LTE-Advanced | CA | Category 6

Technology Reports

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

Router-type Mobile Terminals for LTE-Advanced Category 6 Carrier Aggregation

The growing popularity of data-intensive content is driving the demand for even greater throughput in mobile communications. Studies have been performed on CA—a key technology of LTE-Advanced—as a means of increasing throughput by enabling the simultaneous use of multiple frequency bands. NTT DOCOMO has developed router-type mobile terminals in two models to support the rollout of LTE-Advanced in March 2015. With a maximum throughput of 300 Mbps on the downlink, these terminals support LTE Category 6 CA.

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1. Introduction

The proliferation of data-intensive content such as movies and video clips in recent years has raised expectations for LTE-Advanced, which can deliver higher transmission speeds and greater capacity while maintaining compatibility with the existing LTE system.

NTT DOCOMO has adopted LTE Category 6 achieving a maximum data rate twice that of existing LTE Category 4 and has been providing LTE-Advanced services featuring maximum throughput on the downlink of 225 Mbps since March 2015 under the name PREMIUM 4G™*1. It has also developed new terminals to support LTE-Advanced for this launch.

In this article, we first give an overview of LTE Category 6 features and router-type mobile terminals supporting LTE Category 6 Carrier Aggregation (CA) (hereinafter referred to as "LTE-Advanced mobile terminals"). We then describe the Radio Frequency (RF)*2 configurations for achieving three combinations of 2 DownLink CA (2DL CA)*3 and present the throughput characteristics we obtained through laboratory and field tests.

We note here that the value of maximum throughput in the downlink varies according to the bandwidths that can be applied for CA. The LTE-Advanced mobile terminals introduced in this article can achieve a maximum throughput of 300 Mbps using the 40 MHz bandwidth of LTE Category 6. However, at the time of launching the LTE-Advanced service, NTT DOCOMO operations allowed for bandwidth allocation up to 30 MHz only, so throughput at that time was 225 Mbps.

2. Definition of Mobile Terminal Categories

The 3rd Generation Partnership Project (3GPP) defines categories of combined transmit/receive capability in LTE

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*1 **PREMIUM 4G™:** A trademark of NTT DOCOMO.
*2 **RF:** The radio frequency circuit.
*3 **2DL CA:** An LTE-Advanced technology enabling high-speed communications by bundling two frequency bands on the downlink (from base station to mobile terminal).

mobile terminals [1]. Category 4 LTE mobile terminals and Category 6 LTE-Advanced mobile terminals are compared in **Table 1**.

Existing Category 4 mobile terminals support a maximum transmit/receive bandwidth of 20 MHz. In contrast, Category 6 mobile terminals can support downlink bandwidths in excess of 20 MHz up to 40 MHz by using two frequency bands simultaneously. This bandwidth extension achieves a throughput of 300 Mbps, which is twice that of Category 4 mobile terminals. However, using only a single frequency band at the time of transmission results in a maximum throughput of 50 Mbps, the same as existing LTE mobile terminals.

The above description pertains to Category 6 in general. But as a specific implementation, NTT DOCOMO uses three combinations of frequency bands, namely, 2 GHz + 800 MHz *4, 2 GHz + 1.5 GHz, and 1.7 GHz + 800 MHz. The 2 GHz + 800 MHz and 2 GHz + 1.5 GHz combinations are implemented throughout Japan while the 1.7 GHz + 800 MHz combination is currently being used in the Tokyo, Nagoya, and Osaka regions. Since the maximum operating bandwidth at the time of LTE-Advanced service launch in March 2015 was 30 MHz, maximum throughput on the downlink was 225 Mbps at that time. 3GPP specifications define a maximum bandwidth of 35 MHz for the frequency-band combinations described above [2], so NTT DOCOMO foresees an eventual data rate of 262.5 Mbps.

3. Overview of LTE-Advanced Mobile Terminals

The LTE-Advanced mobile terminals developed by NTT DOCOMO are shown in **Figure 1** and their basic specifications are listed in **Table 2**. These mobile terminals boast high-speed packet communications based on LTE-Advanced and feature stable communications. They are mobile Wi-Fi routers compatible with quad-band LTE*5. To make full use of the high-speed features offered by LTE-Advanced, wireless LAN communications between the mobile terminal and Wi-Fi client adopt the Wi-Fi IEEE 802.11ac*6 standard, which makes it relatively difficult for the client to be affected by Wi-Fi signal interference while enabling high-speed communications of 876 Mbps. The idea here was to make high-speed communications noticeable not only on the WAN side but on the LAN side as well.

