

(2) Communication-Control Protocol Stack Software

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Protocol stack software for controlling communications with the network has been developed for FOMA terminals. With this software, DoCoMo has achieved services and functions that are first in Japan and has improved communication quality and basic performance. This software is becoming a common platform for FOMA terminals developed by leading mobile-terminal vendors.

1. Introduction

Amidst predictions of increasingly severe competition among telecommunication operators in the years to come, DoCoMo needs to support advanced services and functions as early as possible, improve communication quality and basic performance in an ongoing manner, and increase competitiveness by lowering mobile-terminal prices. To satisfy these needs, DoCoMo has developed Protocol Stack Software (PSS) for mobile terminals to control communications mainly with the radio access network^{*1} and core network^{*2}. This article presents examples of advanced services and functions, improvements in communication quality and basic performance, made possible by this PSS to demonstrate its benefits and advantages.

2. PSS Overview and Development Objectives

Using the PSS provided by software vendors for its mobile terminals, there are several restriction to realize “providing early support for advanced services and functions” and “making ongoing improvements in communication quality and basic per-

formance.” Vendor-supplied software makes it difficult to uncover latent needs and to maintain superiority in communication quality and basic performance in competition with other telecommunication operators. And developing PSS separately by mobile-terminal vendors is also a factor in the high cost of mobile terminals. In addition, mobile terminals must be able to support Global System for Mobile communications (GSM)^{*3}, which is now used by more than 70% of mobile-network subscribers in the world, to provide global-roaming services.

To solve these problems, DoCoMo has developed communication-control PSS as a common platform for its FOMA terminals. This PSS consists of three protocol groups supporting not only the W-CDMA single mode [1] but also W-CDMA/GSM dual mode. It runs on a Real-Time Operating System (RTOS)^{*4} called Micro Industrial-The Real-time Operating System Nucleus (μ ITRON)^{*5} that is capable of real-time processing (**Figure 1**).

The developed PSS features the following functions:

- 1) Processing of radio-resource-control protocol (Radio Resource Control (RRC)^{*6}, Radio Link Control (RLC)^{*7}, Packet Data Convergence Protocol (PDCP)^{*8}, etc.) between the mobile terminal and radio access network.
- 2) Processing of mobile-management and call-control protocol (Mobility Management (MM)^{*9}, Call Control (CC)^{*10}, Supplementary Service (SS)^{*11}, etc.) between the mobile terminal and core network.
- 3) Control of W-CDMA/GSM layer 1 (frequency search, cell selection, radio-channel initialize/terminate, handover, etc.)
- 4) Control of communications with the application-processing section via a terminal adaptor and control of the human-machine interface
- 5) Reading and writing of User Identity Module (UIM)^{*12} information (related to location registration, cipher, etc.)

3. Support of Advanced Services and Functions

This chapter describes services and functions that have come to be achieved ahead of time in PSS development by

*1 Radio access network: A network positioned between the core network and mobile terminals consisting of radio base stations and radio-resource control equipment.

