3

WCDMA

3.1 Nature and Principles

WCDMA is the version of DS-CDMA proposed by the 3GPP to meet the needs of the UMTS defined by IMT-2000. Under the banner of WCDMA there are actually two different standards, WCDMA-FDD and WCDMA-TDD. They both use a common network architecture and differ primarily at the physical level. The specifications have evolved through a series of releases. This book is based on Releases 4 and 5 functionality, where the basic distinction between these two is inclusion in the latter of support for the Internet multimedia core (IM) to provide both PS and CS core-network functions (see Section 8.1). The earliest UMTS networks make use of R1999 specifications (the last release before Release 4), which has essentially the same QoS features as Release 4. In this and other chapters, the references are to published ETSI standards in preference to 3GPP draft specifications, but at the time of writing the Release 5 material had not been published in this way, so general 3GPP references are given for these (this applies particularly to Chapter 8).

Apart from code division based on spreading codes, the other main characteristic of WCDMA is the use of power control as the means of controlling quality for a given bit rate. The specifications contain detailed recommendations for the power that should be used for various combinations of error rate and bit rate. Use of excessive power will cause interference problems. The aim is to use the minimum power necessary to achieve a specified level of quality and performance, rather than to try to obtain top quality for an individual transmission.

Unlike GSM or cdma2000, WCDMA does not require precise synchronization. This makes operation within large or overshadowed buildings, where reception of GPS timing signals is obstructed, much easier, but this has the downside of making search and handover procedures harder (see Section 3.4.7).

A UMTS mobile network consists of a UTRAN and a fixed core network; together they constitute a public land mobile network (PLMN). The architecture of the UTRAN is shown in Figure 3.1 and its features are described in this chapter. (The interface to the core network is covered in Chapter 8.)

The main components of the UTRAN are as follows:

- *UE:* This refers to the complete unit of a 3G mobile phone, its SIM card, and any terminal equipment that may be docked onto the phone.
- *Node B:* This is the logical function of the base transceiver station (BTS) concerned primarily with the physical level functions. Higher-level control is directed by the RNC. A single Node B can support several cells.

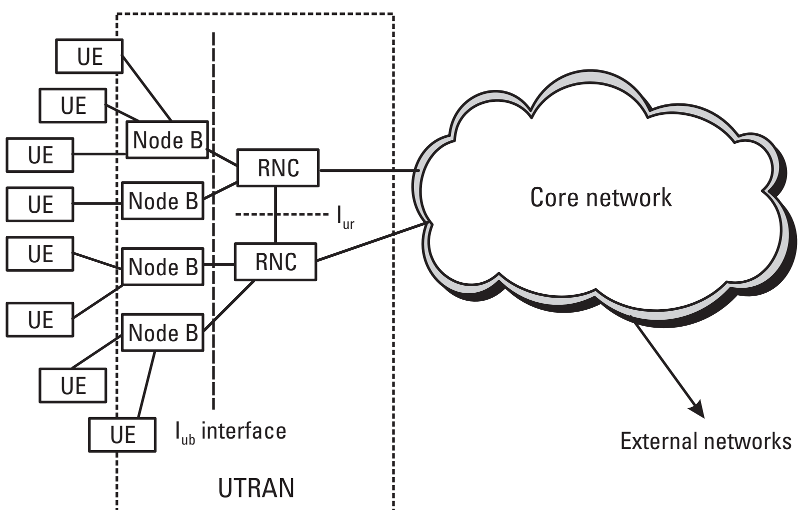

Figure 3.1 UMTS architecture.

- *Radio network controller (RNC):* This is responsible for resource control for one or more Node B, and for providing the interfaces to the core network. In general, the UTRAN will operate in more than one frequency band, each of which represents a different radio network subsystem (RNS) containing at least one Node B and at least one RNC. In order to support handovers of users as they move through the network, the functionality of the RNC is divided into several distinct roles. A single physical RNC supports all the functions, but a single UE may obtain the functions from separate physical RNCs. These roles are as follows.

    1. *Controlling RNC (CRNC):* The RNC that controls a given Node B is its CRNC and is responsible for load and congestion control of all its cells on the basis of UL interference and DL power reports from the Node B.
    2. *Serving RNC (SRNC):* The SRNC is the RNC that is responsible for handling both the signaling and user traffic for a single UE from the UTRAN to the core network, and also terminates the radio resource control (RRC) signaling between the UE and the UTRAN. It sets the quality target for UL signals that form the basis of outer loop power control (see Section 3.4) and also performs the layer 2 functions (see Section 3.3) for the data transfer between the RNC and the radio link. An SRNC may be the CRNC for the Node B used by the UE at any time, but not necessarily so. Each UE has a single SRNC at any one time.
    3. *Drift RNC (DRNC):* Because of mobility a UE may make use of more than one cell and more than one RNC at any time; the DRNC is any other RNC whose cells the UE is communicating with. The DRNC can combine the signals from the separate cells (see Chapter 6 for the benefits of doing so). It does not perform level 2 processing but passes data for dedicated channels transparently from the Node B to RNC interface on to the interface between the distinct physical RNCs.

The interface between a Node B and its CRNC is referred to as the I_{ub} interface, and that between two distinct physical RNCs is the I_{ur} interface. Signaling over the I_{ub} [1] is covered by Node B application part (NBAP) specifications [2], while the radio access network application part (RANAP) [3] governs that over the I_{ur}.

A single physical RNC, Node B, or UE may support both WCDMA-FDD and TDD, but need not do so. The basic distinctions between FDD and TDD are described in the following paragraphs.

3.1.1 WCDMA-FDD

In most parts of the world this will operate in the frequency band 1,920 to 1,980 MHz for the UL from the UE to the base station (usually referred to as Node B in 3GPP documents), and in the band 2,110 to 2,170 MHz for the DL from the base to the user. There will also be a few areas where the corresponding bands are likely to be 1,850 to 1,910 and 1,930 to 1,990 MHz. The spacing between individual transmission channels is a nominal 5 MHz, while the central frequencies must be integral multiples of 200 KHz. Frequency pairing in FDD operation has the result that if traffic volumes are highly asymmetric between UL and DL (e.g., with data streamed to mobiles from hosts on the Internet), then there is liable to be unusable spare capacity in the less heavily loaded direction (the UL in this example). National authorities issue licenses to operators for a portion of this bandwidth in their area of jurisdiction—with 15 MHz a fairly typical allocation–thereby permitting several carrier frequencies each.

3.1.2 WCDMA-TDD

WCDMA-TDD uses the same overall 2-GHz frequency band, but unlike the FDD version, the UL and DL operate at the same frequency. This is achieved by using synchronized time intervals for the two operations. WCDMA-TDD has a wideband option using the same 3.84-Mcps rate as for FDD, but also a narrowband option at 1.28 Mcps. In the wideband version a standard radio frame of 10 ms duration is divided into 15 timeslots on the basis of 2,560 chips per slot. Unlike FDD, TDD can share bandwidth between UL and DL according to demand, so a higher grade of service overall can be provided if the asymmetric applications can be put onto TDD.

WCDMA radio interface has a three-tier architecture roughly corresponding to the open systems interface (OSI) protocol stack, as shown in Table 3.1. The relationship between these functions, and whether they belong to the control- or user-plane, is shown in the protocol architecture diagram of Figure 3.2.

The roles of these layers are described in the following sections.

