Further evolution of the GSM/EDGE radio access network

Frank Müller, Joakim Sorelius and Dalibor Turina

The next evolutionary step for the GSM/EDGE cellular system is a standardization of enhancements that yield greater alignment with UMTS/UTRAN, thus further evolving GSM toward third-generation wireless systems. These enhancements are currently being specified for the GSM/EDGE radio access network (GERAN) in coming releases of the 3GPP standard. By using the EDGE high-speed transmission technique, and combining it with a GPRS radio link interface (and further enhancing it), GERAN provides efficient support for all QoS service classes defined for UMTS. Thus, GERAN can support a range of new applications, including IP multimedia. GERAN is also adopting the UMTS architecture—through its support of the *Iu* interface, GERAN connects to the same UMTS core network as UTRAN.

Introduction

The standardization of the first releases of third-generation cellular systems was finalized in ETSI/3GPP Release 99. Two major systems in this standard are the universal mobile telecommunications system (UMTS) and the global system for mobile communication/enhanced data rates for global evolution (GSM/EDGE).

UMTS has been tailored to offer third-generation services—that is, high user data rates for real-time as well as traditional non-real-time applications. The tailoring comprises both the UMTS core network and the WCDMA-based UMTS terrestrial radio access network.[1]

UMTS is currently intended for use in the designated UMTS/IMT-2000 spectrum (and possibly 1,900 MHz), whereas the aim of GSM/EDGE is to evolve GSM and TDMA to provide coverage for third-generation services in existing spectrum bands (700, 850, 900, 1,800 and 1,900 MHz), and to complement UTRAN as a fully capable radio access network that can be connected to the UMTS core network.

By introducing high-level modulation in the GSM radio interface, it is expected that EDGE will successfully manage to provide support for high data rates. The next step in the GSM/EDGE evolution is to provide support for conversational and streaming service classes (real-time services). A driver of this evolution is the shift within the telecommunications world from circuit switching to packet switching. This shift is valid for traditional non-real-time data services, such as e-mail and Web browsing, as well as for real-time services, such as video conferencing and voice over IP (VoIP).

The second-generation packet-switched core network (which was defined for general packet radio service, GPRS) and the current GSM/EDGE radio access network must each be modified to support real-time services. This includes adopting the *Iu* interface to the third-generation UMTS core network. Doing so simplifies the alignment of services that will be provided in UMTS,

BOX A, ABBREVIATIONS

3GPP	Third-generation Partnership Project
8-PSK	8-phase-shift keying
AMR	Adaptive multirate
ATM	Asynchronous transfer mode
BCCH	Broadcast common control channel
BSC	Base station controller
BSS	Base station subsystem
BTS	Base transceiver system
CC	Call control
CDMA	Code-division multiple access
CN	Core network
CS	Circuit-switched
ECSD	Enhanced circuit-switched data
EDGE	Enhanced data rates for global evolution
EFR	Enhanced full-rate
ETSI	European Telecommunications Standards Institute
FR	Full-rate
GERAN	GSM/EDGE radio access network
GMM	GPRS mobility management
GMSK	Gaussian minimum-shift keying
GPRS	General packet radio service
GSM	Global system for mobile communication
HR	Half-rate
IETF	Internet Engineering Task Force
IP	Internet protocol
IPv4	IP version 4
LA	Location area
LAN	Local area network
LAPDm	Link access protocol on the Dm channel
LLC	Logical link control
MAC	Medium access control
MAIO	Mobile allocation index offset
MM	Mobility management
MS	Mobile station (terminal)
MSC	Mobile switching center
PCU	Packet control unit
PDCP	Packet data convergence protocol
PHY	Physical layer
PS	Packet-switched
QoS	Quality of service
RA	Routing area
RAB	Radio access bearer
RAN	Radio access network
RANAP	RAN application part
RLC	Radio link control
RNC	Radio network controller
ROHC	Robust header compression
RR	Radio resource
RRC	Radio resource control
RTP	Real-time protocol
SDU	Service data unit
SGSN	Serving GPRS support node
SIP	Session initiation protocol
SM	Session management
SMS	Short message service
SNDCP	Subnetwork-dependent convergence protocol
SS	Signaling subsystem
TCP	Transmission control protocol
TDMA	Time-division multiple access
TSG	Technical Specification Group
UDP	User datagram protocol
UMM	UMTS mobility management
UMTS	Universal mobile telecommunications system
UTRAN	UMTS terrestrial radio access network
VoIP	Voice over IP
WCDMA	Wideband CDMA
WWW	World Wide Web

and enables connection to the same third-generation core network.

