Ojanpera, T. & Gray, S.D. “An Overview of cdma2000, WCDMA, and EDGE”
Mobile Communications Handbook
Ed. Suthan S. Suthersan
Boca Raton: CRC Press LLC, 1999

An Overview of cdma2000, WCDMA, and EDGE

Tero Ojanpera
Nokia Research Center

Steven D. Gray
Nokia Research Center

Abstract—In response to the International Telecommunications Union's (ITU) call for proposals, third generation cellular technologies are evolving at a rapid pace where different proposals are vying for the future market place in digital wireless multimedia communications. While the original intent for third generation was to have a convergence of cellular based technologies, this appears to be an unrealistic expectation. As such, three technologies key for the North American and European markets are the third generation extension of TIA/EIA-95B based Code Division Multiple Access (CDMA) called cdma2000, the European third generation CDMA called WCDMA, and the third generation Time Division Multiple Access (TDMA) system based on EDGE. For packet data, EDGE is one case where second generation technologies converged to a single third generation proposal with convergence of the US TDMA system called TIA/EIA-136 and the European system GSM. This chapter provides an overview of the air interfaces of these key technologies. Particular attention is given to the channel structure, modulation, and offered data rates of each technology. A comparison

is also made between cdma2000 and WCDMA to help the reader understand the similarities and differences of these two CDMA approaches for third generation.

36.1 Introduction

The promise of third generation is a world where the subscriber can access the World Wide Web (WWW) or perform file transfers over packet data connections capable of providing 144 kbps for high mobility, 384 kbps with restricted mobility, and 2 Mbps in an indoor office environment [1]. With these guidelines on rate from the ITU, standards bodies started the task of developing an air interface for their third generation system. In North America, the Telecommunications Industry Association (TIA) evaluated proposals from TIA members pertaining to the evolution of TIA/EIA-95B and TIA/EIA-136. In Europe, the European Telecommunications Standards Institute (ETSI) evaluated proposals from ETSI members pertaining to the evolution of GSM.

While TIA and ETSI were still discussing various targets for third generation systems, Japan began to roll out their contributions for third generation technology and develop proof-of-concept prototypes. In the beginning of 1997, the Association for Radio Industry and Business (ARIB), a body responsible for standardization of the Japanese air interface, decided to proceed with the detailed standardization of a wideband CDMA system. The technology push from Japan accelerated standardization in Europe and the U.S. During 1997, joint parameters for Japanese and European wideband CDMA proposals were agreed. The air interface is commonly referred to as WCDMA. In January 1998, the strong support behind wideband CDMA led to the selection of WCDMA as the UMTS terrestrial air interface scheme for FDD (Frequency Division Duplex) frequency bands in ETSI. In the U.S., third generation CDMA came through a detailed proposal process from vendors interested in the evolution of TIA/EIA-95B. In February 1998, the TIA committee TR45.5 responsible for TIA/EIA-95B standardization adopted a framework that combined the different vendors' proposals and later became known as cdma2000.

For TDMA, the focus has been to offer IS-136 and GSM operators a competitive third generation evolution. WCDMA is targeted toward GSM evolution; however, Enhanced Data Rates for Global TDMA Evolution (EDGE) allows the operators to supply IMT-2000 data rates without the spectral allocation requirements of WCDMA. Thus, EDGE will be deployed by those operators who wish to maintain either IS-136 or GSM for voice services and augment these systems with a TDMA-based high rate packet service. TDMA convergence occurred late in 1997 when ETSI approved standardization of the EDGE concept and in February 1998 when TIA committee TR45.3 approved the UWC-136 EDGE-based proposal.

The push to third generation was initially focused on submission of an IMT-2000 radio transmission techniques (RTT) proposal. To date, the evaluation process has recently started in ITU [2] where Fig. 36.1 depicts the time schedule of the ITU RTT development. Since at the same time regional standards have started the standards writing process, it is not yet clear what is the relationship between the ITU and regional standards. Based upon actions in TIA and ETSI, it is reasonable to assume that standards will exist for cdma2000, WCDMA, and EDGE and all will be deployed based upon market demands.

The chapter is organized as follows: issues effecting third generation CDMA are discussed followed by a brief introduction of cdma2000, WCDMA, and EDGE. A table comparing cdma2000 and WCDMA is given at the end of the CDMA section. For TDMA, an overview of the IS-136-based evolution is given including the role played by EDGE.

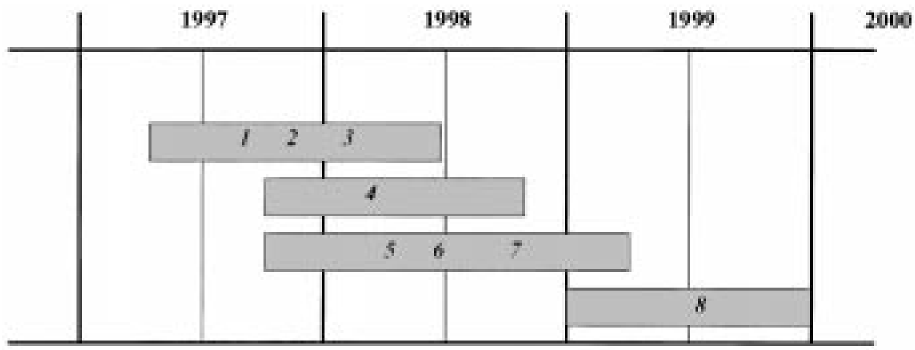

FIGURE 36.1: ITU timelines: 1, 2, 3—RTTs request, development, & submission; 4—RTT evaluation; 5—review outside evaluation; 6—assess compliance with performance parameters; 7—consideration of evaluation results and consensus on key characteristics; 8—development of detailed radio interface specifications.

36.2 CDMA-Based Schemes

Third generation CDMA system descriptions in TIA and ETSI have similarities and differences. Some of the similarities between cdma2000 and WCDMA are variable spreading, convolutional coding, and QPSK data modulation. The major differences between cdma2000 and WCDMA occur with the channel structure, including the structure of the pilot used on the forward link. To aid in comparison of the two CDMA techniques, a brief overview is given to some important third generation CDMA issues, the dedicated channel structure of cdma2000 and WCDMA, and a table comparing air interface characteristics.

36.3 CDMA System Design Issues

36.3.1 Bandwidth

An important design goal for all third generation proposals is to limit spectral emissions to a 5 MHz dual-sided passband. There are several reasons for choosing this bandwidth. First, data rates of 144 and 384 kbps, the main targets of third generation systems, are achievable within 5 MHz bandwidth with reasonable coverage. Second, lack of spectrum calls for limited spectrum allocation, especially if the system has to be deployed within the existing frequency bands already occupied by the second generation systems. Third, the 5 MHz bandwidth improves the receiver's ability to resolve multipath when compared to narrower bandwidths, increasing diversity and improving performance. Larger bandwidths of 10, 15, and 20 MHz have been proposed to support highest data rates more effectively.

