3-2 Technology and Devices for 4th Generation Mobile Communication Terminals using Software Defined Radio

SUNAGA Terumi, TERASHIMA Yoshiaki, KIYOHARA Ryozo, SUEMATSU Noriharu, ITAKURA Tetsuro, and HIROSE Yoshio

In the future mobile communication, it is expected that various wireless communication systems will coexist. Therefore mobile terminal must have multi-band/multi-mode features.Software defined radio (SDR) is one of the technique achieve these functions. In this paper, we describe the development results of device and key technology for SDR.

Keywords
4th Generation mobile communication system, Software defined radio, Multi-band, Multi-mode

1 Introduction

Recent years, mobile communication systems such as 3rd-generation cellular systems and wireless LANs have been diffused rapidly. We expect that sometime after 2010, 4th-generation mobile communication systems offering maximum transmission bit rates of 100 Mbit/s in mobile conditions will be realized. Future mobile communication systems will not consist solely of 4th-generation systems, but will most likely involve multiple coexisting wireless systems that will include 3rd-generation and wireless LAN systems currently in use, and it is predicted that communications will be established through selection of the most appropriate wireless system according to user needs[1]. Terminals for future mobile systems must therefore incorporate multi-band/multi-mode features to allow communications over multiple wireless systems using different frequency bands and transmission methods. Software-defined radio (SDR) technology is one of key technologies that will realize such terminals. Accordingly, Mitsubishi Electric Corporation, Toshiba Corporation, and Fujitsu Limited carried out research of SDR technologies and devices for a multi-band/multi-mode terminal from August 2002 to March 2006 as a commissioned research project entitled "Research and Development for the Realization of 4th-Generation Mobile Communication Systems" sponsored by the National Institute of Communications Technology. In this paper, we will describe the multi-band antenna and Radio-frequency (RF) circuit/device technology in Section **2**, high-speed low-power-dissipation A/D and D/A converters in Section **3**, and the architecture of a multi-mode terminal and a comprehensive system of evaluation for the technologies presented in these sections in Section **4**. Section **5** will introduce the platform LSI technology that allows the reconfiguration of functions that will lead to the construction of a multi-mode terminal. Section **6** will introduce the Distributed-Object and Download Technologies. Section **7** will provide a summary of the results of commissioned research for distributed-object and download technologies.

2 Antenna and RF circuit/device technologies

RF circuits and compact antennas that are compatible with frequency bands used by different systems are essential in the realization of a multi-band/multi-mode terminal. In particular, compact designs and IC integration are required to ensure compatibility with various systems that feature different modulation systems and signal bandwidths; accordingly, antennas and RF circuits for multi-band/multi-mode terminals in the 800 MHz-5 GHz band have been developed.

Figure 1 shows the principle of operation of a compact, wide-band antenna modeled on the assumption that the radiating element and the virtual ground conductor of the antenna correspond to the ground of the package board inside the mobile terminal and the person holding the terminal, respectively. The contact terminal—a square several millimeters in size that secures contact between the package board ground and the human body—is the only component exclusively for the antenna, and its performance when installed in the mobile terminal yields a value of VSWR < 3 in the 0.8–6 GHz range (Fig. 2). Further, when the terminal is held in the hand, the average gain in the horizontal plane is -8.0 dBi to -4.3 dBi (0.8–6 GHz), demonstrating sufficient capacity for practical use[2].

This commissioned research included studies of the RF circuit/devices required for a multi-band/multi-mode terminal, such as RF circuit configuration, the quadrature mixer, quadrature modulator, and wide-band amplifier of the terminal. In Figures 3 (a) and (b), microphotographs of the wide-band quadrature mixer (Q-MIX) for the receiver unit and of the quadrature modulator (Q-MOD) for the transmitter unit, respectively, are presented as example results of these development efforts. Both devices offer wide-band/high-precision quadrature characteristics through the integration of SiGe-MMIC, and the results of evaluation of Q-MIX using W-CDMA modulating signals showed that the vector error was 2.1% rms at 800 MHz and 2.7% rms at 2.1 GHz. The results for wireless LAN (IEEE 802.11a)

