Overview Of The GSM System and Protocol Architecture

We can use GSM as a basic framework to define and develop the standards for handling the mobility-specific functions of next-generation PCNs.

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Global system for mobile telecommunication (GSM) comprises the CEPT-defined standardization of the services, functional/subsystem interfaces, and protocol architecture, based on the use of worldwide standards produced by CCITT and CCIR, for a pan-European digital land mobile system primarily intended to serve users in motor vehicles. The digital mobile radio networks, for which GSM represents the European standards, provide powerful message signaling capabilities that facilitate and enhance roaming, compared to the first generation analogue systems, through automatic network location detection and registration.

GSM provides terminal mobility, with personal mobility provided through the insertion of a subscriber identity module (SIM) into the GSM network (mobile station). The SIM carries the personal number assigned to the mobile user. The GSM-based cellular mobile networks are currently in widespread use in Europe. At the present time, the next generation of personal communication services (PCS) beyond GSM is also being considered. These third generation systems, known as universal personal communication networks (PCN) will be using lower power handsets to provide personal mobility to pedestrians, as well. The PCS low-power handsets are expected to eliminate the need to have different handsets for wide-area (cellular) and local (cordless) applications. The universal PCS will also provide a higher quality of personal-service mobility across the boundaries of many different networks (mobile and fixed, wide- and local-area).

Many network capabilities, however, such as mobility management, user security protection, and resource allocation, addressed in GSM, are also some of the critical requirements and issues in UPC networks of the future. GSM is expected to play a major role in the specification of the standards for UPC. In the United Kingdom, PCN is already being designed and deployed with close adherence to the GSM standards other than the different operating frequencies (GSM operates at 900 MHz and the United Kingdom PCN operates at 1800 MHz). Generally, GSM may be viewed as a framework for studying the functions and issues that are specific to cellular type personal communication networks, whatever the means of implementation might be.

In applying and extending GSM to the next generation personal communication networks, however, one should be careful in differentiating some of the implementation specifics unique to the GSM network architecture and application from the functions and issues that would be more or less generally applicable and relevant to cellular networking. It is with this point in mind that the reader should view GSM as a framework or platform on which to build his or her vision of how GSM may be used as a guide to design and build the next generation networks. In that regard, a good understanding of the GSM standards and network functions is essential for the professional working on the next generation personal communication networks. This article is intended to assist with this objective.

The Cellular Concept

Cellular mobile communication is based on the concept of frequency reuse. That is, the limited spectrum allocated to the service is partitioned into, for example, N non-overlapping channel sets, which are then assigned in a regular repeated pattern to a hexagonal cell grid. The hexagon is just a convenient idealization that approximates the shape of a circle (the constant signal level contour from an omnidirectional antenna placed at the center) but forms a grid with no gaps or overlaps. The choice of N is dependent on many tradeoffs involving the local propagation environment, traffic distribution, and costs. The propagation environment determines the interference received from neighboring co-channel cells which in turn governs the reuse distance, that is, the distance allowed between co-channel cells (cells using the same set of frequency channels).

The cell size determination is usually based on the local traffic distribution and demand. The more the concentration of traffic demand in the area,

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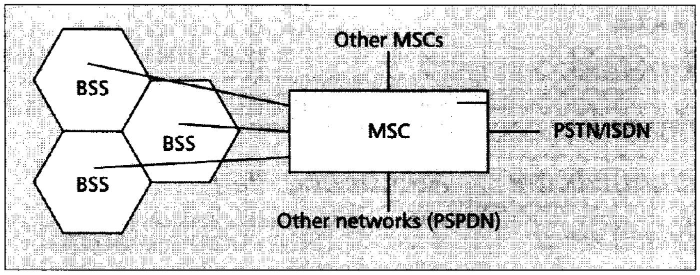
the smaller the cell has to be sized in order to avail the frequency set to a smaller number of roaming subscribers and thus limit the call blocking probability within the cell. On the other hand, the smaller the cell is sized, the more equipment will be needed in the system as each cell requires the necessary transceiver and switching equipment, known as the base station subsystem (BSS), through which the mobile users access the network over radio links. The degree to which the allocated frequency spectrum is reused over the cellular service area, however, determines the spectrum efficiency in cellular systems. That means the smaller the cell size, and the smaller the number of cells in the reuse geometry, the higher will be the spectrum usage efficiency. Since digital modulation systems can operate with a smaller signal to noise (i.e., signal to interference) ratio for the same service quality, they, in one respect, would allow smaller reuse distance and thus provide higher spectrum efficiency. This is one advantage the digital cellular provides over the older analogue cellular radio communication systems. The interested reader may refer to [1,2] for the details on spectrum efficiency analysis in cellular network.

It is worth mentioning that the digital systems have commonly used sectored cells with 120-degree or smaller directional antennas to further lower the effective reuse distance. This allows a smaller number of cells in the reuse pattern and makes a larger fraction of the total frequency spectrum available within each cell. Currently, research is being done on implementing other enhancements such as the use of dynamic channel assignment strategies for raising the spectrum efficiency in certain cases, such as high uneven traffic distribution over cells.

