# 1

# Introduction to Radio and Core Networks of UMTS

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Mobile networks were first designed for one single service which was voice telephony. The very first mobile radio telephone system was introduced in 1918 by the German national railway *Deutsche Reichsbahn*, which offered their first-class passengers a radio-based telephone link in the Berlin area (Feyerabend *et al.* 1927, p. 872). However, the first large mobile network was established in 1958. It was the so-called *A-Netz*. The terminals were huge and their cost immense. Also, the number of subscribers was limited due to the simple implementation.

The successor, the so-called *B-Netz*, was introduced in 1972. An important new feature of the system allowed the subscribers to set up a call on their own. In the previous networks a central operator was involved in any call setup procedure.

The last analogue technology was the *C-Netz*, which began in 1986 and was shut down in 2000. The terminals were still quite expensive, but at *only* 6.5 kg they were real lightweights compared to the previous generations.

Mobile telephony as we know it today began in the early 1990s. In 1990 the second generation (2G) of mobile communication technology, namely the Global System for Mobile Communications (GSM), was introduced by the European Telecommunications Standards Institute (ETSI), supporting digital transmission of voice data. The number of mobile terminals started to ramp up very quickly and after 15 years they had already exceeded the number of fixed telephone systems in Austria.
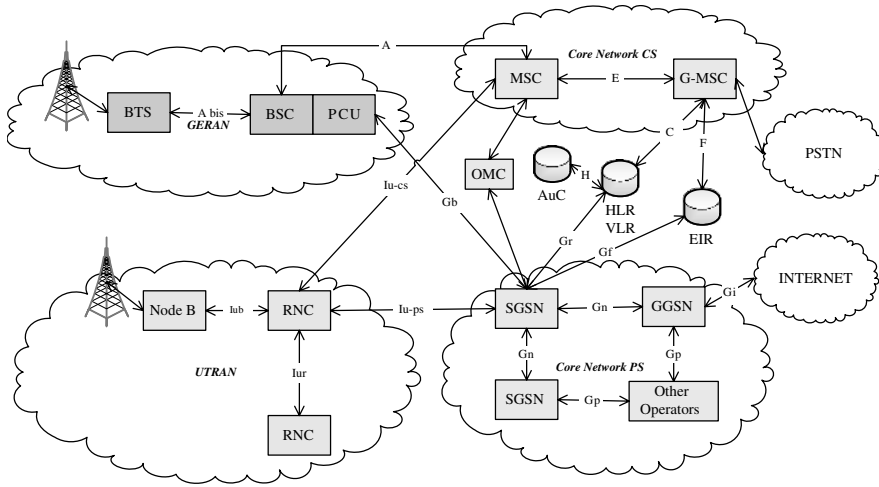
Figure 1.1  Network elements for 2.5G and 3G mobile networks.

Meanwhile, another technology began to emerge: the Internet. The number of Internet hosts also started to grow rapidly. This evolution also had an impact on mobile communication networks. End terminals could only process audio/voice data as input data. Therefore, users had to use a modem to transfer data traffic via GSM. This method of data transport is quite inefficient. To prevent such shortcomings the GSM group standardized a new technology for packet-switched traffic only: the General Packet Radio Service (GPRS). To minimize changes and costs, only minor parts of the GSM system were adopted. Consequently, GPRS is referred to as 2.5G. GPRS was introduced to the Austrian market in autumn 1999 by mobilkom austria AG. Thereafter, the Internet and the mobile networks went into a merging process, which today (2009) here in Austria-Europe, results in mobile flat rate contracts being cheaper than rates for fixed-line access.

At the end of the last century the standardization process of the third generation (3G) of mobile communication technologies, the Universal Mobile Telecommunications System (UMTS), was finalized (Holma and Toskala 2004). This new technology was a leap forward to the replacement of fixed Internet access technologies. While GPRS supports only data rates in the order of fixed analogue modems (for example, 10–60 kbit/s), UMTS, in Dedicated Channel (DCH) mode, can support up to 386 kbit/s and beyond. With the increase of data rate came a reduction of the Round Trip Time (RTT) from 1000 ms to 140 ms. These parameters are already close to the performance of an Asymmetric Digital Subscriber Line (ADSL). Just six years later UMTS was further improved by the introduction of High Speed Downlink Packet Access (HSDPA). Currently (2007), it enables user download rates of up to 7.2 Mbit/s per host. Introduced in 2002, UMTS increased the number of available services to the end terminal even further. The higher data rate, the possibility to use advanced Quality of Service (QoS) settings and to choose between Circuit Switched (CS) and Packet Switched (PS) bearers enabled new advanced services such as live video streaming, video telephony and so on.

Figure 1.1 depicts a top-level view of a 3G core network including a GPRS and a UMTS Radio Access Network (RAN). From this figure we learn that GPRS was *attached* to the existing GSM by adding the Packet Control Unit (PCU), while in UMTS the packet-switched data is processed in the same device as the voice and video calls. GPRS is the first mobile technology purely to target data traffic.

This part of the book is but a brief introduction to the large topic of mobile communication systems. Later, we will refer to the associated standards of Third Generation Partnership Program (3GPP), which some may find hard to read. For a comprehensive overview of the topic of mobile cellular communications, see Eberspächer and Vögel (1999), Taferner and Bonek (2002) and Holma and Toskala (2004, 2006). Furthermore, detailed information on parts of each system can be found in Heine (2001, 2002) (GPRS), Heine (2004, 2006) (UMTS) and Blomeier (2005, 2007) and Blomeier and Barenburg (2007) (HSDPA).

# 1.1 UMTS Network Architecture

The UMTS system is built according to the same well-known architecture that has been used by all major second generation systems in Europe. At a high level, the UMTS network consists of three parts (3GPP TS 23.002 2002). These are the Mobile Station (MS), in 3G now called User Equipment (UE) as the interface between the user and the radio part, the UMTS Terrestrial Radio Access Network (UTRAN) containing radio-related functionality and the Core Network (CN) responsible for the connection to external networks. This high-level system architecture, as well as the most important nodes and interfaces, is presented in Figure 1.2.
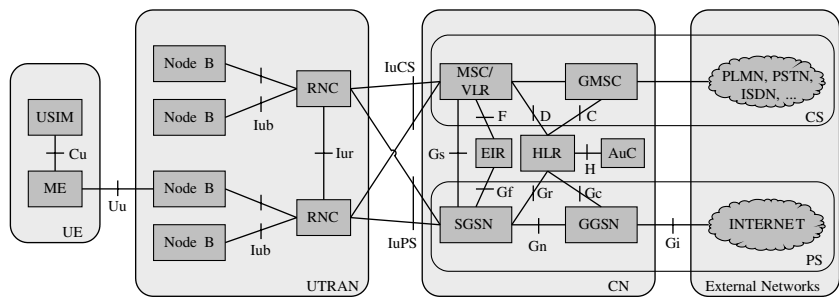


Figure 1.2  UMTS network architecture and interfaces.

The UE consists of the physical equipment used by a Public Land Mobile Network (PLMN) subscriber, which comprises the Mobile Equipment (ME) and the Subscriber Identity Module (SIM). It is called the UMTS Subscriber Identity Module (USIM) for Rel. 99 and following. The ME comprises the Mobile Termination (MT), which, depending on the application and services, may support various combinations of Terminal Adapter (TA) and Terminal Equipment (TE) functional groups to provide end-user applications and to terminate the upper layers.

Within the UTRAN, several Base Stations (NodeB) – each of them controlling several cells – are connected to one Radio Network Controller (RNC). The main task of the NodeB is the performance of physical layer processing including channel coding, interleaving, rate adaptation, spreading and so on. Furthermore, some Radio Resource Management (RRM) operations such as the Inner Loop Power Control (ILPC) as well as the fast Hybrid Automatic Repeat reQuest (HARQ), scheduling and priority handling for HSDPA have to be performed in the NodeB. The RRM tasks performed in the RNC are the load and congestion control of its own cells, admission control and code allocation for new radio links to be established in those cells as well as handover decisions and the Outer Loop Power Control (OLPC). The RNC performs the layer-two processing of the data to/from the radio interface and macrodiversity combining in case of soft handover.

While the UE and the UTRAN contain new specific protocols as well as a new radio interface (WCDMA), Rel. 99 UMTS CN was inherited from the GSM system and both UTRAN and GSM Edge Radio Access Network (GERAN) connect to the same core network. As presented in Figure 1.2, the core network consists of the circuit switched domain for the real time data and the packet switched domain for non-real-time packet data. In the CS domain the Mobile Switching Center (MSC) including the Visitor Location Register (VLR) connects to the RNCs. It switches the CS data transactions and stores the visiting user's profiles and location. The Gateway MSC (GMSC) connects UMTS to external networks such as, for example, the Public Switched Telephone Network (PSTN). In the Home Location Register (HLR) the user's service profiles and the current UE locations are stored and the Equipment Identity Register (EIR) is a database for identification of UEs via their International Mobile Equipment Identity (IMEI) numbers. The Serving GPRS Support Node (SGSN) is the equivalent to the MSC but for the PS domain. It is responsible for the user mobility and for security (authentication). With the Gateway GPRS Support Node (GGSN) the connection to external networks such as the Internet is realized.