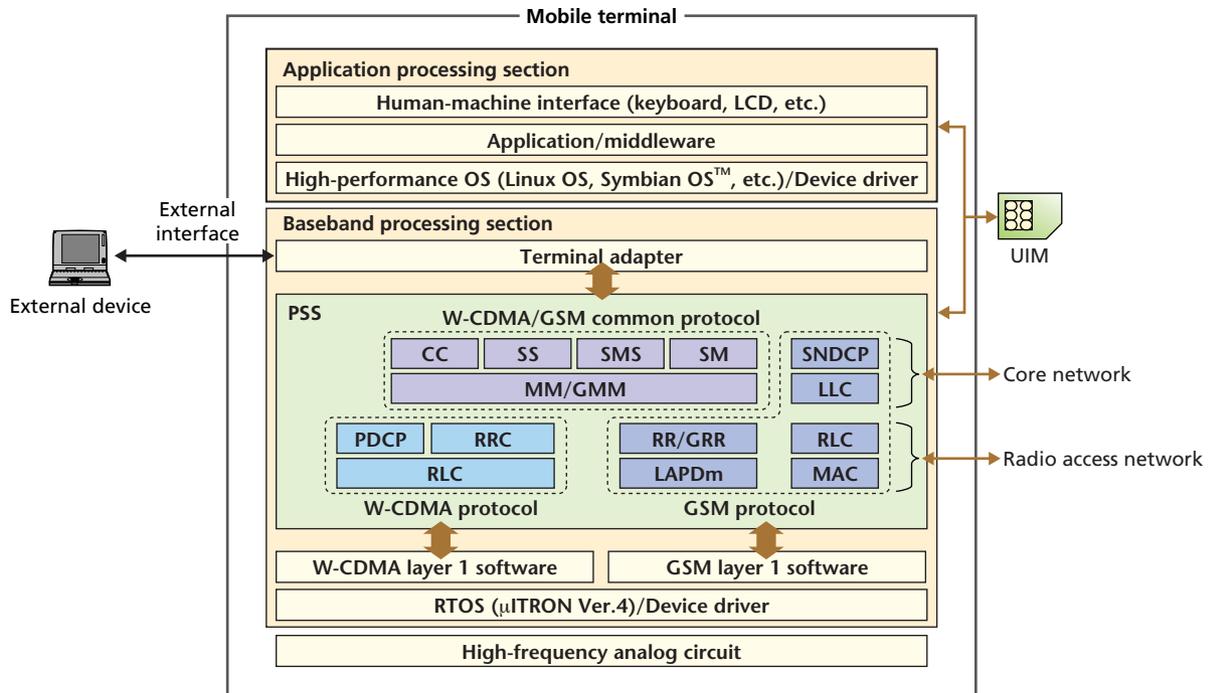
*2 Core network: A network consisting of switches and subscriber-information management equipment. Mobile terminals communicate with the core network via the radio access network.

*3 GSM: A Second-Generation mobile communications system used widely around the world, especially in Europe and Asia.

*4 RTOS: An OS equipped with functions for performing real-time processing. It is used in embedded equipment such as Personal Digital Assistant (PDA) and home appliances that incorporate a CPU and software for specific applications.

*5 μ ITRON: An RTOS provided by the TRON Association and used widely such as in mobile terminals. Its compact configuration makes for easy loading onto various types of processors.

*6 RRC: Layer 3 protocol for controlling radio resources in W-CDMA.



GMM (GPRS Mobility Management): Protocol performing mobile management such as location registration and user authentication in the packet-switching domain.

GRR (GPRS RR): Protocol used in GPRS of GSM to control radio resources.

LAPDm (Link Access Protocol on the Dm channel): Based on the LAPD data-transfer-control procedure used on the ISDN D-channel, this protocol amends that procedure for use in a mobile environment and specifically in GSM.

LinuxOS: An open-source Unix-type OS that can be freely redistributed under GNU Public License (GPL).

LLC (Logical Link Control): Protocol providing logical connections with retransmission control and confidentiality functions in GPRS of GSM.

MAC (Medium Access Control): Protocol used in GPRS of GSM to control LLC-frame mapping above the physical channel.

RR (Radio Resource): Protocol used in GSM to control radio resources.

SM (Session Management): Protocol controlling originating/terminating calls in packet communications.

SMS (Short Message Service): Protocol for controlling a service for sending and receiving short text-based messages mainly between mobile terminals.

SNDCP (Sub-Network Dependent Convergence Protocol): Protocol used in GPRS of GSM for compressing/expanding packets as optional functions.

Symbian OS™: An OS for mobile terminals developed and licensed by Symbian Ltd. (UK).

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Figure 1 PSS configuration

incorporating 3GPP R4^{*13} and later specifications while difficult to achieve within the range of Release 99 of 3GPP (3rd Generation Partnership Project)^{*13} specifications.

3.1 Priority Connection for Emergency Calls

In Japan, at times of network congestion due to a natural disaster or other crisis, emergency calls made to police (110), fire and ambulance (119) and the Maritime Safety Agency (118) are suppose to be given priority connections despite a state of

restricted access. In this regard, a system enabling an emergency-call-setup procedure during restricted access has been specified in 3GPP R99. This system enables the procedure only when the emergency number stored in the UIM is dialed by the user. The basis for this system, however, is GSM specifications, which were standardized in Europe where only one emergency number exists. Thus, with this procedure, there is no way to notify the network of the specific connection destination (110/118/119), accordingly, there is no way to identify the con-

*7 RLC: A protocol for controlling retransmission and other functions as a sublayer of layer 2 in GSM and W-CDMA.