In the 3GPP standardization, this next phase of evolution is called GSM/EDGE radio access network or GERAN (Box B). The two main objectives of GERAN are

- the alignment of GSM/EDGE and UMTS services—this mainly relates to providing conversational and streaming service classes; and
- the ability to interface with the third-generation UMTS core network over the *Iu* interface used in UTRAN.

In addition, GERAN will enhance the performance of existing services.

The first phase of the GSM/EDGE concept has already been presented and evaluated.[2] This article focuses on the subsequent evolution, describing the overall challenges of supporting real-time services in GERAN.

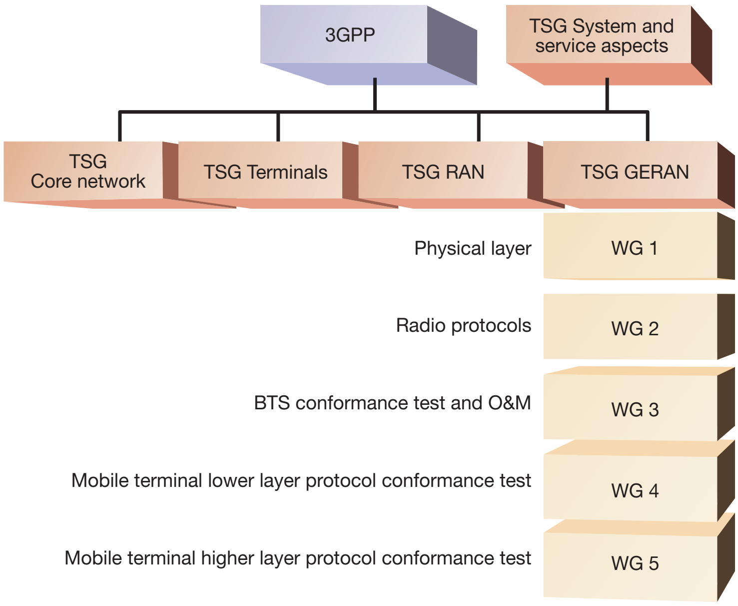

Figure 1
Standardization of GERAN in 3GPP: Technical Specification Group (TSG) GERAN.

Why GERAN?

The motivation behind the standardization activity for evolving GSM/EDGE toward, and aligning it with, UMTS can perhaps best be described in terms of target group—that is, in terms of operators, vendors, and end-users.

For mobile operators and vendors, the prime driving forces are directly related to reduced operating costs and increased revenues. Operators want to use existing (relatively cheap) GSM frequency bands as a complement to the newly acquired UMTS bands. And because GERAN offers the same third-generation bearer services as those defined for UMTS, any new investments that operators make in equipment for the GSM bands will be secured for the foreseeable future. Operators might also look forward to closer cooperation and integration between their different networks (GSM/EDGE and UMTS). This can partially be achieved through an interface between the base station controller (BSC) and radio network controller (RNC).

Vendors want the solutions for implementing GSM/EDGE to facilitate convergence with the development and manufacturing processes for UMTS. Happily, the prerequisites for achieving this objective are provided through the GERAN enhancements, whose prime goal is alignment with UMTS. This requirement also guarantees long-term revenue streams from GSM/EDGE equipment.

Obviously, end-users must also perceive the benefits of the new technology, for example, by being able to seamlessly roam between different radio access technologies (GERAN or UTRAN) to access third-generation UMTS services, such as real-time IP multimedia. And because application developers will now have a uniform environment for creating new and advanced third-generation services, these services can thus be made available to end-users in a timely manner.

BOX B, STANDARDIZATION OF GERAN IN 3GPP

ETSI (STC SMG2) standardized the GSM radio interface and made enhancements to EDGE. The introduction of the *Iu* mode motivated a closer coupling to 3GPP, and consequently, in the summer of 2000, ETSI/SMG2 was transferred to the 3GPP Technical Specification Group (TSG) GERAN, and all existing ETSI specifications were adopted as 3GPP specifications under new numbers. Release 99 thus became the last release of the GSM/EDGE standard delivered by ETSI. TSG GERAN has subgroups for radio aspects, protocol aspects, BTS conformance tests, and mobile station conformance tests (Figure 1).

