UMTS Protocols and Protocol Testing

Definition

Universal Mobile Telecommunications System (UMTS) is envisioned as the successor to Global System for Mobile Communications (GSM). UMTS signals the move into the third generation (3G) of mobile networks. UMTS also addresses the growing demand of mobile and Internet applications for new capacity in the overcrowded mobile communications sky. The new network increases transmission speed to 2 Mbps per mobile user and establishes a global roaming standard.

Overview

UMTS, also referred to as wideband code division multiple access (W–CDMA), is one of the most significant advances in the evolution of telecommunications into 3G networks. UMTS allows many more applications to be introduced to a worldwide base of users and provides a vital link between today's multiple GSM systems and the ultimate single worldwide standard for all mobile telecommunications, International Mobile Telecommunications–2000 (IMT–2000).

This tutorial explores the history of mobile communications leading to the proposal of UMTS. The tutorial then explains the architecture of UMTS and the protocols, interfaces, and technologies that go along with it. Finally, this tutorial looks at UMTS measurement and testing where tutorial participants will find real-world situations with practical suggestions for measurement approaches.

Topics

Glossary

1. Evolution of Mobile Communications

Early Stages: 1G to 3G

Electromagnetic waves were first discovered as a communications medium at the end of the 19th century. The first systems offering mobile telephone service (car phone) were introduced in the late 1940s in the United States and in the early 1950s in Europe. Those early single cell systems were severely constrained by restricted mobility, low capacity, limited service, and poor speech quality. The equipment was heavy, bulky, expensive, and susceptible to interference. Because of those limitations, less than one million subscribers were registered worldwide by the early 1980s.

First Generation (1G): Analog Cellular

The introduction of cellular systems in the late 1970s and early 1980s represented a quantum leap in mobile communication (especially in capacity and mobility). Semiconductor technology and microprocessors made smaller, lighter weight, and more sophisticated mobile systems a practical reality for many more users. These 1G cellular systems still transmit only analog voice information. The most prominent 1G systems are Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), and Total Access Communication System (TACS). With the 1G introduction, the mobile market showed annual growth rates of 30 to 50 percent, rising to nearly 20 million subscribers by 1990.

Second Generation (2G): Multiple Digital Systems

The development of 2G cellular systems was driven by the need to improve transmission quality, system capacity, and coverage. Further advances in semiconductor technology and microwave devices brought digital transmission to mobile communications. Speech transmission still dominates the airways, but the demands for fax, short message, and data transmissions are growing rapidly. Supplementary services such as fraud prevention and encrypting of user data have become standard features that are comparable to those in fixed networks. 2G cellular systems include GSM, Digital AMPS (D-AMPS), code division multiple access (CDMA), and Personal Digital Communication (PDC). Today, multiple 1G and 2G standards are used in worldwide mobile communications. Different standards serve different applications with different levels of mobility, capability, and service area (paging systems, cordless telephone, wireless local loop, private mobile radio, cellular systems, and mobile satellite systems). Many standards are used only in one country or region, and most are incompatible.

GSM is the most successful family of cellular standards (GSM900, GSM–railway [GSM–R], GSM1800, GSM1900, and GSM400), supporting some 250 million of the world's 450 million cellular subscribers with international roaming in approximately 140 countries and 400 networks.

2G to 3G: GSM Evolution

Phase 1 of the standardization of GSM900 was completed by the European Telecommunications Standards Institute (ETSI) in 1990 and included all necessary definitions for the GSM network operations. Several tele-services and bearer services have been defined (including data transmission up to 9.6 kbps), but only some very basic supplementary services were offered. As a result, GSM standards were enhanced in Phase 2 (1995) to incorporate a large variety of supplementary services that were comparable to digital fixed network integrated services digital network (ISDN) standards. In 1996, ETSI decided to further enhance GSM in annual Phase 2+ releases that incorporate 3G capabilities.

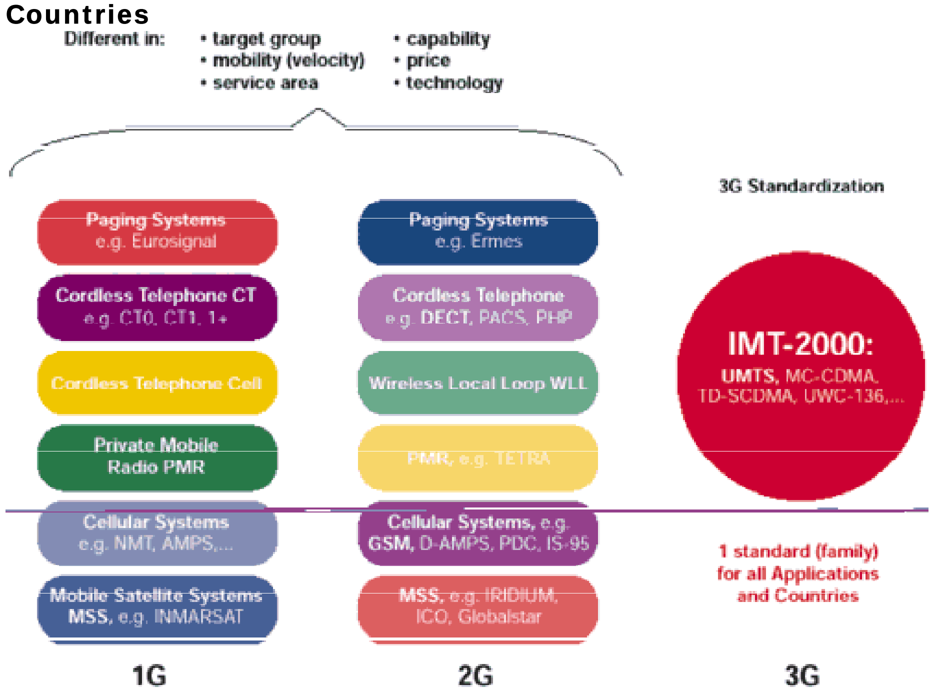
GSM Phase 2+ releases have introduced important 3G features such as intelligent network (IN) services with customized application for mobile enhanced logic (CAMEL), enhanced speech compression/decompression (CODEC), enhanced full rate (EFR), and adaptive multirate (AMR), high–data rate services and new transmission principles with high-speed circuit-switched data (HSCSD), general packet radio service (GPRS), and enhanced data rates for GSM evolution (EDGE). UMTS is a 3G GSM successor standard that is downward-compatible with GSM, using the GSM Phase 2+ enhanced core network.

IMT–2000

The main characteristics of 3G systems, known collectively as IMT–2000, are a single family of compatible standards that have the following characteristics:

- Used worldwide
- Used for all mobile applications
- Support both packet-switched (PS) and circuit-switched (CS) data transmission
- Offer high data rates up to 2 Mbps (depending on mobility/velocity)
- Offer high spectrum efficiency

Figure 1. Multiple Standards for Different Applications and Countries



IMT–2000 is a set of requirements defined by the International Telecommunications Union (ITU). As previously mentioned, IMT stands for International Mobile Telecommunications, and “2000” represents both the scheduled year for initial trial systems and the frequency range of 2000 MHz (WARC’92: 1885–2025 MHz and 2110–2200 MHz). All 3G standards have been developed by regional standards developing organizations (SDOs). In total, proposals for 17 different IMT–2000 standards were submitted by regional SDOs to ITU in 1998—11 proposals for terrestrial systems and 6 for mobile satellite systems (MSSs). Evaluation of the proposals was completed at the end of 1998, and negotiations to build a consensus among differing views were completed in mid 1999. All 17 proposals have been accepted by ITU as IMT–2000 standards. The specification for the Radio Transmission Technology (RTT) was released at the end of 1999.

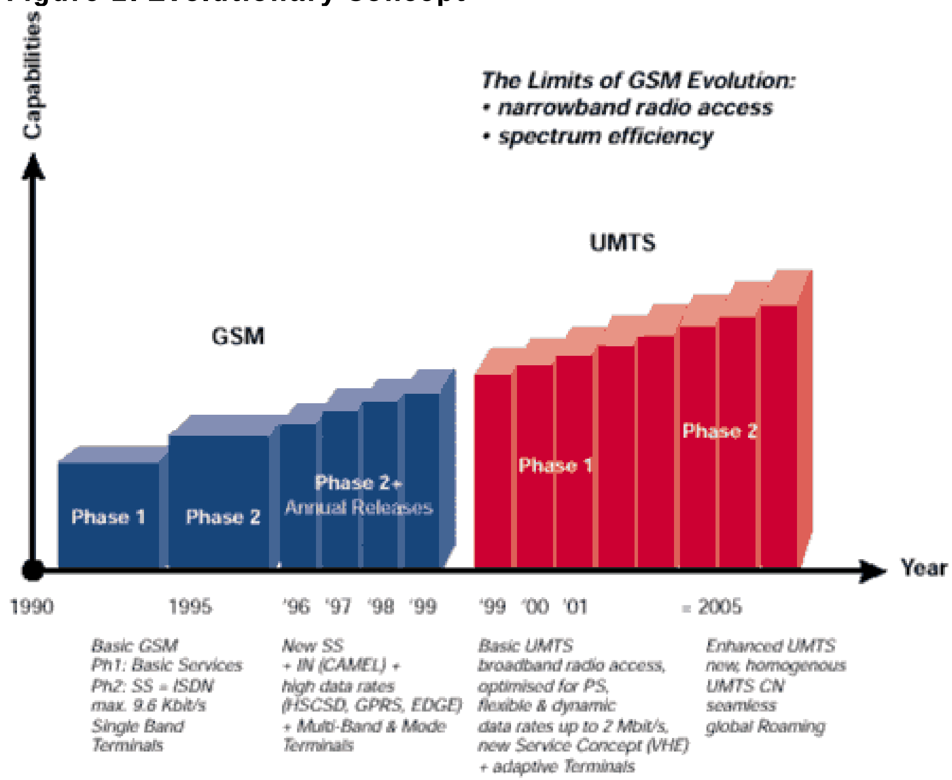
The most important IMT–2000 proposals are the UMTS (W-CDMA) as the successor to GSM, CDMA2000 as the interim standard ’95 (IS–95) successor, and time division–synchronous CDMA (TD–SCDMA) (universal wireless communication–136 [UWC–136]/EDGE) as TDMA–based enhancements to D–AMPS/GSM—all of which are leading previous standards toward the ultimate goal of IMT–2000.

