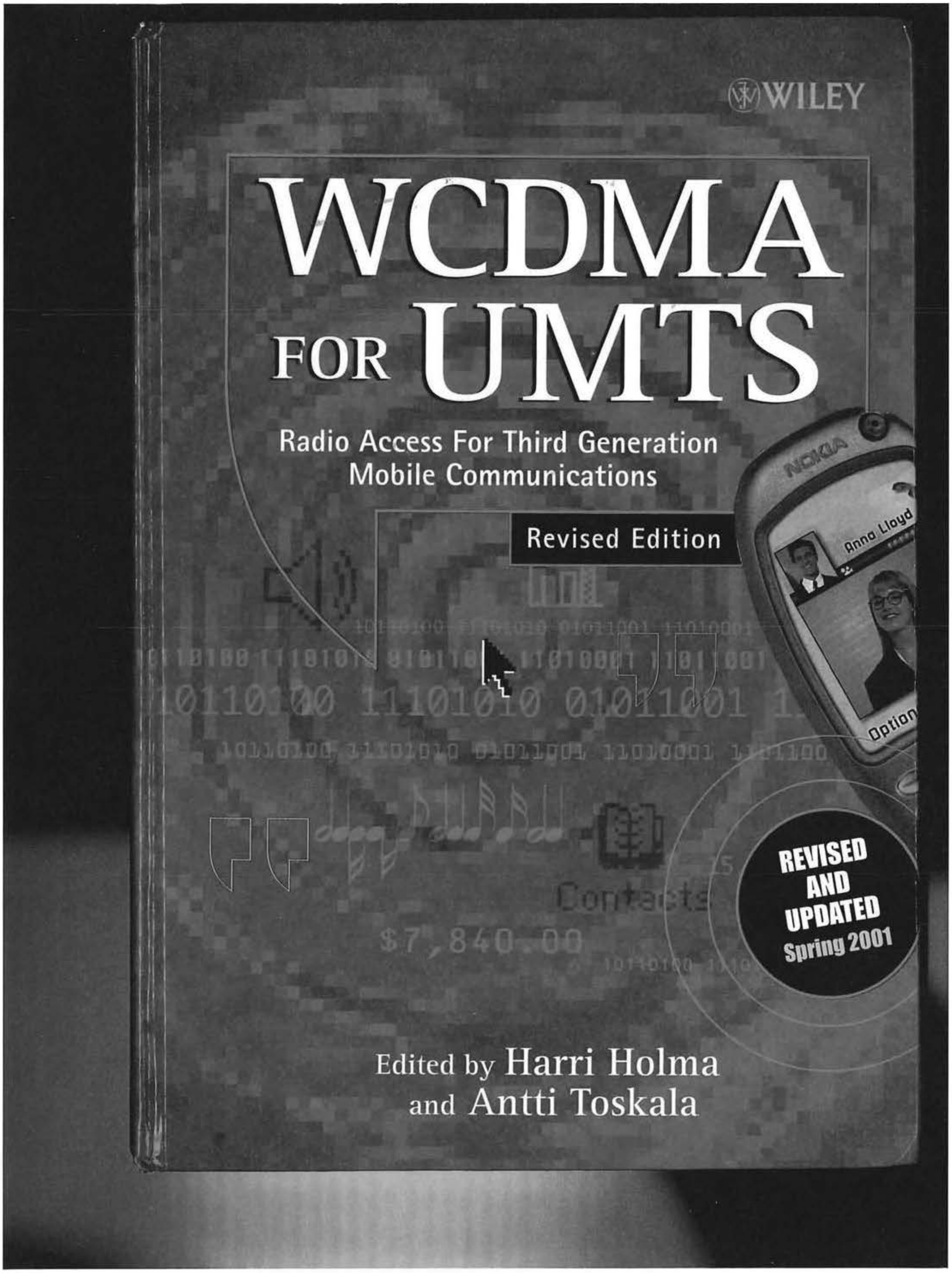
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WCDMA FOR UMTS

Radio Access For Third Generation Mobile Communications

Revised edition

Edited by
Harri Holma and Antti Toskala
Both of Nokia, Finland

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Contents

Preface

Second generation telecommunication systems, such as GSM, enabled voice traffic to go wireless: the number of mobile phones exceeds the number of landline phones and the mobile phone penetration exceeds 70% in countries with the most advanced wireless markets. The data handling capabilities of second generation systems are limited, however, and third generation systems are needed to provide the high bit rate services that enable high quality images and video to be transmitted and received, and to provide access to the web with high data rates. These third generation mobile communication systems are referred to in this book as UMTS (Universal Mobile Telecommunication System). WCDMA (Wideband Code Division Multiple Access) is the main third generation air interface in the world and will be deployed in Europe and Asia, including Japan and Korea, in the same frequency band, around 2 GHz. The large market for WCDMA and its flexible multimedia capabilities will create new business opportunities for manufacturers, operators, and the providers of content and applications. This book gives a detailed description of the WCDMA air interface and its utilisation. The contents are summarised in Figure 1

Chapter 1 introduces the third generation air interfaces, the spectrum allocation, the time schedule, and the main differences from second generation air interfaces. Chapter 2 presents example UMTS applications, concept phones and the quality of service classes. Chapter 3 introduces the principles of the WCDMA air interface, including spreading, Rake receiver, power control and handovers. Chapter 4 presents the background to WCDMA, the global harmonisation process and the standardisation. Chapters 5–7 give a detailed presentation of the WCDMA standard, while Chapters 8–11 cover the utilisation of the standard and its performance. Chapter 5 describes the architecture of the radio access network, interfaces within the radio access network between base stations and radio network controllers (RNC), and the interface between the radio access network and the core network. Chapter 6 covers the physical layer (layer 1), including spreading, modulation, user data and signalling transmission, and the main physical layer procedures of power control, paging, transmission diversity and handover measurements. Chapter 7 introduces the radio interface protocols, consisting of the data link layer (layer 2) and the network layer (layer 3). Chapter 8 presents the guidelines for radio network dimensioning, gives an example of detailed capacity and coverage planning, and covers GSM co-planning. Chapter 9 covers the radio resource management algorithms that guarantee the efficient utilisation of the air interface resources and the quality of service. These algorithms are power control, handovers, admission and load control. Chapter 10 depicts packet access and verifies the approach presented in dynamic system simulations. Chapter 11 analyses the coverage and capacity of

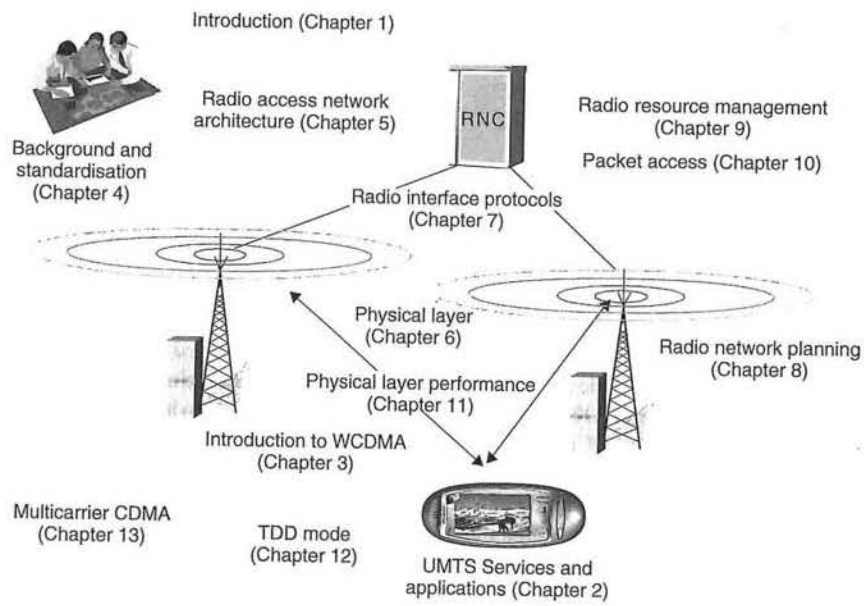

Figure 1. Contents of this book

the WCDMA air interface with bit rates up to 2 Mbps. Chapter 12 introduces the time division duplex (TDD) mode of the WCDMA air interface and its differences from the frequency division duplex (FDD) mode. In addition to WCDMA, third generation services can also be provided with EDGE or with multicarrier CDMA. EDGE is the evolution of GSM for high data rates within the GSM carrier spacing. Multicarrier CDMA is the evolution of IS-95 for high data rates using three IS-95 carriers, and is introduced in Chapter 13.

This reprint of the book includes the key modifications of 3GPP specification done since the official completion of Release'99 until December 2000.

This book is aimed at operators, network and terminal manufacturers, service providers, university students and frequency regulators. A deep understanding of the WCDMA air interface, its capabilities and its optimal usage is the key to success in the UMTS business.

This book represents the views and opinions of the authors, and does not necessarily represent the views of their employers.

Acknowledgements

The editors would like to acknowledge the time and effort put in by their colleagues in contributing to this book. Besides the editors, the contributors were Zhi-Chun Honkasalo, Seppo Hämäläinen, Markku Juntti, Janne Laakso, Jaana Laiho, Ukko Lappalainen, Otto Lehtinen, Fabio Longoni, Atte Länsisalmi, Peter Muszynski, Mika Raitola, Oscar Salonaho, Jouni Salonen, Kari Sipilä, Jukka Vialen, Heli Väätäjä, Achim Wacker and Juha Ylitalo.

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We are extremely grateful to our families, as well as the families of all the authors, for their patience and support, especially during the late night and weekend editing sessions near different production milestones.

Special thanks are due to our employer, Nokia Networks, for supporting and encouraging such an effort and for providing some of the illustrations in this book.

Finally, we would like to acknowledge the efforts of our colleagues in the wireless industry for the great work done within the 3rd Generation Partnership Project to produce the global WCDMA standard in merely a year and thus to create the framework for this book. Without such an initiative this book would never have been possible.

The editors and authors welcome any comments and suggestions for improvements or changes that could be implemented in forthcoming editions of this book. The email address for gathering such information is *wcdma.for.umts@pp.nic.fi*.

Espoo, Finland — Harri Holma & Antti Toskala

Abbreviations

3GPP	3rd Generation partnership project (produces WCDMA standard)
3GPP2	3rd Generation partnership project 2 (produced cdma2000 standard)
AAL2	ATM Adaptation Layer type 2
AAL5	ATM Adaptation Layer type 5
ACELP	Algebraic code excitation linear prediction
ACIR	Adjacent channel interference ratio, caused by the transmitter non-idealities and imperfect receiver filtering
ACLR	Adjacent channel leakage ratio, caused by the transmitter non-idealities, the effect of receiver filtering is not included
ACTS	Advanced communication technologies and systems, EU research projects framework
AICH	Acquisition indicatio channel
ALCAP	Access link control application part
AM	Acknowledged mode
AMD	Acknowledged mode data
AMR	Adaptive multirate (speech codec)
ARIB	Association of radio industries and businesses (Japan)
ARQ	Automatic repeat request
ASC	Access service class
ASN.1	Abstract syntax notation one
ATM	Asynchronous transfer mode
AWGN	Additive white Gaussian noise
BB SS7	Broad band signalling system #7
BCCH	Broadcast control channel (logical channel)
BCFE	Broadcast control functional entity
BCH	Broadcast channel (transport channel)
BER	Bit error ratio
BLER	Block error ratio
BMC	Broadcast/multicast control protocol
BoD	Bandwidth on demand
BPSK	Binary phase shift keying
BS	Base station
BSS	Base station subsystem
BSC	Base station controller

CA-ICH	Channel assignment indication channel
CB	Cell broadcast
CBC	Cell broadcast center
CBS	Cell broadcast service
CCCH	Common control channel (logical channel)
CCH	Common transport channel
CCH	Control channel
CD-ICH	Collision detection indication channel
CDF	Cumulative distribution function
CDMA	Code division multiple access
CFN	Connection frame number
CIR	Carrier to interference ratio
CM	Connection management
CN	Core network
C-NBAP	Common NBAP
CODIT	Code division test bed, EU research project
CPCH	Common packet channel
CPICH	Common pilot channel
CRC	Cyclic redundancy check
CRNC	Controlling RNC
C-RNTI	Cell-RNTI, radio network temporary identity
CS	Circuit switched
CSICH	CPCH status indication channel
CTCH	Common traffic channel
CWTS	China wireless telecommunications standard group
DCA	Dynamic channel allocation
DCCH	Dedicated control channel (logical channel)
DCFE	Dedicated control functional entity
DCH	Dedicated channel (transport channel)
DECT	Digital enhanced cordless telephone
DF	Decision feedback
DL	Downlink
D-NBAP	Dedicated NBAP
DPCCH	Dedicated physical control channel
DPDCH	Dedicated physical data channel
DRNC	Drift RNC
DRX	Discontinuous reception
DS-CDMA	Direct spread code division multiple access
DSCH	Downlink shared channel
DTCH	Dedicated traffic channel
DTX	Discontinuous transmission
EDGE	Enhanced data rates for GSM evolution
EFR	Enhanced full rate speech codec
EIRP	Equivalent isotropic radiated power
EP	Elementary procedure
ETSI	European telecommunications standards institute

FACH	Forward access channel
FBI	Feedback information
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FER	Frame error ratio
FP	Frame protocol
FPLMTS	Future public land mobile telecommunications system
FRAMES	Future radio wideband multiple access system, EU research project
FTP	File transfer protocol
GGSN	Gateway GPRS support node
GMSC	Gateway MSC
GPRS	General packet radio system
GPS	Global positioning system
GSIC	Groupwise serial interference cancellation
GSM	Global system for mobile communications
GTP-U	User plane part of GPRS tunnelling protocol
HLR	Home location register
IC	Interference cancellation
ID	Identity
IETF	Internet engineering task force
IMSI	International mobile subscriber identity
IMT-2000	International mobile telephony, 3rd generation networks are referred as IMT-2000 within ITU
IN	Intelligent network
IP	Internet protocol
IPI	Inter-path interference
IRC	Interference rejection combining
IS-2000	IS-95 evolution standard, (cdma2000)
IS-136	US-TDMA, one of the 2nd generation systems, mainly in Americas
IS-95	cdmaOne, one of the 2nd generation systems, mainly in Americas and in Korea
ISDN	Integrated services digital network
ISI	Inter-symbol interference
ITU	International telecommunications union
ITUN	SS7 ISUP Tunnelling
L2	Layer 2
LAI	Location area identity
LAN	Local area network
LCS	Location services
LP	Low pass
MA	Midamble
MAC	Medium access control
MAI	Multiple access interference
MAP	Maximum a posteriori
MCU	Multipoint control unit
ME	Mobile equipment

MF	Matched filter
MLSD	Maximum likelihood sequence detection
MM	Mobility management
MMSE	Minimum mean square error
MPEG	Motion picture experts group
MR-ACELP	Multirate ACELP
MS	Mobile station
MSC/VLR	Mobile services switching centre/visitor location register
MT	Mobile termination
MTP3b	Message transfer part (broadband)
MUD	Multiuser detection
NAS	Non access stratum
NBAP	Node B application part
NRT	Non-real time
ODMA	Opportunity driven multiple access
O&M	Operation and maintenance
OVSF	Orthogonal variable spreading factor
PAD	Padding
PC	Power control
PCCC	Parallel concatenated convolutional coder
PCCCH	Physical common control channel
PCCH	Paging channel (logical channel)
PCCPCH	Primary common control physical channel
PCH	Paging channel (transport channel)
PCPCH	Physical common packet channel
PCS	Personal communication systems, 2nd generation cellular systems mainly in Americas, operating partly on IMT-2000 band
PDC	Personal digital cellular, 2nd generation system in Japan
PDCP	Packet data converge protocol
PDP	Packet data protocol
PDSCH	Physical downlink shared channel
PDU	Protocol data unit
PER	Packed encoding rules
PHS	Personal handy phone system
PHY	Physical layer
PI	Page indicator
PIC	Parallel interference cancellation
PICH	Paging indicator channel
PLMN	Public land mobile network
PNFE	Paging and notification control function entity
PRACH	Physical random access channel
PS	Packet switched
PSCH	Physical shared channel
PSTN	Public switched telephone network
P-TMSI	Packet-TMSI
PU	Payload unit

PVC	Pre-defined virtual connection
QoS	Quality of service
QPSK	Quadrature phase shift keying
RAB	Radio access bearer
RACH	Random access channel
RAI	Routing area identity
RAN	Radio access network
RANAP	RAN application part
RB	Radio bearer
RF	Radio frequency
RLC	Radio link control
RNC	Radio network controller
RNS	Radio network sub-system
RNSAP	RNS application part
RNTI	Radio network temporary identity
RRC	Radio resource control
RRM	Radio resource management
RSSI	Received signal strength indicator
RSVP	Resource reservation protocol
RT	Real time
RTCP	Real time transport control protocol
RTP	Real time protocol
RTSP	Real time streaming protocol
RU	Resource unit
SAAL-NNI	Signalling ATM adaptation layer for network to network interfaces
SAAL-UNI	Signalling ATM adaptation layer for user to network interfaces
SAP	Service access point
SAP	Session announcement protocol
SCCP	Signalling connection control part
SCCPCH	Secondary common control physical channel
SCH	Synchronisation channel
SCTP	Simple control transmission protocol
SDD	Space division duplex
SDP	Session description protocol
SDU	Service data unit
SF	Spreading factor
SFN	System frame number
SGSN	Serving GPRS support node
SHO	Soft handover
SIB	System information block
SIC	Successive interference cancellation
SID	Silence indicator
SINR	Signal-to-noise ratio where noise includes both thermal noise and interference
SIP	Session initiation protocol
SIR	Signal to interference ratio

SM	Session management
SMS	Short message service
SN	Sequence number
SNR	Signal to noise ratio
SRB	Signalling radio bearer
SRNC	Serving RNC
SRNS	Serving RNS
SS7	Signalling system #7
SSCF	Service specific co-ordination function
SSCOP	Service specific connection oriented protocol
STD	Switched transmit diversity
STTD	Space time transmit diversity
TCH	Traffic channel
TCP	Transport control protocol
TCTF	Target channel type field
TD/CDMA	Time division CDMA, combined TDMA and CDMA
TDD	Time division duplex
TDMA	Time division multiple access
TE	Terminal equipment
TF	Transport format
TFCI	Transport format combination indicator
TFCS	Transport format combination set
TFI	Transport format indicator
TMSI	Temporary mobile subscriber identity
TPC	Transmission power control
TR	Transparent mode
TS	Technical specification
TSTD	Time switched transmit diversity
TTA	Telecommunications technology association (Korea)
TTC	Telecommunication technology commission (Japan)
TxAA	Transmit adaptive antennas
UDP	User datagram protocol
UE	User equipment
UL	Uplink
UM	Unacknowledged mode
UMTS	Universal mobile telecommunication system
URA	UTRAN registration area
URL	Universal resource locator
U-RNTI	UTRAN RNTI
USCH	Uplink shared channel
USIM	UMTS Subscriber identity module
US-TDMA	IS-136, one of the 2^{nd} generation systems mainly in USA
UTRA	UMTS Terrestrial radio access (ETSI)
UTRA	Universal Terrestrial radio access (3GPP)
UTRAN	UMTS Terrestrial radio access network
VAD	Voice activation detection

VoIP	Voice over IP
WARC	World administrative radio conference
WCDMA	Wideband CDMA, Code division multiple access
WLL	Wireless local loop
WWW	World wide web
ZF	Zero forcing

5

Radio Access Network Architecture

Fabio Longoni and Atte Länsisalmi

5.1 System Architecture

This chapter gives a wide overview of the UMTS system architecture, including an introduction to the logical network elements and the interfaces. The UMTS system utilises the same well-known architecture that has been used by all main second generation systems and even by some first generation systems. The reference list contains the related 3GPP specifications.

The UMTS system consists of a number of logical network elements that each has a defined functionality. In the standards, network elements are defined at the logical level, but this quite often results in a similar physical implementation, especially since there are a number of open interfaces (for an interface to be 'open', the requirement is that it has been defined to such a detailed level that the equipment at the endpoints can be from two different manufacturers). The network elements can be grouped based on similar functionality, or based on which sub-network they belong to.

Functionally the network elements are grouped into the Radio Access Network (RAN, UMTS Terrestrial RAN = UTRAN) that handles all radio-related functionality, and the Core Network, which is responsible for switching and routing calls and data connections to external networks. To complete the system, the User Equipment (UE) that interfaces with the user and the radio interface is defined. The high-level system architecture is shown in Figure 5.1.

From a specification and standardisation point of view, both UE and UTRAN consist of completely new protocols, the design of which is based on the needs of the new WCDMA radio technology. On the contrary, the definition of CN is adopted from GSM. This gives the system with new radio technology a global base of known and rugged CN technology that accelerates and facilitates its introduction, and enables such competitive advantages as global roaming.

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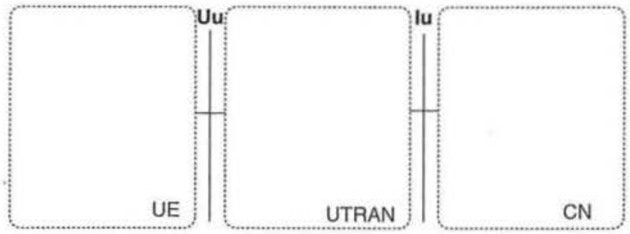

Figure 5.1. UMTS high-level system architecture

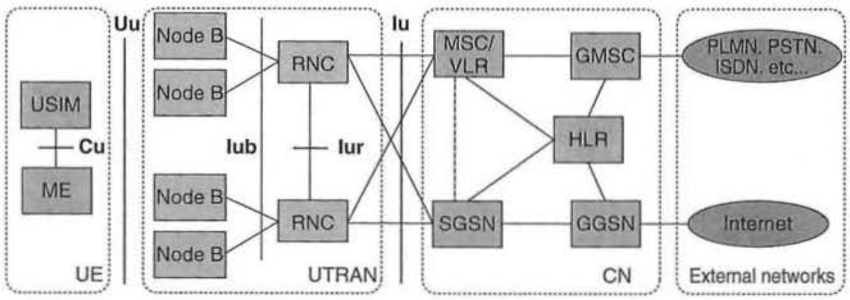

Figure 5.2. Network elements in a PLMN

Another way to group UMTS network elements is to divide them into sub-networks. The UMTS system is modular in the sense that it is possible to have several network elements of the same type. In principle, the minimum requirement for a fully featured and operational network is to have at least one logical network element of each type (note that some features and consequently some network elements are optional). The possibility of having several entities of the same type allows the division of the UMTS system into sub-networks that are operational either on their own or together with other sub-networks, and that are distinguished from each other with unique identities. Such a sub-network is called a UMTS PLMN (Public Land Mobile Network). Typically one PLMN is operated by a single operator, and is connected to other PLMNs as well as to other types of networks, such as ISDN, PSTN, the Internet, and so on. Figure 5.2 shows elements in a PLMN and, in order to illustrate the connections, also external networks.

The UTRAN architecture is presented in Section 5.2. A short introduction to all the elements is given below.

The UE consists of two parts:

- The Mobile Equipment (ME) is the radio terminal used for radio communication over the Uu interface.
- The UMTS Subscriber Identity Module (USIM) is a smartcard that holds the subscriber identity, performs authentication algorithms, and stores authentication and encryption keys and some subscription information that is needed at the terminal.

UTRAN also consists of two distinct elements:

- The Node B converts the data flow between the Iub and Uu interfaces. It also participates in radio resource management. (*Note that the term 'Node B' from the corresponding 3GPP specifications is used throughout Chapter 5. The more generic term 'Base Station' used elsewhere in this book means exactly the same thing.*)
- The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Node Bs connected to it). RNC is the service access point for all services UTRAN provides the CN, for example management of connections to the UE.

The main elements of the GSM CN (there are other entities not shown in Figure 5.2, such as those used to provide IN services) are as follows:

- HLR (Home Location Register) is a database located in the user's home system that stores the master copy of the user's service profile. The service profile consists of, for example, information on allowed services, forbidden roaming areas, and Supplementary Service information such as status of call forwarding and the call forwarding number. It is created when a new user subscribes to the system, and remains stored as long as the subscription is active. For the purpose of routing incoming transactions to the UE (e.g. calls or short messages), the HLR also stores the UE location on the level of MSC/VLR and/or SGSN, i.e. on the level of serving system.
- MSC/VLR (Mobile Services Switching Centre/Visitor Location Register) is the switch (MSC) and database (VLR) that serves the UE in its current location for Circuit Switched (CS) services. The MSC function is used to switch the CS transactions, and the VLR function holds a copy of the visiting user's service profile, as well as more precise information on the UE's location within the serving system. The part of the network that is accessed via the MSC/VLR is often referred to as the CS domain.
- GMSC (Gateway MSC) is the switch at the point where UMTS PLMN is connected to external CS networks. All incoming and outgoing CS connections go through GMSC.
- SGSN (Serving GPRS (General Packet Radio Service) Support Node) functionality is similar to that of MSC/VLR but is typically used for Packet Switched (PS) services. The part of the network that is accessed via the SGSN is often referred to as the PS domain.
- GGSN (Gateway GPRS Support Node) functionality is close to that of GMSC but is in relation to PS services.

The external networks can be divided into two groups:

- CS networks. These provide circuit-switched connections, like the existing telephony service. ISDN and PSTN are examples of CS networks.
- PS networks. These provide connections for packet data services. The Internet is one example of a PS network.

The UMTS standards are structured so that internal functionality of the network elements is not specified in detail. Instead, the interfaces between the logical network elements have been defined. The following main open interfaces are specified:

- Cu Interface. This is the electrical interface between the USIM smartcard and the ME. The interface follows a standard format for smartcards.
- Uu Interface. This is the WCDMA radio interface, which is the subject of the main part of this book. The Uu is the interface through which the UE accesses the fixed part of the system, and is therefore probably the most important open interface in UMTS. There are likely to be many more UE manufacturers than manufacturers of fixed network elements.
- Iu Interface. This connects UTRAN to the CN and is introduced in detail in Section 5.4. Similarly to the corresponding interfaces in GSM, A (Circuit Switched) and Gb (Packet Switched), the open Iu interface gives UMTS operators the possibility of acquiring UTRAN and CN from different manufacturers. The enabled competition in this area has been one of the success factors of GSM.
- Iur Interface. The open Iur interface allows soft handover between RNCs from different manufacturers, and therefore complements the open Iu interface. Iur is described in more detail in Section 5.5.1.
- Iub Interface. The Iub connects a Node B and an RNC. UMTS is the first commercial mobile telephony system where the Controller-Base Station interface is standardised as a fully open interface. Like the other open interfaces, open Iub is expected to further motivate competition between manufacturers in this area. It is likely that new manufacturers concentrating exclusively on Node Bs will enter the market.

5.2 UTRAN Architecture

UTRAN architecture is highlighted in Figure 5.3.

UTRAN consists of one or more Radio Network Sub-systems (RNS). An RNS is a sub-network within UTRAN and consists of one Radio Network Controller (RNC) and one or more Node Bs. RNCs may be connected to each other via an Iur interface. RNCs and Node Bs are connected with an Iub Interface.

Before entering into a brief description of the UTRAN network elements (in this section) and a more extensive description of UTRAN interfaces (in the following sections), we present the main characteristics of UTRAN that have also been the main requirements for

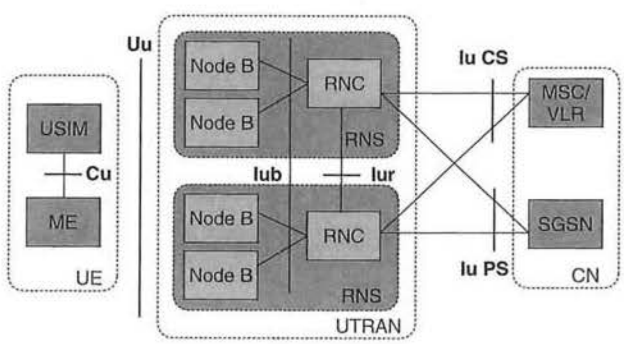

Figure 5.3. UTRAN architecture

the design of the UTRAN architecture, functions and protocols. These can be summarised in the following points:

- *Support of UTRA* and all the related functionality. In particular, the major impact on the design of UTRAN has been the requirement to support *soft handover* (one terminal connected to the network via two or more active cells) and the WCDMA-specific *Radio Resource Management* algorithms.
- Maximisation of the *commonalities in the handling of packet- switched and circuit-switched data*, with a unique air interface protocol stack and with the use of the same interface for the connection from UTRAN to both the PS and CS domains of the core network.
- Maximisation of the *commonalities with GSM*, when possible.
- Use of the *ATM transport* as the main transport mechanism in UTRAN.

5.2.1 The Radio Network Controller

The RNC (Radio Network Controller) is the network element responsible for the control of the radio resources of UTRAN. It interfaces the CN (normally to one MSC and one SGSN) and also terminates the RRC (Radio Resource Control) protocol that defines the messages and procedures between the mobile and UTRAN. It logically corresponds to the GSM BSC.

5.2.1.1 Logical Role of the RNC

The RNC controlling one Node B (i.e. terminating the Iub interface towards the Node B) is indicated as the *Controlling RNC* (CRNC) of the Node B. The Controlling RNC is responsible for the load and congestion control of its own cells, and also executes the admission control and code allocation for new radio links to be established in those cells.

In case one mobile–UTRAN connection uses resources from more than one RNS (see Figure 5.4), the RNCs involved have two separate logical roles (*with respect to this mobile–UTRAN connection*):

- *Serving RNC*. The SRNC for one mobile is the RNC that terminates both the Iu link for the transport of user data and the corresponding RANAP signalling to/from the

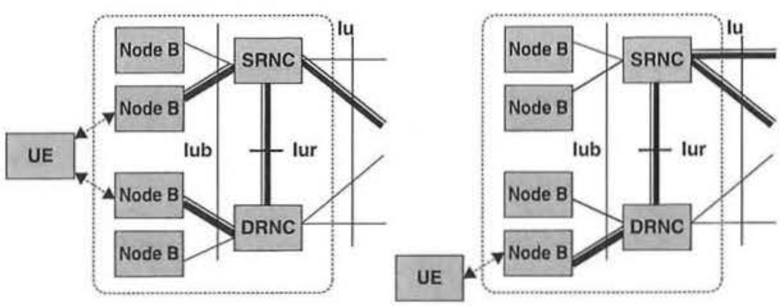

Figure 5.4. Logical role of the RNC for one UE UTRAN connection. The left-hand scenario shows one UE in inter-RNC soft handover (combining is performed in the SRNC). The right-hand scenario represents one UE using resources from one Node B only, controlled by the DRNC

core network (this connection is referred to as the RANAP connection). The SRNC also terminates the Radio Resource Control Signalling, that is the signalling protocol between the UE and UTRAN. It performs the L2 processing of the data to/from the radio interface. Basic Radio Resource Management operations, such as the mapping of Radio Access Bearer parameters into air interface transport channel parameters, the handover decision, and outer loop power control, are executed in the SRNC. The SRNC may also (but not always) be the CRNC of some Node B used by the mobile for connection with UTRAN. One UE connected to UTRAN has one and only one SRNC.

- *Drift RNC.* The DRNC is any RNC, other than the SRNC, that controls cells used by the mobile. If needed, the DRNC may perform macrodiversity combining and splitting. The DRNC does not perform L2 processing of the user plane data, but routes the data transparently between the Iub and Iur interfaces, except when the UE is using a common or shared transport channel. One UE may have zero, one or more DRNCs.

Note that one physical RNC normally contains all the CRNC, SRNC and DRNC functionality.

5.2.2 The Node B (Base Station)

The main function of the Node B is to perform the air interface L1 processing (channel coding and interleaving, rate adaptation, spreading, etc.). It also performs some basic Radio Resource Management operation as the inner loop power control. It logically corresponds to the GSM Base Station. The enigmatic term 'Node B' was initially adopted as a temporary term during the standardisation process, but then never changed.

The logical model of the Node B is described in Section 5.5.2.

5.3 General Protocol Model for UTRAN Terrestrial Interfaces

5.3.1 General

Protocol structures in UTRAN terrestrial interfaces are designed according to the same general protocol model. This model is shown in Figure 5.5. The structure is based on the principle that the layers and planes are logically independent of each other, and if needed, parts of the protocol structure may be changed in the future while other parts remain intact.

