Current and Future R&D at NTT DOCOMO for the 5G Era

Current State and Progress in Each Area

Radio Access Network in 5G Era

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Standardization of the specifications for 5G at the 3GPP was completed in June, 2018. Due to the 5G capabilities of increased data rate and capacity, low latency, and massive-terminal connectivity, 5G is expected to lead to creation of new industries and solutions to problems in society. Japan and other leading nations are considering commercial introduction of 5G around 2019 or 2020. This article introduces NTT DOCOMO's view of the world regarding 5G, scenarios for the deployment of 5G and also prospects for further development of 5G in the future.

1. Introduction

As smartphones have continued to spread, the use of mobile services such as social networking services and video streaming have expanded, and data traffic from mobile phones continues to increase. With such circumstances, mobile telecommunication operators have a duty to ensure that data rate and capacity of the wireless networks are increased so that users can communicate without feeling stress, even when users are in concentrated areas such as around train stations during rush hour. On the other hand, there is increasing anticipation for realizing the Internet of Things (IoT), connecting all kinds of objects to the Internet, creating new industries through collaboration with enterprises and organizations in other industries, and contributing to solutions for various issues in society. With IoT, since many devices could be in locations where it is difficult to secure power or could be in motion, the wireless network is expected to play an important role. The ability to connect with many devices simultaneously is also a feature of 5G, so in addition to increasing data rate and capacity of the wireless network, aspects such as low power consumption in terminals, expanding coverage areas, increasing reliability, reducing latency, and reducing cost must also be supported.

To meet all of these requirements, NTT DOCOMO began R&D on 5th Generation mobile communications system (5G) in around 2010, and has participated actively in creating standard specifications with the 3rd Generation Partnership Project (3GPP), an international standardization organization for mobile communications. The 3GPP standard specifications for 5G were completed in June 2018, and major countries around the world, including Japan, are planning to introduce commercial 5G services in around 2019 or 2020.

This article introduces the view of the world regarding 5G held by NTT DOCOMO and describes the main technologies for implementing 5G, along with deployment scenarios. Finally, it describes prospects for the further development of 5G in the future.

2. The 5G World Ahead

The greatest advancements from 2G (Personal Digital Cellular (PDC)*1, PDC-Packet (PDC-P)*2) to 3G (Wideband Code Division Multiple Access (W-CDMA), High Speed Packet Access (HSPA)*3), and from 3G to 4G (LTE, LTE-Advanced) were increases in the data rate and capacity of mobile communications. From 3G to 4G, the data rate increased from 10 to 50 times, and capacity increased from three to five times. NTT DOCOMO introduced 4G in 2010, and at almost the same time, smartphones began to become common. Since then, as smartphones have advanced, the transition to 4G networks and increase of the data rate have continued. This progress is still continuing, and as of September 2018, NTT DOCOMO has achieved reception data rates of up to 988 Mbps. One could say 4G has matured together with the smartphone and become an indispensable tool providing comfort and convenience to life.

As such, what sort of network is anticipated with 5G? NTT DOCOMO's view of the world regarding 5G is "Building an advanced and flexible network able to connect all things and provide safe and stress-free use of mobile services. A network able to create a new ecosystem*4 exceeding the frameworks of industry."

As discussed at both the International Telecommunication Union – Radiocommunications sector (ITU-R) and the 3GPP, 5G has been developed along three major axes, which are: high speed and capacity, low latency, and massive-terminal connectivity. Earlier generations were developed along the high speed and capacity axis, but even higher data rates will be essential for providing highly realistic media services such as 4K/8K high-definition video distribution and Virtual Reality (VR). On the other hand, low latency is anticipated for applications such as supporting control of self-driving vehicles and factory automation. Massive-terminal connectivity is an important technology for providing services using all kinds of IoT devices, in applications like smart cites and smart agriculture. **Figure 1** shows relationships among services envisioned utilizing these three axes. Each of the services is

*1 PDC: A Second-generation mobile communications system widely used in Japan, adopted by NTT DOCOMO and others.

