CHAPTER 1

INTRODUCTION TO CDMA2000 STANDARDS EVOLUTION

1.1 INTRODUCTION

The ongoing growth in demand for high-speed packet data services and multimedia applications over mobile wireless networks has set new system requirements and objectives for the next generation of air interface protocols and network architectures.

Although the channelization, signaling, and access protocols of second-generation (2G) cellular systems were designed to efficiently support symmetric circuit switched data and voice traffic, most of the new data applications are IP based with highly asymmetric and packet-switch traffic. This asymmetric and bursty nature of multimedia packet data traffic along with the variability of data rates and packet sizes and complexity of quality of service (QoS) management makes conventional voice-oriented channelization and access protocols of 2G systems inefficient.

The third generations of radio access technologies, commonly known as 3G systems, are expected to use new physical and logical channelization schemes with enhanced media and link access control protocols. Also, to maximize the spectrum efficiency, the physical layer designs must utilize advanced coding, link adaptation, and diversity schemes as well as power and interference control mechanisms.

In the late 1990s, these observations and requirements motivated major efforts and studies in the International Telecommunication Union (ITU) and other regional standardization groups to define and harmonize a common set of specifications for new International Mobile Telecommunications standards referred to as IMT2000 systems. In Europe the IMT2000 is also referred to as Universal Mobile Telecommunication Services (UMTS).

ITU activities on IMT2000 are comprised of international standardization, including frequency spectrum and technical specifications for radio and network components, tariffs and billing, technical assistance, and studies on regulatory and policy aspects.

In this chapter we briefly present the overview of 3G evolution paths while we defer a more detailed description of technologies to later chapters.

The IMT2000 has defined a globally acceptable spectrum for the deployment of 3G systems, including uniband spectrum to support the time division duplex (TDD) mode as well as paired-band spectrum to allow the frequency division duplex

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(FDD) mode. In the FDD mode the system uses different frequency bands for the mobile station transmissions in the "uplink" and base station transmissions in the "downlink." In the TDD mode the uplink and downlink transmissions are on the same frequency channel but they are separated by time slots. Although most 3G deployments are expected to be in paired frequencies or in FDD mode, the TDD mode may also be used in unlicensed bands and when an FDD allocation is not feasible.

In early 1998, to expedite the process of IMT2000/3G standardization and the global acceptance of proposed radio transmission technologies (RTTs), a concept of a "Partnership Project" was proposed by the European Telecommunications Standards Institute (ETSI). This proposal initiated two Third-Generation Partnership Projects (3GPP and 3GPP2) with two different, but related, areas of focus. Each of the 3GPP and 3GPP2 projects involves a number of regional standardization bodies as organizational partners as shown in Figure 1.1.

For 3GPP the original scope was to produce globally applicable and acceptable technical specifications for a Third-Generation Mobile System based on evolved Global System for Mobile communication (GSM) core networks. Initially, the objective was to focus on the Universal Terrestrial Radio Access (UTRA) technologies with both FDD and TDD modes. This scope was subsequently amended to include the maintenance and development of Technical Specifications for GSM and its evolution to General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE).

Similarly, the scope of the 3GPP2 work was to harmonize different variations of cdma2000® in a single family of standards that is based on the evolution of cdmaONE air interface. This scope was also expanded to include the development of a data-optimized air interface called the high-rate packet data (HRPD) system. In the development of cdma2000 systems the core network specifications are based on an evolved ANSI-41 and IP network; however, the specifications also include the necessary capabilities for operation with an evolved GSM-MAP-based core network. For more information on 3GPP and 3GPP2 the reader is referred to [1,2].

