Chapter 6

WCDMA

6.1 INTRODUCTION

This chapter presents the WCDMA air interface, referred also as UMTS terrestrial radio access (UTRA), developed by the third-generation partnership project (3GPP). 3GPP has the goal to harmonize and standardize in detail the similar proposals from ETSI, ARIB, TTC, TTA, and T1.

Table 6.1 lists the parameters of WCDMA. WCDMA has two modes characterized by the duplex method: FDD (frequency division duplex) and TDD (time division duplex), for operating with paired and unpaired bands, respectively [1]. The TDD mode is described in Chapter 7.

The chip rate of the system is 3.84 Mcps. The frame length is 10 ms and each frame is divided into 15 slots (2560 chip/slot at the chip rate 3.84 Mcps). Spreading factors range from 256 to 4 in the uplink and from 512 to 4 in the downlink. Thus, the respective modulation symbol rates vary from 960 k symbols/s to 15 k symbols/s (7.5 k symbols/s) for FDD uplink. For separating channels from the same source, orthogonal variable spreading factor (OVSF) channelization codes are used. In the downlink, Gold codes with a 10-ms period (38400 chips at 3.84 Mcps) are used to separate different cells, with the actual code itself length 2^{18}-1 chips. In the uplink, Gold codes with a 10-ms period, or alternatively short codes with a 256-chip period, are used to separate the different users.

For the channel coding three options are supported: convolutional coding, turbo coding, or no channel coding. Channel coding selection is indicated by upper layers. Bit interleaving is used to randomize transmission errors. The modulation scheme is QPSK.

The carrier spacing has a raster of 200 kHz and can vary from 4.2 to 5.4 MHz. The different carrier spacings can be used to obtain suitable adjacent channel protections depending on the interference scenario. Figure 6.1 shows an example for the operator bandwidth of 15 MHz with three cell layers. Larger carrier spacing can be applied between operators than within one operator’s band in order to avoid inter-operator interference. Interfrequency measurements and handovers are supported by

WCDMA to utilize several cell layers and carriers.

This chapter is organized as follows. WCDMA specification structure is given in Section 6.2. Protocol structure and logical and transport channels are described in Section 6.3. Physical channels, spreading, multirate schemes (variable data rates), packet data, and handover are discussed in Sections 6.4–6.8. Section 6.9 describes the future evolution of the WCDMA covering release 2000 standards and beyond.

6.2 WCDMA SPECIFICATIONS

The air interface description in the following is based on the 3GPP wideband CDMA specifications as listed in Table 6.2. The physical layer is specified in TS25 series of 3GPP specifications.

Table 6.1
Parameters of WCDMA

Channel bandwidth	5 MHz
Duplex mode	FDD and TDD
Downlink RF channel structure	Direct spread
Chip rate	3.84 Mbps
Frame length	10 ms
Spreading modulation	Balanced QPSK (downlink) Dual-channel QPSK(uplink) Complex spreading circuit
Data modulation	QPSK (downlink) BPSK (uplink)
Channel coding	Convolutional and turbo codes
Coherent detection	User dedicated time multiplexed pilot (downlink and uplink), common pilot in the downlink
Channel multiplexing in downlink	Data and control channels time multiplexed
Channel multiplexing in uplink	Control and pilot channel time multiplexed I&Q multiplexing for data and control channel
Multirate	Variable spreading and multicode
Spreading factors	4–256 (uplink), 4–512 (uplink)
Power control	Open and fast closed loop (1.6 kHz)
Spreading (downlink)	OVSF sequences for channel separation Gold sequences 2^{18}-1 for cell and user separation (truncated cycle 10 ms)
Spreading (uplink)	OVSF sequences, Gold sequence 2^{41} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms)
Handover	Soft handover Interfrequency handover

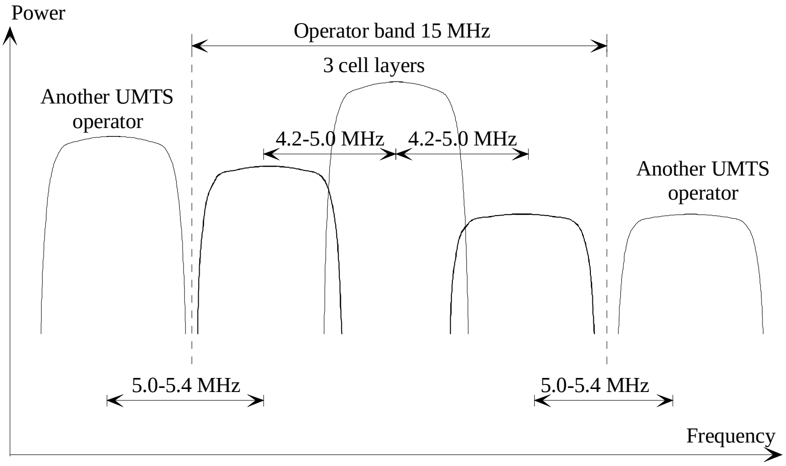

Figure 6.1 Frequency utilization with WCDMA.

6.3 PROTOCOL ARCHITECTURE

Figure 6.2 shows the air interface protocol architecture. The protocol architecture is similar to the current ITU-R protocol architecture, ITU-R M.1035. The air interface is layered into three protocol layers:

- The physical layer (layer 1, L1);
- The data link layer (layer 2, L2);
- Network layer (layer 3, L3).

The physical layer interfaces the medium access control (MAC) sublayer of layer 2 and the radio resource control (RRC) layer of layer 3. The physical layer offers different transport channels to MAC. A transport channel is characterized by how the information is transferred over the radio interface. Transport channels are channel coded and then mapped to the physical channels specified in the physical layer. MAC offers different logical channels to the radio link control (RLC) sublayer of layer 2. A logical channel is characterized by the type of information transferred.

Layer 2 is split into following sublayers: MAC, RLC, packet data convergence protocol (PDCP) and broadcast/multicast control (BMC). Layer 3 and RLC are divided into control and user planes. PDCP and BMC exist in the user plane only. In the control plane, layer 3 is partitioned into sublayers where the lowest sublayer, denoted as RRC, interfaces with layer 2. The RLC sublayer provides ARQ functionality closely coupled with the radio transmission technique used.

Table 6.2

3GPP RAN Specifications

Specification number	Name	Scope
TS 25.201	Physical layer – general description	Describes the contents of the layer 1 documents (TS 25.200 series); where to find information; a general description of layer 1
TS 25.211	Physical channels and mapping of transport channels onto physical channels (FDD)	Establishes the characteristics of the layer-1 transport channels and physical channels in the FDD mode, and specifies: • transport channels • physical channels and their structure • relative timing between different physical channels in the same link, and relative timing between uplink and downlink; • mapping of transport channels onto the physical channels.
TS 25.212	Multiplexing and channel coding (FDD)	Describes multiplexing, channel coding, and interleaving in the FDD mode and specifies: • coding and multiplexing of transport channels; • channel coding alternatives; • coding for layer 1 control information; • different interleavers; • rate matching; • physical channel segmentation and mapping.
TS 25.213	Spreading and modulation (FDD)	Establishes the characteristics of the spreading and modulation in the FDD mode, and specifies: • spreading • generation of channelization and scrambling codes; • generation of random access preamble codes; • generation of synchronization codes; • modulation.
TS 25.214	Physical layer procedures (FDD)	Establishes the characteristics of the physical layer procedures in the FDD mode, and specifies: • cell search procedures; • power control procedures; • random access procedure.
TS 25.215	Physical layer - measurements (FDD)	Establishes the characteristics of the physical layer measurements in the FDD mode, and specifies: • the measurements performed by layer 1; • reporting of measurements to higher layers and network; • handover measurements and idle-mode measurements.

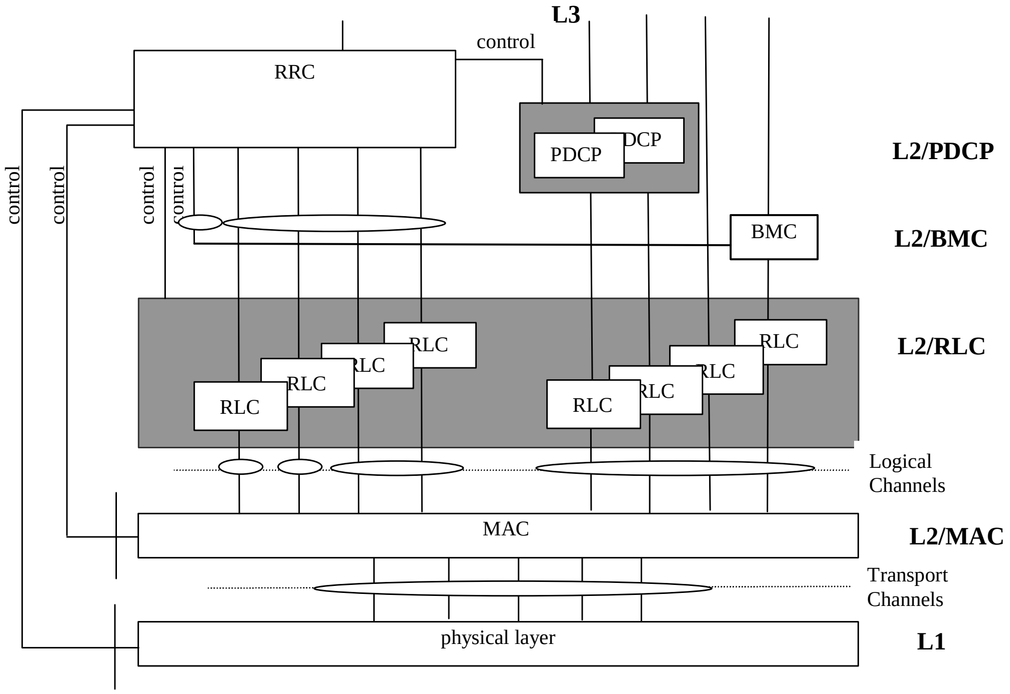

Figure 6.2 Air interface protocol architecture.

6.3.1 Logical Channels

The MAC layer provides data transfer services on logical channels. A set of logical channel types is defined for different kinds of data transfer services as offered by MAC. Each logical channel type is defined by the type of information that is transferred. Logical channel types are depicted in Figure 6.3. Logical channels are classified into two groups:

- Control channels for the transfer of control plane information (Table 6.3)
- Traffic channels for the transfer of user plane information (Table 6.4).