*2 PDC-P: A mobile packet communications system which applied packet exchange technology to the PDC system, enabling flexible, high-speed data transmission with few transmission errors.

*3 HSPA: A specification for increasing packet-data rates in W-CDMA, and a general term encompassing High Speed Downlink Packet Access (HSDPA), which increases the speed from the base station to the mobile terminal, and High Speed Uplink Packet Access (HSUPA), which increases speed from the terminal to the base station.

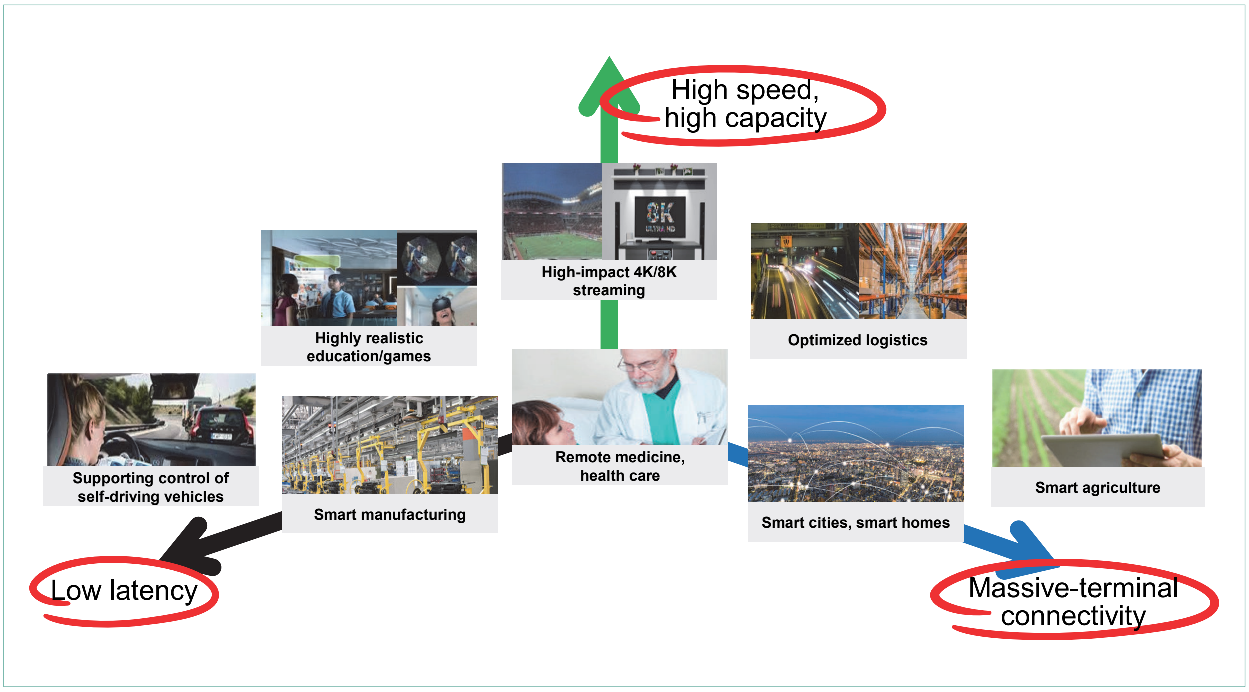

Figure 1 The 5G world ahead

shown combining technologies, and even more connections to all kinds of things can be provided by extending these three axes further. Creation of such new services will be made possible by building a network that can expand with flexibility to provide the functionality needed.

