

# Third-generation radio access standards

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Second-generation radio access has been a major success story for the global telecommunications industry, delivering telephony and low bit-rate data services to mobile end-users. The growth rate of second-generation mobile telephony indicates that mobile communication is well on its way toward full mass-market penetration. Thanks to the tremendous growth of the Internet, multimedia is also penetrating the mass market at an explosive pace. Combined, the digital cellular footprint and the multimedia services of the Internet form the basis of tomorrow's integrated wireless communication and multimedia access system.

The transition to third-generation capabilities must be based on a feasible migration path that defines a way of integrating multimedia, packet switching and wideband radio access into the dominating second-generation systems of our day. Although the standards behind these systems were initially defined on a regional basis, standardization bodies and members of the telecommunications industry have finally agreed on a harmonized global scenario for third-generation radio access standards.

The author describes this newly harmonized global scenario, and how the developing third-generation radio access standards will cater for requirements for multimedia and flexibility, spectrum allocation, and successful migration from second-generation systems.

## Second-generation standards

Various digital cellular standards were developed in several regional standards bodies during the late 1980s and early 1990s. The first-generation standards had been developed some ten years earlier.

### GSM

The development of the new pan-European digital cellular standard got under way in 1985. GSM has since evolved into the leading global second-generation standard, in terms of number of subscribers and area of coverage (Figure 2).

GSM is an eight-slot, time-division multiple-access (TDMA) system with 200 kHz carrier spacing. In terms of service, GSM is mobile ISDN (integrated services digital network), with support for a wide variety of services. Intelligent network (IN) support in the mobile environment has also been defined for GSM—for example, the virtual home environment—as well as many advanced data services. And today, thanks to general packet radio services (GPRS), packet access can also be integrated into GSM.

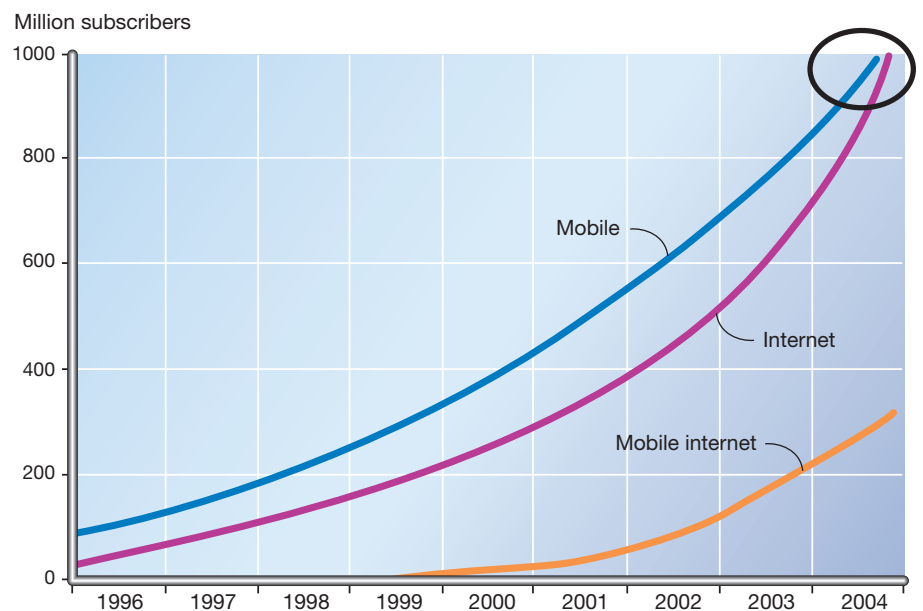
### TDMA/136

The TDMA/136 specification, which was defined in the USA, in 1988, by the Telecommunications Industry Association (TIA), was developed with the aim of digitizing the analog advanced mobile phone service (AMPS). To maintain compatibility with AMPS, the TDMA specification stipulates 30 kHz carrier spacing in a three-slot TDMA solution.

### PDC

The development of the personal digital cellular (PDC) specification was drafted by the

Figure 1  
Growth of mobile telephony and the Internet.



RCR (1990), which later became the Association of Radio Industries and Broadcasting (ARIB). To ensure compatibility with the Japanese analog systems, a carrier spacing of 25 kHz was maintained in a three-slot TDMA solution.

### CDMA/IS-95

The narrowband code-division multiple-access (CDMA) IS-95 specification stipulates 1.25 MHz carrier spacing for telephony services. TTA began defining this specification in 1991.

Each of the second-generation standards essentially defines a mobile telephony system—that is, a system that provides mobile end-users with circuit-switched telephony services. Apart from voice services, these systems support supplementary services and some low-bit-rate data services.

## Drivers of third-generation development

Much as second-generation radio access brought mobile telephony capabilities to the mass market, third-generation radio access will introduce value that extends beyond basic telephony. The widespread growth of the Internet has created a mass-market base for multimedia and information services. The challenge is to merge mobile telephony coverage and the associated user base with the Internet and other multimedia applications. To successfully meet this challenge, third-generation radio access must provide

- flexible multimedia management;
- Internet access;
- flexible bearer services; and
- cost-effective packet access for best-effort services.

Most new multimedia services will be offered via the Internet. Therefore, a characteristic feature of third-generation radio access is that it provides mobile Internet. Multimedia requires considerable flexibility—that is, the cost-effective ability to support different bearer services with very different requirements, such as different bit rates (constant or variable), real-time or best-effort service, and packet- or circuit-switched service.

In addition, third-generation radio access must provide full-area coverage (same as second-generation voice service); high-peak bit-rate services (384 kbit/s full-area coverage, 2 Mbit/s local coverage); and any kind of service mix. Finally, third-generation

