LTE | Data communication terminal | Throughput

Technology Reports

Special Articles on "Xi" (Crossy) LTE Service—Toward Smart Innovation—

Mobile Data Communication Terminals Compatible with "Xi" (Crossy) LTE Service

*With the growth of high bandwidth services such as streaming video, the demand for data communication services has grown dramatically and there is a growing need for fast inexpensive mobile broadband. For the launch of the "Xi" (Crossy)[*1] service on December 24, 2010, NTT DOCOMO developed two mobile data communication terminals compatible with LTE, UMTS and GPRS functions.*

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1. Introduction

Demand for data communication services has risen dramatically in recent years, and there are strong calls for mobile broadband services offering higher speed at lower cost. On December 24, 2010, amid the ongoing global effort into the research and development of LTE and the provision of commercial services, NTT DOCOMO launched the "Xi" (Crossy) service as one of the world leaders in this field, and developed mobile data communication terminals (hereinafter referred to as "LTE terminals") having LTE, Universal Mobile Telecommunications System (UMTS)[*2] and General Packet Radio Service (GPRS)[*3] functions, and functions for performing handovers between LTE and UMTS.

In this article, we present a general overview of the LTE terminals and their basic specifications, and we describe their baseband[*4] transceiver configuration, particularly with regard to the wireless communication device used for LTE communication. We also present an antenna evaluation method that plays an important role in the realization of high-speed LTE communications, and we describe the throughput[*5] characteristics of the outdoor field trials.

2. Overview of LTE Terminals

Photo 1 shows the appearance of the LTE terminals, and **Table 1** lists their basic specifications. These are triple-mode LTE terminals that not only support LTE high-speed packet communication but are also compatible with UMTS and GPRS. NTT DOCOMO's L-02C and F-06C terminals support handover between LTE and UMTS automatically in standby and during data transmission, which means they can be used seamlessly in LTE areas and 3G areas.

Our "Xi" (Crossy) products are

*1 **"Xi" (Crossy)**: "Xi" (read "Crossy") and its logo are trademarks of NTT DOCOMO.

*2 **UMTS**: A European third-generation mobile communication system which includes W-CDMA (as used by NTT DOCOMO) and other access methods such as Time Division (TD)-CDMA.

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

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

*5 **Throughput**: Effective amount of data transferred without errors per unit time.

equipped with PC interfaces so they can be connected to a PC — the L-02C has a USB interface, and the F-06C has an ExpressCard interface. By combining the F-06C with a PC card adapter, it can also be used on PCs with a PC Card slot that supports the Personal Computer Memory Card International Association (PCMCIA)*6 standard, for which there is a strong demand from businesses. Our LTE terminals are thus compatible with three types of interface that users can select freely depending on their PC environment and individual requirements.

These LTE terminals are compatible with "Zero Install" functions whereby application software such as drivers and connection management software is automatically installed simply by connecting the terminal to a PC, in the same way as conventional data commu-

(a) L-02C (b) F-06C

Photo 1 LTE terminals

Table 1 L-02C/F-06C basic specifications

		L-02C	F-06C	L-05A (reference)
Radio frequency band	LTE	2 GHz	2 GHz	—
	W-CDMA	800 MHz/850 MHz/2 GHz	800 MHz/850 MHz/1.7 GHz/2 GHz	800 MHz/850 MHz/2 GHz
	GSM/GPRS	GPRS 900 MHz/1,800 MHz/1,900 MHz	GPRS 900 MHz/1,800 MHz/1,900 MHz	GSM 850 MHz/900 MHz/1,800 MHz/1,900 MHz
Data transmission rate		Receive up to 100 Mbit/s Transmit up to 50 Mbit/s	Receive up to 100 Mbit/s Transmit up to 50 Mbit/s	Receive up to 7.2 Mbit/s Transmit up to 5.6 Mbit/s
UE category	LTE	Category 3	Category 3	—
	HSUPA	Category 6	Category 6	Category 6
	HSDPA	Category 8	Category 8	Category 8
Supported IP protocols		IPv4, IPv6	IPv4, IPv6	IPv4
Interface		USB	ExpressCard PCMCIA Type II (when using PC card adapter)	USB
Size (height × width × thickness)		Approx. 90 × 35 × 12.9 (mm)	Approx. 115 × 34 × 5.0 (mm); thickest part: approx. 10.0 mm	Approx. 80 × 32 × 13.0 (mm)
Weight		Approx. 44 g	Approx. 35 g	Approx. 37 g
Supported OS platforms		Windows 7 SP1 or later Windows Vista® SP2 or later Windows XP Professional SP3 or later Windows XP Home Edition SP3 or later Mac OS® X 10.5.8/10.6.4-10.6.6	Windows 7 SP1 or later Windows Vista SP2 or later Windows XP Professional SP3 or later Windows XP Home Edition SP3 or later Mac OS X 10.5.8/10.6.4-10.6.6	Windows 7 SP1 or later Windows Vista SP1 or later Windows XP Professional SP2 or later Windows XP Home Edition SP2 or later Windows 2000 Professional SP4 or later Mac OS X 10.4.11/10.5.6-10.5.8/10.6-10.6.6
Supply voltage		DC5.0 V	DC3.3 V	DC5.0 V