In developing the two models of LTE-Advanced mobile terminals shown here (HW-02G and L-01G), NTT DOCOMO

Table 1 Comparison of Category 4 and Category 6 mobile terminals (Mbps)

		Total Bandwidth (MHz)				
		20	25	30	35	40
Throughput (theoretical value)	Terminal category 4	150	—	—	—	—
	Terminal category 6	150	187.5	225	262.5	300

Figure 1 LTE-Advanced Wi-Fi routers

*4 **2 GHz + 800 MHz:** Notation for CA using the 2 GHz and 800 MHz frequency bands in which the "+" symbol is used to indicate that combination. Likewise, "2 GHz + 1.5 GHz" indicates CA using the 2 GHz and 1.5 GHz frequency bands and "1.7 GHz + 800 MHz" that using the 1.7 GHz and 800 MHz frequency bands.

*5 **Quad-band LTE:** An LTE service using four frequency bands: 2 GHz, 800 MHz, 1.5 GHz, and 1.7 GHz.

*6 **Wi-Fi IEEE802.11ac:** A wireless LAN standard using the 5 GHz frequency band that can achieve high-speed data communications of 433 Mbps – 6.93 Gbps through a maximum bandwidth of 160 MHz, a multi-value modulation signal (256-QAM), and a MIMO system extension (8×8 MIMO).

Table 2 Basic specifications of HW-02G/L-01G terminals

		HW-02G	L-01G
Frequency	LTE-Advanced	2 GHz+1.5 GHz/1.7 GHz+800 MHz/ 2 GHz+800 MHz[*1]	2 GHz+1.5 GHz/1.7 GHz+800 MHz/ 2 GHz+800 MHz[*1]
	LTE	800 MHz/1.5 GHz/1.7 GHz[*2]/2 GHz[*2]	800 MHz/1.5 GHz/1.7 GHz[*2]/2 GHz[*2]/ 2.6 GHz[*2, 3]
	W-CDMA	800 MHz/850 MHz[*2]/2 GHz[*2]	800 MHz/850 MHz[*2]/2 GHz[*2]
	GPRS[*2]	—	850 MHz/900 MHz/1,800 MHz/1,900 MHz
Max. data rate (UE category)	LTE-Advanced	DL : 262.5 Mbps (Category 6) UL : 50 Mbps (Category 6)	DL : 262.5 Mbps (Category 6) UL : 50 Mbps (Category 6)
	LTE	DL : 150 Mbps (Category 4) UL : 50 Mbps (Category 4)	DL : 150 Mbps (Category 4) UL : 50 Mbps (Category 4)
	HSDPA/ HSUPA	DL : 14.4 Mbps (Category 10) UL : 5.7 Mbps (Category 6)	DL : 14.4 Mbps (Category 10) UL : 5.7 Mbps (Category 6)
Dimensions		Approx. 90 mm (H) × 35 mm (W) × 12.9 mm (D)	Approx. 115 mm (H) × 34 mm (W) × 5.0 mm (D) (Max. depth: approx. 10.0 mm)
Weight		Approx. 110 g	Approx. 187 g
Wi-Fi (LAN side)[*4]		802.11a/b/g/n (2.4 GHz/5 GHz)/ac	802.11a/b/g/n (2.4 GHz/5 GHz)/ac
Battery capacity		2,400 mAh	4,880 mAh
Ethernet connection (when using supplied cradle)		802.3ab (1000Base-T)	—

*1 Function addition by software update
*2 Roaming support
*3 TD-LTE support
*4 Only 2.4 GHz Wi-Fi provided when placing in cradle (802.11b, 802.11g, 802.11n)

took into account the environments where users would tend to use each model to determine what functions to give to each, as discussed below.

1) HW-02G

The concept of the HW-02G Wi-Fi router focuses on users whose indoor use is relatively heavy. The design keeps the terminal small so that it can easily be placed on a desk in a study, on a telephone stand in a living room, etc. thereby enabling Wi-Fi to be used just about anywhere in the house. To this end, Wi-Fi functions were enhanced in this model so that it could be used even in places where Wi-Fi signals are difficult to propagate, such as spacious single-family homes or condominiums in which Wi-Fi clients may be located at a distance from the router or behind signal obstructions such as doors, walls, and furniture. Specifically, the cradle supplied with the HW-02G model is equipped with a chip for producing high-power Wi-Fi signals in the 2.4 GHz band. When placing the HW-02G unit in the cradle, the HW-02G built-in Wi-Fi chip is shut down and a switch is made to the Wi-Fi chip on the cradle side. Making an indoor Wi-Fi connection in this way enables high-power signals to be transmitted compared to what could be provided by the Wi-Fi router itself making it possible to use LTE-Advanced even in spacious indoor areas.