The term *GERAN*, which is short for GSM/EDGE radio access network, is used in standardization effective from Release 99. However, the term is more frequently associated with the adoption of the UMTS architecture for the GSM/EDGE; that is, the adoption of the *Iu* interface, which is to be included in a later release.

After Release 99, all subsequent releases will not be formed as yearly releases, but rather as functional releases at regular intervals. Accordingly, the coming releases will be called Release 4 (Rel-4), Release 5 (Rel-5), and so on.

While GERAN Rel-4 introduced only minor enhancements to the standard, major enhancement packages are expected to come with Rel-5 and Rel-6—GERAN Rel-5 will introduce

- the UMTS architecture (that is, the *Iu* interface and protocol architecture); and
- all other enhancements related to the radio interface (for example, support for the conversational service class and IP multimedia).

In terms of contributions and participation, Ericsson is one of the leading companies in TSG GERAN.

GERAN support for UMTS QoS classes in packet-switched domain

Second-generation radio access technology brought mobile telephony to a broad market. By contrast, third-generation radio access technology will extend beyond basic telephony: a common, IP-based service platform will offer mobile users an abundance of real-time and non-real time (traditional data) services.

Typical services with real-time requirements are voice and video, as well as delay-sensitive applications, such as traffic-signaling systems, remote sensoring, and systems that provide interactive access to World Wide Web (WWW) servers.

The challenge is to implement end-to-end services based on the Internet protocol (IP). The main benefit of running IP end-to-end—including over the air interface—is service flexibility. Indeed, flexibility more or less eliminates dependencies between applications and underlying networks, for example, access networks. To date, cellular access networks have been optimized in terms of voice quality and spectrum efficiency for circuit-switched voice applications. However, for services such as IP multimedia, which includes voice, the main challenge is to retain comparable quality and spectrum efficiency without decreasing service flexibility. Today, for example, we can suffer considerable protocol overhead when we bridge the air interface with real-time protocol (RTP), user datagram protocol (UDP) or IP packets (which carry media frames). Needless to say, this runs counter to the goal of spectrum efficiency.

To achieve spectrum efficiency, we can instead characterize different packet data streams in terms of bandwidth and delay requirements. Characterization of this kind is useful when implementing admission-access algorithms that accommodate multiple user data streams in available spectrum. Different methods of limiting data (such as header compression and session signaling compression) must also be applied to obtain adequate spectrum efficiency.

QoS classes in UMTS and GSM/EDGE

Because frequency spectrum is a sparse resource, we readily see the benefit of classifying traffic to guarantee system capacity and quality of service (QoS). By differentiating traffic flows in the network, four application-related QoS classes have been defined within UMTS and GSM/EDGE:

- The conversational service class is used for real-time services, such as ordinary telephony voice—that is, IP-telephony and video-conferencing. The vital characteristics of this class are low transmission delay and preserved time relationships, or low-delay variation, in the traffic flow.
- The streaming service class applies to real-time audio and video-streaming applications. In contrast to the conversational class, this category comprises one-way transport.
- Typical applications associated with the interactive service class are WWW browsing and telnet. The fundamental characteristic of this service class is a request-response pattern. Consequently, the round-trip delay is an important factor.
- The background service class is used for best-effort traffic. Examples of services in this class are electronic mail (e-mail), short message service (SMS), and file transfer. In this service class, the requirements that apply to transfer delay are less stringent.

These four QoS classes are supported in GERAN and UTRAN by adequate radio access bearers.

Radio access bearer realizations in GERAN

Radio access bearers (RAB) provide bearer services through the radio access network. Each radio access bearer is associated with a set of attributes that

- specifies the required quality; and
- supplies information on the characteristics of the traffic flow.