Windows Vista® : A trademark or registered trademark of Microsoft Corp. in the United States, Japan and/or other countries.
Mac OS® : A trademark or registered trademark of Apple Inc. in the United States, Japan and/or other countries.

*6 **PCMCIA**: An organization set up to develop standard for memory cards connected to PCs.

*7 **APN**: An address name that is set as the destination of a connection when performing data communication over a network connection.

*8 **Mobile Broadband**: Connectivity software supplied with Windows 7 OS to provide wireless Internet access.

*9 **Windows®**: A trademark or registered tradenication terminals. This software also incorporates functions for purposes such as automatically switching a network connection on and off, configuring an Access Point Name (APN)*7 for connection to outside networks, and configuring the network settings for use in other countries.

Furthermore, to visualize the network status of the area with which the terminal is communicating, it is possible to confirm this information through the color of an LED in the main unit of the mobile terminal, or an icon in the connection management software running on a PC.

In addition to the connection management software provided with the mobile terminal, it is also possible to perform data communication using a dialup connection or the Mobile Broadband*8 connection management software provided as standard in the Windows®*9 7 operating system, thereby supporting a wide range of different usage methods to suit the users' needs and operating environments.

3. LTE Terminal Transceiver Configuration and Antenna Evaluation Method

3.1 Transceiver Configuration

In the LTE system which provides fast high-capacity wireless communication, Orthogonal Frequency Division Multiple Access (OFDMA) is used as the downlink access method. OFDMA transmits data in parallel via a large number of low symbol rate multi-carrier signals generated by inserting guard intervals*10 into the original high-speed broadband signals. This enables it to transmit signals in a variable bandwidth with a high degree of freedom, and with a high level of robustness against multipath interference*11 [1]. Further speed increases are achieved through the introduction of Multi Input Multi Output (MIMO)*12 in LTE to transmit and receive signals via multiple antennas [2]. The concept of MIMO is shown in **Figure 1**. The signals received from different antennas on the base station (transmitting side) are received using multiple antennas on the terminal (receiving side) and are subjected to a signal separation process whereby it is possible to receive different transmitted data in the same band at the same frequency, resulting in a data throughput rate that is theoretically proportional to the number of transmitting and receiving antennas. In the illustration of Fig. 1, this means that it is possible to obtain twice the throughput that would be obtained with a single antenna.

Single-Carrier FDMA (SC-FDMA)*13 is used as the LTE uplink access method [1]. The OFDMA used as the downlink access method has a high Peak-to-Average Power Ratio (PAPR)*14 and requires a power amplifier with a high-performance linear waveform characteristic, which makes it difficult to apply this method to uplink access on mobile terminals. On the other hand, since SC-FDMA can flexibly vary the transmission bandwidth according to the transmission rate of the uplink signal, it is possible to perform single-carrier transmission, and by suppressing the PAPR, it is able to restrict the power consumption of the power amplifier in the mobile terminal.

The baseband transceiver configuration of an LTE terminal is shown in **Figure 2**.

