New Technology Report

Special Article on IMT-2000 Services (2)
– Launch of FOMA, the Pioneer of the New Mobile Age –

Mobile Terminal Technologies

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This article reviews the mobile terminal technologies in IMT-2000 with reference to the terminal architecture and distinguishing technologies, as well as the basic specifications and the characteristics of FOMA terminals.

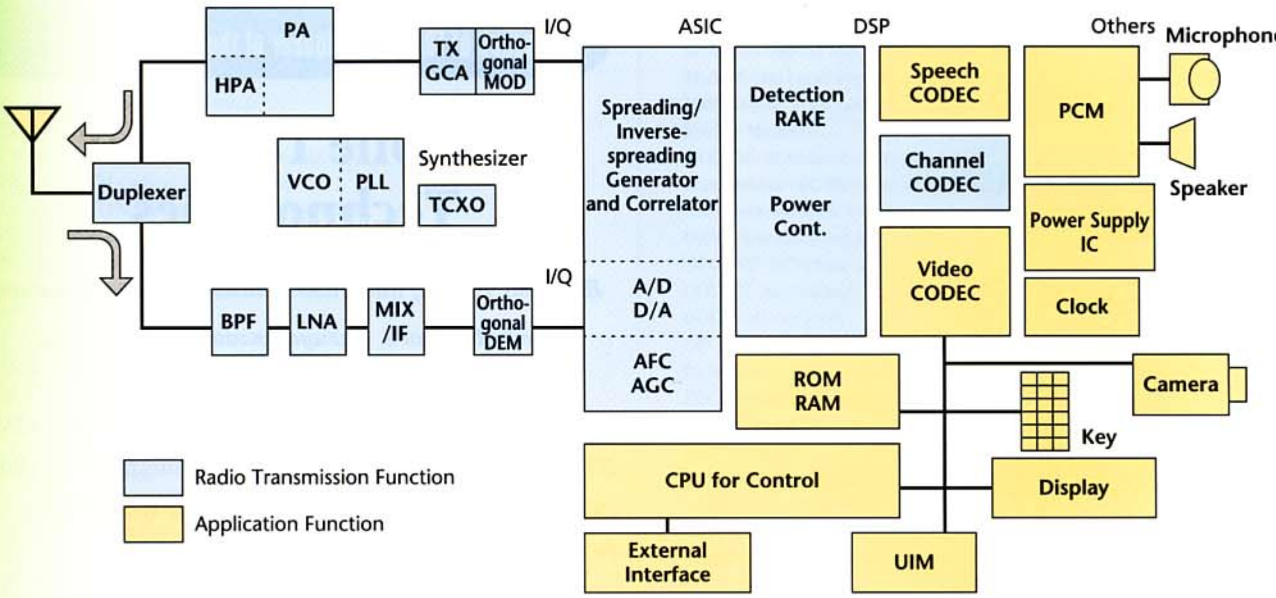
1. Introduction

International Mobile Telecommunications-2000 (IMT-2000) assumes a wide variety of mobile terminals [1]. IMT-2000 terminals are distinguishable for their transmission power between radio zones, their multimedia capabilities as hardware devices which are demonstrated by their displays, and their ability to accommodate a wide range of multimedia applications. NTT DoCoMo is engaged in the development of terminals that will make the characteristics of IMT-2000 more appealing, in order to facilitate the market penetration and expansion of IMT-2000 services.

This article reviews the mobile terminal technologies applied to IMT-2000 terminals with reference to the terminal architecture and distinguishing technologies, as well as the basic specifications and the characteristics of terminals designed for Freedom Of Mobile multimedia Access (FOMA), which is NTT DoCoMo's IMT-2000 service launched on an introductory basis on May 30, 2001.

2. Terminal Architecture

Figure 1 shows an example of an IMT-2000 mobile terminal configuration. The mobile terminal can broadly be divided into two functions: the radio transmission function and the application function. The terminal is designed to demonstrate the required radio properties and Layer 1 functions, and offer a wide range of multimedia functions. The configuration and functions of the terminal's software and hardware are as described below.