2) L-01G

The concept of the L-01G Wi-Fi router focuses on users whose outside use is relatively heavy. Here, the design enables long-term use even if battery charging cannot be performed while on the go. The unit is equipped with a 4,880-mAh large-capacity battery to enable extended use when out and a function enabling it to serve as an auxiliary battery. As a result, the L-01G Wi-Fi router can be used not only for data communications but also as a mobile battery in the event that the user's smartphone or tablet runs out of power. It also supports 3G, General Packet Radio Service (GPRS)*7, Frequency Division Duplex (FDD)-LTE*8 for overseas roaming as well as Time Division Duplex (TDD)-LTE*9 (2.6 GHz). As such, the L-01G Wi-Fi router is a product that meets the needs of overseas travelers for high-speed data communications.

4. Overview of RF Configurations for Three Combinations of 2DL CA

4.1 Two Methods of Frequency Separation

NTT DOCOMO implements three combinations of 2DL CA in one mobile terminal. Typical RF configurations for implementing CA are shown in **Figure 2**. To achieve CA, two frequency bands must be separated and simultaneous communication by those bands must be enabled. There are two methods for doing so. The first method uses a DIPlexer (DIP)*10 situated directly under an antenna as a filter for separating two frequency bands with low loss (Fig. 2 (a) and (b)). The other method uses two antennas for separate and simultaneous communication in two frequency bands (Fig. 2(c)). In the method using DIP, the technical problem is how to suppress insertion loss and prevent drops in signal power, while in the antenna-separation method, the problem is how to minimize the antenna installation space.

4.2 RF Configurations

The RF configuration for achieving 2DL CA for global use (Fig. 2 (a)) differs from the RF configurations for the LTE-Advanced mobile terminals developed by NTT DOCOMO (Fig. 2 (b) and (c)). The global configuration generally places the DIP directly under the antenna to separate low-band frequencies (1 GHz and lower) from high-band frequencies (1.7 GHz and higher) and achieves CA by a low-band and high-band combination. However, to achieve the three types of CA combinations adopted by NTT DOCOMO, the 1.5 GHz band used only in Japan presents a problem. This is because, when applying the DIP used in the global configuration described above, the 1.5 GHz band corresponds to a stopband owing to DIP filter characteristics with the result that filtering loss becomes excessively large. For this reason, NTT DOCOMO has standardized in 3GPP a specification that extends the passband on the high-frequency side of the DIP directly under the antenna to the 1.5 GHz band as shown in Fig. 2 (b) [2]. Consequently, by applying a configuration that couples this DIP with another lower DIP for separating the 1.5 GHz and 2 GHz bands, or a configuration that

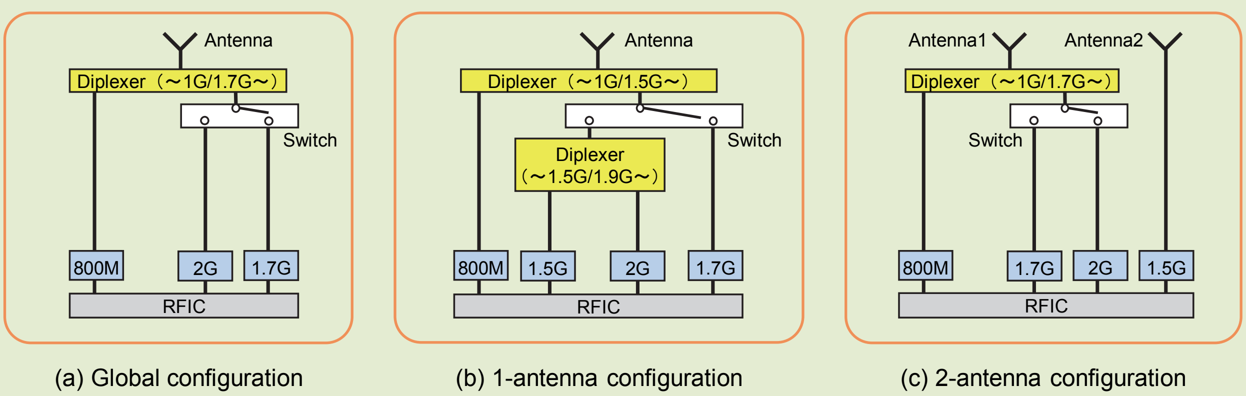

Figure 2 Examples of RF configurations in mobile terminal

*7 **GPRS:** A packet switching service available on GSM network.

*8 **FDD-LTE:** An LTE system applying FDD technology.

*9 **TDD-LTE:** An LTE system applying TDD technology.

