Harmonization of Global Third-Generation Mobile Systems

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ABSTRACT

The International Telecommunication Union launched the third-generation project in 1986 with the aim to provide global personal communication using an inexpensive mobile terminal that can truly facilitate communication "anywhere, anytime." In recent years, standardization activities toward IMT-2000 have accelerated toward concrete specifications. By June 1998, a total of 15 proposals from around the world had been submitted to the ITU as radio transmission technology candidates. Since then, the 3G standardization landscape has seen many changes — a steady progression of the convergence process. This article provides a comprehensive overview of the worldwide harmonization efforts on the standardization of third-generation terrestrial mobile communication systems. The status, as of October 1999 when this article was written, of the technical specifications within 3G partnership projects are also summarized.

INTRODUCTION

The standardization of third-generation (3G) mobile systems is accelerating at a fast pace due to the proliferation of high-speed wireless multimedia communications and mobile Internet services. Testimony to this is the tight schedule of the International Mobile Telecommunications in 2000 (IMT-2000) standardization within the International Telecommunication Union (ITU) and the intensive pre-ITU activities undertaken by various regional standardization organizations [1]. This global 3G standard is expected to play an important role in the multimedia society of the next millennium and reshape the worldwide telecommunications infrastructure.

The aim of IMT-2000 standardization is to produce a truly global standard for 3G mobile systems with four key objectives:

- Achieve significantly higher transmission speed capability encompassing circuit- and packet-switched networks as well as support of multimedia services
- Higher spectral efficiency and overall cost improvement by utilizing advanced technologies
- Maximizing the commonality of radio interfaces for multiple operating environments
- Compatibility of services within IMT-2000 and fixed networks

In response to the request by the ITU — Radiocommunication Standardization Sector (ITU-R) for submission of candidate radio transmission technologies (RTTs) for IMT-2000, a total of 15 proposals were received by the June 1998 closing date. An additional RTT proposal intended for satellite communications (INX by Iridium) was received by September 1998. Of the 10 RTT candidates put forth for terrestrial mobile systems, eight were based on direct-sequence code-division multiple access (CDMA) digital technology. Detailed specifications of these proposals can be found in [2, 3].

Given that most of the candidate RTTs for terrestrial systems are based on CDMA technology but with a number of different choices in key parameters and technical details, it is imperative to carry out harmonization activities in order to either achieve a single converged global 3G standard or maximize the commonality between specifications of different RTT proposals. This will also translate into reduced development and operational costs. As such, a merged/updated wideband packet CDMA (WP-CDMA) proposal was submitted to the ITU-R in January 1999 by the United States Telecommunications Industry Association (TIA) TR46.1 and T1P1.5 groups. This updated proposal constitutes a merger of the existing W-CDMA/NA and WIMS W-CDMA RTT proposals. Besides, the harmonization process is inevitable due to the 2G legacy, to minimize the 3G investment risks for the mobile operators by seamlessly evolving the existing pre-IMT-2000 networks toward 3G service capabilities. This task is crucial to ensure that the 3G systems will work well with all existing major mobile networks, particularly the core networks of the 2G systems (i.e., GSM-MAP and ANSI-41), for the benefit of operators and customers worldwide.

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Drivers of Harmonization

Technical harmonization activities are driven by three main aspects: operator, manufacturer, and subscriber requirements. The general consensus is that convergence of the current RTT proposals into a common global standard will directly translate into benefits for consumers, operators, and manufacturers.

Operator Requirements

Perhaps the most important consideration for a harmonized proposal from the service provider viewpoint is to minimize their 3G investment risk by ensuring a smooth and compatible evolution path from existing infrastructure. It is very unlikely over the next five years that operators will abandon their current infrastructure and replace it with new incompatible systems. Thus, seamless internetworking between the 3G core network with the two well established core networks (ANSI-41 and GSM-MAP) is essential. Besides, it should be recognized that these two major core network architectures will evolve toward a common 3G core network. Additionally, a harmonized global 3G specification should minimize the possible frequency conflicts (e.g., accommodate regional needs for different spectrum allocations), increase the competition in the supplier base (thereby reducing cost), and refocus competition to service-based rather than technology-based differentiation.

Manufacturer Requirements

From the manufacturers' viewpoint, the convergence of a global standard is attractive because it eliminates costly duplication of R&D efforts associated with multiple standards and also reduces the development cost. Furthermore, a common global standard circumvents the potential intellectual proprietary rights (IPR) conflicts. In a harmonized standard, it can be expected that there would be free flow of IPR to allow innovations and greater consumer choice. Harmonization activities can generally speed up the completion of the 3G standardization process, which may be critical to meet the commercialization plans of all countries around the world.

Subscriber/Customer Requirements

From the subscriber standpoint, the general consensus is that a harmonized standard will maximize the customers' ability to roam with their services across regions, countries, and systems, and also minimize the 3G costs for the mobile industry (both devices and services) due to scale of economy and increased market competition.

Although the ITU[1] initially aimed to achieve a single set of technical specifications for each radio access, recent developments may have prompted the ITU to endorse the "family of modes" concept instead. The current mandate is to produce a common global standard with multiple operational modes as early as possible to meet market requirements and to safeguard interoperability between all major core networks irrespective of access technique. In fact, the global IMT-2000 standard was expected to be finalized by the end of 1999 [3]. In the remaining parts of this article, we first review the differences in the key specifications of CDMA-based RTTs (which may hamper the progress on the convergence into a global 3G standard) and then describe the role of the Operators' Harmonization Group (OHG) and 3G Partnership Projects (3GPPs) in harmonizing these RTT candidates. Detailed descriptions of the convergence trends of various proposals to common specifications within 3GPP and 3GPP2, and their current status are also provided.

Major Differences between CDMA-Based RTT Candidates

In [2], the similarities and differences of all the CDMA-based RTT proposals were presented. In general, the cdma2000 and CDMA I proposals are quite similar in terms of the key parameter specifications; similarly, W-CDMA, UTRA, W-CDMA/NA, WIMS W-CDMA, and CDMA II can be grouped together. The distinction between these two groups mainly lies in the selection of chip rate, synchronous/asynchronous base station (BS) operation, and pilot structure (TDM/CDM, common/dedicated). These differences and IPR-related issues are among the issues that need to be resolved in order to achieve a converged/harmonized 3G standard.

