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Overview of GSM: Philosophy and Results

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The work on GSM, a standardized European second-generation cellular system, was started in 1982 in order to prevent the fragmentation of the first-generation cellular market from continuing into the second generation. The goal was to define a system with open interfaces for Pan-European use that would offer the best compromise between a number of conflicting requirements, such as spectrum economy, high speech quality, low cost, and a large range of services. A broad outline of the novel features is presented, both concerning the architecture of the system and of the services offered, as well as the reasoning behind the more important choices. Finally, some views are presented concerning the future development of GSM and of the third-generation system, the co-called Future Public Land Mobile Telecommunication System, commonly referred to as FPLMTS.

KEY WORDS: Digital cellular; network architecture; radio interface; wireless services.

1. BACKGROUND

Following the decision at WARC '79 to open the 900-MHz band for land mobile use, the standardization organization of European PTTs, CEPT, decided in 1982 to allocate the bands 890–915 and 935–960 MHz for use by a new Pan-European Public Land Mobile Network (PLMN). In some countries, parts of the band had already been or were being used, and the PTTs realized that, unless a decision was made immediately, the possibility of creating a Pan-European PLMN would be gone for a long time, since no other band was available. The rapid development of mobile technology and user demand in combination with traditional protectionist attitudes in many countries had led to a fragmentation of the first-generation cellular market. Thus, with the exception of the Nordic countries, service was generally limited to national territories and the lack of uniformity made large-volume production difficult. To stop this trend, CEPT set up a committee, which was given the name Groupe Spécial Mobile (GSM) to standardize the interfaces in the second-generation European cellular system, whereby any user would be able to use his/her own set all over Europe. (Later, the name GSM was transferred to the system which the group specified, while the committee itself has taken the name SMG.)

The goal was to find the best compromise, in view of the expected applications of the system, between high-spectrum economy, low cost, high speech quality, and other conflicting requirements. The choice of analog or digital technology was not mentioned in the mandate, but would have to be addressed in due course. It was agreed from the start, however, that there had to be the fullest possible utilization of recent developments, such as the Digital Network (ISDN) within the limitations set by the radio environment. The system would have to offer the same or similar services as the fixed network, and, furthermore, it was realized that, since the system would be introduced in competition with the first-generation cellular systems, such as TACS (Total Access Communication System) and NMT (Nordic Mobile Telephone), it would have to be at least equal to those systems in a number of the following respects and superior in at least one of them:

- frequency economy
- quality of speech transmission

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- cost of the mobile unit
- cost of the system infrastructure
- viability of handheld mobiles

and finally

- ease of introduction of new services
- security

As time went by, it was realized that improvements over the first-generation systems would be required in all of those aspects.

Of all the interfaces in the system, the air interface is clearly the most important, due to the fact that international roaming has always been considered to be one of the great features of the system, one that obviously requires a standardized air interface. Although it would have been possible to design a system in which nothing beyond the air interface was standardized, it was realized that in order to meet the requirements for

- standardized ISDN-like services,
- close coordination with the multitude of different telephone networks in Europe,
- drawing full use of CCITT Signalling System No. 7 (commonly referred to as SS 7) and other novel features in the fixed networks

and last but not least

- exchangeability of equipment, an important aim in this era of open borders,

it was necessary for the committee to go far beyond the air interface, so a number of interfaces between the major functional building blocks in the system had to be specified.

2. ARCHITECTURE

From the beginning of the work, the operators considered it to be of vital importance to secure competition between suppliers. An open structure with nonproprietary interfaces was therefore seen as an essential feature of the system.

One of the fundamental considerations concerned the range of services to be offered, since this choice was likely to have a considerable impact upon the whole system structure. The first-generation cellular systems—AMPS, TACS, NMT, and others—are basically telephone systems with radio access, and even in GSM telephony will remain the dominating service for quite some time. However, an important strategic target of GSM is the mobile office of the person travelling for business, so it is important to give users access to as many features of the ISDN as possible. In addition to telephony, a wide range of tele- and bearer services is therefore foreseen. This will no doubt lead to much better utilization of the radio medium than in present systems because of the higher efficiency of data information compared with speech and because of a considerably lower percentage of calls that are lost when the called subscriber is not available.

