General Packet Radio Services

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Introduction

The Global System for Mobile Communications (GSM) is a cellular telephony system that essentially provides voice and circuit switched data services. A TDMA based system, GSM provides a data rate of around 14.4 KBPS per TDMA time-slot.

With the advent of Internet and WAP based services, a packet data service logically seems more appropriate, especially if the data access is over the radio interface, where cost of air time is a important parameter. The General Packet Radio Services (GPRS) of the GSM is designed to provide packet data services over the radio interface. Being a packet data service, GPRS optimizes the use of network and radio resources. Based on the same radio spectrum with more or less identical network architecture as GSM, GPRS allows easy migration for a GSM operator to GPRS.

This paper provides an insight into GPRS system. It is organized as follows- Section 0 provides and overview of GPRS services, Section 0 introduces the network architecture and the nodes, Section 0 discusses the Radio Interface, Section 02 describes the Mobility Management functionality, Section 03 discusses procedures for setting up of a packet data session for user data transfer, while Section 04 discusses issues related to data transfer. Lastly Section 05 concludes the GPRS system and peeps into the future of cellular technology and data services.

The appendices at the end of the paper contain some useful information. Appendix A lists the identities used in GPRS, Appendix B lists the various information elements maintained in different node elements, Appendix C contains glossary of abbreviations used.

Overview of the GPRS system

Since GPRS is an evolution of GSM, it is also a TDMA system - with each radio frequency divided into TDM frames and each frame containing 8 TDMA time-slots (Section 4 will discuss this in detail). The radio frequency and time-slots are allocated dynamically by the network to the mobile station (MS) for uplink (UL) and downlink (DL) data transfer. Radio resources for uplink & downlink are allocated independently. Depending on the resources allocated to a MS and the capability of the MS, data rates varying from 9 to 150 KBPS can be achieved per user.

The network operator can dynamically allocate radio resources between for GSM circuit switched and GPRS packet switched services depending on service requirements and loading conditions.

GPRS supports common packet data protocols like IP and X.25. IP and X.25 Protocol Data Units (PDUs) are transferred transparently over the GPRS network between a IP or X.25 user to a node in the IP or X.25 destination. This is achieved through PDU tunneling and encapsulation in the GPRS network. This allows addition of new networks to be added to GPRS without change to the GPRS radio interface.

GPRS supports several quality of service (QoS) profiles for data transfer. It is designed for fast reservation to begin transmission of packets, typically 0.5 to 1 second. Charging should typically depend on the amount of data transferred as against the time the mobile station (MS) is attached to the network. Authentication and ciphering procedures are identical to GSM.

1. A MS upon activation selections an optimal cell in an appropriate PLMN through cell selection procedures (a Radio Resource Management function).
2. It will then make its presence known to the network through a procedure called GPRS attach (a Mobility Management function). At this point the network is aware of the cell or group of cells called Routing Area (RA), that the MS is located in. The network can then page the MS through paging procedures when it needs to initiate a link with the MS.
3. After a MS is GPRS attached, it can start a data session. But before it is able to transmit or receive data, a Packet Data Protocol (PDP) Session Activation procedure (PDP activation) is initiated where MS receives a PDP address that it wishes to use for the data session (Session Management function). This operation makes the MS known in the external Packet Data Network (PDN) with the associated PDP address.

Network Architecture

Figure 1 below shows the various GPRS network nodes and the interfaces defined between the nodes. Refer [1] for a detailed description of the GPRS architecture.

Figure 1. GPRS general Architecture

The MS-SGSN transmission plane is shown in Figure 2 and the MS-SGSN Signalling plane is shown in Figure 3.

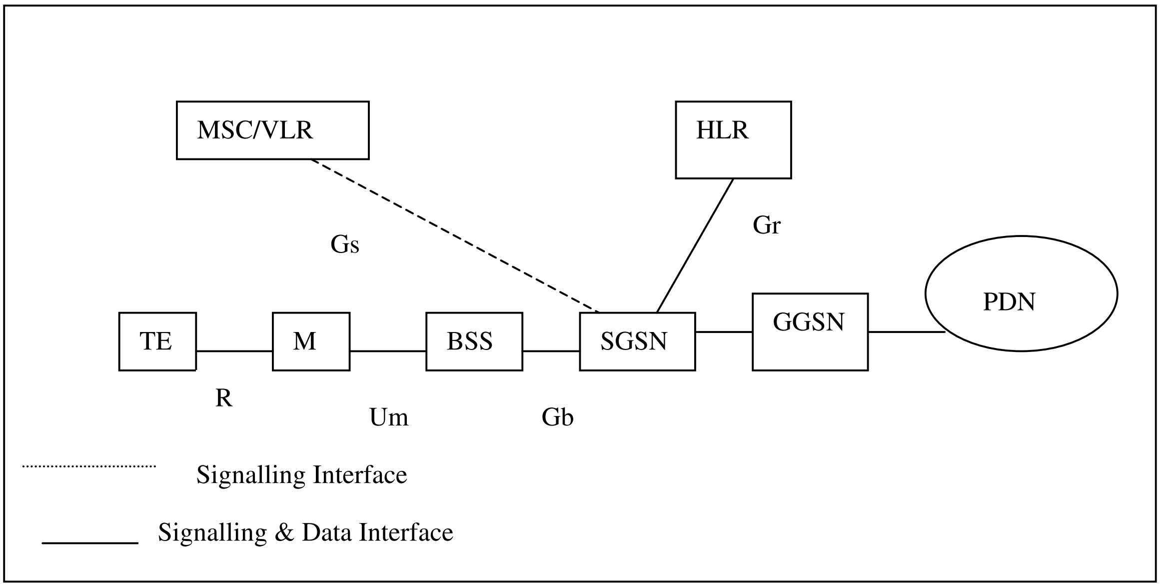
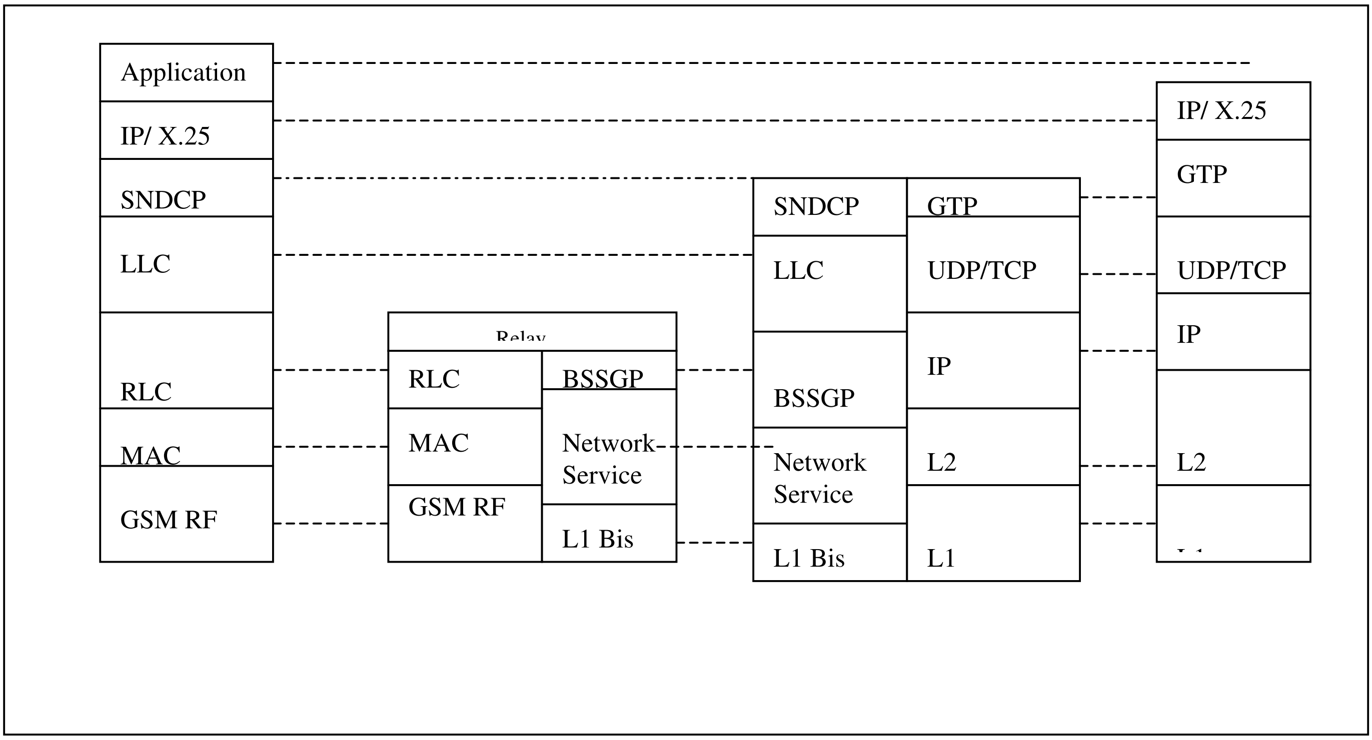
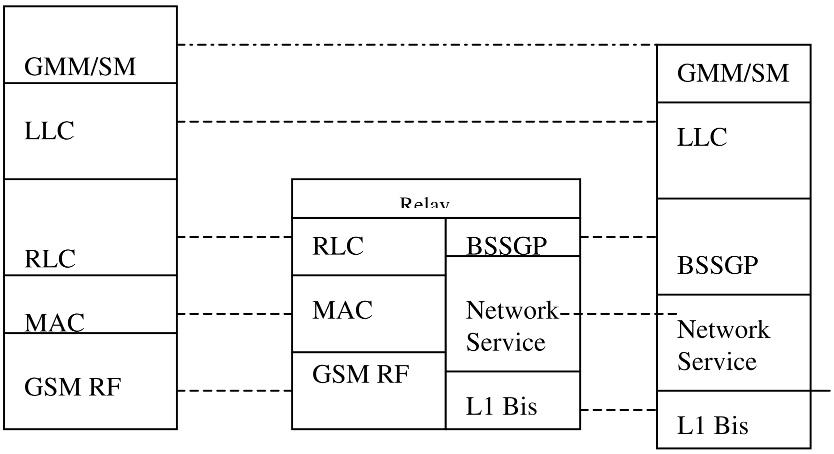


Figure 2. Protocol entities in the MS-SGSN transmission plane

Figure 3. Protocol entities in the MS-SGSN Signalling





Mobile Station (TE + ME)

MS is the node from which the subscriber access GPRS services. Both GPRS and GSM circuit switched services may be supported by a MS. Depending on the manner in which these services are supported, 3 classes of MS are defined -

1. Class A: The MS can attach both to GSM and GPRS services and simultaneously support data transfer on both.
2. Class B: The MS can attach both to GSM and GPRS services but can operate data services over only one service at a time.
3. Class C: The MS is attached only to GPRS services.