*10 **DIP:** A filter for separating two frequency bands at low loss. It consists of a low pass filter (that treats the low-frequency side as the passband and the high-frequency side as the attenuation band) and a high pass filter (that treats the high-frequency side as the passband and the low-frequency side as the attenuation band).

uses a separate antenna to transmit and receive signals only in the 1.5 GHz band as shown in Fig. 2 (c), it becomes possible to achieve 2DL CA through a middle-band and high-band combination (2 GHz + 1.5 GHz). This is in addition to the 2 GHz + 800 MHz and 1.7 GHz + 800 MHz combinations achievable by the global configuration that separates low and high bands.

4.3 Problems and Countermeasures

A multi-level DIP configuration as shown in Fig. 2 (b) results in a decrease in terminal usage time, an increase in generated heat, and a drop in receive sensitivity owing to an increase in insertion loss. Achieving low-loss DIPs was therefore considered. In contrast, separating frequency bands through the use of two antennas and performing simultaneous communications accordingly as shown in Fig. 2 (c) does not generate the loss associated with the above multi-level DIP configuration. However, a terminal having the configuration of Fig. 2 (c) separates frequency bands using different antennas while supporting a 2×2 Multiple Input Multiple Output (MIMO)*11 configuration on the downlink, which requires a total of four antennas within the same housing. Antenna performance may therefore drop as a result of size limitations and mutual coupling between antennas. To deal with these problems, measures have been taken in the LTE-Advanced mobile terminals that have been developed to enhance antenna structure and optimize the arrangement between transmit/receive antennas and the arrangement of receive antennas.

5. Test Results for Downlink Data Rates in LTE-Advanced Mobile Terminals

We performed maximum throughput tests of LTE-Advanced mobile terminals using actual base station equipment in both laboratory and field test environments. For the laboratory test environment, the base station and mobile terminal were connected by cable thereby creating an ideal environment having no interference or fading in radio quality. In the test, data was transferred from a file server to the mobile terminal and throughput on the Medium Access Control (MAC) layer*12 [3] [4] was measured. Results are listed in **Table 3**. For a 35 MHz bandwidth, a throughput of 241 Mbps was measured. This figure agrees with the theoretical value obtained by subtracting the radio control signal needed for our operation.

We next performed a similar test in an field test environment, in which we made measurements in a static state at a location near the base station having a small amount of interference from other base stations and mobile terminals. For a 35 MHz bandwidth, a throughput of 238 Mbps was measured, which shows that a throughput nearly the same as that of the laboratory test environment could be achieved.

In an actual commercial environment, the base station varies transmission speed adaptively based on the number of connected mobile terminals, the amount of interference, distance from the base station, and radio quality. Thus, while data rates will differ depending on the usage environment, the results of these tests demonstrate that both the LTE-Advanced mobile terminal and base station exhibit sufficient performance.

6. Conclusion

In this article, we overviewed the specifications and features of the NTT DOCOMO HW-02G and L-01G

Table 3 Theoretical values and test results for downlink data rate (Mbps)

		Total bandwidth (MHz)				
		20	25	30	35	40
Theoretical value		150	187.5	225	262.5	300
Measured value	Laboratory test environment	135	166	205	241	—
	Field test environment	—	—	199	238	—

*11 **MIMO:** A wireless communication technique that utilizes multiple paths between multiple antennas at the transmitting and receiving ends to exploit spatial propagation properties, causing the capacity of wireless links to increase in proportion with the number of antennas.

*12 **MAC layer:** A radio-interference protocol in LTE and LTE-Advanced. As a sub-layer of Layer 2, it allocates radio resources, performs data mapping, and controls retransmission.

Wi-Fi routers developed as LTE-Advanced mobile terminals for the LTE-Advanced (PREMIUM 4G) service launched in March 2015. We also described the RF configurations for achieving three combinations of 2DL CA adopted by NTT DOCOMO, explained the definitions of mobile terminal categories, clarified throughput characteristics in both laboratory and field test environments, and showed that throughput could be obtained in line with theoretical values.

Going forward, we will conduct more laboratory/field evaluations in multi-user environments, heavy-interference environments, etc. toward improved performance. We also plan to develop mobile terminals capable of 3DL CA (Category 9*) that uses three frequency bands simultaneously to increase throughput even further. Our goal here is to achieve a throughput of 300 Mbps at an operating bandwidth of 40 MHz.

References

[1] 3GPP TS36.306 V10.11.0: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio access capabilities," Dec. 2013.

[2] 3GPP TS36.101 V10.17.0: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio transmission and reception," Dec. 2014.

[3] 3GPP TS36.321 V10.10.0: "Evolved Universal Terrestrial Radio Access (EUTRA); Medium Access Control (MAC) protocol specification," Dec. 2013.

[4] 3GPP TS36.213 V10.12.0: "Evolved Universal Terrestrial Radio Access (EUTRA); Physical layer procedures," Mar. 2014.

* Specifications call for an upper performance limit of 450 Mbps at a bandwidth of 60 MHz.