According to the presented network architecture, Figure 1.3 shows the layered UMTS bearer architecture, where each bearer on a specific layer offers its individual services using those provided by the layers below. To realize a certain network QoS, a bearer service with clearly defined characteristics and functionality is to be set up from the source (left TE) to the destination (right TE) of a service, passing MT, RAN, CN edge node (SGSN) and CN gateway (GGSN). Details of the UMTS QoS concept and architecture can be found in reference 3GPP TS 23.107 2002 and the interaction and QoS negotiation with other neighbouring networks is specified within reference 3GPP TS 23.207 2005.

Note, the presented CN architecture refers to Rel. 99/4. Further details of the UMTS CN architecture and its evolution within Rel. 5, 6 and 7 can be found in Holma and Toskala (2004) as well as in the corresponding versions of reference 3GPP TS 23.002 2002.

## 1.2   UTRAN Architecture

In this section the overall architecture of UTRAN is described. The UTRAN consists of two basic elements – base stations NodeB and RNC. The functions of both elements are discussed as well as their interfaces and the corresponding protocol architecture of the user plane and the control plane. As a part of the International Mobile Telecommunications at 2000 MHz (IMT-2000) standards of the International Telecommunications Union (ITU),
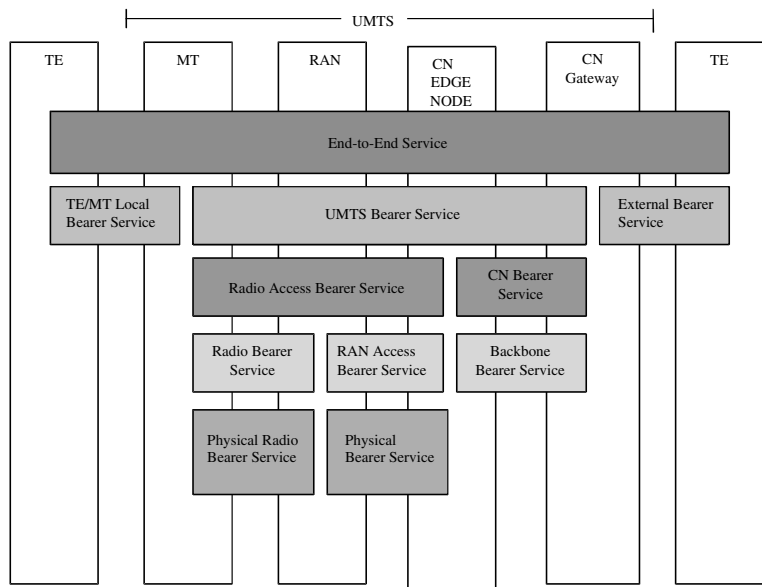
Figure 1.3  Architecture of UMTS bearer services.

UMTS is specified within the 3G Partnership Project (3GPP) where its main radio access technologies based on WCDMA are called Universal Terrestrial Radio Access (UTRA), Frequency Division Duplex (FDD) and Time Division Duplex (TDD).

3GPP specifies UMTS in several steps, from Rel. 99/4 offering theoretical bit rates of up to 2 Mbit/s, to Rel. 5 and 6 reaching higher bit rates beyond 10 Mbit/s with the introduction of HSDPA and High Speed Uplink Packet Access (HSUPA). Whereas 2G systems such as GSM were designed for voice communications, UMTS as a 3G communication system with its high data rates, low delay and high flexibility is designed for the delivery of multimedia services.

## 1.2.1   UTRAN Protocol Architecture

A general overview of the UMTS radio interface protocol architecture (3GPP TS 25.301 2005) is presented in Figure 1.4. The radio interface is in three protocol layers: L1 (physical layer), L2 (data link layer) and L3 (network layer), and L2 is further split into the following sublayers: Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and Broadcast Multicast Control (BMC). Vertically, L3 and RLC are divided into control and user planes, where the control plane is used for all UMTS-specific control signalling including the Radio Resource Control (RRC) as the lowest L3 sublayer.

In Figure 1.4 the Service Access Points (SAPs) for peer-to-peer communication are marked with ellipses at the interface between sublayers. The service provided by Layer 2 is referred to as the Radio Bearer (RB). The control plane RBs, which are provided by RLC to RRC, are denoted as signalling RBs.
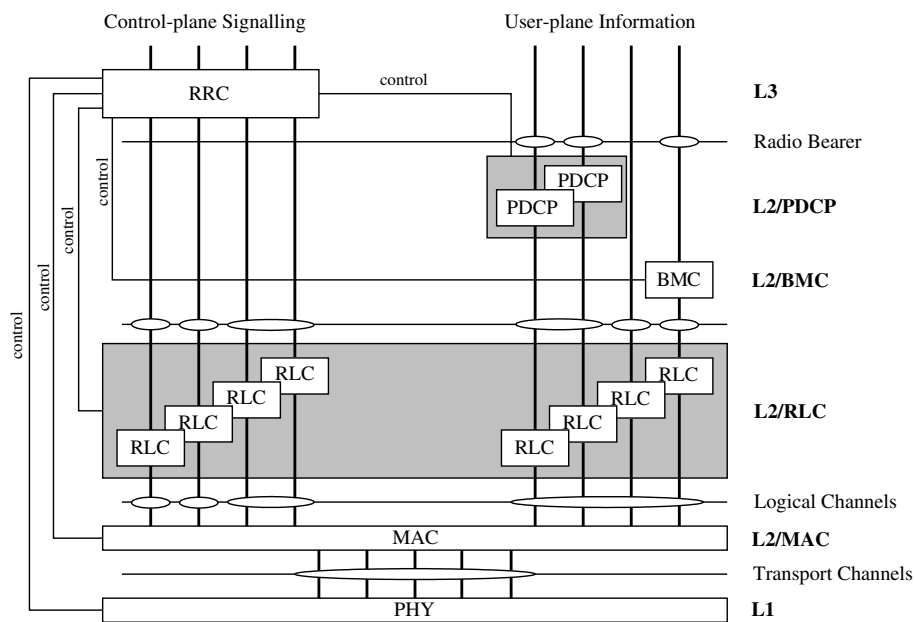
Figure 1.4  UMTS radio interface protocol architecture.

A fundamental part of the UTRAN architecture is the channel concept – the different functions of the channels and the channel mapping. The logical channels provide an interface for the data information exchange between the MAC protocol and the RLC protocol. There are two types of logical channel: control channels for the transfer of control plane information and traffic channels for the transfer of user plane information. Table 1.1 presents an overview of available logical channels in UTRAN.

Table 1.1  Logical channels.

| | |
|---|---|
| **Control Channels (CCHs):** | Broadcast Control Channel (BCCH) |
| **Traffic Channels (TCHs):** | Paging Control Channel (PCCH) |
| | Dedicated Control Channel (DCCH) |
| | Common Control Channel (CCCH) |
| | Shared Control Channel (SHCCH) |
| | MBMS point-to-multipoint Control Channel (MCCH) |
| | MBMS point-to-multipoint Scheduling Channel (MSCH) |
| | Dedicated Traffic Channel (DTCH) |
| | Common Traffic Channel (CTCH) |
| | MBMS point-to-multipoint Traffic Channel (MTCH) |

Whereas the logical channels are separated by the information they are transporting, the transport channels are separated by how the information is transmitted over the air interface

(in a shared connection or via a dedicated link). The transport channels provide the bearers for the information exchange between the MAC protocol and the physical layer. In contrast to the logical channels, which can be bidirectional, all transport channels are unidirectional. A list of transport channels as well as the possible mapping to the logical channels is presented in Figure 1.5. The arrows show whether the mapping is for DownLink (DL) and UpLink (UL) or unidirectional only.
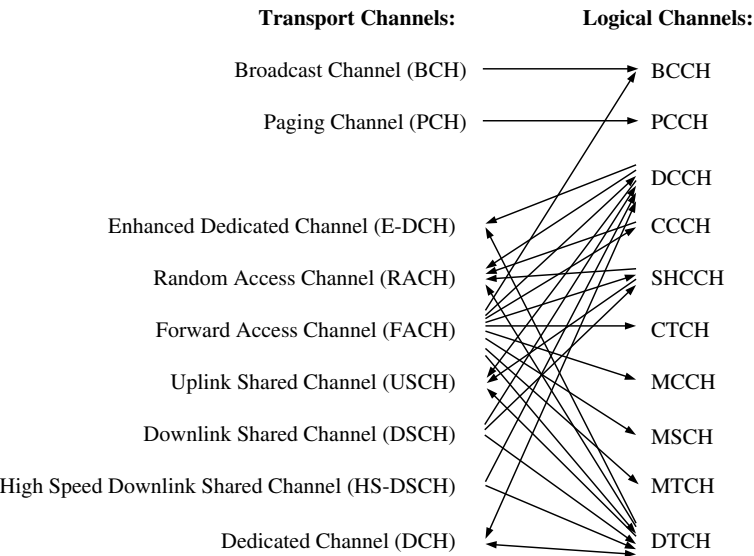


Figure 1.5 Mapping between transport channels and logical channels (seen from UE side).

The RRC (3GPP TS 25.331 2004) is the central and most important protocol within the UTRAN protocol stack as it controls most of the UE, NodeB and RNC protocols and configures the physical layer through the transfer of peer-to-peer RRC-signalling messages. The main tasks of the RRC are the establishment, maintenance and release of an RRC connection between the UE and UTRAN as well as paging, QoS control, UE measurement reporting and the OLPC. The PDCP (3GPP TS 25.323 2006) performs header compression and decompression of IP data streams, for example TCP/IP and RTP/UDP/IP headers,[1] at the transmitting and receiving entity, respectively.