36.3.2 Chip Rate

Given the bandwidth, the choice of chip rate depends on spectrum deployment scenarios, pulse shaping, desired maximum data rate and dual-mode terminal implementation. Figure 36.2 shows the relation between chip rate (CR), pulse shaping filter roll-off factor (α) and channel separation (Δf). If raised cosine filtering is used, spectrum is zero (in theory) after CR/2($1+\alpha$). In Fig. 36.2, channel separation is selected such that two adjacent channel spectra do not overlap. Channel separation

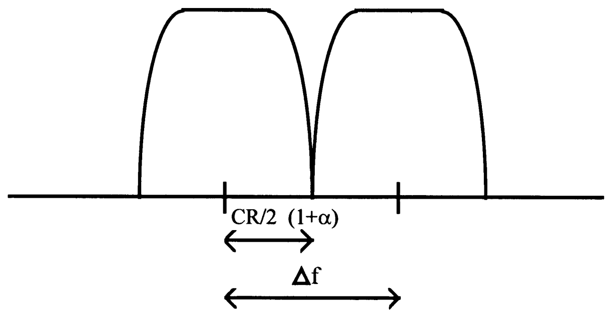

FIGURE 36.2: Relationship between chip rate (CR), roll-off factor (α), and channel separation (Δf).

should be selected this way, if there can be high power level differences between the adjacent carriers. For example, for WCDMA parameters minimum channel separation ($\Delta f_{\min}$) for nonoverlapping carriers is $\Delta f_{\min} = 4.096(1 + 0.22) = 4.99712$ MHz. If channel separation is selected in such a way that the spectrum of two adjacent channel signals overlap, some power leaks from one carrier to another. Partly overlapping carrier spacing can be used, for example, in micro cells where the same antenna masts are used for both carriers.

A designer of dual-mode terminals needs to consider the relation between the different clock frequencies of different modes. Especially important are the transmitter and receiver sampling rates and the carrier raster. A proper selection of these frequencies for the standard would ease the dual mode terminal implementation. The different clock frequencies in a terminal are normally derived from a common reference oscillator by either direct division or synthesis by the use of a PLL. The use of a PLL will add some complexity. The WCDMA chip rate has been selected based on consideration of backward compatibility with GSM and PDC. cdma2000 chip rate is a direct derivation of the TIA/EIA-95B chip rate.

36.3.3 Multirate

Multirate design means multiplexing different connections with different quality of service requirements in a flexible and spectrum efficient way. The provision for flexible data rates with different quality of service requirements can be divided into three subproblems: how to map different bit rates into the allocated bandwidth, how to provide the desired quality of service, and how to inform the receiver about the characteristics of the received signal. The first problem concerns issues like multicode transmission and variable spreading. The second problem concerns coding schemes. The third problem concerns control channel multiplexing and coding.

Multiple services belonging to the same session can be either time- or code-multiplexed as depicted in Fig. 36.3. The time multiplexing avoids multicode transmissions thus reducing peak-to-average power of the transmission. A second alternative for service multiplexing is to treat parallel services completely separate with separate channel coding/interleaving. Services are then mapped to separate physical data channels in a multicode fashion as illustrated in the lower part of Fig. 36.3. With this alternative scheme, the power, and consequently the quality, of each service can be controlled independently.

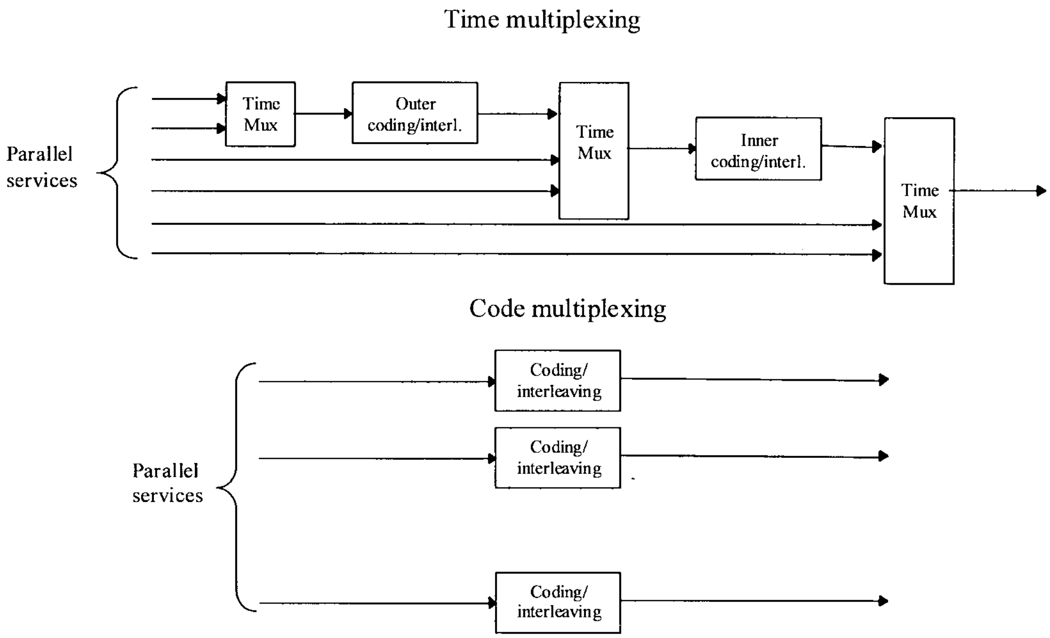

FIGURE 36.3: Time and code multiplexing principles.

36.3.4 Spreading and Modulation Solutions

A complex spreading circuit as shown in Fig. 36.4 helps to reduce the peak-to-average power and thus improves power efficiency.

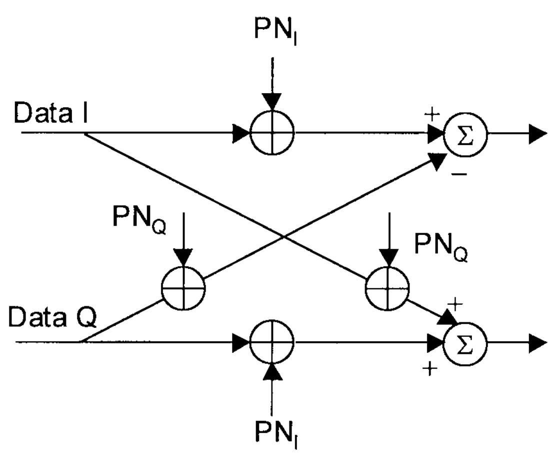

FIGURE 36.4: Complex spreading.

The spreading modulation can be either balanced- or dual-channel QPSK. In the balanced QPSK spreading the same data signal is split into I and Q channels. In dual-channel QPSK spreading the symbol streams on the I and Q channels are independent of each other. In the forward link, QPSK data modulation is used in order to save code channels and allow the use of the same orthogonal sequence for I and Q channels. In the reverse link, each mobile station uses the same orthogonal codes; this allows for efficient use of BPSK data modulation and balanced QPSK spreading.

36.3.5 Coherent Detection in the Reverse Link

Coherent detection can improve the performance of the reverse link up to 3 dB compared to non-coherent reception used by the second generation CDMA system. To facilitate coherent detection a pilot signal is required. The actual performance improvement depends on the proportion of the pilot signal power to the data signal power and the fading environment.

36.3.6 Fast Power Control in Forward Link

To improve the forward link performance fast power control is used. The impact of the fast power control in the forward link is twofold. First, it improves the performance in a fading multipath channel. Second, it increases the multiuser interference variance within the cell since orthogonality between users is not perfect due to multipath channel. The net effect, however, is improved performance at low speeds.

36.3.7 Additional Pilot Channel in the Forward Link for Beamforming

An additional pilot channel on the forward link that can be assigned to a single mobile or to a group of mobiles enables deployment of adaptive antennas for beamforming since the pilot signal used for channel estimation needs to go through the same path as the data signal. Therefore, a pilot signal transmitted through an omnicell antenna cannot be used for the channel estimation of a data signal transmitted through an adaptive antenna.