### BOX A, ABBREVIATIONS

3GPP/3GPP2	Third-generation (3G) Partnership Project	ITU	International Telecommunication Union
8PSK	Eight-phase shift keying	ITU-R	ITU Radio Communication Sector
AMPS	Advanced mobile phone service	ksps	Kilosymbols per second
ANSI-41		MC	Multicarrier
ARIB	Association of Radio Industries and Broadcasting	Mcps	Megachips per second
BSS	Base station subsystem	MM	Mobility management
CC	Call control	OHG	Operators Harmonization Group
CDMA	Code-division multiple access	PCS	Personal communication services
cdma2000		PDC	Personal digital communication
CDMA/IS-95	Digital cellular standard IS-95	RACE	R&D in advanced communications technologies in Europe
CN	Core network	RCR	Research & Development Center for Radio Systems (Japan)
CODIT	Code-division testbed (RACE II mobile project R2020)	RLC	Radio link control
DECT	Digital enhanced cordless telecommunications	RNC	Radio network controller
DS	Direct sequence	SIR	Signal-to-interference ratio
ECSD	Enhanced circuit-switched data	TDD	Time-division duplex
EDGE	Enhanced data rates for GSM and TDMA/136 evolution	TDMA	Time-division multiple access
EGPRS	Enhanced GPRS	TDMA/136	Digital cellular standard IS-136
ETSI	European Telecommunications Standards Institute	TD-SCDMA	Time-division synchronous CDMA
FDD	Frequency-division duplex	TFCI	Transport format combination indicator
FMA2	FRAMES Multiple Access 2	TIA	Telecommunications Industry Association
GMSK	Gaussian minimum-shift keying	TPC	Transmit power control
GPRS	General packet radio services	UMTS	Universal mobile telecommunications system
GPS	Global positioning system	UTRA	UMTS terrestrial radio access
GSM	Global system for mobile communication	UTRAN	UTRA network
HCS	Hierarchical cell structure	UWCC	Universal Wireless Communications Consortium
IMT-2000	International mobile telecommunication	VoIP	Voice-over-IP
IN	Intelligent network	WBTD	Wideband Test Bed
IP	Internet protocol	WCDMA	Wideband CDMA
ISDN	Integrated services digital network		

### BOX B, DIGITAL CELLULAR STANDARDS, END OF JUNE 1999

Standard	Subscribers	Countries/Network on air	Monthly growth (approximate)
GSM	183.3 million	120/284	7.6 million
PDC	42.3 million	1/30 (Japan)	0.6 million
TDMA	24.3 million	34/104	1.4 million
CDMA	31.5 million	12/31	1.5 million

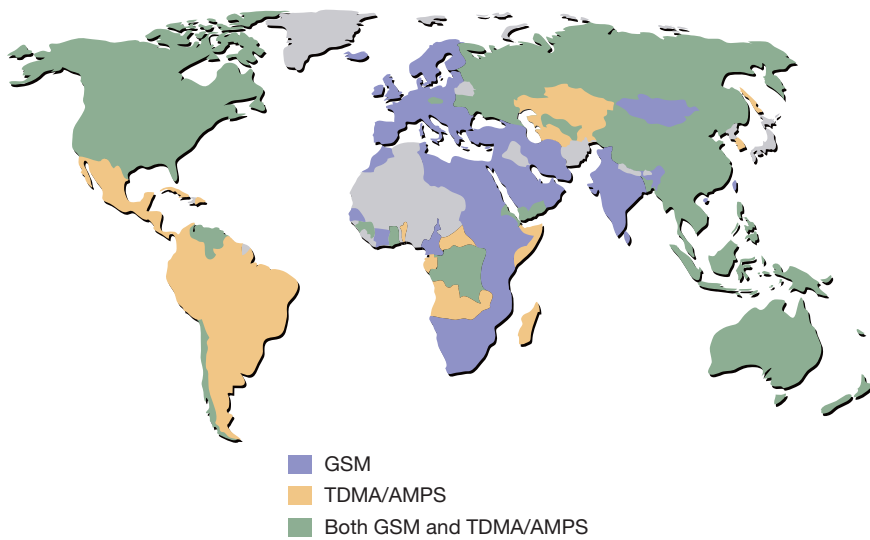


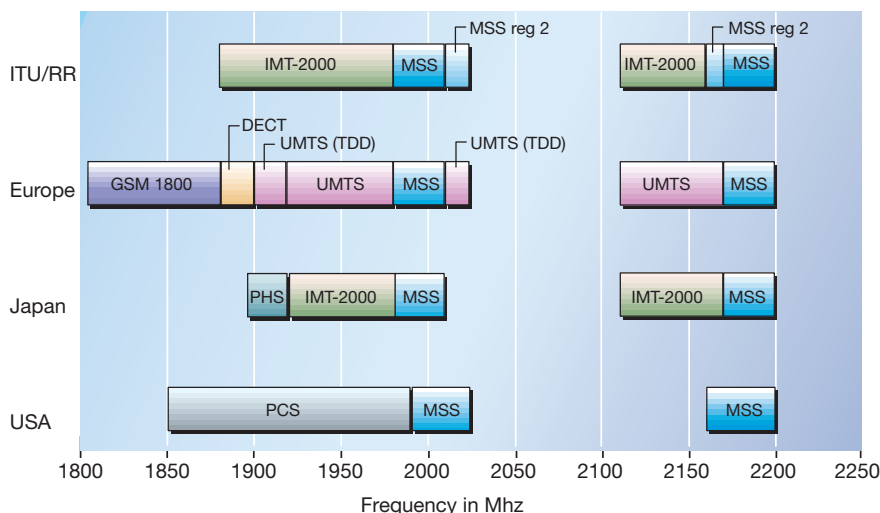
Figure 2  
Examples of second-generation mobile radio coverage.

radio access must use the radio spectrum and network resources in a cost-effective fashion.

### Migration

To succeed, the third-generation standards must facilitate efficient migration from second-generation radio access. The introduction of multimedia into mobile communication will proceed gradually over time. Thus, a step-by-step migration plan must be catered for that begins with the state of present-day second-generation systems.

Figure 3  
Spectrum allocation.



Given that there are four separate second-generation standards (GSM, TDMA, PDC, and IS-95), different migration paths must be offered.

### Spectrum allocation

Spectrum is allocated differently in different parts of the world. Moreover, the availability of spectrum varies greatly from operator to operator. In many regions of the world, new spectrum is to be allocated within parts of the 2 GHz IMT-2000 frequency band defined by the International Telecommunication Union (ITU). According to the ITU's recommendation, Europe will allocate 1920-1980 MHz and 2110-2170 MHz for the operation of frequency-division duplex (FDD), and 1900-1920 MHz and 2010-2025 MHz for the operation of time-division duplex (TDD). In Japan, an identical allocation has been made for the operation of FDD, but no allocation has been made for the operation of TDD. The allocation of spectrum in the USA differs from that of Europe and Japan (Figure 3), since parts of the 2 GHz frequency band have already been allocated for use by personal communication services (PCS) systems.

Although spectrum has been reserved in certain parts of the world for IMT-2000 services, this does not mean that similar services cannot be provided in other bands. For instance, EDGE (which is a migration path for GSM and TDMA/136) and multicarrier cdma2000 (which is a migration path for IS-95) support the majority of IMT-2000 services. Accordingly, we can expect to see the following developments in the market:

- operators will be allocated new spectrum, either paired (FDD) or unpaired (TDD) bands; and
- operators will migrate existing second-generation spectrum, adding support for third-generation services.

In summary, the third-generation standards must effectively cater for requirements for multimedia and flexibility, second-generation to third-generation migration, and spectrum allocation.

## Family of harmonized third-generation standards

Throughout the past decade, the ITU Radio Communications Sector (ITU-R) has elaborated on a framework for global third-generation standards. At the same time,

since the early 1990s, the industry has been actively researching third-generation radio access.

