UMTS overview

by K. W. Richardson

The Universal Mobile Telecommunications System (UMTS) as specified by the Third Generation Partnership Project (3GPP) was formally adopted by the ITU as a member of its family of IMT-2000 Third Generation Mobile Communication standards in November 1999. This paper provides some background to the UMTS standard and an overview of the system architecture. Some information about the current status of technology trials is provided as well as predictions for the services that future UMTS networks are likely to deliver to the end user.

1 Introduction

The goal of third generation (3G) mobile communication systems is the delivery of multimedia services to the user in the mobile domain[1]. This requires the provision of user data rates that are substantially higher than those provided by today's second generation (2G) networks. In GSM (Global System for Mobile communications), for example, only data rates of 9·6 kbit/s are currently supported[2–4]. In UMTS users will be provided with data rates of up to 144 kbit/s in macrocellular environments, up to 384 kbit/s in microcellular environments and up to 2 Mbit/s in indoor or picocellular environments.

These requirements address the limitations of GSM, which, despite its enormous world-wide success (320 operational networks in 118 countries by the end of 1998)[5], was designed primarily for mobile digital telephony with only a limited data capability. Although the introduction of a packet-switched data service and further enhancements based on a higher modulation scheme address these limitations within GSM itself, UMTS will provide the user with an even higher data rate capability.

A further key requirement for UMTS is the need for an evolution of the core network architecture used in GSM (which employs a signalling protocol known as MAP*) to allow current GSM operators to protect their infrastructure investments during the upgrade of their networks to support UMTS.

2 Early initiatives

The origin of UMTS can be traced back to the research activities that formed part of the European Commission's collaborative research RACE projects. Indeed it was the RACE Mobile Definition project which first defined the term UMTS in 1986.

RACE projects such as CODIT and ATDMA considered

* A list of key abbreviations and their meanings, including those not defined in this paper, is given on page 92.

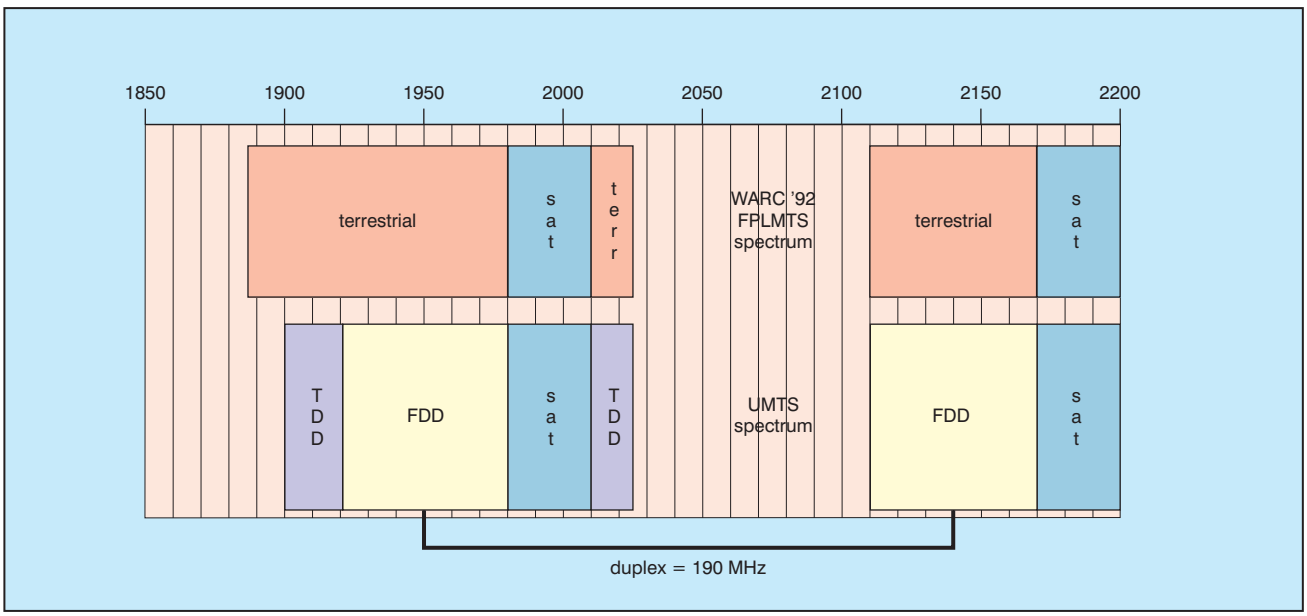

Fig. 1 UMTS spectrum allocation

different and competing multiple access schemes for the air interface, and MONET investigated the network aspects of a future UMTS system.

The subsequent ACTS FRAMES project (1995–9) built upon the work of CODIT and ATDMA and proposed a multiple access scheme for the UMTS air interface known as FMA (FRAMES Multiple Access)[6]. It consisted of two modes: FMA1, a TDMA (Time Division Multiple Access) scheme with an optional spreading component within the timeslots, and FMA2, based on DS-CDMA (Direct Sequence Code Division Multiple Access).