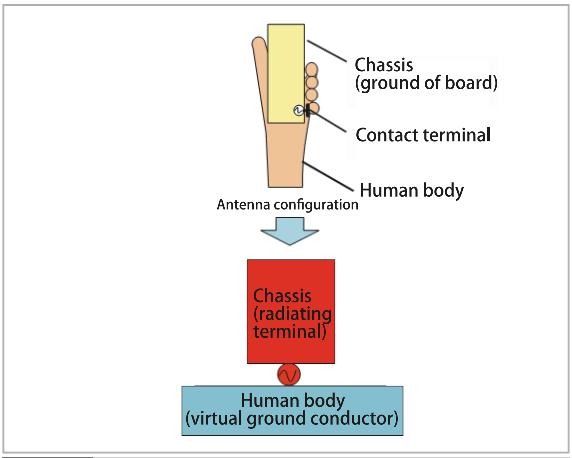

Fig.1 Principle of operation of antenna

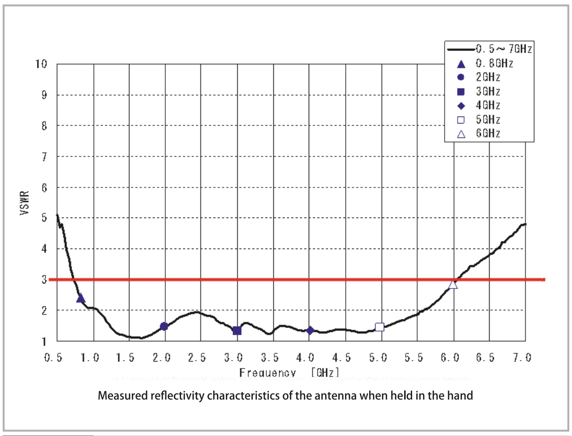

Fig.2 Measurement of the reflectivity characteristics of the antenna

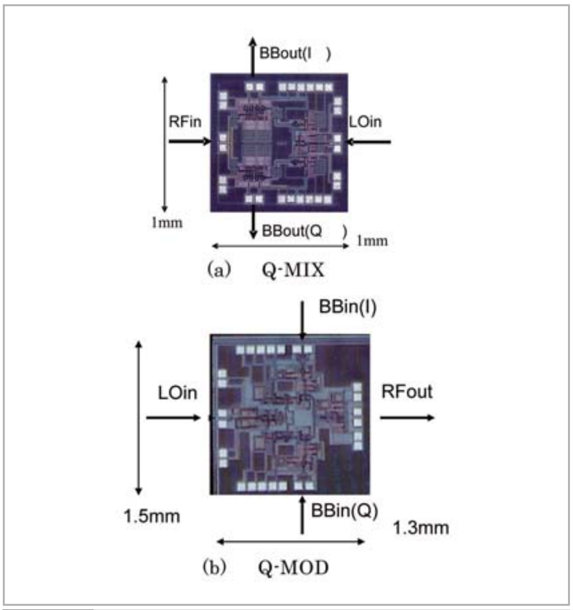

Fig.3 Photograph of the RF device chips

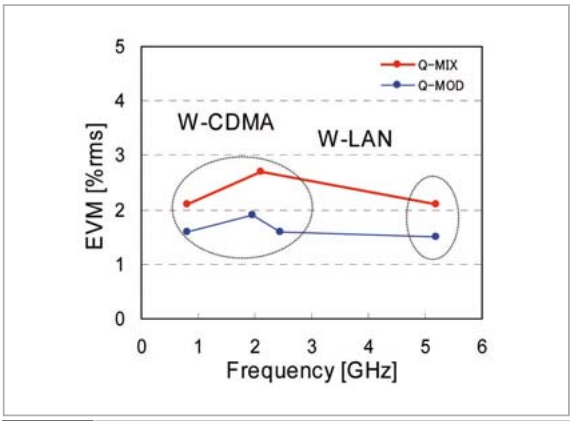

Fig.4 Results of vector error evaluation

indicated error of 2.1% rms in the modulating signals at 5.2 GHz (Fig. 4). Similarly, based on the results of evaluations of Q-MOD using W-CDMA modulating signals, the vector errors were 1.6% rms at 800 MHz and 1.9% rms at 1.95 GHz, and the error for wireless LAN (IEEE 802.11a) modulating signals was 1.5% rms at 5.2 GHz. As a result, it was confirmed that the present Q-MIX and Q-MOD together with the antenna described above[3] can be used for W-CDMA in the 800-MHz / 2-GHz band and for wireless LANs in the 5.2 GHz band.