*8 PDCP: A protocol having optional functions such as packet compression/decompression and cell reselection for no packet loss as a sublayer of layer 2 in W-CDMA.

*9 MM: A protocol for mobile management performing location registration, authentication, and other functions in circuit switching.

*10 CC: A protocol for controlling originating/terminating calls in circuit switching.

*11 SS: A protocol for controlling supplementary services.

*12 UIM: A smart card that stores subscriber information such as a telephone number. It is inserted into the mobile terminal to identify the user. A FOMA card is an example of UIM.

nection destination on the network side. It would therefore be necessary to send voice instructions, for example, and have the caller specify the connection destination to avoid this problem. Such an approach, however, would detract from the convenience that emergency reporting should provide. There has consequently been no other choice so far but to use a UIM that does not store emergency numbers and that applies the normal-call-setup procedure when dialing 110, 118, or 119 resulting in no priority connection during restricted access.

At the same time, the congestion resulting from an increasing number of FOMA subscribers can no longer be ignored and the need has grown for giving priority connections to calls made to the 110/118/119 emergency numbers. It was therefore decided to take the initiative, and implement part of a key function specified in 3GPP R4 specifications [2] in the PSS developed for the FOMA 901iS terminals. This function extends the emergency-call-setup procedure so that the network can be notified of “service category” information identifying “police”, “fire,” etc. thereby enabling emergency calls to be connected without having the caller select an emergency agency by voice instructions.

We note here that even if mobile terminals equipped with the above 3GPP function existed, existing UIMs do not store emergency numbers with the result that the normal-call-setup procedure would still have to be applied when dialing 110, 118, or 119. Also, supposing that existing UIMs were to be replaced by UIMs that do store the 110/118/119 numbers and that these new UIMs were to be inserted in existing FOMA terminals, an emergency-call-setup procedure that can not identify the connection destination would still be in effect even when dialing 110, 118, or 119. The sense of emergency would therefore be lost.

For the above reasons, the PSS developed for the FOMA 901iS terminals incorporates a function for applying an emergency-call-setup procedure with number identification whenever dialing 110, 118, or 119 within Japan regardless of whether these emergency numbers are stored in the UIM.

This function makes it easy to establish a connection for

emergency calls even during periods of network congestion following a natural disaster or during the New Year’s holiday season. It also contributes to the realization of a safe and secure society. The ability to make emergency calls on priority connections with the FOMA 901iS terminals during restricted access is a first for W-CDMA system of Japan. The plan is to implement this function in new mobile terminals from here on.

3.2 Audio/Video Switching During a Communication

The videophone is a distinctive service provided by the FOMA system. For a caller with a videophone-capable terminal, however, it is not always clear whether the other party is also capable of using a videophone. As a result, callers are often hesitant to make calls by videophone and the use of this service has not expanded as expected.

To promote the use of the FOMA videophone service, we have added a function for switching to videophone mode from normal audio mode without having to redial. With this function, the caller can first make a call in audio mode to see if the other party would also like to talk by videophone, and then directly switch to videophone if the called party agrees.

To implement this audio/video switching function, we adopted the Service Change and UDI Fallback (SCUDIF)^{*14} function [3] specified in the 3GPP R5^{*13} specifications. Here, however, charges for audio and video calls are different, and the need arose for displaying those charges separately when providing this function. We therefore installed a function in the PSS for counting those charges separately. We also added an interface for notifying the user of multiple charges in response to inquiries from the human-machine interface.

While the FOMA system allows for simultaneous use of packet communications and audio phone calls, it is not currently capable of handling packet transmissions and videophone calls simultaneously. Thus, in the event of a switching request from audio mode to videophone mode during packet communications, the switching request may be denied, and in general, we have incorporated measures that take various types of system conflicts into account.

*13 3GPP R**: A project aiming to standardize a Third-Generation mobile communication system. Because ongoing standardization activities to incorporate requirements for new functions hinder the freezing of specifications and make the development difficult, it was decided to issue releases in a stepwise manner starting with R99 and upgrading to R4, R5, R6, etc.

*14 SCUDIF: A system defined by the 3GPP R5 for changing bearers while a circuit-switched call is in progress.