3. Radio Access Technologies for Realizing 5G

3.1 Promotion of 3GPP Standardization

In around 2010, NTT DOCOMO began technical studies foreseeing the implementation of 5G and has advanced various activities such as proposing technology concepts that will pioneer the new era, conducting experimental demonstrations, and promoting 5G related research projects. At the 3GPP RAN Workshop on 5G held in September 2015, we made proposals to promote phased creation of 5G standard specifications, with the initial targets of increased data rate and capacity. Regarding standardization of the radio access network, we also created a proposal on technologies to link New Radio (NR) (i.e., a new radio access technology for 5G) and LTE/LTE-Advanced, and a proposal on making the front-haul interface*5 as open technologies for 5G [1]. Since the 3GPP began concrete work on this, in addition to submitting many technical proposals, we also contributed to completing the initial 3GPP 5G specifications in June 2018 by managing progress and coordinating among involved parties as the Rapporteur*6 for creating the 5G NR standard specifications, and taking on the roles of chairperson and vice-chairperson of the specification study group.

*4 Ecosystem: A system in which multiple enterprises collaborate within a certain field or for business purposes, making use of each other's technologies and resources and even involving consumers and society. It gives form to the flow of processes from R&D to sales, advertising, and consumption.

*5 Front-haul interface: On base stations, the optical fiber interface connecting the baseband processor, which handles digital signal processing, with the radio component, which handles radio transmission and reception.

*6 Rapporteur: A position whose role includes managing progress, summarizing discussion, and editing technical reports that capture results of discussion for Work Items.

3.2 Major 5G Radio Technologies

An overview of the 5G technologies specified by the 3GPP, on the axes of increased data rate and capacity, low latency, and massive-terminal connectivity, is given below.

1) Technologies for Realizing High Speed and Capacity

Technologies for realizing high speed and capacity include ultra-wideband transmission using high frequency bands, and antenna technologies such as Massive Multiple Input Multiple Output (Massive MIMO). Up to 4G, the specifications created used frequencies below 6 GHz, but for 5G, use of high frequencies up to the 100 GHz band in addition to these frequencies is also being studied. Currently, 5G standardization for using several frequency bands in the range of around 25 to 40 GHz in various countries, in addition to frequencies under 6 GHz, is being studied concretely [2]. In particular, the radio propagation characteristics of frequencies in the 25 to 40 GHz range are different than in bands below 6 GHz, so new factors suitable to using such high frequencies (subcarrier*7 intervals, etc.) and a channel bandwidth of 400 MHz have been specified. This is twenty times the channel bandwidth of 20 MHz used by LTE. Although area coverage is different, we can expect a 20-times increase in capacity and data rate.

An overview of Massive MIMO [3] is shown in **Figure 2**. Massive MIMO is a technology that is able to optimize area configurations according to the environment, by using many antenna elements to control the shapes of transmission and reception beams. In an environment emphasizing area coverage, signals for each antenna element can be synthesized in-phase*8, to focus the energy in a particular direction (Fig. 2 (a)). Or, in an environment with many users, multiple beams can be generated simultaneously, equivalent to having

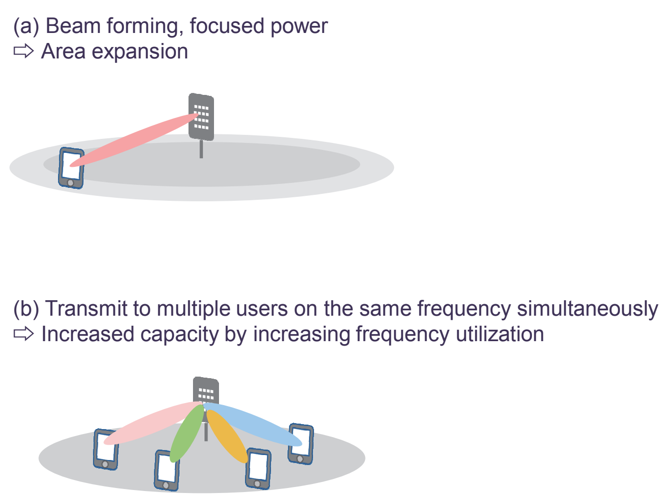

Figure 2 Massive MIMO

*7 **Subcarrier:** An individual carrier for transmitting a signal in a multi-carrier transmission scheme such as Orthogonal Frequency Division Multiplexing (OFDM).