Base Sub Station (BSS)

The radio interface terminates at the BSS. BSS provides functionalities to provide radio access to the MS. A BSS serves a subset of cells that constitute a Routing Area (RA). It manages allocation and release of physical resources associated with GPRS channels. It monitors GPRS channel utilization to detect under-utilized or congested GPRS channels and initiates congestion control procedures. It broadcasts GPRS channel configuration information to MSs. It initiates paging procedures when the network needs to send a downlink PDU to an attached MS.

Gateway GPRS Support Nodes (GGSN)

The Gateway GPRS Support Node (GGSN) is the node that is accessed by the external packet data network due to evaluation of the PDP address. It contains routing information for attached GPRS users.
The routing information is used to tunnel PDUs to the MS's current point of attachment, i.e., the Serving GPRS Support Node. The GGSN may request location information from the HLR via the optional Gc interface.
The GGSN is the first point of PDN interconnection with a GSM PLMN supporting GPRS (i.e., the Gi reference point is supported by the GGSN).

Serving GPRS Support Nodes (SGSN)

The Serving GPRS Support Node (SGSN) is the node that is serving the MS. At GPRS attach, the SGSN establishes a mobility management context containing information pertaining to e.g., mobility and security for the MS. At PDP Context Activation, the SGSN establishes a PDP context, to be used for routing purposes, with the GGSN that the GPRS subscriber will be using. The SGSN may send location information to the MSC/VLR via the optional Gs interface. The SGSN may receive paging requests from the MSC/VLR via the Gs interface.

Home Location Register (HLR)

The HLR contains GPRS subscription data and routing information. The HLR is accessible from the SGSN via the Gr interface and from the GGSN via the Gc interface. For roaming MSs, HLR may be in a different PLMN than the current SGSN.

Mobile Switching Centre & Visitor Location Register (MSC/VLR)

A GSM Node, MSC switches circuit switched GSM calls. The VLR contains subscription and routing information for a MS that is not registered with the PLMN that the MSC belongs to and is visiting.

Radio Interface

The layered radio interface is shown in Figure 2 and consists of the physical RF layer, MAC-RLC layer, LLC and the SNDCP later. This section describes the physical and RLC/MAC [2] layers.

The Physical RF Layer

GSM/GPRS use TDMA and FDMA techniques to access the radio spectrum assigned. The radio spectrum is partitioned both in frequency and time as defined in section 1.1.1 and 1.1.2.

Spectrum

Following band of radio spectrum is assigned for GSM-GPRS –

1. Standard or primary GSM 900 Band, P-GSM :

   For Standard GSM 900 band, the system is required to operate in the following frequency band:
   - 890 - 915 MHz: mobile transmit, base receive
   - 935 - 960 MHz: base transmit, mobile receive
2. Extended GSM 900 Band, E-GSM (includes Standard GSM 900 band) :

   For Extended GSM 900 band, the system is required to operate in the following frequency band:
   - 880 - 915 MHz: mobile transmit, base receive
   - 925 - 960 MHz: base transmit, mobile receive
3. Railways GSM 900 Band, R-GSM (includes Standard and Extended GSM 900 Band)

   For Railways GSM 900 band, the system is required to operate in the following frequency band:
   - 876 - 915 MHz: mobile transmit, base receive
   - 921 - 960 MHz: base transmit, mobile receive
4. DCS 1 800 Band:

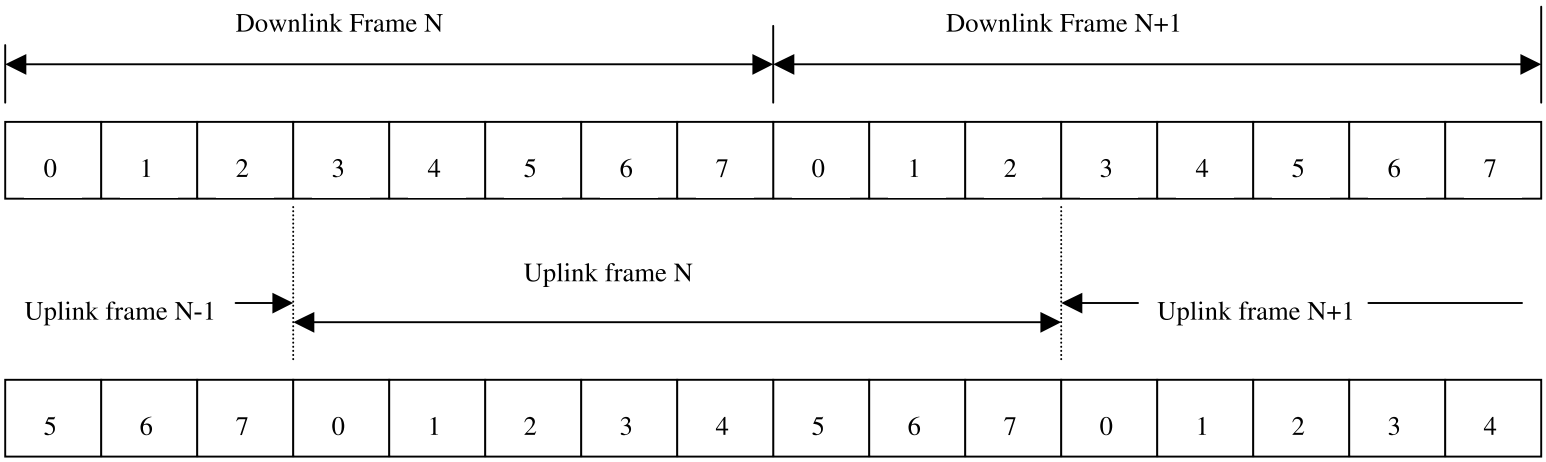
   For DCS 1 800, the system is required to operate in the following band:
   - 1710 - 1 785 MHz: mobile transmit, base receive
   - 1805 - 1 880 MHz: base transmit, mobile receive

Each base tranceiver station is alloted a subset of this spectrum by the network operator

1.1.1 Division in the frequency domain

The spectrum is divided into bands of width 200 KHz. The carrier frequency is at the centre of the band. Each carrier frequency is associated with a number called ARFCN - absolute radio frequency channel number, which also identifies the band.

If ARFCN = n, then the carrier frequency corresponding to n, is computed as follows



Band	Frequency value in the lower band	1 <= n <= 124	Frequency value in the lower band
P-GSM 900	Fl(n) = 890 + 0.2*n	1 <= n <= 124	Fu(n) = Fl(n) + 45
E-GSM 900	Fl(n) = 890 + 0.2*n	0 <= n <= 124	Fu(n) = Fl(n) + 45
E-GSM 900	Fl(n) = 890 + 0.2*(n-1024)	975 <= n <= 1023	Fu(n) = Fl(n) + 45
DCS 1 800	Fl(n) = 1710.2 + 0.2*(n-512)	512 <= n <= 885	Fu(n) = Fl(n) + 95

Table 1. Definition of SRFCN in different bands

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Figure 4. Frame Format for GSM TDMA

Thus for each n, there are 2 carriers - one in the lower band and one in the upper band. The carrier in the lower band is used in the network to MS direction (downlink) and the one in the upperband is used in the MS to network direction (uplink).

1.1.2 Division in the time domain

Time is divided into TDMA frames, each of duration 60/13 millisecond. Each TDMA frame is made of 8 TDMA time slots each of duration15/26 millisecond. Refer Figure 4.

At the base transceiver station the TDMA frames on all of the radio frequency channels in the downlink are aligned.

At the base transceiver station the start of a TDMA frame on the uplink is delayed by the fixed period of 3 timeslots from the start of the TDMA frame on the downlink. This is done to avoid the need for transmitting and receiving simultaneously on the same time slot in the MS.

At the mobile station this delay will be variable to allow adjustment for signal propagation delay. The process of adjusting this advance is known as adaptive frame alignment and is section 01.1.7.

The time-slots are numbered from 0 to 7. The frames are numbered from 0 to (26 x 51 x 2048) - 1.
The is a large as it is used as an input to the ciphering algorithms.

A physical channel uses a combination of frequency and time division multiplexing and is defined as a sequence of radio frequency channels and time slots. The complete definition of a particular physical channel consists of a description in the frequency domain, and a description in the time domain.
The physical channel dedicated to packet data traffic is called a Packet Data Channel (PDCH).

GPRS Logical Channels

Logical channel is a subset of TDMA time-slots on a physical channel, that carries logically related information. The logical channels are mapped on the physical channel as per defined rules [3]. A physical channel may carry one or more logical channels. Following logical channels are defined in GPRS -

1.1.3 Packet Common Control Channel (PCCCH)

PCCCH comprises logical channels for common control signalling used for packet data as described in the following subclauses.

1.1.3.1 Packet Random Access Channel (PRACH) - uplink only

PRACH is used by MS to initiate uplink transfer for sending data or signalling information. Packet Access burst and Extended Packet Access burst are used on PRACH.