5.3.2 Horizontal Layers

The protocol structure consists of two main layers, the Radio Network Layer and the Transport Network Layer. All UTRAN-related issues are visible only in the Radio Network Layer, and the Transport Network Layer represents standard transport technology that is selected to be used for UTRAN but without any UTRAN-specific changes.

5.3.3 Vertical Planes

5.3.3.1 Control Plane

The Control Plane is used for all UMTS-specific control signalling. It includes the Application Protocol (i.e. RANAP in Iu, RNSAP in Iur and NBAP in Iub), and the Signalling Bearer for transporting the Application Protocol messages.

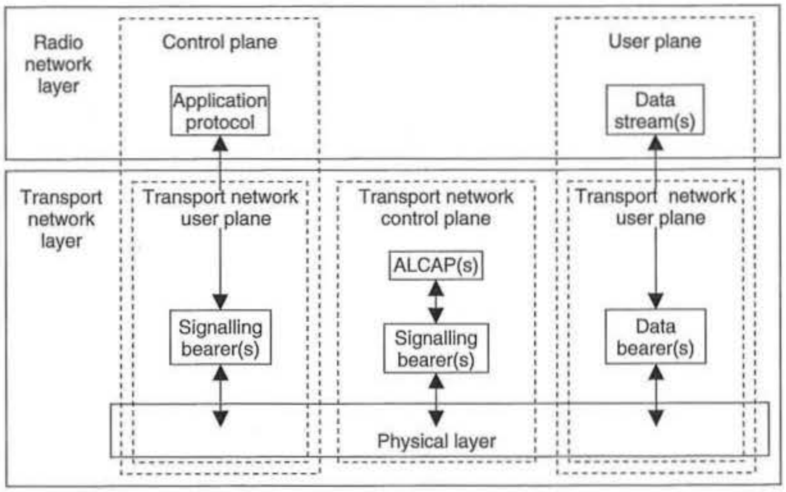

Figure 5.5. General protocol model for UTRAN terrestrial interfaces

The Application Protocol is used, among other things, for setting up bearers to the UE (i.e. the Radio Access Bearer in Iu and subsequently the Radio Link in Iur and Iub). In the three-plane structure the bearer parameters in the Application Protocol are not directly tied to the User Plane technology, but rather are general bearer parameters.

The Signalling Bearer for the Application Protocol may or may not be of the same type as the Signalling Bearer for the ALCAP. It is always set up by O&M actions.

5.3.3.2 User Plane

All information sent and received by the user, such as the coded voice in a voice call or the packets in an Internet connection, are transported via the User Plane. The User Plane includes the Data Stream(s), and the Data Bearer(s) for the Data Stream(s). Each Data Stream is characterised by one or more frame protocols specified for that interface.

5.3.3.3 Transport Network Control Plane

The Transport Network Control Plane is used for all control signalling within the Transport Layer. It does not include any Radio Network Layer information. It includes the ALCAP protocol that is needed to set up the transport bearers (Data Bearer) for the User Plane. It also includes the Signalling Bearer needed for the ALCAP.

The Transport Network Control Plane is a plane that acts between the Control Plane and the User Plane. The introduction of the Transport Network Control Plane makes it possible for the Application Protocol in the Radio Network Control Plane to be completely independent of the technology selected for the Data Bearer in the User Plane.

When the Transport Network Control Plane is used, the transport bearers for the Data Bearer in the User Plane are set up in the following fashion. First there is a signalling transaction by the Application Protocol in the Control Plane, which triggers the setup of the Data Bearer by the ALCAP protocol that is specific for the User Plane technology.

The independence of the Control Plane and the User Plane assumes that an ALCAP signalling transaction takes place. It should be noted that ALCAP might not be used for all types of Data Bearers. If there is no ALCAP signalling transaction, the Transport Network Control Plane is not needed at all. This is the case when preconfigured Data Bearers are used. It should also be noted that the ALCAP protocol(s) in the Transport Network Control Plane is/are not used for setting up the Signalling Bearer for the Application Protocol or for the ALCAP during real-time operation.

The Signalling Bearer for the ALCAP may or may not be of the same type as that for the Application Protocol. The UMTS specifications assume that the Signalling Bearer for ALCAP is always set up by O&M actions, and do not specify this in detail.

5.3.3.4 Transport Network User Plane

The Data Bearer(s) in the User Plane, and the Signalling Bearer(s) for the Application Protocol, also belong to the Transport Network User Plane. As described in the previous section, the Data Bearers in the Transport Network User Plane are directly controlled by the Transport Network Control Plane during real-time operation, but the control actions required for setting up the Signalling Bearer(s) for the Application Protocol are considered O&M actions.

5.4 Iu, the UTRAN–CN Interface

The Iu interface connects UTRAN to CN. Iu is an open interface that divides the system into radio-specific UTRAN and CN which handles switching, routing and service control. As can be seen from Figure 5.3, the Iu can have two different instances, which are Iu CS (Iu Circuit Switched) for connecting UTRAN to Circuit Switched (CS) CN, and Iu PS (Iu Packet Switched) for connecting UTRAN to Packet Switched (PS) CN. The original design goal in the standardisation was to develop only one Iu interface, but then it was realised that fully optimised User Plane transport for CS and PS services can only be achieved if different transport technologies are allowed. Consequently, the Transport Network Control Plane is different. One of the main design guidelines has still been that the Control Plane should be the same for Iu CS and Iu PS, and the differences are minor.

5.4.1 Protocol Structure for Iu CS

The Iu CS overall protocol structure is depicted in Figure 5.6. The three planes in the Iu interface share a common ATM (Asynchronous Transfer Mode) transport which is used for all planes. The physical layer is the interface to the physical medium: optical fibre, radio link or copper cable. The physical layer implementation can be selected from a variety of standard off-the-shelf transmission technologies, such as SONET, STM1, or E1.

5.4.1.1 Iu CS Control Plane Protocol Stack

The Control Plane protocol stack consists of RANAP, on top of Broad Band (BB) SS7 (Signalling System #7) protocols. The applicable layers are the Signalling Connection Control Part (SCCP), the Message Transfer Part (MTP3-b) and SAAL-NNI (Signalling ATM Adaptation Layer for Network to Network Interfaces). SAAL-NNI is further divided into Service Specific Co-ordination Function (SSCF), Service Specific Connection Oriented Protocol

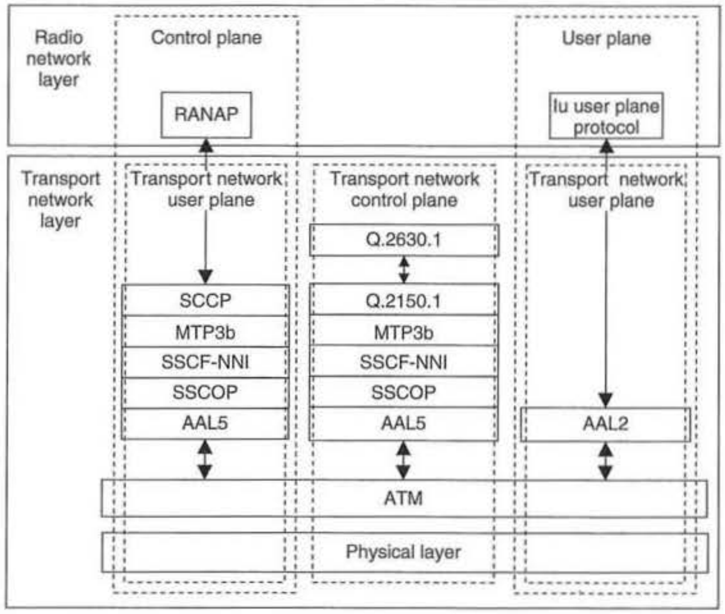

Figure 5.6. Iu CS protocol structure

(SSCOP) and ATM Adaptation Layer 5 (AAL) layers. SSCF and SSCOP layers are specifically designed for signalling transport in ATM networks, and take care of such functions as signalling connection management. AAL5 is used for segmenting the data to ATM cells.

5.4.1.2 Iu CS Transport Network Control Plane Protocol Stack

The Transport Network Control Plane protocol stack consists of the Signalling Protocol for setting up AAL2 connections (Q.2630.1 and adaptation layer Q.2150.1), on top of BB SS7 protocols. The applicable BB SS7 are those described above without the SCCP layer.

5.4.1.3 Iu CS User Plane Protocol Stack

A dedicated AAL2 connection is reserved for each individual CS service. The Iu User Plane Protocol residing directly on top of AAL2 is described in more detail in Section 5.4.4.

5.4.2 Protocol Structure for Iu PS

The Iu PS protocol structure is depicted in Figure 5.7. Again, a common ATM transport is applied for both User and Control Plane. Also the physical layer is as specified for Iu CS.

5.4.2.1 Iu PS Control Plane Protocol Stack

The Control Plane protocol stack again consists of RANAP, and the same BB SS7-based signalling bearer as described in Section 5.4.1.1. Also as an alternative, an IP-based signalling bearer is specified. The SCCP layer is also used commonly for both. The IP-based signalling bearer consists of M3UA (SS7 MTP3—User Adaptation Layer), SCTP (Simple

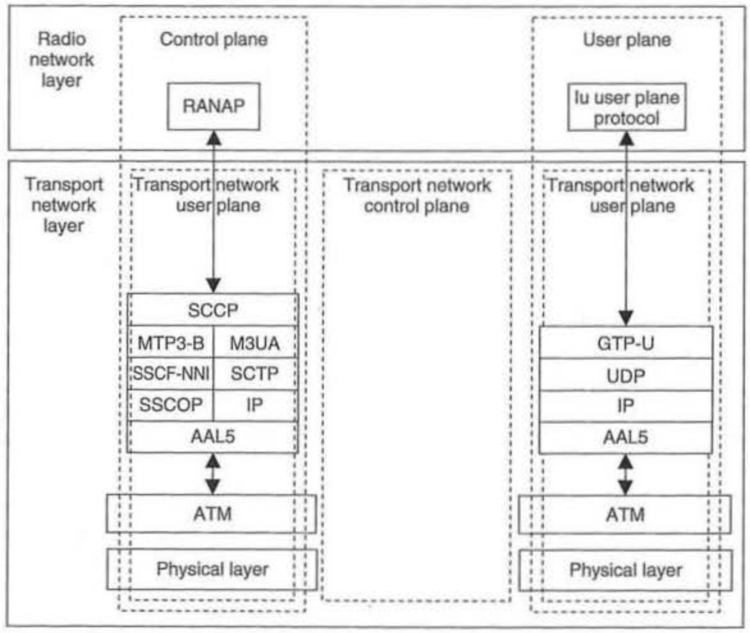

Figure 5.7. Iu PS protocol structure

Control Transmission Protocol), IP (Internet Protocol), and AAL5 which is common to both alternatives. The SCTP layer is specifically designed for signalling transport in the Internet. Specific adaptation layers are specified for different kinds of signalling protocols, such as M3UA for SS7-based signalling.

5.4.2.2 Iu PS Transport Network Control Plane Protocol Stack

The Transport Network Control Plane is not applied to Iu PS. The setting up of the GTP tunnel requires only an identifier for the tunnel, and the IP addresses for both directions, and these are already included in the RANAP RAB Assignment messages. The same information elements that are used in Iu CS for addressing and identifying the AAL2 signalling are used for the User Plane data in Iu CS.

5.4.2.3 Iu PS User Plane Protocol Stack

In the Iu PS User Plane, multiple packet data flows are multiplexed on one or several AAL5 PVCs. The GTP-U (User Plane part of the GPRS Tunnelling Protocol) is the multiplexing layer that provides identities for individual packet data flow. Each flow uses UDP connectionless transport and IP addressing.

5.4.3 RANAP Protocol

RANAP is the signalling protocol in Iu that contains all the control information specified for the Radio Network Layer. The functionality of RANAP is implemented by various RANAP Elementary Procedures. Each RANAP function may require the execution of one or more EPs. Each EP consists of either just the request message (class 2 EP), the request and response message pair (class 1 EP), or one request message and one or more response messages (class 3 EP). The following RANAP functions are defined:

- Relocation. This function handles both SRNS Relocation and Hard Handover, including intersystem case to/from GSM:
  - SRNS Relocation: the serving RNS functionality is relocated from one RNS to another without changing the radio resources and without interrupting the user data flow. The prerequisite for SRNS relocation is that all Radio Links are already in the same DRNC that is the target for the relocation.
  - Inter RNS Hard Handover: used to relocate the serving RNS functionality from one RNS to another and to change the radio resources correspondingly by a hard handover in the Uu interface. The prerequisite for Hard Handover is that the UE is at the border of the source and target cells.
- RAB (Radio Access Bearer) Management. This function combines all RAB handling:
  - RAB Setup, including the possibility for queuing the setup,
  - modification of the characteristics of an existing RAB,
  - clearing an existing RAB, including the RAN-initiated case.
- Iu Release. Releases all resources (Signalling link and U-Plane) from a given instance of Iu related to the specified UE. Also includes the RAN-initiated case.
- Reporting Unsuccessfully Transmitted Data. This function allows the CN to update its charging records with information from UTRAN if part of the data sent was not successfully sent to the UE.
- Common ID management. In this function the permanent identification of the UE is sent from the CN to UTRAN to allow paging coordination from possibly two different CN domains.
- Paging. This is used by CN to page an idle UE for a UE terminating service request, such as a voice call. A paging message is sent from the CN to UTRAN with the UE common identification (permanent Id) and the paging area. UTRAN will either use an existing signalling connection, if one exists, to send the page to the UE or broadcast the paging in the requested area.
- Management of tracing. The CN may, for operation and maintenance purposes, request UTRAN to start recording all activity related to a specific UE–UTRAN connection.
- UE–CN signalling transfer. This functionality provides transparent transfer of UE–CN signalling messages that are not interpreted by UTRAN in three cases:
  - Transfer of the first UE message from UTRAN to UE: this may be, for example, a response to paging, a request of a UE-originated call, or just registration to a new area. It also initiates the signalling connection for the Iu.
  - Direct Transfer: used for carrying all consecutive signalling messages over the Iu signalling connection in both the uplink and downlink directions.

    - CN Information Broadcast: allows the CN to set system information to be broadcast repetitively to all users in a specified area.

- Security Mode Control. This is used to set the ciphering or integrity checking on or off. When ciphering is on, the signalling and user data connections in the radio interface are encrypted with a secret key algorithm. When integrity checking is on, an integrity checksum, further secured with a secret key, is added to some or all of the Radio Interface signalling messages. This ensures that the communication partner has not changed, and the content of the information has not been altered.
- Management of overload. This is used to control the load over the Iu interface against overload due, for example, to processor overload at the CN or UTRAN. A simple mechanism is applied that allows stepwise reduction of the load and its stepwise resumption, triggered by a timer.
- Reset. This is used to reset the CN or the UTRAN side of the Iu interface in error situations. One end of the Iu may indicate to the other end that it is recovering from a restart, and the other end can remove all previously established connections.
- Location Reporting. This functionality allows the CN to receive information on the location of a given UE. It includes two elementary procedures, one for controlling the location reporting in the RNC and the other to send the actual report to the CN.

5.4.4 Iu User Plane Protocol

The Iu User Plane protocol is in the Radio Network Layer of the Iu User Plane. It has been defined so that it would be, as much as possible, independent of the CN domain that it is used for. The purpose of the User Plane protocol is to carry user data related to RABs over the Iu interface. Each RAB has its own instance of the protocol. The protocol performs either a fully transparent operation, or framing for the user data segments and some basic control signalling to be used for initialisation and online control. Based on these cases, the protocol has two modes:

- Transparent Mode. In this mode of operation the protocol does not perform any framing or control. It is applied for RABs that do not require such features but that assume fully transparent operation.
- Support Mode for predefined SDU sizes. In this mode the User Plane performs framing of the user data into segments of predefined size. The SDU sizes typically correspond to AMR (Adaptive Multirate Codec) speech frames, or to the frame sizes derived from the data rate of a CS data call. Also, control procedures for initialisation and rate control are defined, and a functionality is specified for indicating the quality of the frame based, for example, on CRC from the radio interface.

5.5 UTRAN Internal Interfaces

5.5.1 RNC–RNC Interface (Iur Interface) and the RNSAP Signalling

The protocol stack of the RNC to RNC interface (Iur interface) is shown in Figure 5.8.

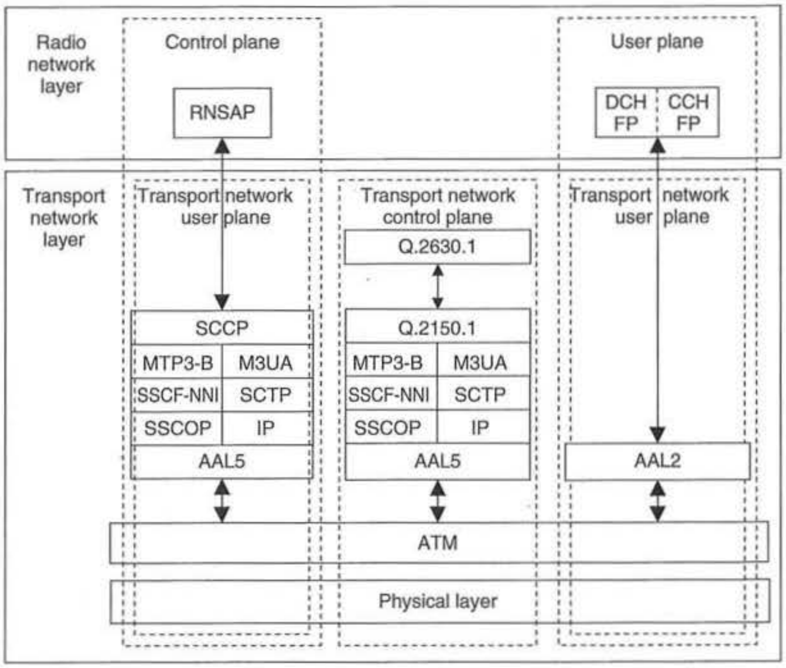

Figure 5.8. Protocol stack of the Iur interface. As for the Iu interface, two options are possible for the transport of the RNSAP signalling: the SS7 stack (SCCP and MTP3b) and the new SCTP/IP based transport. Two User Plane protocols are defined (DCH: dedicated channel; CCH: common channel)

Although this interface was initially designed in order to support the inter-RNC soft handover (shown on the left-hand side of Figure 5.4), more features were added during the development of the standard and now the Iur interface provides four distinct functions:

1. Support of Basic Inter-RNC Mobility
2. Support of Dedicated Channel Traffic
3. Support of Common Channel Traffic
4. Support of Global Resource Management

For this reason the Iur signalling protocol itself (RNSAP, *Radio Network System Application Part*) is divided into four different *modules* (to be intended as groups of procedures). In general, it is possible to implement only part of the four Iur functions between two Radio Network Controllers, according to the operator's need.

5.5.1.1 Iur1: Support of the Basic Inter-RNC Mobility

This functionality requires the *basic* module of RNSAP signalling as described in [25.423]. This first brick for the construction of the Iur interfaces provides by itself the functionality needed for the mobility of the user between the two RNCs, but does not support the exchange of any user data traffic. If this module is not implemented, the Iur interface as such does not exist, and the only way for a user connected to UTRAN via the RNS1 to utilise a cell in RNS2 is to disconnect itself temporarily from UTRAN (release the RRC connection).

> *The functions offered by the Iur basic module include:*
>
> - *Support of SRNC relocation*
> - *Support of inter-RNC cell and UTRAN registration area update*
> - *Support of inter-RNC packet paging*
> - *Reporting of protocol errors*

Since this functionality does not involve user data traffic across Iur, the User Plane and the Transport Network Control Plane protocols are not needed.

5.5.1.2 Iur2: Support of Dedicated Channel Traffic

This functionality requires the *Dedicated Channel* module of RNSAP signalling and allows the dedicated channel traffic between two RNCs. Even if the initial need for this functionality is to support the inter-RNC soft handover state, it also allows the anchoring of the SRNC for all the time the user is utilising dedicated channels (dedicated resources in the Node B), commonly for as long as the user has an active connection to the circuit-switched domain.

This functionality requires also the User Plane *Frame Protocol* for the dedicated channel, plus the Transport Network Control Plane protocol (*Q.2630.1*) used for the setup of the transport connections (AAL2 connections). Each dedicated channel is conveyed over one transport connection, except the coordinated DCH used to obtain unequal error protection in the air interface.

The *Frame Protocol* for dedicated channels, in short DCH FP [25.427], defines the structure of the *data frames* carrying the user data and the *control frames* used to exchange measurements and control information. For this reason, the Frame Protocol specifies also simple messages and procedures. The user data frames are normally routed transparently through the DRNC; thus the Iur frame protocol is used also in Iub and referred to as Iur/Iub DCH FP.

> *The functions offered by the Iur DCH module are:*
>
> - *Establishment, modification and release of the dedicated channel in the DRNC due to hard and soft handover in the dedicated channel state*
> - *Setup and release of dedicated transport connections across the Iur interface*
> - *Transfer of DCH Transport Blocks between SRNC and DRNC*
> - *Management of the radio links in the DRNS, via dedicated measurement report procedures and power setting procedures*

5.5.1.3 Iur3: Support of Common Channel Traffic

This functionality allows the handling of common and shared channel data streams across the Iur interface. It requires the Common Transport Channel module of the RNSAP protocol and the Iur Common Transport Channel Frame Protocol (in short, CCH FP). The Q.2630.1

not exist, and the only way for a user connected to UTRAN via the RNS1 to utilise a cell in RNS2 is to disconnect itself temporarily from UTRAN (release the RRC connection).

The functions offered by the Iur basic module include:

- *Support of SRNC relocation*
- *Support of inter-RNC cell and UTRAN registration area update*
- *Support of inter-RNC packet paging*
- *Reporting of protocol errors*

Since this functionality does not involve user data traffic across Iur, the User Plane and the Transport Network Control Plane protocols are not needed.

5.5.1.2 Iur2: Support of Dedicated Channel Traffic

This functionality requires the *Dedicated Channel* module of RNSAP signalling and allows the dedicated channel traffic between two RNCs. Even if the initial need for this functionality is to support the inter-RNC soft handover state, it also allows the anchoring of the SRNC for all the time the user is utilising dedicated channels (dedicated resources in the Node B), commonly for as long as the user has an active connection to the circuit-switched domain.

This functionality requires also the User Plane *Frame Protocol* for the dedicated channel, plus the Transport Network Control Plane protocol (*Q.2630.1*) used for the setup of the transport connections (AAL2 connections). Each dedicated channel is conveyed over one transport connection, except the coordinated DCH used to obtain unequal error protection in the air interface.

The *Frame Protocol* for dedicated channels, in short DCH FP [25.427], defines the structure of the *data frames* carrying the user data and the *control frames* used to exchange measurements and control information. For this reason, the Frame Protocol specifies also simple messages and procedures. The user data frames are normally routed transparently through the DRNC; thus the Iur frame protocol is used also in Iub and referred to as Iur/Iub DCH FP.

The functions offered by the Iur DCH module are:

- *Establishment, modification and release of the dedicated channel in the DRNC due to hard and soft handover in the dedicated channel state*
- *Setup and release of dedicated transport connections across the Iur interface*
- *Transfer of DCH Transport Blocks between SRNC and DRNC*
- *Management of the radio links in the DRNS, via dedicated measurement report procedures and power setting procedures*

5.5.1.3 Iur3: Support of Common Channel Traffic

This functionality allows the handling of common and shared channel data streams across the Iur interface. It requires the Common Transport Channel module of the RNSAP protocol and the Iur Common Transport Channel Frame Protocol (in short, CCH FP). The Q.2630.1

signalling protocol of the Transport Network Control Plane is also needed if signalled AAL2 connections are used.

If this functionality is not implemented, every inter-RNC cell update always triggers an SRNC relocation, i.e. the serving RNC is always the RNC controlling the cell used for common or shared channel transport.

The identification of the benefits of this feature caused a long debate in the relevant standardisation body. On the one hand, this feature allows the implementation of the total anchor RNC concept, avoiding the complex SRNC relocation procedure (via the CN); on the other hand, it requires the splitting of the Medium Access Control layer functionality into two network elements, generating inefficiency in the utilisation of the resources and complexity in the Iur interface. The debate could not reach an agreement, thus the feature is supported by the standard but is not essential for the operation of the system.

The functions offered by the Iur common transport channel module are:

- *Setup and release of the transport connection across the Iur for common channel data streams*
- *Splitting of the MAC layer between the SRNC (MAC-d) and the DRNC (MAC-c and MAC-sh). The scheduling for DL data transmission is performed in the DRNC*
- *Flow control between the MAC-d and MAC-c/MAC-sh*

5.5.1.4 Iur4: Support of Global Resource Management

This functionality provides signalling to support enhanced radio resource and O&M features across the Iur interface. It is implemented via the *global module* of the RNSAP protocol, and does not require any User Plane protocol, since there is no transmission of user data across the Iur interface. The function is considered optional. This function is not present in the Release'99 UTRAN specification, but it is foreseen to be introduced in subsequent releases for the support of advanced positioning methods and Iur optimisation purposes.

The functions offered by the Iur global resource module are:

- *Transfer of cell measurements between two RNCs*
- *Transfer of Node B timing information between two RNCs*

5.5.2 RNC–Node B Interface and the NBAP Signalling

The protocol stack of the RNC–Node B interface (Iub interface) is shown, with the typical triple plane notation, in Figure 5.9.

In order to understand the structure of the interface, it is necessary to briefly introduce the logical model of the Node B, depicted in Figure 5.10. This consists of a common control port (a common signalling link) and a set of traffic termination points, each controlled by a dedicated control port (dedicated signalling link). One traffic termination point controls a number of mobiles having dedicated resources in the Node B, and the corresponding traffic is conveyed through dedicated data ports. Common data ports outside the traffic termination points are used to convey RACH, FACH and PCH traffic.

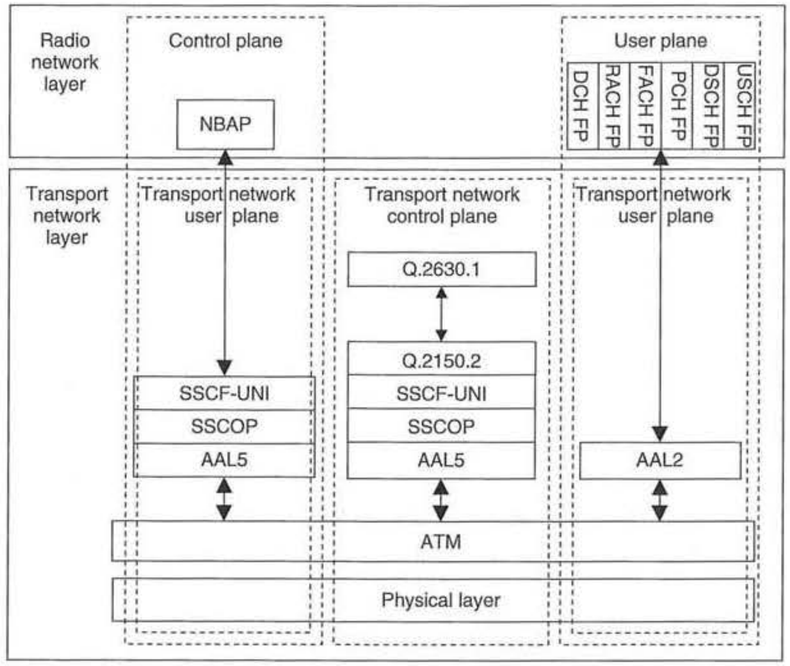

Figure 5.9. Protocol stack of the Iub interface. This is similar to the Iur interface protocol, the main difference being that in the Radio Network and Transport Network Control Planes the SS7 stack is replaced by the simpler SAAL-UNI as signalling bearer. Note also that the SCTP/IP option is not present here

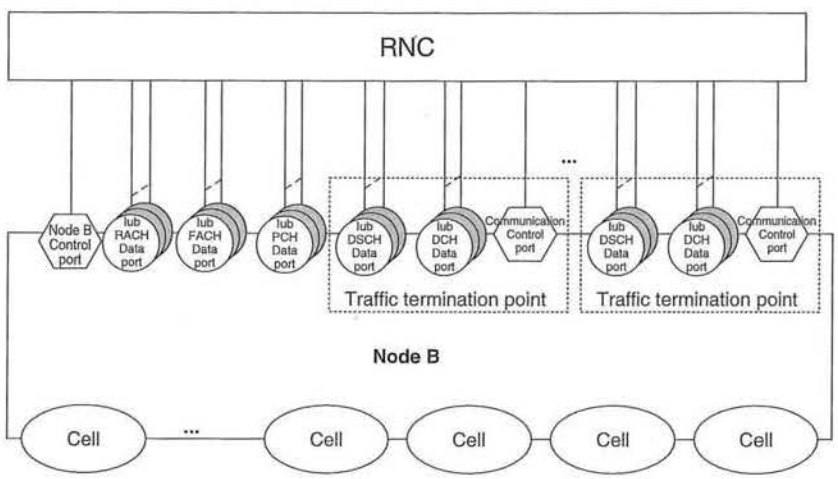

Figure 5.10. Logical model of the Node B for FDD

Note that there is no relation between the traffic termination point and the cells, i.e. one traffic termination point can control more than one cell, and one cell can be controlled by more than one traffic termination point.

The Iub interface signalling (NBAP, *Node B Application Part*) is divided into two essential components: the common NBAP, that defines the signalling procedures across the common signalling link, and the dedicated NBAP, used in the dedicated signalling link.

The User Plane Iub frame protocols define the structures of the frames and the basic in-band control procedures for every type of transport channel (i.e. for every type of data port of the model). The Q.2630.1 signalling is used for the dynamic management of the AAL2 connections used in the User Plane.

5.5.2.1 Common NBAP and the Logical O&M

The common NBAP (C-NBAP) procedures are used for the signalling that is not related to one specific UE context already existing in the Node B. In particular, the C-NBAP defines all the procedures for the logical O&M (Operation and Maintenance) of the Node B, such as configuration and fault management.

The main functions of the Common NBAP are:

- *Setup of the first RL of one UE, and selection of the traffic termination point*
- *Cell configuration*
- *Handling of the RACH/FACH and PCH channels*
- *Initialisation and reporting of Cell or Node B specific measurement*
- *Fault management*

5.5.2.2 Dedicated NBAP

When the RNC requests the first radio link for one UE via the C-NBAP *Radio Link Setup* procedure, the Node B assigns a traffic termination point for the handling of this UE context, and every subsequent signalling related to this mobile is exchanged with dedicated NBAP (D-NBAP) procedures across the dedicated control port of the given Traffic Termination Point.

The main functions of the Dedicated NBAP are:

- *Addition, release and reconfiguration of radio links for one UE context*
- *Handling of dedicated and shared channels*
- *Handling of softer combining*
- *Initialisation and reporting of radio link specific measurement*
- *Radio link fault management*

References

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6

Physical Layer

Antti Toskala

6.1 Introduction

In this chapter the WCDMA (UTRA FDD) physical layer is described. The physical layer of the radio interface has been typically the main discussion topic when different cellular systems have been compared against each other. The physical layer structures naturally relate directly to the achievable performance issues, when observing a single link between a terminal station and a base station. For the overall system performance the protocols in the other layers, such as handover protocols, also have a great deal of impact. Naturally it is essential to have low Signal-to-Interference Ratio (SIR) requirements for sufficient link performance with various coding and diversity solutions in the physical layer, since the physical layer defines the fundamental capacity limits. The performance of the WCDMA physical layer is described in detail in Chapter 11.

The physical layer has a major impact on equipment complexity with respect to the required baseband processing power in the terminal station and base station equipment. As well as the diversity benefits on the performance side, the wideband nature of WCDMA also offers new challenges in its implementation. As third generation systems are wideband from the service point of view as well, the physical layer cannot be designed around only a single service, such as speech; more flexibility is needed for future service introduction. The new requirements of the third generation systems and for the air interface are summarised in Section 1.4. This chapter presents the WCDMA physical layer solutions to meet those requirements.

This chapter uses the term 'terminal' for the user equipment. In 3GPP terminology the terms User Equipment (UE) and Mobile Equipment (ME) are often used, the difference being that UE also covers the Subscriber Identification Module (SIM) as shown in Chapter 5, in which the UTRA network architecture is presented. The term 'base station' is also used throughout this chapter, though in part of the 3GPP specifications the term Node B is used to represent the parts of the base station that contain the relevant parts from the physical layer perspective. The UTRA FDD physical layer specifications are contained in references [1–5].

