NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

GSM ARCHITECTURE

Graduation Project
EE- 400

Student: Cüneyt Demirbağ (940774)

Supervisor: Prof. Dr. Fakhreddin Mamedov

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LIST OF ABBREVIATIONS

AGCH	Access Grant Channel
AM	Amplitude Modulation
AMPS	Advanced Mobile Phone System
ARQ	Automatic Request for retransmission
AuC	Authentication Center
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
Bps	Bits per second
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver System
CC	Call Control
CCCH	Communication Control Channel
CCF	Call Control Function
CDMA	Code-Division Multiple Access
CEPT	Conference Europeenne des Postes et Telecommunications
CGI	Cell Global Identity Number
CM	Communication Management
dB	decibel
DCCH	Dedicated Control Channel
DECT	Digital Enhanced Cordless Telecommunication
DF	Data Frame
DRX	Discontinuous Receive
DTX	Discontinuous Transmission
EC	European Commission
EFR	Enhanced Full Rate
EIR	Equipment Identity Register
ETSI	European Telecommunications Standards Institute
FACCH	Fast Associated Control Channel
FCC	Federal Communications Commission
FCCH	Frequency Correction Channel

FDMA	Frequency-Division Multiple Access
FM	Frequency Modulation
GHz	Gigahertz
GIWU	GSM Interworking Unit
GMSC	Gateway Mobile Services Switching Center
GMSK	Gaussian Minimum Shift Keying
GP	Guard Period
GSM	Global System for Mobile communications
HLR	Home Location Register
Hz	Hertz
IEEE	Institute of Electrical and Electronic Engineers
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Station Identification
IMTS	Improved Mobile Telephone Service
IN	Intelligent Network
ISDN	Integrated-Service Digital Network
ITA	Interim Type Approval
ITU	International Telecom Union
kbps	kilo Bits Per Second
kHz	kilohertz
LA	Location Area
LAI	Location Area Identity
LSF	Line Supervision Frame
MHz	Megahertz
MIC	Mobile Internal Call
MM	Mobility Management
MoU	Memorandum of Understanding
MS	Mobile Station
MSC	Mobile Switching Center
MSISDN	Mobile Subscriber ISDN

MSN	Mobile Service Node
MSRN	Mobile Station Roaming Number
MT	Mobile Termination
MTF	Maintenance Test Frame
MTSO	Mobile Phone Switching Office
MXE	Message Center
NMT	North Mobile Telephony
NSS	Network Switching Subsystem
OAM	Operation, Administration, Maintenance
OMC	Operation Maintenance Centers
OSS	Operational Subsystem
PCH	Paging Channel
PCM	Pulse Code Modulation
PCN	Personal Communications Networks
PCS	Personal Communications Services
PIN	Personal Identification Network
PLMN	Public Land Mobile Network
POTS	Plain Old Telephone Service
PS	Personal Station
PSTN	Public Switching Telephone Network
RACH	Random Access Channel
RCC	Radio Common Carrier
RF	radio frequency
RPE-LPC	Regular Pulse Excited-Linear Predicture Coder
RPE-LTP	Regular Pulse Excited-Long-Term Predictive
RR	Radio Resources Management
RS	Radio System
SACCH	Slow Associated Control Channel
SCH	Synhronization Channel
SDCCH	Stand-alone Dedicated Contol Channel
SIM	Subscriber Identity Module
SMS	Short Message Service
SS	Switching System
TACS	Total Access Communications System

TCH	Traffic Channel
TCH/F	Traffic Channel/Full rate
TCH/H	Traffic Channel/Half rate
TDMA	Time-Division Multiple Access
TM	Telemetry Site
UMTS	Universal Mobile Telecommunications System
VAD	Voice Activity Detection
VLR	Visitor Location Register
WAP	Wireless Application Process

ABSTRACT

GSM (Global System of Mobile Communication) has been well known as the world's most popular standard for new cellular radio and personal communication equipment throughout the world.

Global System for Mobile (GSM) is a second generation cellular system standard that was developed to solve the fragmentation problems of the first cellular systems in Europe.