2.1. Service Categories

Following the ISDN definition, GSM telecommunication services are subdivided into two basic categories (see Fig. 1):

- Bearer services, which provide transmission capability between access points or, in OSI terms, up to layer 3. An overview of bearer services is given in Section 4.1.
- Teleservices, which are based on the use of one (or a few) bearer services, provide complete communication capability (including terminal functions) for communication between users, i.e., OSI layers 4–7. One example of this group of services is telephony, which is the most important service offered in GSM. Some services are derived from telephony, e.g., emergency calling and voice messaging. Other teleservices are described in Section 4.2.

In addition, there are a large number of Supplementary Services, which are not standalone services, but are used to modify a bearer or teleservice. Among the services in this category, one could mention the following examples (the list is far from exhaustive):

- Call Forwarding Unconditional
  - " on Mobile Subscriber Busy
  - MS is busy
  - " on No Reply
  - " on Mobile Subscriber Not Reachable
- Barring of All Outgoing Calls
  - " Outgoing International Calls
  - " " except to the Home PLMN Country
  - " All Incoming Calls
- Calling Number Identification Presentation

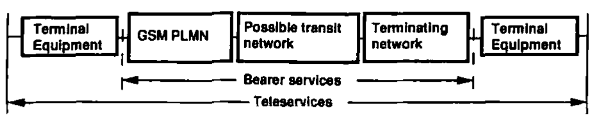

Fig. 1. GSM telecommunication services.

- Calling Number Identification Restriction
- Malicious Call Identification
- Call Waiting
- Closed User Group
- Advice of Charge
- Reverse Charging

2.2. Subsystems

With reference to Fig. 2, three distinct functional blocks can be defined as follows.

2.2.1. Mobile Station (MS)

The Mobile Station (MS) comprises two elements:

- the Mobile Equipment (ME) which is the "anonymous," non-customer-related piece of hardware which the user purchases from a dealer,

and

- the Subscriber Identity Module (SIM) which is a smart card, issued at the time of subscription and containing a great deal of subscriber data. The principle of Personal Communications is applied in GSM in the sense that a call is not directed to a particular piece of hardware as in the present cellular systems, but to a subscriber, who personalizes an ME into an MS by inserting a SIM.

2.2.2. Base Station Subsystem (BSS)

The Base Station Subsystem links the Mobile services Switching Centre (MSC) with the mobile stations in a certain area. It consists of two functional blocks, i.e.,

- the Base Transceiver Station (BTS) comprising the radio equipment (transmitter, receiver, signalling equipment specific to the radio interface)

and

- the Base Station Controller (BSC), which is in effect a small switch, in charge of the switching functions in the BSS, i.e., controlling handover between cells and also management of the radio channels. In a BSS, there is only one BSC, but there may be (in fact, in the typical BSS there *are*) several BTSs. If the BTSs and the BSC in a certain area are colocated, it is probably economically attractive to integrate them. In that case, the interface BSC–BTS (the "A-bis" interface) vanishes. The protocols in this interface are the ISDN LAPD protocols.

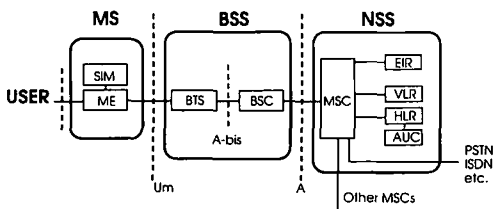

Fig. 2. System architecture.

The reason for the split between BSC and BTS, an interface which many manufacturers might consider to be a purely internal matter of no concern to the operator, is basically that integration of BTS and BSC, often very attractive in a big city, would not be economically feasible in sparsely populated areas, typically with long communication lines and few channels per BTS, a situation which exists to some degree in almost every country. By separating the two and defining their interface, a solution much more attractive for such areas could be found and at the same time the principle of open, competitive interfaces was preserved both for the BTS and the BSC.

2.2.3. Network and Switching Subsystem (NSS)

This subsystem is the block which performs the switching functions in the system and which takes care of communication with other networks such as the Public Switched Telephone Network (PSTN), the Integrated Services Digital Network (ISDN), the Circuit Switched Public Data Network (CSPDN), and the Packet Switched Public Data Network (PSPDN). It also takes care of the differences between the protocols and transmission rates in GSM on the one hand and those in the fixed networks on the other by the Interworking Functions (IWF), functional entities which are located at the border to the partner networks and may be integrated with the Mobile services Switching Centre (MSC) or implemented as a separate unit.