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This chapter has been divided as follows. First, the transport channels are described together with their mapping to different physical channels in Section 6.2. Spreading and modulation for uplink and downlink are presented in Section 6.3, and the physical channels for user data and control data are described in Sections 6.4 and 6.5. In Section 6.6 the key physical layer procedures, such as power control and handover measurements, are covered.

6.2 Transport Channels and their Mapping to the Physical Channels

In UTRA the data generated at higher layers is carried over the air with transport channels, which are mapped in the physical layer to different physical channels. The physical layer is required to support variable bit rate transport channels to offer bandwidth-on-demand services, and to be able to multiplex several services to one connection. This section presents the mapping of the transport channels to the physical channels, and how those two requirements are taken into account in the mapping.

Each transport channel is accompanied by the Transport Format Indicator (TFI) at each time event at which data is expected to arrive for the specific transport channel from the higher layers. The physical layer combines the TFI information from different transport channels to the Transport Format Combination Indicator (TFCI). The TFCI is transmitted in the physical control channel to inform the receiver which transport channels are active for the current frame; the exception to this is the use of Blind Transport Format Detection (BTFD) that will be covered in connection with the downlink dedicated channels. The TFCI is decoded appropriately in the receiver and the resulting TFI is given to higher layers for each of the transport channels that can be active for the connection. In Figure 6.1 two transport channels are mapped to a single physical channel, and also error indication is

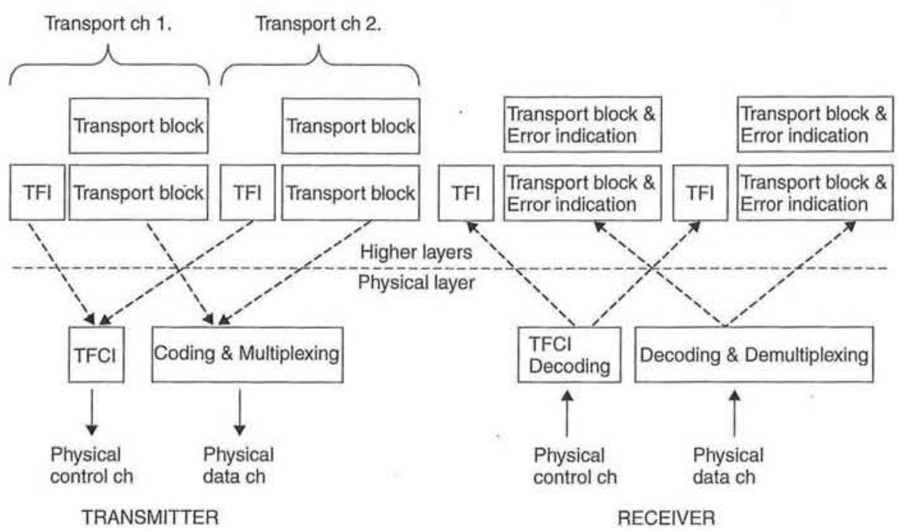

Figure 6.1. The interface between higher layers and the physical layer

provided for each transport block. The transport channels may have a different number of blocks and at any moment not all the transport channels are necessarily active.

One physical control channel and one or more physical data channels form a single Coded Composite Transport Channel (CCTrCh). There can be more than one CCTrCh on a given connection but only one physical layer control channel is transmitted in such a case.

The interface between higher layers and the physical layer is less relevant for terminal implementation, since basically everything takes place within the same equipment, thus the interfacing here is rather a tool for specification work. For the network side the division of functions between physical and higher layers is more important, since there the interface between physical and higher layers is represented by the Iub-interface between the base station and Radio Network Controller (RNC) as described in Chapter 5. In the 3GPP specification the interfacing between physical layer and higher layers is covered in [6].

Two types of transport channels exist: dedicated channels and common channels. The main difference between them is that a common channel is a resource divided between all or a group of users in a cell, whereas a dedicated channel resource, identified by a certain code on a certain frequency, is reserved for a single user only. The transport channels are compared in Section 10.3 for the transmission of packet data.

6.2.1 Dedicated Transport Channel

The only dedicated transport channel is the dedicated channel, for which the term DCH is used in the 25-series of the UTRA specification. The dedicated transport channel carries all the information intended for the given user coming from layers above the physical layer, including data for the actual service as well as higher layer control information. The content of the information carried on the DCH is not visible to the physical layer, thus higher layer control information and user data are treated in the same way. Naturally the physical layer parameters set by UTRAN may vary between control and data.

The familiar GSM channels, the traffic channel (TRCH) or associated control channel (ACCH), do not exist in UTRA physical layer. The dedicated transport channel carries both the service data, such as speech frames, and higher layer control information, such as handover commands or measurement reports from the terminal. In WCDMA a separate transport channel is not needed because of the support of variable bit rate and service multiplexing.

The dedicated transport channel is characterised by features such as fast power control, fast data rate change on a frame-by-frame basis, and the possibility of transmission to a certain part of the cell or sector with varying antenna weights with adaptive antenna systems. The dedicated channel supports soft handover.

6.2.2 Common Transport Channels

There are currently six different common transport channel types defined for UTRA, which are introduced in the following sections. There are a few differences from second generation systems, for example transmission of packet data on the common channels, and a downlink shared channel for transmitting packet data. Common channels do not have soft handover but some of them can have fast power control.

6.2.2.1 Broadcast Channel

The Broadcast Channel (BCH) is a transport channel that is used to transmit information specific to the UTRA network or for a given cell. The most typical data needed in every network is the available random access codes and access slots in the cell, or the types of transmit diversity methods used with other channels for that cell. As the terminal cannot register to the cell without the possibility of decoding the broadcast channel, this channel is needed for transmission with relatively high power in order to reach all the users within the intended coverage area. From a practical viewpoint the information rate on the broadcast channel is limited by the ability of low-end terminals to decode the data rate of the broadcast channel, resulting in a low and fixed data rate for the UTRA broadcast channel.

6.2.2.2 Forward Access Channel

The Forward Access Channel (FACH) is a downlink transport channel that carries control information to terminals known to locate in the given cell. This is so, for example, after a random access message has been received by the base station. It is also possible to transmit packet data on the FACH. There can be more than one FACH in a cell. One of the forward access channels must have such a low bit rate that it can be received by all the terminals in the cell area. When there is more than one FACH, the additional channels can have a higher data rate as well. The FACH does not use fast power control, and the messages transmitted need to include inband identification information to ensure their correct receipt.

6.2.2.3 Paging Channel

The Paging Channel (PCH) is a downlink transport channel that carries data relevant to the paging procedure, that is, when the network wants to initiate communication with the terminal. The simplest example is a speech call to the terminal: the network transmits the paging message to the terminal on the paging channel of those cells belonging to the location area that the terminal is expected to be in. The identical paging message can be transmitted in a single cell or in up to a few hundreds of cells, depending on the system configuration. The terminals must be able to receive the paging information in the whole cell area. The design of the paging channel affects also the terminal's power consumption in the standby mode. The less often the terminal has to tune the receiver in to listen for a possible paging message, the longer will the terminal's battery last in the standby mode.

6.2.2.4 Random Access Channel

The Random Access Channel (RACH) is an uplink transport channel intended to be used to carry control information from the terminal, such as requests to set up a connection. It can also be used to send small amounts of packet data from the terminal to the network. For proper system operation the random access channel must be heard from the whole desired cell coverage area, which also means that practical data rates have to be rather low, at least for the initial system access and other control procedures. The coverage of the random access channel compared to the dedicated channel is presented in Section 11.2.2.

6.2.2.5 Uplink Common Packet Channel

The uplink common packet channel (CPCH) is an extension to the RACH channel that is intended to carry packet-based user data in the uplink direction. The pair providing the data in the downlink direction is the FACH. In the physical layer, the main differences from the RACH are the use of fast power control, a physical layer-based collision detection mechanism and a CPCH status monitoring procedure. The uplink CPCH transmission may last several frames in contrast with one or two frames for the RACH message.

6.2.2.6 Downlink Shared Channel

The downlink shared channel (DSCH) is a transport channel intended to carry dedicated user data and/or control information; it can be shared by several users. In many respects it is similar to the forward access channel, but the shared channel supports the use of fast power control as well as variable bit rate on a frame-by-frame basis. The DSCH does not need to be heard in the whole cell area and can employ the different modes of transmit antenna diversity methods that are used with the associated downlink DCH. The downlink shared channel is always associated with a downlink DCH.

6.2.2.7 Required Transport Channels

The common transport channels needed for the basic network operation are RACH, FACH and PCH, while the use of DSCH and CPCH is optional and can be decided by the network.

6.2.3 Mapping of Transport Channels onto the Physical Channels

The way different transport channels are mapped to different physical channels is shown in Figure 6.2, though some of the transport channels are carried by identical (or even the same) physical channel.

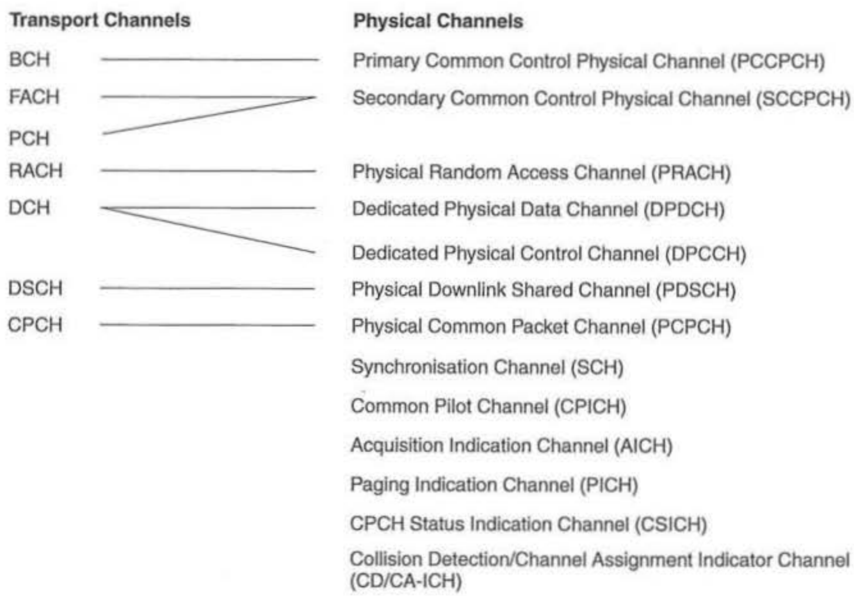

Figure 6.2. Transport-channel to physical-channel mapping

In addition to the transport channels introduced earlier, there exist physical channels to carry only information relevant to physical layer procedures. The Synchronisation Channel (SCH), the Common Pilot Channel (CPICH) and the Acquisition Indication Channel (AICH) are not directly visible to higher layers and are mandatory from the system function point of view, to be transmitted from every base station. The CPCH Status Indication Channel (CSICH) and the Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH) are needed if CPCH is used.

The dedicated channel (DCH) is mapped onto two physical channels. The Dedicated Physical Data Channel (DPDCH) carries higher layer information, including user data, while the Dedicated Physical Control Channel (DPCCH) carries the necessary physical layer control information. These two dedicated physical channels are needed to support efficiently the variable bit rate in the physical layer. The bit rate of DPCCH is constant, while the bit rate of DPDCH can change from frame to frame.

6.2.4 Frame Structure of Transport Channels

The UTRA channels use the 10 ms radio frame structure. The longer period used is the system frame period. The System Frame Number (SFN) is a 12-bit number used by several procedures that span more than a single frame. Physical layer procedures, such as the paging procedure or random access procedure, are examples of procedures that need a longer period than 10 ms for correct definition.

6.3 Spreading and Modulation

6.3.1 Scrambling

The concept of spreading the information in a CDMA system is introduced in Chapter 3. In addition to spreading, part of the process in the transmitter is the scrambling operation. This is needed to separate terminals or base stations from each other. Scrambling is used on top of spreading, so it does not change the signal bandwidth but only makes the signals from different sources separable from each other. With the scrambling, it would not matter if the actual spreading were done with identical code for several transmitters. Figure 6.3 shows the relation of the chip rate in the channel to spreading and scrambling in UTRA. As the chip rate is already achieved in the spreading by the channelisation codes, the symbol rate is not affected by the scrambling. The concept of channelisation codes is covered in the following section.

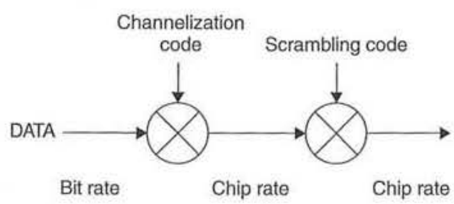

Figure 6.3. Relation between spreading and scrambling

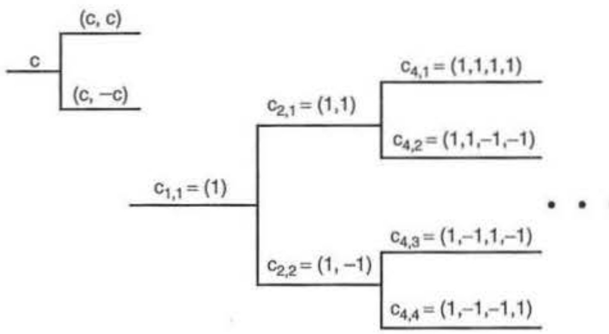

Figure 6.4. Beginning of the channelisation code tree

6.3.2 *Channelisation Codes*

Transmissions from a single source are separated by channelisation codes, i.e. downlink connections within one sector and the dedicated physical channel in the uplink from one terminal. The spreading/channelisation codes of UTRA are based on the Orthogonal Variable Spreading Factor (OVSF) technique, which was originally proposed in [7].

The use of OVSF codes allows the spreading factor to be changed and orthogonality between different spreading codes of different lengths to be maintained. The codes are picked from the code tree, which is illustrated in Figure 6.4. In case the connection uses a variable spreading factor, the proper use of the code tree also allows despreading according to the smallest spreading factor. This requires only that channelisation codes are used from the branch indicated by the code used for the smallest spreading factor.

There are certain restrictions as to which of the channelisation codes can be used for a transmission from a single source. Another physical channel may use a certain code in the tree if no other physical channel to be transmitted using the same code tree is using a code that is on an underlying branch, i.e. using a higher spreading factor code generated from the intended spreading code to be used. Neither can a smaller spreading factor code on the path to the root of the tree be used. The downlink orthogonal codes within each base station are managed by the radio network controller (RNC) in the network.

The functionality and characteristics of the scrambling and channelisation codes are summarised in Table 6.1. Their usage will be described in more detail in Section 6.3.3.

The definition for the same code tree means that for transmission from a single source, from either a terminal or a base station, one code tree is used with one scrambling code on top of the tree. This means that different terminals and different base stations may operate their code trees totally independently of each other; there is no need to coordinate the code tree resource usage between different base stations or terminals.

6.3.3 *Uplink Spreading and Modulation*

6.3.3.1 Uplink Modulation

In the uplink direction there are basically two additional terminal-oriented criteria that need to be taken into account in the definition of the modulation and spreading methods. The

Table 6.1. Functionality of the channelisation and scrambling codes

	Channelisation code	Scrambling code
Usage	Uplink: Separation of physical data (DPDCH) and control channels (DPCCH) from same terminal Downlink: Separation of downlink connections to different users within one cell	Uplink: Separation of terminal Downlink: Separation of sectors (cells)
Length	4–256 chips (1.0–66.7 µs) Downlink also 512 chips	Uplink: (1) 10 ms = 38400 chips or (2) 66.7µs = 256 chips Option (2) can be used with advanced base station receivers Downlink: 10 ms = 38400 chips
Number of codes	Number of codes under one scrambling code = spreading factor	Uplink: Several millions Downlink: 512
Code family	Orthogonal Variable Spreading Factor	Long 10 ms code: Gold code Short code: Extended S(2) code family
Spreading	Yes, increases transmission bandwidth	No, does not affect transmission bandwidth

uplink modulation should be designed so that the terminal amplifier efficiency is maximised and/or the audible interference from the terminal transmission is minimised.

Discontinuous uplink transmission can cause audible interference to audio equipment that is very close to the terminal, such as hearing aids. This is a completely separate issue from the interference in the air interface. The audible interference is only a nuisance for the user and does not affect network performance, such as its capacity. With GSM operation we are familiar with the occasional audible interference with audio equipment that is not properly protected. The interference from GSM has a frequency of 217 Hz, which is determined by the GSM frame frequency. This interference falls into the band that can be heard by the human ear. With a CDMA system, the same issues arise when discontinuous uplink transmission is used, for example with a speech service. During the silent periods no information bits need to be transmitted, only the information for link maintenance purposes, such as power control with a 1.5 kHz command rate. With such a rate the transmission of the pilot and the power control symbols with time multiplexing in the uplink direction would cause audible interference in the middle of the telephony voice frequency band. Therefore, in a WCDMA uplink the two dedicated physical channels are not time multiplexed but I-Q/code multiplexing is used.

The continuous transmission achieved with an I-Q/code multiplexed control channel is shown in Figure 6.5. Now, as the pilot and the power control signalling are maintained on a separate continuous channel, no pulsed transmission occurs. The only pulse occurs when the data channel DPDCH is switched on and off, but such switching happens quite seldom.

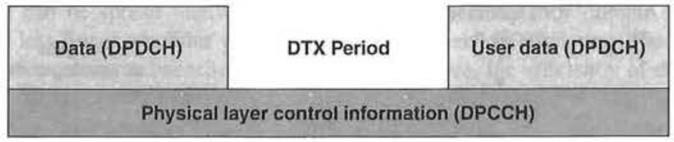

Figure 6.5. Parallel transmission of DPDCH and DPCCH when data is present/absent (DTX)

The average interference to other users and the cellular capacity remain the same as in the time-multiplexed solution. In addition, the link level performance is the same in both schemes if the energy allocated to the pilot and the power control signalling is the same.

For the best possible power amplifier efficiency, the terminal transmission should have as low peak-to-average (PAR) ratio as possible to allow the terminal to operate with a minimal amplifier back-off requirement, mapping directly to the amplifier power conversion efficiency, which in turn is directly proportional to the terminal talk time. With the I-Q/code multiplexing, called also dual-channel QPSK modulation, the power levels of the DPDCH and DPCCH are typically different, especially as data rates increase and would lead in extreme cases to BPSK-type transmission when transmitting the branches independently. This has been avoided by using a complex-valued scrambling operation after the spreading with channelisation codes.

The signal constellation of the I-Q/code multiplexing before complex scrambling is shown in Figure 6.6. The same constellation is obtained after descrambling in the receiver for the data detection.

The transmission of two parallel channels, DPDCH and DPCCH, leads to multicode transmission, which increases the peak-to-average power ratio (crest factor). In Figure 6.6 the peak-to-average ratio changes when G (the relative strengths of the DPDCH and DPCCH) is changed. By using the spreading modulation solution shown in Figure 6.7 the transmitter power amplifier efficiency remains the same as for normal balanced QPSK transmission in general. The complex scrambling codes are formed in such a way that the rotations between consecutive chips within one symbol period are limited to $\pm 90°$. The full 180° rotation can happen only between consecutive symbols. This method further reduces the peak-to-average ratio of the transmitted signal from the normal QPSK transmission.

The efficiency of the power amplifier remains constant irrespective of the power difference G between DPDCH and DPCCH. This can be explained with Figure 6.8, which shows

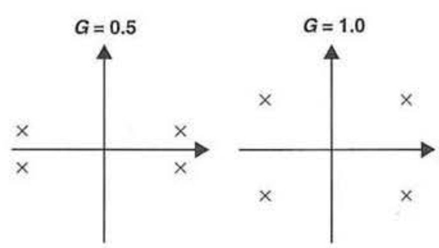

Figure 6.6. Constellation of I-Q/code multiplexing before complex scrambling. G denotes the relative gain factor between DPCCH and DPDCH branches

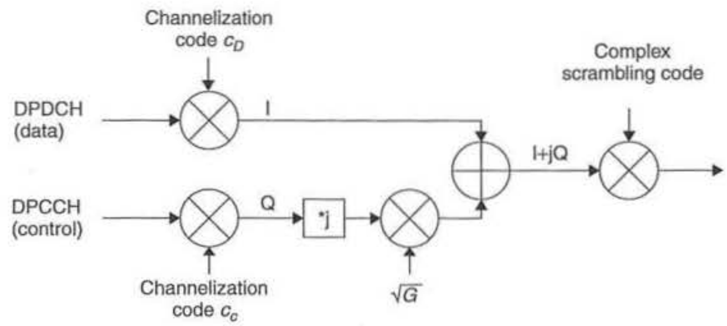

Figure 6.7. I-Q/code multiplexing with complex scrambling

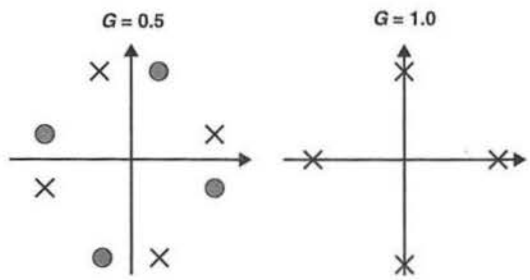

Figure 6.8. Signal constellation for I-Q/code multiplexed control channel with complex scrambling. G denotes the power difference between DPCCH and DPDCH

the signal constellation for the I-Q/code multiplexed control channel with complex spreading. In the middle constellation with $G = 0.5$ the possible constellation points are only circles or only crosses during one symbol period. Their constellation is the same as for the rotated QPSK. Thus the signal envelope variations with complex spreading are very similar to QPSK transmission for all values of G . The I-Q/code multiplexing solution with complex scrambling results in power amplifier output back-off requirements that remain constant as a function of the power difference between DPDCH and DPCCH.

The power difference between DPDCH and DPCCH has been quantified in the UTRA physical layer specifications to 4-bit words, i.e. 16 different values. At a given point in time the gain value for either DPDCH or DPCCH is set to 1 and then for the other channel a value between 0 and 1 is applied to reflect the desired power difference between the channels. Limiting the number of possible values to 4-bit representation is necessary to make the terminal transmitter implementation simple. The power differences can have 15 different values between −23.5 dB and 0.0 dB and one bit combination for no DPDCH when there is no data to be transmitted.

UTRA will face challenges in amplifier efficiency when compared to GSM. The GSM modulation is GMSK (Gaussian Minimum Shift Keying) which has a constant envelope and is thus optimised for amplifier peak-to-average ratio. As a narrowband system, the de

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GSM signal can be spread relatively more widely in the frequency domain. This allows the use of a less linear amplifier with better power conversion efficiency. The narrowband amplifier is also easier to linearise if necessary. In practice, the efficiency of the WCDMA power amplifier is slightly lower than that of the GSM power amplifier. On the other hand, WCDMA uses fast power control in uplink, which reduces the average required uplink transmission power.

Instead of applying combined I-Q and code multiplexing with complex scrambling, it would be possible to use pure code multiplexing. With code multiplexing, multicode transmission occurs with parallel control and data channels. This approach increases transmitted signal envelope variations and sets higher requirements for power amplifier linearity. Especially for low bit rates, as for speech, the control channel can have an amplitude more than 50% that of the data channel, which causes more envelope variations than the combined I-Q/code multiplexing solution.

6.3.3.2 Uplink Spreading

For the uplink DPCCH spreading code, there is an additional restriction. The same code cannot be used by any another code channel even on a different I or Q branch. The reason for this restriction is that physical channels transmitted with the same channelisation codes on I and Q branches with the dual channel QPSK principle cannot be separated before the DPCCH has been detected and channel phase estimates are available.

In the uplink direction the spreading factor on the DPDCH may vary on a frame-by-frame basis. The spreading codes are always taken from the earlier described code tree. When the channelisation code used for spreading is always taken from the same branch of the code tree, the despreading operation can take advantage of the code tree structure and avoid chip-level buffering. The terminal provides data rate information, or more precisely the Transport Format Combination Indicator (TFCI), on the DPCCH, to allow data detection with a variable spreading factor on the DPDCH.

6.3.3.3 Uplink Scrambling Codes

The transmissions from different sources are separated by the scrambling codes. In the uplink direction there are two alternatives: short and long scrambling codes. The long codes with 25 degree generator polynomials are truncated to the 10 ms frame length, resulting in 38400 chips with 3.84 Mcps. The short scrambling code length is 256 chips. The long scrambling codes are used if the base station uses a Rake receiver. The Rake receiver is described in Section 3.4. If advanced multiuser detectors or interference cancellation receivers are used in the base station, short scrambling codes can be used to make the implementation of the advanced receiver structures easier. The base station multiuser detection algorithms are introduced in Section 11.5.2. Both of the two scrambling code families contain millions of scrambling codes, thus in the uplink direction the code planning is not needed.

The short scrambling codes have been chosen from the extended S(2) code family. The long codes are Gold codes. The complex-valued scrambling sequence is formed in the case of short codes by combining two codes, and in the case of long codes from a single sequence where the other sequence is the delayed version of the first one.

The complex-valued scrambling code can be formed from two real-valued codes c_1 and c_2 with the decimation principle as:

$$c_{\text{scrambling}} = c_1(w_0 + jc_2(2k)w_1),\ k = 0, 1, 2 \ldots \qquad (6.1)$$

with sequences w_0 and w_1 given as chip rate sequences:

$$w_0 = \{1 \quad 1\}, w_1 = \{1 \quad -1\} \tag{6.2}$$

The decimation factor with the second code is 2. This way of creating the scrambling codes will reduce the zero crossings in the constellation and will further reduce the amplitude variations in the modulation process.

6.3.3.4 Spreading and Modulation on Uplink Common Channels

The Random Access Channel (RACH) contains preambles that are sent using the same scrambling code sequence as with the uplink transmission, the difference being that only 4096 chips from the beginning of the code period are needed and the modulation state transitions are limited in a different way. The spreading and scrambling process on the RACH is BPSK-valued, thus only one sequence is used to spread and scramble both the in-phase and quadrature branches. This has been chosen to reduce the complexity of the required matched filter in the base station receivers for the RACH reception.

The RACH message part spreading and modulation, including scrambling, is identical to that for the dedicated channel. The codes available for RACH scrambling use are transmitted on the BCH of each cell.

For the peak-to-average reduction, an additional rotation function is used on the RACH preamble, given as:

$$b(k) = a(k)e^{j\left(\frac{\pi}{4}+\frac{\pi}{2}\right)}, k = 0, 1, 2, \ldots, 4095 \tag{6.3}$$

where $a(k)$ is the binary preamble and $b(k)$ is the resulting complex-valued preamble with limited 90° phase transition between chips. The autocorrelation properties are not affected by this operation.

The RACH preambles have a modulation pattern on top of them, called signature sequences. These have been defined by taking the higher Doppler frequencies as well as frequency errors into account. The sequences have been generated from 16 symbols, which have additionally been interleaved over the preamble duration to avoid large inter-sequence cross-correlations in case of large frequency errors that could otherwise severely degrade the cross-correlation properties between the signature sequences. The 16 signature sequences have been specified for RACH use, but there can be multiple scrambling codes each using the same set of signatures.

The CPCH spreading and modulation are identical to those of the RACH in order to maximise the commonality for both terminal and base station implementation when supporting CPCH. RACH and CPCH processes will be described in more detail in connection with the physical layer procedures.

6.3.4 Downlink Spreading and Modulation

6.3.4.1 Downlink Modulation

In the downlink direction normal QPSK modulation has been chosen with time-multiplexed control and data streams. The time-multiplexed solution is not used in the uplink because it would generate audible interference during discontinuous transmission. The audible interference generated with DTX is not a relevant issue in the downlink since the common channels have continuous transmission in any case. Also, as there exist several parallel code transmissions in the downlink, similar optimisation for peak-to-average (PAR) ratio as with single code (pair) transmission is not relevant. Also, reserving a channelisation code just for DPCCH purposes results in slightly worse code resource utilisation when sending several transmissions from a single source.

Since the I and Q branches have equal power, the scrambling operation does not provide a similar difference to the envelope variations as in the uplink. The discontinuous transmission is implemented by gating the transmission on and off.

6.3.4.2 Downlink Spreading

The spreading in the downlink is based on the channelisation codes, as in the uplink. The code tree under a single scrambling code is shared by several users; typically only one scrambling code and thus only one code tree is used per sector in the base station. The common channels and dedicated channels share the same code tree resource. There is one exception for the physical channels: the synchronisation channel (SCH), which is not under a downlink scrambling code. The SCH spreading codes are covered in a later section.

In the downlink, the dedicated channel spreading factor does not vary on a frame-by-frame basis; the data rate variation is taken care of with either a rate matching operation or with discontinuous transmission, where the transmission is off during part of the slot.

In the case of multicode transmission for a single user, the parallel code channels have different channelisation codes and are under the same scrambling code as normally are all the code channels transmitted from the base station. The spreading factor is the same for all the codes with multicode transmission. Each coded composite transport channel (CCTrCh) may have different spreading factor even if received by the same terminal.

The special case in the downlink direction is the downlink shared channel (DSCH) which may use a variable spreading factor on a frame-by-frame basis. In this case the channelisation codes taking care of the spreading are allocated from the same branch of the code tree to ease the terminal implementation. The restriction specified is illustrated in Figure 6.9 which shows the spreading factor for maximum data rate and the part of the code tree that may be used by the network to allocate codes when the lower data rate is needed. In such a frame-by-frame operation the DPCCH of the dedicated channel contains the TFCI information,

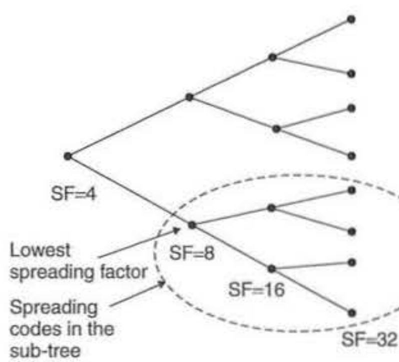

Figure 6.9. DSCH code tree example

which informs the receiver of the spreading code used, as well as other transport format parameters for the DSCH.

6.3.4.3 Downlink Scrambling

The downlink scrambling uses long codes, the same Gold codes as in the uplink. The complex-valued scrambling code is formed from a single code by simply having a delay between the I and Q branches. The code period is truncated to 10 ms; no short codes are used in the downlink direction. The downlink set of the (primary) scrambling codes is limited to 512 codes, otherwise the cell search procedure described in the physical layer procedures section would become too excessive. The scrambling codes must be allocated to the sectors in the network planning. Because the number of scrambling codes is so high, the scrambling code planning is a trivial task and can be done automatically by the network planning tool. The 512 primary scrambling codes are expected to be enough from the cell planning perspective, especially as the secondary scrambling codes can be used in the case of beam steering as used on dedicated channels. This allows the capacity to evolve with adaptive antenna techniques without consuming extra primary scrambling codes and causing problems for downlink code planning.

The actual code period is very long with the 18-degree code generator, but only 38400 chips are used from the beginning. Limiting the code period was necessary from the system perspective; the terminals would have difficulty in finding the correct code phase with a code period spanning several frames and 512 different codes to choose from.

The secondary downlink scrambling codes can be applied with the exception of those common channels that need to be heard in the whole cell and/or prior to the initial registration. Only one scrambling code should be used per cell or sector to maintain the orthogonality between different downlink code channels. With adaptive antennas the beams provide additional spatial isolation and the orthogonality between different code channels is less important. However, in all cases the best strategy is still to keep as many users as possible under a single scrambling code to minimise downlink interference. If a secondary scrambling code needs to be introduced in the cell, then only those users not fitting under the primary scrambling code should use the secondary code. The orthogonality is degraded most if the users are shared evenly between two different scrambling codes.

6.3.4.4 Synchronisation Channel Spreading and Modulation

The downlink synchronisation channel (SCH) is a special type of physical channel that is not visible above the physical layer. It contains two channels, primary and secondary SCHs. These channels are utilised by the terminal to find the cells, and are not under the cell-specific primary scrambling code. The terminal must be able to synchronise to the cell before knowing the downlink scrambling code.