Several RLC instances are placed in the control and user planes without differences. As a classical data link layer (L2) application the main function of the RLC (3GPP TS 25.322 2006) is the exchange of higher layer Protocol Data Units (PDUs) between RNC and UE. Further tasks of the RLC are the segmentation and de-segmentation of higher layer PDUs, overflow protection via discard of Service Data Units (SDUs), for example after a maximum number of retransmissions or timeout, error correction by retransmissions and in-sequence delivery in case of retransmissions. The RLC can work in three different modes. In RLC

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[1]Internet Protocol (IP), Transport Control Protocol (TCP), Real-time Transport Protocol (RTP), User Datagram Protocol (UDP).

Transparent Mode (TM) the RLC-protocol simply conveys higher layer SDUs to the peer RLC-entity without error detection and correction mechanisms, ciphering or in-sequence delivery. The RLC Unacknowledged Mode (UM) enables in-sequence delivery and error detection but no retransmissions and thus error correction mechanisms need to be taken care of by higher layers. The RLC Acknowledged Mode (AM) guarantees the error-free transmission (by means of retransmissions) and in-sequence delivery of upper layer PDUs to the peer entity.

In the MAC-layer (3GPP TS 25.321 2006) the logical channels are mapped to the transport channels and an appropriate Transport Format (TF) is selected from the Transport Format Combination Set (TFCS) for each transport channel, depending on the instantaneous source rate. Further functions of the MAC protocol are priority handling between data flows of one UE and also between UEs by means of dynamic scheduling (for the Forward Access CHannel (FACH) and the DSCH), service multiplexing for RACH/FACH/Corrosion Packet Channel (CPCH) and the DCH, ciphering in case of RLC TM and dynamic transport channel type switching. The processing of the layer-three packets within the UTRAN protocol stack can also be seen in Figure 1.6, where the data flow for non-transparent RLC and non-transparent MAC is shown.
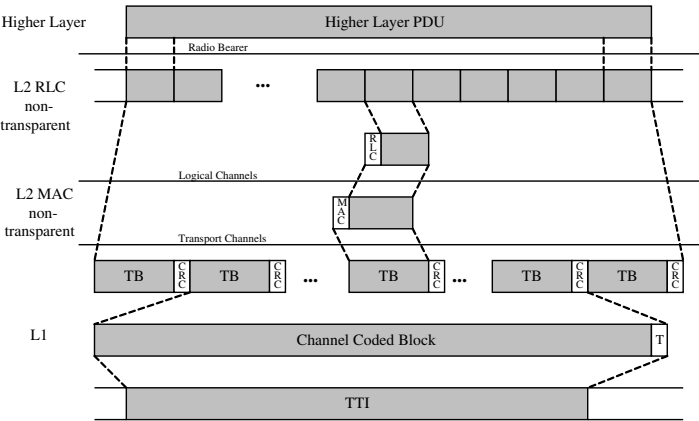


Figure 1.6   Schematic illustration of a packetization example for the transmission over UMTS.

One higher layer PDU (for example, IP packet) coming from the user plane in layer three will be delivered via the corresponding radio bearers to layer two where it can be processed either by PDCP to perform header compression (the packet can be handled by the BMC), or it can be delivered directly to the RLC layer. There, the higher layer PDUs may be segmented into smaller packets. In case of a bearer with a data rate below or equal to 384 kbit/s, usually a 320-bit (40-byte) payload within the RLC packets is used (3GPP TS 25.993 2006). For non-transparent RLC (RLC AM/UM), a header will be added to the packets, then forming RLC PDUs. The header size for the RLC AM is 16 bit, whereas the RLC UM packet header contains 8 bits. These RLC PDUs are then transported via the logical channels to the MAC layer where a MAC header is added if transport channel multiplexing (non-transparent MAC)

is used in the system. After that, the Transport Blocks (TB = MAC PDU) are sent via the transport channels to the physical layer.

## 1.2.2 Physical Layer Data Processing in the UTRAN Radio Interface

The first process in the physical layer after delivering the so-called TBs via the transport channels is a Cyclic Redundancy Check (CRC) of the packet data (3GPP TS 25.201 2005; 3GPP TS 25.302 2003). Then, after attaching the CRC bit to the TBs (3GPP TS 25.212 2006), these are segmented or concatenated in order to fit to the block size of the channel coding (3GPP TS 25.944 2001). For packet oriented applications, usually turbo coding is used with a coding rate of 1/3, which can further be punctured to match the rate with the physical resources.
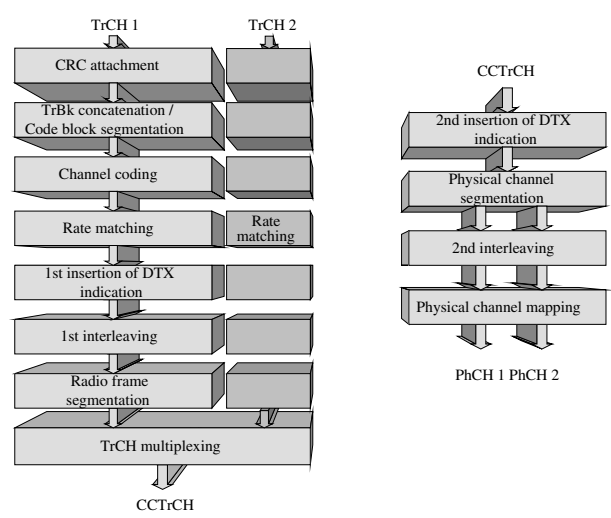


Figure 1.7  UTRAN physical layer procedures.

Figure 1.7 shows a sequential illustration of the physical layer processes such as rate matching, first Discontinuous Transmission (DTX) insertion indication, first interleaving (over one coded block), radio frame segmentation and then multiplexing of the various transport channels. The Coded Composite Transport Channel (CCTrCH) is then, after a second insertion of DTX indication, segmented into the appropriate physical channels. After a second interleaving (over one radio frame) the data bits are mapped onto the correct physical channel. In order to illustrate the physical layer procedures and their sequential processing, the data flow of an example for a bearer with 64 kbit/s user data rate is presented in Figure 1.8.

In this example user data from a DTCH enters the physical layer in the form of one TB of 1280-bit size. It is shown that this 1280-bit TB is transmitted within two radio frames (10-ms/radio frame) which gives the required 64 kbit/s. The first processing step in the physical layer is the adding of a CRC information to the TB followed by the coding of the resulting data block via turbo code with rate 1/3. Rate matching has to be performed
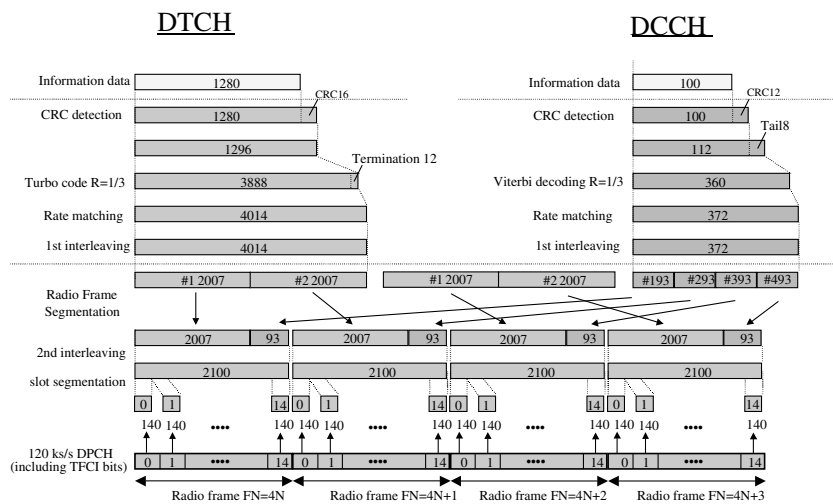
Figure 1.8  Data flow in the UTRAN physical layer for 64 kbit/s reference channel (3GPP TS 34.121 2004).

so that the coded data bit fits into the associated radio frames. After a first interleaving and radio frame segmentation, the bit of the DTCH get multiplexed with the information data of the DCCH which transmits TBs of 100 bits over four radio frames (40 ms) and thus reaches a data rate of 2.5 kbit/s. After the transport channel multiplexing, a second interleaving over one radio frame (10 ms) is performed. The resulting 2100-bit data blocks are transmitted within one radio frame, reaching a bit rate of 210 kbit/s at that point. Every 2100-bit data block is then segmented into 15 140-bit blocks each for fitting into the 15 slots per radio frame. Considering Quadrature Phase Shift Keying (QPSK)[2] modulation of the Dedicated Physical Channel (DPCH), together with physical layer control data, results in 120 kbaud/s which become 3.84 Mchip/s due to the spreading operation with a Spreading Factor (SF) of 32 (3GPP TS 25.213 2003). In Figure 1.9 the mapping of transport channels onto corresponding physical channels is shown. In the case of the DCH, the data from DTCH and DCCH is mapped onto the Dedicated Physical Data Channel (DPDCH) and multiplexed with the Dedicated Physical Control Channel (DPCCH) which contains the Transmit Power Control (TPC), Transport Format Combination Indicator (TFCI) and Pilot bit. In the UMTS DL the DPDCH and the DPCCH are time multiplexed and modulated via QAM whereas in the UL the DPCCH and the DPDCH are modulated according to two orthogonal PAM schemes separately in order to prevent an interference of the transmitting UL signal with audio equipment as in GSM. An exemplary illustration of the slot structures in UL and DL is presented in Figure 1.10.

