveforms in frequency/time domains

^{*27} **Channel estimation:** Estimation of the amount of attenuation and phase change in the received signal when a signal is transmitted over a radio channel. The estimated values obtained (the channel data) are used for separating MIMO signals and demodulation at the receiver, and to compute channel data which is fed back to the transmitter.

^{*28} **CP:** A guard time inserted between symbols in OFDM signals, etc. to minimize interference between prior and subsequent symbols caused

by multipath effects.

^{*29} **Out-of-band radiation:** Emission of power outside the frequency band allocated for communications.

^{*30} **Sub-band:** A frequency unit making up part of the entire frequency band.

collaborating with DOCOMO Communications Laboratories Europe on detailed studies to compare and evaluate the benefits of different types of signal waveforms and their affinity with MIMO [6].

3.2 Dynamic TDD and Flexible Duplex

Mobile communications systems up to 4G basically applied either Frequency Division Duplex (FDD)^{*31} that separates the uplink and downlink in the frequency domain or Time Division Duplex (TDD)^{*32} that separates the uplink and downlink in the time domain. However, in mobile communications using wide frequency bands as envisioned for 5G, the possibility exists of applying different types of duplex schemes to different types of frequency bands, so there is a need for “flexible duplex” that can support various types of duplex schemes in a flexible manner. To this end, it would be desirable to support an extension to dynamic TDD that can dynamically change the ratio of downlink subframes and uplink subframes (DL/UL configuration) in TDD, and to support the Phantom cell concept that performs C/U splitting among different frequency bands regardless of the duplex schemes used in those bands. In short, component technologies for “flexible duplex” in 5G can encompass flexible selection and simultaneous connection of communication links such as FDD, TDD, or for that

matter, TDD DL only or TDD UL only (one-way TDD in either the downlink or uplink), as well as technology for adaptively selecting frequency bands including unlicensed bands, technology for achieving CA/DC, and countermeasures to interference between the uplink and downlink in such duplex communications.

3.3 NOMA

1) Overview

Multiple access methods in mobile communications systems evolved from Frequency Division Multiple Access (FDMA)^{*33} in 1G to Time Division Multiple Access (TDMA)^{*34} in 2G and CDMA in 3G, while 4G uses OFDMA that preserves orthogonality among users by multiplexing them over adjacent resources in the frequency domain. In contrast, Non-Orthogonal Multiple Access (NOMA), which is now under study for 5G, is a multiple access method that exploits the power domain to intentionally multiplex users in a non-orthogonal manner over the same resources in the frequency domain. Thus, when applied to the downlink, signals intended for multiple users within a cell are combined and transmitted simultaneously using the same radio resource by the base station. This scheme is expected to further improve spectrum efficiency and is considered to be a promising component technology for LTE evolution and

5G [7].

2) Basic Principle

The basic principle of the NOMA method is shown in **Figure 9**. Among User Equipment (UE) connected within a cell with their downlinks as a target, the base station selects a pair of terminals with one near the base station in the center of the cell having good reception (UE₁ in the figure) and the other near the cell's edge having poor reception (UE₂ in the figure), and multiplexes and transmits the signals to those terminals using the same time slot and same frequency resource. Here, more transmit power is allocated to the signal intended for UE₂ than to the signal intended for UE₁. Now, turning to the receive side, inter-user interference occurs at UE₁ near the base station since this terminal receives a multiplexed signal consisting of UE₁ and UE₂ signals. However, a simple interference cancellation process can be used to separate these two signals as long as a certain power difference exists between them.

For example, at UE₁ near the base station, such a process can first decode only the signal intended for UE₂ that has been allocated strong transmit power and use this decoded signal to create a signal replica^{*35}, which can then be subtracted from the receive signal before separation after which the signal intended for UE₁ can be decoded. This signal separation process is called Successive

^{*31} **FDD:** A scheme for transmitting signals using different carrier frequencies and frequency bands in the uplink and downlink.

^{*32} **TDD:** A scheme for transmitting signals using the same carrier frequency and frequency band but different time slots in the uplink and downlink.

^{*33} **FDMA:** The transmission of multiple user signals using mutually different frequencies within the same radio access system band.

^{*34} **TDMA:** The transmission of multiple user signals using mutually different times within the same radio access system band.