When the ITU-R issued a call for proposals, in 1998, ten terrestrial candidates were submitted. Although derived from different standards bodies, several of the candidates were quite similar.

The European Telecommunications Standards Institute (ETSI) responded with the UTRA terrestrial radio access (UTRA) interface (for IMT-2000).

In parallel to the wideband CDMA (WCDMA) activities in Europe, extensive work on third-generation WCDMA was being carried out in Japan, Korea, and the USA. The standardization bodies in these countries each submitted their own variants of WCDMA as candidates for IMT-2000. It should be noted, however, that considerable cooperation and coordination took place between the WCDMA proponents; therefore, in the end, the four variants of WCDMA were more or less identical. Today, there is only one WCDMA standard, since the regional standardization bodies—ETSI (Europe), T1P1 (USA), ARIB/TTC (Japan) and TTA(Korea) have joined forces in the 3G Partnership Project (3GPP).

The ITU also received other CDMA proposals:

- the cdma2000 specification proposed by standardization bodies in the USA and Korea (cdma2000 proposals contained two modes: a direct-spread mode across the entire 5 MHz band, and a multicarrier mode with three IS-95 carriers in a multicarrier format in the downlink); and
- the UWC-136 specification (EDGE and a wideband TDMA mode) proposed by TIA (USA).

In total, the ITU received three families of FDD proposals (WCDMA, cdma2000, and UWC-136) and three TDD proposals (UTRA/TDD, TD-SCDMA, and DECT—Europe, China and Europe respectively).

Since submitting these proposals to the ITU, the industry and standards bodies have coordinated their efforts to harmonize the IMT-2000 candidates and arrive at a smaller set of third-generation standards.

The most recent harmonization activity was initiated by the Operators Harmonization Group (OHG), a group of major operators from all parts of the world who operate different variants of second-generation systems (GSM, PDC, IS-136 and IS-95). The focus of this group's discussions has been on CDMA-based third-generation systems:

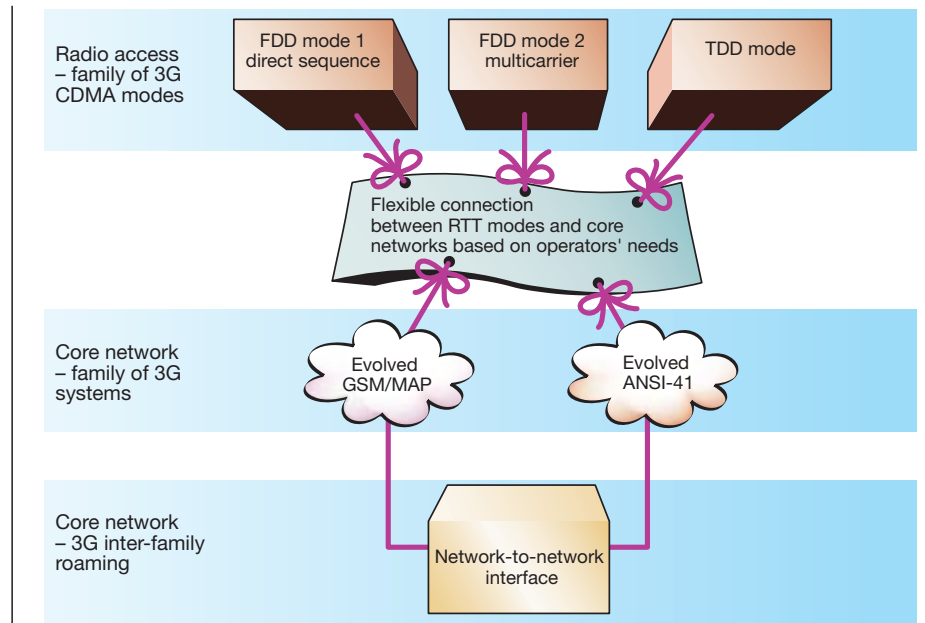


Figure 4  
OHG framework of the third-generation harmonization activity for different CDMA modes.

tems: UTRA FDD and TDD, cdma2000 (direct-spread and multicarrier) and TD-SCDMA. At its first meeting, the OHG set the framework for third-generation standards:

1. There must be three modes of CDMA-based radio interfaces:
  - direct-spread CDMA (DS);
  - multicarrier CDMA (MC); and
  - time-division duplex (TDD).
2. There must be two kinds of core network:
  - GSM-based core networks, including circuit-switched GSM and packet-switched GPRS; and
  - ANSI-41-based core networks, including circuit- and packet-switched networks.
3. All radio-access network modes must be able to connect to either type of core network (Figure 4).

In the spring of 1999, the OHG invited major manufacturers in the telecommunications industry to join the debate, and in May 1999, the OHG and participating manufacturers concluded the harmonization discussion at a meeting in Toronto, Canada, agreeing on the following CDMA-based third-generation systems:

- The direct-spread CDMA mode must be based on WCDMA (as specified by 3GPP), with some minor modifications

to the existing specifications (also specified by the 3GPP).

- The WCDMA standard must include hooks that make it possible to connect WCDMA with ANSI-41-based networks.
- The multicarrier mode must be based on the multicarrier cdma2000 mode (specified by 3GPP2).
- The multicarrier cdma2000 specifications must also include hooks that make it possible to connect multicarrier cdma2000 to GSM-based networks.
- The TDD mode must be based on the UTRA TDD mode—work is currently under way to harmonize the UTRA TDD mode with the Chinese TD-SCDMA system.
- The TDD specifications must allow for connections to GSM- and ANSI-41-based networks.

In summary, the harmonization activities resulted in a single third-generation CDMA standard with three modes: a direct-sequence mode based on WCDMA, a multicarrier mode based on cdma2000, and a TDD mode based on UTRA TDD, plus one third-generation TDMA standard being developed for EDGE/UWC-136. At present, the 3GPP and 3GPP2 standardization projects are working out the final details of the different third-generation CDMA modes with the intention of delivering the first complete specifications by the end of 1999.

## Harmonized family of four

For operators to provide third-generation services, the family of radio access standards must cater for every spectrum and migration scenario. To achieve this goal, the main

task of harmonizing third-generation radio-access systems has been to minimize the number of different air-interface techniques.

In keeping with early proposals from Ericsson, the industry and global standardization processes have now established a third-generation radio-access scenario, which we call the harmonized family of four.