The central unit in the NSS is the MSC, which communicates with the BSS through the "A" interface. It performs the switching functions for mobile stations located in a certain geographical area, the MSC area. In addition, the MSC allocates ratio resources and performs various functions concerning the mobility of the subscribers. It also has to perform the functions needed for handover. The MSC also communicates with other entities, such as certain databases (see below), other MSCs, the fixed networks, and the Operations and Maintenance Subsystem. In the MSC interfaces, SS 7 protocols are used.

In the NSS, there are three functionally different databases, i.e., the Home Location Register (HLR), the

Visitor Location Register (VLR), and the Authentication Centre (AUC), all of which are concerned with subscriber data management. The HLR is a database which handles the management of mobile subscribers. For this, it needs to store information for each subscriber belonging to that HLR concerning the subscriber's subscription (services, etc.) as well as location, thereby enabling the network to route a call toward the MSC in whose area the called MS is operating.

The VLR controls the mobile stations roaming in the area or areas for which it is responsible by temporarily storing information about their subscriptions, their current location, etc., and sends the necessary information to a visiting subscriber's HLR in order to permit routing of calls to this subscriber. In addition, the VLR contains the information needed to handle the calls set up or received by the MSs registered in the area. Since the VLR is in very close contact with its MSC, the two are usually for practical reasons combined in one entity. An incoming call to the GSM system is routed to an MSC, unless the fixed network is able to interrogate the HLR directly. That MSC is termed the Gateway MSC (GMSC).

The Authentication Centre (AUC) is a strongly protected database which handles the authentication and encryption keys, as will be described in Section 5. Its interface with the MSC is through the HLR, with which it may be integrated.

The MSC is also in close contact with a fourth database, the Equipment Identity Register (EIR), which is concerned with mobile equipment data management rather than subscriber data management as the previous three databases were. As mentioned in Section 2.2.1, the SIM contains the subscriber data, and, thus, there is no connection between equipment identity and subscriber identity. The EIR is used for administrative reasons, such as tracking of faulty equipment or stolen equipment, depending on national regulations. It communicates with the MSC and other equipment through the SS 7 network, and is therefore often considered part of the NSS. It has nothing to do with traffic handling, however, and, functionally, it is more appropriate to consider it as part of the Operation Sub-System (OSS), which is not dealt with in this paper.

3. THE RADIO INTERFACE, Um

Perhaps the most important decision to be made in the course of the specification word was the choice of digital or analog radio interface. It was at the start very uncertain whether the requirements for improved speech quality and for frequency spectrum economy could be met at the same time. After extensive tests, it was found that the best compromise between the many conflicting requirements was a TDMA solution with the digital channels multiplexed in groups of 8 in FDM channels of 200 kHz each. One of the advantages of time division is that, since the mobile is receiving and transmitting in bursts, there is time to monitor other channels in the intervals between the bursts, an advantage that was exploited in GSM, as will be explained below.

Both broadband and narrowband TDMA solutions were studied. While a broadband system with large, multichannel BTSs might be attractive in densely populated areas, where the base stations could be economically designed for big bundles of traffic channels, the principle would be less feasible in sparsely populated areas with little traffic and few channels per base station. A narrowband solution with 8 full-rate traffic channels per carrier was therefore chosen. The time slot structure on the radio path is shown in Fig. 3.

At the start of a slot, there is a group of 3 tail bits, all logical zeros, followed by a burst of 57 information bits and a flag, used to indicate speech or data. In the middle, there is an equalizer training sequence of 26 bits, after which there is another burst of 1 + 57 bits, followed by 3 tail bits and a guard space of 8.25 msec. The carrier spacing was set to 200 kHz, thereby allowing 2 × 124 carriers for the two directions in the allocated band of spectrum.