Chip Rate Selection — cdma2000 advocates the use a chip rate of multiples of 1.2288 Mchips/s to ensure greater compatibility with existing cdmaOne systems. Thus, a chip rate of 3.6864 Mchips/s has been specified for the wideband carrier. On the contrary, W-CDMA, UTRA, WIMS W-CDMA, W-CDMA/NA, and CDMA II use a chip rate of 4.096 Mchips/s. Obviously, higher capacity may be attained using a higher chipping rate due to the increased protection level with spreading. However, there have been some contradicting viewpoints on the 3G white paper issued by the CDMA Development Group (CDG) on the out-of-band emission issue for the higher-value chip rate.

The Pilot Structure for the Data Channel — There is a contention whether to use dedicated time-division multiplexed (TDM) or code-division multiplexed (CDM) pilots on the downlink. CDM pilots yield slightly better performance and provide greater flexibility when used in conjunction with beamforming techniques. Although a TDM pilot structure is attractive due to its simplicity of mobile receiver processing, it may result in exhaustion of forward link codes to support various services.

Synchronous/Asynchronous Base Station Operation — The intercell synchronous mode has been suggested for cdma2000, CDMA I, and TD-SCDMA. This operation mode is currently used in the IS-95 standard, and the common timestamps are obtained using the global positioning system (GPS). Alternative methods of synchronization are also currently being

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[1] The ITU has adopted a top-down systems approach to the overall standardization of IMT-2000, with the aim of defining a "family of radio interfaces" suitable for a wide range of radio operating environments. This flexible approach aims to maximize commonality within the radio "family." Hence, the key to standardization of IMT-2000 RTT is the selection of a "family of radio interfaces" which lend themselves well to software adaptation techniques.

The European Telecommunication Standards Institute initiated the concept of a third-generation partnership project at the beginning of 1998 to encourage the development of a joint technical committee at the international level.

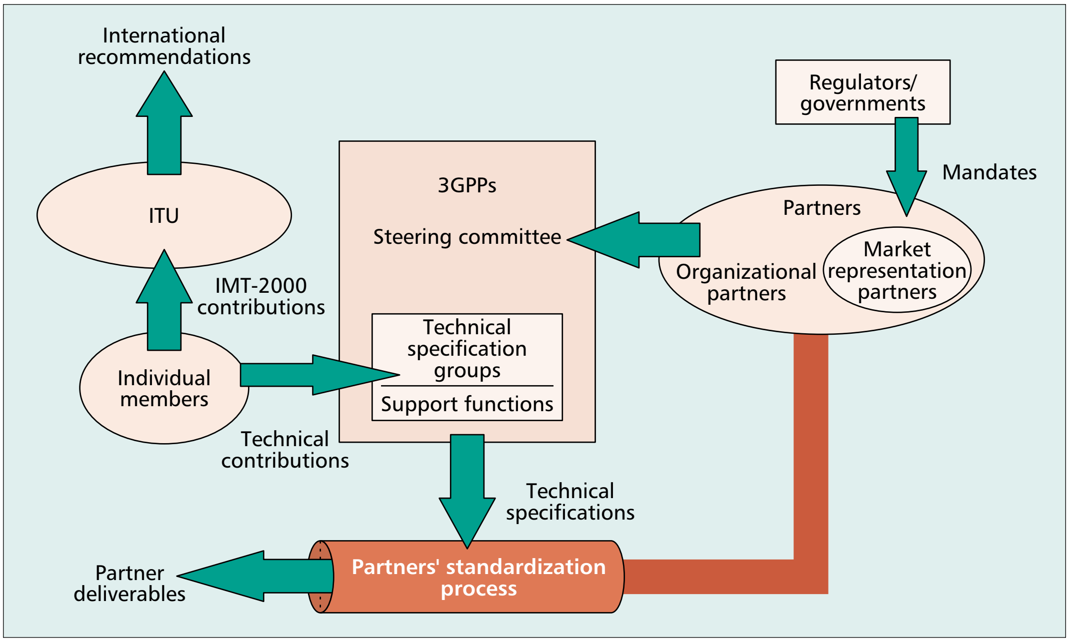

Figure 1. *The standardization process of the 3G partnership projects.*

investigated to remove any GPS-related issues. On the other hand, the intercell asynchronous mode[2] suggested in W-CDMA, UTRA, W-CDMA/NA, WIMS W-CDMA, and CDMA II for the frequency-division duplex (FDD) mode (paired bandwidth) allows easier system deployment, particularly in indoor environments because no external timing source is required. However, this is achieved at the expense of increased cell search time (i.e., time spent before finding the best site to access) and slightly poorer performance with respect to synchronous operation [4].

Choice of Frame Length — All the RTT candidates based on CDMA, except for cdma2000, suggested using a 10 ms frame length for FDD mode. The obvious advantage of a shorter frame length is that it reduces end-to-end delay in the system. On the other hand, a frame length of 20 ms is more efficient in terms of overhead, which translates into higher throughput at the expense of a slight degradation in latency performance.

In addition to achieving agreement (or compromise) on the above specifications, seamless internetworking between the existing 2G core networks (GSM-MAP and ANSI-41) without resorting to switch-external "hardware and software box" implementations is crucial for convergence toward a truly global standard, which is in line with the "IMT-2000 Family of Systems" concept.

3G Harmonization Activities

Since July 1998, there have been a number of debates concerning the possibility of harmonizing the existing CDMA RTT candidates for 3G systems. While this notion is supported by the majority of operators and manufacturers worldwide, opinions vary as to how to achieve this goal. Harmonization has been further complicated by IPR disputes between proponents of alternative CDMA schemes. The main debate centers around the transition from 2G to 3G systems. Failure to agree on a common specification has led to the establishment of partnership projects, and operators started playing a more proactive role to merge the disparate groups in order to achieve convergence on the 3G standard.

3G Partnership Projects

3GPP — The European Telecommunication Standards Institute (ETSI) initiated the concept of a third-generation partnership project at the beginning of 1998 to encourage the development of a joint technical committee at the international level which would handle pre-ITU and interregional specification work for IMT-2000 RTTs and related network specifications.

In December 1998 five standards development organizations[3] — ARIB (Japan), ETSI (Europe), T1 (USA), TTA (Korea), and TTC (Japan) — launched the Third Generation Partnership Project (3GPP). The project (also known as 3GPP1) was spearheaded by ETSI. The purpose of 3GPP is to prepare, approve, and maintain globally applicable technical specifications and technical reports for a 3G mobile system based on the evolved Global System for Mobile Communications (GSM) core network and Universal Terrestrial Radio Access (UTRA), to be transposed by relevant standardization bodies (organizational partners) into appropriate deliverables (e.g., standards).