1.1.3.2 Packet Paging Channel (PPCH) - downlink only

PPCH is used to page an MS prior to downlink packet transfer. PPCH uses paging groups in order to allow usage of DRX mode. PPCH can be used for paging of both circuit switched and packet data services. The paging for circuit switched services on PPCH is applicable for class A and B GPRS MSs in Network operation mode I.

1.1.3.3 Packet Access Grant Channel (PAGCH) - downlink only

PAGCH is used in the packet transfer establishment phase to send resource assignment to an MS prior to packet transfer.

1.1.3.4 Packet Notification Channel (PNCH) - downlink only

PNCH is used to send a PTM-M (Point To Multipoint - Multicast) notification to a group of MSs prior to a PTM-M packet transfer. DRX mode shall be provided for monitoring PNCH. Furthermore, a PTM- M new message indicator may optionally be sent on all individual paging channels to inform MSs interested in PTM-M when they need to listen to PNCH. The PTM-M service is not specified in GPRS Phase 1.

1.1.3.5 Packet Broadcast Control Channel (PBCCH) - downlink only

PBCCH broadcasts packet data specific System Information. If PBCCH is not allocated, the packet data specific system information is broadcast on BCCH.

1.1.4 Packet Traffic Channels

1.1.4.1 Packet Data Traffic Channel (PDTCH)

PDTCH is a channel allocated for data transfer. It is temporarily dedicated to one MS or to a group of MSs in the PTM-M case. In the multislot operation, one MS may use multiple PDTCHs in parallel for individual packet transfer. All packet data traffic channels are uni-directional, either uplink (PDTCH/U), for a mobile originated packet transfer or downlink (PDTCH/D) for a mobile terminated packet transfer.

1.1.5 Packet Dedicated Control Channels

1.1.5.1 Packet Associated Control Channel (PACCH)

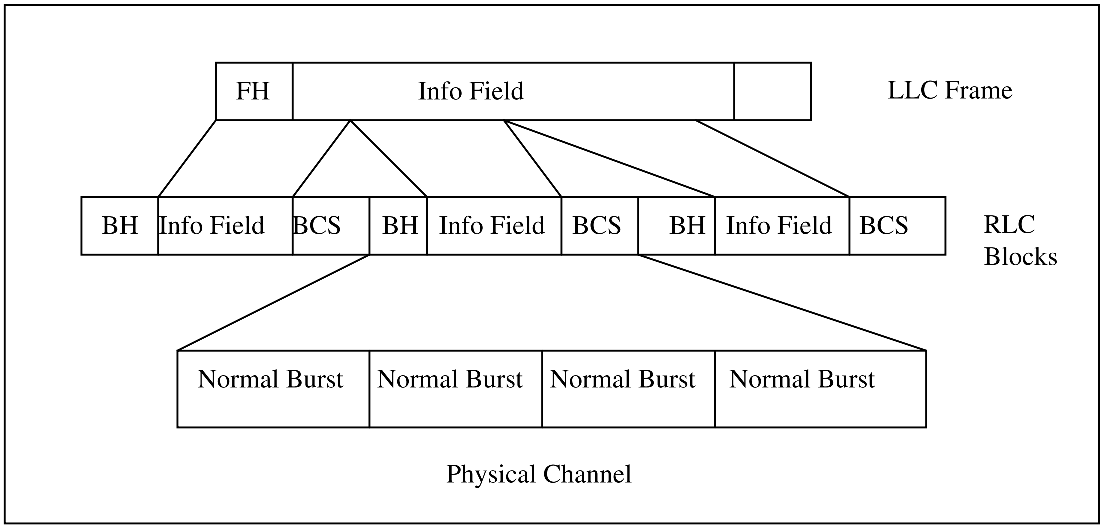


Figure 5. Fragmentation by RLC into Radio Blocks that fit into 4 Radio Bursts

PACCH conveys signalling information related to a given MS. The signalling information includes e.g. acknowledgments and Power Control information. PACCH carries also resource assignment and reassignment messages, comprising the assignment of a capacity for PDTCH(s) and for further occurrences of PACCH. The PACCH shares resources with PDTCHs, that are currently assigned to one
MS. Additionally, an MS that is currently involved in packet transfer, can be paged for circuit switched services on PACCH.

1.1.5.2 Packet Timing advance Control Channel, uplink (PTCCH/U)

PTCCH/U is used to transmit random access burst to allow estimation of the timing advance for one MS in packet transfer mode.

1.1.5.3 Packet Timing advance Control Channel, downlink (PTCCH/D)

PTCCH/D is used to transmit timing advance information updates to several MS. One PTCCH/D is paired with several PTCCH/U s.

Physical Link Layer

The purpose of the Physical Link layer is to convey information across the GSM radio interface, including RLC/MAC information. The Physical Link layer supports multiple MSs sharing a single physical channel.
The Physical Link layer is responsible for:

- Forward Error Correction (FEC) coding, allowing the detection and correction of transmitted code words and the indication of uncorrectable code words. This is discussed in section 1.1.6.
- Rectangular interleaving of one Radio Block over four bursts in consecutive TDMA frames, as shown in Figure 5.
- Procedures for detecting physical link congestion.
- Synchronization procedures, including means for determining and adjusting the MS Timing Advance to correct for variances in propagation delay. This is discussed in section 1.1.7.
- Monitoring and evaluation procedures for radio link signal quality;
- Cell (re-)selection procedures;
- Transmitter power control procedures; and
- Battery power conservation procedures, e.g. Discontinuous Reception (DRX) procedures.

1.1.6 Channel Coding

Four coding schemes, CS-1 to CS-4, are defined for the packet data traffic channels to achieve different levels of error correction and detection. The coding procedure is shown in Figure 7 and Figure 6. CS1, CS2, CS3 use half rate convolutional coding for FEC. CS4 has no FEC. Block Check Sequence encoded in a 40 bit FIRE code in CS1. CS2, CS3, CS4 generate same 16 bit CRC for BCS. Table 2 captures the characteristics of the 4 coding schemes.

Scheme	FEC	BCS	USF	Data Rate
CS1	Yes	40 bit FIRE code	Convolutionally coded	9.05
CS 2	Yes	16 bit CRC for BCS	Generates 12 bit code	13.4
CS 3	Yes	16 bit CRC for BCS	Generates 12 bit code	15.6
CS 4	No	16 bit CRC for BCS	Generates 12 bit code	21.4

Table 2. **Coding scheme characteristics**

1.1.7 Timing Advance

The timing advance procedure is used to derive the correct value for timing advance that the MS has to use for the uplink transmission of radio blocks. The timing advance procedure comprises two parts:
- initial timing advance estimation;
- continuous timing advance update.

1.1.7.1 Initial timing advance estimation

The initial timing advance estimation is based on the single access burst that the MS sends to the network to request for packet channel (to send or receive PDUs). The network responds with Packet Uplink Assignment or Packet Downlink Assignment. The assignment carries the estimated timing advance value to the MS. This value shall be used by the MS for the uplink transmissions until the continuous timing advance update provides a new value.

The network can also send a Packet Polling Request to the MS. This triggers the MS to transmit Packet Control Acknowledgment which is formatted as four access burst from which the timing advance can be estimated. The network may also send a Packet Downlink (/Uplink) Assignment without timing advance information. In that case it is indicated to the MS that it can only start the uplink transmission after the timing advance is obtained by the continuous timing advance update procedure.

1.1.7.2 Continuous timing advance update

The continuous timing advance update procedure is carried on the PTCCH allocated to the MS. Network assigns Timing Advance Index (TAI) and the PTCCH to the MS The TAI specifies the PTCCH sub- channel to be used by the MS. The sub-channel occurs once in 8 TDMA multiframe.