The primary SCH contains a code word with 256 chips, with an identical code word in every cell. The primary SCH code word is sent without modulation on top. The code word is constructed from shorter 16-chip sequences in order to optimise the required hardware at the terminal. When detecting this sequence there is normally no prior timing information available and typically a matched filter is needed for detection. Therefore, for terminal complexity and power consumption reasons, it was important to optimise this synchronisation sequence for low-complexity matched filter implementation.

The secondary SCH code words are similar sequences but vary from one base station to another, with a total of 16 sequences in use. These 16 sequences are used to generate a total of 64 different code words which identify to which of the 64 code groups a base station belongs. Like the primary SCH, the secondary SCH is not under the base station-specific scrambling code, but the code sequences are sent without scrambling on top. The SCH code words contain modulation to indicate the use of open loop transmit diversity on the BCH. The SCH itself can use time-switched transmit antenna diversity (TSTD) and is the only channel in UTRA FDD that uses TSTD.

6.3.5 *Transmitter Characteristics*

The pulse shaping method applied to the transmitted symbols is root-raised cosine filtering with a roll-off factor of 0.22. The same roll-off is valid for both the terminals and the base stations. There are a few other key RF parameters that are introduced here and that have an essential impact on the implementation as well as on system behaviour.

The nominal carrier spacing in WCDMA is 5 MHz but the carrier frequency in WCDMA can be adjusted with a 200 kHz raster. The central frequency of each WCDMA carrier is indicated with an accuracy of 200 kHz. The target of this adjustment is to provide more flexibility for channel spacing within the operator's band.

The Adjacent Channel Leakage Ratio (ACLR) determines how much of the transmitted power is allowed to leak into the first or second neighbouring carrier. The concept of ACLR is illustrated in Figure 6.10, where $ACLR_1$ and $ACLR_2$ correspond to the power level integrated over the first and second adjacent carriers with 5 MHz and 10 MHz carrier separation respectively. No separate values are specified for other values of carrier spacing.

On the terminal side the ACLR values for the power classes of 21 dBm and 24 dBm have been set to 33 dB and 43 dB for $ACLR_1$ and $ACLR_2$ respectively. On the base station side the corresponding values are 45 dB and 50 dB. In the first phase of network deployment it is also likely that most terminals will belong to the 21 dBm power class and the network needs to be planned accordingly.

The higher the ACLR requirement, the more linearity is required from the power amplifier and the lower is the efficiency of the amplifier. The terminal needs to have a value that allows a power-efficient amplifier. The impact of the ACLR on system performance is studied in Section 8.5.

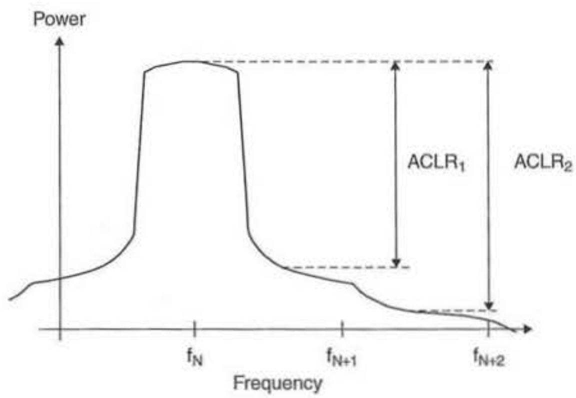

Figure 6.10. Adjacent Channel Leakage Ratio for the first and second adjacent carriers

The frequency accuracy requirements are also directly related to the implementation cost, especially on the terminal side. The terminal frequency accuracy has been defined to be ±0.1 ppm when compared to the received carrier frequency. On the base station side the requirement is tighter: ±0.05 ppm. The baseband timing is tight to the same timing reference as RF. The base station value needs to be tighter than the terminal value, since the base station carrier frequency is the reference for the terminal accuracy. The terminal needs also to be able to search the total frequency uncertainty area caused by the base station frequency error tolerance on top of the terminal tolerances and the error caused by terminal movement. With the 200 kHz carrier raster the looser base station frequency accuracy would start to cause problems. In 3GPP the RF parameters for terminals are specified in [8] and for base stations in [9].

6.4 User Data Transmission

For user data transmission in second generation systems, such as the first versions of GSM, typically only one service has been active at a time, either voice or low-rate data. From the beginning, the technology base has required that the physical layer implementation be defined to the last detail without real flexibility. For example, puncturing patterns in GSM have been defined bit by bit, whereas such a definition for all possible service combinations and data rates is simply not possible for UTRA. Instead, algorithms for generating such patterns are defined. Signal processing technology has also evolved greatly, thus there is no longer a need to have items like puncturing on hardware as in the early days of GSM hardware development.

6.4.1 Uplink Dedicated Channel

As described earlier, the uplink direction uses I-Q/code multiplexing for user data and physical layer control information. The physical layer control information is carried by the Dedicated Physical Control Channel (DPCCH) with a fixed spreading factor of 256. The higher layer information, including user data, is carried on one or more Dedicated Physical Data Channels (DPDCHs), with a possible spreading factor ranging from 256 down to 4. The uplink transmission may consist of one or more Dedicated Physical Data Channels (DPDCH) with a variable spreading factor, and a single Dedicated Physical Control Channel (DPCCH) with a fixed spreading factor.

The DPDCH data rate may vary on a frame-by-frame basis. Typically with a variable rate service the DPDCH data rate is informed on the DPCCH. The DPCCH is transmitted continuously and rate information is sent with Transport Format Combination Indicator (TFCI), the DPCCH information on the data rate on the current DPDCH frame. If the TFCI is not decoded correctly, the whole data frame is lost. Because the TFCI indicates the transport format of the same frame, the loss of the TFCI does not affect any other frames. The reliability of the TFCI is higher than the reliability of the user data detection on the DPDCH. Therefore, the loss of the TFCI is a rare event. Figure 6.11 illustrates the uplink dedicated channel structure in more detail.

The uplink DPCCH uses a slot structure with 15 slots over the 10 ms radio frame. This results in a slot duration of 2560 chips or about 666 μs. This is actually rather close to the GSM burst duration of 577 μs. Each slot has four fields to be used for pilot bits, TFCI,

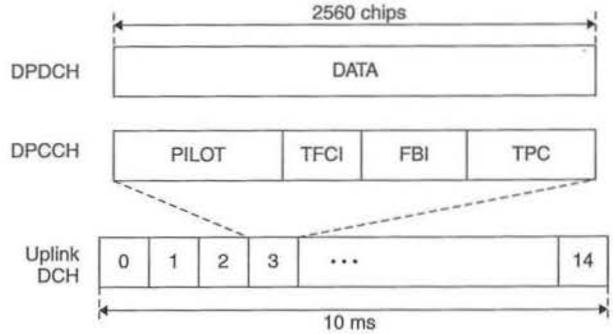

Figure 6.11. Uplink dedicated channel structure

Transmission Power Control (TPC) bits and Feedback Information (FBI) bits. The pilot bits are used for the channel estimation in the receiver, and the TPC bits carry the power control commands for the downlink power control. The FBI bits are used when closed loop transmission diversity is used in the downlink. The use of FBI bits is covered in the physical layer procedures section. There exist a total of six slot structures for uplink DPCCH. The different options are 0,1 or 2 bits for FBI bits and these same alternatives with and without TFCI bits. The TPC and pilot bits are always present and their number varies in such a way that the DPCCH slot is always fully used.

It is beneficial to transmit with a single DPDCH for as long as possible, for reasons of terminal amplifier efficiency, because multicode transmission increases the peak-to-average ratio of the transmission, which reduces the efficiency of the terminal power amplifier. The maximum user data rate on a single code is derived from the maximum channel bit rate, which is 960 kbps without channel coding with spreading factor 4. With channel coding the practical maximum user data rate for the single code case is in the order of 400–500 kbps.

When higher data rates are needed, parallel code channels are used. This allows up to six parallel codes to be used, raising the channel bit rate for data transmission up to 5740 kbps, which can accommodate 2 Mbps user data or an even higher data rate if the coding rate is $\frac{1}{2}$. Therefore, it is possible to offer a user data rate of 2 Mbps even after retransmission. The achievable data rates with different spreading factors are presented in Table 6.2. The rates given assume $\frac{1}{2}$-rate coding and do not include bits taken for coder tail bits or the Cyclic Redundancy Check (CRC). The relative overhead due to tail bits and CRC bits has significance only with low data rates.

The uplink receiver in the base station needs to perform typically the following tasks when receiving the transmission from a terminal:

- The receiver starts receiving the frame and despreading the DPCCH and buffering the DPDCH according to the maximum bit rate, corresponding to the smallest spreading factor.
- For every slot
  - — obtain the channel estimates from the pilot bits on the DPCCH
  - — estimate the SIR from the pilot bits for each slot

Table 6.2. Uplink DPDCH data rates

DPDCH spreading factor	DPDCH channel bit rate (kbps)	Maximum user data rate with $\frac{1}{2}$-rate coding (approx.)
256	15	7.5 kbps
128	30	15 kbps
64	60	30 kbps
32	120	60 kbps
16	240	120 kbps
8	480	240 kbps
4	960	480 kbps
4,with 6 parallel codes	5740	2.3 Mbps

  - send the TPC command in the downlink direction to the terminal to control its uplink transmission power
  - decode the TPC bit in each slot and adjust the downlink power of that connection accordingly.
- For every second or fourth slot
  - decode the FBI bits, if present, over two or four slots and adjust the diversity antenna phases, or phases and amplitudes, depending on the transmission diversity mode.
- For every 10 ms frame
  - decode the TFCI information from the DPCCH frame to obtain the bit rate and channel decoding parameters for DPDCH.
- For Transmission Time Interval (TTI, interleaving period) of 10, 20, 40 or 80 ms
  - decode the DPDCH data.

The same functions are valid for the downlink as well, with the following exceptions:

- In the downlink the dedicated channel spreading factor is constant, as well as with the common channels. The only exception is the Downlink Shared Channel (DSCH) which also has a varying spreading factor.
- The FBI bits are not in use in the downlink direction.
- There is a common pilot channel available in addition to the pilot bits on DPCCH. The common pilot can be used to aid the channel estimation.
- In the downlink transmission may occur from two antennas in the case of transmission diversity. The receiver does the channel estimation from the pilot patterns sent from two antennas and consequently accommodates the despread data sent from two different antennas. The overall impact on the complexity is small, however.

6.4.2 Uplink Multiplexing

In the uplink direction the services are multiplexed dynamically so that the data stream is continuous with the exception of zero rate. The symbols on the DPDCH are sent with equal power level for all services. This means in practice that the service coding and channel multiplexing needs in some cases to adjust the relative symbol rates for different services in order to balance the power level requirements for the channel symbols. The rate matching function in the multiplexing chain in Figure 6.12 can be used for such quality balancing

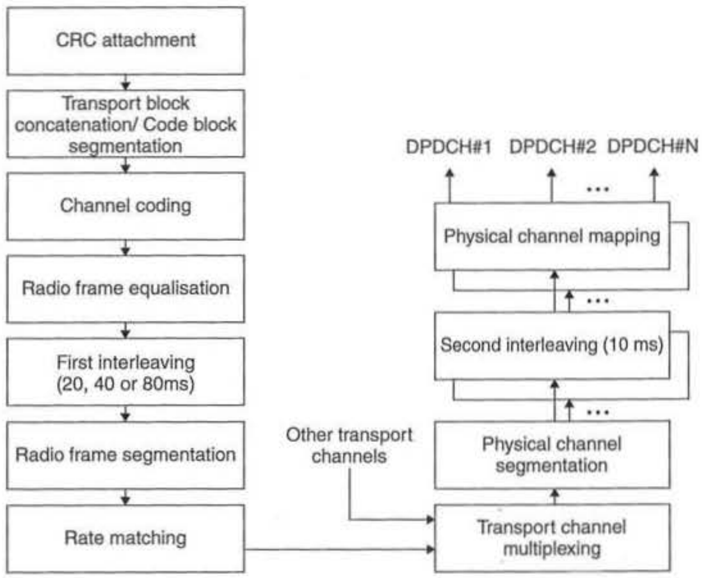

Figure 6.12. Uplink multiplexing and channel coding chain

operations between services on a single DPDCH. For the uplink DPDCH there do not exist fixed positions for different services, but the frame is filled according to the outcome of the rate matching and interleaving operation(s). The uplink multiplexing is done in 11 steps, as illustrated in Figure 6.12.

After receiving a transport block from higher layers, the first operation is CRC attachment. The CRC (Cyclic Redundancy Check) is used for error checking of the transport blocks at the receiving end. The CRC length that can be inserted has four different values: 0,8, 12 16 and 24 bits. The more bits the CRC contains, the lower is the probability of an undetected error in the transport block in the receiver. The physical layer provides the transport block to higher layers together with the error indication from the CRC check.

After the CRC attachment, the transport blocks are either concatenated together or segmented to different coding blocks. This depends on whether the transport block fits the available code block size as defined for the channel coding method. The benefit of the concatenation is better performance in terms of lower overhead due to encoder tail bits and in some cases due to better channel coding performance because of the larger block size. On the other hand, code block segmentation allows the avoidance of excessively large code blocks that could also be a complexity issue. If the transport block with CRC attached does not fit into the maximum available code block, it will be divided into several code blocks.

The channel encoding is performed on the coding blocks after the concatenation or segmentation operation. For some service or bit classes no channel coding is applied. This is so, for example, with AMR class c bits that are sent without channel coding. In that case there is no limitation on the coding block size, as there is no actual coding performed at the physical layer.

The function of radio frame equalisation is to ensure that data can be divided into equal-sized blocks when transmitted over more than a single 10 ms radio frame. This is done by padding the necessary number of bits until the data can be in equal-sized blocks per frame.

The first interleaving or inter-frame interleaving is used when the delay budget allows more than 10 ms of interleaving. The interlayer length of the first interleaving has been defined to be 20, 40 and 80 ms. The interleaving period is directly related to the Transmission Time Interval (TTI), which indicates how often data arrives from higher layers to the physical layer. The start positions of the TTIs for different transport channels multiplexed together for a single connection are time aligned. The TTIs have a common starting point, i.e. a 40 ms TTI goes in twice, even for an 80 ms TTI on the same connection. This is necessary to limit the possible transport format combinations from the signalling perspective. The timing relation with different TTIs is illustrated in Figure 6.13. If the first interleaving is used, the frame segmentation will distribute the data coming from the first interleaving over 2, 4 or 8 consecutive frames in line with the interleaving length.

Rate matching is used to match the number of bits to be transmitted to the number available on a single frame. This is achieved either by puncturing or by repetition. In the uplink direction, repetition is preferred, and basically the only reason why puncturing is used is when facing the limitations of the terminal transmitter or base station receiver. Another reason for puncturing is to avoid multi-code transmission. The rate matching operation in Figure 6.12 needs to take into account the number of bits coming from the other transport channels that are active in that frame. The uplink rate matching is a dynamic operation that may vary on a frame-by-frame basis. When the data rate of the service with lowest TTI varies as in Figure 6.13, the dynamic rate matching adjusts the rate matching parameters for other transport channels as well, so that all the symbols in the radio frame are used. For example, if with two transport channels the other has momentarily zero rate, rate matching increases the symbol rate for the other service sufficiently so that all uplink channel symbols are used, assuming that the spreading factor would stay the same.

The higher layers provide a semi-static parameter, the rate matching attribute, to control the relative rate matching between different transport channels. This is used to calculate the rate matching value when multiplexing several transport channels for the same

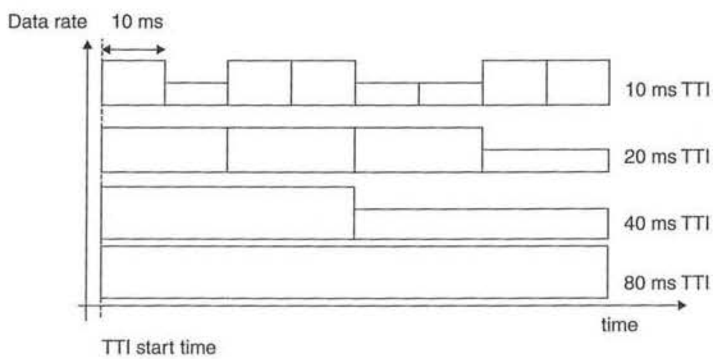

Figure 6.13. TTI start time relation with different TTIs on a single connection

frame. When this rule is applied as specified, with the aid of the rate matching attribute and TFCI the receiver can calculate backwards the rate matching parameters used and perform the inverse operation. By adjusting the rate matching attribute, the quality of different services can be fine-tuned to reach an equal or near-equal symbol power level requirement.

The different transport channels are multiplexed together by the transport channel multiplexing operation. This is a simple serial multiplexing on a frame-by-frame basis. Each transport channel provides data in 10 ms blocks for this multiplexing. In case more than one physical channel (spreading code) is used, physical channel segmentation is used. This operation simply divides the data evenly on the available spreading codes, as currently no cases have been specified where the spreading factors would be different in multicode transmissions. The use of serial multiplexing means also that with multicode transmission the lower rates can be implemented by sending fewer codes than with the full rate.

The second interleaving performs 10 ms radio frame interleaving, sometimes called intraframe interleaving. This is a block interleaver with intercolumn permutations applied to the 30 columns of the interleaver. It is worth noting that the second interleaving is applied separately for each physical channel, in case more than a single code channel is used. From the output of the second interleaver the bits are mapped on the physical channels. The number of bits given for a physical channel at this stage is exactly the number that the spreading factor of that frame can transmit. Alternatively, the number of bits to transmit is zero and the physical channel is not transmitted at all.

6.4.3 User Data Transmission with the Random Access Channel

In addition to the uplink dedicated channel, user data can be sent on the Random Access Channel (RACH), mapped on the Physical Random Access Channel (PRACH). This is intended for low data rate operation with packet data where continuous connection is not maintained. In the RACH message it will be possible to transmit with a limited set of data rates based on prior negotiations with the UTRA network. The RACH operation does not include power control; thus the validity of the power level obtained with the PRACH power ramping procedure will be valid only for a short period, over one or two frames at most, depending on the environment.

The PRACH has as a specific feature preambles that are sent prior to data transmission. These use a spreading factor of 256 and contain a signature sequence of 16 symbols, resulting in a total length of 4096 chips for the preamble. Once the preamble has been detected and acknowledged with the Acquisition Indicator Channel (AICH), the 10 ms (or 20 ms) message part is transmitted. The spreading factor for the message part may vary from 256 up to 32 depending on the transmission needs, but is subject to prior agreement with the UTRA network. Additionally, the 20 ms message length has been defined for range improvement reasons; this is studied in detail in Section 11.2.2. The AICH structure is covered in the signalling part, while the RACH procedure is covered in detail in the physical layer procedures section.

6.4.4 Uplink Common Packet Channel

As well as the previously covered user data transmission methods, an extension for RACH has been defined. The main differences in the uplink from RACH data transmission are the reservation of the channel for several frames and the use of fast power control, which is not needed with RACH when sending only one or two frames. The uplink Common Packet Channel (CPCH) has as a pair the DPCCH in the downlink direction, providing fast power control information. Also the network has an option to tell the terminals to send an 8-slot power control preamble before the actual message transmission. This is beneficial in some cases as it allows the power control to converge before the actual data transmission starts.

The higher layer downlink signalling to a terminal using uplink CPCH is provided by the Forward Access Channel (FACH). The main reason for not using the DPDCH of the dedicated channel carrying the DPCCH for that is that the CPCH is a fast setup and fast release channel, handled similarly to RACH reception by the physical layer at the base station site. The DPDCH content is taken care of by the higher layer signalling protocols, which are located in a Radio Network Controller (RNC). In case the RNC wants to send a signalling message for a terminal as a response to CPCH activity, an ARQ message for example, the CPCH connection might have already been terminated by the base station. The differences in uplink CPCH operation from the RACH procedure are covered in the physical layer procedures section in more detail.

6.4.5 Downlink Dedicated Channel

The downlink dedicated channel is transmitted on the Downlink Dedicated Physical Channel (Downlink DPCH). The Downlink DPCH applies time multiplexing for physical control information and user data transmission, as shown in Figure 6.14. As in the uplink, the terms Dedicated Physical Data Channel (DPDCH) and Dedicated Physical Control Channel (DPCCH) are used in the 3GPP specification for the downlink dedicated channels.

The spreading factor for the highest transmission rate determines the channelisation code to be reserved from the given code tree. The variable data rate transmission may be implemented in two ways:

- In case TFCI is not present, the positions for the DPDCH bits in the frame are fixed. As the spreading factor is also always fixed in the Downlink DPCH, the lower rates are implemented with Discontinuous Transmission (DTX) by gating the transmission on/off. Since this is done on the slot interval, the resulting gating rate is 1500 Hz. As in the uplink, there are 15 slots per 10 ms radio frame; this determines the gating rate. The data rate, in case of more than one alternative, is determined with Blind Transport Format Detection (BTFD) which is based on the use of a guiding transport channel or channels that have different CRC positions for different Transport Format Combinations (TFCs). For a terminal it is mandatory to have BTFD capability with relatively low rates only, such as with AMR speech service. With higher data rates also the benefits from avoiding the TFCI overhead are insignificant and the complexity of BTFD rates starts to increase.
- With TFCI available it is also possible to use flexible positions, and it is up to the network to select which mode of operation is used. With flexible positions it is possible to keep continuous transmission and implement the DTX with repetition of the bits. In such a case the frame is always filled as in the uplink direction.

The downlink multiplexing chain in Figure 6.16 (Section 6.4.6) is also impacted by the DTX, the DTX indication having been inserted before the first interleaving.

In the downlink the spreading factors range from 4 to 512, with some restrictions on the use of spreading factor 512 in the case of soft handover. The restrictions are due to the timing adjustment step of 256 chips in soft handover operation, but in any case the use of a spreading factor of 512 for soft handover is not expected to occur very often. Typically, such a spreading factor is used to provide information on power control, etc., when providing services with minimal downlink activity, as with file uploading and so on. This is also the case with the CPCH where power control information for the limited duration uplink transmission is provided with a DPCCH with spreading factor 512. In such a case soft handover is not needed either.

Modulation causes some differences between the uplink and downlink data rates. While the uplink DPDCH consists of BPSK symbols, the downlink DPDCH consists of QPSK symbols. Although from the downlink DPDCH part of the time is reserved for DPCCH, especially with high data rates, the bit rate that can be accommodated in a single code in the downlink DPDCH is almost double that in the uplink DPDCH with the same spreading factor. These downlink data rates are given in Table 6.3 with raw bit rates calculated from the QPSK-valued symbols in the downlink reserved for data use.

The Downlink DPCH can use either open loop or closed loop transmit diversity to improve performance. The use of such enhancements is not required from the network side

Table 6.3. Downlink Dedicated Channel symbol and bit rates

Spreading factor	Channel symbol rate (kbps)	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Maximum user data rate with $\frac{1}{2}$-rate coding (approx.)
512	7.5	15	3–6	1–3 kbps
256	15	30	12–24	6–12 kbps
128	30	60	42–51	20–24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4,with 3 parallel codes	2880	5760	5616	2.3 Mbps

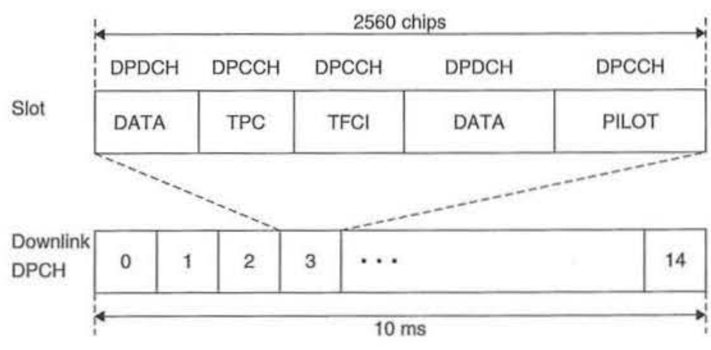

Figure 6.14. Downlink Dedicated Physical Channel (Downlink DPCH) control/data multiplexing

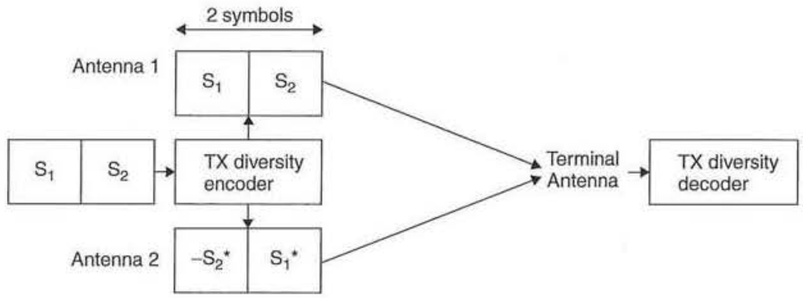

Figure 6.15. Open loop transmit diversity encoding

but is mandatory in terminals. It was made mandatory as it was felt that this kind of feature has a strong relation to such issues as network planning and system capacity, so it was made a baseline implementation capability. The open loop transmit diversity coding principle is shown in Figure 6.15, where the information is coded to be sent from two antennas. The method is also denoted in the 3GPP specification as space time block coding based transmit diversity (STTD). Another possibility is to use feedback mode transmit diversity, where the signal is sent from two antennas based on the feedback information from the terminal. The feedback mode uses phase, and in some cases also amplitude, offsets between the antennas. The feedback mode of transmit diversity is covered in the physical layer procedures section.

6.4.6 Downlink Multiplexing

The multiplexing chain in the downlink is mainly similar to that in the uplink but there are also some functions that are done differently.

As in the uplink, the interleaving is implemented in two parts, covering both intra-frame and inter-frame interleaving. Also the rate matching allows one to balance the required channel symbol energy for different service qualities. The services can be mapped to more than one code as well, which is necessary if the single code capability in either the terminal or base station is exceeded.

There are differences in the order in which rate matching and segmentation functions are performed. Whether fixed or flexible bit positions are used determines the DTX indication insertion point. The DTX indication bits are not transmitted over the air; they are just inserted to inform the transmitter at which bit positions the transmission should be turned off. They were not needed in the uplink where the rate matching was done in a more dynamic way, always filling the frame when there was something to transmit on the DPDCH.

The use of fixed positions means that for a given transport channel, the same symbols are always used. If the transmission rate is below the maximum, then DTX indication bits are used for those symbols. The different transport channels do not have a dynamic impact on the rate matching values applied for another channel, and all transport channels can use the maximum rate simultaneously as well. The use of fixed positions is partly related to the possible use of blind rate detection. When a transport channel always has the same position regardless of the data rate, the channel decoding can be done with a single decoding 'run' and

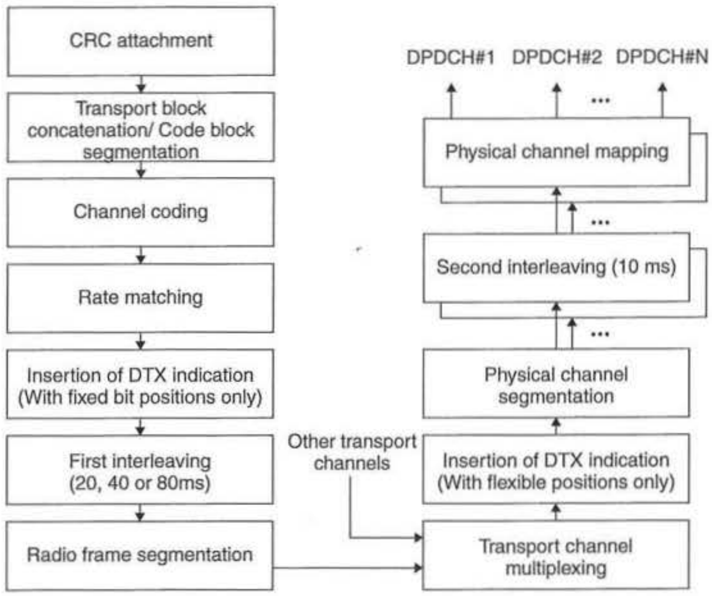

Figure 6.16. Downlink multiplexing and channel coding chain

the only thing that needs to be tested is which position of the output block is matched with the CRC check results. This naturally requires that different rates have different numbers of symbols.

With flexible positions the situation is different since now the channel bits unused by one service may be utilised by another service. This is useful when it is possible to have such a transport channel combination that they do not all need to be able to reach the full data rate simultaneously, but can alternate with the need for full rate transmission. This allows the necessary spreading code occupancy in the downlink to be reduced. The concept of flexible versus fixed positions in the downlink is illustrated in Figure 6.17. The use of blind rate detection is also possible in principle with flexible positions, but is not required by the specifications. If the data rate is not too high and number of possible data rates is not very high, the terminal can run channel decoding for all the combinations and check which of the cases comes out with the correct CRC result.

6.4.7 Downlink Shared Channel

Transmitting data with high peak rate and low activity cycle in the downlink quickly causes the channelisation codes under a single scrambling code to start to run out. To avoid this problem, basically two alternatives exist: use of either additional scrambling codes or common channels. The additional scrambling code approach loses the advantage of the transmissions being orthogonal from a single source, and thus should be avoided. Using a shared channel resource maintains this advantage and at the same time reduces the downlink code resource consumption. As such resource sharing cannot provide a 100% guarantee of

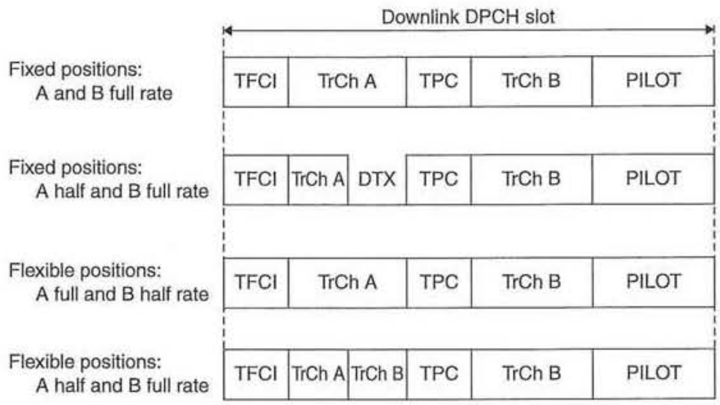

Figure 6.17. Flexible and fixed transport channel slot positions in the downlink

available physical channel resource at all times, its applicability in practice is limited to packet-based services.

As in a CDMA system one has to ensure the availability of power control and other information continuously, the Downlink Shared Channel (DSCH) has been defined to be always associated with a Downlink Dedicated Channel (Downlink DCH). The DCH provides, in addition to the power control information, an indication to the terminal when it has to decode the DSCH and which spreading code from the DSCH it has to despread. For this indication two alternatives have been specified: either TFCI based on a frame-by-frame basis or higher layer signalling based on a longer allocation period. Thus the DSCH data rate without coding is directly the channel bit rate indicated in Table 6.3 for the Downlink DCH. The small difference from the downlink DCH spreading codes is that spreading factor 512 is not supported by DSCH. The DSCH also allows mixing terminals with different data rate capabilities under a single branch from the code resource, making the configuration manageable with evolving terminal capabilities. The DSCH code tree was illustrated in Figure 6.9 in connection with the downlink spreading section.

With DSCH the user may be allocated different data rates, for example 384 kbps with spreading factor 8 and then 192 kbps with spreading factor 16. The DSCH code tree definition allows sharing the DSCH capacity on a frame-by-frame basis, for example with either a single user active with a high data rate or with several lower-rate users active in parallel. The DSCH may be mapped to a multicode case as well; for example, three channelisation codes with spreading factor 4 provide a DSCH with 2 Mbps capability.

In the uplink direction, such concerns for code resource usage do not exist, but there is the question how to manage the total interference level and in some cases the resource usage on the receiver side. Thus an operation similar to DSCH is not specified in the uplink in UTRA FDD.

The physical channel carrying the DSCH is the Physical Downlink Shared Channel (PDSCH). The timing relation of the PDSCH to the associated downlink Dedicated Physical Channel (DPCH) is shown in Figure 6.18. The PDSCH frame may not start before three slots after the end of the associated dedicated channel frame. This ensures that buffering

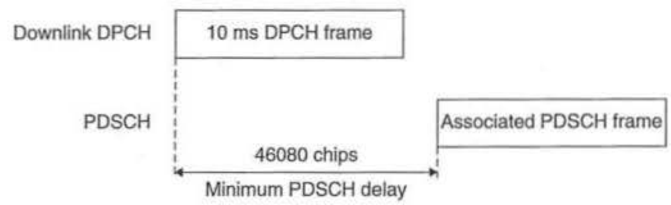

Figure 6.18. PDSCH timing relation to DPCH

requirements for DSCH reception do not increase compared to the other buffering needs in the receiver.

