Special Article on IMT-2000 Services (1)
– Launch of FOMA, the Pioneer of the New Mobile Age –

Technology Overview

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This article describes the standardization process of IMT-2000, and reviews the IMT-2000 radio access technologies and core network technologies adopted by DoCoMo.

1. Introduction

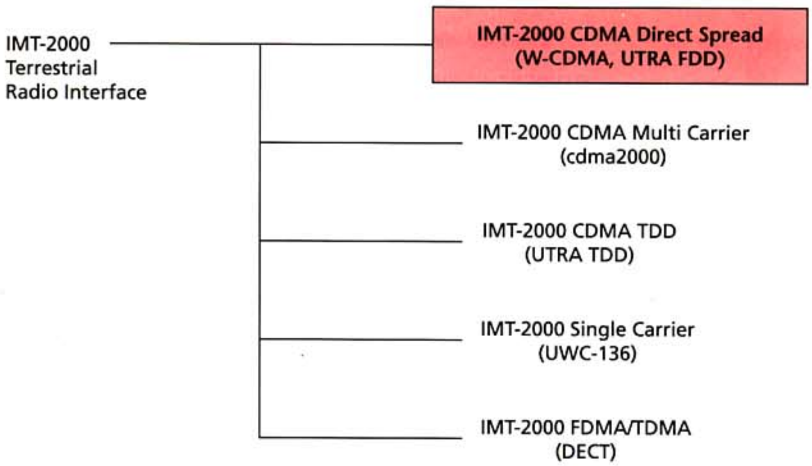
International Mobile Telecommunications-2000 (IMT-2000) is an international standard for third-generation mobile communication systems. This article describes how IMT-2000 became a standard, and reviews the IMT-2000 radio access technologies and core network technologies adopted by DoCoMo.

2. Standardization and Positioning of IMT-2000

2.1 ITU Activities

IMT-2000 stems from the research of radio systems which launched in 1985 by the International Telecommunication Union-Radio communication sector (ITU-R), entitled Future Public Land Mobile Telecommunication Systems (FPLMTS). It has been an important agenda for the International Telecommunication Union-Telecommunication standardization sector (ITU-T) as well. Within ITU-R and ITU-T, efforts have been made to leverage it into a uniform, international standard, and achieve 2Mbit/s high-speed transmission, quality equivalent to fixed networks, and low costs.

ITU-R defined the minimum requirements for IMT-2000 as a radio interface, about 10 systems were proposed by different countries/institutions for terrestrial services. In May 2000, five modes stated in **Figure 1** were officially recognized, in the form of recommendations. IMT-2000 CDMA Direct Spread referred to in Figure 1 is based on the proposal made by the Association of Radio Industries and Businesses in Japan (ARIB) and the European Telecommunications Standards Institute (ETSI). It is generally called the Wideband Code Division Multiple Access (W-CDMA).



IMT-2000: International Mobile Telecommunications-2000
ITU-R: International Telecommunication Union-Radio communication sector
W-CDMA: Wideband Code Division Multiple Access
CDMA: Code Division Multiple Access
UTRA: Universal Terrestrial Radio Access
TDD: Time Division Duplex
FDMA: Frequency Division Multiple Access
TDMA: Time Division Multiple Access

Figure 1 ITU-R Recommendation for IMT-2000

ITU-T, which has been working on the IMT-2000 signal system since 1993, issued a recommendation for specifications of IMT-2000 networks and architectures in March 1999. IMT-2000 is based on a "family concept", which enables carriers to offer global services throughout the different IMT-2000 systems, and to utilize the facilities and assets of existing mobile communication systems in order to meet the market demands.

2.2 Activities of Local Standardization Bodies, 3GPP, etc.

In the standardization process, consensus formation starting from proposals of radio interface and ending with the definition of basic specifications was largely influenced by ITU as a matter of course but also by the harmonization activities led by the operators and cooperation from standardization bodies in various countries/regions. Between December 1998 and January 1999, two organizations were established for regional standardization bodies to formulate a common, standard specification, namely the 3rd Generation Partnership Project (3GPP) and 3GPP2. 3GPP adopts W-CDMA for radio access and an enhanced version of Global System for Mobile communications (GSM) for core networks.

DoCoMo has been promoting research and development in the field of W-CDMA from the early days. DoCoMo, which adopts the enhanced version of GSM for core networks, has contributed to the early development of detailed specifications in 3GPP. As GSM networks had already covered many parts of the world, W-CDMA, which is a radio access technology based on a new frequency band under IMT-2000, is expected to spread out not only in Europe and Japan, but also in many Asian countries and in the U.S.

