HSDPA Terminal Development and Radio Transmission Performance

Hisashi Matsuoka, Takeshi Nakamori, Yosuke Iizuka†, and Shinsuke Ogawa

Abstract

This article outlines two new mobile terminals developed for the HSDPA (high-speed downlink packet access) service. One is a mobile phone designed for high-speed communications, which has new functions such as music download. The other is a card-type terminal for portable computers aimed at business users. Radio transmission throughput performance based on field experiments is also reported.

1. Introduction

In response to demands from users of its FOMA service for greater capacity and higher communication speeds, NTT DoCoMo commenced a commercial high-speed downlink packet access (HSDPA) service in August 2006. This service has a maximum data download speed of 3.6 Mbit/s. At the same time, a new telephone-type mobile terminal, the FOMA N902iX HIGH-SPEED (**Fig. 1**), and a card-type mobile terminal for use in portable computers, FOMA M2501 HIGH-SPEED (**Fig. 2**), were put on sale. The N902iX HIGH-SPEED is compatible with DoCoMo's new music program download service (Music Channel™) and supports a music download service and high-volume file transfer (up to 5 MB) using DoCoMo's i-motion*1 service. The M2501 HIGH-SPEED, which is aimed at business users, supports HSDPA/3G roaming and GSM*2. This article outlines the major points in the development of each of these HSDPA mobile terminals and describes the radio transmission throughput*3 performance based on field experiments.

2. HSDPA mobile terminal categories and maximum throughput

The 3rd Generation Partnership Project (3GPP) classifies HSDPA mobile terminals into 12 categories according to their data transmission capability, as listed in **Table 1** [1]. The maximum number of received codes is the number of multiplexed codes on the high-speed physical downlink shared channel (HS-PDSCH) [2] that receives data. The minimum transmission time interval (TTI) is the minimum time interval allocated to the mobile terminal for receiving data. The values in the table indicate multiples of the minimum TTI of 2 ms. The maximum buffer size for hybrid automatic repeat request (H-ARQ)*4 is determined considering signals received prior to resend and resent signals; it is the maximum number of bits in the receive buffer after demodulation [3]. Categories 1–10 support 16QAM (16 quadrature amplitude modulation)*5. The maximum throughputs for

† NTT DoCoMo R&D Center
Yokosuka-shi, 239-8536 Japan
Email: iiduka@nttdocomo.co.jp

*1 i-motion: An i-mode-related service that distributes video-clips to FOMA terminals and allows the sending and receiving of video-clips via the FOMA system. It was launched in November 2001.

*2 GSM (global system for mobile communications): A second-generation mobile communication system used widely around the world, especially in Europe and Asia, but not deployed in Japan.

*3 Throughput: Effective amount of data transmitted without error per unit time.

*4 Hybrid automatic repeat request (H-ARQ): Technology combining automatic repeat requests (ARQ) and error correction codes to increase error correction capability during repeats and reduce the number of repeats. The retransmitted packets from the BTS and previously received packets are combined to improve reception quality and provide higher efficiency in transmission.

*5 16QAM (16 quadrature amplitude modulation): A digital modulation method that allows transmission of 4 bits of information simultaneously by assigning one value to each of 16 different combinations of amplitude and phase.

Fig. 1. N902iX HIGH-SPEED.

Fig. 2. M2501 HIGH-SPEED.

Table 1. HSDPA mobile terminal categories.

Category	Maximum number of received codes	Minimum TTI	Maximum number of received bits/TTI	Maximum H-ARQ buffer size	16QAM compatibillity	Maximum throughput (Mbit/s)
Category 1	5	3	7298	19,200	Yes	1.2
Category 2	5	3	7298	28,800	Yes	1.2
Category 3	5	2	7298	28,800	Yes	1.8
Category 4	5	2	7298	38,400	Yes	1.8
Category 5	5	1	7298	57,600	Yes	3.6
Category 6	5	1	7298	67,200	Yes	3.6
Category 7	10	1	14,411	115,200	Yes	7.2
Category 8	10	1	14,411	134,400	Yes	7.2
Category 9	15	1	20,251	172,800	Yes	10.2
Category 10	15	1	27,952	172,800	Yes	14.0
Category 11	5	2	3630	14,400	No	0.9
Category 12	5	1	3630	28,800	No	1.8

categories 6, 8, 10, and 12 are 3.6, 7.2, 14, and 1.8 Mbit/s, respectively.