In brief, the spectrum and migration criteria give four main categories of incompatible requirements for radio-access standards:

1. New, or modified, spectrum in paired duplex bands for areas covering third-generation mobile services. This category requires a new, flexible, radio-access technique which has been optimized for multimedia and which can most efficiently utilize new or modified spectrum bands (at least 2 · 5 MHz, preferably 2 · 15-20 MHz per operator). The technique best suited for this is the harmonized WCDMA solution being developed by the 3GPP.
2. New, or modified, unpaired spectrum. For unpaired bands, TDD is the only feasible option.
3. TDMA spectrum migration solution. EDGE, which was defined to support the migration of TDMA bands (either GSM or TDMA/136) toward third-generation mobile communication, introduces high-level modulation and link-adaptation techniques that significantly boost the bit-rate capabilities of TDMA while using the same frequencies. In combination with time-slot aggregation and packet switching, EDGE becomes an especially effective tool for migrating third-generation radio access into TDMA systems (GSM or TDMA/136).

### BOX C, GLOBAL THIRD-GENERATION STANDARD WITH FOUR OPTIONAL MODES

#### Wideband CDMA

##### Direct sequence

- WCDMA as per 3GPP
- New spectrum
- FDD
- Chip rate 3.84 Mcps
- Asynchronous (synchronous operation supported)
- Network signaling
  - phase 1 GSM/MAP
  - phase 2 ANSI-41

##### Multicarrier

- cdma2000 as per 3GPP2
- IS-95 spectrum overlay
- FDD
- Chip rate 3.6864 Mcps
- Synchronous
- Network signaling
  - phase 1 ANSI-41
  - phase 2 GSM/MAP

##### TDD

- As per 3GPP, harmonized with Chinese TD-SCDMA
- Unpaired spectrum operation (TDD)
- Chip rate 3.84 Mcps
- Network signaling
  - phase 1 GSM/MAP
  - phase 2 ANSI-41

#### TDMA

##### EDGE/UWC-136

- As per ETSI/UWC
- Existing spectrum 200 kHz TDMA
- high-level modulation
- with link adaptation
- Network signaling
  - GPRS-based for both GSM/MAP and ANSI-41

4. CDMA/IS-95 spectrum migration solution. To introduce wideband services into the existing IS-95 spectrum, a spectrum overlay solution utilizes either one 1.25 MHz carrier (1X) or three 1.25 MHz carriers (3X) for the downlink. This spectrum-overlay strategy enables second-generation and third-generation services to coexist on the same frequencies.

## Direct sequence

WCDMA has been chosen as the basic radio-access technology for UMTS/IMT-2000 in all major areas of the world. Apart from high-bit-rate services, the WCDMA radio interface offers significant improvements over second-generation narrowband CDMA, including

- improved coverage and capacity, thanks to greater bandwidth and improved coherent uplink detection;
  - support for inter-frequency handover, which is necessary for large-capacity hierarchical cell structures (HCS);
  - support for capacity-enhancing technologies, such as adaptive antennas and multi-user detection; and
  - a fast and efficient packet-access protocol.
- UTRA includes FDD and TDD modes. The FDD mode is based on pure WCDMA, whereas the TDD mode includes an additional TDMA component according to the TD/CDMA proposal. This article focuses on the pure WCDMA-based FDD mode (UTRA/FDD).

## Background to WCDMA

Extensive research on WCDMA has been carried out in Europe for almost a decade. A WCDMA concept that fulfilled the third-generation requirements was first developed in the RACE Code-division Testbed (CODIT) project (1992-1995). The CODIT concept also served as the basis for the hardware test beds that were used to evaluate and verify the performance of WCDMA technology. One example of hardware fashioned after the CODIT concept is the Ericsson Wideband Test Bed (WBTB).

The WCDMA technology was further refined into the FRAMES Multiple Access 2 (FMA2) concept developed within the FRAMES project. In March 1997, the FMA2 concept was submitted to ETSI as a candidate technology for UTRA. Within ETSI, the FMA2 proposal was then merged with other WCDMA proposals into the

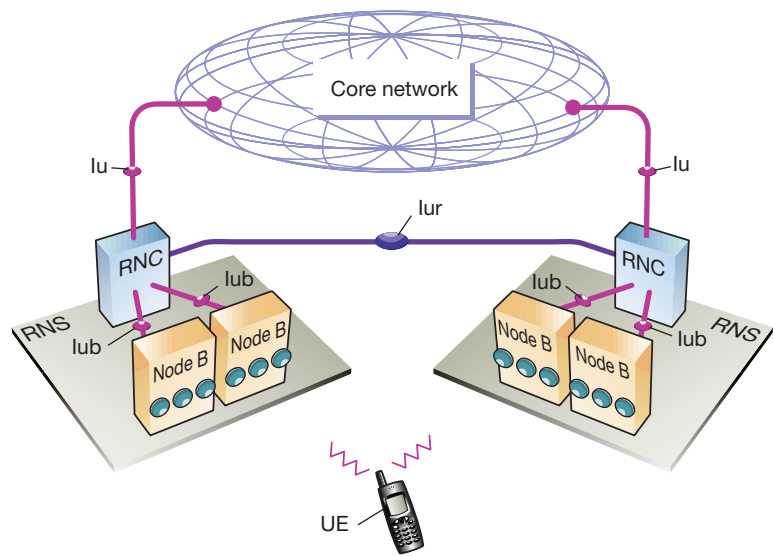


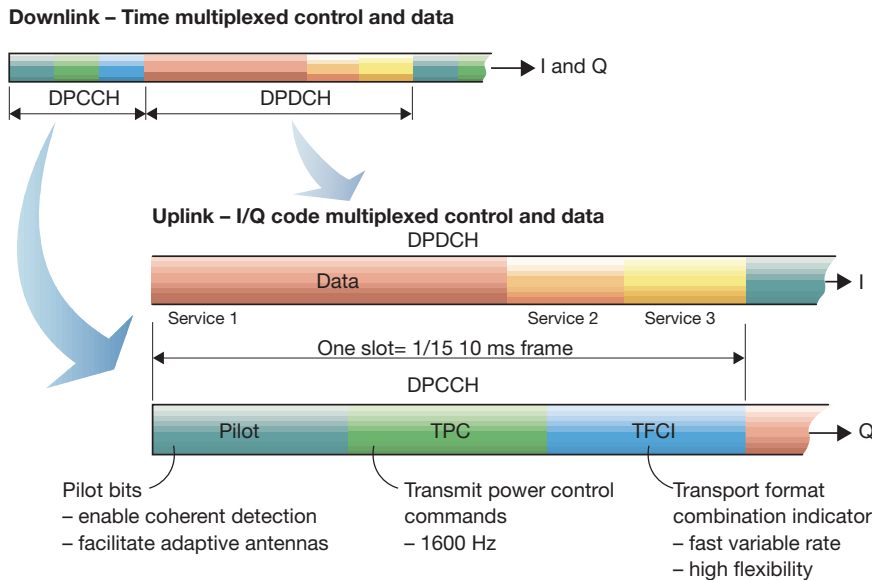
Figure 5  
UMTS terrestrial radio access network (UTRAN).

