

REVIEW

General Packet Radio Service (GPRS): architecture, interfaces, and deployment‡

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Summary

This article provides an overview of General Packet Radio Service (GPRS). GPRS reuses the existing GSM infrastructure to provide end-to-end packet-switched services. Benefits of GPRS include efficient radio usage, fast set-up/access time and high bandwidth with multiple timeslots. GPRS also provides a smooth path for GSM evolution to the third generation mobile network. Specifically, a third generation network can continue to utilize the GPRS IP backbone network. We describe the GPRS network nodes and the interfaces among these nodes. Deployment issues for GPRS are also elaborated. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS

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1. Introduction

In early 2000, only a small portion of GSM subscribers used data services because existing GSM systems do not support easy access, high data rate and attractive prices. GSM operators must offer better services to stimulate the demand. The solution is General Packet Radio Service (GPRS). GPRS reuses the existing GSM infrastructure to provide end-to-end packet-switched services. GPRS standardization was initiated by ETSI/SMG in 1994. The main set of GPRS specifications was approved by SMG #25 in 1997, and was complete in 1999. GPRS products were developed in 1999, and service deployment has been in progress [1]. GPRS core network has also been developed with IS-136 TDMA systems [2], and is anticipated to evolve as the core network for the third generation mobile systems.

To accommodate GPRS, new radio channels are defined, and the allocation of these channels is flexible: one to eight timeslots can be allocated to a user or several active users can share a single timeslot, where the uplink and the downlink are allocated separately. The radio resources can be shared dynamically between speech and data services as a function of traffic load and operator preference. Various radio channel coding schemes are specified to allow bit rates from 9 Kb s^{-1} to more than 150 Kb s^{-1} per user. GPRS fast reservation is designed to start packet transmission within 0.5–1 s. GPRS security functionality is equivalent to the existing GSM security, where a ciphering algorithm is optimized for packet data transmission. By allowing information to be delivered more quickly and efficiently, GPRS is a relatively

inexpensive mobile data service compared to Short Message Service (SMS) and Circuit Switched Data.

An excellent survey on GPRS can be found in Reference [3], which elaborated on GPRS architecture and air interface. In the remainder of this article, we provide a GPRS overview complementary to Reference [3]. We only briefly describe the air interface that has been covered completely in Reference [3] and discuss the air interface for enhanced GPRS. We will emphasize more on the individual protocols in the signaling plane, the industrial solutions of the GPRS network components, GPRS charging, and the development efforts from GSM to GPRS. We first describe the GPRS architecture, then elaborate on GPRS nodes and the interfaces among these nodes. We also describe the GPRS solutions and development of several GPRS vendors. We assume that the reader is familiar with GSM.

2. GPRS Architecture

Figure 1 shows the GPRS network nodes and the corresponding interfaces, where SMS-related components and the Equipment Identity Register are not shown. In this architecture, MS, BSS, Mobile Switching Center/Visitor Location Register (MSC/VLR) and Home Location Register (HLR) in the existing GSM network are modified. For example, the HLR is enhanced with GPRS subscriber information. Two new network nodes are introduced in GPRS. The Serving GPRS Support Node (SGSN) is the GPRS equivalent to the MSC. The Gateway GPRS Support Node (GGSN) provides interworking with external

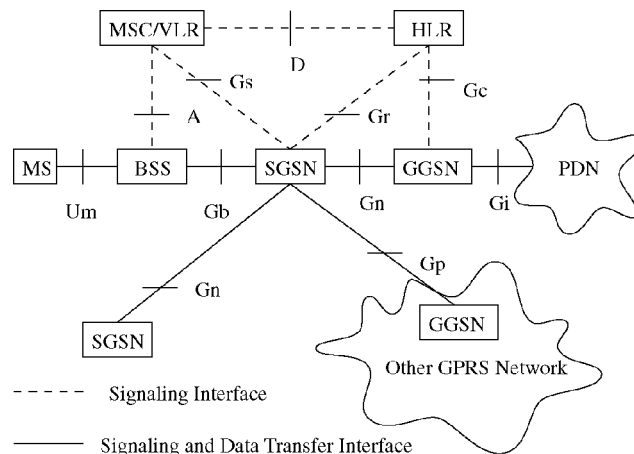


Fig. 1. GPRS architecture. BSS: Base Station System; GGSN: Gateway GPRS Support Node; HLR: Home Location Register; MS: Mobile Station; MSC: Mobile Switching Center; SGSN: Serving GPRS Support Node; PDN: Packet Data Network; VLR: Visitor Location Register.

packet-switched networks, and is connected with SGSNs via an IP-based GPRS backbone network.

The MS and the BSS communicates through the Um interface. The BSS and the SGSN are connected by the Gb interface with Frame Relay. Within the same GPRS network, SGSNs/GGSNs are connected through the Gn Interface. When SGSN and GGSN are in different GPRS networks, they are interconnected via the Gp interface. The GGSN connects to the external networks through the Gi interface. The MSC/VLR communicates with the BSS using the existing GSM A interface, and with the SGSN using the Gs interface. The HLR connects to SGSN with the Gr interface and to GGSN with Gc interfaces. Both Gr and Gc follow GSM Mobile Application Part (MAP) protocol defined in GSM 09.02 [4]. The HLR and the VLR are connected through the existing GSM D interface. Interfaces A, Gs, Gr, Gc, and D are used for signaling without involving user data transmission in GPRS. Note that the A interface is used for both signaling and voice transmission in GSM. Interfaces Um, Gb, Gn, Gp and Gi are used for both signaling and transmission in GPRS.

GPRS transmission plane is shown in Figure 2, which consists of a layered protocol structure for user information transfer and the associated control procedures (e.g., flow control, error detection, error correction and error recovery). Figure 3 shows the GPRS signaling plane that consists of protocols for control and support of the transmission plane functions. Among these protocols, the GPRS specific protocols include SNDCP, LLC, RLC, MAC, BSSGP, BSSAP+ and GTP. PLL, RFL, GMM/SM and MAP are GSM protocols (note that GMM/SM and MAP also contain GPRS-specific protocols). TCAP, SCCP and MTP are

SS7 layers. Other protocols are standard data protocols. Details of the layers of the transmission and the signaling planes will be elaborated in Section 4.

The GPRS relay functions in Figure 2 merit further discussion. In the BSS, this function relays Logical Link Control (LLC) Packet Data Units (PDUs) between the Um and Gb interfaces. In the SGSN, this function relays (PDP) PDUs between the Gb and Gn interfaces. The Gb/Gn relay function adds sequence numbers to PDP PDUs received from the SubNetwork Dependent Convergence Protocol (SNDCP) and from the Gi reference point, respectively. To transparently transport PDP PDUs between external networks and MSs, the PDP PDUs are encapsulated and decapsulated for routing as described in Section 4.3.

Before we elaborate on GPRS mechanisms, we first introduce three GPRS terms: Mobility Management (MM) context, Packet Data Protocol (PDP) context and Quality of Service (QoS) profile. The MM context consists of the MM state and other MM-related information stored in MS and SGSN as described in Sections 3.1 and 3.3.1.

