REPORT 1156

DIGITAL CELLULAR PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS (DCPLMTS)

(Study Programme 39A/8)

(1990)

1. Introduction

Digital cellular public land mobile telecommunication systems (DCPLMTS) are defined to be land mobile systems for voice and data services using digital cellular radio technology for the connection to the public switched telephone network (PSTN), integrated services digital network (ISDN) and public data networks (PDNs).

Part A of this report deals with the general principles of DCPLMTS and, in particular, addresses the rationale for digital cellular systems design. This part also provides a basic comparison with existing analogue cellular systems and discusses some architectural features of these systems.

The major characteristics of some DCPLMTS currently under development are presented in Part B of this report, together with a brief description of the current status of these systems and any unique features of their design.

PART A

GENERAL PRINCIPLES OF DCPLMTS

1. Introduction

Several DCPLMTS are currently under development. A Pan-European system called GSM is now under validation. The specification for a North American system is scheduled for completion by year end 1989. A Japanese system is also at an advanced stage of design. These systems are being designed for international operation and are expected to be widely implemented during the 1990s. In comparison, the on-going studies (Decision 69) necessary to specify future public land mobile telecommunication systems (FPLMTS) are not yet completed. It is expected that the FPLMTS will complement the DCPLMTS in the future. Thus it is timely to develop a report describing the key features of the emerging digital cellular public land mobile telecommunication systems.

2. General objectives

The general objectives of DCPLMTS are to provide:

- systems with high spectrum utilization efficiency, thereby accommodating more users within the limited spectrum resource than existing analogue cellular public land mobile telecommunication system (PLMTS);
- users with a wide range of services and facilities, both voice and non-voice, that are compatible with, and access, those offered by the public fixed networks (PSTN, ISDN, PDN, etc);
- services and facilities exclusive to mobile systems, including facilities for automatic roaming, locating and updating mobile users;
- users with a variety of mobile stations consistent with their requirements, ranging from vehicle mounted to hand-held stations with voice and non-voice interfaces;
- services of high quality and integrity at an economic cost;
- mobile equipment and infrastructure at the reduced cost, weight, size and power drain offered by the adoption of digital processing and VLSI technology.

3. Cellular mobile systems

3.1 Cellular systems background

Cellular systems divide the desired service area into a number of sub-areas (cells) with one or more base stations providing radio coverage to each cell. Appropriate frequency planning permits frequencies to be used several times in a coverage area.

When a mobile station either originates or is prepared to receive a call, the cell which can best serve the station is selected. With proper spacing of co-channels, each frequency may be used simultaneously in several cells in the service area and thereby multiplying the capacity obtainable in non-cellular radio systems.

The general features of a cellular system are:

- accommodation of more than one base station in a service area and thus the expansion of the service area of the system beyond the coverage that a single site could provide;
- "roaming" or automatic registration of mobile stations in appropriate location areas;
- "handover" or transfer of the responsibility for radio contact with a mobile station from one base station to another. This may also involve a transfer from one frequency or time slot to another;

- reuse of the same RF resource simultaneously by more than one base station and for more than one message. This is the basis of the spectral utilization efficiency of cellular systems;

- growth; that is, the system must be able to start with a few large cells and accommodate traffic growth by creating smaller cells at the points of highest traffic density.

These features are the basis for cellular systems. A more complete description of the general and specific aspects of cellular systems can be found in Reports 740 and 742.

3.2 Digital cellular systems

The cellular systems described in the previous section have been very successful. This success has lead to an increasing number of users and to an increasing demand for new and improved services. Since the introduction of the cellular systems, there have also been changes in the telecommunications network. The most notable of these are the services introduced by ISDN. These forces have led to the development of new, digital PLMTS systems.

3.2.1 Digital technology

The digital technology is introduced into the PLMTS in six major areas:

- digital radio modulation/demodulation;

- time division multiple access (TDMA);

- digital speech coding;

- channel coding and digital signal processing;

- digital control and data channels;

- privacy and authentication.

3.2.1.1 Digital radio modulation/demodulation

The digital radio modulation/demodulation makes efficient use of the spectrum and enables operation at lower carrier to interference (C/I) ratios than is possible with analogue systems. This enables the DCPLMTS to accommodate a wide range of cell sizes tailored to suit the local traffic conditions. The use of digital techniques also allows implementation of much of the circuitry using very large scale integration (VLSI) processes and thus reduces costs (particularly of mobile stations). The new modulation techniques, which enable operation at lower C/I ratios, also permit the use of improved frequency re-use patterns and cell sectoring to further increase system efficiency.

3.2.1.2 TDMA

The introduction of TDMA results in much improved system signalling, operation and cost.

A mobile station can exchange system control signals with the base station without interruption of speech (or data) transmission. This facilitates the introduction of new network and user services. The mobile station can also check the signal level from nearby cells by momentarily switching to a new time-slot and radio channel. This enables the mobile station to assist with handover operations and thereby improve the continuity of service in response to motion or signal fading conditions. The availability of signal strength information at both the base and mobile stations, together with suitable algorithms in the station controllers, allows further spectrum efficiency through the use of dynamic channel assignment and power control.

The cost of the base stations using TDMA can be reduced as radio equipment is shared by several traffic channels. A reduced number of transceivers will lead to a reduction of multiplexer complexity. Outside the major metropolitan areas, the required traffic capacity for a base station may, in many cases, be served by one (or two) transceivers. The saving in the number of transceivers results in a significantly reduced cost.

A further advantage of TDMA is increased system flexibility. Different voice and non-voice services may be assigned a number of time-slots appropriate to the service. For example, as more efficient speech codecs are perfected, increased capacity may be achieved by the assignment of a reduced number of time slots for voice traffic. TDMA also facilitates the introduction of digital data and signalling services as well as the possible later introduction of such further capacity improvements as digital speech interpolation (DSI).