ETSI Alpha concept. Finally, in January 1998, ETSI selected the WCDMA-based Alpha concept as the main technology for UTRA FDD.

Work on further enhancements and refinements of UTRA continued within ETSI. The aim of this work was to have a complete description of the radio interface drafted by the end of 1998. Since early 1999, WCDMA standardization has continued within the 3GPP, whose task is to specify a third-generation system with the UTRA radio-access network connected to a GSM-based core network.

### WCDMA description

A close examination of the radio parts of WCDMA shows that several interfaces and functional splits must be standardized (Figure 5). A comparison of the WCDMA architecture with that of GSM shows that the UTRA network (UTRAN) corresponds to the base station subsystem (BSS). Likewise, the Iu interface between UTRAN and the core network corresponds to the A-interface in GSM (Gb interface in GPRS). The Iub interface corresponds to the A' interface. The Iur interface between the radio network controllers, which supports soft-handover functionality, is new. Finally, we have the air interface between the base station and the terminal (nodes B and UE in Figure 5).



**Figure 6**  
Structure of WCDMA physical layer.

Proceeding from the premise that a radio interface is to be based on direct-sequence WCDMA, designers can build a system whose properties fulfill the third-generation requirements. The key properties emphasized in WCDMA are improved performance, a high degree of service flexibility, and a high degree of operator flexibility. By improved performance we mean improved capacity, improved coverage, and third-generation services from second-generation deployment. By service flexibility we mean support of a wide range of services with maximum bit rates exceeding 2 Mbit/s, the ability to provide multiple services on one connection, and a fast and efficient packet-access scheme. And by operator flexibility we mean support for asynchronous inter-base-station operation (which makes for easier deployment in many environments), efficient support for various deployment scenarios, including hierarchical cell structures at hot-spots, and support for evolutionary technologies, such as adaptive antenna arrays and multi-user detection.

As was noted above, the WCDMA standard must contain necessary hooks for future performance enhancements, such as the introduction of smart antenna solutions. This is supported through user-specific pilot information, which is used for direct-

ing antenna beams to the end-user (Figure 6).

To facilitate channel estimation in the terminal, each connection uses a different antenna pattern, which is part of the channel. Other important details in the physical layer are the transmit power control (TPC) commands, and the transport format combination indicator (TFCI). Note: Although it is only necessary for the uplink, the TPC is included in both the uplink and the downlink, since it improves downlink performance. The TFCI facilitates support for fast variable rate, giving improved flexibility.

Another important feature is support for hierarchical cell structures (Figure 7). In an HCS scenario, the two cell layers operate on two separate frequencies. In CDMA, transmission and reception are usually continuous without time for inter-frequency measurements. This implies that measurement support is not provided for handover decisions. To overcome this problem, a compressed mode feature has been introduced. By means of this technique, data is compressed—basically by doubling the power and reducing the spreading factor by one half—which creates a free gap in time for making measurements.

### Hooks and extensions

The initial WCDMA specifications from the 3GPP (prior to the OHG agreement) called for a CDMA system with a chip rate of 4.096 Mcps time-multiplex pilot information for all physical channels. However, the OHG agreement stipulates that the DS mode (WCDMA) should have a chip rate of 3.84 Mcps, to allow for easier implementation of DS and MC dual-mode terminals. The argument is that if the chip rate of the two modes differs by less than 5%, then it will be easier to use the same radio frequency chain in both modes.

The OHG also stipulates that the DS mode should have a common code-multiplex pilot. For cells that lack smart antennas or do not use sophisticated transmit diversity schemes, the common code-multiplex pilot is said to outperform the common time-multiplex pilot.

These modifications (chip rate and common pilot) have been incorporated into the most recent drafts of the 3GPP specifications.

As mentioned earlier, it must be possible to connect the WCDMA radio interface to an ANSI-41 network. Figure 8 shows how this is accomplished in accordance with the OHG agreement.

The connection of WCDMA to a GSM network or to an ANSI-41 network should use the radio protocols defined in 3GPP. Until now, however, 3GPP has only defined a WCDMA-to-GSM core-network connection. Consequently, some hooks (modifications of) and extensions (additions) to the WCDMA radio protocols may be required to guarantee that all services and functionality in an ANSI-41 network can be used together with the WCDMA radio interface. These hooks and extensions have been identified, and the work of specifying them is well under way in the 3GPP and 3GPP2 (completion is expected in March 2000). The hooks to WCDMA protocols must be incorporated into the 1999 draft of the WCDMA specifications; the extensions can be added to subsequent drafts. Call control (CC) and mobility management (MM) are taken from GSM when connecting to a GSM network, and from IS-634 when connecting to an ANSI-41 network.

## EDGE

Two of the major second-generation standards, GSM and TDMA/136, have built the foundation from which to offer a common global radio access for data services. By exploiting a common physical layer (EDGE), each standard follows the same migration path toward providing third-generation services.

EDGE is currently the subject of standardization, the first phase of which will be finalized by the end of 1999, followed by a second phase in the year 2000. Compared to the data services currently available from GSM and TDMA/136, EDGE provides significantly higher user bit rates and spectral efficiency.

EDGE was first proposed to ETSI in the beginning of 1997, as a means of evolving GSM. EDGE reuses the GSM carrier bandwidth and time-slot structure and provides an efficient way of increasing bit rates, thereby facilitating the evolution of existing cellular systems toward third-generation capabilities.

In developing its third-generation wireless technology, the TDMA/136 community opted to base its proposal on the evolution of second-generation systems. In January 1998, the Universal Wireless Communications Consortium (UWCC) adopted EDGE as the outdoor component of the 136 High Speed radio interface, to provide 384 kbit/s data services. Arguments in favor of