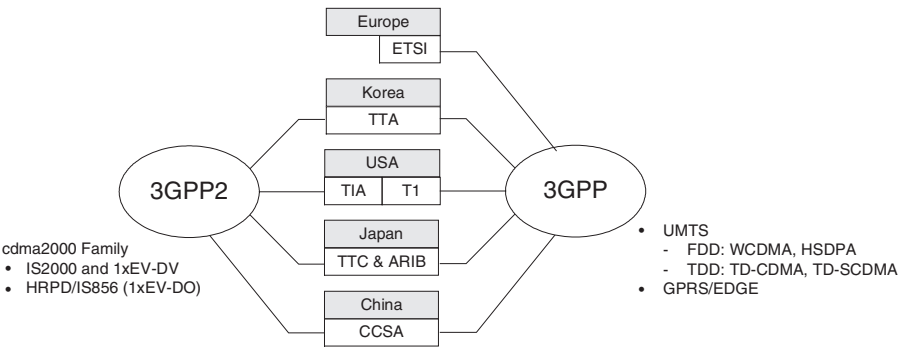

Figure 1.1 Organizational Partners in 3GPP and 3GPP2.

As a result of harmonization efforts in 3GPP and 3GPP2, the following three major technologies have been identified and included in the IMT2000 family of standards:

IMT2000 FDD Mode; Direct Spread: WCDMA (wideband code division multiple access) is one of the key radio access technologies adopted as an IMT2000 standard for global deployment in the FDD spectrum. WCDMA is based on direct spread spectrum technology in 5-MHz radio channels supporting mobile multimedia applications with up to 2 Mbps for local area access or 384 kbps for wide area access. The WCDMA standardization process has evolved from its first release in 1999 to an updated version (Release 5) in 2002, which contains major revisions and additions to the previous releases including a new high-speed data packet access (HSDPA) mode to allow high speed and low latency access for packet data applications.

IMT2000 FDD Mode; Multicarrier: The multicarrier CDMA, commonly referred to as the cdma2000 standards family, is the other FDD component of IMT2000 systems. The main member of the cdma2000 family of standards is the IS2000 air interface with the 1X and 3X components, corresponding to one and three 1.25-MHz carrier systems, respectively. The IS2000 is designed to provide a backward-compatible migration path for 2G-CDMA/IS95A(B) networks. The cdma2000 family also includes the IS856 standard, which was subsequently added as an optional and complementary radio access technology that is optimized HRPD access.

IMT2000 TDD Mode (UTRA-TDD/TD-CDMA): The TDD mode of IMT2000 standards involves a TDD variation of WCDMA, which uses a combination of time- and code division multiple access referred to as TD-CDMA. The TDD mode also has an optional spreading rate of 1.28 Mcps, which is based on synchronous code division multiple access called TD-SCDMA.

Figure 1.2 shows the timeline for the evolution of various 2G technologies toward IMT2000/3G systems, with emphasis on the commonly used FDD technologies [1,2].

Most GSM networks have evolved to include GPRS services and in some cases have been further enhanced to EDGE system for higher-speed packet data services. GPRS reuses GSM radio channels and frame structure and provides higher data rates to allow multislot traffic channels. The EDGE enhances GPRS spectral efficiency by using higher-order modulation with link adaptation but still maintaining GSM radio channels and frame structure.

Most GSM operators are planning or have begun deploying IMT2000/UMTS-based networks using WCDMA technology. Many IS136/TDMA-based networks have also joined the GSM group and have decided to migrate to WCDMA. In Japan the PDC-based networks were among the first to deploy the WCDMA system based on its 1999 release version [3].

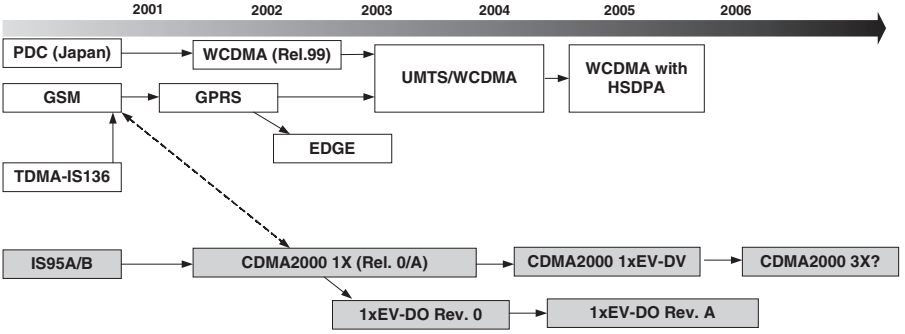

Figure 1.2 2G to 3G technology migration road map.