The MM states specify the MM activities of an MS. The state is IDLE if the MS is not attached to the GPRS mobility management. The state is STANDBY if the MS is attached to GPRS mobility management but has not obtained detailed location information. The state is READY if the location information for the MS has been identified on cell level. Note that a GPRS MS can be IMSI and/or GPRS attached. The IMSI attach is the same as that for a GSM MS. In GPRS attach procedure, both the MS and the SGSN are moved to the READY state, an MM context is created in each of MS and SGSN,

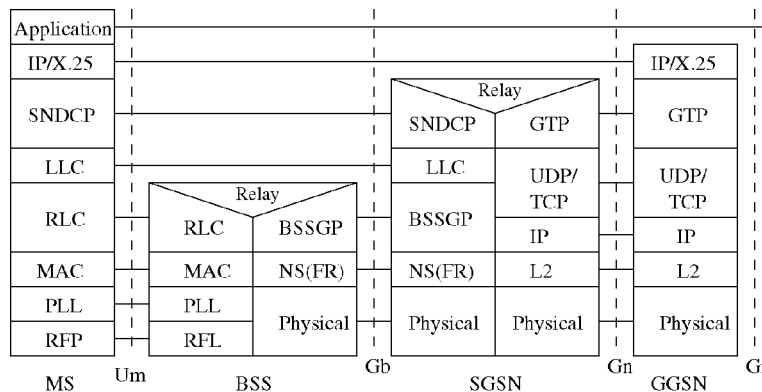


Fig. 2. GPRS transmission plane. BSSGP: BSS GPRS Protocol; FR: Frame Relay; GTP: GPRS Tunneling Protocol; LLC: Logical Link Protocol; MAC: Medium Access Control; NS: Network Service; RFL: Radio Physical Layer; PLL: Physical Link Layer; RLC: Radio Link Control; SNDCP: SubNetwork Dependent Convergence; UDP: User Datagram Protocol; TCP: Transmission Control Protocol.

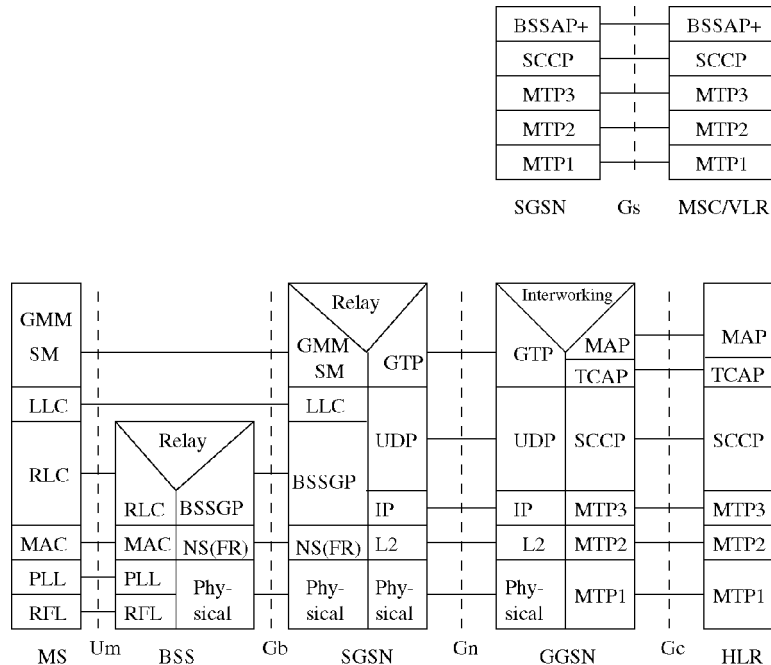


Fig. 3. GPRS signaling plane. BSSAP+: Base Station System Application Part+; GMM: GPRS Mobility Management; MAP: Mobile Application Part; MTP: Message Transfer Part; SCCP: Signaling Connection Control Part; SM: Session Management; TCAP: Transaction Capabilities Application Part.

and authentication/ciphering may be performed. At GPRS attach, a logical link is established between MS and SGSN.

The PDP contexts are stored in the MS, HLR, SGSN and GGSN as described in Sections 3.1, 3.3 and 3.4, which contain mapping and routing information for packet transmission between MS and GGSN. For each GPRS communication of an MS, a PDP context is created to characterize the session. After the PDP context activation, the MS is known to the GGSN and communication to external networks is possible. An MS may have several activated PDP contexts if the terminal supports several IP addresses. When the MS is detached from GPRS, all PDP contexts are deactivated. A PDP context can be in one of the two PDP states: ACTIVE or INACTIVE. An MS in STANDBY or READY MM state may activate a PDP context and moves its PDP state from INACTIVE to ACTIVE. The ACTIVE PDP context becomes INACTIVE when the PDP context is deactivated. A QoS profile is maintained in the PDP context to indicate radio and network resources required for data transmission. The QoS attributes include:

- Precedence class specifies three transmission priority levels. During congestion, the packets with lower priorities are discarded.

- Delay class specifies four delay levels. In 128-octet transfer, for example, the expected transfer speeds for delay classes 1–3 are less than 0.5 s, 5 s, and 50 s, respectively. Delay class 4 supports best-effort transmission without specifying the transfer speed constraints.
- Reliability class defines residual error rates for data loss, out-of-sequence delivery and corrupted data. There are five reliability classes. Reliability class 1 supports acknowledgement for GTP mode, LLC frame mode and RLC block mode, and the LLC data are protected. Reliability class 5 does not support acknowledgment and the LLC data are not protected.
- Peak throughput class specifies the expected maximum data transmission rate. There are nine classes ranging from 8 Kb s^{-1} to 2048 Kb s^{-1} .
- Mean throughput class specifies the average data transmission rate. There are 19 classes ranging from the best effort to 111 Kb s^{-1} .

We will elaborate on the usage of the MM/PDP contexts and QoS profile in subsequent sections.

3. GPRS Network Nodes

This section discusses the GPRS network nodes: MS, BSS, SGSN, GGSN, HLR, and MSC/VLR. We also

describe the solutions for these nodes provisioned by equipment suppliers.

3.1. Mobile station

A GPRS MS consists of Mobile Terminal (MT) and Terminal Equipment (TE). An MT communicates with the BSS over the air. The MT is equipped with software for GPRS functionality, which establishes links to SGSN. A TE can be a computer attached to the MT. Existing GSM MS does not support GPRS. For example, GPRS MS utilizes Automatic Re-transmission (ARQ) at the data link layer to re-transmit the error frames. In GSM, no re-transmission is provided in a GSM voice channel. With multiple timeslots, GPRS may provide high transmission rate. GSM only offers single timeslot for voice.

Three MS operation modes are introduced in GPRS 07.60 [5]. Class A mode of operation allows simultaneous circuit-switched and packet-switched services. Duplexer is required to support this mode. Class B mode of operation provides automatic choice of circuit-switched or packet-switched service, but only one at a time. A Class B MS involved in packet transfer can receive a page for circuit-switched activity. In this case, the MS suspends the data transfer for the duration of the circuit-switched connection and afterwards resumes the data transfer elaborated in Section 4.4. Class C mode of operation supports packet-switched data only. Neither Class B nor Class C mode requires duplexer.

The MSs access the GPRS services that are with or without GPRS-aware Subscriber Identity Modules (SIMs). An MS maintains MM and PDP contexts to support GPRS mobility management. Some of the MM context fields stored in GPRS-aware SIM are listed next:

- International Mobile Subscriber Identity (IMSI) that uniquely identifies the MS. IMSI is used as the key to search the databases in VLR, HLR, and GSN.
- Packet Temporary Mobile Subscriber Identity (P-TMSI) which is the GPRS equivalent of TMSI in GSM.
- Address of the routing area where the MS resides. A routing area is a subset of a location area defined in GSM.
- Current ciphering key Kc and its Ciphering Key Sequence Number (CKSN).