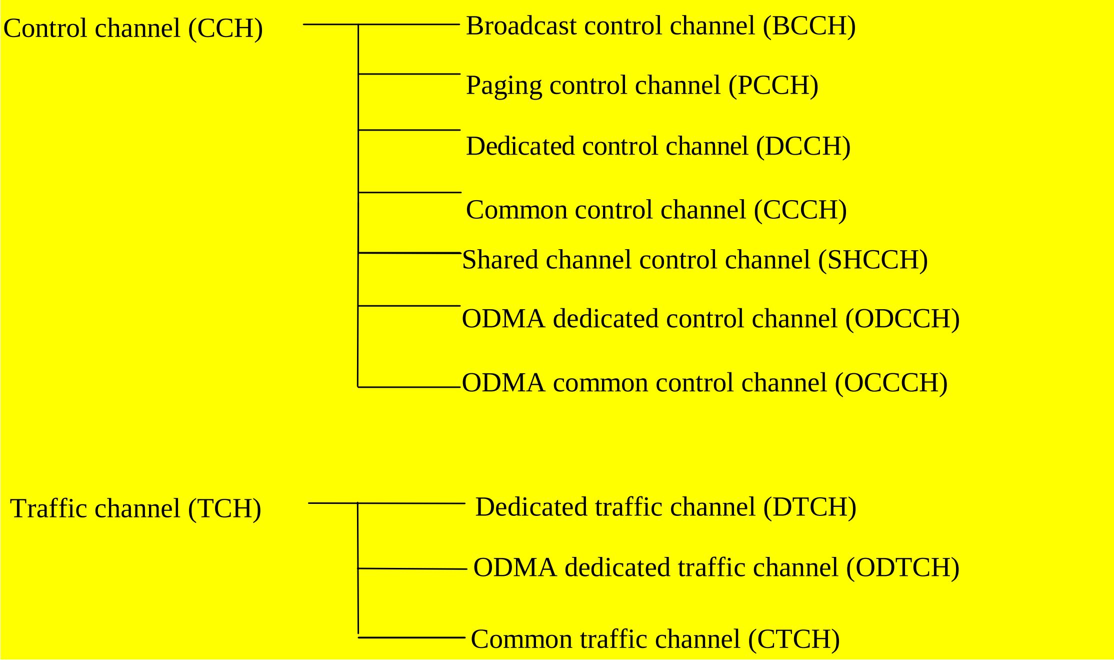

Figure 6.3 Logical channel structure.

Table 6.3
Logical Control Channels

Broadcast control channel (BCCH)	Downlink channel for broadcasting system control information.
Paging control channel (PCCH)	Downlink channel that transfers paging information and is used when: • Network does not know the location cell of the mobile station; • The mobile station is in the cell connected state (utilizing sleep mode procedures).
Common control channel (CCCH)	Bidirectional channel that transfers control information between network and mobile stations. This channel is used: • By the mobile stations having no RRC connection with the network; • By the mobile stations using common transport channels when accessing a new cell after cell reselection.
Dedicated control channel (DCCH)	Point-to-point bidirectional channel that transmits dedicated control information between a mobile station and the network. This channel is established through RRC connection setup procedure.
ODMA common control channel (OCCCH)	Bidirectional channel for transmitting control information between mobile stations.
ODMA dedicated control channel (ODCCH)	Point-to-point bidirectional channel that transmits dedicated control information between mobile stations. This channel is established through RRC connection setup procedure.

Table 6.4
Traffic Channels

Dedicated traffic channel (DTCH)	Point-to-point channel, dedicated to one mobile station, for the transfer of user information. A DTCH can exist in both uplink and downlink.
ODMA dedicated traffic channel (ODTCH)	Point-to-point channel, dedicated to one mobile station, for the transfer of user information between mobile stations. An ODTCH exists in relay link. A point-to-multipoint unidirectional channel for transfer of dedicated user information for all or a group of specified mobile stations.

6.3.2 Transport Channels

A transport channel is defined by how and with what characteristics data is transferred over the air interface. There exist two types of transport channels:

- Dedicated channels;
- Common channels, listed in Table 6.5.

There is one dedicated transport channel, the dedicated channel (DCH), which is a downlink or uplink transport channel. The DCH is transmitted over the entire cell or over only a part of the cell using beam-forming antennas. The DCH is characterized by the possibility of fast rate change (every 10 ms), fast power control, and inherent addressing of mobile stations.

6.3.2.1 Mapping Between Logical Channels and Transport Channels

Figure 6.4 shows the mapping between logical and transport channels. The following connections exist:

- BCCH is connected to BCH and may also be connected to FACH.
- PCCH is connected to PCH.
- CCCH is connected to RACH and FACH.
- SHCCH is connected to RACH and USCH/FACH and DSCH.
- DTCH can be connected to either RACH and FACH, to RACH and DSCH, to DCH and DSCH, to a DCH, a CPCH (FDD only).
- CTCH is connected to FACH.
- DCCH can be connected to either RACH and FACH, to RACH and DSCH, to DCH and DSCH, to a DCH, a CPCH to FAUSCH, CPCH.

Table 6.5
Common Transport Channels

Broadcast channel (BCH)	Downlink transport channel that is used to broadcast system- and cell-specific information. The BCH is always transmitted over the entire cell with a low fixed bit rate.
Forward access channel (FACH)	Downlink transport channel. The FACH is transmitted over the entire cell or over only a part of the cell using beam-forming antennas. The FACH uses slow power control.
Paging channel (PCH)	Downlink transport channel. The PCH is always transmitted over the entire cell. The transmission of the PCH is associated with the transmission of a physical layer signal, the paging indicator, to support efficient sleep mode procedures.
Random access channel (RACH)	Uplink transport channel. The RACH is always received from the entire cell. The RACH is characterized by a limited size data field, a collision risk and by the use of open loop power control.
Common packet channel (CPCH)	Uplink transport channel. The CPCH is a contention-based random access channel used for transmission of bursty data traffic. CPCH is associated with a dedicated channel on the downlink, which provides power control for the uplink CPCH.
Downlink shared channel (DSCH)	Downlink transport channel shared by several mobile stations The DSCH is associated with a DCH.

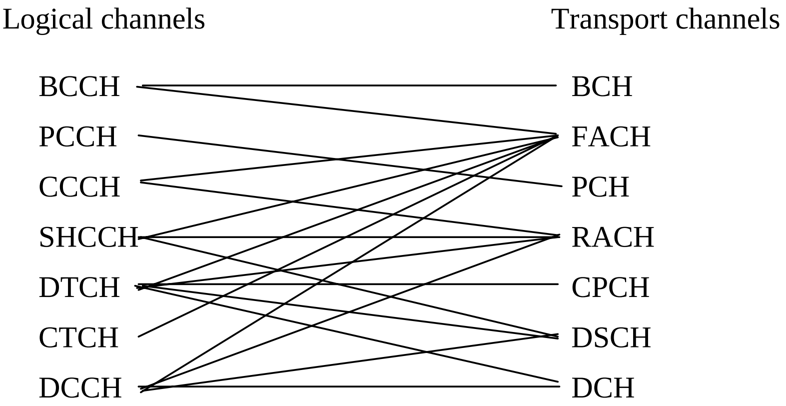

Figure 6.4 Mapping between logical and transport channels.

6.4 PHYSICAL CHANNELS

The transport channels are channel coded and matched to the data rate offered by physical channels. Thereafter, the transport channels are mapped on the physical channels. Physical channels consist of radio frames and time slots. The length of a radio frame is 10 ms and one frame consists of 15 time slots. A time slot is a unit, which consists of fields containing bits. The number of bits per time slot depends on the physical channel. Depending on the symbol rate of the physical channel, the configuration of radio frames or time slots varies. The basic physical resource is the code/frequency plane. In addition, on the uplink, different information streams may be transmitted on the I and Q branch. Consequently, a physical channel corresponds to a specific carrier frequency, code, and, on the uplink, relative phase (0 or p/2). In Section 6.4.1, the different physical channels and their structure are presented.

6.4.1 Uplink Physical Channels

There are two uplink dedicated physical and two common physical channels:

- The uplink dedicated physical data channel (uplink DPDCH) and the uplink dedicated physical control channel (uplink DPCCH);
- The physical random access channel (PRACH) and physical common packet channel (PCPCH).

The uplink DPDCH is used to carry dedicated data generated at layer 2 and above (i.e., the dedicated transport channel (DCH)). There may be zero, one, or several uplink DPDCHs on each layer 1 connection. The uplink DPCCH is used to carry control information generated at layer 1. Control information consists of known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, feedback information (FBI), and an optional transport-format combination indicator (TFCI). The transport-format combination indicator informs the receiver about the instantaneous parameters of the different transport channels multiplexed on the uplink DPDCH, and corresponds to the data transmitted in the same frame. For each layer 1 connection there is only one uplink DPCCH.

Figure 6.5 shows the principle frame structure of the uplink dedicated physical channels. Each frame of length 10 ms is split into 15 slots, each of length $T_{\text{slot}} = 2560$ chips, corresponding to one power-control period.

The parameter k in Figure 6.5 determines the number of bits per uplink DPDCH/DPCCH slot. It is related to the spreading factor (SF) of the physical channel as $\text{SF} = 256/2^k$. The DPDCH spreading factor may thus range from 256 down to 4. An uplink DPDCH and uplink DPCCH on the same layer 1 connection generally are of different rates and thus have different spreading factors.

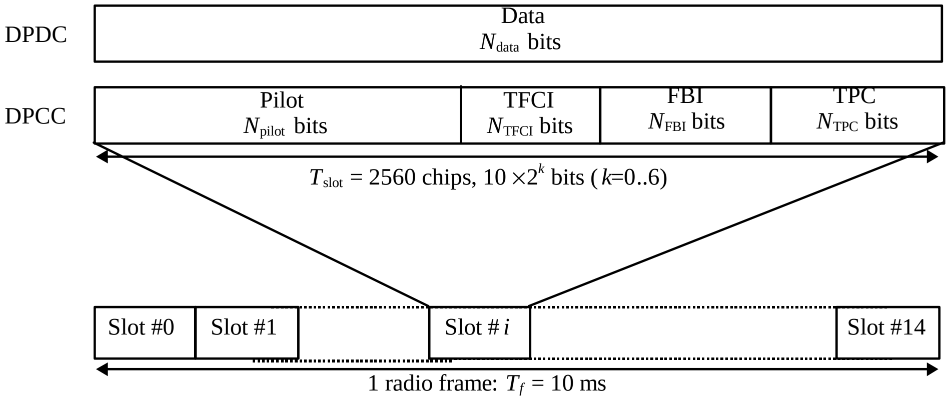

Figure 6.5 Frame structure for uplink DPDCH/DPCCH. (*Source*: [3], reproduced with permission from ETSI.)

Multiple parallel variable rate services (= dedicated logical traffic and control channels) can be time multiplexed within each DPDCH frame. The overall DPDCH bit rate is variable on a frame-by-frame basis. In most cases, only one DPDCH is allocated per connection, and services are jointly interleaved sharing the same DPDCH. Multiple DPDCHs can also be allocated, however. When multicode transmission is used, several parallel DPDCHs are transmitted using different channelization codes. There is only one DPCCH per connection, however.

The PRACH is used to carry the RACH. The random-access transmission is based on a slotted ALOHA approach with fast acquisition indication. The mobile station can start the transmission at a number of well-defined time-offsets, denoted access slots. There are 15 access slots per two frames and they are spaced 5120 chips apart. Figure 6.6 shows the access slot numbers and their spacing to each other. Information on what access slots are available in the current cell is given by higher layers. The structure of the random-access transmission is shown in Figure 6.7. The random-access transmission consists of one or several preambles of length 4096 chips and a message of length 10 or 20 ms. The mobile station indicates the length of the message part to the network by using specific signatures.

