17

Third generation mobile communication systems

17.1 INTRODUCTION

In the previous chapters we presented examples of existing mobile communication systems. Among the second generation systems there are several cellular systems which have attracted millions of subscribers, such as GSM, IS-95, IS-136 and PDC (the last two only mentioned in this book), wireless telephony like DECT, PACS and PHS, data transmission systems like GPRS and EDGE or personal satellite communication systems (e.g. Iridium, Globalstar). A large variety of systems differing in applications requires different equipment. It is also worth noting that the existing systems operate in selected environments only. Thus, it would be desirable to create a universal system which could operate anywhere, anytime using a unified equipment.

The research on third generation systems was initiated long before the potential of the GSM and other second generation systems was exhausted.The aim was to create a global standard which would enable global roaming. The International Telecommunications Union (ITU) began to work on the third generation mobile communication system by defining the basic requirements. The system was initialy called *Future Public Land Mobile Telecommunication System* (FPLMTS) and now is know as *International Mobile Telecommunications* (IMT-2000). The basic requirements are as follows:

- Throughput rates up to
  - 2 Mbit/s indoors and for pedestrians
  - 384 kbit/s for terminals moving at no more than 120 km/h in urban areas
  - 144 kbit/s in rural areas and for fast moving vehicles
- Support of global mobility

- Independence of the IMT-2000 services from the applied radio interface technology. This allows use of different air interfaces. On the other hand, multimode terminals must be used.
- Seamless switching between fixed and wireless telecommunication services
- Support of circuit- and packet-switched services
- Support of multimedia and real-time services
- Implementation of the *Virtual Home Environment* (VHE). The user interface features typical for his/her home environment remain the same during roaming in different networks

The implementation of a system which would fulfill the above requirements was left to the following regional bodies:

- ETSI (*European Telecommunications Standard Institute*), which since 1995 has worked on proposals for UMTS (*Universal Mobile Telecommunication System*) WCDMA (*Wideband CDMA*) radio access,
- the T1P1 committee in the USA which has coordinated research on the evolution of the second generation systems used in the USA (IS-95, IS-136 and GSM 1900) which resulted in the proposal of a multicarrier CDMA based on IS-95,
- ARIB (*Association for Radio Industries and Businesses*) in Japan, which proposed an air interface very similar to the UMTS interface,
- TTA (*Telecommunications Technology Association*) in South Korea which proposed to use CDMA in the air interface proposal, too.

In 1998 the 3GPP (*3rd Generation Partnership Project*) group was established in order to define a common wideband CDMA standard. As a result the UMTS was defined. However, an alternative standard called *cdma2000* was also promoted by those partners who wished to extend the IS-95 system. This way the 3GPP2 (*3rd Generation Partnership Project 2*) was also established. In fact, three different IMT-2000 standards were agreed upon:

- UTRA (*UMTS Terrestrial Radio Access*) – wideband CDMA transmission with FDD and TDD modes and 5 MHz carrier spacing
- MC CDMA (*Multicarrier CDMA*)
- UWC136 (*Universal Wireless Communications*) – the standard based on the convergence of IS-136 and GSM EDGE. The UWC136 will be a natural extension of TDMA systems.

Figure 17.1 presents the evolution from the second generation systems to the third generation systems.

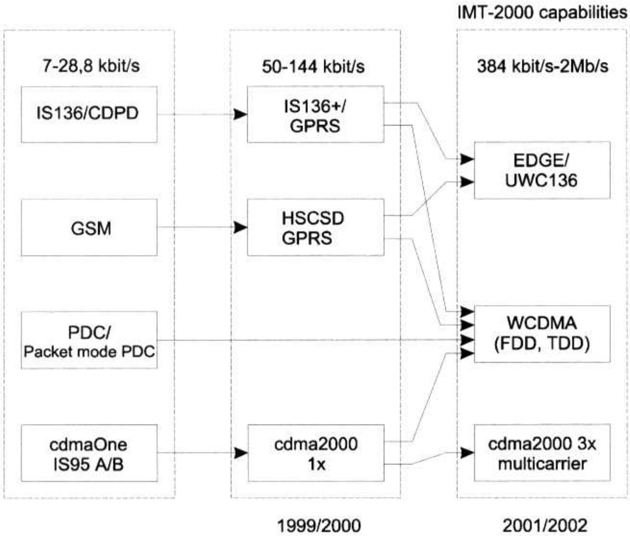

Figure 17.1 Evolution of the second generation systems resulting in the third generation systems

So far we have discussed the evolution of radio access standards. As we know, radio access is only a part of a whole communication system. Another part is the core network, which connects different elements of the radio access system with the fixed part of the system and with other networks such as PSTN, ISDN, the Internet and PDSN. The evolution has taken place in this respect, too. It has been decided that the UMTS and EDGE systems (evolving from GSM) will initially work with the GSM core network. On the other hand, the cdma2000 and EDGE (evolving from IS136) will initially work with the IS-41 core network. Both core networks will be equipped with interworking functions to enable roaming and other services. In a longer time perspective, all IMT-2000 networks will cooperate with the IP core network similar to the present core network of the GPRS system.

The implementation of third generation systems depenfd on the spectrum allocation made by the administrative bodies. Figure 17.2 presents spectrum allocation agreed upon during the World Radiocommunications Conference WRC-2000. Let us note that the spectrum for IMT-2000 has been allocated in almost all countries except the USA, where the third generation system will be allocated a new spectrum in the future, or the existing PCS system spectrum will change its application.

In the following we will briefly describe the most important third generation systems: UMTS and cdma2000. Currently, whole books are devoted exclusively to UMTS or cdma2000, so the reader searching for details is asked to study [1], [2] [3] and [4].

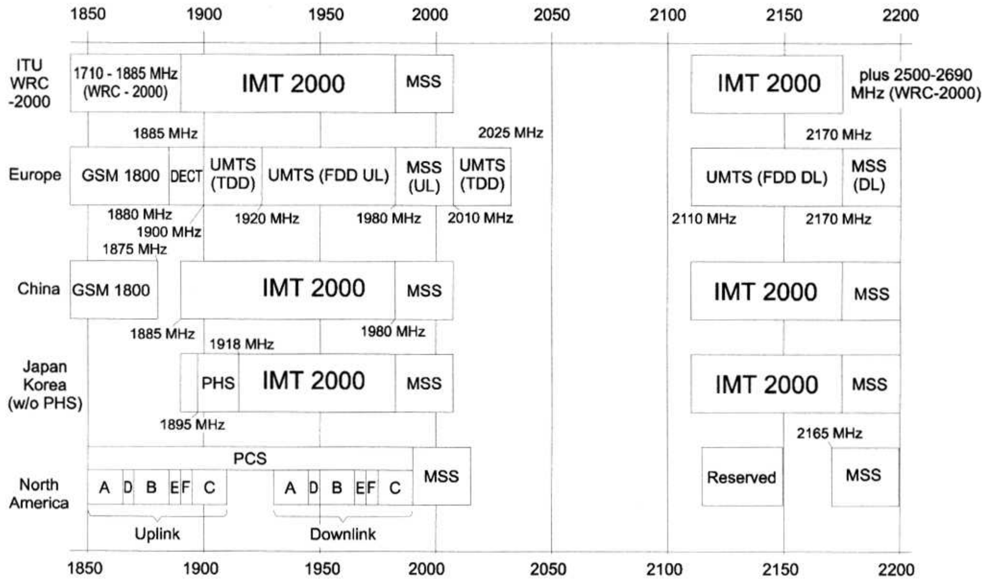

Figure 17.2 Spectrum allocation for IMT-2000 in different parts of the world agreed upon during WRC-2000 (MSS - mobile satellite systems)

17.2 THE CONCEPT OF UMTS

The basic purpose of introducing the UMTS is to support integrated digital wireless communications at the data rates up to 2 Mbit/s in the 2 GHz band. Table 17.1 presents the bands allocated to the UMTS.

Table 17.1 UMTS spectrum allocation

Frequency [MHz]	Bandwidth [MHz]	Destination
1900–1920	20	UMTS (terrestrial), TDD
1920–1980	60	UMTS (terrestrial) FDD, UL
1980–2010	30	UMTS (satellite) FDD, UL
2010–2025	15	UMTS (terrestrial) TDD
2110–2170	60	UMTS (terrestrial) FDD, DL
2170–2200	30	UMTS (satellite) FDD, DL

The UMTS requirements are similar to those stated for IMT-2000. They are:

- **Operation in various types of environment**. The terrestrial part of the UMTS will operate in several environments, from rural to indoor environment. There will be three basic types of cells fitted to these environments: picocells.

microcells and macrocells with appropriate physical layers of the UMTS. The satellite segment of the UMTS will constitute a supplement of the land mobile system and will work in the areas of very low traffic density or under-developed infrastructure.

- **The choice of duplex transmission.** The bandwidth allocated by WRC'92 consists of two paired bands and two unpaired bands. This implies the necessity to apply frequency division duplex transmission in the paired bands and time division duplex transmission in the unpaired bands (see Tab. 17.1).
- **A wide service offer.** The UMTS should support a large selection of services, from voice transmission to fast data transmission. The traffic can be asymmetric. The system should be flexible enough to allow for the introduction of new services in the future. For this purpose the radio access system should support unidirectional links based on a few basic bearer services.
- **Cooperation with fixed networks.** The UMTS will be integrated with wireline wideband networks such as B-ISDN. *Intelligent Networks* (IN) technology will be applied.

Following the above requirements a list of services has been proposed and their quality has been defined. Table 17.2 (based on [5] with modifications) shows the UMTS service proposals. The UMTS offers voice, data and videotelephony transmission. Besides that, it can be treated as a wireless extension of integrated services digital networks. Therefore, the system supports basic ISDN access at the rate of 144 kbit/s (two B channels plus a D channel). Data transmission at the rate of 2 Mbit/s, possible in a limited range, allows transmission of compressed video.

Similar to the second generation systems, the UMTS will ensure a high level of security of transmitted data. It is important not only for the privacy of individual telephone calls, but also for support of tele-banking and e-commerce.

The UMTS applies a high quality *Adaptive Multi-Rate* (AMR) speech coding based on ACELP coding with discontinuous transmission and comfort noise insertion. It works at 8 different bit rates: 4.75, 5.15, 5.90, 6.70, 7.40, 7.95, 10.20 and 12.20 kbit/s. Three of them are compatible with speech coders applied in the existing second generation systems: 6.70 kbit/s – PDC EFR, 7.40 kbit/s – IS-641 (US TDMA/IS-136) and 12.20 kbit/s – GSM EFR. The data rate of the AMR coder depends on the network load, the service level specified by the network operator and the current SNR value.

17.3 UMTS RADIO ACCESS NETWORK ARCHITECTURE

As we have already mentioned, the UMTS takes advantage of the existing GSM and GPRS networks, which serve as a core network in the UMTS infrastructure. Figure 17.3 presents the UMTS radio access network architecture.

There are three main elements of this architecture:

- *User Equipment* (UE), which consists of

Table 17.2 Examples of services in UMTS

Type of service	Data rate [kbit/s]	Error rate	Allowable delay [ms]
Speech transmission	4.75–12.2	10^{-4}	40
Voiceband data	2.4–64	10^{-6}	200
Hi-Fi sound	940	10^{-5}	200
Videotelephony	64–144	10^{-7}	40–90
Short messages/paging	1.2–9.6	10^{-6}	100
E-mail	0–384	10^{-6}	many minutes
Facsimile (G4)	64	10^{-6}	100
Broadcast or multicast transmission	1.2–9.6	10^{-6}	100
Web browsing	16–64 (UL) 96–384 (DL)	10^{-6} 10^{-6}	seconds
Digital data without specified limitations	64–1920	10^{-6}	100
Access to data bases	2.4–768	10^{-6}	200
Teleshopping	2.4–768	10^{-7}	90
Electronic newspaper	2.4–2000	10^{-6}	200
Remote control	1.2–9.6	10^{-6}	100
Navigation and location	64	10^{-6}	100
Teleworking	32–64	10^{-6}	90

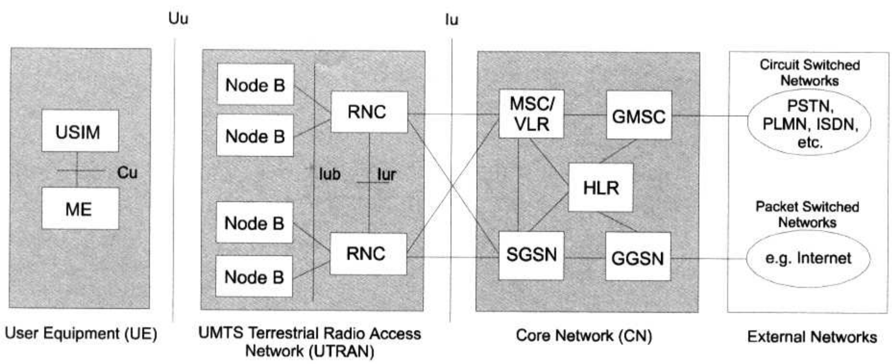

Figure 17.3 UMTS radio access network

- *Mobile Equipment* (ME), which is a radio terminal connecting a UMTS subscriber through the radio interface *Uu* with the fixed part of the UMTS system

- *UMTS Subscriber Identity Module* (USIM), which is a smart card similar to the SIM card used in the GSM system. The card contains the subscriber identity, authentication algorithms, authentication and encryption keys etc.