Figure 6. Channel coding scheme for CS1, CS2, CS3

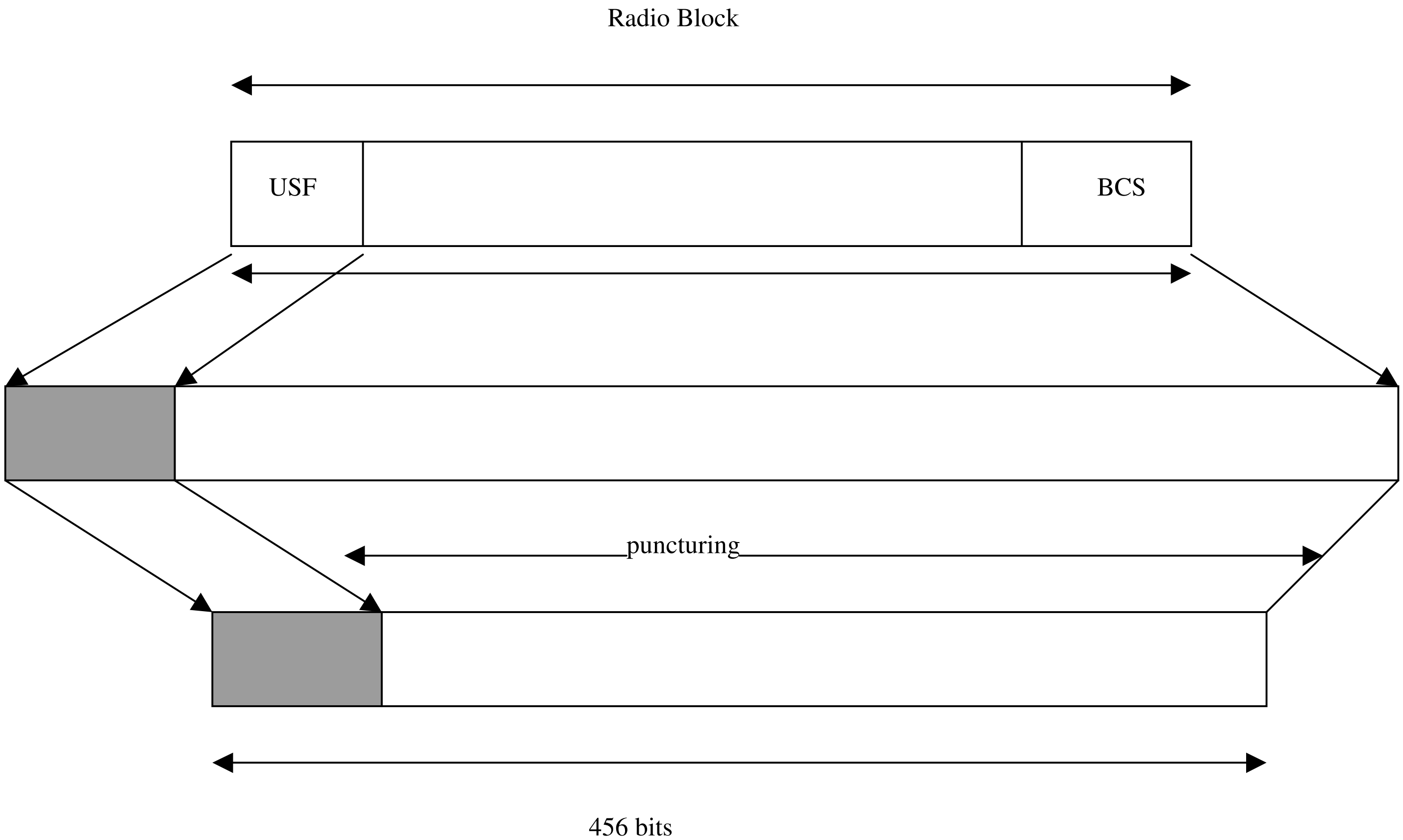
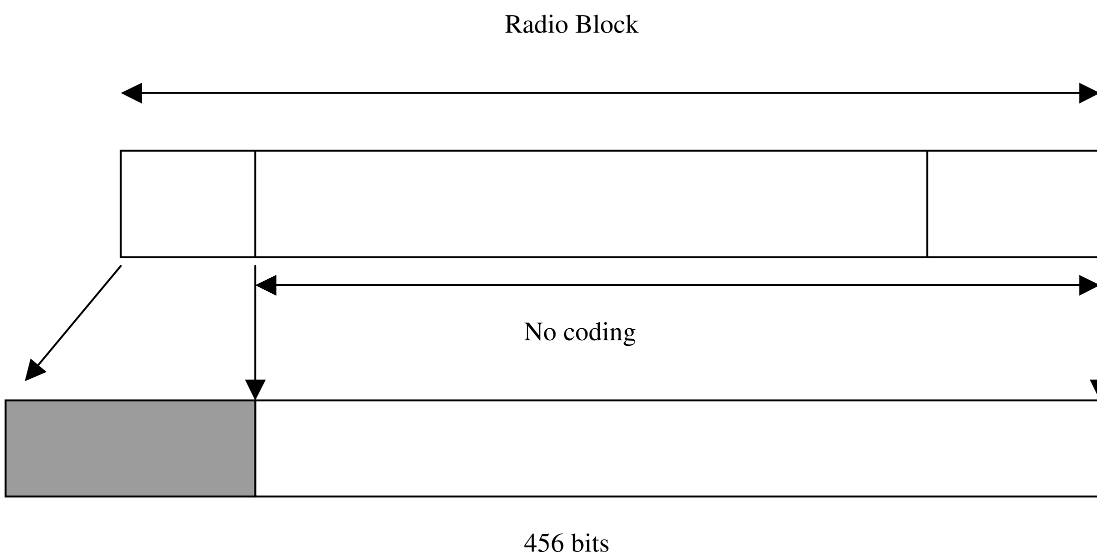


Figure 7. Channel coding for CS4



The MS sends access burst on the PTCCH sub-channel from which network derives the timing advance. It sends the new timing advance values via a downlink signalling message (TA-message) on PTCCH/D.

1.1.8 Medium Access Control and Radio Link Control (MAC/RLC)

The MAC function defines the procedures that enable multiple MSs to share a common transmission medium, which may consist of several physical channels. The MAC function provides arbitration between multiple MSs attempting to transmit simultaneously and provides collision avoidance, detection and recovery procedures. The operations of the MAC function may allow a single MS to use several physical channels in parallel.

RLC function is responsible for mapping LLC-PDUs from LLC to MAC and vice-versa. It is responsible for fragmentation and reassembly and performs Backward Error Correction (BEC).

1.1.8.1 Fragmentation and Reassembly

RLC fragments a LLC frame into Radio Blocks that contain RLC-MAC header (Block Header). Each Radio block is transmitted over 4 bursts in the physical layer (Refer Figure 5)

1.1.8.2 Medium Access

MAC multiples multiple MSs over the radio interface, both in the uplink and downlink. The control resides with the network. On the downlink, multiplexing is controlled by a scheduling mechanism.

On the uplink, multiplexing is controlled by medium allocation to individual users (e.g., in response to service request). The access to GPRS uplink uses a Slotted-Aloha based reservation protocol.

1.1.8.2.1 Dynamic/Extended Dynamic Allocation

This is achieved through Uplink state Flag (USF) and Temporary Flow Identity (TFI).

USF - The USF comprises 3 bits at the beginning of each Radio Block that is sent on the downlink. It enables the coding of 8 different USF states. On PCCCH,

- one USF value is used to denote PRACH.
- the other USF values are used to reserve the uplink for different MSs.

On PDCHs not carrying PCCCH, the eight USF values are used to reserve the uplink for different MSs.

One USF value shall be used to prevent collision on uplink channel, when MS without USF is using uplink channel. The USF points either to the next uplink Radio Block or the sequence of 4 uplink Radio Blocks starting with the next uplink Radio Block.

When network allocated radio channels to a MS in the Packet Uplink Assignment message, it includes

- the list of PDCHs
- the corresponding USF value per PDCH.

The MS monitors the USFs on the allocated PDCHs. When MS detects a USF alloted to itself, it transmits Radio blocks on the next uplink Radio Block on that PDCH.

Temporary Block Flow (TBF) and Temporary Flow Identity (TFI) - The network may allocate radio resources on one or more PDCH for data transfer is a particular direction. This allocation is referred to as TBF. It is temporary and is valid only for the current assignment and data transfer. Associated with the TBF is a Temporary Flow Identity (TFI) that is also assigned in the resource assignment message. It is
unique among concurrent TBFs in each directions and is used instead of the MS identity in the RLC/ MAC layer. TFI is used in all RLC/MAC headers for radio blocks corresponding to that TBF.

The MS may be allowed to use the uplink resources as long as there is queued data on the RLC/MAC layer to be sent from the MS. In that sense the radio resources are assigned on the initially unlimited time basis. Alternatively, the uplink assignment for each assignment may be limited to a number of radio blocks in order to offer more fair access to the medium at higher loads.

1.1.8.2.2 Fixed Allocation

Fixed allocation uses the Packet Uplink Assignment message to communicate a detailed fixed uplink resource allocation to the MS. The fixed allocation consists of -

- a start frame,
- slot assignment,
- and block assignment bitmap representing the assigned blocks per timeslot.

The MS waits until the start frame indicated and then transmits radio blocks on those blocks indicated in the block assignment bitmap. The fixed allocation does not include the USF and the MS is free to transmit on the uplink without monitoring the downlink for the USF. Unused USF value is used to prevent other mobiles to transmit. If the current allocation is not sufficient, the MS may request additional resources in one of the assigned uplink blocks. A unique TFI is allocated and is thereafter included in each RLC block related to that Temporary Block Flow. The number of blocks an MS requests in the initial and subsequent allocation request messages shall only account for the number of data and control blocks it intends to send. The MS shall not request additional blocks for the retransmission of erroneous blocks.

1.1.8.3 BEC in RLC

This is achieved through Sliding Window Protocol. The sending RLC entity transmits radio blocks within a window. Each block is numbered. The receiver sends ACK/NACK message when needed.

This indicates blocks that were received successfully and those that were not. In the acknowledged mode, the transmitter than selectively re-transmits those blocks that were unsuccessfully received. Erroneously received block can be used as a measure of channel quality. In uplink data transfer, the network may allocate additional resources based on the error rate.

1.1.8.4 Channel allocation for Mobile Originated Data Transfer

MS can request for channel using

- one phase packet access method, or
- two phase packet access method.

MS sends a Packet Channel Request message to the network on either PRACH or RACH. On RACH, there is only two cause values available for denoting GPRS. This can be used to

- request limited resources or
- opt for two phase access.

On PRACH, the Packet Channel Request may contain more adequate information about the requested resources and, consequently, uplink resources on one or several PDCHs can be assigned by using the Packet Uplink Assignment message.

In one phase access, the network responds with the Packet Uplink Assignment, reserving the resources on PDCH(s) for uplink transfer of a number of Radio blocks. The reservation is done accordingly to the information about the requested resources that is comprised in the Packet Channel Request.

In the two phase access, the Packet Channel Request is responded with the Packet Uplink Assignment which reserves the uplink resources for transmitting the Packet Resource Request. The Packet Resource Request message carries the complete description of the requested resources for the uplink transfer. The MS can indicate the medium access method, it prefers to be used during the TBF.

The network responds with the Packet Uplink Assignment reserving resources for the uplink transfer and defining the actual parameters for data transfer (e.g. medium access mode).

1.1.8.5 Release of resources for Mobile Originated Data Transfer

After the MS has sent its last RLC Data Block (indicated by the countdown field), the acknowledgment is expected from the network side. By sending the last block, the MS may no longer use the same assignment unless a negative acknowledgment arrives. It also means that the network side may reallocate the same USF(s) to some other user as soon as all the RLC Data Blocks belonging to that Temporary Block Flow are correctly received; that regardless of the possible later errors in the acknowledgments.

The next step, in the case of all RLC Data Blocks being correctly received, is that the network sends Packet Ack/Nack which is to be immediately acknowledged in the reserved uplink block period. It must be possible for the network not to use the mechanism of acknowledgment for Packet Ack/Nack in which case the release of the resources procedure relies only on timers. The TFI can be reused for another assignment either upon the reception of the acknowledgment for Packet Ack/Nack or after expiry of the guard timer.