3 Spectrum allocation (Fig. 1)

The process of reserving and allocating frequency spectrum for the deployment of new radio systems takes many years. As far back as 1992 the World Administrative Radio Conference (WARC) allocated 230 MHz of spectrum for the implementation of a single world-wide 3G mobile system (or FPLMTS as it was then known) from the year 2000. The allocation was split into the frequency bands 1885–2025 MHz and 2110–2200 MHz, within which the subbands 1980–2010 MHz and 2170–2200 MHz are for the satellite component and the remainder for the terrestrial component.

Within Europe, the European Radiocommunications Committee (ERC) of the European Conference of Postal and Telecommunication Administrations (CEPT) is responsible for the actual allocation of radio frequencies. CEPT Decision ERC/DEC/(97)07 specifies that 155 MHz of spectrum shall be reserved for the terrestrial component of 3G systems.

The 155 MHz is split into the 'paired band' (2×60 MHz) for frequency division duplex (FDD) operation and 'unpaired bands' (separate 20 MHz and 15 MHz allocations) for time division duplex (TDD) operation where one carrier is switched in time between uplink and downlink transmissions.

4 Standards

A crucial aspect in the development of 3G technology has been the process of standardisation within the various regional and global forums. It is vital that standards exist to define 'open' interfaces between the various system components. This enables the interworking of equipment produced by different manufacturers and provides network operators and mobile phone users with choice and lower costs through competition.

The final authority for the adoption of global standards is the International Telecommunication Union[7] (ITU), and it set its timetable (see Fig. 2) back in 1995 for the standardisation process of its 3G standard, IMT-2000 (this acronym having replaced FLPMTS).

Submissions of candidate radio transmission technologies (RTTs) were invited by June 1998, either from individual countries or regional bodies.

In Europe, the European Telecommunications Standards Institute (ETSI) is the body responsible for the technical development of GSM and UMTS. Throughout the second half of 1997 its SMG2 committee compared five alternative proposals for the multiple access scheme to be employed on the air interface (Table 1).

The Alpha, Gamma and Delta groups were based on the technical inputs provided by the FRAMES project. FMA1 with spreading provided the basis for the Delta Concept, FMA1 without spreading the basis for the Gamma concept and FMA2 the basis for the Alpha concept.

The outcome of the evaluation process was the landmark decision highlighted in Fig. 3 that was taken at a

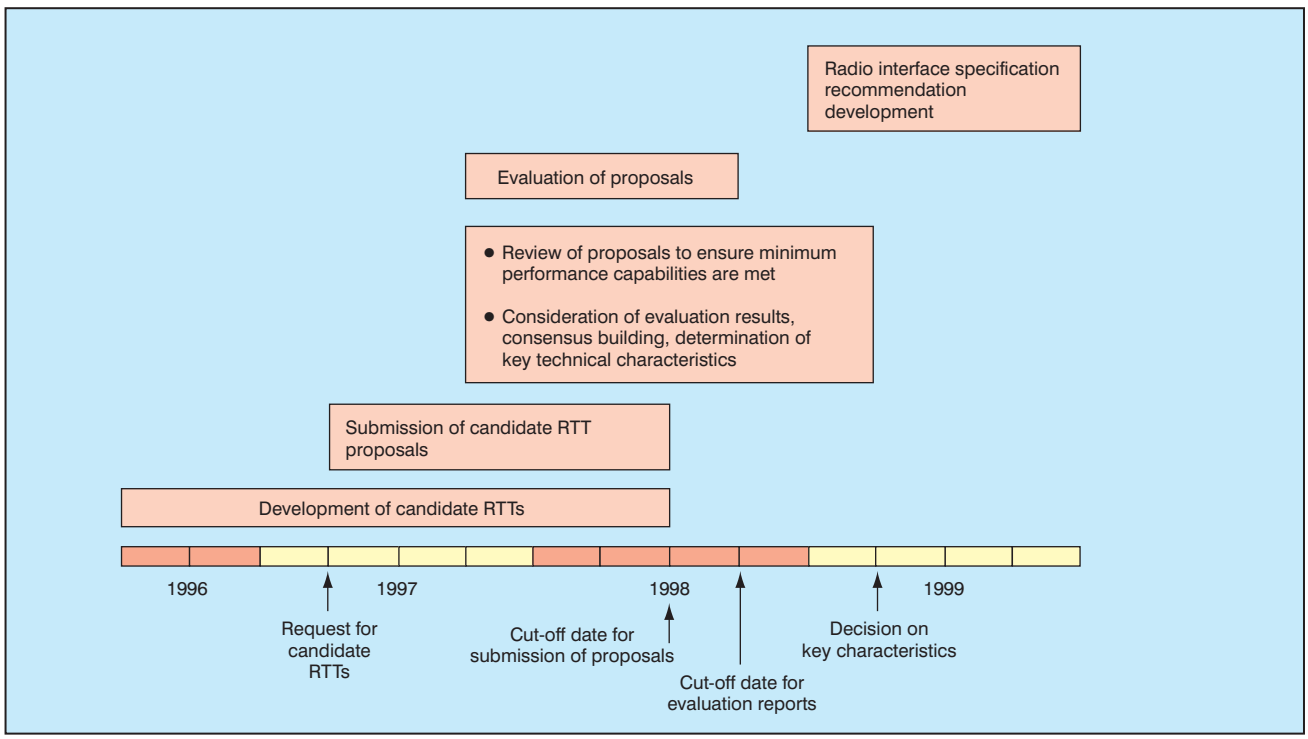

Fig. 2 ITU timeline for 3G standardisation

specially convened SMG Plenary meeting in Paris in January 1998.[8]

