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GSM PHASE 2+ GENERAL PACKET RADIO SERVICE GPRS: ARCHITECTURE, PROTOCOLS, AND AIR INTERFACE

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ABSTRACT

The General Packet Radio Service (GPRS) is a new bearer service for GSM that greatly improves and simplifies wireless access to packet data networks, e.g., to the Internet. It applies a packet radio principle to transfer user data packets in an efficient way between mobile stations and external packet data networks. This tutorial gives an introduction to GPRS. The article discusses the system architecture and its basic functionality. It explains the offered services, the session and mobility management, the routing, the GPRS air interface including channel coding, and the GPRS protocol architecture. Finally, an interworking example between GPRS and IP networks is shown.

The impressive growth of cellular mobile telephony as well as the number of Internet users promises an exciting potential for a market that combines both innovations: cellular wireless data services. Within the next few years, there will be an extensive demand for wireless data services. In particular, high-performance wireless Internet access will be requested by users.

Existing cellular data services do not fulfill the needs of users and providers. From the user's point of view, data rates are too slow and the connection setup takes too long and is rather complicated. Moreover, the service is too expensive for most users. From the technical point of view, the drawback results from the fact that current wireless data services are based on circuit switched radio transmission. At the air interface, a complete traffic channel is allocated for a single user for the entire call period. In case of bursty traffic (e.g., Internet traffic), this results in a highly inefficient resource utilization. It is obvious that for bursty traffic, packet switched bearer services result in a much better utilization of the traffic channels. This is because a channel will only be allocated when needed and will be released immediately after the transmission of the packets. With this principle, multiple users can share one physical channel (statistical multiplexing).

In order to address these inefficiencies, two cellular packet data technologies have been developed so far: cellular digital packet data (CDPD) (for AMPS, IS-95, and IS-136) and the General Packet Radio Service (GPRS). GPRS is the topic of this paper. It was originally developed for GSM, but will also be integrated within IS-136 (see [1]). We treat GPRS from the point of view of GSM.

GPRS is a new bearer service for GSM that greatly improves and simplifies wireless access to packet data networks, e.g., to the Internet. It applies a packet radio principle to transfer user data packets in an efficient way between GSM mobile stations and external packet data networks. Packets can be directly routed from the GPRS mobile stations to packet switched networks. Networks based on the Internet Protocol (IP) (e.g., the global Internet or private/corporate intranets) and X.25 networks are supported in the current version of GPRS.

Users of GPRS benefit from shorter access times and higher data rates. In conventional GSM, the connection setup takes several seconds and rates for data transmission are restricted to 9.6 kbit/s. GPRS in practice offers session establishment times below one second and ISDN-like data rates up to several ten kbit/s.

In addition, GPRS packet transmission offers a more user-friendly billing than that offered by circuit switched services. In circuit switched services, billing is based on the duration of the connection. This is unsuitable for applications with bursty traffic. The user must pay for the entire airtime, even for idle periods when no packets are sent (e.g., when the user reads a Web page). In contrast to this, with packet switched services, billing can be based on the amount of transmitted data. The advantage for the user is that he or she can be "online" over a long period of time but will be billed based on the transmitted data volume.

To sum up, GPRS improves the utilization of the radio resources, offers volume-based billing, higher transfer rates, shorter access times, and simplifies the access to packet data networks.

GPRS has been standardized by ETSI (the European Telecommunications Standards Institute) during the last five years. It finds great interest among many GSM network providers. At the moment field trials are being carried out, and it is expected that GPRS will be implemented in various countries by the middle of 2000 (see, e.g., [2][3] for Germany).

This article provides an introduction to GPRS. We assume that the reader is familiar with the basic concepts of cellular networks. A brief overview of the GSM system can be found in [4]. In addition, there exists a variety of books on GSM, e.g., [5][6][7]. The structure of the paper is as follows. First we describe the GPRS system architecture and discuss the fundamental functionality. We then describe the offered services and the Quality of Service parameters. Afterward we show how a GPRS mobile station registers with the network, and how the network keeps track of its location. An example of how packets are routed in GPRS is given. Next, the physical layer at the air interface is explained, and we discuss the concept of multiple access, radio resource management, and the logical channels and their mapping onto physical channels. We then consider GPRS channel coding, and follow this with a discussion of the GPRS protocol architecture. Finally, we give an example of a GPRS-Internet interconnection.