Further, the network can initiate premature release or change of assignment for one MS. The MS, then interrupts the Temporary Block Flow. It shall then reorganize the uplink buffer and issue a new Packet Channel Request to send the untransferred RLC Data Blocks.

1.1.8.6 Channel allocation for Mobile Terminated Data Transfer

1.1.8.6.1 Packet Paging

The network initiates packet transfer to an MS that is in Standby state by sending a Packet Paging Request on the downlink PPCH or PCH. The MS responds to the Packet Paging Request by initiating a procedure for page response.

After the Packet Paging Response, the mobility management state of the MS is Ready state.

1.1.8.6.2 Downlink Packet Transfer

Transmission of a packet to an MS in the Ready state is initiated by the network using the Packet Downlink Assignment message. In case there is PCCCH allocated in the cell, the Packet Downlink Assignment is transmitted on PAGCH. In case there is no PCCCH allocated in the cell, the Immediate Assignment is transmitted on AGCH. The Packet Downlink Assignment message includes the list of PDCH(s) that will be used for downlink transfer. The Timing Advance and Power Control information is also included.

The network sends the Radio blocks belonging to one Temporary Block Flow on downlink on the assigned downlink channels.

Multiplexing the Radio blocks destined for different MSs on the same PDCH downlink is enabled with an identifier, e.g. TFI, included in each Radio Block.

1.1.8.6.3 Release of resources

The release of the resources is initiated by the network by terminating the downlink transfer and polling the MS for a final Packet Downlink Ack/Nack. The handling of TFI is steered with the same timer that runs on both the MS and the network side after the last RLC Data Block is sent to the MS. When it expires, the current assignment becomes invalid for the MS and TFI can be reused by the network.

Further, TFI may be reused already upon the reception of the final Packet Downlink Ack/Nack from the MS.

Radio Resource management

The radio resource management [8] functions include

- Allocation and release of radio channels.
- Monitoring GPRS channel utilization to detect under-utilized or congested channels.
- Initiate congestion release procedures.
- Broadcast channel configuration information to the mobile stations.

2 Mobility Management

The Mobility Management (MM) functions [7],[8] in a GPRS network are responsible for registering a MS with the network. This naturally implies that the MM also handles functions relating to user identification, user authentication and subscriber management. The MM is also responsible for maintaining the current location of the MS in the GPRS PLMN. Location is in terms of

- the Routing Area Identity (RAI) of the Routing Area, the GPRS attached MS is currently present in
- the cell identity of the cell the GPRS attached MS is currently camped on.

The information is present in what is known as a MM context that is created in the MS and the SGSN.
This section describes the MM procedures and functionalities.

Mobility Management States

MM could be in either of the three states - IDLE, STANDBY or READY. These states refer to the amount of mobility management related information available in the MM context in the MS and in the Network. The MM state is independent of current user data sessions.

2.1.1 IDLE

In GPRS IDLE state, the subscriber is not attached to the GPRS mobility management. The MS and SGSN context hold no valid location or routing information for the subscriber. The MS however performs GPRS cell selection and re-selection processes. The MS may receive PTM-M transmissions.
Paging of the subscriber and PTP, PTM-G data transfers are not possible. The GPRS MS is seen as not reachable in this case. In order to establish MM contexts in the MS and the SGSN, the MS shall perform the GPRS Attach procedure. The MS then enters the READY state.

2.1.2 READY State

In READY state, the SGSN MM context corresponds to the STANDBY MM context extended by location information for the subscriber on cell level. The MS performs mobility management procedures to provide the network with the actual selected cell. In this state, the MS may send and receive PTP PDUs (in addition to PTM-M and PTM-G data).

The network initiates no GPRS pages for an MS in READY state, pages for CS services may be done via the SGSN. The MS may receive PTM-M and PTM-G data in READY state.

Regardless if a radio resource is allocated to the subscriber or not, the MM context remains in the READY state even when there is no data being communicated. The READY state is supervised by the READY timer. An MM context moves from READY state to STANDBY state when the READY timer expires.

If the MS initiates the GPRS Detach procedure in the READY state, it moves to IDLE state.

2.1.3 STANDBY State

In STANDBY state, the subscriber is attached to GPRS mobility management. The MS and SGSN have established MM contexts for the subscriber's IMSI. The MS may receive PTM-M and PTM-G data.
It is possible to page the MS for PTP or PTM-G data. It is also possible to receive pages for the CS services via the SGSN. PTP data reception and transmission, and PTM-G data transmission, are
not possible in this state.

If the MS enters a new RA during cell re-selection, it initiates a MM procedure called GPRS Routing Area Update. The MS does not inform the SGSN on a change of cell in the same RA. Therefore, the location information in the SGSN MM context contains only the GPRS RAI for MSs in STANDBY state.

If the SGSN needs to send a PDU to the MS in the STANDBY state, it sends a Paging Request in the routing area where the MS is located. The MM state in the MS is changed to READY when the MS responds to the page, and in the SGSN when the page response is received. Also, the MM state in the MS is changed to READY when data or signalling information is sent from the MS and, accordingly, the MM state in the SGSN is changed to READY when data or signalling information is received from the MS.

The MS or the network may initiate the GPRS Detach procedure to move to the IDLE state. The MM context is then be deleted both in the MS and in the network.

MM Timers

The MM state transition also depends on the following timers -

- READY Timer,
- Mobile Reachable Timer and
- the Periodic RA Update Timer.

These are described next

2.1.4 READY Timer

The READY timer function is maintained in the MS and SGSN. The READY timer controls the time an MS remains in READY state in the MS and the SGSN. The READY timer is reset and begins running in the MS when an LLC PDU is transmitted, and in the SGSN when an LLC PDU is correctly received.

When the READY timer expires, the MS and SGSN MM contexts shall return to STANDBY state.
The length of the READY timer is the same in the MS and SGSN. It is set by the SGSN and informed to the MS in the Attach Accept, Routing Area or Update Accept message.

2.1.5 Periodic RA Update Timer

The Periodic RA Update Timer function monitors the periodic RA update procedure in the MS. The length of the periodic RA update timer is sent in the Routing Area Update Accept or Attach Accept message. Upon expiry of the periodic RA update timer, the MS starts a periodic routing area update procedure. If the MS is out of GPRS coverage when the periodic RA update timer expires, then, the MS performs periodic RA update procedure as soon as the MS returns to GPRS coverage.

2.1.6 Mobile Reachable Timer Function

The Mobile Reachable Timer function monitors the periodic RA update procedure in the SGSN.
The is slightly longer than the periodic RA update timer used by an MS. The mobile reachable timer is stopped when the READY state is entered. The mobile reachable timer is reset and started when the state returns to STANDBY.
SGSN pages a mobile if a flag called Paging Proceed Flag (PPF) is set. It is maintained in the SGSN and is set when an MS first registers in an SGSN. If the mobile reachable timer expires, the SGSN shall clear PPF. This causes the SGSN to stop sending GPRS paging or CS paging messages to the MS. PPF is set when the next activity from the MS is detected.

2.1.7 Interaction between SGSN and MSC/VLR for MM procedures

SGSN and the MSC/VLR can directly interact with one another if the Gs interface is installed. If this interface is provides, then a MS that supports both GSM CS services and GPRS services can perform many of the mobility management functions in a combined manner. Otherwise the MS will have to perform the procedures separately for each service and add to signalling overhead. The association supports the following actions:

- IMSI attach and detach via SGSN. This makes combined GPRS / IMSI attach and combined GPRS / IMSI detach possible.
- Co-ordination of LA update and RA update, including periodic updates. A combined RA / LA update is sent from the MS to the SGSN. SGSN forwards the LA update to the VLR.
- Paging for a CS connection via the SGSN.
- Alert procedures for non-GPRS services.
- Identification procedure.
- MM Information procedure.

Combined procedures are however not initiated when a CS call is in progress.

2.1.8 Administration of the SGSN - MSC/VLR association

The SGSN - MSC/VLR association is created at the when the combined MM procedures described above are initiated. The association is initiated by the SGSN. The association is updated when an MS changes VLR or when an MS changes SGSN. Updation depends on the class of the MS (A,B,C), type of the network operation mode (type1,2,3) and the current state of circuit switched data service in the MS.

2.1.9 Combined RA / LA Updating

When the MS is both IMSI and GPRS-attached, the LA and RA updating is done in a co-ordinated way if supported by the network operation mode. When the MS enters a new RA in network operation mode I, then the MS sends a Routing Area Update Request message to the SGSN. The LA update is included in the RA update. The SGSN then forwards the LA update to the MSC/VLR. An MS in class-A mode of operation involved in a CS connection makes only RA updates and no combined RA / LA updates to the SGSN. An MS in class-B mode of operation involved in a CS connection does not make any updates during the CS connection. An MS in class-C mode of operation never makes combined RA / LA updates.

2.1.10 CS Paging through SGSN (Paging Co-ordination)

If an association between the SGSN and the MSC/VLR exists, paging for circuit-switched and packet switched services can be co-ordinated. Paging co-ordination means that the network sends paging messages for circuit-switched services on the same channel as used for packet-switched services, i.e

- on the GPRS paging channel, or
- GPRS traffic channel

The MS needs only to monitor only that channel.

Three network modes of operation are possible

1. Network operation mode III: No link exists between the SGSN and the MSC/VLR. The network sends a CS paging message for a GPRS-attached MS on the CCCH paging channel, and sends a GPRS paging message on -
   - the packet paging channel (if allocated in the cell) or
   - on the CCCH paging channel.

This means that an MS that wants to receive pages for both circuit-switched and packet-switched services shall monitor both paging channels if the packet paging channel is allocated in the cell.

2. Network operation mode II: As in mode III, no link exists between the SGSN and MSC/VLR. However, the network sends a CS paging message for a GPRS-attached MS on the CCCH paging channel, and this channel is also used for GPRS paging.