All 2G-CDMA (IS95/B)-based networks and some IS136/TDMA systems have migrated or are planning to migrate to cdma2000-1X technology, primarily based on the IS2000 Release 0 standard, and they are expected to transition their networks to either Release A or Release D (1xEV-DV) depending on the timing of their upgrade. Some operators who decided to devote separate carriers for high-speed packet data to complement their existing voice-based services have opted to use 1xEV-DO (or HRPD) carriers as an overlay to their existing 2G carriers. The deployment of multicarrier cdma2000 networks may happen in a later time frame.

We will revisit the overall CDMA technology evolution later in this chapter, after a brief overview of 3GPP2 and its standardization process.

1.2 3GPP2 AND CDMA2000 STANDARDIZATION

All standardization efforts related to cdma2000 are organized and managed under 3GPP2. There are five major regional standard organizations that contribute to 3GPP2 as Organizational Partners (see Fig. 1.1). These organizations are the following:

- ARIB: Association of Radio Industries and Businesses for Japan
- CCSA: China Communications Standards Association for China
- TIA: Telecommunications Industry Association for North America
- TTA: Telecommunications Technology Association for Korea
- TTC: Telecommunications Technology Committee for Japan

There are also a number of participating member companies, each required to be affiliated with at least one of the Organizational Partners.

The work of producing 3GPP2's specifications resides in four Technical Specification Groups (TSGs), comprised of representatives from Individual Member companies. The TSGs are:

- TSG-A (Access Network Interfaces)
- TSG-C (CDMA2000 Family of Standards)

- TSG-S (Services and Systems Aspects)
- TSG-X (Intersystem Operations)

There are different Working Groups within each TSG that focus on different areas within the main task. All 3GPP2 TSGs report to the Steering Committee, which is tasked with managing the overall work process and adopting the technical specifications forwarded by each of the TSGs. The following describes the function of each TSG.

TSG-A is responsible for the specifications of Interoperability Specifications (IOS) and interfaces between the radio access network and core network, as well as interfaces within the access network. One of the main IOS standards developed by TSG-A is specification for cdma2000 access network interfaces or IS-2001, which has gone through Revisions A–C. Meanwhile, the interworking function specification for the interface of 3GPP radio access technology to ANSI-41 core network is assigned to TSG-R.

TSG-C covers the radio layer 1–3 specification, mobile station MS and BS minimum performance specification, radio link protocols, support for enhanced privacy, authentication, and encryption. TSG-C is also responsible for developments related to digital speech and video codecs, data and other ancillary services support, conformance test plans, Removable User Identity Module (R-UIM), and location-based services support. TSG-C has so far developed cdma2000 air interface specifications IS-2000 Revisions 0 and A–D; air interface specification for High-Rate Packet Data IS-856; EVRC and SMV vocoders; and many other air interface-related specifications.

TSG-S is responsible for defining and developing system services and capabilities, stage 1 feature and service requirements definition, system reference model development and maintenance, as well as requirement definition for international roaming and operation, administration, management, and provisioning (OAM&P). Some of the working groups within TSG-S are focusing on a number of new features in the services and system aspects, such as enhanced messaging service, multimedia messaging service, broadcast/multicast, and multimedia streaming. Another key responsibility of TSG-S is coordinating and managing the working relationship among all TSGs.

TSG-X is responsible for the core network part of systems, including core network internal interfaces, IP support for packet data, voice, and multimedia services, and charging, accounting and billing specifications, etc. More specifically, TSG-X will address the following areas of work and the related technological developments:

- Evolution of core network to support interoperability and intersystem operations and International Roaming
- Network support for enhanced privacy, authentication, data integrity, and other security aspects, including User Identity Module (UIM) support
- Support for new supplemental services (including ISDN interworking)
- Wireless IP and multimedia services (e.g., voice over IP) and QoS support
- IP mobility management

To better capture and address the needs of operators and end users, 3GPP2 works with Market Representation Partners (MRPs), voiced by operators, who offer market advice and bring a consensus view of market requirements (e.g., services, features, and functionality) falling within the 3GPP2 scope. One of the main MRPs is the CDMA Development Group (CDG).