^{*35} **Replica:** A regeneration of the received signal using predicted values for the transmitted signal.

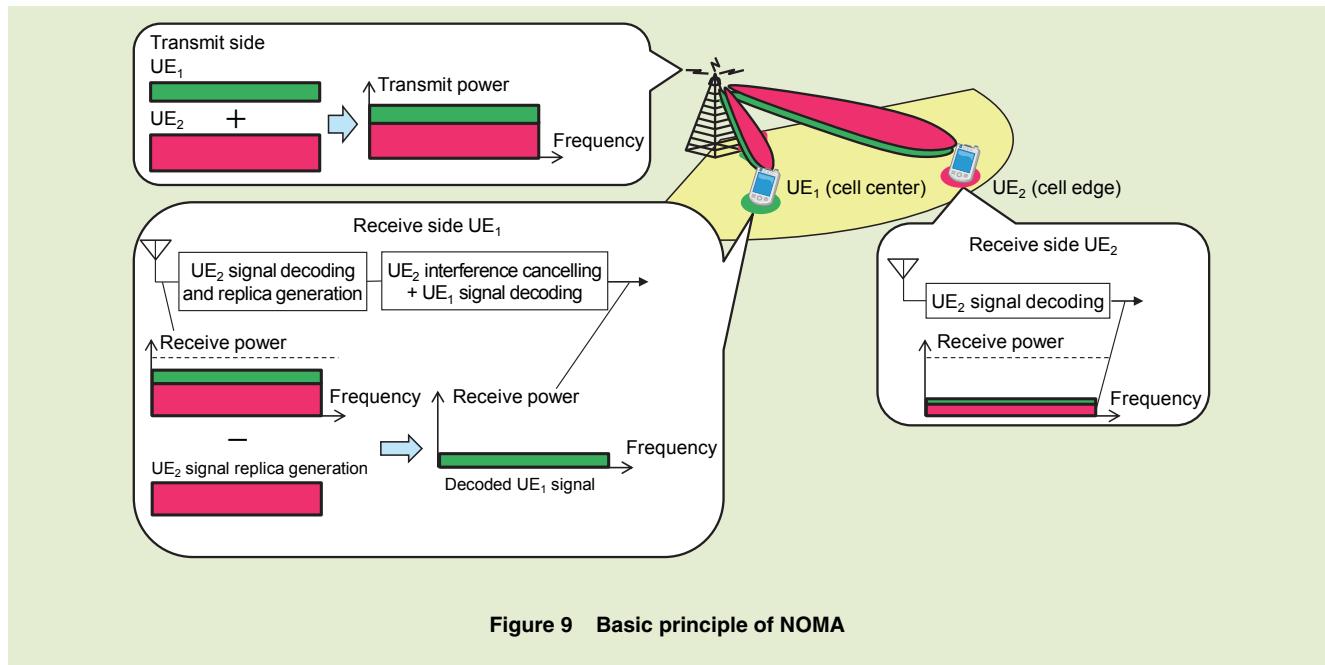


Figure 9 Basic principle of NOMA

Interference Cancellation (SIC)^{*36}, and while it has been under study since the 3G era, the need for advanced processing on the terminal side has made it difficult to implement. Today, however, rapid progress in terminal processing power will make such technology feasible in the near future.

Next, on the UE₂ side, the fact that low transmit power has been allocated to the UE₁ signal that constitutes an interference signal to the UE₂ signal means that the signal intended for UE₂ can be directly decoded without applying SIC.

In addition, the need for applying NOMA can be dynamically selected in subframe^{*37} units in the base station's scheduler, which means that NOMA can coexist on a network that supports existing LTE/LTE-Advanced terminals.

NOMA can also be combined with technologies that are being applied in LTE. For example, combining NOMA with MIMO in LTE would make it possible to multiplex data streams^{*38} at a number exceeding the number of transmit antennas thereby increasing system performance.

3) Performance Evaluations and Transmission Experiments

To assess the effectiveness of NOMA, NTT DOCOMO performed performance evaluations using computer simulations and transmission experiments using prototype equipment [8]–[11]. In this study, the radio frame configuration was based on that of LTE Release 8 and the target of these evaluations was Transmission Mode 3 (TM3) and Transmission Mode 4 (TM4) that respectively does not and

does feed back a user Precoding Matrix Index (PMI)^{*39} to the base station.