The preamble part of the random-access burst consists of 256 repetitions of a signature. There are a total of 16 different signatures, based on the Hadamard code set of length 16.

Figure 6.8 shows the structure of the random-access message part radio frame. The 10 ms message part radio frame is split into 15 slots, each of length T_{slot} = 2560 chips. Each slot consists of two parts, a data part that carries layer 2 information and a control part that carries layer 1 control information. The data and control parts are transmitted in parallel. A 20-ms-long message part consists of two consecutive message part radio frames.

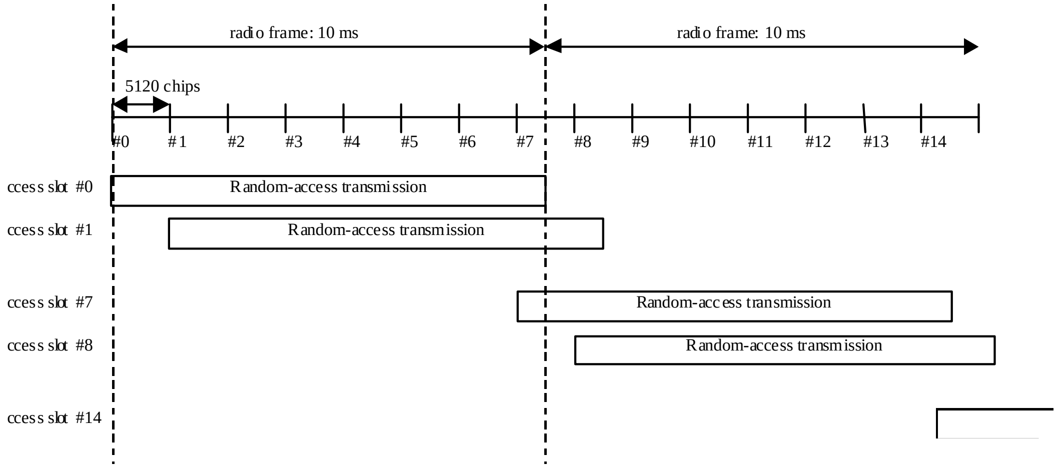

Figure 6.6 RACH access slot numbers and their spacing. (*Source*: [3], reproduced with permission from ETSI.)

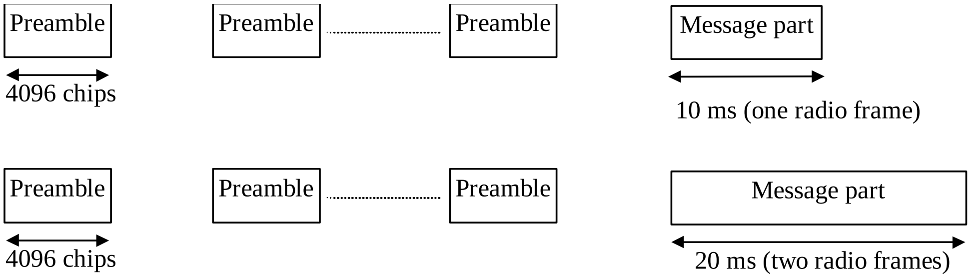

Figure 6.7 Structure of the random-access transmission. (*Source*: [3], reproduced with permission from ETSI.)

The data part consists of $10\text{x}2^k$ bits, where k= 0, 1, 2, 3. This corresponds to a spreading factor of 256, 128, 64, and 32, respectively, for the message data part.

The control part consists of eight known pilot bits to support channel estimation for coherent detection and two TFCI bits. This corresponds to a spreading factor of 256 for the message control part.

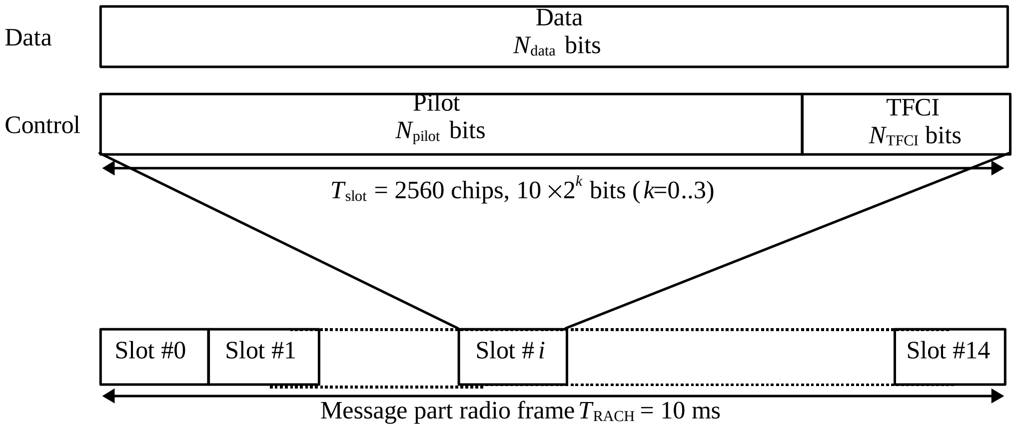

Figure 6.8 Structure of the random-access message part radio frame. (*Source*: [3], reproduced with permission from ETSI.)

The PCPCH is used to carry the CPCH transport channel. The CPCH transmission is based on DSMA-CD approach with fast acquisition indication. The mobile station can start transmission at a number of well-defined time-offsets, relative to the frame boundary of the received BCH of the current cell. The structure of the CPCH random access transmission is shown in Figure 6.9. The CPCH random-access transmission consists of one or several access preambles of length 4096 chips, one collision detection preamble (CD-P) of length 4096 chips, a DPCCH power control preamble (PC-P) (which is either 0 slots or 8 slots in length), and a message of variable length Nx10 ms.

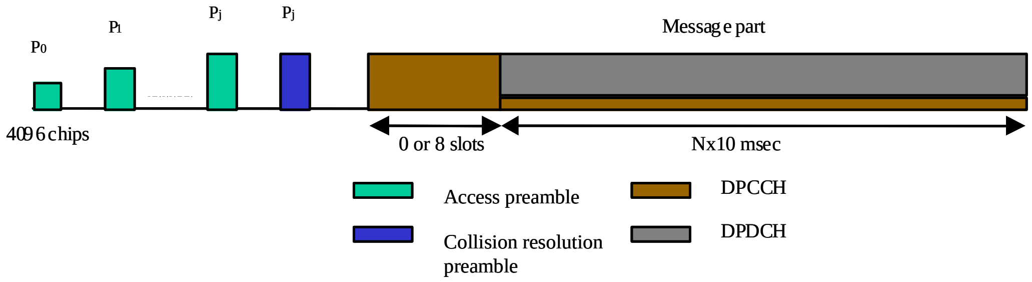

Figure 6.9 Structure of the CPCH random-access transmission. (*Source*: [3], reproduced with permission from ETSI.)

6.4.2 Downlink Physical Channels

There is one downlink dedicated physical channel, one shared and five common control channels:

- Downlink dedicated physical channel (DPCH);
- Physical downlink shared channel (DSCH);
- Primary and secondary common pilot channels (CPICH);
- Primary and secondary common control physical channels (CCPCH);
- Synchronization channel (SCH).

Figure 6.10 shows the frame structure of the DPCH. On the DPCH, the dedicated transport channel is transmitted time multiplexed with control information generated at layer 1 (known pilot bits, power-control commands, and an optional transport-format combination indicator). DPCH can contain several simultaneous services when TFCI is transmitted or a fixed rate service when TFCI is not transmitted. The network determines if a TFCI should be transmitted.

When the total bit rate to be transmitted exceeds the maximum bit rate for a downlink physical channel, multicode transmission is employed (i.e., several parallel downlink DPCHs are transmitted using the same spreading factor). In this case, the layer 1 control information is put on only the first downlink DPCH.

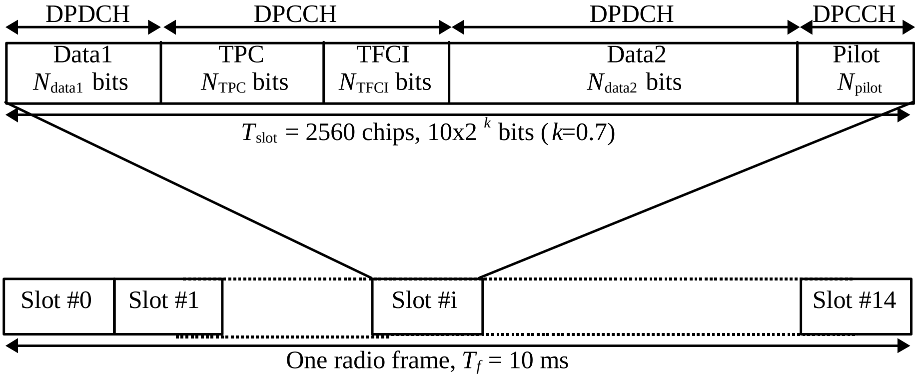

Figure 6.10 Frame structure for downlink DPCH. (*Source*: [3], reproduced with permission from ETSI.)

Common pilot channel (CPICH) is a fixed-rate (30 Kbps, SF=256) downlink physical channel that carries a predefined bit/symbol sequence. There are two types of common pilot channels, the primary and secondary CPICH, as shown in Table 6.6.

The primary CCPCH is a fixed-rate (30 Kbps, SF=256) downlink physical channels used to carry the BCH. Common control physical channels are not inner-loop power controlled. Figure 6.11 shows the frame structure of the primary CCPCH. The primary CCPCH is not transmitted during the first 256 chips of each slot. Instead, primary and secondary SCHs are transmitted during this period.

Table 6.6
Primary and Secondary CPICH

Primary CPICH	• Uses the same channelization code always; • Scrambled by the primary scrambling code; • One per cell; • Broadcast over the entire cell; • The primary CPICH is the phase reference for the SCH, primary CCPCH, AICH, PICH. It is also the default phase reference for all other downlink physical channels.
Secondary CPICH	• Zero, one, or several per cell; • May be transmitted over only a part of the cell; • A secondary CPICH may be the reference for the secondary CCPCH and the downlink DPCH. If this is the case, the mobile station is informed about this by higher-layer signaling.

