2 Introduction to UMTS

This chapter serves as a system level introduction to UMTS. We begin by describing the 3rd Generation Partnership Project, which is the organisation that defines the architecture and operation of the system. We continue by examining the architecture of UMTS, the interfaces between the different hardware components, and the protocol stacks that they use. At the end of the chapter are two shorter sections that describe the data flows within the system and the allocation of frequency spectrum to third generation systems. By the end of this chapter, you should have an appreciation of how the system fits together, and be ready to take on the details that are covered later in the book.

2.1 The 3rd Generation Partnership Project

Most of the information in this book originates in the specifications that define the architecture and operation of UMTS. These specifications are written by an organisation called the *3rd Generation Partnership Project* (3GPP). In this section, we will describe how 3GPP is organised, and go on to discuss the specifications themselves.

2.1.1 Organisation of 3GPP

The 3rd Generation Partnership Project was formed in December 1998, to produce the technical specifications for UMTS. The formation of 3GPP came during the International Telecommunication Union's selection process for 3G telecommunication systems, and the first set of specifications was used as the member organisations' submission to the ITU. More recently, 3GPP has developed the UMTS specifications further and has expanded its role to handle the specifications for GSM, which had previously been produced by the *European Telecommunications Standards Institute* (ETSI).

https://doi.org/10.1017/CBO9780511800443.003

Table 2.1 *3GPP organisational partners.*

Organisation	Abbreviation	Country
Association of Radio Industries and Businesses	ARIB	Japan
Alliance for Telecommunications Industry Solutions	ATIS	USA
China Communications Standards Association	CCSA	China
European Telecommunications Standards Institute	ETSI	Europe
Telecommunications Technology Association	TTA	Korea
Telecommunication Technology Committee	TTC	Japan

The project is structured as a collaboration between a number of telecommunication standards bodies that are known as organisational partners (Table 2.1). Each organisational partner has a membership comprising a large number of telecommunication companies, and the specifications are written by representatives from those member companies. As with other telecommunication standards, the member companies own a considerable amount of intellectual property that has been included in the UMTS specifications, and the resultant royalties can be a significant cost for manufacturers.

Internally, 3GPP is organised into a *project co-ordination group* (PCG) that handles the overall project management, and four *technical specification groups* (TSGs) that do the actual technical work. The individual TSGs (Table 2.2) meet either four or five times a year, to agree on updates to their respective specifications. Within each TSG are a number of different working groups, each of which concentrates on a particular part of the system.

There are many other telecommunication standards bodies, which produce specifications for the other systems described in Chapter 1, and for application software that is independent of the underlying

Table 2.2 *3GPP technical specification groups.*

Technical specification group	Abbreviation
Services and system aspects	TSG SA
Core network and terminals	TSG CT
Radio access network	TSG RAN
GSM EDGE radio access network	TSG GERAN

communication network. The only one we will mention is the *3rd Generation Partnership Project 2* (3GPP2), which is a parallel body to 3GPP that produces the specifications for cdma2000.

2.1.2 3GPP specifications

We now move on to the specifications, which are the actual documents that define the system. At a high level, the specifications are organised into *releases*, each of which is a version of the system with a particular set of features. 3GPP maintains the specifications for all the releases of UMTS in parallel. This allows it to add new features to the system as part of each new release, while making the occasional technical correction to the older, more stable releases that are used by manufacturers.

Each release is developed over a period of months or even years, but the most important event happens when the release is frozen. After it has been frozen, there are no more changes to a release's technical features, although some issues such as the details of the protocols and the conformance tests will usually lag behind. Technical corrections can of course continue for a long time after freezing.

The first release of UMTS was *release 99*, which was frozen in March 2000. This release specified a 3G telecommunication system based on the core network of GSM, but with a new air interface that used wideband code division multiple access (W-CDMA). Most of the technical features described in this book were introduced in release 99. The plan was then to have one release per year, using a numbering scheme of release 00, release 01 and so on. However, it was soon realised that this was too ambitious, so

Table 2.3 *Releases of the UMTS specifications, highlighting the date when the release was frozen and the most important new features to appear.*

Release	Date frozen	New features
99	March 2000	W-CDMA air interface
4	March 2001	Bearer independent CS architecture TD-SCDMA
5	June 2002	HSDPA IP multimedia subsystem
6	March 2005	HSUPA
7	September 2007	HSPA+
8		Long Term Evolution

the numbering scheme was changed to uncouple it from the calendar year, and the next release became known as release 4. Using this scheme, release 99 is synonymous with release 3, while the numbers 1 and 2 are reserved for draft specifications.

Table 2.3 lists the different releases of UMTS, together with their freeze dates and their most important technical features. (At the time this book was written, release 8 was at an early stage of the specification process.) It is worth noting that equipment manufacturers and network operators do not have to implement all the features of a particular release. Instead, some features (such as the definitions of the signalling messages) are mandatory, while others (such as whether or not to implement high speed packet access) are optional.

Within each release, the different specifications are organised into series, each of which covers a different part of the system. Series 21 to 36 describe UMTS, including aspects of the system that are common with GSM, and these are listed in Table 2.4. Other series refer to features that are unique to GSM: series 00 to 13 were used up to release 99, and series 41 to 55 are for release 4 onwards.

Individual specifications have document numbers like (for example) TS 25.331 v 6.12.0. Here, TS stands for technical specification – there are also documents that do not actually define any part of the system, which are known as technical reports and denoted TR; 25 is the series

Table 2.4 *List of the 3GPP specification series that refer to UMTS.*

Series	Description
21	Requirement specifications
22	Stage 1 service specifications
23	Stage 2 service specifications; network architecture
24	Air interface non-access stratum
25	Air interface access stratum; radio access network
26	Codecs
27	R interface
28	Tandem-free operation of speech codecs
29	Core network
30	3GPP programme management
31	Cu interface
32	Network management and charging
33	Security procedures
34	UE test specifications
35	Cryptographic algorithms
36	Air interface Long Term Evolution

number; 331 is the specification number within that series; 6 is the release number; 12 is the technical version number (which is incremented after technical changes to a specification); and 0 is the editorial version number (incremented after non-technical changes). This particular specification describes the *radio resource control* (RRC) protocol, which we will say a lot about in the course of the book.

There are several hundred specifications altogether, which can be downloaded from the 3GPP website, www.3gpp.org. They are rather heavy reading, however, as their only purpose is to define precisely how the system operates, without any attempt at context or explanation.

2.2 System architecture

In this section, we will discuss the architecture of UMTS, starting from a high level and moving down to the individual components. Most of the components have long-winded names, and are usually referred to by acronyms. It is worth taking the trouble to learn these acronyms, as they will make regular appearances in the later chapters of the book, and will be essential if the reader is to have a fluent conversation about UMTS.

2.2.1 High level architecture

Figure 2.1 shows the high level architecture of a UMTS public land mobile network. In keeping with the generic architecture that we introduced in Chapter 1, it has three main parts: the core network, the radio access network and the mobile.

The core network (CN) contains two *domains*. The circuit switched (CS) domain transports voice calls using circuit switched technology. It has interfaces to fixed line telephone systems that are known as *public switched telephone networks* (PSTNs), and to circuit switched domains that are run by other network operators. The packet switched (PS) domain transports data streams using packet switching. It communicates with data servers that are controlled by the network operator itself, with external *packet data networks* (PDNs) like the Internet, and with packet switched domains that are controlled by other network operators. The two domains were carried over from GSM and GPRS respectively, with only a few modifications.

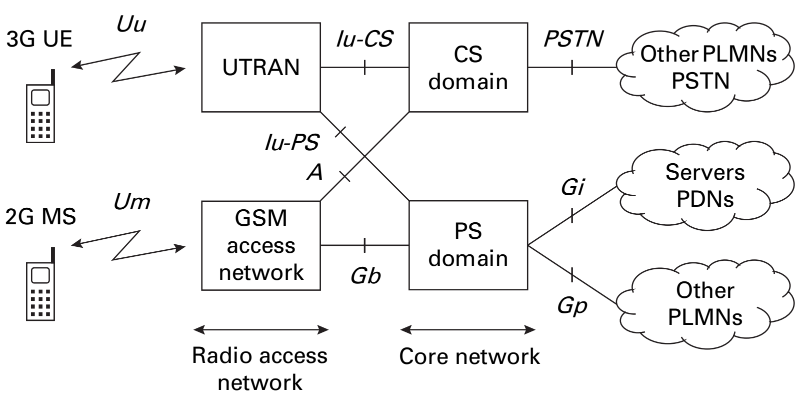

Figure 2.1 High level architecture of UMTS.

The most important part of the radio access network is the *UMTS terrestrial radio access network* (UTRAN), which was introduced as part of release 99. However the system continues to support the GSM radio access network as well, to provide backwards compatibility with GSM. It is likely that other types of radio access network, such as satellite-based access, will eventually be introduced as well.

The UMTS mobile is known as the *user equipment* (UE). This is a change in terminology from GSM, where it was known as the *mobile station* (MS). Most UMTS mobiles are actually dual mode devices that support GSM as well: they communicate using 3G technology in regions of UMTS coverage, but revert to 2G in regions where UMTS base stations have not yet been deployed.