3 A/D and D/A converters for terminals

The A/D and D/A converters for multimode terminals are first and foremost required to be compatible with the communication system using the widest band. Assuming that a 4th-generation mobile communication system will use a signal bandwidth of approximately 50 MHz for its baseband signal, the goal for the sampling rate was set at 100–200 Msample/s. Furthermore, in order to ensure compatibility with modulation systems having large peak/average power ratios, as with OFDM, the target resolution was set at 10–12 bits. Additionally, since the terminals will be battery-powered, power dissipation must be reduced to the fullest extent possible, and so the target value in this case was set as less than or equal to 100 mW.

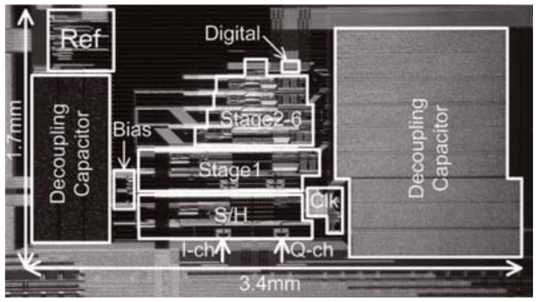

Fig.5 Microphotograph of a 55-mW, 12-bit, 100-Msample/s A/D converter

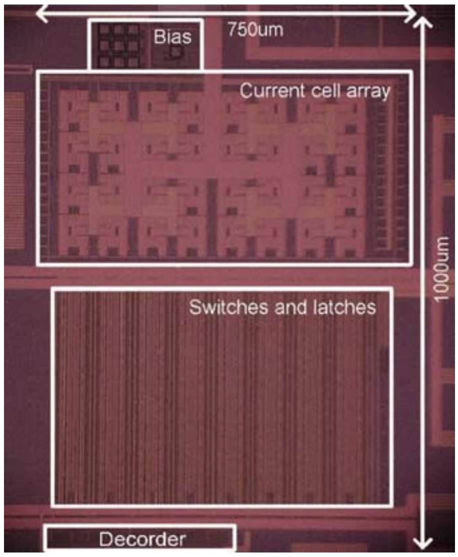

Fig.6 Microphotograph of a 20-mW, 12-bit, 200-Msample/s D/A converter

Low power dissipation was given priority in the development of the A/D converter, and so efforts were made to improve the performance to the limit allowed with a power dissipation of ≤100 mW. First, a primary prototype of a 10-bit 100 Msample/s converter was fabricated[4]; we then proceeded to take on the challenging task of improving the sampling rate to 200 Msample/s[5]. In the final year of the project, we tried to improve the resolution to 12 bits[6], and in each case, the measured power dissipation was ≤100 mW. We made the most of time-division sharing of the functional blocks in order to reduce power dissipation. In particular, we took advantage of the fact that there are two baseband signals for the radio receivers—the I and Q channels—and with the technology developed for time-division sharing of the circuit between two sets of A/D converters, we were able to achieve a large reduction in power dissipation and succeeded in obtaining the best efficiency of signal-conversion per unit power.

The current consumption of the D/A converter is nearly equal to the maximum output signal current, and so some difficulty is encountered in any attempt to reduce this value. Efforts were thus focused on securing performance with a low power-supply voltage. Since the breakdown voltage is becoming lower in more advanced microsemiconductors, power-supply voltages are also decreasing. Thus, measures must be developed to devise converters that are compatible with a low power-supply voltage. By designing wiring configurations for efficient distribution of the power-supply voltage, we were able to confirm operation of a 200-Msample/s, 12-bit D/A converter at 20 mW for a power-supply voltage of 1.2 V[7].