UMTS allows many more applications to be introduced to a worldwide base of users and provides a vital link between today’s multiple GSM systems and IMT–2000. The new network also addresses the growing demand of mobile and Internet applications for new capacity in the overcrowded mobile communications sky. UMTS increases transmission speed to 2 Mbps per mobile user and establishes a global roaming standard.

UMTS is being developed by Third-Generation Partnership Project (3GPP), a joint venture of several SDOs—ETSI (Europe), Association of Radio Industries and Business/Telecommunication Technology Committee (ARIB/TTC) (Japan), American National Standards Institute (ANSI) T-1 (USA), telecommunications technology association (TTA) (South Korea), and Chinese Wireless Telecommunication Standard (CWTS) (China). To reach global acceptance, 3GPP is introducing UMTS in phases and annual releases. The first release (UMTS Rel. '99), introduced in December of 1999, defines enhancements and transitions for existing GSM networks. For the second phase (UMTS Rel. '00), similar transitions are being proposed as enhancements for IS–95 (with CDMA2000) and TDMA (with TD–CDMA and EDGE).

The most significant change in Rel. '99 is the new UMTS terrestrial radio access (UTRA), a W–CDMA radio interface for land-based communications. UTRA supports time division duplex (TDD) and frequency division duplex (FDD). The TDD mode is optimized for public micro and pico cells and unlicensed cordless applications. The FDD mode is optimized for wide-area coverage, i.e., public macro and micro cells. Both modes offer flexible and dynamic data rates up to 2 Mbps. Another newly defined UTRA mode, multicarrier (MC), is expected to establish compatibility between UMTS and CDMA2000.

Figure 2. Evolutionary Concept



2. UMTS Network Architecture

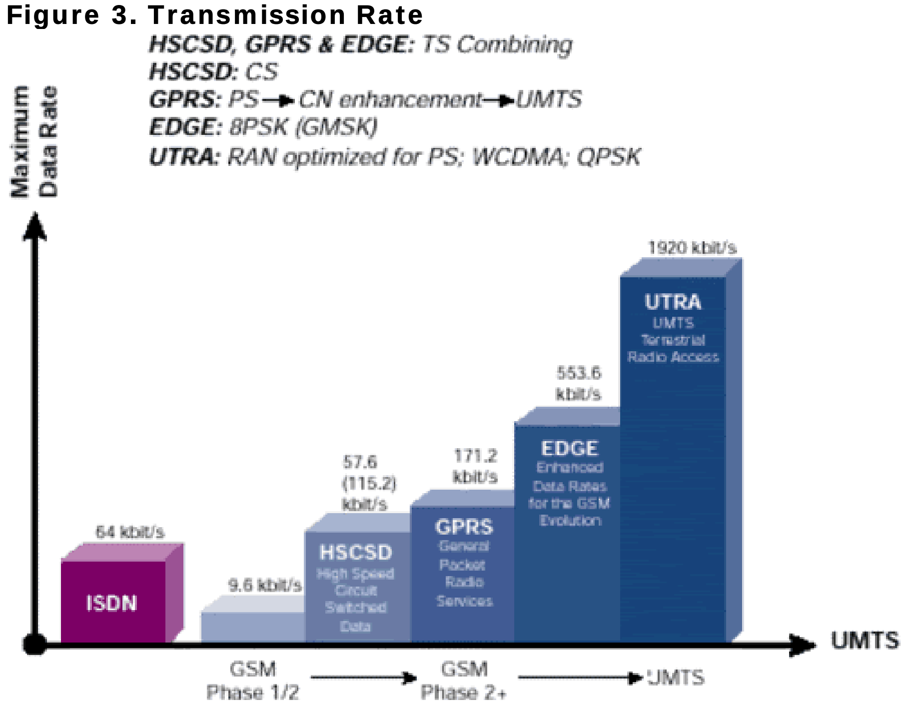
UMTS (Rel. '99) incorporates enhanced GSM Phase 2+ Core Networks with GPRS and CAMEL. This enables network operators to enjoy the improved cost-efficiency of UMTS while protecting their 2G investments and reducing the risks of implementation.

In UMTS release 1 (Rel. '99), a new radio access network UMTS terrestrial radio access network (UTRAN) is introduced. UTRAN, the UMTS radio access network (RAN), is connected via the Iu to the GSM Phase 2+ core network (CN). The Iu is the UTRAN interface between the radio network controller (RNC) and CN; the UTRAN interface between RNC and the packet-switched domain of the CN (Iu–PS) is used for PS data and the UTRAN interface between RNC and the circuit-switched domain of the CN (Iu–CS) is used for CS data.

"GSM–only" mobile stations (MSs) will be connected to the network via the GSM air (radio) interface (Um). UMTS/GSM dual-mode user equipment (UE) will be connected to the network via UMTS air (radio) interface (Uu) at very high data rates (up to almost 2 Mbps). Outside the UMTS service area, UMTS/GSM UE will be connected to the network at reduced data rates via the Um.

Maximum data rates are 115 kbps for CS data by HSCSD, 171 kbps for PS data by GPRS, and 553 kbps by EDGE. Handover between UMTS and GSM is supported, and handover between UMTS and other 3G systems (e.g., multicarrier CDMA [MC–CDMA]) will be supported to achieve true worldwide access.

Figure 3. Transmission Rate



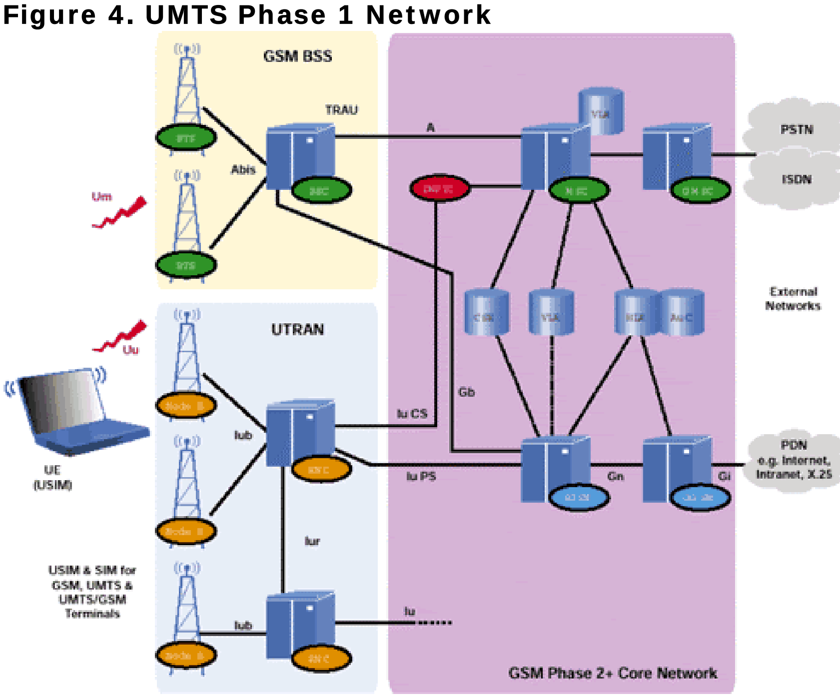
The public land mobile network (PLMN) described in UMTS Rel. '99 incorporates three major categories of network elements:

- GSM Phase 1/2 core network elements: mobile services switching center (MSC), visitor location register (VLR), home location register (HLR), authentication center (AC), and equipment identity register (EIR)
- GSM Phase 2+ enhancements: GPRS (serving GPRS support node [SGSN] and gateway GPRS support node [GGSN]) and CAMEL (CAMEL service environment [CSE])
- UMTS specific modifications and enhancements, particularly UTRAN

Network Elements from GSM Phase 1/2

The GSM Phase 1/2 PLMN consists of three subsystems: the base station subsystem (BSS), the network and switching subsystem (NSS), and the operations support system (OSS). The BSS consists of the functional units: base station controller (BSC), base transceiver station (BTS) and transcoder and rate adapter unit (TRAU). The NSS consists of the functional units: MSC, VLR, HLR, EIR, and the AC. The MSC provides functions such as switching, signaling, paging, and inter–MSC handover. The OSS consists of operation and maintenance centers (OMCs), which are used for remote and centralized operation, administration, and maintenance (OAM) tasks.