3. Radio Access Technologies

3.1 Characteristics of W-CDMA

In general, the merits of Code Division Multiple Access (CDMA) include: (1) easy to achieve highly efficient spectrum use; (2) no need to manage radio frequency; (3) peak power can be reduced during transmission by mobile phone; and (4) uplink and downlink radio resources can be used independently of each other.

W-CDMA has the following additional merits due to its wideband properties.

(1) Wide Range of Data Transmission Speeds

Wideband enables transmission at high speed. It also enables the efficient provision of services when there is a combination of low-speed services and high-speed services.

(2) Improved Multipath Resolution

RAKE diversity reception technology will first separate the multipath into indivisuals and then sum them up to produce better receiving efficiency. As the wideband improves the resolution of transmission paths and increases the number of paths, weaker reception power is required due to the path diversity effect. As a result, smaller transmission power is required, which leads to an increase in system capacity. A typical example is the chip rate: field tests at approx. 4Mcps have revealed that necessary transmission power is about 3dB less than at approx. 1Mcps.

(3) Statistical Multiplexing Effect

Since the wideband increases the number of users to be multiplexed by each carrier, the capacity increases due to the statistical multiplexing effect. Especially in relatively high-speed data communications, the efficiency decreases in narrowband as the number of channels that can be accommodated by each carrier is limited, whereas in wideband, the efficiency improves due to the statistical multiplexing effect.

(4) Reduced Intermittent Reception Rate

Wideband enables the control channel data rate in high speed, and therefore makes it possible to reduce the rate of intermittent reception, which makes the mobile terminal to receive limited signals when it is in the standby mode to save power. This enables the mobile terminal to be in the standby mode for longer hours.

3.2 Basic Specifications and Technologies of W-CDMA

Table 1 shows the basic specifications of W-CDMA.

(1) Bandwidth

Initially, ARIB and ETSI advocated radio systems based on 5MHz, followed by 10MHz and 20MHz carriers. 3GPP concentrated on completing the specifications for the 5MHz bandwidth and scrapped specifications for other bands due to the fact that a 5MHz-band carrier is enough to achieve 2Mbit/s transmission, and for the purpose of polishing up the detailed specifications as quickly as possible. Hence, the first version of specifications by 3GPP and standards by ARIB and ETSI are limited to the 5MHz bandwidth.

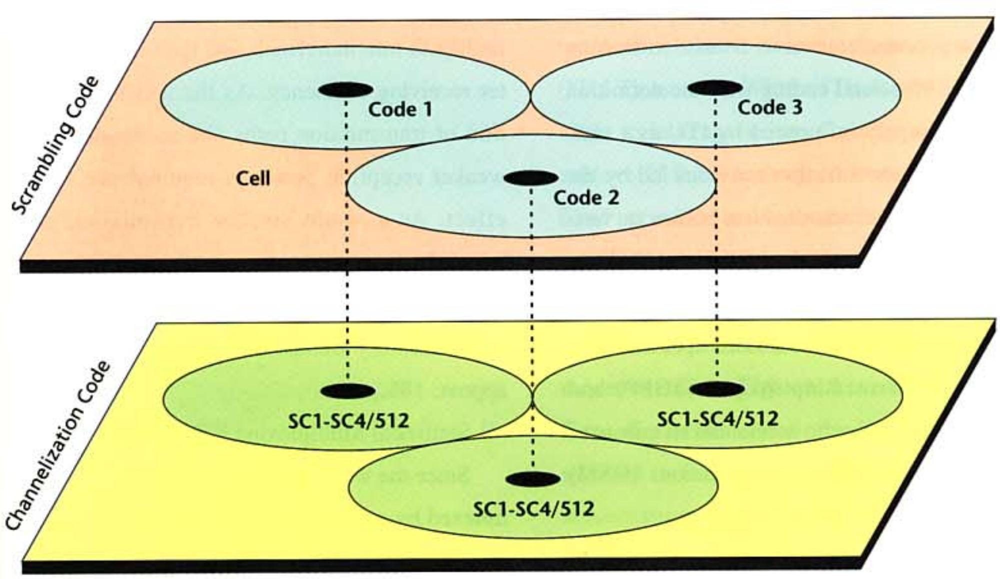
(2) Inter-BS Asynchronous Mode

Asynchronous mode between base stations has no need to maintain accurate synchronicity between all base stations and has merit of easy deployment of base stations in a seamless manner when moved from indoors to outdoors. **Figure 2** illustrates the spreading code allocation for downlink. Spreading code is generated by multiplying the scrambling code and the channelization code. The scrambling code is a code assigned to each cell for cell identification purposes, and treats interfering signals from other cells as noise. The channelization code is for identifying each user, and a set of codes that are orthogonal to each other are used in each cell. Here, the mobile terminal is