Participation in 3GPP is classified into two categories: partners (organizational partners and market representation partners) and individual members (Fig. 1). 3GPP consists of a project coordination group (PCG), which is responsible for the overall timeframe and management of technical work, and four technical specification groups (TSGs): Core Network (TSG-CN), Radio Access Network (TSG-RAN),

[2] *Synchronous operation is adopted for time-division duplex (TDD) mode (unpaired bandwidth).*

[3] *The Chinese Wireless Telecommunication Standards (CWTS) group formally joined 3GPP2 and 3GPP as an organizational partner in May 1999.*

Service and System Aspects (TSG-SA), and Terminal (TSG-T).

TSG-SA is responsible for the definition, evolution, and maintenance of the overall architecture, including the assignment of functions to particular subsystems (e.g., UTRAN, CN, terminal, SIM) and identification of key information flows, development of a framework for services, service capabilities, service architecture, charging and consideration of need for default services and/or applications, and definition of a security framework and review of security aspects of the overall system. In addition, it also has responsibility for cross-TSG coordination. TSG-CN specifies the core network part. Its work areas include user equipment/core network layer 3 radio protocols (call control, session management, mobility management), core network internal interfaces for call-associated and non-call-associated signaling, and interconnection of the core network with external networks. TSG-RAN takes care of radio access layer issues. These issues include radio layers 1 and 2 specification, radio layer 3 radio resource specification, Iub, Iur, and Iu interface, UTRAN operations and maintenance (O&M) requirements, transport of implementation-specific O&M between the management system and node B, conformance testing of all aspects of the base station, and specifications for radio performance and RF system aspects. TSG-T is responsible for the terminal equipment interfaces. More specifically, its work areas cover service capability protocols, messaging, services end-to-end interworking, the UMTS subscriber interface module (USIM) to mobile terminal interface, the model/framework for terminal interface and services execution, and conformance test of terminals (including radio aspects).

3GPP2 — Parallel to the 3GPP initiative, the American National Standards Institute (ANSI) spearheaded the creation of 3GPP2 after ETSI declined to expand its proposal to include other "non-GSM" technologies so that the 3G partnership project could accommodate all industry participants. In January 1999, four standards development organizations — ARIB, TIA (USA), TTA, and TTC — agreed to cooperate in the preparation of globally applicable technical specifications for a 3G mobile system based on the evolved ANSI/TIA/EIA-41 core networks and cdma2000 RTT.

Similar to the 3GPP operating structure, 3GPP2 consists of a steering committee and six TSGs. The assigned technical areas of these groups are the 3G core network evolved from ANSI-41, cdma2000, wireless packet data networking, A-interface, services and systems aspects, and an interface for 3GPP radio access technology to the 3G core network evolved from ANSI-41, respectively. TSG-N is responsible for core-network-related issues. These issues include evolution of the core network from intersystem operation within ANSI-41 family members, UIM support, support for enhanced privacy, authentication, encryption, and other security aspects, support for new supplemental services (including ISDN interworking), virtual home environment (VHE), an optimal interoperability specification for international roaming, new features for international roaming (global emergency number, optimal routing), and IMT-2000 issues necessary to ensure support of the ANSI-41 family. The work areas covered by TSG-C are radio layer 1–3 specification, mobile station (MS)/BS radio performance specification, radio link protocol, support for enhanced privacy, authentication and encryption, digital speech codecs, video codec adoption, data and other ancillary services support, conformance test, and MS-adapter interface. TSG-P mainly works on wireless IP services (including IP mobility management), wireless IP network architecture design, voice over IP, secure private network access, Internet access, packet data accounting, multimedia support, and QoS support. A-interface-related issues are specified by TSG-A, including physical links, transports and signaling, support for access network mobility, 3G capabilities (e.g., high-speed data support), Abis interface, interoperability specification, and support for 3GPP2 radio access technologies. The Service and System Aspects TSG (TSG-S) addresses areas of work including system capability set development, stage 1 feature and service requirements definition, system reference model development and maintenance, requirements for international roaming, and definition of state 1 high-level requirements for operation, administration, management, and provisioning (OAM&P) across all TSGs. The interworking function specification for the interface of 3GPP radio access technology to ANSI-41 core network is assigned to TSG-R.

Relationships between the 3GPPs and ITU — It is expected that the 3GPP and 3GPP2 results will be transposed into relevant standards by the organizational partners. The 3GPP and 3GPP2 work will also form the basis of ITU members' contributions in accordance with the existing procedures and will support interworking between IMT-2000 family members. These efforts will accelerate the IMT-2000 standardization activities.

Additionally, it is recognized that related work spanning the two families (GSM/MAP and ANSI/TIA/EIA-41) is being undertaken outside of the partnership projects. Although not under a single organizational structure, the 3GPP and 3GPP2 efforts have agreed to cooperate in the development and support of the technical objectives for harmonization and consolidation of similar wideband CDMA air interface specifications (as prestandardization work to feed into ITU-R SG8 TG 8/1), and network-to-network interface specifications for 3G mobile systems. These two efforts have similar operating procedures, so future convergence of work activities is facilitated.

THE OPERATORS' HARMONIZATION GROUP

To prevent a multiple standard problem, mobile communications operators from around the world took an increasingly active role in the standardization of 3G systems after the Harmonization Forum in October 1998 in Beijing. In November, an operator group known as the Operators' Harmonization Group (OHG)[4] was

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[4] The OHG started with 10 operators from Europe, Asia, and North America, and now comprises 35 operators and 12 manufacturers.

The OHG initiative received immediate and extensive support from all major user equipment and base station manufacturers. In June 1999, the ITU endorsed the harmonization efforts made by the OHG for the CDMA component of the IMT-2000 standard.