Figure 4. UMTS Phase 1 Network



Network Elements from GSM Phase 2+

GPRS

The most important evolutionary step of GSM toward UMTS is GPRS. GPRS introduces PS into the GSM CN and allows direct access to packet data networks (PDNs). This enables high–data rate PS transmission well beyond the 64 kbps limit of ISDN through the GSM CN, a necessity for UMTS data transmission rates of up to 2 Mbps. GPRS prepares and optimizes the CN for high–data rate PS transmission, as does UMTS with UTRAN over the RAN. Thus, GPRS is a prerequisite for the UMTS introduction.

Two functional units extend the GSM NSS architecture for GPRS PS services: the GGSN and the SGSN. The GGSN has functions comparable to a gateway MSC (GMSC). The SGSN resides at the same hierarchical level as a visited MSC (VMSC)/VLR and therefore performs comparable functions such as routing and mobility management.

CAMEL

CAMEL enables worldwide access to operator-specific IN applications such as prepaid, call screening, and supervision. CAMEL is the primary GSM Phase 2+ enhancement for the introduction of the UMTS virtual home environment (VHE) concept. VHE is a platform for flexible service definition (collection of service creation tools) that enables the operator to modify or enhance existing services and/or define new services. Furthermore, VHE enables worldwide access to these operator-specific services in every GSM and UMTS PLMN and introduces location-based services (by interaction with GSM/UMTS mobility management). A CSE and a new common control signaling system 7 (SS7) (CCS7) protocol, the CAMEL application part (CAP), are required on the CN to introduce CAMEL.

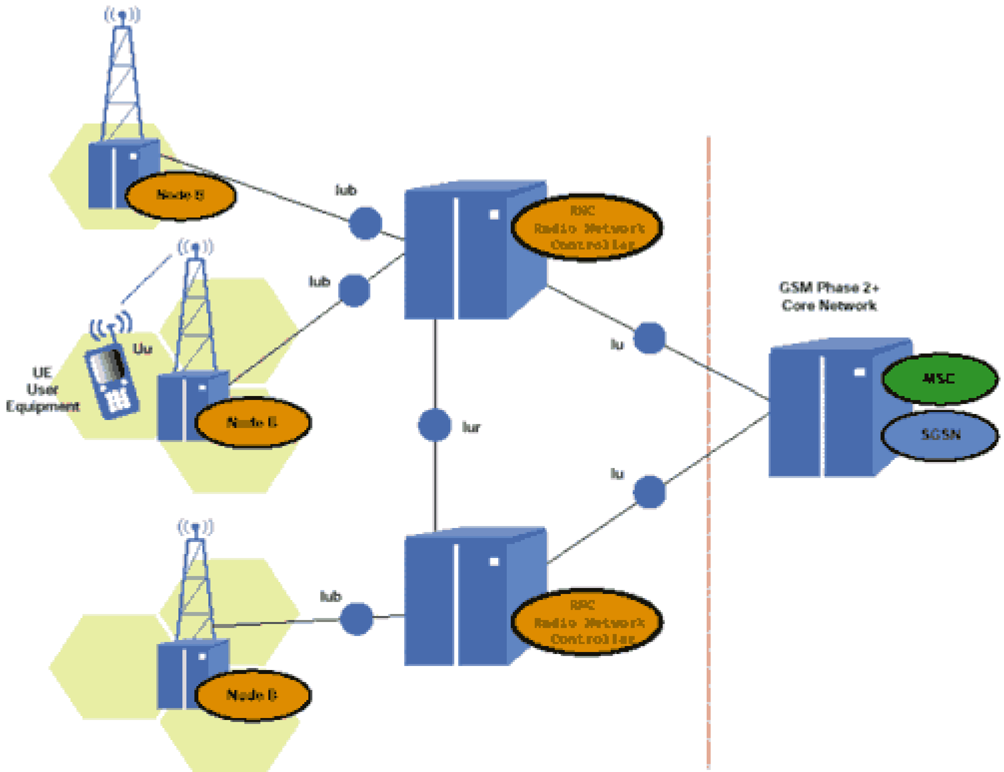
Network Elements from UMTS Phase 1

As mentioned above, UMTS differs from GSM Phase 2+ mostly in the new principles for air interface transmission (W–CDMA instead of time division multiple access [TDMA]/frequency division multiple access [FDMA]). Therefore, a new RAN called UTRAN must be introduced with UMTS. Only minor modifications, such as allocation of the transcoder (TC) function for speech compression to the CN, are needed in the CN to accommodate the change. The TC function is used together with an interworking function (IWF) for protocol conversion between the A and the Iu–CS interfaces.

UTRAN

The UMTS standard can be seen as an extension of existing networks. Two new network elements are introduced in UTRAN, RNC, and Node B. UTRAN is subdivided into individual radio network systems (RNSs), where each RNS is controlled by an RNC. The RNC is connected to a set of Node B elements, each of which can serve one or several cells.

Figure 5. UMTS Phase 1: UTRAN



Existing network elements, such as MSC, SGSN, and HLR, can be extended to adopt the UMTS requirements, but RNC, Node B, and the handsets must be completely new designs. RNC will become the replacement for BSC, and Node B fulfills nearly the same functionality as BTS. GSM and GPRS networks will be extended, and new services will be integrated into an overall network that contains both existing interfaces such as A, Gb, and Abis, and new interfaces that include Iu, UTRAN interface between Node B and RNC (Iub), and UTRAN interface between two RNCs (Iur).

UMTS defines four new open interfaces:

- Uu: UE to Node B (UTRA, the UMTS W–CDMA air interface)
- Iu: RNC to GSM Phase 2+ CN interface (MSC/VLR or SGSN)

- Iu-CS for circuit-switched data
    - Iu-PS for packet-switched data
- Iub: RNC to Node B interface
- Iur: RNC to RNC interface, not comparable to any interface in GSM

The Iu, Iub, and Iur interfaces are based on ATM transmission principles.

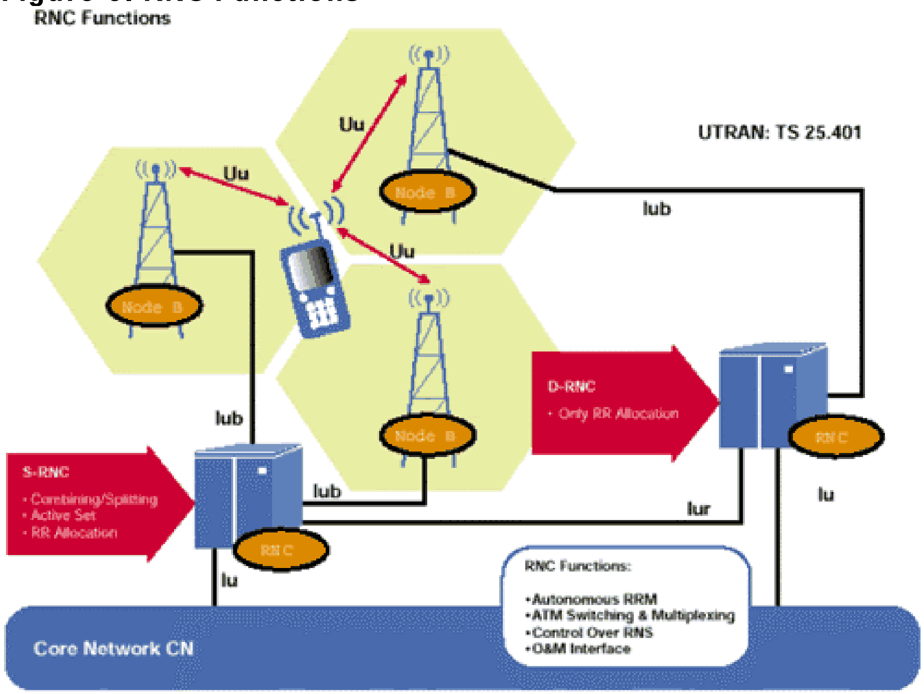
The RNC enables autonomous radio resource management (RRM) by UTRAN. It performs the same functions as the GSM BSC, providing central control for the RNS elements (RNC and Node Bs).

The RNC handles protocol exchanges between Iu, Iur, and Iub interfaces and is responsible for centralized operation and maintenance (O&M) of the entire RNS with access to the OSS. Because the interfaces are ATM–based, the RNC switches ATM cells between them. The user's circuit-switched and packet-switched data coming from Iu–CS and Iu–PS interfaces are multiplexed together for multimedia transmission via Iur, Iub, and Uu interfaces to and from the UE.

The RNC uses the Iur interface, which has no equivalent in GSM BSS, to autonomously handle 100 percent of the RRM, eliminating that burden from the CN. Serving control functions such as admission, RRC connection to the UE, congestion and handover/macro diversity are managed entirely by a single serving RNC (SRNC).

If another RNC is involved in the active connection through an inter–RNC soft handover, it is declared a drift RNC (DRNC). The DRNC is only responsible for the allocation of code resources. A reallocation of the SRNC functionality to the former DRNC is possible (serving radio network subsystem [SRNS] relocation). The term controlling RNC (CRNC) is used to define the RNC that controls the logical resources of its UTRAN access points.