Table 3.1
WCDMA Protocol Components

Layer	WCDMA Functions
3	RRC
2	Media access control (MAC)
2	Radio link control (RLC)
2	Packet Data Convergence Protocol (PDCP)
2	Broadcast and multicast control (BMC)
1	Physical layer

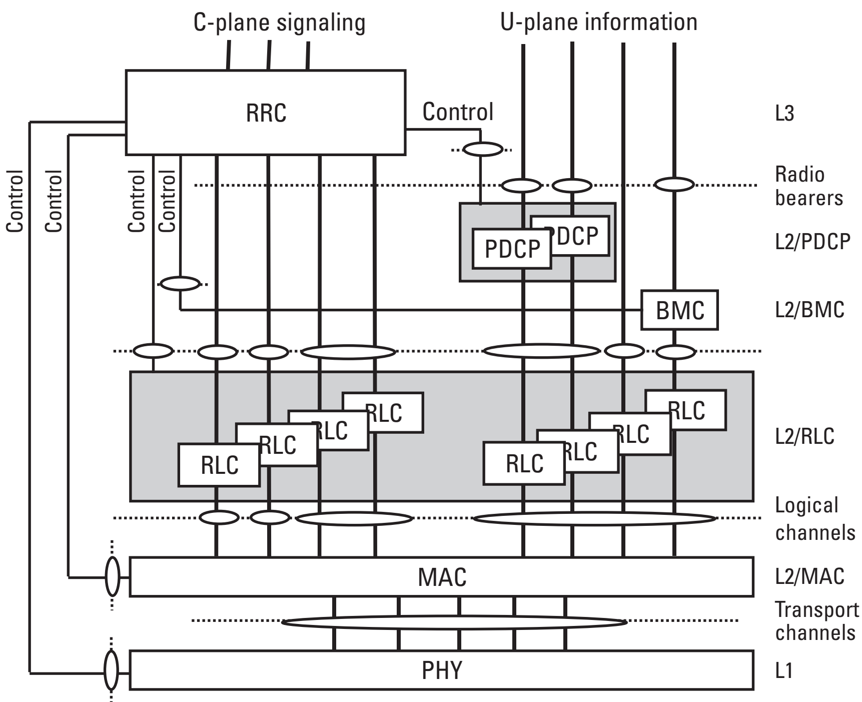

Figure 3.2 Radio protocol architecture. (*Source:* [4] © ETSI 2001.)

3.2 Layer 3 (RRC)

This layer is responsible for radio control in general; in particular, it is responsible for the routing of higher layer messages, broadcast control, paging of mobile devices without an active connection, dedicated control of all functions specific to one mobile, and handling of transfers. It exists in the control-plane and to a lesser extent in the user-plane. There is also a small duplication avoidance sublayer between the RRC and the core network transport. The RRC consists of four functional entities [5] as follows:

- *Routing function entity (RFE):* This handles the routing of higher layer messages to the appropriate UE mobility management or call management entities or the core network functions.
- *Broadcast control function entity (BCFE):* This is responsible for delivering resource control broadcasts, notably system information.
- *Paging notification function entity (PNFE):* This is responsible for paging UEs that do not have resource control connections.
- *Dedicated control function entity (DCFE):* This handles all the control functions that are dedicated to a single UE. In the case of TDD it is supplemented by a shared control function entity (SCFE) that handles UL and DL resources for shared PS channels.

The procedures that affect QoS for a specific UE belong to DCFE and are as follows:

1. Establishment, reconfiguration, and release of radio bearers compatible with requested QoS;
2. Control of transport format combinations;
3. Assignment of access service class priority for use of random access channels;
4. Control of UE capability exchange between UE and UTRAN;
5. Traffic and signal quality measurements;
6. Outer-loop power control;
7. Physical channel allocation for TDD.

Radio bearers (RBs) comprise both signaling radio bearers (SRBs) for resource control messages and radio access bearers (RABs) for the user traffic.

The RRC sets up three or four SRBs, two for resource control messages, one for high-priority network access signaling and optionally another such bearer for lower priority messages. A single call from a UE may make use of radio links to more than one cell, with several RABs on each with different QoS features (e.g., for audio and video in a multimedia application). A request for radio bearer establishment or reconfiguration may contain information elements that are directly related to lower layer functions. These include RLC information for SRBs (see Section 3.3.3), RLC, PDCP (see Section 3.3.1), RB mapping information on transport format sets (see Section 3.4) for RAB, and a quality target for dedicated traffic channels.

The transport format sets specify combinations of data block sizes that can be multiplexed onto transport channels at level 1; PDCP handles data header compression; and UE capability exchange is required to support codec and media negotiation between end points to avoid transcoding and its consequent delays and corruption.

Communication between the Node B and RNC [2] uses ATM as a transport protocol, employing AAL5 cells for control traffic and AAL2 (see Section 7.3) for user traffic. This contributes a few milliseconds to network transfer delays, but otherwise has no significant effect on QoS.

The RRC is logically situated between various network service access points and service access points to the top RLC part of layer 2. Physically it is located in the RNC that controls the Node B logical base stations and the mobile. The RNC is itself normally colocated with one or more Node B; for example, there may be several sectors of a cell being supported from the same location.

Both the UE and Node B (base transceiver) possess an RRC layer with associated states, modes, and processes. The processes are those that entail changes in radio resources, such as initial cell selection or reselection, establishment or reconfiguration of radio bearers (the level 2 services), control of requested QoS, UE quality measurement reporting and control, and outer loop power control. The modes for a UE, when switched on, are either idle or connected, with the latter having several states. In idle mode the UE just looks for higher priority networks. It initiates establishment of a connection to the UTRAN by sending an RRC connection request to the UTRAN. The RRC layer in the RNC performs admission control, assigns radio resource parameters [e.g., transport channel types and formats (see Section 3.3.4)], and establishes radio links from relevant Node Bs if a dedicated channel is involved. If connected to the UTRAN but not in the process of executing a call, the UE will be in either the URA_PCH or CELL_PCH states, essentially listening to paging and broadcast messages, performing measurements, reselecting cells, and looking for higher priority networks. An important QoS procedure that can occur at this stage is the sending of a UE capability information element (IE) to the UTRAN in response to a UE capability inquiry or automatically with the connection request. There are many components to this, but some of the more important for QoS are PDCP capability, physical channel capability (types and speeds), radio frequencies supported, RLC capability (buffer and window sizes), transport channel capability (types, numbers, block sizes, and formats), and timer values (see Section 3.6). In order to execute a call, a radio bearer must be established.

The main state for active calls is CELL_FACH in which the UE has both dedicated control channels (DCCHs) and dedicated traffic channels (DTCHs) available. The RRC functions of the UE in this state are to perform cell reselection as required, carry out measurements, run cell update timers, and listen to all forward access channel (FACH) transport channels that are mapped onto its control channel.

The UTRAN broadcasts a large number of system information blocks via Node B to the UEs. Each of these message blocks has a header with a scope field (e.g., CELL) and a state field (e.g., CELL_FACH), so that a UE updates its system information if the scope and state are appropriate to its condition. There are 18 such blocks, but they are not directly related to QoS features.

One of the main ways in which the RRC controls quality is through the transport combination format set (TFCS) that it passes to the media access control (MAC) layer (see Section 3.3.4). Another essential factor is the monitoring of signal-to-interference ratio (SIR) on a pilot channel. The RRC issues outer power loop control messages on the basis of this information. The RRC communicates with the top of the four level 2 sublayers, radio link control (RLC) via the radio bearers, which are separate channels depending on the type of information sent (see Figure 3.2).

3.3 Level 2

3.3.1 Packet Data Convergence Protocol

The Packet Data Convergence Protocol (PDCP) [6] is another level 2 function that provides services to the nonaccess stratum (NAS) at the UE or relays at the RNC. Its main role is in control of header compression for IP packet data. This is important for QoS for any real-time traffic that uses small IP packets (e.g., speech) because the headers may be several times as long as the actual user traffic and hence increase by a large factor both the transmission time and capacity used. For example, VoIP is often carried in RTP/UDP/IP where the uncompressed header is 40-bytes long, while the speech typically only occupies 20 to 24 bytes (depending on the voice codec), but compression can cut the header to only 4 bytes most of the time. Header compression is not helpful for large packets and, hence, is not often used by file transfer applications.

Several distinct header compression protocols can be used, and PDCP inserts a protocol identifier field (PID) in the protocol data unit (PDU) to indicate the type, if any, to be used. This is a 4-bit field, with "0" indicating no header compression, and most of the others being options defined within the Internet RFC2507 and RFC3095 on compression. RFC3095 (represented by PID 9–11) is the most resilient method on error-prone links such as the radio link. The significance of these options is described in Section 7.4.10, where the features and benefits of the protocols are described. No method is currently defined for SIP (see Section 7.4. 8) header compression, and this may have to be added later.

3.3.2 Broadcast and Multicast Control

There is one broadcast and multicast control (BMC) entity per cell in the UTRAN [7]. It communicates with the RLC by means of the UM mode. Its functions include the following: storage of cell broadcast messages, traffic volume and radio resource information to CBS, scheduling of BMC messages to UE, delivery of BMC to UE, and delivery of CBS messages to NAS. There is also an extension to this layer that handles multimedia multicasts [8].

The traffic volume information is an estimate of the current cell broadcast service data rate requirement in kilobits per second; this is sent to the RRC.