The figure also labels the interfaces between the different parts of the network. Most of these are for reference, but it is worth remembering the two types of Iu interface (Iu-CS and Iu-PS) that lie between the UTRAN and the core network, and the Uu interface between the UTRAN and the mobile. We will describe the different interfaces in more detail in Section 2.3, along with their associated protocol stacks.

The internal details of the core and radio access networks are rather complex, and have evolved somewhat since the release 99 specifications were written. We therefore describe the components of the release 99 architecture first, and then cover the changes that have taken place in releases 4 to 7. We will leave components that are just used by individual services until Chapter 5, and we will also delay any discussion of release 8 until Chapter 6.

2.2.2 Core network

Figure 2.2 shows the internal architecture of the release 99 core network, for both the circuit switched and packet switched domains. The notation for switches and databases is carried over from Figure 1.1, although this is only for guidance as some of the components are more flexible than these simple names imply. Dotted lines denote interfaces used only for signalling, while solid lines denote interfaces used for both traffic and signalling.

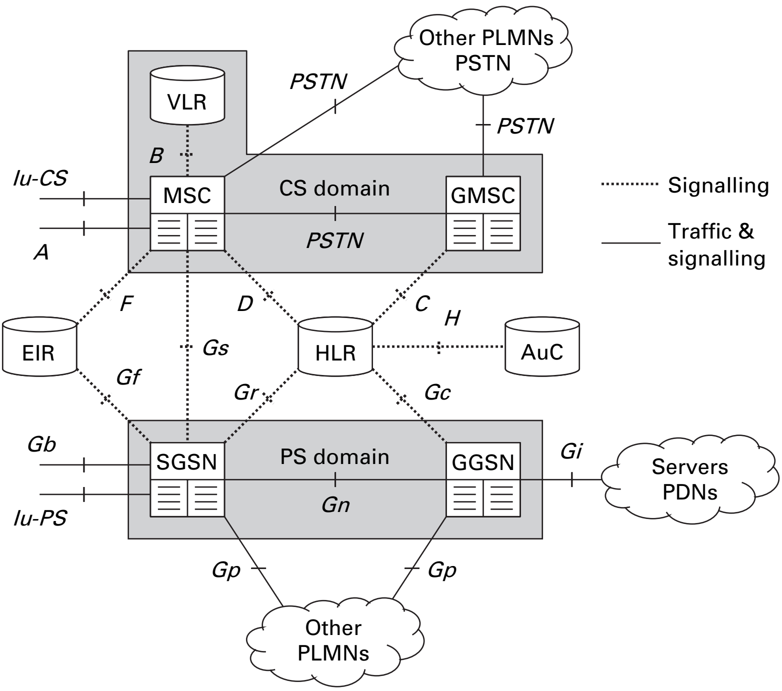

Figure 2.2 Architecture of the core network in release 99. (Adapted from 3GPP TS 23.002.)

A few components are shared between the two domains. The most important of these is the *home location register* (HLR), which is the network operator's central database. The HLR contains information about the operator's subscribers such as their identities, their current locations and the services they have subscribed to. The *authentication centre* (AuC) contains security related information about the subscribers. Examples include secure keys that the network uses to confirm their identities and prevent unauthorised access. The *equipment identity register* (EIR) is an optional component: if implemented, it contains information such as a list of stolen mobiles.

The main component in the circuit switched domain is the *mobile switching centre* (MSC). A small network can just contain one MSC, but most networks have more than one, each of which looks after a particular geographical area known as an MSC area. The MSC acts as a switch for voice calls, and it also handles signalling communications with the mobiles that are in its MSC area. An MSC may be designated as a *gateway MSC* (GMSC), which acts as a point of entry into the network for incoming calls.

The *visitor location register* (VLR) looks after one or more geographical regions known as *location areas*. Each VLR contains a local copy of the HLR's information about the mobiles in its location areas, which minimises the communication needed between the two. The MSC and VLR are usually implemented as a single piece of hardware, so the interface between them does not actually exist as a physical entity. For this reason, we often won't bother to distinguish them in the chapters that follow, referring to them instead as a single MSC/VLR combination.

There are two components in the packet switched domain. The *serving GPRS support node* (SGSN) combines the functions of the MSC and the VLR by acting as a router for data transfers, keeping a local copy of information about the mobiles in its SGSN area, and handling all the signalling communications with those mobiles.

The *gateway GPRS support node* (GGSN) is rather different from the gateway MSC, however. It acts as an interface to data servers and to other networks for both incoming and outgoing data streams. It does not look after a geographical area in the same way that an SGSN does, although one piece of hardware can implement both sets of logical functions.

If a mobile is roaming, then the home network contains the HLR and AuC, and the visited network contains the MSC, VLR and SGSN. The gateways to external networks can be in either the home network or the visited one, depending on the circumstances.

It is worth remembering all the hardware components introduced here, as most of them will make a lot of appearances as the book goes on. The interface names are less important: we will refer to them when we describe the protocol stacks in Section 2.3, but hardly at all thereafter.

Before closing this section, it is useful to introduce a few numbers that are used to identify the network. The *mobile country code* (MCC) is a three-digit number that identifies the country that a network is in, while the *mobile network code* (MNC) is a two- or three-digit number that identifies a network operator in that country. In the UK, for example, the mobile country code is 234, while T-Mobile uses a mobile network code of 30. Together, the two numbers make up the *public land mobile network identity* (PLMN-ID).

2.2.3 Radio access network

The radio access network is shown in Figure 2.3. The most important part for us is the UMTS terrestrial radio access network (UTRAN), which has two components: the *Node B* and the *radio network controller* (RNC). The Iub interface connects a Node B to an RNC, while the Iur interface connects two RNCs. All the interfaces in the figure carry both traffic and signalling.

The *Node B* is a UMTS base station. It controls one or more cells (three in the figure), and transmits and receives radio signals to and from the mobiles that are in those cells; roughly speaking, it implements the physical layer of the air interface. The name 'Node B' does not stand for anything in particular: it was introduced as a temporary name, but the name stuck.

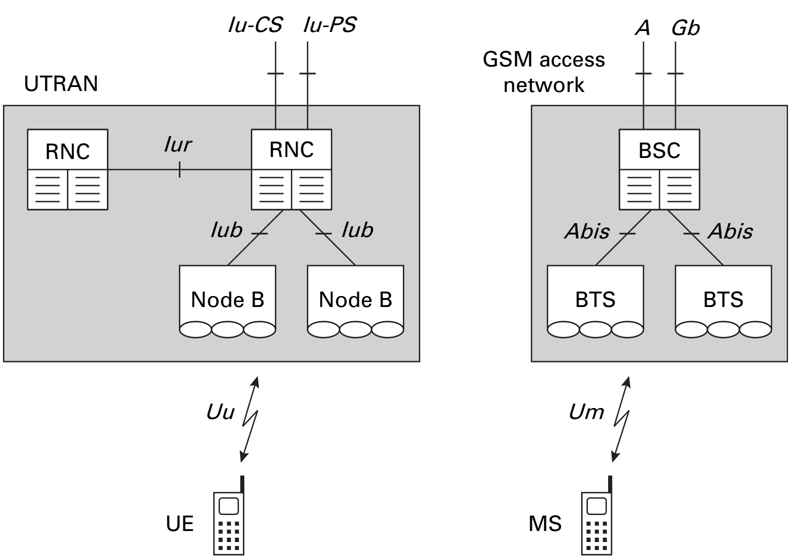

Figure 2.3 Architecture of the radio access network in release 99. (Adapted from 3GPP TS 23.002.)

The radio network controller is an intermediate component between the Node B and the core network. The RNC has three main functions, and an individual RNC can acquire up to three different names depending on which of these functions it is implementing. First, each Node B is controlled by a particular RNC, which is known as its *controlling RNC* (CRNC). A controlling RNC distributes downlink traffic to the Node Bs that it controls, collects traffic from them on the uplink, and exchanges signalling messages with them. Second, each mobile is controlled by a particular RNC, which is known as its *serving RNC* (SRNC). A serving RNC exchanges signalling messages with the mobiles that it serves, and acts as their sole point of contact with the core network. It also implements the layer 2 communications between the mobile and the network, for example by handling any retransmissions that are required over the air interface.

In some situations, a serving RNC may not actually control the Node B that a mobile is communicating with. This situation is handled by introducing a third function (Figure 2.4a), that of a *drift RNC* (DRNC). A drift RNC uses the Iur interface to carry mobile specific traffic and signalling messages between the Node B and the serving RNC.

In other situations, a mobile can communicate with more than one cell at a time. This state is known as *soft handover*, and is illustrated in

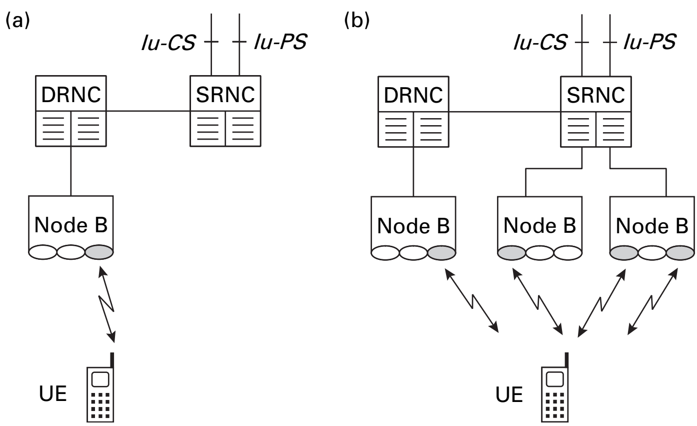

Figure 2.4 Example geometries for the air interface. (a) Use of a drift RNC. (b) Soft handover.