Following this decision and prior to the June 1998 deadline for ITU submissions, a process of parameter harmonisation of the FDD and TDD modes was undertaken within SMG2. This resulted in the UTRA (UMTS Terrestrial Radio Access) submission to the ITU being based upon the key parameters shown in Table 2.[9]

A total of ten submissions were received by the ITU (Table 3) and in accordance with the ITU's timeplan a process of harmonisation and rationalisation of the proposals commenced.

Table 1: ETSI UTRA air interface technology proposals

Concept group	Multiple access scheme
Alpha	wideband code division multiple access (W-CDMA)
Beta	orthogonal frequency division multiple access (OFDM)
Gamma	wideband time division multiple access (wideband TDMA)
Delta	time division/code division multiple access (TD-CDMA)
Epsilon	opportunity driven multiple access (ODMA)

Table 2: UTRA parameters (at time of submission of RTT to ITU)

	FDD	TDD
Multiple access scheme	W-CDMA	TD-CDMA
Carrier spacing	4·4 – 5·2 MHz	5 MHz
Chip rate	4·096 Mchip/s (Mcps)	
Modulation	QPSK	
Pulse shaping	root raised cosine, roll-off = 0·22	
Frame length	10 ms	
Timeslots per frame	16	

5 A global view

Japan has been at the forefront of the research, development and deployment of trial technology for 3G systems with a particular focus on wideband CDMA (W-CDMA) as the multiple access technology. The phenomenal uptake of digital mobile telephony in Japan (currently over 40 million subscribers) forced a view of 3G as a means of providing a solution to network capacity problems as well as opening up opportunities for new services through enhanced data rates. Unlike GSM, there are no scheduled enhancements to PDC, the Japanese 2G system, to bridge the gap to 3G.

For these reasons, Japan will be the first country to deploy 3G networks, with commercial operation expected to begin in 2001. The Japanese were also keen to forge a single global standard and initiated a process of co-operation and harmonisation of W-CDMA with ETSI's UTRA proposal.

In the USA, as in Europe, the provision of an evolutionary path from 2G legacy networks is an important issue in order for existing operators to protect their infrastructure and spectrum investments but the situation in the USA is more complicated. Unlike Europe and Japan, there is no common 2G standard and there are no national network operators. There are three main 2G standards: a TDMA-based standard (IS-136) and a CDMA-based standard (IS-95), which are deployed in the cellular and PCS bands, as well as the GSM derivative PCS1900, which is deployed in the PCS band only. The core network standard in the USA is ANSI-41, which performs similar functions to GSM MAP.

The US cdma2000 and UWC-136 candidate submissions to the ITU were therefore evolutions from the IS-95 and IS-136 standards, respectively, and suitable for deployment in the existing cellular and PCS bands.

6 Global harmonisation

In December 1998, a body called the Third Generation Partnership Project[10] (3GPP) was established with the aim of harmonising the various proposals based on W-CDMA. Its objective was and remains to 'co-operate in the production of a globally applicable ... 3rd Generation Mobile System based on evolved GSM core networks'[11]. It was founded by the following regional standardisation bodies: ARIB (Japan), ETSI (Europe), T1 (United States), TTA (Korea), TTC (Japan), and later joined by CWTS, the Chinese standards body.

- In the paired band (FDD—Frequency Division Duplex) of UMTS the system adopts the radio access technique formerly proposed by the WCDMA group.
- In the unpaired band (TDD—Time Division Duplex) the UMTS system adopts the radio access technique formerly proposed by the TD-CDMA group.
- The ETSI Objective is to provide low-cost UMTS terminals, ensuring harmonisation with GSM and providing FDD/TDD dual-mode operation.
- UTRA should support operation in a spectrum allocation as small as 2 × 5 MHz but should also be designed for a broader spectrum allocation.

Fig. 3 ETSI decision, January 1998

Table 3: ITU Terrestrial radio transmission technology proposals, June 1998

Proposal	Description	Source of Proposal
DECT	Digital Enhanced Cordless Telecommunications*	ETSI Project DECT (Europe)
UWC-136	Universal Wireless Communications	TIA TR-45.3 (USA)
WIMS W-CDMA	Wireless Multimedia and Messaging Services W-CDMA	TIA TR-46 (USA)
TD-SCDMA	Time Division Synchronous CDMA	CATT (China)
W-CDMA	Wideband CDMA	ARIB (Japan)
DMA II	Asynchronous DS-CDMA	TTA (South Korea)
UTRA	UMTS Terrestrial Radio Access	ETSI SMG2 (Europe)
NA: W-CDMA	North American: Wideband CDMA	ATIS T1P1 (USA)
cdma2000	Wideband CDMA (IS-95)	TIA TR-45.5 (USA)
CDMA I	Multiband Synchronous DS-CDMA	TTA (South Korea)

*DECT coverage does not extend to the vehicular (macrocellular) environment.