As listed in Table 1, for categories 1–10, the maximum throughput increases as the maximum number of received codes increases or as the minimum TTI decreases. This requires a corresponding increase in the maximum buffer size for H-ARQ, and since the signal processing function becomes more complex, the mobile terminal requires higher capabilities. To strike a good balance between achievable throughput and signal processing complexity, DoCoMo commenced its service with Category 6, which has a throughput of 3.6 Mbit/s. This means that the mobile terminals must be able to demodulate up to five code-multiplexed signals, perform high-speed signal processing with a minimum TTI of 2 ms, and support 16QAM.

Table 2. Basic specifications of N902iX HIGH-SPEED.

	N902iX HIGH-SPEED	N902i (reference)
Radio frequency band	2 GHz, 800 MHz	2 GHz, 800 MHz
Send-receive frequency interval	190 MHz (when used in the 2-GHz band) 45 MHz (when used in the 800-MHz band)	190 MHz (when used in the 2-GHz band) 45 MHz (when used in the 800-MHz band)
Data transmission speed	Send Up to 384 kbit/s Receive Up to 3.6 Mbit/s	Send Up to 64 kbit/s Receive Up to 384 kbit/s
Mobile terminal capability with HSDPA	Category 6	—
Size	106 x 51 x 25 mm	106 x 51 x 25 mm
Weight	133 g	127 g
Continuous standby time	Approximately 520 hours (stationary) Approximately 390 hours (in transit)	Approximately 520 hours (stationary) Approximately 390 hours (in transit)
Continuous talk time (voice/videophone)	Approximately 150 minutes/100 minutes	Approximately 140 minutes/90 minutes
LCD	Main LCD 2.5 inch, 240 x 345 dots Sub LCD 1.0 inch, 120 x 90 dots	Main LCD 2.5 inch, 240 x 345 dots Sub LCD 1.0 inch, 120 x 90 dots
Main camera	2 megapixels, Super CCD Honeycomb	2 megapixels, Super CCD Honeycomb
Memory size for i-motion	5 MB (both streaming and downloading)	500 kB (downloading), 2 MB (streaming)
Memory size for music channel	25 MB	—
Encoding system for full music tracks	HE-AAC Enhanced aacPlus	—

Enhanced aacPlus: An audio compression and encoding scheme providing similar sound quality at a lower bit rate to HE-ACC.
HE-ACC: An audio compression and encoding scheme providing similar sound quality at approximately half the bit rate of MPEG-4 ACC. An enhanced MPEG-4 ACC specification.

3. Overview of HSDPA mobile terminals

3.1 N902iX HIGH-SPEED

The N902iX HIGH-SPEED mobile terminal is based on the N902i and shares, as much as possible, the component layout and chassis components. Its basic specifications are listed in **Table 2**. To support high-speed packet communication, the communications CPU (central processing unit) has been changed and an HSDPA-compatible accelerator[*6] has been added. A dedicated memory (3.75 Gbit) has been added to store the content downloaded from the Music Channel™[*7] and other music contents downloads. Power consumption has increased somewhat due to the addition of new hardware, but improvements made to the sleep function of the application CPU have resulted in a standby/talk time equal to or better than that of the N902i.

The major development points are:

- Music Channel application
- Music player
- Compatibility with i-motion (up to 5-MB files)

The music player can handle three types of content: (1) downloaded music contents, (2) music tracks stored on miniSD memory cards [4] with SD-Binding[*8] [5] (SD: secure digital), and (3) music copied from commercial CDs using ripping software and stored in SD-Audio format. It also supports playlists and can display album cover art and song lyrics. Moreover, an enhanced range request[*9] function [6] allows the user to reacquire lost content following a failure or interruption during a Music Channel download (25 MB), a music content download (up to 5 MB), or i-motion download (up to 5 MB).

