From LTE-Advanced to 5G: Mobile Access System in Progress

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There is a surge in the amount of mobile data traffic due to the growing popularity of smartphones and tablets and the increasing use of diversified applications that use pictures and movie files. The amount of mobile data traffic is expected to continue increasing with the rise of the Internet of Things (IoT) era, due to a huge increase in the number of telecommunication devices and technological advancements for enhancing the resolution of video data. The current prevalent system is LTE-Advanced—the so-called fourth-generation (4G) mobile access system—while technology is already under development across the world for fifth-generation (5G) systems. 5G involves very advanced technological requirements as it aims to increase transmission capacity by a thousand-fold compared with the current LTE. One of the required technological developments is to increase cell density. This paper first explains the mobile access system technology developed to counter increasing data traffic, and then it describes the centralized base band unit supporting LTE-Advanced and indoor femtocell base stations, each developed by Fujitsu. It also discusses the technological trends for 5G mobile access systems, with descriptions of activities to realize such technology.

1. Introduction

Mobile data traffic is reported to be increasing at the approximate rate of 160% per annum, and this trend is expected to continue in the future. Further, in the coming age of the Internet of Things (IoT), various devices and sensors will have built-in communication capability, and besides conventional human-to-human communication, thing-to-thing communication, and human-to-thing communication will be carried out. As a result, the number of communication devices and the amount of transmitted data are expected to dramatically increase, causing a significant increase in traffic. To cope with this situation, in the area of mobile access systems, introduction of LTE-Advanced, which is a fourth-generation (4G) system more advanced than the preceding LTE system, has begun. Further, technology development for a fifth-generation (5G) mobile access system is actively being conducted.

This paper describes the current status of mobile data traffic and measures, and introduces the centralized base band unit supporting LTE-Advanced and indoor femtocell base stations, each developed by Fujitsu. It also describes the technological trends for the 5G mobile access system, with descriptions of Fujitsu's activities to realize such technology.

2. Status of mobile data traffic and measures

According to figures published in the Information & Communications Statistics Database of the Ministry of Internal Affairs and Communications[1], domestic mobile data traffic increased an annual average of 1.68 times in the three-year period from 2011 to 2014. Global mobile data traffic[2] likewise increased, growing approximately 1.7 times in 2014. This trend is expected to continue, with global mobile data traffic growth of approximately 10 times (annual average of approximately 1.6 times) over the five-year period from 2014 to 2019.

The technical elements required to deal with such traffic increase by improving the communication capacity of mobile access systems fall under the following three main categories.

1) Cell density increase (cell downsizing)

By reducing the size of the geographical area (cell) covered by a radio base station and closely arranging multiple base stations in the same area, the number of users per base station can be reduced and the communication capacity per unit area can be increased.

2) Expansion of available frequencies and support of high frequencies

Radio frequencies being a public resource, only a predetermined range of radio frequencies can be used for mobile communication. Given that the frequency band used for mobile communication is already used by different systems and there are no free frequencies, newly allocating a broad frequency range is difficult. Therefore, a wide band of frequency resources in a higher frequency range than conventional is to be allocated. This will allow increasing the frequency bandwidth that can be used by mobile access systems, and thus the communication capacity.

3) Improvement of spectral efficiency

To allow effective use of the allocated limited frequency band, the amount of data that can be transmitted per unit frequency (1 Hz) (spectral efficiency) when a base station communicates with terminals will be increased. Examples of wireless technologies for improving spectral efficiency are the use of multi-level modulation and the increase of multiplexing order through multiple-input/multiple-output (MIMO).

Mobile access systems have been growing more sophisticated in order to cope with increasing traffic and provide more advanced communication services. The evolution of mobile access systems and the trends in applied technologies thus far are described next. As shown in **Figure 1**, mobile access systems advance by one generation roughly every ten years, with the 5G system slated to enter practical use around the year 2020. Further, within each generation, relatively large enhancements are made about once every five years.

