The 3GPP Proposal for IMT-2000

Prodip Chaudhury, Siemens Information and Communication Networks, Inc.
Werner Mohr, Siemens AG
Seizo Onoe, NTT DoCoMo

ABSTRACT Market expectations for third-generation mobile radio systems (IMT-2000) show an increasing demand for a wide range of services from voice to low, high, and advanced data rate services to support mobile multimedia. This leads to technical requirements for IMT-2000 which are currently being standardized worldwide. Circuit- and packet-oriented services will be supported. These systems will operate in all radio environments to provide service to anyone, anytime, anywhere. The ITU has identified spectrum for the allocation of IMT-2000. However, these frequency bands are currently not available worldwide. In different regions research activities on IMT-2000 have been initiated to support the international consensus building process and standardization activities. Based on these activities system proposals have been submitted to ITU TG 8/1. In particular, the newly formed Third Generation Partnership Projects 3GPP and 3GPP2 have the objective of harmonizing similar proposals and defining detailed standards. Proposals from Europe, Japan, Korea, and the United States are very similar. Recent activities, which were initiated by major international operators, led to a harmonized concept for the CDMA-based radio interface. The evolution and migration of second-generation systems to the third generation takes into account the deployed investment to save today's investment where useful and necessary. This article focuses on market and technical requirements and, in particular, the technical approach of 3GPP based on the big footprint of the GSM system.

Third-generation mobile radio systems — International Mobile Telecommunications in the year 2000 (IMT-2000) — are currently one of the key communication technologies in research, development, and international standardization bodies due to the high market demand for advanced wireless communication. The European version of IMT-2000 is the Universal Mobile Telecommunication System (UMTS).

Second-generation mobile radio systems, which use digital technology in contrast to the first-generation systems, are very successful worldwide in providing service to users. The customer base is increasing much faster than expected. The UMTS Forum expects around 400 million mobile subscribers worldwide in 2000 and nearly 1800 million subscribers in 2010 (Fig. 1) [1]. Especially in Asia, a tremendous growth with a dominant subscriber base is expected in 2010.

These second-generation systems are dominated by Global System for Mobile Communications (GSM), IS-136, IS-95 code-division multiple access (CDMA), and in Japan by Personal Digital Cellular (PDC) and Personal Handyphone System (PHS) technology. GSM is the mobile radio standard with the highest penetration worldwide today. The penetration of analog systems (first generation) is starting to decrease. However, these second-generation systems are limited in maximum data rate. On the other hand, the percentage of mobile multimedia users will increase significantly after 2000. According to the UMTS Forum, in 2010 about 60 percent of the traffic in Europe will be created by mobile multimedia applications [1]. A similar growth of mobile data traffic is expected worldwide, with an expected growth rate per year on the order of 70 percent in the next five years, starting from about 3 million data users in 1998 to about 77 million data users in 2005.

More advanced services than current voice and low-data-rate services are foreseen and will bring together the three worlds according to the three basic categories:

- Computer data with Internet access, e-mail, real-time image transfer, multimedia document transfer, mobile computing
- Telecommunications with mobility, videoconferencing, GSM, and integrated services digital network (ISDN)-like services, video telephony, wideband data services
- Audio/video-content with video on demand, interactive video services, infotainment, electronic newspaper, teleshopping, value-added Internet services, TV, and radio contribution

Future multimedia services will range from low to high user data rates (maximum 2 Mb/s). The transmission of a large presentation of 2 Mbytes would need 8 s with a 2 Mb/s service compared to current data transmission in GSM with 9.6 kb/s, where 28 min is necessary. The GSM Association, an organization of GSM operators, is expecting a high grade of asymmetry between the uplink and downlink for data transmission (e.g., for Internet access) with much higher capacity needed on the downlink (Fig. 2).

Within the third-generation system (IMT-2000) these different service needs are supported in a spectrum-efficient way by a combination of frequency- and time-division duplex (FDD and TDD). The FDD component supports wide area coverage mainly for symmetrical services, whereas TDD is suited especially for asymmetrical services.

Technical Requirements and Radio Environments

These market requirements and service needs result in technical requirements for the ongoing definition of third-generation mobile radio systems (IMT-2000) in America, Asia, and Europe [2, 3]. These systems aim to support a wide range of bearer services from voice and low-rate to high-rate data services with up to at least 144 kb/s in vehicular, 384 kb/s in outdoor-to-indoor, and 2 Mb/s in indoor and picocell environments. Circuit-switched and packet-oriented services for symmetric and asymmetric traffic will be supported.

Third-generation systems will be operated in all radio environments such as urban and suburban areas, hilly and mountainous areas, and microcell, picocell, and indoor environments. These requirements are quite well aligned in America, Asia, Europe, and the ITU. This enables a much wider application range of third-generation systems than of the second generation. In addition, the ability for global roaming has to be supported in the system design.

International Standardization Activities

The international standardization activities for IMT-2000 have been mainly concentrated in the different regions in the European Telecommunications Standards Institute (ETSI) Special

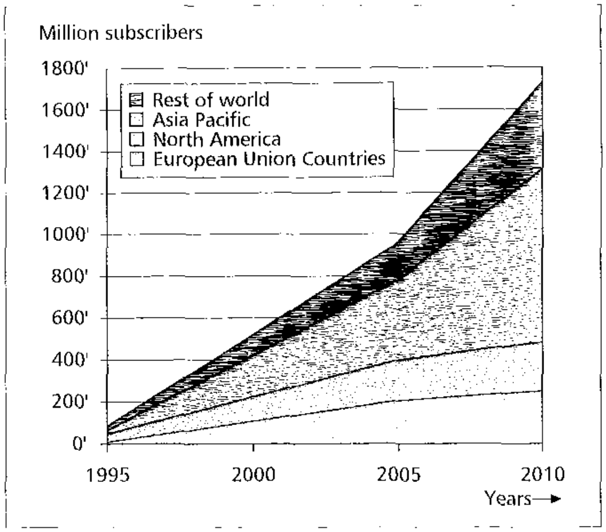

Figure 1. *World mobile subscribers.*

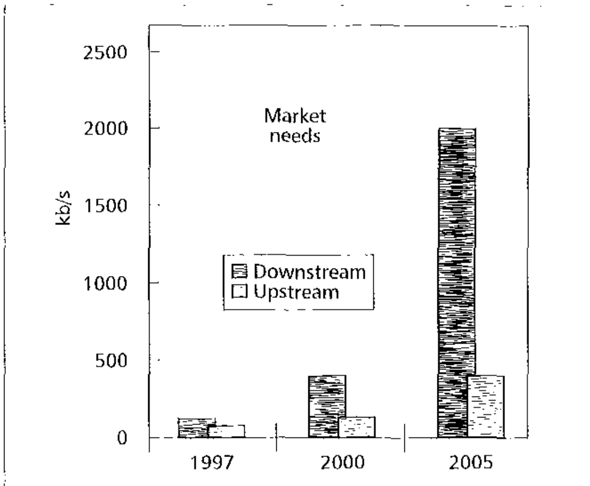

Figure 2. *Asymmetrical data traffic.*

Mobile Group (SMG) in Europe, Research Institute of Telecommunications Transmission (RITT) in China, Association of Radio Industry and Business (ARIB) and Telecommunication Technology Committee (TTC) in Japan, Telecommunications Technologies Association (TTA) in Korea, and Telecommunications Industry Association (TIA) and T1P1 in the United States. The second-generation systems are dominated by GSM, IS-136, IS-95 CDMA, and PDC, which have been taken into account by the related regional bodies in the design of system proposals for backward compatibility (Fig. 3). These systems are connected to the two types of core networks, MAP and ANSI-41, and their evolution to the third generation.