The requirement for flexibility was met by this choice, which provided a relatively low number of channels per carrier, yet provided a sufficiently long time between the time slots for the mobiles to perform the necessary monitoring and handover preparations. Every cell is equipped with a broadcast channel and every active mobile receives via its own control channel information that enables it to locate the broadcast channels of adjacent cells. The mobile uses this information to

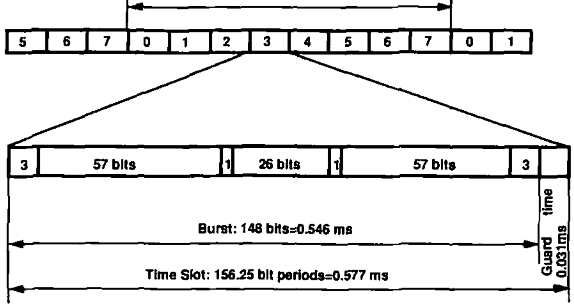

Fig. 3. Time slot structure on the radio path.

monitor those channels as well as the broadcast channel of its own cell. The results concerning power levels, etc., are reported regularly to the BSC to which the mobile is attached. The network then decides whether to order handover and, if so, to what cell.

Another reason for choosing a digital technique was the increased capacity that the technique offers. One obvious way to increase the capacity is to decrease the cell size, which however leads to an increased frequency of handovers. In some of the present analog systems, this would not be acceptable to users in view of the slow handover in those systems and, thus, the GSM handover process had to be significantly improved compared with the analog systems on the market, as is shown below.

The capacity was further increased by increasing the resistance to interference by channel coding and error protection so that the reuse factor could be increased. In addition, a decrease in interference for a given cluster size led to further improvement in the reuse factor. This decrease was achieved by averaging of the worst cases by means of frequency hopping and through the use of power control both in the mobile and in the BSC. Discontinuous transmission of the radio signal (associated with voice activity detection) further decreases the interference level.

The radio subsystem provides a number of logical channels that fall into two groups, traffic channels (TCH), which correspond to an ISDN B-channel but with a lower bit rate, and control channels (CCH), corresponding to an ISDN D-channel. The traffic channels, which may be either full-rate or half-rate, carry user-generated speech or data while the control channels, of which several types are provided, carry signalling information. In most cases, only slow information transfer is needed in these channels, the exception being in the case of handover. In that case, the capacity of the normal signalling channels cannot provide the desired fast handover, so the full capacity of the dedicated channel is momentarily stolen for the handover signalling.

For the modulation scheme, a solution was chosen where all the redundancy was put in the coding in order to allow interleaving of the frames, rather than a scheme where some of the redundancy was put in the modulation whereby interleaving would be impossible. The final choice was a GSMK modulation with BT = 0.3. This modulation scheme is a compromise between the demands for a high frequency economy and low demodulation complexity. The gross bit rate for the full-rate TCH was set to 22.8 kbit/s, which gave a net rate of 13 kbit/s. Based on this and on the outcome of extensive studies of speech coders, it was decided to choose a coder of the RPE-LPC type, combined with Long-Term Prediction (LTP). Furthermore, a half-rate coder with a gross bit rate of 11.4 kbit/s is being studied and the specification for the half-rate coder is expected to be completed during the first half of 1994. The relative timing between the outgoing and incoming bit sequences, seen at the BSS, is important in order for the received burst from the MS to fit into the right time slot. This presents no problem at short range, but in sparsely populated areas, cell radii can be up to 35 km, and the propagation delay is considerable. A timing advances is therefore introduced in the MS in order to keep the right timing relation between uplink and downlink at the base. This timing advance is calculated by the BTS and the information transferred to the MS via the signalling system.

The link protocol on the radio path is termed LAPDm and is specific to GSM (this is in contrast to the other GSM interfaces, whose link layer protocols are either the LAPD protocol from ISDN or the MTP 2 protocol from SS 7). In the link layer, the information is structured into frames, and the LAPDm uses the synchronization scheme on the radio interface to carry information on frame limits, rather than the 8-bit flags used in the well-known HDLC protocol. One of the benefits of this is that some capacity is saved, which can then be used for error detection, etc.

The main parameters in the radio interface are shown below:

Frequency bands (MHz)	Uplink, 890–915; downlink, 935–960
Full-rate speech channel bit rate	13 kbit/s
Full-rate channels per carrier	8
Equalization for multipath delay	16 μsec
Full-rate transmission delay due to interleaving	65 msec
Frequency hopping (operator option)	217 hops/sec
Modulation	GMSK with BT = 0.3
Half-rate channels for data and for speech	
Discontinuous transmission	

4. DATA SERVICES AND FACILITIES

The use of data transmission is becoming increasingly important as time passes, and, furthermore, the first-generation cellular systems are capable of providing some data services. It was therefore clear that GSM must provide such services at the earliest possible time, preferably the same services as in the fixed networks. Some constraints are inevitable because of the characteristics of the radio medium with its limited spectrum and higher bit error rate than in the fixed networks, however. On the other hand, some services are introduced in GSM that have no counterpart in today's fixed network, services which are particularly valuable in a mobile environment, such as the Short Message Services.