(1) NOMA link level evaluation

Given the application of a Code Word level SIC (CWIC) receiver^{*40}, **Figure 10** shows multiplex power ratio (P_1) of a cell-center user versus required Signal to Noise Ratio (SNR)^{*41} for which Block Error Ratio (BLER) of the cell-center user applying CWIC satisfies 10^{-1} . Here, we set the number of multiplexed users to 2 and applied 2-by-2 closed-loop Single User (SU)-MIMO^{*42} (in which feedback information from the user terminal is unnecessary) based on LTE TM3 [12]. The Modulation and Coding Scheme (MCS)^{*43} of each user was 64 Quadrature Amplitude Modulation (64QAM)^{*44}

^{*36} **SIC:** A signal separation method in which multiple signals making up a received signal are detected one by one and separated by a canceling process.

^{*37} **Subframe:** A unit of radio resources in the time domain consisting of multiple OFDM symbols (generally 14 OFDM symbols).

^{*38} **Data streams:** Separate streams of data when performing parallel transmission as in MIMO. For example, the maximum number of data

streams when applying 2-by-2 MIMO is 2.

^{*39} **PMI:** A matrix based on precoding weights for controlling the phase and amplitude of the transmit signal.

^{*40} **CWIC receiver:** An SIC receiver that decodes the interfering-user signal, generates an interfering replica signal, and applies an interference cancellation process.

^{*41} **Required SNR:** The minimum value of SNR required for performing MIMO signal separation

to obtain a predetermined error rate or better.

^{*42} **SU-MIMO:** A technology for transmitting and multiplexing multiple signal streams by multiple antennas between a base station and terminal with one user as target.

^{*43} **MCS:** Combinations of modulation scheme and coding rate decided on beforehand when performing AMC.

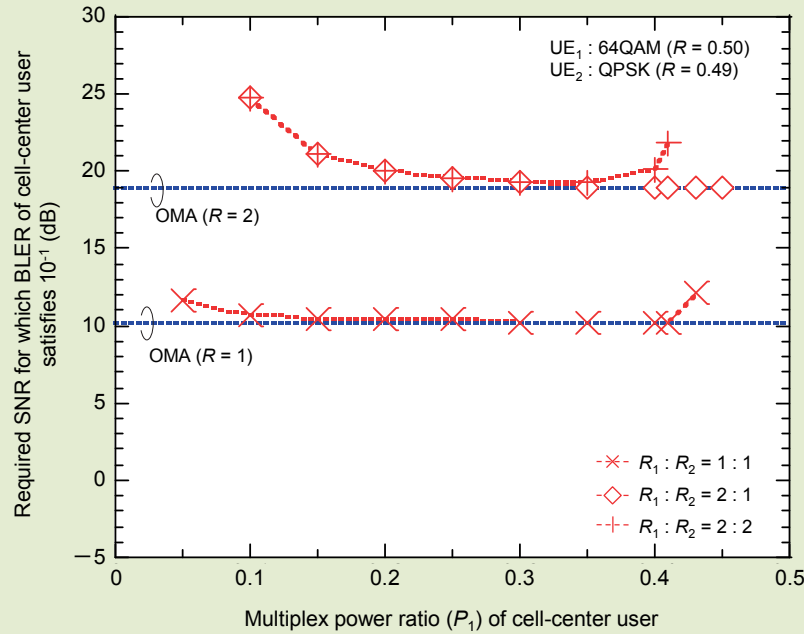


Figure 10 NOMA link-level evaluation results

(code rate: $R = 0.5$) for the cell-center user and Quadrature Phase Shift Keying (QPSK)^{*45} ($R = 0.49$) for the cell-edge user. Furthermore, in combining NOMA and MIMO, there are multiple combinations of the number of MIMO transmission streams (transmission rank) for each user as determined by the receive quality at each user's terminal. In this study, we used three combinations of rank values for the cell-center user and cell-edge user ($R_1 : R_2$), namely, 1:1, 2:1, and 2:2. Additionally, for comparison purposes, the figure includes characteristics for Orthogonal Multiple Access (OMA)^{*46} applied in LTE (i.e.,