3.2.1.3 Digital speech coding

The advanced digital coding of speech (at rates less than 16 kbit/s) contributes to system efficiency. This coding also provides potential for capacity growth through the use of "half-rate" codecs (when they are perfected). The digital coding of the speech also allows powerful error correction and detection techniques to be used. This contributes significantly to improved speech quality and to satisfactory operation at low C/I ratios.

3.2.1.4 Channel coding and digital signal processing

In cellular systems the use of adequate digital error control and signal processing techniques can contribute to system spectral efficiency. The error control allows operation at low C/I ratios and in high noise radio environments. Digital signal processing techniques also facilitate the use of adaptive channel equalization processes to compensate for dispersion in the radio channel. Digital signal processing also permits the use of diversity, frequency hopping, and interleaving techniques to improve operation in a signal fading environment.

3.2.1.5 Digital control and data channels

The digital control and data channels are the key to the flexibility of the new systems and to the introduction of new services. Digital data may be transmitted at high rates to the mobile stations with improved error control and protection. The digital control channel provides an improved facility for the introduction of network services such as message services and simultaneous voice and data communications. The digital control channels also facilitate the introduction of ISDN services into the PLMTS.

3.2.1.6 Privacy and authentication

The combination of the digital coding of the speech and the digital control channels facilitates provision of effective privacy and authentication. The digital speech may be easily protected through the use of digital privacy coding algorithms. The control channel facilitates the proper distribution of privacy keys. Through the control channel, other system resources (such as the home location register (HLR) and the authentication centre (AUC)) can provide the positive authentication of the mobile users. Authentication assures the accuracy of billing information and facilitates the roaming of users throughout a wide geographic area and between networks. The positive authentication of the mobile user by the authentication centre can also facilitate the introduction of new services which would otherwise not be practical. (This could include, for example, access to account records, or stored message retrieval.)

3.2.2 Practical concerns

The introduction of digital technology is not without some penalties however.

It must be noted that the TDMA technique with interleaving and low bit rate digital speech coding will introduce significant delay into the speech path. Careful concern for echo control will be necessary when the digital mobile systems are connected to the PSTN/ISDN.

The digital system must also be concerned with time synchronization in a dispersive radio channel. This will be of particular concern if the digital radio signals have a wide bandwidth.

The TDMA technique requires higher peak to average power ratio. This has to be taken into account when estimating battery life and possible radiation effects.

4. Comparison with existing designs

The DCPLMTS build upon some of the technology and system design concepts already in use by analogue cellular systems. However, several new features are consequential upon the use of digital techniques and the time division multiplexing method.

4.1 Commonalities

- The RF band used (around 800 - 1 000 MHz) has remained the same as for many analogue cellular systems, leaving the basic propagation statistics (path loss, delay spread, Rayleigh distributed envelope, etc.) unchanged;

- the basic cellular frequency reuse opportunities remain similar, since the standard deviation of path loss is unchanged, as are the outage design goals;

- the network architecture, as dictated by a number of factors, is essentially unchanged. Other constant network attributes are: numbering plan, roaming techniques, and charging methods.

4.2 Differences

- The digital modulation yields potential design economies and lower C/I requirements relative to earlier techniques;

- the digital modulation also offers enhanced ISDN compatibility;

- the time division multiplexing (TDM) offers further design flexibilities, including mobile-assisted handover and commonality between bearer information and control information formats;

- the channel coding adds another dimension of design control;

- for optimum performance of a digital channel, adaptive equalization is required;

- the TDM, interleaving and digital speech coding introduce appreciable (50-100 ms) delay, which necessitates echo control as long as 2-wire land-line circuits are encountered;

- the digital speech coding changes the way the system sounds when impairments are encountered, relative to a companded analogue system. The peak quality of speech in the absence of impairments is an intrinsic characteristic of each system;

- in a digital system, enhanced privacy is relatively simple to implement.

5. Services

5.1 General

The development of the DCPLMTS is driven by the increasing world-wide demand by mobile subscribers for voice and non-voice services. The current emphasis is more towards the provision of enhanced capacity for voice service, but there is a growing demand for non-voice services. These cannot be conveniently or efficiently supported on existing analogue systems. The DCPLMTS will offer a much greater variety of enhanced services.

In parallel with the need for enhanced capacity and services, there is a growing demand for improved quality of service. The DCPLMTS, through the use of such techniques as advanced modulation and coding, can offer improved voice and non-voice service quality.

5.2 Service types

The basic telecommunication services offered by the DCPLMTS can be divided into two types:

- bearer services which give the user the capacity needed to transmit appropriate signals between certain access points;

- teleservices which provide the user with the full capacity, including terminal equipment functions, to communicate with other users.

Supplementary services are also available in association with the basic services.

The services supported by the DCPLMTS in each of these categories are related to those offered by the ISDN, but are confined to lower bit rate channels (typically less than 16 kbit/s) by the limitations of the radio channel. All the DCPLMTS support some services in each category, but the range offered varies between systems.

5.3 Bearer services

Typical bearer services offered include:

- synchronous, asynchronous and packet data at rates up to a maximum of 9.6 kbit/s;
- unrestricted digital capability at specific bit rates (generally less than 16 kbit/s).

In general, connection of voice band modems to the speech path of mobile stations is not supported. Equivalent service to that offered by the use of voice band modems on the PSTN or ISDN can be provided via the bearer services listed above.

5.4 Teleservices

All the DCPLMTS support telephony and facsimile teleservices. Some extend the teleservice offerings to include Videotex, Teletex, etc.

5.5 Supplementary services

The range of supplementary services supported by the DCPLMTS varies depending on the system and also the particular implementation.

6. Architecture common to all digital systems

6.1 Base station layout

The geographical distribution of base stations is organized around two types of structure:

- regular cell structures using omnidirectional antennas and,
- sector cell structures using directional antennas.

Each of these techniques is already used in analogue cellular systems. More details on cellular base station layout can be found in Report 740.