ITU — Radiocommunication Standardization Sector (ITU-R) Task Group (TG) 8/1 called for radio transmission technology (RTT) proposals by June 1998 and for system evaluation by September 1998 [3]. ITU intends to freeze international Recommendations at the end of 1999.

The ETSI process started at the end of 1996 and was subdivided into phases: a grouping, refinement, and synthesis phase and a definition phase. ETSI SMG decided on the basic access scheme in January 1998 to be wideband CDMA (WCDMA) in paired bands (FDD), and for time-division CDMA (TD-CDMA) in unpaired bands (TDD). In addition, the implementation of dual-mode terminals for FDD and TDD should be economically feasible, including the harmonization to GSM. This UMTS Terrestrial Radio Access (UTRA) concept also fits into 2 * 5 MHz spectrum allocation [4]. Parameter harmonization of the FDD and TDD components has been achieved with respect to the implementation of terminals and achieving a worldwide standard. ETSI SMG has submitted the UTRA concept to ITU-R for IMT-2000.

China has presented to ITU-R a TD-SCDMA proposal based on a synchronous TD-CDMA scheme for TDD and wireless local loop (WLL) applications.

The Japanese standardization body ARIB decided on WCDMA. The Japanese and European WCDMA proposals for FDD are aligned. The ARIB WCDMA concept was submitted to ITU-R. ARIB froze the specification in the first half of 1999, so commercial services can begin in 2001.

TTA in Korea has prepared two proposals for ITU-R; one is close to the ARIB WCDMA scheme, and the other is similar to the Telecommunications Industry Association (TIA) cdma2000 approach.

In the United States TIA has prepared several proposals for the third generation with UWC-136 as an evolution of IS-136, cdma2000 as an evolution of IS-95 and a WCDMA system called WIMS. T1P1 is supporting WCDMA-NA, which corresponds to UTRA FDD. WCDMA-NA and WIMS WCDMA have been merged into wideband packet CDMA (WP-CDMA). All these concepts have been submitted to ITU-R.

Details of all proposals for IMT-2000 are available in [5]. The international consensus building and harmonization activities between different regions and bodies are currently ongoing. A harmonization would lead to a quasi world standard, which would allow economical advantages for customers, network operators, and manufacturers. Therefore, two international bodies have been established:

- The Third Generation Partnership Project (3GPP) to harmonize and standardize in detail the similar ETSI, ARIB, TTC, TTA, and T1 WCDMA and related TDD proposals
- 3GPP2 for the cdma2000-based proposals from TIA and TTA

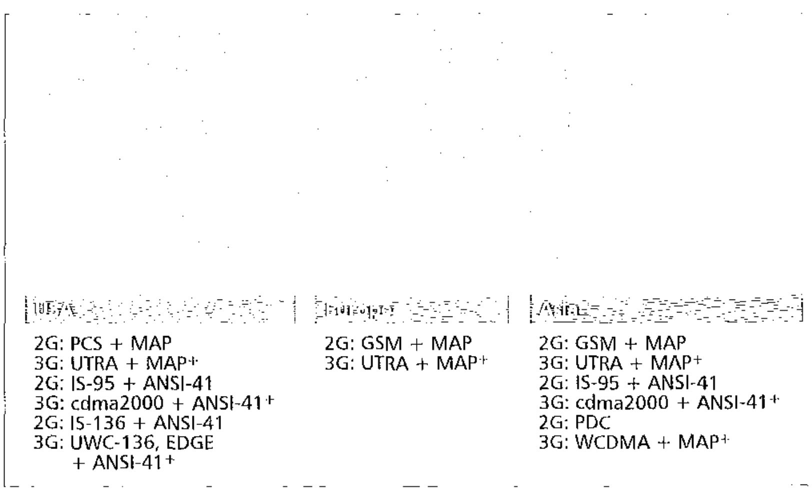

Figure 3. *Second-generation system backward compatibility and third-generation standards in different regions.*

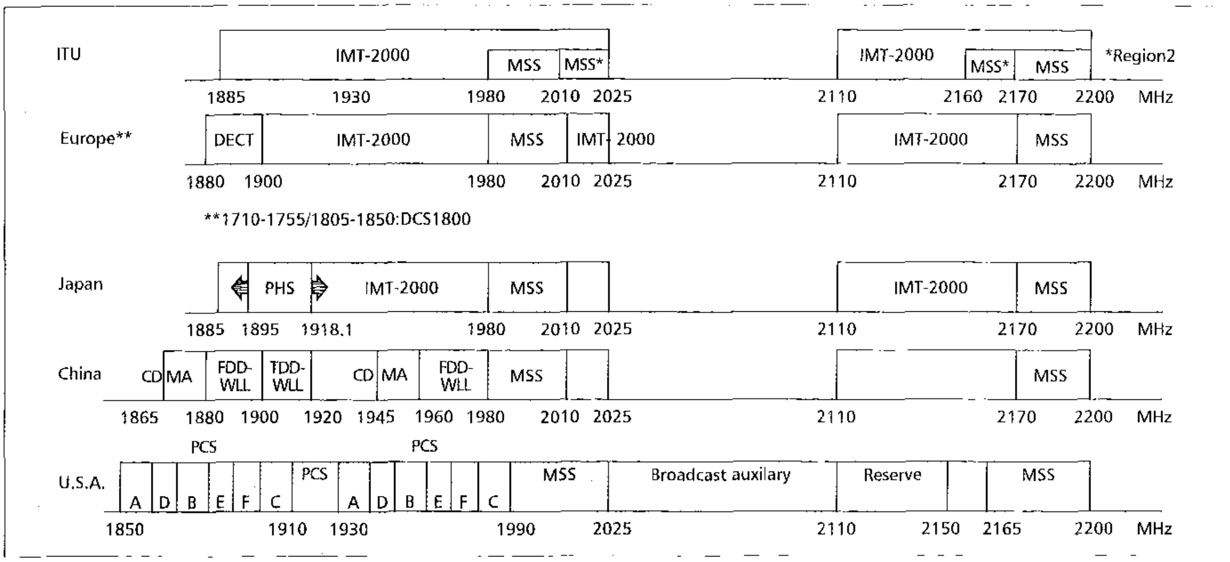

Figure 4. *Worldwide frequency allocation.*

In addition, major international operators initiated a harmonization process between 3GPP and 3GPP2 in the context of the ITU-R process, which will result in a globally harmonized concept (discussed later).

International Frequency Allocation

Available spectrum is a prerequisite for the economical success of a new system. Therefore, World Administrative Radio Conference (WARC) 1992 identified spectrum for third-generation mobile radio systems (Fig. 4).

Europe and Japan have basically followed these recommendations for FDD systems. In the lower band, parts of the spectrum are currently used for Digital Enhanced Cordless Telecommunications (DECT) and PHS, respectively. The FCC in the United States has allocated a significant part of the WARC spectrum in the lower band to second-generation personal communications services (PCS) systems. Most of the American countries are following the FCC frequency allocation. In China big parts of the WARC spectrum are currently allocated to WLL applications. Currently, no common spectrum is available worldwide for third-generation mobile radio systems. Additional spectrum is requested from WARC 2000.