36.3.8 Seamless Interfrequency Handover

For third generation systems hierarchical cell structures (HCS), constructed by overlaying macro cells on top of smaller micro or pico cells, have been proposed to achieve high capacity. The cells belonging to different cell layers will be in different frequencies, and thus an interfrequency handover is required. A key requirement for the support of seamless interfrequency handover is the ability of the mobile station to carry out cell search on a carrier frequency different from the current one, without affecting the ordinary data flow. Different methods have been proposed to obtain multiple carrier frequency measurements. For mobile stations with receiver diversity, there is a possibility for one of the receiver branches to be temporarily reallocated from diversity reception and instead carry out reception on a different carrier. For single-receiver mobile stations, slotted forward link transmission could allow interfrequency measurements. In the slotted mode, the information normally transmitted during a certain time, e.g., a 10 ms frame, is transmitted in less than that time, leaving an idle time that the mobile can use to measure on other frequencies.

36.3.9 Multiuser Detection

Multiuser Detection (MUD) has been the subject of extensive research since 1986 when Verdu formulated an optimum multiuser detector for AWGN channel, maximum likelihood sequence estimation

(MLSE) [3]. In general, it is easier to apply MUD in a system with short spreading codes since cross-correlations do not change every symbol as with long spreading codes. However, it seems that the proposed CDMA schemes would all use long spreading codes. Therefore, the most feasible approach seems to be interference cancellation algorithms that carry out the interference cancellation at the chip level, thereby avoiding explicit calculation of the cross-correlation between spreading codes from different users [4]. Due to complexity, MUD is best suited for the reverse link. In addition, the mobile station is interested in detecting its own signal in contrast to the base station, which needs to demodulate the signals of all users. Therefore, a simpler interference suppression scheme could be applied in the mobile station. Furthermore, if short spreading codes are used, the receiver could exploit the cyclostationarity, i.e., the periodic properties of the signal, to suppress interference without knowing the interfering codes.

36.3.10 Transmit Diversity

The forward link performance can be improved in many cases by using transmit diversity. For direct spread CDMA schemes, this can be performed by splitting the data stream and spreading the two streams using orthogonal sequences or switching the entire data stream between two antennas. For multicarrier CDMA, the different carriers can be mapped into different antennas.

36.4 WCDMA

To aid in the comparison of cdma2000 and WCDMA, the dedicated frame structure of WCDMA is illustrated in Figs. 36.5 and 36.6. The approach follows a time multiplex philosophy where the Dedicated Physical Control Channel (DPCCH) provides the pilot, power control, and rate information and the Dedicated Physical Data Channel (DPDCH) is the portion used for data transport. The forward and reverse DPDCH channels have been convolutional encoded and interleaved prior to framing. The major difference between the forward and reverse links is that the reverse channel structure of the DPCCH is a separate code channel from the DPDCH.

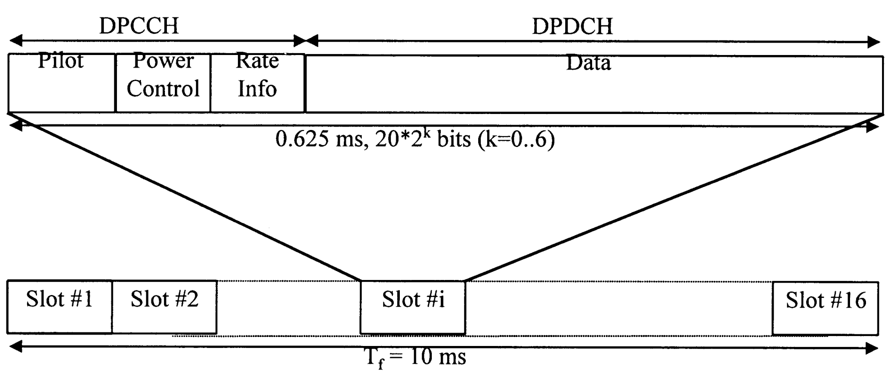

FIGURE 36.5: Forward link dedicated channel structure in WCDMA.

After framing, the forward and reverse link channels are spread as shown in Figs. 36.7 and 36.8. On the forward link orthogonal, variable rate codes, c_{ch}, are used to separate channels and pseudo

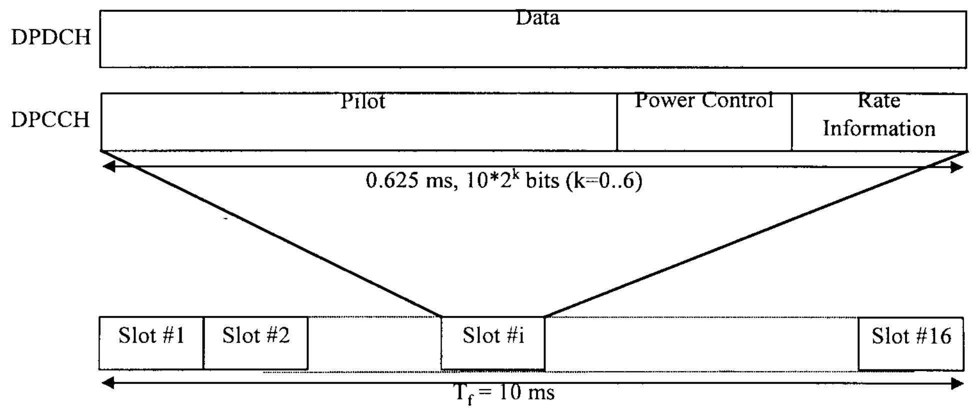

FIGURE 36.6: Reverse link dedicated channel structure in WCDMA.

random scrambling sequences, c_{scramb}, are used to spread the signal evenly across the spectrum and separate different base stations. On the reverse link, the orthogonal channelization codes are used as in the forward link to separate CDMA channels. The scrambling codes, c'_{scramb} and c''_{scramb}, are used to identify mobile stations and to spread the signal evenly across the band. The optional scrambling code is used as a means to group mobiles under a common scrambling sequence.

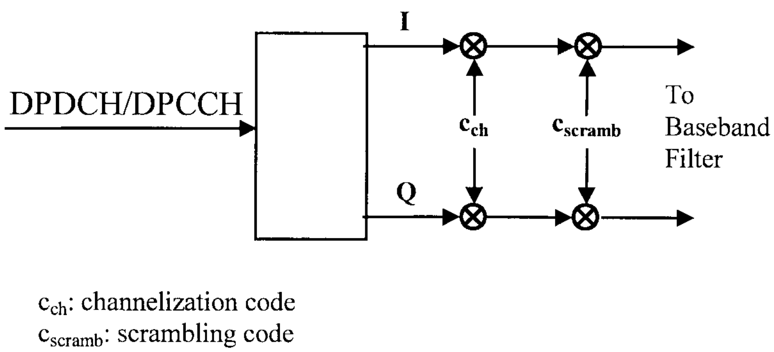

FIGURE 36.7: Forward link spreading of DPDCH and DPCCH.