The maximum downlink transmission rate was 384 kbps for the third-generation (3G) Wideband-Code Division Multiple Access (W-CDMA), and 14.4 Mbps for High Speed Packet Access (HSPA), called 3.5G, but 300 Mbps for LTE, called 3.9G, and 3 Gbps for LTE-Advanced, thus increasing in steps between 10-fold and 20-fold each time. To achieve such an increase in the transmission rate, the frequency bandwidth used by each user had to be increased, from 5 MHz for 3G, to up to 20 MHz for LTE, and up to 100 MHz (with a five-carrier maximum) for LTE-Advanced owing to the introduction of carrier aggregation technology that uses multiple carrier frequencies simultaneously. MIMO technology, which uses multiple antennas for transmission and reception, is also effective for increasing the transmission rate. In order to increase the transmission rate through MIMO technology, the number of antennas used must be increased. Whereas W-CDMA and HSPA are standards that support transmission using two antennas, the supported number of antennas for LTE was expanded to up to four, and that for LTE-Advanced to up to eight antennas. In this manner, in the evolution from 3G to 4G, emphasis was placed on expanding the frequency bandwidth, improving spectral efficiency through MIMO, and improving the maximum transmission speed.

On the other hand, the evolution to LTE and LTE-Advanced of recent years has seen the introduction of cell size reduction technology besides the promotion of spectral efficiency and higher transmission speed. For example, the configuration using a hierarchical structure that places small cells under wide-area macro cells, which is called a heterogeneous network (HetNet), and inter-cell interference coordination technologies such as enhanced inter-cell interference coordination (eICIC) and coordinated multi-point transmission/reception (CoMP), which are premised on HetNet, have been standardized.[3),4)] This is linked to the fact that cell density increase is an important factor as a measure for coping with traffic increases, and further density increase is being pursued not only by using the

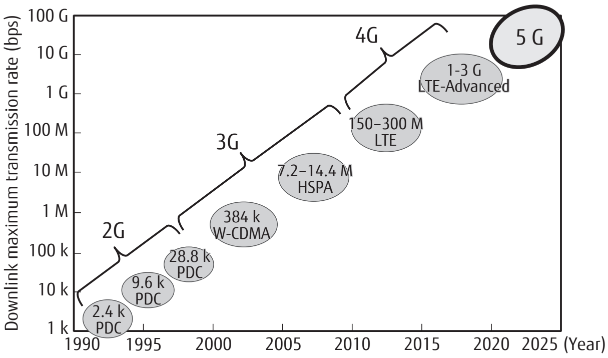


Figure 1
Evolution of mobile access systems.

traditional approach of increasing density by merely reducing cell size, but also by more aggressively applying advanced interference coordination technology.

3. LTE and LTE-Advanced application status

Next, the endeavors toward the practical use of LTE and LTE-Advanced are explained. There are still countries and areas in the world where second-generation (2G) and third-generation (3G) systems account for a large percentage of the systems in operation, but the adoption of LTE is steadily progressing. In Japan, LTE services began in 2010 and already have become widespread. Moreover, in March 2015, the LTE-Advanced services were launched and they are also expected to rapidly spread.

Against this background, Fujitsu has developed LTE and LTE-Advanced compliant base stations that are operated in existing cellular systems. The LTE-Advanced compliant high-density wireless base station equipment developed by Fujitsu [**Figure 2 a)**], which is called a Centralized Base Band Unit (C-BBU), can accommodate a large number of cells in a single unit. It can accommodate up to 48 cells consisting of macrocells that cover a wide area and small cells that cover a limited area. By connecting C-BBU units with wireless transceivers called remote radio heads (RRH) [**Figure 2 b)**] with optical fiber, advanced centralized radio access networks (C-RAN)[note] that include a large number of small cells can be constructed.[5),6)] The features of advanced C-RAN are described below.