In essence the merging of the ETSI and Japanese proposals into a single common standard was completed by 3GPP and further development and refinement of the standard has since continued. Subsequent to the establishment of 3GPP, a second body, 3GPP2, was established around the cdma2000 proposal.

In June 1999, a group of international operators, the Operator Harmonisation Group (OHG), proposed a harmonisation of the 3GPP and 3GPP2 concepts, to be known as G3G (Global Third Generation), in order to allow interoperability and interworking between UTRA and cdma2000.[12]

The final piece in the UTRA jigsaw fell into place when these OHG proposals were accepted by both 3GPP and 3GPP2 to produce a standard with the following three modes of operation:

- CDMA-DS (CDMA - Direct Sequence), based on UTRA FDD
- CDMA-MC (CDMA - Multi Carrier), based on cdma2000
- CDMA-TDD, based on UTRA TDD.

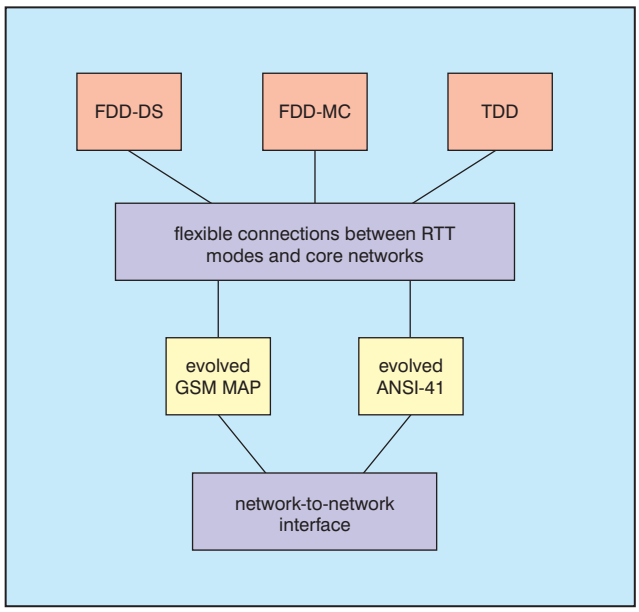

Fig. 4 G3G interworking

The harmonisation process involved the modification of some key radio parameters, such as the UTRA chip rate (and consequent reduction in the number of timeslots per frame from 16 to 15) in order to simplify the design of multimode terminals. To satisfy the requirement for evolution from both ANSI-41 and GSM MAP core networks a combined higher layer protocol stack was adopted (Fig. 4). Responsibility for the detailed specification for each mode remained within the respective standardisation bodies, i.e. 3GPP and 3GPP2.

When the ITU-R group met at the beginning of November 1999 to formally adopt its family of IMT-2000 standards, the ten original proposals had been reduced to six, grouped into five modes (Table 4). However, it seems clear that the G3G concept encompassing three of these modes is set to become the dominant world-wide 3G standard.

7 UTRA system architecture

UTRA has been defined as an access network (the UMTS Terrestrial Radio Access Network, or UTRAN) as shown in Fig. 5. This means that the radio interface independent functions, essentially call control and mobility management, are outside the scope of the UTRAN specifications and handled by the core network. A UTRAN

Table 4: Standards adopted for IMT-2000

Mode	Description	Standard(s)
IMT-MC	multicarrier	cdma2000
IMT-SC	single carrier	UWC-136
IMT-DS	direct sequence	UTRA FDD
IMT-TC	TDMA/CDMA	UTRA TDD, TD-SCDMA
IMT-FT	FDMA/TDMA	DECT

consists of one or more radio network subsystems (RNSs), which in turn consist of base stations (termed Node Bs) and radio network controllers (RNCs). A Node B may serve one or multiple cells. Mobile stations are termed user equipments (UEs) and in practice are likely to be multimode to enable handover between the FDD and TDD modes and, prior to complete UMTS geographical coverage, GSM as well.

The UTRAN permits, under certain circumstances, the use of multiple radio links across multiple cells in support of a single UTRAN–UE connection (termed soft handover). These links may exist across different Node Bs in neighbouring RNCs, in which case the necessary signalling and data transfers occur across the I_{ur} interface. The I_{ur} also participates in mobility switching (hard handover) where switching between I_u instances occurs.

Fig. 6 shows a simplified version of the protocols running between a UE and the UTRAN. Transport channels carry control plane or user plane data between the UE and RNC, mapping onto physical channels on the air (U_u) interface (allocated by the radio resource control (RRC) layer) and ATM AAL2 connections over the I_{ub} interface. An important point to note is that on the network side the medium access control (MAC) layer and radio link control (RLC) layer reside in the RNC, which is where most of the UTRAN intelligence is concentrated. The Frame Protocol (FP) is responsible for the relaying of transport channels between the UE and the RNC via the Node B.