- *UMTS Terrestrial Radio Access Network* (UTRAN), which is a system of base stations and their controllers. It consists of two kinds of elements:
  - base stations called *Nodes B* (in accordance with the 3GPP), which perform physical layer processing such as channel coding, data interleaving, rate matching, modulation, etc. Briefly, a base station converts the data between the *Uu* radio interface and the *Iub* interface connecting a *Node B* with the *Radio Network Controller.*
  - *Radio Network Controllers* (RNCs), which control *Nodes B* connected to them and manage radio resources assigned to them. In this sense the RNC performs the data link layer processing and participates in the handover procedures. The RNC is considered a service acccess point of UTRAN for the core network. It is connected to a single MSC/VLR to route circuit-switched traffic and to a single SGSN to route packet-switched traffic.
- *Core Network* (CN) is shared with GSM and GPRS. It therefore contains typical elements both for circuit-switched and packet-switched systems, i.e.:
  - *Home Location Register* (HLR) performing functions similar to those in the GSM and GPRS systems,
  - *Mobile Switching Center/Visitor Location Register* (MSC/VLR) handling the circuit-switched traffic,
  - *Gateway MSC* (GMSC) connecting the UMTS with external *Circuit-Switched* (CS) networks,
  - *Serving GPRS Support Node* (SGSN) similar to that in GPRS and serving the packet-switched traffic,
  - *Gateway GPRS Support Node* (GGSN) connecting the UMTS with external *Packet Switched* (PS) networks.

Let us turn our attention to the interfaces shown in Figure 17.3. Most of the interfaces have been defined with such accuracy that elements of the UMTS can be produced by different manufacturers. Thus, the system can be attractive to many manufacturers and can gain more popularity. Below we list the UMTS interfaces and present their basic functions. They are as follows:

- *Cu Interface* connects the hardware part of the UMTS terminal with the USIM smart card. It conforms to a standard format of smart cards.
- *Uu Interface* is the radio interface between UMTS terminals and the base stations (*Nodes B*). It is precisely defined to allow for functioning of terminals of different brands. The novel contribution of the UMTS is this definition of the *Uu* interface.
- *Iub Interface* defines communication between base stations and an appropriate RNC.
- *Iur Interface* is the interface between different RNCs. Let us note that there is no equivalent of *Iur* interface in GSM; however, in the UMTS the *Iur* is necessary

to perform a soft handover with the participation of two base stations which are controlled by two different RNCs. This interface is also used if a connection from a base station is routed from the so-called *Drift RNC* to the *Serving RNC*, which finally, through the *Iu* interface, directs it to the core network.

- *Iu Interface* connects the UTRAN with the core network and is functionally similar to the *A* interface in GSM and the *Gb* interface in GPRS.

In the literature and the descriptions of UMTS standards one can find detailed considerations on different aspects of protocol layering. The interested reader is directed for example to [1]. Here we will only quote the general protocol model for UTRAN interfaces, which is directly related to above considerations on the UMTS radio access network and defined interfaces. This protocol model is shown in Figure 17.4.

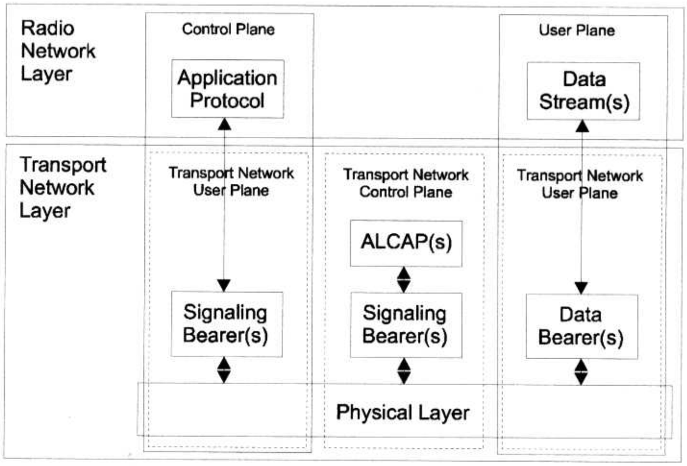

Figure 17.4 General protocol model for UTRAN interfaces

The protocol model consists of horizontal layers and vertical planes. Two main horizontal layers have been introduced:

- *Transport Network Layer*, in which data from the User Plane and Control Plane are mapped onto dedicated and shared *Transport Channels.* Transport channels, in turn are mapped onto *Physical Channels*
- *Radio Network Layer*, which is concerned with UTRAN-related issues, e.g. access to UTRAN via the *Iu* interface.

The following vertical planes have been defined across the Radio Network Layer and the Transport Network Layer:

- *Control Plane* used for UMTS control signaling, consisting of an *Application Protocol* specific for the appropriate interface and a *Signaling Bearer* used for the Application Protocol messages,

- *User Plane*, in which all user data such as encoded voice or packet data are transported. Within the user plane there are *Data Streams* and *Data Bearers* associated with them. Data streams are characterized by one or more frame protocols.

Within the Transport Network Layer the following vertical planes are defined:

- *Transport Network Control Plane* used for all control signaling within the Transport Layer. It consists of
  - *Access Link Control Application Part* (ALCAP) responsible for configuration of transport channels with respect to the given requirements and for combining the user and control data into dedicated and common channels, and
  - *Signaling Bearers* needed to perform the ALCAP.
- *Transport Network User Plane* which contain Signaling Bearers for the Application Protocol and data bearers in the User Plane.

17.4 UMTS AIR INTERFACE

The *UMTS Terrestrial Radio Access* (UTRA) interface was defined by the 3rd Generation Partnership Project (3GPP). It is often called WCDMA (*Wideband CDMA*) interface. WCDMA has two modes of operation differing in the kind of duplex transmission. As we have already mentioned, in the paired bands the UMTS operates in the FDD mode, whereas in the unpaired bands, the standard is the TDD mode. Both modes differ in their potential applications and details of their air interfaces. Table 17.3 presents the basic features these two modes.

Before we consider the WCDMA air interface, let us clarify its layered structure. Figure 17.5 presents the meaningful components of the air interface protocol architecture.

All the protocols can be placed in one of the three lowest OSI layers: the physical (PHY) layer, the Data Link Control (DLC) layer and the network layer.

The physical layer offers information transfer services in the form of transport channels. In the physical layer all the signal processing functions, channel coding, interleaving, modulation, spreading, synchronization, etc. are performed. One of them is mapping of transport channels onto physical channels.

The Data Link Control layer is divided into the following sublayers:

- *Medium Access Control* (MAC) sublayer
- *Radio Link Control* (RLC) sublayer
- *Packet Data Convergence Protocol* (PDPC) sublayer
- *Broadcast/Multicast Control* (BMC) sublayer.

Table 17.3 Basic parameters of WCDMA interfaces

	UTRA FDD	UTRA TDD
Multiple access method	CDMA	TDMA/CDMA
Duplex method	FDD	TDD
Channel bandwidth	5 MHz	
Chip rate	3.84 Mchip/s	
Frame length	10 ms	
Time slot structure	15 slots/frame	
Multirate method	Multicode, multislot and OVSF[a]	Multicode and OVSF[a]
Spreading (DL)	OVSF sequences for channel sep., truncated Gold seq. (2^{18}-1) for cell and user sep.	
Spreading (UL)	OVSF sequences, truncated Gold seq. (2^{25}) for user separation	
Spreading factor	4–512	1–16
Channel coding	Convolutional coding (R=1/2, 1/3, K=9), turbo coding (8-state PCCC, R=1/3), service specific coding	
Interleaving	Inter-frame interleaving (10, 20, 40 and 80 ms)	
Modulation	QPSK	
Pulse shaping	Square-root raised cosine with roll-off factor = 0.22	
Detection	Coherent, based on pilot symbols	Coherent, based on midamble
Burst types	Not applicable	Traffic, random access and synchronization bursts
Dedicated channel power control	Fast closed loop (rate - 1500 Hz)	UL: open loop (100 or 200 HZ) DL: closed loop ($\leq$ 800 Hz)
Intra-frequency handover	Soft handover	Hard handover
Inter-frequency handover	Hard handover	
Channel allocation	No DCA[b] required	Slow and fast DCA[b] possible
Intra-cell interference cancellation	Joint detection possible	Advanced receivers at base stations possible

[a] OVSF - *Orthogonal Variable Spreading Factor* – a type of spreading code used in UTRA, see the air interface description below.
[b] DCA - *Dynamic Channel Allocation*

The MAC sublayer performs data transfer services on logical channels, which are defined with respect to the type of information which is transferred on them.

The RLC sublayer performs ARQ algorithms, is responsible for segmentation and assembly of user data, controls the appropriate sequence of data blocks and ensures avoiding block duplication.

The PDPC sublayer provides transmission and reception of network Protocol Data Units (PDUs) in acknowledged or unacknowledged and transparent RLC modes. In turn, the BMC sublayer performs broadcast and multicast transmission service in transparent or unacknowledged mode.

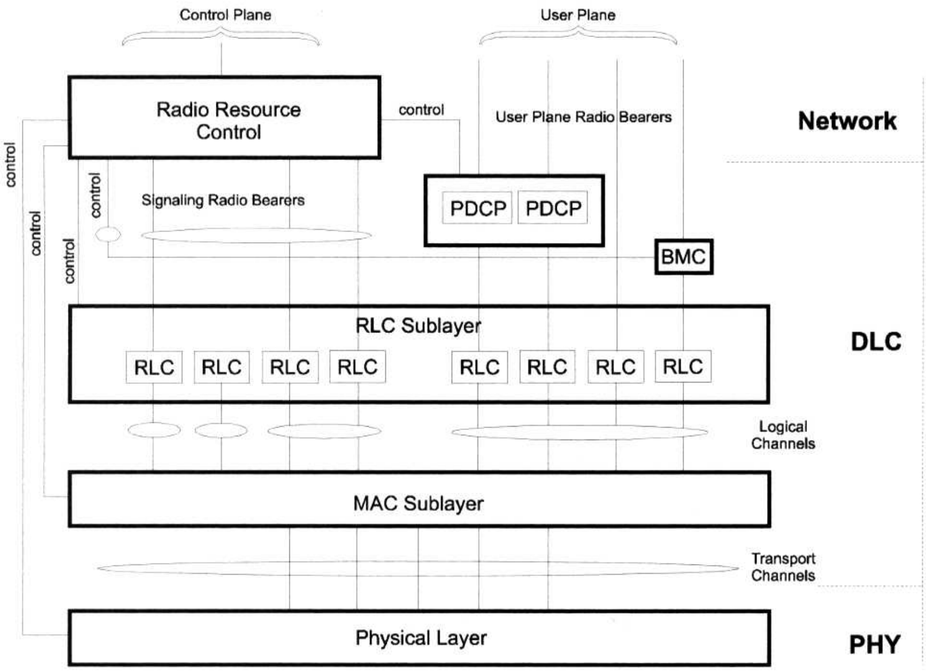

Figure 17.5 Air interface protocol architecture (after [6])

Finally, the lowest sublayer of the Network Layer shown in Figure 17.5 is the *Radio Resource Control* (RRC) sublayer. The RRC sublayer fulfills the following functions [7]: broadcasting of system information, radio resource handling, control of requested quality of service, measurement reporting and control.

Summarizing, to ensure that the higher sublayers perform particular functions, the MAC sublayer offers *logical channels* to those sublayers. In order to realize the MAC functions, *transport channels* remain at the disposal of the MAC sublayer. They are finally mapped onto *physical channels* in the physical layer.