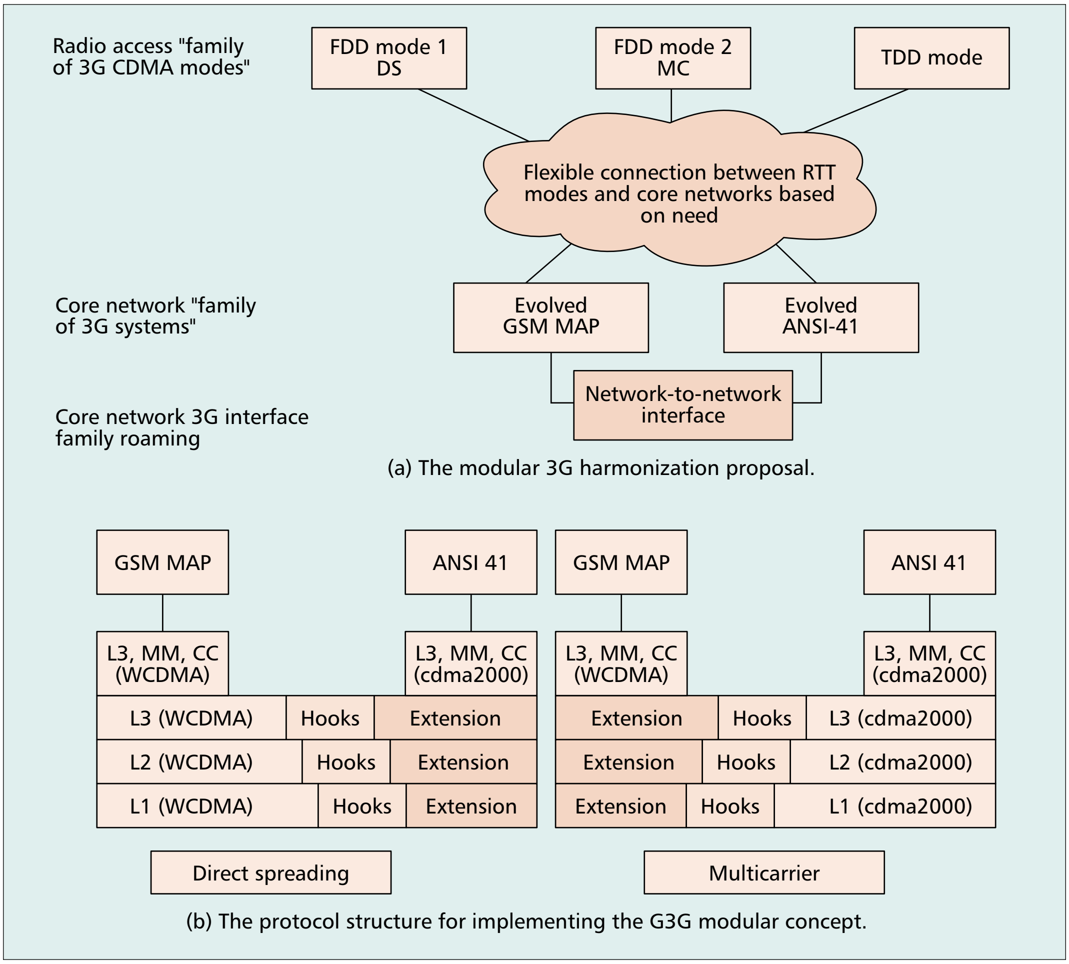


Figure 2. *The modular concept and protocol structure for G3G harmonization.*

set up primarily to harmonize various CDMA proposals for ITU IMT-2000 systems. Over the following months, a series of meetings were held by the OHG to define what operators need for 3G systems and to determine how the various CDMA proposals can be harmonized. The majority of operators expressed their strong interest in a harmonized global 3G CDMA standard consisting of three modes: direct spread (DS), multicarrier (MC), and time-division duplex (TDD). In late May 1999, the OHG agreed on a harmonized Global 3G (G3G) CDMA technical framework at its fifth meeting in Toronto. This is a formal attempt to merge the 3GPP and 3GPP2 proposals. In the harmonized G3G specifications of the OHG, a modular structure[5] was proposed for G3G harmonization, as shown in Fig. 2a, and the following key parameters have been defined:

- The harmonized standard for the DS mode will be based on the W-CDMA proposal with a chip rate of 3.84 Mchips/s.
- The harmonized standard for the MC mode will be based on the cdma2000 proposal which a chip rate of 3.686 Mchips/s.
- The parameters for the harmonized standard for the TDD mode have not been considered in detail with the exception of a recommendation of 3.84 Mchips/s as the chip rate.

The modular structure allows 3G operators to select one or more radio access modules together with one or more core network modules to implement a G3G system subject to the regulatory requirements of their nation or region as well as their market and business needs. In order to implement the modular concept, the OHG has recommended a protocol structure (as shown in Fig. 2b) to satisfy the following harmonization requirements:

- ANSI-41 and GSM MAP-based services should be fully supported in the radio access network associated with all three 3G CDMA modes.
- It should support functionality-based synchronous operation such as location calculation.
- It should support seamless handoff between the harmonized DS and MC, including IS-95 for ANSI-41 and the equivalent for UMTS/GSM.
- It should minimize the complexity of dual-mode and multiband terminals and equipment.

CURRENT STATUS

The OHG initiative received immediate and extensive support from all major user equipment and base station manufacturers. In June 1999 the ITU endorsed the harmonization efforts of the OHG for the CDMA component of the IMT-

[5] *Later, the ITU-R Task Group 8/1 meeting in Helsinki (October 25–November 5, 1999) approved a modular structure for IMT-2000 consisting of a set of five terrestrial and satellite radio interface specifications (IMT-DS, IMT-MC, IMT-TC, IMT-SC, IMT-FT).*

Parameters	3GPP2 (cdma2000)	3GPP (W-CDMA)
Multiple access technique and duplexing scheme	Multiple access: DS-CDMA (UL); MC-CDMA(DL) Duplexing: FDD	Multiple access: DS-CDMA Duplexing: FDD
Chip rate	N x 1.2288 Mchip/s (N = 1, 3, 6, 9, 12)	3.84 Mchips/s
Pilot structure	Code-divided continuous dedicated pilot (UL) Code-divided continuous common pilot (DL) Code-divided continuous common or dedicated auxiliary pilot (DL)	Dedicated pilots (UL) Common and/or dedicated pilots (DL)
Frame length	5, 10, 20, 40, 80 ms	10 ms with 15 slots
Modulation and detection	Data modulation: UL-BPSK, DL-QPSK Spreading modulation: UL-HPSK, DL-QPSK Detection: pilot-aided coherent detection	Data modulation: UL-dual channel QPSK; DL-QPSK Spreading modulation: QPSK Detection: pilot-aided coherent detection
Channelization code	Walsh codes (UL) Walsh codes or quasi-orthogonal codes (DL)	Orthogonal variable spreading factor codes
Scrambling code	Long code (with a period of $2^{42} - 1$ chips for $N = 1$) Short PN code (with a period of 2^{15} chips for $N = 1$). (N is the spreading rate number)	UL-short code (256 chips from the family of S(2) codes or long code (38,400 chips, Gold-code-based) DL: Gold-code-based
Access Scheme	RsMa — flexible random access scheme allowing three modes of access: –Basic access –Power controlled access –Reserved access Designated access scheme — access scheme initiated by the base station message	Acquisition-indication-based random access mechanism with power ramping on preamble followed by message
Inter-base-station operation	Synchronous	Asynchronous Synchronous (optional)