CDG is an international consortium of CDMA wireless equipment manufacturers and operators that have joined together to lead and help in the adoption and evolution of CDMA wireless systems around the world. One of the main tasks of CDG is to work with vendors and operators on CDMA-related technical requirements and deployment issues and to create consensus among the players and provide inputs to the standard organizations. CDG activities involve a number of technical teams with special interest areas ranging from interoperability specifications (IOS) and international roaming to applications and testing [4].

Another MRP of 3GPP2 is the IPv6 Forum. The IPv6 Forum is a worldwide consortium of leading Internet vendors and Research and Education Networks aimed at promoting IPv6-based solutions and interoperable implementations of IPv6 standards and also resolving issues that create barriers to IPv6 deployment.

1.3 CDMAONE EVOLUTION TO CDMA2000

The application of code division multiple access (CDMA) technology was introduced in cellular systems in the early 1990s with the development and commercialization of the IS-95 standard. Since then, the technology has been widely deployed throughout the world, reaching the 180 million subscriber mark in late 2003. Since its commercialization, the CDMA technology has evolved from IS-95 to cdma2000 and beyond with significant enhancements in voice capacity, data speed, and network features. Throughout this technology evolution each new standard or release is designed to maintain full backward compatibility with previous systems (see Fig. 1.3).

IS95 and its PCS version J-STD-008 appeared around 1994 as TIA standards, offering significant capacity improvement over existing TDMA-based networks. This CDMA technology uses direct sequence spread spectrum with frequency reuse of one and benefits from frequency and multipath diversity as well as statistical voice multiplexing to provide a high spectral efficiency.

After a few years of CDMA deployment experience, IS95-B was introduced in 1998, including the following enhancements:

- Support for medium-rate packet data service option, up to 64 kbps, using aggregation of code channels
- Improved soft handoff performance with dynamic thresholds
- Enhanced interfrequency handoff procedure to facilitate multicarrier network deployment
- Improved system access in handoff areas with access state handoff procedures
- Other improvements related to allowing position location and global roaming

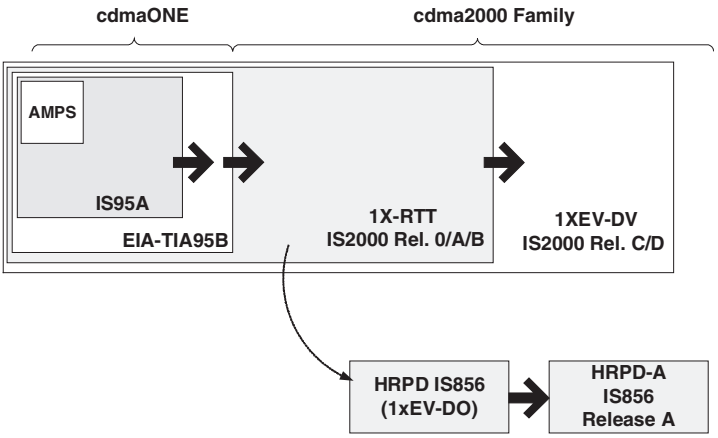

Figure 1.3 Backward compatibility in the evolution of cdma2000.

IS-95-A/B, which are subsequently called IS95A/B, along with some of their signaling standards form the basis of the 2G cellular technology known as cdmaONE.

Despite its improved feature sets and performance, IS95B was not widely deployed as most operators waited for the next generation of CDMA technology based on cdma2000 standards.

Following the IMT2000 efforts initiated by ITU the standardization of cdma2000 radio transmission technology (RTT) started in late the 1990s in TIA under the TR45.5 group, and it was subsequently continued more globally by 3GPP2.

The cdma2000 standardization aims at IMT2000 objectives on one hand and backward compatibility with existing cdmaONE networks and voice terminals on the other hand.