3.2 M2501 HIGH-SPEED

In addition to providing high-speed packet communication using HSDPA, the M2501 HIGH-SPEED is

*6 Accelerator: A peripheral or additional device used to improve processing performance such as CPU performance and screen display. In this article, it refers to an additional LSI (large-scale integrated circuit) used to improve the processing speed of the communications CPU.
*7 Music Cannel™: A trademark of NTT DoCoMo, Inc.
*8 SD-binding: One of the specifications of the SD (secure digital) format. It enables the embedding of conditions for extracting the encoding key (FOMA card (user information module (UIM)) and mobile terminal model information) when encoding and storing downloaded content in SD memory. Only used when decoding is compatible with encoding conditions.
*9 Range request: A method supported by HTTP (hypertext transfer protocol) for obtaining only part of the content in a specified range. Used when a download is resumed after being interrupted or when only part of a file is desired.

Table 3. Basic specifications of M2501 HIGH-SPEED.

	M2501 HIGH-SPEED	F2402 (reference)
Radio frequency band (W-CDMA)	2 GHz, 800 MHz	2 GHz
Radio frequency band (GSM)	900 MHz, 1800 MHz, 1900 MHz	—
Send-receive frequency interval	190 MHz (when used in the 2-GHz band) 45 MHz (when used in the 800-MHz band)	190 MHz (when used in the 2-GHz band) 45 MHz (when used in the 800-MHz band)
Data transmission speed	Send Up to 384 kbit/s Receive Up to 3.6 Mbit/s	Send Up to 384 kbit/s Receive Up to 384 kbit/s
Mobile terminal capability with HSDPA	Category 6	—
Interface	PCMCIA Type II	PCMCIA Type II
Size	Approximately 54.0 mm x 130 mm x 18.0 mm	Approximately 54.0 mm x 120.8 mm x 12.4 mm
Weight	Approximately 70 g	Approximately 50 g
Compatible operating systems	Windows® XP Professional/Home Edition Windows2000 Professional	WindowsXP Professional/Home Edition Windows2000 Professional Windows98/98SE, WindowsMe
Power supply voltage	DC5.0V	DC5.0V

PCMCIA: Personal Computer Memory Card International Association. An entity established to regulate standards for IC cards connected to personal computers.
Windows®: A registered trademark or trademark of the Microsoft Corporation of the USA and other countries.

the first FOMA card-type mobile terminal compatible with international roaming. It works with both UMTS (universal mobile telecommunications system)*10 and GSM/GPRS*11 (GPRS: general packet radio service), so it can be used in more than 132 countries. It has a multiband-compatible internal antenna: 800 and 2100 MHz for HSDPA/UMTS and 900, 1800, and 1900 MHz for GSM/GPRS. The utility software provided supports voice communication, a phonebook, and communications status display. In addition, various network service settings such as an answer-phone service are available to improve usability.

4. HSDPA handover and mobile terminal throughput performance

4.1 HSDPA handover

HSDPA is based on technologies such as adaptive modulation and coding (AMC), H-ARQ for retransmitting and combining packet data, and base transceiver station (BTS) scheduling for controlling the allocation of users. It can support peak data rates beyond 10 Mbit/s [7]. Since these technologies require a constant one-to-one connection between the HSDPA mobile terminal and the BTS, hard handover is essential in addition to soft handover*12 used in the conventional W-CDMA system. In hard handover, the destination BTS is selected each time the cell changes. The HSDPA handover procedure is as follows:

1) The quality level of the common pilot channel (CPICH) sent at fixed power from a cell in the vicinity is measured by the mobile terminal.

2) If a CPICH has a quality level exceeding a fixed threshold (reported by the network as a parameter) in relation to the handover source cell CPICH quality level, the relevant cell is reported to the radio network controller (RNC)*13. (If multiple cells exceed the threshold value, the cell with the highest quality level is reported.)

3) The RNC sets up the handover destination cell based on the report sent from the mobile terminal and issues a handover notification to the mobile terminal.

4) The mobile terminal receiving the handover notification disconnects from the handover source cell and connects to the handover destination cell.

In accordance with this procedure, the HSDPA mobile terminal selects and reports cells having a sat-

*10 UMTS (universal mobile telecommunications system): The third-generation European mobile communications system. Uses either W-CDMA (also used by DoCoMo) or TD-CDMA (unique to Europe). The card-type terminal M2501 HIGH-SPEED uses the W-CDMA system.