Since GSM is inherently a digital system, it will be capable of providing data transmission as an integral part of the system, and interfaces to ISDN-type terminals have therefore been defined. In the present cellular systems, however, data transmission is performed by use of modems and various add-on equipment more or less as it is done in the PSTN, and the GSM users must therefore also have the possibility of using the standard data equipment with V or X series interfaces available on the market today.

A reference configuration, showing the functional interfaces in an MS, is shown in Fig. 4. In this figure, the Mobile Termination blocks (MT 0, 1, and 2) support functions in the radio interface, Um, layers 1, 2, and 3, and adapt the information flow to those required by the terminal functions at the access points 1 and 2 ("S" and "R" reference points). The simplest Mobile Termination is MT 0, an integrated arrangement of the terminal equipment, the mobile termination functions, and, if applicable, the adaptation functions. Such a basic station offering only tele- and supplementary services without any additional interfaces is found today in all speech terminals, and it is expected that similar integrated arrangements will be put on the market in the future for other services, for instance for fax terminals. The Terminal Equipment (TE 1 or TE 2) supports the man–machine interface to the user at access point 3 and may or may not present a physical interface at access points 1 and 2. TE 1 presents an ISDN interface, while TE 2 presents a non-ISDN interface, such as a V or X series interface. TA is an ISDN adaptation function for adapting between access points 1 and 2.

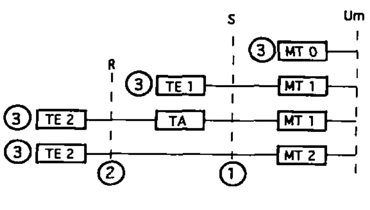

Fig. 4. GSM reference configuration.

4.1. Bearer Services

A large group of bearer services is provided:

Data circuit duplex asynchronous	Rates 300–9600 bit/sec
PAD access circuit asynchronous	" "
Data circuit duplex synchronous R	Rates 1200–9600 bit/sec
Alternate speech/ unrestricted digital transfer	" "
Speech followed by data	" "
Data packet duplex synchronous	Rates 2400–9600 bit/sec
12 kbit/sec unrestricted digital transfer	

4.2. Teleservices

In addition to telephony which was already mentioned in Section 2.1, specifications have been worked out for provision of the following data-oriented teleservices, either as parts of GSM or in some cases (3, 4, and 5) to provide access to such services outside GSM:

1. Short Message Services (SMS)
2. Facsimile
3. Message Handling Service (MHS)
4. Videotex
5. Teletex

4.2.1. Short Message Service (SMS)

Three kinds of SMS are foreseen, two of which are point-to-point—Mobile Originated and Mobile Terminated. In addition, a Cell Broadcast service is foreseen, in which the calls are always Mobile Terminated. The point-to-point SMS services allow transmission of messages of limited length outside the normal traffic channel, i.e., the exchange of messages can take place during an ongoing communication. They are based upon the use of a Service Centre (SC), a store and forward center which is functionally an add-on to the system. For practical reasons, however, it may be integrated with the MSC. The point-to-point messages are limited to a length of 140 octets, i.e., 160 7-bit ASCII characters.

The Cell Broadcast SMS aims at providing information, for instance, road information, to all idle subscribers in a specified area within the PLMN. It is based upon the use of a Cell Broadcast Centre which is connected to one or more BSCs. The messages are limited to 82 octets or 93 7-bit ASCII characters. Up to 15 messages may be concatenated and treated as segments of a longer message. The CBS messages are broadcast periodically by the BTS according to the information provider's orders.