If the SIM is not GPRS-aware then the above fields are stored in the mobile equipment. The mobile

equipment also stores several non-SIM-related fields listed next (a partial list):

- MM state (either IDLE, STANDBY or READY as described in Section 2).
- Identity of the cell where the MS resides.
- Ciphering algorithm that is defined in GSM 01.61 [6].
- Radio access classmark for the radio capabilities (e.g., multiple timeslot capability and power class) and SGSN classmark for network-related capabilities (e.g., ciphering capability).

For data routing purpose, the MS maintains PDP contexts including (a partial list):

- PDP type (either X.25, PPP, or IP).
- PDP address (e.g., an X.121 address).
- PDP state (either ACTIVE or INACTIVE as described in Section 2).
- Dynamic-Address-Allowed that specifies whether the MS is allowed to use a dynamic address.
- Requested and negotiated QoS profiles described in Section 2.

GSM chips for GPRS MS are available. For example, SMARTi (PMB6250) [7] is a single chip GSM multi-band transceiver that supports multi-timeslots data, which can be used to support GPRS MS. Another example is Lucent's Sceptre 3 system-on-a-chip solution that enables full GPRS to 115.2 Kb s^{-1} . By integrating digital signal processing, microprocessing, read only memory, random access memory, and laser programmability on one chip, such technologies provide flexible architecture for future MS design.

3.2. Base station system

To accommodate GPRS, the Base Transceiver Station (BTS) and the Base Station Controller (BSC) in the BSS are modified, and a new component Packet Control Unit (PCU) is introduced. The BTS is modified to support new GPRS channel coding schemes. The BSC forwards circuit-switched calls to the MSC, and packet-switched data (through PCU) to the SGSN. Every BSC can only connect to one SGSN. The Gb interface described in Section 4.2 is implemented to accommodate functions such as paging and mobility management for GPRS. The BSS should also manage GPRS-related radio resources such as allocation of packet data traffic channels in cells. As will

be described in Section 4.1, the Um radio interface is modified to support GPRS features. To support GPRS traffic, the transmission capacity of the BSS is increased through standard upgrade process.

The PCU is viewed as the equivalence of a Transcoder and Rate Adaptor Unit (TRAU) for the packet data services. The PCU is either located locally with the BTS or remotely located in the BSC or the SGSN. Most vendors follow the remote PCU options so that no hardware modifications to the BTS/BSC are required. In the remote options, existing Abis interface between the BTS and the BSC is reused, and the GPRS data/signaling messages are transferred in modified TRAU frames with a fixed length of 320 bits (20 ms). The PCU is responsible for the Medium Access Control and Radio Link Control layer functions such as packet segmentation and reassembly, packet data traffic channel management (e.g., access control, scheduling, and ARQ), and radio channel management (e.g., power control, congestion control, broadcast control information).

In Nortel's solution, existing GSM BTS and second generation BSC 12 000 are reused with upgraded software. The PCU and Gb functions are implemented in PCUSN based on Nortel's GSM Passport Platform. The PCUSN concentration capability is up to 12 BSCs per cabinet. Similarly, in Alcatel's solution [8], both BTS and BSC are reused with upgraded software. The PCU and Gb functions are implemented in A935 Multi-Functional Server (MFS) that can connect up to 22 BSSs and supports 480 activated GPRS radio channels per BSC. Ericsson follows one PCU per BSC design. A PCU can cover 512 BTSs and up to 4096 GPRS radio channels (1750 channels practically).

3.3. GPRS support node

Two kinds of GSNs are introduced in GPRS: Serving GSN (SGSN) and Gateway GSN (GGSN). The functionality of SGSN and GGSN can be combined in a physical node (e.g., Symmetry's UWS-GSN [9] and Ericsson's Combined SGSN/GGSN or CGSN [10]) or distributed in separated nodes (e.g., Nortel, Motorola/Cisco, and Alcatel solutions). A GSN is typically implemented at multiple processor system platform with hardware redundancy and robust software infrastructure that support uninterrupted operation [10]. A vendor may develop GSN with various capacities. Ericsson, for example, has developed two GSN models. Model GSN-25 is a small-capacity GSN used to enable fast deployment of the GPRS service.

With the same capability as GSN-25, Model GSN-100 provides larger capacity in terms of throughput and number of attached users.

3.3.1. Serving GPRS support node

The role of SGSN is equivalent to that of MSC/VLR in the current GSM network. SGSN connects BSS to GGSN, which provides ciphering, mobility management (e.g., inter-SGSN routing area update and inter-PLMN roaming), charging and statistics collection (i.e., support of billing records). To provide services to a GPRS MS, the SGSN establishes an MM context containing mobility and security information for the MS. At PDP context activation, the SGSN establishes a PDP context that will be used to route data between the MS and the GGSN. SGSN maintains MM/PDP context information when the MS is in STANDBY or READY MM states. For an MS, the SGSN MM context includes:

- IMSI, P-TMSI and Mobile Station ISDN Number (MSISDN).
- MM state.
- Routing area identity and cell identity.
- Address of the VLR currently serving the MS.
- IP address of the new SGSN where the buffered packets should be forwarded to.
- Authentication and ciphering parameters.
- Current ciphering key Kc and the selected ciphering algorithm.
- MS radio access capabilities and GPRS network access capabilities.
- MNRG (Mobile Station Not Reachable for GPRS flag) indicating whether activity from the MS should be reported to the HLR.
- NGAF (Non-GPRS Alert Flag) indicating whether activity from the MS should be reported to the VLR.
- PPF (Paging Proceed Flag) indicating whether paging for GPRS and non-GPRS services can be initiated.

Each MM context associates with zero or more of the following PDP contexts (a partial list):

- PDP context identifier, PDP type, PDP address, and PDP state.
- Access point name to the external data network.
- Subscribed, requested, and negotiated QoS profiles.
- IP address of the GGSN currently used by the activated PDP context.

- Identifier of the charging records generated by SGSN and GGSN.

Most vendors developed SGSN based on existing multiple processor system products where the control processors are configured with hot standby redundancy. Lucent's solution supports 40 000 attached users and 4000 simultaneous active GPRS data sessions. For Nortel Passport 8380G and Symmetry UWS-GMS, the number of GPRS users that can be attached to an SGSN is 50 000, the number of PDP context activation is 20 000, the number of SS7 links to VLR/HLR is eight, the number of E1 links for Gb interface is 10, and the throughput is 20 Mb s⁻¹. In Alcatel's SGSN solution, the number of attached users is 52 000–96 000, the number of SS7 signaling links is eight, the number of E1 links to Gb interface is 16, and the throughput is 16–48 Mb s⁻¹. It is clear that Alcatel's SGSN has larger capacity than Nortel and Symmetry's SGSNs. This design is owing to the fact that in Alcatel's solution, every GPRS network is supported by one SGSN. Thus large-capacity SGSN is required.

3.3.2. Gateway GPRS support node

GGSN is mainly provisioned by router, which supports traditional gateway functionality such as publishing subscriber addresses, mapping addresses, routing and tunneling packets, screening messages, and counting packets. A GGSN may contain DNS functions to map routing area identifiers with serving SGSNs, and Dynamic Host Configuration Protocol (DHCP) functions to allocate dynamic IP addresses to MSs.

The GGSN maintains activated PDP context for tunneling the packets of the attached MS to the corresponding SGSN. The information items include (a partial list):

- IMSI.
- PDP type, PDP address.
- Dynamic address indication.
- QoS profile negotiated.
- IP address of the SGSN currently serving this MS.
- Access point name of the external data network.
- Charging id.
- MNRG flag indicating whether the MS is marked as not reachable for GPRS at the HLR.