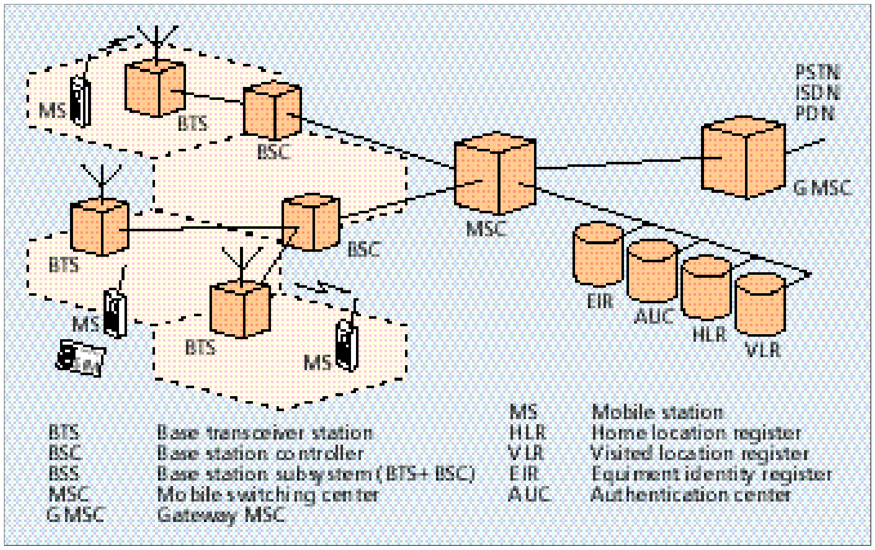


FIGURE 1. GSM system architecture with essential components.

SYSTEM ARCHITECTURE

GENERAL GSM CONCEPT

In order to understand the GPRS system architecture, let us review the general GSM system concept and GSM addressing [5].

GSM System Architecture — Fig. 1 shows the system architecture of a GSM public land mobile network (PLMN) with essential components [5]. A GSM mobile station is denoted as MS. A cell is formed by the radio area coverage of a base transceiver station (BTS). Several BTSs together are controlled by one base station controller (BSC). The BTS and BSC together form the base station subsystem (BSS). The combined traffic of the mobile stations in their respective cells is routed through a switch, the mobile switching center (MSC). Connections originating from or terminating in the fixed network (e.g., ISDN) are handled by a dedicated gateway mobile switching center (GMSC). GSM networks are structured hierarchically. They consist of at least one administrative region, which is assigned to a MSC. Each administrative region is made up of at least one location area (LA). A location area consists of several cell groups. Each cell group is assigned to a BSC.

Several data bases are available for call control and network management: the home location register (HLR), the visited location register (VLR), the authentication center (AUC), and the equipment identity register (EIR).

For all users registered with a network operator, permanent data (such as the user's profile) as well as temporary data (such as the user's current location) are stored in the HLR. In case of a call to a user, the HLR is always first queried, to determine the user's current location. A VLR is responsible for a group of location areas and stores the data of those users who are currently in its area of responsibility. This includes parts of the permanent user data that have been transmitted from the HLR to the VLR for faster access. But the VLR may also assign and store local data such as a temporary identification. The AUC generates and stores security-related data such as keys used for authentication and encryption, whereas the EIR registers equipment data rather than subscriber data.

GSM Addresses and Identifiers — GSM distinguishes explicitly between user and equipment and deals with them separately. Besides phone numbers and subscriber and equipment identifiers, several other identifiers have been defined; they are needed for the management of subscriber mobility and for addressing of all the remaining network elements.

The international mobile station equipment identity (IMEI) uniquely identifies a mobile station internationally. It is a kind of serial number. The IMEI is allocated by the equipment manufacturer and registered by the network operator who stores it in the EIR.