3.3.3 RLC

The RLC [9] sits between the level 3 RRC and the MAC layer. It has three modes of operation—transparent mode (TM), unacknowledged mode (UM), and acknowledged mode (AM)—that are directly relevant to QoS. Transparent mode takes data to or from the RRC and segments or reassembles it, but does not add other header information; it is used for delay-sensitive traffic that is tolerant of errors. Unacknowledged mode also performs these functions, but adds or checks sequence numbers for the MAC layer and may add ciphering if needed; it is used for traffic that requires delivery in sequence and does not require delivery of errored packets. The acknowledged service is for data that has a low error tolerance and includes addition of a CRC field, flow control, and error checking to the UM functions, with ARQ retransmission when errors are found. AM guarantees delivery of data, but either with or without sequencing.

The RRC uses different radio bearers for signaling and user traffic. Those for signaling are shown in Table 3.2, which shows the control channel (see Section 3.3.4) supported and the RLC mode used. The NAS above posts user traffic to the RLC, bypassing the RRC, but possibly going through the PDCP (see Section 3.3.1) or BMC (see Section 3.3.2) layers. The bearer configuration is determined by the RRC and is defined in terms of static, semistatic, and dynamic parameters determined by the required QoS. The static part includes the RLC information, whose main features are the choice of mode, whether sequencing is required, the permitted RLC PDU sizes, the acknowledgment timer, and the transmit/receive window sizes in terms of RLC PDUs. The semistatic and dynamic parts relate primarily to the transport formats specified for MAC to L1 operation. RLC segmentation and reassembly fits data from higher or lower levels into the permitted PDU sizes, with an extension flag and length indicator after the sequence number at the start of the PDU if several higher level SDUs are fitted into a single PDU. There is one such indicator per SDU, each indicating the number of octets in the SDU.

The majority of quality control features in RLC, therefore, lie in the use of acknowledged mode. Flow control is based on a 12-bit sequence number, window sizes, and an implementation-dependent superfield for

Table 3.2
Use of Radio Bearers for Signaling

RB Number	Services Carried
0	All RRC messages on common control channel (CCCH)
	RLC-TM on UL, RLC-UM on DL
1	Messages on DCCH when using RLC-UM
2	Messages on DCCH when using RLC-AM
3	Messages on DCCH RLC-AM that carry higher-level signals
4	Optionally the same as 3
5–31	Messages on DCCH using RLC-TM

Source: [5].

selective acknowledgments of received and missing PDUs. An error burst indicator can be used to show that the next codeword received in the superfield will indicate the number of subsequent PDUs that are erroneous. The RLC also receives information from the RRC specifying the maximum number of retransmissions permitted for a PDU and how often the transmitter should poll the receiver in the case of a PDU or SDU containing a poll bit.

The RLC communicates with the MAC layer via logical channels that depend on the function of the information; these are more detailed than the radio bearer selections above. AM is only applicable to two types of logical channel: DCCH and DTCH.

3.3.4 MAC Layer

The MAC configuration is controlled by the RRC, and the MAC [10] uses logical channels to communicate with the RLC and transport channels to communicate with the physical layer. The logical channels consist of control channels and traffic channels as follows:

- *Control channels:* Broadcast (BCCH), paging (PCCH), DCCH, CCCH, and shared (SHCCH);
- *Traffic channels:* DTCH and common transport channel (CTCH).

The transport channel types, each of which is defined unidirectionally, include random access channels (RACHs), FACHs, DL shared channels (DSCHs), common packet channels (CPCHs) for FDD on UL only, UL shared channels (USCHs) for TDD only, broadcast channels (BCHs), paging channels (PCHs), and dedicated transport channels (DCHs). Each RLC radio bearer can use up to two logical channels, where one is for control traffic and the other for user traffic.

The MAC layer has three functional entities, as shown in Table 3.3. Each UE has one MAC-b, while the UTRAN has one MAC-b per cell. There is one MAC-c/sh in the UE that handles the transport-channel-type field (TCTF) header field in the MAC to indicate common logical channel type for a common channel. For dedicated logical channels, it handles UE identification, transport format (TF) selection, and TF combination (TFC) selection on the basis of TFC set configured by the RRC. There is one MAC-c/sh in the UTRAN that is located in the CRNC. It performs priority

Table 3.3
MAC Functional Entities

Entity	Function
MAC-b	Handles the BCH
MAC-d	Handles DCHs
MAC-c/sh	Handles the remainder, notably CTCHs

handling via the access service class for the FACH and DSCH, TCTF multiplexing, TFC selection, and DL code allocation for use on DSCH.

The MAC-d in the UE performs transport channel switching on the basis of decisions by the RRC, multiplexing of multiple dedicated logical channels onto a single transport channel, TFC selection on the UL, and ciphering/deciphering for RLC-TM if required. The MAC-d for the UTRAN is situated in the SRNC. Its functions are similar to those for the UE but with the addition of priority setting on data received from the DCCH or DTCH, DL priority and schedule handling of transport channels allowed by RRC, and flow control towards the MAC-c/sh in order to limit level 2 buffering and latency.

For peer-to-peer communication, a MAC-PDU consists of a bit string whose length is not necessarily a multiple of eight. It consists of a MAC-SDU plus an optional header, where the MAC-SDU is either a bit string of any nonzero length or an integer multiple of octets and the header is of variable size. The header consists of the following:

- TCTF of variable size to identify the logical channel type being used over a FACH or RACH transport channel (e.g., BCCH, CCCH, CTCH, SHCCH, or dedicated logical channel);
- A UE identity type and UE identity;
- A C/T field that indicates the instance (1–15) of a logical channel when multiple logical channels of the same type are carried over a single transport channel.

When a DTCH or DCCH is mapped onto a DCH without any multiplexing of dedicated channels, no MAC header is required; if there is any such multiplexing, then the header consists of the C/T field. Numerous other situations require other headers; one that requires each of the above fields is the mapping of a DTCH or DCCH to RACH or FACH.

The UE identity type can either be an UTRAN radio network temporary identity (U-RNTI) with 32-bit identifier, or a cell radio network temporary identity (C-RNTI) of 16 bits.

The MAC receives configuration information from the RRC in MAC-Config-REQs that specify the priority, 1 to 8, to assign to each logical channel carried on a radio bearer when the latter is set up or reconfigured. This priority is used to select the TFC in the UE.

The manner in which different logical channels can be combined into transport channels for MAC to L1 communication is determined by the transport formats [11] controlled by the RRC layer. The basic entities involved in this are as follows:

- *Transport block (TB):* This is the basic unit exchanged between the MAC and level 1 and corresponds to a MAC PDU.
- *Transport block set (TBS):* This is a set of TB that can be exchanged between the MAC and L1 at the same time and on the same transport channel. All blocks in a TBS must have the same size.
- *Transport block size:* This is the number of bits within a TB. It is set to accommodate the RLC size plus any appropriate MAC header. Permissible sizes are 1 to 5,000 bits.
- *Transport block set size:* This is the number of bits in a TBS.
- *Transmission time interval (TTI):* This is a key parameter for QoS that is defined as the interarrival time for TBS. It is a multiple of the 10-ms radio frame duration, with possible values of 10, 20, 40, or 80 ms.
- *TF:* This determines the format for TBS exchange between L1 and MAC and consists of dynamic and semistatic parts. The dynamic attributes are transport block size and transport block set size for both FDD and TDD, plus TTI in the case of TDD only. The semistatic attributes are the TTI for FDD (and optionally for non-real-time TDD), the error protection scheme to use, and the CRC size. The error protection scheme consists of the type of channel coding to use, if any (i.e., convolution or turbo), the coding rate, and the static rate matching parameter. TTI and the TB set size together determine the instantaneous bit rate of the transport channel.

- *TFS:* A single transport channel may be permitted to use more than one TF, provided that they all have the same semistatic part and the set of permissible values defines the TFS.
- *TFCS:* Level 1 can multiplex several transport channels together to form a single physical channel (see Section 3.4), in which case each transport channel has its own TFS, but only certain combinations of these (the TFCS) are allowed.
- *Transport format indicator (TFI):* This is an index used by L1 and MAC to identify a specific TF in the TFS.
- *Transport format combination indicator (TFCI):* This is an index used to identify one particular TFC from the TFCS. On the basis of the radio priorities, the MAC makes the choice of TFC for the available TB.