Note that the GGSN does not need to record subscribed and requested QoS profiles. Both of them are maintained in the SGSN.

Most suppliers use existing router platforms to provide this function. For example, Alcatel GGSN is developed based on Cisco 7200 series router, Nokia's GGSN is developed based on its commercial IP routing platform, and Nortel GGSN is developed based on Bay CES 4500. Existing GGSN implementations typically support 5000–48 000 simultaneous data tunnels, and 25 000–48 000 simultaneously attached data users. The switching capability is, for example, 20 Mb s⁻¹ in the Alcatel solution.

3.4. HLR and VLR

To accommodate GPRS subscription and routing information, new fields in the MS record are introduced in HLR, which are accessed by SGSN and GGSN using the IMSI as the index key. These fields are used to map an MS to one or more GGSNs, update the SGSN of the MS at attach and detach, and store a fixed IP address and QoS profile for a transmission path. In the HLR, the GSN-related information includes:

- IMSI and MSISDN.
- SS7 address of the SGSN that serves the MS.
- IP address of the SGSN that serves the MS.
- MS Purged for GPRS flag that indicates if the MM and PDP contexts of the MS are deleted from the SGSN.
- MNRG that indicates if the MS is not reachable for GPRS service.
- GGSN-list that provides a GGSN IP address list to be contacted for MS activity when MNRG is set.

The PDP context-related information includes PDP context identifier, PDP type, PDP address, QoS profile subscribed, and the access point to the external packet data network.

In MSC/VLR, a new filed SGSN number is added to indicate the SGSN currently serving the MS. The MSC/VLR may contact SGSN to request location information or paging for voice calls. It also performs signaling coordination for class B mobile through the Gs interface and suspends/resumes GPRS activities through the A and Gb interfaces.

4. GPRS Interfaces

This section describes the GPRS interfaces shown in Figure 1: Um, Gb, Gn, Gp, Gs and Gi.

4.1. Um interface

Um is the radio interface between MS and BTS. GPRS radio technology is based on GSM radio architecture, which introduces new logical channel structure to control signaling and traffic flow in the Um radio interface. In this subsection, we elaborate on the Um channel structure, Um protocol layers and the enhanced Um for GPRS.

4.1.1. Radio channel structure

The physical channel dedicated to packet data traffic is called a Packet Data Channel (PDCH). Different packet data logical channels can occur on the same PDCH. The logical channels are described below.

GPRS utilizes Packet Data Traffic Channel (PDTCH) for data transfer. High spectral efficiency is achieved through timeslot sharing where multiple users may share one PDTCH. Furthermore, a user may simultaneously occupy multiple PDTCHs.

Several Packet Common Control Channels (PCCCHs) are introduced in GPRS. The Packet Random Access Channel is the only uplink PCCCH, which is sent from the MS to the BTS to initiate uplink transfer for data or signaling. The following downlink PCCCHs are sent from the BTS to the MS.

- Packet Paging Channel pages an MS for both circuit-switched and packet data services.
- Packet Access Grant Channel is used in the packet transfer establishment phase for resource assignment.
- Packet Notification Channel is used to send a Point-To-Multipoint Multicast (PTM-M) notification to a group of MSs prior to a PTM-M packet transfer.
- Packet Broadcast Control Channel, GPRS (PBCCH) broadcasts system information specific for packet data. If PBCCH is not allocated, the packet data specific system information is broadcast on the existing GSM BCCH channel.

Several Packet Dedicated Control Channels are defined in GPRS:

- Packet Associated Control Channel (PACCH) conveys signaling information such as power control, resource assignment and reassignment information. The PACCH shares resources with PDTCHs. An MS currently involved in packet transfer can be paged for circuit-switched services on PACCH.

- Packet Timing Advance Control Channel in the Uplink direction (PTCCH/U) is used by an MS to transmit a random access burst. With this information, the BSS estimates timing advance. In the downlink, the BSS uses PTCCH/D to transmit timing advance information updates to several MSs.

The GPRS common control signaling is conveyed on PCCCH. If PCCCH is not allocated, the existing GSM Common Control Channel is used. Two concepts are employed for GPRS channel management. In the master-slave concept, a master PDCH accommodates PCCCHs to carry all necessary control signaling for initiating packet transfer. Other PDCHs serve as slaves for user data transfer (PDTCH) and for dedicated signaling. In the capacity-on-demand concept, PDCHs are dynamically allocated based on the actual amount of packet transfers. Also, the number of allocated PDCHs in a cell can be increased or decreased according to traffic change. GPRS performs fast release of PDCH to share the pool of radio resources for both packet and circuit-switched services.

4.1.2. Um protocol layers

As shown in Figure 2, Um protocol layers include Physical RF, Physical Link Layer (PLL), and Radio Link Control/Medium Access Control (RLC/MAC) layers. Physical RF layer performs modulation/demodulation received from/sent to PLL. PLL provides services for information transfer over a physical channel including data unit framing, data coding, and the detection and correction of physical medium transmission errors.

The RLC/MAC layer provides services for information transfer over the GPRS physical layer. These functions include backward error correction procedures enabled by the selective retransmission of erroneous blocks. RLC is responsible for block segmentation and reassembly, buffering and re-transmission with backward error correction. MAC is responsible for channel access (scheduling, queueing, contention resolution), PDCH multiplexing, and power control.

Four GPRS coding schemes CS1, CS2, CS3 and CS4 are defined, whose characteristics are listed in Table I. Initially only CS1 and CS2 will be developed. The table indicates that the GPRS channel coding schemes increase data rate at the cost of decreasing protection (correction capability). These coding schemes also reduce worst link budget and cell range. For GSM, the worst link budget is 142.5 dB and the

Table I. Characteristics of the GPRS coding schemes.

Coding scheme	CS1	CS2	CS3	CS4
User data rate	9.05 Kb s ⁻¹	13.4 Kb s ⁻¹	15.6 Kb s ⁻¹	21.4 Kb s ⁻¹
Correction capability	Highest			None
Worst link budget	135 dB	133 dB	131 dB	128.5 dB
Maximum cell range	450 m	390 m	350 m	290 m

maximum cell range is 730 m. On the other hand, the GPRS worst link budget is 135–128.5 dB and the maximum cell range is 450–290 m.

4.1.3. Enhanced data rates for GSM evolution

With GSM radio technology, GPRS only provides limited data capacity. To increase the GSM data rate, Enhanced Data Rates for GSM Evolution (EDGE) was introduced under the same GSM frame structure. EDGE standardization has been in progress, and the EDGE Link Quality Control (LQC) scheme was agreed in the first quarter of 1999. Based on EDGE, Enhanced GPRS (EGPRS) provides user data rates two to three times higher than GPRS (up to 470 Kb s⁻¹ for indoor and 144 Kb s⁻¹ for outdoor) and its spectrum efficiency is two-to-six times higher than GPRS (up to 0.7 b s⁻¹ Hz⁻¹ per site). These goals are achieved by utilizing 8-PSK modulation and adapting user rate to channel quality. To be compatible with GMSK used in GSM and IS-136, EDGE accommodates both GMSK and 8-PSK. EDGE follows the same TDMA format, carrier spacing (200 KHz), symbol rate (271 Ksymb s⁻¹), burst format and training sequences used in GSM. EGPRS also utilizes same spectrum and same amount of ISI from modulation as GSM does. Thus EDGE can reuse GSM sites and frequency plan.