Figure 6. RNC Functions



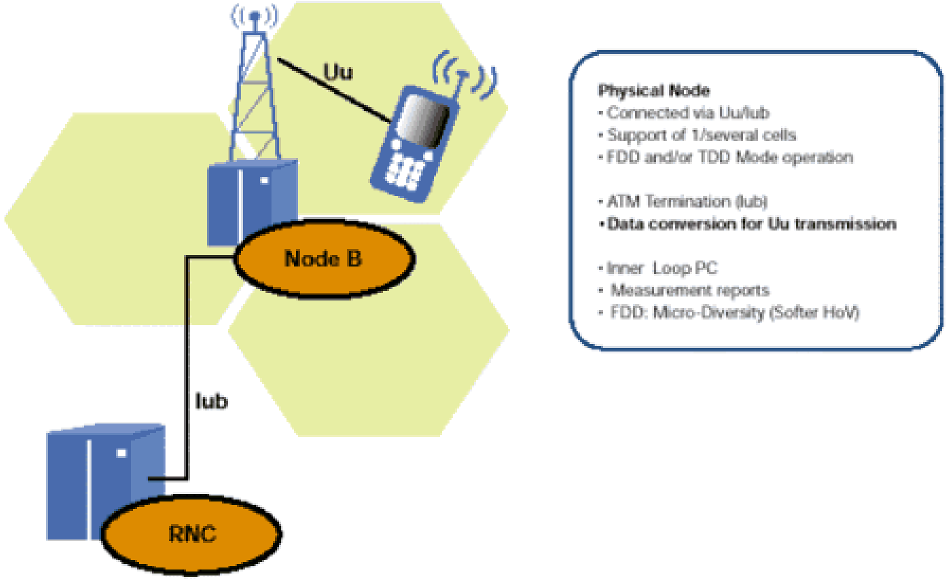
Node B

Node B is the physical unit for radio transmission/reception with cells. Depending on sectoring (omni/sector cells), one or more cells may be served by a Node B. A single Node B can support both FDD and TDD modes, and it can be co-located with a GSM BTS to reduce implementation costs. Node B connects with the UE via the W–CDMA Uu radio interface and with the RNC via the Iub asynchronous transfer mode (ATM)–based interface. Node B is the ATM termination point.

The main task of Node B is the conversion of data to and from the Uu radio interface, including forward error correction (FEC), rate adaptation, W–CDMA spreading/despreading, and quadrature phase shift keying (QPSK) modulation on the air interface. It measures quality and strength of the connection and determines the frame error rate (FER), transmitting these data to the RNC as a measurement report for handover and macro diversity combining. The Node B is also responsible for the FDD softer handover. This micro diversity combining is carried out independently, eliminating the need for additional transmission capacity in the Iub.

The Node B also participates in power control, as it enables the UE to adjust its power using downlink (DL) transmission power control (TPC) commands via the inner-loop power control on the basis of uplink (UL) TPC information. The predefined values for inner-loop power control are derived from the RNC via outer-loop power control.

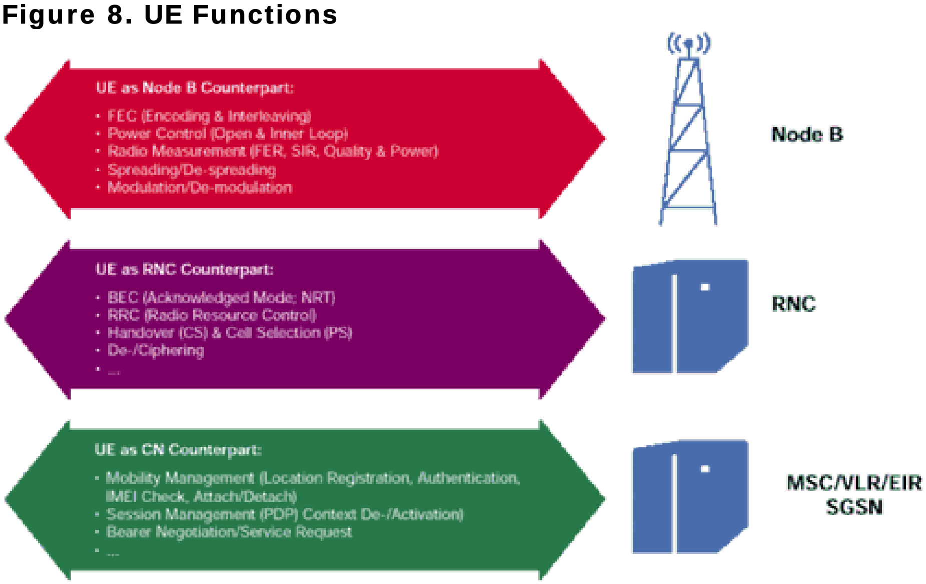
Figure 7. Node B Overview



UMTS UE

The UMTS UE is based on the same principles as the GSM MS—the separation between mobile equipment (ME) and the UMTS subscriber identity module (SIM) card (USIM). *Figure 8* shows the user equipment functions. The UE is the counterpart to the various network elements in many functions and procedures.

Figure 8. UE Functions



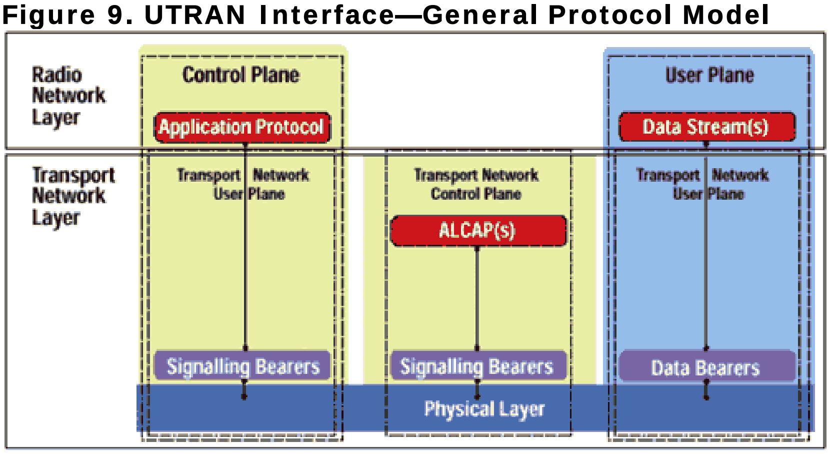
3. UMTS Interfaces

Many new protocols have been developed for the four new interfaces specified in UMTS: Uu, Iub, Iur, and Iu. This tutorial is organized by the protocols and shows their usage in the interfaces. That means protocols will be described individually. Only the references to the interfaces are indicated. Interface specific explanations of the protocols are, however, not included. Before we review the individual interface protocols, we introduce the UMTS general protocol model.

General Protocol Model [3G TS 25.401]

UTRAN interface consists of a set of horizontal and vertical layers (see *Figure 9*). The UTRAN requirements are addressed in the horizontal radio network layer across different types of control and user planes. Control planes are used to control a link or a connection; user planes are used to transparently transmit user data from the higher layers. Standard transmission issues, which are independent of UTRAN requirements, are applied in the horizontal transport network layer.

Figure 9. UTRAN Interface—General Protocol Model



Five major protocol blocks are shown in *Figure 9*:

- Signaling bearers are used to transmit higher layers' signaling and control information. They are set up by O&M activities.

- Data bearers are the frame protocols used to transport user data (data streams). The transport network–control plane (TN–CP) sets them up.

- Application protocols are used to provide UMTS–specific signaling and control within UTRAN, such as to set up bearers in the radio network layer.

- Data streams contain the user data that is transparently transmitted between the network elements. User data is comprised of the subscriber's personal data and mobility management information that are exchanged between the peer entities MSC and UE.

- Access link control application part (ALCAP) protocol layers are provided in the TN–CP. They react to the radio network layer's demands to set up, maintain, and release data bearers. The primary objective of introducing the TN–CP was to totally separate the selection of the data bearer technology from the control plane (where the UTRAN–specific application protocols are located). The TN–CP is present in the Iu–CS, Iur, and Iub interfaces. In the remaining interfaces where there is no ALCAP signaling, preconfigured data bearers are activated.

Application Protocols

Application protocols are Layer-3 protocols that are defined to perform UTRAN–specific signaling and control. A complete UTRAN and UE control plane protocol architecture is illustrated in *Figure 10*. UTRAN–specific control protocols exist in each of the four interfaces.