Table 1 Basic Specifications of W-CDMA

Multiple Access	Direct Sequence CDMA
Duplex	FDD
Bandwidth	5MHz
Chip Rate	3.84Mcps
Carrier Spacing	200kHz raster
Data Speed	Up to 2Mbit/s
Frame Length	10, 20, 40, 80ms
Forward Error Correction	Turbo Code, Convolutional Code
Data Modulation	Downlink: QPSK, Uplink: BPSK
Spreading Modulation	Downlink: QPSK, Uplink: HPSK
Spreading Factor	4 - 512
Synchronization between Base Stations	Asynchronous (sync operation possible)
Speech Coding	AMR (1.95k-12.2kbit/s)

AMR: Adaptive Multi Rate
BPSK: Binary Phase Shift Keying
CDMA: Code Division Multiple Access
FDD: Frequency Division Duplex
HPSK: Hybrid Phase Shift Keying
QPSK: Quadrature Phase Shift Keying



SC: Synchronization Code

Figure 2 Downlink Code Allocation in Asynchronous Mode between Base Stations

required to make an effort to detect the cell quickly to which it belongs. The system made the asynchronous mode between the base stations possible by adopting a three-step, high-speed cell search technology which radically reduces the time consumed by the mobile terminals in cell searching.

(3) Modulation and Pilot Structure

The data modulation for downlink is the Quadrature Phase Shift Keying (QPSK) and the Binary Phase Shift Keying (BPSK) for uplink. Spreading modulation for uplink is the Hybrid Phase Shifting Keying (HPSK). Pilot-symbol aided coherent detection is applied not only for downlink but also for uplink. For downlink with reference to pilot symbols, data symbols are time-multiplexed. This minimizes the delays in transmission power control and streamlines the reception process in the mobile station. The pilot system used for time-multiplexing downlink-dedicated channels are also effective in controlling the power of high-speed downlink transmissions.

On the other hand, for uplink with reference to pilot symbols, data symbols are IQ-multiplexed. In other words, they are subjected to BPSK modulation, and are synthesized at phase