The Network Infrastructure

The cellular concept of networking is based on the superposition of a distributed star type network architecture on the existing fixed landline telephony communication infrastructure. The basic network architecture is illustrated in Fig. 1. The telephony network is used to provide not only the communication links between a mobile user and a fixed landline user, but also to provide the connectivity between the mobile users roaming in remotely located cells or in the domain of mobile networks operated by different service providers. The BSSs, provide management of the radio resources, and the switching between the radio channels and the TDM slots on their connections with the mobile switching center (MSC). MSCs link groups of neighboring BSSs through point-to-point landline or microwave-based E1 trunks. The MSC acts as the nerve center of the system. It controls call signaling and processing, and coordinates the handover of the mobile connection from one base station to another as the mobile roams around. Each MSC is in turn connected to the local public switched telephony network (PSTN, or ISDN) to provide the connectivity between the mobile and the fixed telephony users, as well as the necessary global connectivity among the MSCs of the cellular mobile network. This is intended to make it possible for any mobile user to communicate with any other mobile or fixed telephony user in the world. Thus, the global connectivity provided by the existing landline telephony infrastructure is used to link up the cellular mobile subscribers throughout the world.



■ **Figure 1.** *Cellular network infrastructure.*

Direct links between certain "local" MSCs may also be provided to allow the communication between two mobile users to bypass the telephony network when there is considerable traffic flow between the mobile users roaming in the areas under the coverage of those MSCs. Thus, the communication path between any two mobile users roaming under the coverage of two "local" MSCs may or may not switch through the public telephony network. It depends on the connectivity provided between the two MSCs. The MSC may also connect to public data networks (PDN), such as the packet-switched networks, to provide the mobiles with access to data services.

Network Databases and Standardization

GSM defines a number of network databases that are used in performing the functions of mobility management and call control in a public land mobile network (PLMN). These elements include the location registers consisting of the home location register (HLR), and the visiting location register (VLR), the equipment identity register (EIR), and the authentication center (AC). The HLR maintains and updates the mobile subscriber's location and his or her service profile information. The VLR maintains the same information locally, where the subscriber is roaming. The VLR is defined as a stand-alone function (see following paragraph), but is usually viewed by vendors as part of the MSC. These registers are called service control points (SCP) in the terminology used in intelligent networking (IN). The EIR is used to list the subscribers' equipment identities, which are used for identification of unauthorized subscriber equipment, and hence denial of service by the network. The AC provides the keys and algorithm for maintaining the security of subscriber identities, and for encrypting information passed over the air interface. The MSC is equipped with a service switching point (SSP) module which is used to query the databases such as a location register to identify where a mobile subscriber is located and what his or her service profile is, for the routing, and processing of calls to (or by) the subscriber.

The GSM specifications have defined logically separate functions and standard interfaces for each of the databases, to allow each function to be implemented on a physically separate network component. The interfaces are specified via the mobile application part (MAP) that uses the transaction capability applications part (TCAP) of (SS7). These are all elements of an IN. GSM is considered an IN application and GSM providers are considering the GSM implementation as experience in intelligent networking.

In GSM, the radio channels are based on a TDMA structure that is implemented on multiple frequency subbands (TDMA/ FDMA).

Numbering Plan

The numbering consists of at least one international ISDN number allocated to either the mobile subscriber, if the mobile is card operated, or to the mobile station, otherwise. The mobile station ISDN (MSISDN) conforms to the CCITT E.164 recommendation, and should, in each country, comply to that country's ISDN numbering plan. The MSISDN number basically consists of a country code (CC), a "national destination code (NDC), which specifies a PLMN within that country, and a subscriber number (SN). This structure is shown in Fig. 2.

The MSISDN number is used for dialing by a calling subscriber from the PSTN/ISDN, and is used to route the call to the gateway MSC of the GSM network. The GSM MSC then uses the MSISDN to interrogate the appropriate HLR for the re-routing information required to extend the call to the mobile's visiting MSC.

The rerouting information is specified by the mobile station roaming number (MSRN) which is obtained from the HLR and is used to progress the call to the called mobile. The MSRN is a temporary number, allocated by the VLR (associated with the mobile's visiting MSC) and sent to the mobile's HLR either on location update (discussed in a later section) or on a per call basis. The MSRN has the same structure as the MSISDN numbers in the visiting location area where it is allocated.

For provision of mobile packet data services, a mobile international data number conforming to CCITT recommendation X.121 may be specified. GSM recommendation 03.70 discusses the requirements for the numbering interworking functions required in this case.

Addressing and Call Routing

The MSISDN number is used for the routing of calls within the PSTN/ISDN networks. The details of call routing requirements are discussed in GSM recommendation 03.04. The following paragraphs provide a summary discussion of possible scenarios involved in call routing.

National Calls from the Fixed Network

A local or transit exchange, when receiving a call destined for a mobile, recognizes the NDC, and routes the call to a gateway MSC. The gateway MSC performs the HLR query for the MSRN, which it then uses to reroute the call.