AFC: Automatic Frequency Control
AGC: Automatic Gain Control
ASIC: Application Specific IC
BPF: Band Pass Filter
CODEC: COrder DECorder
CPU: Central Processing Unit
DEM: DEModulator
DSP: Digital Signal Processor
GCA: Gain Control Amplifier
HPA: High Power Amplifier
I/Q: In phase and Quadrature-phase signals
IC: Integrated Circuit
IF: Intermediate Frequency
LNA: Low Noise Amplifier
MIX: MIXer
MOD: MODulator
PA: Power Amplifier
PCM: Pulse Code Modulation
PLL: Phase Locked Loop
RAM: Random Access Memory
ROM: Read Only Memory
TCXO: Temperature Compensated Crystal Oscillator
TX: Transmitter
UIM: User Identification Module
VCO: Voltage Controlled Oscillator

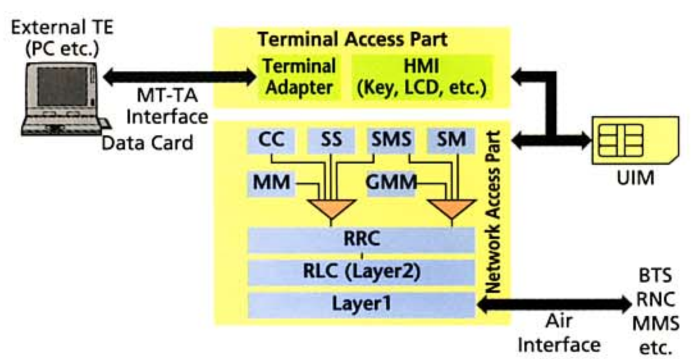
Figure 1 Configuration of IMT-2000 Mobile Terminal (Example)

2.1 Software Configuration

(1) Configuration of Communication Protocols

Figure 2 shows the configuration of communication protocols. Communication protocols are broadly divided into the terminal access part, which accepts communication requests from the user or external equipment such as PCs, and the network access part, which carries out the communication with the network according to such requests.

The terminal access part is in compliance with the Mobile Termination-Terminal Adaptation (MT-TA) interface set forth in the standard specifications by the Association of Radio Industries and Businesses (ARIB) [2], and is designed to ensure extensibility in terms of connections with external equipment. On the other hand, the network access part is geared with communication protocols such as Radio Link Control (RLC), Radio Resource Control (RRC), Mobility Management (MM), Call Control (CC), Supplementary Service (SS), GPRS Mobility Management (GMM), Session Management (SM) and Short Message Service (SMS), which are set forth by the 3rd Generation Partnership Project (3GPP) specifications [3]-[6] and ARIB standard specifications. The network access part, which applies these protocols for general purposes, has been designed to enable roaming control in the future.



BTS: Base Transceiver Station
CC: Call Control
GMM: GPRS Mobility Management
HMI: Human Machine Interface
MM: Mobility Management
MMS: Mobile Multimedia switching System
MT-TA: Mobile Termination-Terminal Adaptation
RLC: Radio Link Control
RNC: Radio Network Controller
RRC: Radio Resource Control
SM: Session Management
SMS: Short Message Service
SS: Supplementary Service
TE: Terminal Equipment
UIM: User Identification Module

Figure 2 Configuration of Communication Protocols

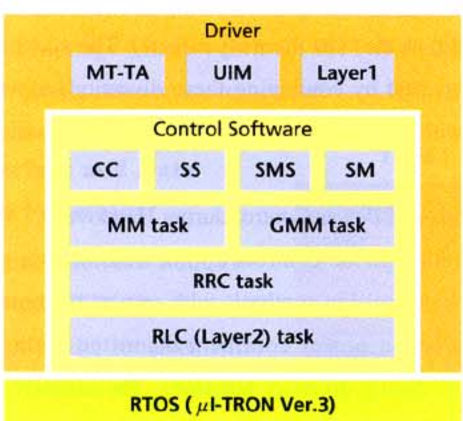
The communication protocols allow connection with the User Identification Module (UIM) to set forth under the 3GPP specifications, which has the merit of enabling users to use different terminals according to purpose and easily swap models.