GSM was first introduced into the European market in 1991. By the end of 1993, several non European countries in South America, Asia, and Australia had adopted GSM and the technically equivalent offshots, DCS 1800, which supports Personal Communication Services (PCS) in the 1.8 GHz to 2.0 GHz radio bands recently created by the governments throughout the world. GSM's success has exceeded the expectations of virtually everyone, and it is now the world's most popular standard for new cellular radio and Personal Communication Equipment throughout the world. It is predicted that by the year 2001, there would be 500 million GSM subscribers worldwide.

The GSM system architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The subsystems are the Base Station Subsystem (BSS), Network and Switching Subsystem (NSS), and The Operration Support Subsystem (OSS). The Mobile Station (MS) is also a subsystem, but is usually considered to be part of the BSS for architecture purposes. Equipment and Services are designed within GSM to support one or more of these specific subsystems.

The first subsystem named Base Station Subsystem (BSS), provides and manages radio transmission path between the mobile station and the mobile switching center. Second subsysten of GSM Architecture is Network and Switching Subsystem (NSS). This subsystem manages the switching functions of the system and allows the mobile switching centers to communicate with other networks. The last subsytem is known as Operation Support Subsystem (OSS). This subsystem's major functionality consists of supporting the operation and maintenance of GSM. It allows the system engineers to monitor, diagnose and troubleshoot all aspects of the GSM system. The above three basic subsystems built the GSM Architecture.

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INTRODUCTION

During the early 1980s, analog cellular telephone systems were experiencing rapid growth in Europe, particularly in Scandinavia and the United Kingdom, but also in France and Germany. GSM (Global System for Mobile Communications) is a European digital communications standard which provides full duplex data traffic to any device fitted with GSM capability, such as a phone, fax or pager, at a rate of 9600 bps using the TDMA communications scheme. Mobile phones may be thought of as cordless phones with elaborate portable and base units.The Radio Interface is the interface between the mobile stations and the fixed infrastructure. The GSM System Architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The Subsystems are the Base Station Subsystems (BSS), Network and Switching Subsystem (NSS), and the Operation Support Subsystem (OSS).

This thesis is aimed to examine GSM Architecture parts separately and demonstrate the GSM network functions tasks.

The thesis consists of the introduction, four chapters and conclusion.

The Chapter 1 introduces first History of GSM, then continues with Services provided by GSM. Finally the Chronology of communication and wireless systems up to 1982 and the developments of GSM from 1982 until Todays are also given.

Chapter 2 presents briefly overview of mobile phones, then we observed the parts of mobile phones and tried to give the detailed operations in mobile phones is illustrated with figures. Finally the call Operations between wireline-to-wireline, mobile-to-wireline, mobile-to-mobile and Advanced mobile phone services is examined.

Chapter 3 studies the GSM radio Interface in details, channel structure and coding, interleaving, ciphering, modulation, Discontinuous Transmission, timing advance, power control Discontinuous reception and finally Multipath and Equalization is also examined.

Chapter 4 is concerned to the GSM Architecture. This chapter is the most important aim of my Graduation Project. I illustrate the process of GSM Architecture and the GSM Functions in details.

1. INTRODUCTION OF GSM

1.1 OVERVIEW

GSM (Global System for Mobile Communications) is a European digital communications standard which provides full duplex data traffic to any device fitted with GSM capability, such as a phone, fax, or pager, at a rate of 9600 bps using the TDMA communications scheme. Since GSM is purely digital, it can easily interface with other digital communications systems, such as ISDN, and digital devices, such as Group 3 facsimile machines.

Unlike any other service, GSM products such as cellular phones require the use of a Subscriber Identity Module, or SIM card. These small electronic devices are approximately the size of a credit card and record all of the user information it. This includes data such as programmed telephone numbers and network security features, which identify the user. Without this module, the device will not function. This allows for greater security and also greater ease of use as this card may be transported from one phone to another, while maintaining the same information available to the user. GSM is also present outside of Europe but known by different names.