International Research Activities

European Research Activities in the ACTS FRAMES Project

The European Commission has partly funded research activities in the Advanced Communication Technologies and Services (ACTS) framework related to third-generation mobile radio systems to support consensus building and international standardization activities [6]. Preceding framework research programs were Research of Advanced Communication Technology in Europe (RACE) I and II, especially in the ATDMA and CODIT projects to investigate advanced TDMA and CDMA-based radio interfaces. The European Commission has launched a fifth framework program with the theme "Creating a User Friendly Information Society," which is also open to non-European countries.

The ACTS program started in 1995 with about 250 projects in total. More than 25 projects are related to the mobile domain with the areas and projects [7]:

- Enabling technologies: FIRST, SORT, SUCOMS, SUNBEAM, TSUNAMI II
- Services and applications: CAMELEON, MEMO, MICC, MOMENTS, MONTAGE, MOVE, OnTheMove, UMPTIDUMPTI, USECA
- UMTS: Cobuco, Exodus, FRAMES, Momusys, RAINBOW, STORMS
- WLANs, MBS: Awacs, CABSINET, Median, Samba, WAND
- Satellites: Asset, CRABS, Insured, Newtest, Secoms, Sinus, SUMO, Tomas, WISDOM

The Future Radio Wideband Multiple Access System (FRAMES) Project was the only ACTS project dealing with the terrestrial component of the UMTS radio interface. It is a consortium comprising partners from manufacturers, operators, small to medium-sized enterprises (SMEs), and the research community [8]. Its main goal was to develop a radio interface proposal which fulfills the requirements for terrestrial third-generation mobile radio systems. The definition of the original FRAMES Multiple Access (FMA) scheme fulfilled these requirements and took into account the big worldwide footprint of the GSM family with respect to harmonized radio parameters and the GSM core network.

Based on the UMTS requirements, and the activities and decisions in different regions of the world at the beginning of the project, the FMA scheme was developed in 1996. It combined TDMA and CDMA techniques into one harmonized platform to cope with all possible UMTS scenarios and to address possible technical solutions from a global perspective (Fig. 5) [7–9]:

- Mode 1 (FMA 1): wideband TDMA with and without spreading
- Mode 2 (FMA 2): wideband CDMA

The FRAMES Project assumes that UMTS (and partly IMT-2000) will build on an evolved GSM platform with several hundred million subscribers at the time of launch. Under the assumption that UMTS and GSM will operate in parallel for a long time, it is important that dual-mode terminals be easy to build. Therefore, FMA was harmonized with the GSM network in terms of radio parameters and protocol stack as far as possible.

With respect to the status of worldwide standardization activities at the time the FMA concept was defined at the end of 1996 the main goal of harmonization was to meet different system needs of different possible access schemes in different regions and to ensure compatibility with second-generation systems. Unnecessary differences from a technical point of view between TDMA- and CDMA-based schemes are avoided without sacrificing the good aspects of each technology. The harmonized approach between a TDMA and CDMA mode and the GSM family minimizes terminal hardware complexity.

At the beginning of 1998 the FRAMES Project adopted the ETSI consensus decision on the UTRA concept for further investigations. These investigations have been focused in more detail on channel coding and modulation, receiver algorithms, layer 1 aspects, and network aspects for the FDD and TDD components to optimize the selected scheme even further. In addition, the TDD component was developed in the FRAMES project.

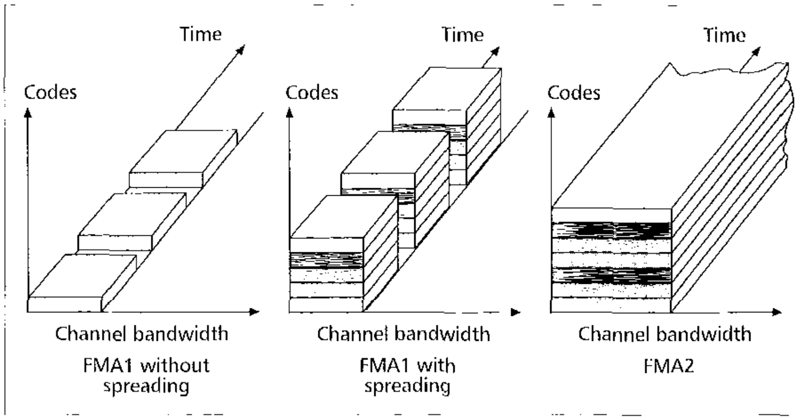

Figure 5. *Basic FMA multiple access schemes.*

The results and proposals of FRAMES have been used successfully as input to the ETSI standardization and evaluation process for the UTRA concept. In addition, FRAMES partners have contributed to the Japanese standardization process in ARIB, to TTA in Korea, and to the TIA in the United States. The ETSI SMG decision on the UTRA concept with the FDD component WCDMA is based on FMA2, and the TDD component TD-CDMA is based on FMA1 with spreading. UWC-136 in the United States is based on FMA1 without spreading for the high-speed component and on EDGE.

Japanese Research Activities

To promote the ongoing activities at the Telecommunications Technology Council of the Ministry of Posts and Telecommunications (MPT), the IMT-2000 Study Committee (then called FPLMTS Study Committee) was established in ARIB, then named Research and Development Center for Radio Systems (RCR) in 1993. Thereafter, standardization activities for third-generation mobile communications systems and studies on its radio transmission technology started on a full-fledged basis. At the same time, the Telecommunication Technology Committee (TTC) of Japan established its UPT/FPLMTS Working Group to perform studies on network-related aspects of the next-generation system.

The IMT-2000 Study Committee formed the Radio Transmission Technology Special Group in 1994 to select and evaluate the radio interface to be proposed to ITU-R from Japan. The group studied a variety of radio access candidate technologies. Initially, there were 20 proposals, including CDMA- and TDMA-based ones. Through simulations and verification experiments using test equipment, the number of candidates was narrowed to three CDMA-based proposals (Core A, Core B, and Core C) and one TDD proposal. For TDMA, the candidates were reduced to two proposals, MTDMA and BDMA. In November 1996 the Radio Transmission Technology Special Group adopted the following conclusion: to merge the three CDMA-based proposals into one, centering on Core A, and combine it with the TDD proposal to treat it as one candidate. Since this CDMA proposal had sufficient backing with experiment data, it was deemed feasible for implementation by the year 2000. Thus, the merged CDMA proposal entered into a detailed study phase, finishing its basic study activities. The group at the same time decided to continue the studies for the two TDMA-based proposals, and judge later whether to perform detailed studies for these proposals or not.

With this decision, the group started its full-fledged studies on WCDMA as the most promising RTT candidate to be submitted from Japan. When the group concluded one year later not to adopt the two TDMA proposals, WCDMA became the sole proposal to be submitted from Japan to ITU-R. The key parameters for the CDMA FDD Core A and TDD proposals, the starting point of the WCDMA studies, are summarized in [10–12].

With the reorganization of the IMT-2000 Study Committee in 1997, several working groups were established to perform detailed studies on WCDMA. Thereafter, the Air Interface Working Group took over the responsibility of conducting studies on WCDMA from the Radio Transmission Technology Special Group. In particular, air interface layer 1, which is closely related to the radio transmission technology, was studied in detail by Sub-Working Group 2 formed under the Air Interface Working Group.