Now let us consider all three types of channels. Let us start with logical channels. They are divided into two classes:

- *Control Channels* (CCH) used for the information transfer performed in the control plane
- *Traffic Channels* (TCH) used to carry information in the user plane.

The following types of logical control channels exist:

- *Broadcast Control Channel* (BCCH) used in the downlink to broadcast system control information,
- *Paging Control Channel* (PCCH) applied in the downlink to page the mobile station or wake it up if it is in the sleeping mode

- *Common Control Channel* (CCCH) applied in the downlink and uplink to transfer control information
- *Dedicated Control Channel* (DCCH) used in point-to-point transmission to transfer dedicated control information between the network and a mobile station during establishment of the RRC connection.

The logical traffic channels are divided into the following types:

- *Dedicated Traffic Channel* (DTCH) used in point-to-point transmission between a mobile station and the network to transfer user information; it can be established in the downlink and uplink,
- *Common Traffic Channel* (CTCH) applied in point-to-multipoint transmission, carrying information for a group of mobile stations.

The logical channels realized on the level of the RLC sublayer are mapped by the MAC sublayer onto the transport channels. Among transport channels there is a single *Dedicated Channel* (DCH) and six common channels.

The DCH is a point-to-point bidirectional channel carying both user data and higher level control data. It can be transmitted to the whole cell or a part of it if a beamforming antenna is used. It can rapidly change its parameters (data rate, power level, etc.).

The common transport channels carry control data and small amounts of user data without establishing a dedicated connection with the user. There are the following common transport channels:

- *Broadcast Channel* (BCH), which sends system- and cell-specific information at a low data rate to reach all mobile stations in a cell; it carries part of the logical BCCH channel,
- *Forward Access Channel* (FACH), which operates in the downlink, sending control information containing another part of the BCCH channel and realizing the packet data link; there can be more than one FACH in a cell, of which at least one is transmitted at a low data rate and at high power,
- *Paging Channel* (PCH), which is a point-to-multipoint channel used to page a mobile station,
- *Downlink Shared Channel* (DSCH), which is an optional transport channel shared by several mobile stations; it provides dedicated user data and is associated with the Dedicated Channel (DCH),
- *Random Access Channel* (RACH), which is an uplink low rate channel. It has to be received by a base station when transmitted from any place in a cell and is used by a mobile station to set a connection or to send a small amount of data to the network,

- *Common Packet Channel* (CPCH), which is an optional uplink transport channel operating according to the contention principle and used for transmission of bursty data.

Each type of transport channel is associated with a *Transport Format* (TF) set. The TF determines possible mapping, encoding and interleaving of a given type of transport channel. The MAC layer procedure selects an appropriate transport format for a given transport frame. The features of the applied transport format are contained in a block called *Transport Format Indicator* (TFI), which usually accompanies the tranport blocks and indicates how the transport channel is realized.

After channel coding and interleaving, several transport channels can be multiplexed. This way the received data stream is assigned to the *physical data channel.* Accordingly, the multiplexed transport format indicators form a *Transport Combination Format Indicator* (TFCI) which is transmitted on a *physical control channel.* Figure 17.6 illustrates this process.

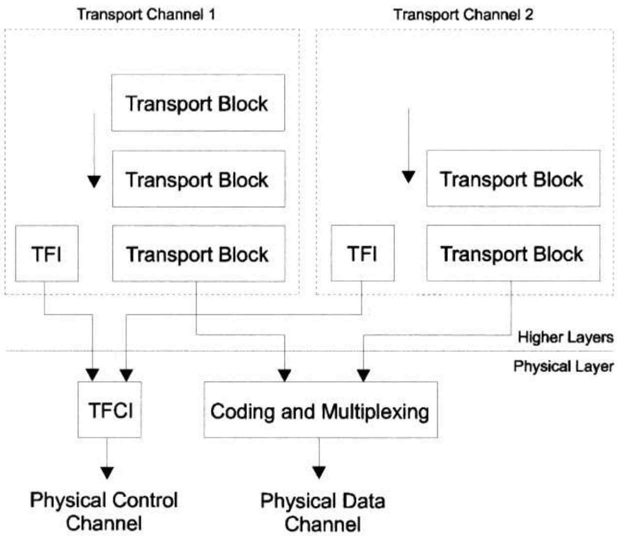

Figure 17.6 Example of mapping of the transport channels onto physical channels

Because transport channels can consist of a different number of transport blocks, the TFCI also informs which transport channel is active in a given frame. At the receiver, after decoding the TFCI, the data received in the physical data channel can be demultiplexed and decoded and the transport blocks of the appropriate transport channels can be extracted.

17.4.1 UTRA FDD mode

In the physical layer of the UMTS time is divided into 10-ms frames. The frames, in turn, are divided into 15 slots 666.67 μs long. In case of applying the FDD mode, this time division is not a result of using a multiple access method, because a CDMA scheme is applied; however, the slots are time units in which the transmission of the appropriate channel blocks takes place. Knowing that the basic chip rate is 3.84 Mchip/s, we find that each time slot lasts for 2560 chips.

In the UMTS FDD mode a physical channel is determined by the carrier frequency, the applied spreading sequence and the applied signal component (in the uplink, in-phase and quadrature components can carry different physical channels).

In the physical layer, two types of dedicated physical channels have been defined for uplink and downlink. They are:

- *Dedicated Physical Control Channel* (DPCCH)
- *Dedicated Physical Data Channel* (DPDCH).

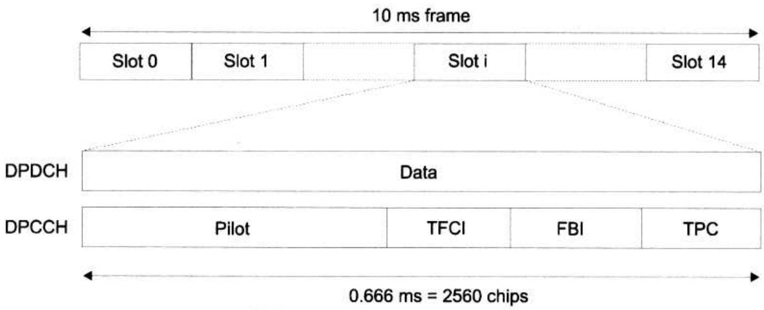

Figure 17.7 Uplink *Dedicated Physical Channel* structure

One dedicated physical control channel and up to six dedicated data channels are assigned to each connection. In the uplink the binary stream of the DPDCH is fed to the in-phase input of the transmitter, whereas the binary stream of DPCCH is fed to the quadrature input of the transmitter. If the number of data channels (DPDCH) is higher than one, then the odd-numbered channels are summed, weighted and transmitted using the in-phase component, whereas the even-numbered channels are summed, weighted and transmitted together with the control channel (DPCCH), using the quadrature component.

The DPDCH transmits user data and the DPCCH sends a pilot signal needed in the base station receiver for channel estimation, the TFCI block indicating the DPDCH format, the *Feedback Information* (FBI) for downlink transmit diversity and the *Transmit Power Control* (TPC) block for implementation of fast power control in the downlink (see Figure 17.7). Both data streams are spread using two different mutually orthogonal *channelization codes.* Thanks to them 4 to 256–ary spectrum spreading is achieved, depending on the information sequence data rate. The *Spreading Factor* $SF = 256/2^k$, $k = 0, 1, \ldots, 6$, so the number of bits transmitted in one of fifteen slots of the 10-ms frame is 10×2^k. Because the data rates in both physical channels can be different, the mean power of the in-phase and quadrature inputs can be different, too, and the applied spreading matches the current data rate in the data channel, resulting in the desired bandwidth. The variability of the spreading factor is obtained thanks to the application of the *Orthogonal Variable Spreading Factor* (OVSF) codes [8].

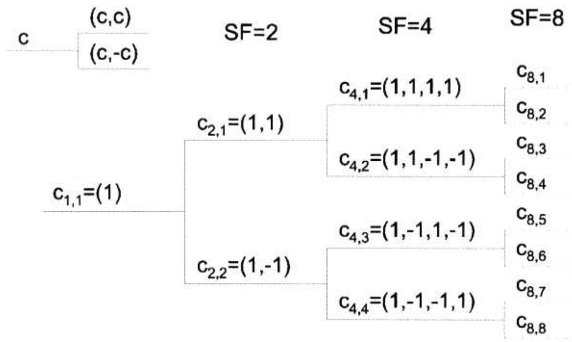

Figure 17.8 OVSF code tree

The OVSF codes are defined by a tree shown in Figure 17.8. Considering any node of the tree, we see that new code words are created by appending the preceding code word with itself (in the upper branch originating from the node) or with its negation (in the lower branch growing from this node). Mutual orthogonality of different code words is achieved by their appropriate selection from the code tree. A code word c_i is orthogonal to a code word c_j, if and only if the code word c_j is not associated with the branch leading from the branch associated with the code c_i to the root of the tree or is not located in the subtree below the code word c_i. For example, if bits of a particular data stream are spread using the code word $c_{8,5} = (1,-1,1,-1,1,-1,1,-1)$ with the spreading factor $SF = 8$, then for another data stream requiring the spreading factor $SF = 4$ all the code words $c_{k,i}$ except $c_{4,3}$ can be applied.

The resulting pair of data streams spread by the OVSF code words can be interpreted as a complex signal with the real part being the in-phase component and the imaginary part being the quadrature component of the data signal. This complex signal undergoes a complex scrambling[1] operation. The scrambling sequence consists of two components interpreted as the real and imaginary parts of the complex scrambling signal. Let us note that the scrambling operation does not increase the bandwidth, i.e. the chip rate at the output of the scrambler is the same as at its input. The aim of scrambling is to differentiate cells. The reason for selection of a complex scrambling sequence is the possible unequal power of the in-phase and quadrature components carrying DPDCH and DPCCH or their sums, respectively. By applying a complex scrambling sequence the mean powers of both components become equal. Two types of complex scrambling

[1]A popular method of scrambling performed in the transmitter is modulo-2 summing of a binary information sequence with a given pseudorandom sequence. The pseudorandom sequence is selected to ensure good statistical properties of the transmitted sequence. Repeating the same operation in the receiver allows recovery of the original binary information sequence. In our case the modulo-2 addition is replaced by multiplication of scrambled signals by a scrambling bipolar signal.

sequences are standardized. The short sequence is 256-bit long. It is repeated at the frequency of 15000 Hz. Such sequence is applied when joint detection receivers (see Chapter 10) are used in the base stations. The long sequence is a pair of Gold sequences of the period $2^{25} - 1$ truncated to a 10-ms interval and applied when a regular RAKE receiver is used in the base station [7].

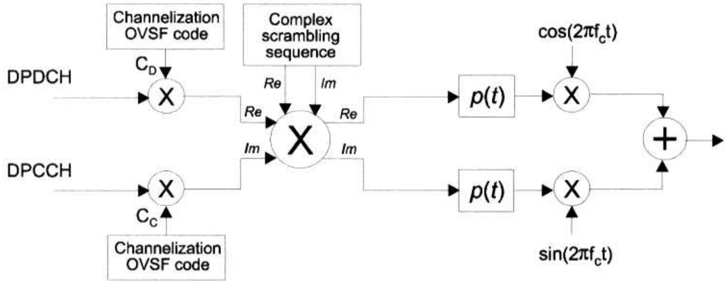

Figure 17.9 Generation of DPDCH and DPCCH signal in the uplink

The complex in-phase and quadrature pulse stream resulting from the complex scrambling operation is shaped by the filters with square-root raised cosine characteristics (roll-off factor $\alpha = 0.22$) and placed in the destination band by a pair of orthogonal modulators (see Figure 17.9).