In North America it is known as PCS 1900 and elsewhere are DCS 1800 (also known as PCS). The only difference between these systems is the frequency at which operate. The number stands for the operating frequency in megahertz. While each system uses the GSM standard, they are not compatible with each other.

1.2 HISTORY OF GSM

During the early 1980s, analog cellular telephone systems were experiencing rapid growth in Europe, particularly in Scandinavia and the United Kingdom, but also in France and Germany. In the Nordic and Benelux countries the NMT 450 was developed, TACS in the UK and C-Netz in West Germany. The Radio com 2000 was in France and RTMI/RTMS in Italy. But each system was incompatible with everyone else's in equipment and operation and as business was becoming increasingly international, the cutting edge of the communications industry focused on exclusively local cellular solutions. These systems were fine if you wanted to call the office if you were in your own home, but not if you were with a client in another country. Also home

market revenue simply wouldn't justify sustained programs of investment. As a solution in 1982 CEPT, the Conference des Administrations Europeans des Postes et Telecommunications comprised the telecom administrations of twenty-six European countries, established the Group Special Mobile (GSM). Its objective was to develop the specification for a pan-European mobile communications network capable of supporting the many millions of subscribers likely to turn to mobile communications in the years ahead. The home market revenue simply wouldn't justify sustained programs of investment so to further progress they lobbied for support from some political heavyweights. In 1985, the growing commitment to resolving the problem became evident when West Germany, France and Italy signed an agreement for the development of GSM. The United Kingdom added its name to the agreement the following year. By this time, CEPTs Group Special Mobile could argue persuasively that the standards they were developing held the key to a technically and economically viable solution as their standard was likely to employ digital rather than analogue technology and operate in the 900MHz frequency band. Digital technology offered an attractive combination of performance and spectral efficiency. In other words, it would provide high quality transmission and enable more callers simultaneously to use the limited radio band available. In addition, such a system would allow the development of advanced features like speech security and data communications. Handsets could be cheaper and smaller. It would also make it possible to introduce the first hand-held terminals - even though in the early days in terms of size and weight these would be practically indistinguishable from a brick. Finally, the digital approach neatly complemented the Integrated Services Digital Network (ISDN), which was being developed by land-based telecommunications systems throughout the world. But the frequencies to be employed by the new standard were being snapped up by the analogue networks. Over-capacity crisis had started to sound alarm bells throughout the European Community. Demand was beginning to outstrip even the most optimistic projections. The Group Special Mobile's advocacy of digital cellular technology was on hand to offer light at the end of the tunnel. The Directive ensured that every Member State would reserve the 900MHz frequency blocks required for the rollout program. Although these were somewhat smaller than the amount advocated by the CEPT, the industry had finally achieved the political support it needed to advance its objectives. The logistical nightmare in the GSM, which followed soon left this achievement as a distant, dream so single, permanent organization at the helm. In1986 the GSM Permanent Nucleus was formed

and its head quarters established in Paris. It was all very well agreeing the technology and standards for this new product. But what about the creation of a market? It was essential to forge a commercial agreement between potential operators who would commit themselves to implementing the standard by a particular date. Without such an agreement there could be no network. Without the network there would be no terminals. Without network and terminals there would be no service. Stephen Temple of the UK's Department of Trade and Industry was charged with the task of drafting the first Memorandum of Understanding (MoU). In September 1987 network operators from thirteen countries signed a MoU in Copenhagen. One of the most important conclusions drawn from the early tests was that the new standard should employ Time Division Multiple Access (TDMA) technology. The strength of its technical performance ensured that narrowband TDMA had the support of major players like Nokia, Ericsson and Siemens. This promised the flexibility inherent in having access to a broad range of suppliers and the potential to get product faster into the marketplace. But as always as soon as one problem was solved other problems looming on the horizon. In 1989, the UK Department of Trade and Industry published a discussion document called "Phones on the Move". This advocated the introduction of mass-market mobile communications using new technology and operating in the 1800 MHz frequency band. The UK government licensed two operators to run what became known as Personal Communications Networks (PCN). Operating at the higher frequency gave the PCN operators virtually unlimited capacity, where as 900MHz was limited. The next hurdle to over come was that of the deadline. If the 1 July 1991 launch date was not met there was a real danger that confidence in GSM technology would be fatally undermined but moral received a boost when in 1989 the responsibility for specification development passed from the GSM Permanent Nucleus to the newly created European Telecommunications Standards Institute (ETSI). In addition, the UK's PCN turned out to be more of an opportunity than a threat. The new operators decided to utilize the GSM specification - slightly modified because of the higher frequency - and the development of what became known as DCS 1800 was carried out by ETSI in parallel with GSM standardization. In fact, in 1997 DCS 1800 was renamed GSM 1800 to reflect the affinity between the two technologies. With so many manufacturers creating so many products in so many countries, it soon became apparent that it was critical that each type of terminal was subject to a rigorous approval regime. Rogue terminals could cause untold damage to the new networks. The solution was the introduction of Interim