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[2]Despite the fact that QPSK and Binary Phase Shift Keying (BPSK) are mentioned throughout the documents in 3GPP, a modulation scheme AM in the form of Quadrature Amplitude Modulation (QAM) and Pulse Amplitude Modulation (PAM) with root raised cosine transmit pulse-shaping filter (roll-off factor $\alpha = 0.22$ (3GPP TS 25.104 2007)) is used while the terms QPSK or BPSK just indicate the symbol constellation (3GPP TS 25.213 2003).

| Transport Channels | Physical Channels |
|---|---|
| DCH ——————— | Dedicated Physical Data Channel (DPDCH) |
| | Dedicated Physical Control Channel (DPCCH) |
| RACH ——————— | Physical Random Access Channel (PRACH) |
| CPCH ——————— | Physical Common Packet Channel (PCPCH) |
| | Common Pilot Channel (CPICH) |
| BCH ——————— | Primary Common Control Physical Channel (P-CCPCH) |
| FACH ——————— | Secondary Common Control Physical Channel (S-CCPCH) |
| PCH | |
| | Synchronization Channel (SCH) |
| DSCH ——————— | Physical Downlink Shared Channel (PDSCH) |
| | Acquisition Indicator Channel (AICH) |
| | Access Preamble Acquisition Indicator Channel (AP-AICH) |
| | Paging Indicator Channel (PICH) |
| | CPCH Status Indicator Channel (CSICH) |
| | Collision-Detection/Channel-Assignment Indicator Channel (CD/CA-ICH) |

Figure 1.9  Mapping of transport channels onto physical channels (3GPP TS 25.211 2002).

UMTS Downlink:

| DPDCH | DPCCH | DPCCH | DPDCH | DPCCH |
|---|---|---|---|---|
| Data1 $N_{data1}$ bits | TPC $N_{TPC}$ bits | TFCI $N_{TFCI}$ bits | Data2 $N_{data2}$ bits | Pilot $N_{pilot}$ bits |

$T_{slot} = 2560$ chips

| Slot #0 | Slot #1 | | Slot #i | | Slot #14 |
|---|---|---|---|---|---|

one radio frame, $T_f = 10$ ms

UMTS Uplink:

DPDCH

| Data $N_{data}$ bits |
|---|

$T_{slot} = 2560$ chips

DPCCH

| Pilot $N_{pilot}$ bits | TFCI $N_{TFCI}$ bits | FBI $N_{FBI}$ bits | TPC $N_{TPC}$ bits |
|---|---|---|---|

$T_{slot} = 2560$ chips, 10 bits

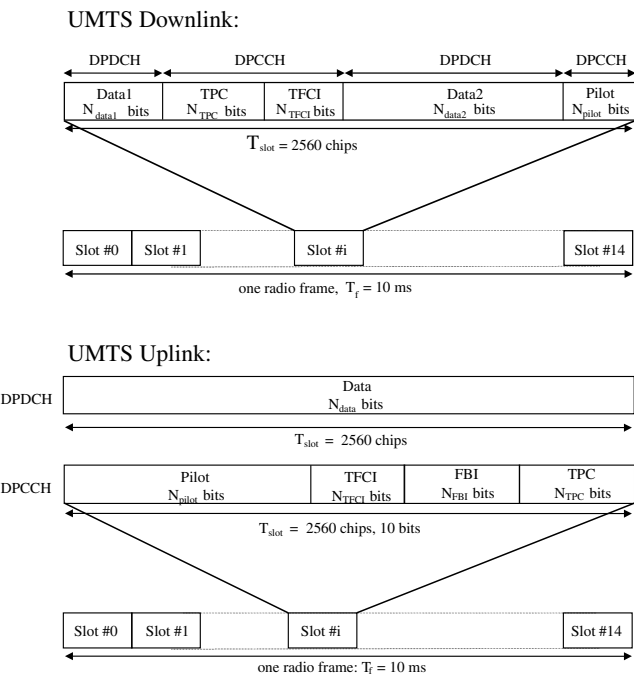| Slot #0 | Slot #1 | | Slot #i | | Slot #14 |
|---|---|---|---|---|---|

one radio frame: $T_f = 10$ ms

Figure 1.10  Downlink and uplink slot structure example (3GPP TS 25.211 2002).

## 1.3   UMTS PS-core Network Architecture

The initial design goal of GSM was to support voice services which are on the same level as the Integrated Services Digital Network (ISDN) combined with mobility. In the late 1990s the user focus started to shift from pure voice to voice-and-data traffic. The GPRS standard was agreed upon as a basis to build for data-only services. Although this was a first step to mobile packet-switched networks, it was only a placeholder for a new technology which could serve PS and CS services by default. UMTS was designed to serve the needs of both the CS and the PS domains. To minimize the cost of the core network the structure and functions of the components are very similar to the GSM/GPRS units. In fact, from UMTS Rel. 5 on, the UMTS units can also serve GPRS and GSM RANs. Figure 1.11 depicts the key elements of the 3G mobile network.
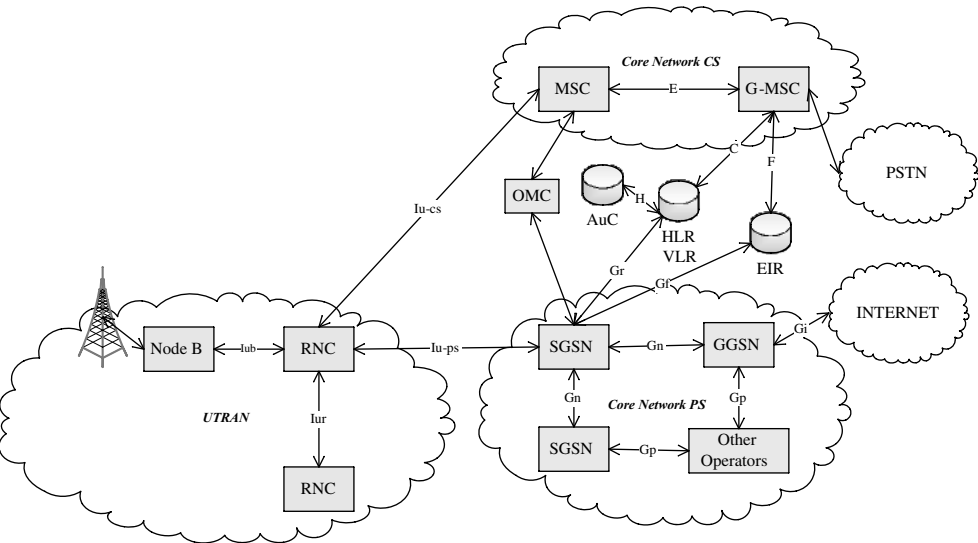
Figure 1.11  Network elements of a 3G cellular mobile network.

**Radio Network Controller (RNC)**   The RNC covers all radio resource management tasks. The NodeB itself has quite a simple function set; therefore, the RNC has to manage the scrambling code tree and the transmit power for each active radio link. The RRC protocol is established between the UE and the RNC to support the manipulation of the radio link between the NodeB and the UE. Towards the core network the RNC terminates the GPRS Tunnel Protocol tunnels. This is different from the GPRS network where the SGSN was the endpoint of the GPRS Tunnelling Protocol (GTP) tunnel. The NodeB has no caching for data packets; therefore, the RNC also has to process the flow control algorithms.

**Serving GPRS Support Node (SGSN)**   The SGSN is the switching centre for the data traffic. In the downlink direction the SGSN is connected to several RNCs using Iu-Ps protocols. A certain SGSN serves a group of RNCs and therefore covers a given geographical area. The number of necessary SGSNs is given simply by the processing power that is needed to serve the given traffic in the area. The common tasks of an SGSN are: session management including attach, detach and mobility management, ciphering, cell updates, paging, compression and so on. The billing in mobile cellular networks is volume based, therefore the SGSN generates billing tickets per user and sends these tickets to a central database. The protocols used by the SGSN are the Sub Network Dependent Convergence Protocol (SNDCP), the Logical Link Control (LLC), the Base Station Subsystem GPRS Protocol (BSSGP) and GTP.

**Gateway GPRS Supporting Node (GGSN)**   The GGSN is the boarder node between the core network of the mobile operator and the external packet data network. GPRS supports different Packet Data Protocols (PDPs) such as IP, Point-to-Point Protocol (PPP) and X.25. The GGSN must be able to handle all these PDPs. The type of PDP can be chosen by the mobile subscriber by creating a PDP-context. The PDP-context creation request marks the start of a data session. It holds the information about the Access Point Name (APN) and the settings the user requests from the mobile network. The GGSN is connected to the external network via the Gi. There is a firewall in common between the GGSN and the external network, protecting the mobile core infrastructure from attacks. If the user accesses an IP network, the GGSN will convert the user datagram from the mobile network to IP packets and replace the GTP identifier, which is the ID for a specific user within the mobile network, with an external IP-address. The GGSN also takes care of the QoS profiles for each PDP-context. One user can have several PDP-contexts, each with a different QoS profile. This can be used to access different services with different QoS settings. For more details, see reference 3GPP TS 23.060 2006.