6.4.8 *Forward Access Channel for User Data Transmission*

The Forward Access Channel (FACH) can be used for transmission of user (packet) data. The channel is typically multiplexed with the paging channel to the same physical channel, but can exist as a standalone channel as well. The main difference with the dedicated and shared channels is that FACH does not allow the use of fast power control and applies either slow power control or no power control at all. Slow power control is possible if a lot of data is transmitted between the base station and the terminal and the latter provides feedback on the quality of the received packets. This type of power control cannot combat the effect of the fading channel but more the longer-term changes in the propagation environment. For less frequent transmission FACH needs to use more or less the full power level. The power control for FACH is also typically very slow, since the FACH data transmission is controlled by RNC, which means rather a large delay for any feedback information from the base station.

Whether the FACH contains pilot symbols or not depends on whether it applies beam forming techniques. Normally FACH does not contain pilot symbols and the receiver uses the common pilot channel as phase reference.

As FACH needs to be received by all terminals, the primary FACH cannot use high data rates. If higher data rates were desired of FACH, this would require a separate physical channel where only the capabilities in terms of maximum data rates of those terminals allocated to that channel need to be taken into account. The necessary configuration would become rather complicated when terminals with different capabilities are included. The FACH has a fixed spreading factor, and reserving FACH for very high data rates is not optimised from the code resource point of view, especially if not all the terminals can decode the high data rate FACH.

Messages on FACH normally need in-band signalling to tell for which user the data was intended. In order to read such information, the terminal must decode FACH messages first. Running such decoding continuously is not desirable due to power consumption, especially with higher FACH rates.

6.4.9 *Channel Coding for User Data*

In UTRA two channel coding methods have been defined. Half-rate and $\frac{1}{3}$-rate convolutional coding are intended to be used with relatively low data rates, equivalent to the data rates provided by second generation cellular networks today, though an upper limit has not been specified. For higher data rates $\frac{1}{3}$-rate turbo coding can be applied and typically brings performance benefits when large enough block sizes are achieved. It has been estimated that roughly 300 bits should be available per TTI in order to give turbo coding some gain over convolutional coding. This also depends on the required quality level and operational environment.

The convolutional coding is based on constraint length 9 coding with the use of tail bits. The selected turbo encoding/decoding method is 8-state PCCC (parallel concatenated convolutional code). The main motivation for turbo coding for higher bit rates has been performance, while for low rates the main reason not to use it has been both low rate or low block length performance as well as the desire to allow the use of simple blind rate detection with low rate services such as speech. Blind rate detection with turbo coding typically requires detection of all transmission rates, while with convolutional coding trial methods can allow only a single Viterbi pass for determining which transmission rate was used. This is performed together with the help of CRC and applying a proper interleaving technique.

Turbo coding has specific interleaving which has been designed with a large variety of data rates in mind. The maximum turbo coding block size has been limited to 5114 information bits, since after that block size only memory requirements increase but no significant effect on the performance side can be observed. For the higher amount of data per interleaving period, several blocks are used, with a block size as equal as possible at or below 5114 bits. The actual block size for data is a little smaller, since the tail bits as well as CRC bits are to be accommodated in the block size.

The minimum block size for turbo coding was initially defined to be 320 bits, which corresponds to 32 kbps with 10 ms interleaving or down to 4 kbps with 80 ms interleaving. The possible range of block sizes was, however, extended down to 40 bits, since with variable rate connection it is not desirable to change the codec 'on the fly' when coming down from the maximum rate. Nor may a transport channel change the channel coding method on a frame-by-frame basis. Data rates below 40 bits can be transmitted with turbo coding as well, but in such a case padding with dummy bits is used to fill the 40 bits minimum size interleaver.

With speech service, AMR coding uses an unequal error protection scheme. This means that the three different classes of bits have different protection. Class A bits—those that contribute the most to voice quality—have the strongest protection, while class C bits are sent without channel coding. This gives around 1 dB gain in Eb/No compared to the equal error protection scheme. The coding methods usable by different channels are summarised in Table 6.4. Although the FACH has two options given, the cell access use of FACH is based on convolutional coding, as not all terminals support turbo coding.

Table 6.4. Channel coding options with different channels

DCH	Turbo coding or convolutional coding
CPCH	Turbo coding or convolutional coding
DSCH	Turbo coding or convolutional coding
FACH	Turbo coding or convolutional coding
Other common channels	$\frac{1}{2}$-rate convolutional coding

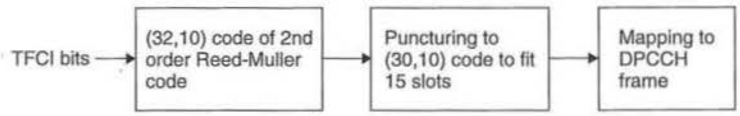

Figure 6.19. TFCI information coding

6.4.10 Coding for TFCI information

The Transport Format Combination Indicator (TFCI) may carry from 1 to 10 bits of transport format information. As well as the normal mode of operation, there is also 'split' mode where the TFCI code word is sent with two different code words and not every cell necessarily sends both code words. In this case both code words are capable of carrying 5 bits. The typical split mode operation would be that an RNC for a downlink dedicated channel would be different from an RNC for controlling a DSCH. The split mode is valid for the downlink direction only.

The coding in the normal mode is second-order Reed Muller code punctured from 32 bits to 30 bits, carrying up to 10 bits of information. The TFCI coding is illustrated in Figure 6.19. The coding with split mode is biorthogonal (16,5) block code.

6.5 Signalling

For signalling purposes a lot of information needs to be transmitted between the network and the terminals. The following chapters describe the methods used for transmitting signalling messages generated above the physical layer, as well as the required physical layer control channels needed for system operation but not necessarily visible for higher layer functionality.

6.5.1 Common Pilot Channel (CPICH)

The common pilot channel is an unmodulated code channel, which is scrambled with the cell-specific primary scrambling code. The function of the CPICH is to aid the channel estimation at the terminal for the dedicated channel and to provide the channel estimation reference for the common channels when they are not associated with the dedicated channels or not involved in the adaptive antenna techniques.

UTRA has two types of common pilot channels, primary and secondary. The difference is that the Primary CPICH is always under the primary scrambling code with a fixed channelisation code allocation and there is only one such channel for a cell or sector. The Secondary CPICH may have any channelisation code of length 256 and may be under a secondary scrambling code as well. The typical area of Secondary CPICH usage would be operations with narrow antenna beams intended for service provision at specific 'hot spots' or places with high traffic density.

An important area for the primary common pilot channel is the measurements for the handover and cell selection/reselection. The use of CPICH reception level at the terminal for handover measurements has the consequence that by adjusting the CPICH power level the cell load can be balanced between different cells. Reducing the CPICH power causes part of the terminals to hand over to other cells, while increasing it invites more terminals to hand over to the cell as well as to make their initial access to the network in that cell.

The CPICH does not carry any higher layer information, neither is there any transport channel mapped to it. The CPICH uses the spreading factor of 256. It may be sent from two antennas in case transmission diversity methods are used in the base station. In this case, the transmissions from the two antennas are separated by a simple modulation pattern on the CPICH transmitted from the diversity antenna, called diversity CPICH. The diversity pilot is used with both open loop and closed loop transmission diversity schemes.

6.5.2 Synchronisation Channel (SCH)

The Synchronisation Channel (SCH) is needed for the cell search. It consists of two channels, the primary and secondary synchronisation channels.

The Primary SCH uses a 256-chip spreading sequence identical in every cell. The system-wide sequence has been optimised for matched filter implementations, as described in connection with SCH spreading and modulation in Section 6.3.4.4.

The Secondary SCH uses sequences with different code word combination possibilities representing different code groups. Once the terminal has identified the secondary synchronisation channel, it has obtained frame and slot synchronisation as well as information on the group the cell belongs to. There are 64 different code groups in use, pointed out by the 256 chip sequences sent on the secondary SCHs. Such a full cell search process with a need to search for all groups is needed naturally only at the initial search upon terminal power-on or when entering a coverage area, otherwise a terminal has more information available on the neighbouring cells and not all the steps are always necessary.

As with the CPICH, no transport channel is mapped on the SCH, as the code words are transmitted for cell search purposes only. The SCH is time multiplexed with the Primary Common Control Physical Channel. For the SCH there are always 256 chips out of 2560 chips from each slot. The Primary and Secondary SCH are sent in parallel, as illustrated in Figure 6.20. Further details on the cell search procedure are covered in Section 6.6.

6.5.3 Primary Common Control Physical Channel (Primary CCPCH)

The Primary Common Control Physical Channel (Primary CCPCH) is the physical channel carrying the Broadcast Channel (BCH). It needs to be demodulated by all the terminals in

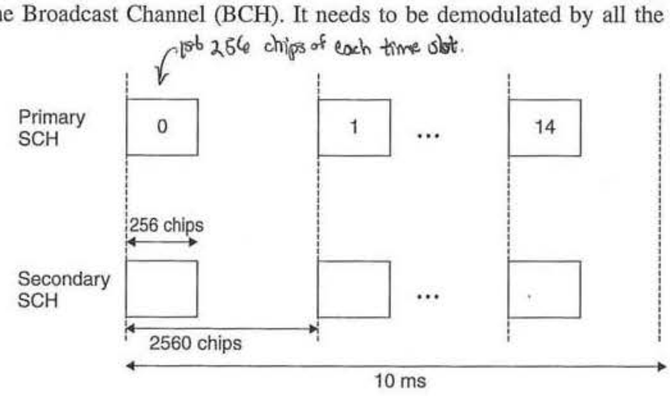

Figure 6.20. Primary and secondary synchronisation channel principle

the system. As a result, the parameters with respect to, for example, the channel coding and spreading code contain no flexibility, as they need to be known by all terminals made since the publication of the Release-99 specifications. The contents of the signalling messages have room for flexibility as long as the new message structures are such that they do not cause unwanted or unpredictable behaviour in the terminals deployed in the network.

The Primary CCPCH contains no Layer 1 control information as it is fixed rate and does not carry power control information for any of the terminals. The pilot symbols are not used, since the Primary CCPCH needs to be available over the whole cell area and does not use specific antenna techniques but is sent with the same antenna radiation pattern as the common pilot channel. This allows the common pilot channel to be used for channel estimation with coherent detection in connection with the Primary CCPCH.

The channel bit rate is 30 kbps with spreading ratio of the permanently allocated channelisation code of 256. The total bit rate is reduced further as the Primary CCPCH alternates with the Synchronisation Channel (SCH), reducing the bit rate without coding available for system information to 27 kbps. This is illustrated in Figure 6.21, where the 256-chip idle period on the Primary CCPCH is shown.

The channel coding with the Primary CCPCH is $\frac{1}{2}$-rate convolutional coding with 20 ms interleaving over two consecutive frames. It is important to keep the data rate with the Primary CCPCH low, as in practice it will be transmitted with very high power from the base station to reach all terminals, having a direct impact on system capacity. If Primary CCPCH decoding fails, the terminals cannot access the system if they are unable to obtain the critical system parameters such as random access codes or code channels used for other common channels.

As a performance improvement method, the Primary CCPCH may apply open loop transmission diversity. In such a case the use of open transmission diversity on the Primary CCPCH is indicated in the modulation of the Secondary SCH. This allows the terminals to have the information before attempting to decode the BCH with the initial cell search.

6.5.4 Secondary Common Control Physical Channel (Secondary CCPCH)

The Secondary Common Control Physical Channel (Secondary CCPCH) carries two different common transport channels: the Forward Access Channel (FACH) and the Paging Channel

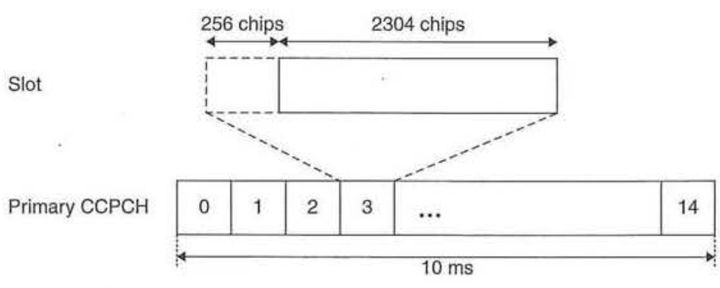

Figure 6.21. Primary CCPCH frame structure

(PCH). The two channels can share a single Secondary CCPCH or can use different physical channels. This means that in the minimum configuration each cell has at least one Secondary CCPCH. In case of a single Secondary CCPCH fewer degrees of freedom exist in terms of data rates, and so on, since again all the terminals in the network need to be able to detect the FACH and PCH. Since there can be more than one FACH or PCH, however, for the additional Secondary CCPCHs the data rates can vary more, as long as the terminals not capable of demodulating higher data rates using another, lower data rate Secondary CCPCH.

The spreading factor used in a Secondary CCPCH is fixed and determined according to the maximum data rate. The data rate may vary with DTX or rate matching parameters, but the channelisation code is always reserved according to the maximum data rate. The maximum data rate usable is naturally dependent on the terminal capabilities. As with the Primary CCPCH, the channel coding method is $\frac{1}{2}$-rate convolutional coding when carrying the channels used for cell access, FACH or PCH. When used to carry PCH, the interleaving period is always 10 ms. For data transmission with FACH, turbo coding or $\frac{1}{3}$-rate convolutional coding may also be applied.

The Secondary CCPCH does not contain power control information, and for other layer 1 control information the following combinations can be used:

- Neither pilot symbols nor rate information (TFCI). Used with PCH and FACH when no adaptive antennas are in use and a channel needs to be detected by all terminals.
- No pilot symbols, but rate information with TFCI. Used typically with FACH when it is desired to use FACH for data transmission with variable transport format and data rate. In such a case variable transmission rates are implemented by DTX or repetition.
- Pilot symbol with or without rate information (TFCI). Typical for the case when an uplink channel is used to derive information for adaptive antenna processing purposes and user-specific antenna radiation patterns or beams are used.

The FACH and PCH can be multiplexed to a single Secondary CCPCH, as the paging indicators used together with the PCH are multiplexed to a different physical channel, called the Paging Indicator Channel (PICH). The motivation for multiplexing the channels together is base station power budget. Since both of the channels need to be transmitted at full power for all the terminals to receive, avoiding the need to send them simultaneously obviously reduces base station power level variations. In order to enable this multiplexing, it has been necessary to terminate both FACH and PCH at RNC.

As a performance improvement method, open loop transmission diversity can be used with a Secondary CCPCH as well. The performance improvement of such a method is higher for common channels in general, as neither Primary nor Secondary CCPCH can use fast power control. Also, since they are often sent with full power to reach the cell edge, reducing the required transmission power level improves downlink system capacity.

6.5.5 Random Access Channel (RACH) for Signalling Transmission

The Random Access Channel (RACH) is typically used for signalling purposes, to register the terminal after power-on to the network or to perform location update after moving from one location area to another or to initiate a call. The structure of the physical RACH for signalling purposes is the same as when using the RACH for user data transmission, as described in connection with the user data transmission. With signalling use the major difference is that the data rate needs to be kept relatively low, otherwise the range achievable with RACH signalling starts to limit the system coverage. This is more critical, the lower the data rates used as a basis for network coverage planning. RACH range issues are studied in detail in Chapter 11. The detailed RACH procedure will be covered in connection with the physical layer procedures.

The RACH that can be used for initial access has a relatively low payload size, since it needs to be usable by all terminals. The ability to support 16 kbps data rate on RACH is a mandatory requirement for all terminals regardless of what kind of services they provide.

6.5.6 Acquisition Indicator Channel (AICH)

In connection with the Random Access Channel, the Acquisition Indicator Channel (AICH) is used to indicate from the base station the reception of the random access channel signature sequence. The AICH uses an identical signature sequence as the RACH on one of the downlink channelisation codes of the base station to which the RACH belongs. Once the base station has detected the preamble with the random access attempt, then the same signature sequence that has been used on the preamble will be echoed back on AICH. As the structure of AICH is the same as with the RACH preamble, it also uses a spreading factor of 256 and 16 symbols as the signature sequence. There can be up to 16 signatures, acknowledged on the AICH at the same time. Both signature sets can be used with AICH. The procedure with AICH and RACH is described in the physical layer procedures section.

For the detection of AICH the terminal needs to obtain the phase reference from the common pilot channel. The AICH also needs to be heard by all terminals and needs to be sent typically at high power level without power control.

The AICH is not visible to higher layers but is controlled directly by the physical layer in the base station, as operation via a radio network controller would make the response time too slow for a RACH preamble. There are only a few timeslots to detect the RACH preamble and to transmit the response to the terminal on AICH.

6.5.7 Paging Indicator Channel (PICH)

The Paging Channel (PCH) is operated together with the Paging Indicator Channel (PICH) to provide terminals with efficient sleep mode operation. The paging indicators use a

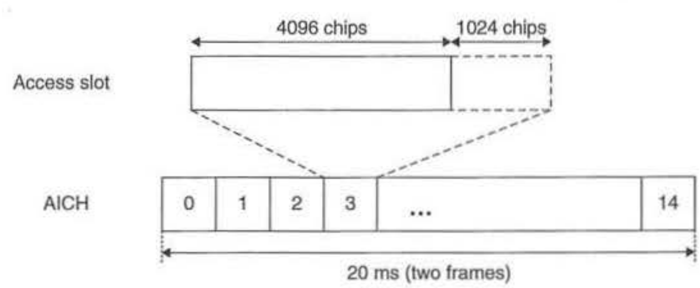

Figure 6.22. AICH access slot structure

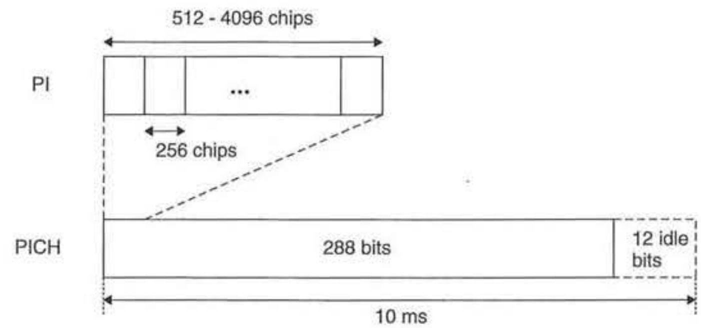

Figure 6.23. PICH structure with different PI repetition rates

channelisation code of length 256. The paging indicators occur once per slot on the corresponding physical channel, the Paging Indicator Channel (PICH). Each PICH frame carries 288 bits to be used by the paging indicator bit, and 12 bits are left idle. Depending on the paging indicator repetition ratio, there can be 18, 36, 72 or 144 paging indicators per PICH frame. How often a terminal needs to listen to the PICH is parameterised, and the exact moment depends on running the system frame number (SFN).

For detection of the PICH the terminal needs to obtain the phase reference from the CPICH, and as with the AICH, the PICH needs to be heard by all terminals in the cell and thus needs to be sent at high power level without power control. The PICH frame structure with different PI repetition factors is illustrated in Figure 6.23.

6.5.8 Physical Channels for CPCH Access Procedure

For the CPCH access procedure, a set of CPCH specific physical channels has been specified. These channels carry no transport channels, but only information needed in the CPCH access procedure. The channels are:

- CPCH Status Indication Channel (CSICH)
- CPCH Collision Detection Indicator Channel (CD-ICH)
- CPCH Channel Assignment Indicator Channel (CA-ICH)
- CPCH Access Preamble Acquisition Channel (AP-AICH)

The CSICH uses the part of the AICH channel that is defined as unused, as shown in Figure 6.22. The CSICH bits indicate the availability of each physical CPCH channel and are used to tell the terminal to initiate access only on a free channel but, on the other hand, to accept a channel assignment command to an unused channel. The CSICH shares the downlink channelisation code resource with the AP-AICH.

The CD-ICH carries the collision detection information to the terminal. When the CA-ICH channel is used, the CD-ICH and CA-ICH are sent in parallel to the terminal. Both have 16 different bit patterns specified.

The AP-AICH is identical to the AICH used with RACH and may share the same channelisation code when sharing access resources with RACH. In this case CSICH uses also the same channelisation code as the CPCH and RACH AICH channels.

6.6 Physical Layer Procedures

In the physical layer of a CDMA system there are many procedures essential for system operation. Examples include the fast power control and random access procedures. Other important physical layer procedures are paging, handover measurements and operation with transmit diversity. These procedures have been naturally shaped by the CDMA-specific properties of the UTRA FDD physical layer.

6.6.1 Fast Closed Loop Power Control Procedure

The fast closed loop power control procedure is denoted in the UTRA specifications as inner loop power control. It is known to be essential in a CDMA-based system due to the uplink near–far problem illustrated in Chapter 3. The fast power control operation operates on a basis of one command per slot, resulting in a 1500 Hz command rate. The basic step size is 1 dB. Additionally, multiples of that step size can be used and smaller step sizes can be emulated. The emulated step size means that the 1 dB step is used, for example, only every second slot, thus emulating the 0.5 dB step size. 'True' step sizes below 1 dB are difficult to implement with reasonable complexity, as the achievable accuracy over the large dynamic range is difficult to ensure. The specifications define the relative accuracy for a 1 dB power control step to be ±0.5 dB. The other 'true' step size specified is 2 dB.

Fast power control operation has two special cases: operation with soft handover and with compressed mode in connection with handover measurements. Soft handover needs special concern as there are several base stations sending commands to a single terminal, while with compressed mode operation breaks in the command stream are periodically provided to the terminal.

In soft handover the main issue for terminals is how to react to multiple power control commands from several sources. This has been solved by specifying the operation such that the terminal combines the commands but also takes the reliability of each individual command decision into account in deciding whether to increase or decrease the power.

In the compressed mode case, the fast power control uses a larger step size for a short period after a compressed frame. This allows the power level to converge more quickly to the correct value after a break in the control stream. The need for this method depends heavily on the environment and it is not relevant for the lower terminal or very short transmission gap lengths.

The SIR target for closed loop power control is set by the outer loop power control. The latter power control is introduced in Section 3.5 and described in detail in Section 9.2.2.

On the terminal side it is specified rather strictly what is expected to be done inside a terminal in terms of (fast) power control operation. On the network side there is much greater freedom to decide how a base station should behave upon reception of a power control command, as well as the basis on which the base station should tell a terminal to increase or decrease the power.

6.6.2 Open Loop Power Control

In UTRA FDD there is also open loop power control, which is applied only prior to initiating the transmission on the RACH or CPCH. Open loop power control is not very accurate, since it is difficult to measure large power dynamics accurately in the terminal equipment. The mapping of the actual received absolute power to the absolute power to be transmitted shows large deviations, due to variation in the component properties as well as to the impact of environmental conditions, mainly temperature. Also, the transmission and reception occur at different frequencies, but the internal accuracy inside the terminal is the main source of uncertainty. The requirement for open loop power control accuracy is specified to be within ±9 dB in normal conditions.

Open loop power control was used in earlier CDMA systems, such as IS-95, being active in parallel with closed loop power control. The motivation for such usage was to allow corner effects or other sudden environmental changes to be covered. As the UTRA fast power control has almost double the command rate, it was concluded that a 15 dB adjustment range does not need open loop power control to be operated simultaneously. Additionally, the fast power control step size can be increased from 1 dB to 2 dB, which would allow a 30 dB correction range during a 10 ms frame.

The use of open loop power control while in active mode also has some impact on link quality. The large inaccuracy of open loop power control can cause it to make adjustments to the transmitted power level even when they are not needed. As such behaviour depends on terminal unit tolerances and on various environmental variables, running open loop power control makes it more difficult from the network side to predict how a terminal will behave in different conditions.

6.6.3 Paging Procedure

The Paging Channel (PCH) operation is organised as follows. A terminal, once registered to a network, has been allocated a paging group. For the paging group there are Paging Indicators (PI) which appear periodically on the Paging Indicator Channel (PICH) when there are paging messages for any of the terminals belonging to that paging group.

Once a PI has been detected, the terminal decodes the next PCH frame transmitted on the Secondary CCPCH to see whether there was a paging message intended for it. The terminal may also need to decode the PCH in case the PI reception indicates low reliability of the decision. The paging interval is illustrated in Figure 6.24.

The less often the PIs appear, the less often the terminal needs to wake up from the sleep mode and the longer the battery life becomes. The trade-off is obviously the response time to the network-originated call. An infinite paging indicator interval does not lead to infinite battery duration, as there are other tasks the terminal needs to perform during idle mode as well.

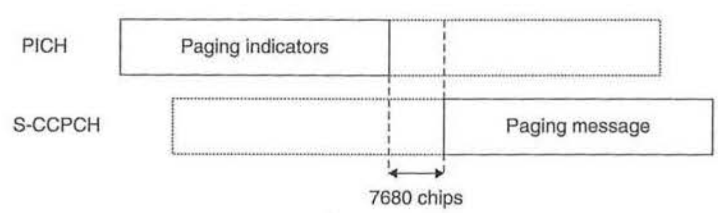

Figure 6.24. PICH relation to PCH

6.6.4 RACH Procedure

The Random Access procedure in a CDMA system has to cope with the near–far problem, as when initiating the transmission there is no exact knowledge of the required transmission power. The open loop power control has a large uncertainty in terms of absolute power values from the received power measurement to the transmitter power level setting value, as stated in connection with the open loop description. In UTRA the RACH procedure has the following phases:

- The terminal decodes the BCH to find out the available RACH sub-channels and their scrambling codes and signatures.
- The terminal selects randomly one of the RACH sub-channels from the group its access class allows it to use. Furthermore, the signature is also selected randomly from among the available signatures.
- The downlink power level is measured and the initial RACH power level is set with the proper margin due to the open loop inaccuracy.
- A 1 ms RACH preamble is sent with the selected signature.
- The terminal decodes AICH to see whether the base station has detected the preamble.
- In case no AICH is detected, the terminal increases the preamble transmission power by a step given by the base station, as multiples of 1 dB. The preamble is retransmitted in the next available access slot.
- When an AICH transmission is detected from the base station, the terminal transmits the 10 ms or 20 ms message part of the RACH transmission.

The RACH procedure is illustrated in Figure 6.25, where the terminal transmits the preamble until acknowledgement is received on AICH, and then the message part follows.

In the case of data transmission on RACH, the spreading factor and thus the data rate may vary; this is indicated with the TFCI on the DPCCH on PRACH. Spreading factors from 256 to 32 have been defined to be possible, thus a single frame on RACH may contain up to 1200 channel symbols which, depending on the channel coding, maps to around 600 or 400 bits. For the maximum number of bits the achievable range is naturally less than what can be achieved with the lowest rates, especially as RACH messages do not use methods such as macro-diversity as in the dedicated channel.

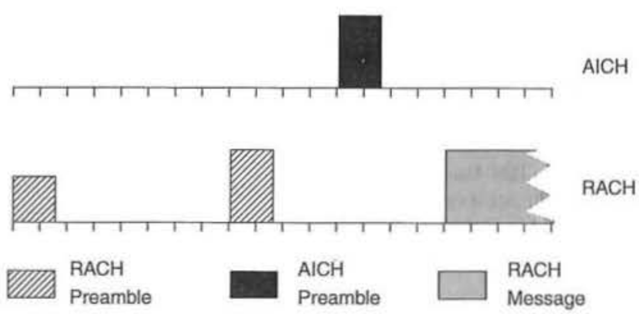

Figure 6.25. PRACH ramping and message transmission

6.6.5 CPCH Operation

Uplink Common Packet Channel (CPCH) operation is rather similar to RACH operation. The main difference is the Layer 1 Collision Detection (CD) based on a signal structure similar to that of the RACH preamble. The operation follows the RACH procedure until the terminal detects AICH, as illustrated in Figure 6.26. After that a CD preamble with the same power level is still sent back with another signature, randomly chosen from a given set. Then the base station is expected to echo this signature back to the terminal on the CD Indication Channel (CD-ICH) and in this way to create a method of reducing the collision probability on layer 1. After the correct preamble has been sent by the base station on the collision detection procedure, the terminal starts the transmission, which may last over several frames. The longer duration of the transmission highlights the need for the physical layer-based collision detection mechanism. In RACH operation only one RACH message may end up lost due to collision, whereas with CPCH operation an undetected collision may cause several frames to be sent and cause only extra interference.

The fast power control on CPCH helps to reduce the interference due to the data transmission while it also highlights the importance of the added collision detection to RACH. A terminal transmitting data over several frames and following a power control command stream intended for another terminal would create a severe interference problem in the cell, especially when high data rates are involved. At the beginning of the CPCH transmission, an optional power control preamble can be sent before actual data transmission is initiated. This is to allow power control to converge, as there is a longer delay with CPCH than with RACH between the acknowledged preamble and actual data frame transmission. The 8-slot power control preamble also uses a 2 dB step size for faster power control convergence.

A CPCH transmission needs to have a restriction on maximum duration, since CPCH supports neither soft handover nor compressed mode to allow inter-frequency or inter-system measurements. UTRAN sets the maximum CPCH transmission during service negotiations.

The latest addition to CPCH operation is the status monitoring and channel assignment functionality. The CPCH Status Indication Channel (CSICH) is a separate physical channel, sent from the base station, that has indicator bits to indicate the status of different CPCH channels. This avoids unnecessary access attempts when all CPCH channels are busy, so it will also improve CPCH throughput. The Channel Assignment functionality is a system option, in the form of a CA message that may direct the terminal to a CPCH channel other than the one used for the access procedure. The CA message is sent in parallel with the collision detection message.

6.6.6 Cell Search Procedure

The cell search procedure or synchronisation procedure in an asynchronous CDMA system differs greatly from the procedure in a synchronous system like IS-95. Since the cells in an asynchronous UTRA CDMA system use different scrambling codes and not just different code phase shifts, terminals with today's technology cannot search for 512 codes of 10 ms duration without any prior knowledge. There would be too many comparisons to make and users would experience too long an interval from power-on to the service availability indication in the terminal.

The cell search procedure using the synchronisation channel has basically three steps, though from the standards point of view there will be no requirements as to which steps

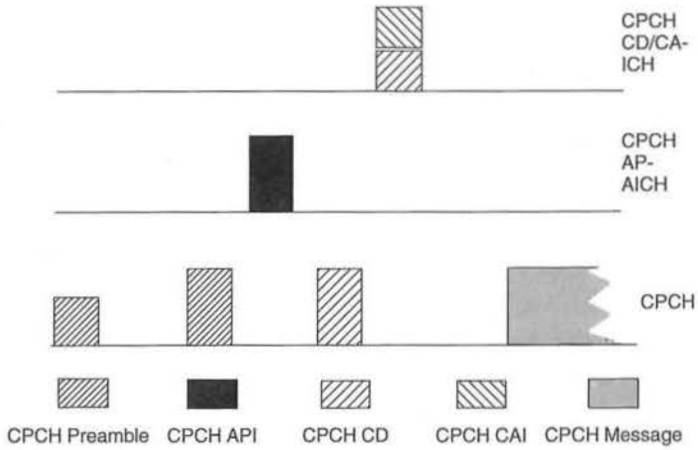

Figure 6.26. CPCH access procedure operation

to perform and when. Rather the standard will set requirements for performance in terms of maximum search duration in reference test conditions. The basic steps for the initial cell search are typically as follows:

1. The terminal searches the 256-chip primary synchronisation code, being identical for all cells. As the primary synchronisation code is the same in every slot, the peak detected corresponds to the slot boundary.
2. Based on the peaks detected for the primary synchronisation code, the terminal seeks the largest peak from the Secondary SCH code word. There are 64 possibilities for the secondary synchronisation code word. The terminal needs to check all 15 positions, as the frame boundary is not available before Secondary SCH code word detection.
3. Once the Secondary SCH code word has been detected, the frame timing is known. The terminal then seeks the primary scrambling codes that belong to that particular code group. Each group consists of eight primary scrambling codes. These need to be tested for a single position only, as the starting point is known already.

When setting the network parameters, the properties of the synchronisation scheme need to be taken into account for optimum performance. For the initial cell search there is no practical impact, but the target cell search in connection with handover can be optimised. Basically, since there are rather a large number of code groups, in a practical planning situation one can, in most cases, implement the neighbouring cell list so that all the cells in the list for one cell belong to a different code group. Thus the terminal can search for the target cell and skip step 3 totally, just confirming detection without needing to compare the different primary scrambling codes for that step.