Some applications (e.g., multimedia) may use several distinct traffic streams, each with its own block sizes and QoS needs. In that case they are likely to use more than one logical channel and transport channel, each with its own transport formats. Some may also have variable bit rates (e.g., AMR voice where the degree of compression and type of coding varies according to signal quality), and this is achieved by having several possible block sizes in the dynamic part of the TFS. A formal example of this is shown in Figure 3.3.

This diagram shows two transport channels (TrCHs): TrCH (1) and TrCH (2), with TTI (1) and TTI (2), respectively. TrCH (1) has only one block size, TB (1), but has a block set of either one or two blocks depending on the particular transmission interval; whereas TrCH (2) has a block set of one, but a TFS that includes the two sizes for TB (2) and TB (3). In the case

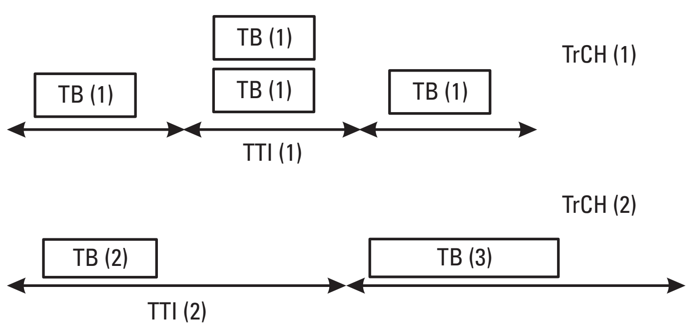

Figure 3.3 Transport formats.

of TrCH (2), a TFI is needed to indicate which size is in use for any given TTI period.

The dynamic part of the TF in FDD consists of the block size and block set size; so in this diagram the TFS for TrCH (1) has two formats, $\{x,x\}$ and $\{x,2x\}$, where x denotes the block size of TB (1). TrCH (2) also has two possible formats with dynamic parts, $\{y,y\}$ and $\{z,z\}$, where y and z are the block sizes of TB (2) and TB (3), respectively, and z is greater than y.

In general, several transport channels are likely to be multiplexed onto a single CCTrCH, and level 3 then dictates the combinations of TF that may be used. One of the main criteria used is to create TFCs that permit the MAC to perform simple rate control without involving any signaling to level 3. This is achieved by specifying combinations that tend to average the overall rate through combining low throughput options for some channels with higher rate formats for others and by forbidding combinations of extreme formats. Thus, in the case of the very simple example in Figure 3.3, the TF (1) with dynamic part $\{x,x\}$ would be combined with the TF (2) with dynamic part $\{z,z\}$, while $\{x,2x\}$ would go with $\{y,y\}$, thereby giving a TFCS with these two TFC. The choice of TFC can vary on a per radio frame basis and is usually indicated by a 10-bit TFCI (coded for resilience to 32 bits) in the frame, but with blind format detection (based on either CRC or power analysis) as an alternative for relatively fixed rates.

One of the simplest possible real examples would be the case of a speech call using GSM-EFR (see Section 10.1.1). This uses three classes of speech bit with different error protection requirements, so that they are sent on separate transport channels. Each uses a TTI of 20 ms and a block set consisting of a single block, but with block sizes of 81, 103, and 60 bits, respectively. There is only one TF for each channel with respective dynamic parts, {81,81}, {103,103}, and {60,60}, while the semistatic parts of the three TF each have TTI of 20 ms, but differing coding parameters. On the FDD UL (and often on the DL) these would be combined into the same CCTrCH with a single trivial TFC. The default speech codec for UMTS is UMTS-AMR, which has multiple formats for each of three channels, and this is discussed in more detail in Chapter 10.

The MAC layer performs scheduling via status indications to the RLC. These indicate the number and size of PDUs that the RLC can send in the TTI for each logical channel. The MAC also uses the priorities assigned to the logical channels by the RRC to decide which TFC combination to use from the TFCS, and it must use that which allows transmission of the most high priority data. The MAC for the UE must estimate the power required for the TFC and only use those that are within its maximum power capability. This selection takes place at the start of the shortest TTI for any member of the TFCS.

The MAC sends traffic measurements directly to the RRC for dynamic radio bearer control. These consist of buffer occupancies for RLC entities and are made both periodically and on a threshold alarm basis.

3.4 Level 1—The Physical Layer

3.4.1 General

The physical level communicates with its own MAC layer via the transport channels and with its peer physical layer via physical channels. Layers 2 and 3 are very similar for WCDMA-FDD and TDD, but there are major differences at layer 1, and unless otherwise indicated, the following refers to FDD.

A physical channel is defined as a code or set of codes in WCDMA-FDD and additionally by a sequence of timeslots in WCDMA-TDD. The information rate of a physical channel varies with the symbol rate derived from the chip rate of 3.84 Mcps and the spreading factor (SF). SF varies from 256 to 4 in FDD on the UL and from 512 to 4 on the FDD DL, while in TDD it varies from 16 to 1. These give respective symbol rates from 15k to 960k symbols/s on FDD UL and 7.5k to 960k for FDD DL, with 3.84M symbols/s to 240 k/s in TDD in either direction.

Spreading codes (as outlined in the previous chapter) are used to distinguish between the following:

- Different channels from the same source via channelization codes;
- Different cells via scrambling codes;
- Different UE via another set of scrambling codes.

One of the main factors influencing QoS is the mapping of transport channels to physical channels.

3.4.2 Physical Channels

Layer 1 maps the various transport channels to/from the MAC layer to specific physical channels that are transmitted at level 1 on the UL and DL. The way in which these channels are mapped is shown in Figure 3.4 for FDD. Physical channels without any transport association are purely for layer 1 functionality between the UE and Node B.

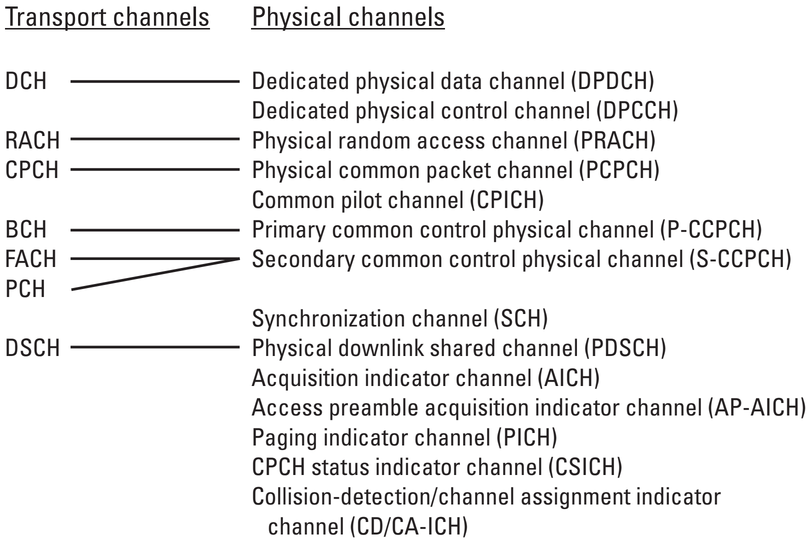

Figure 3.4 Transport and physical channels. (*Source:* [12] © ETSI 2001.)

The role of many physical channels is outside the scope of this book, and only a subset with above average significance for quality is described below. Physical channels are characterized by means of a specific carrier frequency, scrambling code, channelization code (optional, but used on many), stop and start times in relation to chips, and for the UL only a relative phase. Radio frames correspond to a duration of 15 slots of 2,560 chips each or 38,400 chips in all, hence a duration of 10 ms at 3.84 Mcps.

3.4.2.1 Dedicated Physical Channels

The channels most directly relevant to the transmission of user data are the dedicated physical channels, DPDCH and dedicated physical control channel (DPCCH). CS and most real-time traffic use dedicated channels, while intermittent data traffic can use common or shared channels. The UL DPDCH carries the DCH transport channel from the MAC, while the control channel (DPCCH) is used purely for control information generated in layer 1. In either case each 10-ms radio frame is split into 15 slots of 2,560 chips corresponding to single power cycles, that for DPDCH containing data, while the DPCCH slots carry control information, as shown in Figure 3.5.