At the same time, ARIB formed a Coordination Group under the Standard Subcommittee with the goal of achieving a global standard. The Coordination Group paid close attention to movements abroad, and carried out various activities for harmonization. Thanks to the proposals from some European members, the harmonization with UTRA was facilitated. The Coordination Group also convened regular meetings with TTA of Korea. Meanwhile, harmonization with the cdma2000 concept was also discussed. For that purpose the Ad Hoc S Group was formed to take care of its technical studies, and the outcome is now reflected in the WCDMA specifications. All these study results were reflected in drafting the final Japanese proposal submitted to ITU-R in June 1998.

In parallel with these standardization activities, individual companies are also involved in their own research activity to support the standardization. A 2 Mb/s transmission field trial was conducted successfully with WCDMA technology. WCDMA system tests are now being conducted using a tentative air interface specification of ARIB WCDMA. These system tests are conducted not only in Japan but also in Asian countries such as Singapore, Malaysia, South Korea, and China.

The 3GPP-Based Technical Proposal for IMT-2000

The Basic UTRA Concept in Europe for 3GPP

The UTRA concept comprises FDD and TDD components to efficiently support the different UMTS service needs for symmetrical and asymmetrical services. During the evaluation process on UTRA in ETSI SMG2, mainly the FDD component was investigated. The original TD-CDMA concept (FMA1 with spreading) has been adapted to TDD, including the harmonization of parameters between FDD and TDD. The current status of the standardization activities and working assumptions are summarized in the ETSI SMG contributions to ITU at the end of June and end of September 1998 [7, 8, 13]. Key parameters of the UTRA concept are presented in Table 1.

THE BASIC CONCEPT IN JAPAN FOR 3GPP

The WCDMA proposal of ARIB also consists of the FDD and TDD components. Due to the harmonization with the WCDMA concept of ETSI SMG2, which was performed even before the ETSI decision in January 1998, the FDD component was already quite similar to the ETSI UTRA concept. TDD, on the other hand, was designed based on the same concept as the FDD component, but adopted some distinctive characteristics such as open-loop power control and transmit diversity technology. After the ETSI SMG decision in January 1998, the access scheme became more adequate to be called TD-CDMA instead of simply WCDMA, because some TDMA components were included to take advantage of the technical merits of TD-CDMA (Table 1). The parameters are quite well aligned between the ETSI SMG and ARIB proposals.

THE NORTH AMERICAN CONCEPT FOR 3GPP

Compared to other regions, in the United States different second-generation mobile radio systems have been deployed, which have different requirements with respect to backward compatibility (Fig. 3). There are two fully established core networks currently being used for second-generation systems in the U.S. market: ANSI-41 and GSM MAP. The ANSI-41 core network is used by AMPS, IS-136, and IS-95 air interface systems. The GSM MAP core network is used by GSM air interface based systems. Both these core networks will evolve into the third generation, and they must interwork.

ANSI-41 specification and standardization work is being done in TIA committee TR-45 (specifically TR45.2), and its evolution to third generation is being carried out in the technical specification groups of 3GPP2. The ANSI-41-based core network will be used by cdma2000-based radio access networks.

GSM specification work is being done in the ETSI SMG committees and harmonized for U.S. requirements in T1P1.5. This relationship has not changed for the third-generation standardization work. GSM evolution to the third generation will be carried out in 3GPP and harmonized to U.S. requirements in T1P1. The GSM MAP-based core network will be used by UTRAN-based radio access networks.

Four RTT proposals were submitted to ITU from the United States in June 1998. They were WCDMA-NA from T1P1, WIMS from TR46.1, UWC-136 from TR45.3, and cdma2000 from TR45.5. Subsequently, WCDMA-NA and WIMS converged to become WP-CDMA to strengthen WCDMA's RTT position in the United States. As a result, WP-CDMA became the fifth RTT proposal submitted to ITU in January 1999. When T1 became a member of 3GPP, T1 submitted proposals to include the packet features of WP-CDMA in 3GPP.

As a parallel effort, 3GPP2 and UWCC are also working to have their third-generation technologies specified by the end of 1999. In turn, there will not be a single third-generation standard for CDMA in the United States.

In addition, established operators and greenfield operators have to be distinguished with respect to the available spectrum for the third generation in the United States. Established operators can currently only use the available PCS spectrum for the deployment of third-generation systems. Therefore, strong requirements for backward compatibility and system deployment in available frequency slots must be taken into account. On the other hand, greenfield operators are more free in the selection of third-generation technology without being concerned with requirements on backward compatibility.

Therefore, the GSM Alliance and UWCC's joint agreement of using EDGE as the common evolution path for GSM and IS-136 TDMA results in speculation that EDGE will be the third-generation standard for GSM/TDMA in the United States mainly for established operators. The logic is as follows:

	UTRA concept in ETSI SMG		WCDMA in ARIB	
	UTRA FDD	UTRA TDD	WCDMA FDD	WCDMA TDD
Multiple access method	WCDMA (DS-CDMA-based)	TD-CDMA	WCDMA (DS-CDMA-based)	TD-CDMA
Carrier chip rate	4.096 Mchips/s	4.096 Mchips/s [1]	4.096 (1.024/8.192/16.384) Mcps	4.096 (1.024/8.192/16.384)Mcps [2]
Pulse shape	Root raised cosine $r = 0.22$	Root raised cosine $r = 0.22$ [1]	Root raised cosine $r = 0.22$	Root raised cosine $r = 0.22$ [2]
Carrier spacing	5 MHz	5 MHz [1]	5 (1.25/10/20) MHz	5 (1.25/10/20) MHz [2]
Frame length	10 ms	10 ms [1]	10 ms	10 ms [2]
No. of power control groups/time slots	16	16 [1]	16	16 [2]
Time slot duration	625 μs	625 μs [1]	625 μs	625 μs [2]
Data modulation (DL/UL)	QPSK	QPSK [1]	QPSK/BPSK	QPSK/QPSK
Spreading modulation (DL/UL)	QPSK	QPSK [1]	QPSK/HPSK	QPSK/QPSK
Spreading factor	Short codes, variable, 4–256	1, 2, 4, 8, and 16 variable spreading	Short codes, variable, 1–512	Short codes, variable, 1–512 [2]
Notes:	[1] Same as UTRA FDD. [2] Same as ARB FDD			

Table 1. *Basic parameters of UTRA FDD and TDD, and of ARIB WCDMA FDD and TDD.*

Both WCDMA and EDGE are basically capable of delivering 384 kb/s data in an outdoor/vehicular environment. However, WCDMA is able to support this data rate with full coverage in the deployment area due its larger carrier bandwidth of 5 MHz with a cluster of 1, whereas EDGE can only support this data rate under good radio conditions with significantly reduced coding overhead and low cochannel interference or using a much bigger cluster size (on the order of 27) than for GSM voice or narrowband data services due to the GSM-compatible carrier bandwidth of 200 kHz. When an operator exchanges GSM voice carrier units for EDGE carrier units by keeping the frequency planning, the EDGE coverage for 384 kb/s is significantly reduced from that of narrowband services.