Further ways of improving cell search performance include the possibility of providing information on the relative timing between cells. This kind of information, which is being measured by the terminals for soft handover purposes in any case, can be used to improve especially the step 2 performance. The more accurate the relative timing information, the fewer slot positions need to be tested for the Secondary SCH code word, and the better is the probability of correct detection.

6.6.7 Transmit Diversity Procedure

As was mentioned in connection with the downlink channels, UTRA uses two types of transmit diversity transmission for user data performance improvement, as studied in Chapter 11. These methods are classified as open loop and closed loop methods. In this section the feedback procedure for closed loop transmit diversity is described. The open loop method was covered in connection with the downlink dedicated channel description.

In the case of closed loop transmit diversity, the base station uses two antennas to transmit the user information. The use of these two antennas is based on the feedback from the terminal, transmitted in the Feedback (FB) bits in the uplink DPCCH. The closed loop transmit diversity itself has two modes of operation.

In mode 1, the terminal feedback commands control the phase adjustments that are expected to maximise the power received by the terminal. The base station thus maintains the phase with antenna 1 and then adjusts the phase of antenna 2 based on the sliding averaging over two consecutive feedback commands. With this method, thus four different phase settings are applied to antenna 2.

In mode 2, the amplitude is adjusted in addition to the phase adjustment. The same signalling rate is used, but now the command is spread over four bits in four uplink DPCCH slots, with a single bit for amplitude and three bits for phase adjustment. This gives a total of eight different phase and two different amplitude combinations, thus a total of 16 combinations for signal transmission from the base station. The amplitude values have been defined to be 0.2 and 0.8, while the phase values are naturally distributed evenly for the antenna phase offsets, from $-135°$ to $+180°$ phase offset. In this mode the last three slots of the frame contain only phase information, while amplitude information is taken from the previous four slots. This allows the command period to go even with 15 slots as with mode 1, where the average at the frame boundary is slightly modified by averaging the commands from slot 13 and slot 0 to avoid discontinuities in the adjustment process.

The closed loop method may be applied only on the dedicated channels or with a DSCH together with a dedicated channel. The open loop method may be used on both the common and dedicated channels.

6.6.8 Handover Measurements Procedure

Within the UTRA FDD the possible handovers are as follows:

- Intra-mode handover, which can be soft handover, softer handover or hard handover. Hard handover may take place as intra- or inter-frequency handover.
- Inter-mode handover as handover to the UTRA TDD mode.
- Inter-system handover, which in Release-99 means only GSM handover. The GSM handover may take place to a GSM system operating at 900 MHz, 1800 MHz and 1900 MHz. Release-2000 is expected to cover additional details needed for hard handover to the Multi-Carrier CDMA, described in Chapter 13.

The main relevance of the handover to the physical layer is what to measure for handover criteria and how to obtain the measurements.

6.6.8.1 Intra-Mode Handover

The UTRA FDD intra-mode handover relies on the Ec/No measurement performed from the common pilot channel (CPICH). The quantities defined that can be measured by the terminal from the CPICH are as follows:

- Received Signal Code Power (RSCP), which is the received power on one code after despreading, defined on the pilot symbols.
- Received Signal Strength Indicator (RSSI), which is the wideband received power within the channel bandwidth.
- Ec/No, representing the received signal code power divided by the total received power in the channel bandwidth, which is defined as RSCP/RSSI.

There are also other items that can be used as a basis for handover decisions in UTRAN, as the actual handover algorithm decisions are left as an implementation issue. One such parameter mentioned in the standardisation discussions has been the dedicated channel SIR, giving information on the cell orthogonality and being measured in any case for power control purposes.

Additional essential information for soft handover purposes is the relative timing information between the cells. As in an asynchronous network, there is a need to adjust the transmission timing in soft handover to allow coherent combining in the Rake receiver, otherwise the transmissions from the different base stations would be difficult to combine, and especially the power control operation in soft handover would suffer additional delay. The timing measurement in connection with the soft handover operation is illustrated in Figure 6.27. The new base station adjusts the downlink timing in steps of 256 chips based on the information it receives from the RNC.

When the cells are within the 10 ms window, the relative timing can be found from the primary scrambling code phase, since the code period used is 10 ms. If the timing uncertainty is larger, the terminal needs to decode the System Frame Number (SFN) from the Primary CCPCH. This always takes time and may suffer from errors, which requires

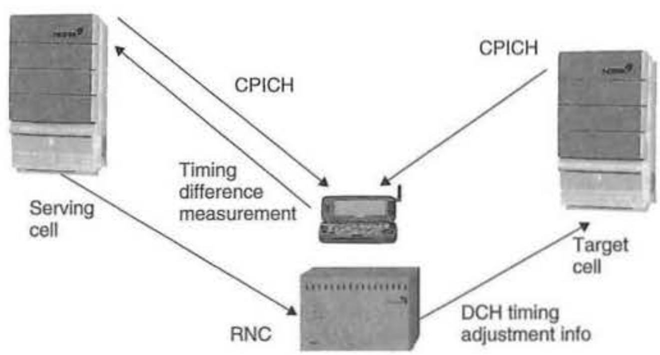

Figure 6.27. Timing measurement for soft handover

also a CRC check to be made on the SFN. The 10 ms window has no relevance when the timing information is provided in the neighbouring cell list. In such a case only the phase difference of the scrambling codes needs to be considered, unless the base stations are synchronised to chip level.

For the hard handover between frequencies such accurate timing information on chip level is not needed. Obtaining the other measurements is slightly more challenging as the terminal must make the measurements on a different frequency. This is typically done with the aid of compressed mode, which is described later in this chapter.

6.6.8.2 Inter-Mode Handover

On request from UTRAN, the dual-mode FDD–TDD terminals operating in FDD measure the power level from the TDD cells available in the area. The TDD CCPCH bursts sent twice during the 10 ms TDD frame can be used for measurement, since they are guaranteed to always exist in the downlink. The TDD cells in the same coverage area are synchronised, thus finding one slot with the reference midamble means that other TDD cells have roughly the same timing for their burst with reference power. UTRA TDD is covered in further detail in Chapter 12.

6.6.8.3 Inter-System Handover

For UTRA–GSM handover, basically similar requirements are valid as for GSM–GSM handover. Normally the terminal receives the GSM Synchronisation Channel (GSM SCH) during compressed frames in UTRA FDD to allow measurements from other frequencies. GSM 1800 set special requirements for compressed mode and required that compressed mode was specified for the uplink also. This was also needed for TDD measurements.

Other systems will be covered in Release-2000, with the focus on Multi-carrier CDMA (MC mode). The main concern for the FDD mode is to measure the pilot channel reception level from the MC mode downlink. The handover between UTRA FDD (also called DS mode) and the MC mode is always hard handover, such as handover to GSM. The need for the compressed mode depends on the terminal capability as well as on the location of the frequency band used by the MC mode. In general the same principles are valid from the measurements point of view as from the FDD–FDD inter-frequency point of view, as long as sufficient information on the MC mode system parameters is provided to the terminal via UTRAN. The Release-99 measurement procedures, like the compressed mode technique, are expected to be usable to provide measurements from the MC mode as well.

6.6.9 Compressed Mode Measurement Procedure

The compressed mode, often referred to as the slotted mode, is needed when making measurements from another frequency in a CDMA system without a full dual receiver terminal. The compressed mode means that transmission and reception are halted for a short time, in the order of a few milliseconds, in order to perform measurements on the other frequencies. The intention is not to lose data but to compress the data transmission in the time domain. Frame compression can be achieved with three different methods:

- Lowering the data rate from higher layers, as higher layers have knowledge of the compressed mode schedule for the terminal.

- Increasing the data rate by changing the spreading factor. For example, using spreading factor 64 instead of spreading factor 128 doubles the number of available symbols and makes it very straightforward to achieve the desired compression ratio for the frame.
- Reducing the symbol rate by puncturing at the physical layer multiplexing chain. In practice, this is limited to the rather short Transmission Gap Lengths (TGL), since puncturing has some practical limits. The benefit is obviously in keeping the existing spreading factor and not causing new requirements for channelisation code usage.

The compressed frames are provided normally in the downlink and in some cases in the uplink as well. If they appear in the uplink, they need to be simultaneous with the downlink frames, as illustrated in Figure 6.28.

The specified TGL lengths are 3, 4, 7, 10 and 14 slots. TGL lengths of 3, 4 and 7 can be obtained with both single- and double-frame methods. For TGL lengths of 10 or 14 only the double-frame method can be used. An example of the double-frame method is illustrated in Figure 6.29, where the idle slots are divided between two frames. This allows minimising the impact during a single frame and keeping, for example, the required increment in the transmission power lower than with the single frame method.

The case when uplink compressed frames are always needed with UTRA is the GSM 1800 measurements, where the close proximity of the GSM 1800 downlink frequency band

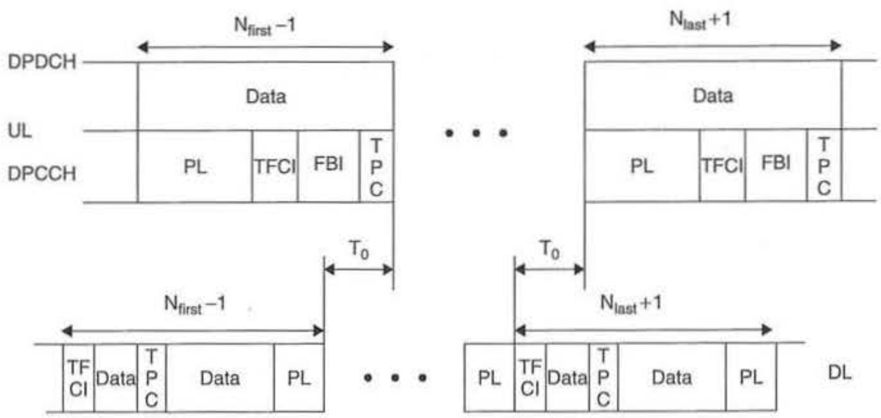

Figure 6.28. Compressed frames in the uplink and downlink

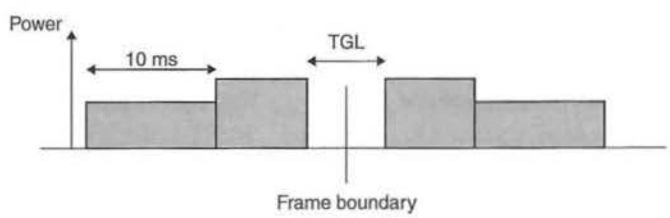

Figure 6.29. Compressed mode with the double frame method

to the core UTRA FDD uplink frequency band at 1920 MHz and upwards is too close to allow simultaneous transmission and reception.

Use of the compressed mode in the uplink with GSM 900 measurements or UTRA inter-frequency handover depends on terminal capability. For maintaining the continuous uplink, the terminal needs to have a means of generating the additional frequency parallel while maintaining the existing frequency. In practice, this means additional oscillators for frequency generation as well as some other duplicated components, which add to terminal power consumption.

The use of compressed mode has an inevitable impact on link performance, as studied in [10] for the uplink compressed mode and in [11] for the downlink. Link performance does not deteriorate very much if the terminal is not at the cell edge, since there is room to compensate the momentary performance loss with fast power control. The impact is largest at the cell edge; the difference in uplink performance between compressed mode and non-compressed mode is very slight until headroom is less than 4 dB. At 0 dB headroom the difference from normal transmission is between 2 and 4 dB, depending on the transmission gap duration with compressed frames. The 0 dB headroom corresponds to terminal operation at full power at the cell edge with no possibility of (soft) handover and with no room to run fast power control any more. The use of soft handover (or handover in general) will improve the situation, since low headroom values are less likely to occur, as with typical planning there is some overlap in the cell coverage area and the 0 dB headroom case should occur only when leaving the coverage area. The compressed mode performance is analysed in Section 9.3.2.

The actual time available for sampling on another frequency is reduced from the above values, due to the time taken by the hardware to switch the frequency; thus very short values of 1 or 2 slots have been excluded, since there is no really practical time available for measurements. The smallest value used in the specifications is 3, which itself allows only a very short measurement time window and should be considered for use only in specific cases.

6.6.10 Other Measurements

In the base station other measurements are needed to give RNC sufficient information on uplink status and base station transmission power resource usage. The following have been specified for the base station, to be supported by signalling between base station and RNC:

- RSSI, to give information on the uplink load.
- Uplink SIR on the DPCCH.
- Total transmission power on a single carrier at a base station transmitter, giving information on the available power resources at the base station.
- The transmission code on a single code for one terminal. This is used, for example, in balancing power between radio links in soft handover.
- Block Error Rate (BLER) and Bit Error Rate (BER) estimates for different physical channels.

The BLER measurement is to be supported by the terminals as well. The main function of terminal BLER measurement is to provide feedback for outer loop power control operation in setting the SIR target for fast power control operation.

Support of position location functionality needs measurements from the physical layer. For that purpose a second type of timing measurements has been specified that gives the timing difference between the primary scrambling codes of different cells with $\frac{1}{4}$-chip resolution for improved position location accuracy. The achievable position accuracy in theory can thus be estimated from the fact that a single chip corresponds to roughly 70 m in distance. In a cellular environment there are obviously further factors contributing to the achievable accuracy. To alleviate the impact of the near–far problem for a terminal that is very close to a base station, the specifications contain also a method of introducing idle periods in base station transmission. This enables timing measurements from base stations that would otherwise be too weak due to close proximity of the serving base station.

6.6.11 Operation with Adaptive Antennas

UTRA has been designed to allow the use of adaptive antennas, also known as beamforming, both in the uplink and downlink direction. Basically there are two types of beamforming one may use. Either a beam may use the secondary common pilot channel (S-CPICH) or then any may use only the dedicated pilot symbols. From the physical layer point of view the use of adaptive antennas is fully covered with Release-99 but the exact performance requirements for the terminals in different operation scenarios shall be covered for the later Release only, starting with Release 4.

Table 6.5. Application of beamforming concepts on downlink physical channel types

Physical channel type	Beamforming with S-CPICH	Beamforming without S-CPICH
P-CCPCH	No	No
SCH	No	No
S-CCPCH	No	No
DPCH	Yes	Yes
PICH	No	No
PDSCH (with associated DPCH)	Yes	Yes
AICH	No	No
CSICH	No	No

Whether beamforming may be applied to particular channels depends on certain factors. For example, does the channel contain dedicated pilot symbols?, or does the base station know, in the case of common channels, for which terminal is the data in the downlink direction intended? Table 6.5 shows the application of the beamforming concepts on different downlink physical channel types.

If it is desired to use beamforming together with any of the transmit diversity modes, then S-CPICH needs to be transmitted, including the diversity pilot, in the same antenna beam.

6.7 Terminal radio access capabilities

As explained in Chapter 2, the class mark approach of GSM in not applied in the same way with UMTS. Instead a terminal upon connection establishment informs a network of a large set of capability parameters and not only one or more class mark values. The reason for this approach has been the large variety of capabilities and data rates with UMTS terminals, which would have resulted to very high number of different class marks. For practical guidance reference classes were specified anyway.

Table 6.6. Terminal radio access capability parameter combinations for downlink decoding

Reference combination	32 kbps class	64 kbps class	128 kbps class	384 kbps class	768 kbps class	2048 kbps class
Transport channel parameters						
Maximum sum of number of bits of all transport blocks being received at an arbitrary time instant	640	3840	3840	6400	10240	20480
Maximum sum of number of bits of all turbo coded transport blocks being received at an arbitrary time instant	Not Supported	3840	3840	6400	10240	20480
Maximum number of simultaneous Coded Composite Transport Channels (CCTrCHs), higher value with PDSCH support	1	2/1	2/1	2/1	2	2
Maximum total number of transport blocks received within TTIs that end at the same time	8	8	16	32	64	96
Maximum number of Transport Format Combinations (TFC) in the TFC Set (TFCS)	32	48	96	128	256	1024
Maximum number of Transport Formats	32	64	64	64	128	256
Physical channel parameters						
Maximum number of DPCH/PDSCH codes simultaneously received, higher value with DSCH support	1	2/1	2/1	3	3	3
Maximum number of physical channel bits received in any 10 ms interval (DPCH, PDSCH, S-CCPCH), higher value with DSCH support.	1200	3600/2400	7200/4800	19200	28800	57600
Support of Physical DSCH	No	Yes/No	Yes/No	Yes/No	Yes	Yes

The reference classes in [12] have a few of common values as well, which are not covered here. For example the support for spreading factor 512 is not expected to be covered by any of the classes by default. For the channel coding methods the turbo coding is supported with classes above 32 kbps class and with higher classes the higher data rates above 64 kbps are

Table 6.7. Terminal radio access capability parameter combinations for uplink encoding

Reference combination	32 kbps class	64 kbps class	128 kbps class	384 kbps class	768 kbps class
Transport channel parameters					
Maximum sum of number of bits of all transport blocks being transmitted at an arbitrary time instant	640	3840	3840	6400	10240
Maximum sum of number of bits of all turbo coded transport blocks being transmitted at an arbitrary time instant	Not Supported	3840	3840	6400	10240
Maximum total number of transport blocks transmitted within TTIs that start at the same time	4	8	8	16	32
Maximum number of Transport Format Combinations (TFC) in the TFC Set (TFCS)	16	32	48	64	128
Maximum number of Transport Formats	32	32	32	32	64
Physical channel parameters					
Maximum number of DPDCH bits transmitted per 10 ms	1200	2400	4800	9600	19200

supported with turbo coding only as can be seen in tables 6.6 and 6.7. For the convolutional coding all the classes have the value of 640 bits at an arbitrary time instant for both encoding and decoding. This is needed in any case for decoding of broadcast channels. All the classes, except 32 kbps uplink, support atleast 8 parallel transport channels.

The value given for the number of bits received at an arbitrary time instant needs to be converted to the maximum data rate supported by considering at the same time the interleaving length (or TTI length with 3GPP terminology). For example the value 6400 bits for 384 kbps class can be converted to the maximum data rate with particular TTI as follows: The data rate of the application is 256 kbps, thus the number of bits per 10 ms is 2560 bits. With 10 ms or 20 ms TTI lengths the number of bits per interleaving period stays below 6400 bits but with 40 ms TTI the 6400 limit would be exceeded and the terminal would not have enough memory to operate with such a configuration. Respectively 384 kbps data rate with a terminal of a same class could be maintained with 10 ms TTI but 20 ms TTI would exceed the limit.

The value ranges given in [12] range from beyond what the classes contain, for example it is possible for a terminal to indicate values allowing 2 Mbps with 80 ms TTI. The minimum values haven been determined by the necessary capabilities needed to access the system, e.g. to listen the BCH or to access the RACH.

The key physical channel parameter is the maximum number of physical channel bits received/transmitted per 10 ms interval. This determines which spreading factors are supported. For example value 1200 bits for the 32 kbps class indicated that in the downlink the spreading factors supported are 256,128 and 64 while in the uplink the smallest value supported would be 64. The difference is coming from the from the use of QPSK modulation in the downlink and BPSK modulation in the uplink as explained earlier in this chapter in the section on modulation.

There are also parameters that are not dependant on a particular reference combination. Such a parameters indicate, for example, support for a particular terminal position location method. In the RF side the class independent parameters allow to indicate, for example, supported frequency bands or the terminal power class.

The parameters in table 6.7 and 6.8 cover The UTRA FDD while for UTRA TDD there are few additional TDD specific parameters in the complete tables [12] such as number of slots to be received etc.

References

[1] 3GPP Technical Specification 25.211, Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD).

[2] 3GPP Technical Specification 25.212, Multiplexing and Channel Coding (FDD).

[3] 3GPP Technical Specification 25.213, Spreading and Modulation (FDD).

[4] 3GPP Technical Specification 25.214, Physical Layer Procedures (FDD).

[5] 3GPP Technical Specification 25.215, Physical Layer—Measurements (FDD).

[6] 3GPP Technical Specification 25.302, Services Provided by the Physical Layer.

[7] Adachi, F., Sawahashi, M., and Okawa, K., 'Tree-structured Generation of Orthogonal Spreading Codes with Different Lengths for Forward Link of DS-CDMA Mobile', *Electronics Letters*, 1997, Vol. 33, No. 1, pp. 27–28.

[8] 3GPP Technical Specification 25.101, UE Radio Transmission and Reception (FDD).

[9] 3GPP Technical Specification 25.104, UTRA (BS) FDD; Radio Transmission and Reception.

[10] Toskala, A., Lehtinen, O. and Kinnunen, P., 'UTRA GSM Handover from Physical Layer Perspective', *Proc. ACTS Summit 1999*, Sorrento, Italy, June 1999.

[11] Gustafsson, M., Jamal, K., and Dahlman, E., 'Compressed Mode Techniques for Inter-Frequency Measurements in a Wide-band DS-CDMA System', *Proc. IEEE Int. Conf. on Personal Indoor and Mobile Radio Communications*, PIMRC'97, Helsinki, Finland, 1–4 September 1997, Vol. 1, pp. 231–235.

[12] 3GPP Technical Specification 25.306, UE Radio Access Capabilities, version 3.0.0., December 2000.

7

Radio Interface Protocols

Jukka Vialén

7.1 Introduction

The radio interface protocols are needed to set up, reconfigure and release the Radio Bearer services (including the UTRA FDD/TDD service), which were discussed in Chapter 2.

The protocol layers above the physical layer are called the data link layer (layer 2) and the network layer (layer 3). In the UTRA FDD radio interface, layer 2 is split into sublayers. In the control plane, layer 2 contains two sublayers—Medium Access Control (MAC) protocol and Radio Link Control (RLC) protocol. In the user plane, in addition to MAC and RLC, two additional service-dependent protocols exist: Packet Data Convergence Protocol (PDCP) and Broadcast/Multicast Control Protocol (BMC). Layer 3 consists of one protocol, called Radio Resource Control (RRC), which belongs to the control plane. The other network layer protocols, such as Call Control, Mobility Management, Short Message Service, and so on, are transparent to UTRAN and are not described in this book.

In this chapter the general radio interface protocol architecture is first described before going into deeper details of each protocol. For each protocol, the logical architecture and main functions are described. In the MAC section also the logical channels (services offered by MAC) and mapping between logical channels and transport channels are explained. For MAC and RLC, an example layer model is defined to describe what happens to a data packet passing through these protocols. In the RRC section, the RRC service states are described together with the main (RRC) functions and signalling procedures.

7.2 Protocol Architecture

The overall radio interface protocol architecture [1] is shown in Figure 7.1. This figure contains only the protocols that are visible in UTRAN.

The physical layer offers services to the MAC layer via transport channels [2] that were characterised by *how and with what characteristics* data is transferred (transport channels were discussed in Chapter 6).

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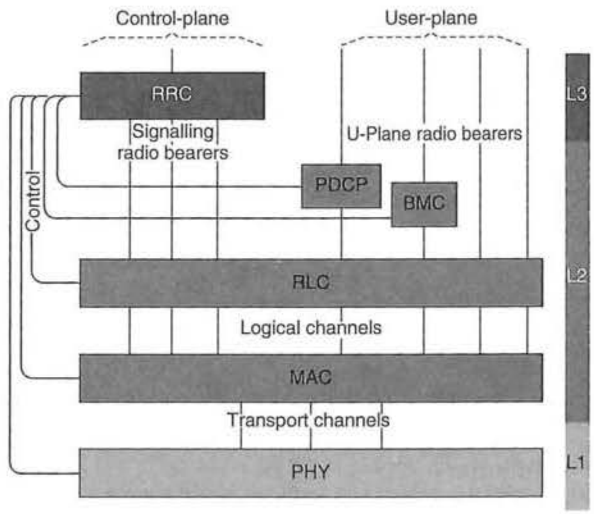

Figure 7.1. UTRA FDD Radio Interface protocol architecture

The MAC layer, in turn, offers services to the RLC layer by means of logical channels. The logical channels are characterised by *what type of data* is transmitted. Logical channels are described in detail in Section 7.3.

The RLC layer offers services to higher layers via service access points (SAPs), which describe how the RLC layer handles the data packets and if, for example, the automatic repeat request (ARQ) function is used. On the control plane, the RLC services are used by the RRC layer for signalling transport. On the user plane, the RLC services are used either by the service- specific protocol layers PDCP or BMC or by other higher-layer u-plane functions (e.g. speech codec). The RLC services are called Signalling Radio Bearers in the control plane and Radio Bearers in the user plane for services not utilising the PDCP or BMC protocols. The RLC protocol can operate in three modes—transparent, unacknowledged and acknowledged mode. These are further discussed in Section 7.4.

The Packet Data Convergence Protocol (PDCP) exists only for the PS domain services. Its main function is header compression. Services offered by PDCP are called Radio Bearers.

The Broadcast Multicast Control protocol (BMC) is used to convey over the radio interface messages originating from Cell Broadcast Center. In Release'99 of the 3GPP specifications, the only specified broadcasting service is the SMS Cell Broadcast service, which is derived from GSM. The service offered by BMC protocol is also called a Radio Bearer.

The RRC layer offers services to higher layers (to the Non Access Stratum) via service access points, which are used by the higher layer protocols in the UE side and by the Iu RANAP protocol in the UTRAN side. All higher layer signalling (mobility management, call control, session management, and so on) is encapsulated into RRC messages for transmission over the radio interface.

The control interfaces between the RRC and all the lower layer protocols are used by the RRC layer to configure characteristics of the lower layer protocol entities, including parameters for the physical, transport and logical channels. The same control interfaces are used by the RRC layer, for example to command the lower layers to perform certain types of measurements and by the lower layers to report measurement results and errors to the RRC.

7.3 The Medium Access Control Protocol

In the Medium Access Control (MAC) layer [5] the logical channels are mapped to the transport channels. The MAC layer is also responsible for selecting an appropriate transport format (TF) for each transport channel depending on the instantaneous source rate(s) of the logical channels. The transport format is selected with respect to the transport format combination set (TFCS) which is defined by the admission control for each connection.

7.3.1 MAC Layer Architecture

The MAC layer logical architecture is shown in Figure 7.2.

The MAC layer consists of three *logical entities*:

- **MAC-b** handles the broadcast channel (BCH). There is one MAC-b entity in each UE and one MAC-b in the UTRAN (located in Node B) for each cell.
- **MAC-c/sh** handles the common channels and shared channels—paging channel (PCH), forward link access channel (FACH), random access channel (RACH), uplink Common Packet Channel (CPCH) and Downlink Shared Channel (DSCH). There is one MAC-c/sh entity in each UE that is using shared channel(s) and one MAC-c/sh in the UTRAN (located in the controlling RNC) for each cell. Note that the BCCH logical channel can be mapped to either the BCH or FACH transport channel. Since the MAC header format for the BCCH depends on the transport channel used, two BCCH instances are shown in the figure. For PCCH, there is no MAC header, thus the only function of the MAC layer is to forward the data received from PCCH to the PCH at the time instant determined by RRC.
- **MAC-d** is responsible for handling dedicated channels (DCH) allocated to a UE in connected mode. There is one MAC-d entity in the UE and one MAC-d entity in the UTRAN (in the serving RNC) for each UE.

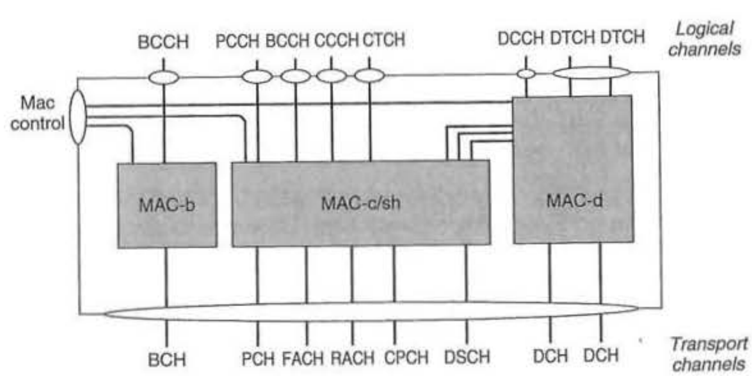

Figure 7.2. MAC layer architecture

7.3.2 MAC Functions

The functions of the MAC layer include:

— **Mapping between logical channels and transport channels.**

— **Selection of appropriate Transport Format (from the Transport Format Combination Set) for each Transport Channel, depending on the instantaneous source rate.**

— **Priority handling between data flows of one UE**. This is achieved by selecting 'high bit rate' and 'low bit rate' Transport Formats for different data flows.

— **Priority handling between UEs by means of dynamic scheduling**. A dynamic scheduling function may be applied for common and shared downlink transport channels FACH and DSCH.

— **Identification of UEs on common transport channels**. When a common transport channel (RACH, FACH or CPCH) carries data from dedicated-type logical channels (DCCH, DTCH), the identification of the UE (Cell Radio Network Temporary Identity (C-RNTI) or UTRAN Radio Network Temporary Identity (U-RNTI)) is included in the MAC header.

— **Multiplexing/demultiplexing of higher layer PDUs into/from transport blocks delivered to/from the physical layer on common transport channels**. MAC handles service multiplexing for common transport channels (RACH/FACH/CPCH). This is necessary, since it cannot be done in the physical layer.

— **Multiplexing/demultiplexing of higher layer PDUs into/from transport block sets delivered to/from the physical layer on dedicated transport channels**. MAC allows service multiplexing also for dedicated transport channels. While the physical layer multiplexing makes it possible to multiplex any type of service, including services with different quality of service parameters, MAC multiplexing is possible only for services with the same QoS parameters. Physical layer multiplexing is described in Chapter 6.

— **Traffic volume monitoring**. MAC receives RLC PDUs together with status information on the amount of data in the RLC transmission buffer. MAC compares the amount of data corresponding to a transport channel with the thresholds set by RRC. If the amount of data is too high or too low, MAC sends a measurement report on traffic volume status to RRC. The RRC can also request MAC to send these measurements periodically. The RRC use these reports for triggering reconfiguration of Radio Bearers and/or Transport Channels.

— **Dynamic Transport Channel type switching**. Execution of the switching between common and dedicated transport channels is based on a switching decision derived by RRC.

— **Ciphering**. If a radio bearer is using transparent RLC mode, ciphering is performed in the MAC sub-layer (MAC-d entity). Ciphering is a XOR operation (as in GSM and GPRS) where data is XORed with a ciphering mask produced by a ciphering algorithm. In MAC ciphering, the time-varying input parameter (COUNT-C) for the ciphering algorithm is incremented at each transmission time interval (TTI), that is, once every 10,20,40 or 80 ms depending on the transport channel configuration. Each radio bearer is ciphered separately. The ciphering details are described in 3GPP specification TS 33.102 [10].

— **Access Service Class (ASC) selection for RACH transmission**. The PRACH resources (i.e. access slots and preamble signatures for FDD) may be divided between different Access Service Classes in order to provide different priorities of RACH usage. Maximum number of ASCs is 8. MAC indicates the ASC associated with a PDU to the physical layer.

7.3.3 Logical Channels

The data transfer services of the MAC layer are provided on logical channels. A set of logical channel types is defined for the different kinds of data transfer services offered by MAC. A general classification of logical channels is into two groups: Control Channels and Traffic Channels. Control Channels are used to transfer control plane information, and Traffic Channels for user plane information.

The Control Channels are:

— Broadcast Control Channel (BCCH). A downlink channel for broadcasting system control information.

— Paging Control Channel (PCCH). A downlink channel that transfers paging information.

— Dedicated Control Channel (DCCH). A point-to-point bidirectional channel that transmits dedicated control information between a UE and the RNC. This channel is established during the RRC connection establishment procedure.

— Common Control Channel (CCCH). A bidirectional channel for transmitting control information between the network and UEs. This logical channel is always mapped onto RACH/FACH transport channels. A long UTRAN UE identity is required (U-RNTI, which includes SRNC address), so that the uplink messages can be routed to the correct serving RNC even if the RNC receiving the message is not the serving RNC of this UE.

The Traffic Channels are:

— Dedicated Traffic Channel (DTCH). A Dedicated Traffic Channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

— Common Traffic Channel (CTCH). A point-to-multipoint downlink channel for transfer of dedicated user information for all or a group of specified UEs.

7.3.4 Mapping Between Logical Channels And Transport Channels

The mapping between logical channels and transport channels is shown in Figure 7.3. The following connections between logical channels and transport channels exist:

— PCCH is connected to PCH.