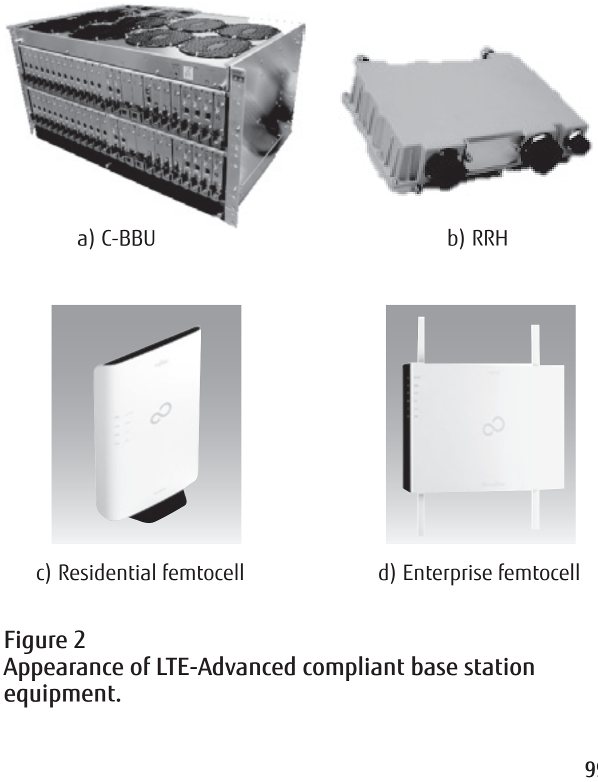
1) Support of carrier aggregation between macrocells and additional small cells (add-on cells)
2) Maintenance of connectivity and mobility through macrocells
3) Improvement of communication capacity of networks through the addition of add-on cells
4) Support of wireless network expansion

Through the above features, communication capacity can be increased by, for example, accommodating users traveling at high speed with macrocells, and adding small cells in hot spot areas where there is high traffic.

C-BBUs excel at covering areas that have a high number of cells and users in both outdoor and indoor environments. On the other hand, in smaller indoor environments such as residences and offices, it is more advantageous to deploy femtocells, which offer easy installation and lower cost. Multiple types of devices have been developed for use in different environments, for example small femtocells (residential femtocells) [**Figure 2 c)**] suitable for residences, and femtocells designed to be used in locations with a comparatively large number of users such as offices and shopping malls (enterprise femtocells) [**Figure 2 d)**]. These femto base stations feature plug-and-play functionality and can thus be installed easily by simply connecting them to the user's broadband environment. Moreover, through the use of multi-band and interference coordination technology, optimized control of transmission power and other aspects is possible in environments that present a high degree of interference between femtocells.

4. Technology trends for 5G mobile communication systems

As mentioned above, mobile access systems have undergone generation changes over a period of approximately ten years, and 5G services are expected to begin around the year 2020. In 2020, the number of things that will be connected to the Internet is



a) C-BBU b) RRH

c) Residential femtocell d) Enterprise femtocell

Figure 2
Appearance of LTE-Advanced compliant base station equipment.

note) Network architecture proposed by NTT DOCOMO.

expected to reach fifty billion,[7] and all sorts of things, including humans, will be connected to networks, and a world (hyper-connected world) that creates new value[8] is expected to emerge. Further, support of high transmission speed to allow the shift to ultra-high-definition video transmission such as 4K and 8K and the realization of virtual reality is needed. In order to accommodate such a large amount of mobile data traffic, communication capacity per unit area that is 1,000-fold that of LTE, and peak transmission speed of 10 Gbps are required for 5G.[9]

Various studies are being conducted toward increasing communication capacity by this 1,000-fold figure for 5G. As regards frequencies, compared with the frequency band used by systems up to LTE-Advanced (700 MHz to 3.5 GHz), use of a higher frequency band of up to 80 GHz is being considered for 5G.[10] Use of frequency bands below 6 GHz in particular is expected to become possible from an early stage (from about 2020).

Figure 3 shows an overall image of the technical elements and the system for 5G. Inter-cell interference coordination technology is important in order to construct a communication area with a configuration that separates the C-Plane and the U-Plane for transmitting the control information (C-Plane) and user data (U-Plane) from different base stations, and to promote density increase and higher capacity. Various techniques[11] are being studied, including a new radio access technology (RAT) supporting a greater number of devices and reducing delay, high-speed transmission using high frequencies and wide bandwidth such as millimeter wave transmission, and beamforming through multi-element antennas (Massive BF).[12]