6.2 Channel design

Two basic categories of channel are defined for DCPLMTS:

- traffic channels (TCH) which are used for voice and data transmission (i.e. bearer services and teleservices);
- control channels (CCH) which are used for signalling and control purposes, including handover.

The CCH are further divided into three broad types:

- common control channels (CCCH) which are used for paging, random access, etc;
- broadcast control channels (BCCH) which are used for broadcast messages, and/or synchronization and frequency correction;

- associated control channels (ACCH) which can be divided into slow ACCH (SACCH) and fast ACCH (FACCH) and provide control and signalling functions for individual users.

Some systems may also define other types of control channel for particular applications (e.g. stand-alone dedicated control channels).

The basic terminologies for some of these control channels can be found in the CCITT Q.1000-Series of Recommendations.

6.3 Network architecture and assignment of functions

Figure 1 shows the basic system architecture for a DCPLMTS, including the major functional components. The communication protocols are specified according to the 7-layer OSI model, while the interfaces between mobile switching centres (MSCs) and the interfaces to the ISDN, PSTN and PDN are all specified according to CCITT Recommendations. The numbering plan also follows CCITT Recommendations.

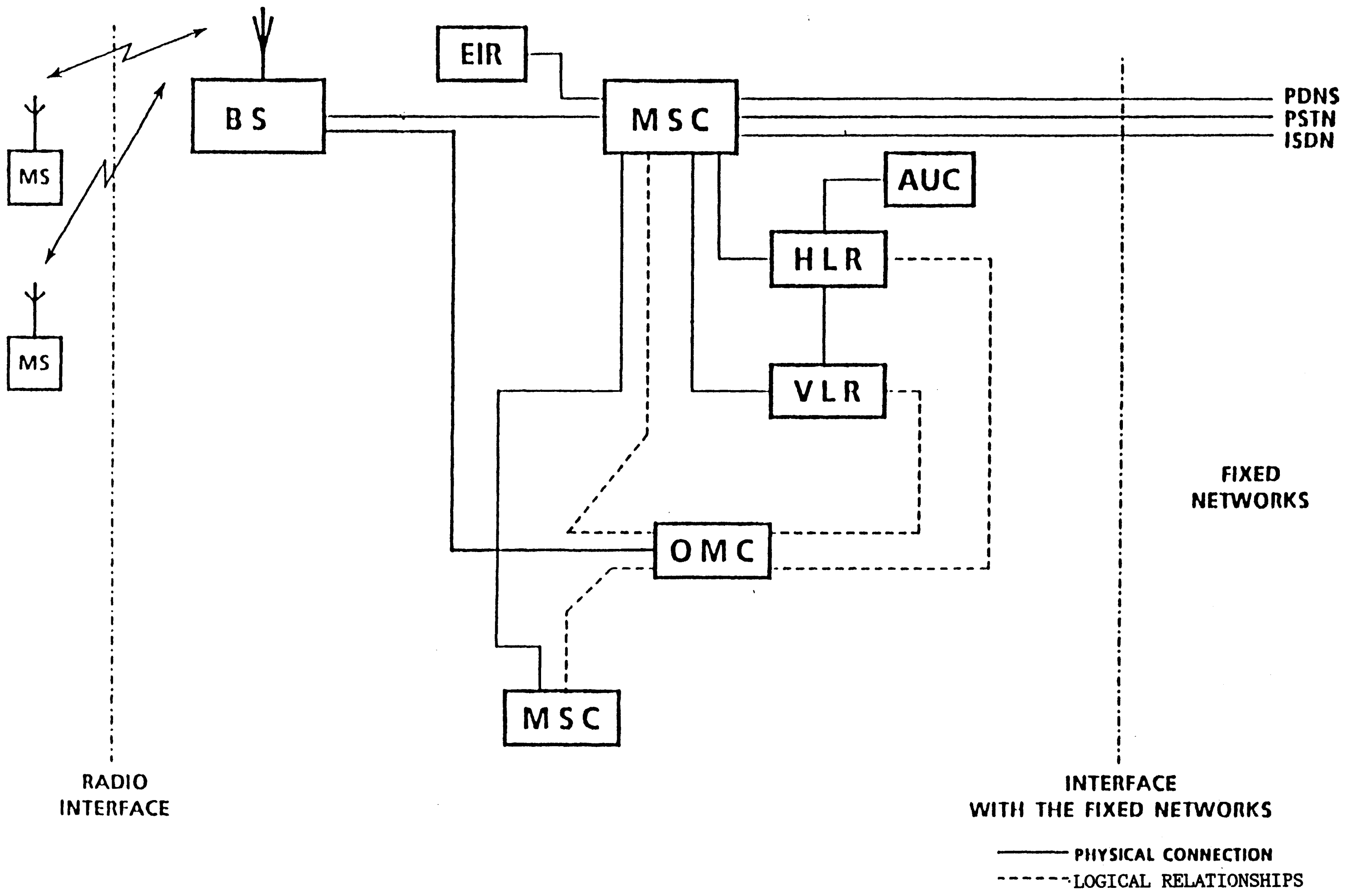

FIGURE 1 - Network architecture

MS : MOBILE STATION
BS : BASE STATION
MSC : MOBILE SERVICES SWITCHING CENTRE
HLR : HOME LOCATION REGISTER
VLR : VISITOR LOCATION REGISTER
OMC : OPERATION AND MAINTENANCE CENTERE
EIR : EQUIPMENT IDENTITY REGISTER
AUC : AUTHENTICATION CENTRE

PART B

DCPLMTS SYSTEMS BEING INSTALLED OR PLANNED

1. Introduction

High capacity DCPLMTS are being developed in Europe, North America and Japan. Each of these systems has the basic objectives and characteristics outlined in Part A of this report. However, each is being developed with a slightly different focus and with different constraints. This has produced three different system specifications. Each of these systems is introduced below and more detailed descriptions can be found in Annexes I through III.