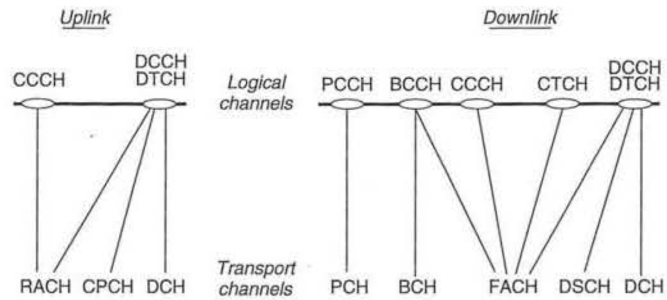

Figure 7.3. Mapping between logical channels and transport channels, uplink and downlink directions

— BCCH is connected to BCH and may also be connected to FACH.
— DCCH and DTCH can be connected to either RACH and FACH, to CPCH and FACH, to RACH and DSCH, to DCH and DSCH, or to a DCH and DCH.
— CCCH is connected to RACH and FACH.
— CTCH is connected to FACH.

7.3.5 Example Data Flow Through The MAC Layer

To illustrate the operation of the MAC layer, a block diagram in Figure 7.4 shows the MAC functions when data is processed through the layer. To keep the figure readable, the viewpoint is selected to be a network side transmitting entity, and uplink transport channels RACH and CPCH are omitted. The right-hand side of the figure describes the building of a MAC PDU when a packet received from DCCH or DTCH logical channel is processed by the MAC functions, which are shown in the left-hand side of the figure. In this example the MAC PDU is forwarded to the FACH transport channel.

A data packet arriving from the DCCH/DTCH logical channel triggers first the transport channel type selection in the MAC layer. In this example, the FACH transport channel is selected. In the next phase, the multiplexing unit adds a C/T field indicating the logical channel instance where the data originates. For common transport channels, such as FACH, this field is always needed. For dedicated transport channels (DCH) it is needed only if several logical channel instances are configured to use the same transport channel. The C/T field is 4 bits, allowing up to 15 simultaneous logical channels per transport channel (the value '1111' for the C/T field is reserved for future use). The priority tag (not part of the MAC PDU) for FACH and DSCH is set in MAC-d and used by MAC-c/sh when scheduling data onto transport channels. Priority for FACH can be set per UE; for DSCH it can be set per PDU. A flow control function in Iur interface (chapter 5) is needed to limit buffering between MAC-d and MAC-c/sh (which can be located in different RNCs). After receiving the data from MAC-d, the MAC-c/sh entity first adds the UE identification type (2 bits), the actual UE identification (C-RNTI 16 bits, or U-RNTI 32 bits), and the Target Channel Type Field (TCTF, in this example 2 bits) which is needed to separate the logical channel type using the transport channel (for FACH, the possible logical channel types could be BCCH, CCCH, CTCH or DCCH/DTCH). Now the MAC PDU is ready and the task for the scheduling/priority

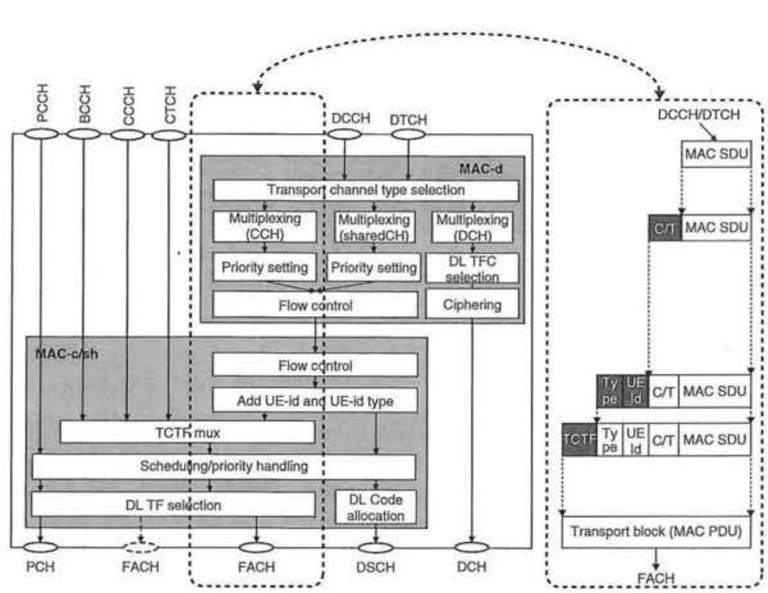

Figure 7.4. UTRAN side MAC entity (left side of figure) and building of MAC PDU when data received from DTCH or DCCH is mapped to FACH (right side of figure)

handling function is to decide the exact timing when the PDU is passed to layer 1 via the FACH transport channel (with an indication of the transport format to be used).

7.4 The Radio Link Control Protocol

The radio link control protocol [6] provides segmentation and retransmission services for both user and control data. Each RLC instance is configured by RRC to operate in one of three modes: transparent mode (Tr), unacknowledged mode (UM) or acknowledged mode (AM). The service the RLC layer provides in the control plane is called Signalling Radio Bearer (SRB). In the user plane, the service provided by the RLC layer is called a Radio Bearer (RB) only if the PDCP and BMC protocols are not used by that service, otherwise the RB service is provided by the PDCP or BMC.

7.4.1 RLC Layer Architecture

The RLC layer architecture is shown in Figure 7.5. All three RLC entity types and their connection to RLC-SAPs and to logical channels (MAC-SAPs) are shown. Note that the transparent and unacknowledged mode RLC entities are defined to be unidirectional, whereas the acknowledged mode entities are described as bidirectional.

For all RLC modes, the CRC error detection is performed on physical layer and the result of the CRC check is delivered to RLC together with the actual data.

In **transparent mode** no protocol overhead is added to higher layer data. Erroneous protocol data units (PDUs) can be discarded or marked erroneous. Transmission can be of the streaming type in which higher layer data is not segmented, though in special

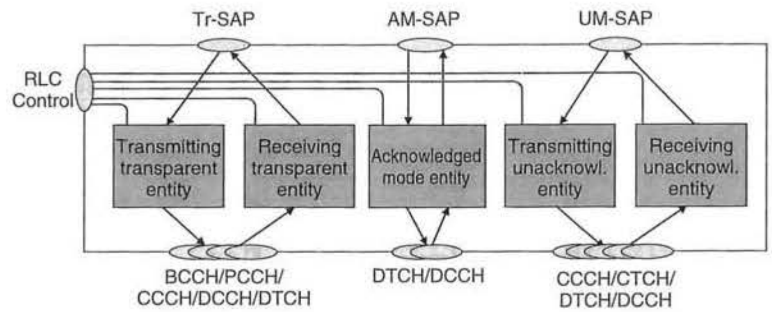

Figure 7.5. RLC layer architecture

cases transmission with limited segmentation/reassembly capability can be accomplished. If segmentation/reassembly is used, it has to be negotiated in the radio bearer setup procedure. The UMTS Quality of Service classes, including the streaming class, were introduced in Chapter 2.

In **unacknowledged mode** no retransmission protocol is in use and data delivery is not guaranteed. Received erroneous data is either marked or discarded depending on the configuration. On the sender side, a timer based discard without explicit signalling function is applied, thus RLC SDUs which are not transmitted within a specified time are simply removed from the transmission buffer. The PDU structure includes sequence numbers so that the integrity of higher layer PDUs can be observed. Segmentation and concatenation are provided by means of header fields added to the data. An RLC entity in unacknowledged mode is defined as unidirectional, because no association between uplink and downlink is needed. The unacknowledged mode is used, for example, for certain RRC signalling procedures, where the acknowledgement and retransmissions are part of the RRC procedure. Examples of user services that could utilize unacknowledged mode RLC are the cell broadcast service (see Section 7.6) and voice over IP (VoIP).

In the **acknowledged mode** an automatic repeat request (ARQ) mechanism is used for error correction. The quality vs. delay performance of the RLC can be controlled by RRC through configuration of the number of retransmissions provided by RLC. In case RLC is unable to deliver the data correctly (max number of retransmissions reached or the transmission time exceeded), the upper layer is notified and the RLC SDU is discarded. Also the peer entity is informed of a SDU discard operation by sending a Move Receiving Window command (in a STATUS message), so that also the receiver removes all AMD PDUs belonging to the discarded RLC SDU. An acknowledged mode RLC entity is bidirectional and capable of 'piggybacking' an indication of the status of the link in the opposite direction into user data. RLC can be configured for both in-sequence and out-of-sequence delivery. With in-sequence delivery the order of higher layer PDUs is maintained, whereas out-of-sequence delivery forwards higher layer PDUs as soon as they are completely received. In addition to data PDU delivery, *status* and *reset* control procedures can be signalled between peer RLC entities. The control procedures can even use a separate logical channel, thus one AM RLC entity can use either one or two logical channels. The acknowledged mode is the normal RLC mode for packet-type services, such as Internet browsing and email downloading, for example.

7.4.2 *RLC Functions*

The functions of the RLC layer are:

— **Segmentation and reassembly**. This function performs segmentation/reassembly of variable-length higher layer PDUs into/from smaller RLC Payload Units (PUs). One RLC PDU carries one PU. The RLC PDU size is set according to the smallest possible bit rate for the service using the RLC entity. Thus, for variable rate services, several RLC PDUs need to be transmitted during one transmission time interval when any bit rate higher than the lowest one is used.

— **Concatenation**. If the contents of an RLC SDU do not fill an integral number of RLC PUs, the first segment of the next RLC SDU may be put into the RLC PU in concatenation with the last segment of the previous RLC SDU.

— **Padding**. When concatenation is not applicable and the remaining data to be transmitted does not fill an entire RLC PDU of given size, the remainder of the data field is filled with padding bits.

— **Transfer of user data**. RLC supports acknowledged, unacknowledged and transparent data transfer. Transfer of user data is controlled by QoS setting.

— **Error correction**. This function provides error correction by retransmission in the acknowledged data transfer mode.

— **In-sequence delivery of higher layer PDUs**. This function preserves the order of higher layer PDUs that were submitted for transfer by RLC using the acknowledged data transfer service. If this function is not used, out-of-sequence delivery is provided.

— **Duplicate detection**. This function detects duplicated received RLC PDUs and ensures that the resultant higher layer PDU is delivered only once to the upper layer.

— **Flow control**. This function allows an RLC receiver to control the rate at which the peer RLC transmitting entity may send information.

— **Sequence number check (Unacknowledged data transfer mode)**. This function guarantees the integrity of reassembled PDUs and provides a means of detecting corrupted RLC SDUs through checking the sequence number in RLC PDUs when they are reassembled into a RLC SDU. A corrupted RLC SDU is discarded.

— **Protocol error detection and recovery**. This function detects and recovers from errors in the operation of the RLC protocol.

— **Ciphering** is performed in the RLC layer for acknowledged and unacknowledged RLC modes. The same ciphering algorithm is used as for MAC layer ciphering, the only difference being the time-varying input parameter (COUNT-C) for the algorithm, which for RLC is incremented together with the RLC PDU numbers. For retransmission, the same ciphering COUNT-C is used as for the original transmission (resulting in the same ciphering mask); this would not be so if ciphering were on the MAC layer. An identical ciphering mask for retransmission is essential, for example for Hybrid Type II ARQ, which is not part of a 3GPP Release-99 but a working item that may be added later to the standards. The ciphering details are described in 3GPP specification TS 33.102 [10].

— **Suspend/resume function for data transfer**. Suspension is needed during the security mode control procedure so that the same ciphering keys are always used by the peer entities. Suspensions and resumptions are local operations commanded by RRC via the control interface.

7.4.3 Example Data Flow Through The RLC Layer

This section takes a closer look at how data packets pass through the RLC layer. Figure 7.6 shows a simplified block diagram of an AM-RLC entity. The figure shows only how an AMD PDU can be constructed. It does not show how separate control PDUs (*status, reset*) between RLC entities are build.

Data packets (RLC SDUs) received from higher layers via AM-SAP are segmented and/or concatenated to payload units (PU) of fixed length. The PU length is a semi-static value that is decided in the Radio Bearer setup and can only be changed through the (RRC) Radio Bearer reconfiguration procedure. For concatenation or padding purposes, bits carrying information on the length and extension are inserted into the beginning of the last PU where data from an SDU is included. If several SDUs fit into one PU, they are concatenated and the appropriate length indicators are inserted into the beginning of the PU.

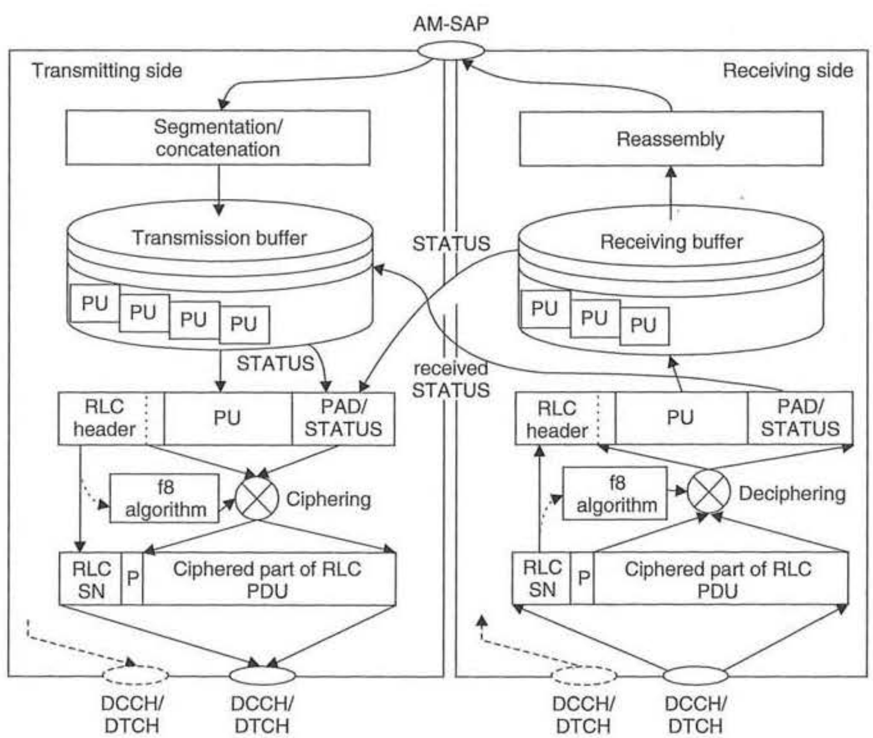

Figure 7.6. A simplified block diagram of an RLC AM entity

The PUs are then placed in the transmission buffer, which, in this example, also takes care of retransmission management.

An RLC AMD PDU is constructed by taking one PU from the transmission buffer, adding a header for it and, if the data in the PU does not fill the whole RLC AMD PDU, a PADding field or piggybacked STATUS message is appended. The piggybacked STATUS message can originate either from the receiving side (if the peer entity has requested a status report) or from the transmitting side to indicate a RLC SDU discard. The header contains the RLC PDU sequence number SN (12 bits for AM-RLC), poll bit P (which is used to request STATUS from the peer entity) and optionally a length indicator (7 or 15 bits), which is used if concatenation of SDUs, padding or a piggybacked STATUS PDU takes place in the RLC PDU.

Next, the AM RLC PDU is ciphered, excluding the two first octets which comprise the PDU sequence number (SN) and the poll bit (P). The PDU sequence number is one input parameter to the ciphering algorithm (forming the least significant bits of a COUNT-C parameter), and it must be readable by the peer entity to be able to perform deciphering. The details of the ciphering process are described in 3GPP specification TS 33.102 [10].

After this the PDU is ready to be forwarded to the MAC layer via a logical channel. In Figure 7.6, extra logical channels are shown by dashed lines, indicating that one RLC entity can be configured to send control PDUs and data PDUs using different logical channels. Note, however, that Figure 7.6 does not describe how the separate control PDUs are constructed.

The receiving side of the AM entity receives RLC AMD PDUs through one of the logical channels from the MAC sublayer. Errors are checked with the (physical layer) CRC, which is calculated over the whole RLC PDU. The actual CRC check is performed in the physical layer and the RLC entity receives result of this CRC check together with the data. After deciphering, the whole header and possible piggybacked status information can be extracted from the RLC PDU. If the received PDU was a control message or if status information was piggybacked to an AMD PDU, the control information (STATUS message) is passed to the transmitting side, which will check its retransmission buffer against the received status information. The PDU number from the RLC header is needed for deciphering and also when storing the deciphered PU into the receiving buffer. Once all PUs belonging to a complete SDU are in the receiving buffer, the SDU is reassembled. After this (not shown in the figure), the checks for in-sequence delivery and duplicate detection are performed before the RLC SDU is delivered to the higher layer.

7.5 The Packet Data Convergence Protocol

The Packet Data Convergence Protocol (PDCP) [7] exists only in the user plane and only for services from the PS domain. The PDCP contains compression methods, which are needed to get better spectral efficiency for services requiring IP packets to be transmitted over the radio. For 3GPP Release-99 standards, a header compression method is defined, for which several header compression algorithms can be used. As an example of why header compression is valuable, the size of the combined RTP/UDP/IP headers is at least 40 bytes for IPv4 and at least 60 bytes for IPv6, while the payload, for example for IP voice service, can be about 20 bytes or less.

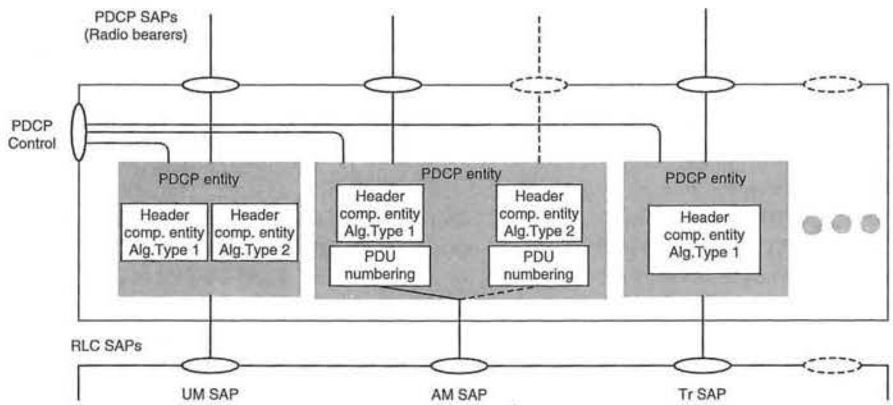

Figure 7.7. The PDCP layer architecture

7.5.1 PDCP Layer Architecture

An example of the PDCP layer architecture is shown in Figure 7.7. Multiplexing of Radio Bearers in the PDCP layer is not part of 3GPP Release-99 but is one possible feature for future releases. The multiplexing possibility is illustrated in Figure 7.7 with the two PDCP SAPs (one with dashed lines) provided by one PDCP entity using AM RLC. Every PDCP entity uses zero, one or several header compression algorithm types with a set of configurable parameters. Several PDCP entities may use the same algorithm types. The algorithm types and their parameters are negotiated during the RRC Radio Bearer establishment or reconfiguration procedures and indicated to the PDCP through the PDCP Control Service Access Point.

7.5.2 PDCP Functions

The main PDCP functions are:

— Compression of redundant protocol control information (e.g. TCP/IP and RTP/UDP/IP headers) at the transmitting entity, and decompression at the receiving entity. The header compression method is specific to the particular network layer, transport layer or upper layer protocol combinations, for example TCP/IP and RTP/UDP/IP. The only compression method that is mentioned in the PDCP Release-99 specification is RFC2507 [13].

— Transfer of user data. This means that the PDCP receives a PDCP SDU from the non-access stratum and forwards it to the appropriate RLC entity and vice versa.

— Support for lossless SRNS relocation. In practice this means that those PDCP entities which are configured to support lossless SRNS relocation have PDU sequence numbers, which, together with unconfirmed PDCP packets are forwarded to the new SRNC during relocation. Only applicable when PDCP is using acknowledged mode RLC with in-sequence delivery.

7.6 The Broadcast/Multicast Control Protocol

The other service-specific layer 2 protocol—the Broadcast/Multicast Control (BMC) protocol [8]—exists also only in the user plane. This protocol is designed to adapt broadcast and multicast services, originating from the Broadcast domain, on the radio interface. In the Release-99 of the standard, the only service utilising this protocol is the SMS Cell Broadcast service. This service is directly taken from GSM. It utilises UM RLC using the CTCH logical channel which is mapped into the FACH transport channel. Each SMS CB message is targeted to a geographical area, and RNC maps this area into cells.

7.6.1 BMC Layer Architecture

The BMC protocol, shown in Figure 7.8, does not have any special logical architecture.

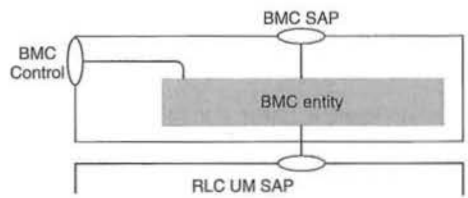

Figure 7.8. The Broadcast/Multicast Control layer architecture

7.6.2 BMC Functions

The main functions of the BMC protocol are:

— **Storage of Cell Broadcast messages**. The BMC in RNC stores the Cell Broadcast messages received over the CBC—RNC interface for scheduled transmission.

— **Traffic volume monitoring and radio resource request for CBS**. On the UTRAN side, the BMC calculates the required transmission rate for the Cell Broadcast Service based on the messages received over the CBC—RNC interface, and requests appropriate CTCH/FACH resources from RRC.

— **Scheduling of BMC messages**. The BMC receives scheduling information together with each Cell Broadcast message over the CBC—RNC interface. Based on this scheduling information, on the UTRAN side the BMC generates schedule messages and schedules BMC message sequences accordingly. On the UE side, the BMC evaluates the schedule messages and indicates scheduling parameters to RRC, which are used by RRC to configure the lower layers for CBS discontinuous reception.

— **Transmission of BMC messages to UE**. This function transmits the BMC messages (Scheduling and Cell Broadcast messages) according to the schedule.

— **Delivery of Cell Broadcast messages to the upper layer**. This UE function delivers the received non-corrupted Cell Broadcast messages to the upper layer.

When sending SMS CB messages to a cell for the first time, appropriate capacity has to be allocated in the cell. The CTCH has to be configured and the transport channel used has to be indicated to all UEs via (RRC) system information broadcast on the BCH. The capacity allocated for SMS CB is cell-specific and may vary over time to allow efficient use of the radio resources.

7.7 The Radio Resource Control Protocol

The major part of the control signalling between UE and UTRAN is Radio Resource Control (RRC) [3][9] messages. RRC messages carry all parameters required to set up, modify and release layer 2 and layer 1 protocol entities. RRC messages carry in their payload also all higher layer signalling (MM, CM, SM, etc.). The mobility of user equipment in the connected mode is controlled by RRC signalling (measurements, handovers, cell updates, etc.).

7.7.1 RRC Layer Logical Architecture

The RRC layer logical architecture is shown in Figure 7.9.

The RRC layer can be described with four *functional entities:*

— The Dedicated Control Function Entity (DCFE) handles all functions and signalling specific to one UE. In the SRNC there is one DCFE entity for each UE having an RRC connection with this RNC. DCFE uses mostly acknowledged mode RLC (AM-SAP), but some messages are sent using unacknowledged mode SAP (e.g. RRC Connection Release) or transparent SAP (e.g. Cell Update). DCFE can utilize services from all Signalling Radio Bearers, which are described in Chapter 7.7.3.4.

— The Paging and Notification control Function Entity (PNFE) handles paging of idle mode UE(s). There is at least one PNFE in the RNC for each cell controlled by this RNC. The PNFE uses the PCCH logical channel normally via transparent SAP of RLC. However, the specification mentions that PNFE could utilize also UM-SAP. In this example architecture the PNFE in RNC, when receiving a paging message from an Iu interface, needs to check with the DCFE whether or not this UE already has

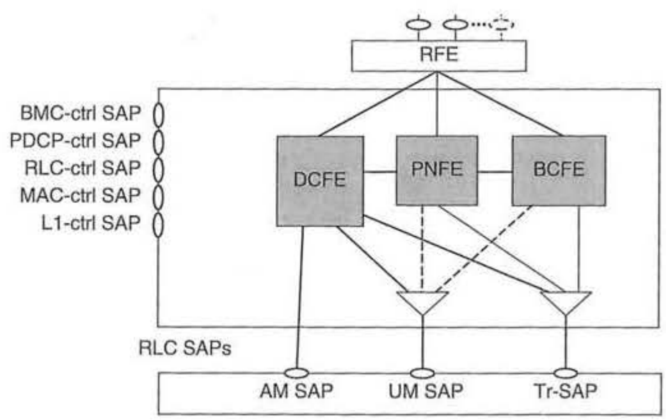

Figure 7.9. RRC layer architecture

an RRC connection (signalling connection with another CN domain); if it does, the paging message is sent (by the DCFE) using the existing RRC connection.

— The broadcast control function entity (BCFE) handles the system information broadcasting. There is at least one BCFE for each cell in the RNC. The BCFE uses either BCCH or FACH logical channels, normally via transparent SAP. The specification mentions that BFCE could utilize also UM-SAP.

— The fourth entity is normally drawn outside of the RRC protocol, but still belonging to access stratum and 'logically' to RRC layer, since the information required by this entity is part of RRC messages. The entity is called Routing Function Entity (RFE) and its task is the routing of higher layer (non access stratum) messages to different MM/CM entities (UE side) or different core network domains (UTRAN side). Every higher layer message is piggybacked into the RRC *Direct Transfer* messages (three types of Direct Transfer messages are specified, *Initial Direct Transfer* (uplink), *Uplink Direct Transfer* and *Downlink Direct Transfer).*

7.7.2 RRC Service States

The two basic operational modes of a UE are *idle mode* and *connected mode*. The connected mode can be further divided into service states, which define what kind of physical channels a UE is using. Figure 7.10 shows the main RRC service states in the connected mode. It also shows the transitions between idle mode and connected mode and the possible transitions within the connected mode.

In the idle mode [4], after the UE is switched on, it selects (either automatically or manually) a PLMN to contact. The UE looks for a suitable cell of the chosen PLMN, chooses that cell to provide available services, and tunes to its control channel. This choosing is known as 'camping on a cell'. The cell search procedure described in Chapter 6 is part of this camping process. After camping on a cell in idle mode, the UE is able to receive system information and cell broadcast messages. The UE stays in idle mode until it transmits a request to establish an RRC connection (Section 7.7.3.4). In idle mode the UE is identified by non-access stratum identities such as IMSI, TMSI and P-TMSI. In addition, the UTRAN has no information of its own about the individual idle mode UEs and can only address, for example, all UEs in a cell or all UEs monitoring a paging occasion.

In the **Cell_DCH** state a dedicated physical channel is allocated to the UE, and the UE is known by its serving RNC on a cell or active set level. The UE performs measurements and sends measurement reports according to measurement control information received from

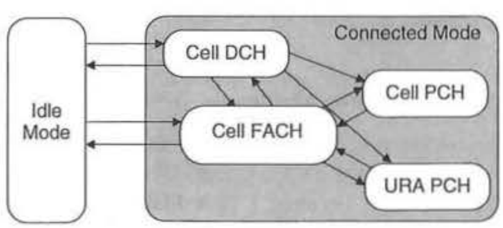

Figure 7.10. UE modes and RRC states in connected mode

RNC. The DSCH can also be used in this state, and UEs with certain capabilities are also able to monitor the FACH channel for system information messages.

In the **Cell_FACH** state no dedicated physical channel is allocated for the UE, but RACH and FACH channels are used instead, for transmitting both signalling messages and small amounts of user plane data. In this state the UE is also capable of listening to the broadcast channel (BCH) to acquire system information. The CPCH channel can also be used when instructed by UTRAN. In this state the UE performs cell reselections, and after a reselection always sends a Cell Update message to the RNC, so that the RNC knows the UE location on a cell level. For identification, a C-RNTI in the MAC PDU header separates UEs from each other in a cell. When the UE performs cell reselection it uses the U-RNTI when sending the Cell Update message, so that UTRAN can route the Cell Update message to the current serving RNC of the UE, even if the first RNC receiving the message is not the current SRNC. The U-RNTI is part of the RRC message, not in the MAC header. If the new cell belongs to another radio access system, such as GPRS, the UE enters idle mode and accesses the other system according to that system's access procedure.

In the **Cell_PCH** state the UE is still known on a cell level in SRNC, but it can be reached only via the paging channel (PCH). In this state the UE battery consumption is less than in the Cell_FACH state, since the monitoring of the paging channel includes a discontinuous reception (DRX) functionality. The UE also listens to system information on BCH. A UE supporting the Cell Broadcast Service (CBS) is also capable of receiving BMC messages in this state. If the UE performs a cell reselection, it moves autonomously to the Cell_FACH state to execute the Cell Update procedure, after which it re-enters the Cell_PCH state if no other activity is triggered during the Cell Update procedure. If a new cell is selected from another radio access system, the UTRAN state is changed to idle mode and access to the other system is performed according to that system's specifications.

The **URA_PCH** state is very similar to the Cell_PCH, except that the UE does not execute Cell Update after each cell reselection, but instead reads UTRAN Registration Area (URA) identities from the broadcast channel, and only if the URA changes (after cell reselection) does UE inform its location to the SRNC. This is achieved with the URA Update procedure, which is similar to the Cell Update procedure (the UE enters the Cell_FACH state to execute the procedure and then reverts to the URA_PCH state). One cell can belong to one or many URAs, and only if the UE cannot find its latest URA identification from the list of URAs in a cell does it need to execute the URA Update procedure. This 'overlapping URA' feature is needed to avoid ping-pong effects in a possible network configuration, where geographically succeeding base stations are controlled by different RNCs.

The UE leaves the connected mode and returns to idle mode when the RRC connection is released or at RRC connection failure.

7.7.2.1 Enhanced State Model For Multimode Terminals

Figure 7.11 presents an overview of the possible state transitions of a multimode terminal, in this example a UTRA FDD—GSM/GPRS terminal. With these terminal types it is possible to perform inter-system handover between UTRA FDD and GSM, and inter-system cell reselection from UTRA FDD to GPRS. The actual signalling procedures that relate to the thick arrows in Figure 7.11 are described in Section 7.7.3.

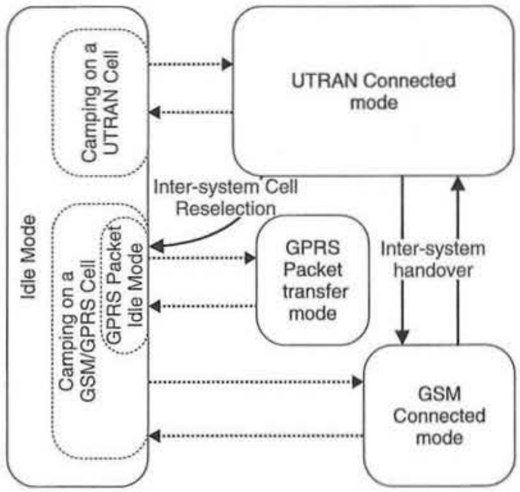

Figure 7.11. UE RRC states for a dual mode UTRA FDD—GSM/GPRS terminal

7.7.3 RRC Functions And Signalling Procedures

Since the RRC layer handles the main part of control signalling between the UEs and UTRAN, it has a long list of functions to perform. Most of these functions are part of the RRM algorithms, which are discussed in Chapters 9 and 10, but since the information is carried in RRC layer messages, the specifications list the functions as part of the RRC protocol. The main RRC functions are:

— Broadcast of system information, related to access stratum and non-access stratum
— Paging
— Initial cell selection and reselection in idle mode
— Establishment, maintenance and release of an RRC connection between the UE and UTRAN
— Control of Radio Bearers, transport channels and physical channels
— Control of security functions (ciphering and integrity protection)
— Integrity protection of signalling messages
— UE measurement reporting and control of the reporting
— RRC connection mobility functions
— Support of SRNS relocation
— Support for downlink outer loop power control in the UE
— Open loop power control
— Cell broadcast service related functions
— Support for UE Positioning functions.

In the following sections, these functions and related signalling procedures are described in more detail.

