TDMA frame can be combined. Depending on the codec speed (see sidebar table), this allows for transmission speeds of up to 171.2 kbps (8 timeslots @ 21.4 kbps).

(Note: CS-3 and CS-4 require modifications to the Base Tranceiver Station and won't be implemented by most operators in the beginning.)

- Asymmetric resource allocation: Uplink and downlink resources are allocated separately and may differ in size/capacity/rate.

EDGE (Enhanced Data Rates for Global Evolution) increases the data throughput of GSM systems to over 473 kbps per carrier and is also called EGRPS (Enhanced General Radio Packet Service). As the term EDGE suggests, this technology supports higher data rates via enhanced modulation schemes on the radio interface, known as 8-PSK (Phase Shift Keying) and GMSK (Gaussian Minimum Shift Keying). EDGE, expected to be deployed in 2001, is a mayor step in providing 3G services over GSM systems. As an overlay solution to existing networks, EDGE does not require modifications to the existing air interface. EDGE is especially designed for operators that do not have additional spectrum allocated for UMTS, but still wish to offer competitive applications (e.g. multimedia) using the existing band allocation.

Network Architecture

The GSM Environment Today

Existing GSM networks (Phase 1or Phase 2) consist of a radio access network called a Base Station Subsystem (BSS), a core network solution referred to as a Network Switching Subsystem (NSS), and an Operation Subsystem (OSS). The BSS consists of Base Station Controllers (BSC) which are responsible for the radio resource control, Base Transceiver Stations (BTS) which handle ciphering, encoding, burst generation, radio frequency generation, etc. The Transcoder and Rate Adaptor Unit (TRAU) compresses 64 kpbs voice data to 13 kbps (Full Rate), 12.2 kbps (Enhanced Full Rate), and 5.6 kbps (Half Rate) and performs rate adaptation for data applications.

The NSS is made up of Mobile Services Switching Centers (MSC), which perform classical exchange tasks including traffic switching, flow control, and signaling data analysis. In cooperation with other network elements, the NSS handles mobile-specific tasks such as mobility management and authentication. Logically, MSCs may be either Visited MSCs (VMSC), which are responsible for all the mobile devices in its supply area, or Gateway MSCs (GMSC), which are the interworking nodes to the external public telephone networks. The Visitor Location Register (VLR) associated with the VMSC holds relevant subscriber data for all subscribers currently within the range of the VMSC - including international mobile subscriber identity (IMSI) and a record of subscribed services. The Home Location Register (HLR) supplies the VLRs with this data and supports the Mobile Terminating Calls (MTC). The Authentication Center (AC or AuC) generates the Triplets (RAND, SRES, kc) necessary for the authentication of the subscriber. Finally, the optional Equipment Identity Register (EIR) is used to check the validity of the subscribers' handheld. GSM networks are circuit switched and normally use SS7 for signaling and control information.

GPRS Enhancements to the GSM Network

With the introduction of GPRS, both the BSS and the NSS must be enhanced to support the key features outlined above (see GPRS: Preparing GSM Networks for the Internet). Several new logical network elements[5] enable the following high-level GPRS functions:

Network Access Control – A set of procedures are defined in GPRS to control access to the network's services and facilities. The subscriber may access the network via the air interface or an external packet data network. The operator can offer support for several protocols (X.25, IPv4, etc.) for access to external PDNs. The operator determines the extent to which services and access are restricted; six network access control functionalities are defined within the GPRS recommendations:

1. Registration: The user and the services to which he or she has subscribed must be known at the HLR. This includes the packet data protocols (PDP) subscribed for, the external PDNs (so-called access points) he or she is allowed to use, and the addresses (X.25, IPv4, etc.) of the mobile device.
2. Authentication and Authorization: These processes verify the subscriber's right to access the network and to use a specific service. The accompanying procedures correspond to those used in GSM.
3. Admission Control: When a subscriber requests a certain minimum amount of resources (quality of service) with a service, admission control checks whether they can be made available.
4. Message Screening: This functionality is used to filter unsolicited and unauthorized messages/data to and from the subscriber. In GPRS Phase 1, this is only network controlled.
5. Packet Terminal Adaptation: The maximum size of packets which can be transmitted via the GPRS network is limited to 1500 octets. Larger packets have to be segmented.
6. Billing Data Collection

[5] These new network elements are described below in the GPRS Network Element Overview section.