Table 1. *The air interface specification for 3GPP's proposals.*

2000 standard during the 17th meeting of Task Group 8/1 at Beijing. This reaffirmed the role of ITU as the "one-stop shop" for 3G global standards to ensure that the radio recommendations for IMT-2000 meet industry needs worldwide. Subsequently, in July 1999 both 3GPP and 3GPP2 agreed to accept the OHG recommendations and to modify their technical specifications to produce standards for the DS, MC, and TDD modes. In addition to modifying the technical specifications for G3G CDMA DS and MC modes, 3GPP and 3GPP2 standardization efforts are also currently focused on identifying necessary "hooks" and "extensions"[6] to enable seamless handoff and compatibility. It is expected that the specifications with *hooks* to will be completed by December 1999 in 3GPP and March 2000 in 3GPP2. Also, the specifications with *extensions* to support ANSI-41 and GSM core networks are expected to be completed by February 2000 in 3GPP and June 2000 in 3GPP2.

Next, the current status of the 3GPPs' harmonized radio interface specifications are briefly described. Since the key parameters for the G3G standard of the OHG for TDD mode have not been considered in detail with the exception of a recommendation on chip rate, we restrict our discussions on the physical layer of the frequency-division duplex (FDD) mode of the 3GPPs' proposals in line with the OHG's recommendations. The main parameters of the two 3GPPs' proposals are summarized in Table 1.

The 3GPP Proposal

Channel Structure — The physical channels are defined by a specific carrier frequency, scrambling code, channelization code, time start/stop, and, on the uplink, the relative phase. In the 3GPP W-CDMA proposal, the following types of physical channels are defined:

- Dedicated physical channel (DPCH) — A downlink or uplink dedicated physical channel used to carry user or control information to user equipment (UE) over an entire cell or part of a cell that uses, for instance, beamforming antennas.
- Physical random access channel (PRACH) — A common uplink physical channel used to carry control information or short user packets from UE.
- Physical common packet channel (PCPCH) — A common uplink physical channel used to carry short and medium-sized user packets. It is always associated with a downlink channel for power control.
- Common pilot channel (CPICH) — A fixed-rate downlink physical channel that carries a predefined bit/symbol sequence.
- Primary common control physical channel (P-CCPCH) — A fixed-rate downlink channel used to broadcast system and cell-specific information. The P-CCPCH is not transmitted during the first 256 chips of each slot (i.e., 90 percent duty cycle).

[6] The concept of "hooks" is defined by OHG as any functionality that is specified for the initial release of the standards so that the extensions needed to satisfy the OHG harmonization requirements can be defined in detail. The concept of "extensions" is defined as any additional functionality at any layer which needs to be specified in detail to meet OHG harmonization requirements.

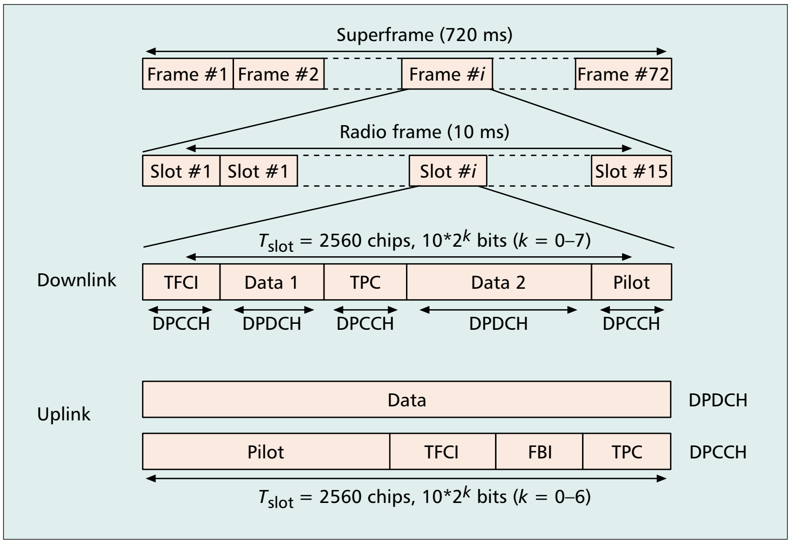


Figure 3. *The frame structure for the dedicated physical channel.*

- Secondary common control physical channel (S-CCPCH) — A downlink physical channel used to carry the FACH and PCH transport channel.
- Synchronization channel (SCH) — A downlink signal used for cell search. The SCH consists of two sub hannels, the primary and secondary SCH, which are transmitted during the P-CCPCH idle period.
- Physical downlink shared channel (PDSCH) — A downlink channel used to carry the DSCH transport channel.
- Acquisition indicator channel (AICH) — A fixed-rate downlink physical channel used to carry access preamble acquisition indicators for the random access procedure.
- Access preamble acquisition indicator channel (AP-AICH) — A fixed-rate downlink physical channel used to carry access preamble acquisition indicators of CPCH.
- Paging indicator channel (PICH) — A fixed-rate downlink physical channel used to carry the paging indicators to indicate the presence of a page message on the PCH.
- CPCH status indicator channel (CSICH) — A fixed-rate downlink physical channel used to carry CPCH status information. A CSICH is always associated with a physical channel used for transmission of CPCH AP-AICH, and uses the same channelization and scrambling codes.
- Collision-detection/channel-assignment indicator channel (CD/CA-ICH) — A fixed-rate common downlink physical channel used to carry CD indicator only if the CA is not active, or a CD/CA indicator at the same time if the CA is active.

We would like to point out that a continuous CDM pilot signal has been introduced on the downlink, which is inherited from cdma2000. W-CDMA defines two types of common pilot channels, the primary and secondary CPICHs. The primary CPICH (P-CPICH) is broadcast over the entire cell and is the phase reference for the following downlink channels: SCH, P-CCPCH, AICH, and PICH. The P-CPICH is also the default phase reference for all other downlink physical channels. The secondary CIPCH (S-CPICH) may be transmitted only over a part of the cell, not the entire cell. It may be used as the reference for the S-CCPCH and downlink DPCH.