Figure 10. Iu RANAP Protocol Architecture

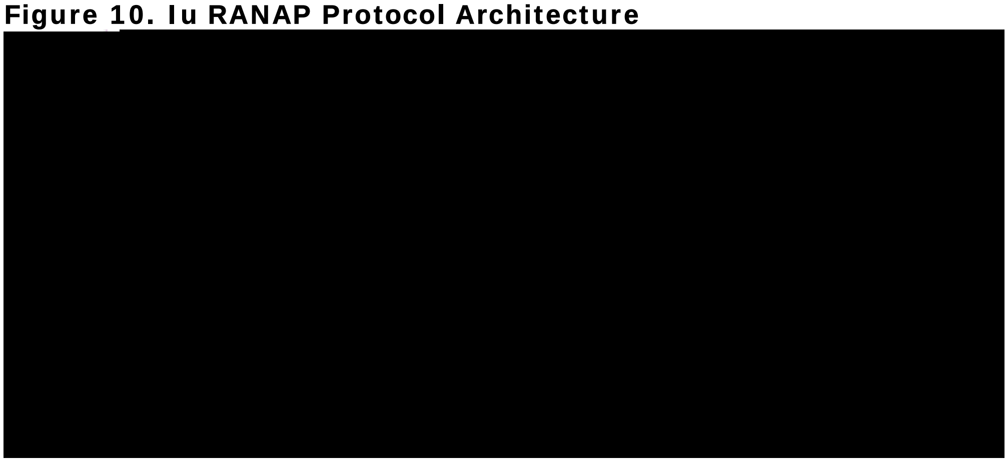
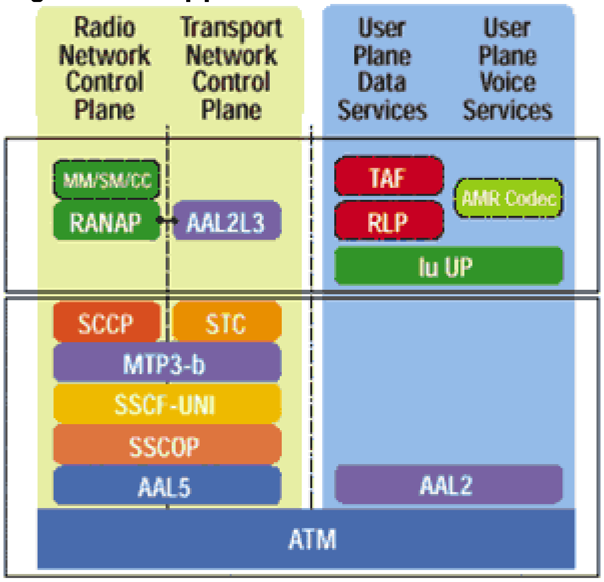


Figure 11. Application Protocols



Iu: Radio Access Network Application Part (RANAP) [3G TS 25.413]

This protocol layer provides UTRAN–specific signaling and control over the Iu (see *Figure 11*). The following is a subset of the RANAP functions:

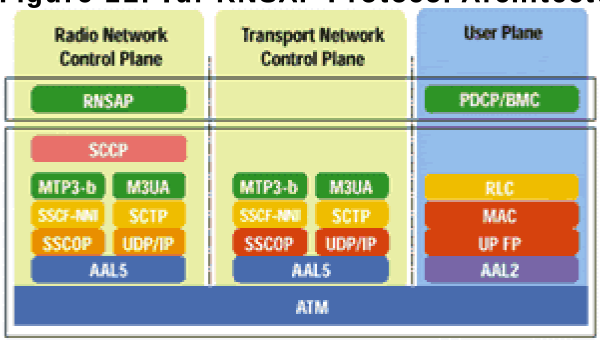
- Overall radio access bearer (RAB) management, which includes the RAB's setup, maintenance, and release
- Management of Iu connections
- Transport of nonaccess stratum (NAS) information between the UE and the CN; for example, NAS contains the mobility management signaling and broadcast information.
- Exchanging UE location information between the RNC and CN
- Paging requests from the CN to the UE
- Overload and general error situation handling

Iur: Radio Network Sublayer Application Part (RNSAP) [3G TS 25.423]

UTRAN–specific signaling and control over this interface contains the following:

- Management of radio links, physical links, and common transport channel resources
- Paging
- SRNC relocation
- Measurements of dedicated resources

Figure 12. Iur RNSAP Protocol Architecture



Iub: Node B Application Part (NBAP) [3G TS 25.433]

UTRAN specific signaling and control in the Iub includes the following (see *Figure 13*):

- Management of common channels, common resources, and radio links
- Configuration management, such as cell configuration management
- Measurement handling and control
- Synchronization (TDD)
- Reporting of error situations

Uu: Radio Resource Control (RRC) [3G TS 25.331]

This layer handles the control plane signaling over the Uu between the UE and the UTRAN (see also *Figure 13*). Some of the functions offered by the RRC include the following:

- Broadcasting information
- Management of connections between the UE and the UTRAN, which include their establishment, maintenance, and release

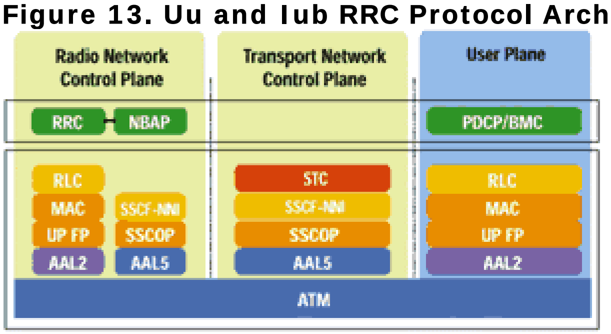
- Management of the radio bearers, which include their establishment, maintenance, release, and the corresponding connection mobility
- Ciphering control
- Outer loop power control
- Message integrity protection
- Timing advance in the TDD mode
- UE measurement report evaluation
- Paging and notifying

(Note: The RRCs also perform local inter-layer control services, which are not discussed in this document.)

Two modes of operation are defined for the UE—the idle mode and the dedicated mode. In the idle mode the peer entity of the UE's RRC is at the Node B, while in the dedicated mode it is at the SRNC. The dedicated mode is shown in *Figure 10*.

Higher-layer protocols to perform signaling and control tasks are found on top of the RRC. The mobility management (MM) and call control (CC) are defined in the existing GSM specifications. Even though MM and CC occur between the UE and the CN and are therefore not part of UTRAN specific signaling (see *Figure 15*), they demand basic support from the transfer service, which is offered by duplication avoidance (see 3G TS 23.110). This layer is responsible for in-sequence transfer and priority handling of messages. It belongs to UTRAN, even though its peer entities are located in the UE and CN.

Figure 13. Uu and Iub RRC Protocol Architecture



Transport Network Layer: Specific Layer-3 Signaling and Control Protocols

Two types of layer-3 signaling protocols are found in the transport network layer:

- Iu, Iur: Signaling Connection Control Part (SCCP) [ITU-T Q.711–Q. 716] This provides connectionless and connection-oriented services. On a connection-oriented link, it separates each mobile unit and is responsible for the establishment of a connection-oriented link for each and every one of them.

- Iu–CS, Iur, Iub: ALCAP [ITU–T Q.2630.1, Q.2150.1, and Q.2150.2]. Layer-3 signaling is needed to set up the bearers to transmit data via the user plane. This function is the responsibility of the ALCAP, which is applied to dynamically establish, maintain, release, and control ATM adaptation layer (AAL)–2 connections. ALCAP also has the ability to link the connection control to another higher layer control protocol. This and additional capabilities were specified in ITU–T Q.2630.1. Because of the protocol layer specified in Q.2630.1, a converter is needed to correspond with underlying sublayers of the protocol stack. These converters are called (generically) signaling transport converter (STC). Two converters are defined and applied in UTRAN:
    - Iu–CS, Iur: AAL–2 STC on message transfer part (MTP) level 3 (broadband) for Q.2140 (MTP3b) [Q.2150.1]
    - Iub: AAL–2 STC on service-specific connection-oriented protocol (SSCOP) [Q.2150.2]

Transport Network Layer Specific Transmission Technologies

Now that we have a circuit-switched and packet-switched domain in the CN and a growing market for packet-switched network solutions, a new RAN must be open to both types of traffic in the long run. That network must also transmit the Layer-3 signaling and control information. ATM was selected as the Layer-2 technology, but higher-layer protocols used in the transport network layer demonstrate the UMTS openness to a pure IP solution.

Iu, Iur, Iub: ATM [ITU-T I.361]

Broadband communication will play an important role with UMTS. Not only voice but also multimedia applications such as videoconferencing, exploring the Internet, and document sharing are anticipated. We need a data link technology that can handle both circuit-switched and packet-switched traffic as well as isochronous and asynchronous traffic. In UMTS (Release '99), ATM was selected to perform this task.

An ATM network is composed of ATM nodes and links. The user data is organized and transmitted in each link with a stream of ATM cells. AALs are defined to enable different types of services with corresponding traffic behavior. Two of these are applied in UTRAN:

- **Iu–CS, Iur, Iub: AAL–2 [ITU-T I.363.2]**—With AAL–2, isochronous connections with variable bit rate and minimal delay in a connection-oriented mode are supported. This layer was designed to provide real-time service with variable data rates, such as video. Except for the Iu–PS interface, AAL–2 is always used to carry the user data streams.

- **Iu–PS, Iur, Iub: AAL–5 [ITU-T I.363.5]**—With AAL–5, isochronous connections with variable bit rate in a connection-oriented mode are supported. This layer is used for Internet protocol (IP) local-area network (LAN) emulation, and signaling. In UTRAN, AAL–5 is used to carry the packet-switched user traffic in the Iu–PS-interface and the signaling and control data throughout.

In order to carry signaling and control data, the AAL–5 has to be enhanced. Here, UTRAN offers both a classical ATM solution and an IP–based approach:

- **Signaling AAL and MTP3b**—To make signaling AAL (SAAL) available in place of the AAL–5 service-specific convergence sublayer (SSCS), the SSCOP, which provides a reliable data transfer service, and the service-specific coordination function (SSCF), which acts as coordination unit, are defined.

- **Iu, Iur, Iub: SSCOP [ITU–T Q.2110]**—The SSCOP is located on top of the AAL. It is a common connection-oriented protocol that provides a reliable data transfer between peer entities. Its capabilities include the transfer of higher-layer data with sequence integrity, flow control, connection maintenance in case of a longer data transfer break, error correction by protocol control information, error correction by retransmission, error reporting to layer management, status report, and more.