In an OFDMA baseband receiver, the guard intervals are first removed from the signals received by each antenna, and a Fast Fourier Transform (FFT) is used to perform parallel separation of the multi-carrier signals distributed across a broad bandwidth. Signal separation and demodulation

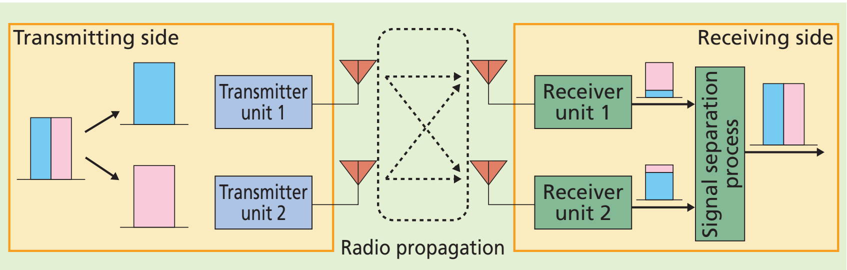


Figure 1 The concept of MIMO

mark of Microsoft Corp. in the United States and other countries.

*10 **Guard interval**: A redundant space provided between symbol data in order to reduce intersymbol interference.

*11 **Multipath interference**: Interference caused by delayed waves arriving via reflections from obstacles such as buildings.

*12 **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.

*13 **SC-FDMA**: A single-carrier frequency-division multiplexing method used as a radio access method for uplink signals in LTE.

*14 **PAPR**: The ratio of a transmitter's peak power level to its average power level; used as an indicator for evaluating the performance and power consumption of a power amplifier.