Readers are also referred to [5] for a detailed description on the transport channels (i.e., services offered by layer 1 to the higher layers) and a summary of mapping of transport channels onto the physical channels. It is also noted that the structure of SCCPCH is derived from the existing UTRA-FDD. The key difference is the addition of a new set of slot structures with N_{pilot} = 0 to be used when the SCCPCH is transmitted over the entire cell as opposed to a specific user (e.g., directive antenna).

Chip Rate — Based on the OHG's recommendation, the chip rate of the W-CDMA proposals has been lowered from 4.096 Mchips/s to 3.84 Mchips/s, which is closer to the 3.686 Mchips/s adopted in the MC mode of the harmonized G3G CDMA proposal. This modification facilitates the design of low-cost multimode terminals, particularly cost savings on RF components.

Physical Frame Structure — Figure 3 illustrates the frame structure and slot structure for both the uplink and downlink. Due to a change of chip rate from 4.096 Mchips/s to 3.84 Mchips/s, each radio frame of 10 ms is split into 15 slots, instead of 16 slots as proposed in the previous version. For FDD the uplink physical channels DPDCH and DPCCH are I/Q multiplexed, while the downlink channels are time multiplexed within each slot. DPCH, the channel on which the user data is transmitted, is always associated with a DPCCH containing layer 1 information. The Transport Format Combination Indicator (TFCI) field is used to indicate the demultiplexing scheme of the data stream. The TFCI field does not exist for combinations that are static (i.e., fixed bit rate allocations) or where blind transport format detection is employed. The Feedback Information (FBI) field is used for transmit and site diversity functions. The Transmit Power Control (TPC) bits are used for power control. On the downlink, a number of dedicated pilot bits may be included (the exact range of N_{pilot} is to be decided according to the OHG report).

For the uplink, the maximum physical channel bit rate is 960 kb/s using a spreading factor of 4. A user may use several physical channels to obtain higher bit rates. The channel bit rate of the DPCCH is fixed to 16 kb/s. For the downlink, the maximum channel bit rate is 1920 kb/s with a spreading factor of 4. The maximum spreading factors are 512 for the downlink and 256 for the uplink.

Spreading and Modulation — On the uplink, dual-channel quadrature phase shift keying (QPSK) (i.e., separate binary PSK, BPSK, on I and Q channels) is used for data modulation. The DPCCH is mapped to the Q branch, while the first DPDCH is mapped to the I branch. Subsequently added DPDCHs can be mapped alternatively to the I or Q branches. The I and Q branches are then spread to the chip rate with two different channelization codes and subsequently complex scrambled by a UE-specific complex scrambling code. The channelization codes are orthogonal variable spreading factor (OVSF) codes. There are 2^{24} uplink scrambling codes. Either short (256 chips from the family of S(2) codes) or long (38,400 chips = 1 frame length, Gold code based) scrambling is used on the uplink. The short scrambling code is typically used in cells where the base station is equipped with an advance receiver, such as a multi-user detector or interference canceller, whereas the long codes give better interference averaging properties.

On the downlink, data modulation is QPSK where each pair of two bits are serial-to-parallel converted and mapped to the I and Q branches, respectively. The I and Q branches are then spread to the chip rate with the same channelization code and subsequently scrambled by a complex scrambling code. OVSF codes are used to preserve orthogonality between downlink channels of different rates and spreading factors. There are a total of 512 x 512 = 262,144 scrambling codes. The scrambling codes are divided into 512 sets each of a primary scrambling code and 511 secondary scrambling codes. Each cell is allocated one and only one primary scrambling code. The primary CCPCH is always transmitted using the primary scrambling code. The other downlink physical channels can be transmitted with either the primary scrambling code or a secondary scrambling code from the set associated with the primary scrambling code of the cell.

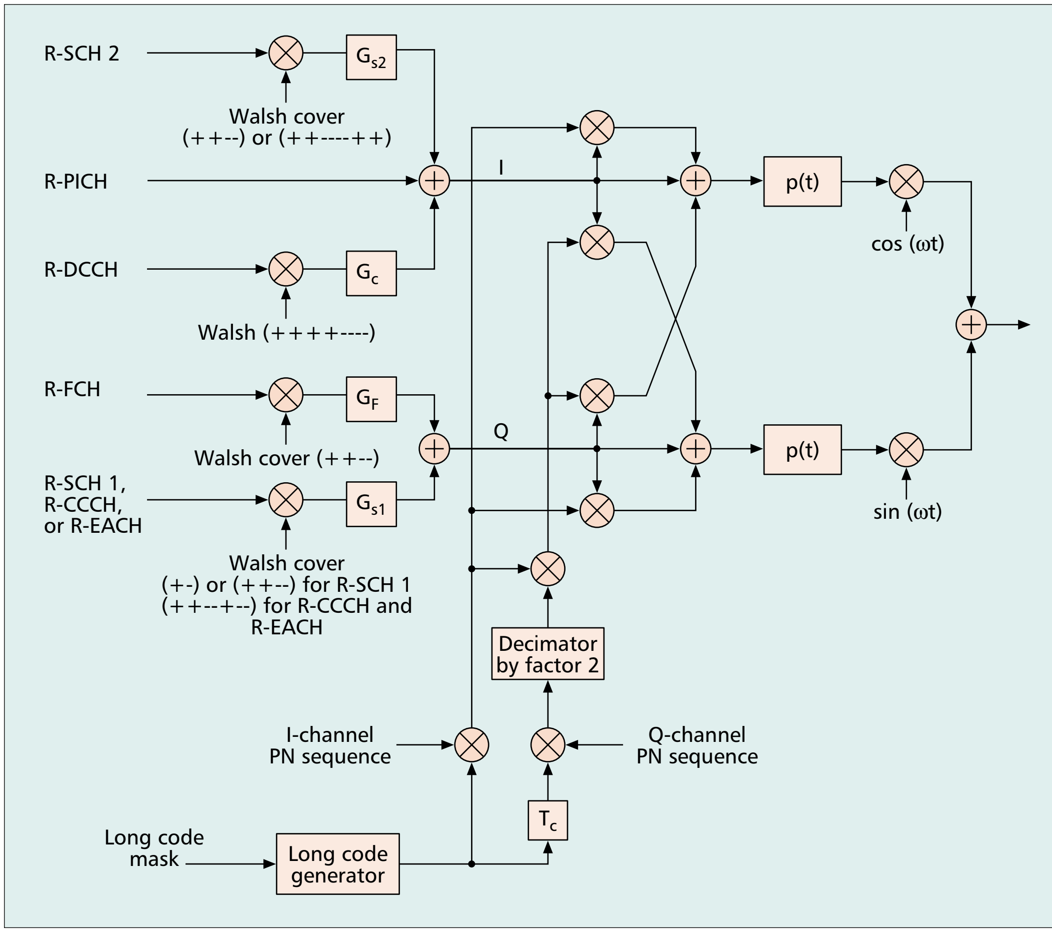
THE 3GPP2 PROPOSAL

Channel Structure — Readers are referred to Figs. 6 and 7 in [5] for a graphical illustration of the channel structures in cdma2000 (for both uplink and downlink). The following types of physical channels are defined:

- Pilot channel — On both downlink and uplink, the pilot channels are unmodulated spread spectrum signals. On the downlink, pilot channels are used for synchronization by a mobile station operating within the coverage area of the base station. Four types of pilot channels are specified for the downlink: the forward pilot channel (F-PICH), transmit diversity pilot channel (F-TDPICH), auxiliary pilot channel (F-APICH), and auxiliary transmit diversity pilot channel (F-ATDPICH). The F-PICH is transmitted at all times by the base station on each active forward CDMA channel. The F-APICH is transmitted in a beamforming application. The F-TDPICH and F-ATDPICH are transmitted when transmit diversity is used. On the uplink, the reverse pilot channel (R-PICH) is used to assist the BS in detecting the MS transmission. The MS also inserts a reverse power control subchannel in the reverse pilot channel.
- Sync channel (F-SYNCH) — A downlink physical channel used by MSs operating within the coverage area of the BS to acquire initial time synchronization.
- Paging channel (F-PCH) — A downlink physical channel used by the BS to transmit system overhead information and MS-specific messages.
- Broadcast channel (F-BCH) — A downlink physical channel used by the BS to transmit system overhead information.
- Common control channel — On the downlink, the forward common control channel (F-CCCH) is used by the BS to transmit MS-specific messages. On the uplink, the reverse common control channel (R-CCCH) is used for the transmission of user and signaling information to the BS when reverse traffic channels are not in use. The R-CCCH can be used in one of two possible modes: reservation access and designated access. R-CCCHs are uniquely identified by their long codes.
- Quick paging channel (F-QPCH) — A downlink physical channel used by the BS to inform MSs, operating in the slotted mode while in the idle state, whether or not to receive the F-CCCH, F-BCH, or F-PCH.
- Common power control channel (F-CPCCH) — A downlink physical channel used by the BS for transmitting common power control subchannels (1-bit subchannel) for power control of multiple R-CCCHs and F-EACHs. The common power control subchannels are time multiplexed on the F-CPCCH. Each common power control subchannel controls an R-CCCH or F-EACH.
- Common assignment channel (F-CACH) — A downlink physical channel used by the BS to provide quick assignment of the R-CCCH.
- Access channel (R-ACH) — An uplink common physical channel used by the MS to initiate communication with the BS and to respond to paging channel messages.
- Enhanced access channel (R-EACH) — An uplink physical channel used by the MS to initiate communications with the BS or to respond to an MS-directed message. The R-EACH can be used in three possible modes: basic access, power controlled access, and reservation access. R-EACHs are uniquely identified by their long codes.
- Traffic channel — A dedicated physical channel used for transmission of user and/or signaling information to/from a specific MS during a call. Signals transmitted on the traffic channel are specified by radio configurations. There are six radio configurations for the uplink, and nine for the downlink. On both the up- and downlink, the traffic channels with radio configurations 1 and 2 include the fundamental channel (F/R-FCH) and supplemental code channel (F/R-SCCH). With other radio configurations — radio configurations 3–6 for the uplink and 3–9 for the downlink — the traffic channels include the dedicated control channel (F/R-DCCH), fundamental channel (F/R-FCH), and supplemental channel (F/R-SCH). On the downlink, the forward traffic channels also include the forward power control subchannel which is used to transmit reverse power control commands and is transmitted on either the forward fundamental channel or forward dedicated control channel.

The primary CCPCH is always transmitted using the primary scrambling code. The other downlink physical channels can be transmitted with either the primary scrambling code or a secondary scrambling code from the set associated with the primary scrambling code of the cell.

In order to support seamless handoff between the harmonized G3G DS-mode and MC-mode systems, it is necessary to define the protocol layers associated with interconnecting the radio access modes to the evolved GSM-MAP or the evolved ANSI-41 core networks.



■ **Figure 4.** *The cdma2000 reverse dedicated channel structure.*

Spreading and Modulation — cdma2000 uses QPSK for data modulation in each physical channel on the downlink. The modulation symbols are spread with the appropriate Walsh or quasi-orthogonal function to provide orthogonal channelization among different channels and different users, and then spread by a quadrature pair of PN sequences. Quasi-orthogonal functions (QOFs) are created using a nonzero sign multiplier QOF mask and a nonzero rotate enable Walsh function. When operating in spreading rate N(N = 3, 6, 9, or 12) multicarrier mode, the output symbols from the block interleaver are demultiplexed into N pairs of quadrature modulation symbols, with each pair spread to a chip rate of 1.2288 Mchips/s and transmitted on N adjacent carriers.

On the uplink, BPSK is used for data modulation, and hybrid PSK (HPSK) — that is, orthogonal constrained QPSK (OCQPSK) — is used for spreading. For example, the spreading and modulation operation for spreading rate 3 is shown in Fig. 4. It is apparent from this figure that each physical channel is first spread with a Walsh code to provide orthogonal channelization and then mapped into the I or Q channel. The I and Q channel data are multiplied by a complex spreading sequence before baseband filtering. The in-phase spreading sequence is formed by modulo-2 addition of the I-channel pseudo-noise (PN) sequence and the I long code sequence. The quadrature spreading sequence is formed by modulo-2 addition of the following three terms: the W_1^2 Walsh function, the in-phase spreading sequence, and the decimated by 2 output of the modulo-2 addition of the Q-channel PN sequence and Q long code sequence (i.e., the I long code delayed by one chip).

Interoperability between Radio Access Modes and Core Networks

In order to support seamless handoff between harmonized G3G DS mode and MC mode systems, it is necessary to define the protocol layers associated with interconnecting[7] the radio access modes to the evolved GSM-MAP or ANSI-41 core networks. For instance, Fig. 5a illustrates a protocol architecture for connecting the MC radio access mode to the evolved GSM-MAP core network for both packet- and circuit-switched services, which has been proposed by 3GPP2. The CDMA-MC protocol stack plays the role of the access stratum protocols and is extended to support upper GSM-MAP nonaccess stratum protocols (GSM-MAP MM and CM) as well as internetwork with the network protocols on the Iu interface (RANAP). Similarly, the OHG has recommended a protocol architecture for connecting DS mode to an ANSI network, as depicted in Fig. 5b.