36.4.1 Spreading Codes

WCDMA employs long spreading codes. Different spreading codes are used for cell separation in the forward link and user separation in the reverse link. In the forward link Gold codes of length 2^{18} are truncated to form cycles of 2^{16} times 10 ms frames. In order to minimize the cell search time, a special short code mask is used. The synchronization channel of WCDMA is masked with an orthogonal short Gold code of length 256 chips spanning one symbol. The mask symbols carry information about the BS long code group. Thus, the mobile station first acquires the short mask

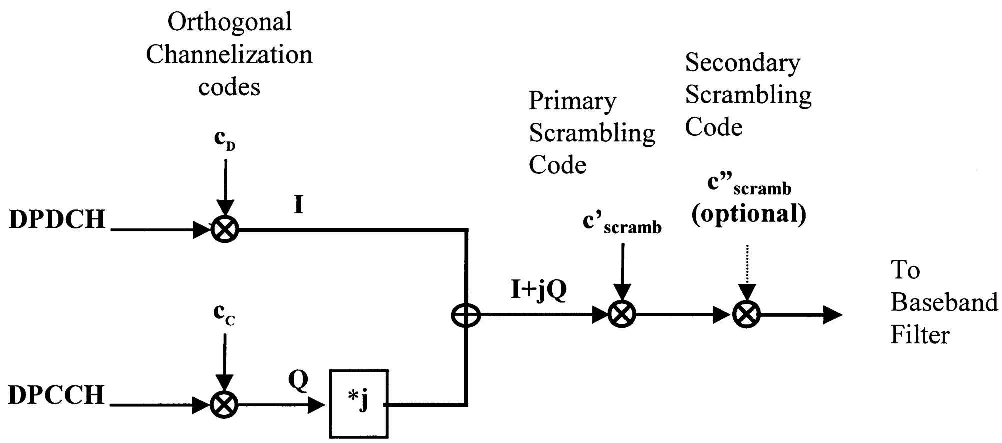

FIGURE 36.8: Reverse link spreading for the DPDCH and DPCCH.

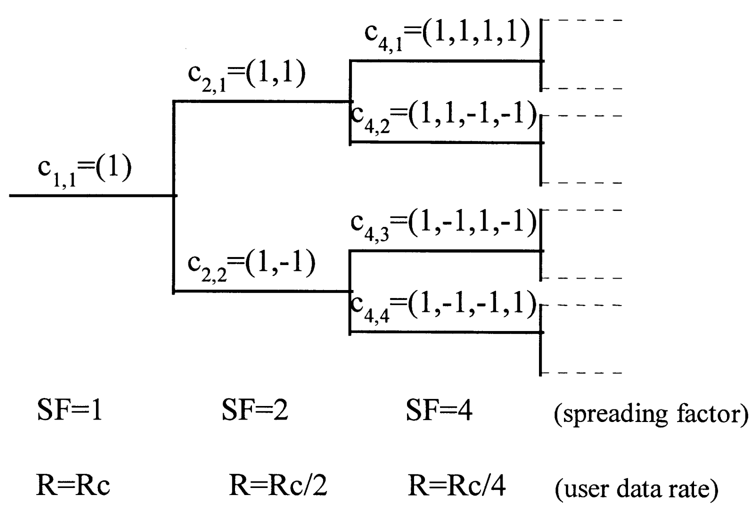

FIGURE 36.9: Construction of orthogonal spreading codes for different spreading factors.

code and then searches the corresponding long code. A short VL-Kasami code has been proposed for the reverse link to ease the implementation of multiuser detection. In this case, code planning would also be negligible because the number of VL-Kasami sequences is more than one million. However, in certain cases, the use of short codes may lead to bad correlation properties, especially with very small spreading factors. If multiuser detection were not used, adaptive code allocation could be used to restore the cross-correlation properties. The use of short codes to ease the implementation of advanced detection techniques is more beneficial in the forward link since the cyclostationarity of the signal could be utilized for adaptive implementation of the receiver.

Orthogonality between the different spreading factors can be achieved by tree-structured orthogonal codes whose construction is illustrated in Fig. 36.9 [5]. The tree-structured codes are generated recursively according to the following equation,

$$c_{2n} = \begin{pmatrix} c_{2n,1} \\ c_{2n,2} \\ \vdots \\ c_{2n,2n} \end{pmatrix} = \begin{pmatrix} \begin{pmatrix} c_{n,1} & c_{n,1} \\ c_{n,1} & -c_{n,1} \end{pmatrix} \\ \vdots \\ \begin{pmatrix} c_{n,n} & c_{n,n} \\ c_{n,n} & -c_{n,n} \end{pmatrix} \end{pmatrix}$$

where C_{2n} is the orthogonal code set of size $2n$. The generated codes within the same layer constitute a set of orthogonal functions and are thus orthogonal. Furthermore, any two codes of different layers are also orthogonal except for the case that one of the two codes is a mother code of the other. For example code $c_{4,4}$ is not orthogonal with codes $c_{1,1}$ and $c_{2,2}$.

36.4.2 Coherent Detection and Beamforming

In the forward link, time-multiplexed pilot symbols are used for coherent detection. Because the pilot symbols are user dedicated, they can be used for channel estimation with adaptive antennas as well. In the reverse link, WCDMA employs pilot symbols multiplexed with power control and rate information for coherent detection.

36.4.3 Multirate

WCDMA traffic channel structure is based on a single code transmission for small data rates and multicode for higher data rates. Multiple services belonging to the same connection are, in normal cases, time multiplexed as was depicted in the upper part of Fig. 36.3. After service multiplexing and channel coding, the multiservice data stream is mapped to one or more dedicated physical data channels. In the case of multicode transmission, every other data channel is mapped into Q and every other into I channel. The channel coding of WCDMA is based on convolutional and concatenated codes. For services with BER $= 10^{-3}$, a convolutional code with constraint length of 9 and different code rates (between 1/2–1/4) is used. For services with BER $= 10^{-6}$, a concatenated coding with an outer Reed-Solomon code has been proposed. Typically, block interleaving over one frame is used. WCDMA is also capable of interframe interleaving, which improves the performance for services allowing longer delay. Turbo codes for data services are under study. Rate matching is performed by puncturing or symbol repetition.

36.4.4 Packet Data

WCDMA has two different types of packet data transmission possibilities. Short data packets can be appended directly to a random access burst. The WCDMA random-access burst is 10 ms long, it is transmitted with fixed power, and the access principle is based on the slotted Aloha scheme. This method, called common channel packet transmission, is used for short infrequent packets, where the link maintenance needed for a dedicated channel would lead to an unacceptable overhead. Larger or more frequent packets are transmitted on a dedicated channel. A large single packet is transmitted using a single-packet scheme where the dedicated channel is released immediately after the packet has been transmitted. In a multipacket scheme the dedicated channel is maintained by transmitting power control and synchronization information between subsequent packets.

36.5 cdma2000

The dedicated channels used in cdma2000 system are the fundamental, supplemental, pilot,[1] and dedicated control channels. Shown for the forward link in Fig. 36.10 and for the reverse in Fig. 36.11, the fundamental channel provides for the communication of voice, low rate data, and signalling where power control information for the reverse channels is punctured on the forward fundamental channel. For high rate data services, the supplemental channel is used where one important difference between the supplemental and the fundamental channel is the addition of parallel-concatenated turbo codes. For different service options, multiple supplemental channels can be used. The code multiplex pilot channel allows for phase coherent detection. In addition, the pilot channel on the forward link is used for determining soft handoff and the pilot channel on the reverse is used for carrying power control information for the forward channels. Finally, the dedicated control channel, also shown in Fig. 36.10 for the forward link and in Fig. 36.11, for the reverse, is used primarily for exchange of high rate Media Access Control (MAC) layer signalling.

36.5.1 Multicarrier

In addition to direct spread, a multicarrier approach has been proposed for the cdma2000 forward link since it would maintain orthogonality between the cdma2000 and TIA/EIA-95B carriers [6]. The multicarrier variant is achieved by using three 1.25 MHz carriers for a 5 MHz bandwidth where all carriers have separate channel coding and are power controlled in unison.