The preliminary release of cdma2000 that was proposed as an RTT to ITU was IS2000 Release 0, which is also referred to as the 1X-RTT system. Although this release was not a complete release, it was developed and built into the new CDMA chipsets and offered widely to the global market. Some of the key features of cdma2000 included in Release 0 are the following:

- Backward compatibility with IS95B including access and traffic state handoff enhancements
- Coherent uplink demodulation with reverse pilot
- Fast forward power control
- Variable-length Walsh spreading
- Data rates of up to 150 kbps or 300 kbps depending on the traffic channel radio configuration
- QPSK modulation on both forward and reverse links
- Enhanced channel coding with turbo encoders at higher data rates

- Optional support for transmit diversity
- Increased mobile terminal battery life with a new quick paging channel

The combination of all these enhancements provides a voice capacity that is twice that of the cdmaONE systems and a data rate of 153.6 kbps or 307.2 kbps depending on the radio configuration. The commercial deployment of cdma2000-based systems began as early as 2000 in South Korea and very soon in expanded in other countries including the US. Some have argued that as 1xRTT does not fully comply with IMT2000 requirements of 384 kbps data rate for pedestrian and 2 Mbps for fixed terminal it should be considered a "2.5G" system. The IMT2000 data rate requirements could only be met with the wideband direct spread or multicarrier 3X options of cdma2000, which have not yet been implemented.

The first complete cdma2000 release was Release A, which was published in the year 2000, including both the narrowband (1X) and the wideband (3X) multicarrier (MC) modes occupying 1.25 MHz and 3.75 MHz, respectively. As a result of harmonization efforts between cdma2000 and WCDMA, and to maintain only one direct spread (DS) mode for IMT2000 standards, the direct spread mode of cdms2000 with 3.68Mcps was withdrawn from IS2000 release A [5].

The high data rate requirements of IMT2000 can be achieved in IS-2000A by aggregating three standard 1.25-MHz carriers in a multicarrier forward link signal. The reverse link of the 3X MC mode can optionally be transmitted using either a 1.2288 or a 3.6864 Mcps chip rate. The 3X forward/1X reverse mode leverages existing base station receiver and mobile transmitter designs while allowing higher forward link data rates for asymmetric packet data services.

Another important feature introduced in cdma2000 is the support of both IS-41 (native to IS-95) and the GSM's Mobile Application Part (MAP) network signaling. With the later option that is called cdma2000 MC-MAP, while the radio interface is handled according to the cdma2000 specification, the call control, mobility management, and other network signaling operate as per the GSM signaling protocol. This feature facilitates the worldwide adoption of cdma2000 radio technology and allows international roaming of cdma2000 terminals in the existing GSM-based networks.

Some of the key features of Release A are as follows:

- Backward compatibility to cdmaONE and Release 0
- Complete signaling support for MC 3X channels while DS mode is removed
- Signaling support for new common channels used for enhanced access and short data burst transmissions
- Enhanced signaling for concurrent services
- Flexible rates and frame formats
- QoS negotiation
- Enhanced encryption algorithm

Shortly after Release A, Release B of IS2000 was published with a few signaling protocol improvements such as rescue Channel Code Combining Soft Handoff, CDMA Off-Time Reporting, and Improved Traffic to Idle transition.

Following the widespread deployment of Release 0, and despite the significant improvements in the standard, Releases A and B of IS2000 did not motivate operators to upgrade their networks. Because Release 0 had already given operators enough voice capacity and because the pickup in demand for high-speed data was delayed by various factors, the costly upgrades to the new releases could not be justified.

Meanwhile, some operators who did want to introduce high-speed packet data services demanded much higher forward link data rates than the 150 kbps offered by cdma2000. Motivated by this demand 3GPP2 favorably considered a proposed data-only overlay radio technology based on a proprietary packet data optimized High Data Rate (HDR) air interface developed by Qualcomm Inc. 3GPP2 studied the original HDR specifications and further improved and published them as a new standard called High-Rate Packet Data (HRPD) in late 2000 [6]. This standard is also referred to as IS856 or 1xEV-DO because it is a Data-Optimized EVolution of, but not backward compatible to, the 1xRTT system.