Figure 2.4b. As shown in the figure, the cells can be controlled by the same Node B, or by different Node Bs, or even by different RNCs. If more than one RNC is involved, then one acts as the serving RNC, and the others act as drift RNCs. The cells used in soft handover are collectively known as the *active set*. We will have more to say about the implementation of soft handover in later chapters.

The system also supports the GSM radio access network, which is known as the *base station subsystem* (BSS). The main components in the BSS are the *base transceiver station* (BTS) and the *base station controller* (BSC). These are roughly analogous to the Node B and the RNC, but the division of functions between them is rather different, and release 99 BSCs have no equivalent of the Iur interface.

The internal structure of the UTRAN is important, and we will refer to it in several places as the book goes on. We will not have much to say about the GSM radio access network, however.

2.2.4 User equipment

Figure 2.5 shows the internal architecture of the user equipment (UE). There are two main components, the *mobile equipment* (ME) and the *universal integrated circuit card* (UICC). The ME is the mobile phone itself, while the UICC is a smart card that plugs into the mobile phone.

In a simple mobile phone, the ME is usually a single device, but in data terminals, its functions are often split in two: the *mobile termination* (MT) handles all the 3G communication functions, while the *terminal equipment* (TE) is the point where the data streams begin and

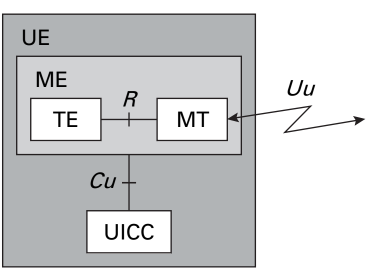

Figure 2.5 Internal architecture of the mobile. (Adapted from 3GPP TS 27.001.)

end. The MT might be a plug-in UMTS card for a laptop, for example, while the TE might be the laptop itself.

The UICC evolved from the subscriber identity module (SIM), which was first introduced in GSM. The terminology has changed because UMTS makes a clear distinction between hardware and software: the UICC is the smart card hardware, while the *universal subscriber identity module* (USIM) is a software protocol that runs there. The UICC stores data that are associated with the subscriber and the network operator. Examples include the subscriber's identity, the services the subscriber can use, and the subscriber's personal phone book. However, the UICC is not just a data store. It also carries out calculations that are related to the network's security procedures, and it can run application software as well. The use of a UICC makes it easy for people to upgrade their mobile phones, by simply switching the UICC from one phone to another. If there is no UICC installed, the only thing the mobile can do is make emergency calls.

Mobiles have a wide range of capabilities, and can vary in parameters such as the highest data rate they can handle and the maximum number of simultaneous data streams they support. As a simple example, speech mobiles can only handle a low data rate, but for mobiles that support video the maximum data rate is much higher. Similarly, most UMTS mobiles can also communicate using GSM, but some are unable to do so.

In this book, we will normally refer to the user equipment as the mobile or the UE. Most of the functions we will describe are implemented in the MT, because this is the part that handles the 3G communication functions. However, we will only distinguish the UE's components when there is a good reason to do so, usually when discussing its internal operation.

Earlier, we introduced some numbers that describe individual networks, and we can now do the same thing for the mobile. The *mobile station integrated services digital network number* (MS-ISDN) is simply the user's phone number, and has the same format as phone numbers everywhere. The *international mobile equipment identity* (IMEI) is a unique identifier for the ME: it contains a type allocation code and a serial number. Similarly, the *international mobile subscriber identity*

(IMSI) identifies the subscriber and the UICC: it consists of the mobile country code and mobile network code, followed by a number that identifies the subscriber within the specified network. The IMEI and IMSI are only used for bookkeeping purposes: to avoid the risk of cloning, they are transmitted as rarely as possible and should never be released to the outside world.

2.2.5 Enhancements in later releases

The fixed network has had a number of architectural enhancements in releases 4 to 7. The details are less important than those of release 99, so we will only describe them briefly. To illustrate the main enhancements, Figure 2.6 shows the architecture of the core network at the end of

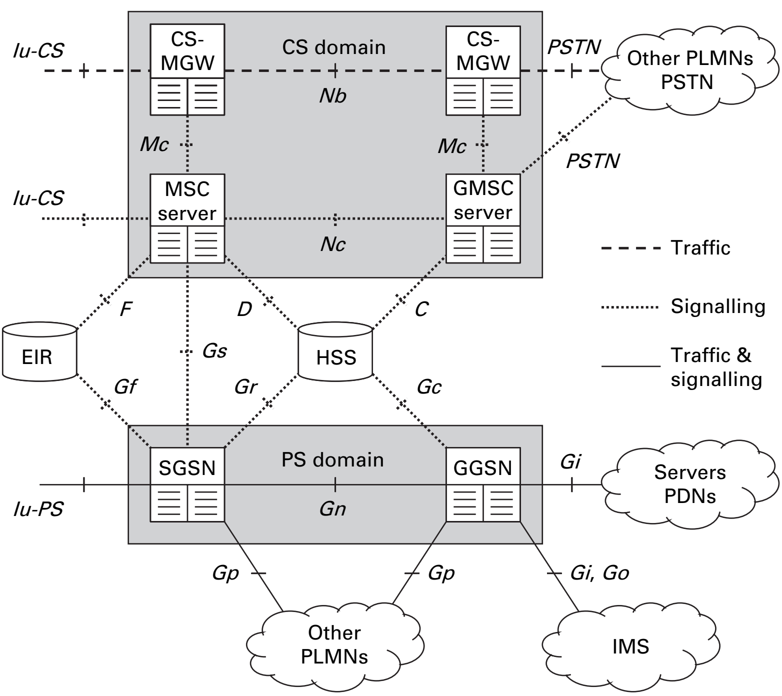

Figure 2.6 Architecture of the core network in release 7. (Adapted from 3GPP TS 23.002.)

release 7. Dotted and solid lines are used in the same way as before, while interfaces shown with dashed lines are only used for traffic. The changes to the radio access network are relatively few.

The first enhancement was the *bearer independent circuit switched core network* in release 4. In this architecture, the mobile switching centre is split in two. The *circuit switched media gateway* (CS-MGW) handles the traffic functions of the MSC, but uses different transport protocols that we will see in the next section. It also includes a media conversion function, which allows it to communicate with networks that are using other types of transport protocol. The *MSC server* combines the signalling functions of the MSC with those of the VLR, and also controls the CS-MGW over a signalling interface that lies between them. A GMSC server is built in the same way.

The main network enhancement in release 5 is the *IP multimedia subsystem* (IMS). This is an extra network which interfaces with the packet switched domain, and which provides users with real time packet switched services that cannot be supplied using the packet switched domain alone. The *home subscriber server* (HSS) was also introduced in release 5, and combines the functions of the HLR and the AuC. The third release 5 enhancement (not shown in the figure) is an architectural feature known as *IuFlex*. In earlier releases, each radio network controller was connected to just one MSC and one SGSN. IuFlex introduces a more flexible architecture in which each RNC can be connected to multiple MSCs and multiple SGSNs.

The main release 6 enhancement is *wireless local area network* (WLAN) *interworking*. This allows users to access the network operator's packet switched services using a wireless LAN. The services are supplied either by the IMS, or by data servers that are controlled by the network operator and directly connected to a GGSN. The connection uses some extra core network components that are not shown in the figure, known as the *WLAN access gateway* (WAG) and *packet data gateway* (PDG).

There have also been improvements to the GSM radio access network, which is known as the *GSM EDGE radio access network* (GERAN) from release 4. The network has a new interface between base station controllers which is denoted Iur-g, and which includes some of the features of the Iur interface. A release 4 BSC can also communicate with the core network using the same Iu interface protocols that are used by UMTS, instead of the older protocols that were used by GSM.

2.3 Interfaces and protocols

A UMTS network contains a large number of interfaces, each of which has its own protocol stack. In this section, we will discuss the protocols that are used for signalling, transport and data manipulation, and show how those protocols are combined into stacks on the individual interfaces. Some of the protocols are more important than others, and the more important ones will be highlighted in the text. As in the case of the hardware components, it is worth learning the names of the important protocols, as they will make a lot of appearances later on in the book.

2.3.1 Introduction

The protocol stacks vary a lot from one interface to another, but they all follow the basic pattern shown in Figure 2.7. Each protocol stack has two main layers. The application layer creates and interprets the UMTS signalling messages and manipulates the data streams, while the transport layer just transfers them from one network component to another. The mapping of these layers onto the open systems interconnection (OSI) stack is not always clear but, roughly speaking, the application layer contains OSI layers 5 to 7, while the transport layer contains OSI layers 1 to 4.