**The Home Location Register (HLR)**   The HLR is the heart of the GSM network (3GPP TS 11.131 1995). It is a database holding management data for each user of the mobile operator. The HLR holds all permanent user data such as Mobile Subscriber ISDN Number (MSISDN), available services, QoS, international ID, the IMSI and further temporal data such as the location area where the ME was last seen, the actual VLR or the Mobile Subscriber Roaming Number (MSRN). The HLR can be accessed by the MSC via the C interface and by the VLR via the D interface. The HLR itself is closely connected to the Authentification Centre (AUC). The AUC takes care of the generation of security-related data that the HLR needs to authenticate users. The HLR has to hold at least one entry per subscriber and to fulfil real-time requests from the MSC units. To solve this issue a HLR unit normally consists of several discrete units managing the huge load of data and requests. This can also be seen in the International Mobile Subscriber Identity (IMSI). The IMSI is structured as shown in Figure 1.12.

The first three digits are fixed by the country of the operator. The next two digits identify the operator itself. The following HLR part identifies the HLR in which the user data is stored. Finally, the last eight digits are the unique identifier at this HLR for the searched user. At the terminal side this information is stored in the SIM card.

| MCC | MNC | HLR | SN |
|-----|-----|-----|-----|

Example:

| | | | |
|------|--------------------------|----------|----------|
| MCC… | Mobile Country Code (3)  | 232      | Austria  |
| MNC… | Mobile Network Code (2)  | 01       | Mobilkom |
| HLR… | HLR-Number (2)           | 20       | HLR 20   |
| SN…  | Subscriber Number (8)    | 12121212 | User X   |

Figure 1.12  Structure of the IMSI.

**The Visitors Location Register (VLR)**    The VLR is a database holding MS specific data allocated to one or several MSC unit(s). One could think of the visitors of one MSC unit, either in their home operators network or in roaming mode. As the user population will change over time, this database, in contrast to the HLR, is highly dynamic. The first request of a MSC will target the VLR; this instance takes the load from the central HLR unit and can be seen as a kind of cache instance. The VLR makes more sense when thinking about an instance directly implemented in the MSC enabling local caching of user information over a period of time. More details can be found in references 3GPP TS 29.016 2005 and 3GPP TS 11.132 1995.

**The Operation and Maintenance Center (OMC)**    The OMC uses the O-interface to monitor and control all the network components. The protocols deployed on this interface are SS7 and X.25. Typical tasks are status reports, generation of billing tickets, user billing and security screening.

**The Equipment Identity Register (EIR)**    The EIR holds user equipment information in the form of IMEIs (3GPP TS 22.016 2008). The idea of the EIR was to blacklist stolen or malfunctioning devices to ensure that they are not able to enter the network of a mobile subscriber. Although the intention itself was good, it suffers from the fact that the mobile providers do not update this list regularly and that the IMEI is easily re-programmable on most devices.

**The AUthentication Center (AUC)**    The AUC holds the authentication key `Ki`, which is also stored at the SIM-card. By using this shared secret a new key, called `Kc`, can be derived to secure the radio link of the mobile network. Although treated separately from the HLR in this introduction, the AUC normally is a part of the HLR because the relation between these units is very close.

## 1.4   A Data Session in a 3G Network

In a mobile cellular network several steps are necessary in order to set up a data connection for IP transmissions. Figure 1.13 presents the most important steps to establish a connection. The PDP-context must not be activated prior to a GPRS Mobility Management (GMM) activation. The mobility management transfers GPRS related subscription data of the subscriber. This subscription data is needed to clarify which PDP-contexts may be established by the user interface. After the GPRS attachment the subscriber can activate a PDP-context at any time.

The session management for PDP-context activation takes place only between the UE and the SGSN. The SGSN communicates the PDP-context activation data to the GGSN via a GTP tunnel.

After a successful PDP-context activation procedure the subscriber can now transmit user data on the IP layer to an external packet data network. In the case of roaming, the setup procedure has to initiate an intra-SGSN handover first. The QoS profiles may be modified to the needs of the new SGSN (3GPP TS 4.008 2000).
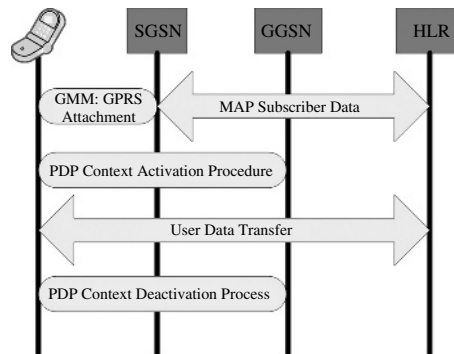


Figure 1.13 Session management procedures.

The PDP-context is similar to a dial-up session which is known from the fixed wired networks. For each context the subscriber is assigned a unique IP address. In the following chapters the IP address information at the Gn interface is sometimes used to represent a user session. A context represents a user session with volume, duration and frequency of use.

## 1.4.1 The UMTS (PS-core) Protocol Stack

In UMTS the lower layers rely on the Asynchronous Transfer Mode (ATM). This allows for a simple integration of high-speed optical fibre systems as a physical layer. The ATM protocol connects RNC, SGSN, GGSN and GMSC. For user data the ATM tunnels even reach up to the NodeB. The CS domain uses the ATM Adaptation Layer v2 (AAL2) version of ATM which is connection oriented. AAL2 supports the transmission and multiplexing of many real-time data streams, offering a low delay, small jitter and less data rate fluctuation. The PS domain uses the AAL5. It is connection-less and implements more or less a best-effort approach, suitable for non-real-time services such as Internet traffic. The AAL5 layer does not support connection management. Therefore, the PS domain in UMTS needs an additional layer using the GTP. The GTP protocol builds up a user-specific data tunnel between the GGSN and the RNC. At the RNC the GTP protocol is converted over to the PDCP. The PDCP supports a more efficient coding of the headers, which is suitable for the radio link where resources are expensive.

## 1.4.2   The Protocols

Figure 1.14 presents the UMTS protocol stack for all three domains. From this figure we learn that there is a second splitting into 'Access Stratum' and 'Non Access Stratum'. The idea is to separate the services in the upper layers. The breakdown allows the UMTS network to migrate to different parts on its own. For example, the change to an all-IP network in the 'Access Stratum' will have no effect on the 'Non Access Stratum'. As long as the interface stays the same, both systems can still interact.
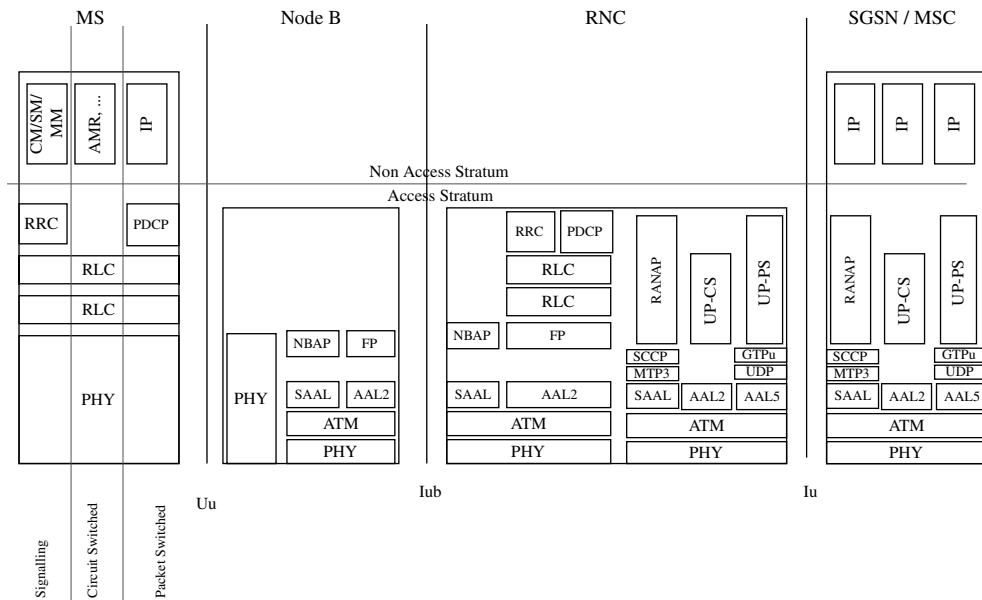


Figure 1.14  UMTS protocol stack.

### Radio Access Network Application Part (RANAP)

The Radio Access Network Application Part (RANAP) handles the signalling between the UTRAN and the core network, via the Iu interface. It is responsible for tasks such as booking ATM lines, changing radio setup and so on; see reference 3GPP TS 29.108 2006. All control procedures needed by the UTRAN can be executed by using instances from the three elementary classes:

- general control service;

- notification service;

- dedicated control service.

All necessary functions can be constructed by using these three elementary classes. Examples for these procedures are

- Iu release;

- overload control;

- RAB assignment.

**Signalling Connection Control Part (SCCP)**

The Signalling Connection Control Part (SCCP) delivers an abstraction between UMTS-related layers and the used transport layers (3GPP TS 29.800 2006). It allows different transport systems (ATM, IP) to be used. The main functions are:

- connection-less and connection-oriented extension to MTP;

- address translation;

- full layer 3 Open Systems Interconnection (OSI) compatibility;

- below SS7 protocol.