384 kb/s is currently seen in the United States as adequate for any known multimedia applications for the wireless PCS market. EDGE is not capable of providing 2 Mb/s data rates for indoor environments, in contrast to a true IMT-2000 RTT proposal. Wireless LAN (WLAN), local multipoint distribution system (LMDS), and so on are alternatives for established operators without additional spectrum for third-generation systems to support high-data-rate services in the indoor environment at multimegabit data rates, which are deployed in new and available frequency bands.

There are three reasons to motivate the GSM operators in the United States to support both the WCDMA effort in 3GPP and EDGE standardization in UWCC.

First, activities on third-generation systems did not start in the United States before the ITU-R IMT-2000 Radio Transmission Technology Workshop held in Toronto, Canada, in September 1997. This was largely due to the lack of a high-data-rate market in the United States, and the ongoing deployment of PCS systems for voice and narrowband data traffic. When Japan and Europe foresaw a definite wireless data market need (e.g., for Internet access), the U.S. operators did not expect wireless applications requiring 2 Mb/s data rates. Currently, operators believe that 384 kb/s is sufficient for the foreseeable future in the United States. The TDMA-based EDGE technology is capable of supporting 384 kb/s. It should also be taken into account that most of the data applications have no hard delay requirements, which enables packet transmission. In packet-oriented applications the carrier data rate is shared by different users, which results in throughput dependent on service requirements.

Second, the heavy second-generation infrastructure investment has not depreciated yet. Therefore, their main concern is to meet the voice traffic demand to pay off their investment. Unlike WCDMA, EDGE is a technology which can overlay on top of the existing second-generation mobile radio network to provide up to 384 kb/s data services. This allows them to keep on using their second-generation infrastructure to provide voice and low-data-rate service. As a result, many U.S. operators see WCDMA as a 3G technology ideal for greenfield deployment only. The same approach is true for the other IMT-2000 proposals from the United States.

Last but not least, the lack of IMT-2000 frequency spectrum in the United States causes U.S. operators to consider EDGE as a logical solution to support third-generation services. Without new spectrum for third-generation systems, the 5 MHz carrier of WCDMA for FDD and TD-CDMA for TDD is a stumbling block to the 2 times 5 MHz licenses holders. These operators have to refarm their entire frequency block to deploy a WCDMA carrier.

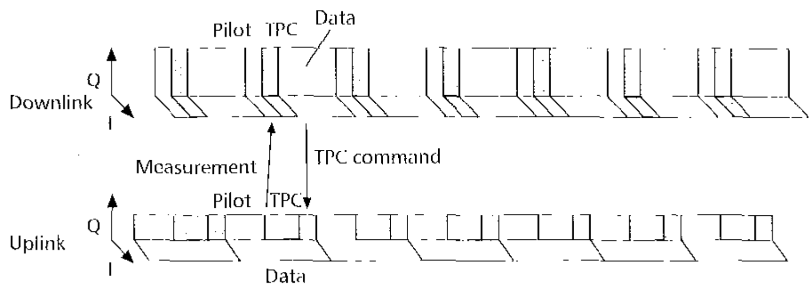

Figure 6. *Downlink and uplink frame structure and multiplexing of the pilot symbol.*

Technical Concepts in 3GPP

The FDD Component — The frame structure in the FDD component is different in uplink and downlink. In the uplink, data (DPDCH — dedicated physical data channel) and control channels (DPCCH — dedicated physical control channel) are I/Q multiplexed, whereas in the downlink data and control channels (DPCH — dedicated physical channel) are time multiplexed (Fig. 6) [7, 8, 13]. For example, in handover measurements the super frame length is defined as 720 ms = 6 * 120 ms as an integer multiple of the corresponding GSM super frame length for backward compatibility. The slots correspond to power control groups.

Due to the time multiplexed pilot symbols on the downlink, the delay from transmitter power control can be minimized. This is advantageous in order to simplify the receiver of the mobile station. The I/Q multiplexed pilot symbols together with data on the uplink enable continuous transmission for variable-rate transmission, which minimizes the peak factor of the transmit waveform. Both pilots and data are spread with different spreading codes. This solution is effective to reduce the impact in an electromagnetic environment and to alleviate the requirements on the mobile station transmit amplifier.

Dedicated pilot symbols for channel estimation and coherent detection are adopted as the transmission method in both links. This scheme is beneficial for fast closed-loop transmitter power control (TPC) on the downlink. It is also possible to apply a common pilot scheme, where the pilot symbols of common control channels are used by each traffic channel. However, the dedicated pilot scheme is an extremely effective solution in terms of securing expandability to adopt, say, adaptive antennas. These pilot symbols are provided with each user signal, and thus in the same antenna beam as the user data.

The FDD component applies a two-layered code structure consisting of spreading codes and scrambling (long) codes. The I/Q multiplexed DPDCH and DPCCH in the uplink are quadrature phase shift keying (QPSK) modulated. Each channel is scrambled with a specific code C_D for DPDCH and C_C for DPCCH, and then scrambled with a mobile station specific code C_{scramb} to distinguish different mobile stations. Each DPDCH is assigned its own channelization code. On the downlink multiple codes are transmitted with possibly different spreading factors for the different DPCHs depending on the service. The data modulation is QPSK. Spreading is performed by channelization codes C_{ch} for each DPCH and a cell specific scrambling code C_{scramb} to distinguish different cells. Each additional downlink DPCH in the case of multicode transmission is modulated in the same way. Orthogonal variable spreading factor (OVSF) codes are employed for the spreading codes, in order to preserve the orthogonality between different rates and spreading factors in both uplink and downlink. The OVSF codes are generated from sets of orthogonal codes (e.g., the Hadamard matrix) using the tree structure of orthogonal codes. Scrambling is carried out after the spreading. In the downlink, the scrambling code is a cell-specific 10 ms (40,960 chips) segment of a Gold code of length $2^{18} - 1$. Details are also described in [7, 8, 13].

Different coding schemes are under investigation depending on the bit error rate (BER) and delay requirements of different services. Convolutional codes with rate 1/3 and 1/2 and constraint length 9 are applied for services with BER requirements on the order of 10^{-3}. For services with higher BER requirements on the order of 10^{-6} and less stringent delay requirements, convolutional coding in concatenation with outer Reed-Solomon (coding rate in the order of 4/5) coding plus outer interleaving is used. Turbo codes are currently under investigation for higher-data-rate and high-quality services. For each service, coding and interleaving is applied; the resulting data stream is rate matched and multiplexed on the carrier.

The FDD component supports both asynchronous and synchronous intercell operations. WCDMA employs an intercell asynchronous network to make the network robust and easy to build, as well as in areas where the Global Positioning System (GPS) signal is not available. In order to realize smooth and quick cell acquisition even in an inter-cell asynchronous cell network, a fast cell search function is required. This function is provided by the specific structure of the perch channel. Fast cell search is realized by using a common spreading code for detecting of slot timing and the scrambling code group identification code, so that the search range of scrambling codes can be narrowed down. The first search code is a 256-chip code, which is transmitted once every slot; it is the same for every base station in the system. The second search codes are transmitted in parallel with the first. Each second search code is chosen from a set of 17 different orthogonal codes of length 256. This sequence indicates to which among the 32 different code groups the base station downlink scrambling code belongs. Search code symbols are spread only with orthogonal Gold codes so that the receiver can easily detect them. With this perch channel structure, the speed of cell acquisition by the mobile station can be significantly accelerated. During the cell search process, the mobile station searches the base station to which it has the lowest path loss. The initial cell search process is carried out in three steps: slot/symbol synchronization, frame synchronization and code-group identification, and scrambling-code identification. With the spreading and scrambling codes designated, the measurement of the received levels of the perch channels in the neighboring cells/sectors can be performed by reading the content of the BCCH.