A protocol stack also has up to three planes. Roughly speaking, the user plane carries information intended for the user such as voice or

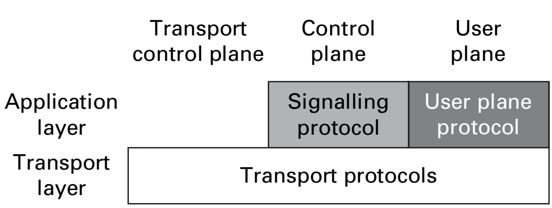

Figure 2.7 Model of the protocol stacks in UMTS.

packet data, while the control plane carries signalling messages that are only of interest to the network. (There are a few cases where information swaps over between these planes: we will see some examples in due course.) If the data are being transported using ATM, then the transport control plane carries internal signalling messages that set up, modify and tear down any temporary virtual circuits that are required. These messages are only of interest to the transport layer, so the transport control plane does not extend any higher.

This lets us classify the protocols into three groups. In the application layer, the control plane contains signalling protocols that the network elements use to communicate with each other. The user plane protocols manipulate the data that the user is interested in, for example by compression and decompression. In the transport layer, most of the interfaces use the standard protocols that we introduced in Chapter 1. The big exception is the air interface, which uses protocols that are unique to UMTS. We will describe the protocols in these three groups in the sections that follow.

2.3.2 Signalling protocols

The first protocols to consider are the signalling protocols, in the application layer's control plane. We can illustrate how they operate by considering the *radio resource control* (RRC) protocol, which lies between the mobile and its serving radio network controller. Using this protocol, the SRNC sends signalling messages to the mobile to control how it behaves, and the mobile sends responses and information messages to the SRNC. The RRC specification contains precise definitions of the messages, their associated parameters, and the ways in which they are organised into signalling procedures. It's a lengthy document, the release 7 version coming to over 1200 pages.

Figure 2.8 shows an example signalling procedure, which the SRNC can use to find a mobile's capabilities. The procedure is shown as a *message sequence chart*, which indicates the messages that are exchanged between the mobile and the SRNC, together with the protocols that are responsible. It hides the low level details, such as the way in which the

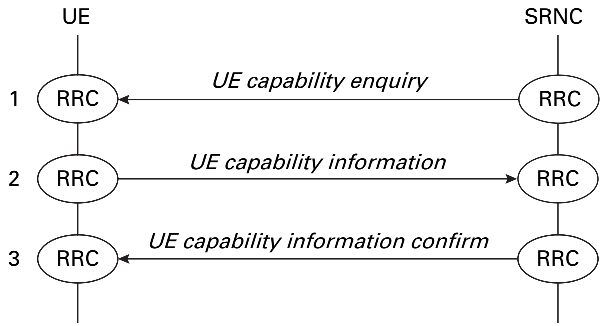

Figure 2.8 Operation of the RRC protocol in the UE capability enquiry procedure.

messages are transported, and the way in which they pass through the Node B. (We will see some of those details later in the chapter.)

In step 1, the SRNC composes an RRC message known as *UE capability enquiry*, and sends it to the mobile. The mobile replies with a message called *UE capability information* (2), which includes several parameters that describe its capabilities. Examples include its maximum data rate, the number of simultaneous data streams it can handle, and whether or not it supports GSM. On receiving this information, the SRNC replies with a message called *UE capability information confirm* (3). It now knows how it should control the mobile, for example whether it can hand the mobile over from UMTS to GSM.

The procedures also define what happens in cases of abnormal behaviour. If, for example, a timer in the mobile expires before it receives the SRNC's confirmation message, then it is obliged to retransmit its capability information. We will not normally address cases of abnormal behaviour in this book; it will be enough to know that they exist.

UMTS has many different signalling protocols, which are listed in Table 2.5. They all behave in much the same way as the RRC protocol, in that they allow network elements to exchange signalling messages with each other.

It is worth highlighting the most important protocols in the table, as the operation of these protocols will be the main subject of Chapters 4 and 5. The *mobile application part* (MAP) handles signalling communications across most of the interfaces in the core network. For

Table 2.5 *List of signalling protocols in UMTS, grouped according to the part of the system where the protocol is used.*

Location	Protocol	Description
CS domain	BICC	Bearer independent call control protocol
	ISUP	ISDN user part
	MEGACO	Media gateway control protocol
	TUP	Telephone user part
CS and PS domains	BSSAP+	Base station subsystem application part plus
	MAP	Mobile application part
PS domain	GTP-C	GPRS tunnelling protocol control part
UTRAN	NBAP	Node B application part
	RANAP	Radio access network application part
	RNSAP	Radio network subsystem application part
Uu non-access stratum	CC	Call control
	GMM	GPRS mobility management
	MM	Mobility management
	SM	Session management
Uu access stratum	RRC	Radio resource control
UE	AT	Attention commands
	USIM	UMTS subscriber identity module

example, when an incoming call arrives for a mobile at a gateway MSC, the GMSC sends a MAP message to the home location register in which it asks for the mobile's current location, so that it can forward the call to the correct MSC. The *Node B application part* (NBAP), *radio access network application part* (RANAP) and *radio network subsystem application part* (RNSAP) have similar roles within the radio access network, on the Iub, Iu and Iur interfaces respectively.

The air interface has two levels, the *non-access stratum* (NAS) and the *access stratum* (AS). Protocols in the non-access stratum exchange messages between the mobile and the core network. There are four of these. The *call control* (CC) protocol runs in the mobile and the circuit switched domain, and sets up, manages and tears down phone calls. Its companion in the packet switched domain is the *session management* (SM) protocol, which sets up, manages and tears down packet data transfers. The *mobility management* (MM) and *GPRS mobility management* (GMM) protocols handle bookkeeping messages that only affect the internal operation of the system, and are not related to any kind of data stream. The RRC protocol lies in the access stratum, and is used to exchange messages between the mobile and the radio access network.

2.3.3 Transport protocols

We now turn to the protocols in the transport layer, which are listed in Table 2.6. They fall into two distinct groups.

In the air interface's access stratum, information is transported using protocols that are unique to UMTS. The most important one is the air interface's physical layer. This carries out most of the processes that we described in Section 1.3, such as modulation, code division multiple access and error correction. We will spend much of Chapter 3 describing how this protocol works.

The physical layer is assisted by two layer 2 protocols. The *medium access control* (MAC) protocol controls the physical layer, for example by deciding how much data should be transmitted to or from a mobile at a particular time. The *radio link control* (RLC) protocol manages the data link between the mobile and the radio access network, by tasks such as retransmitting data packets if they arrive incorrectly. Roughly speaking, the physical layer is implemented in the mobile and Node B, while the MAC and RLC are implemented in the mobile and its serving RNC.

The fixed network uses standard transport protocols. In release 99, the circuit switched domain transmits voice calls using *pulse code modulation* (PCM), which is the transport mechanism used in digital fixed line telephone networks. In PCM, the analogue speech signal is digitised with 8 bit

Table 2.6 *List of transport protocols in UMTS, grouped according to the part of the system where the protocol is used.*

Location	Protocol	Description
CS domain	PCM	Pulse code modulation
CS domain PS domain	ALCAP	Access link control application protocol
UTRAN	ATM	Asynchronous transfer mode
	IP	Internet protocol
	MTP	Message transfer part
Uu access stratum	MAC	Medium access control
	PHY	Air interface physical layer
	RLC	Radio link control

resolution at a sample rate of 8 kHz, to give a bit rate of 64 kbps. The resultant signal is converted to symbols, mixed with a carrier and multiplexed with other PCM signals, before transmission over the network. There is no other processing such as compression or error correction.

In other parts of the fixed network, data are transported using the protocols that we introduced in Section 1.2.3: asynchronous transfer mode (ATM), the Internet protocol (IP), and the message transfer part (MTP) of the SS7 protocol stack. As the system has evolved from one release to another, there has been a trend for IP to replace MTP and ATM, and we will see this trend reflected in the protocol stacks that follow.

The *access link control application protocol* (ALCAP) is only required if the data are being transported using ATM temporary virtual circuits. It is situated in the transport control plane, and sets up, manages and tears down the virtual circuits under command from higher layers.

There are several places in the fixed network where the actual protocol stacks are more complex than the ones we showed earlier, to handle issues like mixtures of different protocols. These issues are beyond the scope of this book, so in the protocol stacks that follow, we will simply describe the fixed network transport layers as ‘ATM’, ‘IP over ATM’ and so on.

2.3.4 User plane protocols

The user plane protocols manipulate the data that the user is interested in, in ways that are specific to UMTS. They also carry a small number of signalling messages, which control tasks that are closely related to their respective data streams such as timing synchronisation.

The best example is the *adaptive multi rate* (AMR) *codec*. In release 99, the circuit switched domain transports voice calls at a rate of 64 kbps. This is too fast for the air interface, because the signal-to-noise ratios are rather low there, so the maximum data rate is low. To deal with this problem, the AMR codec compresses the information on the path between the mobile and the MSC, to a rate between 4.75 and 12.2 kbps. This greatly increases the number of mobiles that a cell can support. From release 4 onwards, the information can be compressed all the way from one mobile to the other. If this is done, then the AMR codec is only implemented in the mobile, and the core network transports the information in compressed form using ATM or IP.