BOX C, TERMINOLOGY

A-interface	Interface between the BSC and second-generation circuit-switched core network.
Abis interface	Interface between the BTS and BSC.
EDGE	Enhanced data rates for global evolution. Comprises enhancements for packet- and circuit-switched data (EGPRS and ECSD). EDGE has been standardized in ETSI for Release 99 and introduces 8-phase-shift keying (8-PSK) modulation and other physical layer and protocol enhancements. Release 99 was also referred to as EDGE phase 1.
EDGE phase 2	Has been superseded by GERAN.
Gb interface	Interface between the BSS and second-generation packet-switched core network.
GERAN	GSM/EDGE radio access network. This term was originally introduced in order to brand-name the development leading to the introduction of the *Iu* interface. However, since GERAN can include connections to the *A*, *Gb* and *Iu* interfaces in different combinations, the GSM/EDGE network based on Release 99 and the improvements made for Rel-4 can be called GERAN. Support for the *Iu* interface will be introduced in Rel-5.
Iu interface	UMTS interface between the radio access network and the core network.
Iu-cs interface	*Iu* interface to the circuit-switched part of core network.
Iu-ps interface	*Iu* interface to the packet-switched part of core network.
Iur-g interface	Control signaling carrier interface.
Um interface	Interface between the mobile terminal and the base transceiver station.

Some examples of attributes are service class, maximum bit rate, service data unit (SDU) loss rate, residual bit error ratio, transfer delay, and guaranteed bandwidth. This information is essential for providing a connection with good quality through the radio access network and for using spectrum efficiently. The different QoS classes specified for UMTS are characterized by specific value ranges for different RAB attributes.

The radio access bearer services provided by GERAN will be aligned with those supported by UTRAN through adapting and supporting the complete UMTS QoS model. The UMTS service concept is thus reused and each QoS class can be supported independently of the radio access network.

GERAN currently supports interactive and background service classes over the *Gb* interface (Release 99). Further enhancements to the cell re-selection procedure, which will shorten the interruptions during cell changes, will enable support for the streaming service class in Release 4 (Rel-4). Finally, all four service classes specified for UMTS will be supported by GERAN Release 5 (Rel-5) when operating in the *Iu* mode. That is, in the 3GPP standardization (Box B), it was decided that the conversational service class will solely be supported in *Iu* mode. Consequently, handover mechanisms with pre-allocation for resources for the packet-switched domain are being introduced in GERAN Rel-5 specifically for the *Iu* mode of operation.

Bearers for voice service in GERAN

The GERAN standard supports all classical GSM circuit-switched voice services—full-rate (FR), half-rate (HR), enhanced full-rate (EFR), and adaptive multirate (AMR), as well as narrowband HR and FR. As in GSM Release 98, all these services can be realized over the *A*-interface using Gaussian minimum-shift keying (GMSK) modulation on the physical layer. GERAN Rel-5 also discusses the introduction of AMR half-rate services using eight-phase-shift keying (8-PSK) modulation as an enhancement to existing AMR half-rate voice on the physical layer. GERAN will also support a wideband AMR voice codec.

GERAN system architecture

One might think that providing support for packet-based real-time services and the adoption of the UMTS QoS architecture would require that changes should be made to the second-generation GPRS core network. However, an alternative solution is to connect GERAN to the third-generation UMTS core network, which supports real-time services and the UMTS QoS architecture. This approach employs a common core network for UTRAN and GERAN over a common interface.

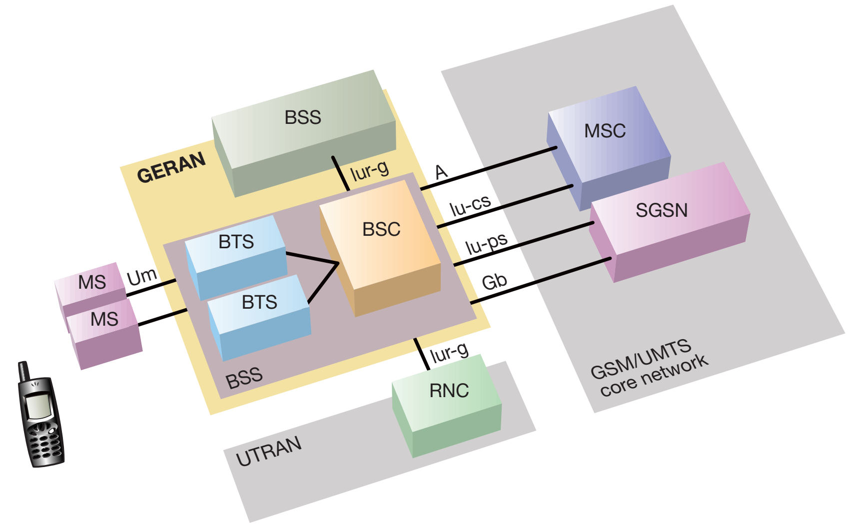

Figure 2
The GERAN reference architecture.