The pilot field bits conform to one of a specified set of preset patterns and are used in frame synchronization. TFCI is used for variable rate channels or for channels carrying multiple services, but not for single fixed rate

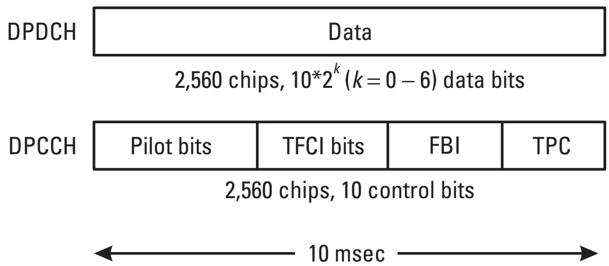

Figure 3.5 UL DPCH slot. (*Source:* [12] © ETSI 2001.)

channels—the decision on TFCI usage is determined by the UTRAN, not the UE. The feedback information (FBI) field is used in relation to diversity [13] and power control during soft handovers. Transmit power control (TPC) indicates whether to change transmitter power level (see Section 3.4.6).

On the DL there is only one type of dedicated physical channel, the DPCH, and it carries multiplexed DPDCH and DPCCH traffic. A single slot contains two data segments and two control segments, as in Figure 3.6.

The two DPDCH segments have unequal sizes that are specified in tables and are dependent on the spreading factor and control TFCI [12], while the parameter k is related to the spreading factor by

$$\mathrm{SF} = 512/2^k$$

The DPCCH information consists of TFCI, where applicable, TPC as on UL, and another set of pilot bits with numbers as per the tables. It is possible

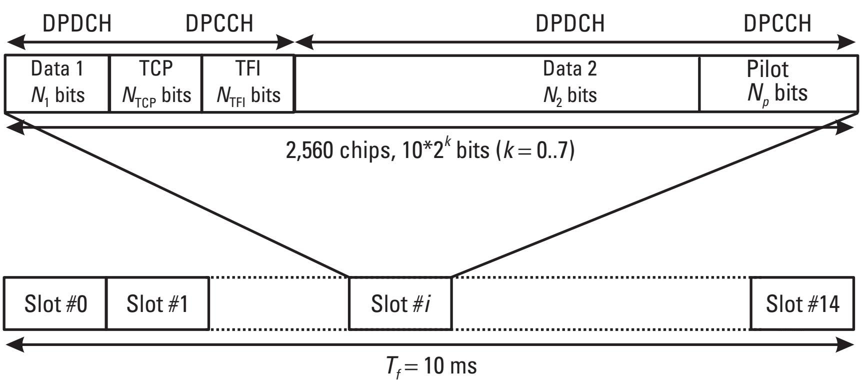

Figure 3.6 DL DPCH slot structure. (*Source:* [12] © ETSI 2001.)

to have more than one DPDCH if the required rate is too high for a single channel. If so, then the spreading factor is 4 for each such channel.

Other physical channels have different structures for their slots [12].

3.4.2.2 Common Physical Channels

The UL random access channel carries 4,096 chip preambles and a 10-ms message radio frame slit into 15 slots, each of which has both data and control parts.

On the DL there are two types of common pilot channel (CPICH) with a fixed rate of 30 Kbps: a primary that is common to an entire cell and defines a phase reference for all other DL channels, except possibly the DPCH, and a secondary for part or all of a cell that gives the phase reference for the DPCH in the exceptional case.

The synchronization channel (SCH) is a DL signal that the UE uses for cell search. It consists of primary and secondary subchannels, so that each slot contains a primary synchronization code of length 256 common to an entire cell, together with a secondary code characterizing a scrambling code in the range 0 to 63 and a slot number in the range of 0 to 14, corresponding to the slot position in the 15 slot subdivision of the 10-ms radio frame.

3.4.3 Physical-Level Procedures

The main functions of the physical level [14] are as follows:

- Error detection on transport channels and indication to higher layers;
- FEC encoding/decoding and interleaving/deinterleaving of transport channels;
- Multiplexing of transport channels and demultiplexing of coded composite transport channels;
- Rate matching;
- Mapping of coded composite transport channels on physical channels;
- Power weighting and combining of physical channels;
- Modulation and spreading/demodulation and despreading of physical channels;
- Frequency and time (chip, bit, slot, frame) synchronization;

- Measurements and indication to higher layers [e.g., frame error rate (FER), SIR, interference power, transmit power];
- Closed-loop power control;
- Combining signals for soft handover;
- Radio frame processing.

3.4.4 Multiplexing, Channel Coding, and Interleaving of Transport Channels

This group of functions [15] prepares the transport channels for transmission over the physical channels and have the greatest relationship to QoS. The main steps in this are as follows:

1. Addition of CRC field to transport block;
2. Concatenation and segmentation;
3. Channel coding;
4. Radio frame equalization;
5. Rate matching;
6. Interleaving;
7. Radio frame segmentation;
8. Multiplexing of transport channels;
9. Physical channel segmentation;
10. Mapping to physical channels.

The size of the CRC check field to add to each transport channel block is decided by higher layers.

All transport blocks to be sent on a specific transport channel within the TTI are concatenated prior to coding. If the resultant code block exceeds the maximum bit size permitted for the type of channel coding to be used, then it is first segmented. The limit sizes are 504 bits for convolution coding and 5,114 for turbo coding, with no limit if no channel coding is required. Specific block sizes are recommended that depend on the data rate and type of transport channel, with turbo coding being used for the highest data rates. The possible code rates are 1/2 or 1/3 for convolutional and 1/3 for turbo. These fractions determine the proportion of transport block bits (as opposed to FEC bits) on the radio link.

Radio frame equalization is used on the UL to ensure that the number of frames is equal to the integral value, F, specified for that transport channel.

This requirement is automatically met on the DL. The technique of equalization is to pad the bit sequence until this criterion is met.

Specific interleaving patterns are used depending on the TTI, whose possible values are 10, 20, 40, or 80 ms, with the complexity and resultant degree of error dispersal increasing with TTI. Where TTI exceeds 10 ms, the radio frames are also segmented into the required number F of frames.

Bits may have to be repeated or punctured in order to ensure that the multiplexed transport channels exactly match the bit rate of the physical channel. Higher layers using detailed algorithms control this.

The resultant frames are then multiplexed into a coded composite transport channel (CCTrCH). WCDMA-FDD has only one CCTrCH on the UL, but can have multiple such channels on the DL. Transport channels that are multiplexed onto the CCTrCH should have comparable QoS needs and, more specifically, the same C/I requirement. Where multiple CCTrCH are in use, each can have its own TFCI but not always, since blind detection of format is sometimes used for each 10-ms frame with fixed rate services. The RACH, CPCH, and BCH are always mapped 1:1 to the corresponding physical channel, but other transport channels may be multiplexed in this way. Dedicated and common transport channels cannot be mixed, so on the FDD UL there is both a dedicated channel CCTrCH and a common channel CCTrCH, of which only one can be active at any instant. The number of transport channels that can be multiplexed onto a single CCTrCH depends on the capability of the UE and on the TTI. This multiplexing is based on taking 10-ms frames from each transport channel involved per TTI. The DPCCH is multiplexed with one of the DPDCH.

More than one physical channel is sometimes used for a single CCTrCH. In that case the CCTrCH is segmented between them by means of a demultiplexing unit, and each of the physical channels must have the same spreading factor. After more interleaving the segments are ready for transmission.

An example of these multiplexing and interleaving procedures is shown in Figure 3.7 for the case of the 12.2-Kbps reference measurements [16] using the transport parameters in Table 3.4.

Table 3.4 and Figure 3.7 show how the DPDCH and DPCCH are multiplexed/demultiplexed and interleaved on a DL DPCH at a rate of 30 k symbols/s for reference measurements. The data rate for the DTCH is the transport block set size divided by the TTI, hence 12.2 Kbps as indicated, which is the typical rate for a speech channel. The CRC (whose size is specified for the TrCH by the RNC) is added to the transport block set, followed by a set of tail bits to enable the coder to determine the code-block boundary.