1.1 GSM

The development and specification of this Pan-European system in the 900 MHz band has been carried out through cooperation among more than 16 European countries. The system will be operated by one or more operators in each country from the beginning of the nineties.

The international aspects of the GSM system were taken into account from the very beginning, making GSM a true international public land mobile network (PLMN). For example, GSM supports roaming between countries and full access to the international PSTN, ISDN and PDNs.

1.2 North America

In North America, a digital cellular standard has been developed. This standard has been designed to meet the requirements to introduce new digital services and to provide additional traffic capacity while maintaining compatibility with the existing advanced mobile phone service (AMPS) analogue standard. The new digital standard will be used in North America, and a similar design can be used by over forty countries that have adopted, installed or specified AMPS or its derivatives (TACS).

The dual mode digital and analogue North America Cellular Standard for PLMTS has evolved from the existing AMPS standard to provide both voice and data services with a ten-times traffic capacity improvement as the goal. The North America Digital Standard supports international roaming and full access to the PSTN, ISDN and PDN.

1.3 Japan

Due to the rapid increase in the number of mobile subscribers in Japan, the capacity of the existing analogue cellular system is approaching saturation. To accommodate more subscribers and provide a greater variety of services, digital cellular technology offers promising opportunities. The Japanese Digital Cellular standard provides new digitized traffic and control channels. The standard is applicable to both the 800/900 MHz and 1.5 GHz bands.

2. Explanation of table

Annexes I, II and III give details of digital cellular systems emanating from Europe, North America and Japan respectively. Table I presents the core parameters for these three systems. In each case complete specifications are, or will be, available from the relevant authorities as indicated in the annexes.

TABLE I

Core parameters

FEATURE	GSM	North America	Japan
Class of emission - traffic channels - control channels	 271KF7W 271KF7W	 40K0G7WDT 40K0G1D	 tbd. tbd.
Transmit frequency bands (MHz), - base stations - mobile stations	 935 - 960 890 - 915	 869 - 894 824 - 849	 810 -830 (1.5GHz tbd.) 940 - 960 (1.5GHz tbd.)
Duplex Separation (MHz)	45	45	130 48 (1.5GHz)
RF Carrier spacing (kHz)	200	30	25 interleaved 50
Total number of RF duplex channels	124	832	tbd
Maximum base station erp (W) - peak RF carrier - traffic channel average	 300 37.5	 300 100	 tbd tbd
Nominal mobile station transmit power (W) peak - average	20 - 2.5 8 - 1.0 5 - 0.625 2 - 0.25	9 - 3 4.8 - 1.6 1.8 - 0.6 tbd - tbd	tbd
Cell radius (km) - min - max	 0.5 35 (up to 120)	 0.5 20	 0.5 20
Access method -traffic channels/RF carrier -initial -design capability	TDMA 8 16	TDMA 3 6	TDMA 3 6

Note.- tbd. = to be defined

Table I (continued)

Modulation	GMSK (BT = 0.3)	π /4 diff. encoded QPSK (roll off=0.25)	π /4 diff. encoded QPSK (roll off=0.5)
-transmission rate (kbit/s)	270.833	48.6	37 - 42
Traffic channel structure			
- full rate speech codec			
- bit rate (kbit/s)	13.0	8	6.5 - 9.6
-error protection	9.8kbit/s FEC + speech processing	5 kbit/s FEC	~3 kbit/s FEC
-coding algorithm	RPE-LTP	CELP	tbd
- half rate speech codec			
-initial	tbd	tbd	tbd
-future	yes	yes	yes
-data			
-initial net rate (kbit/s)	up to 9.6	2.4, 4.8, 9.6	1.2, 2.4, 4.8
-other rates (kbit/s)	up to 12	tbd	8 and higher
Channel coding	Rate one half convolutional code with interleaving plus error detection	Rate one half convolutional code	tbd
Control channel structure			
-common control channel	yes (3)	shared with AMPS	yes
-associated control channel	Fast & slow	Fast & slow	Fast & slow
-broadcast control channel	yes (3)	yes	yes
Delay spread equalisation capability (us)	20	60	tbd

Note.- tbd. = to be defined
diff. = differentially

Table I (continued)

Handover - mobile assisted - inter system capability with existing analogue system	 yes no	 yes between digital and AMPS	 yes no
International roaming capability	yes >16 countries	yes	yes
Design capability for multiple system operators in same area	yes	yes	yes

ANNEX I

GENERAL DESCRIPTION OF THE GSM SYSTEM

1. Introduction

The characteristics of the GSM system that are common to most of the digital cellular systems can be found in Part A of this report.

Therefore this annex highlights only original aspects of the GSM system, and, in fact, only parts of them.

The driving force of the GSM has been its international lay out based on a common availability of virtually "clear" frequency bands. This situation offered a unique opportunity of optimizing the usage of new technologies and therefore spectrum efficiency with a rather limited number of constraints. A very advanced radio design was therefore possible.

Full detailed information on the specifications of the GSM system is given in the reference list.

2. Services

In the process of drafting the GSM standard, the details of the implementation of each particular service together with the required interworking mechanisms have been specified in order to offer full access to the services while roaming, and to minimize the complexity of the mobile station.

2.1 Bearer services

The bearer services offered by the GSM PLMN include transparent and non-transparent data services for circuit as well as packet mode, up to a net data rate of 12 kbits/s.

2.2 Teleservices

Among the main teleservices supported by the GSM are:

- speech i.e. telephony and emergency calls;
- short message service;
- data message handling system access;
- Videotex;
- facsimile.

2.3 Supplementary services

The supplementary services offered by GSM operators can be divided into four main groups:

- call forwarding;
- call completion;

- advice of charge;
- call restriction.