4.2.2. Facsimile

Facsimile Service ("fax" for short) has reached immense popularity worldwide with around 23 million fax machines in use in the PSTN today, one of the reasons being that standard fax machines with the usual two-wire PSTN interface can be used in analog cellular systems. It was therefore clearly necessary to provide for GSM use of standard fax machines to interwork with any Group 3 fax machine in the PSTN, and there is no doubt that Facsimile Service is the most important of the nonspeech services in GSM. Many difficulties were encountered in providing this service, however, for several reasons. One was caused by the delay introduced by the radio channel, which makes some timing conditions in the existing standardized fax protocols very critical. Another was due to the separation of the fax machine and the modem in the Interworking Function (IWF) which is located in the MSC. In today's fax machines, alternative use of speech and data is normal. Therefore, alternate speech/fax Group 3 is a teleservice, specified in GSM, in addition to automatic fax Group 3. It was found that, in order to fulfill the requirements, a special fax adaptor between the R interface in the MS and the fax machine was required.

Despite the inclusion of this adaptor, however, it was necessary to manipulate the fax protocols according to CCITT Rec. T. 30 to some degree. This is done in the Interworking Function (IWF) (see Section 2.2.3 for an explanation of this functional entity).

4.2.3. Other Data-Oriented Teleservices

Message Handling Service, Videotex, and Teletex are established services outside GSM and are not integral parts of GSM. Specifications have been worked out in order to provide access to such services in the fixed networks through the use of existing bearer services.

5. SECURITY

Radio transmission is inherently very vulnerable to attacks from impostors attempting to avoid paying for the use of the system and from eavesdroppers who attempt to gain access to information. One of the advantages in a digital system is the ease with which security can be improved by many orders of magnitude over the analog systems, an advantage which has been exploited to a great extent in GSM.

Among the data contained in the SIM are a secret key, Ki, assigned at the time of subscription, and a permanently assigned number, the International Mobile Subscriber Identity (IMSI) according to CCITT Rec. E. 213, which contains information indicating the country code, the network to which the subscriber belongs, the subscriber's HLR, etc. The Ki, which is not accessible outside the SIM, is stored in only one place on the network side, i.e., in the Authentication Centre, and is the basis for the authentication of the mobile subscriber as well as for the encryption of the information on the radio path. The procedure is as follows (see Fig. 5).

A challenge in the form of a Random Number (RN) is sent from the network to the MS, where an authentication algorithm uses the RN and Ki to produce a Signed Response (SRES), which is returned to the network and compared with the SRES produced on the network side using the same inputs. If the two responses are identical, the authentication is accomplished and service may be granted. Using another algorithm, an encryption key, Kc, is produced in the MS as well as in the network and used for encryption on the radio path of the signalling and user-generated information. Protection of the user identity on the radio path is achieved by the use of an alias in the form of a temporary identity (TMSI), which is assigned to the user by the network when the user enters the area and which is used as long as he/she stays in that area. Thus, use of IMSI over the air is normally not necessary.

In order to avoid unnecessarily long delay in computing and fetching the RN, SRES, and Kc every time a visitor has to be authenticated and at the same time avoid having to send Ki outside the home network, a supply of triplets is sent to the visited network at the time of the first authentication of a visitor.

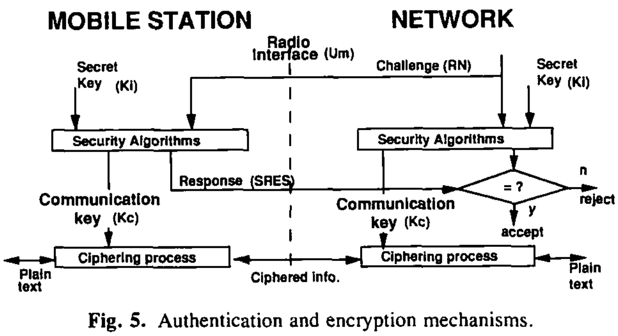

Fig. 5. Authentication and encryption mechanisms.

It is worth noting that the security features in GSM do not constitute a service that the user subscribes to—they are built-in features. The introduction of the SIM could turn out to have interesting consequences for the telecommunications community. Since a SIM contains all necessary information for identification of the user, it can be used with any kind of equipment able to read it, irrespective of whether that equipment is stationary or mobile and of the kind of network the user is logging on to. The SIM can therefore be seen as a step toward a universal telecommunication card.

6. PCN

Strong interest in several countries, in particular the UK, in a Personal Communications Network (PCN) in 1990 prompted a decision by ETSI to charge the GSM Technical Committee with the task of developing specifications for such a system. In view of the need for an early system start for the PCN networks, the specifications were based on the GSM specifications, which were already then in an advanced stage of development. Thus, the changes made to the specifications mainly consist in shifting the frequency band to the 1800-MHz range, in adding lower-output power classes, and (for phase 1 of GSM and DCS 1800) in modifying certain details of the signalling system as a consequence of the changes to the RF parts. The specifications for a first phase of this system, which is now known by the name DCS 1800, were completed by the end of 1990.