To connect to the third-generation UMTS core network, GERAN must use the *Iu* interface (3GPP Release 5 of the specification).[3] This interface can be seen as comprising two parts: the *Iu-ps* connects to the packet-switched domain of the core network, whereas the *Iu-cs* connects to the circuit-switched domain. Note: the two parts of the *Iu* interface share the control plane (the radio access network application part, RANAP, protocol) and have similar user planes.

Figure 2 shows that GERAN also connects to second-generation core network nodes. The *Gb* interface and the connection to the serving GPRS support node (SGSN) are needed for support of Rel-4 (and earlier) terminals. The *Iu-ps* interface could not be used for legacy terminals, since for the *Iu-ps* interface, the functional split between the radio access network (RAN) and the core network differs from that for the *Gb* inter-

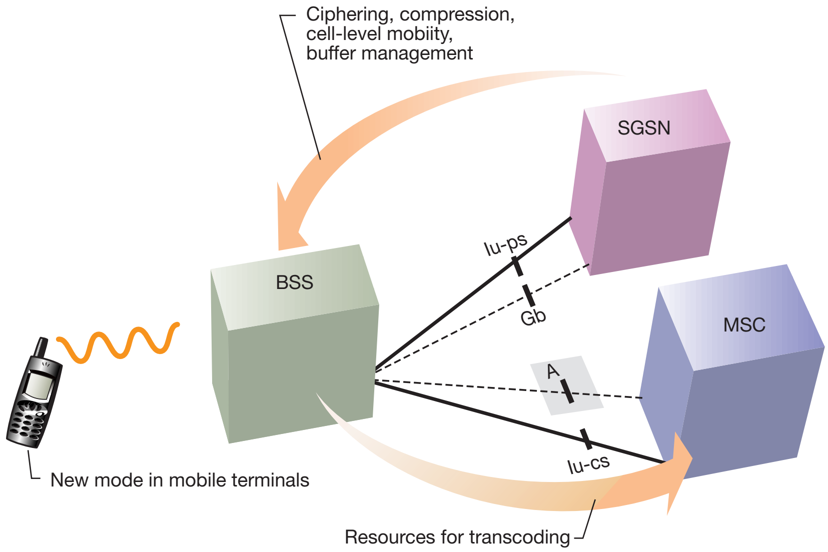

Figure 3
The impact of introducing the UMTS architecture.

face. The preferred solution is thus to support legacy terminals over the *A/Gb* interfaces.

The air interface between the mobile terminal (also called mobile station, MS) and GERAN, called the *Um* interface, is based in part on the radio link interface of Release 99. However, several enhancements being specified on different radio link protocol layers will provide adequate radio bearers for real-time packet services. Examples of these enhancements are support for handover for the packet-switched domain, separation of the user and control planes, and transparent modes in radio link protocol layers.

Functional split

Figure 2 shows the overall GERAN reference architecture. At a high level, the GERAN base station subsystem (BSS) consists of the base transceiver system (BTS) and the BSC. Unlike in UTRAN, the functional split of the GERAN BSS is not specified in the standard. In GERAN, the radio link controller (RLC) and medium access control (MAC) protocol can be placed in any BSS node or even in the core network. This architectural freedom remains in GERAN Rel-5. However, at a functional level, there are some important restrictions that follow from adopting the *Iu* interface in the core network. For instance, user data must be ciphered on the RLC or MAC protocol layers. Additionally, when operating in circuit-switched mode over the *Iu* interface, the voice transcoders must be located in the core network (Figure 3).

Modes of operation

As indicated in Figure 2, GERAN can be connected to

- a second-generation core network via the *A*- and *Gb* interfaces; and
- a third-generation core network via the *Iu-ps* (for the packet-switched domain) and *Iu-cs* (for the circuit-switched domain) interfaces.