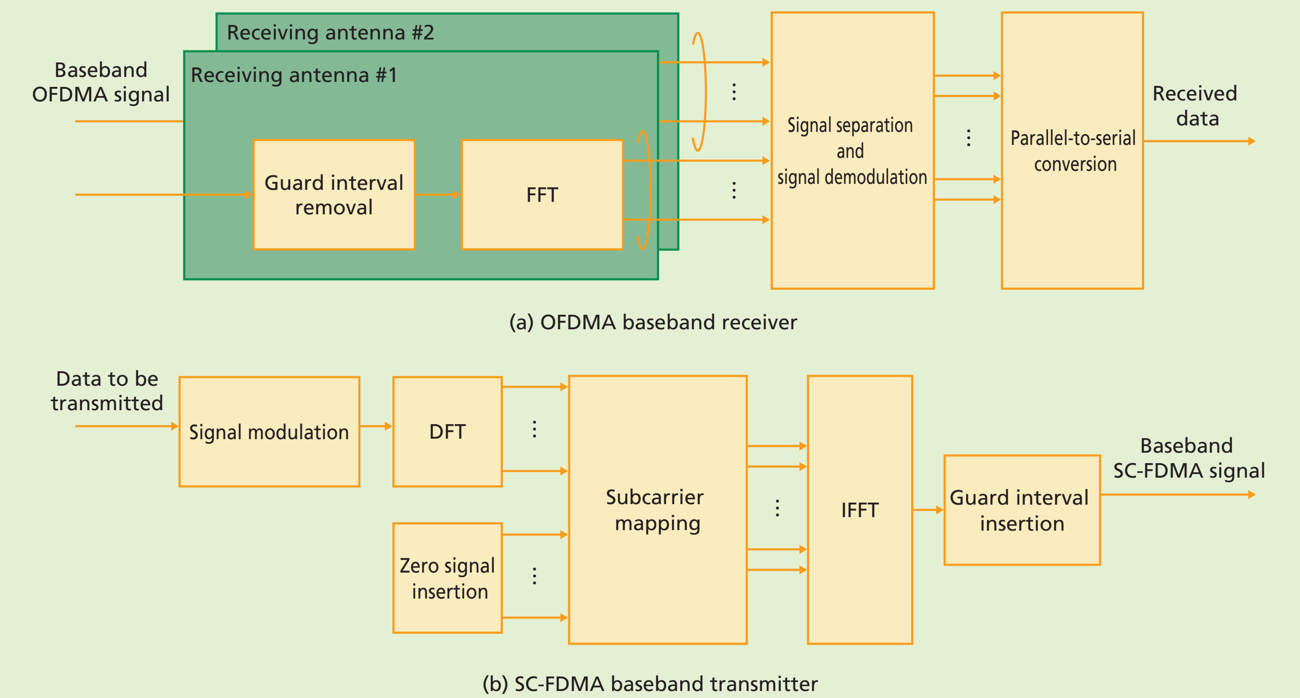


Figure 2 Baseband transceiver configuration of LTE terminal

processes are then performed for each antenna and each carrier, and the received data is obtained by converting the parallel received data into serial form. Meanwhile, in the SC-FDMA baseband transmitter, the data to be transmitted is modulated using a technique such as Quadrature Phase Shift Keying (QPSK)[*15] or 16 Quadrature Amplitude Modulation (16QAM)[*16], and a Discrete Fourier Transform (DFT) is performed to arrange the modulated signals in the frequency domain. After that, the frequencies are shifted to match the transmission bandwidth reported from the network, "zero" signals are inserted in bands where nothing is transmitted (subcarrier mapping[*17]), and an Inverse FFT (IFFT)[*18] is performed to obtain the SC-FDMA signal.

Thus, since achieving fast wireless communication in an LTE access system requires the reception of signals transmitted from different antennas, precise signal separation processing and the processing of matrix computations such as FFTs (with a minimum period of 1 ms), the terminal side requires multiple high-gain antennas, an accurate signal separation algorithm, and signal processing performance that is fast enough to support high-speed communication.

3.2 MIMO Antenna Evaluation Method

To implement multiple high-gain antennas, NTT DOCOMO has proposed the MIMO Over-The-Air (OTA) measurement method which is a MIMO antenna evaluation method for LTE terminals.

To evaluate the performance of multiple antennas for terminals that use MIMO transmission (MIMO antennas), it is insufficient to simply evaluate the antenna performance based on conventional radiation pattern measurements. Instead, MIMO OTA measurements must be performed to evaluate the overall wireless performance using OTA in an environment that simulates a multipath environment. The feasibility of such measurements is also being studied by the 3GPP [3]. Antenna parameters that determine the MIMO perfor-

*15 **QPSK**: A digital modulation method that uses a combination of signals with four different phases to enable the simultaneous transmission of two bits of data.

*16 **16QAM**: A digital modulation method that allows transmission of 4 bits information simultaneously by assigning one value to each of 16 different combinations of amplitude and phase.

*17 **Subcarrier mapping**: A process for arranging transmitted symbol data on the frequency axis.

*18 **IFFT**: In this article, the method used when transforming each subcarrier signal from a frequency component into digital data.

*19 **Rayleigh fading**: Fading characteristics typical of a non-line-of-sight environment in mobile communications.

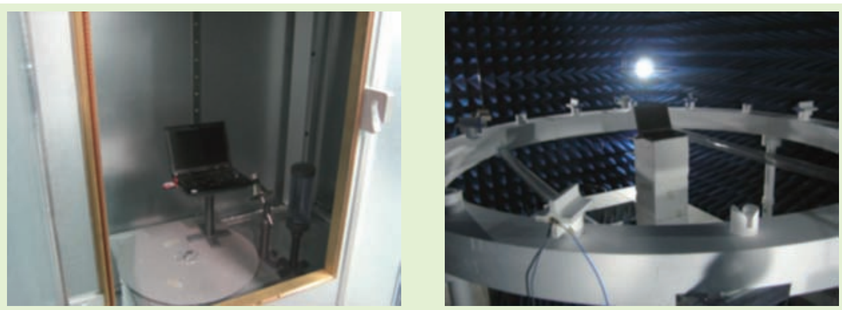
*20 **Anechoic chamber**: An experimental facilimance include the antenna gain imbalance and antenna correlation. NTT DOCOMO have made technical proposals to the 3GPP for a MIMO OTA measurement method that can suitably evaluate these parameters. Two MIMO OTA measurement systems we developed are shown in **Photo 2**. The reverberation chamber method can quickly and easily generate a three-dimensional uniform Rayleigh fading[*19] environment, and the multi-probe method using an anechoic chamber[*20] can generate an arbitrary multipath environment in a temporal and spatial domain. Using these measurement systems, it is possible to generate propagation environments that are faithful to the actual usage environment with sufficient reproducibility in laboratory tests, enabling evaluation of the overall wireless performance of LTE terminals, including their antenna performance. Furthermore, by basing the evaluations on throughput, which is a faithful indicator of user experience, the development of antennas for LTE terminals using this MIMO OTA measurement method will make a large contribution to the improvement of quality.