In view of what was said above, it is clear that, apart from the radio aspects, there is from a technical point of view very little difference between GSM (in particular handheld, low-power GSM terminals), and DCS 1800. The difference is in services and features which people will demand. The focus is on the mass market and on the provision of good-quality service to persons, i.e., both business users and consumers outdoors and indoors. For more details about this system, refer to the paper by Ramsdale [1] in this issue.

7. IMPLEMENTATION

The European operators wished to make it clear to the manufacturers that they intended to implement the GSM system by 1991. Therefore, a Memorandum of Understanding was signed by 13 operators in 1987, giving the manufacturers the assurance they needed for undertaking the substantial effort in the development of the system hardware and software, and at the same time creating an operators' forum, usually referred to as MoU. Since that time, the group of signatories has grown and, as of May 1993, 33 European operators in 21 countries have announced that they are operating or will be operating GSM systems, and 12 countries in Africa and the Asian-Pacific area have agreed to implement GSM through signing an MoU. Although the USA and Japan are not among these countries, there is no doubt that GSM is the closest thing to a world standard today.

8. FUTURE DEVELOPMENT

Because of the very large volume of work required for completion of the system, it was decided several years ago to divide the work into two phases. The first phase, offering speech, emergency service, and SMS, was opened for commercial use during 1991–1992 in a number of countries, later followed by fax service. Phase 2 specifications, comprising the other services described here, will be completed in 1993. Naturally, there will be further enhancements after that time, but they will be additions to phase 2 (phase 2+) without any degradations of functionality or compatibility.

Several "firsts" were introduced with the advent of GSM. The system is the first public cellular system that uses digital access, it is the first cellular system to offer such a wide range of services, and it is the first truly international cellular system with completely open architecture and interfaces. This offers excellent opportunities for further development and many ideas have been presented as to the use of GSM as a vehicle for other, not yet specified services. From a network point of view, the three basic management services are

- connection management, i.e., the switching function
- radio resource management, i.e., allocation of channels, etc.
- mobility management, i.e., management of the databases HLR, VLR, etc.

Clearly, the modular way in which the system is built provides connection management and mobility management, irrespective of what radio resources are being used. Therefore, both operators and manufacturers are now looking into how to add more radio resource management modules to the system, in order to use the GSM fixed network architecture while modifying the radio access system to support other radio interfaces, such as DECT, DCS 1800, or even the North American Digital Cellular Standard. There is room for such expansion in the protocols. The GSM protocols are based on message-oriented transactions, and large number of the messages are used for Connection Management and Mobility Management, but a number are still left for future introduction of new services. As examples of what could be introduced in the future, one could mention

- new encryption services
- advanced mobile features
- negotiation of bearer capability (bandwidth)
- modified and enhanced roaming services
- extended services

However, the use of the GSM platform need not be limited to radio-based systems. Radio access is, after all, only a small portion of the entire system, and most of it concerns only the MS–BSS area. Consequently, GSM could also be used as a platform for a Personal Telecommunication Network with mobile subscribers in the fixed network, or even a combination of both, unified in the MSC.

9. FPLMTS AND UMTS—THE NEXT GENERATION

The ultimate desire of all standardization people, no matter what the subject is, is probably to develop world standards, and those working in radio communications are no different. In the mid 1980s, the CCIR started studying the possibility of one world standard for the third-generation systems, the Future Public Land Mobile Telecommunication System (FPLMTS). The CCITT is heavily involved in studying the service definitions and network aspects of the FPLMTS, and also ETSI is involved in similar studies under the label UMTS. The aim is to define a system that unifies the various radio access systems now in use, preferably with one single radio interface. Some of the salient features might be:

- common standards for public cellular systems and cordless telephones with full interworking, preferably even trunked systems and paging systems
- mass-market pocket telephones
- high-capacity infrastructure with all calls connected to the Integrated Broadband Communications Network
- possibility of carrying a wide range of data services
- technical and economical ability to replace the fixed network in many instances
- better coverage than in the present systems through satellite access in remote areas