[7] *The ITU has recently approved six sets of specifications for the network aspects of IMT-2000 during the ITU-T SG11 meeting in Geneva (December 1999) which allows internetworking between three core networks (evolved GSM-MAP, evolved ANSI-41, IP-based networks).*

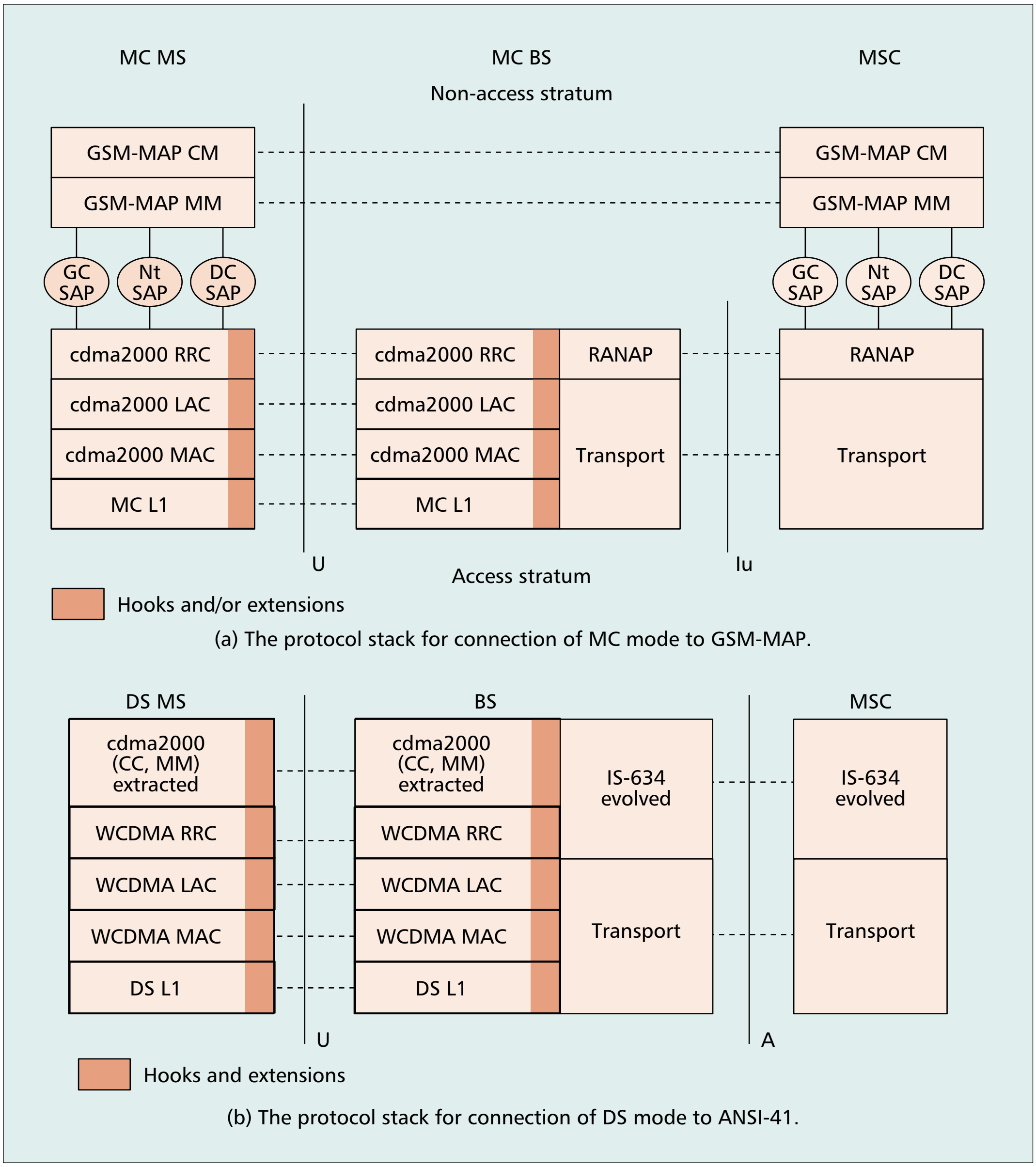


Figure 5. *The protocol stack for MC mode to GSM-MAP and DS mode to ANSI-41 connections.*

Further harmonization is expected if 3GPP and 3GPP2 merged into a single entity. This merger will provide the focus in developing a unified core network for the future as well as ensuring that air interfaces and associated protocol layers will be fully harmonized.

Concluding Remarks

Due to the 2G legacy (the need for smooth migration to 3G) as well as the need to harmonize the technical specifications for various RTT candidates, it is imperative to carry out harmonization at an international level. This has led to the formation of multiple committees and partnership projects around the world to accelerate the standardization process of IMT-2000. This article describes the convergence trends among eight CDMA-based RTT candidates within two 3G partnership projects since their submission to the ITU in June 1998. The role of the OHG in preventing multiple 3G CDMA standards is also discussed. In addition to the convergence on CDMA RTT specifications achieved thus far, further harmonization is expected if 3GPP and 3GPP2 merge into a single entity. This merger would provide focus in developing a unified core network for the future as well as ensuring that air interfaces and associated protocol layers are fully harmonized. The OHG has offered to facilitate this merger by December 2000. It should be emphasized that the exclusion of UWC-136 and DECT RTTs from the 3GPPs and OHG should not be construed as reflecting negatively on their suitability for IMT-2000 systems. Rather, it is mainly due to their significantly different architectures which fall outside the scope of harmonization activities. In accordance with the OHG's recommendations (which have been endorsed by the ITU, 3GPP, and 3GPP2), the specifications for CDMA MC mode will be based on a harmonized 3GPP2 proposal, and the specifications for CDMA DS and CDMA TDD modes will be based on a harmonized 3GPP proposal. Finally, we would like to highlight that the World Radiocommunication Conference (WRC 2000) in Istanbul recently approved additional spectrum requirements for IMT-2000 and identified the 806–960 MHz, 1710–1885 MHz, and 2500–2690 MHz bands globally to provide advanced 3G services.

In accordance with the OHG's recommendations, the specifications for the CDMA MC mode will be based on the harmonized 3GPP2 proposal, and the specifications for the CDMA DS and CDMA TDD modes will be based on the harmonized 3GPP proposal.

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ADDITIONAL READING

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BIOGRAPHIES

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