According to the standard, a mobile terminal may not connect to the second- and third-generation core networks simultaneously. It must operate in either *A/Gb* mode or *Iu* mode. This restriction was stipulated to avoid very complex coordination of the two modes of operation in a multiservice scenario. The GERAN, on the other hand, can provide simultaneous services from the second- and third-generation core networks to different mobile terminals. In addition, GERAN is required to multiplex traffic to and from mobile terminals that operate in different modes onto the same physical channel over the air interface: timeslot or half timeslot.

The *Iur-g* interface

An important new feature is the option to have two BSCs, as well as a BSC and a UTRAN RNC, connected through the *Iur-g* interface (Figure 2). The main advantages of the interface, which has been designed to carry control signaling only, are

- greater alignment with the UMTS architecture (which splits the core network from the radio access network) by allowing the definition of RAN internal registration areas. These can span over multiple cells that belong to different GERAN BSCs, and UTRAN RNCs. The use of registration areas reduces mobility management signaling to the core network;
- improved performance of the cell-reselection procedures within GERAN; and
- support for the serving RNC or serving BSC relocation procedures as defined in UTRAN. This improves the performance of the cell re-selection procedure between UTRAN and GERAN.

It might also be possible to further enhance the *Iur-g* interface to achieve traffic steering and load distribution between GSM/EDGE and UMTS.

Protocol models

When introducing the *Iu* interface in GERAN, the designers endeavored to interject as few changes as possible to the protocols that relate to this interface as well as to the core network nodes and to UTRAN. Consequently, they adopted the associated *Iu* protocols—mainly the RANAP protocol. However, on the radio side, the introduction of the *Iu* interface meant that the protocol stacks of GSM/GPRS had to be modified (see Figures 4 and 5, which show the protocols influenced by the *Iu* and *A*/*Gb* interfaces).

The most noticeable difference in the user plane of the packet-switching mode is that the packet data convergence protocol (PDCP) is used as a radio link layer protocol for operation over the *Iu-ps* interface (instead of the SNDCP/LLC protocols, which are used for operation over the *Gb* interface), and that a transparent RLC mode has been introduced (Figure 4).

In the user plane of the circuit-switching mode, the *Iu-cs* interface partly uses the same protocol stack as that of the *Iu-ps* interface, but operates with RLC and MAC protocol layers in transparent mode. The protocol stack for the *A*-interface is unchanged (Figure 4).

In the control plane, the packet- and circuit-switching channels are handled by the radio resource control (RRC) protocol when the *Iu* interface is used; the radio resource (RR) protocol of GSM/GPRS is reused when the *A*/*Gb* interface is used. The only exception is for common control channels (such as the broadcast control channel, BCCH). In this case, the RR protocol is used regardless of service (Figure 5).

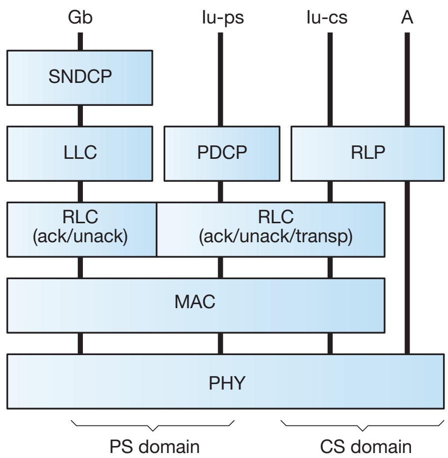

Figure 4
GERAN protocol models in the user plane.

Transport in GERAN

The transport options on the GERAN interfaces comply with the UMTS standard. As such, transport over the *Iu* and *Iur-g* interfaces is not limited to what has been specified to date (for example, asynchronous transfer mode, ATM) but will also adopt other options (such as IP) when they have been standardized by 3GPP.

GERAN mobility management

As in UMTS, when the mobile terminal is connected in GERAN *Iu* mode, all cell-level mobility functionality resides in the radio access network. This is a major departure

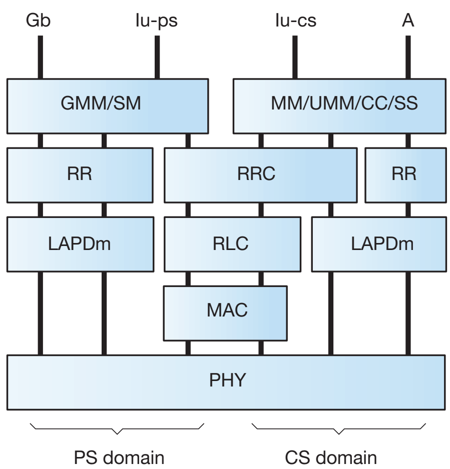

Figure 5
GERAN protocol models in the control plane.