2.4 Security aspects

Further to the provision of a wide range of services, the GSM system has also been designed to ensure a high level of security. Therefore security features are provided to protect the access to the services and the privacy of user-related information. The following security features are implemented in the GSM system:

- subscriber identity confidentiality: it ensures that the mobile subscriber identity (IMSI) cannot be disclosed;
- subscriber identity authentication: it verifies that the subscriber identity sent by the mobile is the one claimed (not duplicated or impersonated);
- user data confidentiality: it ensures that the user data, including speech, transferred on the radiopath cannot be disclosed by unauthorized bodies;
- signalling information element confidentiality: it is the property that a given piece of signalling information (subscriber and equipment identities, directory numbers, etc.) exchanged on the radiopath cannot be used by unauthorized individuals or entities.

The IMSI is the information which uniquely identifies the subscriber, and that has to be present and valid to allow the operation of the mobile station.

Each mobile station has a unique identity that shall be implemented by the manufacturer: the international mobile equipment identity (IMEI).

The security functions for authentication of the subscriber related information, and all processes involving the authentication key are contained in a removable piece of the mobile station called the subscriber identity module (SIM).

3. Overview of the system

The GSM system has been standardized by administrations, operators and manufacturers of over 16 European countries in order to provide full service access to international roamers. The standard of the GSM is described in terms of interfaces and functional entities.

Two interfaces are mandatory: the radio interface (Um) and the interface "A" between the mobile services switching centre (MSC) and the base station system (BSS). A further interface "A bis" within the BSS system is being specified but its implementation is not mandatory.

The functional architecture is given in Figure 2. It shows:

- the MSC, the home location register (HLR), and the visitor location register (VLR), where the networking and switching functions are performed;

- the BSS which includes the base station controller (BSC) and the base station transceivers;

- the operations and maintenance centre (OMC);

- the mobile station (MS).

The MAP is the mobile application part of CCITT Signalling System No. 7 which has been specified to allow the routing of calls to MS which have roamed to different MSC areas or to different networks.

The MSC, HLR, and VLR execute interworking with partner networks, call control, and encryption of signalling and user speech and data. These functions also include authentication of the mobile user, location updating as roaming occurs, and paging of the mobile to indicate incoming calls.

The BSS performs the radio channel management functions which include administration of the radio channel configurations, allocations of radio channels and link supervision, scheduling of messages on broadcast channels, choice of frequency hopping sequences whenever needed, and power control.

4. Technical radio characteristics

These characteristics are specified in GSM Recommendation Series 05 and 06.

4.1 RF equipment requirements

In accordance with GSM Recommendation 05.05 (see reference list).

4.2 Carrier spacing

200 kHz carrier spacing yields at least 18 dB adjacent RF channel selectivity within the system. Second adjacent RF channel at 400 kHz spacing yields at least 50 dB selectivity within the system. The corresponding third adjacent RF channel selectivity yields at least 58 dB.

Frequency hopping is a possible feature.

4.3 Class of emission

271KF7W according to Radio Regulations RR4, i.e. Gaussian minimum shift keying GMSK(BT = 0.3) with modulation rate 270.83 kbit/s per carrier using time division multiple access (TDMA) scheme for 8 basic physical channels.