A recent study found that, as cell density increases, cooperative control using a larger number of transmission points (distributed antennas) is effective for increasing capacity.[13),14] **Figure 4** shows an example of an ultra-high-density distributed antenna system for multipoint cooperation. This example shows communication with multiple terminals through transmitting antennas positioned at various points and connected to a C-BBU. The bright areas in this figure indicate areas with favorable radio signal conditions. The aim is for the C-BBU to perform cooperative control of the directivity, power, and user allocation of the multi-point antennas so that all users can enjoy favorable communication conditions at all times. In terms of what needs to be done in order to realize such a system, it is important that we study technologies that coordinate reception across a large number of transmission points: cooperative control technology for optimizing transmission, and cooperative beamforming technology. For ultra-high density distributed antenna systems, station placement optimization technology that optimizes the types of antennas to be installed (for example, whether antennas should have beamforming capability), the number of antennas to be installed, and

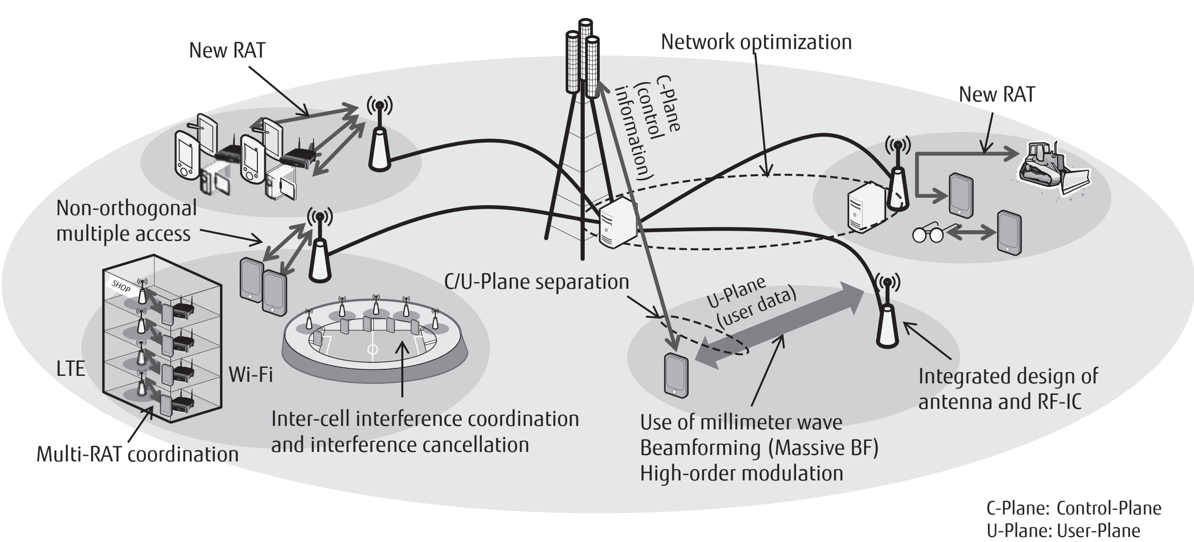


Figure 3
Image of 5G system.

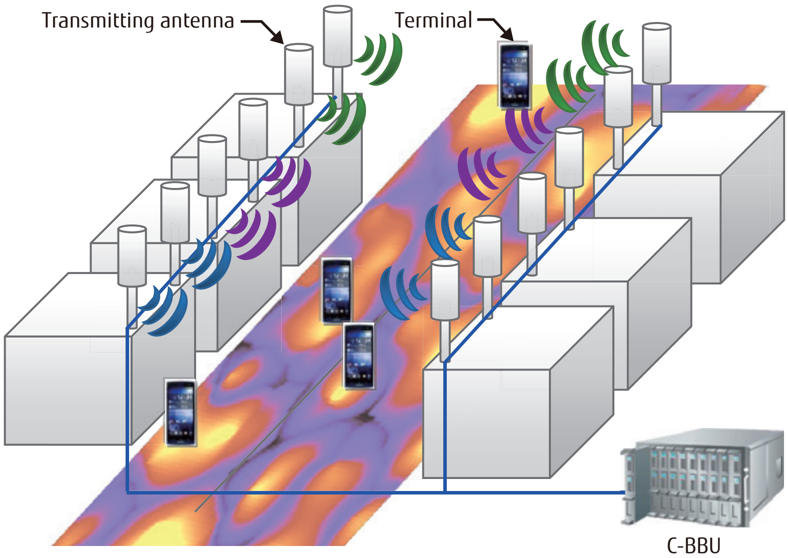


Figure 4
Ultra-high-density distributed antenna system.

installation locations, as well as methods to efficiently and economically interconnect the C-BBU and distributed antennas, are all important aspects that need to be studied.