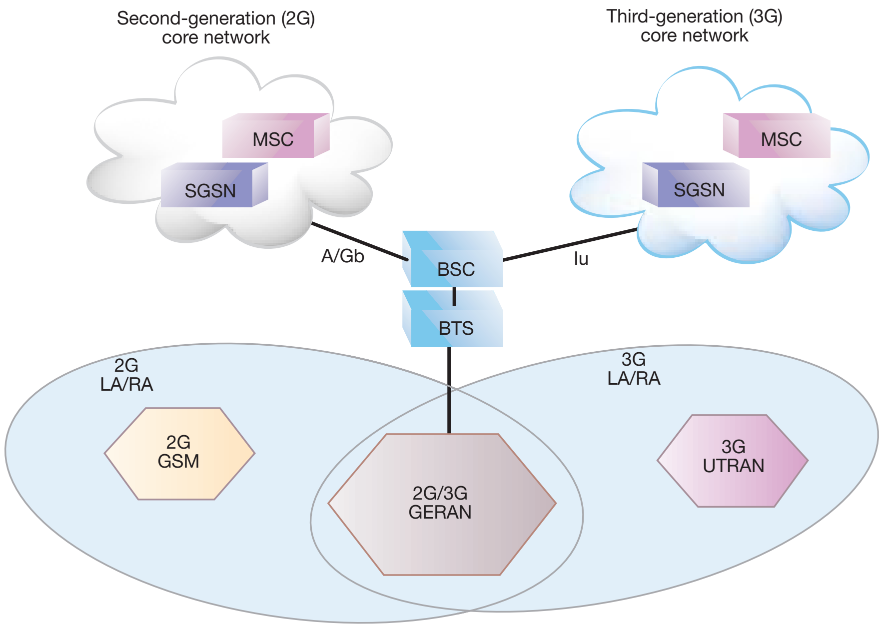

Figure 6
Mobility management: separate second- and third-generation core networks.

from GERAN operating in *A/Gb* mode, where cell-level mobility is handled by the core network. A feature of GERAN mobility management in *Iu* mode is that it allows mobile terminals in connected mode to use common registration areas for GERAN and UTRAN. This reduces signaling over the core network interface.

As explained above, one GERAN cell can connect to the core network via the *A/Gb* and *Iu* interfaces. In fact, one GERAN cell can simultaneously connect to second- and third-generation core networks, regardless of whether they are separate or have been integrated (Figures 6 and 7).

GERAN physical layer

GERAN must be able to multiplex, on the same physical channel, traffic from mobile terminals operating in *Iu* mode and *A/Gb* mode. Accordingly, the GERAN physical layer must remain backward compatible. However, several features that will enhance the operation of the physical layer are under discussion in standardization groups, including

- enhanced power control;
- mobile allocation index offset (MAIO) hopping; and
- flexible layer-one concept.

Enhanced power control

GERAN Rel-5 will allow power control to operate on a 120 ms basis—as compared to the current 480 ms. This enhancement will increase capacity in multipath fading environments.

MAIO hopping

Ericsson has proposed an MAIO hopping algorithm that improves interference diversity. The idea is to improve the current frequency-hop algorithm (where mobile terminals in one cell hop together) to let mobile terminals hop with different offsets, thereby increasing the diversity in co-channel and adjacent-channel interference.

Flexible layer-one concept

A drawback of the current GSM/EDGE system is that layer one is relatively inflexible. Standards groups must agree on new schemes for optimized channel coding each time a new radio bearer service (such as for wideband AMR or VoIP) is proposed. Ericsson proposes a new, flexible layer-one concept, whose parameters, such as error protection, channel coding, puncturing, and interleaving, are controlled by the radio access network. This way, the introduction of a new service will only require a new set of parameters.