This protocol stack is common to both FDD and TDD modes with only minor differences required, for example, to support macrodiversity in the FDD mode and timing advance for the TDD mode.

Fig. 7 shows the radio resource control protocols within UTRA. These include the Node B Application Part (NBAP) which runs over the I_{ub} interface, the Radio Network Subsystem Application Part (RNSAP) over the I_{ur} interface and the Radio Access Network Application Part (RANAP) over the I_u interface. These protocols are effectively extensions of the RRC and are responsible for the management and control of radio resources within the UTRAN.

The NBAP protocol is responsible for the allocation and control of radio resources, e.g. carrier frequencies and spreading codes (and timeslots in TDD mode), to Node Bs. The RNSAP protocol is responsible for co-ordination of radio resources between Node Bs in neighbouring RNCs, i.e. in support of links across the I_{ur} interface during soft-handover.

The RANAP protocol is used to support signalling across the I_u interface. In particular RANAP supports the transfer of Layer 3 messages between the UE and the core network (e.g. for the transfer of data during registration and authentication). RANAP is also used during the establishment of Layer 3 connections (e.g. user data connections) between the UTRAN and the core network.

The key parameters of the two air interface modes are shown in Table 5.

The features of UTRA FDD are described in a subsequent article in this issue[13]. UTRA TDD is based on a fundamental TDMA structure with a spreading feature — a hybrid of TDMA and CDMA known as TD-CDMA. This means that more than one burst may be transmitted within a timeslot, each with a separate CDMA spreading code. Different service requirements are met by assigning a combination of slots and codes to users to provide the required instantaneous data rates.

Table 5: UTRA Key Parameters

	FDD	TDD
Multiple access scheme	W-CDMA	TD-CDMA
Carrier spacing	4·4 – 5·2 MHz	5 MHz
Chip rate	3·84 Mchip/s (Mcps)	
Spreading factor range	4–512	1–16
Modulation	QPSK	
Pulse shaping	root raised cosine, roll-off = 0·22	
Frame length	10 ms	
Timeslots per frame	15	

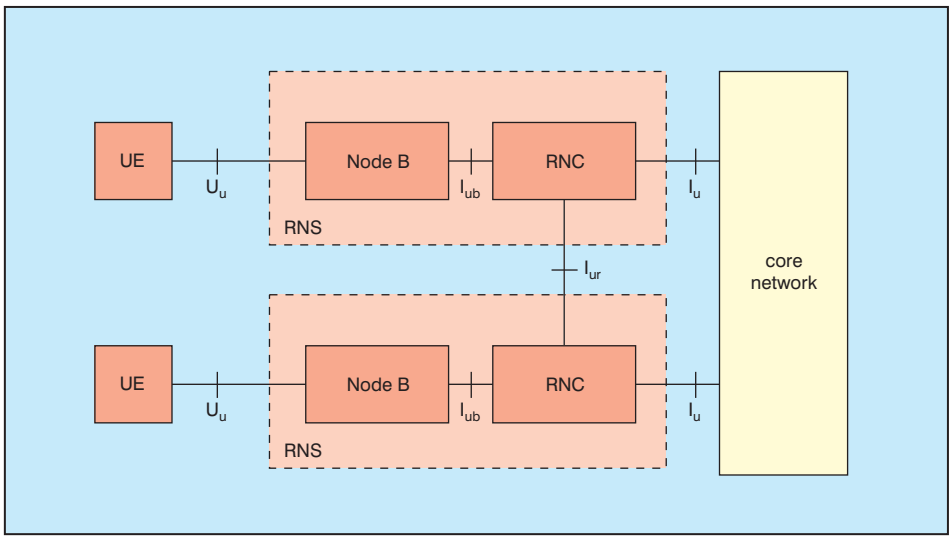

Fig. 5 UTRAN system architecture

The use of low spreading factors within a TDMA frame structure enables the efficient implementation of receivers employing joint detection, a process where all of the active user signals within each timeslot are simultaneously received and despread, thus reducing the effect of intracell interference.

The TDD mode allows for the adjustment of the uplink/downlink switching points and thus the ratio of uplink to downlink traffic. This permits the support of aggregate traffic asymmetry, matching the requirement of applications such as Web browsing where greater bandwidth is required in the downlink than in the uplink.

It is likely that FDD will be used to provide macro- and microcellular coverage in much the same way as GSM is deployed today, with TDD being reserved for picocellular deployments, including indoor and corporate office environments.

The standardisation of UTRA is scheduled to progress by 3GPP on the basis of annual releases in much the same way as GSM. 3GPP Release 99 specifies an ATM (Asynchronous Transfer Mode) implementation on the I_{ub} interface but it is likely that the next release, Release 2000, will see a migration of the I_{ub} interface to become IP (Internet Protocol) based with the possibility of all services (including voice) being provided over IP transport.

8 Trials

A key step in the introduction of UMTS technology is the development of technology demonstrators. These serve several functions: they prove the technology concepts, provide measurement results, build up operator experience of a new technology and provide useful input to the standardisation process.