4 Architecture of a multi-band/multi-mode terminal and a corresponding evaluation system

One of the issues that must be resolved for any multi-band/multi-mode terminal compatible with future wireless communication systems lies in ensuring seamless handover between different wireless communication systems. To this end, we initiated a study of the architecture for a wireless transmission unit within a terminal that will execute such seamless handover. Figure 7 presents the architecture of the wireless transmission unit. A terminal compatible with seamless handover features two systems for wireless transmission functions; while the terminal is connected to current communication systems using one transmission function, the other transmission function will be used to switch the software in preparation for the next handover, thereby enabling the required seamless transition. Based on the architecture which is

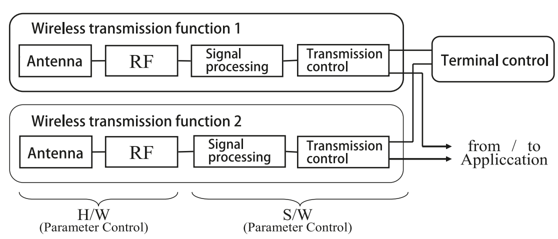

Fig.7 *Block diagram of the multi-mode terminal functions*

drawn in Fig.7, we also investigate a sequence of the switching process for cases in which the multi-mode terminal must execute seamless system switching between wireless systems[8]. We developed an evaluation system by integrating some of the results obtained in the present study, followed by basic tests to evaluate the terminal. The developed evaluation system is a receiver part of the multi-band/multi-mode SDR terminal. It handovers between MC-CDMA[9] which is assumed 4^{th} generation system, and W-CDMA. Here, the W-CDMA signals made use of the 2-GHz band at 3.84 Mchips/s (bit rate of 384 kbit/s) and the MC-CDMA signals used the 5-GHz band at a bandwidth of 20 MHz. Figure 8 is a schematic diagram of the evaluation system. Note that in addition to the sampling-rate-conversion technology[10] and the software-switching-compatible demodulation module developed in the present study, the evaluation system also integrates the wide-band antenna and wide-band RF circuit (quadrature mixer for receiver unit) described in Section **2** and the 10-bit A/D converter primary prototype (as described in Section **3**) which operates at 80 Msample/s. Also note that the A/D converter and the sampling-rate converter were equipped on the A/D board and that the demodulation module is equipped on the DSP board[11]. Due to the restrictions imposed by the processing capacity of this DSP, the bandwidth for MC-CDMA was set at 20 MHz, and the number of OFDM subcarriers was set at the value stipulated under IEEE 802.11a.