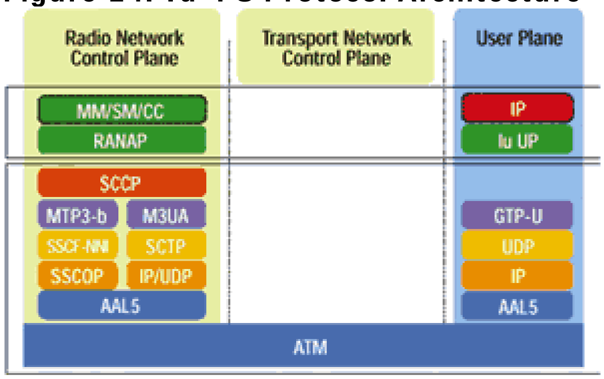
Two versions of the SSCF are defined: one for signaling at the user-to-network interface (UNI), and one for signaling at the network to node interface (NNI):

- **Iub: SSCF for at the UNI (SSCF) [ITU–T Q.2130]**—The SSCF–UNI receives Layer-3 signaling and maps it to the SSCOP and visa versa. The SSCF–UNI performs coordination between the higher and lower layers. Within UTRAN, it is applied in Iub with the NBAP and ALCAP on top of the SSCF–UNI.

- **Iu, Iur: SSCF at the NNI (SSCF-NNI) [ITU–T Q.2140]**—The SSCF-NNI receives the SS7 signaling of a Layer 3 and maps it to the

SSCOP, and visa versa. The SSCF-NNI performs coordination between the higher and the lower layers. Within UTRAN, MTP3b has the higher Layer 3, which requires service from the SSCOP-NNI.

Figure 14. Iu–PS Protocol Architecture



Originally the SS7 protocol layer, SCCP relies on the services offered by MTP, so the Layer-3 part of the MTP must face the SCCP layer:

- **Iu, Iur: MTP3b [ITU–T Q.2210]**—Signaling links must be controlled in level 3 for: message routing, discrimination and distribution (for point-to-point link only), signaling link management, load sharing, etc. The specific functions and messages for these are defined by the MTP3b, which requires the SSCF–NNI to provide its service.

The Layer-3 signaling and control data can also be handled by an enhanced IP stack using a tunneling function (see *Figure 12*). Tunneling is also applied for packet-switched user data over the Iu–PS interface (see *Figure 14*).

- IP over ATM
  - lu-PS, Iur: IP [IETF RFC 791, 2460, 1483, 2225], user datagram protocol (UDP) [IETF RFC 768] The IP can be encapsulated and then transmitted via an ATM connection, a process which is described in the RFC 1483 and RFC 2225. Both IP version 4 (IPv4) and IP version 6 (IPv6) are supported. IP is actually a Layer-3 protocol. UDP is applied on top of the unreliable Layer-4 protocol. The objective is to open this signaling link to future pure IP network solutions.

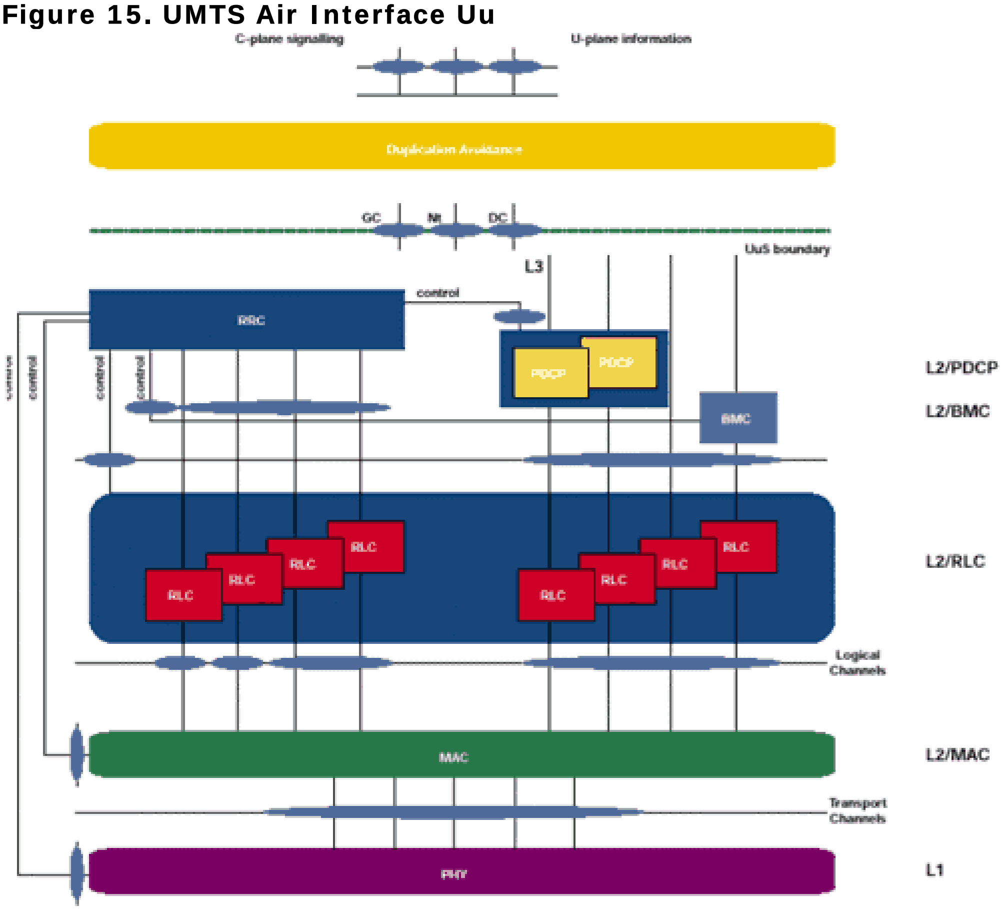
In order to tunnel SCCP or ALCAP signaling information, two protocols are applied:

- **Iu–PS and Iur: Simple Control Transmission Protocol (SCTP) [IETF SCTP]**—This protocol layer allows the transmission of signaling protocols over IP networks. Its tasks are comparable with MTP3b. On Iu–CS, SS7 must be tunneled between the CN and the RNC. The plan is that this is to be done with the Iu–PS and Iur [IETF M3UA].

The following does the tunneling of packet-switched user data:

- **Iu–PS: GPRS tunneling protocol (GTP) [3G TS 29.060]**—The GTP provides signaling through GTP–control (GTP–C) and data transfer through GTP–user (GTP–U) procedures. Only the latter is applied in the Iu–PS interface because the control function is handled by the RANAP protocol. The GTP–U is used to tunnel user data between the SGSN and the RNC.

Figure 15. UMTS Air Interface Uu



Iu, Iur, Iub: The Physical Layers [3G TS 25.411]

The physical layer defines the access to the transmission media, the physical and electrical properties, and how to activate and deactivate a connection. It offers to the higher-layer physical service access points to support the transmission of a uniform bit stream. A huge set of physical-layer solutions is allowed in UTRAN, including ETSI synchronous transport module (STM)–1 (155 Mbps) and STM–4 (622 Mbps); synchronous optical network (SONET) synchronous transport signal (STS)–3c (155 Mbps) and STS–12c (622 Mbps); ITU STS–1 (51 Mbps) and STM–0 (51 Mbps); E-1 (2 Mbps), E-2 (8 Mbps), and E-3 (34 Mbps); T-1 (1.5 Mbps) and T-3 (45 Mbps); and J-1 (1.5 Mbps) and J-2 (6.3 Mbps).

With the above protocol layers, the interfaces Iu, Iur, and Iur are fully described. There is only the air interface left for a more detailed analysis:

The Air Interface Uu [3G TS 25.301]

The air interface solution is usually a major cause for dispute when specifying a new RAN. *Figure 15* shows the realization of the lower parts of the protocol stack in the UE. As can be seen, a physical layer, data link layer, and network layer (the part for the RRC) have been specified.

The physical layer is responsible for the transmission of data over the air interface. The FDD and TDD W–CDMA solutions have been specified in UMTS Rel. '99. The data link layer contains four sublayers:

- **Medium Access Control (MAC) [3G TS 25.321]**—The MAC layer is located on top of the physical layer. Logical channels are used for communication with the higher layers. A set of logical channels is defined to transmit each specific type of information. Therefore, a logical channel determines the kind of information it uses. The exchange of information with the physical layer is realized with transport channels. They describe how data is to be transmitted over the air interface and with what characteristics. The MAC layer is responsible for more than mapping the logical channels into the physical ones. It is also used for priority handling of UEs and the data flows of a UE, traffic monitoring, ciphering, multiplexing, and more.

- **Radio Link Control (RLC) [3G TS 25.322]**—This is responsible for acknowledged or unacknowledged data transfer, establishment of RLC connections, transparent data transfer, quality of service (QoS) settings, unrecoverable error notification, ciphering, etc. There is one RLC connection per radio bearer.

The two remaining Layer-2 protocols are used only in the user plane:

- **Packet Data Convergence Protocol (PDCP) [3G TS 25.323]—** This is responsible for the transmission and reception of radio network layer protocol data units (PDUs). Within UMTS, several different network layer protocols are supported to transparently transmit protocols. At the moment, IPv4 and IPv6 are supported, but UMTS must be open to other protocols without forcing the modification of UTRAN protocols. This transparent transmission is one task of PDCP; another is to increase channel efficiency (by protocol header compression, for example).