A logical channel is defined by the type of information transferred. The logical channel structure of WCDMA basically follows ITU-R Recommendation M.1035. The logical channel types are:

- Control channels (CCH) with logical broadcast control channel (L-BCCH), logical paging channel (L-PCH), logical forward access channel (L-FACH), logical random access channel (L-RACH), and dedicated control channel (DCCH)
- Traffic channels (TCH) with dedicated traffic channel (DTCH) and user packet traffic channel (UPCH)

The physical layer offers information transfer services to the medium access control (MAC) and higher layers. The physical layer transport services are described by how and with what characteristics data are transferred over the radio interface. An adequate term for this is the *transport channel*. Transport channels can be generally classified into the two groups:

- Common channels with broadcast control channel (BCCH), paging channel (PCH), forward access channel (FACH), and random access channel (RACH)
- Dedicated channels (DCH)

In the FDD component, a physical channel is defined by code and frequency, and, in the uplink, also by the relative phase (I/Q) for the perch channel, common physical channels, and dedicated physical channels.

UTRA FDD supports intrafrequency handover, interfrequency handover, and intersystem handover. For intrafrequency handover dedicated circuit-switched channels use soft handover, dedicated packet data channels can use soft or hard handover, and the common channels use hard handover. In the case of interfrequency handover, hard handover is applied, where the mobile measurements on other frequencies are performed in slotted mode downlink transmission or with a dual receiver. Intersystem handover is needed between UTRA and at least GSM. This is a hard handover procedure.

TDD Component — The TDD component is based on TD-CDMA, which is a combination of TDMA and CDMA. Each time slot comprises several (maximum 16) orthogonal spreading codes. Different user bit rates are supported by code and/or time slot pooling. In the uplink the variable orthogonal spreading factor is also applied. Up to eight users can share up to 16 spreading codes. Due to the small number of spreading codes per time slot, this approach enables multi-user detection or joint detection with today's technology to mitigate intracell interference [7, 8, 14].

In joint detection several simultaneous received spread signals within one time slot are detected jointly by using zero forcing or minimum mean square error algorithms [14]. Therefore, the requirements on power control accuracy, especially in the uplink, are relaxed. Due to the TDMA component, interference avoidance algorithms by means of dynamic channel allocation (DCA) can be applied for both coordinated and uncoordinated operation. Joint detection is facilitated by a special training sequence for joint channel estimation. In contrast to the FDD component, the uplink midamble signals in the TDD component are time multiplexed as in the downlink. I/Q multiplexed signals for channel estimation would not show advantages in a discontinuous TDD component. In addition, the same structure for uplink and downlink is desirable when direct mobile-to-mobile communication is taken into account. These midambles of different active users in the same time slot are time-shifted versions of one single periodic basic code [7, 8]. Therefore, the joint channel estimation of the channel impulse responses of different users can be achieved by a single cyclic correlator. The different user-specific channel impulse responses are obtained sequentially in time at the correlator output.

The basic frame structure of UTRA TDD is similar to UTRA FDD with a frame length of 10 ms and 16 time slots. These slots are used for an additional TDMA component in the multiple access scheme. Figure 7 shows the frame structure, including the spreading codes within each time slot. The super frame length has been selected as 720 ms = 6 * 120 ms for handover and backward compatibility with GSM.

For downlink signaling (e.g., BCCH, FACH, PCH, SCH, paging), up to two time slots are allocated. They are also applied to power control and handover measurements in the downlink. The common control channel for uplink is the random access channel (RACH). The ratio of asymmetry between downlink and uplink traffic can be selected between DL:UL = 15/1 up to 1/7. Between uplink and downlink several switching points are supported to enable a higher power control update rate than on a frame basis.

For multiplexing and coding, similar schemes as for UTRA FDD are applied; for real-time services forward error correction (FEC), and for non-real-time services a combination of automatic repeat request (ARQ) and FEC are used. Data are QPSK modulated. The data signal is spread by orthogonal spreading codes with length between 1 and 16 and the same modulation scheme as for FDD. Raised cosine pulse shaping is applied in both FDD and TDD.

Due to the same carrier frequency in uplink and downlink, a TDD system requires a *frame synchronized network to control* interference for coordinated operation. The flexibility for asymmetrical switching points and their alignment with adjacent cells depends, in the case of one available carrier per operator, on the distribution of users in the coverage area, the load in the network, and the availability of time slots for DCA to escape from close mobile-to-mobile interference in the time domain. These requirements are significantly relaxed for more carriers due to the additional frequency component.

The channel structure in TDD is similar to FDD. UTRA TDD supports interfrequency hard handover and intersystem handover, at least to GSM. Soft handover is an option.

Evolution and Migration from Second- to Third-Generation Systems

In different regions different second-generation mobile radio systems have been deployed as in Fig. 3, which are the starting points for the evolution and migration to third-generation systems. In the fixed network an evolutionary path is envisaged, whereas in the radio interface a revolutionary approach is needed to support high-rate services. This enables a stepwise introduction of third-generation features from increasing capacity to higher data rates with, for example, GSM2+ services in the core network to wireless multimedia applications.

It is assumed that IMT-2000 will start in islands as business areas, where more capacity and advanced services are needed. Figure 8 shows a possible evolutionary scenario for the introduction of third-generation systems from the GSM and Japanese points of view.