4. Mobile Terminal throughout Characteristics

We compared the throughput of an L-02C LTE terminal with that of an High Speed Downlink Packet Access (HSDPA)[*21] category 8 terminal, which is capable of a maximum throughput of 7.2 Mbit/s. Tests were carried out in an LTE area in Tokyo, and the comparison was performed with the LTE transmission bandwidth set to 5 MHz (the same as HSDPA) and a maximum throughput of 37.5 Mbit/s.

For the throughput measurements, the mobile terminal was attached to a PC, and after it had connected to the content server, a high-capacity file was downloaded by File Transfer Protocol (FTP)[*22], and we measured average throughput at the TCP layer over a period of one second.

Table 2 shows the results of fixed-point tests to measure the throughput characteristics. At test point A, which is directly below the base station, the Reference Signal Received Power (RSRP)[*23] showing the LTE received signal strength was a very high −72.2 dBm, the maximum throughput was 27.4 Mbit/s, and the average throughput was 24.8 Mbit/s. At test points B and C, which were situated a few hundred meters away from the base station, we were still able to obtain high throughput characteristics with a maximum throughput of 15.4 Mbit/s and 11.4 Mbit/s, and an average throughput of 10.3 Mbit/s and 7.2 Mbit/s respectively. For the HSDPA terminal, we obtained a maximum throughput of 3.2 Mbit/s and an average throughput of 1.9 Mbit/s at test point A. At this measurement point,



(a) Reverberation chamber (b) Anechoic chamber multiprobe

Photo 2 MIMO OTA measurement system for throughput evaluation

Table 2 Results of throughput characteristic tests while at rest

Measurement point (distance from base station)	Downlink reception quality RSRP (LTE)	Maximum throughput and average throughput	
		LTE	HSDPA (reference)
Point A (directly below)	−72.2 dBm	Max. 27.4 Mbit/s Avg. 24.8 Mbit/s	Max. 3.2 Mbit/s Avg. 1.9 Mbit/s
Point B (a few hundred meters away)	−74.9 dBm	Max. 15.4 Mbit/s Avg. 10.3 Mbit/s	Max. 1.2 Mbit/s Avg. 0.7 Mbit/s
Point C (a few hundred meters away)	−79.6 dBm	Max. 11.4 Mbit/s Avg. 7.2 Mbit/s	Max. 1.8 Mbit/s Avg. 0.8 Mbit/s

ty that blocks the penetration of external radio waves and suppresses wave reflection by covering the six interior walls of the chamber with radio-wave absorbers.

*21 **HSDPA**: A high-speed downlink packet transmission system based on W-CDMA. Maximum downlink transmission speed under the 3GPP standard is approximately 14 Mbit/s. Optimizes the modulation method and cording rate according to the radio reception status of the mobile terminal.

*22 **FTP**: A protocol that is generally used for transferring files over a TCP/IP network such as the Internet.

*23 **RSRP**: The received power of a signal measured by a mobile terminal in LTE. Used as an indicator of the receiver sensitivity of mobile terminals.

the LTE terminal outperforms the HSDPA terminal by a factor of approximately 8.6 in terms of maximum throughput and about 13 times in terms of average throughput.

5. Conclusion

In this article, we have presented an overview of the LTE terminals L-02C and F-06 terminals developed for the "Xi" (Crossy) LTE service which was launched on December 24, 2010, and we have described the characteristics of these terminals. We have also presented a MIMO antenna evaluation method and clarified the throughput characteristics in outdoor environments.

From the results of downlink throughput measurements in outdoor environments, we have shown that compared with an HSDPA terminal, it is possible to obtain peak throughput characteristics that are 8.6 times better and average throughput characteristics that are 13 times better in fixed point measurements.

In the future, we will continue to evaluate the terminal performance including the MIMO antenna characteristics and the outdoor throughput, and we will continue with development efforts aimed at achieving further performance improvements.

References

[1] 3GPP TS36.211 V8.9.0: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation," Dec. 2009.

[2] 3GPP TS36.213 V8.8.0: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures," Sep. 2009.

[3] 3GPP TR37.976 V1.1.0: "Measurements of radiated performance for MIMO and multi-antenna reception for HSPA and LTE terminals," Jun. 2010.