*8 **In-phase:** When to different signals with the same period have the same timing within the cycle.

multiple small cells, increasing the number of simultaneous connections and realizing higher capacity (Fig. 2 (b)).

2) Technologies for Realizing Low Latency

Methods that have been standardized for reducing the latency in the radio access network are shown in **Figure 3**. Further reductions in latency have been achieved by shortening the smallest unit of radio transmission (the Transmission Time Interval (TTI)*9) in 5G NR. The time required to decode data with 5G NR was reduced by transmitting data in units of 0.25 ms instead of 1 ms, which was the transmission unit for conventional 4G. Another technology being studied for further reducing latency is a self-contained mechanism that sends ACKnowledgement/Negative ACK (ACK/NACK)*10 signals for completing reception in the same subframe as the received data.

To realize low latency services, the end-to-end latency must be reduced, so in addition to the radio access network, delay must be reduced on the wired segment. For example, when a user in Osaka accesses a server in Tokyo, the wired segment is the dominant contributor to the time interval. As such, methods such as placing server equipment closer to the edge (the base station) are being studied to reduce the delay in the wired segment.

3) Technologies for Realizing Massive-terminal Connectivity

One use case envisioned for massive-terminal connectivity is where wireless devices such as environment sensors or meters are installed in locations that cannot always be supplied power. In such use cases, power can be maintained by using batteries, but it can be difficult to change these batteries,