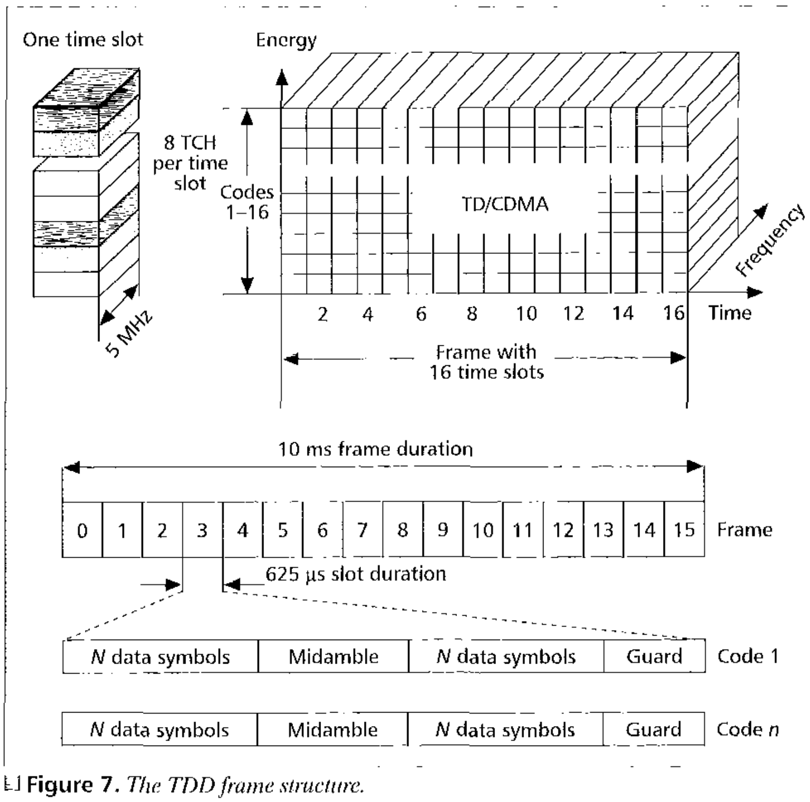

Figure 7. *The TDD frame structure.*

Third-generation mobile radio systems may be connected to public third-generation radio access networks (RANs) as well as private small office/home office (SOHO) networks. To *maintain full coverage for second-generation services, dual-mode* terminals can also be connected to second-generation RANs as GSM. Second-generation RANs are linked in the case of GSM to the related fixed network via the A interface and the mobile switching center (MSC) for circuit-switched services and via the Gb interface, the serving Generic Packet Radio Service (GPRS) support node (SGSN), and the gateway GPRS support node (GGSN) for packet-oriented services. The fixed network can comprise narrowband integrated services digital network (N-ISDN) and/or public switched telephone network (PSTN) and Internet networks. Asynchronous transfer mode (ATM) may be used in the backbone network for transport.

For an evolutionary introduction of IMT-2000 in islands, an evolved GSM core network comprising MSC, home location register (HLR), visitor location register (VLR), SGSN, and GGSN functions together with future-proof innovations from GPRS Phase 2, ATM transport, and enhancements with IP technology is very attractive for current mobile operators to reuse investment. Access to the Internet has to be optimized by broadband backbone networks for high quality of service. The Web will be one key application for third-generation mobile systems.

The mobility management is envisaged to be based on the mobile application part (MAP) by reusing the HLR and VLR databases. The I_u interface between the radio network controller (RNC) and the MSC/SGSN will be completely standardized.

In Japan, the PDC radio access scheme and core networks based on PDC MAP are used for the second-generation system; there are no GSM core networks in place. Therefore, the planned scenario for the implementation of third-generation networks in this environment is to deploy an evolved GSM core network as an overlay to the second-generation network to connect the second- and third-generation systems via an interworking function. In this case, it is also possible to have an integrated network for circuit-switched and packet services, by introducing equipment that takes full advantage of such new technologies as ATM, because new equipment must be deployed in any case (Fig. 8).

With respect to the situation of different deployed second-generation systems in different regions, 3GPP and 3GPP2 are working under the auspices of the Operator Harmonization Group (OHG) to find ways for interworking between the ANSI-41 and GSM MAP systems. At the end of May 1999 an agreement between major international operators and manufacturers was achieved on the harmonization for a Global Third Generation (G3G) CDMA approach [15]. The goal was to harmonize the radio parameters as much as possible, and to enable the connection of the 3GPP and 3GPP2 concepts to an evolved GSM core network as well as to an evolved ANSI-41 core network to ensure terminal mobility and global roaming. The G3G approach includes:

- FDD direct spread (DS), based on WCDMA in 3GPP — called G3G CDMA DS

• FDD multicarrier (MC), based on cdma2000 in 3GPP2 — called G3G CDMA MC
• TDD, based on 3GPP — called G3G CDMA TDD

Concerning inter-base-station synchronization, WCDMA will support either asynchronous or synchronous operation, where cdma2000 only supports synchronous operation. The downlink pilot will be a combination of connection-dedicated pilot signals in time-division multiplexing (TDM) mode based on WCDMA, and a common pilot in code-division multiplexing (CDM) mode based on cdma2000. The chip rate in WCDMA and in the TDD component is reduced to 3.84 Mchips/s, where the chip rate in the MC component remains 3.68 Mchips/s as in the original cdma2000 concept. The reduction in the chip rate in WCDMA simplifies the development of the RF part of multimode terminals (DS and MC FDD, TDD), where the chip rate of the MC component ensures backward compatibility for IS-95 operators. The additional requirement to enable the connection of the G3G radio interface to an evolved GSM MAP and ANSI-41 core network should be ensured by modified protocol stacks in both core networks (Fig. 9). As preparation for the necessary extensions to a given protocol stack, so-called hooks will be introduced in both protocol stacks.

The combination of aligned radio parameters and a combined protocol stack should enable the necessary flexibility for terminal and global roaming to support the needs of international operators and end users. This concept was submitted to ITU-R [15], 3GPP, and 3GPP2. Therefore, the international standardization activities are ongoing based on this concept, and are supported by the community of network operators and manufacturers.

Conclusions

A tremendous growth of mobile subscribers is expected, with nearly 1.8 billion in the year 2010 with a dominant base in Asia. GSM is the mobile radio standard with the highest penetration worldwide. Mobile multimedia will increase after the year 2000 to about 60 percent of traffic in the year 2010. Therefore, third-generation systems have to support a wide range of services from voice to low-data-rate up to high-data-rate circuit-switched and packet-oriented services. In addition, a high grade of asymmetry for data applications is expected. These needs are efficiently supported by a combination of FDD and TDD. They are reflected in the technical requirements of international standardization bodies with respect to the supported data rates and radio environments.

In different regions different second-generation systems are deployed, which are the starting points for the evolution and migration to the third generation. Based on these conditions the regional standardization bodies have prepared technical proposals, which are submitted to ITU-R. These activities have been supported by international research activities. The European Commission has partly funded research projects within the ACTS framework related to third-generation mobile radio systems (IMT-2000/UMTS). One main area of research was the development of a radio interface to provide technology which fulfills the IMT-2000 requirements. The ACTS FRAMES Project has developed a spectrum-efficient UMTS radio interface (FMA). The original FMA concept was based on a harmonized approach (TDMA- and CDMA-based). This proposal was submitted to the ETSI SMG standardization process for UMTS. ETSI SMG has decided on WCDMA in the paired bands and TD-CDMA in the unpaired bands.

The international consensus building process and the detailed specification of standards is facilitated by newly established partnership projects. 3GPP deals with the proposals from Europe (UTRA), Japan (ARIB, TTC), Korea (TTA), and the United States (T1P1); 3GPP2 is working on the cdma2000-based proposals.