OFDMA). Now, examining these results, it can be seen that the effects of inter-user interference increased and required SNR increased in the region corresponding to P_1 greater than 0.4. However, in the region corresponding to P_1 from 0.2 to 0.4 in which the probability of applying NOMA multiplexing is high, about the same required SNR was achieved as that when applying OMA. This result indicates that CWIC has high interference cancellation performance. (2) NOMA system level evaluation

The results of a system level evaluation of throughput gain by NOMA over OMA are listed in **Table 1**. Here, we set the number

of multiplexed users to 2 and the antenna configuration to 2-by-2, and applied LTE TM3 and TM4 [12]. Furthermore, assuming that inter-user interference can be ideally cancelled out, we show results for sub-band scheduling^{*47} that performs resource allocation and MCS selection in sub-band units and wideband scheduling^{*48} that performs resource allocation and MCS selection using the entire band. It can be seen from these results that NOMA achieves a gain over OMA in all cases, and when applying TM3 and Case 3, that NOMA improves cell throughput and cell-edge user throughput by 30.6% and 34.2%, respectively. These

*44 **64QAM:** A digital modulation method that allows for transmission of 6 bits of information simultaneously by assigning one value to each of 64 different combinations of amplitude and phase.

*45 **QPSK:** A digital modulation method that uses a combination of signals with four different phases to enable the simultaneous transmission of two bits of data.

*46 **OMA:** A multiple access scheme that prevents mutual interference between adjacent resources

on the time or frequency axis. Orthogonal mutual access on the frequency axis is OFDMA.

*47 **Sub-band scheduling:** A scheduling method that feeds back the average Channel Quality Indicator (CQI) in sub-band units to the base station and allocates user resources and MCS likewise in sub-band units.

*48 **Wideband scheduling:** A method that feeds back the average CQI of the entire band to the base station and schedules the user using the entire band.

results demonstrate that NOMA has an enhancement effect with respect to user throughput.

(3) Results of measurements using prototype transmission equipment

Finally, we present the results of an experiment in an indoor radio-wave environment using prototype equipment. This NOMA prototype transmission equipment is shown in **Figure 11** (a) and examples of meas-

urement results are shown in Fig. 11 (b). As shown in Fig. 11 (a), UE₁ and UE₂ are both stationary, the former installed near the base station and the latter at a point about 50 m from the base station (to the right outside the view in the photo). On evaluating throughput characteristics when applying 2-by-2 SU-MIMO, results showed NOMA could obtain a gain of approximately 80% over

OFDMA.

New multiple access methods using non-orthogonal schemes in this way have been attracting much attention in recent years and have been taken up as key topics in overseas projects and international conferences [13]. In particular, study of these methods commenced in April 2015 at 3GPP, a leading international standardization body, as a Study

Table 1 NOMA system-level evaluation results

		2 × 2 MIMO, TM3			2 × 2 MIMO, TM4		
		OMA	NOMA	Gain	OMA	NOMA	Gain
Case 1: Sub-band scheduling and sub-band MCS selection	Cell throughput	21.375	27.053	26.56 %	21.97	27.866	26.84 %
	Cell-edge user throughput	0.472	0.633	34.11 %	0.544	0.777	42.83 %
Case 2: Sub-band scheduling and wideband MCS selection	Cell throughput	21.59	26.29	21.77 %	22.291	27.499	23.36 %
	Cell-edge user throughput	0.476	0.62	30.25 %	0.552	0.769	39.31 %
Case 3: Wideband scheduling and wideband MCS selection	Cell throughput	19.068	24.894	30.55 %	19.577	25.515	30.33 %
	Cell-edge user throughput	0.401	0.538	34.16 %	0.451	0.649	43.90 %