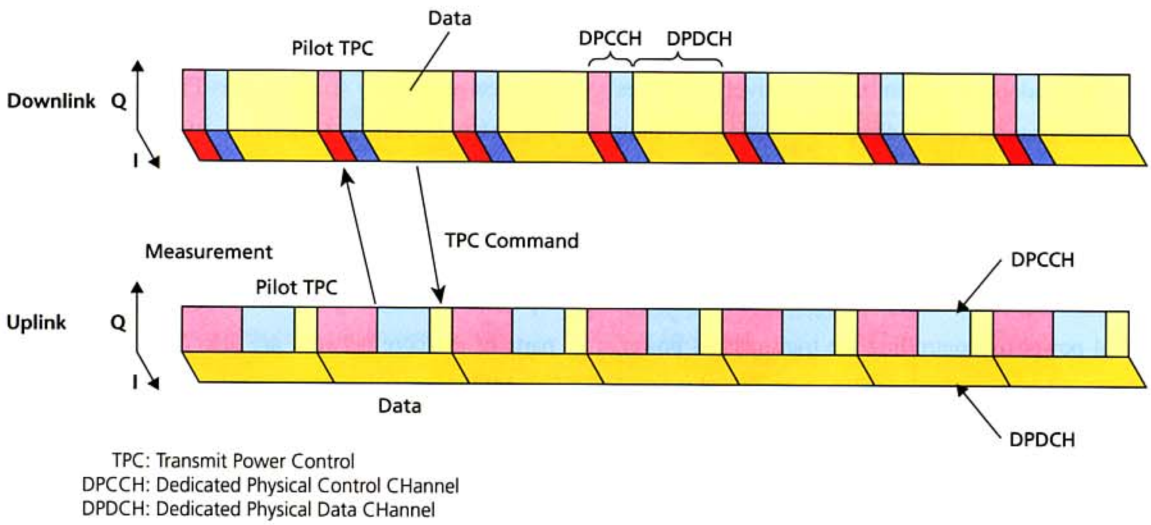


Figure 3 Pilot Structure

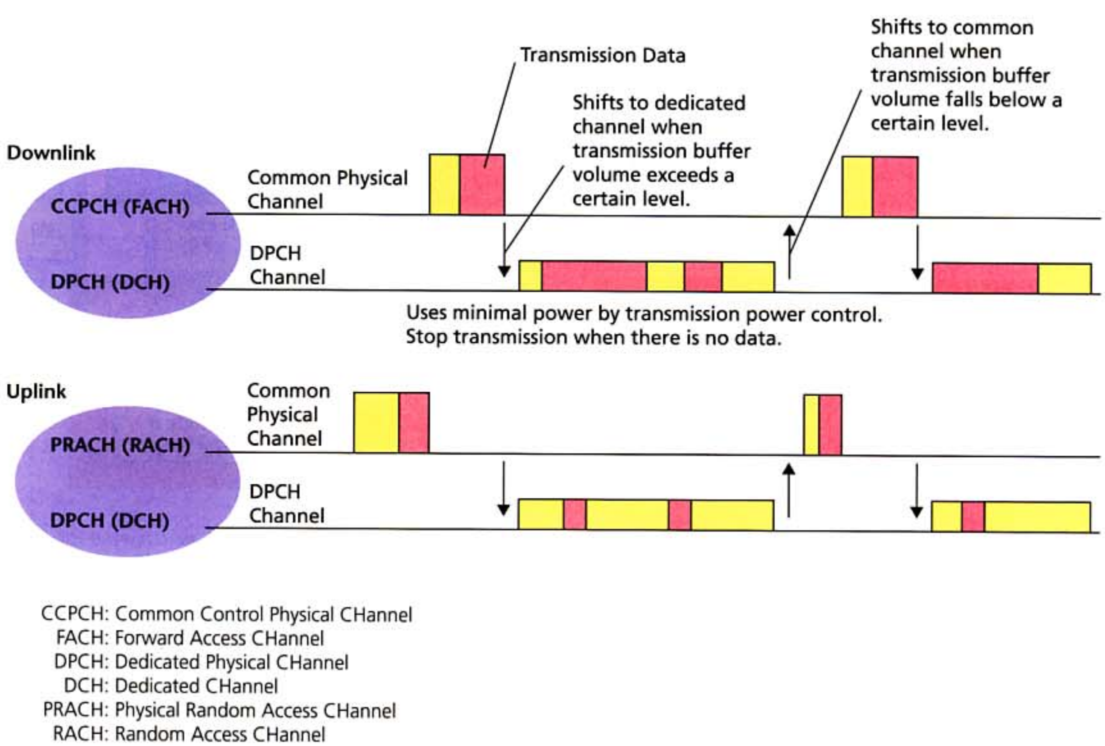


Figure 4 Packet Access System

zero and $\pi/2$. This results makes variable-rate uplink transmissions seamless and nonbursty. It also minimizes the peak factor in the transmission waveform and relaxes the requirements of the transmission amplifier in the mobile terminal. **Figure 3** illustrates how pilot and data multiplexing works.

(4) Orthogonal Variable Spreading Factor (OVSF)

Variable spreading factor is applied to achieve multi-rate. For downlink, orthogonal variable spreading factor is applied. Multi-code may also be used.

(5) Packet Access Method

As the packet transmission constitutes the key to IMT-2000 services, various efforts were made on the transmission technologies. W-CDMA adopts a system that adaptively switches between a common channel and dedicated channels depending on the data traffic, to harness the characteristics of CDMA in packet transmission. **Figure 4** shows the mechanism of packet transmission. When the volume of transmission data is large, it is more efficient to assign a Dedicated Physical Channel (DPCH) and use minimal power by controlling the transmission power. On the other hand, when the volume of data is small and the traffic is limited, it is more efficient to use a common channel than assigning DPCH.

(6) Other Technologies

As with forward error correction, W-CDMA adopts not only convolutional codes but also turbo codes with high error-correcting performance for relatively high-speed transmissions. In addition, various types of technologies including transmission diversity are adopted to increase performance. Dedicated pilots are considered to be able to apply adaptive antenna and other technologies for further improvement.

3.3 Architecture of Radio Access Network

Figure 5 illustrates the system architecture of W-CDMA. The Radio Access Network (RAN) consists of the Radio Network Controller (RNC) and Node B, and is connected via the core network (switching system network) and Iu interface.

Figure 6 shows DoCoMo's W-CDMA system configuration. Although the radio base station is referred to as Node B as a logical node in terms of architecture, it is called the Base Transceiver Station (BTS) in this Figure, as a physical device. Signal-processing functions of the Multimedia signal Processing Equipment (MPE) may be added to RNC as it constitutes some part of RNC in terms of architecture— however, the signal-processing device is depicted as a separate piece of equipment in this Figure. As the signal-processing functions in parts of the core network are also collectively added to MPE, the MPE is connected with the switch. Both the core network and the radio access network adopt the Asynchronous Transfer Mode (ATM) technology, as described in the next chapter.

4. Core Network Technologies

Figure 7 illustrates an architecture model of a code network specified by 3GPP.

