LTE-Advanced | CA | Advanced C-RAN

Technology Reports

Special Articles on PREMIUM 4G—Introduction of LTE-Advanced—

LTE-Advanced as Further Evolution of LTE for Smart Life

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*LTE-Advanced, which was launched in March 2015 as PREMIUM 4G™*1, is an LTE-based mobile system with even higher bit rates and system capacity. NTT DOCOMO has developed Advanced C-RAN and terminals supporting LTE-Advanced to make the most of LTE-Advanced features and improve transmission data rates and radio capacity. Advanced C-RAN provides stable high-speed communications even in areas with particularly high traffic such as train stations and large commercial complexes thereby supporting an effective rollout of the LTE-Advanced system.*

1. Introduction

Mobile data traffic is increasing at a dramatic rate driven by the popularity of smartphones and new ways of using the mobile network as represented by social networking and video streaming. According to a report issued by the Ministry of Internal Affairs and Communications (MIC) [1], mobile traffic in Japan increased by approximately 1.5 times in a recent one-year period generating a problem that must be addressed in common by Japan's mobile communications operators.

In December 2010, NTT DOCOMO introduced LTE featuring "high-speed," "large-capacity," and "low-delay" to improve the customer experience, increase transmission data rates to open up new possibilities in services, and support the continuously increasing volumes of mobile traffic. The introduction of LTE enabled data rates to be increased by approximately ten times, capacity to be expanded by approximately three times, and delay to be reduced to approximately one-fourth the existing levels compared to the High Speed Packet Access (HSPA)*2 specification in use at that time. These improvements significantly enhanced the convenience of using smartphones and other smart devices.

As of March 2015, LTE was operating in approximately 150 countries by more than 300 operators—it had been introduced at an extremely fast pace around the world compared to any other standardized mobile system to date. The en-

*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.

*2 **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.

hanced form of LTE is LTE-Advanced, which holds promise of being a vitally important and influential technology in society.

NTT DOCOMO launched LTE-Advanced as a commercial service under the name “PREMIUM 4G” in March 2015. In this article, we present an overview of LTE-Advanced technologies and of our newly developed Advanced Centralized Radio Access Network (C-RAN), which enables Carrier Aggregation (CA) between cells, improves throughput while maintaining mobility characteristics, and increases capacity. Other special articles in this issue provide details on control schemes and equipment in Advanced C-RAN and on mobile terminal technologies supporting LTE-Advanced [2]–[4].

2. LTE-Advanced Requirements

A specifications study for LTE-Advanced as an enhancement of LTE began in June 2008 and LTE-Advanced requirements were subsequently compiled in a 3GPP Technical Report [5]. In addition to coexistence with LTE, migration scenario from LTE, and improved performance, a reduction in power and operating costs was also included as one of the requirements. Main requirements for LTE-Advanced are described below.

1) Coexistence with LTE

LTE-Advanced is, of course, expected to surpass LTE in system performance, but it must also enable a smooth migration from existing LTE. In short, backward and forward compatibility with LTE is a key requirement.

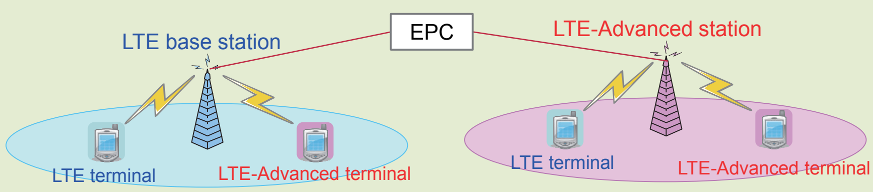
Here, we define backward and forward compatibility in terms of terminal capabilities as shown in **Figure 1**. First, LTE terminals must naturally be able to connect to the LTE-Advanced network, and second, LTE-Advanced terminals must exhibit a significant improvement in performance when connected to the LTE-Advanced network while being able to connect to the LTE network as well.