As the results of evaluation when the

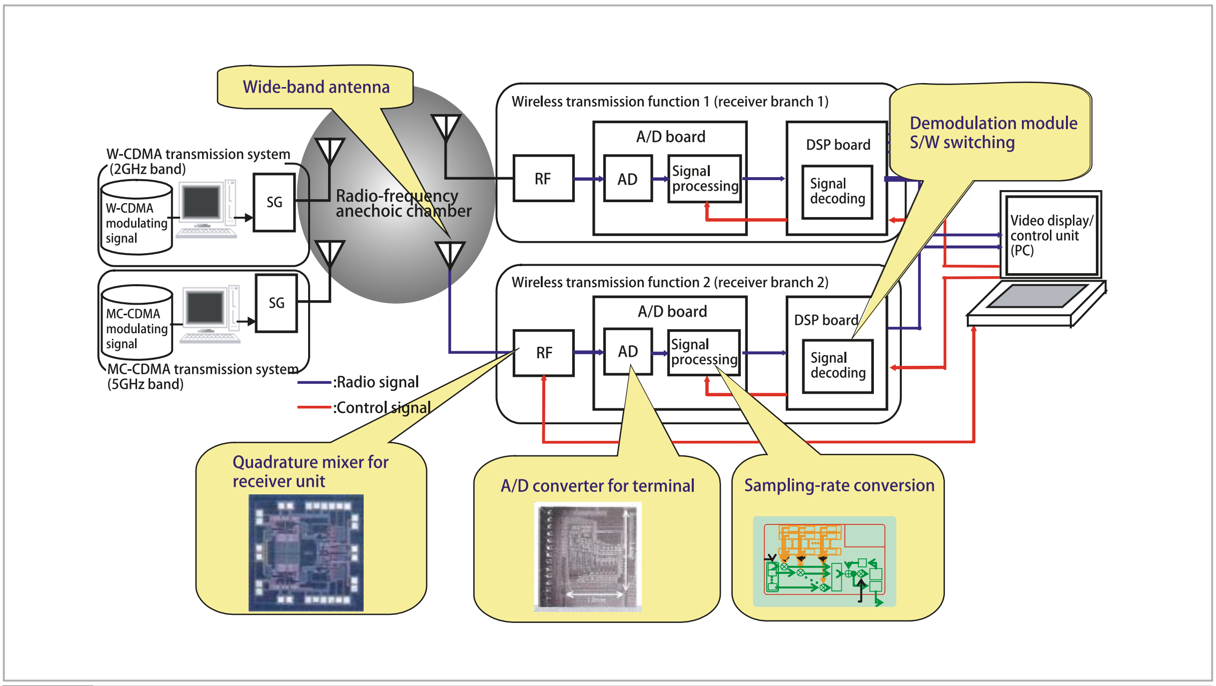

Fig.8 *Schematic diagram of the comprehensive evaluation system*

transmitter and receiver are connected via radio, it was confirmed that seamless system switching between wireless systems using the proposed terminal architecture was feasible. The results of evaluation of the time required for software switching during wireless system handover gave a practical switching time of approximately 1 second.

5 Platform LSI technology for software-defined radio

With the ever-increasing speed of data transfer and growing sophistication of wireless systems, the requirements for digital baseband processing capacity in wireless communication systems are dramatically increasing. These demands are increasing at a rate far outpacing corresponding increases in DSP performance, as predicted under Moore's Law. In a software-defined radio system (particularly with respect to terminals), it is not realistic to attempt to perform all processing tasks using the DSP; instead it is believed that hardware dedicated to the target processing ought to be implemented.

Our strategy is to execute a certain amount of routine and common processing on hardware with adjustable parameter settings, while performing processing tasks that require some degree of freedom on processing-elements-arrayed reconfigurable-logic blocks. Examples of the former type of processing could include a filtering circuit and error correction, for which the basic procedures are the same for all wireless systems; only certain parameters would need to be changed. Examples of the latter include synchronization and calibration, which generally vary even within a single wireless communication method, due to the overall pursuit of differentiation of performance within any given wireless system.

In the present project, a prototype for a hybrid LSI platform was fabricated using a parameter-adjustable hardware circuit and a reconfigurable circuit. Since it is expected that OFDM and CDMA will form the basic technologies for future wireless communication systems, our aim was to develop an LSI technology which realizes both IEEE802.11a for the former prototype and IEEE802.11b for the latter prototyhpe (not CDMA in the strict sense, but it utilizes DS-SS which forms the basis for this technology).

Table 1 presents the specifications of the platform LSI, and Fig. 9 shows a microphotograph of the LSI and the evaluation board.

Our newly developed reconfigurable logic blocks (RLB)[12] comprise approximately two-thirds of the LSI. A single cluster consists of 32 processing elements of various types such as the ALU, MAC, RAM, address generator, etc., and a single cluster group consists of seven clusters. The LSI is equipped with three cluster groups. The total RLB processing capability for the three cluster groups is 103 GOPS (giga-operations per second).

An experiment was conducted in which two evaluation boards were connected, one for Tx and the other for Rx, and the two wireless systems (IEEE802.11a and IEEE802.11b) were run; the results confirmed the success of high-speed switching between the systems. The time required for system switching was approximately 5 ms.