International Calls from the Fixed Network

When a local or transit exchange receives an international call and recognizes the international prefix, it routes the call to the nearest ISC. The ISC recognizes that the NDC indicates a PLMN. If it can support HLR query (i.e., if it has TCAP signaling connectivity to the HLR) it queries the HLR and receives the called subscriber's roaming number and routes the call to the visiting MSC. If not, it routes the call to the ISC of the home PLMN of the called subscriber.

CC	NDC	SN

■ **Figure 2.** *The structure for the GSM MSISDN.*

National Calls from Within the PLMN

When a local exchange (MSC) receives a call destined for a mobile, it queries the mobile's HLR for the roaming number of the mobile. On receipt of the MSRN, it routes the call to the called mobile's visiting MSC.

Addressing Other Components of a PLMN

Other components of a PLMN, which may be addressed for the routing of various signaling messages, are the MSCs, and the location registers. If these elements are addressed from within the same PLMN, the SS7 point codes (PC) can be used. Otherwise, for interPLMN routing, global titles (GT) derived, for instance, from the mobile country code (MCC) and the national destination codes (NDC) are used.

Radio Channel Structure in GSM

In GSM, the radio channels are based on a TDMA structure that is implemented on multiple frequency subbands (TDMA/FDMA). Each base station is equipped with a certain number of these preassigned frequency/time channels.

CEPT has made available two frequency bands to be used by the GSM system. These are: 890-915 MHz for the direction mobile to base station, and 935-960 MHz for the direction base station to mobile terminal. These bands are divided into 124 pairs of carriers spaced by 200 kHz, starting with the pair 890.2 MHz. Each cell site has a fixed assignment of a certain number of carriers, ranging from only one to usually not more than 15 channels. The cell ranges in size from 1 to several km.

The assigned spectrum of 200 kHz per channel is segmented in time by using a fixed allocation, time-division multiple access (TDMA) scheme. The time axis is divided into eight time slots of length 0.577 ms. The slots numbered from time slot 0 to 7 form a frame with length 4.615 ms. The recurrence of one particular time slot in each frame makes up one physical channel.

The TDMA scheme uses a gross bit rate of about 270 kb/s (with a Gaussian minimum shift keying modulation, GMSK) and requires sophisticated adaptive receiver techniques to cope with the transmission problems caused by multipath fading. The TDMA factor of 8 in combination with a carrier spacing of 200 kHz would correspond to the earlier analog system using single-channel per-carrier with a 25 kHz carrier spacing. The GSM digital system allowed operation at lower carrier to interference (C/I) ratio by using the gains provided by digital voice compression along with channel coding (powerful error correction). The reduced C/I ratio in turn allowed the use of shorter channel reuse distances to achieve spectrum efficiencies competitive to that achieved by the analog systems.

The TDMA structure is applied in both the forward (base station to mobile) and the reverse (mobile to base station) directions. The numbering, however, is staggered by three time slots, to prevent the mobile station from transmitting and receiving at the same time. These time slots are used to carry user, and signaling or control information in bursts. The bursts are slightly shorter than the slots, namely .546 ms, to allow for burst timing alignment errors, delay dispersion on the propagation path, and for smooth switch on/off of the transmitter.

GSM defines a variety of traffic and signaling/control channels of different bit rates. These channels are assigned to logical channels derived from multiframe structuring of the basic eight slotted TDMA frames just discussed. For this purpose, two multiframe structures have been defined: one consisting of 26 time frames (resulting in a recurrence interval of 120 ms), and one comprising 51 time frames (or 236 ms).

The 26 multiframe is used to define traffic channels (TCH), and their slow and fast associated control channels (SACCH and FACCH) that carry link control information between the mobile and the base stations. The TCH have been defined to provide six different forms of services, that is, full-rate speech or data channels supporting effective bit rates of 13 kb/s (for speech), 2.4, 4.8, and 9.6 kb/s; and the half-rate channels with effective bit-rates of 6.5 (for speech) and kb/s, 2.4 kb/s, and 4.8 kb/s for data (note that the gross bit rates on these channels are higher due to required channel coding, 22.8 kb/s for full-rate speech). The full-rate TCHs are implemented on 24 frames of the multiframe, with each TCH occupying one time slot from each frame. The SACCH is implemented on frame 12 (numbered from 0), providing eight SACCH channels, one dedicated to each of the eight TCH channels. Frame 25 in the multiframe is currently idle and reserved to implement the additional eight SACCH required when half-rate speech channels become a reality. The FACCH is obtained on demand by stealing from the TCH, and is used by either end for signaling the transfer characteristics of the physical path, or other purposes such as connection handover control messages. The stealing of a TCH slot for FACCH signaling is indicated through a flag within the TCH slot.

The 51-frame multiframe has a more complex structure and we will refer the reader to GSM Recommendation 05.0 for the specific positions of the various logical channels in the multiframe. The 51-frame structure, however, is used to derive the following signaling and control channels.

SDCCH — Stand-alone dedicated control channel is used for the transfer of call control signaling to and from the mobile during call setup. Like the TCHs, the SDCCH has its own SACCH and is released once call setup is complete.

BCCH — Broadcast control channel is used in the BSS to mobile direction to broadcast system information such as the synchronization parameters, available services, and cell ID. This channel is continuously active, with dummy bursts substituted when there is no information to transmit, because its signal strengths are monitored by mobiles for handover determination.