At the physical layer, blind detection of modulation is used to avoid signaling before changing modulation and parallel equalizations. In EDGE transmitter design, the Power Amplifiers (PAs) utilize linear modulation that is more complex than constant envelop modulation used in GSM. For the same PA, maximum average power for 8-PSK is lower than that for GMSK. The Peak to Average Ratio (PAR) for 8-PSK is 3.2dB while the PAR for GMSK is 0dB. The equalizer in EDGE receiver design is different from that in GSM. For GMSK, 5 tap equalizing window is enough. For 8-PSK, 7-8 tap equalizing window is necessary. For the same ISI, 8-PSK is more sensitive to interference than GMSK is.

EDGE LQC combines link adaption and incremental redundancy. Link adaption selects modulation

and coding schemes (MCSs) based on link quality measurements. In the link adaption procedure, the MS first measures the downlink performance, and reports the results to the BSS. The BSS measures the uplink performance, chooses the uplink and downlink MCSs based on the collected measurements. The BSS sends an uplink MCS command to the MS. Based on the command, the MS selects appropriate MCS for uplink transmission.

Incremental redundancy increases robustness for retransmission in EDGE. Specifically, the more often a data block is retransmitted, the more overhead (increments to acknowledgement and signaling) is added to the data block. Incremental redundancy relies little on measurements, which is mandatory for EDGE MSs.

To implement EDGE, the BTS in the existing GSM standard should be modified [11]. Specifically, the transceiver units should be enhanced to accommodate new power amplifiers in the transmitter and new equalizers in the receiver. Furthermore, transmission capacity between BTS and BSC must be increased. EGPRS supports maximum bit rate up to 8 × 59.2 Kb s⁻¹ at the RLC/MAC layer. This high data rate is achieved under good propagation conditions. Thus EDGE and EGPRS is appropriate for indoor environments with pico- and micro-cells.

4.2. Gb interface

The Gb interface connects the BSS and the SGSN, which allows many users to be multiplexed over the same physical resource. Unlike GSM A interface where the resources of a circuit-switched connection are dedicated to a user throughout the whole session, GPRS Gb interface only allocates resources to a user during the periods when data are actually delivered. As shown in Figure 2, the Gb interface protocol layers (from the highest to the lowest) include LCC, SNDCP, Base Station System GPRS Protocol (BSSGP), Network Service (NS) Layer, Link Layer 2, and Physical Layer. The Gb link layer 2 establishes Frame Relay virtual circuits between SGSN and BSS. On these virtual circuits, the NS transports

BSSGP Packet Data Units (PDUs) between a BSS and an SGSN. On the BSS side, the Relay function is required to provide buffering and parameter mapping between the RLC/MAC (for the Um interface between the BSS and the MS) and the BSSGP (for the Gb interface between the BSS and the SGSN). LLC is a sublayer of layer 2. The purpose of LLC is to convey information between layer-3 entities in the MS and SGSN. LLC provides one or more logical link connections with sequence control (to maintain the sequential order of frames across a logical link connection), flow control, detection of transmission, format and operational errors on a logical link connection and recovery from detected transmission, format, and operational errors. LLC maintains a ciphered data link between an MS and an SGSN, which is independent of the underlying radio interface protocols. This connection is maintained as the MS moves between cells served by the same SGSN. When the MS moves to a new SGSN, the existing connection is released and a new logical connection is established with the new SGSN. The LLC layer supports several QoS delay classes with different transfer delay characteristics described in Section 2. The LLC layer supports transmission with both unacknowledged and acknowledged modes. LLC provides service to the GPRS Mobility Management (GMM) protocol in the signaling plane (see Figure 3). GPRS Mobility Management (GMM) uses the services of the LLC layer to transfer messages between the MS and the SGSN. GMM includes functions such as attach and authentication, and transport of session management messages for functions such as PDP context activation and deactivation. In the transmission plane in Figure 2, the SNDCP above the LLC performs multiplexing of data coming from the different sources to be sent across LLC. It also performs segmentation and reassembly, compression of redundant protocol information and user data. GPRS supports several network layer protocols providing protocol transparency for the users of the service. Introduction of new network layer protocols to be transferred over GPRS will be possible without any changes to GPRS. SNDCP ensures that all functions related to transfer of network layer PDU are carried out in a transparent way by the GPRS network entities. Based on compression techniques, the SNDCP also provides functions that help to improve channel efficiency. The set of protocol entities above SNDCP consists of commonly used network protocols. They all use the same SNDCP entity, which then performs multiplexing of data coming from different sources

to be sent using the service provided by the LLC layer.

4.2.1. Network service

The NS Layer delivers encapsulated packets between SGSN and BSS that are connected directly by a frame relay link or indirectly through cascading links in a frame relay network. Each physical frame relay link supports one or more Network Service Virtual Links (NS-VLs). The NS-VLs are connected to construct an end-to-end virtual path between the BSS and SGSN. This path is called Network Service Virtual Connection (NS-VC). The NS manages NS-VCs with operations such as

- Blocking (when a NS-VC is not available)
- Unblocking (when a NS-VC becomes available again)
- Resetting (when, e.g., a new NS-VC is set up)
- Testing (to check that end-to-end communication exists between peer NS entities on a given NS-VC)

The NS also performs load sharing to distribute the packet traffic among the unblocked NS-VCs of the same BVC. The NS utilizes UNITDATA service primitive to transfer packets, CONGESTION service primitive to report congestion, and STATUS primitive to inform the NS user of events such as change in the available transmission capabilities.

A group of NS-VCs supports a BSSGP Virtual Connection (BVC) used to transport packets between NS users. BVCs provide communication paths between BSSGP entities. Each BVC is used in the transport of BSSGP PDUs between peer point-to-point functional entities, peer point-to-multipoint functional entities and peer signaling functional entities. For every BVC, QoS profile and the MS identification are used to create queues and contexts in both the SGSN and the BSS. The flow control mechanism is exercised based on these queues and contexts to be elaborated next.

4.2.2. BSS GPRS protocol

BSSGP provides the radio-related QoS and routing information required to transmit user data between a BSS and an SGSN. It also enables the SGSN and BSS to operate node management control functions. If an SGSN simultaneously communicates with multiple BSSs, then there is one BSSGP protocol machine in the SGSN corresponding to each of the BSSs. Several

service models are supported by BSSGP: BSSGP/RL, GMM, and NM.

BSSGP service model in the SGSN controls the transfer of LLC frames across the Gb interface. Relay (RL) service model in the BSS controls the transfer of LLC frames between the RLC/MAC function and BSSGP. Examples of the RL/BSSGP service primitives provided by the BSSGP are DL-UNITDATA and UL-UNITDATA. An UL-UNITDATA PDU is delivered from the BSS to the SGSN. A DL-UNITDATA PDU is delivered from the SGSN to the BSS. Besides the user information (an LLC packet), the PDU contains RLC/MAC-related information such as MS radio access capability, QoS profile, and the PDU lifetime. If the PDU is queued in the BSS longer than the PDU lifetime, then it is discarded at the BSS. Based on the QoS profile, a layer-3 signaling PDU may be transmitted over the Um interface with higher protection compared with a data PDU. The PDU is either acknowledged using RLC/MAC ARQ functionality or unacknowledged using RLC/MAC unitdata functionality.