Table 2.7 lists the user plane protocols that are used by UMTS. Some of the protocols are only used by particular services, which are listed in the final column of the table. They are less important to us than the signalling or transport protocols, but a few of them will appear from time to time.

2.3.5 Circuit switched domain

We now have enough information to show the protocol stacks on each of the interfaces in UMTS. We will use the same shading scheme as in Figure 2.8, denoting the signalling protocols in grey and the user plane protocols with white letters on a dark background. We will also indicate the releases in which the later protocol options appear.

Figure 2.9 shows the protocol stacks in the circuit switched domain. On the internal signalling interfaces (Figure 2.9a), the network elements exchange signalling messages that are written using the mobile application part. These messages are transported using MTP in release 99, or using ATM or IP from release 4.

Table 2.7 *List of user plane protocols in UMTS, grouped according to the part of the system where the protocol is used.*

Location	Protocol	Description	Service
CS domain	Nb UP	Nb user plane protocol	
PS domain	GTP-U	GPRS tunnelling protocol user part	GPRS
UTRAN	Iu UP	Iu user plane protocol	
	Iub UP	Iub user plane protocol	
	Iur UP	Iur user plane protocol	
Uu non-access stratum	AMR	Adaptive multi rate codec	Voice
	RLP	Radio link protocol	CS data
	SMS	Short message service protocol	SMS
Uu access stratum	BMC	Broadcast multicast control	CBS
	PDCP	Packet data convergence protocol	GPRS
UE	USAT	USIM application toolkit	

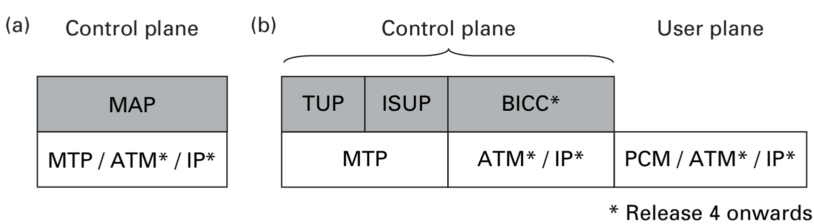

Figure 2.9 Protocol stacks used by the circuit switched domain and the shared components of the core network. (a) Internal signalling interfaces (A to G, Gc, Gf and Gr). (b) PSTN interface to an external network.

The PSTN interface (Figure 2.9b) lies between the network and the outside world. In release 99, signalling messages are written using the ISDN user part or telephone user part, and are transported using MTP. From release 4, the *bearer independent call control* (BICC) protocol has the same functions as TUP or ISUP, but can use any underlying transport layer. Speech signals in release 99 are transported using pulse code modulation; from release 4, they can also be transported in compressed form using ATM permanent virtual circuits or using IP.

2.3.6 Bearer independent circuit switched domain

Figure 2.10 shows the new protocol stacks that were introduced in release 4, to control the bearer independent circuit switched core network. The Nb interface (Figure 2.10a) is a user plane interface between two media gateways, while Nc (Figure 2.10b) is a signalling interface between two MSC servers. Mc (Figure 2.10c) is the signalling interface by which an MSC server controls a media gateway, by means of the *media gateway control protocol* (MEGACO). These interfaces are less important to us than most of the others, and we will not discuss them further.

2.3.7 Packet switched domain

Figure 2.11 shows the protocol stacks in the packet switched domain. Between an SGSN and a GGSN (Figure 2.11a), the *GPRS tunnelling protocol user part* (GTP-U) routes data packets from one network element to another, using a mechanism known as tunnelling that will be covered in

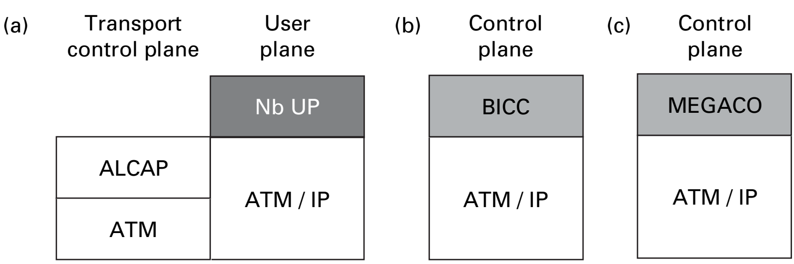

Figure 2.10 Protocol stacks used by the bearer independent circuit switched domain from release 4 (a) Nb interface between two CS-MGWs. (b) Nc interface between two MSC servers. (c) Mc interface between an MSC server and a CS-MGW.

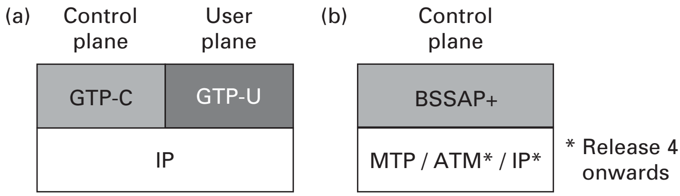

Figure 2.11 Protocol stacks used by the packet switched domain. (a) Gn and Gp interfaces, between an SGSN and a GGSN. (b) Gs interface between an SGSN and an MSC.

Chapter 5. Signalling messages are handled by the *GPRS tunnelling protocol control part* (GTP-C), which has procedures for setting up, managing and tearing down tunnels, plus other functions that are similar to those of MAP.

The Gs interface (Figure 2.11b) transfers signalling messages between the circuit switched and packet switched domains, to support mobiles that are communicating with both. The signalling protocol is a modified version of the one used between the core network and the GSM radio access network, and is known as the *BSS application part plus* (BSSAP+).

2.3.8 Radio access network

The protocol stacks in the radio access network are shown in Figure 2.12. In these protocol stacks, the RANAP, RNSAP and NBAP protocols carry signalling messages between the different network elements. The user plane protocols carry data, plus a few closely related signalling messages that handle tasks such as timing synchronisation.

Depending on the particular interface being considered, the transport layer can use some or all of ATM, IP over ATM or (from release 5 onwards) IP alone. When ATM is used, the data are usually routed using temporary virtual circuits, which are managed by the access link control application protocol. On the Iu-PS interface, however, the data are always routed using IP, by means of the same tunnelling process that we noted above. On that interface, any ATM virtual circuits are permanent ones, so ALCAP is not required.

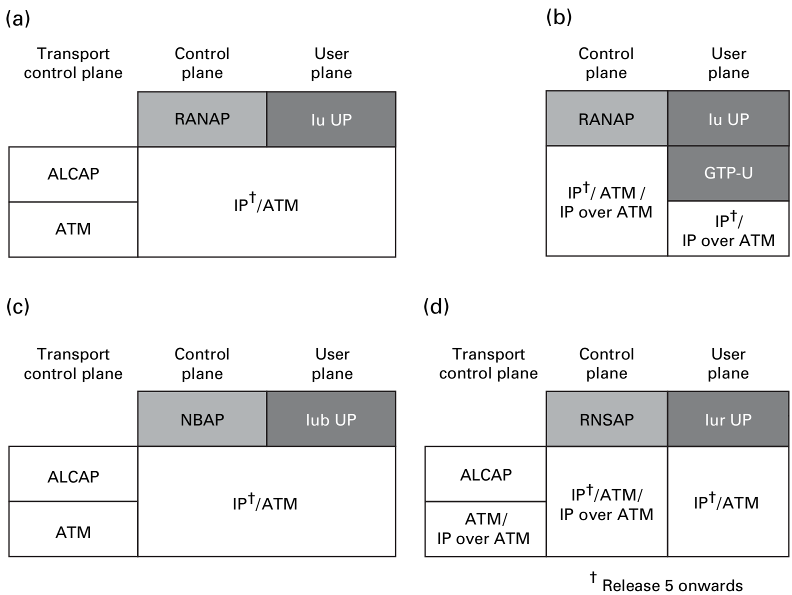

Figure 2.12 Protocol stacks used by the radio access network. (a) Iu-CS interface between an RNC and the CS domain. (b) Iu-PS interface between an RNC and the PS domain. (c) Iub interface between an RNC and a Node B. (d) Iur interface between two RNCs. (Adapted from 3GPP TS 25.410, 25.420 and 25.430.)

2.3.9 Air interface

The interface between the mobile and the network is more complex than the others. It has two levels, known as strata, which are shown in Figure 2.13. The non-access stratum (NAS) protocols exchange data and signalling messages between the mobile and the core network. Examples include the call control and session management protocols that we saw in Section 2.3.2, and the AMR codec from Section 2.3.4.

The information is transported using the protocols in the two access strata below. The Uu access stratum (AS) contains the protocols that exchange data and signalling messages between the mobile and the radio access network, such as the RRC protocol that we saw earlier. Similarly, the Iu access stratum transfers information between the radio access

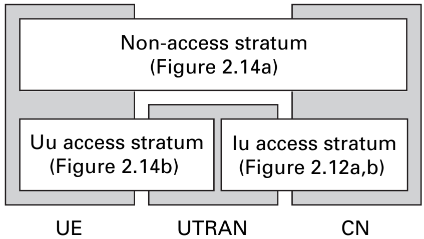

Figure 2.13 Model of the air interface protocol stack. (Adapted from 3GPP TS 25.401.)