**GPRS Tunnelling Protocol (GTP v0)**

The GPRS Tunnelling Protocol (GTP v0) is the main protocol in the core network. It allows the end users in a GPRS or UMTS network to move between different cells while having continuing connects to the Internet. This is achieved by transmitting the subscriber's data from the current sub-network to the GGSN. It is used for connections between RNC, SGSN and GGSN. The data payload is attached to the GTP headers (8 byte). It can handle signalling and data traffic (3GPP TS 9.060 2003; 3GPP TS 29.060 2008). The header of the GTP v0 protocol is shown in Figure 1.15. The GTP-C(ontrol) is used to transport control information. It transmits GPRS mobility management messages between GGSN and SGSN nodes. Logically GTP-C is attached to the GTP-U(ser) tunnel – physically it is separated. The main functions are:

- Create/Update/Change PDP Context;

- Echo Request/Response;

- RAN Information.

The GTP-U(ser) is used to transport user data. It basically hides terminal mobility from the IP layer of the user supporting the reordering of Transport-PDUs. Note, a Transport-PDU is the encapsulation of data communicated by the transport layer via the network layer. The used Tunnel Endpoint Identifier (TEID) is always unique. The main functions are:

- data transmission;

- tunnel setup/release/error;
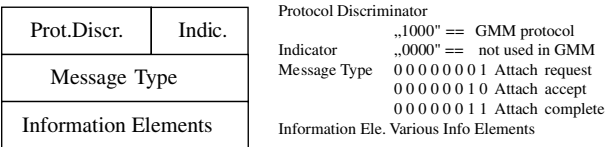
- echo request/response.

| Prot.Discr. | Indic. |
|:---:|:---:|
| Message Type | |
| Information Elements | |

Protocol Discriminator
"1000" == GMM protocol
Indicator        "0000" ==   not used in GMM
Message Type   0 0 0 0 0 0 0 1  Attach  request
                      0 0 0 0 0 0 1 0  Attach  accept
                      0 0 0 0 0 0 1 1  Attach  complete
Information Ele. Various Info Elements

Figure 1.15  GTP header and description.

**GPRS Mobility Management (GMM)**

This protocol is defined in reference 3GPP TS 23.060 2006. It offers in UMTS the same functions as in GPRS: managing the mobility of the terminals. This protocol was designed to reduce the number of terminals in active state consuming radio resources. Therefore, three states were defined:

- idle;

- ready;

- standby.

The transition between these states is initialized by well-defined events. A normal mobile sending data will be in the ready state. After a time period (set timeout) of not sending data the mobile will drop to standby. The state indicates that the mobile is expected to become active again. If there is no data transmission up to a second timeout the mobile will finally drop to the IDLE state. The algorithm is known by the RNC and the mobile terminal. Therefore, we do not need any signalling to initialize the state transitions. Figure 1.16 presents the state transmission diagram.
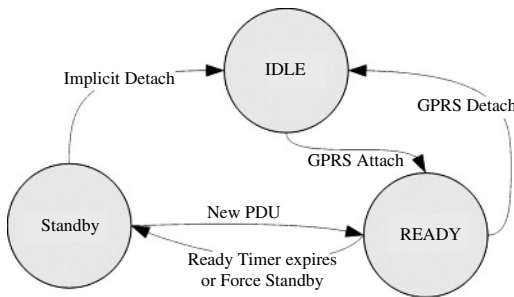


Figure 1.16  States of the GMM protocol.

However, if a mobile terminal tries to change its state it has to send a signal to the higher instances in the core network. GMM offers this functionality. It can handle basic procedures in the attachment process, such as 'attach', 'accept', 'request' and 'complete'.

### 1.4.3   Bearer Speed in UMTS

The bearer speed in a wireless mobile network is a term for the net data rate that is available to the UE. User data in UMTS may be transferred using two different implementations: DCH or High Speed Packet Access (HSPA) (3GPP TS 25.213 2006; 3GPP TS 25.308 2007). In case a very low amount of user data has to be transmitted, a random or common channel can also serve for data transmission. However, normal Internet applications will initiate data transfers triggering a DCH or HSPA channel assignment.

The DCH channel has different bearer speeds depending on the chosen spreading factor. For a fixed transmit power, a larger spreading factor allows more reliable transmission at the cost of a lower user data rate. Therefore, users with a higher distance to the base station will only achieve a lower data rate. In addition to this, as part of the network optimization process, the RNC monitors the actual data rate the user needs and adjusts it, via the SF, accordingly. Table 1.2 shows the available options for the DCH from our live network.

Table 1.2  DCH data rates for different spreading codes.

| User Data Rate | Interface Data Rate | Spreading Factor |
|---|---|---|
| 12.2 kbit/s | 30 kbit/s | 128 |
| 32 kbit/s | 60 kbit/s | 64 |
| 64 kbit/s | 120 kbit/s | 32 |
| 128 kbit/s | 240 kbit/s | 16 |
| 384 kbit/s | 480 kbit/s | 8 |

HSPA extends the radio interface of the UMTS network. A data symbol on the radio interface can transmit up to 4 bits of data, while standard UMTS symbols transmit only 2 bits of data. The data rate assignment in HSDPA differs from DCH. The physical channel is set to a fixed spreading factor of 16, which equals a data rate of 14.4 Mbit/s. This is a strong improvement over the 384 kbit/s in the DCH. However, 14.4 Mbit/s is the total rate of the entire HSDPA cell. All users have to share this resource. HSDPA uses a slot length of 2 ms; within each slot 15 different code channels are transmitted. A scheduler in the NodeB assigns code channels to the specific users according to the UE capabilities and the data rate need. A UE capable of class five can decode five code channels within one time slot, which equals a user data rate of 3.6 Mbit/s.

## 1.5   Differences between 2.5G and 3G Core Network Entities

The GSM standard was introduced to build a telephone system that could carry the services found in ISDN and combine it with mobility all over the world. At the air interface GSM initially used 935–960 MHz in the downlink and 890–915 MHz in the uplink. Later upgrades, also called GSM 1800, introduced more frequencies at around 1700–1900 MHz.

GPRS was initially standardized in GSM phase 2+. Today, in 2007, it is hosted by the 3GPP. The integration of GPRS into GSM was introduced in a very smooth way; the

physical channels stayed unchanged and most of the infrastructure was reused. The only two new nodes introduced were the GGSN and the SGSN. In 2.5G GPRS implemented packet-oriented data services to the GSM network. GPRS directly supports packet-oriented protocols such as IP or X.25. It is therefore possible to communicate directly with the Internet – no modem is needed. The billing is implemented volume based and not per time interval. To extend the data rate the GPRS specification allows the use of all eight time slots by a single user. In practice, most mobile equipments feature only one common receiver/sender unit and therefore will only support up to four time slots in downlink and two in uplink. In GPRS the connection between the core network and the mobile equipment is only permanent for the logical layer – the physical resources in the cell will be scheduled according to the actual load in the cell and the user data in the buffer of the SGSN.

GPRS offers packet-switched IP-based services to users in GSM environments. The IP routing is available through the entire network, beginning at the UE and ending at the GGSN. In contrast to GSM, where each active user occupies exactly one time slot, GPRS users can use up to eight time slots in parallel in order to boost their data rate.

### 1.5.1    GPRS Channels

The GSM relies on a Time Division Multiple Access (TDMA) transmission system. The TDMA technique uses a fixed time grid to serve different users at the same frequency slot. All the active mobile stations are synchronized and each of them is assigned a certain time slot that it can use to transmit its data. Figure 1.17 depicts a simple example of the GSM time frames. Bins with the same number belong to the same physical channel.
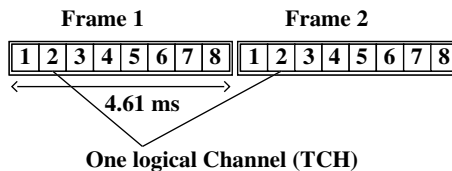


Figure 1.17  GPRS physical channel.

#### Logical Channels

The Traffic CHannels (TCHs) are used to transport user data, for example the output of the Adaptive Multi Rate (AMR) coder. The data rate of a full rate TCH is 22.8 kbit/s. It consumes a full slot in every frame. Therefore, signalling data has to be sent using a different time slot. There exists also a different implementation of the voice codec, which needs less data rate and leaves some room for strong encryption. The Control CHannels (CCHs), in contrast to the traffic channels, consist of three different channel types, each group featuring four different channels. These channels have a low bit rate. In fact the signalling traffic normally consumes only one of the eight time slots. The different channels are multiplexed to this time slot. In other words a channel X that occupies only one time slot every tenth frame can be multiplexed

for several mobile equipments. To structure this multiplexing, GSM knows hyper, super and multiframes.

The Broadcast Control CHannel (BCCH) acts like a lighting house for a GSM cell. It broadcasts all the important information that mobile equipment needs to attach to the cell. The data transmitted includes cell ID, schedule of the signalling channels and information about the cell neighbours. The BCCH features sub-channels for frequency correction, Frequency Correction CHannel (FCCH), and time synchronization, Synchronization CHannel (SC). Also, paging is realized via the BCCH, therefore, everything powered on mobiles will monitor this channel. The channel is unidirectional only.