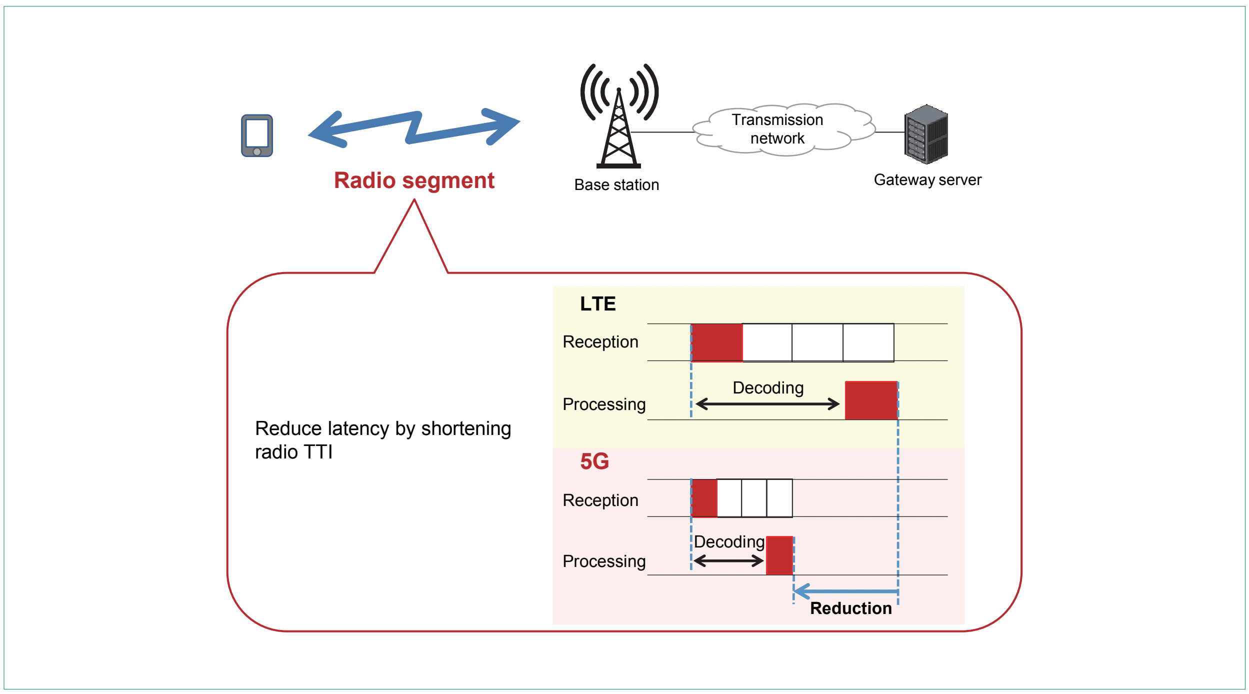

Figure 3 Reduction of latency on radio segment

*9 TTI: Transmission time per data item transmitted via a transport channel.

*10 ACK/NACK: Control signals sent from the receiving party to the transmitting party indicating whether the data signal was received properly.

particularly when many terminals have been deployed. As such, battery life is an important issue for these terminals. Usually with such use cases, only a small amount of data is sent infrequently, so battery life is greatly affected by power consumption while the terminal is not communicating (while standing by). For this reason, the standard specifications stipulate simplifications to signal processing by extending the cycle of intermittent reception and reducing the transmission bandwidth, as shown in **Figure 4**.

4. Initiatives toward Commercialization of 5G

4.1 5G Deployment Scenarios

5G is expected to be deployed gradually in the areas needed, according to various use cases as discussed above. Deployment scenarios are shown in **Figure 5**. It will proceed, using the ultra-wideband characteristics of 5G to increase capacity in areas with high user density and very high traffic, such as business districts, shopping malls, train stations, and stadiums.

Then, by introducing 5G in environments requiring low latency, such as for smart manufacturing in factories and remote diagnosis and treatment in medicine, and environments requiring massive-terminal connectivity, such as for smart agriculture in agricultural areas and for implementing smart cities and smart homes in urban and suburban residential areas, we will contribute to creating new industries, solving societal issues, and regional revitalization.

4.2 Smooth Introduction of 5G

1) Introduction of LTE-Advanced with Advanced C-RAN*11

When NTT DOCOMO introduced LTE-Advanced, we advocated the concept of Advanced C-RAN [4] [5],