36.5.2 Spreading Codes

On the forward link, the cell separation for cdma2000 is performed by two M-sequences of length 3×2^{15}, one for I and one for Q channel, which are phase shifted by PN-offset for different cells. Thus, during the cell search process only these sequences are searched. Because there are a limited number of PN-offsets, they need to be planned in order to avoid PN-confusion [7]. In the reverse link, user separation is performed by different phase shifts of M-sequence of length 2^{41}. The channel separation is performed using variable spreading factor Walsh sequences, which are orthogonal to each other.

36.5.3 Coherent Detection

In the forward link, cdma2000 has a common pilot channel, which is used as a reference signal for coherent detection when adaptive antennas are not employed. When adaptive antennas are used, an auxiliary pilot is used as a reference signal for coherent detection. Code multiplexed auxiliary pilots are generated by assigning a different orthogonal code to each auxiliary pilot. This approach reduces the number of orthogonal codes available for the traffic channels. This limitation is alleviated by expanding the size of the orthogonal code set used for the auxiliary pilots. Since a pilot signal is not modulated by data, the pilot orthogonal code length can be extended, thereby yielding an increased number of available codes, which can be used as additional pilots. In the reverse link, the pilot signal is time multiplexed with power control and erasure indicator bit (EIB).

[1] Dedicated for the reverse link and common for the forward link.

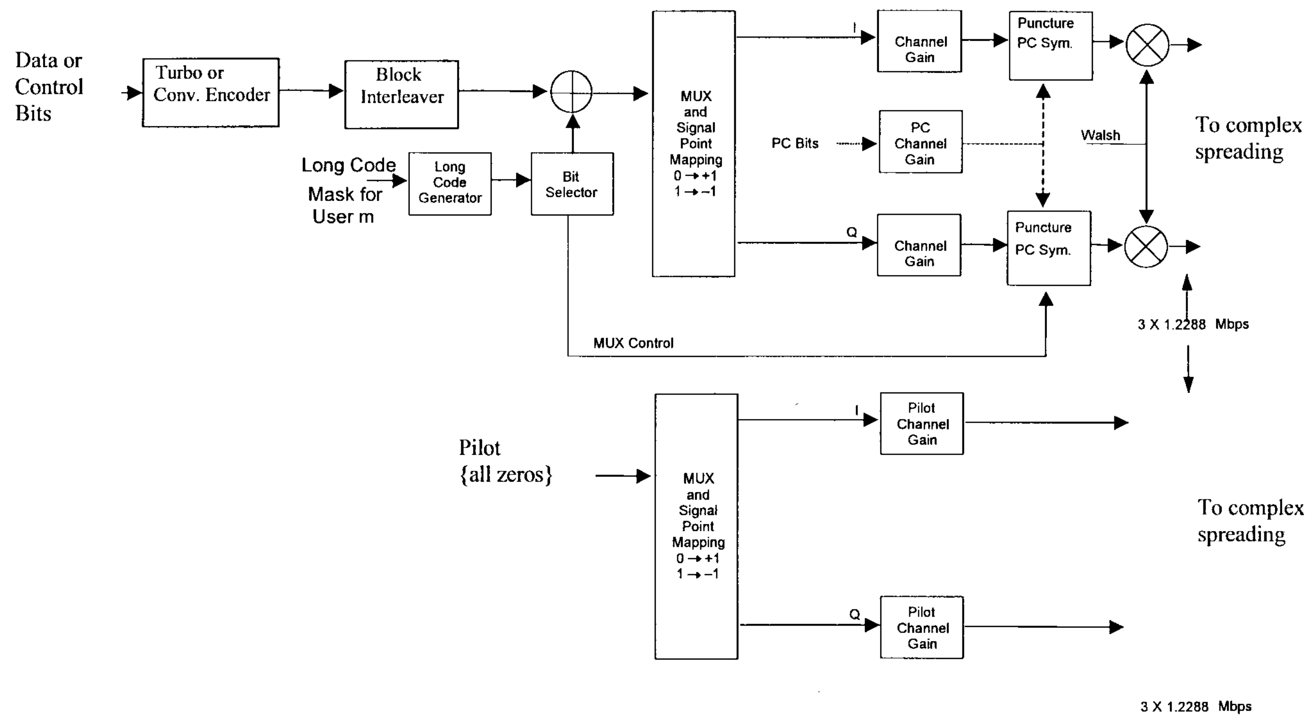

FIGURE 36.10: Forward link channel structure in cdma2000 for direct spread. (*Note:* dashed line indicates that it is only used for the fundamental channel).

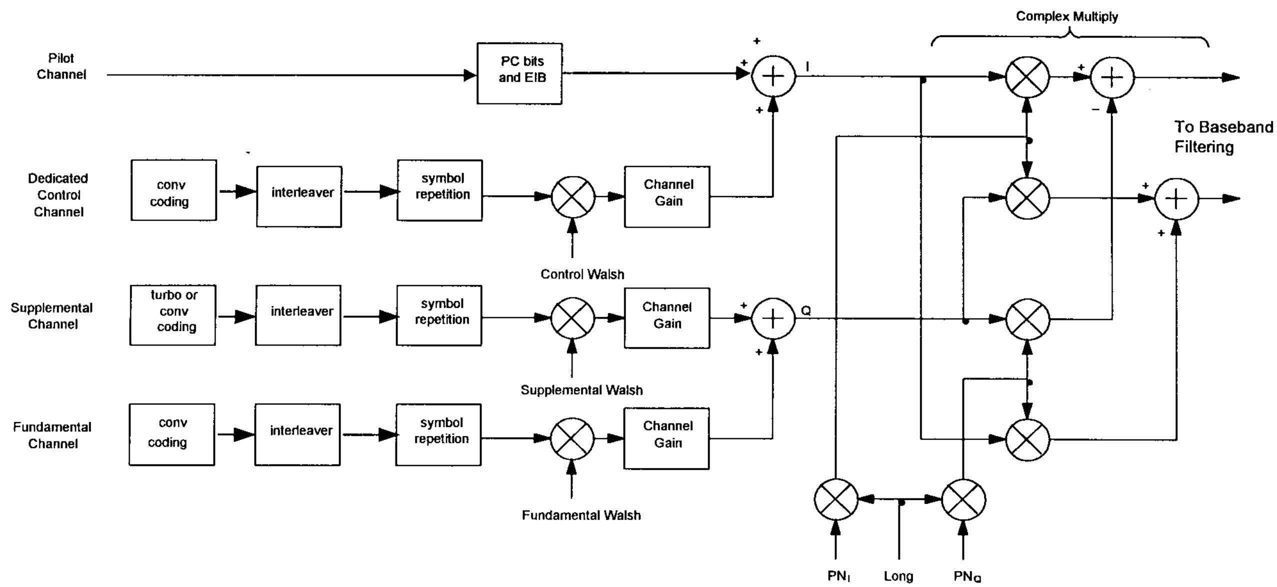

FIGURE 36.11: Reverse link channel structure in cdma2000.

36.5.4 Multirate Scheme

cdma2000 has two traffic channel types, the fundamental and the supplemental channel, which are code multiplexed. The fundamental channel is a variable rate channel which supports basic rates of 9.6 kbps and 14.4 kbps and their corresponding subrates, i.e., Rate Set 1 and Rate Set 2 of TIA/EIA-95B. It conveys voice, signalling, and low rate data. The supplemental channel provides high data rates. Services with different QoS requirements are code multiplexed into supplemental channels. The user data frame length of cdma2000 is 20 ms. For the transmission of control information, 5 and 20 ms frames can be used on the fundamental channel or dedicated control channel. On the fundamental channel a convolutional code with constraint length 9 is used. On supplemental channels convolutional coding is used up to 14.4 kbps. For higher rates Turbo codes with constraint length 4 and rate 1/4 are preferred. Rate matching is performed by puncturing, symbol repetition, and sequence repetition.