SCH — Synchronization channel carries information from the BSS for frame synchronization.

FCCH — Frequency control channel carries information from the BSS for carrier synchronization.

CCCH — Common control channels are used for transferring signaling information between all mobiles and the BSS for call origination and call-paging functions. There are three common control channels:

- PCH: paging channel used to call (page) a mobile from the system.
- RACH: random access channel used by the mobiles trying to access the system. The mobiles use the slotted Aloha scheme over this channel for requesting a DCCH from the system at call initiation.
- AGCH: access grant channel used by the system to assign resources to a mobile such as a DCCH channel.

Note that the AGCH and the PCH are never used by a mobile at the same time, and therefore are implemented on the same logical channel. All the control signaling channels, except the SDCCH, are implemented on time slot 0 in different TDMA frames of the 51 multiframes using a dedicated RF carrier frequency assigned on a per cell basis. The multiframe structure for the SDCCH and its associated slow associated control channel (SACC) is implemented on one of the physical channels (TDM slots and RF carriers) selected by the system operator.

Common control channels are used for transferring signaling information between all mobiles and the BSS for call origination and call-paging functions.

Mobility Management

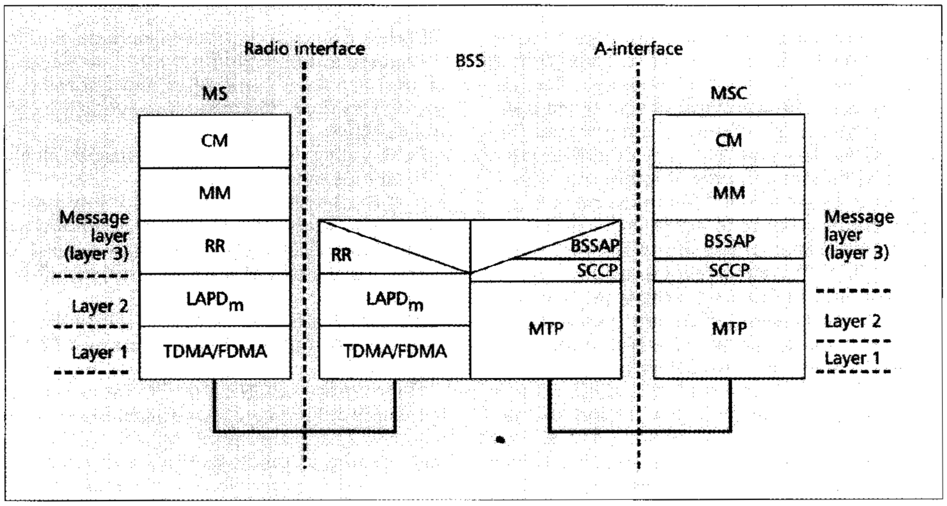
Mobility management is concerned with the functions of tracking the location of roaming mobiles and registering the information in appropriate network elements, and handling connection handoffs for users in the communication process. These functions are discussed in the following sections.

Connection Handoffs

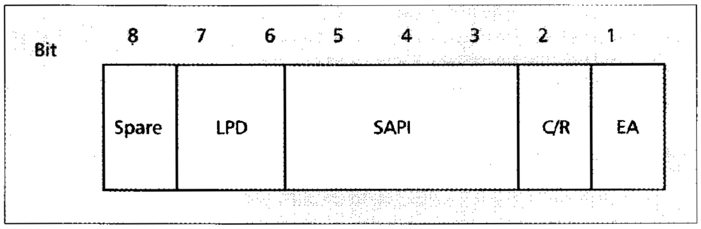
This may be done between channels in the same cell, between channels in different cells under the same BSS coverage, or between cells under the coverage of different BSSs, and even different MSCs. In GSM, the BSS may autonomously handle the connection handoffs in the same cell, or between cells under its own coverage. This is called internal connection handoffs. The MSC is involved in managing connection handoffs that need to take place between cells under coverage of two different BSSs. These are called external connection handoffs. When the BSS indicates that an external handover is required, the decision of when and whether an external handover should occur is then taken by the MSC. The MSC uses the signal quality measurement information reported by the mobile stations (MSs) which are pre-processed at the BSS for external handover determination.

The original MSC handling a call will always keep control of the call in an external handover to a different and even a subsequent MSC.

When the BSS performs an internal connection handoff, it informs the MSC at the completion of the process. The need for a connection handoff may be indicated by the mobile user, through messaging on the FACH, for instance, or by the BSS as it keeps tracking the quality of the signals received. The BSS monitors the quality of the radio signal received and also transmits such results to the MSC who keeps a more global view on the radio channels belonging to its BSSs. The



■**Figure 3.** *GSM protocol architecture.*



Bit	8	7	6	5	4	3	2	1
	Spare	LPD		SAPI			C/R	EA

■**Figure 4.** *LAPDm "address field" format.*

MSC may also initiate the need for a connection handoff for traffic reasons in an attempt to balance out the traffic load in the network.