   This means that the MS needs only to monitor the CCCH paging channel.

   However the MS has to continue to monitor CCCH for CS pages even when a packet traffic channel is alloted to the MS. This is so since CS paging is not sent over packet channels.

3. Network operation mode I: The Gs interface is installed between the SGSN and the MSC/VLR. The network can send a CS paging message for a GPRS-attached MS on the same channel as the GPRS paging channel i.e
   - the packet paging channel or the CCCH paging channel,
   - or on a GPRS traffic channel, if one is currently assigned.

This means that the MS needs only to monitor one paging channel.

The network operation mode (mode I, II, or III) shall be indicated as system information to MSs. Based on the mode of operation provided by the network, the MS can then choose, according to its capabilities, whether it can attach to GPRS services, to non-GPRS services, or to both.

MM Procedures

MM performs the following procedures -

- Attach Function
- Detach Function
- Location Management Function
- Security Function
- Subscriber management Function

The CS and GPRS MM functions can be combined as discussed in section 2.1.7. In this case all signalling PDUs are sent through the LLC-RLC/MAC path (Figure 3). Since it is possible for user data to be lost during MM procedures, user data transfer is usually suspended.

The following sections discuss the MM procedures in detail.

2.1.11 Attach Function

A GPRS attach is made to the SGSN. In the attach procedure, MS provides the following information to SGSN -

- its identity - this is the Packet TMSI, if it is valid, else it's IMSI.
- an indication of which type of attach that is to be executed (GPRS attach, IMSI attach, combined GPRS/IMSI attach).

At the RLC/MAC layer, the MS shall identify itself with a Local or Foreign TLLI if the MS is already GPRS-attached and is performing an IMSI attach. Otherwise, the MS shall identify itself with a Foreign TLLI, or a Random TLLI if a valid P-TMSI is not available. The Foreign or Random TLLI is used as an identifier during the attach procedure until a new P-TMSI is allocated.

After having executed the GPRS attach, the MS is in READY state and MM contexts are established in the MS and the SGSN. The MS may then activate PDP contexts as described in section 3.

If the network operates in mode I, then an MS that is both GPRS-attached and IMSI-attached shall perform the Combined RA / LA Update procedures. If the network operates in mode II or III, then a GPRS-attached MS that has the capability to be simultaneously GPRS-attached and IMSI-attached shall perform the (non-combined) Routing Area Update procedures.

2.1.12 Detach Function

The Detach function -

- allows an MS to inform the network that it wants to make a GPRS and/or IMSI detach,
- and it allows the network to inform an MS that it has been GPRS-detached or IMSI-detached by the network.

The different types of detach are:

- IMSI detach;
- GPRS detach; and
- combined GPRS / IMSI detach (MS-initiated only).

The MS is detached from GPRS either explicitly or implicitly.

- Explicit detach: The network or the MS explicitly requests detach.
- Implicit detach: The network detaches the MS, without notifying the MS, a configuration- dependent time after the mobile reachable timer expired, or after an irrecoverable radio error causes disconnection of the logical link.

In the explicit detach case, a Detach Request (Cause) is sent by the SGSN to the MS, or by the MS to the SGSN. The MS can make an IMSI detach in one of two ways depending on if it is GPRS-attached or not:

- A GPRS-attached MS sends a Detach Request message to the SGSN, indicating an IMSI detach. This can be made in combination with GPRS detach.
- An MS not attached to the GPRS makes the IMSI detach as already defined in GSM.

In the MO Detach Request message there is an indication to tell if the detach is due to switch off or not. The indication is needed to know whether a Detach Accept message should be returned or not.

All active PDP contexts are deactivated at GPRS detach. In the network-originated Detach Request message there may be an indication to tell the MS that it is requested to initiate GPRS Attach and PDP Context Activation procedures for the previously activated PDP contexts.

2.1.13 Location Management Function

The Location Management function provides mechanisms for

- cell and PLMN selection
- provides a mechanism for the network to know the Routing Area for MSs in STANDBY and READY states;
- provides a mechanism for the network to know the cell identity for MSs in READY state.

The MS detects that a new cell has been entered by comparing the cell's identity with the cell identity stored in the MS's MM context.

The MS detects that a new RA has been entered by periodically comparing the RAI stored in its MM context with that received from the new cell.
When the MS camps on a new cell, possibly in a new RA, this indicates one of three possible scenarios:

- a cell update is required
- a routing area update is required; or
- a combined routing area and location area update is required.

In all three scenarios the MS stores the cell identity in its MM context.

If the MS enters a new PLMN, the MS shall either perform a routing area update, or enter IDLE state.

In network mode of operation II and III, whenever an MS determines that it shall perform both an LA update and an RA update, the MS shall perform the LA update first.

Routing Area Update Request messages shall be sent unciphered, since in the inter SGSN routing area update case the new SGSN shall be able to process the request.
The following sub-sections discuss the various location update procedures.

2.1.13.1 Cell Update Procedure

A cell update takes place when the MS enters a new cell inside the current RA and the MS is in READY state. If the RA has changed, a routing area update is executed instead of a cell update.
The SGSN records this MS's change of cell, and further traffic directed towards the MS is conveyed over the new cell.

2.1.13.2 Routing Area Update Procedure

A routing area update takes place when

- a GPRS-attached MS detects that it has entered a new RA,
- when the periodic RA update timer has expired, or
- when a suspended MS is not resumed by the BSS.

The SGSN detects that it is an intra SGSN routing area update by noticing that it also handles the old RA. In this case, the SGSN has the necessary information about the MS and there is no need to inform the GGSNs or the HLR about the new MS location.

A periodic RA update is always an intra SGSN routing area update.

2.1.13.3 Combined RA / LA Update Procedure

A combined RA / LA update takes place in network operation mode I when -

- the MS enters a new RA or
- when a GPRS-attached MS performs IMSI attach.

The MS sends a Routing Area Update Request indicating that an LA update may also need to be performed, in which case the SGSN forwards the LA update to the VLR. This concerns only idle mode as no combined RA / LA updates are performed during a CS connection.

2.1.13.4 Security Function

The Security function is an important requirement in a cellular system for the following reasons -

1. To guard against unauthorized GPRS service usage. This is achieved through authentication and service request validation procedures.
2. To provide user identity confidentiality. This is achieved through temporary identification and ciphering.

3. To provide user data confidentiality. This is achieved through ciphering.

The procedures are described in the following sub-sections.

2.1.13.5 Authentication of Subscriber

Authentication procedures are executed from the SGSN. Additionally, the authentication procedure performs the selection of the ciphering algorithm and the synchronization for the start of ciphering. Authentication triplets are stored in the SGSN. The procedure is as follows -

1. SGSN sends Authentication Info (IMSI) to the HLR. The HLR responds with Send Authentication Info Ack (Authentication Triplets). Each Authentication Triplet includes RAND, SRES and Kc. SGSN stores these for future use.
2. The SGSN sends Authentication Request (RAND, CKSN, Ciphering Algorithm). The MS responds with Authentication Response (SRES).
3. SGSN compares the SRES sent by the MS and the HLR. If the two are identical, then the MS is authenticated.

The MS starts ciphering after sending the Authentication Response message. The SGSN starts ciphering when a valid Authentication Response is received from the MS.

2.1.13.6 User Identity Confidentiality

2.1.13.6.1 Packet TMSI (P-TMSI)

P-TMSI is allocated to the MS by the SGSN at GPRS Attach.

MS derives an identity called Temporary Logical Link Identity (TLLI) from the P-TMSI allocated. (In case a valid P-TMSI is still not available, a temporary TLLI is created).

TLLI identifies a GPRS user. The relationship between TLLI and IMSI is known only in the MS and in the SGSN.

The SGSN can reallocate the P-TMSI at any time when the MS is in READY state. The reallocation procedure is performed by the P-TMSI Reallocation procedure, or it can be included in the Attach or Routing Area Update procedures.

2.1.13.6.2 P-TMSI Signature

P-TMSI Signature is optionally sent by the SGSN to the MS in Attach Accept and Routing Area Update Accept messages.

If the P-TMSI Signature has been sent by the SGSN to the MS, then the MS has to include the P-TMSI Signature in the next Routing Area Update Request and Attach Request for identification checking purposes.

The SGSN shall compare the P-TMSI Signature sent by the MS with the signature stored in the SGSN. If the values do not match, the SGSN should use the security functions to authenticate the MS. The P- TMSI Signature parameter has only local significance in the SGSN that allocated the signature.

2.1.13.7 User Data and GMM/SM Signalling Confidentiality

The scope of ciphering in existing GSM if from the MS to the BSS. The scope of GPRS ciphering is from the ciphering function at the SGSN to the ciphering function in the MS. Ciphering is done in the LLC layer, and from the perspective of the existing GSM MS-BTS radio path, an LLC PDU is transmitted as plain text. A ciphering algorithm to be used for GPRS ciphering is selected from the ones defined for GPRS.

In GSM, ciphering uses the TDMA frame number, which is not known at the SGSN. Therefore, LLC frame number replaces the TDMA frame number as an input to the algorithm.

2.1.14 Subscriber Management Function

The Subscriber Management function provides a mechanism to inform the GPRS nodes about changes of the GPRS subscription data for a specific GPRS subscriber.

Whenever the GPRS subscription data is changed for a GPRS subscriber in the HLR, and the changes affect the GPRS subscription data stored in the SGSN, then the SGSN node is informed about these changes by means of the following procedures:

- Insert Subscriber Data procedure, used to add or modify GPRS subscription data in the SGSN. This includes insertion and modification of general GPRS subscription data for a GPRS subscriber. It may also mean change of PDP context parameters, like QoS Profile Subscribed and VPLMN Address Allowed.
- Delete Subscriber Data procedure, used to remove GPRS subscription data in the SGSN. The HLR may also request the deletion of one or several PDP contexts from the SGSN.