At WARC 92, spectrum allocation for the FPLMTS was discussed at great length. Initially there was no consensus that this would be the best use of the spectrum, and in some quarters there were doubts that the FPLMTS was needed at all. However, WARC decided in the end to set aside a block of 230 MHz in the 2-GHz range for the FPLMTS, and the work in CCIR is continuing on that basis. Many observers have expressed doubts that the goal of having one universal interface for many different applications can be achieved. However that may be, it does not preclude the possibility of reaching agreement on globally standardized interfaces for particular applications or groups of applications. There are many obstacles on the road to this goal, however. One is the consequences of having different time perspectives in various parts of the world. In the USA, the view appears to be that the third-generation system is needed around 1996, while in Europe and Japan the target is the turn of the century or shortly thereafter. The time available for development of a world standard is short if the US estimate is to prevail, and, without alot of new development, the performance of FPLMTS is likely to fall far short of the CCIR target. If the timetables are not changed, it appears to be difficult to obtain agreement on one interface on both sides of the Atlantic, and the third generation will not be a global standard. It is true that the SIM card, as mentioned earlier, permits roaming between incompatible systems, since it makes it easy for a visitor to log on to a foreign network when he/she goes abroad and rents a car with a built-in mobile, and it could therefore be considered as a substitute for a true standard. It is doubtful whether this would satisfy users, however. The trend in mobile development is very clearly toward small handheld sets, something which the PCN operators are very keen on emphasizing, and users would probably prefer to take along their own handheld sets on trips abroad rather than renting sets. Therefore, it is difficult to see the smart card as anything but the second best thing compared to true standards in mobile communications.

With the described goals, FPLMTS is likely to be very complex, at least some of the mobile-stations types. The experience does not indicate that complexity is a very serious problem, however, when the issue is standardization of a system for many millions of sets. Similar problems have been encountered many times in connection with electronic equipment, and the outcome is invariably the same, i.e., when the production volume is great, the cost per set can be very low despite heavy development costs. PC development can be taken as an example of this.

An interesting question concerns to what extent the

FPLMTS can build on the present structures and technology. It has been pointed out that, while the demands placed on the system would require a revolutionary design of the radio technology, the network design would be evolutionary. Several arguments can be presented for this view. The fixed networks are always slower in changing than the radio environment, so, purely for inertia reasons, it would be difficult to envisage a totally transformed network in the timespan in question. There has already been a great deal of development in the field of Intelligent Networks, which no doubt will be well-established when the FPLMTS is becoming reality. Therefore, the FPLMTS will be based on the Intelligent Network (IN) as developed by CCITT and others.

One question that has to be solved in this context is the question of interconnection between the two types of networks. A recent study by the CEPT outlines two scenarios for this interconnection, i.e., independent networks and open networks. In the former case, the providers of mobile services operate networks that are completely independent from each other as far as intelligence is concerned. In that case, the fixed network operators are allowed to directly offer mobility services based on their fixed intelligent networks. Obviously, there is a need for further study as to how these functions should be arranged, and the regulatory authorities will certainly have their say in order to maintain the competitive situation.

The other scenario, the open network, assumes that the resources of the fixed intelligent networks may be required to be accessed by competitive providers of mobile services. There is then a need for further study of which interface points in the fixed INs have to be accessible for the provision of mobile services. In both cases, the need for regulatory mechanisms is great, and it could turn out that the technical problems concerning the global standard are easier to solve than the regulatory ones, given the great differences between the legal situations in different countries.

An emerging conclusion which is also in line with the GSM experience is that the borderline between radio-based and wire-based systems is likely to become less and less distinct as time goes by. The fixed networks will gradually develop into an architecture where the database functions are separated from the switch functions, so that they will be able to support many functions, not feasible in the present networks. Thus, future networks will be able to support the intelligence functions that are needed for the provision of mobile service in systems like GSM and PCN, which at the present time are completely separate from the fixed networks. Maybe the blurring of the borderline between radio and fixed networks will make us regard cellular systems as one of several forms of personal communication systems rather than "radio," which after all is only indicating the technology in the access medium.

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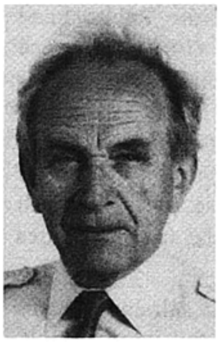

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