Type Approval (ITA). Essentially, this was a procedure in which only a subset of the approval parameters was tested to ensure that the terminal in question would not create any problems for the networks. In spite of considerable concern expressed by some operators, ITA terminals became widely available in the course of 1992. True hand held terminals hit the market at the end of that year and the GSM bandwagon had finally started to roll. From here the G.S.M became a success story. In 1987, the first of what was to become an annual event devoted to the worldwide promotion of GSM technology was staged by conference organizers IBC Technical Services. The Pan European Digital Cellular Conference. This year it celebrated its tenth anniversary in Cannes, attracting over 2,400 delegates. By the end of 1993, GSM had broken through the 1 million-subscriber barrier with the next million already on the horizon. By June 1995 Phase 2 of standardization came in to play and a demonstration of fax, video and data communication via GSM. When the GSM standard was being drawn up by the CEPT, six separate systems were all considered as the base. There were seven criteria deemed to be of importance when assessing which of the six would be used. Each country developed its own system, which was incompatible with everyone else's in equipment and operation. This was an undesirable situation, because not only was the mobile equipment limited to operation within national boundaries, which in a unified Europe were increasingly unimportant, but there was also a very limited market for each type of equipment, so economies of scale and the subsequent savings could not be realized. The Europeans realized this early on, and in 1982 the Conference of European Posts and Telegraphs (CEPT) formed a study group called the Group Special Mobile (GSM) to study and develop a pan-European public land mobile system. The proposed system had to meet certain criteria. In 1989, GSM responsibility was transferred to the European Telecommunication Standards Institute (ETSI), and phase-I of the GSM specifications were published in 1990. Commercial service was started in mid-1991, and by 1993 there were 36 GSM networks in 22 countries with 25 additional countries having already selected or considering GSM. This is not only a European standard - South Africa, Australia, and many Middle and Far East countries have chosen GSM. Although standardized in Europe, GSM is not only a European standard. Over 200 GSM networks (including DCS1800 and PCS1900) are operational in 110 countries around the world. In the beginning of 1994, there were 1.3 million subscribers worldwide, which had grown to more than 55 million by October 1997. With North America making a delayed entry into the GSM field with a derivative of GSM called

PCS1900, GSM systems exist on every continent, and the acronym GSM now aptly stands for Global System for Mobile communications. The developers of GSM chose an unproven (at the time) digital system, as opposed to the then-standard analog cellular systems like AMPS in the United States and TACS in the United Kingdom. They had faith that advancements in compression algorithms and digital signal processors would allow the fulfillment of the original criteria and the continual improvement of the system in terms of quality and cost. The over 8000 pages of GSM recommendations try to allow flexibility and competitive innovation among suppliers, but provide enough standardization to guarantee proper inter-working between the components of the system. This is done by providing functional and interface descriptions for each of the functional entities defined in the system. The development of GSM started in 1982, when the Conference of European Posts and Telegraphs (CEPT) formed a study group called Group Special Mobile (the initial meaning of GSM). The group was to study and develop a pan-European public cellular system in the 900 MHz range, using spectrum that had been previously allocated. At that time, there were many incompatible analog cellular systems in various European countries. Some of the basic criteria for their proposed system were:

- Good subjective speech quality.
- Low terminal and service cost.
- Support for international roaming.
- Ability to support handheld terminals.
- Support for range of new services and facilities.
- Spectral efficiency.
- ISDN compatibility.