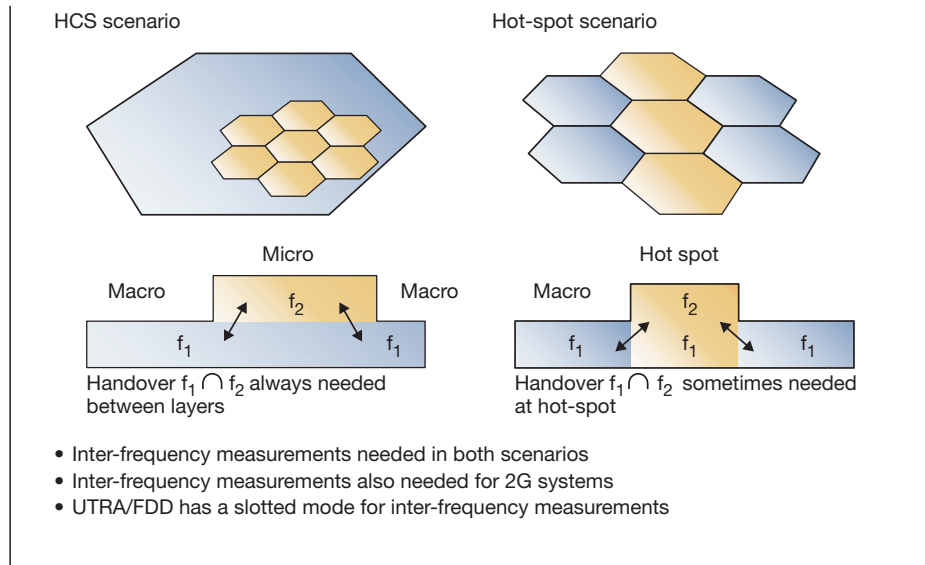


Figure 7 Support for HCS (inter-frequency handover).

this approach are that the technology applies to both GSM and TDMA/136 systems and that it paves the way for global roaming. EDGE has since been developed concurrently by ETSI and the UWCC to guarantee a high degree of synergy for GSM and TDMA/136 alike.

The roadmap for EDGE standardization shows two phases. Initially, emphasis will be placed on enhanced GPRS (EGPRS) and

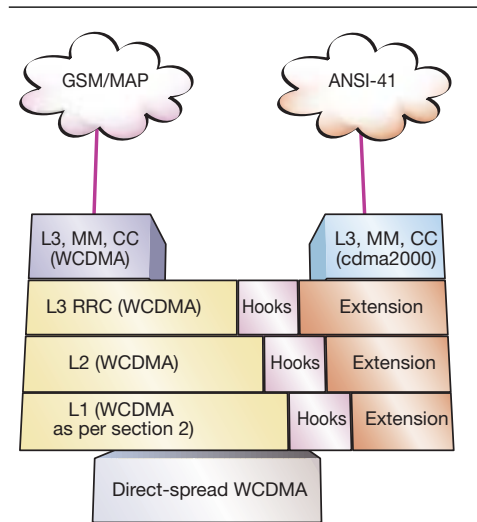


Figure 8 Connection of WCDMA to GSM and ANSI-41 networks. The words "Hooks" and "Extensions" indicate modifications and additions respectively.

Figure 9  
Typical channel quality distribution (left) and, given an eight-slot terminal (right), perceived user quality in terms of bit rate for EDGE and standard GPRS.

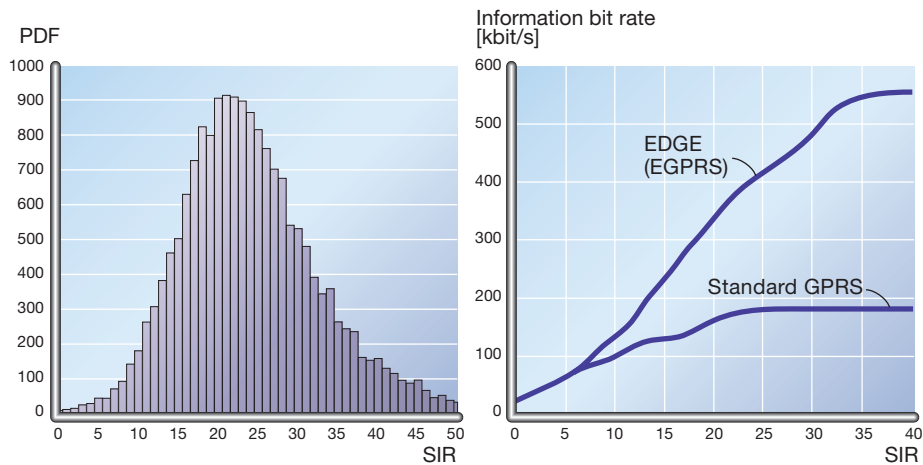
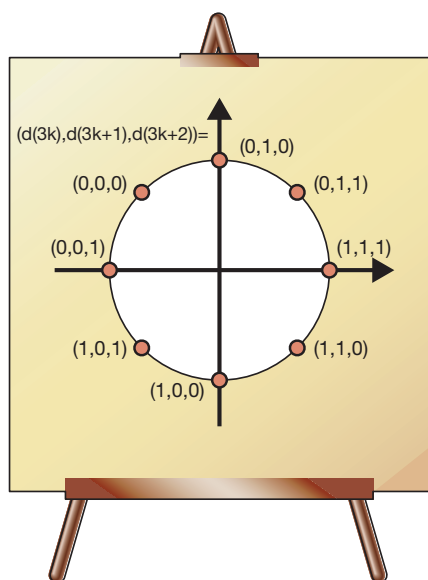


Figure 10  
8PSK modulation: signal constellation in the phase plane.



enhanced circuit-switched data (ECSD). ETSI aims to release standards for these technologies in 1999. Products will appear shortly afterward. The second phase of standardization, which is targeted for release in 2000, will define improvements for multimedia and real-time services. Other objectives will include the alignment of services with the universal mobile telecommunications system (UMTS) and evolution toward a radio-access network which is independent of the core network (CN) and which will allow EDGE and UMTS to share a common core network.

### EDGE phase I

EDGE phase I is primarily concerned with improving the radio interface. However, in a more general context, it can also be viewed as a system concept that allows the GSM and TDMA/136 radio access networks to offer a set of new radio access bearers to their core networks.

A fundamental characteristic of cellular systems is that, in terms of signal-to-interference ratio (SIR), different end-users tend to experience different channel quality due to differences in distance to the base station, fading, and interference. Figure 9 (left) shows a typical distribution of channel quality in a system. Notice that a large part of the population experience excessive

SIR; that is, excellent channel quality from which they cannot benefit using traditional service, such as voice. Thus, we see that there is room for improving spectral efficiency.

### Basic parameters of the radio interface

The EDGE air interface is intended to facilitate higher bit rates than those currently achievable in present-day cellular systems. To increase the gross bit rate, linear high-level modulation is introduced. The eight-phase shift keying (8PSK) modulation scheme was selected for its high data rates, high spectral efficiency and moderately complex implementation (Figure 10). The Gaussian minimum-shift keying (GMSK) modulation defined in GSM is also part of the EDGE system concept. The symbol rate of each modulation is 271 kbps, which yields a gross bit rate per time slot (including two stealing bits per burst) of 22.8 kbit/s for GMSK and 69.2 kbit/s for 8PSK. The 8PSK pulse shape is linearized GMSK, meaning that 8PSK fits into the GSM spectrum mask.