The signaling method of 3GPP core network is based on

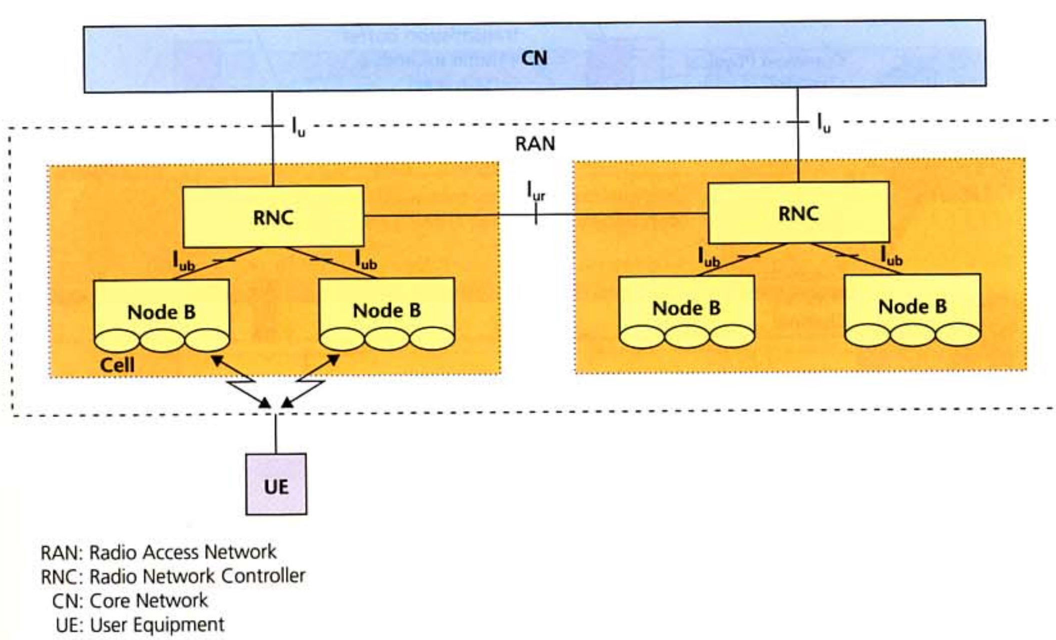
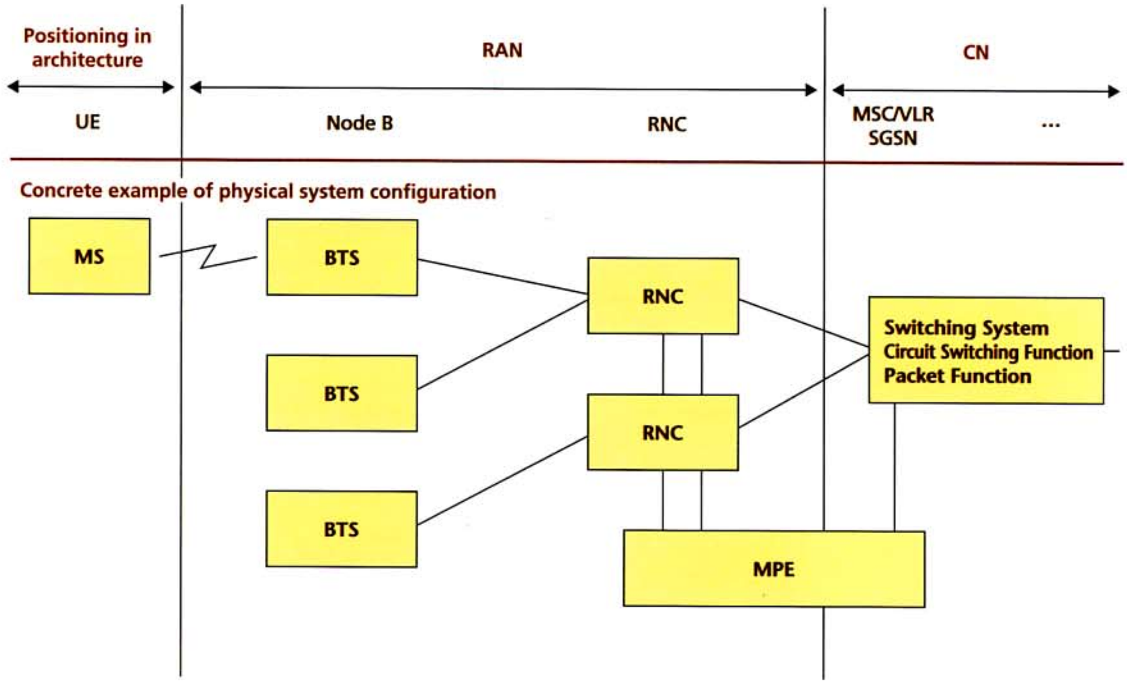
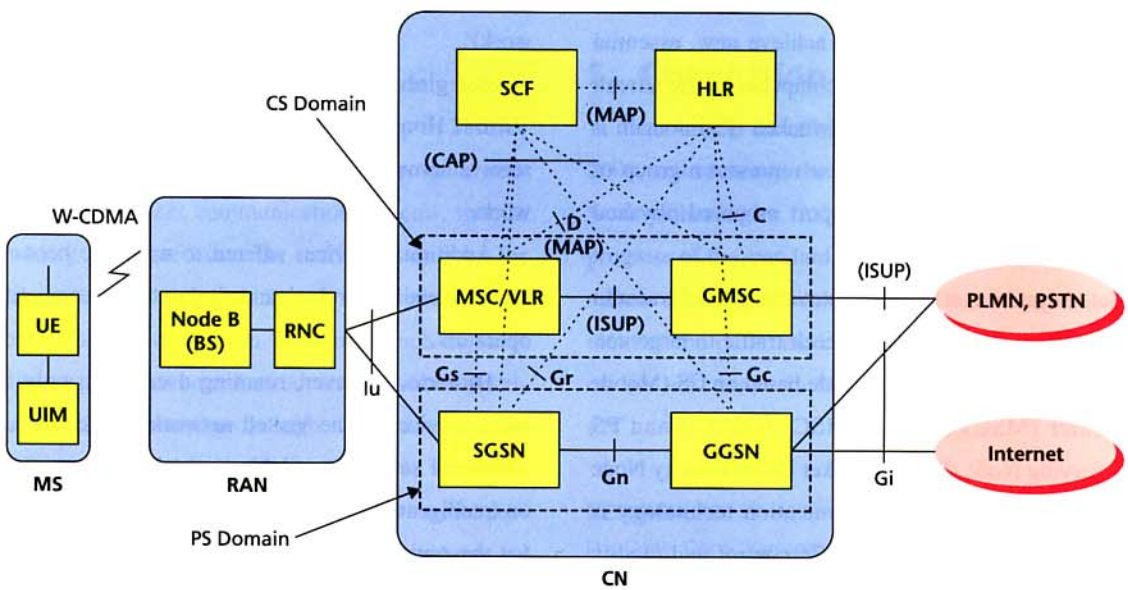