The Dedicated Control CHannel (DCCH) is a bidirectional signalling channel that can be used by the mobile to interact with the cell, for example register. Its schedule is broadcast via the BCCH. The TCH is allocated using the standalone DCCH (SDCCH). Combined with a booked TCH, the mobile station uses the slow associated DCCH (SACCH) to exchange system data such as the channel quality and the receiving power strength. Should the need for signalling data rate not be fulfilled by the SACCH, the mobile can book an additional signalling channel called the Forward Access Common CHannel (FACCH). This channel steals time slots from the TCH channel and uses them for signalling information. Such situations typically arise when there are handovers between different Base Transceiver Station (BTS) units.

The Common Control CHannel (CCCH) carries all the call management information. If a BTS has a call for an MS, it broadcasts this information using the Paging CHannel (PCH). A mobile station that wants to react to this paging uses the Random Access CHannel (RACH) to send its information to the BTS. The access is obtained using the ALOHA protocol, which is an OSI layer 2 protocol for LAN networks. A successful connection will receive a free TCH via the Access Grant CHannel (AGCH).

## 1.5.2 GPRS Core Network Architecture

The network elements of the GPRS core network are very similar to the elements found in UMTS. Figure 1.18 displays all interfaces and core nodes of a GPRS network. In order to make the integration of GPRS smooth, the Base Station Subsystem (BSS) extended the Base Station Controller (BSC) with the PCU which handles the new packet-switched signalling procedures. It converts data received via the Gb interface from the SGSN in order that it can be processed by the BSC. The second component of the BSS is the Base Station Transmitter (BST), which is only a relay station transmitting the information via the air interface. This element was also present in GSM.

The GGSN and SSGN nodes have already been introduced in the UMTS Section. A more detailed description of the nodes can be found in the standard (3GPP TS 23.060 2006).

The GGSN, SGSN, HLR and VLR nodes have the same functions as in UMTS. Some of the interfaces connecting the nodes have names that differ from the UMTS scheme, as the protocol stack is not identical for these interfaces; for example Gb replaces Iu.

## 1.5.3 The GPRS Protocol Stack

The protocol stack of GPRS is split into transmission and signalling planes. Figure 1.19 depicts the transmission plane for GPRS (3GPP TS 29.060 2008). As in UMTS the GTP protocol routes user-packets within a tunnel from the GGSN to the actual position of the UE.
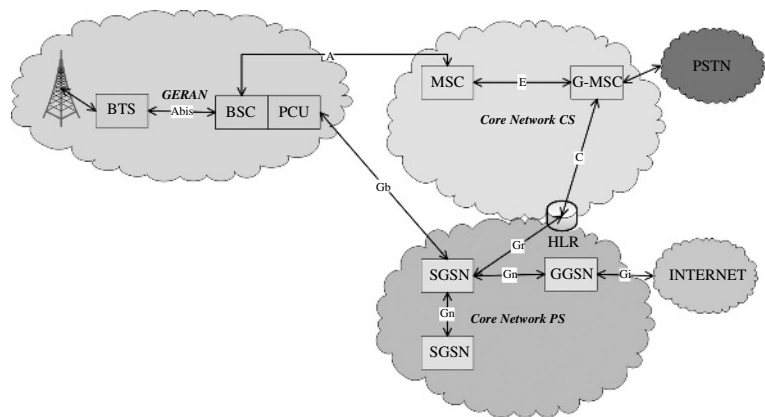
Figure 1.18  GPRS core nodes and interfaces (3GPP TS 23.060 2006).

The GTP builds up a tunnel between the GGSN and the MS. Below the GTP, UDP is used to transport the information between the different GPRS core nodes, for example SGSN and GGSN. At the SGSN the GTP protocol is replaced by the SNDCP protocol to adapt the data flow to different implementations of the PCUs. The CS design of the BSS had no features to provide reliable data transport. Therefore, the LLC layer was introduced featuring different kinds of ARQ and FEQ modes, granting reliable transmission of the data packet units. Finally, BSSGP is used for QoS aware routing between the SGSN and the target BSS. At the BSS the MAC manages the media access and maps the LLC frames to physical channels. The RLC layer provides a reliable connection over the radio interface.
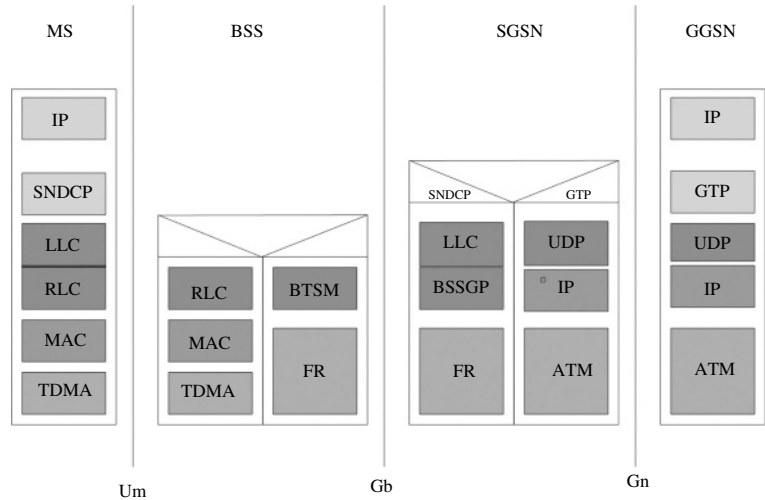


Figure 1.19  GPRS stack: transmission plane.

The SNDCP is a transparent network layer protocol for IP data (3GPP TS 44.065 2006). The protocol offers two important features: header and data compression. Therefore, it can improve performance as it reduces the amount of data transferred.

The RLC protocol layer transfers PDUs from the Logical Link Layer (LLC) protocol. The LLC offers a logical link from the SGSN to the UE over Gb and Um interfaces. It covers flow control and ciphering for the logical link (3GPP TS 43.064 2006; 3GPP TS 44.064 2007). Finally, the MAC protocol takes care of the physical properties of the radio channel.

### 1.5.4   Bearer Speed in GPRS and EDGE

The physical link in GPRS is a TDMA implementation. It offers eight slots in the uplink and the downlink directions, respectively. A normal GSM voice call uses one time slot, GPRS UEs can allocate up to eight time slots. Each added slot upgrades the data rate available to the user. The number of free slots is a function of the cell load and has an upper limit which is bound by the capabilities of the UE.

In addition to this, three new Code Sets (CSs) were introduced with the start of GPRS. The code sets offer different strengths of data protection. Higher data protection secures the transmission and the signal is more resistant to noise and interference. However, a stronger code needs more parity bit, thereby reducing the user data rate. The assignment of the code is limited due to the Signal-to-Noise Ratio (SNR) at the UE; the fastest code set, CS-4, can only be activated close to the base station transmitter. The maximum possible data rate for GPRS is 160 kbit/s. Table 1.3 shows the data rates for one time slot and different code sets in GPRS and Enhanced GPRS (EGPRS) also called Enhanced Data rates for GSM Evolution (EDGE).

Table 1.3  GPRS and EDGE data rates for one time-slot and different CSs.

| Code Set | User kbit/s | Interface kbit/s | User kbit/s | Interface kbit/s |
|---|---|---|---|---|
| CS-1 | 8.0 | 9.0 | 22.4 | 27.0 |
| CS-2 | 12.0 | 13.4 | 29.6 | 40.2 |
| CS-3 | 14.4 | 15.6 | 44.8 | 46.8 |
| CS-4 | 20.0 | 21.4 | 59.2 | 64.6 |

The EDGE service uses 3 bits per symbol at the air interface, in contrast to the one bit per symbol of GPRS. Therefore, EDGE pushes the data rate by a factor of three to a maximum of approximately 473.6 kbit/s.

## 1.6   HSDPA: an Evolutionary Step

The goal of HSDPA was the introduction of higher bit rates for the UE, hence keeping the changes to the architecture to a minimum. HSDPA was introduced by the 3GPP in Rel. 5. It is an extension to UMTS Rel. 99. The features introduced in HSDPA are:

- shorter radio frames (2 ms instead of 10 ms);

- introduction of Channel Quality Indication (CQI) as feedback means from UEs to NodeB;

- new up- and downlink channels (HS-PDSCH, HS-DPCCH and HS-SCCH);

- 16 QAM modulation type additionally to 4 QAM;

- Adaptive Modulation and Coding (AMC);

- Hybrid-ARQ (HARQ);

- MAC scheduling functionality within NodeB.

We will now give a short introduction to the main changes of architecture compared to UMTS, as well as to the new features of HSDPA.

## 1.6.1   Architecture of HSDPA

The migration from GPRS towards UMTS was a paradigm change in the connection of UEs and NodeBs. In GSM and GPRS a mobile is connected to one base station at a time; in UMTS the UEs support so-called soft handover modes. In this mode the UE is connected to several (up to six) base stations. This feature reduces the risk of call drops which often occur in hard-handover scenarios. However, as all NodeBs have to offer the same data stream to the UE, the next hierarchical entity, in this case the RNC, has to manage all the packets and radio link parameters. Therefore, the local NodeB cannot adapt the data rates accordingly to the actual channel conditions. As this was considered necessary for higher data rates, the idea of soft handover was withdrawn and NodeB was given a local scheduler to allow for adaptive modulation and coding and fast scheduling. Figure 1.20 depicts the changes that took place, starting with Release 5.
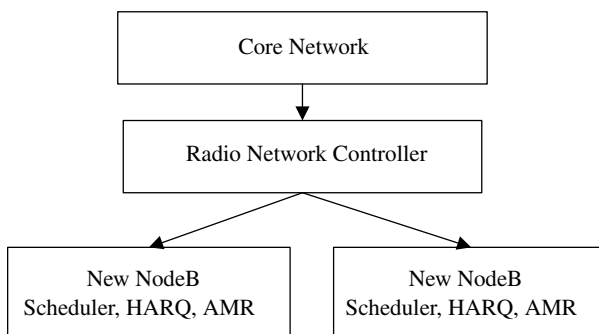


Figure 1.20  Changes in architecture from Rel. 99 towards HSDPA.