GPRS Mobility Management (GMM) service model performs mobility management functions between an SGSN and a BSS. Examples of the GMM service primitives provided by the BSSGP are PAGING, SUSPEND, and RESUME. The PAGING procedure is invoked by SGSN to inform the BSS for packet-switched (if initiated by the SGSN) or circuit-switched (if initiated by an MSC/VLR) transmissions. In this procedure, the SGSN will instruct the BSS to page one or more cells. To suspend a GPRS service, an MS initiates the SUSPEND procedure by requesting the BSS to send a SUSPEND PDU to the SGSN. On the other hand, when an MS resumes its GPRS service, the BSS instructs the MS to update the routing area. Alternatively, the BSS may send a RESUME PDU to the SGSN to indicate that the MS should be resumed for GPRS service.

Network Management (NM) service model handles functions related to Gb interface and BSS/SGSN node management. Examples of the NM service primitives provided by the BSSGP are FLOW-CONTROL-BVC and FLOW-CONTROL-MS used to control the downlink loading of the BSS per BVC and per MS, respectively. No flow control is performed in the uplink direction because the packet sending rate at the MS is anticipated to be lower than the packet processing rate on the network side. There is a downlink buffer for each BVC. If a PDU in the downlink is not transferred to the MS before its lifetime expires, the PDU is deleted from the BVC downlink

buffer and this action is reported to the SGSN. To control downlink transmission at the SGSN, a flow control message FLOW-CONTROL-BVC (FLOW-CONTROL-MS) with parameters such as the bucket size and the bucket leak rate for a given BVC (MS) are sent from the BSS to the SGSN.

4.3. Gn and Gp interfaces

Both Gn and Gp interfaces utilize the GPRS Tunneling Protocol (GTP). GTP tunnels user data and signaling messages between GSNs. In the Gn interface, the GSNs are within the same GPRS network. On the other hand, Gp involves the GSNs in different GPRS networks. Basically Gp is the same as Gn except that extra security functionality is required for inter-network communications over the Gp interface. The security functionality is based on mutual agreements between operators. With GTP, an SGSN may communicate with multiple GGSNs and a GGSN may connect to many SGSNs. MS, BSS, MSC/VLR, and HLR are unaware of the existence of GTP.

In the transmission plane in Figure 2, GTP is supported by Transmission Control Protocol (TCP) for connection-oriented transmission and is supported by User Datagram Protocol (UDP) for connectionless transmission. GTP transmission uses a tunneling mechanism to carry user data packets. A tunnel is a two-way point-to-point path. Tunneling transfers encapsulated data between GSNs from the point of encapsulation to the point of decapsulation. GTP follows out-of-band signaling where the signaling path is logically separated from the data tunnels. In the signaling plane, GTP is supported by UDP, which enables the SGSN to provide GPRS network access for an MS.

More than one path may be established between two GSNs either in the same network or in different networks, and a path may be used by one or more tunnels. A GTP tunnel is defined by the associated PDP contexts in two GSN nodes and is identified with a Tunnel ID. GTP performs (1) path management, (2) tunnel management, (3) location management, and (4) mobility management. In path management, the GSNs exchange the Echo_Request and Response message pair to quickly detect failures occurring in the path.

Location management is required if a GGSN does not support SS7 MAP for communications with HLR. In this case, the interaction between the GGSN and the HLR is done indirectly through a specific GSN that performs GTP-MAP protocol conversion.

Tunnel management and mobility management are described in the following subsections.

4.3.1. GTP tunnel management

GTP tunnel management creates, updates, and deletes tunnels. Some of the tunnel management messages are described below.

To activate a PDP context for an MS, Create_PDP_Context_Request and Response message pair is exchanged between SGSN and GGSN. The SGSN selects the IP address of a GGSN from a list maintained in the Domain Name Service (DNS) server, and sends the Create_PDP_Context_Request message to that GGSN. If the GGSN does not respond, the SGSN continues to send the request message to the next GGSN in the DNS list until the request message is accepted or the list is exhausted. Upon receipt of this message, the GGSN creates a PDP context entry for the MS and generates a charging identification. The new entry allows the GGSN to route and charge packets between the SGSN and the external PDP network. Based on the capabilities and current load of the GGSN, the negotiated QoS may be more restricted than the requested QoS specified by SGSN. The GGSN returns a Create_PDP_Context_Response message to the SGSN. The message indicates whether TCP or UDP will be used to transport user data. Note that only one path is used between any given GSN-pair to tunnel end user traffic in both directions.

To update the routing area information or a PDP context, an SGSN sends the Update_PDP_Context_Request message to a GGSN. The message includes the new SGSN address, tunnel identification and QoS negotiated. Upon receipt of this message, the GGSN may reject the update request if QoS negotiated received from the SGSN is not compatible (for example, the reliability class is insufficient to support the PDP type). The GGSN may also restrict QoS negotiated based on its capabilities and the current load. If the GGSN returns a negative Update_PDP_Context_Response message, the SGSN deactivates the PDP context. GTP may also use this message pair to redistribute PDP contexts for load balancing.

To detach an MS or to deactivate a PDP context, an SGSN and a GGSN exchange the Delete_PDP_Context_Request and Response message pair. This action deactivates an activated PDP context. To activate a PDP context, the GGSN sends the PDU_Notification_Request message to the SGSN indicated by the HLR, i.e., the SGSN serving the MS. When receiving this

message, the SGSN is responsible for requesting the MS to activate the indicated PDP context, and replies PDU_Notification_Response message to the GGSN.

4.3.2. GTP mobility management

GTP mobility management supports functions such as GPRS attach, GPRS routing area update and activation of PDP contexts. Some of them are described next.

When an MS moves from the old SGSN to the new SGSN, it sends P-TMSI to the new SGSN. The new SGSN then exchanges the Identification_Request and Response message pair with the old SGSN to obtain the IMSI of the MS. The IMSI is used to retrieve the MS record in the HLR. The Identification_Request and Response message pair is equivalent to the MAP_SEND_IDENTIFICATION message pair in GSM.

SGSN_Context_Request message is sent from the new SGSN to the old SGSN to obtain the MM and all active PDP contexts of an MS. The message includes old routing area identification, old P-TMSI, new SGSN Address and so on. Upon receipt of the message, the old SGSN sends the requested contexts (MM context, PDP contexts, and LLC Acknowledgement) to the new SGSN by the SGSN_Context_Response message.

After the new SGSN receives these contexts, it acknowledges the old SGSN by sending the SGSN_Context_Acknowledge message. This message implies that the new SGSN is ready to receive the data packets for the corresponding MS. Then the old SGSN starts to forward user data packets to the new SGSN.

4.4. Gs interface

The Gs interface connects the databases in the MSC/VLR and the SGSN, which does not involve user data transmission. Base Station System Application Part+ (BSSAP+) implements the functionality for the Gs interface. As shown in Figure 3, BSSAP+ utilizes SS7 Signaling Connection Control Part [12] as the lower layer protocol.

The BSSAP+ procedures coordinate the location information of MSs that are both IMSI and GPRS attached. It is also used to convey some GSM procedures via the SGSN. The paging, suspend, resume, and location update procedures are described here. Other Gs procedures can be found in Reference [13].

The paging procedure for the MSC/VLR-based services allows the VLR to utilize GPRS to page a

Class A or a B MS that is simultaneously IMSI and GPRS attached. By doing so, the system needs not repeat paging of an MS for both GSM and GPRS services, and the overall paging load on the radio interface is expected to be reduced. The VLR initiates this procedure by sending the GPRS_PAGING message to the SGSN. This message has a structure similar to the PAGING message delivered on the A interface. When the SGSN receives the GPRS_PAGING message, it checks if the MS is GPRS attached and is known by the SGSN. If so, the SGSN sends the Gb PAGING message to the BSS as described in Section 4.2. The SGSN then forwards the paging result back to the VLR. If the MS does not respond, the VLR or the BSS should retransmit the paging message. The SGSN is not responsible for retransmission of the Gb PAGING message.