Packet Routing and Transfer – Routing is the process of determining the paths available for transmitting data packets from their source to their destination, selecting the most appropriate path and adapting datagram formats to fit the underlying transmission technology. If a connectionless network service is applied, datagrams can take different routes between the same source and destination. Several functions are closely related to packet routing and transfer: *Relay, Address Translation* and *Mapping, Encapsulation, Tunneling, Compression, Encryption,* and *Domain Name Server*. This last function is used to translate logical names into the corresponding network element addresses. The logical name "Internet" can be translated so that the subscriber is connected to the closest network element providing Internet access.

Mobility Management – Keeping track of subscribers' locations is a crucial task in mobile networks. Instead of administrative sets of cells organized into Location Areas, Routing Areas are introduced in GPRS. Each Routing Area is assigned to an SGSN.

Logical Link Management – When running bursty applications, subscribers only require physical resources when sending or receiving data. While there is no transmission, these physical resources can be released and allocated to other subscribers. By doing so, higher resource efficiency can be realized on both the air interface and the transmission lines. But as long as the subscriber has not terminated the session, a logical link must continue to exist, so that downloads can be continued after a break, etc.

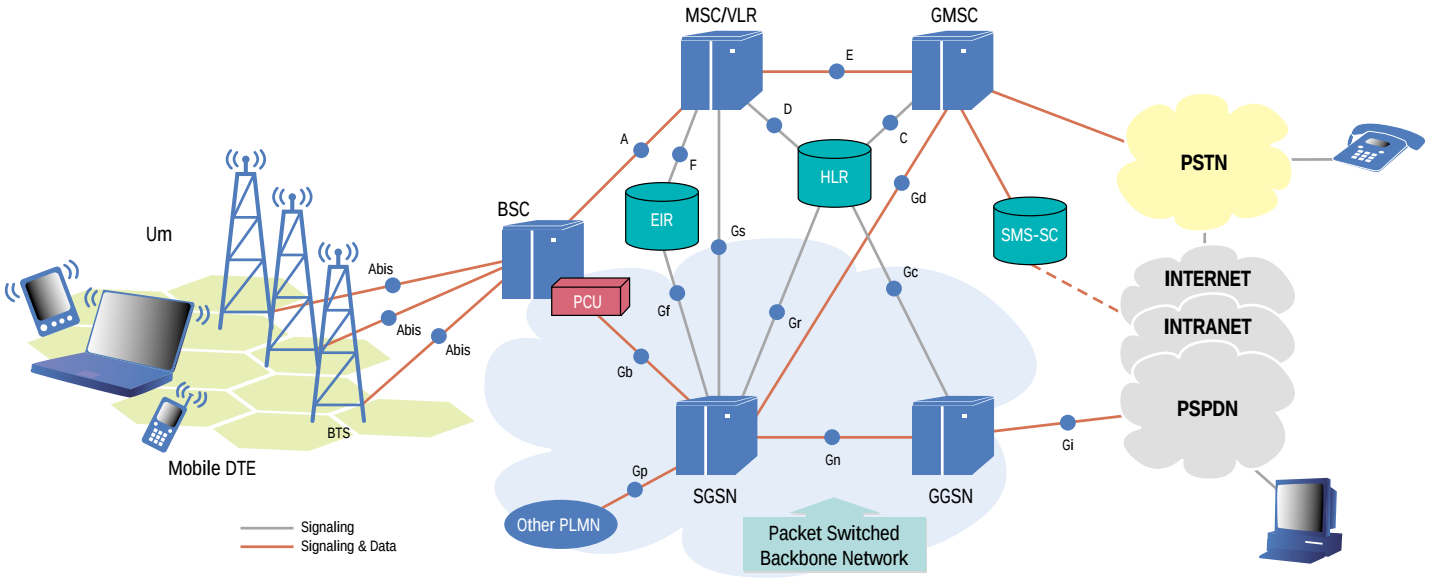
Radio Resource Management – This function comprises three functional groups:

- U_m Interface: realizes the "capacity on demand" concept.
- U_m Tranx: Medium access, the packet multiplexing, error detection and correction of the packet switched traffic via the air interface must be controlled and combined with a flow control.
- Path Management: The operator can determine the maximum amount of packet switched traffic realized by a set of cells. Hence, only a certain capacity of transmission resources are necessary between the BSS and the packet switched part of the NSS. The data rate over an established link for an individual subscriber can fluctuate over time. Therefore, the subscribers' traffic should be multiplexed on the transmission line between the BSS and NSS.