Many EDGE physical-layer parameters are identical to those of GSM. The carrier spacing is 200 kHz, and the TDMA frame structure of GSM is unchanged. Moreover, the 8PSK burst format is similar: a burst includes a training sequence of 26 symbols in

the middle, 3 tail symbols at either end and 8.25 guard symbols at one end. Each burst carries  $2 \cdot 58$  data symbols, each of which is composed of three bits (Figure 11).

#### Radio protocol design

When possible, the EDGE radio protocol strategy reuses the protocols of GSM and GPRS. This minimizes the need for implementing new protocols. However, due to the higher bit rates and to new insights obtained through research, some protocols have been modified to optimize performance. The EDGE concept includes a packet-switched mode (EGPRS) and a circuit-switched mode (ECSD).

#### Packet-switched transmission—EGPRS

The current GSM/GPRS standard supports data rates from 11.2 to 22.8 kbit/s per time slot. By contrast, EGPRS will allow data rates from 11.2 to 59.2 kbit/s per time slot, which in a multislot configuration yields a data rate well over 384 kbit/s.

Due to the higher bit rate and the need for adapting the data protection to channel quality, the EDGE radio link control (RLC) protocol is somewhat changed from the corresponding GPRS protocol. The main changes involved improving the link quality control scheme. As mentioned, above, link quality control is a common term for techniques that adapt the robustness of the radio link to varying channel quality. Examples of link quality control techniques are link adaptation and incremental redundancy.

A link-adaptation scheme regularly estimates link quality and selects the most appropriate modulation and coding scheme for coming transmissions, in order to maximize the user bit rate. Incremental redundancy is another way of coping with variations in link quality. According to this scheme, information is initially sent with very little coding, which if decoding is immediately successful, yields a high bit rate. If decoding fails, additional coded bits (redundancy) are sent until the decoding succeeds. More coding means lower bit rate and greater delay.

EGPRS supports a combined link-adaptation and incremental-redundancy scheme, in which the initial code rate for incremental redundancy is based on measurements of link quality. The benefits of this approach are robustness and high throughput of the incremental redundancy operation in combination with shorter delays and reduced memory requirements.

#### Circuit-switched transmission—ECSD

The current GSM standard supports transparent and non-transparent radio access bearers. Eight transparent bearers are defined, offering constant bit rates in the range of 9.6 to 64 kbit/s.

A non-transparent bearer employs a radio link protocol to ensure virtually error-free data delivery. Eight bearers offer maximum user bit rates ranging from 4.8 to 57.6 kbit/s. The actual user bit rate may vary according to channel quality and the resulting rate of retransmission.

The introduction of EDGE does not affect the bearer definitions; that is, the bit rates remain unchanged. However, the way in which the bearers are realized, in terms of channel coding schemes, is new. For example, with EDGE, a 57.6 kbit/s non-transparent bearer can be realized with two time slots, whereas with standard GSM (using the TCH/F14.4 coding scheme) the same bearer requires four time slots. Thus, EDGE circuit-switched transmission yields high-bit-rate bearers using fewer time slots.

#### EDGE phase II

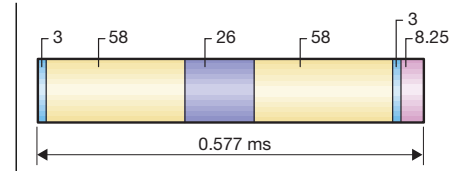
The main focus of EDGE phase II will be on real-time services delivered via the Internet protocol (IP); for example, voice over IP (VoIP). The introduction of these services will have an impact on radio access, the system architecture, and the core network. A single core network for UTRA and EDGE radio access will thus evolve.

## Multicarrier

Originally, the cdma2000 specification contained the variants, 1X, 3X and direct-spread. After the harmonization work has been concluded, the global direct-spread multicarrier will be based on WCDMA, thereby putting an end to work on cdma2000 DS. In essence, 1X and 3X are specified in such a way that it is possible to add a spectrum-overlay solution.

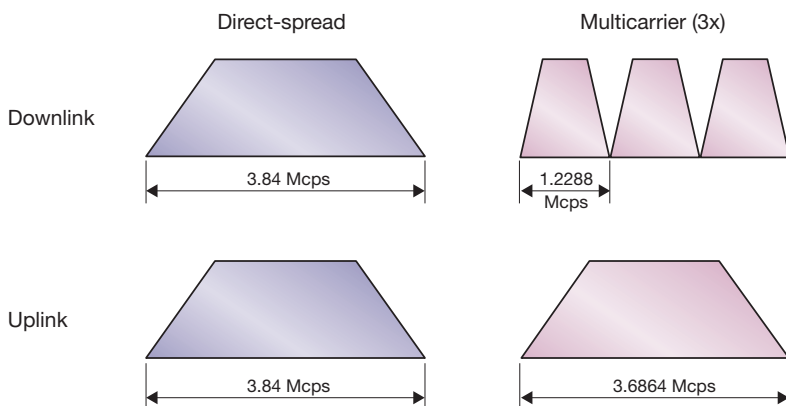
To utilize spectrum overlay on current IS-95 services, the solution must reuse much of the IS-95 lower layers. The multicarrier (1X, 3X) signal must also maintain orthogonality to the underlying IS-95 carriers in the downlink. A 1.25 MHz carrier is used for 1X. Notwithstanding, several aspects of 1X have been enhanced to better suit third-generation services.

The use of 3X triples the bandwidth capabilities of reaching the highest bit rates envisaged for third-generation radio access.



**Figure 11**

The burst format for EDGE is similar to that of GSM. It includes a training sequence of 26 symbols in the middle, 3 tail symbols at either end, and 8.25 guard symbols at one end. Each burst carries  $2 \cdot 58$  data symbols.



**Figure 12**  
Overlaying in spectrum.

This is accomplished by multicasting the wideband signal in three 1.25 MHz carriers on the downlink. To avoid unnecessary terminal complexity associated with transmitting three carriers, direct spread is also used for the 3X uplink (Figure 12).

In contrast to the direct-spread mode, the multicarrier mode does not use a wideband CDMA carrier on the downlink. Instead,

data is converted from serial to parallel and transmitted in several parallel narrowband CDMA carriers, each of which has the same characteristics as a second-generation IS-95 carrier.

Multicarrier downlink transmission facilitates the overlay of a third-generation system on top of a second-generation IS-95 system. Although slightly less efficient than the direct-spread mode, the multicarrier mode permits IS-95 operators with limited spectrum to offer third-generation services (operators who cannot exclusively allocate a part of their spectrum to third-generation services).

The uplink of the multicarrier mode is similar to the uplink of the direct-spread mode; that is, it uses a wideband carrier. However, compared to the direct-spread mode, the uplink of the multicarrier mode uses a somewhat lower chip rate in order to match the chip rate of the multicarrier downlink.