Handling of Location Information

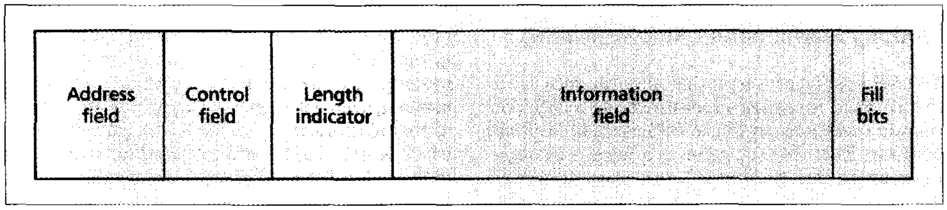
Location information is maintained and used by the network to locate the user for call routing purposes. The network registers the user's location in a register called the user's, HLR, which is associated with an MSC located in the PLMN, to which the user is subscribed. Each BSS keeps broadcasting, on a periodic basis, the cell identities on the "broadcast control channels" of the cells under its coverage. The mobiles within each cell keep monitoring such information. As changes in location are detected (from the last information recorded by them), they each report the new location to the BSS which routes it to the VLR, of the MSC to which it is connected. The VLR, in turn, sends the location information to the user's HLR, where it is also recorded. In the meantime, the HLR directs the old VLR to delete the old visiting location of the mobile from its data base, and also sends a copy of the user's service profile to the new VLR. Location updating is performed by the mobility management (MM) protocol sublayer that will be discussed later in the article.

Call Routing and Signaling

A call may be initiated by a mobile user to another mobile or a fixed landline user, or in reverse, by a fixed landline user to a mobile. For routing a call to a mobile user, however, the network signaling needs to first locate the mobile. We will illustrate this for the case when a call is initiated by a landline user, and then comment on the scenario in which the call is initiated by a mobile to another mobile. When the call is initiated by a mobile to a landline user, the procedure is rather straightforward.

In the case of a call initiated by a landline user, the PSTN may use the mobile station ISDN number, MSISDN, to route the call to the closest Gateway MSC within the mobile's PLMN. The GMSC in turn uses the MSISDN to interrogate the mobile's HLR for the routing information required to extend the call to the visiting MSC of the mobile at the time. This visiting MSC (or more specifically the, VLR within the local MSC) is identified in the mobile's HLR by the MSRN which specifies the visiting MSC. The MSRN is a temporary number allocated by the VLR and sent to the HLR on location updating, or call initiation. The MSRN should have the same structure as the MSISDN numbers in the VLR area where it is allocated. The VLR then initiates the paging procedure and the MSC pages the mobile station with a paging broadcast to all BSSs of the location area, as the exact base station area of the mobile may not be known. After paging response, the current BSS is located. The RR and MM connections are established, during which both authentication of the user (for access to the network), as well as cipher mode setting are performed. The VLR then sends the required parameters for call setup to the MSC, and may also assign the mobile a new TMSI for the call. The MSC sends a setup message to the mobile station.

The mobile station, on receiving the set-up message performs a compatibility check and returns a call-confirmed message to the network, which may include the bearer capability of the mobile station. The BSS may at this point assign a traffic channel, TCH, to the call, or may assign it at a later stage, the latest being on receipt of the "connect message" from the mobile station. If user alerting is carried out at the MS, an alerting message is sent to the calling subscriber. When, the subscriber answers the call, the MS sends a connect message, which at the network side initiates the completion of the traffic channel allocation and switch through of the connection. The connect message is progressed to the calling subscriber. The network also sends an acknowledgement to the MS, that enters the active state.



■ **Figure 5.** *LAPDm general frame format.*

Protocol Layering Architecture

The GSM protocol architecture used for the exchange of signaling messages pertaining to mobility, radio resource, and connection management functions is shown in Fig. 3. The protocol layering consists of the physical layer, the data link layer, and the Layer 3. It is noted to the OSI-minded reader to be careful in not confusing the Layer 3 protocol functions defined by GSM with what is normally defined to be the Layer 3 functions in the OSI model. The GSM Layer 3 protocols are used for the communication of network resource, mobility, code format and call-related management messages between the various network entities involved. Since, in the OSI model, some of these functions are actually provided by the higher layers, the term "message layer" may be a more appropriate term for refering to the Layer 3 in GSM. The message layer (Layer 3) protocol is made up of three sublayers called the resource management (RR) implemented over the link between the MS and the BSS, the mobility management (MM), and connection management (CM) sublayers providing the communication between the MS and the MSC. Layer 3 also implements the message transport part (MTP), level 3, and the signaling connection control part of the CCITT SS7 on the link between the BSS and the MSC (the A interface) to provide the transport and addressing functions for signaling messages belonging to the various calls routed through the MSC.In discussing the functionality provided by the Layer 3 in the GSM protocol stack, particular attention should be paid to not confuse the details of this layer's functionality with what is commonly provided by the Layer 3 of the OSI protocol stack. In GSM, the CM, and MM sublayers, for instance, provide actually some of the functionalities which are realized by the transport, the session, and the presentation layers of OSI, as will be seen later. The functions of each protocol layer/sublayer is discussed in some detail in the following.