*11 GRPS (general packet radio service): A packet-switching service available on GSM networks.

*12 Soft handover: A process that involves receiving, selecting, and synthesizing signals from multiple base stations connected simultaneously to ensure that cell switching does not interrupt communications.

*13 Radio network controller (RNC): Equipment defined by the 3GPP for performing radio circuit control and mobility control in the FOMA network.

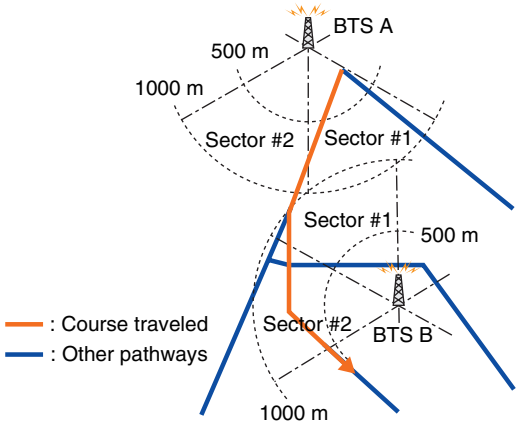

Fig. 3. Course between BTS A and B.

isfactory reception level and repeats the handover in accordance with instructions issued from the RNC to move between cells.

4.2 HSDPA mobile terminal throughput performance

The throughput performance of the HSDPA mobile terminal has been measured in an actual field environment while the terminal moved from one BTS to another. A 2.5-km course between BTSs A and B was traveled at a speed of 30 to 40 km/h (**Fig. 3**). The throughput performances over time for the N902iX HIGH-SPEED and the conventional W-CDMA terminal are shown in **Fig. 4**. Each mobile terminal was connected to a personal computer. Then, after it had accessed a content server, a large file was downloaded using file transfer protocol (FTP)[*14] and the throughput of the transmission control protocol (TCP) layer averaged over 4 seconds was measured. The blue, yellow, red, and green lines in the graph indicate throughput when connected to BTS A sectors #1 and #2 and BTS B sectors #1 and #2, respectively, while the purple dashed line indicates throughput for the conventional W-CDMA terminal. The changes in received signal code power (RSCP)[*15] over time for sectors #1 and #2 of BTSs A and B are shown in **Fig. 5**.

In the first stage (0–50 s) of the measurement course, that is, under line-of-sight propagation conditions for BTS A sector #1, the characteristics were satisfactory (1.5–2.9 Mbit/s). However, as the mobile terminal moved, the signal power (or interference waveforms) from other cells increased and throughput deteriorated (50–140 s). The received signal level for BTS B sector #1 exceeded that of BTS A sector #1 at an elapsed time of approximately 140 s, and while throughput temporarily spiked downwards, the transition of the handover to the destination BTS improved the received signal level. In addition, after 150 s, hard handover (in which the destination BTS was switched in response to the received level from the BTS) was repeated, and movement continued with the throughput being varied to suit the radio environment. Since the transmission power of the conventional W-CDMA terminal is controlled to maintain a constant level of received signal quality, throughput remained constant irrespective of the received signal level from the BTS. Average throughput obtained with the N902iX HIGH-SPEED on this course was 1.4 Mbit/s—an improvement by a factor of approximately 3.8 times compared with the conventional W-CDMA terminal.

5. Conclusion

This article outlined the characteristics of the N902iX HIGH-SPEED and M2501 HIGH-SPEED mobile terminals for HSDPA service, which commenced in August 2006. It also described HSDPA handover and clarified the throughput performance during handover based on a field experiment using the N902iX HIGH-SPEED. The experimental results for average throughput obtained by the testing station

*14 FTP (file transfer protocol): A protocol commonly used for file transfer on TCP/IP (transmission control protocol Internet protocol) networks such as the Internet and intranets.

*15 RSCP (received signal code power): The received power measured at a mobile terminal. An index of signal sensitivity at the mobile terminal.