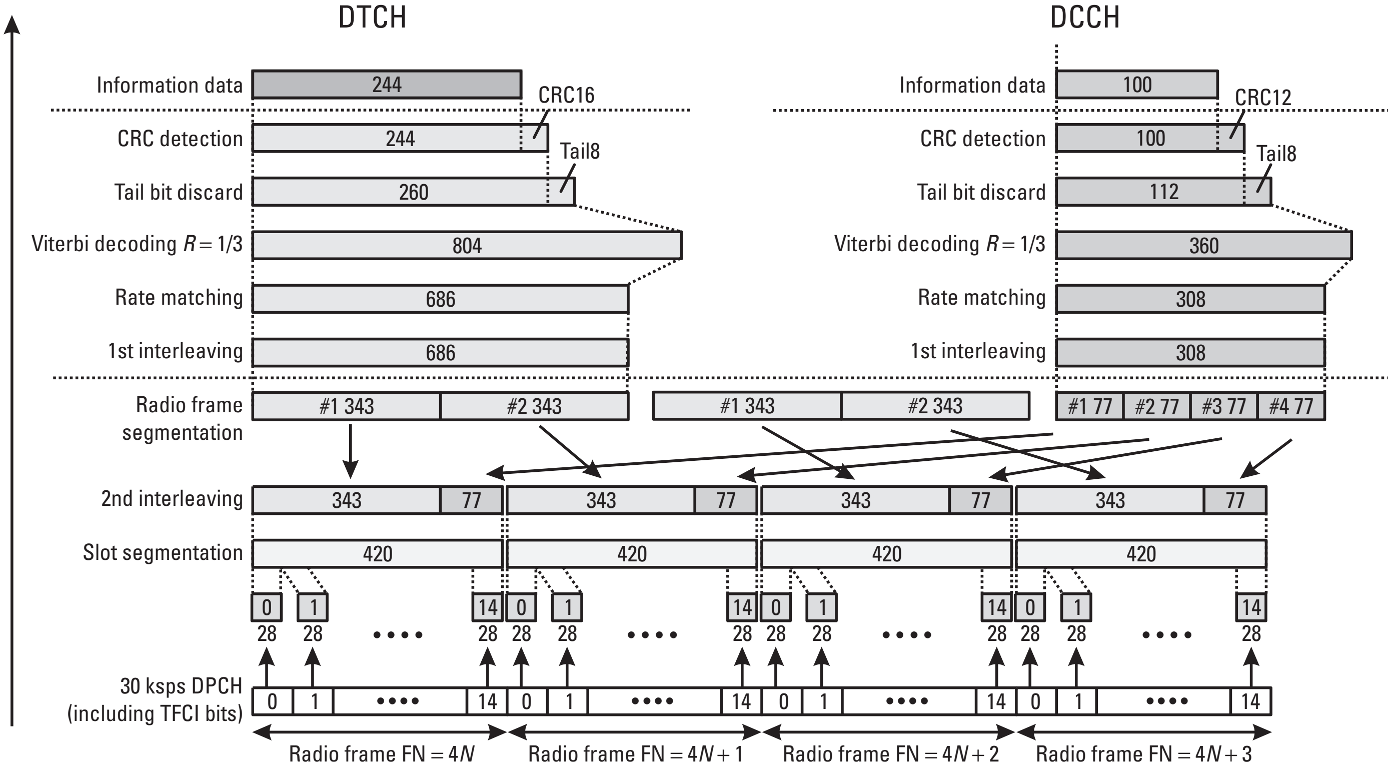

Figure 3.7 Multiplexing/demultiplexing. (*Source:* [16] © ETSI 2001.)

Table 3.4
DL Transport Parameters for 12.2-Kbps Reference Measurements

Parameter	DTCH	DCCH
Transport channel number	1	2
Transport block size (bits)	244	100
Transport block set size	244	100
TTI (ms)	20	40
Type of error protection code	Convolution	Convolution
Coding rate	1/3	1/3
Rate matching attribute	256	256
Size of CRC (bits)	16	12
Position of Tr channel in frame	Fixed	Fixed

Source: [16] © ETSI 2001.

On the DL, higher layer scheduling through the rate matching attribute and resultant padding or puncturing automatically controls rate matching. Each of the 15 slots within a 10-ms radio frame has 2,560 chips, corresponding to 10×2^k bits, where $512/2^k$ is the spreading factor, as in Figure 3.6, where the numbers of bits of various types (e.g., power control and TFCI) within the DPCCH and DPDCH are given by tables [12]. The first interleaving is intrinsic to the separate channels here, and radio frame segmentation is required because the TTI exceeds 10 ms in both channels. The second interleaving combines the first two DCCH segments with the two DPCH segments, and the last two with an additional two DPCH segments for their next TTI. Slot segmentation then splits each of the interleaved segments into 15 slots.

3.4.5 Physical Layer Measurements

In order to achieve the necessary quality, the physical layer has to perform measurements of such features as the block error rate, the SIR, and interference power, all of which must be reported to higher levels so that the RRC in particular can take appropriate action [17]. Maintenance of quality depends on the ability of the system to monitor signal strengths, error rates, and timings, and this is carried out both by the UE and by the UTRAN.

The main measurement made by the UE is the block error rate (BLER) based on the number of CRC errors received.

The UTRAN performs a more complex set of tasks. These include the measurement of the following:

- SIR according to the formula SIR = (RSCP/ISCP) × SF, where SF is the spreading factor, RSCP the received signal code power, and ISCP the interference code power;
- Transmitted power on one channel code on one scrambling code on one carrier;
- Transport channel BER for the DPDCH;
- Physical channel BER for DPCCH;
- Round-trip time (RTT) where RTT = $T_{RX} - T_{rx}$. T_{rx} is the time of transmission of the beginning of the DPCH to the UE, and T_{RX} is the time of reception of the beginning of the corresponding DPCCH/DPDCH from the UE;
- Propagation delay on the PRACH.

In addition to these periodic measures, there are also several sets of measurements to be made at specific stages of operation:

1. Handover measures to compare the relative signal strengths of different cells and, for FDD, the timing relation between cells for support of the soft asynchronous handover procedure;
2. Specific measures for handover to GSM 900/1,800 if relevant;
3. Measures for the UE before random access process;
4. Measures for dynamic channel allocation in TDD.

Some of these measurements have to be made on a different carrier frequency, which can only be made by many UE if DL transmissions are interrupted. In order to enable this, a specific way of operating, called compressed mode, is used. It is implemented by halving the spreading factor (and so doubling the data rate) and using a different scrambling offset by a standard amount from the normal.

3.4.6 Power Control

Power control [13] is a vital feature of WCDMA for limiting interference and controlling quality. As mentioned above, there are several distinct power control loops. The initial power level of the UE is set on the basis of open loop power control. For the UL this entails the UE setting a value for the random access channel based on broadcast information for the cell, while initial strength on the DL is based on measurements by the UE.

The power used on the dedicated physical channels of a call in progress is based on outer and inner loop power control. Outer loop control sets the long-term quality target for the inner loop. Outer loop control resides in the SRNC for the UL and sets the target quality for the inner loop based on measurements of the transport channel quality. In the case of the DL, the function is contained in the UE, but based on targets sent by the SRNC.

Inner loop power control handles the very rapid changes in power that have to be made as a result of the motion of the UE (see Chapter 6), and the function is located in both the UE and Node B. Each serving cell must monitor the quality of signals received on the UL DPCH. The SIR is estimated and compared to the target value. On the basis of this measurement, the serving cell must send a TPC command for every slot (i.e., 1,500 times per second) to the UE indicating 0 if SIR exceeds the target value or 1 if it does not. The UE should increase its transmit power for the UL on receipt of TPC 1 by either 1 dB or a specified TPC_StepSize depending on which of two algorithms is in use.

The UE can also send TPC commands on the UL dedicated physical control channel to the Node B on the basis of its comparison of received quality with the target for adjustment of the DL power.

The power on the physical channel depends on the data rate, so it has to be changed if the TFC is altered. Whenever compressed mode is used to enable the UE to make measurements on the DL, the data rate is increased and hence the power has to be changed.

3.4.7 Cell Search and Handover

One of the most critical stages in a call for QoS problems is at handover. Cell search is required at registration and as the UE moves through the network. During the cell search, the UE searches for a suitable cell based on pilot channel signal strengths [18] and determines the DL scrambling code and frame synchronization of that cell. The cell search [19] is typically carried out in three steps:

1. *Slot synchronization:* During the first step of the cell search procedure, the UE uses the SCH's primary synchronization code to acquire slot synchronization to a cell.
2. *Frame synchronization and code-group identification:* During the second step of the cell search procedure, the UE uses the SCH's secondary synchronization code to find frame synchronization and identify the code group of the cell found in the first step. This is done by correlating the received signal with all possible secondary synchronization code sequences and identifying the maximum correlation value. Since the cyclic shifts of the sequences are unique, both the code group and the frame synchronization are determined.
3. *Scrambling-code identification:* During the third and last step of the cell search procedure, the UE determines the exact primary scrambling code used by the found cell. The primary scrambling code is typically identified through symbol-by-symbol correlation over the CPICH with all codes within the code group identified in the second step. After the primary scrambling code has been identified, the primary common control physical channel (CCPCH) can be detected and the system- and cell-specific BCH information can be read.