**The `MAC-hs`**

The new functions of HSDPA are implemented into a new logical layer called `MAC-hs`. The `MAC-hs` is a new entity. It transmits data over the HS-DSCH channel, a new set of channels introduced in HSDPA. It also manages the physical resources allocated and can be configured from higher layers; see references 3GPP TS 25.308 2007; 3GPP TS 25.321 2006. The function set of the `MAC-hs` is depicted in Figure 1.21.
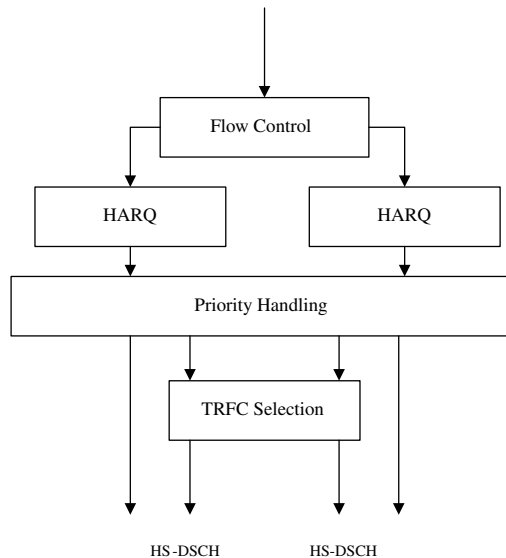


Figure 1.21  Structure of the `MAC-hs` entity.

## 1.6.2   Difference between UMTS and HSDPA

UMTS Rel. 99 allows for up to 384 kbit/s while HSDPA targets for much higher data rates of up to 14.4 Mbit/s. It achieves this by the implementation of new coding schemes and modulation techniques combined with scheduling techniques directly in the NodeBs. In other words the SF is no longer variable and there is no more fast power control available. These two elements of Rel. 99 are replaced by Adaptive Modulation and Coding (AMC), Fast retransmission strategy (called HARQ) and scheduling algorithms (3GPP TS 25.213 2006; 3GPP-25.848 2003). These new functions are described in the following sections.

**Scheduling Algorithms**

The place of the scheduling systems in Rel. 99 is inside the RNC. In HSDPA the function has been moved into the NodeBs, which allows for faster scheduling as there is no more 'reaction' delay present. The scheduler in HSDPA also has an additional task. Besides selecting the correct modulation and coding scheme and the HARQ process, it now schedules

the transmission for all users. In Rel. 99 the scheduler was implemented on a per user base only. The implemented scheduler may follow different strategies such as:

- equal throughput per user (Round-Robin);

- balance cell and user throughput (Proportional Fair);

- maximum cell throughput (Maximum C/I).

## Hybrid ARQ: A Fast Retransmission Strategy

The retransmission logic moved from the RNC entity into the NodeB. There exist two different error control and recovery methods to guarantee error-free transmissions to and from the UE, namely Forward Error Correction (FEC) and Automatic Repeat reQuest (ARQ); see references 3GPP TS 25.214 2008; 3GPP TS 25.302 2007; 3GPP TS 25.331 2008.

FEC introduces a set of redundant bit information added to the payload of each protocol and derived following some code scheme. This information allows the receiver to detect and recover errors as occurring from channel impairments. FEC information is added to each packet regardless of the actual channel state. Therefore, no feedback channel is needed. However in good channel conditions available data rate is wasted by the redundant information.

The ARQ error correction scheme improves on the main disadvantage of the FEC scheme. Error correction information is only requested on erroneous received packets. An ARQ system offers functions for error detection, acknowledgment, time-out and retransmission request. Typically, the basic functions are implemented using either a selective retransmission or a stop-and-wait procedure.

The disadvantage of these two methods is the delay that occurs in the case of a packet error. This can be overcome by combining the ARQ and the FEC methods in a so-called HARQ mode. The FEC is set to cover the most frequent error patterns and therefore will reduce the number of retransmissions. The ARQ part covers less frequent error patterns, allowing the number of bits added by the FEC to be reduced. There are different types of HARQ method available and the performance in total depends on the channel conditions, receiver equipment and other related parameters. Considering the complexity of a UMTS radio implementation, choosing the 'correct' or 'best' retransmission strategy is a wide field for ongoing research.

## Adaptive Modulation and Coding (AMC)

The original implementation of UMTS-Rel. 99 offered one fixed modulation scheme. The adaptation to the actual radio channel is then performed using a power control algorithm. The instantaneous data rate is set by choosing an appropriate spreading factor offering the necessary gain for the given signal to interference situation.

In HSDPA the method was changed. Instead of relying on a fast power control, the SF was fixed and the modulation now follows the channel conditions, both modulation and coding format adapting in accordance with variations in the channel conditions. This system is called AMC, or link adaptation. Compared to standard power control, such methods deliver higher data rates. In HSDPA the AMR scheme assigns higher order modulation with higher code rates, such as 16 QAM.

### 1.6.3 Transport and Control Channels

The implementation of HSDPA into the physical layer of UMTS required major changes. At layer two of the transport network new entities were created to allow for fast MAC handling. One of these changes is the definition of new high-speed physical channels, namely: the High Speed Physical Downlink Shared CHannel (HS-PDSCH), the High Speed Dedicated Physical Control CHannel (HS-DPCCH) and the High Speed Shared Control CHannel (HS-SCCH). The main features of the physical channels are now presented.

**High Speed Downlink Shared Channel (HS-DSCH)**

The HS-DSCH is the new transport channel for user data introduced in HSDPA. To achieve the full advantage of moving the scheduling from the RNC to NodeB the round-trip time had to be reduced. This was accomplished by reducing the Transmission Time Interval (TTI) from 10 ms (Rel. 99) to 2 ms; see reference 3GPP TS 25.211 2007. The higher data rate is possible due to a higher order modulation scheme, namely 16 QAM, and a dynamic error protection. The combination of these two allows for higher peak data rates.

As discussed, the new transport channel has a fixed SF equal to 16. Based on this every code slot can offer up to 15 parallel codes to transmit user data, each of them unique by its specific channelization code. Each of these codes represents an HS-DSCH channel. A single HS-DSCH with 16 QAM achieves a data rate of 960 kbit/s. All 15 codes in parallel allow for the peak data rate of HSDPA equal to 14.4 Mbit/s. The assignment of codes is assigned on the per slot base by the scheduler in the NodeB. A single UE can have several codes in parallel within the same TTI. Users can be served simultaneously within one slot. These features allow for a better utilization of the available data rate.

**High Speed Shared Control Channel (HS-SCCH)**

The new transport channel, the HS-DSCH, no longer belongs exclusively to a single user. Therefore, the NodeB must now transmit control information associated to the HS-PDSCH, indicating to the user terminal which schedule will take place in the upcoming TTI. This is the task of the HS-SCCH. Aside from the obvious task already mentioned, the channel contains signalling and control information such as modulation scheme, HARQ information and transport format. There must be one HS-SCCH per each user active on the HS-DSCH; see references 3GPP TS 25.211 2007; 3GPP TS 25.212 2006; 3GPP TS 25.321 2006. The rate of the HS-SCCH is fixed to 60 kbit/s and an SF of 128. This results in 40 bit/slot and 120 bit/subframe. The duration of such a frame is three slots equal to 2 ms and it consists of two parts. The first part contains the time-sensitive information, such as the codes to de-spread and the modulation in the next TTI. The terminal needs this data to start the decoding process of the HS-DSCH. The other part holds the CRC and the HARQ information, which is no longer time critical.

**Uplink High Speed Dedicated Physical Control Channel (HS-DPCCH)**

The uplink channel for HSDPA carries feedback signalling related to the correlated downlink HS-DSCH channel. This information consists of the HARQ part and the CQI part. Each subframe is of length 2 ms or three slots. The payload of the packet is 10 bits, which are

encoded to 30 bits by the error protection. The SF is set to 256; see references 3GPP TS 25.211 2007; 3GPP TS 25.214 2008.

The first 10 bits of encoded information carry the Ack/Nack messages for the HARQ scheme of the NodeB. They indicate the receiver if the last transmission was successful or if a retransmission has to take place. The second part of the subframe, another 20 bits of encoded information, carry the CQI value. This value is a type of quality index reporting on the channel conditions at the UE side. The CQI indicates which estimated block size, modulation type and number of parallel codes could have been received correctly in the downlink direction, thus indicating the quality of the link back to the scheduling system in the NodeB. The CQI value is based on the quality of the CPICH (Ec/No) channel broadcast in the cell averaged over 2 ms. It is calculated at the UE side and can have values between zero and 30, where larger is better. With this value the UE reports an estimate for the maximum setting of estimated block size, modulation type and number of parallel codes considering a probability for a TB error of less than 10%. Values above 15 allow for 16 QAM modulations while values below only allow for 4 QAM modulations. The CQI estimation process is a difficult task for the UE as there exists no standardized mapping by the 3GPP.

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