2.1.15 Classmark Handling

To support efficient radio interface usage in GPRS, the classmark is sent in MM messages to the network and stored in the network as long as the MS is GPRS-attached, avoiding redundant classmark retransmissions over the radio interface. MS classmark contains information elements that describe
the capabilities of the MS to the network. In order to allow introduction of new radio access technologies in the future, the MS classmark is split into two distinct and independent information
elements, the radio access classmark, and the SGSN classmark.

2.1.15.1 Radio Access Classmark

The radio access classmark contains the radio capabilities of the MS (e.g., multislot capability, power class), and more generally all the information that should be known by the BSS in order to handle radio
resources for that MS. The radio access classmark is a container for a multiplicity of radio access technology-dependent information, i.e., within the radio access classmark there are independent sub- fields for various technologies such as GSM 900, GSM 1800, Satellite, UMTS, etc. The coding shall allow a BSS to extract only the sub-fields relevant to it without interpreting the other sub-fields. This ensures that the radio classmark does not need to be interpreted by the NSS, and the full radio classmark is always sent by the MS to the SGSN, and thereafter provided to the BSS irrespective of the actual BSS capabilities.

2.1.15.2 SGSN Classmark

The SGSN classmark contains non radio-related capabilities, e.g., the ciphering capability. The SGSN stores the SGSN classmark which is used both locally by the SGSN and for transfer to the new SGSN at all types of inter SGSN RA update.

3 PDP activation

Once a MS is GPRS attached to the network and wants to send/receive user data, it has to activate a Packet Data Protocol Session (PDP Session). This is a Session Management procedure and results in establishment of a PDP context - both in the MS and the SGSN. The context includes information like the PDP type (IP/X.25), PDP address with which the session will be known to the external PDNs, the Access Point Network (APN) to which the PDP wishes to connect to.

PDP States

The PDP state indicates whether the PDP address is activated for data transfer or not.

INACTIVE State

The INACTIVE state characterizes the data service for a certain PDP address of the subscriber as not activated. The PDP context contains no routing or mapping information to process PDUs related to that PDP address. No data can be transferred. A changing location of a subscriber causes no update for the PDP context in INACTIVE state even if the subscriber is attached to the GPRS MM.

Mobile-terminated PTP packets received in INACTIVE state by the GGSN may initiate the Network- Requested PDP Context Activation procedure if the GGSN is allowed to initiate the activation of the PDP context for that PDP address.

The MS initiates the movement from INACTIVE to ACTIVE state by initiating the PDP Context Activation procedure.

3.1.1 ACTIVE State

In ACTIVE state, the PDP context for the PDP address in use is activated in MS, SGSN and GGSN. The PDP context contains mapping and routing information for transferring PDUs for that particular PDP address between MS and GGSN.

The PDP state ACTIVE is permitted only when the mobility management state of the subscriber is STANDBY or READY. All active PDP contexts for an MS are moved to INACTIVE state when the MM state changes to IDLE.

An active PDP context for an MS is moved to INACTIVE state when the deactivation procedure is initiated.

PDP Addresses

A PDP may have Static or Dynamic address.

3.1.2 Static Address

Here the HPLMN operator assigns a PDP address permanently to the MS (static PDP address). For every IMSI, zero, one, or more static PDP addresses per PDP type can be subscribed to. Only static PDP addressing is applicable in the network-requested PDP context activation case.

3.1.3 Dynamic Address

Here the HPLMN operator assigns a PDP address to the MS when a PDP context is activated (dynamic HPLMN PDP address); or - the VPLMN operator assigns a PDP address to the MS when a PDP context is activated (dynamic VPLMN PDP address).

It is the HPLMN operator that defines in the subscription whether a dynamic HPLMN or VPLMN PDP address can be used. For every IMSI, zero, one, or more dynamic PDP address per PDP type can be assigned. When dynamic addressing is used, it is the responsibility of the GGSN to allocate and release the dynamic PDP address.

QoS Profile

A QoS profile is associated with each PDP context. It defines the quality of service expected in terms the following attributes:

- precedence class
- delay class
- reliability class
- peak throughput class; and
- mean throughput class.

A PLMN may support only a limited subset of the possible QoS profiles. During PDP activation MS negotiates a QoS profile with the network for that PDP.

The RLC/MAC layer supports four radio priority levels and an additional level for signalling messages as defined in [2]. Upon uplink access the MS can indicate one of the four priority levels, and whether the cause for the uplink access is user data or signalling message transmission. This information is used by the BSS to determine the radio access precedence (i.e., access priority) and the service precedence (i.e., transfer priority under congested situation). During PDP Context Activation, network decides the radio priority level to be used for user data transmission and informs the MS during the PDP Context Activation.

3.1.4 Precedence Class

The service precedence indicates the relative importance of maintaining the service commitments under abnormal conditions, for example which packets are discarded in the event of problems such as limited resources or network congestion. Three precedence classes are defined High Priority, Normal Priority and Low Priority.

3.1.5 Delay Class

Delay class determines the per-packet GPRS network transit delay. Four delay classes (1 to 4). The network operator should provision adequate transmission resources on the radio and network communication channels in order to support the expected number of subscribers within each cell at a given delay class. A PLMN may support only a subset of the delay classes. As a minimum, the PLMN shall support the best effort delay class (4).

3.1.6 Reliability Class

Data reliability is defined in terms of the residual error rates f

- probability of data loss
- probability of data delivered out of sequence
- probability of duplicate data delivery; and
- probability of corrupted data.

The combinations of the transmission modes (acknowledged, unacknowledged, protected, unprotected) of the these layers - GTP, LLC, and RLC determine reliability. Five levels of reliability class are defined.

3.1.7 Throughput Classes

The throughput is defined by both peak and mean classes.

3.1.7.1 Peak Throughput Class

The peak throughput is measured at the Gi and R reference points in units of octets per second. It specifies the maximum rate at which data is expected to be transferred across the network for an individual PDP context. There is no guarantee that this peak rate can be achieved or sustained for any time period, this depends upon the MS capability and available radio resources. The network may limit the subscriber to the negotiated peak data rate, even if additional transmission capacity is available. 9 levels of Peak Throughput Class are defined with data rates varying from 8KBPS to 2.048KBPS.

3.1.7.2 Mean Throughput Class

The mean throughput is measured at the Gi and R reference points in units of octets per hour. It specifies the average rate at which data is expected to be transferred across the GPRS network during the remaining lifetime of an activated PDP context. The network may limit the subscriber to the negotiated mean data rate (e.g., for flat-rate charging), even if additional transmission capacity is available. 19 levels of Mean Throughput Class are defined with data rates from 100 to 5000000 octets per hour.

4 Data Transfer

At the MS, GPRS data user interfaces to the SNDCP layer (refer). The user forwards N-PDUs (Network PDUs) to SNDCP. The maximum size of this packet is fixed at 1500 octets in GPRS. SNDCP compresses and forwards it to the LLC. The maximum frame size supported at LLC is dynamically negotiated between peer LLC layers (XID negotiation). SNDCP needs to fragment N-PDUs depending on the current LLC frame size. SNDCP also supports compression.

LLC supports logical links between the SGSN and the MS. It supports acknowledged and unacknowledged data transfer modes. It also supports ciphering. SNDCP and LLC are discussed in this section.

Subnetwork Dependent Convergence Functionality

The Subnetwork Dependent Convergence (SNDC) protocol [5] is situated below the network layer and above the Logical Link Control layer in the MS and the SGSN, as shown in figure 2. A variety of network layers are supported, e.g., IP and X.25. The network-layer packet data protocols share the same SNDCP, that then performs multiplexing of data coming from the different sources to be sent across LLC.

The SNDC function provides the following services to the network layer:

- Transmission and reception of N-PDUs in acknowledged and unacknowledged LLC mode. In acknowledged mode, the receipt of data shall be confirmed at the LLC layer, and the data shall be transmitted and received in order per NSAPI. In unacknowledged mode, the receipt of data shall not be confirmed at the SNDCP layer nor at the LLC layer.
- Transmission and reception between the MS and SGSN of variable-length N-PDUs.
- Transmission and reception of N-PDUs between the SGSN and MS according to the negotiated QoS profile.
- Transfer of the minimum amount of data possible between the SGSN and MS through compression techniques. SNDCP supports V.42bis [8] data compression and RFC1144 TCP/IP header compression algorithms [9].

Logical Link Control Functionality

The Logical Link Control (LLC) protocol [4] provides a reliable logical link between the MS and its SGSN. LLC layer is situated below the SNDC layer. TLLI is used for addressing at the LLC layer.

LLC provides the services necessary to maintain a ciphered data link between an MS and an SGSN. The LLC connection is maintained as the MS moves between cells served by the same SGSN. When the MS moves to a cell being served by a different SGSN, the existing connection is released and a new logical connection is established with the new SGSN.

The LLC connection can be used to transfer point-to-point and point-to-multipoint data between the MS and its SGSN.

LLC shall be independent of the underlying radio interface protocols. In order to allow LLC to operate with a variety of different radio interface protocols, and to ensure optimum performance, it may be necessary to adjust e.g., the maximum LLC PDU length and the LLC protocol timer values. Such adjustments can be made through negotiation between the MS and the SGSN.

The Logical Link Control layer supports

- procedures for detecting and recovering from lost or corrupted LL-PDUs;
- procedures for flow control of LL-PDUs between the MS and the SGSN
- procedures for ciphering of LL-PDUs.

5 Future trends and Conclusion

With GPRS it will provide an efficient means to access internet on the fly. This will usher in a new set of mobile internet based services WAP, mobile email, SMS to name a few. It will allow the user, the network provider and the application and content providers to experiment with newer set applications.

Presently as GPRS is being deployed for commercial services, work ig going on to set up standards for third generation cellular techology which speaks of data rates of the order of 1 MBPS. This can support more advanced applications like VoIP, Real time video, audio and so on.