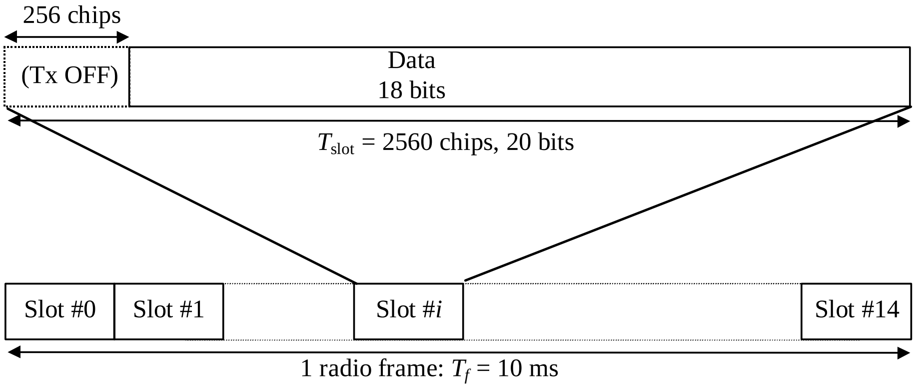

Figure 6.11 Frame structure for primary CCPCH. (*Source*: [3], reproduced with permission from ETSI.)

The frame structure of the secondary CCPCH is shown in Figure 6.12. The secondary CCPCH is used to carry the FACH and PCH. The main difference between the primary and secondary CCPCH is that the primary CCPCH has a fixed predefined rate while the secondary CCPCH can support variable rate. Furthermore, a primary CCPCH is continuously transmitted over the entire cell while a secondary CCPCH is only transmitted when there is data available and may be transmitted in a narrow lobe in the same way as a dedicated physical channel (only valid for a secondary CCPCH carrying the FACH).

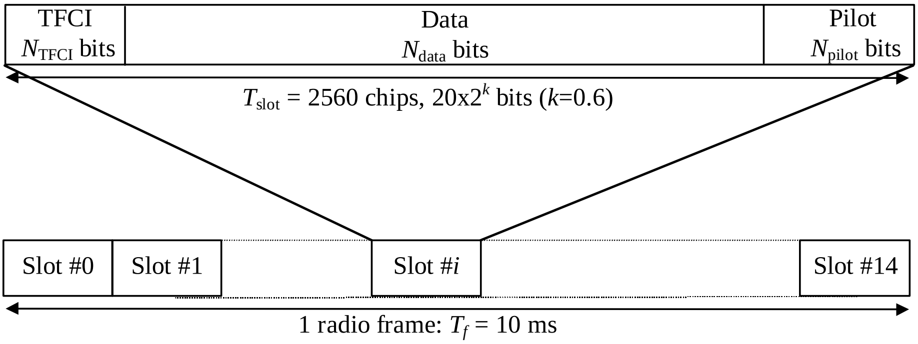

Figure 6.12 Frame structure for secondary CCPCH. (*Source*: [3], reproduced with permission from ETSI.)

Figure 6.13 depicts the structure of the synchronization channel (SCH) used for cell search. The SCH consists of two subchannels, the primary and secondary SCH.

The primary SCH consists of a modulated code of length 256 chips, the primary synchronization code (PSC) denoted c_p in Figure 6.13, transmitted once every slot. The PSC is the same for every cell in the system.

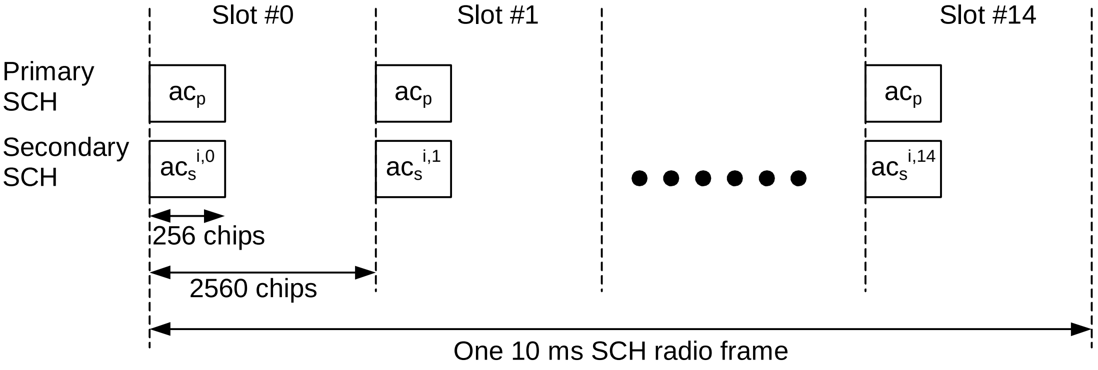

Figure 6.13 Structure of synchronization channel. (*Source*: [3], reproduced with permission from ETSI.)

The secondary SCH consists of repeatedly transmitting a length 15 sequence of modulated codes of length 256 chips, the secondary synchronization codes (SSC), transmitted in parallel with the primary SCH. The SSC is denoted $c_s^{i,k}$, where i = 1, 2, …, 64 is the number of the scrambling code group, and k = 0, 1, …, 14 is the slot number. Each SSC is chosen from a set of 16 different codes of length 256. This sequence on the secondary SCH indicates to which of the code groups the cell's downlink scrambling code belongs.

The physical downlink shared channel is used to carry the downlink shared channel. It is shared by users based on code multiplexing. The structure of the PDSCH is shown in Figure 6.14. As the DSCH is always associated with a DCH, the PDSCH is always associated with a downlink DPCH. For PDSCH the spreading factors may vary from 256 to 4. If the spreading factor and other physical layer parameters can vary on a frame-by-frame basis, the TFCI shall be used to inform the mobile stations of the instantaneous parameters of PDSCH.

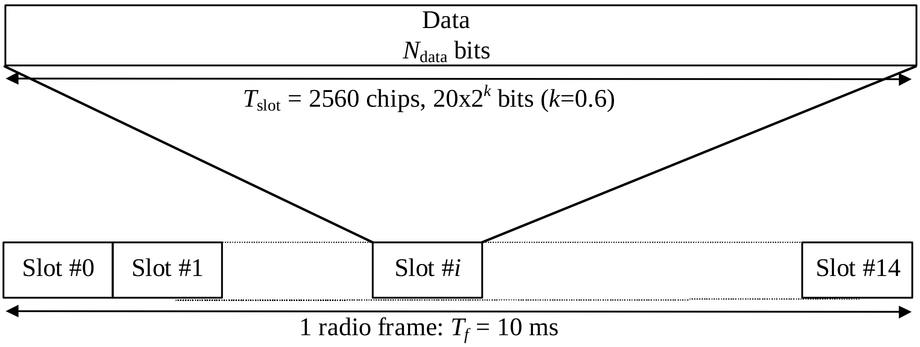

Figure 6.14 Frame structure for the PDSCH. (*Source*: [3], reproduced with permission from ETSI.)

The acquisition indicator channel (AICH) is a physical channel used to carry acquisition indicators, which correspond to signature *s* on the PRACH or PCPCH.

The page indicator channel (PICH) is a fixed-rate (SF=256) physical channel used to carry the page indicators. The PICH is always associated with a secondary CCPCH to which a PCH transport channel is mapped.

6.5 MULTIRATE USER DATA TRANSMISSION

WCDMA has a flexible multirate transmission scheme that enables transmission of different types of services using different data rates and quality of service parameters. For example, channel coding type, interleaving depth, and data rate can be varied to achieve the desired quality of service.

Figure 6.15 and Figure 6.16 show the multirate transmission and multiplexing schemes for the uplink and downlink, respectively. Data from transport channels is encoded and thereafter mapped to the physical channels and transmitted over the radio transmission link. The channel coding scheme is a combination of error detection, error correcting, rate matching, interleaving, and transport channels mapping onto physical channels.

Data arrives to the coding/multiplexing unit in the form of transport block sets once every transmission time interval, which is transport-channel specific and can be 10, 20, 40, or 80 ms. Multirate transmission consists of following steps:

- Addition of cyclic redudancy check (CRC) to each transport block;
- Concatenation of transport block and segmentation of code block;

- Channel coding;
- Rate matching;
- Insertion of discontinuous transmission (DTX) indication bits;
- Interleaving;
- Segmentation of radio frames;
- Multiplexing of transport channels;
- Segmentation of physical channel;
- Mapping to physical channels.

Error detection is provided on transport blocks through CRC. The CRC is 24, 16, 12, 8, or 0 bits, and higher layers signal what CRC length should be used for each transport channel.

After CRC addition, transport block concatenation and code block segmentation are performed. All transport blocks in are serially concatenated. If the number of bits in the transmission time interval is larger the maximum size of the used code block, then code block segmentation is performed after the concatenation of the transport blocks. The maximum size of the code blocks depends on whether convolutional coding, turbo coding, or no coding is used. The maximum code block sizes are:

- Convolutional coding: 504;
- Turbo coding: 5114;
- No channel coding: unlimited.

Radio frame size equalization is padding the input bit sequence in order to ensure that the output can be segmented in consecutive radio frames of the same size. Radio frame size equalization is only performed in the uplink. In the downlink, rate matching output block length is already suitable for radio frame segmentation.

When the transmission time interval is longer than 10 ms, the input bit sequence is segmented and mapped onto consecutive radio frames. This enables interleaving over several radio frames improving spectrum efficiency.

Because WCDMA provides flexible data rates, the number of bits on a transport channel can vary between different transmission time intervals. The rate matching adapts this resulting symbol rate to the limited set of possible symbol rates of a physical channel. Rate matching means that bits on a transport channel are repeated or punctured according to the defined rate matching attribute, which is semistatic and can only be changed through higher layer signaling.

In the downlink the transmission is interrupted if the number of bits is lower than maximum (i.e., DTX is used to fill up the radio frame with bits). The insertion point of DTX indication bits depends on whether fixed or flexible positions of the transport channels in the radio frame are used. It is up to the network to decide for each transport channel whether fixed or flexible positions are used during the connection. DTX indication bits only indicate when the transmission should be turned off, they are not transmitted.

One or more physical channels can be used to transmit the result. When more than one physical channel is used, physical channel segmentation divides the bits among the different channels. After the second interleaving, physical channel mapping is performed.