(2) Software Configuration

Figure 3 shows the software configuration. The software is designed so that it can be separated into two parts: the Control Software, which executes processes that are not dependent on the hardware type, such as the termination of protocols including RLC, RRC, MM, CC, SS, GMM, SM and SMS; and the Driver, which is dependent on the Hardware, such as Layer 1. As this allows one Control Software to run on hardware and drivers provided by multiple vendors, it is possible to develop the Control Software in an efficient manner.

Each communication protocol is assigned to execute a process for a different task, in order to ensure the communication stability. Furthermore, it can flexibly accommodate functional enhancements based on the 3GPP specifications in the future, based on inter-protocol communications compliant with service primitive in 3GPP specifications.

As the Control Software and some of the software in the Driver perform high-speed parallel processing, they run on the event-triggered type Real Time Operating System (RTOS), which is capable of multitask processing. The RTOS used here is the Micro Industrial-The Real-time Operating system Nucleus (μ I-TRON) Ver.3 [7]. As the general-purpose System Call is applied to the development of software, it is easier to migrate to other RTOS.



CC: Call Control
GMM: GPRS Mobility Management
MM: Mobility Management
MT-TA: Mobile Termination-Terminal Adaptation
RLC: Radio Link Control
RRC: Radio Resource Control
RTOS: Real Time Operating System
SM: Session Management
SMS: Short Message Service
SS: Supplementary Service
UIM: User Identification Module

Figure 3 Software Configuration

2.2 Hardware Configuration

As shown in Figure 1, the terminal hardware consists of the antenna, the radio transceiver which has the radio transmission and reception function, the base band signal processor, the display which offers the Human Machine Interface (HMI), etc. The characteristics of each block are as follows:

(1) Antenna

As the frequency band used by IMT-2000 is 2GHz, the propagation loss is larger than Personal Digital Cellular (PDC), which occupies the 800MHz band and 1.5GHz band. This means that IMT-2000 terminals require an antenna with higher gain and efficiency. The mobile-phone type FOMA N2001 and FOMA P2101V use a built-in antenna, whereas the card-type FOMA P2401 uses a folding antenna, as described later.

(2) Radio Transceiver

The spreading rate per carrier in IMT-2000 is 3.84Mchip/s, and the operations take place closely with adjacent channels to improve the efficiency of frequency use. It is necessary to reduce the adjacent channel leakage power in order to decrease interference with adjacent channels. High-speed and closed-loop transmission power control is performed from the base station to the mobile terminal to increase the system capacity of each carrier. The transmission power control must be carried out in a dynamic range at 70dB or higher, $\pm$1dB step per slot (667μs) (when the maximum transmission power is 24dBm). Accordingly, strong linear properties are required on the transmission amplifier. Highly efficient and low power consumption is also essential to make long calls possible, not only at times of maximum power transmission but also upon low power transmission. On the other hand, the receiver must have many adjacent channels to choose from, in order to suppress the interference with adjacent channels. The required properties can be achieved based on the comprehensive design of an intermediate frequency filter, base-band filter, etc.

Figure 4 shows an example of a measurement of terminal transmission power during transmission power control.

(3) Base Band Signal Processor

The transmission side consists of the spreading modulator, whereas the reception side consists of multiple inverse-spreaders, a path searcher for receiving multipath signals, and a RAKE synthesizer. Due to the limited circuit size, it is necessary to achieve an optimal design for the number of fingers of the RAKE synthesizer and the path window width, while meeting the reception property requirements. In addition, intensive integration and low power consumption is required to minimize the size and weight of the terminal, and maximize the call time and standby time.