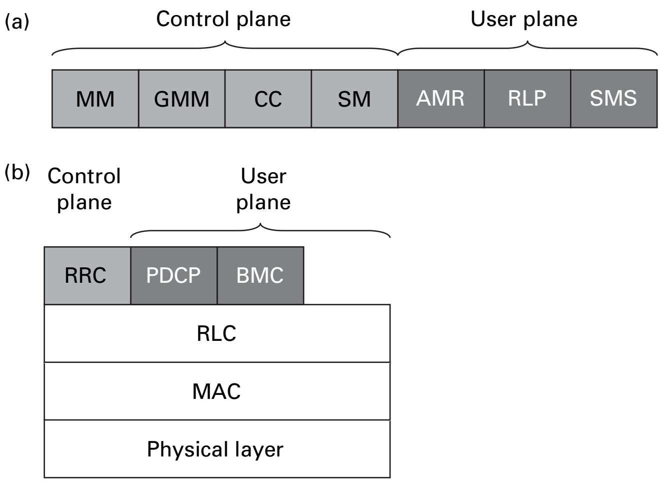

Figure 2.14 Protocol stacks used by the air interface. (a) Non-access stratum between the mobile and the core network. (b) Uu interface access stratum between the mobile and the radio access network.

network and the core network. We have already seen the protocol stacks that it uses, in Figures 2.12a and 2.12b.

Figure 2.14a shows the protocol stack for the non-access stratum. We have already introduced most of the protocols here, notably the four signalling protocols (mobility management, GPRS mobility management, call control and session management), and the adaptive multi rate codec. The other two protocols are less important. The *radio link protocol* (RLP) handles circuit switched data streams such as fax transmissions, while the short message service (SMS) protocols transfer text messages between the mobile and the core network.

Figure 2.14b shows the protocol stack for the Uu access stratum. We have already seen the radio resource control protocol and the three transport protocols (radio link control, medium access control, and the air interface's physical layer). As before, the others are less important: the *packet data convergence protocol* (PDCP) compresses the headers of IP packets, and the *broadcast multicast control* (BMC) protocol handles a service known as the cell broadcast service.

2.3.10 User equipment

Inside the UE, the Cu interface (Figure 2.15a) lies between the mobile equipment and the universal integrated circuit card. The *universal subscriber identity module* (USIM) is best understood as a signalling protocol, while the *USIM application toolkit* (USAT) transfers data to and from applications that are running on the UICC. The transport protocols follow specifications for generic smart card platforms that are produced by the European Telecommunications Standards Institute (ETSI).

The R interface (Figure 2.15b) is used if the ME is split into the mobile termination and the terminal equipment. Most of this interface lies outside the scope of UMTS; instead, it uses a variety of open standards such as the universal serial bus (USB) and Bluetooth. However the specifications define a few issues, notably a set of *attention* (AT) commands that exchange signalling messages between the two devices.

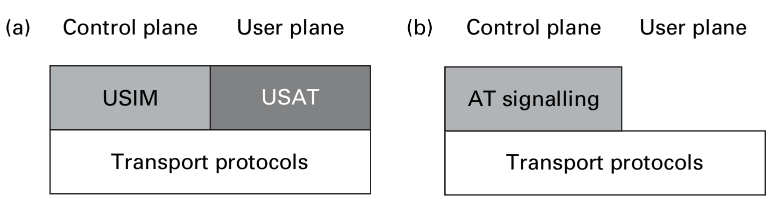

Figure 2.15 Protocol stacks used inside the mobile. (a) Cu interface between the ME and the UICC. (b) R interface between the MT and the TE.

2.4 UMTS data streams

At this point, the reader is probably wondering how these protocol stacks fit together. There are many different answers, the choice depending on issues like the type of information being transferred and the configuration of the air interface. We will show a couple of examples later in this section.

First, however, we need to introduce two types of data stream that have special names in UMTS: bearers and channels. By analogy with the discussion of protocols in Section 1.2.2, these data streams can be viewed either as exchanges of information between different parts of the system, or as exchanges between the different layers of a single protocol stack. The first viewpoint turns out to be more useful for the bearers, while the second is more useful for the channels.

2.4.1 Bearers

A *bearer* is a data stream that spans some part of the system and has a specific *quality of service* (QoS). Figure 2.16 shows the most important bearers in UMTS.

When the mobile and the network agree to set up a data stream, the system first implements it using a *UMTS bearer*. This carries information

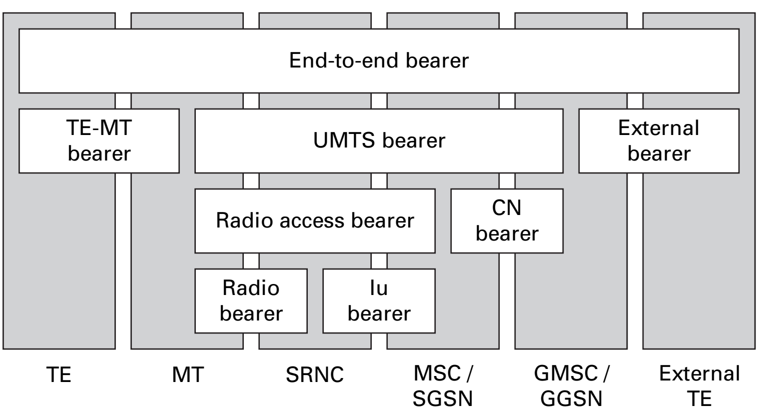

Figure 2.16 Bearers used in UMTS. (Adapted from 3GPP TS 23.107.)

Table 2.8 *Signalling radio bearers in UMTS.*

Bearer	Purpose
SRB 0	Access stratum signalling for a UE in RRC Idle mode
SRB 1	Access stratum signalling using RLC unacknowledged mode
SRB 2	Access stratum signalling using RLC acknowledged mode
SRB 3	High priority non-access stratum signalling
SRB 4	Low priority non-access stratum signalling

such as voice or packet data between the mobile termination and the far end of the core network (an MSC, GMSC or GGSN). If the MT and TE are implemented as two different devices, then another bearer transports information between them. However, this bearer lies outside the scope of UMTS, so we will not consider it further. The same applies to the bearer that lies beyond the far end of the core network.

The UMTS bearer is associated with a number of quality of service parameters. These describe the service that the user expects to receive, using parameters such as the required data rate, error rate and delay. The system cannot supply this quality of service right away, because the UMTS bearer spans different interfaces that use different transport protocols. It therefore breaks the UMTS bearer down into bearers that have a smaller scope. A *CN bearer* handles the path over the core network, while a *radio access bearer* (RAB) handles the path between the mobile and its first point of contact there. In turn, the radio access bearer is broken down into an *Iu bearer* between the core network and the SRNC, and a *radio bearer* between the SRNC and the mobile.

Each bearer is then implemented using the transport protocols that are appropriate for the corresponding interface, which provide the user with the quality of service expected. On the air interface, for example, the radio bearer is implemented using the RLC, MAC and physical layer protocols, which we will be describing in Chapter 3.

Five special radio bearers carry signalling messages between the mobile and its serving RNC. They are known as *signalling radio bearers* (SRBs), and are listed in Table 2.8. Each of them is implemented in a particular way that is appropriate for a particular type of message. SRB 0 is used to

Table 2.9 *Logical channels in UMTS release 99.*

Channel	Name	Direction	Information carried
BCCH	Broadcast control channel	DL	System information messages
PCCH	Paging control channel	DL	Paging messages
CCCH	Common control channel	UL, DL	Signalling to/from a UE in RRC Idle mode
DCCH	Dedicated control channel	UL, DL	Signalling to/from a UE in RRC Connected mode
CTCH	Common traffic channel	DL	Broadcast/multicast traffic
DTCH	Dedicated traffic channel	UL, DL	Traffic to/from a single UE

set up signalling communications between the mobile and the network; the other signalling radio bearers handle all subsequent communications. SRBs 1 and 2 carry RRC messages between the mobile and its serving RNC, the main difference between them being in the configuration of the RLC protocol. SRBs 3 and 4 are used to forward non-access stratum messages that begin or end in the core network. SRB 4 is optional, but if it is implemented, then SRB 3 is used for high priority messages, and SRB 4 is used for low priority ones.

2.4.2 Channels

In the air interface's access stratum (Figure 2.14b), the data flows between the different protocols are known as *channels*. There are many different types of channel, which are distinguished by the information they carry and the ways in which they are used. They can be collected into three different classes, which are used at three different levels of the protocol stack.

Logical channels (Table 2.9) lie between the radio link control and medium access control protocols. There are two ways to distinguish them.

Table 2.10 *Transport channels in UMTS release 99. (The list excludes a few channels that were deleted in later releases.)*

Channel	Name	Direction	Information carried
BCH	Broadcast channel	DL	BCCH
PCH	Paging channel	DL	PCCH
FACH	Forward access channel	DL	Traffic and signalling on a common CDMA code
RACH	Random access channel	UL	Traffic and signalling on a common CDMA code
DCH	Dedicated channel	UL, DL	Traffic and signalling on a dedicated CDMA code

The *dedicated traffic channel* (DTCH) and *dedicated control channel* (DCCH) are *dedicated logical channels*, and always carry information for a single mobile; the others are known as *common logical channels*, and can carry information for more than one mobile. *Logical traffic channels* carry user plane information such as voice or packet data, while *logical control channels* carry signalling messages in the control plane. For our purposes, the logical channels are the least important of the three classes, and we will not refer to them much.