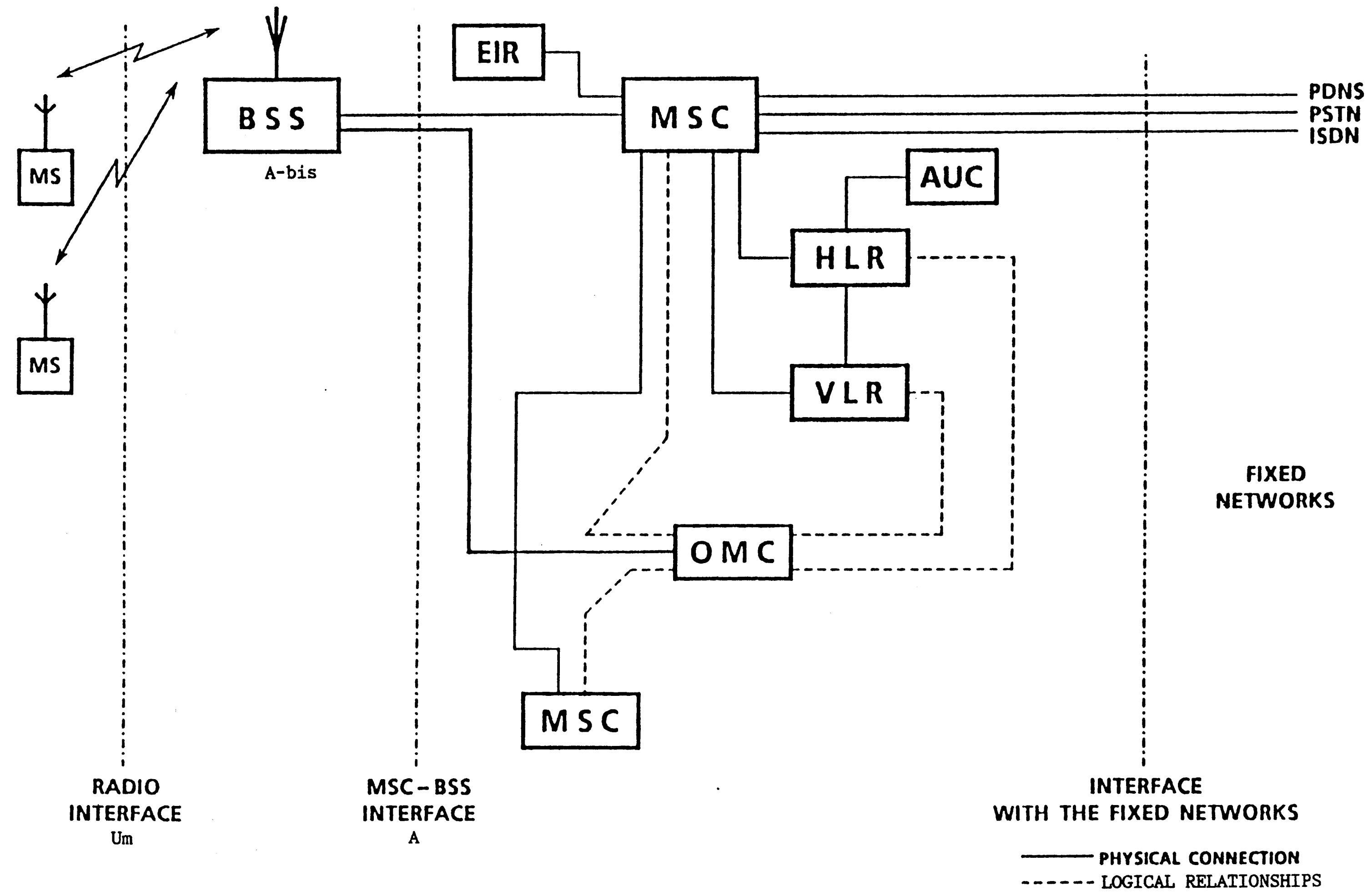

FIGURE 2 - GSM 01.02 System architecture

MS : MOBILE STATION
BSS : BASE STATION SYSTEM
MSC : MOBILE SERVICES SWITCHING CENTRE
HLR : HOME LOCATION REGISTER
VLR : VISITOR LOCATION REGISTER
OMC : OPERATION AND MAINTENANCE CENTRE
EIR : EQUIPMENT IDENTITY REGISTER
AUC : AUTHENTICATION CENTRE

4.4 Cell structure and carrier reuse

It is possible to use large cells (up to 35 km base - mobile distance) in rural areas as well as small cells (down to 1 km diameter) in urban areas.

Extended cell operation ranging up to 120 km base-mobile distance is also possible.

In high traffic density peak areas (e.g. city centres) it is possible to build a sector cell structure using directional antennas with a channel concentration at the traffic peak area.

Co-channel protection ratio down to C/I = 9 dB is acceptable by the system and yields a possible reuse corresponding to a 9-cell cluster. (3 cell reuse patterns with three sectors per cell.)

The sensitivity, similar to that of existing analogue systems, allows an average power in transmitters about 9 dB lower than in current analogue systems, given the same requirements for maximum cell sizes and the same RF device choices.

4.5 Time-slots and TDMA frames

A burst containing 148 bits, corresponding to 114 coded bits, is sent within a time-slot duration of 0.577 ms. A set of 8 time-slots is used to build up a TDMA frame containing 8 basic physical channels. On each physical channel logical channels are mapped i.e. traffic channels and control channels.

The useful information is distributed in the time-slots in a manner allowing for recovery from total erasure of some time-slots.

Two multiframe structures are defined: one consisting of 26 TDMA frames (recurrence interval of 120 ms) for traffic channels and their associated control channels, and one for the other control channels comprising 51 TDMA frames (recurrence interval of 236 ms).

4.6 Traffic channels

4.6.1 Full and half rate traffic channels

The system is able to support both full and half rate traffic channels, corresponding respectively to the gross bit rates of 22.8 and 11.4 kbit/s. The half rate channel is obtained by the use of only half of the time-slots used by the full rate channel. A carrier therefore provides up to 8 full rate or 16 half rate traffic channels (or a combination of both) with their respective associated control channels.

4.6.2 Speech traffic channels

The full rate speech codec, and the associated error correction and detection mechanisms have been defined (see Report 903). Speech frames of 20 ms, comprising each 260 bits, provide a net bit rate of 13 kbit/s. The coding method, "Regular pulse excited linear prediction coding with long term prediction (RPE-LTP)", has been designed to achieve robustness to transmission errors, and to offer a quality close to that of PSTN, while using a limited bit rate.

Error correction (consisting of a 1/2 rate convolutional code) and interleaving schemes, to selectively protect the most important bits within the speech frame (70% of the bits) have been specified. Furthermore an error detection mechanism has been included, associated with extrapolation techniques which have been described and/or recommended, in order to minimize the impairment of the speech quality resulting of speech frames not correctly received. The usage of speech activity detectors has also been specified in the GSM system. Details can be found in [de Brito and Natvig, 1988] for the speech coding aspects and in [Maloberti, 1989] for the transmission aspects.

4.6.3 Data traffic channels

Transparent and non-transparent data services of up to 9.6 kbit/s are supported by different rate adaptions, channel coding and interleaving schemes, on full rate and/or half rate channels.

Unrestricted digital bearer services with a net bit rate of 12 kbit/s are also supported.

4.6.4 Discontinuous transmission

All traffic channels may use, when possible, discontinuous transmission (i.e. transmitter is silent when no relevant information is to be transmitted). In the case of speech this is possible due to the specification of speech activity detectors.

This feature, combined with frequency hopping which introduces interferer diversity, is expected to increase the system capacity. It will also prolong battery life in handheld-portable stations.

4.7 Control channels

Three categories of control channels are defined: broadcast, common and dedicated.

4.7.1 Broadcast channels

Broadcast channels are divided into frequency correction, synchronisation and broadcast control channels.

4.7.2 Common control channels

Common control channels are divided into paging, random access and access grant channels.

4.7.3 Dedicated control channels

Dedicated control channels are divided into slow and fast associated control channels, as well as stand-alone dedicated control channels with their associated control channels. Under this category also a cell broadcast channel is defined to carry short message service cell broadcast.

Short message, service mobile terminated and mobile originated point-to-point, is supported by the stand-alone dedicated control channel or the slow associated control channels.

5. Operational characteristics

5.1 Cell selection

Whilst in idle mode the mobile station is camped on a cell from which it can reliably decode downlink data, and with which it has a high probability of communicating on the uplink.

The condition to perform cell selection is based on path loss criteria. If these criteria are not met or the mobile station fails to decode paging blocks or fails to make access on the uplink, the mobile station starts to re-select.