Figure 5 Architecture of Radio Access Network



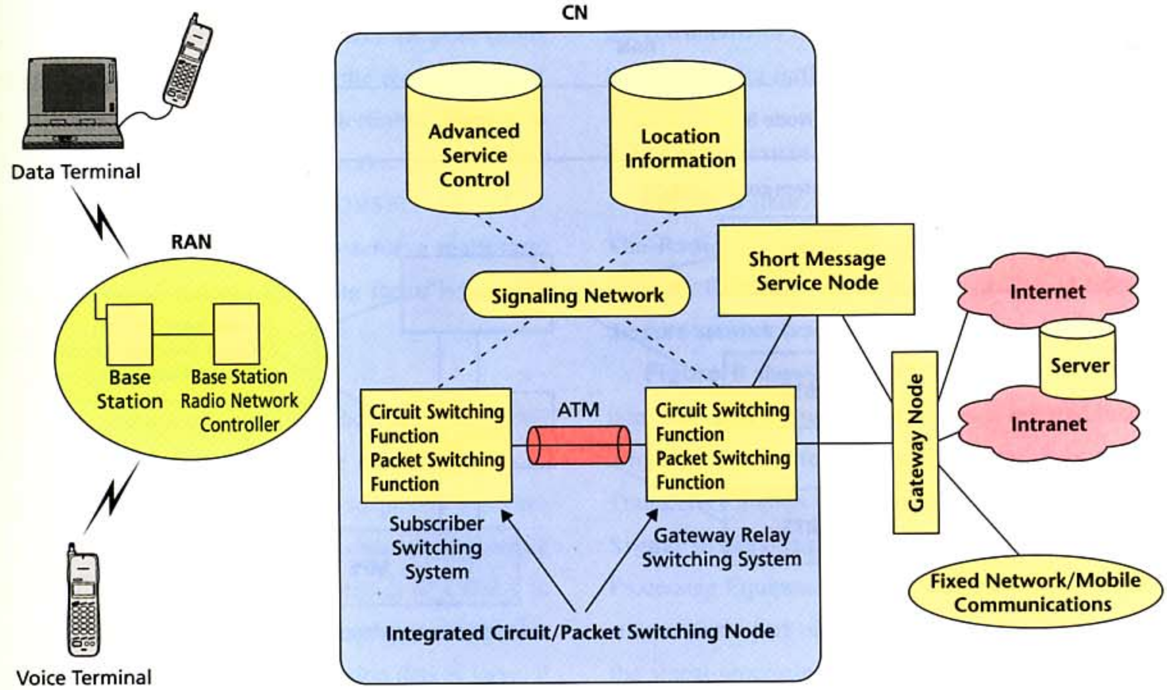
BTS: Base Transceiver Station
CN: Core Network
MPE: Multimedia signal Processing Equipment
MS: Mobile Station
MSC: Mobile Switching Center
RAN: Radio Access Network
RNC: Radio Network Controller
SGSN: Serving GPRS Support Node
UE: User Equipment
VLR: Visitor Location Register
W-CDMA: Wideband Code Division Multiple Access