Transport channels (Table 2.10) lie between the MAC and the physical layer. There is nearly a one-to-one mapping between the transport and physical channels, and the two classes can often be considered together. We will look at the information flows through the transport channels in a moment.

Physical channels (Table 2.11) lie below the air interface's physical layer. Roughly speaking, each physical channel is an allocation of a CDMA code for a particular purpose. There are two ways to distinguish them, but the distinctions are subtly different from the ones we saw earlier. The *dedicated physical data channel* (DPDCH) and *dedicated physical control channel* (DPCCH) are *dedicated physical channels*, in which the

Table 2.11 *Physical channels in UMTS release 99. (The list excludes a few channels that were deleted in later releases.)*

Channel	Name	Direction	Information carried
PCCPCH	Primary common control physical channel	DL	BCH
SCCPCH	Secondary common control physical channel	DL	PCH and FACH
PRACH	Physical random access channel	UL	RACH
DPDCH	Dedicated physical data channel	UL, DL	DCH
PICH	Paging indicator channel	DL	Control signals to support the PCH
AICH	Acquisition indicator channel	DL	Control signals to support the RACH
DPCCH	Dedicated physical control channel	UL, DL	Control signals to support the DCH
SCH	Synchronisation channel	DL	Control signals to support acquisition
CPICH	Common pilot channel	DL	Pilot signal to assist the UE receiver

CDMA code is assigned to a single mobile; in the others, known as *common physical channels*, the CDMA code can be used by more than one mobile. *Physical traffic channels* (the first four channels listed) map onto higher level channels, and carry both user plane data and control plane signalling messages. *Physical control channels* help the operation of the physical layer: they are composed in the physical layer of the transmitter and interpreted by the physical layer of the receiver, and are completely invisible to higher layers.

There are too many acronyms to remember easily, but there are really only five types of information flow, which correspond to the five transport channels. They are shown in Figure 2.17, in rough order of their

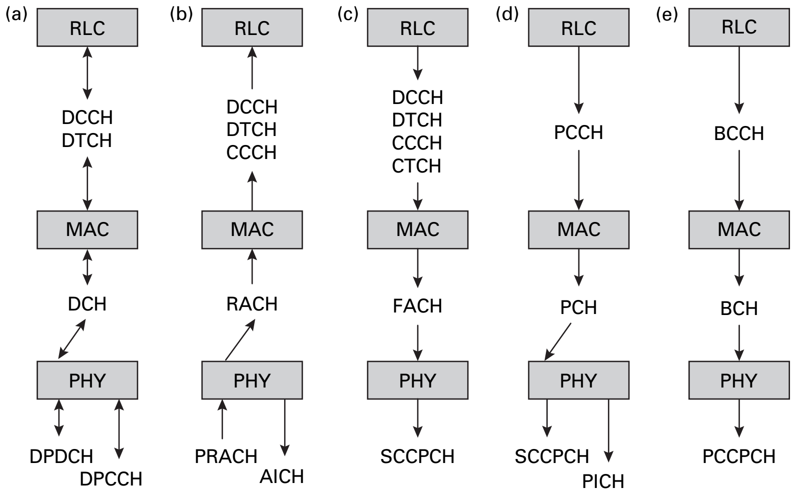

Figure 2.17 Mapping of the logical, transport and physical channels for five information flows. (a) Use of a dedicated physical channel. (b) Use of a common physical channel in the uplink. (c) Use of a common physical channel in the downlink. (d) Paging messages. (e) System information broadcasts.

importance to us. The figure is drawn from the network's point of view, so that up and down arrows refer to the uplink and downlink respectively.

Figure 2.17a shows how information is sent using a dedicated physical channel, whose CDMA code is assigned to a single mobile. The *dedicated channel* (DCH) and the dedicated physical data channel carry data and signalling messages in both the uplink and downlink. They are assisted by the dedicated physical control channel, which sends physical layer control signals from the transmitter to the receiver. This is the usual scenario during a phone call; it is also the only scenario in which soft handover is supported. These three channels are the most important ones for this book, and we will examine their operation in some detail in Chapter 3.

Information can also be sent using a common physical channel, whose CDMA code can be used by more than one mobile. On the uplink (Figure 2.17b), the *random access channel* (RACH) and *physical random access channel* (PRACH) carry data and signalling messages from the mobile to the network. They are assisted by the *acquisition indicator* *channel* (AICH), which sends physical layer control signals in the opposite direction. On the downlink (Figure 2.17c), the information is sent on the *forward access channel* (FACH) and the *secondary common control physical channel* (SCCPCH). We will examine the operation of these channels in Chapter 3 as well.

Figure 2.17d is used for paging messages, which alert mobiles to incoming calls, while Figure 2.17e is used for system information broadcasts, which tell the mobiles in a cell about how the cell is configured. We will examine these two processes in Chapter 4.

Figure 2.17 left out two channels that only appear in the physical layer: the *common pilot channel* (CPICH) and the *synchronisation channel* (SCH). These are downlink-only channels which help the operation of the mobile's physical layer, and which will make an appearance in Chapters 3 and 4. There are also some more channels not listed here. First, release 99 defined some other channels that were later removed from the specifications because nobody implemented them, and we will not consider those channels at all. Second, more channels have been introduced in later releases of UMTS, particularly to support high speed packet access. We will describe those channels in Chapter 3.

2.4.3 Example signalling flows

We can now examine some of the information flows over the air interface, to show how the protocol stacks, bearers and channels fit together. There are many different scenarios, but a couple of examples will illustrate how it all works.

Figure 2.18 shows the protocols that are used to exchange signalling messages between the mobile and its serving radio network controller, for a scenario where the mobile is just communicating with one Node B and one RNC. These protocols might be used for the capability enquiry procedure that we saw in Figure 2.8.

First let's look at the downlink. The SRNC composes its message using the RRC protocol, and sends it on signalling radio bearer 1 or 2. It then processes the message using the RLC and MAC, and sends it to the Node B using the Iub user plane protocol. (This is one example in

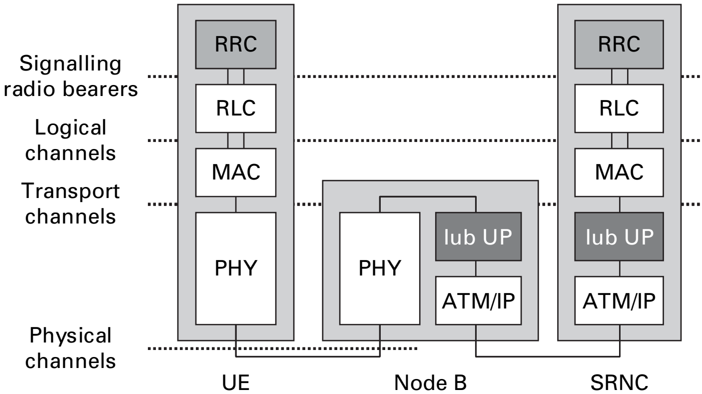

Figure 2.18 Signalling flows between a mobile and an RNC, for a case where the mobile is communicating with one Node B and one RNC.

which a control plane message crosses into the user plane for part of its journey. The Iub control plane has a different purpose, namely signalling communications between a Node B and its controlling RNC using the Node B application part.) The Node B transmits the message using the DPDCH or SCCPCH, depending on whether it is using a dedicated or a common CDMA code, and the mobile receives and processes it. On the uplink, the flows are reversed, and the message is transmitted using the DPDCH or PRACH.

Figure 2.19 is a more complex scenario, which introduces three new features. First, the mobile is now in soft handover with cells that are controlled by two Node Bs. Soft handover is only supported when using dedicated channels, so on the air interface, the information is sent and received on the DPDCH. The receivers need some special mechanisms to combine the two signals, and we will describe those in Chapter 3. Second, one of the Node Bs is controlled by a different RNC, which is labelled as a drift RNC. Information is sent between the serving RNC and the drift RNC over the Iur interface, using the Iur user plane protocol.