36.5.5 Packet Data

cdma2000 also allows short data burst using the slotted Aloha principle. However, instead of fixed transmission power it increases the transmission power for the random access burst after an unsuccessful access attempt. When the mobile station has been allocated a traffic channel, it can transmit without scheduling up to a predefined bit rate. If the transmission rate exceeds the defined rate, a new access request has to be made. When the mobile station stops transmitting, it releases the traffic channel but not the dedicated control channel. After a while it also releases the dedicated control channel as well but maintains the link layer and network layer connections in order to shorten the channel set-up time when new data needs to be transmitted.

36.5.6 Parametric Comparison

For comparison, Table 36.1 lists the parameters of cdma2000 and WCDMA. cdma2000 uses a chip rate of 3.6864 Mcps for the 5 MHz band allocation with the direct spread forward link option and a 1.2288 Mcps chip rate with three carriers for the multicarrier option. WCDMA uses direct spread with a chip rate of 4.096 Mcps. The multicarrier approach is motivated by a spectrum overlay of cdma2000 carriers with existing TIA/EIA-95B carriers [6]. Similar to EIA/TIA-95B, the spreading codes of cdma2000 are generated using different phase shifts of the same M-sequence. This is possible due to the synchronous network operation. Since WCDMA has an asynchronous network, different long codes rather than different phase shifts of the same code are used for the cell and user separation. The code structure determines how code synchronization, cell acquisition, and handover synchronization are performed.

36.6 TDMA-Based Schemes

As discussed, TIA/EIA-136 and GSM evolution have similar paths in the form of EDGE. The UWC-136 IMT 2000 proposal contains, in addition to the TIA/EIA-136 30 kHz carriers, the high rate capability provided by the 200 kHz and 1.6 MHz carriers shown in Table 36.2. The targets for the IS-136 evolution were to meet IMT-2000 requirements and an initial deployment within 1 MHz spectrum allocation. UWC-136 meets these targets via modulation enhancement to the existing 30 kHz channel (136+) and by defining complementary wider band TDMA carriers with bandwidths of 200 kHz for vehicular/outdoor environments and 1.6 MHz for indoor environments. The 200 kHz carrier, 136 HS (vehicular/outdoor) with the same parameters as EDGE provides medium bit rates up to

TABLE 36.1 Parameters of WCDMA and cdma2000

	WCDMA	cdma2000
Channel bandwidth	5, 10, 20 MHz	1.25, 5, 10, 15, 20 MHz
Forward link RF channel structure	Direct spread	Direct spread or multicarrier
Chip rate	4.096/8.192/16.384 Mcps	1.2288/3.6864/7.3728/11.0593/14.7456 Mcps for direct spread n$\times$1.2288 Mcps (n=1,3,6,9,12) for multicarrier
Roll-off factor	0.22	Similar to TIA/EIA-95B
Frame length	10 ms / 20 ms (optional)	20 ms for data and control/5ms for control information on the fundamental and dedicated control channel
Spreading modulation	Balanced QPSK (forward link) Dual channel QPSK (reverse link) Complex spreading circuit	Balanced QPSK (forward link) Dual channel QPSK (reverse link) Complex spreading circuit
Data modulation	QPSK (forward link) BPSK (reverse link)	QPSK (forward link) BPSK (reverse link)
Coherent detection	User dedicated time multiplexed pilot (forward link and reverse link), common pilot in forward link	Pilot time multiplexed with PC and EIB (reverse link) Common continuous pilot channel and auxiliary pilot (forward link)
Channel multiplexing in reverse link	Control and pilot channel time multiplexed I&Q multiplexing for data and control channel	Control, pilot fundamental, and supplemental code multiplexed I&Q multiplexing for data and control channels
Multirate	Variable spreading and multicode	Variable spreading and multicode
Spreading factors	4-256 (4.096 Mcps)	4-256 (3.6864 Mcps)
Power Control	Open and fast closed loop (1.6 kHz)	Open loop and fast closed loop (800 Hz)
Spreading (forward link)	Variable length orthogonal sequences for channel separation. Gold sequences for cell and user separation	Variable length Walsh sequences for channel separation, M-sequence 3×2^{15} (same sequence with time shift utilized in different cells different sequence in I&Q channel)
Spreading (reverse link)	Variable length orthogonal sequences for channel separation. Gold sequence 2^{41} for user separation (different time shifts in I and Q channel, cycle 2^{16} 10 ms radio frames)	Variable length orthogonal sequences for channel separation, M-sequence 2^{15} (same for all users different sequences in I&Q channels), M-sequence 2^{41} for user separation (different time shifts for different users)
Handhover	Soft handover Interfrequency handover	Soft handover Interfrequency handover

384 kbps and the 1.6 MHz carrier, 136 HS (indoor), highest bit rates up to 2 Mbps. The parameters of the 136 HS proposal submitted to ITU are listed in Table 36.2 and the different carrier types of UWC-136 are shown in Fig. 36.12.

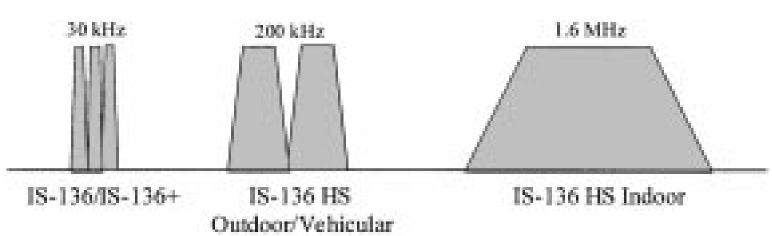

FIGURE 36.12: UWC-136 carrier types.

TABLE 36.2 Parameters of 136 HS

	136 HS (Vehicular/Outdoor)	136 HS (Indoor)
Duplex method	FDD	FDD and TDD
Carrier spacing	200 kHz	1.6 MHz
Modulation	Q-O-QAM	Q-O-QAM
	B-O-QAM	B-O-QAM
	8 PSK	
	GMSK	
Modulation bit rate	722.2 kbps (Q-O-QAM)	5200 kbps (Q-O-QAM)
	361.1 kbps (B-O-QAM)	2600 kbps (B-O-QAM)
	812.5 kbps (8 PSK)	
	270.8 kbps (GMSK)	
Payload	521.6 kbps (Q-O-QAM)	4750 kbps (Q-O-QAM)
	259.2 kbps (B-O-QAM)	2375 kbps (B-O-QAM)
	547.2 kbps (8 PSK)	
	182.4 kbps (GMSK)	
Frame length	4.615 ms	4.615 ms
Number of slots	8	64 (72 μs)
		16 (288 μs)
Coding	Convolutional	Convolutional
	1/2, 1/4, 1/3, 1/1	1/2, 1/4, 1/3, 1/1
	ARQ	Hybrid Type II ARQ
Frequency hopping	Optional	Optional
Dynamic channel allocation	Optional	Optional

36.6.1 Carrier Spacing and Symbol Rate

The motivation for the 200 kHz carrier is twofold. First, the adoption of the same physical layer for 136 HS (Vehicular/Outdoor) and GSM data carriers provides economics of scale and therefore cheaper equipment and faster time to market. Second, the 200 kHz carrier with higher order modulation can provide bit rates of 144 and 384 kbps with reasonable range and capacity fulfilling IMT-2000 requirements for pedestrian and vehicular environments. The 136 HS (Indoor) carrier can provide 2 Mbit/s user data rate with a reasonably strong channel coding.