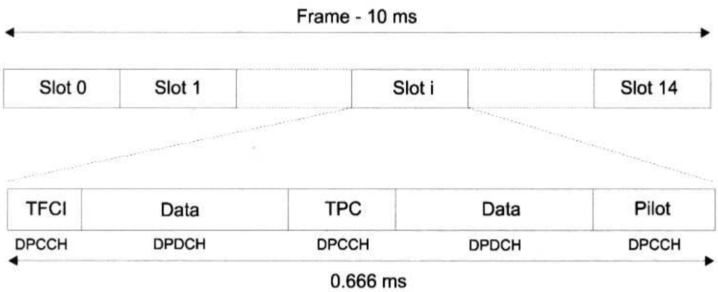

Figure 17.10 Frame structure in the downlink transmission of dedicated channels

The organization of the downlink transmission of dedicated channels is different from that applied in the uplink. The dedicated data and control channels are appropriately multiplexed, as shown in Figure 17.10. Next, they are serially demultiplexed into two parallel data streams which are the bases of the in-phase and quadrature components of the transmitted signal. The binary signals in each branch are spread using the same OVSF code word in both branches. The channelization code words used in the cell sector are selected from the same OVSF code tree. The spread signals in the in-phase and quadrature branch are treated as the real and imaginary parts of the complex signal, so such a signal is scrambled using a complex pseudorandom sequence which is 10 ms long. The complex pseudorandom sequence is created using two appropriately shifted truncated Gold sequences generated by the LFSRs of length 18. A mobile station that wishes to be synchronized with the base station has to find synchronism with this scrambling sequence; therefore, the number of different scrambling sequences is limited to 512. The sequences are divided into 16 groups with 32 sequences in each group. The scrambling sequences are assigned to a cell in the cell planning process. Figure 17.11 presents the process of generation of a WCDMA signal carrying dedicated channels in the downlink.

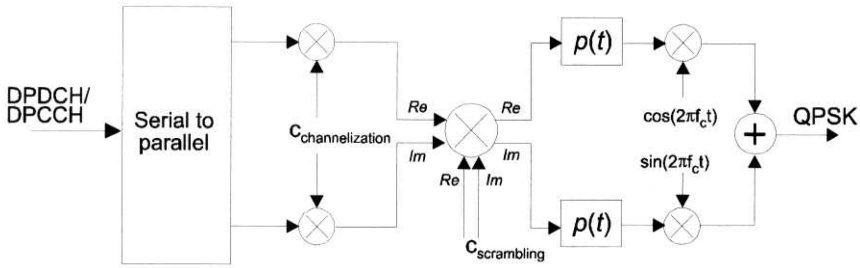

Figure 17.11 Generation of WCDMA signal in the downlink

Let us note that the downlink slot also transmits the pilot signal. The pilot signal ensures the coherent detection in a mobile station and makes it possible to use adaptive antennas in the downlink [7].

Besides dedicated channels, the following physical channels are also applied in the downlink:

- *Common Pilot Channel* (CPICH)
- *Synchronization Channel* (SCH)
- *Primary* and *Secondary Common Control Physical Channels* (P-CCPCH and S-CCPCH)
- *Acquisition Indication Channel* (AICH)
- *Paging Indicator Channel* (PICH).

In turn, in the uplink the *Physical Random Access Channel* (PRACH) and the *Physical Common Packet Channel* (PCPCH) are used. Let us briefly consider the above listed channels.

The *Common Pilot Channel* (CPICH) is transmitted by a base station in each cell to make the channel estimation possible. Therefore, the CPICH carries an unmodulated signal which is spread at the spreading factor equal to 256 and is scrambled with the cell-specific scrambling code. It has to be detected in the whole cell. Besides channel estimation, the CPICH channel is used in measurements in handover and cell selection operations.

The *Synchronization Channel* (SCH) is used in the cell search procedure performed by a mobile station. The SCH consists of two subchannels: the primary and secondary synchronization channel. The primary SCH uses a 256-chip long spreading sequence which is the same in all cells. The secondary SCH carries a sequence of fifteen 256-chip sequences (one sequence in each slot of a frame) which allows for frame and slot synchronization and determination of the group of scrambling codes used in the cell. Both synchronization channels are transmitted in parallel (using different sequences) within the first 256 bits of each slot. The remaining 2304 bits of each slot are occupied by the *Primary Common Control Physical Channel* (P-CCPCH).

The P-CCPCH carries the transport *Broadcast Channel* (BCH). It is transmitted continuously and has to be received by all mobile stations located in any place of the cell. Therefore, the spreading factor of the P-CCPCH channel is equal to 256 and the channel is transmitted with high power. A permanently allocated channelization code is also used. In order to ensure required transmission quality, the rate-1/2 convolutional code with interleaving over two frames (20 ms) is applied.

The *Secondary Common Control Physical Channel* (S-CCPCH) is used to transmit the following transport channels: *Forward Access Channel* (FACH) and *Paging Channel* (PCH). At least one S-CCPCH exists in a cell. If there is one S-CCPCH, it contains both transport channels. If there are more than one, both transport channels can use diferent physical channels. The spreading factor used in the S-CCPCH is fixed and determined by the maximum data rate applied. Again, the rate-1/2 convolutional code is applied in S-CCPCH. In the case of using FACH for data transmission, the rate-1/3 convolutional coding or turbo coding can be applied as well.

The *Physical Random Access Channel* (PRACH) and the *Acquisition Indication Channel* (AICH) are associated with each other, therefore we will describe them jointly.

The PRACH channel is used by a mobile station to access the network (by carrying the transport RACH channel). The random access is based on the slotted ALOHA principle. Two consecutive 10-ms frames are divided into 15 random access slots each 5120 chips long. First, the mobile station acquires timing and frame synchronization in the cell. Then, the mobile station detects the BCH channel in order to determine the random access slots available in a given cell, the scrambling codes and the signatures which can be used in the random access procedure. The mobile station also measures the received power and on the basis of this measurement it sets the power of the RACH preamble sent in the selected random access slot. The preamble is 4096 chip long and contains 256 repetitions of the selected signature. The mobile station periodically transmits the preamble in the available random access slots with gradually increased power till it detects the AICH preamble. When the AICH preamble is finally decoded, the 10 ms or 20 ms RACH message is transmitted.

A similar procedure is applied in data transmission using the *Physical Common Packet Channel* (PCPCH). The transport *Common Packet Channel* (CPCH) is realized using this physical channel. Again, a mobile station periodically sends 4096-chip preambles with gradually increasing power till it receives and detects the AICH preamble. Then it sends a CPCH CD (collision detection) preamble and after receiving the echo from the base station in the form of the *CD Indication Channel* (CDICH) it starts to transmit its packet. The message part lasts for $N \times 10$ ms, although it is restricted to a negotiated maximum length. Figure 17.12 presents the process of sending a packet using the PCPCH channel.

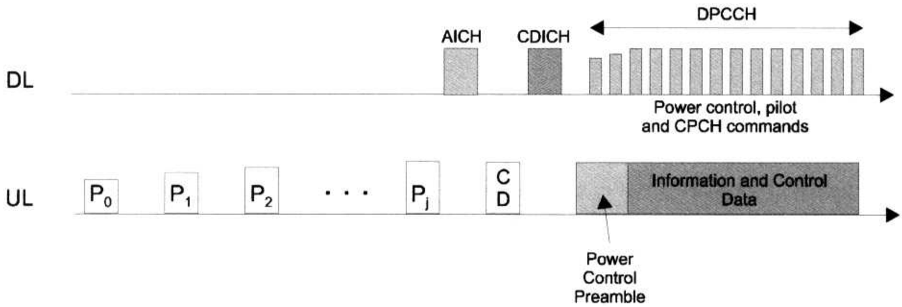

Figure 17.12 CPCH access procedure

One of the important procedures in the UTRA WCDMA is the *cell search.* After power on a mobile station has to find the closest base station. In the UMTS the base stations operate asynchronously and use different scrambling codes selected from the set of 512 sequences of 10 ms duration. In order to simplify and accelerate the cell search, the procedure is performed in the following steps:

- The mobile station searches for the primary synchronization channel (SCH) which is sent in the form of a 256-chip sequence common for all cells. This way the starting points of the slots are found. The search is performed using the filter matched to a known sequence. The mobile station receives the primary SCH signals from a few surrounding cells and selects the highest local maximum of the output signal of the matched filter, which corresponds to the closest (strongest) base station.

- For the detected starting points of the slots the mobile station attempts to acquire frame synchronization and tries to find a code group used in the secondary SCH. The synchronization is performed by the correlation of the received signal (the start of the correlation has been found in the previous step) with 64 possible secondary synchronization code words applied in the secondary SCH. All 15 possible slots have to be checked in order to find the slot No. 0, i.e. to find frame synchronization. The secondary synchronization code word determines a particular code group to which the scrambling code in a given cell is assigned.

- The scrambling code applied in the cell is found in the third step. For this purpose the mobile station correlates the received signal with all possible scrambling signals belonging to the given code group. After identification of the scrambling sequence, the mobile station is able to read the primary common control channel which holds system parameters sent on the broadcast channel (BCH).

Once a mobile station has been registered in the network it is allocated a paging group. The mobile station periodically reads the *Paging Indicator Channel* (PICH), looking for its paging indicator stating that in the secondary common control physical channel a paging message for the mobile station belonging to a given paging group is contained. If the mobile station has detected a paging indicator of its own paging group, it reads the PCH frame contained in the S-CCPCH in order to check if there is a paging message for it. The PICH channel uses a fixed data rate with the spreading factor $SF = 256$. Out of 300 bits transmitted within a 10-ms frame, 288 bits are used for paging indicators. There may be 18, 36, 72 or 144 different paging indicators, which are transmitted as the sequences of ones (if paging is indicated) or zeros.

As we know, power control has a crucial impact on the overall CDMA system capacity. In WCDMA FDD the open and closed loop power control is applied. The open loop power control is used in the RACH and CPCH transmission, as was described above. The accuracy of such an open control loop is not very high, mostly due to internal inaccuracies of a mobile station and due to measuring the signal arriving at the mobile station in a different band than the band of the signal whose level is controlled.

The closed loop power control is performed in each slot, so it is done 15000 times per second. As we remember, in the uplink dedicated physical control channel (DPCCH) block the transmit power control (TPC) field is placed in each slot, which indicates the change of power level by 1 dB or its multiple. In the case of soft handover, when the mobile station is assigned to two neighboring base stations, both of them send commands to the mobile station concerning the power control. In the mobile station the commands are appropriately weighted to work out a final decision on the power control.

The next procedure necessary for proper functioning of a cellular system is *handover*. In WCDMA there are several types handover:

- soft, softer and hard handover
- interfrequency handover
- handover between FDD and TDD modes
- handover between WCDMA and GSM.

In typical situations soft handover is performed, because cells usually operate on the same carrier frequency. A mobile station measures the power level of the common pilot channel (CPICH) and relative timing between cells. The mobile station entering the handover state receives the signal from all base stations participating in the connection. This is possible due to the application of the RAKE receiver whose "fingers" are synchronized with the scrambling and spreading sequences used in the current cell and the cell which will probably overtake the connection. The mobile station signals are received in the base stations participating in the handover procedure and are appropriately combined to perform *macrodiversity*. During the connection, the mobile station searches for a new base station from the list read from the BCH channel using a cell-search algorithm. Considering a new base station as a handover candidate implies sending by the mobile station a request to this base station to adjust the timing offset of the dedicated physical data and physical control channels (DPDCH and DPCCH) with respect to its primary common control physical channel (CCPCH). This way the frame timing differences between signals sent by different base stations and received at the mobile station can be minimized and the mobile station can receive the signal from the new base station as well.

Besides a soft handover, in WCDMA the so-called *softer handover* also occurs. In this state a mobile station is connected to two neighboring cell sectors served by the same base station, so the signals received in both sectors are already combined within the same the base station.

The main reason for *interfrequency handover* is the movement of a mobile station from one cell to another if both belong to different layers of the hierarchical cell structure e.g. pico-, micro- or a macrocell. A certain problem encountered in this case is performing appropriate measurements on other carrier frequencies than the one which is currently in use. There are two possible solutions to this problem. If a mobile station is able to apply space diversity, it uses a *dual receiver*. Then one receiver gets the signal from the current channel, whereas the second one is able to measure a signal on a new carrier frequency. To compensate the lost gain which in the normal case would be achieved due to the diversity reception, the signal sent on the current channel has to be additionally amplified by the base station. This is possible thanks to the closed loop power control.

The second solution of the measurement problem at the interfrequency handover is the application of the *compressed mode*, which is useful if a mobile station does not use a dual receiver. With a certain periodicity, the base station which normally sends its frames in 10-ms intervals transmits the frame contents in a shorter interval, i.e. in 5 ms, leaving the rest of the frame time for measurements performed by the mobile station at different frequencies. The shortening of the transmission time is performed by the application of code puncturing and changing the FEC rate. The signal power must be increased to compensate the loss of power following the application of the former two means. Figure 17.13 shows the principle of the compressed mode.