Table 1 Specifications of the platform LSI

Technology	0.11 μm CMOS, eight-layered copper wiring
Chip size	16.7 mm × 16.7 mm
Number of transistors (total)	56 million (logic) 34 million (memory)
Power-supply voltage	1.2 V (core), 2.5 V (I/O)
Operational frequency	160 MHz at 1.2 V (RLB units) 100 MHz at 1.2 V (other)
Package	1,156-pin FCBGA

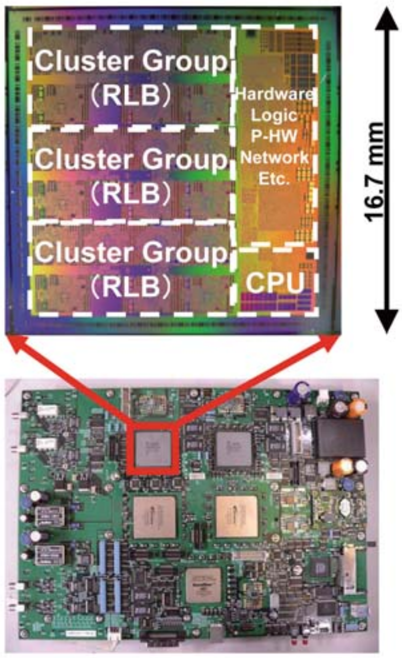

Fig.9 LSI microphotograph and evaluation board

6 Distributed-object/download technologies

6.1 Distributed-object technology

In an environment in which wireless systems with high degrees of freedom are established through a variety of combinations of software components (such as an SDR operating environment), it is important to focus on developing software that is highly distributable. To this end, the Software Communication Architecture (SCA) provided by the Joint Tactical Radio System (JTRS) is coming into the spotlight as a means of creating common software components that will pave the way for wireless communication systems featuring distributed-object architecture using Interface Definition Language (IDL).

In this study, a method of performing a “difference updating” has been proposed that dynamically reconstructs the object configuration, which will be useful in the wireless communication systems under discussion. The effectiveness of this method has been verified by an implementation experiment using a reconfiguration middleware program equipped with this function. “Difference updating” is a method of switching between wireless systems by updating only the portions of the object required for the implementation of a different layer function or algorithm. Since this can reduce both the volume of software downloaded for the updating and reconfiguration procedures, the method is particularly suited for improvements to updating performance. The difference updating method proposed here will enable secure reconfiguration by carrying out rollbacks in the event of reconfiguration failure, and should solve the problem of the two types of load increase caused by complexity in the IDL Call configuration.

The first type of load is generated by the procedure analysis involved in rebooting the object configuration. Rebooting is a process executed by the individual objects, both new and old (hence the term “difference”), in order to construct a new object configuration. For example, the effects of updating one object will extend to other potentially associated objects, as in the case of clients and servers. Therefore, the effect of updating of multiple objects will complicate processes, due for example to the delay entailed in the timing and discovery of the difference object. The second type of load is associated with the process of securing a path for IDL Call between the client and server in a new connection. During the process of difference updating, the client will have to identify servers that had not been anticipated in the development stage, and so a search process will be required. The difference updating method can solve the problem of load using difference updating management functions and indirect connection functions while executing the complex distributed-object reconfiguration process. A performance test of the reconfiguration middleware has confirmed the effectiveness of the difference updating method, which has been shown to enable secure and fast object reconfiguration[13].

6.2 Download technology

In order to switch dynamically between SDRs, the system will need to download the wireless transmission function required by the software in the wireless system unit. To accomplish this task, a common I/F definition and method of implementation for incorporation into the terminal are required. Further, to realize seamless communications, operation must continue even while the wireless transmission functions are updated. Thus, functions are required for the management of terminal conditions (such as the state of connection, out-of-range status, etc.) and dynamic updating of wireless modules.

In this study, the following two points were examined in the context of assessing a method of switching seamlessly among communication systems, and evaluation tests were conducted on the implementation of this method.

(1) Implementation and evaluation of the dynamic updating method for wireless transmission

A standard AT-command-based I/F definition unit was established, with specifications tailored to an evaluation test of the switching function of the wireless system unit using a mobile terminal.