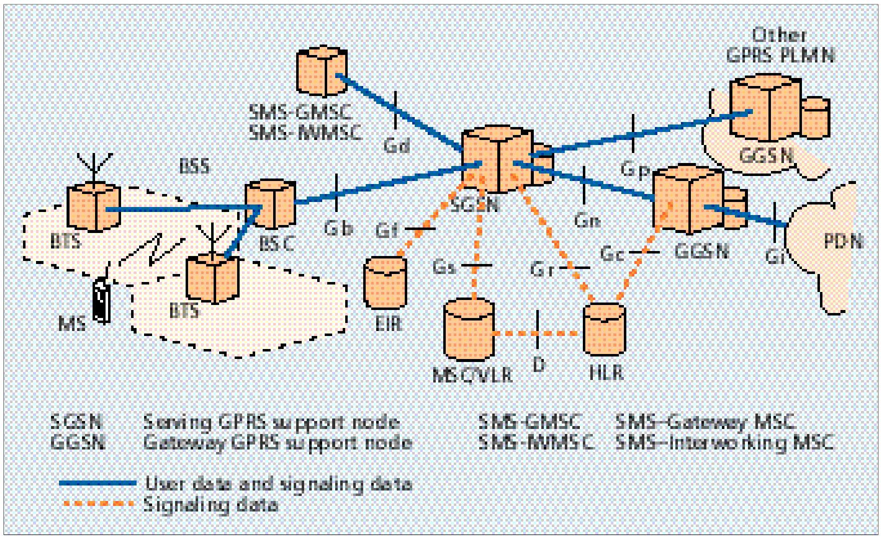
Each registered user is uniquely identified by its international mobile subscriber identity (IMSI). It is stored in the subscriber identity module (SIM) (see Fig. 1). A mobile station can only be operated if a SIM with a valid IMSI is inserted into equipment with a valid IMEI.

The "real telephone number" of a mobile station is the mobile subscriber ISDN number (MSISDN). It is assigned to the subscriber (his or her SIM, respectively), such that a mobile station set can have several MSISDNs depending on the SIM.

The VLR, which is responsible for the current location of a subscriber, can assign a temporary mobile subscriber identity (TMSI) which has only local significance in the area handled by the VLR. It is stored on the network side only in the VLR and is not passed to the HLR.

GPRS SYSTEM ARCHITECTURE

In order to integrate GPRS into the existing GSM architecture, a new class of network nodes, called GPRS support nodes (GSN), has been introduced [8]. GSNs are responsible for the delivery and routing of data packets between the



■ **FIGURE 2.** GPRS system architecture.

packet data networks. It converts the GPRS packets coming from the SGSN into the appropriate packet data protocol (PDP) format (e.g., IP or X.25) and sends them out on the corresponding packet data network. In the other direction, PDP addresses of incoming data packets are converted to the GSM address of the destination user. The readdressed packets are sent to the responsible SGSN. For this purpose, the GGSN stores the current SGSN address of the user and his or her profile in its location register. The GGSN also performs authentication and charging functions.

In general, there is a many-to-many relationship between the SGSNs and the GGSNs: A GGSN is the interface to external packet data networks for several SGSNs; an SGSN may route its packets over different GGSNs to reach different packet data networks.

mobile stations and the external packet data networks (PDN). Fig. 2 illustrates the system architecture.