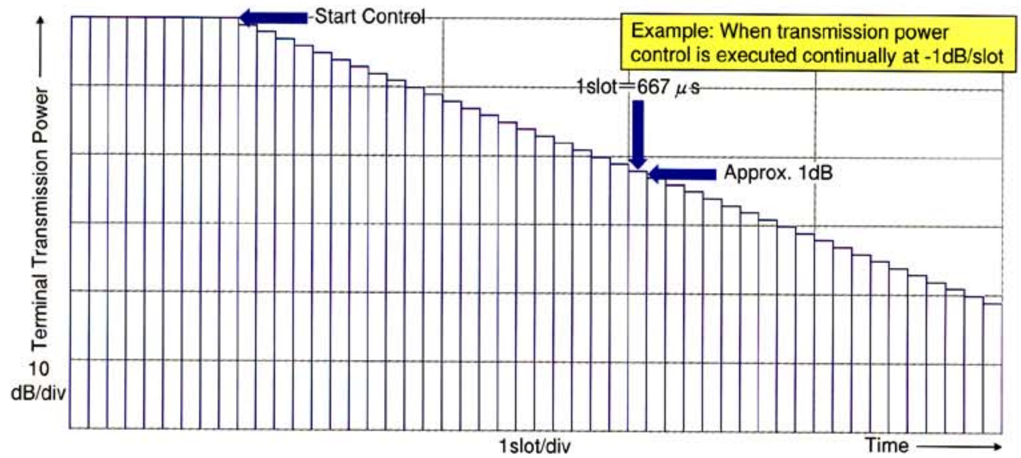


Figure 4 **Measurement of Terminal Transmission Power during Transmission Power Control (Example)**

(4) Display

The display is made of Thin Film Transistor (TFT) and organic ELectroluminescence (EL) elements. TFT uses a thin sheet of transistors. Organic EL elements use particles that emit light when a voltage is applied; organic substances are used as the light emitting elements, which are extremely bright even when the power is low.

3. Distinguishing Technologies applied to IMT-2000 Terminals

3.1 Layer 1 Function

One of the noteworthy technologies in the IMT-2000 system is the diversity handover technology [8]. During communication, when an IMT-2000 terminal moves from cell to cell (base station to base station) or from sector to sector, it communicates by simultaneously establishing connection with multiple cells/sectors in certain regions near the edge of the cell/sector. The implementation of diversity handover enables mobile terminals to maintain stable communications free of burst errors, even when it is moving from one cell/sector to another. It also enables the expansion of the system capacity.

Layer 1 functions, which play a central part in diversity handover operations for mobile terminals, include level measurement during communications, RAKE synthesizing reception between handover branches, and transmission power control during handover.

(1) Level Measurement during Communications

In order to decide the execution of diversity handover, the mobile terminal constantly measures the circuit quality of peripheral cells that have been detected. Peripheral cells that have not been detected are subject to the cell search function during communications, by which candidate cells/sectors are constantly searched. When it detects the scrambling code and the frame timing of a cell/sector above a certain quality level, it starts to measure the circuit quality.

(2) RAKE Synthesizing Reception between Handover Branches

The mobile terminal applies the RAKE synthesizing reception technology to multiple delayed signals arriving via different transmission paths from base stations (multipath) and executes maximum-ratio synthesizing, which makes it possible to even out fluctuations due to fading and reduce the transmission power at the base station (which is referred to as the "path diversity effect"). The same effect can be obtained when maximum-ratio synthesizing is applied to downlink signals transmitted from multiple cells/sectors during diversity handover (which is referred to as the "site diversity effect"). The system capacity can be increased by combining these diversity handover technologies with high-speed and closed-loop transmission power control.

(3) Transmission Power Control during Handover

The mobile phone controls uplink transmission power by executing soft-decision synthesis with respect to command bits for transmission power control transmitted from multiple cells/sectors during diversity handover. The ultimate transmission power is controlled in such a manner that more reliable command bits contribute the most.

Figure 5 shows the data acquired relating to the diversity handover status when an actual FOMA terminal was in motion during a call. The figure shows how diversity handover actually works when inter-cell handover is repeated between two base stations (A and B) and handover is repeated from sector to sector under one base station.