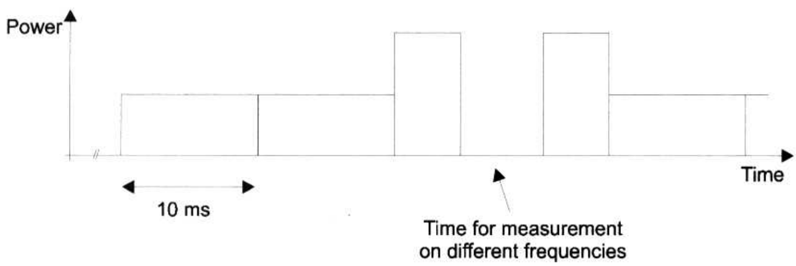

Figure 17.13 Principle of the compressed mode

Handover between FDD and TDD modes is possible if a mobile station can operate in a dual mode. A mobile station measures the power level of TDD cells, using the common control physical channels generated twice within a 10-ms frame of the TDD base stations. A similar situation occurs if a mobile station is able to operate in GSM - UTRA modes. This case is called *inter-system handover*. In the measurement periods a mobile station attempts to find a GSM frequency correction channel followed by the synchronization channel.

17.4.2 UTRA TDD mode

Let us consider the UTRA TDD mode. Its main parameters are presented in Table 17.3. Let us note that a lot of them are common for both FDD and TDD modes, which leads to strong similarities of both transmission types and simplification of mobile stations. As we remember, a part of the spectrum allocated to the UMTS is unpaired. In this part of the spectrum the FDD operation is excluded, so the TDD mode has been applied. Thanks to the time division duplex, time can be asymmetrically divided between two transmission directions. This division can be dynamically adjusted to the current kind of traffic. Multirate transmission can be easily implemented. Channel reciprocity is also an interesting feature of TDD transmission. Due to the fact that the same channel spectrum is used in both transmission directions, the measurements performed in one direction can be utilized in the opposite one, unless the channel is a fast time varying one.

Figure 17.14 presents the frame in the UTRA TDD mode. It lasts for 10 ms and is divided, as in the FDD mode, into 15 time slots. The physical channel is determined by the carrier frequency, the time slot within a frame and the applied spreading code. Several data rates can be achieved through allocation of an appropriate number of physical channels to the connection. This rule is also shown in Figure 17.14.

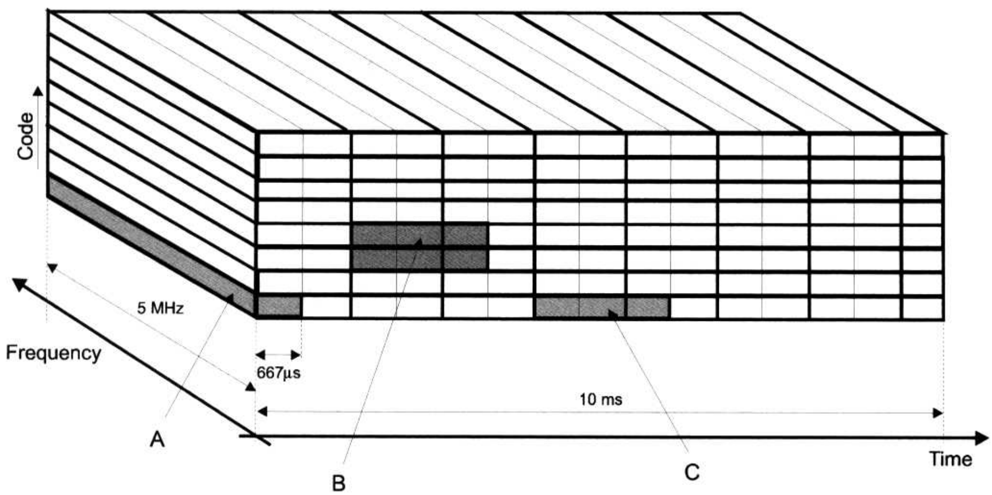

Figure 17.14 Example of the resource allocation for connections with different rates: A – a single channel (1 time slot +1 spreading code word), B – a connection using 3 time slots and 2 spreading code words, C – a connection applying 3 time slots and a single spreading code word.

The spreading codes used in the same slot are mutually orthogonal. They are selected from the OVSF code family. Particular channels are mutually synchronized. The frame consisting of 15 time slots is divided into two transmission directions. Several arrangements are possible [14]. The slot allocation can be symmetric with multiple switching between uplink and downlink within a frame. It can be asymmetric with multiple switching, or symmetric/asymmetric with a single switching within a frame. The main point is that at least one slot has to be allocated for uplink and at least one slot has to be allocated in the downlink in a 15-slot frame.

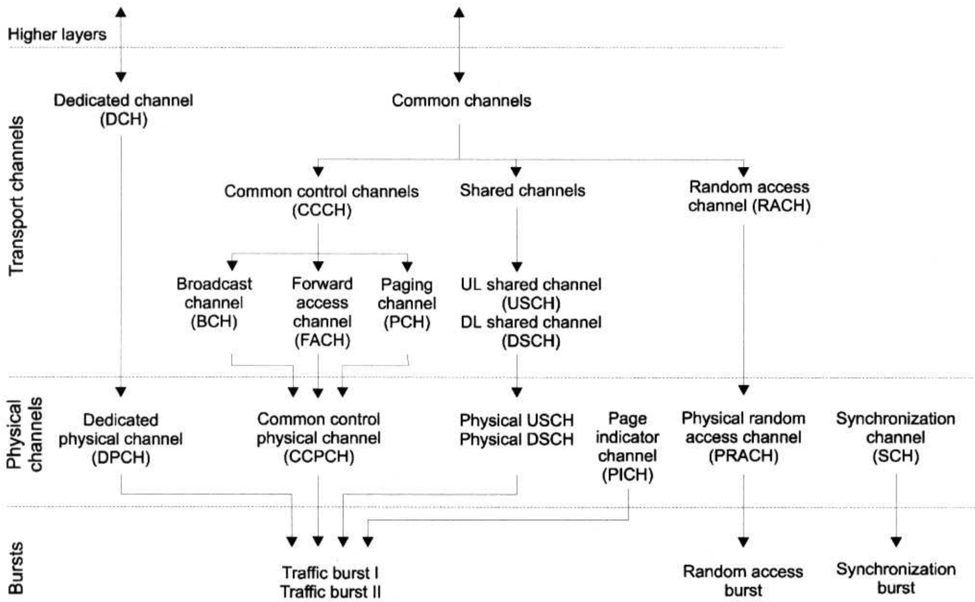

Figure 17.15 Mapping of the TDD transport channels onto physical channels

Transport and physical channels used in the UTRA TDD mode are similar to those applied in the FDD mode. The mapping of the transport channels onto physical channels is presented in Figure 17.15.

The length of each time slot is equivalent to 2560 chips. Transmission of physical channels is performed in the form of bursts. There are basically three types of bursts differing in the internal structure and the guard time length. Each burst contains two data fields, a midamble, and is ended with a guard period. Traffic bursts can also contain the *Transport Format Combination Indicator* (TFCI) and the *Transmission Power Control* (TPC) bit placed on both sides of the midamble. The transmission of TFCI and TPC is negotiated at the call set-up. The TPC field of a particular user is transmitted only once per frame. Figure 17.16 shows the structures of traffic and random access bursts.

Traffic burst type I is used in the uplink. Because of the application of a long midamble, up to 16 channel impulse responses can be estimated. The traffic burst type

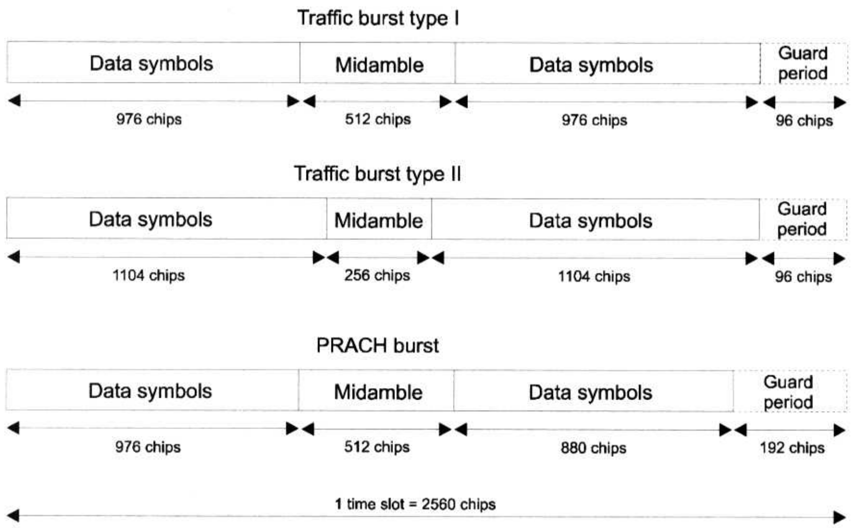

Figure 17.16 Traffic and random access bursts in TDD mode

II is basically used in the downlink and can be also used in the uplink if less than four users are allocated to the same time slot. The midambles used in the same cell are the cyclic shifted versions of the same basic code sequence. Different cells apply different basic code sequences.

Transmitted data is spread in the data symbol fields. Spreading is a two-step process performed by a channelization code and a complex scrambling code, in the same way as in the UTRA FDD mode. Dedicated physical channels use a spreading factor $SF = 16$ in the downlink. As we have mentioned, more than one physical channel using a different channelization code can be assigned to a high rate data link. In case of a single code used in a downlink physical channel, the spreading factor can be equal to 1. In the uplink, dedicated physical channels apply a spreading factor of the value between 1 and 16. Maximum two physical channels can be used by a mobile station per slot to increase the data rate. Simple calculations for the burst type II indicate that transmission with $SF = 16$ using a single code and a single time slot results in the 13.8 kbit/s raw data rate. On the other end, the application of 16 codes and 13 time slots gives the data rate equal to 2.87 Mbit/s. The same result would be achieved if instead of 16 codes with $SF = 16$, one code with $SF = 1$ were applied.

As in the FDD mode, in UTRA TDD the *Primary* and *Secondary Common Control Physical Channels* (P-CCPCH and S-CCPCH) are used. The P-CCPCH carries the BCH transport channel. For that purpose bursts type I with fixed spreading with $SF = 16$ are applied. The *Paging* (PCH) and *Fast Access Channel* (FACH) are carried by the S-CCPCH. Both types of bursts can be applied; however, the spreading factor remains fixed and is equal to 16.

The position of the P-CCPCH within a frame, i.e. the time slot number and the used spreading code, is written in the message carried by the *Synchronization Channel*

(SCH). A synchronization burst is shown in Figure 17.17. One or two synchronization bursts can be placed in a frame. In the first case the synchronization burst is emitted in the same slot of a frame as the P-CCPCH. Every time slot can be selected for this purpose. If two synchronization bursts are applied, then the *Synchronization Channel* (SCH) is allocated in the kth ($k = 0, 1, \ldots, 6$) and $(k + 8)$th slots of the frame, whereas the P-CCPCH is located in the kth time slot. Figure 17.17 illustrates the second case when $k = 0$. The SCH consists of a primary sequence and three secondary sequences, each of them 256-chip long. The sequences start at a specified time offset which is selected from 32 possible values. This prevents the capturing effect which would otherwise occur due to the mutual synchronization of base stations.

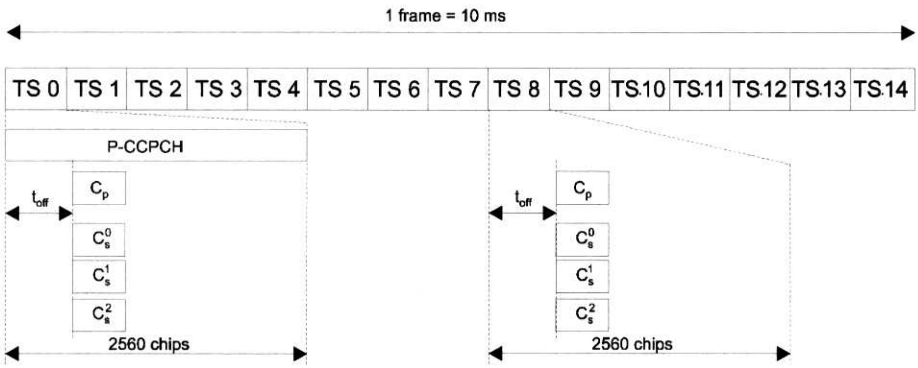

Figure 17.17 Position of the SCH in the TDD frame for $k = 0$ and two SCH bursts in the frame

A mobile station sends a request for access to the channel using the *Physical Random Access Channel* (PRACH). The request is realized by sending a random access burst, shown in Figure 17.16. Let us note that a longer guard time is applied in the burst. It allows operation at the time propagation differences resulting from the distance differences of the order of 7.5 km. Let us also note that a regular guard time applied in traffic bursts is equivalent to the duration of 96 chips which implies differences in propagation time equal to 25 μs. This in turn allows design of cells of the radius of 3.75 km, without applying the timing advance procedure.