Network Management – Existing Operation and Maintenance Systems must be enhanced to supply the operator with all the necessary information to guarantee smooth running of the GSM-GPRS network. This includes alarms, remote control and statistical data collection.

GPRS Network Element Overview

To prepare existing GSM networks for GPRS, six new network elements are introduced.



▶ ***Figure 2:*** *GPRS Network Architecture*

1. GPRS Mobile Station: On the subscriber side, new handhelds are necessary to handle packet switched traffic over the air interface. Three different classes are defined:
   - Class A mobiles can handle both GSM circuit services and GPRS packet switched services simultaneously. GSM and GPRS signaling and control are also carried out simultaneously.
   - Class B mobiles can handle both GSM and GPRS signaling, but only GSM or GPRS traffic can be transmitted at any one time. If for example, a subscriber accepts a circuit switched call while downloading information from the Internet, GPRS data transmission is interrupted. As soon as the voice call is terminated, the download continues since the logical link between the mobile and the GPRS network still exists.
   - Class C mobiles can handle either GSM or GPRS. If a mobile station is connected to a GSM call, it is not available for GPRS traffic (and vice versa).

   Two of the new logical network elements are introduced to upgrade the BSS:
2. Packet Control Unit (PCU): The PCU is responsible for the capacity on demand feature. It decides which radio resources are dynamically allocated to packet switched and circuit switched use. The Base Station Controller (BSC) then manages the radio resources allocated for circuit switched use, while the PCU manages radio resources for the GPRS traffic itself. This includes channel access control, channel bundling, and data packet segmentation and re-assembly. The Um-Management Function and the Um-Tranx-Function are implemented by the GPRS mobile station and the PCU. The location of the PCU can be next to the SGSN (as stand alone unit), it can be next to or within the BSC cabinet, or at the BTS site.
3. Channel Codec Unit (CCU): The CCU implements the new coding schemes, power control, and timing advance procedures. In the beginning, most operators will only introduce the CS-1 and CS-2 codecs, because they can normally be implemented with a BTS software upgrade. The CS-3 and CS-4 codecs, however, require modifications to the BTS and may not be implemented as rapidly.

   In the NSS, a packet switched network is implemented parallel to the circuit switched domain. Three of the new logical network elements are introduced here:
4. Serving GPRS Support Node (SGSN): The SGSN is located on the same hierarchical level as the VMSC/VLR and performs similar tasks as outlined below. An SGSN is connected to the BSS, to neighboring SGSNs and GGSNs.
   - During the Network Access Control process, the SGSN is involved in the authentication and authorization procedures. The admission control procedure includes determination of QoS availability.
   - Mobility Management is realized based on the same principles as in the MSC/VLR. Note: There is a database in the SGSN which realizes the same tasks as the VLR, but is not a logical network element of its own.
   - The SGSN is responsible for switching traffic to the BSS and the network elements which establish the interconnection to external PDNs. An SGSN thus also performs the tasks of an ordinary (packet) router.
   - As several subscribers can be dynamically multiplexed onto a single timeslot, ciphering can no longer be performed by the BTS (as in circuit switched transmission) and is thus outsourced from the BTS to the SGSN. User data must be compressed before it is encrypted, so compression is also performed in the SGSN. On the other end, the same functions are performed by the GPRS mobile station.
   - The domain name server is logically associated with the SGSN.
   - Logical link management is realized between the SGSN and the mobile station, independent of the radio access system. A logical link between the SGSN and the handheld can be maintained even if there are no physical resources in use. Logical link management includes establishment, maintenance, and release.
   - Physical resources are managed between the SGSN and BSS (PCU) as part of the path management.
   - Billing information and statistical data are collected at the SGSN.
   - Interfaces to the BSS (PCU), the GGSNs, neighboring SGSNs, HLRs, EIRs, SMS-Centers, other PLMNs and the MSC/VLR are specified.
5. Gateway GPRS Support Node (GGSN): The GGSN is the interworking node between the external packet data networks and the packet switched part of the Network Switching Substation. It is located on the same hierarchical level as the GMSC in GSM networks and performs comparable tasks.
   - The GGSN is responsible for the packet routing and transfer procedures. The SGSNs and GGSNs are connected via an IP backbone. IPv4 can be implemented initially, but on the long run IPv6 shall be put into action.
   - The GGSN is involved in the Mobility Management process: When a call is placed to a mobile handheld, the GGSN sends a request to the Home Location Register to determine the SGSN currently serving the subscriber.
   - In GPRS Phase 1 it is responsible for the network orientated screening.
   - Billing information and statistical data are collected at the GGSN.
   - Interfaces to the SGSNs, external PDNs, and HLRs are specified.