5. Conclusion

This paper introduces mobile access systems that keep on evolving while supporting increases in mobile data traffic and Fujitsu's current development activities for base station equipment. It goes on to describe trends in the area of technologies supporting high-volume traffic and ultra-high-speed communication technologies for 5G. Regarding LTE and LTE-Advanced, which are already in use, communication capacity increases can be achieved through high-density wireless base station systems that use C-BBU and RRH, and also through the use of advanced C-RAN using femto base stations suitable for small cell construction for indoor environments. In terms of future activities to further increase communication capacity for 5G, ultra-high-density distributed antenna systems that incorporate technologies such as multi-point cooperation and beamforming are important areas. Going forward, further development and enhancement of LTE-Advanced technologies, and the development of various technologies for the practical implementation of 5G will be needed.

References

1) Ministry of Internal Affairs and Communications: Current state of Japan's mobile communication traffic (December 2014) (in Japanese).
http://www.soumu.go.jp/johotsusintokei/field/tsuushin06.html
2) Cisco: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2014–2019 White Paper.
http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html
3) 3GPP: TS 36.300 V11.13.0(2015–03).
http://www.3gpp.org/ftp/Specs/archive/36_series/36.300/
4) 3GPP: TS 36.211 V11.6.0(2015–03).
http://www.3gpp.org/ftp/Specs/archive/36_series/36.211/
5) S. Abeta et al.: LTE-Advanced as Further Evolution of LTE for Smart Life. NTT DOCOMO Technical Journal (English version), Vol. 17, No. 2, pp. 4–9, Oct. 2015.
6) K. Kiyoshima et al.: Commercial Development of LTE-Advanced Applying Advanced C-RAN Architecture—Expanded Capacity by Add-on Cells and Stable communications by Advanced Inter-Cell Cooperation. NTT DOCOMO Technical Journal (English version), Vol. 17, No. 2, pp. 11–18, Oct. 2015.
7) Cisco: Embracing the Internet of Everything To Capture Your Share of $14.4 Trillion. 2013.
http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoE_Economy.pdf

8) World Economic Forum: Risk and Responsibility in a Hyper connected World. January 2014. *http://www3.weforum.org/docs/WEF_RiskResponsibility_HyperconnectedWorld_Report_2014.pdf*
9) ARIB 2020 and Beyond Ad Hoc Group: White Paper, Mobile Communications Systems for 2020 and beyond Ver. 1.0.0. October 8, 2014. *http://www.arib.or.jp/english/20bah-wp-100.pdf*
10) Ministry of Internal Affairs and Communications: Final report of Radio Policy Vision Council. December 2014. *http://www.soumu.go.jp/main_content/000334592.pdf*
11) Fujitsu Laboratories: Fujitsu Achieves Four-User Concurrent Access and 12 Gbps Transmissions by Multiplexing Millimeter-Wave Beams as Step toward 5G. *http://www.fujitsu.com/global/about/resources/news/press-releases/2015/0609-03.html*
12) D. Kimura et al.: Wireless network technologies towards 5G. IEICE Technical Report, Vol. 114, No. 371, NS2014-152, pp. 31–36, December 2014 (in Japanese).
13) T. Kobayashi et al.: A Study on Coordinated Beamforming for 5G Ultra High-Density Small Cells and its Indoor Experiment. IEICE Technical Report, Vol. 115, No. 2, RCS2015–18, pp. 95–100, April 2015 (in Japanese).
14) T. Seyama et al.: A Basic Study on Joint Transmission MU-MIMO in 5G Ultra High-Density Distributed Antenna System. 2015 IEICE Society Conference B–5–64, September 2015.

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