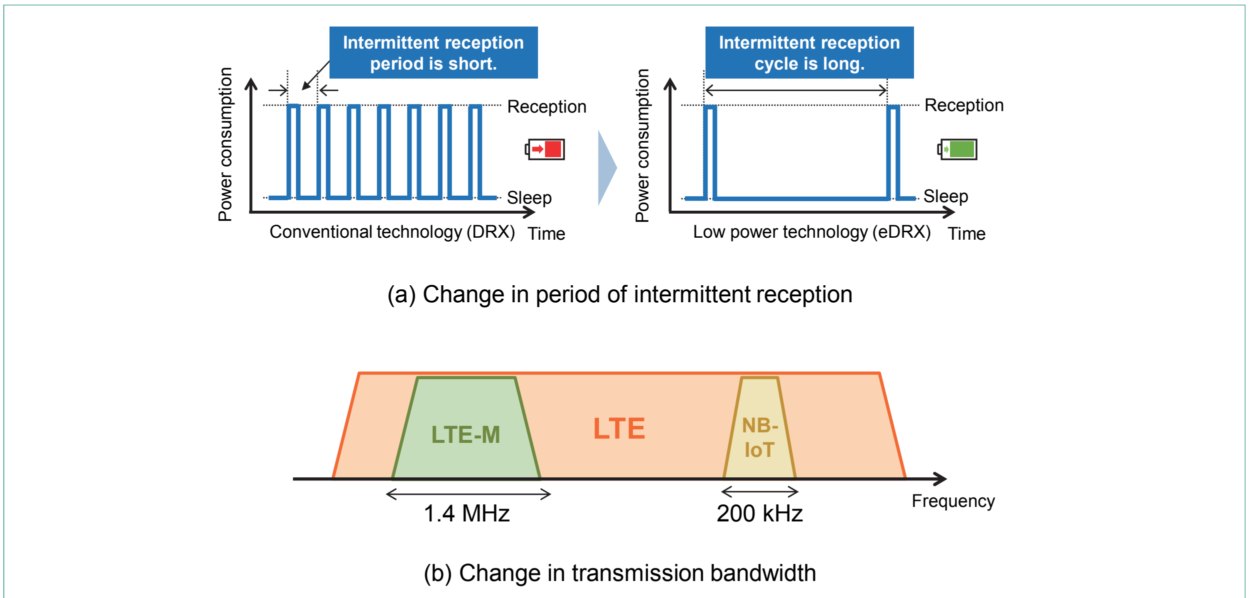

Figure 4 Low power consumption technologies

*11 Advanced C-RAN: A new network architecture for radio access networks being advocated by NTT DOCOMO, which uses a major LTE-Advanced technology called CA (See *13), and a single base-station control component to coordinate between macro cells (See *16), which cover wide areas, and small cells (See *15), which cover more local areas.

as shown in **Figure 6**. This concept gathers together the baseband*12 processing components, enabling it to configure combinations of multiple frequencies with flexibility for Carrier Aggregation (CA)*13, enabling flexible deployment of a heterogeneous network*14. In this way, capacity can be increased