GPRS – often described as a 2.5 generation technology, will be the testing ground for third generation cellular systems. It will enable a net set of mobile applications and help in the migration towards third generation.

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[7] GSM 04.08: "Digital cellular telecommunications system (Phase 2+); Mobile radio interface layer 3 specification.

[8] CCITT Recommendation V.42 bis: "Data communication over the telephone network Data compression procedures for data circuit-terminating equipment (DCE) using error correction procedures".

[9] RFC-1144, V. Jacobson: "Compressing TCP/IP Headers for Low-Speed Serial Links".

A Appendix: Identities

This section lists some of the identities used in GPRS for various purposes.

1. **IMSI**

A unique International Mobile Subscriber Identity (IMSI) is allocated to each mobile subscriber in GSM. This is also the case for GPRS-only mobile subscribers.

2. **Packet TMSI**

A Packet Temporary Mobile Subscriber Identity is allocated to each GPRS-attached MS.

3. **NSAPI and TLLI**

The Network layer Service Access Point Identifier (NSAPI) and Temporary Logical Link Identity (TLLI) are used for network layer routing. An NSAPI / TLLI pair is unambiguous within a routing area

In the MS, NSAPI identifies the PDP-SAP. In the SGSN and GGSN, NSAPI identifies the PDP context associated with a PDP address. When the MS requests the activation of a PDP context, the MS selects one of its unused NSAPIs.

Between the MS and SGSN, TLLI unambiguously identifies the logical link. Within a routing area, there is a one-to-one correspondence between TLLI and IMSI that is only known in the MS and SGSN.
<figure>
TLLI is derived from a P-TMSI, and does then provide user identity confidentiality. The TLLI address range is divided into four ranges: Local, Foreign and Random. The TLLI structure allows the MS and SGSN to deduce the range that a TLLI belongs to.

A Local TLLI is derived from the P-TMSI allocated by the SGSN, and is valid only in the RA associated with the P-TMSI.

A Foreign TLLI is derived from a P-TMSI allocated in another RA

.
A Random TLLI is selected randomly by the MS, and is used when the MS does not have a valid P- TMSI available.
If the MS has a valid P-TMSI associated with the RA where the MS is currently located, then the MS shall use a Local TLLI derived from its P-TMSI, unless the MS performs a GPRS attach. If the MS does not have a valid P-TMSI associated with the current RA, or if the MS performs a GPRS attach, then it shall derive a Foreign TLLI from its P-TMSI, or allocate a Random TLLI if no valid P- TMSI is available.

4. **PDP Address**

A GPRS subscriber identified by an IMSI, shall have one or more network layer addresses, i.e., PDP addresses, temporarily and/or permanently associated with it that conforms to the standard addressing scheme of the respective network layer service used, e.g.: - an IP version 4 address; - an IP version 6 address; or - an X.121 address.
PDP addresses are activated and deactivated through PDP Context Activation, Modification, and Deactivation Functions procedures.

5. **Routing Area Identity Routing Area Identity (RAI)**

Defined by an operator, it identifies one or several cells. RAI is broadcast as system information and is used by the MS to determine, when changing cell, if an RA border was crossed. If that was the case, the MS initiates the RA update procedure.

The location of an MS in STANDBY state is known in the SGSN on an RA level. This means that the MS is paged in the RA where the MS is located when mobile-terminated traffic arrives in the SGSN.

A Routing Area is a subset of one, and only one, Location Area (LA), meaning that an RA cannot span more than one LA. An RA is served by only one SGSN.

6. **Cell Identity Cell Identity (CI)**

Identifies one cell.

7. **Access Point Name**

In the GPRS backbone, Access Point Name is a reference to the GGSN to be used. In addition, Access Point Name may, in the GGSN, identify the external network.

B Appendix: Information Storage

This section lists some of the information elements stored in the HLR, GGSN, SGSN, MS and the MSC/VLR when an association exists between the SGSN and the MSC/VLR. Not all elements are listed. A few key elements have been listed to illustrate the role of a particular network node.

1 Information stored in the HLR

Field	Description
IMSI	IMSI is the main reference key.
SGSN Number	The SS7 number of the SGSN currently serving this MS.
SGSN Address	The IP address of the SGSN currently serving this MS.
GGSN-list	The GSN number and optional IP address pair related to the GGSN that shall be contacted when activity from the MS is detected.

Each IMSI contains zero or more of the following PDP context subscription records. Information elements corresponding to this is listed -

Field	Description
PDP Context	Identifier Index of the PDP context.
PDP Type	PDP type, e.g., X.25 or IP.
PDP Address	PDP address, e.g., an X.121 address. This field shall be empty if dynamic addressing is allowed. QoS Profile Subscribed The quality of service profile subscribed. QoS Profile Subscribed is the default level if a particular QoS profile is not requested.
VPLMN Address Allowed	Specifies whether the MS is allowed to use the APN in the domain of the HPLMN only, or additionally the APN in the domain of the VPLMN.
Access Point Name	A label according to DNS naming conventions describing the access point to the external packet data network.

in the following table

2 Information stored in the SGSN

Field	Description
IMSI	IMSI is the main reference key.
MM State	Mobility management state, IDLE, STANDBY, or READY.
P-TMSI	Packet Temporary Mobile Subscriber Identity.
IMEI	International Mobile Equipment Identity
P-TMSI Signature	A signature used for identification checking purposes.
Routing Area	Current routing area.
Cell Identity	Current cell in READY state, last known cell in STANDBY or IDLE state.
VLR Number	The VLR number of the MSC/VLR currently serving this MS.
New SGSN Address	The IP address of the new SGSN where buffered and not sent N-PDUs should be forwarded to.
Kc	Currently used ciphering key. CKSN Ciphering key sequence number of Kc.
Ciphering algorithm.	Selected ciphering algorithm

Radio Access Classmark	MS radio access capabilities.
SGSN	Classmark MS network capabilities.
DRX	Parameters Discontinuous reception parameters.
PPF	Indicates whether paging for GPRS and non-GPRS services can be initiated.

Each MM context contains zero or more of the following PDP contexts. Information per PDP is listed in the following table.

PDP	Context Identifier Index of the PDP context.
PDP Type	PDP type, e.g., X.25 or IP.
PDP Address	PDP address, e.g., an X.121 address.
NSAPI	Network layer Service Access Point Identifier.
PDP State	Packet data protocol state, INACTIVE or ACTIVE.
Access Point Name	The APN requested by the MS.
GGSN Address in Use	The IP address of the GGSN currently used by the activated PDP context.
VPLMN Address Allowed	Specifies whether the MS is allowed to use the APN in the domain of the HPLMN only, or additionally the APN in the domain of the VPLMN.
QoS Profile Subscribed	The quality of service profile subscribed.
QoS Profile Requested	The quality of service profile requested. QoS Profile Negotiated The quality of service profile negotiated.
Radio Priority	The RLC/MAC radio priority level for uplink user data transmission.
Charging Id	Charging identifier, identifies charging records generated by SGSN and GGSN.

3 Information elements stored in the GGSN

Field	Description
IMSI	International Mobile Subscriber Identity.
NSAPI	Network layer Service Access Point Identifier.
PDP Type	PDP type, e.g., X.25 or IP.
PDP Address	PDP address, e.g., an X.121 address.
Dynamic Address	Indicates whether PDP Address is static or dynamic.
QoS Profile Negotiated	The quality of service profile negotiated.
SGSN Address	The IP address of the SGSN currently serving this MS.
Access Point Name	The APN requested by the MS.
Charging Id	Charging identifier, identifies charging records generated by SGSN and GGSN.

4 Information elements stored in the MS

Field	SIM	Description
IMSI	X	International Mobile Subscriber Identity.
MM State		Mobility management state, IDLE, STANDBY, or READY.
P-TMSI	X	Packet Temporary Mobile Subscriber Identity.
P-TMSI Signature	X	A signature used for identification checking purposes.
Routing Area	X	Current routing area.
Cell Identity		Current cell.
Kc	X	Currently used ciphering key.
CKSN	X	Ciphering key sequence number of Kc.
Ciphering algorithm Selected		ciphering algorithm.
Classmark		MS classmark.
DRX Parameters		Discontinuous reception parameters.

Each MM context contains zero or more of the following PDP contexts. The following table lists information elements maintained per PDP in the MS

PDP Type	PDP type, e.g., X.25 or IP. PDP Address PDP address, e.g., an X.121 address. PDP State
Packet data protocol state,	INACTIVE or ACTIVE.
Dynamic Address Allowed	Specifies whether the MS is allowed to use a dynamic address.
NSAPI	Network layer Service Access Point Identifier.
QoS Profile Requested	The quality of service profile requested.
QoS Profile Negotiated	The quality of service profile negotiated.
Radio Priority	The RLC/MAC radio priority level for uplink user data transmission.

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5 Information elements stored in the MSC/VLR when an association exists with the SGSN

Field	Description
IMSI	IMSI is the main reference key.
SGSN Number	The SGSN number of the SGSN currently serving this MS.

Appendix C Abbreviations

APN Access Point Network
BSS Base Sub-Station
DL Down Link (Direction from Network to the Mobile station)
FEC Forward Error Correction
GGSN Gateway GSN
GPRS General Packet Radio Services
GSM Global System for Mobile Communications
GSN GPRS Service Node
HLR Home Location Register
LLC Logical Link Control
MAC Medium Access Control
MM Mobility Management
MS Mobile Station
MSC/VLR Mobile Switching Centre / Visitor Location Register
PDCH Padcket Data Channel
PDN Packet Data Network
PDU Protocol Data Unit
PLMN Public Land Mobile Network
PPF Paging Proceed Flag
QoS Quality of Service
RA Routing Area
RAI Routing Area Identity
RLC Radio Link Control
SGSN Serving GSN
SM Session Management
SNDCP Sub Network Dependent Convergence Protocol
TDMA Time Division Multiple Access
UL Up Link (Direction from Mobile station to the Network)