In 1989, the responsibility for GSM was transferred to the European Telecommunication Standards Institute (ETSI), and the Phase I recommendations were published in 1990. At that time, the United Kingdom requested a specification based on GSM but for higher user densities with low-power mobile stations, and operating at 1.8 GHz. The specifications for this system, called Digital Cellular System (DCS1800) were published 1991. Commercial operation of GSM networks started in mid-1991 in European countries. By the beginning of 1995, there were 60 countries with operational or planned GSM networks in Europe, the Middle East, the Far East, Australia, Africa,

and South America, with a total of over 5.4 million subscribers. As it turned out, none of the six candidates was actually used! The information collected during the tests did enable the GSM (Group Special Mobile) to design the specifications of the current GSM network. The total change to a digital network was one of the fundamental factors of the success of GSM. Digital transmission is easier to decode than analogue due to the limited number of possible input values (0,1), and as ISDN was becoming de facto at the time, it was logical to avail of digital technology. This also ensured that GSM could evolve properly in an increasingly digital world, for example with the introduction of an 8kps speech coder. It is much easier to change channel characteristics digitally than analogously. Finally, the transmission method decided on for the network was TDMA, as opposed to FDMA and CDMA. In 1989, responsibility for the specification was passed from CEPT to the newly formed and now famous European Telecommunications Standards Institute (ETSI). By 1990, the specifications and explanatory notes on the system were documented extensively, producing 138 documents in total, some reaching sizes of several hundred pages in length services.

1.3 TECHNOLOGY

1.3.1Services Provided by GSM

From the beginning, the planners of GSM wanted ISDN compatibility in terms of the services offered and the control signaling used. However, radio transmission limitations, in terms of bandwidth and cost, do not allow the standard ISDN B-channel bit rate of 64 kbps to be practically achieved. Using the ITU-T definitions, telecommunication services can be divided into bearer services, tele-services, and supplementary services. The digital nature of GSM allows data, both synchronous and asynchronous, to be transported as a bearer service to or from an ISDN terminal. Data can use either the transparent service, which has a fixed delay but no guarantee of data integrity, or a non-transparent service, which guarantees data integrity through an Automatic Repeat Request (ARQ) mechanism, but with a variable delay. The data rates supported by GSM are 300 bps, 600 bps, 1200 bps, 2400 bps, and 9600 bps. The most basic tele-service supported by GSM is telephony. As with all other communications, speech is digitally encoded and transmitted through the GSM network as a digital stream. There is also an emergency service, where the nearest emergency-service provider is notified by

dialing three digits (similar to 911). A variety of data services is offered. GSM users can send and receive data, at rates up to 9600 bps, to users on POTS (Plain Old Telephone Service), ISDN, Packet Switched Public Data Networks, and Circuit Switched Public Data Networks using a variety of access methods and protocols, such as X.25 or X.32. Since GSM is a digital network, a modem is not required between the user and GSM network, although an audio modem is required inside the GSM. Network to inter-work with POTS. Other data services include Group 3 facsimile, as described in ITU-T recommendation T.30, which is supported by use of an appropriate fax adaptor. A unique feature of GSM, not found in older analog systems, is the Short Message Service (SMS). SMS is a bi directional service for short alphanumeric (up to 160 bytes) messages. Messages are transported in a store-and-forward fashion. For point-to-point SMS, a message can be sent to another subscriber to the service, and an acknowledgement of receipt is provided to the sender. SMS can also be used in a cell-broadcast mode, for sending messages such as traffic updates or news updates. Messages can also be stored in the SIM card for later retrieval Supplementary services are provided on top of tele-services or bearer services. In the current (Phase I) specifications, they include several forms of call forward (such as call forwarding when the mobile subscriber is unreachable by the network), and call barring of outgoing or incoming calls, for example when roaming in another country. Many additional supplementary services will be provided in the Phase 2 specifications, such as caller identification, call waiting, multi-party conversations. GSM was designed having interoperability with ISDN in mind, and the services provided by GSM are a subset of the standard ISDN services. Speech is the most basic, and most important, tele-service provided by GSM. In addition, various data services are supported, with user bit rates up to 9600 bps. Specially equipped GSM terminals can connect with PSTN, ISDN, Packet Switched and Circuit Switched Public Data Networks, through several possible methods, using synchronous or asynchronous transmission. Also supported are Group 3 facsimile service, video-tex, and teletex. Other GSM services include a cell broadcast service, where messages such as traffic reports, are broadcast to users in particular cells. A service unique to GSM, the Short Message Service, allows users to send and receive point-to-point alphanumeric messages up to a few tens of bytes. It is similar to paging services, but much more comprehensive, allowing bi-directional messages, store-and-forward delivery, and acknowledgement of successful delivery.