36.6.2 Modulation

First proposed modulation methods were Quaternary Offset QAM (Q-O-QAM) and Binary Offset QAM (B-O-QAM). Q-O-QAM could provide higher data rates and good spectral efficiency. For each symbol two bits are transmitted and consecutive symbols are shifted by $\pi/2$. An offset modulation was proposed, because it causes smaller amplitude variations than 16QAM, which can be beneficial when using amplifiers that are not completely linear. The second modulation B-O-QAM has been introduced, which has the same symbol rate of 361.111 ksps, but where only the outer signal points of the Q-O-QAM modulation are used. For each symbol one bit is transmitted and consecutive symbols are shifted by $\pi/2$. A second modulation scheme with the characteristic of being a subset of the first modulation scheme and having the same symbol rate as the first modulation allows seamless switching between the two modulation types between bursts. Both modulation types can be used in the same burst. From a complexity point of view the addition of a modulation, which is subset of the first modulation, adds no new requirements for the transmitter or receiver.

In addition to the originally proposed modulation schemes, Quaternary Offset QAM (Q-O-QAM) and Binary Offset QAM (B-O-QAM), other modulation schemes, CPM (Continuous Phase Modulation) and 8-PSK, have been evaluated in order to select the modulation best suited for EDGE. The outcome of this evaluation is that 8 PSK was considered to have implementation advantages over Q-O-QAM. Parties working on EDGE are in the process of revising the proposals so that 8 PSK would replace the Q-O-QAM and GMSK can be used as the lower level modulation instead of B-O-QAM. The symbol rate of the 8 PSK will be the same as for GMSK and the detailed bit rates will be specified early in 1999.

36.6.3 Frame Structures

The 136 HS (Vehicular/Outdoor) data frame length is 4.615 ms and one frame consists of eight slots. The burst structure is suitable for transmission in a high delay spread environment. The frame and slot structures of the 136 HS (Indoor) carrier were selected for cell coverage for high bit rates. The HS-136 Indoor supports both FDD and TDD duplex methods. Figure 36.13 illustrates the frame and slot structure. The frame length is 4.615 ms and it can consist of

- 64 1/64 time slots of length 72 μs
- 16 1/16 time slots of length 288 μs

In the TDD mode, the same burst types as defined for the FDD mode are used. The 1/64 slot can be used for every service from low rate speech and data to high rate data services. The 1/16 slot is to be used for medium to high rate data services. Figure 36.13 also illustrates the dynamic allocation of resources between the reverse link and the forward link in the TDD mode.

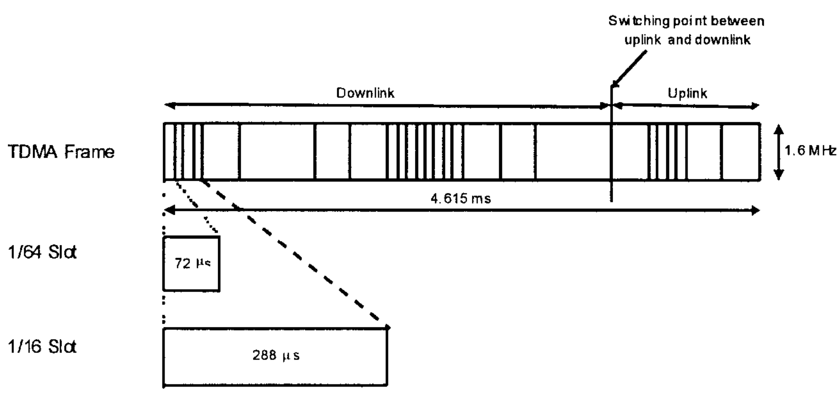

FIGURE 36.13: Wideband TDMA frame and slot structure.

The physical contents of the time slots are bursts of corresponding length. Three types of traffic bursts are defined. Each burst consists of a training sequence, two data blocks, and a guard period. The bursts differ in the length of the burst (72 μs and 288 μs) and in the length of the training sequence (27 symbols and 49 symbols) leading to different numbers of payload symbols and different multipath delay performances (Fig. 36.14). The number of required reference symbols in the training sequence depends on the length of the channel's impulse response, the required signal-to-noise ratio, the expected maximum Doppler frequency shift, and the number of modulation levels. The number of reference symbols should be matched to the channel characteristics, remain practically stable within the correlation window, and have good correlation properties. All 136 based schemes can use interference cancellation as a means to improve performance [8]. For 136 HS (Indoor), the longer sequence can handle about 7 μs of time dispersion and the shorter one 2.7 μs. It should be noted that if the time dispersion is larger, the drop in performance is slow and depends on the power delay profile.

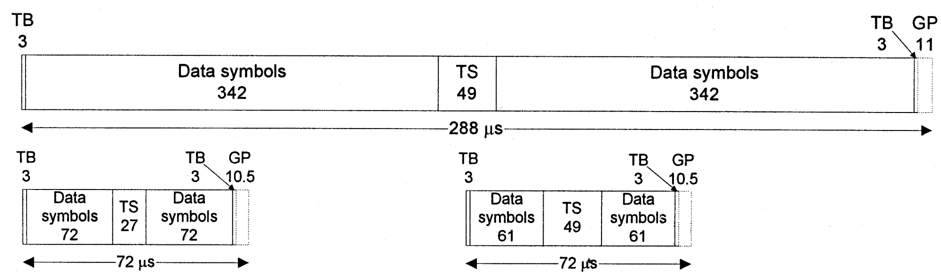

FIGURE 36.14: Burst structure.

36.6.4 Multirate Scheme

The UWC-136 multirate scheme is based on a variable slot, code, and modulation structure. Data rates up to 43.2 kbps can be offered using the 136+ 30 kHz carrier and multislot transmission. Depending on the user requirements and channel conditions a suitable combination of modulation, coding, and number of data slots is selected. 136 HS can offer packet switched, and both transparent and nontransparent circuit switched data services. Asymmetrical data rates are provided by allocating a different number of time slots in the reverse and forward links. For packet switched services the RLC/MAC protocol provides fast medium access via a reservation based medium access scheme, supplemented by selective ARQ for efficient retransmission.

Similar to 136 HS (Outdoor/Vehicular), the 136 HS (Indoor) uses two modulation schemes and different coding schemes to provide variable data rates. In addition, two different slot sizes can be used. For delay tolerant packet data services, error control is based on a Type II hybrid ARQ (automatic repeat request) scheme [5]. The basic idea is to first send all data blocks using a simple error control coding scheme. If decoding at the receiver fails, a retransmission is requested using a stronger code. After the second retransmission, diversity combining can be performed between the first and second transmissions prior to hard decisions. This kind of ARQ procedure can be used due to the ability of the RLC/MAC protocol to allocate resources fast and to send transmission requests reliably in the feedback channel [5].

36.6.5 Radio Resource Management

The radio resource management schemes of UWC-136 include link adaptation, frequency hopping, power control, and dynamic channel allocation. Link adaptation offers a mechanism for choosing the best modulation and coding alternative according to channel and interference conditions. Frequency hopping averages interference and improves link performance against fast fading. For 136 HS (Indoor) fast power control (frame-by-frame) could be used to improve the performance in cases where frequency hopping cannot be applied, for example, when only one carrier is available. Dynamic channel allocation can be used for channel assignments. However, when deployment with minimum spectrum is desired, reuse 1/3 and fractional loading with fixed channel allocation is used.