		BSS		NSS		
Function	**MS**	**PCU**	**CCU**	**SGSN**	**GGSN**	**HLR**
Network Access Control						
Registration	•			•		•
Authentication and Authorization	•			•		•
Admission Control	•	•		•	•	
Packet Terminal Adaptation	•					
Charging Data Collection				•	•	
Packet Routing and Transfer						
Relay	•	•		•	•	
Routing	•	•		•	•	
Address Translation and Mapping	•			•	•	
Encapsulation	•			•	•	
Tunneling				•	•	
Compression	•			•		
Ciphering	•			•		•
Domain Name Server				•		
Mobility Management	•			•	•	•
Logical Link Management						
Logical Link Establishment	•			•		
Logical Link Maintenance	•			•		
Logical Link Release	•			•		
Radio Resource Management						
Um Management	•	•				
Cell Selection	•	•				
Um-Tranx	•		•			
Path Management		•		•		

▶ ***Figure 3:*** *GPRS Functions and Logical Architecture*

6. HLR Extension: The HLR must be extended to store new subscriber data associated with packet switching. While the GGSNs and SGSNs are new hardware elements, the HLR Extension normally is just a software upgrade. The HLR (Extension) is involved in

   - registration, authentication and authorization processes,
   - ciphering (cipher key) and
   - mobility management.

GPRS Interface Overview

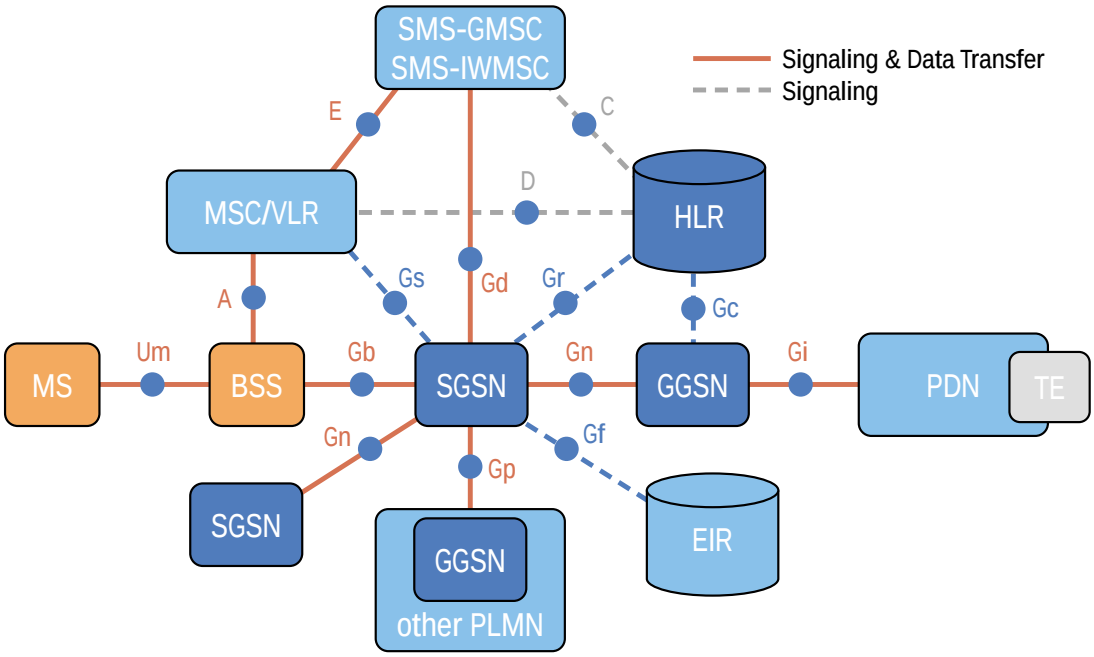
In addition to the GSM interfaces, 9 new interfaces are specified in GPRS, all of them beginning with the letter "G". The GPRS reference model of the European Telecommunications Standards Institute (ETSI) in Figure 5 shows the basic GSM and GPRS network elements and the interfaces specified between them. As shown in the figure, both the GSM circuit switched network and the GPRS packet switched network are connected to the BSS. Additional external networks can also be seen: The GPRS NSS part is connected to external packet data networks, while the GSM NSS part is attached to external PSTNs. Additionally the GPRS network can be directly connected to GGSNs in other operators' mobile networks. The solid lines represent all GPRS interfaces which are used both as transmission and signaling planes, while the dotted lines indicate interfaces used only as signaling planes.