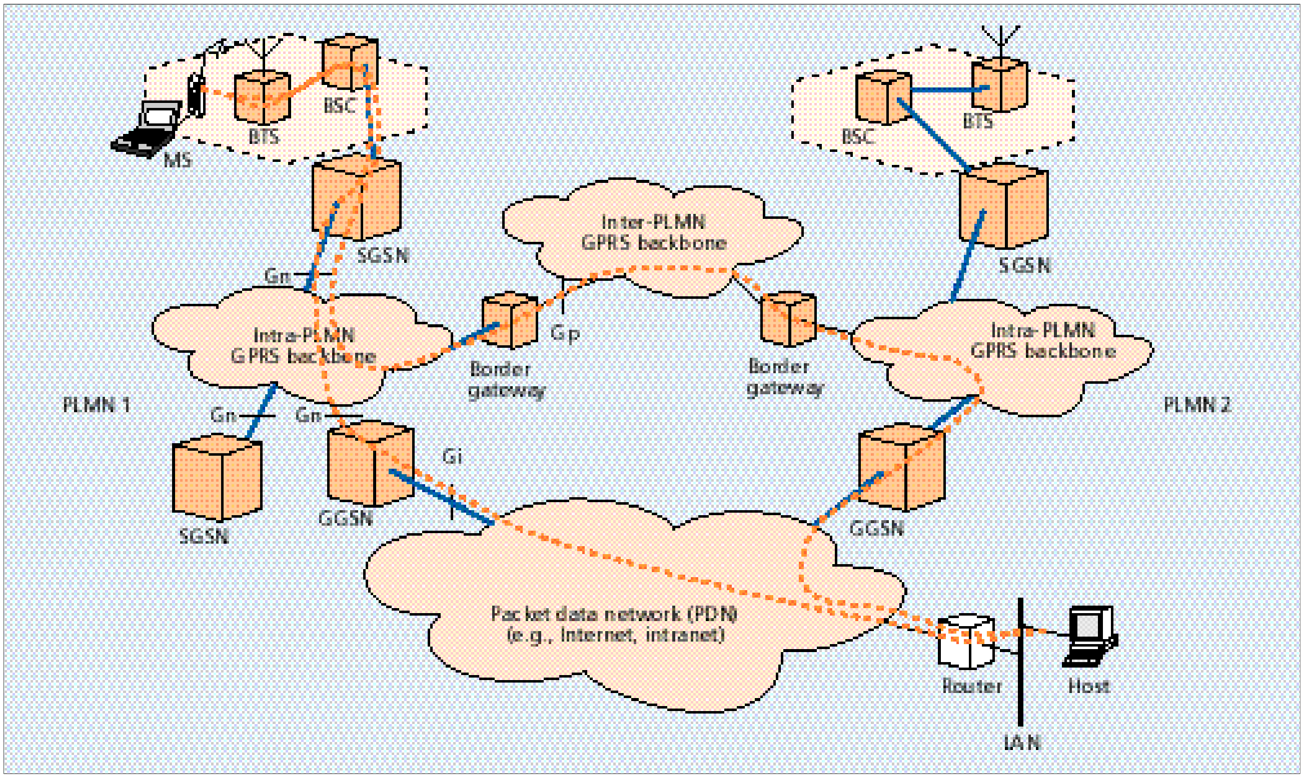
A serving GPRS support node (SGSN) is responsible for the delivery of data packets from and to the mobile stations within its service area. Its tasks include packet routing and transfer, mobility management (attach/detach and location management), logical link management, and authentication and charging functions. The location register of the SGSN stores location information (e.g., current cell, current VLR) and user profiles (e.g., IMSI, address(es) used in the packet data network) of all GPRS users registered with this SGSN.

A gateway GPRS support node (GGSN) acts as an interface between the GPRS backbone network and the external

Fig. 2 also shows the interfaces between the new network nodes and the GSM network as defined by ETSI in [8].

The Gb interface connects the BSC with the SGSN. Via the Gn and the Gp interfaces, user data and signaling data are transmitted between the GSNs. The Gn interface will be used if SGSN and GGSN are located in the same PLMN, whereas the Gp interface will be used if they are in different PLMNs.

All GSNs are connected via an IP-based GPRS backbone network. Within this backbone, the GSNs encapsulate the PDN packets and transmit (tunnel) them using the GPRS Tunneling Protocol GTP. There are two kinds of GPRS backbones:



■ **FIGURE 3.** GPRS system architecture and routing example.

- Intra-PLMN backbone networks connect GSNs of the same PLMN and are therefore private IP-based networks of the GPRS network provider.
- Inter-PLMN backbone networks connect GSNs of different PLMNs. A roaming agreement between two GPRS network providers is necessary to install such a backbone.

Fig. 3 shows two intra-PLMN backbone networks of different PLMNs connected with an inter-PLMN backbone. The gateways between the PLMNs and the external inter-PLMN backbone are called border gateways. Among other things, they perform security functions to protect the private intra-PLMN backbones against unauthorized users and attacks. The illustrated routing example will be explained later.

The Gn and Gp interfaces are also defined between two SGSNs. This allows the SGSNs to exchange user profiles when a mobile station moves from one SGSN area to another.

Across the Gf interface, the SGSN may query the IMEI of a mobile station trying to register with the network.

The Gi interface connects the PLMN with external public or private PDNs, such as the Internet or corporate intranets. Interfaces to IP (IPv4 and IPv6) and X.25 networks are supported.

The HLR stores the user profile, the current SGSN address, and the PDP address(es) for each GPRS user in the PLMN. The Gr interface is used to exchange this information between HLR and SGSN. For example, the SGSN informs the HLR about the current location of the MS. When the MS registers with a new SGSN, the HLR will send the user profile to the new SGSN. The signaling path between GGSN and HLR (Gc interface) may be used by the GGSN to query a user's location and profile in order to update its location register.

In addition, the MSC/VLR may be extended with functions and register entries that allow efficient coordination between packet switched (GPRS) and circuit switched (conventional GSM) services. Examples of this are combined GPRS and non-GPRS location updates and combined attachment procedures. Moreover, paging requests of circuit switched GSM calls can be performed via the SGSN. For this purpose, the Gs interface connects the data bases of SGSN and MSC/VLR.