A mobile station is paged by the message transmitted on the secondary CCPCH; however, first the *Page Indicator Channel* (PICH) has to be used, which is realized by replacing the S-CCPCH and carrying page indicators for appropriate groups of mobile stations. Generally, the paging mechanism is similar to that described for UTRA FDD and will not be described here.

Physical Uplink and *Downlink Shared Channels* (PUSCH and PDSCH) are used for setting and transmitting user-specific parameters such as power control, timing advance or directive antenna settings.

Due to the nature of the TDD mode, hard handover is applied. The network supplies a mobile station with a list of neighboring base stations whose strength should be measured. The mobile station performs the measurements in idle time slots. Similar handover types as in UTRA FDD occur in UTRA TDD. They are: TDD–TDD, TDD–FDD, WCDMA-TDD–GSM handovers.

In the design phase of the UMTS TDD system, several kinds of interference have to be taken into account. Detailed interference analysis [1] allows us to draw the following conclusions:

- TDD base stations managed by a single operator have to preserve frame synchronization; the frame synchronization between base stations managed by different operators is also desired.
- Allocation of asymmetric uplink and downlink traffic in the cell is not fully free, strong interference can potentially arise between transmission directions.
- *Dynamic channel allocation* (DCA) is a powerful tool used to avoid interference in the TDD band. Another possibility is the use of inter-frequency and inter-system handover.
- Special attention has to be paid to mutual influence of FDD and TDD systems, in particular those operating in lower TDD band and FDD uplink band.

Interference among users implies application of advanced receiver structures both in base and mobile stations. In base stations joint detection receivers (see Chapter 10) can be applied. It is a feasible solution due to the fact that the number of simultaneous users in a time slot is relatively low, so the computational complexity of such receivers is still acceptable, in particular when suboptimal solutions are used. In mobile stations, it is possible to apply single user detectors which combine adaptive intersymbol interference equalization with cancellation of multiple access interference (MAI).

* * *

TDMA transmission applied in the UTRA TDD mode has serious consequences for the cell coverage, since discontinuous transmission causes power reduction. Generally, in order to provide the same coverage area as in the FDD mode, more TDD base stations are needed. Therefore, the UMTS in the TDD mode can be applied as a system complementary to the FDD, especially for data transmission and asymmetrical links.

17.5 CDMA2000

As we have already mentioned, the 3rd Generation Partnership Project 2 (3GGP2) developed the air interface called *cdma2000* which has evolved from the second generation CDMA IS-95 air interface popular in America and South Korea.

Cdma2000 is one of the most important proposals for an IMT-2000 air interface. The first phase of cdma2000 called *cdma2000 1x* is an extension of the existing IS-95B standard. It allows doubling of the system capacity and increased data rates up to

614 kbit/s. The second phase called *cdma2000 1xEV* (Evolution) is a further enhancement of cdma2000 1x. It includes *High Data Rate* (HDR) technology providing data rates up to 2.4 Mbit/s. Initially, a dedicated carrier is devoted to high-speed packet data, whereas one or more additional carriers are used to realize voice connections. In later development of the 1xEV, packet data and voice transmission will be combined in the same carrier; however, packet services on a separate carrier can be possible [17]. Finally, in the third phase of cdma2000 development, called *cdma2000 3x*, three independent non-ovelapping CDMA channels are used, retaining backward compatibility with cdma2000 1x and IS-95B. Tripling the bandwidth and giving some additional freedom results in service enhancement and data rates up to 2 Mbit/s. Figure 17.18 shows the spectrum arrangement for cdma2000 1x and 3x. The cdma2000 is designed to operate in the following environments [4]:

- outdoor megacells (cell radius >35 km),
- outdoor macrocells (cell radius 1 - 35 km),
- indoor/outdoor microcells (cell radius $\leq$ 1 km),
- indoor/outdoor picocells (cell radius <50 m),
- wireless local loops.

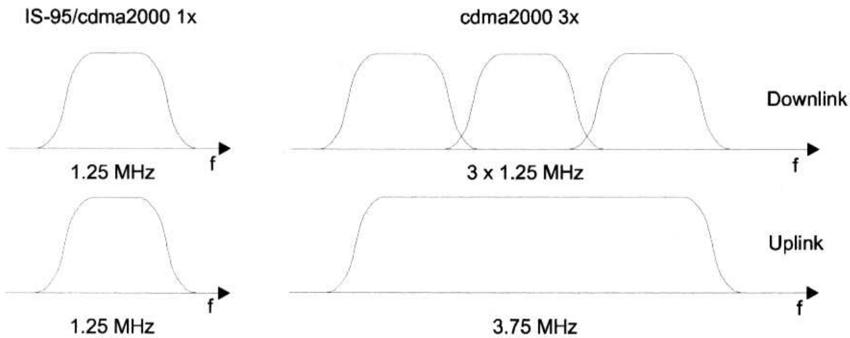

Figure 17.18 Spectrum arrangements for cdma2000 1x and 3x in downlink and uplink

Specific solutions for 3G systems in the USA partially result from the fact that no additional spectrum has been allocated to these type of systems. The PCS band (see Figure 17.2) currently partially used by cdmaOne (IS-95 based systems) and IS-136, has to be gradually reused by new 3G systems. Therefore backward compatibility is a highly desired feature of the 3G systems.

Let us concentrate on the basic features of cdma2000. Table 17.4, based on [3], presents the basic parameters of this system.

In cdma2000, as in IS-95, the downlink and uplink channels are called *forward* and *reverse* channels, respectively. Figure 17.19 presents the list of dedicated and common physical channels used in cdma2000.

Table 17.4 Basic parameters of cdma2000[3]

	cdma2000 1x	**cdma2000 3x**
Channel bandwidth	1.25 MHz	3×1.25 MHz
DL RF channel structure	Direct Spread (DS)	Multicarrier, DS on each carrier
UL RF channel structure	Direct Spread (DS)	Direct Spread (DS)
Chip rate	1.2288 Mchip/s (DL) 1.2288 Mchip/s (UL)	1.2288 Mchip/s per carrier (DL) 3.6864 Mchip/s (UL)
Frame length	20 ms / 5 ms option for signaling bursts	
Timing	Synchronous, derived from GPS	
Channel coding	Convolutional, turbo or no coding	
Modulation	QPSK	
Detection	UL: Coherent, pilot sequence multiplexed with power control bits DL: Coherent, common continuous pilot channel and auxiliary pilot	
Spreading factors	4 - 256	
Spreading in downlink	Variable length orthogonal Walsh sequences (channelization) m-sequence of length 2^{15}(the phase shift determines the cell)	
Spreading in uplink	Variable length orthogonal Walsh sequences (channelization) m-sequence of length 2^{41}-1 (the phase shift determines the user)	
Multirate	Variable spreading and multicode	
Handover	Soft handover, interfrequency handover	
Power control	Open loop and fast closed loop (800 Hz)	

As we see in Figure 17.19, the list of physical channels is very long. The functioning of many channels is very similar to the functioning of the physical channels in the previously described IS-95 system; therefore, we will consider them very briefly. Let us start with the forward link (equivalent to downlink in the UMTS).

The *Forward Pilot Channel* (F-PICH) is used by a mobile station to estimate the channel impulse response necessary in RAKE reception. It is also needed in cell acquisition and handover. It consists of a sequence of logical zeros, spread by the Walsh function No. 0. The actual pilot sequence is received due to the complex scrambling code determining the cell (see Table 17.4 and Chapter 11). The forward pilot signal is common for all mobiles in the cell, so the overhead due to it is not very significant.

The *Forward Sync Channel* (F-SYNC) is used by mobile stations to acquire system synchronization. There are two possible types of a synchronization channel [4]: the *shared* F-SYNC functioning in the IS-95B and cdma2000, which operates in the same area and *wideband* F-SYNC using the entire channel bandwidth and which can be applied in overlay (IS-95B and cdma2000) and non-overlay systems.

The *Forward Paging Channel* (F-PCH) is used to page mobile stations located in a cell and to send them several control messages to them, such as channel assignment, acknowledgments, etc. There may be more than one paging channel in a cell. The applied data rate is 9.6 or 4.8 kbit/s. The data is first convolutionally encoded ($R = 1/2$, $k = 9$), then repetition (if the input data rate is 4.8 kbit/s) and block interlaving are applied. The received signal is modulo-2 summed with the decimated long code which is characteristic for the paging channel. Finally, the signal is spread using an appropriate

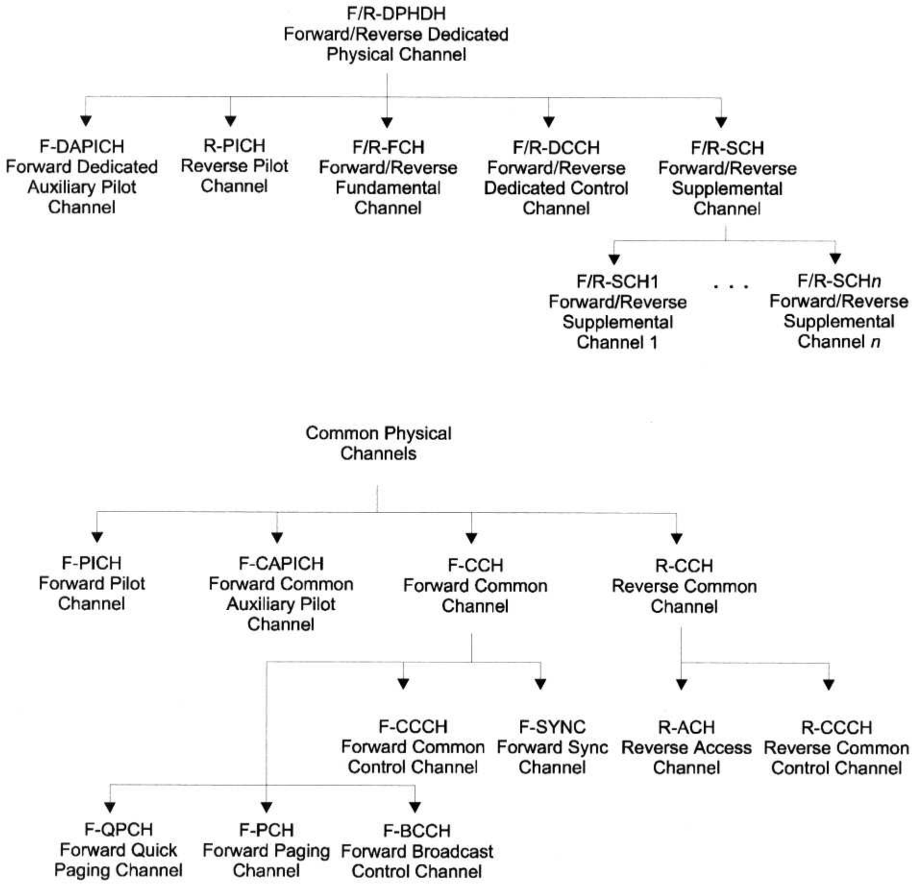

Figure 17.19 Physical channels used in cdma2000

Walsh function and is further processed by the output section. Shared and wideband paging channels are possible, similar to the sync channel.

The *Forward Common Control Channel* (F-CCCH) is used to carry MAC and network layer messages to mobile stations.

The *Forward Common Auxiliary Pilot Channel* (F-CAPICH) is applied to generate spot beams, using adaptive antennas. The F-CAPICH is used by mobile stations located in the generated spot beam. Similarly, the optional *Forward Dedicated Auxiliary Pilot Channel* is applied to target a particular mobile station.

The *Forward Broadcast Common Channel* (F-BCCH) is a type of paging channel which transmits overhead messages and SMS broadcast messages, so the paging channel does not have to transmit them. The number of the Walsh function used by the F-BCCH channel is transmitted on the sync channel.

The *Forward Quick Paging Channel* (F-QPCH) is used to page mobile stations operating in the slotted mode.