36.7 Time Division Duplex (TDD)

The main discussion about the IMT-2000 air interface has been concerned with technologies for FDD. However, there are several reasons why TDD would be desirable. First, there will likely be dedicated frequency bands for TDD within the identified UMTS frequency bands. Furthermore, FDD requires exclusive paired bands and spectrum is, therefore, hard to find. With a proper design including powerful FEC, TDD can be used even in outdoor cells. The second reason for using TDD is flexibility in radio resource allocation, i.e., bandwidth can be allocated by changing the number of time slots for the reverse link and forward link. However, the asymmetric allocation of radio resources leads to two interference scenarios that will impact the overall spectrum efficiency of a TDD scheme:

- asymmetric usage of TDD slots will impact the radio resource in neighboring cells, and
- asymmetric usage of TDD slots will lead to blocking of slots in adjacent carriers within their own cells.

Figure 36.15 depicts the first scenario. MS2 is transmitting at full power at the cell border. Since MS1 has a different asymmetric slot allocation than MS2, its forward link slots received at the sensitivity limit are interfered by MS1, which causes blocking. On the other hand, since the BS1 can have much higher EIRP (effective isotropically radiated power) than MS2, it will interfere BS2's ability to receive MS2. Hence, the radio resource algorithm needs to avoid this situation.

In the second scenario, two mobiles would be connected into the same cell but using different frequencies. The base station receives MS1 on the frequency f1 using the same time slot it uses on the frequency f2 to transmit into MS2. As shown in Table 36.3, the transmission will block the reception due to the irreducible noise floor of the transmitter regardless of the frequency separation between f1 and f2.

TABLE 36.3 Adjacent Channel Interference Calculation

BTS transmission power for MS2 in forward link 1W	30 dBm
Received power for MS1	−100 dBm
Adjacent channel attenuation due to irreducible noise floor	50 to 70 dB
Signal to adjacent channel interference ratio	−60 to −80 dB

Both TDMA- and CDMA-based schemes have been proposed for TDD. Most of the TDD aspects are common to TDMA- and CDMA-based air interfaces. However, in CDMA-based TDD systems the slot duration on the forward and reverse links must be equal to enable the use of soft handoff and prevent the interference situation described in the first scenario. Because TDMA systems do not have soft handoff on a common frequency, slot imbalances from one BS to the next are easier to accommodate. Thus, TDMA-based solutions have higher flexibility. The frame structure for the wide band TDMA for the TDD system was briefly discussed in the previous section. WCDMA

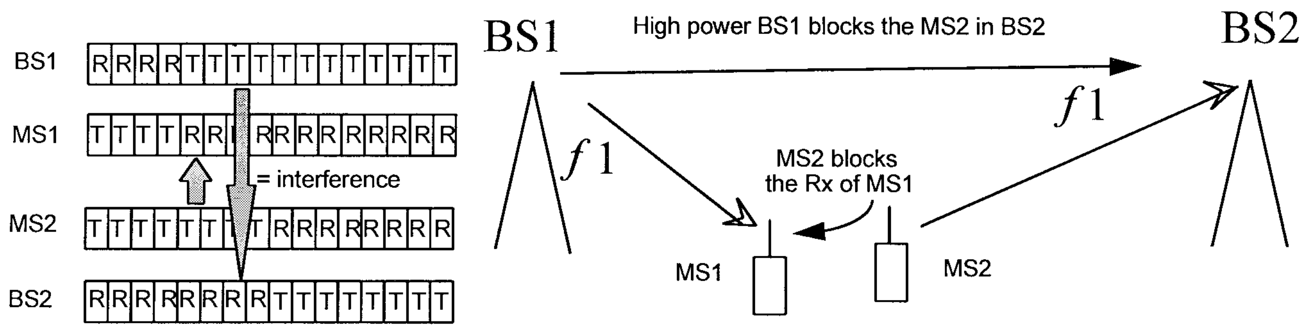

FIGURE 36.15: TDD interference scenario.

has been proposed for TDD in Japan and Europe. The frame structure is the same as for the FDD component, i.e., a 10 ms frame split into 16 slots of 0.625 ms each. Each slot can be used either for reverse link or forward link. For cdma2000, the TDD frame structure is based on a 20 ms frame split into 16 slots of 1.25 ms each.

36.8 Conclusions

Third generation cellular systems are a mechanism for evolving the telecommunications business based primarily on voice telephony to mobile wireless datacomm. In light of events in TIA, ETSI, and ARIB, cdma2000, WCDMA, and EDGE will be important technologies used to achieve the datacomm goal. Standardization related to radio access technologies discussed in this chapter were underway at the time of writing and will offer the European, U.S., and Japanese markets both CDMA and TDMA third-generation options. In comparing CDMA evolution, the European, U.S., and Japanese based systems have some similarities, but differ in the chip rate and channel structure. In the best circumstances, some harmonization will occur between cdma2000 and WCDMA making deployment of hardware capable of supporting both systems easier. In TDMA, the third generation paths of GSM and TIA/EIA-136 are through a common solution. This alignment will offer TDMA systems an advantage in possible global roaming for data services. In spite of the regional standards differences, third generation will be the mechanism for achieving wireless multimedia enabling services beyond the comprehension of second generation systems.

Acknowledgments

The authors would like to thank Harri Holma, Pertti Lukander, and Antti Toskala from Nokia Telecommunications, George Fry, Kari Kalliojarvi, Riku Pirhonen, Rauno Ruismaki, and Zhigang Rong from Nokia Research Center, Kari Pehkonen from Nokia Mobile Phones, and Kari Pulli from the University of Stanford for helpful comments. In addition, contributions related to spectrum and modulation aspects from Harri Lilja from Nokia Mobile Phones are acknowledged.

References

[1] ITU-R M.1225, Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000, 1998.

[2] Special Issue on IMT-2000: Standards Efforts of the ITU, *IEEE Pers. Commun.*, 4(4), Aug. 1997.

[3] Verdu, S., Minimum probability of error for asynchronous gaussian multiple access, *IEEE Trans. on IT.*, IT-32(1), 85–96, Jan. 1986.

[4] Monk, A.M. et al., A noise-whitening approach to multiple access noise rejection—Pt I: Theory and background, *IEEE J. Select. Areas Commun.*, 12(5), 817–827, Jun. 1997.

[5] Nikula, E., Toskala, A., Dahlman, E., Girard, L., and Klein, A., FRAMES multiple access for UMTS and IMT-2000, *IEEE Pers. Commun.*, Apr. 1998.

[6] Tiedemann, E.G., Jr., Jou, Y-C., and Odenwalder, J.P., The evolution of IS-95 to a third generation system and to the IMT-2000 era, *Proc. ACTS Summit*, Aalborg, Denmark, 924–929, Oct. 1997.

[7] Chang, C.R., Van, J.Z., and Yee, M.F., PN offset planning strategies for nonuniform CDMA networks, *Proc. VTC'97*, 3, Phoenix, Arizona, 1543–1547, May 4–7, 1997.

[8] Ranta, P., Lappeteläinen, A., and Honkasalo, Z-C., Interference cancellation by joint detection in random frequency hopping TDMA networks, *Proc. ICUPC96*, 1, Cambridge, MA, 428–432, Sept./Oct. 1996.