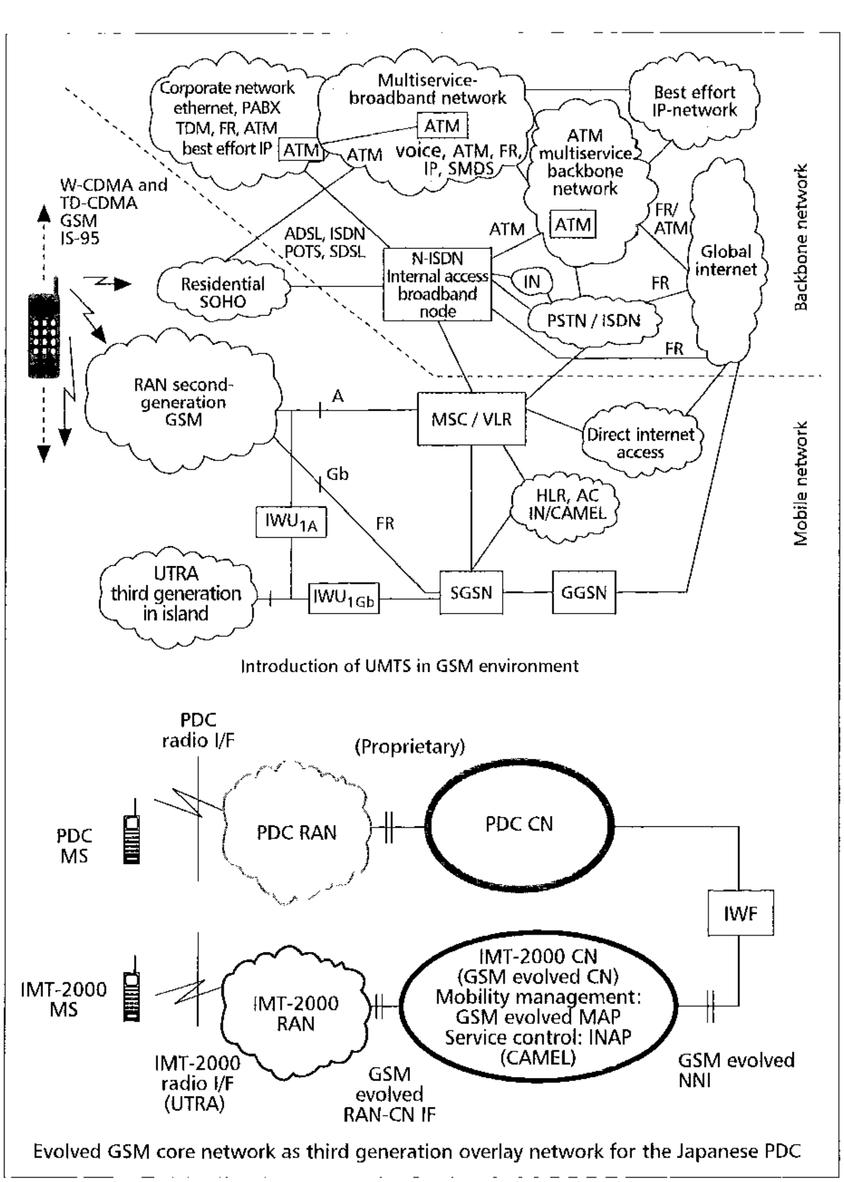

Figure 8. *Introduction of the third-generation mobile radio system with respect to the second-generation environment.*

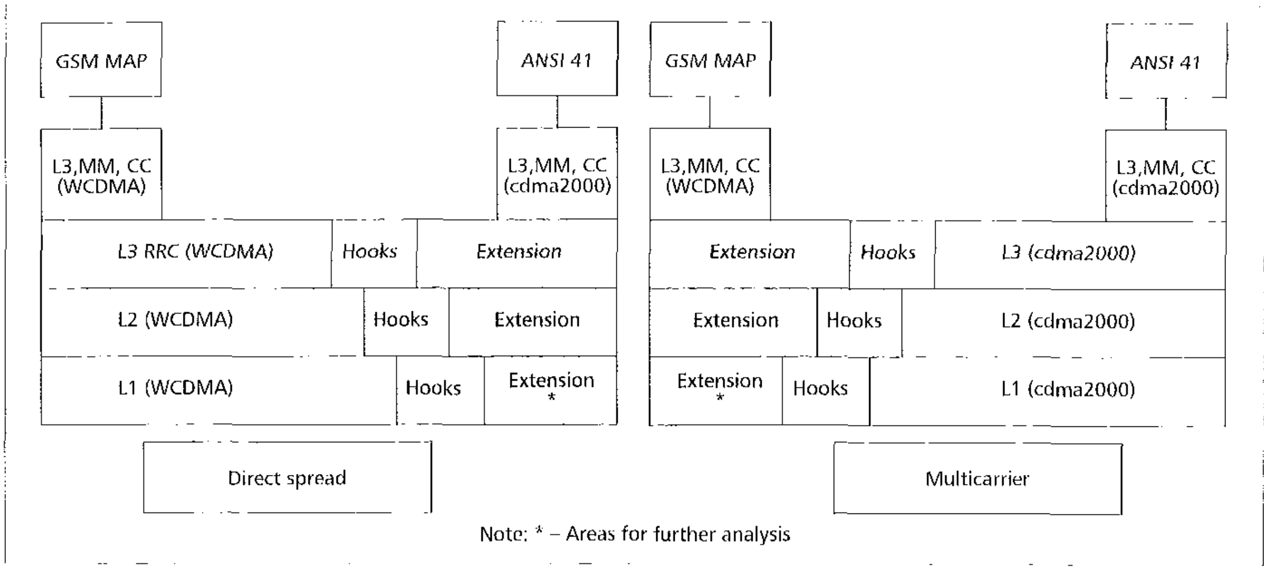

Figure 9. *Protocol structure for implementing the modular concept (source: OHG) [15].*

For economical success sufficient spectrum has to be made available worldwide. The currently ITU-recommended spectrum cannot be used worldwide, which hinders global roaming.

The 3GPP proposal corresponds to a combination of FDD and TDD to support all services and systems needs in a spectrum-efficient way. For the evolution and migration from second generation systems, an evolutionary path in the core network and a revolutionary approach for the radio interface are envisaged. One major evolution path to IMT-2000 is based on the GSM core network with the dominant worldwide subscriber and network base.

The Operators Harmonization Group (OHG) achieved in cooperation with the manufacturer community a harmonized concept for the CDMA-based proposals (G3G) by aligning radio parameters as far as possible, and a combined protocol stack to enable the development of multimode terminals and the connection of this CDMA-based radio interface to evolved GSM MAP and ANSI-41 core networks. This G3G concept should support the needs of international operators and end users for terminal and global roaming. The international standardization activities are ongoing based on this approach.

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Biographies

PRODIP CHAUDHURY, a veteran of Siemens for the past 15 years, is the director of Product Line Management and Systems Engineering in the Wireless Business Unit of Siemens Information and Communication Networks, Inc., Boca Raton, Florida. He graduated from Imperial College of Science and Technology, London University, with a degree in electrical engineering. His experience in the telecommunications industry spans a total of 21 years.

WERNER MOHR [SM] (werner.mohr@icn.siemens.de) graduated from the University of Hannover, Germany, with a Master's degree in electrical engineering in 1981 and a Ph.D. degree in 1987. He is with Siemens AG, Germany, since 1991. He has been responsible for propagation measurements and channel modeling, and involved in the European *RACE-II Project ATDMA*. Since December 1996 he is project manager of the ACTS FRAMES Project. He is vice-president of pre-engineering of Siemens ICN CA. He is member of VDE. In 1990 he received the Award of the ITG in VDE.

SEIZO ONOE (onoe@wsp.yrp.nttdocomo.co.jp) received B.S. and M.S. degrees from Kyoto University in 1980 and 1982, respectively. In 1982 he joined Nippon Telegraph and Telephone Corporation (NTT) Laboratories in Japan. In 1992 he transferred to NTT Mobile Communications Network, Inc. (DoCoMo). In his university days he was engaged in the research of digital data transmission in mobile communications including spread spectrum techniques. Since joining NTT, he has been engaged in the research and development of mobile radio communications systems. His major activities were the research of control signal transmission techniques for the high capacity analog cellular system, design of air interface for digital cellular system (PDC), and development of the base station systems for PDC. He is now responsible for the development of W-CDMA radio access systems for third-generation mobile communications.