3.5-GHz Band | TD-LTE | 3DL CA

Technology Reports

Special Articles on Introducing the 3.5-GHz Band

Router-type Mobile Terminal for TD-LTE in 3.5-GHz Band

Communication Device Development Department Ryosuke Osawa
Tomoya Ohara
Kei Ando
Product Department Tomoya Matsuura

In December 2014, the MIC approved "Establishment Plan of Specified Base Stations for Introduction of Fourth-generation Mobile Communication Systems," and it thus became possible to utilize the 3.5-GHz frequency band in Japan. NTT DOCOMO has introduced TD-LTE using this band—combined with the existing FDD bands by means of CA—and communication services with a maximum data rate of 370 Mbps were launched to evolve our service called "PREMIUM 4G" in June 2016. This article provides an overview of a router-type mobile terminal supporting a maximum downlink data rate of 370 Mbps using TD-LTE and 3DL CA technologies. It also describes 3.5-GHz band standardization activities and presents the results of laboratory and field experiments for downlink data rates.

1. Introduction

The dramatic increase in mobile data traffic in recent years and growing demand for ultra-high-speed data communications is driving the need for greater capacities in new frequency bands.

The 3.5-GHz band has been newly allocated as a frequency band that can provide wide bandwidths. In 3rd Generation Partnership Project (3GPP), it has been specified as band 42 [1] for use with the Time Division Duplex (TDD)*1 transmission method, and it is expected to be used globally in the future. In the development of this standard, NTT DOCOMO promoted specifications that would facilitate the early implementation of low-cost mobile terminals, and these efforts have resulted in the recent launch of commercial services applying TDD-based LTE (hereinafter referred to as "TD-LTE").

In this article, we describe an NTT DOCOMO router-type mobile terminal that achieves high transmission speeds by performing Carrier Aggregation (CA)*2 between the TDD frequency band and existing Frequency Division Duplex (FDD)*3 frequency bands in a scheme called 3DownLink CA (3DL CA)*4.

*1 **TDD:** A signal transmission method that allocates different time slots on the uplink and downlink using the same carrier frequency and frequency band.

2. Categories and Overview of TD-LTE-capable Mobile Terminal in 3.5-GHz Band

1) Mobile Terminal Categories

The newly developed mobile terminal supports 3DL CA that includes two 20-MHz frequency blocks in the 3.5-GHz band each serving as a Component Carrier (CC)[*5]. This makes for a total bandwidth of 60 MHz resulting and a maximum downlink data rate of 370 Mbps. The terminal supports mobile terminal category 9, which is necessary to achieve downlink data rates in excess of 300 Mbps. Mobile terminal categories are compared in **Table 1** [2].

2) Overview

The appearance of the mobile terminal developed by NTT DOCOMO is shown in **Photo 1** and its basic specifications are listed in **Table 2**. This terminal (HW-01H) is a mobile Wi-Fi®[*6] router that achieves high-speed communications by supporting the 3.5-GHz band in addition to the existing 2-GHz, 1.7-GHz, 1.5-GHz, and 800-MHz bands.

It also supports a maximum downlink data rate of 370 Mbps by applying CA between the 3.5-GHz band and either the 2-GHz band or 1.7-GHz band (3.5 GHz + 3.5 GHz + 2 GHz or 3.5 GHz + 3.5 GHz + 1.7 GHz).

The HW-01H terminal targets users in need of a Wi-Fi router while on the go. In addition to offering high-speed communications, it features a 4,750 mAh large-capacity battery for extended usage time. It also supports the USB 3.0 SuperSpeed standard to enable high-speed communications during USB tethering[*7] in addition to high-speed Wi-Fi communications. It is equipped with an extra function for waking up from sleep mode, which is enabled through Bluetooth®[*8] communications via a dedicated mobile app on a smartphone or tablet. For example, this convenient function can be used to wake up a sleeping HW-01H terminal inside the user's bag or briefcase without having to remove the terminal from the bag.

3. Standardization Activities toward Development of Radio Part in 3.5-GHz Terminal

There were two main issues to be resolved in developing the radio part of a terminal supporting the 3.5-GHz band:

Table 1 Maximum data rates for each mobile terminal category

Terminal category	Max. downlink data rate (Mbps)	Max. uplink data rate (Mbps)	No. of MIMO layers
4	150	50	2
6	300	50	2 or 4
9	450	50	2 or 4

Photo 1 Appearance of HW-01H

*2 **CA:** An LTE-Advanced technology enabling high-speed communications by bundling multiple frequency bands on the uplink or downlink.

*3 **FDD:** A scheme for transmitting signals using different carrier frequencies and bands on the uplink and downlink.

*4 **3DL CA:** An LTE-Advanced technology enabling high-speed communications by bundling three frequency bands on the downlink.

*5 **CC:** A term indicating a frequency band targeted for bundling in CA.

*6 **Wi-Fi®:** A registered trademark of the Wi-Fi Alliance.