To perform the circuit-switched activity for a Class B MS that is simultaneously IMSI and GPRS attached, the VLR uses the Suspend procedure to inform the SGSN to suspend the GPRS activities of the MS. When the MS sends the circuit-switched activity request to the VLR, the VLR waits for a period T6-1, then it sends a SUSPEND message to the corresponding SGSN. Upon receipt of the SUSPEND message, the SGSN suspends the GPRS activity of the MS. If the MS sends GPRS signaling message to the SGSN within a period T6-3, the SGSN accepts the message, and may inform the VLR of the situation. On the other hand, if the MS is unknown to the SGSN, then the SGSN returns a SUSPEND_FAILURE message to the VLR. If the VLR does not receive a SUSPEND_FAILURE message within a period T6-2, then the suspend action is considered successful. Otherwise, the action fails.

Upon release of the circuit-switched activity for a Class B MS that is simultaneously IMSI and GPRS attached, the VLR sends a RESUME message to the SGSN to resume the GPRS activities for the MS. If the VLR does not receive a response message from the SGSN within a period T7, then the VLR repeats sending the RESUME message up to N7 times. In the normal situation, the SGSN resumes the GPRS activities for the MS and returns a RESUME_ACKNOWLEDGE message to the VLR.

In GPRS location update, an MS sends a Location Updating Request to the SGSN through the Um and Gb interfaces. If this request is accepted by the SGSN, the SGSN sends a GPRS_LOCATION_UPDATING_Request message to the VLR. The VLR checks if the IMSI is known. If not, the VLR retrieves the MM context of the MS from the HLR. If the SGSN does

not hear from the VLR within a period T8-1 or if the VLR replies a GPRS_LOCATION_UPDATING_Reject message, the SGSN informs the MS that location update fails. If the update is successful, the VLR returns a GPRS_LOCATION_UPDATING_Accept message to the SGSN, and the SGSN sends a positive Location Updating Response message to the MS.

4.5. Gi interface

GPRS interworks with Public Switched Data Network (PSDN) and Packet Data Network (PDN) through the Gi Interface. In the Gi interface, GGSN serves as the access point of the GPRS network to the external data network. The interworking models to PSDN include X.25 and X.75, and the interworking models to PDN include IP and Point-to-Point Protocol (PPP).

Both X.75 and X.25 are supported for GPRS interworking with PSDN. In these models, an MS is assigned an X.121 address to be identified by PSDN. This X.121 address is either permanently allocated by the PSDN operator following the PSDN numbering plan or dynamically assigned by the GPRS network at PDP context activation. In the latter case, the GPRS network maintains a free pool of X.121 addresses to be allocated to the MSs.

GPRS interworks with intranets or the Internet based on the Internet Protocol (IP), either IPv4 or IPv6. Viewing a GGSN as a normal IP router, the external IP network considers the GPRS network as just another IP network. The GPRS operator may maintain a firewall to restrict the usage of IP applications. In the firewall, GPRS may perform screening specified by the operator or the subscriber. This feature is important to avoid unsolicited mobile terminated connection (such as junk mails being sent to the MSs).

Either the external IP network or the GPRS network (specifically, the GGSN) manages a DNS. The IP address of an MS can be statically assigned at the subscription or dynamically assigned at the PDP context activation. If the IP address is dynamically allocated, the address assignment procedure is performed by the GGSN or an external DHCP server.

GPRS may transparently access the Internet and non-transparently access an intranet and/or ISP. In the transparent Internet access, the IP address of an MS is allocated from the GPRS operator's addressing space. This address is used for packet forwarding between the Internet and the GGSN and among

the GGSNs. The MS needs not send any authentication request at PDP context activation and the GGSN needs not involve in user authentication and authorization. Domain name services are provided by GPRS in this case.

In non-transparent access to an Intranet or ISP, the IP address of an MS is allocated from the Intranet/ISP address space where the address allocation server belongs to the Intranet/ISP. At PDP context activation, the MS must be authenticated by the Intranet/ISP using a security protocol agreed upon by the GPRS operator and the Intranet/ISP. Domain name services are provided by the Intranet/ISP.

GPRS may provide connection to intranet/ISP through the transparent Internet access where a bearer service is provided to tunnel a private Intranet using protocols such as IPsec. In this case, GPRS involves in the security processes by using IPsec security or header authentication for user authentication and for the confidentiality of user data.

5. Evolving from GSM to GPRS

By reusing GSM infrastructure, most GPRS implementation costs of the existing GSM nodes are software related. As illustrated in Table II, major hardware impact on the GSM network is limited to the addition of a PCU-model to the BSC and the introduction of two new node types: SGSN and GGSN. GPRS software upgrade can be performed efficiently. In many vendor solutions, GPRS software can be remotely downloaded to BTSs, so that no site visits are needed. In the MS development, a major challenge is to resolve power consumption issue. To support data-related features (e.g., multiple timeslots transmission), GPRS MS consumes much more power than a standard GSM MS.

The GPRS protocols have a good characteristic in that each layer can be reused to support features in different GPRS nodes. The GPRS stack is

Table II. GSM network elements impact by GPRS.

Element	Software	Hardware
MS	Upgraded required	Upgraded required
BTS	Upgraded required	No change
BSC	Upgraded required	PCU interface
TRAU	No change	No change
MSC/VLR	Upgraded required	No change
HLR	Upgraded required	No change
SGSN	New	New
GGSN	New	New

designed so that multiple copies of every layer can be distributed across multiple processors. Thus, it can smoothly scale the network capacity to handle large volumes of data. For example Reference [14], the same SNDCP code can support both SGSN and MS. In other words, the SGSN code can be reused in the MS. GPRS protocol products can be implemented in general computer languages. For example, Trillium delivers its GPRS protocol software in standard C programming language. Lucent/Optimary GmbH provides GPRS protocol stack customization with man machine interface, which is designed to be modular and portable.

GPRS is typically deployed in two phases. Phase 1 deployment implements basic GPRS features including:

- Standard packet services delivery, i.e., point-to-point packet bearer service.
- Support for CS-1 and CS-2 channel coding schemes.
- GPRS internal network interfaces such as Gn, Gb, Gp, and Gs.
- Flexible radio resource allocation, i.e., multiple users per timeslot and multiple timeslots per user.
- Support for Classes B and C MSs.
- GPRS charging, e.g., packet-based billing and QoS-based billing.
- GSM-based services such as SMS over GPRS.
- IP and X.25 interfaces to packet data network.
- Static and dynamic IP address allocation.
- Anonymous access.
- Security, i.e., authentication and ciphering.

In Phase 1 development, most vendors cover parts of, or all above, features with some variations. For example, Nortel's Phase 1 development also considers advanced virtual private network features. Alcatel's Phase 1 deployment covers the entire network with a limited investment such as BSS software update, a single A935 MFS per MSC site, and one SGSN and one GGSN for the entire network. In Ericsson's Phase 1 development, the applications are based on IP, X.25 and SMS.

GPRS Phase 2 development includes the following features:

- Enhanced QoS support in GPRS.
- Unstructured octet stream GPRS PDP type.
- Access to ISPs and Intranets.
- GPRS prepaid.
- GPRS advice of charge.

- Group call.
- Point to multi-point services.