If the UE has received information about which scrambling codes to search for, steps 2 and 3 above can be simplified.

Reselection

According to its capability, the UE may monitor a list up to 32 cells on the original frequency when in idle mode, 32 cells on up to two other FDD frequencies, 32 GSM cells, and, if TDD is supported, up to 32 more on up to three frequencies. Once in connected mode the UE has to be capable of maintaining at least six radio links in an active set of cells [20]. The UE performs regular measurements of signal quality and camps on to another cell if signal quality requires this, as indicated by an active set update message from the UTRAN. Handovers can be soft/softer for FDD-FDD on the same frequency, or hard for FDD-FDD at a different frequency, FDD-TDD and FDD-GSM.

The soft handovers do not entail any interruption to data flow. For the others, however, there is an interval between the last TTI containing a transport block on the old DPDCH and the time the UE starts sending a block on the new DPDCH. This interval depends on the number of cells and whether they are already known to the UE, as well as on the type of hard handover. In most cases, the delay is not long enough to trigger a time-out and retransmission of application level data, but this can sometimes occur. For hard FDD-FDD handovers [e.g., between different layers in a cell hierarchy (see Chapter 6)] the formula for the maximum interval without compressed mode is

$$T = T_{IU} + 40 + 20 \times KC + 150 \times OC \quad \text{ms}$$

where T_{IU} is not more than one 10-ms frame, 40 represents a channel measurement time, KC is the number of known cells, and OC is the number of unknown target cells in the active cell update message. A cell is known if the UE either had it in its previous active cell list or had made measurements on it in the previous 5 seconds. The factor of 20 on KC increases to 50 if compressed mode is used to support measurements on a different frequency. If the UE only supports six radio links, then this interruption will always be less than 1 second. FDD-GSM handovers entail much shorter interruptions than these maxima and should not cause disruption to service.

3.4.8 Physical-Level Differences for TDD

UL and DL operate on the same frequency in TDD mode, and a TDD channel is a burst that is transmitted within one of the 15 timeslots. There are two possible chip rates: 3.84 Mcps (as in FDD) and 1.28 Mcps. The framing structure differs for the 1.28-Mcps version, and each 10-ms frame is composed of two 5-ms subframes, each of which contains seven normal timeslots and three special timeslots [21].

A burst for 3.84-Mcps TDD consists of two data parts, a midamble, and a guard period. The data parts are spread by channelization and scrambling codes, where the OVSF for the former allows spreading factors of 1, 2, 4, 8, or 16, of which the DL only uses the value 16. Each timeslot can be allocated to either direction, subject to there being at least one timeslot in either direction. The guard period is required to prevent conflicts due to the changes in direction. The midamble is used for training. There are three different types of burst, each with differing ratios of these field sizes. The quantity of transport level data carried by a burst with spreading factor of 1 is 1,952, 2,208, or 1,856 bits according to the type, 1, 2, or 3, and reduced pro rata by the spreading factor for higher SF [21]. In each case the two parts of the data are separated by the midamble, with the guard period at the end of the slot. The basic characteristics of the burst types are as follows:

- Type 1 is suitable for either UL or DL and has a relatively long midamble of 512 chips with a guard period of 96.
- Type 2 is also suitable for both UL and DL and has a longer data field at the expense of the midamble (reduced to 256 chips) with a guard period of 96.
- Type 3 is only suitable for UL and has a midamble of 512 chips and a guard period of 192 chips. The extended guard period makes it suitable for initial cell access or handovers.

The TFCI and TPC commands are included in the data portion of the burst, with the TFCI split into two parts on either side of the midamble and the TPC for the UL ahead of the second part of the TFCI. This slot and burst structure for 3.84-Mcps TDD is shown in Figure 3.8.

In the case of 1.28-Mcps TDD, a 10-ms frame consists of two 5-ms (6,400 chip) subframes that can each be split into seven timeslots, of which the first is always for the DL and the last for UL, with the remainder switchable, subject to two switching points in the subframe. Each timeslot is 864 chips long, and the remaining 352 include DL and UL pilot slots and a guard period for the switching points. Bursts for 1.28 Mcps again have two data fields, a midamble, and another guard interval. For SF of 1 the data field

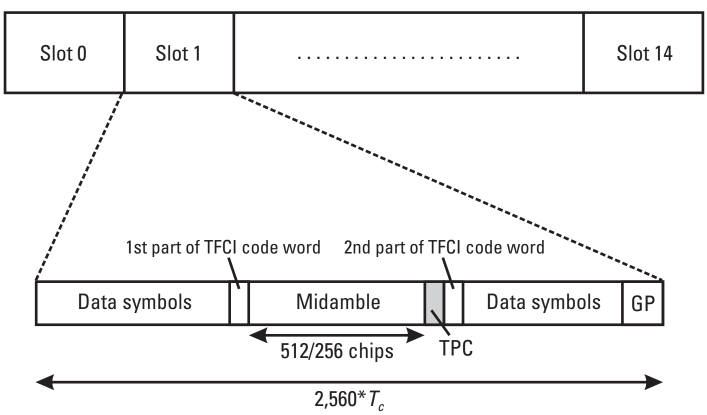

Figure 3.8 TDD slot structure. (*Source:* [21] © ETSI 2001.)

is 352 chips, the midamble 144, and the guard 16, with pro rata reductions for higher SF.

A major consequence of the ability to use slots in either direction is the existence of a UL shared channel, and the possibility to have more than one CCTrCH on the UL as well as the DL.

3.5 High-Speed Downlink Packet Access

High-speed downlink packet access (HSDPA) was introduced in UMTS to provide high throughput PS traffic with low delays and very high peak rates [22]. It entails a new module for the MAC layer, MAC-hs, and a new transport channel, the high speed downlink shared channel (HS-DSCH). It is supported in both FDD and TTD modes. The architecture for HSDPA is shown in Figure 3.9

In this diagram, the frame protocol (HS-DSCH FP) handles the data transport from SRNC to CRNC and from CRNC to Node B, with the MAC-hs situated below the MAC-sh in the CRNC. There is also an alternative mode in which the SRNC is connected directly to Node B, bypassing the CRCN, so that the MAC-sh is not involved.

At RLC level, it only uses AM and UM, rather than TM (omitted on the account of ciphering issues) that normally supports the highest data rates. PDCP can be used as before. It is aimed primarily at the streaming, interactive, and background class applications (see Chapter 9) and is optimized for

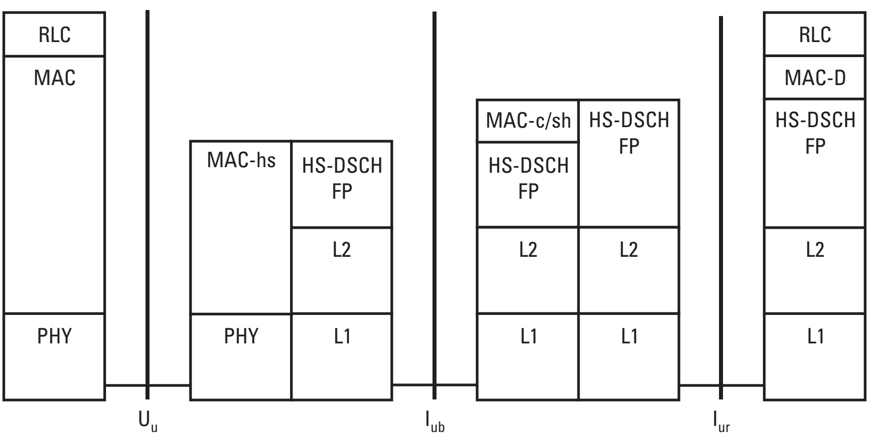

Figure 3.9 HSDPA architecture. (*Source:* [22] © ETSI 2001.)

low- to medium-speed users in urban environments, although also supporting others.