In the above way, incorporating 3GPP R5 specifications in the FOMA 901iS terminals has enabled DoCoMo to be the first in Japan to provide this audio/video switching function [4]. We expect users to have more opportunities to use the FOMA videophone service as the number of mobile terminals equipped with this function increases.

3.3 Circuit-switching/Packet-switching Independent Access Control

During times of network congestion brought on by a natural disaster or other crisis, services like i-mode emergency messaging service and i-mode mail should be available even if telephone calls are difficult to make. This function has already been implemented in Personal Digital Cellular (PDC)^{*15}, but in FOMA, support has been delayed since it was not originally defined in 3GPP specifications and must be realized through subsequent standardization activities. The recent massive disasters, however, has generated a strong need for early realization of this function, and standardization have been progressing well as a matter of social responsibility. In terms of PSS, we have commenced development work in parallel with these standardization activities to provide support for this function as soon as possible.

This function enables access control for circuit-switching calls to be performed independently from that of packet-switching calls. In PSS, we will support the Domain Specific Access Control (DSAC)^{*16} function [5] defined in 3GPP R6^{*13} specifications. Preventing access by circuit-switching calls, for example, will suppress the making of telephone calls but will keep the network running by allowing use of i-mode emergency messaging service and i-mode mail.

4. Improvement of Communication Quality and Basic Performance

As for communication quality and mobile-terminal basic performance, which, as implementation-dependent items, are not particularly specified in 3GPP specifications, we have incorporated measures in the developed PSS to improve the originat-

ing/terminating call completion rates and battery-saving performance. These improvements are described below.

4.1 Improved Originating/Terminating Call Completion Rates

Originating/terminating call completion rates can be used as basic indexes of communication quality. The following describes measures that we have so far incorporated in our PSS for improving these call completion rates.

1) Improved Originating Call Completion Rate

When making a new call directly after a packet-call deactivate procedure, the call-originating procedure can fail if the downlink “RRC Connection Release” message from the network and the uplink “Initial Direct Transfer” message from the call-originating procedure cross each other in transmission. To prevent such a failure from happening, the call-originating procedure is retried after the mobile terminal receives the “RRC Connection Release Complete” message (Figure 2).

2) Improved Terminating Call Completion Rate

A call can be released without going through the normal deactivate procedure if the mobile terminal should enter into an out-of-service area due to radio link failure during a packet call.

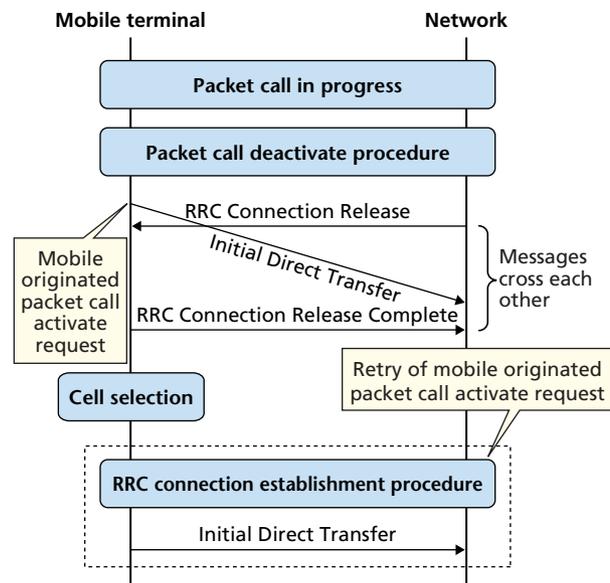


Figure 2 Call originating procedure directly after packet-call deactivate

*15 PDC: A Second-Generation mobile communication system widely used in Japan, adopted by DoCoMo and others.

*16 DSAC: A function that enables access by circuit-switching calls and packet-switching calls to be controlled independently of each other.

At this time, the network will continue to save the previous call state for a certain period of time resulting in a temporary discrepancy between the state known to the network and the mobile terminal's actual state. But even if the mobile terminal should soon reenter the service area, that discrepancy will still exist, and under these conditions, any incoming calls will be lost. To solve this problem, location registration is performed immediately after reentering the service area only for calls released in the above manner thereby shortening the time during which a state discrepancy exists with the network. This releases the call state saved on the network side enabling incoming calls to be received and improving the terminating call completion rate.