The 1X mode is evolved narrowband IS-95 with 1.25 MHz bandwidth. Regular operation of the multicarrier mode calls for three carriers in parallel (3X), which corresponds to a bandwidth of approximately 3.75 MHz. However, other modes may also be standardized (6X, 9X, 12X) with corresponding increases in bandwidth. Because each carrier of the multicarrier downlink should have the same characteristics as an IS-95 downlink carrier, tight intercell synchronization is required, typically by means of global positioning satellite (GPS) reception. This does not apply to the direct-spread mode, which is based on asynchronous WCDMA.

The direct-spread mode consists of wideband CDMA carriers on the uplink and downlink. The multicarrier mode consists of a wideband CDMA carrier on the uplink and numerous parallel narrowband CDMA carriers on the downlink. The chip rate of the carriers on the multicarrier downlink is identical to that of IS-95. The chip rate of the carriers on the multicarrier uplink is exactly three times that of the downlink carriers.

## TDD

In WCDMA, multicarrier, and EDGE modes, the uplink and downlink are separated by means of frequency division. However, in the time-division duplex mode, the uplink and downlink are separated by means of time division. Consequently, in the TDD

### BOX D, APPLICATION SCENARIOS FOR THE TDD MODE

#### Scenario A—enhancing capacity at hot spots in FDD systems

The operator uses FDD in the initial deployment of the third-generation system. Over time, due to the popularity of mobile Internet, the operator might experience capacity problems at certain hot spots, such as shopping malls, airports, and city centers. A TDD system could then be used to provide extra capacity—much in the same way as GSM 1800 is currently used to enhance GSM 900.

#### Scenario B—uncoordinated business systems

A public FDD system operator licenses spectrum to private operators for use in indoor business systems in limited geographical areas. With a dual-mode FDD/TDD terminal, the public operator can cover the business market and extend the services of the public network to users in these environments. (Scenarios A and

B are likely to occur after the FDD systems have been in operation for a few years.)

#### Scenario C—terminal-to-terminal communication

Since terminals must be able to transmit and receive in the same frequency band, according to an approved time schedule, the basic mechanisms for terminal-to-terminal communication are present, opening the door to a completely new range of possibilities:

- Because terminals can relay information between themselves, they can form their own *ad hoc* networks.
- Radio performance and operating times can be improved with multihop networks that transmit data—without path loss—from terminal to terminal until it reaches the base station.
- To prevent dropped calls, operators could use cheap relaying terminals to cover radio shadows.

mode only one frequency band is needed to carry both uplink and downlink traffic. This mode of operation is useful since unpaired spectrum is still available in some parts of the world, mainly Europe. Obviously, paired spectrum is preferred, since it supports FDD allocations. But because it may be difficult to find global allocations of paired spectrum, additional unpaired spectrum slots will probably be identified in the future.

Apart from the physical layer, the main radio parameters and spectral characteristics of TDD are the same as for WCDMA FDD. Because the uplink and downlink are separated in the time domain instead of in the frequency domain, synchronized base stations are needed to manage who may transmit, and when. Otherwise, severe interference results.

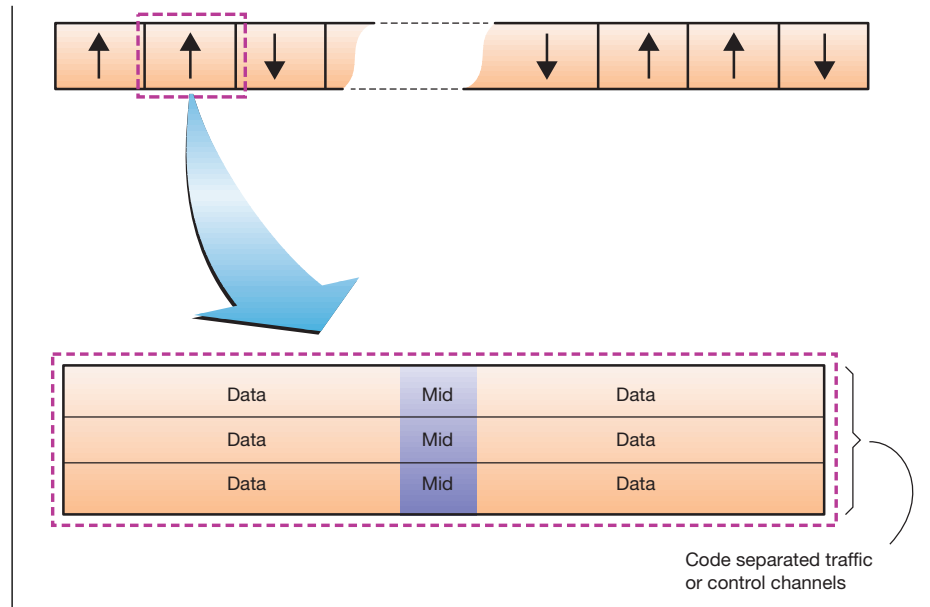
Each radio frame is divided into eight time slots, each of which carries a number of overlaid channels separated by means of code-division techniques (Figure 13). Thus, the TDD mode shares features from TDMA and CDMA. Each slot is allocated a direction for uplink traffic or downlink traffic. The allocation of slots is not predefined, however. Some flexibility is inherent in the TDD mode for accommodating asymmetric services. For example, if the greater part of the traffic is expected on the downlink, then the majority of the slots can be allocated to the downlink.

Midambles are used to estimate channel response. These and other important parameters are designed to facilitate multiuser detection techniques for better performance.

In terms of bit rates, switching method (packet or circuit), asymmetry, and so on, the basic services of the TDD mode are the same as for the WCDMA FDD mode. Although it has no immediate built-in limitations, the TDD mode is best suited for small cells (pico or micro) with little to moderate delay spread (Box D).

## Conclusion

Regional standardization bodies and members of the telecommunications industry have established a global scenario—composed of four optional modes (DS, EDGE, MC and TDD)—for the third generation of radio access standards. The newly harmonized family of third-generation standards caters for requirements for multimedia and flexibility, spectrum allocation, and suc-



**Figure 13**  
Aspects of time and code division. Slots separated by time. Each slot is assigned a direction—uplink or downlink.

cessful migration from second-generation systems.

In terms of migrating major second-generation systems to a fullness of third-generation capabilities, the industry has agreed that there must be one mode of TDMA-based and three modes of wideband CDMA-based radio interfaces and two kinds of core network. In addition, each radio-access network mode must be able to connect to either type of core network.

The 3GPP aims to deliver the first complete specification of the WCDMA (direct-sequence) and TDD modes by the end of 1999. The 3GPP2 will also deliver a complete specification of the cdma2000 multi-carrier mode by the end of 1999. Similarly, EDGE phase I will be finalized by the end of 1999. EDGE phase II will be complete in 2000.