3.2 Application Function

FOMA terminals, which harness the high-speed and high-capacity data communication properties of IMT-2000 services, is able to adapt to larger and more advanced i-mode content, and multimedia applications including videophone functions and video/music distribution. **Table 1** shows the basic specifications of each application function of the introductory service for FOMA terminals.

(1) i-mode Function

This function is added to small basic terminals and video terminals. The presentation of content has been enhanced by expanding the maximum content size to 100kB per page, and by normally supporting JPEG (Joint Photographic Experts Group) as the still picture format, based on the function of 503i Series i-mode mobile phone. The maximum data size of e-mail has been increased to 10kB, and files can be attached to e-mail. In addition, efforts are currently being made to enable the terminals to handle MPEG-4 video data content.

(2) Videophone Function

This function is added to video terminals. Video is encoded by MPEG (Moving Picture Experts Group)-4, and speech is encoded by Adaptive Multi Rate (AMR). Videophone communications is established by transmitting them at bearer speed of 64kbit/s or 32kbit/s.

(3) Video/Music Distribution Functions

FOMA terminals have a high-speed packet bearer and a 64kbit/s Unrestricted Digital (UD) bearer to support M-stage Visual and M-stage Music which are NTT DoCoMo's video and music distribution service respectively.

3.3 Interface and Data Card Functions

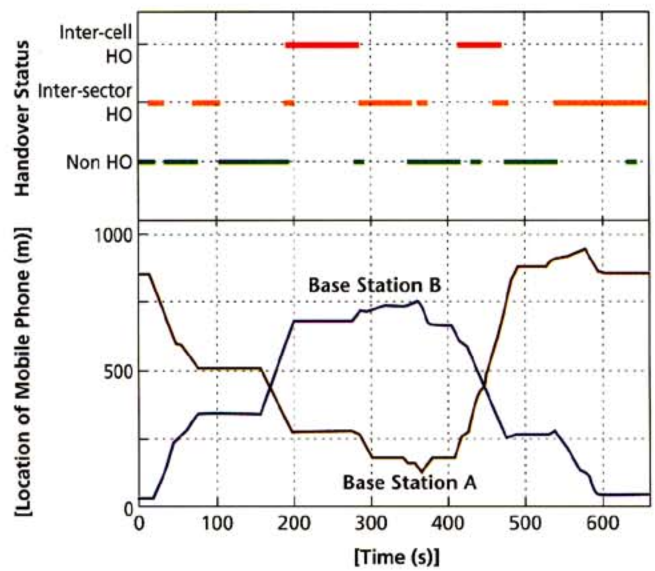
(1) External Interface Requirements of IMT-2000

The following requirements are needed to meet the terminal's external interface.

- Signal speed: It must be high enough to harness the transmission speed in radio zones.
- Power consumption: Increase of signal speed and reduction of terminal's power consumption must coexist.
- Size: The connector must be portable and must not undermine the design. It should also be a smaller external interface module.
- Multipurpose: High connectivity with a wide range of external equipment, including personal computers (PCs) and Personal Digital Assistants (PDA).

In consideration of these requirements, FOMA terminals adopt the connector specified by ARIB [9] as the physical interface, and the Universal Serial Bus (USB) [10] as the logical interface which is highly compatible with PCs (**Figure 6**).

(2) Characteristics of External Interface



Connection is omitted unless it is with base station A or B.

HO: HandOver

Figure 5 Diversity Handover Operation (Example)

Table 1 Basic Specifications of Application Functions of Introductory Service

Application	Transmission Speed	Basic Specifications
i-mode	Uplink 64kbit/s Downlink 384kbit/s	HTML Page: Max. 100kB Still-picture Content: GIF and JPEG support Browser Function: SSL and Java* support E-mail: Attachment of files up to 10kB
Videophone	64kbit/s, 32kbit/s	Video Encoding: ISO MPEG-4 Simple Profile Level 0 (QCIF) Speech Encoding: AMR 12.2kbit/s (64kbit/s) AMR 6.72kbit/s (32kbit/s) Multiplexing: H.223 Annex B
Video	64kbit/s	Video: ISO MPEG-4 Simple Profile Level 0 (QCIF) Speech: WMA 8kbit/s, 8kHz 16kbit/s, 16kHz Format: ASF