5.2 Location updating (roaming)

Roaming is performed in accordance with Recommendation 624.

The mobile station evaluates the received signal and initiates the location updating procedure when necessary.

Roaming is possible between Mobile Service Switching Centres (MSC) and between countries.

5.3 Communication protocols

The communication protocols are layered according to the OSI model and are specified in the GSM Recommendations.

The network layer is divided into three sub-layers: call control, mobile management and radio resource management.

The link layer is based on LapD protocols and makes use of the control channels. Messages between link layer peer entities are source coded into 23 octets, i.e. 184 bits.

5.4 Call setup

5.4.1 Mobile originated call setup

The procedure starts on the random access channel to set up a radio resource. Then authentication is done on the mobile management sub-layer. After ciphering and assignment has been confirmed, the call setup is confirmed on the call control sub-layer.

5.4.2 Mobile terminated call setup

After paging from the network the same procedure follows as in 5.4.1 above.

5.5 Handover

Handover is required to maintain a call in progress as a mobile passes from one cell coverage area to another and may also be employed to meet network management requirements, i.e. relief of congestion (network directed handover).

The handover is done either from a channel on one cell to another channel on another cell, or between channels of the same cell.

The handover strategy employed by the network for radio link control determines the handover decision that will be made based on the measurement results reported by the mobile and base stations and various parameters set for each cell. The exact handover strategies are determined by the network operator.

A procedure is implemented in the mobile station by which it monitors the downlink signal level and quality from its serving cell and the downlink signal level and colour code of surrounding cells.

A procedure is implemented in the base station by which it monitors the uplink signal level and quality from each mobile station being served by the cell.

These radio link measurements are also used for RF power control.

Handover is possible between location areas and between different MSC:s belonging to the same PLMN.

5.6 Radio link failure

The criteria for determining radio link failure are specified in order to ensure that calls which fail either from loss of radio coverage or unacceptable interference are satisfactorily handled by the network. Radio link failure results in either call re-establishment or release of the call in progress.

The criterion for determining radio link failure in the mobile station is based on the success rate of decoding messages on the downlink slow associated control channel.

5.7 Signalling between base station and MSC

The signalling follows a layered approach similar to ISDN in accordance with GSM Recommendations.

5.8 ISDN, PDN and PSTN interfaces

In accordance with CCITT Recommendation Q.700- and Q.1000-series.

5.9 Numbering plan

In accordance with CCITT Recommendations E.164, E.212 and E.213.

5.10 Signalling between MSC:s

CCITT signalling system No. 7 (Recommendations E.214, Q.700-series and GSM 09.02 or CCITT Q.1051).

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ANNEX II

GENERAL DESCRIPTION OF THE NORTH AMERICAN DIGITAL CELLULAR PUBLIC LAND MOBILE TELECOMMUNICATIONS SYSTEM

1. General description

1.1 Objectives

The North America digital cellular system for public land mobile telecommunications system (PLMTS) is designed to provide digital voice and data services and to meet a significantly growing capacity requirement. The standard is suitable for new systems and is also compatible with the existing advanced mobile phone service (AMPS) system. RF carrier spacing is compatible with the AMPS spacing and thus both types can co-exist in the same radio environment.

1.2 Evolution strategy

Because of the compatibility of the RF signals, the system provides operators with a smooth evolutionary path for the introduction of digital services and additional traffic capacity to their existing PLMTS. The digital standard can be incorporated into existing networks to allow both digital and analogue traffic. Users with dual mode terminals can receive service from operators who have added a digital capability, and from those operators who have only analogue facilities. Operators need not install digital equipment until their traffic growth warrants additional facilities. Because the digital and analogue traffic share the same band and control channel, the dual mode terminals can economically share many radio and control components. Section 2 of this document outlines the technical features of the system. As the new standard is compatible with the existing AMPS system, only the digital features are highlighted here. For a further description of the AMPS refer to Report 742.

1.3 Capacity improvement

The system uses a linear modulation technique and low bit rate speech coding to achieve high spectral efficiency. This combination enables each 30 kHz radio frequency carrier to handle three traffic channels. Six traffic channels can be accommodated in the future with half-rate codecs. The linear modulation technique also operates at a lower carrier-to-interference ratio than the present analogue system. Capacity can be further increased by the use of improved frequency reuse patterns, cell sectoring and planning techniques. Together, these techniques provide greatly increased traffic capacity as Table II indicates.

The following assumptions were used in the preparation of the table:

a) a total of 25 MHz is available to the operator,

b) a 2% blocking probability is acceptable,

c) a lower C/I threshold is used for the digital system, and

d) the same ratio of traffic to signalling channels is used for both the analogue and digital systems.

TABLE II

Capacity improvements in the North American digital cellular system over the present analogue system

Evolution stage				Number of TCH	Erlang per Cell	Improve. Factor Relative to (7x3)*	Improve. Factor Relative to (4x6)*
Access Tech-nique	TCH Per RFC	Cell Reuse Pattern	Sector Per Cell				
FDMA	1	7	3	395	37	1.0	
FDMA	1	4	6	395	60	1.6	1.0
TDMA	3	7	3	1185	138	3.7	
TDMA	3	4	6	1185	236	6.4	3.9
TDMA	6	7	3	2370	302	8.7	
TDMA	6	4	6	2370	522	14.1	8.7
TDMA	6	4	3	2370	550	14.9	9.2
TDMA	6	3	3	2370	746	21.3	12.4

TCH - Traffic channels, RFC - Radio frequency carrier

* (mxn) m-cell reuse pattern with n-sectors

2. Technical outline

2.1 RF interface requirements

— Modulation: $\pi/4$ differentially encoded QPSK.

The information is differentially encoded; symbols are transmitted as changes in phase rather than absolute phases.

Gray code is used in the symbol mapping; two di-bit symbols corresponding to adjacent signal phases differ only in a single bit.