2) Improvement in Peak Data Rate, Spectral Efficiency, and Cell Edge User Throughput

LTE-Advanced must provide a dramatic improvement in basic system performance over LTE. The requirement for peak data rate is 1 Gbps in the downlink and 500 Mbps in the uplink.

Additionally, LTE-Advanced is required to improve spectral efficiency by approximately 1.5 times over LTE. Considering that LTE-Advanced requirements were established right after the approval of LTE itself, this requirement for improved spectral efficiency was a very challenging target.

Cell edge user throughput was also taken up as an important performance index. This is because throughput at cell



LTE and LTE-Advanced compatibility

	LTE base station	LTE-Advanced station
LTE base station	LTE	LTE
LTE-Advanced terminal	LTE	LTE-Advanced

EPC : Evolved Packet Core

Figure 1 LTE-Advanced compatibility

edge is an important factor in providing a sufficiently satisfactory service to a cell-edge user whose received quality is low due to a weak radio signal and interference from other cells. In LTE, as well, cell edge user throughput is an important index, but in LTE-Advanced, technologies that could improve throughput especially in such a cell-edge environment were a focus of study.

3. Main Technologies of LTE-Advanced

To satisfy the requirements described above for LTE-Advanced, further advancements in radio interface technologies were proposed as described below.

3.1 CA

For a maximum bandwidth of 20 MHz, LTE achieves a peak data rate of 300 Mbps in the downlink by supporting 4×4 Multiple Input Multiple Output (MIMO)*3 technology. In contrast, a peak data rate of 1 Gbps in the downlink and 500 Mbps in the uplink has been specified as a requirement for LTE-Advanced, so the provision of even broader bandwidths is needed. LTE-Advanced, however, must also ensure backward compatibility with LTE. For this reason, CA was proposed as a means of bandwidth extension achieved by combining multiple frequency blocks, each of which is called a Component Carrier (CC) having a bandwidth supported by LTE [6]. The use of CA enables higher data rates to be achieved while maintaining backward compatibility with existing LTE. It also enables instantaneous load balancing*4 between frequency bands to improve spectral efficiency.

3.2 Advanced Multi-antenna Technology

LTE supports single-user MIMO*5 multiplexing for up to 4 layers*6 in the downlink but supports no MIMO multiplexing in the uplink. In contrast, LTE-Advanced supports single-user MIMO multiplexing for up to 8 layers in the downlink and up to 4 layers in the uplink to satisfy requirements for peak spectral efficiency*7. In addition, multi-user MIMO*8 has been enhanced in LTE-Advanced to improve system capacity. Furthermore, to improve cell edge user throughput, Coordinated Multiple Point transmission and reception (CoMP) technology has been proposed as a means of performing transmission and reception via multiple cells working in cooperation [6].

3.3 Base Station Coordination in HetNet

In LTE-Advanced, lowering the cost of the Radio Access Network (RAN)*9 is also an important requirement. In addition to the conventional deployment of macro cell*10 base stations, implementation of a Heterogeneous Network (HetNet) is also attracting attention. HetNet appropriately deploys and coordinates base stations of various form factors and power levels including the small cell*11 with the aim of lowering costs. Radio interfaces that can efficiently support inter-frequency coordination in conjunction with CA, enhanced Inter-Cell Interference Coordination (eICIC) that mitigates intra-frequency interference, and such have been specified for HetNet.

4. Features of Advanced C-RAN Architecture

Although further advancements in data rates can be achieved using CA as one of the main technologies of LTE-Advanced, technology than can increase capacity for the environments with exceptionally large volumes of traffic, such as the neighborhood surrounding a major train station, is particularly important. Such an environment requires not only the use of more frequencies to accommodate traffic but also an increase in an area capacity by deploying small cells, as part of HetNet. However, user movement in such an environment increases HandOver (HO)*12 occurrences either between small cells or between a macro cell and small cell, which may cause higher probability of call drop.

Moreover, while higher transmission data rates and improved user throughput by load balancing between frequency blocks can be expected with introduction

*3 **MIMO:** A technology for achieving high-speed transmission by simultaneously transmitting different signals from multiple antennas.