7.7.3.1 Broadcast Of System Information

The broadcast system information originates from the Core Network, from RNC and from Node Bs. The *System Information* messages are sent on a BCCH logical channel, which can be mapped to the BCH or FACH transport channel. A System Information message carries *system information blocks* (SIBs), which group together system information elements of the same nature. Dynamic (i.e. frequently changing) parameters are grouped into different SIBs from the more static parameters. One System Information message can carry either several SIBs or only part of one SIB, depending on the size of the SIBs to be transmitted. One System Information message will always fit into the size of a BCH or FACH transport block. If padding is required, it is inserted by the RRC layer.

The system information blocks are organised as a tree (Figure 7.12). A *master information block* (MIB) gives references and scheduling information to a number of system information blocks in a cell. It may also include reference and scheduling information to one or two *scheduling blocks*, which give references and scheduling information for all additional system information blocks. The master information block is sent regularly on the BCH and its scheduling is static. In addition to scheduling information of other SIBs and scheduling blocks, the master information block contains only the parameters 'Supported PLMN Types' and depending on which PLMN types are supported, either 'PLMN identity' (GSM MAP) or 'ANSI-41 Core Network Information'. The system information blocks contain all the other actual system information.

The scheduling information (included in the MIB or in scheduling blocks) for SIBs containing frequently changing parameters contains a SIB specific timers (value in frames), which can be used by the UE to trigger re-reading of each block.

For the other SIBs (with more 'static' parameters) the master information block, or the 'parent' SIB, contains, as part of the scheduling information, a 'value tag' that the UE

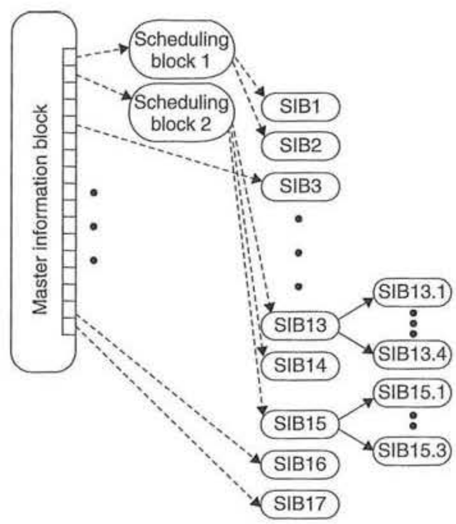

Figure 7.12. The overall structure of system information blocks in 3GPP Release-99. Dotter arrows show an example where scheduling information for each SIB could be included.

compares to the latest read 'value tag' of this system information block. Only if the value tag has changed after the last reading of the SIB in question does the UE re-read it. Thus, by monitoring the master information block and the scheduling blocks, the UE can notice if any of the system information blocks (of the more 'static' nature) has changed. UTRAN can also inform of the change in system information with *Paging* messages sent on the PCH transport channel (see Section 7.7.3.2) or with a *System Information Change Indication* message on the FACH transport channel. With these two messages, all UEs needing information about a change in the system information (all UEs in the Cell_FACH, Cell_PCH and URA_PCH states) can be reached.

The number of system information blocks in 3GPP Release-99 is one master information block, two scheduling blocks and 17 SIBs. Only SIB number 10, containing information needed only in Cell_DCH state, is sent using FACH transport channel, all other SIBs (incl. MIB and scheduling blocks) are sent on BCH. Scheduling information for each SIB can be included only into one place, either in MIB or in one of the scheduling blocks.

7.7.3.2 Paging

The RRC layer can broadcast paging information on the PCCH from the network to selected UEs in a cell. The paging procedure can be used for three purposes:

— At core network-originated call or session setup. In this case the request to start paging comes from the Core Network via the Iu interface

— To change the UE state from Cell_PCH or URA_PCH to Cell_FACH. This can be initiated, for example, by downlink packet data activity.

— To indicate change in the system information. In this case RNC sends a paging message with no paging records but with information describing a new 'value tag' for the master information block. This type of paging is targeted to all UEs in a cell.

7.7.3.3 Initial Cell Selection And Reselection In Idle Mode

The most suitable cell is selected, based on idle mode measurements and cell selection criteria. The cell search procedure described in Chapter 6 is part of the cell selection process.

7.7.3.4 Establishment, Maintenance And Release Of RRC Connection

The establishment of an RRC connection and Signalling Radio Bearers (SRB) between UE and UTRAN (RNC) is initiated by a request from higher layers (non-access stratum) on the UE side. In a network- originated case the establishment is preceded by an RRC *Paging* message. The request from non-access stratum is actually a request to set up a Signalling Connection between UE and CN (Signalling Connection consists of a RRC Connection and a Iu Connection). Only if the UE is in idle mode, thus no RRC connection exists, the UE initiates RRC Connection Establishment procedure. There can always be only zero or one RRC connections between one UE and UTRAN. If more than one signalling connection between UE and CN nodes exist, they all 'share' the same RRC connection.

The 'maintenance' of RRC connection refers to the RRC Connection Re-establishment functionality, which can be used to re-establish a connection after radio link failure. Timers are used to control the allowed time for a UE to return to "in-service-area" and to execute the re-establishment. The re-establishment functionality is included into the Cell Update procedure (7.7.3.9).

The RRC connection establishment procedure is shown in Figure 7.13. There is no need for a contention resolution step such as in GSM [12], since the UE identifier used in the connection equest and setup messages is a unique UE identity (for GSM based core network P-TMSI+RAI, TMSI+LAI or IMSI). In the RRC connection establishment procedure this initial UE identifier is used only for the purpose of uniqueness and can be discarded by UTRAN after the procedure ends. Thus, when these UE identities are later needed for the higher layer (Non Access Stratum) signalling, they must be resent (in the higher layer messages). The RRC *Connection Setup* message may include a dedicated physical channel assignment for the UE (move to Cell_DCH state), or it can command the UE to use common channels (move to Cell_FACH state). In the latter case, a radio network temporary identity (U-RNTI and possibly C-RNTI) to be used as UE identity on common transport channels is allocated to the UE.

The channel names in Figure 7.13 indicate either the logical channel or logical/transport channel used for each message.

The RRC connection establishment procedure creates three (optionally four) Signalling Radio Bearers (SRBs) designated by the RB identities #1 ... #4 (RB identity #0 is reserved for signalling using CCCH). The SRBs can later be created, reconfigured or even deleted with the normal Radio Bearer control procedures. The SRBs are used for RRC signalling according to the following rules:

— RB#1 is used for all messages sent on the DCCH and RLC-UM.

— RB#2 is used for all messages sent on the DCCH and RLC-AM, except for the *Direct Transfer* messages.

— RB#3 is used for the *Direct Transfer* messages (using DCCH and RLC-AM), which carries higher layer signalling. The reason for reserving a dedicated signalling radio bearer for the *Direct Transfer* is to enable prioritisation of UE-UTRAN signalling over the UE-CN signalling by using the RLC services (no need for extra RRC functionality).

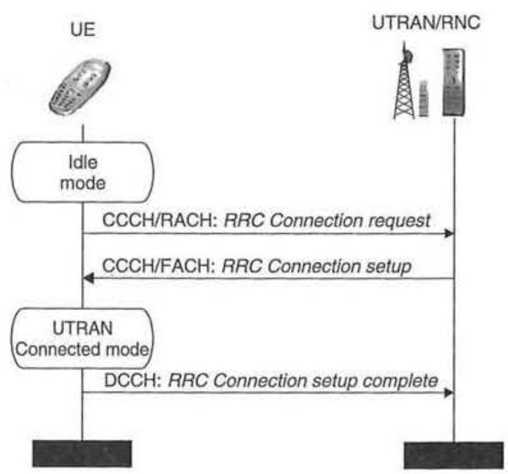

Figure 7.13. RRC connection establishment procedure

— RB#4 is optional and, if it exists, is also used for the *Direct Transfer* messages (using DCCH and RLC-AM). With two SRBs carrying higher layer signalling, UTRAN can handle prioritisation on signalling, RB#4 being used for 'low priority' and RB#3 for 'high priority' NAS signalling. The priority level is indicated to RRC with the actual NAS message to be carried over the radio. An example of low priority signalling could be the SMS.

— For RRC messages utilizing transparent mode RLC and CCCH logical channel (e.g. Cell Update, URA Update), RB identity #0 is used. A special function required in RRC layer for these messages is padding, because RLC in transparent mode does neither impose size requirements nor perform padding but the message size must still equal to a Transport Block size.

7.7.3.5 Control Of Radio Bearers, Transport Channels And Physical Channels

On request from higher layers, RRC performs the establishment, reconfiguration and release of Radio Bearers. At establishment and reconfiguration, UTRAN (RNC) performs admission control and selects parameters describing the Radio Bearer processing in layer 2 and layer 1. The SRBs are normally set up during the RRC Connection Establishment procedure (Section 7.7.3.4) but can also be controlled with the normal Radio Bearer procedures.

The transport channel and physical channel parameters are included in the Radio Bearer procedures but can also be configured separately with transport channel and physical channel dedicated procedures. These are needed, for example, if temporary congestion occurs in the network or when switching the UE between Cell_DCH and Cell_FACH states.

7.7.3.6 Control Of Security Functions

The RRC *Security Mode Control* procedure is used to start ciphering and integrity protection between the UE and UTRAN and to trigger the change of the ciphering and integrity keys during the connection.

The ciphering key is CN domain specific; thus in a typical network configuration (see Chapter 5), two ciphering keys can be used simultaneously for one UE—one for the PS domain services and one for the CS domain services. For the signalling (that uses common Radio Bearer(s) for both CN domains) the newer of these two keys is used. Ciphering is executed on the RLC layer for services using unacknowledged or acknowledged RLC and on the MAC layer for services using transparent RLC.

Integrity protection (see next section) is used only for signalling. In a typical network configuration two integrity keys would be available, but since only one RRC Connection can exist per UE, all signalling is protected with one and the same integrity key, which is always the newer of the keys IK_{CS} and IK_{PS}.

7.7.3.7 Integrity Protection Of Signalling

The RRC layer inserts a 32-bit integrity checksum, called a Message Authentication Code MAC-I, into most RRC PDUs. The integrity checksum is used by the receiving RRC entity to verify the origin and integrity of the messages. The receiving entity also calculates MAC-I and compares it to the one received with the signalling message. Messages received with wrong or missing message authentication code are discarded. Since all higher layer (non access stratum) signalling is carried in *RRC Direct Transfer* messages, all higher layer messages are automatically also integrity protected. The only exception to this is the initial higher layer message carried in *Initial Direct Transfer* message.

The checksum is calculated using UMTS integrity algorithm (UIA) that uses a secret 128-bit integrity key (IK) as one input parameter. The key is generated together with the ciphering key (CK) during the authentication procedure [11]. Figure 7.14 illustrates the calculation of MAC-I using the integrity algorithm f9 [15]. In addition to the IK, other parameters used as input to the algorithm are COUNT-I, which is incremented by one for each integrity protected message, a random number FRESH generated by RNC, DIRECTION bit (uplink/downlink), and the actual signalling message. Also the signalling radio bearer identity should affect the calculation of MAC-I. Since the algorithm f9 was ready when this requirement was identified, no new input parameter could be added to the f9 algorithm. The signalling radio bearer identity is inserted into the MESSAGE before it is given to the integrity algorithm.

Only a few RRC messages cannot be integrity protected; examples are the messages exchanged during RRC Connection Establishment procedure, since the algorithms and parameters are not yet negotiated when these messages are sent.

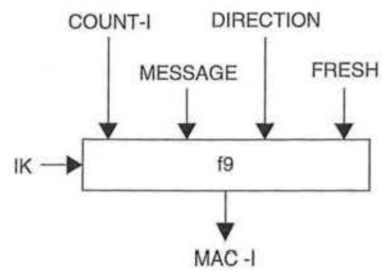

Figure 7.14. Calculation of message authentication code MAC-I

7.7.3.8 UE Measurement Reporting And Control

The measurements performed by the UE are controlled by the RNC using RRC protocol messages, in terms of what to measure, when to measure and how to report, including both UTRA radio interface and other systems. RRC signalling is also used in reporting of the measurements from the UE to the UTRAN (RNC).

Measurement Control

The measurement control (and reporting) procedure is designed to be very flexible. Serving RNC may start, stop or modify a number of parallel measurements in the UE and each of these measurements (including how they are reported) can be controlled independently of each other. The measurement control information is included in *System Information Block Type 12* and *System Information Block Type 11*. For UEs in Cell_DCH state also a dedicated *Measurement Control* message can be used. This is illustrated in Figure 7.15.

The measurement control information includes:

— *Measurement identity number*: A reference number that is used by the UTRAN at modification or release of the measurement and by the UE in the measurement report.

— *Measurement command*: May be either setup, modify or release.

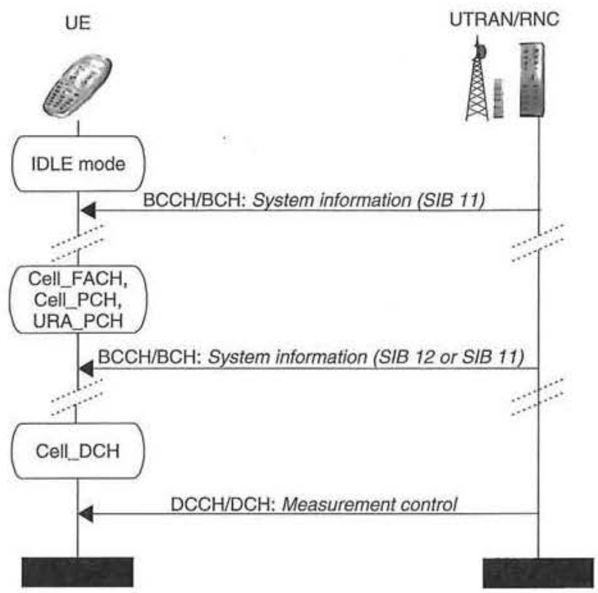

Figure 7.15. Measurement control procedures in different UE states

- *Measurement type*: One of the seven types from a predefined list, where each type describes what the UE measures. The seven types of measurements are defined as:
  - Intra-frequency measurements: measurements on downlink physical channels at the same frequency as the active set
  - Inter-frequency measurements: measurements on downlink physical channels at frequencies that differ from the frequency of the active set
  - Inter-system measurements: measurements on downlink physical channels belonging to a radio access system other than UTRAN, e.g. GSM
  - Traffic volume measurements: measurements on uplink traffic volume, e.g. RLC buffer payload for each Radio Bearer
  - Quality measurements: measurements of quality parameters, e.g. downlink transport channel block error rate
  - Internal measurements: measurements of UE transmission power and UE received signal level.
  - Measurements for Location Services (LCS) [14]. The basic measurement provided by the UE for the network based OTDOA-IPDL positioning method is Observed Time Difference of system frame numbers (SFN) between measured cells.
- *Measurement objects*: The objects the UE shall measure, and corresponding object information. In handover measurements this is the cell information needed by the UE to make measurements on certain intra-frequency, inter-frequency or inter-system cells. In traffic volume measurements this parameter contains transport channel identification.
- *Measurement quantity*: The quantity the UE measures.

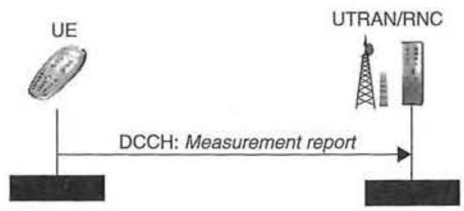

Figure 7.16. Measurement reporting procedure

- *Measurement reporting quantities*: The quantities the UE includes in the report.
- *Measurement reporting criteria*: The criteria that trigger the measurement report, such as periodical or event-triggered reporting.
- *Reporting mode*: This specifies whether the UE transmits the measurement report using acknowledged or unacknowledged data transfer of RLC.

Measurement Reporting

The measurement reporting procedure—shown in Figure 7.16—is initiated from the UE side when the reporting criteria are met. The UE sends a *Measurement Report* message, including the measurement identity number and the measurement results.

The *Measurement Report* message is used in the Cell_DCH and Cell_FACH states. In the Cell_FACH state, it is used only for a traffic volume measurement report. Traffic volume measurements may be triggered also in Cell_PCH and URA_PCH states, but the UE has to first change to Cell_FACH state before being able to send a measurement report.. In order to receive measurement information needed for the immediate establishment of macrodiversity when establishing a dedicated physical channel, the UTRAN may also request the UE to append radio link-related (intra-frequency) measurement reports to the following messages when they are sent on the RACH channel:

- *RRC Connection Request* message sent to establish an RRC connection.
- *Initial Direct Transfer* and *Uplink Direct Transfer* messages.
- *Cell Update* message
- *Measurement Report* message sent to report uplink traffic volume in Cell_FACH state.

7.7.3.9 RRC Connection Mobility Functions

RRC 'connection mobility' means keeping track of a UE's location (on a cell or active set level) while the UE is in UTRAN Connected mode. For this, a number of RRC procedures are defined. When dedicated channels are allocated to a UE, a normal way to perform mobility control is to use *Active Set Update* and *Hard Handover* procedures. When the UE is using only common channels (RACH/FACH/PCH) while in the UTRAN Connected mode, specific procedures are used to keep track of UE location either on cell or on UTRAN Registration Area (URA) level.

The UE mobility-related RRC procedures include:

- *Active Set Update* to update the UE's active set while in the Cell_DCH state.

— *Hard Handover* to make inter-frequency or intra-frequency hard handovers while in the Cell_DCH state.
— *Inter-system handover* between UTRAN and another radio access system (e.g. GSM).
— *Inter-system cell reselection* between UTRAN and another radio access system (e.g. GPRS).
— *Inter-system cell change order* between UTRAN and another radio access system (e.g. GPRS)
— *Cell Update* to report the UE location into RNC while in the Cell_FACH or Cell_PCH state.
— *URA Update* to report the UE location into RNC while in the URA_PCH state.

These procedures are described in the following sections.

Active Set Update

The purpose of the active set update procedure is to update the active set of the connection between the UE and UTRAN while the UE is in the Cell_DCH state. The procedure—shown in Figure 7.17—can have one of the following three functions: radio link addition, radio link removal, or combined radio link addition and removal. The maximum number of simultaneous radio links is 8 and it is possible to remove even all of them with one Active Set Update command. The soft handover algorithm and its performance are discussed in Section 9.3.1.

Figure 7.17. Active Set Update procedure

Hard Handover

The Hard Handover procedure can be used to change the radio frequency band of the connection between the UE and UTRAN or to change the cell on the same frequency when no network support of macro diversity exists. It can also be used to change the mode between FDD and TDD. This procedure is used only in the Cell_DCH state. No dedicated signalling messages have been defined for the Hard Handover but the functionality can be performed as part of the following RRC procedures: Physical channel reconfiguration, Radio bearer establishment, Radio bearer reconfiguration, Radio bearer release and Transport channel reconfiguration.

Inter-System Handover From UTRAN

The inter-system handover from UTRAN procedure is shown in Figure 7.18. This procedure is used for handover from UTRAN to another radio access system when the UE has at least

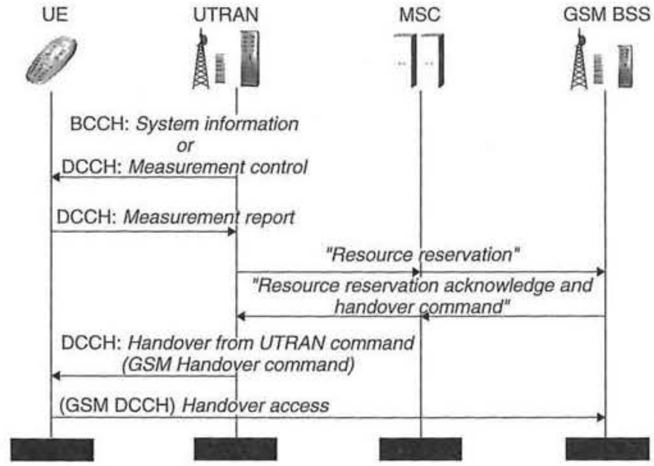

Figure 7.18. Inter-system handover procedure from UTRAN to GSM

one RAB in use for a CS domain service. For Release'99 UE, only support of handover of one RAB is expected, although the specification allows also handover of multiple RABs and even RABs from CS and PS domains simultaneously. In this example the target system is GSM, but the specifications also support handover to PCS 1900 and cdma2000 radio access systems. This procedure may be used in the Cell_DCH and Cell_FACH states. The UE receives the GSM neighbour cell parameters [12] either on *System Information or in a Measurement* Control message. These parameters are required to be able to measure candidate GSM cells. Based on the measurement report from UE, including GSM measurements, RNC makes a handover decision. After resources have been reserved from GSM BSS, the RNC sends an *Handover From UTRAN Command* message that carries a piggybacked *GSM Handover Command.* At this point the GSM RR protocol in UE takes control and sends a *GSM Handover Access* message to GSM BSC. After successful completion of the handover procedure, GSM BSS initiates resource release from UTRAN which will release the radio connection and remove all context information for the UE concerned.

Inter-System Handover To UTRAN

The inter-system handover to UTRAN procedure is shown in Figure 7.19. This procedure is used for handover from a non-UTRAN system to UTRAN. In this example, the other system is again GSM. The dual mode UE receives the UTRAN neighbour cell parameters on *GSM System Information* messages. The parameters required to be able to measure UTRA FDD cells include Downlink Center frequency or UTRA Absolute Radio Frequency Channel Number (UARFCN), Downlink Bandwidth (in 3GPP Release-99, only 5 MHz allowed, but in future other bandwidths may appear), Downlink Scrambling Code or scrambling code group for the Primary Common Pilot Channel (CPICH), and reference time difference for UTRA cell (timing between the current GSM cell and the UMTS cell that is to be measured).

After receiving a measurement report from GSM MS, including UTRA measurements, and after making a handover decision, the GSM BSC initiates resource reservation from UTRAN RNC. In the next phase, GSM BSC sends an *GSM Inter-System Handover Command* [12]

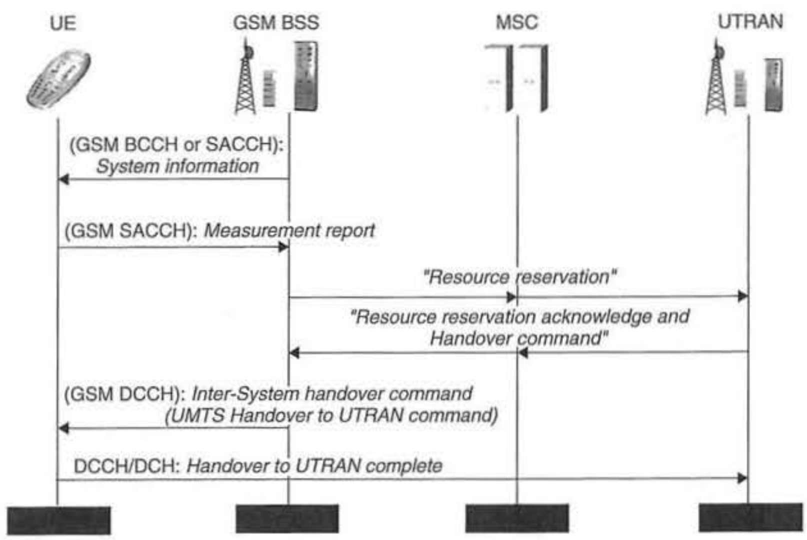

Figure 7.19. Inter-system handover procedure from GSM to UTRAN

including a piggybacked UMTS *Handover To UTRAN Command* message, which contains all the information required to set up connection to a UTRA cell. The GSM handover message (*Inter-System Handover Command*) must fit into one 23-octet data link layer PDU. Since the amount of information that could be included in the *Handover To UTRAN Command* is great, a preconfiguration mechanism is included in the standards. The preconfiguration means that only a reference number to a predefined set of UTRA parameters (Radio Bearer, Transport Channel and Physical Channel parameters) is included in the message. Naturally, the preconfiguration has to be transmitted to the UE beforehand. This can be done by GSM signalling or, if the UE has been earlier in UMTS mode it has been able to read the preconfiguration information from System Information Block type 16. The UE completes the procedure with a *Handover to UTRAN Complete* message to RNC. After successful completion of the handover procedure, RNC initiates resource release from GSM BSS.

Inter-System Cell Reselection From UTRAN

The inter-system cell reselection procedure from UTRAN is used to transfer a connection between the UE and UTRAN to another radio access system, such as GSM/GPRS. This procedure may be initiated in states Cell_FACH, Cell_PCH or URA_PCH. It is controlled mainly by the UE, but to some extent also by UTRAN. When UE has initiated an establishment of a connection to the other radio access system, it shall release all UTRAN specific resources.

Inter-System Cell Reselection To UTRAN

The inter-system cell reselection procedure to UTRAN is used to transfer a connection between the UE and another radio access system, such as GSM/GPRS, to UTRAN. This procedure is controlled mainly by the UE, but to some extent also by the other radio access system. The UE initiates an RRC connection establishment procedure to UTRAN with cause value 'Inter-system cell reselection', and releases all resources specific to the other radio access system.

Inter-System Cell Change Order From UTRAN

The inter-system cell change order procedure—illustrated in Figure 7.20—can be used by the UTRAN to order UE to another radio access system. This procedure is used for UEs having at least one RAB for PS domain services. This procedure may be used in Cell_DCH and Cell_FACH states. Like in the case of inter-system handover from UTRAN, Release'99 UE is expected to be able to perform inter-system cell change with only one PS domain RAB, but the specification does no restrict this.

The procedure is initiated by UTRAN with the *Cell Change Order from UTRAN* message. The message contains at least required information of the target cell. After successful establishment of connection between UE and the other radio access system (e.g. GSM/GPRS), the other radio access system initiates release of the used UTRAN radio resources and UE context information.

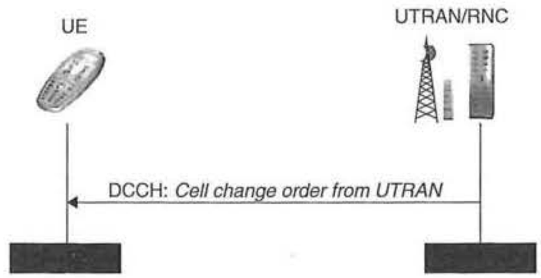

Figure 7.20. Inter-system cell change order from UTRAN

Inter-System Cell Change Order To UTRAN

This procedure is used by the other radio access system (e.g. GSM/GPRS) to command UE to move to UTRAN cell. The "cell change order" message in the other radio access system shall include the identity of the target UTRAN cell. In UTRAN side, the UE shall initiate an RRC connection establishment procedure with "establishment cause" set to "Inter-RAT cell change order".

Cell Update

The Cell Update procedure can be triggered by several reasons, including cell reselection, expiry of periodic cell update timer, initiation of uplink data transmission, UTRAN-originated paging and radio link failure in Cell_DCH state.

The *Cell Update Confirm* may include UTRAN mobility information elements (new U-RNTI and C-RNTI) for the UE. In this case, it responds with an *UTRAN Mobility Information Confirm* message so that the RNC knows that the new identities are taken into use.

The Cell Update Confirm may also include a radio bearer release, radio bearer reconfiguration, transport channel reconfiguration or physical channel reconfiguration. In these cases, the UE responds with suitable 'complete' message, see Figure 7.21.

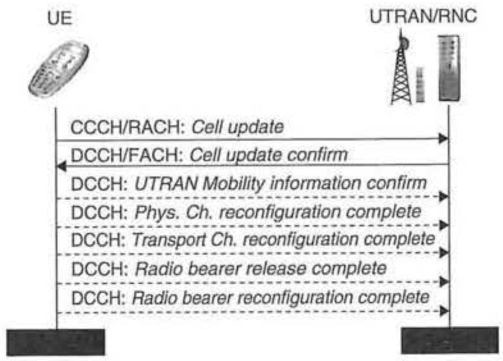

Figure 7.21. Cell Update procedure

URA Update

The UTRAN Registration Area (URA) Update procedure is used in the URA_PCH state. It can be triggered either after cell reselection, if the new cell does not broadcast the URA identifier that the UE is following, or by expiry of periodical URA Update timer. Since no uplink activity is possible in URA_PCH state, the UE has to temporarily switch to Cell_FACH state to execute the signal processing procedure, as shown in Figure 7.22.

UTRAN registration areas may be hierarchical to avoid excessive signalling. This means that several URA identifiers may be broadcast in one cell and that different UEs in one cell may reside in different URAs. A UE in the URA_PCH state always has one and only one valid URA. If a cell broadcasts several URAs, the RNC assigns one URA to a UE in the *URA Update Confirm* message.

The *URA Update Confirm* may assign a new URA Identity that the UE has to follow. It may also assign new RNTIs for the UE. In these cases UE responds with an *UTRAN Mobility Information Confirm* message so that the RNC knows that the new identities are taken into use.

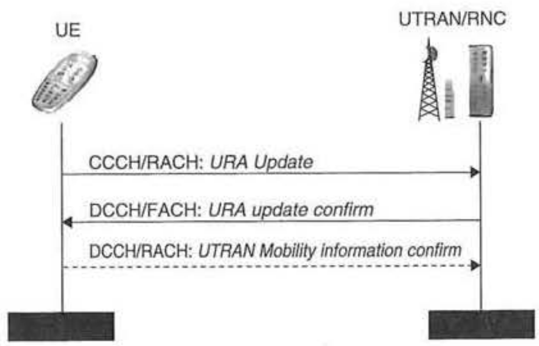

Figure 7.22. URA Update procedure

7.7.3.10 Support Of SRNS Relocation

In the serving RNS relocation procedure (see Chapter 5), the SRNC RRC layer builds a special RRC message—*RRC Information to Target RNC*. The issue that makes this message a 'special' one is it is not targeted for UE but for the new SRNC. Thus, this message is not sent over the air, but carried from the old SRNC to the new one via the Core Network. The initialisation information contains e.g. RRC state information and all the required protocol parameters (RRC, RLC, MAC, PDCP, PHY) that are needed to set up the UE context in the new SRNC. In addition, the expected PDCP sequence numbers (which are normally maintained locally in UE and UTRAN) need to be sent between UE and UTRAN, in any RRC messages which are sent during the SRNS relocation.

7.7.3.11 Support for Downlink Outer Loop Power Control

All RRC messages that can be used to add or reconfigure downlink transport channels (e.g. *Radio Bearer Setup/Reconfiguration/Release, Transport Channel Reconfiguration*) include a parameter 'Quality Target' (BLER quality value) that is used to configure the quality requirement (initial downlink SIR target) for each downlink transport channel separately.

The outer loop power control algorithm and its performance are discussed in Section 9.2.

7.7.3.12 Open Loop Power Control

Prior to PRACH transmission (see Chapter 6), the UE calculates the power for the first preamble as:

$$\text{Preamble\_Initial\_Power} = \text{Primary CPICH DL TX power} - \text{CPICH\_RSCP} + \text{UL interference} + \text{constant value}$$

The value for the CPICH_RSCP is measured by the UE, all other parameters being received on *System Information*.

As long as the physical layer is configured for PRACH transmission, the UE continuously recalculates the Preamble_Initial_Power when any of the broadcast parameters used in the above formula changes. The new Preamble_Initial_Power is then resubmitted to the physical layer.

When establishing the first DPCCH the UE shall start the UL inner loop power control at a power level according to:

$$\text{DPCCH\_Initial\_power} = \text{DPCCH\_Power\_offset} - \text{CPICH\_RSCP}$$

The value for the DPCCH_Power_offset is received from UTRAN on various signalling messages. The value for the CPICH_RSCP shall be measured by the UE.

7.7.3.13 Cell Broadcast Service Related Functions

The CBS-related functions of the RRC layer are as follows:

- Initial configuration of the BMC layer.
- Allocation of radio resources for CBS, in practice allocating the schedule for mapping the CTCH logical channel into the FACH transport channel and further into the S-CCPCH physical channel.
- Configuration of layer 1 and layer 2 for CBS discontinuous reception in the UE.

7.7.3.14 UE Positioning Related Functions

Although the full set of Release'99 UTRAN specifications support only the Cell_ID based positioning method, RRC protocol already is capable of supporting also both UE based and UE assisted OTDOA and GPS methods [14]. This includes capability to transfer positioning related UE measurements to UTRAN and delivery of assistance data for OTDOA and/or GPS from UTRAN to UE, which can be done either with *System Information* or with a dedicated message, called *Assistance Data Delivery*.

References

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WCDMA FOR UMTS

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Revised Edition

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