Third, the figure shows the protocols that are used to exchange non-access stratum signalling messages between the mobile and the core network. These messages are transported across the Uu and Iu interfaces using the RRC and RANAP protocols, by embedding them into

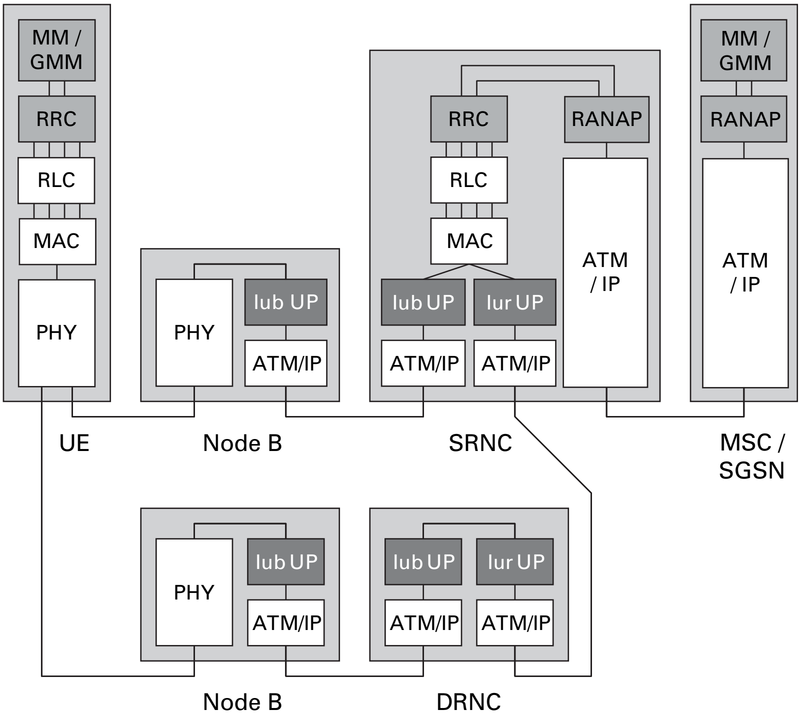

Figure 2.19 Signalling flows between a mobile and the core network, for a case where the mobile is in soft handover, and is communicating with two Node Bs and two RNCs.

special access stratum messages that are known as *direct transfers*. On the Uu interface, the direct transfers are transported using signalling radio bearer 3 or 4.

Figure 2.20a shows an example. In this example, the circuit switched domain wants to confirm the subscriber's identity, perhaps because of a database failure in the core network. To do this, it sends the mobile a mobility management message called an *identity request* (1). In the message it specifies the type of identity that it requires, such as the international mobile subscriber identity (IMSI). The mobile replies with an MM message called *identity response* (2), which contains the identity requested.

The access stratum transports the messages as shown in Figure 2.20b. On the downlink, the core network's request is embedded into a

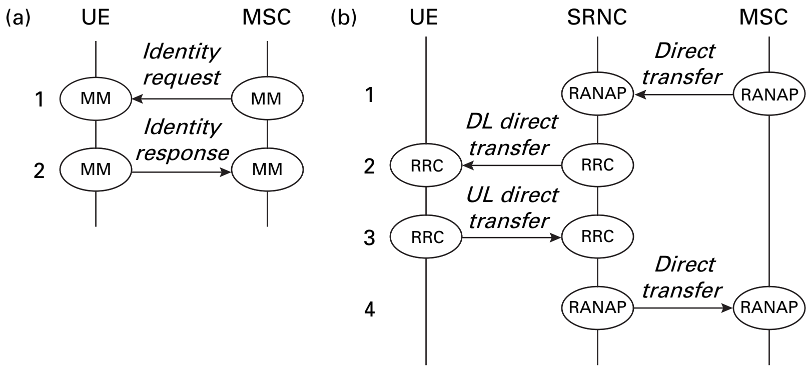

Figure 2.20 Operation of the non-access stratum signalling protocols. (a) MM identification procedure. (b) Implementation of the procedure using RRC and RANAP direct transfers.

RANAP *direct transfer* (1), which is transported like any other RANAP message. The SRNC extracts the core network's request and embeds it into an RRC *downlink direct transfer* (2), which it sends to the mobile. Similarly, the mobile's response is embedded into an RRC *uplink direct transfer* (3), and another RANAP direct transfer (4). The use of different message names by the two protocols is unimportant; it is just an artefact of the specifications. We will see many non-access stratum signalling messages in Chapters 4 and 5, and they will all be transported in this way.

2.5 Frequency allocation

In this final section, we will look at some remaining details of the air interface: the modes in which the air interface can operate, and the way in which carrier frequencies are allocated to UMTS.

2.5.1 FDD and TDD modes

On the air interface, the physical layer transmits and receives radio signals using two distinct modes: *frequency division duplex* (FDD) and *time division duplex* (TDD). These are two techniques for distinguishing the mobiles' transmissions from those of the base stations, to ensure that they do not interfere with each other. FDD uses a paired spectral allocation, in which the base stations and mobiles transmit continuously but on two different frequencies. By contrast, TDD uses an unpaired spectrum, in which the base stations and mobiles transmit on the same frequency but at different times.

Both modes have advantages and disadvantages. FDD networks are easier to implement: they do not require accurate time synchronisation, and the use of two frequencies makes them less prone to interference. On the other hand, TDD uses the air interface more efficiently: if users are downloading more data than they are uploading, then the network can allocate more transmit time to the base stations than to the mobiles.

To date, FDD has proved much more popular than TDD, to the extent that there are very few implementations of the release 99 TDD specifications. Because of this, we will only cover FDD mode in this book. There is one exception, however: the Chinese TD-SCDMA system is actually an option within UMTS TDD mode that entered the specifications as part of release 4.

2.5.2 Worldwide frequency allocations

In UMTS, the individual carrier frequencies are 5 MHz apart, but they can lie in a number of different bands that are defined in the 3GPP specifications. Figure 2.21 shows the most important frequency bands in FDD mode.

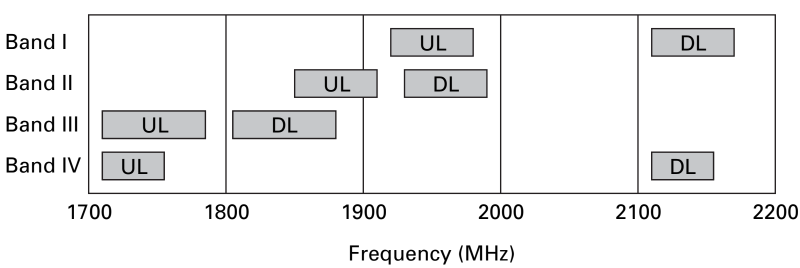

Figure 2.21 Illustration of the most important frequency bands used by UMTS FDD mode.

Most of the world uses band I, which spans 1920–1980 MHz for the uplink and 2110–2170 MHz for the downlink, and provides 12 pairs of carrier frequencies. In North and South America, however, band I is unsuitable because it overlaps with existing allocations. In this region, UMTS is currently transmitted in band II, which actually has the same frequency as one of the 2G bands there: 1850–1910 MHz for the uplink, and 1930–1990 MHz for the downlink. Unfortunately, UMTS requires a much higher bandwidth than any second generation system (or even than cdma2000), so it is hard for network operators there to get licences for UMTS transmission. This is one of the reasons behind the slow take-up of UMTS in the Americas.

The specifications also support transmission in other frequency bands, which have been designed for the future expansion of UMTS. For example, band III is currently used for GSM 1800 transmissions in Europe and East Asia, while band IV is being made available for 3G-only transmissions in North and South America. Release 7 supports a total of ten bands for FDD, and four bands for TDD.

2.5.3 Allocations to network operators in the UK

The frequency bands shown above are awarded to individual network operators, usually on a country-by-country basis. To illustrate this, Figure 2.22 shows the current frequency allocations in the UK.

The licences were allocated by a government auction, which was designed by game theorists to extract as much money as possible from the network operators, and accidentally timed close to the peak of the dotcom boom in 2000. The result was that the operators paid a total licence fee of over £22 billion, or nearly £400 for each person in the country. A similar process happened in Germany, while in other countries the licences were awarded later and far more cheaply.

As shown in the figure, the UK auction included both FDD and TDD frequencies. However, the operators paid very much less for the TDD bands than they did for the FDD bands, and they have scarcely used them.

Note that an operator could run a UMTS network using just one pair of FDD frequencies, with the individual base stations and mobiles

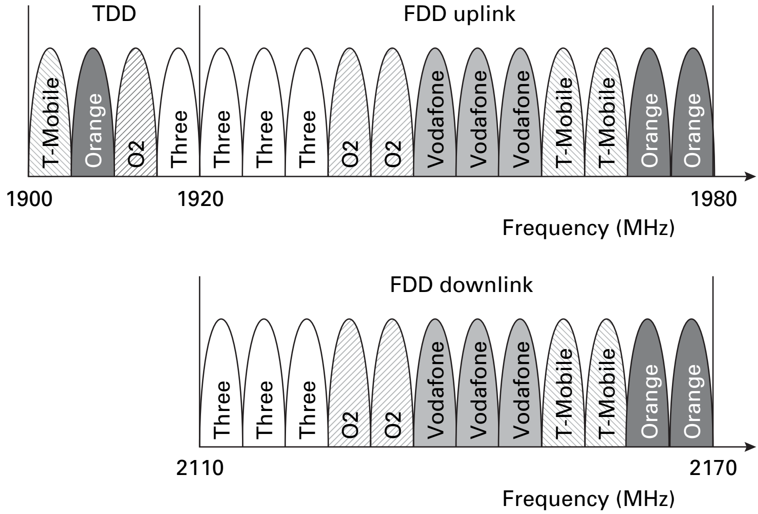

Figure 2.22 Allocation of UMTS carrier frequencies to network operators in the UK. (Reproduced with permission from Imagicom Limited.)

distinguished by the use of CDMA codes. So how do they use multiple carrier frequencies? We will see in Chapter 3 that there is some interference between transmitters on the same frequency, which ultimately sets a limit on the capacity of the system. It turns out that this interference is particularly noticeable between cells of different sizes, so network operators tend to run macrocells on one FDD pair and microcells on another. Other carrier frequencies can be used to increase the capacity of the macro- or microcells, or for a third layer of picocells.