In Nortel's Phase 2 development, the capacities of SGSN and GGSN will be significantly increased. Inter-SGSN handoff is implemented and inter-GPRS network roaming is supported. In Ericsson's Phase 2 development, the enhanced applications will include PTM services, multicast and group call. In Alcatel's Phase 2 development, 935 MFS will be smoothly upgraded, the SGSN and GGSN capacity will be increased, and security will be enhanced.

6. Summary

This article provided an overview of GPRS. We described the GPRS architecture and the related interfaces. Based on our discussion, benefits of GPRS include efficient radio usage, fast set-up/access time, and high bandwidth with multiple timeslots. GPRS reuses GSM infrastructure so that both circuit-switched and packet-switched services co-exist under one subscription. GPRS also provides a smooth path to evolve from GSM to the third generation mobile network. Specifically, a third generation network can continue to utilize the GPRS IP backbone network. However, GPRS has its limitations. For example, based on existing GSM technology, radio resources for GPRS in a cell is limited and the GPRS data rate is probably too low for many data applications. This problem can be resolved by introducing the EDGE or the third generation radio technologies.

Although GPRS is an emerging technology driven by the equipment suppliers instead of the push from the customers, it has generated strong interest among service providers. Owing to the explosive growth of Internet applications, it is believed that data access is an important trend for mobile services. An obvious advantage of GPRS is that no dial-up modem connection is required to access data. After PDP context activation, the MS becomes an 'always-on' device that facilitates instant connections. This feature is required for mobile computing where information should be sent or received immediately as the need arises. Several potential GPRS applications have been identified [8]:

- Vertical applications for specific data communication requirements of companies: since a mobile phone can be an always-on device, a GPRS MS can always be connected to deliver information. Examples include traffic management (e.g., fleet

management, vehicle tracking, vehicle control and guidance) and monitoring automation (e.g., telemetry and security).

- Horizontal applications for individual users: in this type of application, the mobile phone is a media device so that the moving users can receive services such as entertainment (e.g., games and music), location information (e.g., restaurants, cinema, hotels, and parking), and so on.

GPRS also allows commerce transactions when the customers are in motion. Examples include on-line banking transactions, stock transactions, gambling, ticketing (e.g., for cinema, flights, and trains), on-line shopping, and so on.

We note that the high immediacy feature of GPRS is essential for commerce transactions where it is unacceptable to keep the customers waiting.

For a moving user, GPRS is ideal for immediate handling of functions such as quick access to PIM information, E-mail, or note taking, which eliminates the need of accessing to the desktop or laptop's full-featured applications and the broad range of peripherals and services.

Many GPRS contracts are awarded in Asia, Australia, and Europe. The reader is referred to Reference [15] for the details. For an in-depth reading of GPRS documents, the reader is recommended to start with the general descriptions [3, 16, 17] and then continue on specific topics such as Um [6, 18–20], Gb [21, 22], [23] Gs [13] Gn/Gp [24], Gi [25], and charging [26]. Also, vendors' view of GPRS can be found on several Web sites [7, 9, 14, 27]. For the GPRS suppliers' market share, the reader is referred to Reference [15].

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References.

1. Aslundh A. GPRS—General Packet Radio Services. *The Next Generation Wireless Communications Conference* FarEastone, 1999.

2. Faccin S, Hsu L, Koodli R, Le K, Purnadi R. GPRS and IS-136 Integration for Flexible Network and Services Evolution. *IEEE Personal Communications* 1999; 6(3): 48–54.
3. Bettstetter C, Vogel H-J, Eberspacher J. GSM phase 2+ general packet radio service GPRS: architecture, protocols, and air interface. *IEEE Communications Surveys* 1999; 3(3).
4. ETSI/TC. Mobile Application Part (MAP) Specification, Version 4.8.0. *Technical Report Recommendation GSM 09.02*, ETSI, 1994.
5. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); Mobile Station (MS) Supporting GPRS. *Technical Report Recommendation GSM 07.60, Version 7.0.0*, ETSI, 1998.
6. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Ciphering Algorithm Requirements. *Technical Report Recommendation GSM 01.61, Version 6.0.1*, ETSI, 1997.
7. Siemens. <http://www.siemens.de/ic/networks/gg/ca/n3-p31-2.pdf>.
8. Alcatel. <http://www.alcatel.com/telecom/rcd/netsol/operator/mobile/gprs>.
9. Symmetry Communications Systems. <http://www.symmetry-comm.com>.
10. Ericsson. GPRS—Always connected, always on-line. *Private Communications*. Viewgraph: ERA/LKG/T-99:0023 Rev. A, 1999.
11. Javerbring S. EDGE—Enhanced data rates for GSM evolution. *The Next Generation Wireless Communications Conference*, FarEastone, 1999.
12. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Serving GPRS Support Node (SGSN)—Visitors Location Register (VLR) Gs Interface Network Service Specification. *Technical Report Recommendation GSM 09.16, Version 7.0.0*, ETSI, 1998.
13. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Serving GPRS Support Node (SGSN)—Visitors Location Register (VLR) Gs Interface Layer 3 Specification. *Technical Report Recommendation GSM 09.18, Version 1.2.0*, ETSI, 1997.
14. Trillium Digital Systems. GPRS White Paper. <http://www.trillium.com>, 1999.
15. Mobile Lifestreams Limited <http://www.mobileGPRS.com>.
16. ETSI/TC. GPRS Service description Stage 2. *Technical Report Recommendation GSM 03.60, Version 7.0.0 (Phase 2+)*, ETSI, 1998.
17. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Service Description Stage 1. *Technical Report Recommendation GSM 02.60, Version 7.0.0*, ETSI, 1998.
18. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); Overall Description of the GPRS Radio Interface Stage 2. *Technical Report Recommendation GSM 03.64, Version 7.0.0*, ETSI, 1997.
19. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Mobile Station—Serving GPRS Support Node (MS-SGSN) Logical Link Control (LLC) Layer Specification. *Technical Report Recommendation GSM 04.64, Version 6.3.0*, ETSI, 1997.
20. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Mobile Station (MS)—Serving GPRS Support Node (SGSN) Subnetwork Dependent Convergence Protocol (SNDCCP). *Technical Report Recommendation GSM 04.65, Version 6.2.1*, ETSI, 1997.
21. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Base Station System (BSS)—Serving GPRS Support Node (SGSN) Interface; Gb Interface Layer 1. *Technical Report Recommendation GSM 08.14 Version 6.0.0*, ETSI, 1997.
22. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Base Station System (BSS)—Serving GPRS Support Node (SGSN) interface—Network Service. *Technical Report Recommendation GSM 08.16, Version 7.1.0*, ETSI, 1998.
23. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Base Station System (BSS)—Serving GPRS Support Node (SGSN) BSS GPRS Protocol (BSSGP). *Technical Report Recommendation GSM 08.18, Version 7.0.0*, ETSI, 1998.
24. ETSI/TC. GPRS Tunnelling Protocol (GTP) across the Gn and Gp Interface. *Technical Report Recommendation, GSM 09.60, Version 7.0.0 (Phase 2+)*, ETSI, 1998.
25. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Interworking between the Public Land Mobile Network (PLMN) Supporting GPRS and Packet Data Networks (PDN). *Technical Report Recommendation GSM 09.61, Version 7.1.0*, ETSI, 1998.
26. ETSI/TC. European Digital Cellular Telecommunications System (Phase 2+); GPRS Charging. *Technical Report Recommendation GSM 12.15*, ETSI, 1998.
27. Nokia. <http://www.nokia.com/networks/17/gprs/gprs1.html>.