*7 **Tethering:** A function which enables a mobile terminal to be used as an external modem, so that Wi-Fi devices such as game machines or PCs can connect to the Internet through the mobile phone's connection.

Table 2 Basic specifications of HW-01H terminal

			HW-01H	L-01G (Ref.)
Max. data rate	LTE-Advanced	3CA	DL: 370 Mbps UL: 50 Mbps	–
		2CA	DL: 262.5 Mbps UL: 50 Mbps	DL: 262.5 Mbps UL: 50 Mbps
	LTE		DL: 150 Mbps UL: 50 Mbps	DL: 150 Mbps UL: 50 Mbps
	HSDPA		DL: 14.4 Mbps	DL: 14.4 Mbps
	HSUPA		UL: 5.7 Mbps	UL: 5.7 Mbps
Dimensions			64 × 100 × 22 mm	107 × 65 × 20 mm
Weight			Approx. 173 g	Approx. 186 g
Wi-Fi (LAN side)			11a/b/g/n (2.4/5 GHz) /ac	11a/b/g/n (2.4/5 GHz) /ac
Battery capacity			4,750 mAh	4,880 mAh

- Method for developing a 3.5-GHz band filter
- Method for developing CA combinations to include the 3.5-GHz band

Studies were conducted on each of these issues, as described below.

3.1 Achieving a 3.5-GHz Band Filter

Mobile communications make use of a component called a "Radio Frequency (RF) filter" for extracting electrical signals in a specific frequency band. When developing the HW-01H terminal, potential filter technologies to the 3.5-GHz band were evaluated. There are three main types of filter technologies used in mobile terminals: Surface Acoustic Wave (SAW) filter*9, Bulk Acoustic Wave (BAW) filter*10, and LC filter. The SAW filter, which is widely used today in mobile terminals, is achieved by an interdigital transducer*11 having a width proportional to the target wavelength. However, the higher frequencies of the 3.5-GHz band compared with existing FDD frequency bands creates new issues, such as the need for fine processing to fabricate narrower electrodes and for electrical power resistance to withstand the transmission power output from the power amplifier. In contrast, the BAW filter, which uses a thin piezoelectric film, is known to be advantageous for high-frequency use because it has a device structure requiring no fine patterns while featuring good out-of-band attenuation characteristics. On the other hand, signal loss in the 3.5-GHz band is large at the moment, and attempts to reduce such losses have revealed that a long development time may be needed to do so. The LC filter, meanwhile, is existing technology that can accommodate higher frequencies and broader bandwidths while maintaining low-loss and low-cost characteristics. At present, this type of filter is the most appropriate for the 3.5-GHz band. However, its attenuation characteristics with respect to interference signals outside the 3.5-GHz band are poor compared with that of the other two filters. Consequently, when applying this filter to the 3.5-GHz band, there is concern that a receiver specification in the 3GPP radio standard with respect to out-of-band interference will not be able to be satisfied. Thus, given that this standard applies specifications for existing frequency bands to the 3.5-GHz band too, it was decided to optimize a 3.5-GHz band specification taking into account the increase in path loss accompanying high frequencies. As a result, the LC filter as well can now meet the 3GPP receiver requirement, thereby enabling the development of low-cost, low-loss mobile terminals with a shortened development period.

*8 **Bluetooth®:** A registered trademark of Bluetooth SIG Inc. in the United States.

*9 **SAW filter:** An electrical device for extracting signals in a specific frequency band using surface acoustic waves.

*10 **BAW filter:** An electrical device for extracting signals in a specific frequency band using bulk acoustic waves.

*11 **Interdigital transducer:** Comb-shaped electrodes formed by depositing thin metallic film on the surface of a piezoelectric substrate.

3.2 Achieving CA That Includes 3.5-GHz Band

It is known that one method of achieving CA combining the 3.5-GHz band and existing frequency bands is to use a triplexer that separates an incoming signal into three frequency ranges with low loss, as shown in **Figure 1** (a). A triplexer is a filter device that has a function for extending a conventional diplexer to three-times signal branching. When including the 3.5-GHz band, however, there are concerns not just about insertion loss in the 3.5-GHz band but also about an increase in side loss of existing frequency bands. With the aim of resolving this issue, studies were performed with various filter vendors on achieving a low-loss triplexer. These studies resulted in standardizing TDD-FDD CA for the frequency-band combinations of 800 MHz + 3.5 GHz, 1.5 GHz + 3.5 GHz, 1.7 GHz + 3.5 GHz, and 2 GHz + 3.5 GHz while minimizing as much as possible the increase in loss in existing frequency bands. Another method of achieving CA combining the 3.5-GHz band and existing frequency bands is to use separate antennas for the 3.5-GHz band and existing frequency bands, as shown in Fig. 1 (b). The radio part configurations shown in Fig. 1 (a) and (b) are just examples, and what type of configuration to use in developing a mobile terminal depends on the design ideas offered by various terminal vendors. At this time, the implementation should not be limited in specifications that do not include antenna aspects. For this reason, specifications were defined that enable any radio part configuration to be achieved taking as a precondition the configuration of Fig. 1 (a) that takes into account filter insertion loss in the 3.5-GHz band.