To exchange messages of the short message service (SMS) via GPRS, the Gd interface is defined. It interconnects the SMS gateway MSC (SMS-GMSC) with the SGSN.

Services

Bearer Services and Supplementary Services

The bearer services of GPRS offer end-to-end packet switched data transfer. There are two different kinds: The point-to-point (PTP) service and the point-to-multipoint (PTM) service. The latter will be available in future releases of GPRS.

The PTP service [9] offers transfer of data packets between two users. It is offered in both connectionless mode (PTP connectionless network service (PTP-CLNS), e.g., for IP) and connection-oriented mode (PTP connection-oriented network service (PTP-CONS), e.g., for X.25).

The PTM service offers transfer of data packets from one user to multiple users. There exist two kinds of PTM services [10]:

- Using the multicast service PTM-M, data packets are broadcast in a certain geographical area. A group identifier indicates whether the packets are intended for all users or for a group of users.
- Using the group call service PTM-G, data packets are addressed to a group of users (PTM group) and are sent out in geographical areas where the group members are currently located.

Class	Probability for			
	Lost packet	Duplicated packet	Out of sequence packet	Corrupted packet
1	10^{-9}	10^{-9}	10^{-9}	10^{-9}
2	10^{-4}	10^{-5}	10^{-5}	10^{-6}
3	10^{-2}	10^{-5}	10^{-5}	10^{-2}

Table 1. Reliability classes.

Class	128 byte packet		1024 byte packet	
	Mean delay	95% delay	Mean delay	95% delay
1	<0.5s	<1.5s	<2s	<7s
2	<5s	<25s	< 15s	<75s
3	<50s	<250s	<75s	<375s
4	Best effort	Best effort	Best effort	Best effort

Table 2. Delay classes.

It is also possible to send SMS messages over GPRS. In addition, it is planned to implement supplementary services, such as call forwarding unconditional (CFU), call forwarding on mobile subscriber not reachable (CFNRc), and closed user group (CUG).

Moreover, a GPRS service provider may offer additional non-standardized services, such as access to data bases, messaging services, and tele-action services (e.g., credit card validations, lottery transactions, and electronic monitoring and surveillance systems) [9].

Quality of Service

The Quality of Service QoS requirements of typical mobile packet data applications are very diverse (e.g., consider real-time multimedia, Web browsing, and e-mail transfer). Support of different QoS classes, which can be specified for each individual session, is therefore an important feature. GPRS allows defining QoS profiles using the parameters service precedence, reliability, delay, and throughput [9].

- The service precedence is the priority of a service in relation to another service. There exist three levels of priority: high, normal, and low.
- The reliability indicates the transmission characteristics required by an application. Three reliability classes are defined, which guarantee certain maximum values for the probability of loss, duplication, mis-sequencing, and corruption (an undetected error) of packets (see Table 1).
- The delay parameters define maximum values for the mean delay and the 95-percentile delay (see Table 2). The latter is the maximum delay guaranteed in 95 percent of all transfers. The delay is defined as the end-to-end transfer time between two communicating mobile stations or between a mobile station and the Gi interface to an external packet data network. This includes all delays within the GPRS network, e.g., the delay for request and assignment of radio resources and the transit delay in the GPRS backbone network. Transfer delays outside the GPRS network, e.g., in external transit networks, are not taken into account.

- The throughput specifies the maximum/peak bit rate and the mean bit rate.

Using these QoS classes, QoS profiles can be negotiated between the mobile user and the network for each session, depending on the QoS demand and the current available resources. The billing of the service is then based on the transmitted data volume, the type of service, and the chosen QoS profile.

Simultaneous Usage of Packet Switched and Circuit Switched Services

In a GSM/GPRS network, conventional circuit switched services (speech, data, and SMS) and GPRS services can be used in parallel. Three classes of mobile stations are defined [9]:

- A class A mobile station supports simultaneous operation of GPRS and conventional GSM services.
- A class B mobile station is able to register with the network for both GPRS and conventional GSM services simultaneously. In contrast to an MS of class A, it can only use one of the two services at a given time.
- A class C mobile station can attach for either GPRS or conventional GSM services. Simultaneous registration (and usage) is not possible. An exception are SMS messages, which can be received and sent at any time.