MAC-hs supports a new acknowledgment method known as hybrid ARQ (HARQ) and scheduling specific to HSPDA. Flow control is handled jointly by MAC-c/sh (responsible for normal DSCH) and MAC-hs, and scheduling is based on a priority class passed down from the RRC with separate queues per class.

HARQ is a stop and wait (for acknowledgment) protocol. It uses a new data indicator that is incremented each time that the block transmitted differs from its predecessor; new and old data (i.e., retransmissions) cannot be mixed in the same TTI. Blocks also carry a transmission sequence number per priority class for use in reordering.

The HS-DSCH exists only on the DL and is processed from a single CCTrCH, with only one CCTrCH of HS-DSCH type per UE. HSDPA signaling is sent in-band on the DL in the HS-DSCH, but with out-of-band ACKs or NAKs back from the UE. The UE sends an ACK if the block is correctly received or a NAK if it contains an error. Errored or unacknowledged blocks are retransmitted and take priority over new data. On the DL, the UE identity, the new data indicator, TSN, and priority are included in the MAC header.

At the physical level, the DL channel configuration consists of the PDCH together with up to four separate high-speed shared control channels (HS-SCCH) in combination with the high-speed physical downlink shared channel (HS-PDSCH). The HS-SCCH carries the following:

1. A transport format and resource indicator (TFRI) that shows the transport format, channelization codes, and modulation scheme;
2. The HARQ information.

The TTI is much shorter than the normal 10–80-ms range. There is a single TTI for FDD that is 2 ms, while that for 1.28-Mcps TDD is 5 ms, and that for 3.84-Mcps TDD is 10 ms. The type of error protection coding used is turbo at rate 1/3 with a 24-bit CRC; so a 2-ms block at 2 Mbps would correspond to roughly 1,200 input data bits.

3.6 QoS in WCDMA

This section shows how the above features and procedures control the QoS on the radio link, and what can be achieved with particular reference to the user perception outlined in the first chapter.

The first criterion—that of a high chance of successful access—is determined mainly by capacity planning and admission control (which is discussed in Chapter 6) rather than the RF features above. The time taken to log on to the network and to initiate a call is determined by the cell search and random access procedures. The lack of strict time synchronization in WCDMA means that the three-step search procedure above is used instead of the two-step process common to most other mobile technologies, and this takes slightly longer. There are additional delays where it is necessary to set up a dedicated radio bearer for the user traffic instead of a preexisting common channel.

The next issue is whether calls are liable to be dropped in the middle, especially during handover. WCDMA uses a soft handover procedure in which the UE is in constant communication with several cells and is monitoring their respective signal strengths and qualities. The detailed procedures for performing this should ensure that it is seamless for packet data, but there is a slight possibility of loss of synchronization where onward communication to a CS network is involved.

The QoS profile for the call traffic is determined by the requests of the end applications, the subscription rights of the users, and the available capacity. The ultimate decision on this is taken by the core network and signaled back to the RNC (see Section 8.1.3) in the form of the radio bearer information entity.

The attributes used in the UMTS QoS classes are as follows: maximum bit rate, delivery order, maximum SDU size, SDU format information, SDU error rate, residual bit error rate, delivery of erroneous SDUs, transfer delay, guaranteed bit rate, traffic handling priority, allocation/retention priority, and source statistics descriptor. These are used to select the appropriate radio bearer service between levels 3 and 2. The SDU sizes determine the RLC sizes and level and 1 to 2 transport formats. The following paragraphs show how these factors are represented in terms of parameters for the radio link.

Bit-Rate Throughput is critical for real-time streaming applications and is determined in the absence of retransmissions for a transport channel by the formula

$$\text{Bit rate} = (\text{transport block set size}) / \text{TTI}$$

The rates achievable depend on the capability of the DPDCH and the choice of spreading factor. The peak data rate on a single DPDCH is 960 Kbps using the minimum spreading factor of 4, but this rate assumes no channel coding; allowing for a coding rate of 1/2 and overheads associated with monitoring for handover, this drops to an effective maximum user data rate of 400 to 500 Kbps, and 300 to 350 at rate 1/3. A further reduction in throughput will result if any additional processing is required (e.g., sequencing and especially retransmissions), so the maximum is most likely to be achieved with RLC TM. Up to six parallel codes, each associated with its own DPDCH, can be used simultaneously (as well as one DPCCH), leading to a maximum possible user data rate of about 2.5 Mbps in conformity with the IMT-2000 target of 2 Mbps.

Delivery Order This requires the use of sequence numbers by the RLC and hence uses either UM or AM modes.

SDU Error Rate and Bit Error Rate The BER and BLER on the radio link depend on the power used, code rate, and bit rate. BLER is normally in the range 10^{-1} to 10^{-3} with the power levels that should achieve this under test conditions for various bit rates specified in UMTS [16]. Achievement of better error rates entails use of ARQ retransmissions at the RLC level using RLC-AM. The CRNC is responsible for determining the best combination of power and retransmission count and sets a parameter MaxDAT for the latter after which erroneous SDUs are just discarded.

Delivery of Erroneous SDUs Distinction between correct and incorrect frames requires the use of a CRC at the physical level.

Transfer Delay The radio link's contribution to network transfer delay is largely determined by the TTI plus a very small processing element (rather than the radio frame duration) for dedicated channels, plus additional queuing delays (see Chapter 9) for shared channels. The radio frame duration is 10 ms, but the TTI can be 10, 20, 40, or 80 ms, and usually at least 20 ms. All the frames sent in the appropriate TTI are interleaved to reduce errors, so an individual frame cannot be fully processed until the complete set has been received. Turbo-coding entails a few milliseconds of extra delay as compared to convolution owing to internal interleaving between its two stages. For delay-critical traffic such as voice, the 80-ms option is unacceptable in communication with remote networks since the maximum reasonable end-to-end transit time is about 100 ms. Even the 40-ms option is potentially troublesome, so the 20-ms option is used for this. It is therefore important that an application be able to use a suitable TTI (this issue is discussed more fully in the chapters on applications). Transfer delay is increased considerably if

ARQ error correction is required. If N retransmissions are required on average to achieve the required error rate, the transfer delay becomes roughly

$$\text{Transfer delay} = \text{TTI} + N \times (\text{TTI} + Tr)$$

where Tr is a retransmission timer. Several different procedures are possible for this depending on the optional use of a polling bit in RLC AM PDUs with differing timers for retransmission of unacknowledged PDUs [9]. Retransmission of PDUs takes precedence over initial transmissions.

Priority This applies to the common and shared channels. Access service class priority applies in general for the PRACH, while interactive class traffic (see Chapter 9) uses handling priority on shared channels.

Choice of Transport Channel Type

User traffic can be sent over several of the transport channel types in addition to the dedicated traffic channels to ensure efficient use of radio resources; the choice is made by the CRNC. Where a network offers both FDD and TDD, and the UE is capable of both modes, then there is also a choice between these. TDD has two related advantages: the ability to share bandwidth between UL and DL as required, and the ability to support multiple CCTrCH on both DL and UL. These are most useful when the traffic is highly asymmetric and when a user wants support for multiple QoS on the UL. The corresponding applications are receipt of real-time streaming traffic and transmission of multimedia by the UE.

On a dedicated channel the OVSF has to be set on the basis of the highest data rate expected, with the result that they are wasteful if the data has a bursty nature, whereas a shared channel can statistically multiplex bursts from different users, albeit at the expense of some queuing delays (see Section 9.5.1). The dedicated channels also take a relatively long time to set up compared to the common channels, and the latter can sometimes be used to send small amounts of data, such as the Short Message Service (SMS) or e-mail messages. These criteria form the basis of Table 3.5.

The type of channel selected depends in part on the RLC mode, with dedicated channels being used for RLC-AM. CS traffic (e.g., speech and real-time applications) normally make use of dedicated channels. These factors are considered in relation to specific applications and the UMTS QoS classes in Chapter 9.

Table 3.5
Transport Channel Aptitudes

Channel Type	Dedicated	Shared		Common		
Channel	DCH	DSCH	USCH	FACH	RACH	CPCH
Criterion			(TDD only)			
Direction	DL, UL	DL	UL	DL	UL	UL
Soft handover	Yes	No	No	No	No	No
Basis of code usage	Peak rate	User share	User share	Cell	Cell	Cell
Data volume	High/med	High/med	High/med	Low	Low	Med/low
Data-burst suitability	No	Yes	Yes	Yes	Yes	Yes

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