AMR: Adaptive Multi Rate
ASF: Advanced System Format
GIF: Graphic Interchange Format
HTML: HyperText Markup Language
ISO: International Organization for Standardization
JPEG: Joint Photographic Experts Group
MPEG: Moving Picture Experts Group
QCIF: Quarter CIF
SSL: Secure Sockets Layer
WMA: Windows Media Audio

★ Java: An object-oriented programming language suited for used on networks, developed and advocated by Sun Microsystems in the U.S.

The external interface connector includes the Power Supply and Manufacturer-Specific input device, in addition to the USB interface slot. It also has Radio Frequency (RF) input for transmitting and receiving radio signals, taking connections with external antennas into account.

Noteworthy functions of the logical interface include: ① the modem function, which enables the terminals to serve as a conventional model for Windows PCs; ② the OBject EXchange protocol (OBEX) function, which is for storing and writing the mobile phone's address book, schedule data, etc. in PCs; ③ the device information function, which enables the terminals to acquire information on the electric field and battery level even during communication; and ④ the function to connect with external adaptors with an interface compliant to the MT-TA interface specified by ARIB [2].

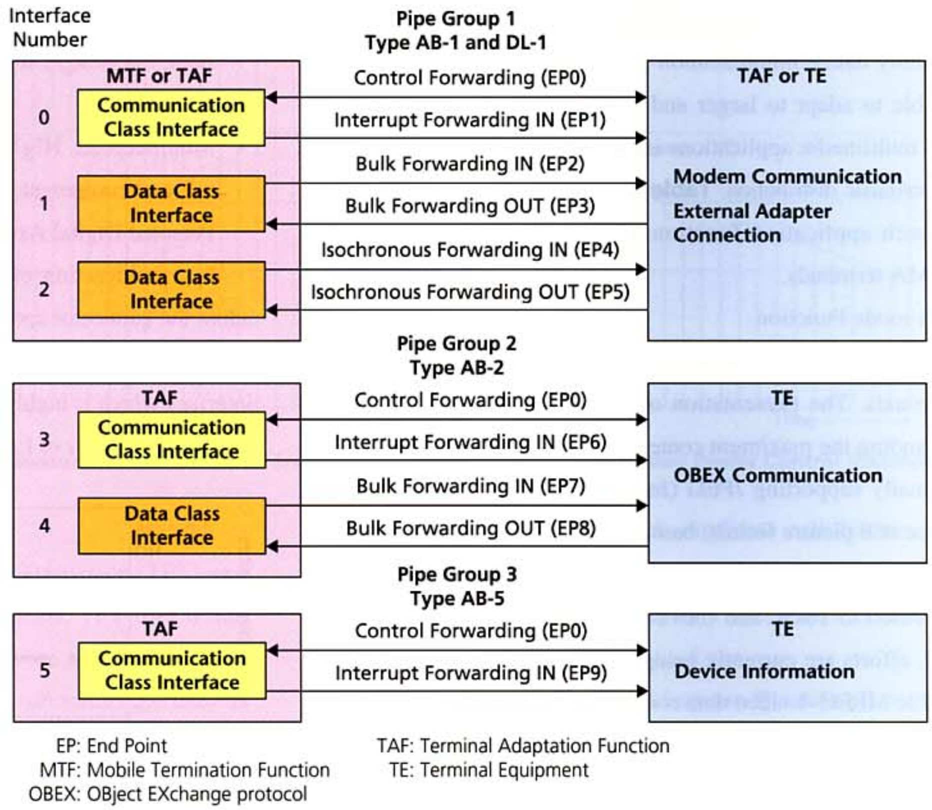


Figure 6 Configuration of USB Interface (Example)

(3) DataCards

NTT DoCoMo developed the data cards to offer 64kbit/s data communication services to FOMA terminals. Notable functions of the data cards are: ① the USB host function for controlling IMT-2000 terminal, which are USB devices; and ② the adapter function to terminate the 64kbit/s data communications protocol, and transmit and receive asynchronous PPP (Point to Point Protocol) data with respect to PCs. The adapter function is controlled by AT command in compliance with the 3GPP specifications.