The central task of GPRS is the transmission of packet data from external networks to the mobile and vice versa. When a user data packet arrives at the GGSN, it must be routed to the SGSN in the supply area where the subscriber is currently located. The packet is then delivered to the BSS for transmission

via the air interface. Finally, the packet arrives at the mobile station, where higher level applications process the user data packet.

Hence following transmission and signaling planes are mandatory for GPRS:

- The G_i interface is the reference point between the external PDNs and the GPRS network. The network operator and the external ISP must agree on the transmission technology (layer 1 and 2) used to connect their packet data networks. Interworking with the X.25 and IPv4 protocols is specified; extensibility to future protocols is given.
- Once the GGSN has accepted the packet, it determines the SGSN where the subscriber is currently located and transmits the packet to the SGSN via the G_n interface. IP routing is used between GPRS Support Nodes.



▶ ***Figure 4:*** *The GPRS Reference Model*

The user data must be transparently transferred between the external packet data network and the GPRS mobile station. The transmission is split into two segments between the GGSN and SGSN, and the SGSN and GPRS mobile station. Methods known as encapsulation and tunneling are applied: The user data packet is equipped with G_n-specific protocol information which reduces the amount of interpretation of the user data packet by the GPRS network and enables an easy introduction of future interworking protocols.

Note: the G_n interface is also defined between different SGSN of the same GPRS network.

- When the user data packet arrives at the SGSN, it must be transmitted to the GPRS mobile station. The logical link to the GPRS mobile station is managed via the G_b interface. In order the perform the physical transmission, the SGSN has to be connected to the BSS (PCU). The PCU receives instructions as to the quality of service with which the user data packet is to be transmitted via the air interface. This information is also sent over the G_b interface from the SGSN to the BSS (PCU).

There are two additional interfaces over which both transmission and signaling planes are implemented, though both are optional and often unnecessary for a basic GPRS network:

- The G_p interface is used between the SGSN and the GGSN in another operator's network. In its functionality it is quite similar to the G_n interface.
- The G_d interface is specified between the SGSN and an SMS gateway (SMS-GMSC/SMS-IWMSC). This interface is based on the SS7 protocol stack and enables the GPRS network to transmit long SMS messages.