1xEV-DO was designed to provide efficient HRPD services without the constraints of supporting legacy circuit switched channels in IS-95. The HRPD technology achieves very high spectral efficiency on the downlink by using high order modulation, fast rate adaptation, and scheduling on a single high-speed data channel that is time multiplexed among active users. The reverse link of HRPD, however, is very much like the 1xRTT system with much lower data rate and higher latencies than the forward link.

One of the main drawbacks of IS856 for some operators was that it would only provide packet data services on a best-effort basis and not applications with strict QoS requirements such as voice. Also, given the uncertainly in the revenue coming from data services, many operators at the time were not ready to dedicate some of their valuable spectrum resources and capital expenditure to data-only carriers. This concern motivated the 3GPP2 to work on a new release of cdma2000 specifically aimed at adding a high-speed packet data mode. The objective was to meet or exceed the HRPD performance without affecting the exiting backward-compatible framework for voice and low-rate data services. The result was the so-called 1xEV-DV system, which was published as Release C of IS2000, in 2002.

Some of the key features of Release C are as follows:

- Introduction of a new forward packet data channel mode and associated protocols
- High-order modulation and link adaptation on the new forward packet data channels supporting a peak data rate of 3.1 Mbps
- Short frames (1.25–5 ms) and fast scheduling to benefit from multiuser diversity
- Dynamic allocation of power and Walsh code resources among up to two packet data channels and the low-rate data/voice channels
- Fast call setup and enhanced authentication
- Data-only forward-link sector throughput comparable to 1xEV-DO

One can consider Release C as a combination of previous releases and the concepts used in 1xEV-DO with few additional improvements.

For some operators the imbalance between forward- and reverse-link throughput and latency performance was acceptable given the inherent traffic asymmetry of IP-based applications. However, for some applications with lower latency requirement such as gaming, instant messaging, and Voice over IP (VoIP), the required QoS could not be provided with 1xEVDO or Release C of IS2000 unless some improvements were made in their uplink.

The 3GPP2 therefore started working on the uplink enhancement for IS2000 as part of Release D and in a parallel and somewhat controversial effort on Release A of HRPD/IS856. The proposed enhancements made in IS2000-D and IS856A were very similar in nature and would bring comparable performance gains for the uplink.

Release D of IS2000 was published in March 2004 by 3GPP2 and includes the following features mostly for uplink enhancements [5]:

- A New high-speed reverse packet data channel and associated protocols
- Link adaptation with improved rate selection and hybrid ARQ
- Shorter frames and lower latency for packet data channel
- A flexible MAC with multiple uplink rate control options and QoS control
- Support for peak data rate of 1.8 Mbps
- Maintenance of backward compatibility with cdmaONE and previous releases of IS2000
- Uplink throughput of more than 600 kbps.

Meanwhile, similar features have been added to the reverse link of 1xEV-DO as part of the IS856 Release A standard but in a design that is backward compatible with the original IS856. As a result, the uplink throughput, latency, and QoS control of HRPD have been significantly improved, providing a much more balanced design between the forward and reverse links.

In the next several chapters we will study the concepts, systems, and protocols features introduced in each of the major cdma2000 standard releases. As each system is backward compatible with the previous ones, we start with the most common denominator of all systems, namely, cdmaONE, and step by step expand our understanding of the cdma2000 family by focusing on new elements introduced in each release.

1.4 REFERENCES

1. The 3GPP2 website: www.3gpp2.org
2. The 3GPP website: www.3gpp.org
3. The CDG website: www.cdg.org
4. *WCDMA for UMTS*, H. Holma and A. Toskala Eds., John Wiley, 2001
5. C.S0001-A to D, Introduction to cdma2000 Standards for Spread Spectrum Systems
6. 3GPP2 C.S0024-0 v4.0 cdma2000 High Rate Packet Data Air Interface Specification, 2002