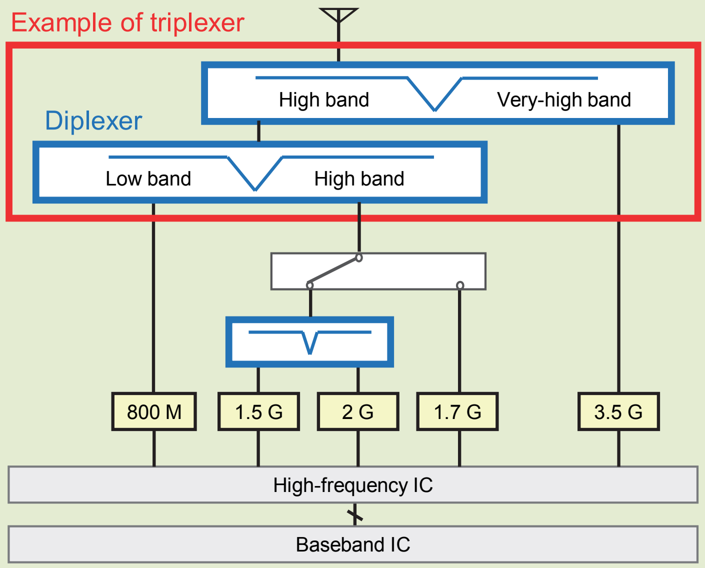

Figure 1 (a) Example of triplexer configuration

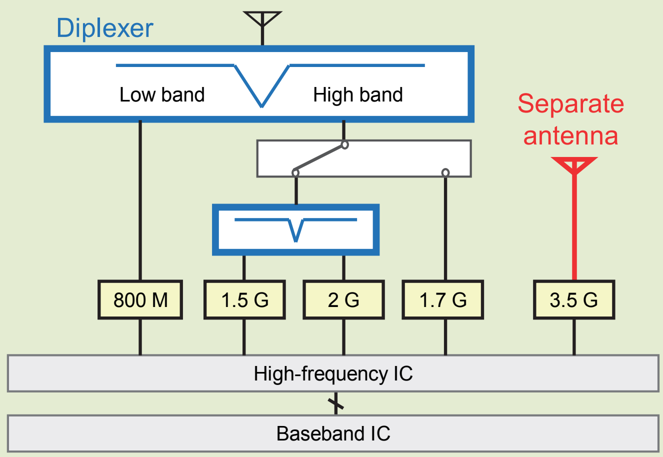

Figure 1 (b) Example of separate antenna configuration

4. Results of Laboratory and Field Experiments on Downlink Data Rates

We evaluated downlink data rates of this 3.5-GHz TD-LTE-capable terminal through laboratory and field experiments.

First, we measured the maximum downlink data rate in a laboratory environment using commercial mobile terminal and base station equipment. In the experiment, we connected the base station and mobile terminal by cable to create an ideal environment with no interference or fading of radio quality. The frequency bands used in the experiment consisted of one 1.7-GHz CC with a bandwidth of 20 MHz and two 3.5-GHz CCs each with a bandwidth of 20 MHz for a total bandwidth of 60 MHz. We transferred data to the mobile terminal and measured downlink data rate including the IP layer*12 header. Results are shown in **Table 3**. A maximum downlink data rate of 343 Mbps was observed compared with a theoretical value of 370 Mbps.

Next, we measured the downlink data rate in a field experiment. For this experiment, we checked signal propagation conditions in the 3.5-GHz band and selected a location having good downlink quality in the range covered by the base station. The base station and mobile terminal were connected by a radio link thereby creating an environment closer to that of commercial services compared with the laboratory experiment. The total frequency bandwidth was the same as that used in the laboratory experiment. The measurements were carried out at a location with good downlink radio quality in a static state. We observed a high-speed downlink data rate of 340 Mbps, which was almost the same as that observed in the laboratory. These results demonstrate that the newly developed router-type mobile terminal can contribute to higher data rates in commercial services.

Table 3 Theoretical and measured values for downlink data rate (60-MHz bandwidth)

Theoretical value	Measured value (laboratory)	Measured value (field)
370 Mbps	343 Mbps	340 Mbps

5. Conclusion

In this article, we described our development of a router-type mobile terminal that makes use of the newly allocated 3.5-GHz band and performs CA combining the FDD and TDD transmission methods. We also presented an overview of the HW-01H mobile terminal and its features, described standardization activities, and presented the results of field experiments on downlink data rates. At NTT DOCOMO, we are committed to developing advanced technologies with the aim of achieving even higher communication speeds for our customers.

References

[1] 3GPP TS36.101 V12.10.1: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio transmission and reception," Jan. 2016.

[2] 3GPP TS36.306 V12.7.0: "Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio access capabilities," Jan. 2016.

*12 **IP layer:** The third layer in the OSI reference model performing routing, relaying, etc. Headers on this layer include source/destination IP addresses.