Physical Layer

The physical layer on the radio link was discussed in the section on radio channel structure. The traffic channels on the landside are formed from TDM slots implemented on 2.048 Mb/s links (E1 trunks). The signaling channels are basically logically multiplexed on an aggregate of the TDM slots.

Link Layer on the Air Interface

The data link layer over the radio link (connecting the MS to the BSS) is based on a LAPD-like protocol, labeled LAPDm, that has been modified for operation within the constraints set by the radio path. In particular, LAPDm uses no flags (and therefore no bit stuffing) for frame delimitation. Instead, frame delimitation in LAPDm is done by the physical layer that defines the transmission frame boundaries. LAPDm uses a "Length Indicator" field to distinguish the information carrying field from fill-in bits used to fill the transmission frame. LAPDm uses an address field to carry the service access point identifier, (SAPI), (3 bits in this case) which LAPD also uses to identify the user of the service provided by the protocol. When using command/control frames, the SAPI identifies the user for which a command frame is intended, and the user transmitting a response frame. The format for the address field is shown in Fig. 4. The 2-bit link protocol discriminator (LPD) is used to specify a particular recommendation of the use of LAPDm, the C/R is a single bit which specifies a command or response frame as used in LAPD, and a 1-bit extended address (EA) is used to extend the address field to more than one octet (the EA bit in the last octet of the address should be set to 1, otherwise to 0). The 8-bit is reserved for future uses.

LAPDm uses a control field as is used in LAPD to carry sequence numbers, and to specify the type of frame. LAPDm uses three types of frames used for supervisory functions, unnumbered information transfer and control functions (unacknowledged mode), and numbered information transfer (multiframe acknowledged mode) as used in LAPD. LAPDm uses no cyclic redundancy check bits for error detection. Error correction and detection mechanisms are, instead, provided by a combination of block and convolutional coding used (in conjuction with bit interleaving) in the physical layer. The general frame format for LAPDm is shown in Fig. 5.

Link Layer on the A Interface

On the terrestrial link connecting the BSS to the MSC (the A interface), the MTP level 2 of the SS7 protocol is used to provide the OSI Layer 2 functions of reliable transport for the signaling messages, such as recovery from transmission errors through error detection and retransmission.

Message Layer Protocols and Functions

Radio Resource (RR) Management Sublayer

The RR management sublayer terminates at the BSS and performs the functions of establishing physical connections over the radio for the purpose of transmitting call-related signaling information such as the establishment of signaling and traffic channels between a specific mobile user and the BSS. The RR management functions are basically implemented in the BSS.

LAPDm is a LAPD-like protocol that has been modified for operation within the constraints set by the radio pass.

Location updating is the procedure for keeping the network informed of where the mobile is roaming.

Mobility Management Sublayer (MM)

The MM sublayer is terminated at the MSC and the related messages from or to the MS are relayed transparently in the BSS using the DTAP process. The MM sublayer provides functions that can be classified into three types of procedures. These are called the MM specific procedures, the MM common procedures, and the MM connection-related procedures. These procedures are discussed in the following.

MM Connection Related Procedures

These are the procedures used to establish, maintain, and release a MM connection between the MS and the network (MSC) over which an entity of the connection management (CM) sublayer can exchange information with its peer. More than one MM connection may be active at the same time to serve multiple CM entities. Each CM entity within the MS will have its own MM connection, and each connection is identified by the protocol discriminator, and a transaction identifier within the related signaling messages exchanged. The transaction identifier is sort of analogous to the call reference used by ISDN to identify signaling messages from different calls on the D channel. Thus parallel calls can be supported by the same MS which are then identified by a different value for the transaction identifier parameter. Establishment of a MM connection requires that no MM-specific procedure (discussed later) be active.

The MM connections provide services to the different entities of the upper connection management (CM) sublayer which currently consist of the call control (CC), the short message services (SMS), and the call-independent supplementary services (SS). An MM connection is initiated by a CM service request message which identifies the requesting CM entity and the type of service required of the MM connection. The services provided by the MM connections include such things as enciphering (for privacy of user information), and authentication (of the users-access to the network and the service requested) which would be actually provided by the presentation, and application layers in the OSI framework. Each of these services would involve the exchange of multiple messages between the MS and the network before the required MM connection is established and the requesting entity within the CM sublayer is notified.

Mobility Management Specific Procedures

The MM specific procedures do not set up an MM connection. They can only be initiated when no other MM-specific procedure is running, and no MM connection is established. These procedures consist of location updating, and the IMSI attach procedures. These are discussed in the following.

Location Updating

Location updating is the procedure for keeping the network informed of where the mobile is roaming. Location updating is always initiated by the mobile station on either detecting that it is in a new location area by periodically monitoring the location information broadcast by the network on the broadcast channel, and comparing it to the information previously stored in its memory, or by receiving an indication from the network that it is not known in the VLR upon trying to establish an MM connection. Anytime, the network updates the mobile's location, it sends it an updated "temporary mobile subscriber identification" (TMSI), in ciphered mode, which is stored in the MS and used for subsequent mobile identification in paging and call initiating operations. The purpose of using the TMSI as opposed to the user's IMSI is to keep the subscriber's identity confidential on the radio link. The TMSI has no GSM-specific structure, and has significance only within the location area assigned. The TMSI has to be combined with the location area identifier (LAI) to provide for unambiguous identification outside the area where it is assigned.