In addition to the aforementioned interfaces, four pure signaling interfaces were defined in the ETSI GSM recommendations. The first three are connections to the registers - their protocol stacks are an enhancement of the

GSM interfaces to the databases:

- The G_r **interface** between the SGSN and the HLR is the only mandatory interface of these 4 interfaces. It is based on the SS7 MTP, SCCP, TCAP, and MAP signaling stacks. If a subscriber appears in the supply area of an SGSN, the SGSN can request subscriber information from the HLR via the G_r interface.
- The G_c **interface** between the GGSN and the HLR is optional. If the first user data packet arrives at the GGSN and the subscriber has a fixed address, the subscriber's location must be retrieved from the HLR. The G_c interface offers a direct path for this query. If this interface does not exist, the request can be sent via the G_n interface to a home SGSN, which then forwards the request to the HLR via the G_r interface. The routing information is then delivered by the HLR to the SGSN, which passes it on to the GGSN.
- The G_f **interface** from the SGSN to the EIR is not mandatory, as the EIR is optional in both GSM and GPRS networks.

The fourth optional signaling interface is a connection between the MSC/VLR and the SGSN:

- The G_s **interface** between the SGSN and the MSC/VLR can be used for common procedures like location updates. If, for example, a subscriber moves from one Location Area to another Location Area, then both location and routing area must be updated. If the G_s interface does not exist, both update procedures must be performed separately over the air interface. If the interface is present, a GPRS routing update can be initiated, and the SGSN informs the MSC/VLR that a location update must also be initiated. The use of the G_s interface thus conserves valuable resources on the air interface. The G_s interface is a strongly reduced version of the A interface protocol stack.

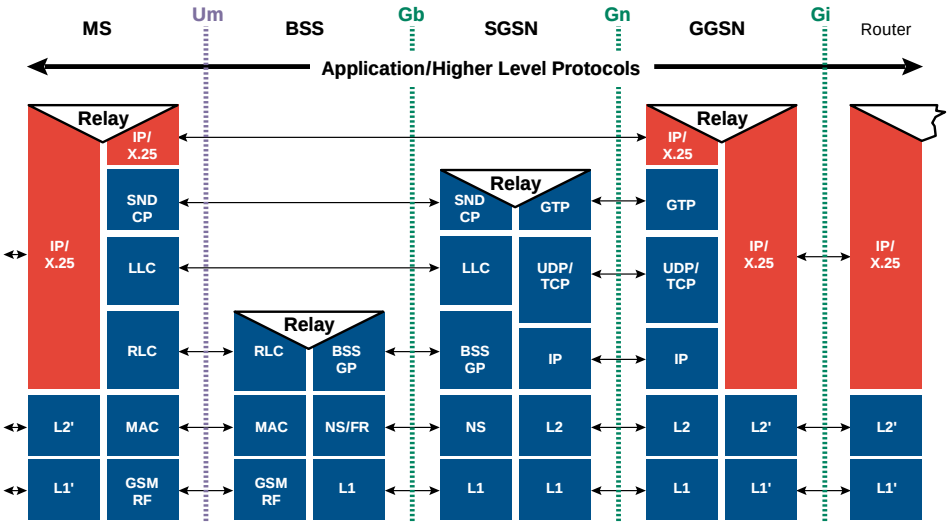
Protocol Layers

Overview

The layered protocol structure realized over the GPRS interfaces distinguishes between transmission and signaling planes. Transmission planes transfer user information, associated with transfer control information such as error correction, error recovery, flow control, multiplexing and de-multiplexing, and segmentation and re-assembly.

The NSS platform is based on a packet switched IP backbone, and is kept independent of the BSS and the radio interface using the G_b interface. Operators interested in migrating their networks to UMTS in the future can reuse investments in the SGSNs, GGSNs, and the transmission network in between.

A logical connection between the GPRS mobile station and the SGSN is maintained using the Logical Link Control Layer (LLC). Above this layer, Subnetwork Dependent Convergence Protocol packets can be transmitted. LLC packets are transparently transmitted between the GPRS mobile station and SGSN.



BSSGP:	BSS GPRS Protocol	**MAC:**	Medium Acces Control
FR:	Frame Relay	**RLC:**	Radio Link Control
GTP:	GPRS Tunneling Protocol	**SNDCP:**	SubNetwork Dependent Convergence Protocol
IP:	Internet Protocol	**TCP:**	Transmission Control Protocol
LLC:	Logical Link Control	**UDP:**	User Datagram Protocol

▶ ***Figure 5:*** *GPRS Transport Protocol Layer*