The *Forward Fundamental Channel* (F-FCH) is used to carry the downlink traffic. The 20 ms frame and the variable data rates are chosen from the data rate sets known from IS-95B: RS1 (1.5, 2.7, 4.8 and 9.6 kbit/s) and RS2 (1.8, 3.6, 7.2 and 14.4 kbit/s) (see Chapter 11). The existence of many configurations of coding, repetition and block interleaving results in a great number of available data rates (see [4] or cdma2000 standards [18]-[21] for details). All configurations yield the same number of 384 bits in a 20 ms frame, which is equivalent to 19.2 kbit/s for the RS1 rate set or 768 bits in a 20 ms frame equivalent to 38.4 kbit/s for RS2 rate set.

The *Forward Supplemental Channel* (F-SCH) is used to carry user information jointly with the fundamental channel at higher rates than can be achieved using the fundamental channel only. Convolutional coding is applied for lower data rates, whereas turbo coding is applied for higher data rates. More than one F-SCH can be allocated to the link at the same time. Several supplemental channels can have different requirements on error rates depending on applications. A wide range of data rates can be achieved, starting from 9.6 kbit/s and ending with 921.6 kbit/s for the RS2 data set applied in the multicarrier cdma2000 configuration. Is is worth noting that such data rates are practically achieved using multicode and multicarrier channel assignment. In transmission on supplemental channels the channelization Walsh functions can have different length (different spreading factor) depending on the input data rate. They are selected in such way that the bandwidth remains constant after spreading.

The *Forward Dedicated Control Channel* (F-DCCH) transmits point-to-point control data at the data rate of 9.6 kbit/s.

As an example let us consider the block chain for data transmitted on the forward supplemental channel with the input data selected from the data rate set RS2 [4] when $N = 3$ carriers as in cdma2000 3x are used (Figure 17.20).

The data block to be transmitted in a 20 ms frame is first appended with 16 CRC bits, then the encoder tail and reserve bits are added. Next the data block is convolutionally encoded by the code of the constraint length $k = 9$ and the coding rate $R = 1/4$. The resulting data are block interleaved and modulo-2 summed with the decimated output of the long code generator with the mask characteristic for the nth user. The data stream is demultiplexed into three branches generating CDMA signals on three carriers (f_1, f_2, and f_3). The binary streams are mapped into the in-phase and quadrature components and changed from the binary into bipolar form. Subsequently, both components are spread using the Walsh functions operating as the channelization codes and scrambled by the 2^{15}-long PN complex sequence. The phase of this sequence determines the cell. The in-phase and quadrature outputs of the scrambling process are spectrally shaped by the baseband filters and modulated using the appropriate carrier frequency. Let us note that besides the signals shown in Figure 17.20 other channels such as pilot, paging, fundamental channel, etc. are also transmitted.

Let us turn our attention to the uplink transmission. We will shortly describe the operation of most of the reverse physical channels shown in Figure 17.19. Reverse physical channels can be divided into dedicated channels which are a means of communication

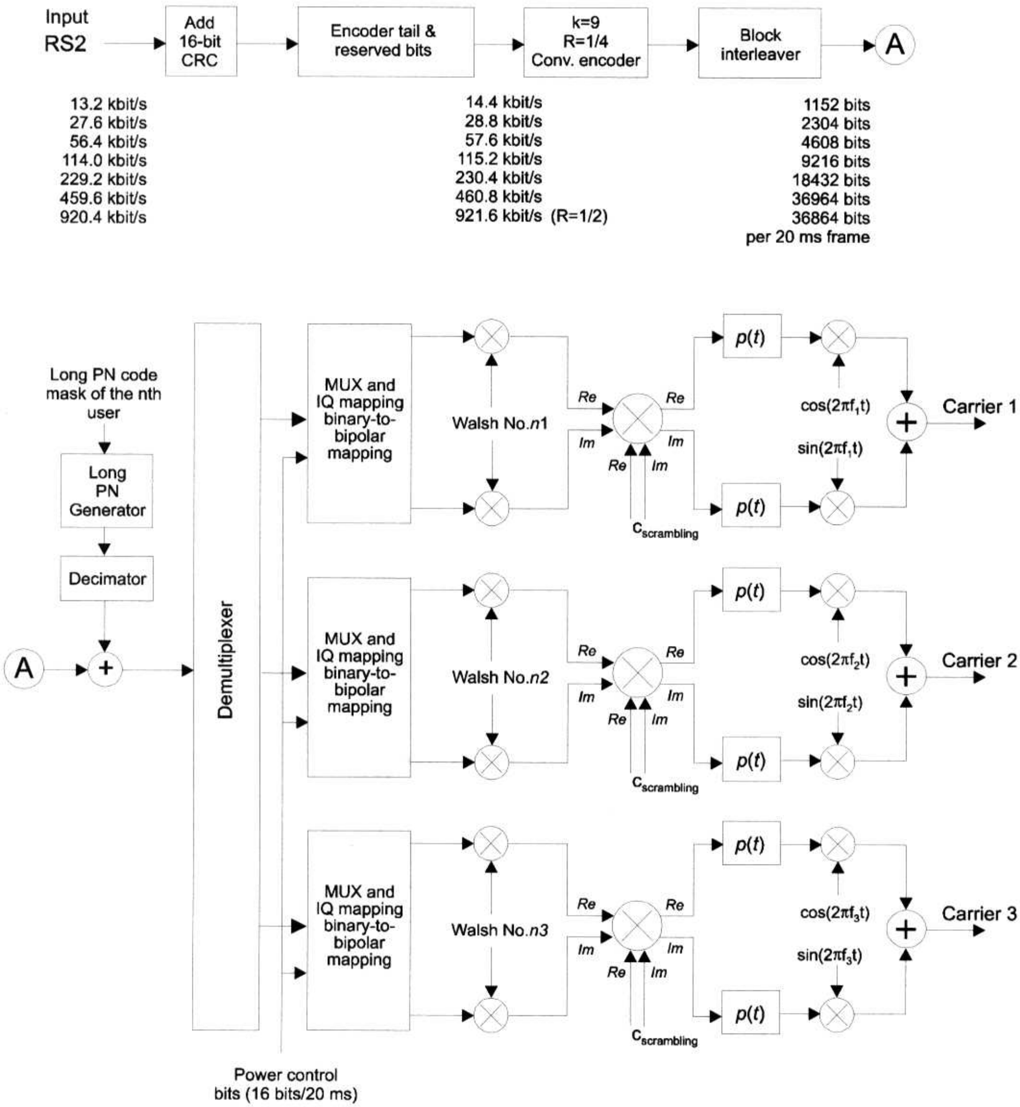

Figure 17.20 Transmission of data at the RS2 rates on the forward supplemental channel with multicarrier CDMA (cdma2000 3x)

between a particular mobile station and the base station, and common channels which are used to send information from multiple mobiles stations to the base station.

The *Reverse Access Channel* (R-ACH) is a multiple channel used by mobile stations to obtain access to the system resources. The slotted ALOHA principle is used in the R-ACH transmission. Let us note that due to the CDMA multiple access, more users can simultaneously attempt to get the access to the medium. More than one R-ACH channel can be used on one carrier frequency. The channels are then differentiated by the applied PN codes.

The *Reverse Common Control Channel* (R-CCCH) is applied to transmit MAC and network layer messages from a mobile station to the base station. The R-CCCH offers extended capabilities as compared with the R-ACH, which enable faster access in packet data transmission.

The *Reverse Pilot Channel* (R-PICH) consists of the pilot sequence originating from setting a fixed value at the channel input, multiplexed with the power control bits which are used in the closed loop power control. The R-PICH is applied in the base station for initial acquisition, time tracking, channel estimation and sequence synchronization used by the RAKE receiver and power control measurements [4].

The *Reverse Dedicated Control Channel* (R-DCCH) is associated with individual transmission from a mobile station to the base station.

The *Reverse Fundamental Channel* (R-FCH) is used to transmit user data. The data rates applied in R-FCH depend on the rate sets. They are equal to 1.5, 2.7, 4.8 and 9.6 kbit/s for RS3 and RS5 rate sets and are equal to 1.8, 3.6, 7.2 and 14.4 kbit/s for the rate sets denoted as RS4 and RS6.

The *Reverse Supplemental Channel* (R-SCH) is an additional channel to carry user data. It can be applied in two modes. In the first one the data rate does not exceed 14.4 kbit/s and the base station has to detect the real data rate without explicit information sent from the mobile station. In the second mode, higher data rates are possible but the data rate is known in advance.

The configuration of the fundamental, supplemental, pilot and dedicated channels differs from an analogous configuration in the downlink. The properly encoded and interleaved data streams sent on the fundamental, dedicated control and supplemental channels are assigned to the in-phase or quadrature components after application of the Walsh channelization codes. They are subsequently scrambled by the PN complex sequence modified by the user-specific long code. Finally, after pulse shaping, the in-phase and quadrature components are placed in the destination band by a pair of orthogonal modulators. Let us stress that the spreading performed by the channelization functions depends on the input data rates and the Walsh functions of different lengths can be used. This is a major difference between cdma2000 and IS-95B. Figure 17.21 presents the channel assignment to appropriate signal components, applied in the uplink (reverse) direction.

Several typical procedures, which have been previously described for UMTS, have to be performed in cdma2000 as well. The most important are: power control, handover, cell search and random access procedures.

Open loop and closed loop power control are applied in cdma2000. Typically, the level of transmitted signal is set on the basis of the measured level of the received signal. In cdma2000, as well as in the UMTS, the FDD mode is applied, so the accuracy of the open loop is limited. In the cdma2000 closed loop power control, the commands dealing with the power level modifications are transmitted in both directions 800 times per second. As a result, medium and fast fading can be compensated.

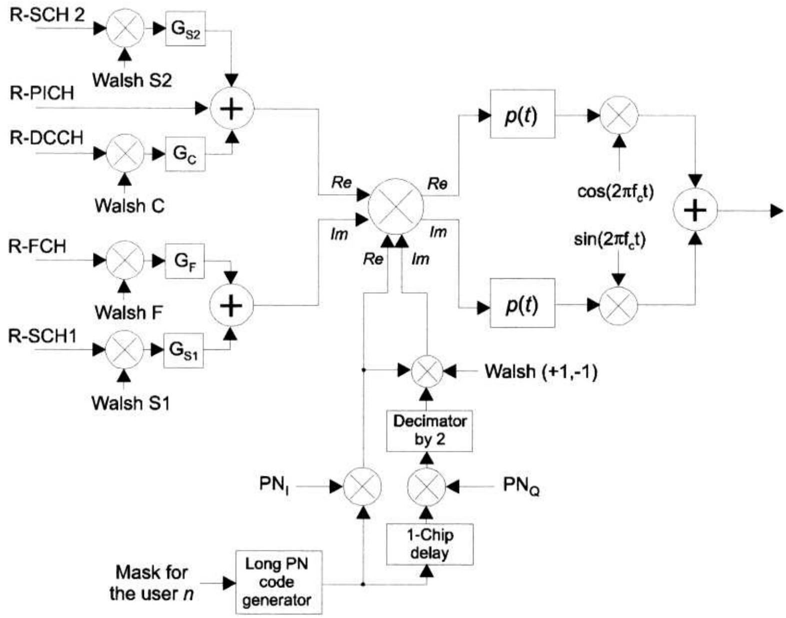

Figure 17.21 Assignment of pilot, dedicated control, fundamental and supplemental channels in the reverse link of cdma2000 (Walsh i denotes the Walsh channelizing function specific for the given type of channel)

The cell search procedure is performed similar to IS-95, because all the cells use the same complex PN sequence; however, in each cell the PN sequence is applied with a cell-specific phase shift. A mobile station searches for the pilot channel transmitting this PN sequence with appropriate phase shift selected from a finite number of shifts.

Cdma2000 applies the soft handover procedure. Intersystem handover between cdma2000 and IS-95 is also supported. The fundamental and supplemental channels are treated differently in the handover procedure. Generally, the number of base stations transmitting the supplemental channel to a mobile station in the handover phase is a subset of the base stations transmitting the fundamental channel [3]. The soft handover procedure tends to use as small a number of base stations as possible to minimize interference and maximize the system capacity.

* * *

In this section we presented a general overview of the physical layer of the cdma2000. The reader interested in the details of the cdma2000 operation is asked to study cdma2000 specifications [18]–[21].