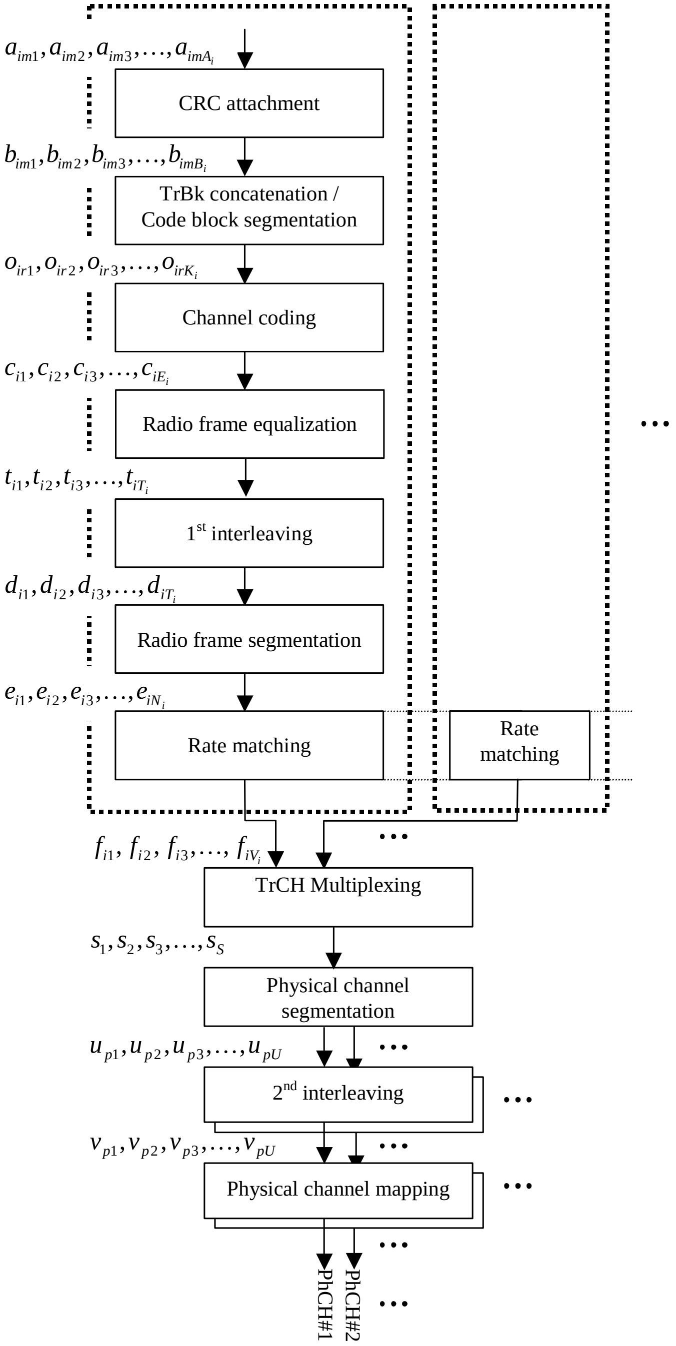

Figure 6.15 Multirate scheme for uplink. (*Source*: [4], reproduced with permission from ETSI.)

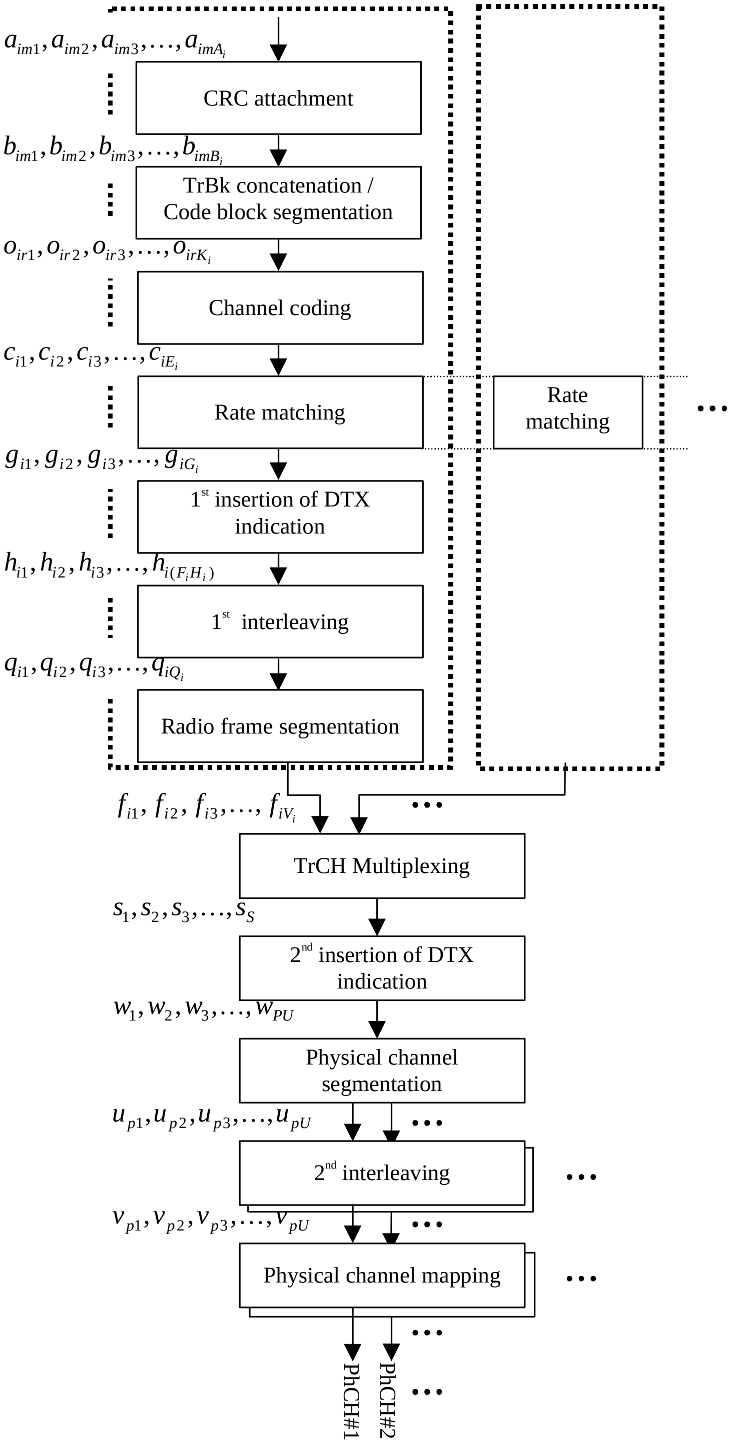

Figure 6.16 Multirate scheme for downlink. (*Source*: [4], reproduced with permission from ETSI.)

6.5.1 Transport Format Detection

Transport format detection can be performed both with and without transport format combination indicator (TFCI). If a TFCI is transmitted, the receiver detects the transport format combination from the TFCI. When no TFCI is transmitted, so-called blind transport format detection may be used (i.e., the receiver side detects the transport format combination using some information, for example, received power ratio of DPDCH to DPCCH or CRC check results).

6.5.2 Channel Coding

Table 6.7 lists the channel coding parameters for different transport channel types. The following channel coding schemes can be applied:

- Convolutional coding with constraints length 9 and coding rate 1/3 or 1/2;
- Turbo coding;
- No channel coding.

The first and second interleaving are both block interleavers with intercolumn permutations.

Table 6.7

Error Correction Coding Parameters

Transport channel type	Coding scheme	Coding rate
BCH	Convolutional code	1/2
PCH		
RACH		
CPCH, DCH, DSCH, FACH		1/3, 1/2
	Turbo code	1/3
	No coding	

The turbo coding scheme is a parallel concatenated convolutional code (PCCC) with eight-state constituent encoders.

The initial value of the shift registers of the PCCC encoder shall be all zeros (see Figure 6.17). The output of the PCCC encoder is punctured to produce coded bits corresponding to the desired code rate. For rate 1/3, none of the systematic or parity bits are punctured.

Figure 6.18 depicts the overall eight-state PCCC turbo coding scheme including turbo code internal interleaver. The turbo code internal interleaver consists of mother interleaver generation and pruning. For arbitrary given block length K, one mother interleaver is selected from the 134 mother interleavers set. After the mother interleaver generation, l-bits are pruned in order to adjust the mother interleaver to the block length K. Tail bits T1 and T2 are added for constituent encoders RSC1 and RSC2, respectively.

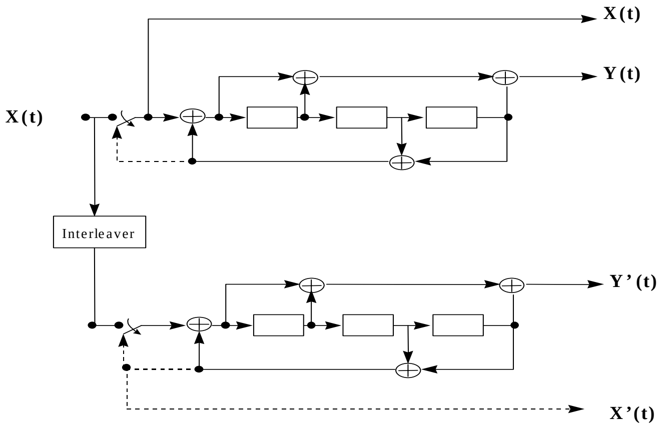

Figure 6.17 Structure of the eight-state PCCC encoder (dotted lines effective for trellis termination only). (*Source*: [4], reproduced with permission from ETSI.)

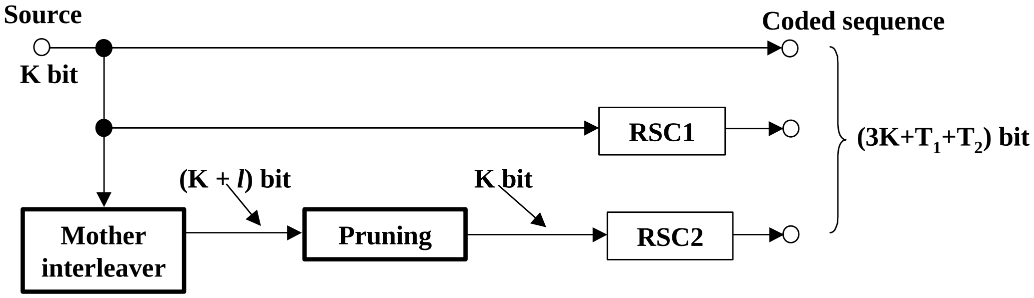

Figure 6.18 Overall eight-state PCCC turbo coding. (*Source*: [4], reproduced with permission from ETSI.)

6.6 SPREADING AND MODULATION

WCDMA applies a two-layered code structure consisting of a orthogonal spreading codes and pseudo-random scrambling codes. Spreading is performed using channelization codes, which transforms every data symbol into a number of chips, thus increasing the bandwidth of the signal. Orthogonality between the different spreading factors can be achieved by the tree-structured orthogonal codes whose construction was described in Chapter 5. Scrambling is used for cell separation in the downlink and user separation in the uplink.

6.6.1 Uplink Spreading

In the uplink, either short or long spreading (scrambling) codes are used. The short codes are used to ease the implementation of advanced multiuser receiver techniques; otherwise, long spreading codes can be used. Short codes are S(2) codes of length 256 and long codes are Gold sequences of length 2^{41}, but the latter are truncated to form a cycle of a 10-ms frame.

IQ/code multiplexing used in the uplink leads to parallel transmission of two channels, and therefore, attention must be paid to modulated signal constellation and related peak-to-average power ratio (crest factor). By using the complex spreading circuit shown in Figure 6.19, the transmitter power amplifier efficiency remains the same as for QPSK transmission in general.