Figure 6 Radio System Configuration of W-CDMA



BS: Base Station
CN: Core Network
CS: Circuit Switched
GGSN: Gateway GPRS Support Node
GMSC: Gateway MSC
HLR: Home Location Resister
MS: Mobile Station
MSC: Mobile Switching Center
PLMN: Public Land Mobile Network
PS: Packet Switched
PSTN: Public Switched Telephone Network
RAN: Radio Access Network
RNC: Radio Network Controller
SCF: Service Control Function
SGSN: Serving GPRS Support Node
UE: User Equipment
UIM: User Identity Module
VLR: Visitor Location Register

Figure 7 Model of 3GPP Core Network Architecture



RAN: Radio Access Network
CN: Core Network
ATM: Asynchronous Transfer Mode

Figure 8 Example of Physical Node Configuration of Integrated Circuit/Packet Switching Network

GSM/GPRS (General Packet Radio Service), which is widely used in second-generation mobile communication systems worldwide. For IMT-2000, it is enhanced to achieve new, essential functions and capabilities. As network components, the Circuit Switched (CS) domain and the Packet Switched (PS) domain is defined separately from each other. These represent a group of logical function units, which may support mounted physical devices and nodes at discretion.

An integrated system can be build to exchange and transmit various types of media, ranging from speech traffic to large-volume data traffic, by achieving a single node based on CS (Mobile Switching Center (MSC)/Gateway MSC (GMSC)) and PS (Packet Data Serving Node (PDSN)/Packet Data Gateway Node (PDGN)). This is where ATM communication technology is effective, since it enables adequate traffic control and quality control with respect to traffic which requires different types of Quality of Service (QoS). **Figure 8** shows the physical node configuration for an integrated circuit-switching and packet-switching network within the core network.

Three functions are required for the achievement of global services: terminal mobility (the ability to receive services with the same terminal regardless of location); personal mobility (the ability to receive services independent of specific terminals); and global roaming (the ability to use services at the roaming destination in the same service environment as in the home network).

For global services, there is an increasing demand for a Virtual Home Environment (VHE), which enables users to receive network services in the same manner as in the home network.

Additional services offered to users are becoming increasingly diversified and advanced, due to the competition between operators.

Hitherto, however, roaming users have only been offered basic services at the visited network, and could not use many additional services available in the home network. VHE based on Intelligent Network (IN) technology is therefore being studied, for the purpose of eliminating such restrictions and enabling users to access a wide range of additional services available in the home network even when they are in the visited network. **Figure 9** shows the control system for VHE. IN separates service control and service execution into the Service Control Point (SCP) and the Mobile Switching Center (MSC), and implements them accordingly. This mechanism is directly used to execute service control at the MSC in the visited network from the SCP in the home network, to make the home net-