The ACTS FRAMES project as well as contributing to the standardisation process was also responsible for producing a TDD demonstrator based on the original ETSI Delta Group concept[14]. A W-CDMA demonstrator, largely derived from the CODIT Project's air interface concept, was also developed internally by Ericsson.

In Japan, NTT DoCoMo has been at the forefront of promoting 3G research, working closely with a number of manufacturers and hosting a series of W-CDMA system trials for test and evaluation purposes. These evaluation trials have recently been extended to the UTRA TDD technology. In addition, NTT DoCoMo have collaborated in similar trials with a number of other operators across Asia.

In Europe, a number of UMTS testbeds have now been delivered to potential 3G operators, who are running their own technology trials prior to larger scale precommercial trials and subsequent commercial

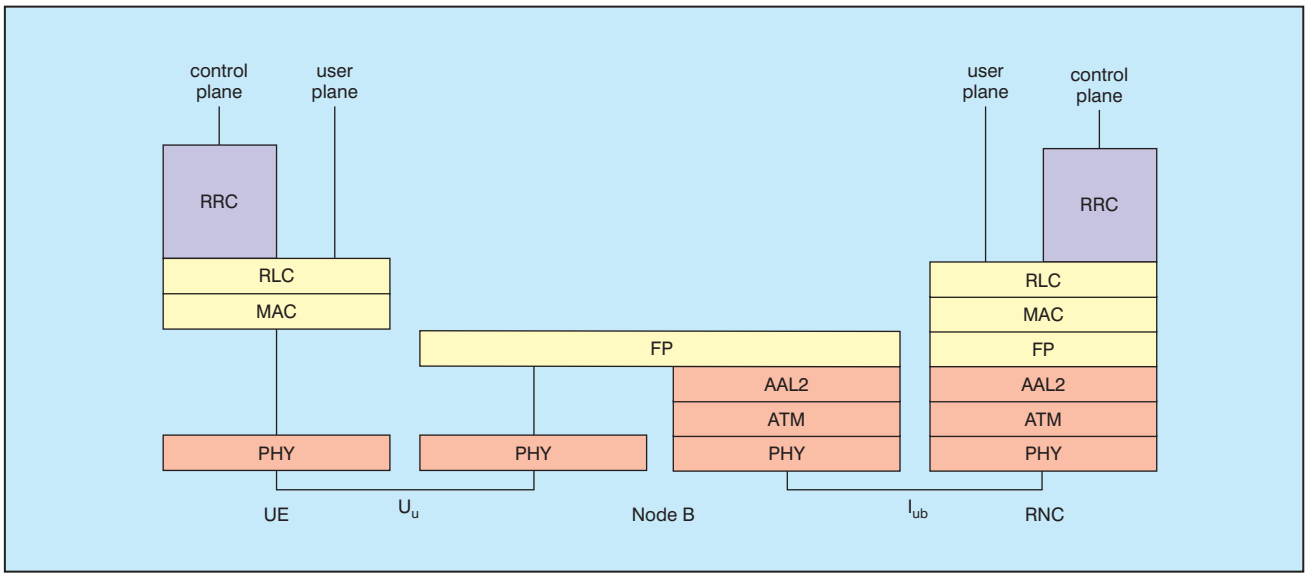

Fig. 6 Simplified protocol diagram

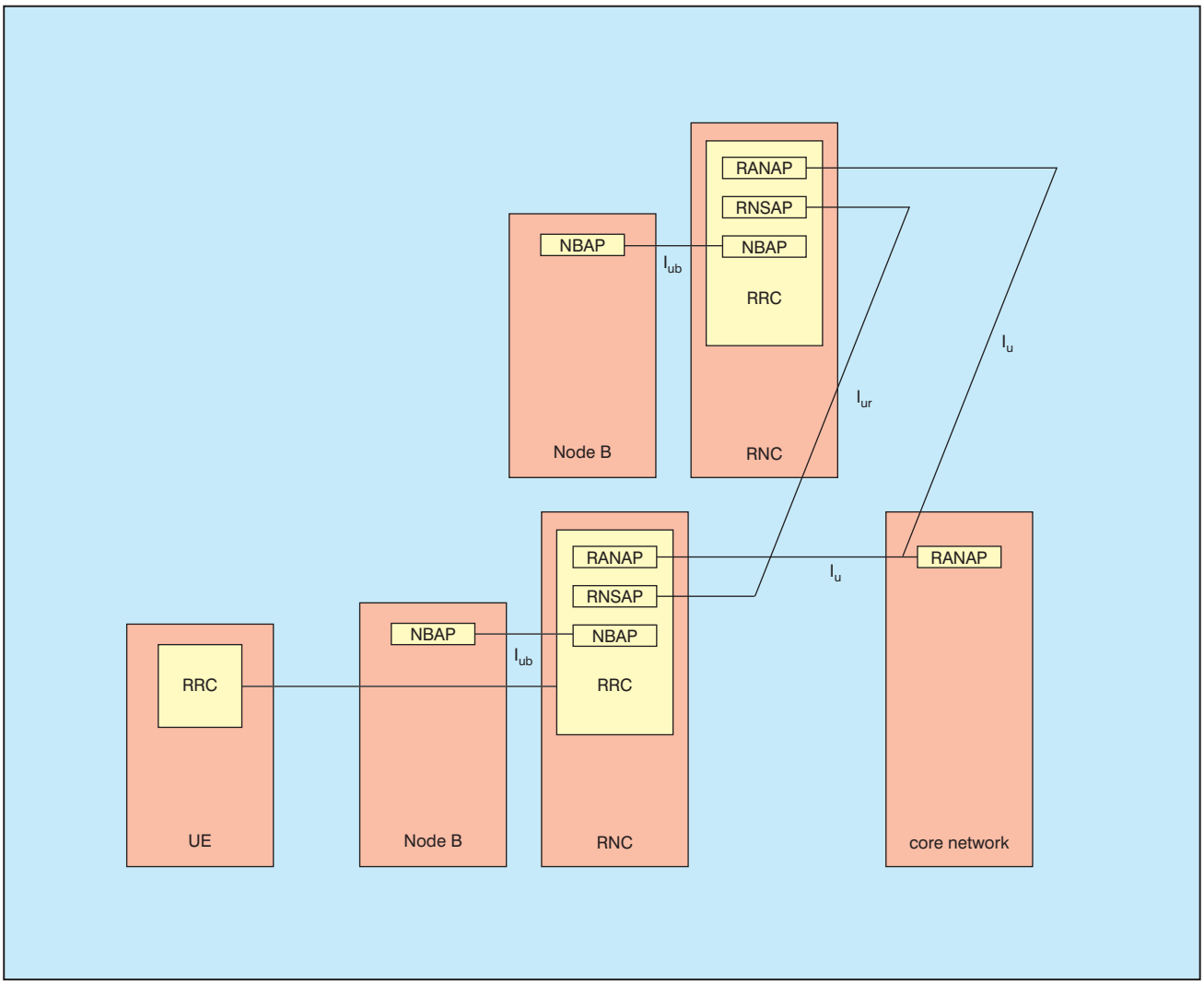

Fig. 7 Radio resource control signalling protocols

deployment and operation.

In the UK, the DTI decided to hold an auction for the award of five UMTS licences, with one of them reserved for a new operator[15]. Applications to take part in the auction had to be submitted on 12th January of this year to be followed by a prequalification stage. At the time of writing the auction itself was scheduled to begin in March. Commercial operation of UMTS in Europe, including the UK, is planned to begin in around 2002.

9 Predictions for services

So far this paper has discussed 3G technology but to the user it is the additional services that this technology will be able to deliver that makes UMTS such an exciting prospect.

It is important to draw a distinction between 3G networks and 3G services. 3G services can be characterised as being data centric — providing a multimedia capability to the user, i.e. the delivery of data, music, graphical images and real-time video — in comparison with the voice-centric services carried by the first and second generation cellular networks.

A key driver for these services is obviously the Internet, the growth and acceptance of which has been phenomenal over the last few years. The growth of the mobile phone market has been almost as spectacular with mobile phones now owned by over 40% of the UK population. In fact there are more mobile phones in the UK than home computers. UMTS will therefore not only combine fast Internet access with mobility but also increase the number of potential Internet users.