4. Basic Specifications and Characteristics of FOMA Terminals

Under FOMA, a wide range of application services are about to roll out, harnessing the high-speed transmission and flexible system. Various types of terminals will be released in line with this, in consideration of the support-required applications, usage style and target user segments. **Table 2** shows the basic specifications of the terminals and the UIM card distributed to trial users when FOMA was launched on an introductory basis on May 30, 2001. **Photo 1** shows the design of the terminals and the UIM card.

The characteristics of the FOMA terminals and the UIM card are as follows.

(1) FOMA N2001

FOMA N2001 is the enhanced version of i-mode terminals designed for PDC networks. It is presumed to be used mainly for speech communications, i-mode services and e-mail. Efforts have been made to make the terminal as small and light as the existing mobile phones in the view of portability, and to make the design more simple and progressive than ever before by adopting a built-in antenna. With the FOMA USB cable, the terminal can adapt to packet-switched communication services at bearer speed of 384kbit/s. With the FOMA data card, the terminal can support data communication services at bearer speed of 64kbit/s.

(2) FOMA P2401

FOMA P2401 is assumed to be used in a mobile computing environment, so it specializes in data communications by PCs. With its PCMCIA (Personal Computer Memory Card International Association) interface, the terminal itself can engage in

Table 2 Basic Specifications of FOMA Terminals for Introductory Service

	N2001	P2101V	P2401
Size	Approx. 103×Approx. 52×Approx. 20 (mm)	Approx. 104×Approx. 56×Approx. 35 (mm)	Approx. 120×Approx. 56×Approx. 13 (mm)
Mass	Approx. 105 (g)	Approx. 152 (g)	Approx. 50 (g)
Display Performance	4096 colors, organic EL	260,000 colors, reflective TFT	–
Terminal Interface	USB	–	PCMCIA Type II
Speech Communications	○	○	–
Videophone	–	○	–
i-mode	○	○	–
M-stage Visual	–	○	–
SMS	○	–	–
64k Data Communications	○	–	○
Packet-switched Communications	Uplink 64kbit/s, Downlink 384kbit/s	–	Uplink 64kbit/s, Downlink 384kbit/s

EL: ELectroluminescence
PCMCIA: Personal Computer Memory Card International Association
SMS: Short Message Service
TFT: Thin Film Transistor
USB: Universal Serial Bus

Photo 1 Lineup of FOMA Terminals and FOMA Card for Introductory Service

circuit-switched data communications at bearer speed of 64kbit/s, and packet-switched communications at bearer speed of 384kbit/s. NTT DoCoMo managed to minimize its size by supplying the power from PCs and liberating the terminal from batteries.

(3) FOMA P2101V

FOMA P2101V is a terminal adapted to video service, which is one of FOMA's multimedia services. The terminal supports M-stage Visual, and is equipped with a small video camera. FOMA P2101V is able to engage in videophone communications with another unit of the same model and other FOMA video terminals due to be released in the future. The terminal has a videophone answering button and a camera button, featuring a user interface with video services in mind. The unit, with a built-in antenna, is noteworthy for its unprecedented, futuristic design with a curved surface.

(4) FOMA Card

The FOMA card is a UIM card applicable to FOMA services, which stores subscriber information. The card can also store 50 entries in its address book and 20 short messages, including both of those transmitted and received.

5. Conclusion

This article reviewed the mobile terminal technologies in IMT-2000 with reference to the terminal architecture and distinguishing technologies, as well as the basic specifications and the characteristics of FOMA terminals. We will continue to enhance the variety of terminals that support the ever-growing mobile multimedia applications, and develop more user-friendly and attractive terminals.

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Glossary

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VCO: Voltage Controlled Oscillator
WMA: Windows Media Audio
μ I-TRON: Micro Industrial-The Real-time Operating system Nucleus