Session Management, Mobility Management, and Routing

In this section, we describe how a mobile station (MS) registers with the GPRS network and becomes known to an external packet data network (PDN). We show how packets are routed to or from mobile stations, and how the network keeps track of the current location of the user.

Attachment and Detachment Procedure

Before a mobile station can use GPRS services, it must register with an SGSN of the GPRS network. The network checks if the user is authorized, copies the user profile from the HLR to the SGSN, and assigns a packet temporary mobile subscriber identity (P-TMSI) to the user. This procedure is called GPRS attach. For mobile stations using both circuit switched and packet switched services it is possible to perform combined GPRS/IMSI attach procedures. The disconnection from the GPRS network is called GPRS detach. It can be initiated by the mobile station or by the network (SGSN or HLR).

Session Management, PDP Context

To exchange data packets with external PDNs after a successful GPRS attach, a mobile station must apply for one or more addresses used in the PDN, e.g., for an IP address in case the PDN is an IP network. This address is called PDP address (Packet Data Protocol address). For each session, a so-called PDP context is created, which describes the characteristics of the session. It contains the PDP type (e.g., IPv4), the PDP address assigned to the mobile station (e.g., 129.187.222.10), the requested QoS, and the address of a GGSN that serves as the access point to the PDN. This context is stored in the MS, the SGSN, and the GGSN. With an active PDP context, the mobile station is "visible" for the external PDN and is able to send and receive data packets. The mapping between the two addresses, PDP and IMSI, enables the GGSN to transfer data packets between PDN and MS. A user may have several simultaneous PDP contexts active at a given time.

The allocation of the PDP address can be static or dynamic. In the first case, the network operator of the user's home-PLMN permanently assigns a PDP address to the user. In the second case, a PDP address is assigned to the user upon activation of a PDP context. The PDP address can be assigned by the operator of the user's home-PLMN (dynamic home-PLMN PDP address) or by the operator of the visited network (dynamic visited-PLMN PDP address). The home network operator decides which of the possible alternatives may be used. In case of dynamic PDP address assignment, the GGSN is responsible for the allocation and the activation/deactivation of the PDP addresses.

Fig. 4 shows the PDP context activation procedure. Using the message "activate PDP context request," the MS informs the SGSN about the requested PDP context. If dynamic PDP address assignment is requested, the parameter PDP address will be left empty. Afterward, usual security functions (e.g., authentication of the user) are performed. If access is granted, the SGSN will send a "create PDP context request" message to the affected GGSN. The latter creates a new entry in its PDP context table, which enables the GGSN to route data packets between the SGSN and the external PDN. Afterward, the GGSN returns a confirmation message "create PDP context response" to the SGSN, which contains the PDP address in case dynamic PDP address allocation was requested. The SGSN updates its PDP context table and confirms the activation of the new PDP context to the MS ("activate PDP context accept").

GPRS also supports anonymous PDP context activation. In this case, security functions as shown in Fig. 4 are skipped, and thus, the user (i.e., the IMSI) using the PDP context remains unknown to the network. Anonymous context activation may be employed for pre-paid services, where the user does not want to be identified. Only dynamic address allocation is possible in this case.

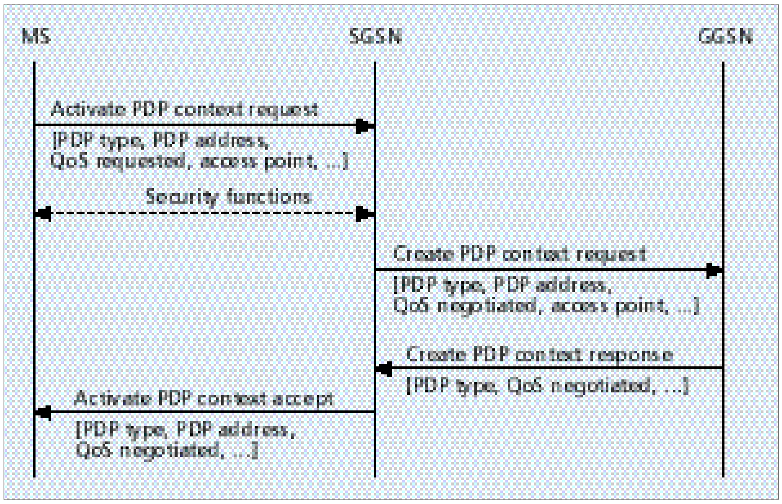


Figure 4. PDP context activation.

Routing

Fig. 3 gives an example of how packets are

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