17.6 APPENDIX - THE SOFTWARE RADIO CONCEPT

17.6.1 Introduction

As we noticed studying the previous chapters, the physical layers of the second and third generation systems have not been unified. Several incompatible air interfaces are applied. To obtain global roaming, a mobile station should be able to function with all types of air interfaces. This can be achieved by application of multimode terminals with duplicated or triplicated RF and DSP blocks. Another solution is the application of *Software Radio.*

In the concept of the *Software Radio* [22], [23], [24], transmitters and receivers of the base stations and mobile stations, implemented in a specialized hardware according to a particular standard, are replaced by a universal system. In this system the RF part is drawn to the minimum and the remaining parts consist of wideband A/D and D/A converters and a DSP processor which realizes the transmit/receive functions in software. The advantage of such a solution is not only the possibility to realize several standards of the air interface but also its universality which enables use of the applied system in the longer term and allows for gradual modifications reflecting the evolution of the standards. A short time from the start of the design to the development of a new product is another advantage. It allows for a faster response to the market needs.

The concept of transmit/receive blocks realized in software can be extended to the concept of *Mobile Software Telecommunications* [25]. The authors of this concept expect that many different standards will coexist and none of them will be able to realize all multimedia services. It is assumed that terminals will be intelligent, i.e. they will be software reconfigurable and will be able to communicate with different networks. Terminals will be reconfigurable according to different standards using a certain minimal software. It is expected that new JAVA-like programming languages will be developed which will allow for definition of new standards and services. Such a programming language will constitute a platform for realization of a communication session by defining the features of a physical connection and realized services. Therefore, at the connection set-up, its details will be defined such as: the speech encoder/decoder, applied modulation, data encryption, the features of realized services, associated protocols and the bandwidth requirements. Because most of the elements necessary to realize the communication session will be implemented in software, only a small part of the physical link realized in hardware needs to be standardized.

17.6.2 Minimum radio standard

In order to realize a communication session it is necessary to define a minimum radio interface which will be used to establish a basic connection and to set the remaining elements of the realized session and services. This interface has to enable network access and mobility management associated with the location of mobile terminals and their paging. In association with these tasks the *Network Access and Connectivity Channel* (NACCH) is defined. Figure 17.22 shows a possible placement of the NACCH modem in the mobile terminal architecture [25].

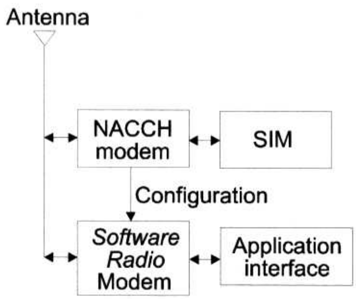

Figure 17.22 The concept of NACCH modem in the architecture of mobile terminal using *Software Radio* technology

Besides the mobility management, the NACCH modem should perform authentication and user registration together with establishing the traffic channels and demanded services. In order to do this, the NACCH modem should set the *Software Radio* modem configuration and program the traffic channels and services. Let us note that the terminal modem consists of two main parts – the NACCH modem and *Software Radio* (SR) modem. In the idle mode, only the NACCH modem is active. The above concept implies sending software subroutines necessary to program the SR modem by the air interface.

Several technical problems would arise in the implementation of this approach [28]. Transmission of the software subroutines by air must be practically error-free, otherwise the SR terminal will not be able to operate reliably. It cannot last too long, otherwise users will be disappointed. Therefore, transmission of the software subroutines by air requires an advance reliable procedure in which the software integrity is checked. On the other hand, this approach is more flexible than the second one – loading the SR software from a smart card.

Using a smart card storing the software enables reliable and fast programming of the SR modem; however, part of the flexibility is lost. This approach requires a whole network of distribution points in which new smart cards can be purchased. The intelligent card technology has to be further developed to enable a huge amount of SR software to be stored.

Another problem associated with the SR technology is the form of the software stored in network data bases or in the memory of a smart card. In order to enable competition among terminal vendors, the software cannot be hardware-dependent. It should be run on several DSP platforms. Therefore, it should have the form of a higher-level language instructions which would be compiled in the SR terminal. In consequence, an SR terminal should contain a compiler which would translate the higher-level language instruction sequence into a hardware-dependent program.

17.6.3 Basic elements of Software Radio architecture

Let us consider the basic scheme of a receiver applied in a mobile communication system (see Figure 17.23) [23].

The signal received in the antenna is filtered in a bandpass (BPF) filter, which extracts the band of a whole system. Subsequently, the signal is amplified in a low noise amplifier (LNA) and demodulated to the intermediate frequency band, using a programmable frequency synthesizer, a mixer and a bandpass filter. The number of intermediate steps is greater than one. After amplification in the automatic gain control (AGC) circuit, the signal is demodulated and shifted to the baseband, where the in-phase and quadrature components are derived. Both component signals are sampled and converted to the digital form. Subsequent processing is typically performed using an ASIC[2] DSP block or a DSP processor.

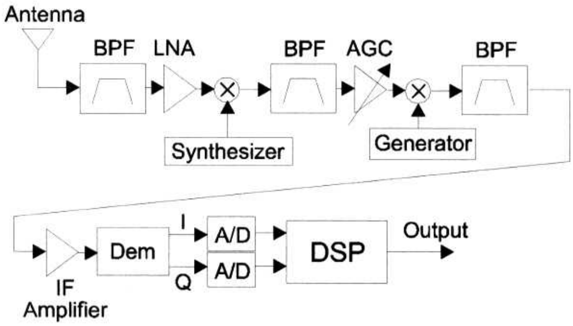

Figure 17.23 Architecture of a typical receiver of a mobile communication system

As we see, the receiver consists of many elements of which a large part is implemented in the analog form. Such a receiver is not a universal solution and is usually fitted to a single air interface. Instead, we can consider the scheme of an idealized receiver in which most of the functions are realized in software. Such a scheme is shown in Figure 17.24.

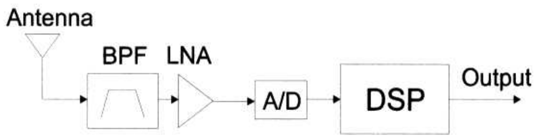

Figure 17.24 Scheme of the idealized software receiver

The analog-to-digital conversion is made in the radio frequency range and the remaining part of the receiver is implemented by a DSP block. This scheme is fully universal and well fitted to the *Software Radio* concept, although at the current state of the D/A technology it is not realizable at the required D/A conversion accuracy. However, it is possible to implement a digital programmable receiver with hardware support of

[2]ASIC – Application Specific Integrated Circuit

down-conversion. The *Programmable Down-Converter* (PDC) realizes down-conversion from the intermediate frequency to the baseband and performs additional filtration in the baseband. Figure 17.25 presents the scheme of the receiver with the PDC. We expect that fast progress in VLSI and A/D and D/A technologies will soon enable the realization of the SR terminal.

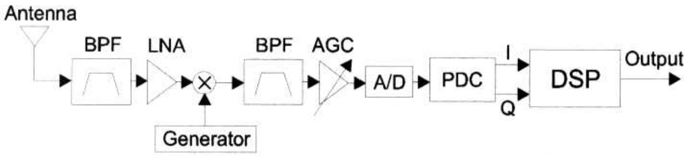

Figure 17.25 The scheme of a digital programmable receiver with the *Programmable Down-Converter* (PDC)

17.6.4 Software Radio in the realization of base stations

The application of the idea of the *Software Radio* in base stations is different from that in mobile stations [23]. The main task of a SR-implemented base station is the integration of the transmit/receive blocks operating on a single carrier in a unified, multifrequency transceiver for a whole base station. The main difficulty in the realization of such a transceiver is ensuring a sufficient A/D accuracy (14-bit conversion at the 50 MHz sampling frequency in case of the GSM system). Another challenge is the design of a highly linear high power amplifier (HPA) whose bandwidth covers a whole system band. In [26] the estimation of the required computational complexity of a GSM base station has been reported. It is expected that soon it will be possible to implement a GSM base station on a fast workstation or a server.

* * *

Software Radio is currently intensively researched by large scientific teams in Europe and the USA. The reader interested in this subject is advised to study the recently published books [29] and [30] and numerous papers published in proceedings of mobile communications conferences.

REFERENCES

1. H. Holma, A. Toskala (eds), *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*, John Wiley & Sons, Ltd., Chichester, 2000

2. J. P. Castro, *The UMTS Network and Radio Access Technology: Air Interface Techniques for Future Mobile Systems*, John Wiley & Sons, Ltd., Chichester, 2001

3. T. Ojanperä, R. Prasad (eds), *WCDMA: Towards IP Mobility and Mobile Internet*, Artech House, Boston, 2001

4. V. K. Garg, *IS-95 and cdma2000. Cellular/PCS Systems Implementation*, Prentice-Hall, Upper Saddle River, N.J., 2000

5. J. Rapeli, "UMTS: Targets, System Concept and Standardization in a Global Framework", *IEEE Personal Communications*, Vol. 2, No. 1, February 1995, pp. 20-28

6. ETSI TS 125.301, Universal Mobile Telecommunications System (UMTS); Radio Interface Protocol Architecture, (3G TS 25.301) V.3.4.0, March 2000

7. E. Dahlman, P. Beming, J. Knutsson, F. Ovesjö, M. Persson, Ch. Roobol, "WCDMA – The Radio Interface for Future Mobile Multimedia Communications", *IEEE Trans. Vehicular Technology*, Vol. 47, No. 4, November 1998, pp. 1105-1117

8. F. Adachi, M. Sawahashi, K. Okawa, "Tree-structured Generation of Orthogonal Spreading Codes with Different Lengths for Forward Link DS-CDMA Mobile", *Electronic Letters*, Vol. 33, No. 1, 1997, pp. 27-28

9. ETSI TS 125.211, Universal Mobile Telecommunications System (UMTS); Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD), V.3.2.0, March 2000

10. ETSI TS 125.212, Universal Mobile Telecommunications System (UMTS); Multiplexing and Channel Coding (FDD), V.3.2.0, March 2000

11. ETSI TS 125.213, Universal Mobile Telecommunications System (UMTS); Spreading and Modulation (FDD), V. 3.2.0, March 2000

12. ETSI TS 125.214, Universal Mobile Telecommunications System (UMTS); Physical Layer Procedures (FDD), V. 3.2.0, March 2000

13. ETSI TS 125.221, Universal Mobile Telecommunications System (UMTS); Physical Channels and Mapping of Transport Channels onto Physical Channels (TDD), V.3.2.0, March 2000

14. ETSI TS 125.222, Universal Mobile Telecommunications System (UMTS); Multiplexing and Channel Coding (TDD), V.3.2.0, March 2000

15. ETSI TS 125.223, Universal Mobile Telecommunications System (UMTS); Spreading and Modulation (TDD), V. 3.2.0, March 2000

16. ETSI TS 125.224, Universal Mobile Telecommunications System (UMTS); Physical Layer Procedures (TDD), V. 3.2.0, March 2000

17. Qualcomm CDMA Technologies, The CDMA Difference, http://www.cdmatech.com/difference/faq/cdma_2000.html

18. 3GPP2 IS-2000.2, Physical Layer Standard for cdma2000 Spread Spectrum Systems

19. 3GPP2 IS-2000.3, Medium Access Control (MAC) Standard for cdma2000 Spread Spectrum Systems

20. 3GPP2 IS-2000.4, Signaling Layer 2 Standard for cdma2000 Spread Spectrum Systems

21. 3GPP2 IS-2000.5, Upper Layer (Layer 3) Signaling Standard for cdma2000 Spread Spectrum Systems.

22. Software Radios, Special Issue of *IEEE Communications Magazine*, May 1995

23. *Software Radio Workshop*, European Commission DG XIII-B, Brussels, May 29, 1997

24. Software Radio and Baseband Technology, Session 1 and 2, *Proc. of ACTS Mobile Summit*, October 7-10, 1997, Aalborg, Denmark

25. G. Fettweis, Ph. Charas, R. Steele, "Mobile Software Telecommunications", *Proc. of European Personal Mobile Communications Conference*, Bonn, 1997, pp. 321-325

26. Th. Turletti D. Tennenhouse, "Estimating the Computational Requirements of a Software GSM Base Station", *Proc. of IEEE International Conference on Communications*, 1997, pp. 169-175

27. W. H. Tuttlebee, "Software Radio Technology: A European Perspective", *IEEE Communications Magazine*, February 1999, pp. 118-123

28. E. Buraccini, "SORT & SWRADIO Concept", *Proc. of ACTS Fourth Mobile Communications Summit*, 1999, pp. 587-593

29. J. Mitola III, *Software Radio Architecture: Object-Oriented Approaches to Wireless Systems Engineering*, John Wiley & Sons, Inc., New York, 2000

30. E. Del Re (ed.), *Software Radio. Technologies and Services*, Springer-Verlag, London, 2001

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