*4 **Load balancing:** The process of reducing load between frequencies or cells by moving users accordingly.

*5 **Single-user MIMO:** Technology that uses MIMO transmission over the same time and frequency for a single user.

*6 **Layer:** In MIMO, each layer corresponds to a stream—multiple streams may be simultaneously transmitted.

*7 **Peak spectral efficiency:** Maximum spectral efficiency that can be achieved according to specifications. Maximum rate efficiency.

*8 **Multi-user MIMO:** Technology that uses MIMO transmission over the same time and frequency for multiple users.

*9 **RAN:** The network consisting of radio base stations and radio-circuit control equipment situated between the core network and mobile terminals.

*10 **Macro cell:** An area in which communication is possible, covered by a single base station, and with a radius from several hundred meters to several tens of kilometers.

*11 **Small cell:** Generic name for a cell covering a small area and having low transmission power relative to a macro cell.

of CA, at the base station with high traffic frequency resources to perform CA are likely to be completely utilized, which makes it difficult to achieve a significant improvement in spectral efficiency.

In light of the above, NTT DOCOMO proposed Advanced C-RAN architecture (**Figure 2**) in March 2012 [7] and commenced its development in 2013. Advanced C-RAN architecture adds a number of small cells on top of a macro cell (hereinafter referred to as "add-on cells") and coordinates the add-on cells and the macro cell through CA.

Advanced C-RAN architecture has the following features achieved by utilizing CA and HetNet features.

(1) High-speed transmission through CA

Increases transmission data rates in a flexible manner depending on the current traffic environment by CA between macro cells and between macro cell and multiple add-on cells.

(2) Comparable mobility characteristics as a conventional macro cell

Maintains the same rate of HO occurrence as in a conventional configuration with only macro cells by adding or deleting add-on cells while maintaining macro-cell connection. This scheme achieves conventional mobility performance even in an environment with add-on cells.

(3) Greater capacity through add-on cells

Improves user throughput in both macro cells and small cells by arranging add-on cells effectively in areas with high traffic and offloading traffic as needed thereby increasing capacity over the entire area.

5. Rollout Scenario

Since 2009, NTT DOCOMO has been deploying an centralized RAN (C-RAN) architecture for LTE in which baseband*13 processing is performed in central node, and radio units may be distributed in different location connect-