IMSI Attach

The IMSI attach procedure is the complement of the IMSI detach procedure, a function of the MM common procedures (discussed later). Both of these procedures are network options whose necessity of usage are indicated through a flag in the system information broadcast on the BCCH channel. The IMSI detach/attach procedures mark the MS as detached/attached in the VLR (and optionally in the HLR) on MS power down or power up or subscriber information module (SIM) removed or inserted (The IMSI detach disables the location updating function to prevent unnecessary signaling overhead on the network). Any incoming calls, in that case, are either rejected or forwarded as may be specified by the user). The IMSI is used to indicate the IMSI as active in the network. This procedure is invoked if an IMSI is activated in a MS (power up, or SIM insertion) in the coverage area of the network, or an activated MS enters the network's coverage area from outside. The IMSI attach procedure is then performed only if the stored location area at the time is the same as the one being broadcast on the BCCH channel of the serving cell. Otherwise, a normal location updating procedure is invoked regardless of whether the network supports IMSI attach/detach procedures.

MM Common Procedures

The MM common procedures can be initiated at any time while a dedicated radio channel exists between the network and the MS. They do not set up an MM connection, but can be initiated during an MM specific procedure, or while an MM connection is in place. The MM Common procedures consist of IMSI detach, TMSI reallocation, and authentication/identification. These are discussed next.

IMSI Detach

The IMSI detach procedure is invoked by the mobile station to indicate inactive status to the network. No response or acknowledgement is returned to the MS by the network on setting the active flag for the IMSI.

The IMSI detach procedure is not started if at the time a MM-specific procedure is active. In that case, the IMSI detach procedure is delayed, if possible until the MM-specific procedure is finished, otherwise the IMSI detach request is omitted.

If at the time of a detach request, a radio connection is in existence between the MS and the network, the MM sublayer will release any ongoing MM connections before the MM detach indication message is sent.

TMSI Reallocation

The purpose of TMSI reallocation is to provide identity confidentiality. That is, to protect the user from being identified and located by an intruder. This procedure must be performed at least at each change of the MSC coverage area. Reallocation in any other case is left to the network operator.

If the TMSI provided by a mobile station is unknown in the network; for instance, in the case of a data base failure, the MS has to provide its IMSI on request from the network. In this case the identification procedure has to be performed before the TMSI procedure can be initiated.

Authentication

The purpose of the authentication procedure is to let the network verify the identity provided by the user when requested, and to provide a new ciphering key to the mobile station. The cases when authentication procedures should be used are defined in GSM Recommendation 02.09. The authentication procedure is always initiated and controlled by the network.

Identification

This procedure is used by the network to request a mobile station to provide specific identification parameters to the network, such as the user's international mobile subscriber or equipment identifiers (IMSI or IMEI). The mobile station should be ready to respond to an identity request message at any time while RR connection exists between the mobile and the network.

Connection Management Sublayer (CM)

The CM sublayer terminates at the MSC and contains entities that currently consist of CC including call-related supplementary services, SMS, and call independent supplementary services support (SS). Once a MM connection has been established, the CM can use it for information transfer. The CC entity uses the CCITT Q.931 protocol, with minor modifications, for the communication of call control-related messages between the MS and the MSC. The SMS is a GSM-defined service that provides for speedy packet mode ("connectionless") communication of messages up to 140 bytes between the MS and a third party service center. These messages can be sent or received by the mobile station while a voice or data call is in the active or inactive state. It is acceptable, however, if the service is aborted while a call is in a transitional state such as handover or busy-to-idle. The service center is responsible for the collection, storage, and delivery of short messages, and is outside the scope of GSM.

BSS Application Part (BSSAP)

The BSS, in addition to providing the channel switching and aerial functions, performs radio resource management, and interworking functions between the data link protocols used on the radio and the BSS-MSC side for transporting signaling-related messages. These functions are provided by the BSS Management Application Process (BSSMAP), and the Direct Transfer Application Process (DTAP).

The BSSMAP is used to implement all procedures between the MSC and the BSS that require interpretation and the processing of information related to single calls, and resource management. Basically, the BSSMAP is the process within the BSS that controls radio resources in response to instructions from the MSC (in that sense, the BSSMAP represents the RR sublayer to the MSC). For instance, the BSSMAP is used in the assignment and switching of radio channels at call setup, and handover processes.

The DTAP process is used for the transparent transfer of MM/CM signaling messages between the MS and the MSC. That is, the DTAP function provides the transport level protocol interworking function for transferring Layer 3 signaling messages from and to the MS to and from the MSC without any analysis of the message contents.

The authentication procedure allows the network to verify the identity provided by the user when requested, and to provide a new ciphering key to the mobile station.