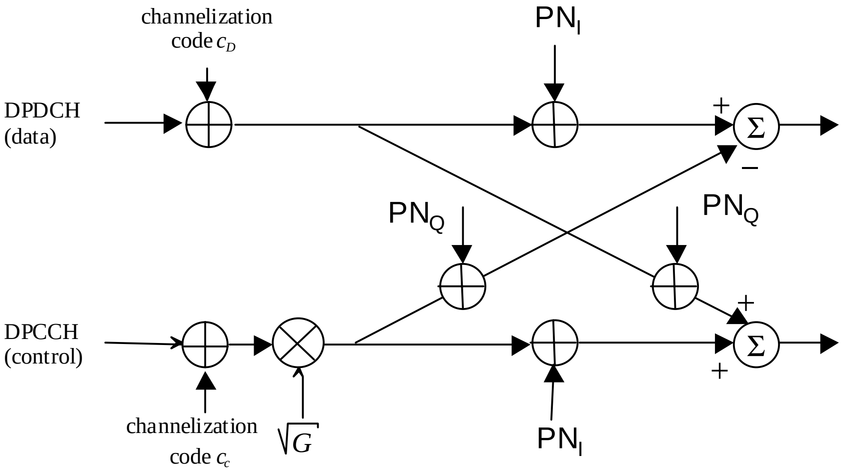

Figure 6.19 IQ/code multiplexing with complex spreading circuit.

Moreover, the efficiency remains constant irrespective of the power difference *G* between DPDCH and DPCCH. Thus, signal envelope variations are very similar to the QPSK transmission for all values of *G*.

The IQ/code multiplexing solution with complex scrambling results in power amplifier output backoff requirements that remain constant as a function of power difference. Furthermore, the achieved output backoff is the same as for one QPSK signal.

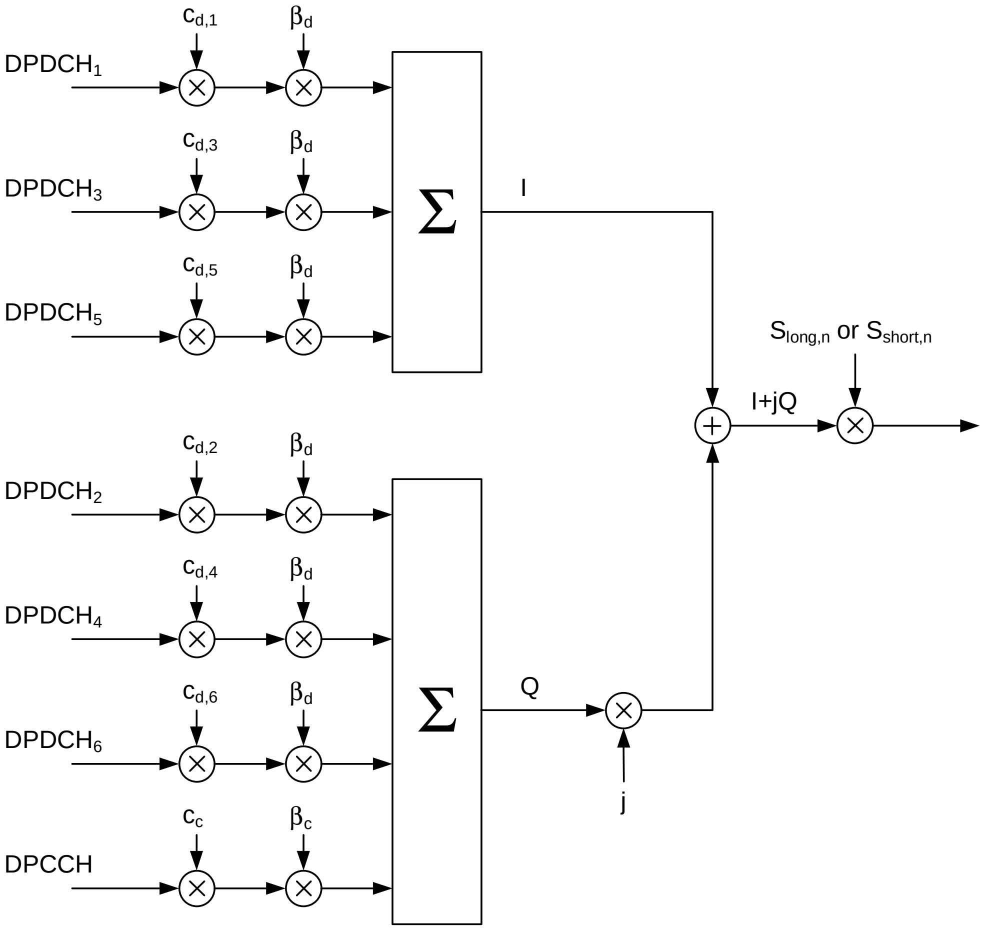

Figure 6.20 Spreading for uplink DPCCH and DPDCHs. (*Source*: [5], reproduced with permission from ETSI.)

Figure 6.20 shows the uplink spreading of DPCCH and DPDCHs, which are spread by different channelization codes. One DPCCH and up to six parallel DPDCHs can be transmitted simultaneously. After channelization, the real-valued spread signals are weighted by gain factors, which is different for DPCCH and DPDCHs but is the same for all DPDCHs. After transforming the signal from real to complex, it is then scrambled by the complex-valued scrambling code, which can be long or short.

6.6.1.1 PRACH Spreading

The PRACH consisted of preamble and message parts. The preamble is a complex-valued code and message part consists of data and control parts. Figure 6.21 shows spreading and scrambling of the PRACH message part. After channelization, the spread signals are weighted by gain factors. Scrambling is performed by a 10-ms-long complex-valued scrambling code.

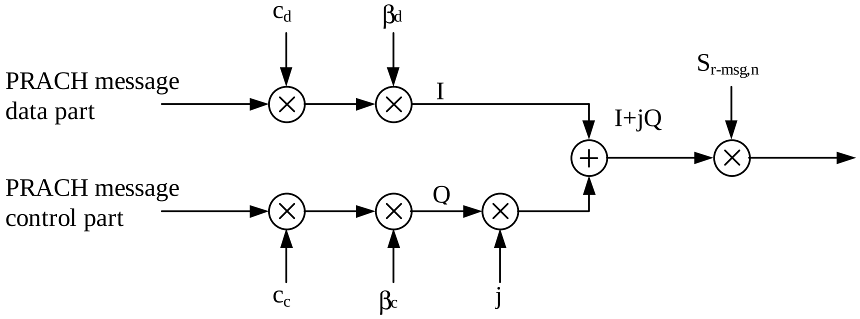

Figure 6.21 Spreading of PRACH message part. (*Source*: [5], reproduced with permission from ETSI.)

6.6.1.2 PCPCH

The PCPCH consists of preamble and message parts. The preamble part consists of a complex-valued code, and the message part consists of data and control parts. Figure 6.22 shows the spreading of the PCPCH message part. The control and data part are spread by different channelization codes After channelization, the spread signals are weighted by gain factors. Scrambling is performed by a 10-ms long complex-valued scrambling code.

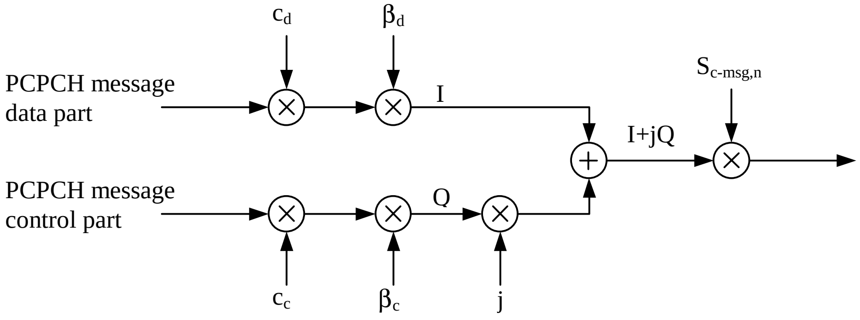

Figure 6.22 Spreading of PCPCH message part. (*Source*: [5], reproduced with permission from ETSI.)

6.6.2 Downlink Spreading

In the downlink, the same orthogonal channelization codes are used as in the uplink. For scrambling, Gold codes of length 2^{18} are used, but they are truncated to form a cycle of a 10-ms frame (i.e., 384,000 chips). To form a complex-valued code, the same truncated code is used with different time shifts in I and Q channels.

It is possible to generate 2^{18}-1 scrambling codes, but only 8191 of them are used. Each cell is allocated one primary scrambling code. In order to reduce the cell search time, the primary scrambling codes are divided into 512 sets. Thus, the mobile station needs to search at maximum 512 10-ms-long codes.

In addition to primary scrambling codes, there are 15 secondary scrambling code sets. Secondary scrambling codes are used when one set of orthogonal channelization codes is not enough. This can be the case when adaptive antennas are used in the downlink. It should be noted that use of the secondary scrambling code destroys the orthogonality between code channels. This is counterweighted, however, by the spatial isolation offered by adaptive antennas.

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

Figure 6.23 illustrates the spreading operation for all downlink physical channels except SCH (i.e., for P-CCPCH, S-CCPCH, CPICH, AICH, PICH, and downlink DPCH). The nonspread physical channel consists of a sequence of real-valued symbols. For all channels except AICH, the symbols can take the three values +1, -1, and 0, where 0 indicates DTX. For AICH, the symbol values depend on the exact combination of acquisition indicators to be transmitted.

Each pair of two consecutive symbols is first serial-to-parallel converted and mapped to an I and Q branch. The mapping is such that even and odd numbered symbols are mapped to the I and Q branch, respectively. For all channels except AICH, symbol number zero is defined as the first symbol in each frame. For AICH, symbol number zero is defined as the first symbol in each access slot. The I and Q branches are then spread to the chip rate by the same real-valued channelization code $C_{ch,SF,m.}$ The sequences of real-valued chips on the I and Q branch are then treated as a single complex-valued sequence of chips. This sequence of chips is scrambled by a complex-valued scrambling code $S_{dl,n}$. In case of P-CCPCH, the scrambling code is aligned with the P-CCPCH frame boundary (i.e., the first complex chip of the spread P-CCPCH frame is multiplied with chip number zero of the scrambling code). In case of other downlink channels, the scrambling code is aligned with the scrambling code applied to the P-CCPCH. In this case, the scrambling code is thus not necessarily aligned with the frame boundary of the physical channel to be scrambled.

Figure 6.24 shows how different downlink channels are combined. Each complex-valued spread channel, corresponding to point S in Figure 6.23, is separately weighted by a weight factor G_i. The complex-valued P-SCH and S-SCH are also weighted separately. All downlink physical channels are then combined using complex addition.

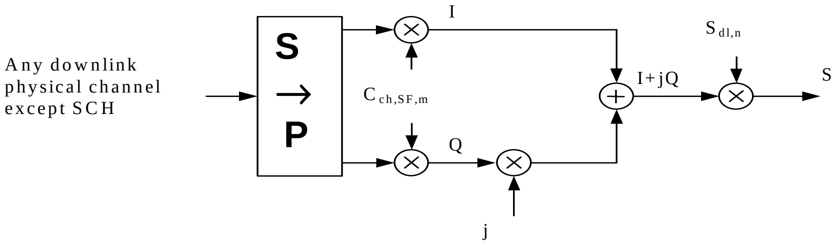

Figure 6.23 Spreading for all downlink physical channels except SCH. (*Source*: [5], reproduced with permission from ETSI.)