GERAN and IP multimedia

When IP multimedia and VoIP were first discussed in the wireless community, vendors and operators quickly identified the need to reduce the large overhead constituted by the IP transport headers in order to make more efficient use of spectral assets. In 3GPP, UTRAN adopted the robust header compression (ROHC) standardized in IETF. This method allows for a reduction of the nominal header size of 40 bytes (IPv4) to an average of 1 byte. This is possible, since most of the elements in the IP header do not vary particularly often. However, if significant changes in the information in the IP header occur, a larger header might need to be transmitted. In this sense, the ROHC algorithm requires a flexible physical layer—to accommodate varying header size, the channel coding of the payload must change to keep the total number of transmitted bits constant.

Given the traditional relative inflexibility of the physical layer of GSM/GPRS, the method of complete header removal was instead discussed for GERAN. However, despite the obvious gain in spectrum efficiency, removing the IP header rules out the possibility of numerous desirable features, such as multiple synchronized flows to a single mobile terminal, and connecting the VoIP flow to an off-the-shelf multimedia application—for example, to a PC.

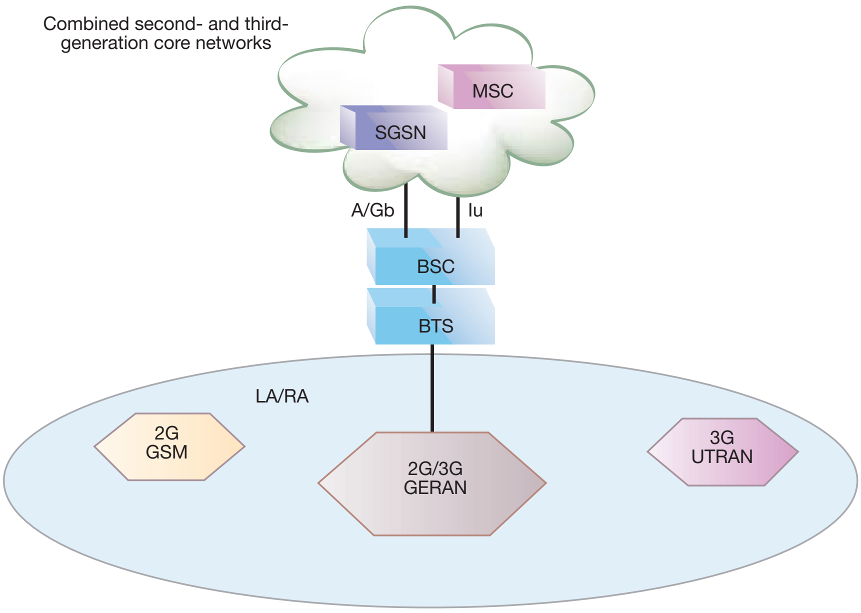

Figure 7
Mobility management – combined second- and third-generation core networks.

Conclusion

The continuous GSM/EDGE standardization in 3GPP offers a common evolution path for GSM and TDMA that provides a cost-effective means of providing third-generation services within existing GSM/TDMA frequency bands.

With Release 99 of the ETSI standard, circuit-switched voice and packet-switched services without strict delay requirements (such as Internet access for Web browsing and e-mail) can be efficiently supported with adequate radio bearers. And with the concept currently being standardized in 3GPP for Release 5, the GSM/EDGE radio access network (GERAN) will provide support for true third-generation wireless services. This includes support for all the service classes specified for UMTS, which in particular, includes support for the conversational service class with its real-time requirements. Furthermore, interfacing to the third-generation UMTS core network over the *Iu* interface yields greater alignment with UMTS.

REFERENCES

1 E. Dahlman et al., "WCDMA – The radio Interface for Future Mobile Multimedia Communications," in IEEE Transactions on Vehicular Technology, vol. 47, no. 4, November 1998.
2 A. Furuskär et al., "EDGE: Enhanced Data Rates for GSM and TDMA/136 Evolution," in IEEE Personal Communications, June 1999, Vol. 6, No. 3.
3 3GPP TS 43.051, "GSM/EDGE Radio Access Network; Overall Description - Stage 2".
4 A. Furuskär et al., "System Performance of the EDGE Concept for Enhanced Data Rates in GSM and TDMA/136," in Proceedings of IEEE WCNC'99.
5 M. Eriksson et al., "Real-time Support in EDGE Phase II; System Overview and Performance Evaluation," in Proceedings of IEEE UWCC2000.
6 G. Eriksson, B. Olin, K. Svanbro and D.Turina, "The challenges of voice-over-IP-over-wireless," in Ericsson Review, Volume 77 (2000):1, pp. 20-31.