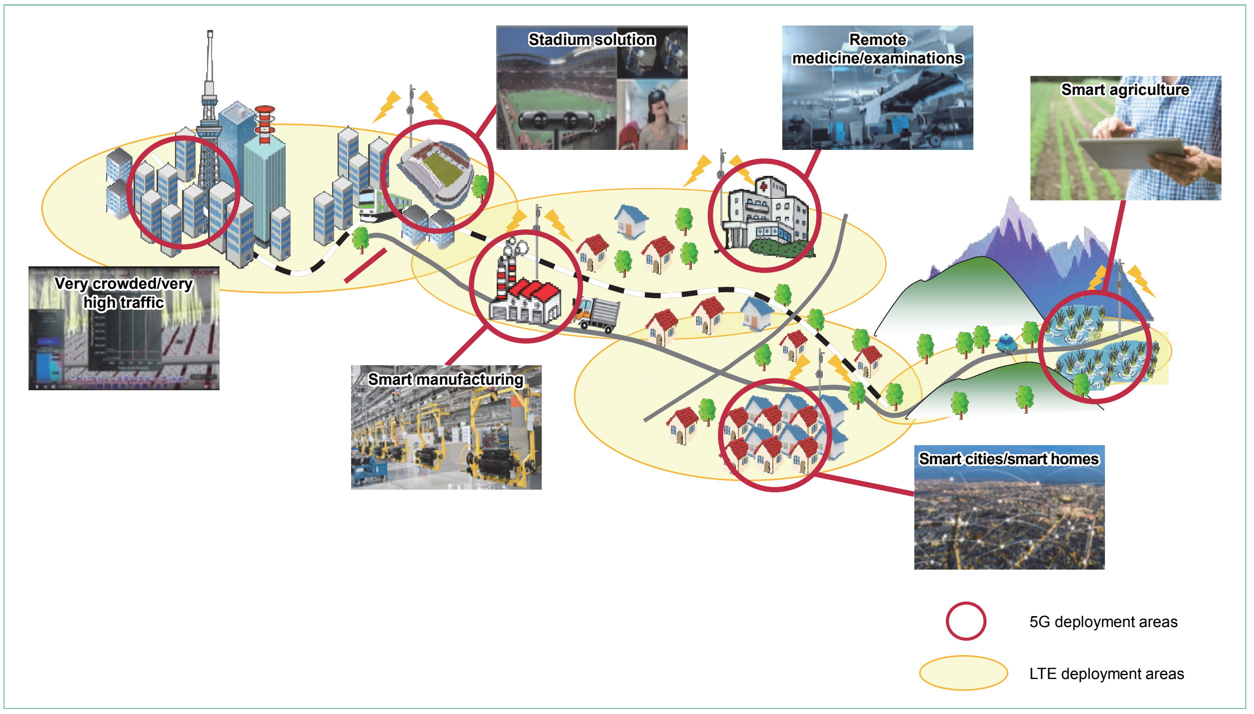

Figure 5 5G deployment scenarios

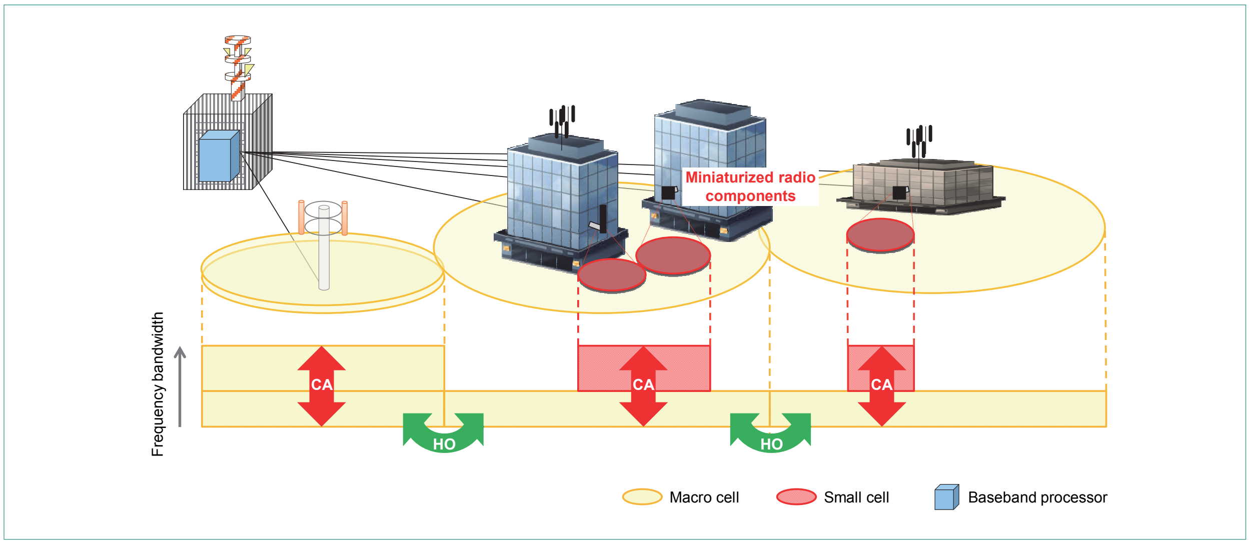

Figure 6 Advanced C-RAN concept

*12 Baseband: The circuits or functional blocks that perform digital signal processing.

*13 CA: A technology for increasing bandwidth and transmission speed, while maintaining backward compatibility, by simultaneously transmitting and receiving multiple carriers.

flexibly, where traffic is heavy, by establishing small cells*15 (hereinafter referred to as "add-on cells") deployed over a macro cell*16 area. The connection between base station and terminal is also maintained by the macro cell, regardless of where add-on cells are deployed, so frequent Hand-Overs (HO)*17 between adjacent add-on cells can be avoided, and increased data rate and capacity while mobility can be realized without degradation in quality.

2) Extension of Advanced C-RAN to 5G

As already mentioned, provision of various new services is expected with 5G, and the network will need to be deployed when and where it is needed, with guaranteed connectivity. NTT DOCOMO is planning to extend the Advanced C-RAN concept to 5G, and deploy a network with Dual Connectivity (DC)*18. **Figure 7** is a schematic diagram of a Non-StandAlone (NSA)*19 network advocated by NTT DOCOMO and agreed upon by the 3GPP. It is anchored by LTE, so it guarantees connectivity with a quality equivalent to current networks, while being able to provide services utilizing 5G features in 5G NR areas.