4.2 Improved Battery-saving Performance

"Continuous stand-by time" as listed in mobile terminal catalogs can be used as an index of basic terminal performance. The following measures implemented in our PSS have been found to be effective in saving battery power and in achieving greatly improved performance compared to early FOMA terminals.

1) Optimal Frequency Search

A mobile terminal has a function that searches for a frequency on which stand-by mode can be entered. The FOMA network operates on the 2-GHz and 800-MHz bands. These bands, together with the 1.7-GHz band whose future availability is anticipated, constitute several hundred frequencies. Searching through all these frequencies would take some time before the terminal could enter stand-by mode, and multiplying this time by the number of times a terminal needs to enter stand-by would result in a significant shortening of continuous stand-by time.

To deal with this problem, we classified frequencies with a usage history into three Lists (**Table 1**), store those Lists in the PSS, and establish a search order to be followed until an available frequency is found. If no available frequency is found from these lists, all frequencies are searched. For example, the search order to be used immediately after turning the terminal's power supply ON is List 2, List 3 and all frequencies. In general, the relationship between these Lists in terms of maximum number

Table 1 Classification of frequencies targeted for searching

Class	Target frequencies
List 1	Frequency group with a usage history after turning power ON
List 2	Frequency group with a usage history while power was ON last time
List 3	Frequency group with a usage history in the past

of recorded frequencies is set as $List2 \leq List1 < List3$. Here, if a frequency is detected that exceeds the maximum number for the List in question, the oldest frequency will be deleted and the latest recorded.

This measure cuts down on exhaustive searches and achieves high-speed frequency searching overall making for improved battery-saving performance.

2) Reduction in Frequency of Receiving Broadcast Information

A mobile terminal obtains area information and other data from broadcast information^{*17}, which is broadcast by each cell to mobile terminals in the area. Receiving this information in itself naturally consumes battery power, and it is important to determine how to keep the lowest frequency of receiving this broadcast information.

The PSS developed here stores received broadcast information for up to one hour in the mobile terminal for each combination of radio frequency and scrambling code. If, at the next

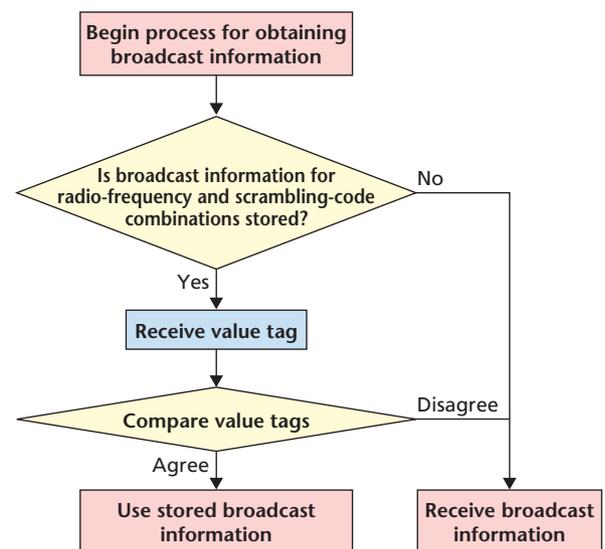


Figure 3 Flow for judging need of receiving broadcast information

*17 Broadcast information: Information broadcast by each cell to mobile terminals, including location number for determining whether location registration is needed, neighboring cell information, and access control information.

scheduled receive time, broadcast information is already stored, only a value tag will be received and compared with the stored value tag. If they agree, the broadcast information presently stored can be used as-is thereby reducing the frequency of receiving broadcast information (**Figure 3**). Here, “value tag” is a value that is counted up every time that broadcast information is updated. It is contained in the System Information Block (SIB)^{*18} as part of broadcast information.

5. Conclusion

While there are a number of Japanese and overseas software vendors that provide protocol stack software, there are no vendors that can consistently and speedily achieve the advanced services and functions provided by DoCoMo. Know-how related to “improving communications quality” and “improving

basic performance” is treated as a valuable asset that helps the company stand out among other telecommunication operators. Providing services, functions, quality and performance that satisfies customer needs through PSS development will continue to be our important goal.

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- [5] 3GPP TS 25.331 v6.8.0, Dec. 2005.

*18 SIB: The unit block for sending broadcast information from a radio base station to mobile terminals in GSM and W-CDMA.