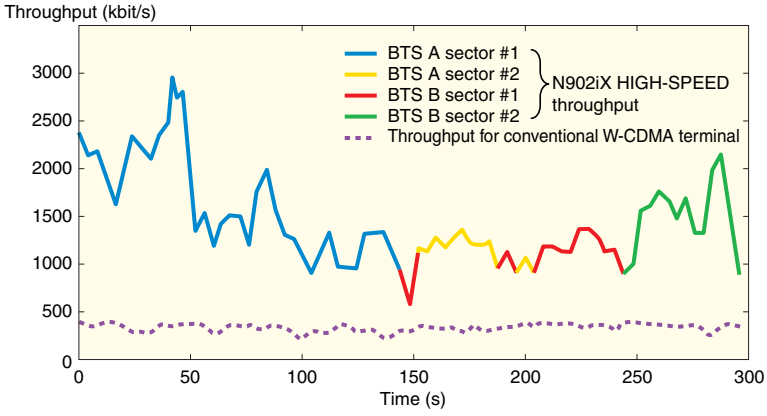

Fig. 4. Changes in throughput performance over time.

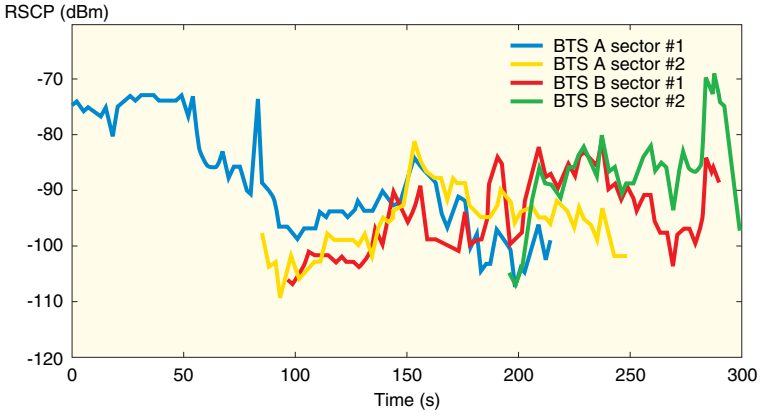

Fig. 5. Changes in RSCP characteristics over time.

on a test course show that the throughput of the N902iX HIGH-SPEED was approximately 3.8 times better than that of the conventional W-CDMA terminal. Topics currently under investigation include supporting higher HSDPA categories for greater speed and introducing high-speed uplink packet access (HSUPA).

References

[1] 3GPP TS 25.306 V5.13.0 (2005-12).
[2] 3GPP TS 25.211 V5.8.0 (2005-12).
[3] 3GPP TS 25.212 V5.10.0 (2005-06).
[4] http://www.sdcard.com/usa/TextPage.asp?Page=4
[4] T. Oi, M. Ueda, E. Yano, and T. Tamechika, "New Applications in FOMA 902i," NTT DoCoMo Technical Journal, Vol. 7, No. 4, pp. 20–26, Mar. 2006.
[5] Y. Hiramatsu, M. Ueda, Y. Inoue, and M. Wakamatsu, "New Applications in 901iS—PDF Viewer and Advanced Browser," NTT DoCoMo Technical Journal, Vol. 7, No. 2, pp. 54–59, Sep. 2005.
[6] S. Tanaka, H. Ishii, T. Sao, U. Iizuka, and T. Nakamori, "HSDPA Throughput Performances Using an Experimental HSDPA Transmission System," NTT DoCoMo Technical Journal, Vol. 6, No. 4, pp. 19–28, Mar. 2005.

Hisashi Matsuoka
Communication Device Development Department, NTT DoCoMo.
He joined NTT Mobile Communications Network (now NTT DoCoMo) in 1999. After working on the development of mobile terminals compatible with mobile satellite communications systems, he is currently engaged in the development of IMT-2000 mobile terminals.

Takeshi Nakamori
Communication Device Development Department, NTT DoCoMo.
He joined NTT DoCoMo in 2003. Since then, he has been engaged in R&D of the W-CDMA system. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Yosuke Iizuka
Communication Device Development Department, NTT DoCoMo.
He joined NTT DoCoMo in 2002. Since then, he has been engaged in R&D of the W-CDMA system. He is a member of IEICE.

Shinsuke Ogawa
Manager, Communication Device Development Department, NTT DoCoMo.
He joined NTT Mobile Communications Network (now NTT DoCoMo) in 1996. Since then, he has been engaged in R&D of the W-CDMA system. He is a member of IEICE.