2.2 Typical cell radius: 0.5 - 20 km.

It is possible to have three and six sector cells using directional antennas with both digital and analog channels for rural and urban areas.

2.3 Channel coding

- Rate one-half convolutional code,
- two levels of error protection,

- cyclic redundancy code (CRC) to protect the most important bits for speech.

2.4 Timeslots and TDMA frames:

Timeslots are arranged in the following order: transmit-receive-idle. The idle timeslots may be used for measuring and channel monitoring purposes.

The numbering scheme is one through six. Currently, six synchronization words are used to allow up to six users to share one TDMA channel.

Provisions are made to allow other conditions of transmission under base station control to support more users and different services on one TDMA channel.

2.5 Traffic Channel Structure:

— Speech: supports full rate and half rate speech codecs.

For full rate speech codec, 13 kbit/s is allocated to speech coding and forward correction. It is possible to support different speech codecs of different rates at the base station.

— Data: provides data services of 2.4, 4.8, 9.6 kbit/s [1] and [2]. Higher rates also will be specified.

2.6 Control Channel Structure:

— Common control channel:

AMPS common control channel [3] will be shared by both digital and analog mobile stations.

Additional messages for mobile stations in digital mode will be handled in the digital traffic channels to support higher dual mode cellular system capacity.

Digital control channel also will be specified.

— Fast and slow control channels: Dedicated in each channel for each user.

The supervisory and other control can be handled by fast and slow associated control channels.

The digital voice color code will be a separate field to provide the function equivalent to the analog Supervisory Audio Tone (SAT) to detect interference.

2.7 Handover

— Intersystem and intrasystem handovers are specified.

— Handovers between digital and analogue channels are possible.

— Mobile Assisted Handover:

It provides the ability for the mobile stations in the digital mode to measure and report both the received signal strength and channel quality over the current digital connection as well as the received signal strength on other channels as requested by the base station.

2.8 System Architecture:

— Communication protocol:

The network communication protocol reference model is designed according to the OSI model.

— Interfaces [4]:

The interfaces between system functional blocks are modeled according to CCITT Q.1000-series.

2.9 Intersystem Cellular Networking:

— Intersystem handover [5]:

The minimum message set provides intersystem location requests, measurements and response. The trunk selection and call connection sequences are specified IS-41-2.

— Intersystem automatic roaming:

Functions and messages of the Home Location Register (HLR) and Visitor Location Register (VLR) are specified based on the CCITT Recommendation.

The data base access procedures for roaming validation, special feature treatment and call delivery also are defined.

— Intersystem data communications:

Using the protocol of CCITT Recommendation X.25 or Message Transfer Part used with CCITT Signalling System No 7 protocol [5].

REFERENCES

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[3] "Cellular System: Mobile Station - Land Station Compatibility Specification", EIA/TIA-553, September 1989.

[4] "Definition of Interface Architecture: U.S. Second Generation Cellular System", EIA/TIA TR45.3.2/88.08-1.

[5] "Cellular Radio Telecommunications Intersystem Operations", EIA/TIA IS-41 (5 Documents), February, 1988.

ANNEX III

GENERAL DESCRIPTION OF THE JAPANESE DIGITAL CELLULAR
PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEM

1. Introduction

The Japanese Digital Cellular PLMTS is specified to provide various services and to accommodate a great number of subscribers.

The system is applicable to both the 800/900 MHz and the 1.5 GHz bands and supports data, facsimile and ISDN services. To realize efficient frequency utilization, the RF carrier spacing is 25 kHz in accordance with the existing analogue standard.

2. Main features

2.1 **RF interface requirements:**

- Channel spacing : 25 kHz interleaved channel spacing, 50 kHz channel spacing.
- Modulation : π/4 differentially encoded QPSK (Roll-off factor;0.5).
- Access method : TDMA;
  - 3 timeslots/25 kHz (for full rate),
  - 6 timeslots/25 kHz (for half rate).
- Transmission bit rate: ranging from 37 to 42 kbit/s will be specified.

2.2 **Cell structure and carrier reuse:**

- Typical cell radius : 0.5 - 20 km.
- Sector cell structure using directional antennas.

2.3 **Timeslots:**

- 3 for full rate, 6 for half rate.

2.4 **Traffic channels:**

- Speech:supports full rate and half rate speech codecs.
  - Full rate speech codecs ranging from 6.5 to 9.6 kbit/s are being tested.
  - Ranging from 9.6 to 12 kbit/s are allocated to speech coding and forward error correction.
  - Half rate speech codec will also be specified.
- Data and other services:
  - Data services of 1.2, 2.4, 4.8 kbit/s. Higher rates will also be specified.
  - Facsimile.
  - ISDN Sub-rate (8 kbit/s).

2.5 Control channels:

- Broadcast control channels (BCCH) : Control channels for broadcast.

- Common control channels (CCCH) : Control channels for signaling, such as paging.

- Associated control channels (ACCH): Slow ACCH and Fast ACCH.

2.6 Cell sélection:

- While in idle mode, the mobile station monitors the downlink signal level and color code from its serving cell and surrounding cells.

2.7 Handover:

- Intersystem and intrasystem handovers are specified.
- Mobile assisted handover.
  - It provides the ability for the mobile stations to measure and report both the received signal strength and channel quality over the current connection as well as the received signal strength on other channels, as requested by the base station.

2.8 Roaming:

- In accordance with Recommendation 624.
- The mobile station evaluates the received signal and coding and initiates the location updating procedure when necessary.
- Roaming is possible between MSCs and between systems.

2.9 System architecture:

- Communication protocol: The network communication protocol reference model is designed according to the OSI model.

- Interfaces : The interfaces between system function blocks are designed according to CCITT Recommendations of the Q.1000-series.

2.10 Networking:

- ISDN and PSTN interfaces: In accordance with CCITT Recommendations Q.700- and Q.1000-series.

- Numbering plan : In accordance with CCITT Recommendations E.164, E.212, and E.213.