5. Prospects for the Further Development of 5G

Various use cases are anticipated with 5G, so a flexible network must be built. It is desirable that the most suitable equipment can be selected and installed in urban areas, rural areas, indoors, stadiums, factories, and so on. To achieve this, the front-haul interface between the radio components and control components must be open, so that equipment from different vendors can interconnect. NTT DOCOMO has been actively working to ensure the open front-haul interface [6]. To support different services with flexibility, we also hope that control components will be virtualizable and that equipment will be implemented with good extensibility.

On the other hand, as 5G spreads, new devices

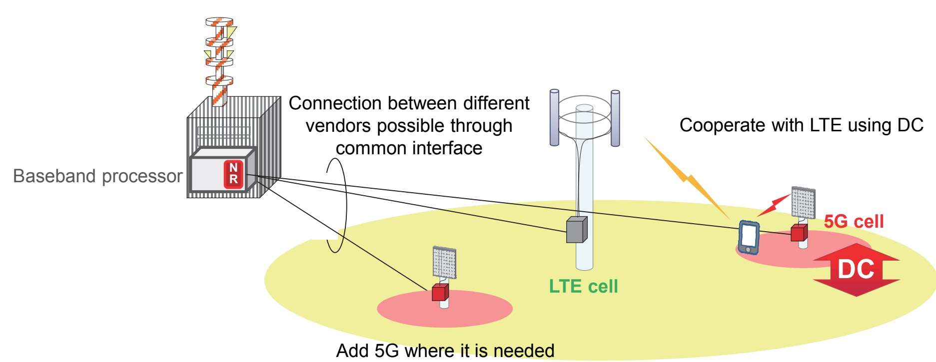

Figure 7 5G NSA deployment using DC

*14 Heterogeneous network: A network structure with overlaid base stations having different transmission power. Macro cell (See *16) base stations covering wide areas are overlaid with small cell (See *15) base stations that transmit with less power.

*15 Small cell: A cell is the area covered by a single base station in a mobile communications system. "Small cell" is a general term for a cell that transmits with low power relative to a macro cell (See *16), which transmits with higher power.

*16 Macro cell: A cell that covers a relatively large area (generally a radius of several hundred meters or more).

*17 HO: A technology for switching from one base station to another without interrupting communications when a terminal is moving.

will enter the market and new services will be created, which will generate new requirements for the radio access network and new technologies to meet those requirements will be needed. It is difficult to anticipate what the world will be like in 2020 and beyond, but radio access networks must be able to see beyond the current era. As an example, if all kinds of objects are to be connected, individual devices may perceive that they are always connected, but from the network perspective, it is more efficient to connect only when communication is needed, and to do so, very low latency connections and data transmission are needed. Also, as machine type communication becomes more common, it may become necessary to transmit metadata of a different dimension than, for example, images that a person would recognize. These may go beyond extensions to 5G requirements, so new breakthroughs may be needed to build the world beyond what we can currently imagine. Battery life has also always been an issue with mobile phones, but if it becomes possible to charge them by capturing energy from radio waves in the air through energy harvesting*20, this problem could be solved instantly. Beyond working to introduce 5G smoothly, we will continue to study future technologies that will develop 5G further and to contribute to development of mobile communications.

6. Conclusion

5G is expected to begin commercial service in 2020, and this article has given an overview of its objectives, principle technologies, and deployment scenarios. 5G will provide all kinds of connectivity and contribute to creating new industries, solving societal issues, and regional revitalization.

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*18 DC: A technology whereby a single terminal can connect to multiple base stations using different frequency bands.

*19 NSA: A 5G radio access network that assumes that it will be used together with LTE (or enhanced LTE (eLTE)), with the benefit that it can be commercialized quickly since it is able to use existing 4G infrastructure.

*20 Energy harvesting: Technology that harvests small amounts of energy from the surrounding environment and converts it to electrical power.