UMTS will include a positioning capability, the network being able to identify the location of a user to within 125 m. This knowledge of location will enable information, for example local cinema listings and timings together with video clips of the latest releases, to be broadcast within specific areas. Tourists will benefit from access to information such as the nearest hotels, room availability and prices.

Prior to the deployment of UMTS, 3G services will be delivered via enhancements to the existing 2G networks. Technologies such as GPRS, HSCSD and EDGE which extend the capability of GSM will provide network operators with the capability to begin the roll out of a wider range of data services.

The nature of the mobile phone itself is set to change: high-end terminals will become multifunctional data

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platforms. The Nokia Communicator, which combines the functions of a phone with those of a personal organiser, is only the start. Digital cameras, larger displays, music and video players and GPS receivers are all functions that are likely to be integrated onto a single platform. This will provide size/weight advantages to the user who wants access to each function individually and enormous scope for the delivery of multimedia services that combine speech, data and video.

3G services will also increase the scope for differentiation between networks. Until now all networks have provided the same basic services and have been differentiated on tariffs and coverage. Consequently, they have been subject to churn as customers have moved to rival networks offering a better deal. However, in the new world of 3G, networks will be differentiated by the information content that they can provide. This has already heralded the formation of 'exclusive' alliances between network operators and content providers such as media groups and this trend seems set to continue.

Although personalised and/or location based information delivery will be the key driver in the initial adoption of 3G services, applications and services are expected to develop soon within the following fields: e-commerce, telemedicine, security and interactive gaming.

Mobile phones will play a dominant role in the evolution to the cashless society, being used to store e-cash that can then be automatically debited, for example at a supermarket checkout or as a person enters a cinema. Instant video transmission will enable journalists to relay footage of breaking news to their newsrooms and doctors will be able to make an earlier prognosis whilst a patient is still *en route* to hospital.