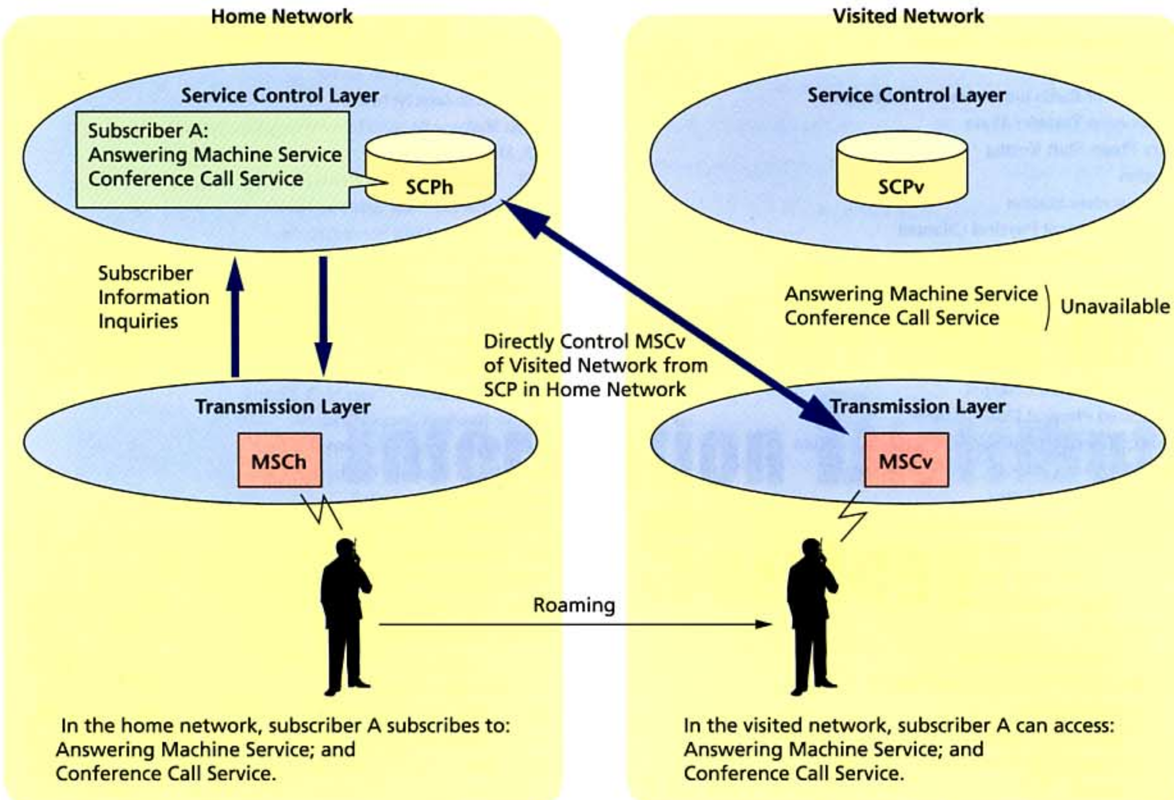


Figure 9 Virtual Home Environment (VHE)

work's services available in the visited network.

In response to demands for high-speed data communications, IMT-2000 will achieve data transfer speed up to 2Mbit/s in mobile networks. As DoCoMo's i-mode represents the second-generation mobile packet communication systems, mobile phones had widely penetrated into the market as devices for Internet access, owing their easy-to-operate features. In IMT-2000, their data storage/notification functions (such as short mail service) are expected to be enhanced, and advanced multimedia services are likely to emerge through connection with the Internet and corporate Local Area Network (LAN). Contents that are likely to be available over the Internet from various service providers in the future including the video telephone by video information communications, music and video distribution, mail with video attachments, chat, Virtual Private Network (VPN) in mobile networks, advanced e-commerce based on mobile terminal authentication, and applications for Intelligent Transport System (ITS). The scope of mobile multimedia services is expected to increase dramatically thereby.

5. Conclusion

This article described the standardization process of IMT-2000, and reviewed the radio access technologies and core network technologies. As further efforts are being made for the progress of the standard, DoCoMo's networks, services and terminals should also evolve. Technologies applied to each equipment of the radio and core network will be explained in detail on the next issue, in "Special Article on IMT-2000 Services (2)".

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[3] 3GPP TS 25.211 V.3.5.0, Dec. 2000.

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[5] 3GPP TS 23.002 V.3.3.

GLOSSARY

3GPP: 3rd Generation Partnership Project
AMR: Adaptive Multi Rate
ARIB: Association of Radio Industries and Businesses
ATM: Asynchronous Transfer Mode
BPSK: Binary Phase Shift Keying
BS: Base Station
BTS: Base Transceiver Station
CCPCH: Common Control Physical CHannel
CDMA: Code Division Multiple Access
CN: Core Network
CS: Circuit Switched
DCH: Dedicated CHannel
DPCCH: Dedicated Physical Control CHannel
DPCH: Dedicated Physical CHannel
DPDCH: Dedicated Physical Data CHannel
ETSI: European Telecommunications Standards Institute
FACH: Forward Access CHannel
FDD: Frequency Division Duplex
FDMA: Frequency Division Multiple Access
FOMA: Freedom Of Mobile multimedia Access
FPLMTS: Future Public Land Mobile Telecommunication Systems
GGSN: Gateway GPRS Support Node
GMSC: Gateway MSC
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LAN: Local Area Network
MPE: Multimedia signal Processing Equipment
MS: Mobile Station
MSC: Mobile Switching Center
PDGN: Packet Data Gateway Node
PDSN: Packet Data Serving Node
PLMN: Public Land Mobile Network
PRACH: Physical Random Access CHannel
PS: Packet Switched
PSTN: Public Switched Telephone Network
QoS: Quality of Service
QPSK: Quadrature Phase Shift Keying
RACH: Random Access CHannel
RAN: Radio Access Network
RNC: Radio Network Controller
SC: Synchronization Code
SCF: Service Control Function
SCP: Service Control Point
SGSN: Serving GPRS Support Node
TDD: Time Division Duplex
TDMA: Time Division Multiple Access
TPC: Transmit Power Control
UE: User Equipment
UIM: User Identity Module
UTRA: Universal Terrestrial Radio Access
VHE: Virtual Home Environment
VLR: Visitor Location Register
VPN: Virtual Private Network
W-CDMA: Wideband Code Division Multiple Access