Signaling Transport Protocols

The CCITT SS7 MTP and SCCP protocols are used to implement both the data link and the Layer 3 transport functions for carrying the call control and mobility management signaling messages on the BSS-MSC link. The MM and CM sublayer signaling information from the mobile station is routed over signaling channels (such as the DCCH, SACCH, FACCH) to the BSS from where they are transparently relayed through the DTAP process to an SCCP, of CCITT SS7 type logical channel, assigned for that call, on the BSS-MSC link for transmission to the peer CC entity in the MSC for processing. Similarly, any call signaling information initiated by the MSC on the SCCP connection is relayed through the DTAP process in the BSS to the assigned signaling channel, using the LAPDm data link protocol, for delivery to the mobile station.

The interworking between the Layer 2 protocol on the radio side and the SS7 on the BSS-MSC link is provided by a distribution data unit within the information field of the SCCP. These parameters are known as the discrimination, and the data link connection identifier (DLCI) parameters. The discrimination parameter (currently dedicated one octet) uses a single bit to address a message either to the DTAP or the BSSMAP processes. The DLCI parameter (sized one octet) is made up of two subparameters that identify the radio channel type (such as the DCCH, SACCH, FACCH), and the "Service Access Point Interface"(SAPI) value (in the LAPDm protocol) used for the message on the radio link. The SCCP provides for the logical multiplexing of signaling information from different calls onto the same physical channel (such as a single 64 kb/s slot of a 2.048 Mb/s E1 trunk) on the BSS-MSC link. For each call supported by a BSS, an SCCP logical connection is established on the BSS-MSC link. Any information pertaining to a specific call flows through its associated SCCP connection and that is how signaling information exchange pertaining to different calls are identified in the BSS or MSC.

The connectionless service mode of the SCCP is also supported for the transfer of OA&M related messages as well as BSSMAP messages that do not pertain to any specific call (Note that BSSMAP messages pertaining to specific calls, such as handoff messages, are transmitted using the SCCP connection established for the call). The SCCP routing function uses the SubSystem Number (SSN) in the Service Information Octet (SIO) within the MTP level 3 message to distinguish messages addressed to the OA&M function from those addressed to either the DTAP or the BSSMAP application parts. The high-level address translation capability of the SCCP, known as global title translation, may then be used to provide additional addressing capabilities such as use of E.164 numbering for addressing different OA&M entities. The global title translation feature of the SCCP also provides the MSC the capability to address signaling messages to remote MSCs that may be located in a different PLMN.

The optimum size for the paging area is determined by a proper balance between the costs of paging and the costs of location updates.

The interworking functions between the CM, MM and BSSMAP entities and the corresponding entities of the SS7 (i.e., the ISDN-UP), MAP, SCCP, and the transactions capabilities application part (TCAP) is provided by the MSC.

Paging

Paging messages for mobiles are sent via the BSSMAP to the BSS as a connectionless message through the SCCP/MTP. The paging message may include the mobile's IMSI in order to allow derivation of the paging population number. A single paging message transmitted to the BSS may contain a list of cells in which the page is to be broadcast. The larger the paging area is defined, the lower the frequency of location updates and hence the associated traffic overhead on the network. On the other hand, large paging areas result in increased use of transmitting power as well as the radio resources (channels). Therefore, the optimum size for the paging area (location area) is detemined by a proper balance between the costs of paging and the costs of location updates.

The paging messages received from the MSC are stored in the BS, and corresponding paging messages are transmitted over the radio interface at the appropriate time. Each paging message relates to only one mobile station and the BSS has to pack the pages into the relevant 04.08 paging message (include Layer 3 information). Once a paging message is broadcast over the radio channel(s), if a response message is received from the mobile, the relevant signaling connection is set up towards the MSC and the page response message is passed to the MSC.

Summary Remarks

The description of the GSM network functions, system architecture and protocols are spread over a large number of GSM documents, each of which contains many details with some of the critical issues and highlights covered within those details. Therefore, it is not an easy task to extract out some of the crucial concepts and design specifics, and present it in some logical and well-related format. I have tried my best, however, to achieve this goal in this article.

This article was meant to provide a concise, brief, but adequately detailed description of the GSM system and protocol architecture that can serve as a quick, rather self-contained conceptual framework for extending and relating the mobility-specific functions of the next generation personal communication networks to the GSM network functions, and the protocols used to achieve them. Finally, a list of references have been provided for any more detailed information on the issues addressed in the article.

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Biography

MOE RAHNEMA received a B.S. degree in engineering science from the University of Kentucky at Lexington in 1978 with honors. He received the M.S. degree and the more advanced engineering degree in Avionics from MIT in 1981. From 1983 to 1984, he taught and studied communication sciences at Northeastern University from which he also received the Engineer degree in electrical and computer engineering with Ph.D-level coursework. He worked as a senior communication design engineer at infinet in Andover, Mass from 1984 to 1985, where he designed the digital signal processing firmware for a 4800 baud modem. From 1985 to 1989, he worked as a member of the technical staff at GTE Laboratories, and developed a new system architecture for fast packet switching based on the slotted ring concept (published in *IEEE Transactions on Communications*, April 1990). From 1989 to 1991, he worked as a principal engineer at Arinc on the design and analysis of air/ground communication networks for the airlines industry. He joined Motorola as a principal communication engineer in 1992, and since has been working on the Iridium satellite project. His interests include wireless networks, communication systems, and digital signal processing.