Instant replays at sports events, remote home access for setting domestic appliances, road tolling, finding a person's current location and controlling access to buildings are just some of the applications that could be available in a few years' time. The range of 3G services will truly only be limited by the imagination of the service provider.

10 Conclusion

UMTS can be summarised as a revolution of the air interface accompanied by an evolution of the core network. Handover and backward compatibility with GSM will ensure that both technologies will coexist for many years. The UMTS Forum[16] predicts that the number of mobile phone users will increase to 1800 million world-wide by 2010[17]. UMTS will be the technology that fuels this growth and delivers a whole range of exciting multimedia services to many new users.

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Principal abbreviations used in this issue

2G	= Second Generation
3G	= Third Generation
3GPP	= Third Generation Partnership Project
AAL	= ATM Adaptation Layer
ACTS	= Advanced Communications Technology and Services
ANSI	= American National Standards Institute
ATDMA	= Advanced TDMA (a RACE project)
ATM	= Asynchronous Transfer Mode
BER	= Bit Error Ratio
CDMA	= Code Division Multiple Access
CEPT	= European Conference of Postal and Telecommunications Administrations
CODIT	= UMTS COde DIvision Testbed (a RACE Project)
DECT	= Digital Enhanced Cordless Telecommunications
DTI	= Department of Trade and Industry
EDGE	= Enhanced Data rates for GSM Evolution
ERC	= European Radiocommunications Committee
ETSI	= European Telecommunications Standards Institute
FDD	= Frequency Division Duplex
FLPMTS	= Future Land Public Mobile Telecommunication System
FMA	= FRAMES Multiple Access
FP	= Frame Procotol
FRAMES	= Future Radio widebAnd Multiple accEss Systems (an ACTS project)
G3G	= Global Third Generation
GPRS	= General Packet Radio Service
GSM	= Global System for Mobile communications
HSCSD	= High Speed Circuit Switched Data
IMT-2000	= International Mobile Telecommunications for the year 2000
IP	= Internet Protocol
IS	= Interim Standard
ISDN	= Integrated Services Digital Network
ITU	= International Telecommunication Union
MAC	= Medium Access Control
MAP	= Mobile Application Part
MONET	= MObile NETworks (a RACE project)
NBAP	= Node B Application Part
OHG	= Operator Harmonisation Group
PCS	= Personal Communication Services
PDC	= Personal Digital Cellular
PHY	= PHYsical
PSTN	= Public Switched Telecommunications Network
QPSK	= Quadrature Phase Shift Keying
RACE	= Research into Advanced Communications in Europe
RANAP	= Radio Access Network Application Part
RLC	= Radio Link Control
RNC	= Radio Network Controller
RNS	= Radio Network Subsystem
RNSAP	= Radio Network Subsystem Application Part
RRC	= Radio Resource Control
RTT	= Radio Transmission Technology
SMG	= Special Mobile Group
TD-CDMA	= Time Division – Code Division Multiple Access
TDD	= Time Division Duplex
TDMA	= Time Division Multiple Access
UE	= User Equipment
UMTS	= Universal Mobile Telecommunications System
UTRA	= UMTS Terrestrial Radio Access
UTRAN	= UTRA Network
WAP	= Wireless Application Protocol
WARC	= World Administrative Radio Conference
W-CDMA	= Wideband CDMA

Links to UMTS and mobile data Web sites

UMTS Forum — *http://www.umts-forum.org*
An international and independent body committed through the building of cross-industry consensus to the successful introduction and development of UMTS/IMT-2000.

3GPP — *http://www.3gpp.org*
The Third Generation Partnership Project is producing the technical specifications for a 3rd generation mobile system based on evolved GSM core networks and UTRA radio access technologies.

Radiocommunications Agency — *http://www.spectrumauctions.gov.uk*
This site provides background information on the UK 3G spectrum auctions.

mobile SMS — *http://www.mobilesms.com*
All about the text messaging Short Message Service (SMS) on mobile phones.

WAP Forum — *http://www.wapforum.org*
The Wireless Application Protocol (WAP) is the *de facto* world standard for wireless information and telephony services on digital mobile phones and other wireless terminals.

Mobile GPRS — *http://www.mobileGPRS.com*
Details of General Packet Radio Service (GPRS) on mobile networks.

Bluetooth — *http://www.bluetooth.com*
Bluetooth is an open specification for wireless communication data and voice.

Mobile Data Initiative — *http://www.gsmdata.com*
The Mobile Data Initiative (MDI) is an industry alliance formed by some of the world's leading mobile telecommunications and information technology companies.

Mobile Data Association — *http://www.mda-mobiledata.org*
The Mobile Data Association (MDA) was established in 1994 to increase awareness of mobile data amongst users and their advisers.

Wireless Data Forum — *http://www.wirelessdata.org*
The Wireless Data Forum is dedicated to publicising successful wireless data applications and customer communities.

GSM Association — *http://www.gsmworld.com*
This Association, established in 1987, represents GSM operators world-wide and has a very active Data section.