- **Broadcast/Multicast Control (BMC) [3G TS 25.324]—**This offers broadcast/multicast services in the user plane. For instance, it stores SMS CB messages and transmits them to the UE.

4. UMTS and UTRAN Measurement Objectives

As noted in the preceding section, four new interfaces have been introduced with UMTS/UTRAN. With the new interfaces came a huge set of protocol layers for mobile communication networks. Dealing with these new protocols presents a demanding challenge to manufacturers, operators, and measurement equipment suppliers.

Tektronix Measurement Approaches

The following will present a case study of Tektronix's measurement approaches. For more information on specific test procedures, please see Tektronix's Virtual Exhibit. Nearly all measurement situations can be considered in three categories with related approaches. Even though there are situations where two or more approaches could be applied to the same interface, the first steps in protocol testing should always be to determine the characteristics of the system under test and the test objectives.

- Do you have a living network that you should not, or are not allowed, to disturb?
  *Use the nonintrusive **monitoring** approach.*

- Do you have a dead node or system that needs to be externally stimulated?
  *Use the **simulation/emulation** approach.*

- Do you need to verify compatibility with standards or with other equipment?
  *Use the **conformance** approach.*

Monitoring [see also CCITT 880 and GSM 12.04]

Monitoring is the process of collecting data from the interface. The main reason for operators and manufacturers to collect data is to retrieve the necessary information for decision-making in relation to a specified objective. The item under investigation can be an individual network element, parts of the PLMN, or even the whole PLMN. The major objectives for monitoring data collections include the following:

- To get an overall view of the actual performance level
- To determine a possible need for an improvement
- To discover the differences between specified and predicted characteristics and its actual performance
- To improve predictions of behavior and potential problems

Interface monitoring can collect data and present results in two ways:

- **Measurement result collection**—Use of cumulative counters to capture the number of occurrences of an event and/or discrete event registers to capture and trace specified results such as overload situations and failures
- **Data review for evaluation**—The storage of measured data for subsequent review and analysis; the amount of data is normally reduced through the filtering of specified events (such as abnormal call termination), the use of statistical methods or the selection of specific conditions (tracing data at a defined address, tracing a call setup, etc.)

Simulation

Simulation is the representation or imitation of a process or system by another device. In a test environment, a simulator can be used in place of a network element or a part of the network to produce desired conditions. For instance, when testing an RNC, the test equipment can simulate the CN behavior, keeping the RNC independent of the network. Simulators are used to do the following:

- To get information about the dependability of a network element (NE); normal and abnormal situations are specified and simulated, and the

NE's ability to cope with the simulated environment allows the operator to predict how well the NE will perform in the field; simulations are also used for conformance testing where standardized conditions are applied to the NE.

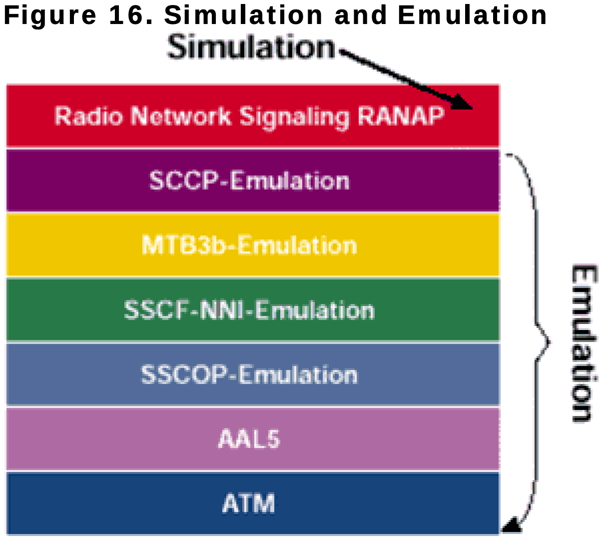
- To substitute missing network elements or parts of a network during the development process; simulation creates a realistic operating environment for the item under development.

- To save development and installation costs; the strong and weak points of an item can be discovered in the development process, before introducing it to an operating network.

Emulation

Emulation is a higher form of simulation where the behaviors of selected layers of communication protocols are simulated automatically and in conformance with standards. For instance, the simulation of the Iu RANAP is based on an emulation of the corresponding lower layers. While the lower layers are defined to act as specified, the simulated layer can be used to deliberately add faults to test an element's ability to handle them.

Figure 16. Simulation and Emulation



Conformance Testing [ETSI ETR 021]

Standards allow different manufacturers to develop systems that can interoperate and exchange and handle information. A system or an implementation is declared conformant when its capabilities and external behavior meet those defined in the referenced standards. Conformance testing is the verification process that determines whether a system or an implementation is conformant.

While specific conformance tests are defined in UMTS for the air interface (see 3G TS 34.xxx series), conformance tests of the remaining UTRAN interfaces are still dependent upon mutual agreement between manufacturers, operators, and measurement suppliers.

5. Appendix

Recommended Documents and Standards	
3G TS 23.110	UMTS Access Stratum Services and Functions
3G TS 25.301	Radio Interface Protocol Architecture
3G TS 25.321	Medium Access Control (MAC) Protocol Specification
3G TS 25.322	Radio Link Control (RLC) Protocol Specification
3G TS 25.323	Packet Data Convergence Protocol (PDCP) protocol
3G TS 25.324	Radio Interface for Broadcast/Multicast Services
3G TS 25.331	Radio Resource Control (RRC) Protocol Specification
3G TS 25.401	UTRAN Overall Description
3G TS 25.410	UTRAN Iu Interface: General Aspects and Principles
3G TS 25.411	UTRAN Iu interface Layer 1
3G TS 25.413	UTRAN Iu Interface: RANAP Signaling
3G TS 25.420	UTRAN Iur Interface: General Aspects and Principles
3G TS 25.423	UTRAN Iur interface RNSAP Signaling
3G TS 25.430	UTRAN Iub Interface: General Aspects and Principles
3G TS	UTRAN Iub interface NBAP Signaling

25.433	
3G TS 29.060	GPRS tunneling protocol (GPT) across the Gn and Gp interface, CCITT Rec. E.880, field data collection and evaluation on the performance of equipment, network, and services
ETSI ETR 021	Advanced Testing Methods (ATM); tutorial on protocol conformance testing (especially OSI standards and profiles) (ETR/ATM-1002)
ETSI GSM 12.04	Digital cellular telecommunication system (Phase 2); performance data measurements
IETF M3UA	G. Sidebottom et al, "SS7 MTP3–User Adaptation Layer (M3UA draft-ietf-sigtran-m3ua-02.txt (Work In Progress), IETF, 10 March 2000
IETF SCTP	R. Stewart, et al, "Simple Control Transmission Protocol," draft-ieft-sigtran-sctp-v0.txt (work in progress), IETF, September 1999
IETF RFC 791	Internet Protocol
IETF RFC 768	User Datagram Protocol
IETF RFC 1483	Multiprotocol Encapsulation over ATM Adaptation Layer 5
IETF RFC 2225	Classical IP and ARP over ATM
IETF RFC 2460	"Internet Protocol version 6 (IPv6) Specification"
ITU–T I.361	B–ISDN ATM layer specification.
ITU–T I.363.2	B–ISDN ATM Adaptation Layer Type 2
ITU–T I.363.5	B–ISDN ATM Adaptation Layer Type 5
ITU–T Q.711	Functional Description of the Signaling Connection Control Part
ITU–T Q.712	Definition and Function of Signaling Connection Control Part Messages
ITU–T Q.713	Signaling Connection Control Part Formats and Codes
ITU–T Q.714	Signaling Connection Control Part Procedures

ITU–T Q.715	Signaling Connection Control Part User Guide
ITU–T Q.716	Signaling Connection Control Part (SCCP) performance
ITU–T Q.2100	B–ISDN Signaling ATM Adaptation Layer (SAAL)—overview description.
ITU–T Q.2110	B–ISDN ATM Adaptation Layer—Service Specific Connection Oriented Protocol (SSCOP).
ITU–T Q.2130	B–ISDN Signaling ATM Adaptation Layer—Service Specific Coordination Function for Support of Signaling at the User Network Interface (SSCF at UNI)
ITU–T Q.2140	B–ISDN ATM adaptation Layer—Service Specific Coordination Function for Signaling at the Network Node Interface (SSCF AT NNI).
ITU–T Q.2150.1	B–ISDN ATM Adaptation Layer—Signaling Transport Converter for the MTP3b
ITU–T Q.2150.2	AAL Type 2 Signaling Transport Converter on SSCOP (Draft)
ITU–T Q.2210	Message Transfer Part Level 3 Functions and Messages Using the Services of ITU–T Recommendation Q.2140.
ITU–T Q.2630.1	AAL Type 2 Signaling Protocol (Capability Set 1)

Self-Test

1. Which of the following is **not** a characteristic of 3G systems?
    a. used worldwide
    b. support only data transmission
    c. offer high data rates
    d. offer high spectrum velocity
2. One of the most important IMT-2000 proposals is having UMTS as the successor to GSM.
    a. true
    b. false

3. UMTS increases the transmission speed to _____ Mbps per mobile user.
    a. 0.5
    b. 1
    c. 2
    d. 3
4. Who is developing UMTS?
    a. ITU
    b. 3GPP
    c. IETF
    d. IEC
5. What does this tutorial cite as the most important revolutionary step of GSM toward UMTS?
    a. GPRS
    b. CAMEL
    c. GGSN
    d. SGSN
6. ________ enables worldwide access to operator-specific IN applications such as prepaid, call screening, and supervision.
    a. PLMN
    b. CAMEL
    c. CN
    d. BSC
7. SCCP is the physical unit for radio transmission/reception with cells.
    a. true
    b. false

8. Which of the following is **not** one of the four new interfaces specified in UMTS?

    a. Uu

    b. Iub

    c. Iuc

    d. Iu

    e. Iur

9. Which of the following is **not** one of the five major UTRAN protocol blocks?

    a. transport signals

    b. data and signaling bearers

    c. data streams

    d. ALCAP

    e. application protocols

10. Based on the Tektronix measurement case study, which of the following is **not** one of the three measurement approaches?

    a. simulation

    b. conformance

    c. emulation

    d. investigation

Correct Answers

1. Which of the following is not a characteristic of 3G systems?

    a. used worldwide

    b. support only data transmission

    c. offer high data rates

    d. offer high spectrum velocity

See Topic 1.