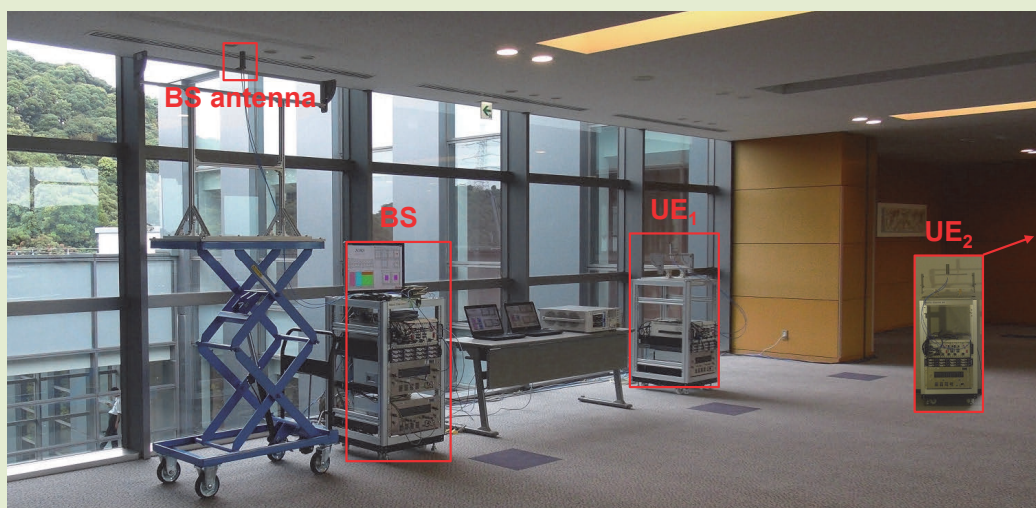


Figure 11 (a) External view of NOMA prototype transmission equipment (indoor experiment environment)

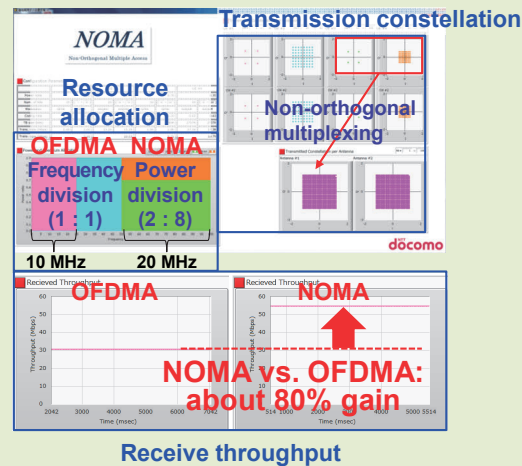


Figure 11 (b) Example of measurement results in NOMA transmission experiment

Item (SI)^{*49} for LTE Release 13 [14] [15]. In addition, NTT DOCOMO is evaluating NOMA in the uplink in addition to the downlink in a collaborative project with DOCOMO Beijing Communications Laboratories [7] [16].

3.4 IoT-related Technologies

In 5G, it is essential that support be provided for IoT in addition to MBB. However, IoT covers a variety of categories with a variety of requirements, and the New RAT design would need to be tailored to each category to meet the requirements. In IoT, key categories that are now attracting attention are massive Machine Type Communications (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC) [13].

One example of mMTC is a large number of sensors that send out small

and short packets. In this case, the design of signal waveforms that support coverage expansion and asynchronous communications is important. In addition, mMTC would benefit from NOMA [16] in the uplink to improve control channel capacity and increase the number of simultaneously connected devices, and it would also benefit from the design of a control channel that requires no control information (e.g., a channel access method that makes pre-authorization when transmitting data unnecessary (grant free access^{*50})). Next, an example of URLLC would be a service like autonomous driving. Key technologies for supporting URLLC would be high-speed uplink/downlink switching and mobile edge computing to exploit the low latency features of the 5G New RAT [17]. Furthermore, in the case of automobiles

and trains in which mobility is an issue, group mobility and mobile backhauling take on importance [18].

4. Conclusion

This article described the 5G radio access technology concept and the promising component technologies for realizing it. The idea here is to effectively combine a wide range of frequency bands from existing low frequency bands to the Extremely High Frequency (EHF) band^{*51} to both maintain coverage and increase capacity while expanding bandwidth. The 5G New RAT therefore needs to be designed to support such a wide range of frequency bands from existing frequency bands to higher frequency bands. Looking to the future, NTT DOCOMO is committed to exploring new ways to further improve spec-

^{*49} SI: The phase of studying a technical issue before starting the work on technical specifications.

^{*50} Grant free access: A radio-channel access method that requires no pre-authorization from the base-station side prior to data transmission. This method enables a terminal to transmit data to the base station at any time.

^{*51} EHF band: Frequency band in the range of 30-300 GHz with wavelengths of 1-10 mm. Also called "millimeter Wave (mmWave) band."

trum efficiency by studying both frequency-band-specific technologies and frequency-band-agnostic technologies.

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