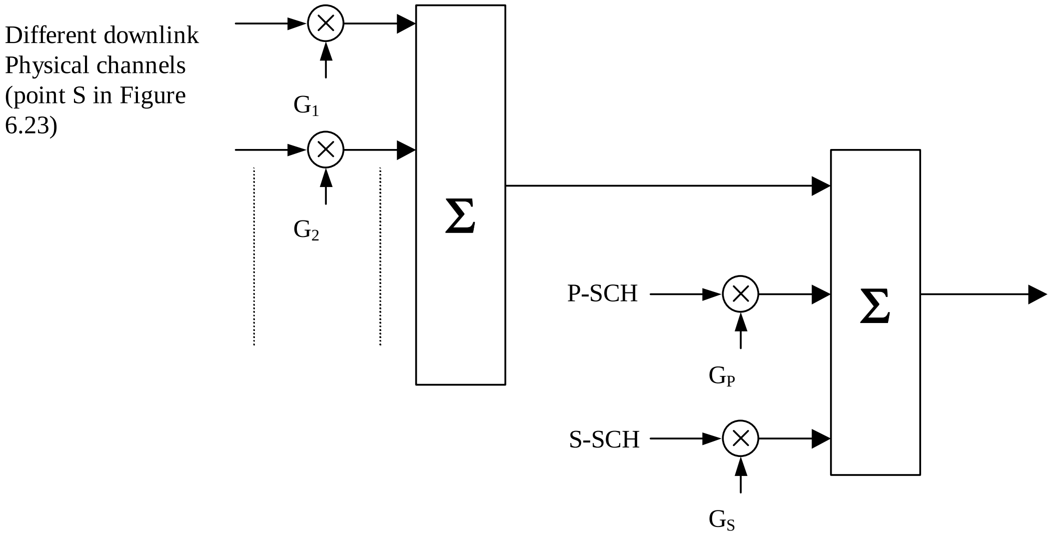

Figure 6.24 Spreading and modulation for SCH and P-CCPCH. (*Source*: [5], reproduced with permission from ETSI.)

6.6.2.1 Synchronization Codes

The primary synchronization code (PSC), CPSC is constructed as a so-called generalized hierarchical Golay sequence. The PSC is furthermore chosen to have good aperiodic autocorrelation properties.

6.6.3 Modulation

The complex-valued chip sequence generated by the spreading process is QPSK modulated. Figure 6.25 illustrates the modulation principle used in the uplink and downlink. The pulse shaping is root-raised cosine with roll-off factor 0.22 and is the same for the mobile and base stations.

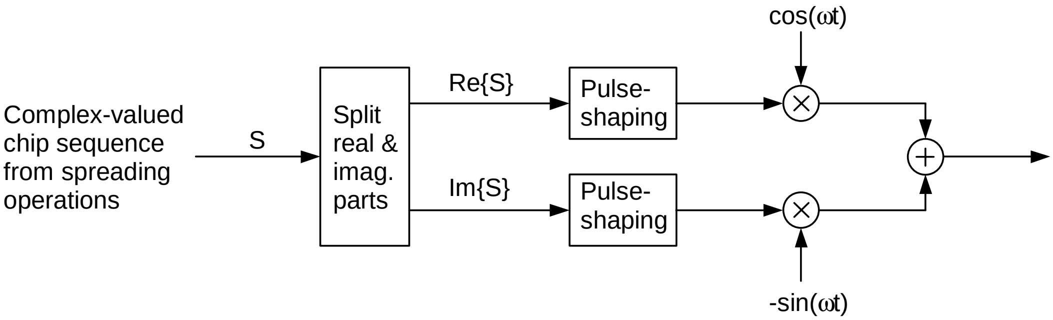

Figure 6.25 Modulation principle. (*Source*: [5], reproduced with permission from ETSI.)

6.7 TRANSMIT DIVERSITY

Two types of diversity mechanism can be used in the downlink of WCDMA: open loop and closed loop. The open-loop downlink transmit diversity employs a space/time block coding–based transmit diversity (STTD). Even though the STTD encoding is optional in the base station, STTD support is mandatory at the mobile station. Another type of open loop transmit diversity, time switched transmit diversity (TSTD), can be applied to the SCH channel. This diversity mechanism is also optional in the base station but mandatory in the mobile station.

Not all diversity methods can be used will all physical channels. Table 6.8 summarizes the possible application of open and closed-loop transmit diversity modes on different downlink physical channels. Simultaneous use of STTD and closed loop modes on DPCH and PDSCH is not allowed.

Table 6.8

Application of Tx Diversity Modes on Downlink Physical Channels

Channel	Open loop mode		Closed loop mode
	TSTD	STTD	
P-CCPCH	-	X	-
SCH	X	-	-
S-CCPCH	-	X	-
DPCH	-	X	X
PICH	-	X	-
PDSCH (associated with DPCH)	-	X	X
AICH	-	X	-

Note: “X” - can be applied, “-” cannot be applied.

6.8 AIR INTERFACE PROCEDURES

Different air interface procedures are required to make a radio system work (i.e., to establish communication and maintain it with a minimum consumption of radio resources). In this section the following air interface procedures are covered:

- Cell search operation;
- Handover;
- Power control;
- Uplink synchronous transmission scheme (USTS).

6.8.1 Cell Search

During the cell search, the mobile station searches for a cell and determines the downlink scrambling code and common channel frame synchronization of that cell. Because the radio frame timing of all common physical channels is related to the timing of P-CCPCH, it is enough to find the timing of P-CCPCH only.

The cell search is typically carried out in three steps: slot synchronization; frame synchronization and code-group identification; and scrambling-code identification. An example procedure from the 3GPP specification TS25.214 is described as follows:

- *Step 1: Slot synchronization.* During the first step of the cell search procedure, the mobile station uses the SCH’s primary synchronization code to acquire slot synchronization to a cell. This can be done with a single matched filter matched to the primary synchronization code that is common to all cells. The slot timing of the cell can be obtained by detecting peaks in the matched filter output.
- *Step 2: Frame synchronization and code-group identification.* During the second

step of the cell search procedure, the mobile station uses the SCH’s secondary synchronization code to find frame synchronization and identify the code group of the cell found in the first step. This is done by correlating the received signal with all possible secondary synchronization code sequences and identifying the maximum correlation value. Because the cyclic shifts of the sequences are unique, the code group and the frame synchronization are determined.

- *Step 3: Scrambling-code identification*. During the third and last step of the cell search procedure, the mobile station determines the exact primary scrambling code used by the found cell. The primary scrambling code is typically identified through symbol-by-symbol correlation over the CPICH with all codes within the code group identified in the second step. After the primary scrambling code has been identified, the primary CCPCH can be detected. And the system- and cell specific BCH information can be read.

In case the mobile station has received information about which scrambling codes to search for, steps 2 and 3 above can be simplified.

6.8.2 Handover

WCDMA has several different types of handovers:

- Soft, softer, and hard handover;
- Interfrequency handover;
- Handover between FDD and TDD modes;
- Handover between WCDMA and GSM.

The handover algorithm to make the handover decision needs different types of measurement information. Table 6.9 lists the measurements that can be carried for handover purposes. The actual handover algorithm implementation is left to equipment manufacturers.

Base stations in WCDMA need not be synchronized, and therefore, no external source of synchronization, like GPS, is needed for the base stations. Asynchronous base stations must be considered when designing soft handover algorithms and when implementing location services.

Before entering soft handover, the mobile station measures observed timing differences of the downlink SCHs from the two base stations. The structure of SCH is presented in Section 6.4.4. The mobile station reports the timing differences back to the serving base station. The timing of a new downlink soft handover connection is adjusted with a resolution of one symbol (i.e., the dedicated downlink signals from the two base stations are synchronized with an accuracy of one symbol). That enables the mobile RAKE receiver to collect the macro diversity energy from the two base stations. Timing adjustments of dedicated downlink channels can be carried out with a resolution of one symbol without losing orthogonality of downlink codes.

Table 6.9
Handover Measurements

Received signal code power (RSCP)	Received power on one code measured on the pilot bits of the primary CPICH. The reference point for the RSCP is the antenna connector at the mobile station.
TDD received signal code power	Received power on one code measured on the PCCPCH from a TDD cell. The reference point for the RSCP is the antenna connector at the mobile station.
Received signal code power after radio link combination	Received power on one code measured on the pilot bits of the DPCCH after radio link combination. The reference point for the RSCP is the antenna connector at the mobile station.
SIR	Signal-to-interference ratio, defined as: $(RSCP/ISCP)\times(SF/2)$, where ISCP = interference signal code power, the interference on the received signal measured on the pilot bits. Only the nonorthogonal part of the interference is included in the measurement. SF = the spreading factor used. The SIR shall be measured on DPCCH after RL combination. The reference point for the SIR is the antenna connector of the mobile station.
RSSI	Received signal strength indicator, the wideband received power within the relevant channel bandwidth. Measurement shall be performed on downlink carrier. The reference point for the RSSI is the antenna connector at the mobile station.
GSM carrier RSSI	Received signal strength indicator, the wideband received power within the relevant channel bandwidth. Measurement shall be performed on a GSM BCCH carrier. The reference point for the RSSI is the antenna connector at the mobile station.
CPICH Ec/No	The received energy per chip divided by the power density in the band. The Ec/No is identical to RSCP/RSSI. Measurement shall be performed on the primary CPICH. The reference point for Ec/No is the antenna connector at the mobile station.
Transport channel BLER	Estimation of the transport channel block error rate (BLER). The BLER estimation shall be based on evaluating the CRC on each transport block after radio link combination. Used in SIR target setting for fast power control in the outer loop power control.
Physical channel BER	The physical channel bit error rate (BER) is an estimation of the average bit error rate before channel decoding of the DPDCH data after radio link combination.
Mobile station transmitted power	The total mobile station transmitted power on one carrier. The reference point for the UE transmitted power shall be the mobile station antenna connector.

6.8.2.1 *Interfrequency Handovers*

Interfrequency handovers are needed for utilization of hierarchical cell structures; macro, micro, and indoor cells (see Chapter 10). Several carriers and interfrequency handovers may also be used for taking care of high capacity needs in hot spots. Interfrequency handovers will be needed also for handovers to second-generation systems like GSM or IS-95. In order to complete interfrequency handovers, an efficient method is needed for making measurements on other frequencies while still having the connection running on the current frequency. Two methods are considered for interfrequency measurements in WCDMA:

- Dual receiver;
- Compressed mode.

The dual receiver approach is considered suitable, especially if the mobile terminal employs antenna diversity. During the interfrequency measurements, one receiver branch is switched to another frequency for measurements, while the other keeps receiving from the current frequency. The loss of diversity gain during measurements needs to be compensated for with higher downlink transmission power. The advantage of the dual receiver approach is that there is no break in the current frequency connection. Fast closed loop power control is running all the time.

The compressed mode approach (also referred as slotted mode) depicted in Figure 6.26 is required for the mobile station without dual receiver. The information normally transmitted during a 10-ms frame is compressed either by code puncturing or by changing the FEC rate. For the performance of different interfrequency handover options, see Section 5.14.5.