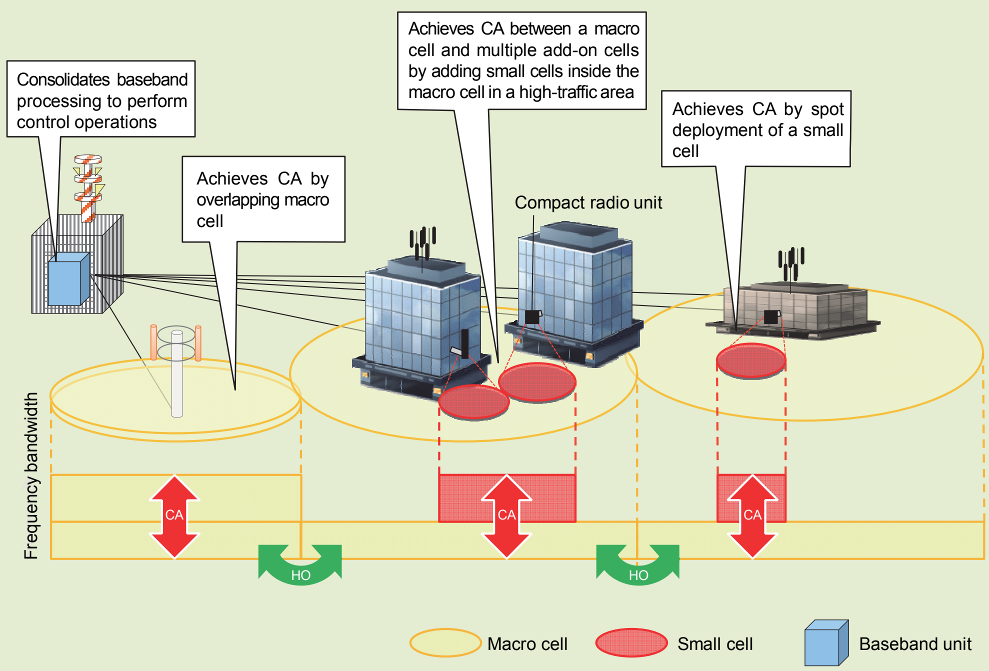


Figure 2 Advanced C-RAN architecture

*12 **HO:** A technology for switching base stations without interrupting communications when a terminal with a call in progress straddles two base stations while moving.

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

ed to the baseband unit via optical fiber [8]. This made it easy to construct a network that can make the most of the features described above by simply replacing the baseband processing unit with new equipment supporting Advanced C-RAN without touching the existing radio units.

We have also been developing radio equipment for add-on cells that is far lighter and smaller than existing equipment [3]. Specifically, we have been able to reduce the size of this equipment to 1/5 that of existing units, which has the effect of relaxing installation conditions for these radio units and broadening their scope of application.

NTT DOCOMO had already been operating LTE on four carriers, and these frequencies have to be used effectively. In Advanced C-RAN architecture, each radio unit operates on one of these carriers, and since these radio units are independent of their common baseband unit, it is relatively easy to combine any of these carriers. At the time of LTE-Advanced introduction, a total bandwidth greater than 30 MHz could be achieved by combining the 800 MHz and 1.7 GHz carriers or the 2 GHz and 1.5 GHz carriers making for a maximum throughput greater than 225 Mbps.

Going forward, the plan is to use a combination of three component carriers (3CC) in conjunction with Time Division Duplex (TDD)*14 on the newly allocated 3.5 GHz carrier and to apply advances in MIMO technology to achieve even higher transmission data rates and greater capacities. The ultimate goal here is to improve the user's quality of experience (**Figure 3**).

6. Conclusion

This article presented an overview of LTE-Advanced technologies reflecting the ongoing evolution of LTE and introduced Advanced C-RAN as network architecture for making the most of LTE-Advanced features. Approximately five years after the introduction of LTE, NTT DOCOMO launched LTE-Advanced services under the banner of PREMIUM 4G in March 2015 to improve the user experience even further. Looking to the future, NTT DOCOMO aims to contribute to society by expanding the service area and enhancing its lineup of mobile devices, and by providing a new and fertile social infrastructure as a Smart Life Partner.

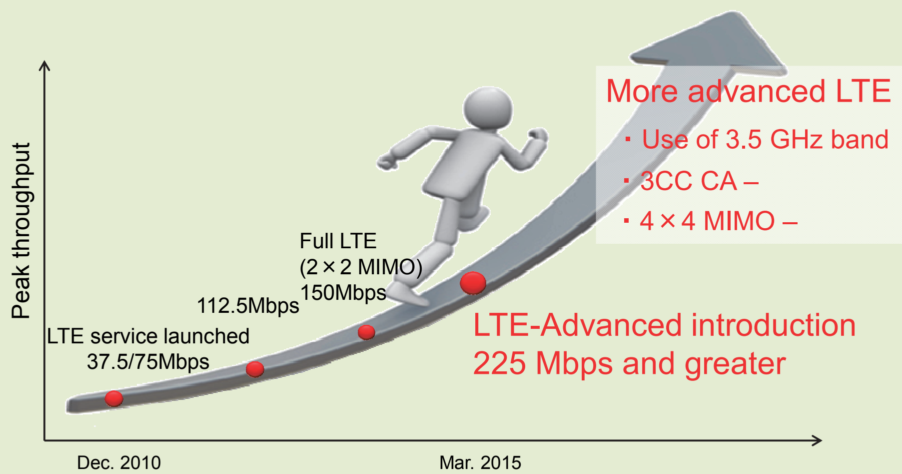


Figure 3 Toward more advanced LTE

*14 **TDD:** A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency band.

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