(2) Implementation of internal terminal management for the purpose of integration with distributed-object technology

The conditions inside the terminal were managed to enable coordinated switching among wireless transmission units within the network.

We have seen that with the implementation

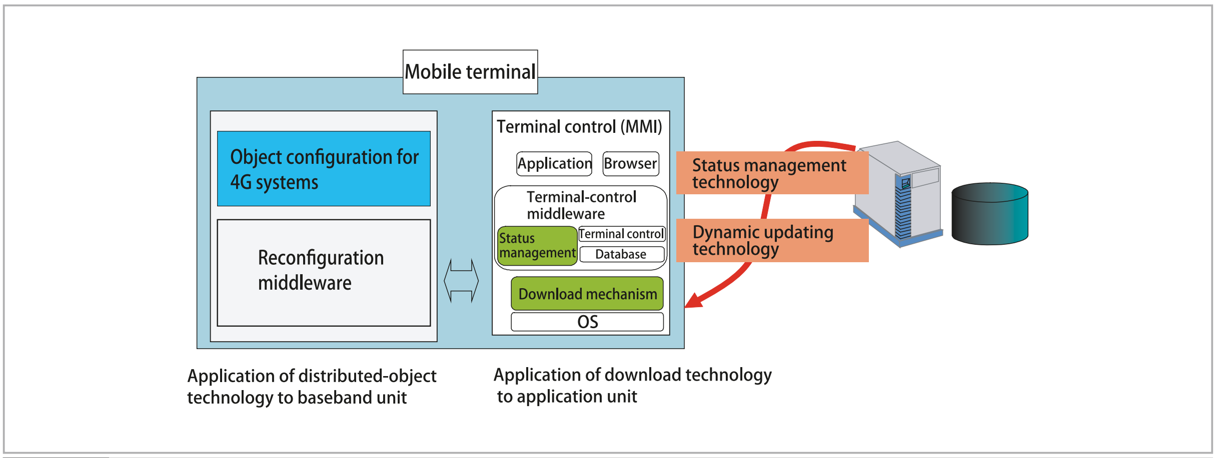

Fig. 10 *Distributed-object technology and download technology*

of these functions it becomes possible to perform dynamic updating of the wireless transmission function and to perform both terminal-initiated and network-initiated handovers through the network-coordinated terminal. Thus, downloading may be performed without interrupting communication functions[14].

7 Conclusions

In this project, research and development were undertaken for devices and technologies applicable to software-defined radio; these technologies will be essential for the realization of 4^{th}-generation mobile communication systems expected to enter practical use sometime around 2010. Through the R&D activities described above, we have been able to establish the basic technologies for a multiband/multi-mode terminal using software-defined radio. Additionally, the three companies to whom this project has been contracted have conducted joint activities with a view to the standardization of these technologies within the ITU-R. As a result, some of the study results and noted technical problems have been selected for inclusion in the ITU-R WP8F Report[15].

Acknowledgments

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***SUNAGA Terumi**, Ph.D.*

Head Researcher, Wireless Communication Technology Dept., Information Technology R & D Center, Mitsubishi Electric Corporation

R & D of Software Defined Radio Techniques

KIYOHARA Ryozo

Team Leader, Ubiquitous Network Systems Dept., Information Technology R & D Center, Mitsubishi Electric Corporation

Middleware for Mobile Phones

***ITAKURA Tetsuro**, Dr. Eng.*

Chief Research Scientist, Mobile Communication Laboratory, Corporate Research and Development Center, Toshiba Corporation

Analog Integrated Circuits

***TERASHIMA Yoshiaki**, Ph.D.*

Head Researcher, Network Security Technology Dept., Information Technology R & D Center, Mitsubishi Electric Corporation

Distributed Processing, Ad-hoc Network

***SUEMATSU Noriharu**, Dr. Eng.*

Team Leader, Electro-Optics & Microwave Electronics Technology Dept., Information Technology R & D Center, Mitsubishi Electric Corporation

R & D of RF Devices for SDR

HIROSE Yoshio

Research Fellow, System LSI Development Laboratories, FUJITSU LABORATORIES LTD.

Reconfigurable LSI, System LSI