2. One of the most important IMT-2000 proposals is having UMTS as the successor to GSM.

   a. true

   b. false

   See Topic 1.

3. UMTS increases the transmission speed to _____ Mbps per mobile user.

   a. 0.5

   b. 1

   c. 2

   d. 3

   See Topic 1.

4. Who is developing UMTS?

   a. ITU

   b. 3GPP

   c. IETF

   d. IEC

   See Topic 1.

5. What does this tutorial cite as the most important revolutionary step of GSM toward UMTS?

   a. GPRS

   b. CAMEL

   c. GGSN

   d. SGSN

   See Topic 2.

6. ________ enables worldwide access to operator-specific IN applications such as prepaid, call screening, and supervision.

   a. PLMN

   b. CAMEL

   c. CN

   d. BSC

   See Topic 2.

7. SCCP is the physical unit for radio transmission/reception with cells.

   a. true

   b. false

   See Topic 2.

8. Which of the following is not one of the four new interfaces specified in UMTS?

   a. Uu

   b. Iub

   c. Iuc

   d. Iu

   e. Iur

   See Topic 3.

9. Which of the following is not one of the five major UTRAN protocol blocks?

   a. transport signals

   b. data and signaling bearers

   c. data streams

   d. ALCAP

   e. application protocols

   See Topic 3.

10. Based on the Tektronix measurement case study, which of the following is not one of the three measurement approaches?

    a. simulation

    b. conformance

    c. emulation

    d. investigation

    See Topic 4.

Glossary

1G
first generation

2G
second generation

3G
third generation

3GPP
Third-Generation Partnership Project (of ETSI)

AAL
ATM adaptation layer

AAL2
ATM adaptation layer type 2

AAL5
ATM adaptation layer type 5

AC
authentication center

ALCAP
access link control application part

AMPS
Advanced Mobile Phone Service

AMR
adaptive multirate

ANSI T1
American National Standards Institute Standards Committee T-1

ARIB/TTC
Association of Radio Industries and Business/Telecommunication Technology Committee

ATM
asynchronous transfer mode

BEC
backward error correction

BHCA
busy hour call attempt

BMC
broadcast/multicast control

BSC
base station controller

BSS
base station subsystem

BTS
base transceiver station

CAMEL
customized application for mobile enhanced logic

CAP
CAMEL application part

CATT
China Academy of Telecommunication Technology

CBR
constant bit rate (data stream)

CC
call control

CCITT
Comité Consultatif International Téléphonique et Telecommunication

CCS7
common control signaling system 7

CDMA
code division multiple access

CDMA2000
3rd Generation Code Division Multiple Access

CM
call management

CN
core network

CODEC
compression/decompression

CRNC
controlling RNC

CS
circuit switched

CS-CN
circuit-switched core network

CSE
CAMEL service environment

CT
conformance test

CWTS
Chinese Wireless Telecommunication Standard

D-AMPS
digital amps

DCH
dedicated channel

DECT
digital enhanced cordless telephone

DL
downlink

DPC
destination point code

DRNC
drift radio network controller

DRNS
drift radio network subsystem

DTE
data terminal equipment

EDGE
enhanced data rates for GSM evolution

EFR
enhanced full rate

EIR
equipment identity register

ESE
emulation scenario editor

ETSI
European Telecommunications Standards Institute

FDD
frequency division duplex

FDMA
frequency division multiple access

FEC
forward error correction

FER
frame error rate

GGSN
gateway GPRS support node

GMM
GPRS mobility management (protocols)

GMSC
gateway MSC

GPRS
general packet radio service

GSM
Global System for Mobile Communication

GSM-R
GSM railway

GsmSCF
GSM service control function

GsmSSF
GSM service switching function

GTP
GPRS tunneling protocol

GTP-C
GTP control

GTP-U
GTP user

HLR
home location register

HO/HoV
handover

HSCSD
high-speed circuit-switched data

ICO
intermediate circular orbits

IETF
Internet Engineering Task Force

IMEI
international mobile equipment identification

IMT–2000
International Mobile Telecommunications 2000

IMUN
international mobile user number

IN
intelligent network

IP
Internet protocol

IPv4
IP version 4

IPv6
IP version 6

IS–95
interim standard ’95

ISDN
integrated services digital network

ISP
Internet service provider

ISUP
ISDN user part

ITU
International Telecommunications Union

ITUN
SS7 ISUP tunneling

Iu
interface between RNC and CN

Iub
interface between Node B and RNC

Iu–CS
interface between RNC and the circuit-switched domain of the CN

Iu–PS
interface between RNC and the packet-switched domain of the CN

Iur
interface between two RNCs

IUT
implementation under test

IWF
interworking function

kbps
kilobits per second

LAN
local-area network

MAC
medium access control

MAP
mobile application part

Mbps
megabits per second

MBS
message building system

MC
multicarrier

MC-CDMA
multicarrier CDMA

MCE
multiprotocol encapsulation

MDTP
multinetwork datagram transmission protocol

ME
mobile equipment

MM
mobility management (protocols)

MS
mobile station

MSC
mobile services switching center, message sequence chart

MSS
mobile satellite system

MT
mobile telephone

MTP
message transfer part

MTP3b
message transfer part level 3 (broadband) for Q.2140

NAS
nonaccess stratum

NBAP
Node B application protocol

NE
network element

NMT
Nordic Mobile Telephone

NNI
network-node interface

Node B
UMTS base station

NSS
network and switching subsystem

O&M
operation and maintenance

OAM
operation, administration, and maintenance

OMC
operation and maintenance centers

OSA
open service architecture

OSS
operations support system

PDC
personal digital communication

PDCP
packet data convergence protocol

PDH
plesiochronous digital hierarchy

PDN
packet data network

PDU
protocol data unit

PLMN
public land mobile network

PMR
private mobile radio

PS
packet switched

PS-CN
public switched core network

PSTN
public switched telephone network

QoS
quality of service (ATM network channels)

QPSK
quadrature phase shift keying (or quaternary phase shift keying)

RAB
radio access bearer

RAN
radio access network

RANAP
RAN application part

RLC
radio link control

RLP
radio link protocol

RNC
radio network controller

RNS
radio network subsystem

RNSAP
radio network subsystem application part

RNTI
radio network temporary identity

RR
radio resource

RRC
radio resource control

RRM
radio resource management

RTT
radio transmission technology

SAAL
signaling ATM adaptation layer

SCCP
signaling connection control part

SCTP
simple control transmission protocol

SDH
synchronous digital hierarchy

SDO
standards developing organization

SGSN
serving GPRS support node

SIM
subscriber identity module

SM
session management protocols

SONET
synchronous optical network

SRNC
serving radio network controller

SRNS
serving radio network subsystem

SS7
signaling system 7

SSCOP
service-specific connection-oriented protocol

SSCF
service-specific coordination function

SSCF–UNI
SSCF at the UNI

SSCS
service-specific convergence sublayer

SSCS–UNI
SSCS at the UNI

SSF
service switching function

STC
signaling transport converter

STM
synchronous transport module

STS
synchronous transport signal

STM1
synchronous transport module level 1

SUT
system under test

TACS
Total Access Communication System

TC
transcoder

TD–CDMA
time division–code division multiple access

TDD
time division duplex

TDMA
time division multiple access

TD–SCDMA
time division–synchronous CDMA

TEID
tunneling endpoint I.D.

TETRA
terrestrial trunked radio access

TIA
telecommunications industry association

TN-CP
transport network-control plane

TPC
transmission power control

TRAU
transcoder and rate adapter unit

TS
technical specification

TTA
telecommunications technology association

UDP
user datagram protocol

UE
user equipment

UL
uplink

Um
GSM air interface

UMTS
Universal Mobile Telecommunication System

UNI
user-to-network interface

UP
user plane

USIM
UMTS subscriber identity module

UTRA
UMTS terrestrial radio access

UTRAN
UMTS terrestrial radio access network

Uu
UMTS air interface

UWC–136
universal wireless communication

VBR
variable bit rate (data stream)

VHE
virtual home environment

VLR
visitor location register

VMSC
visited MSC

W–CDMA
wide-band code division multiple access

WLL
wireless local loop