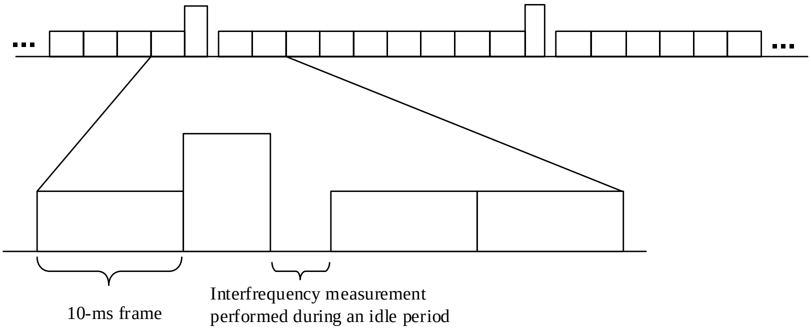

Figure 6.26 Compressed mode structure.

6.8.2.2 *Handover Between GSM and WCDMA*

The handover between the WCDMA system and the GSM system, offering worldwide coverage today, has been one of the main design criteria taken into account in the WCDMA frame timing definition. The GSM-compatible multiframe structure, with the superframe being multiple of 120 ms, allows similar timing for intersystem measurements as in the GSM system itself. Apparently, the needed measurement interval does not need to be as frequent as for GSM terminal operating in a GSM system, as intersystem handover is less critical from an intrasystem interference point of view. Rather, the compatibility in timing is important, so that when operating in WCDMA mode, a multimode terminal is able to catch the desired information from the synchronization bursts in the synchronization frame on GSM carrier with the aid of a frequency correction burst. This way the relative timing between a GSM and WCDMA carriers is maintained similar to the timing between two asynchronous GSM carriers. The timing relation between WCDMA channels and GSM channels is indicated in

Figure 6.27, where the GSM traffic channel and WCDMA channels use a similar 120-ms multiframe structure. The GSM frequency correction channel (FCCH) and GSM synchronization channel (SCH) use one slot out of the eight GSM slots in the indicated frames, with the FCCH frame with one time slot for FCCH always preceding the SCH frame with one time slot for SCH, as indicated in Figure 6.27. Further details on GSM common channel structures can be found in [2].

A WCDMA terminal can do the measurements either by requesting the measurement intervals in a slotted mode form where there are breaks in the downlink transmission, or by performing the measurements independently with a suitable measurement pattern. With independent measurements the dual receiver approach is used instead of the slotted mode because the GSM receiver branch can operate independently of the WCDMA receiver branch.

For smooth interoperation between the systems, information needs to be exchanged between the systems, in order to allow the WCDMA base station to notify the terminal of the existing GSM frequencies in the area. In addition, more integrated operation is needed for the actual handover where the current service is maintained, naturally taking into account the lower data rate capabilities in GSM when compared to the UMTS maximum data rates reaching all the way to 2 Mbps.

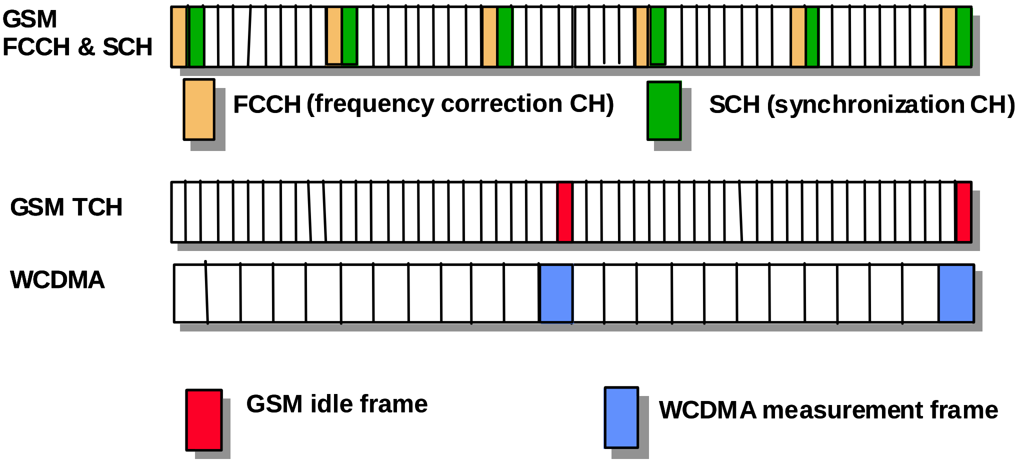

Figure 6.27 Measurement timing relation between WCDMA and GSM frame structures.

The GSM system is likewise expected to be able to indicate the WCDMA spreading codes in the area to make the cell identification simpler. After that the existing measurement practices in GSM can be used for measuring the WCDMA when operating in GSM mode.

As the WCDMA does not rely on any superframe structure as with GSM to find out synchronization, the terminal operating in GSM mode is able to obtain the WCDMA frame synchronization once the WCDMA base station scrambling code timing is acquired. The base station scrambling code has 10-ms period and its frame timing is synchronized to WCDMA common channels.

6.8.3 Power Control

WCDMA has fast closed loop and open loop power control procedures. The fast power control operates with a rate of 1.5 KHz (i.e., one command per slot). The nominal power control step size is 1 dB, but multiples of the nominal step sizes can also be used. Power control commands can only be sent every second slot.

In soft handover state, power control commands from different base stations are combined, taking the reliability of each command into account. In the compressed mode, the fast power control uses a larger step size for a short period after a compressed frame in order to converge faster.

Open loop power control is used before initiating transmission on the RACH or CPCH. Power control accuracy is required to be ±9 dB.

6.8.4 Uplink Synchronous Transmission Scheme

Uplink synchronous transmission scheme is an alternative technology applicable for low mobility terminals. USTS can reduce uplink intracell interference by means of making a cell receive orthogonalized signals from mobile stations. To orthogonalize receiving signals from mobile stations:

- The same scrambling code is allocated to all dedicated physical channels in a cell;
- Different channelization codes are allocated to all dedicated physical channels across all mobile stations in a cell, and the spreading factor and code number of channelization code are delivered from network to each mobile station;
- The channelization codes for DPDCH and DPCCH in a mobile station are chosen from either the upper half part or the lower half part of the OVSF code tree in a mobile station to reduce the peak-to-average power ratio;
- Additional scrambling codes can be allocated if all channelization codes are occupied;
- The signal transmission time of each mobile station is adjusted.

The transmission time control is carried out by two steps. The first step is initial synchronization and the second is tracking:

1. *Initial synchronization:* Adjust transmission time through the initial timing control message over FACH. When the cell receives the signal from the mobile station over RACH, the cell measures the time difference between the received timing and the reference time in the unit of 1/8 chip duration. The message for initial synchronization, which contains the difference in

time, is delivered to mobile station via FACH.

2. *Tracking process (closed loop timing control):* Adjust the transmission time through the time alignment bit (TAB) over DPCCH. UE adjusts its transmission time according to the message. The cell periodically compares the reference time with the received signal timing from mobile station. When the received timing is earlier than the reference time, TAB = 0. When the received timing is later than the reference time, TAB = 1. TAB replaces the TPC bit every timing control period of 20 ms the last TPC bit of every two frames is replaced by TAB. At the mobile station, hard decision on the TAB shall be performed, and when it is judged as 0, the transmission time shall be delayed by 1/8 chip, whereas if it is judged as 1, the transmission time shall be advanced by 1/8 chip.

6.8.5 Packet Data

WCDMA has three different types of packet data transmission possibilities [2]:

- Common channels;
- Dedicated channel;
- Shared channels.

The advantage of using common channels for packet data transmission is the very short link setup time. Common channels RACH (uplink) and FACH (downlink) are used for short infrequent packets. Soft handover cannot be used for these channels. In addition, only open loop power control is in operation. Therefore, RACH and FACH packet transmission should be limited to short packets that only use a limited capacity. Figure 6.28 illustrates packet transmission on RACH.

The common packet channel (CPCH) can be used to transmit short and medium-sized data packets. The setup procedure is similar to RACH, but the channel can be shared in time division fashion between different users and fast power control can be used. Soft handover cannot be used for CPCH.

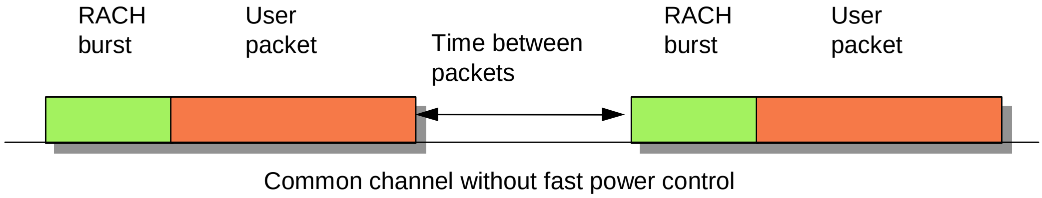

Figure 6.28 Packet transmission on the RACH channel.

Larger or more frequent packets are transmitted on a dedicated channel. Now, soft handover and fast power control are used and thus radio performance is better than transmission in the common channels. The data rate can be varied during the transmission. Consequently, the number of orthogonal codes in the downlink has to be allocated according to the highest bit rate. If several high bit rate dedicated packet access connections exist, there might not be enough orthogonal channels available.

To overcome the limitation of running out of orthogonal codes, downlink shared channel (DSCH) can be used. In this packet transmission mode, a single physical channel is shared using time division. With DSCH, fast power control but not soft handover can be used. Fast power control signaling is carried on a low bit rate dedicated channel.

6.9 WCDMA EVOLUTION – RELEASE 2000 AND BEYOND

WCDMA will continue to evolve based on research and new innovations. Release 2000 (now renamed release 4) specifications will provide efficient IP support enabling provision of services through an all-IP core network. Technical issues to be solved include header compression and QoS. The later 3GPP releases will provide even higher data rates up to approximately 10 Mps. A work item to specify high-speed packet access (HSPA) has been started. The following enhancements are proposed:

- Adaptive modulation and coding (AMCS);
- Hybrid automatic-repeat-request (HARQ);
- Smaller frame size;
- Position of scheduling mechanism;
- Fast cell site selection;
- Uplink DCH associated with a access control channel (ACCH).

REFERENCES

[1] Chaudry, P., M. Mohr, and S. Onoe, "The 3GPP Proposal for IMT-2000," *IEEE Communications Magazine*, Vol. 39, No. 12, December 1999, pp. 72–81.
[2] Holma, H., and A. Toskala (eds.), *WCDMA for UMTS*, Chichester, England: John Wiley & Sons, Ltd., 2000.
[3] TS 25.211, "Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD)," 3GPP Technical Specification, Version 3.2.0, March 2000.[1]
[4] TS 25.212, "Multiplexing and Channel Coding (FDD)," 3GPP Technical Specification, Version 3.2.0, March 2000.
[5] TS 25.213, "Spreading and Modulation (FDD)," 3GPP Technical Specification, Version 3.2.0, March 2000.

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