1.3.2 Specifications of the system

Categories of Service

- **Teleservices**
- **Bearer services**
- **Supplementary services**

GSM Phase 1 Services

Table 1.1 Phase 1 Services

CATEGORY	SERVICE
Teleservices	Telephony Emergency Calls Short Message Service (SMS) Telefax
Bearer Services	Asynchronous Data Synchronous Data Asynchronous PAD* Alternate Speech and Data Telefax
Supplementary Services	Call Forwarding Call Barring

***packet-switched, packet assembler, disassembler access**

GSM Phase 2 Services

Table 1.2 Phase 2 Services

CATEGORY	SERVICE
Teleservices	Telephony (Half rate) Improvements in SMS
Bearer Services	Synchronous dedicated packed data access
Supplementary Services	Calling /connected line identity presentation and restriction Call waiting Call hold Multi-party Communication (Conference) Closed user group On-line charge information Unstructured supplementary services data Operator determined barring

1.4 THE DIFFERENT GSM-BASED NETWORKS

Different frequency bands are used for GSM 900, GSM1800 and GSM 1900 (Table 1.3.). In some countries, an operator applies for the available frequencies. In other countries, e.g. United States, an operator purchases available frequency bands at auctions.

Table 1.3 Frequency bands for the different GSM-based networks

Network type	Frequency band UL / DL	Implementations
GSM 900	890-915 / 935-960 MHz	GSM 900
GSM1800	1710 – 1785 / 1805 -1880 MHz	GSM 1800
GSM1900	1850-1910 / 1930-1990 MHz	GSM1900

1.4.1 Where are GSM Frequencies Used?

GSM networks presently operate in three different frequency ranges. These are:

a) GSM 900

(Also called GSM) operates in the 900 MHz frequency range and is the most common in Europe and the world.

b) GSM 1800

(Also called PCN (Personal Communication Network), and DCS 1800) - operates in the 1800 MHz frequency range and is found in a rapidly-increasing number of countries including France, Germany, Switzerland, the UK, and Russia. A European Commission mandate requires European Union members to license at least one DCS 1800 operator before 1998.

c) GSM 1900

(Also called PCS (Personal Communication Services), PCS 1900, and DCS 1900) - the only frequency used in the United States and Canada for GSM. Note that the terms PCS is commonly used to refer to any digital cellular network operating in the1900 MHz frequency range, not just GSM.

1.5 CHRONOLOGY OF COMMUNICATION AND GSM SYSTEM

1.5.1 Chronology of communication and wireless systems up to 1982

- **1799** Invention of Telegraph by Samuel Morse.
- **1844** First active telegraph lines between Washington and Baltimore.
- **1858** The first transatlantic cable between US and Europe.
- **1870's** Invention of telephone by Alexander Graham.

Introduction of wireless communication.

- Wireless communication was first developed to enable communication of ships on the sea.
- **1906** Human voice was transferred succesfully over radio for the first time.
- **1915** The invention of mobile radios.
- **1921** In the Detroit police department the first Vehicular mobile radio was used(One way communication system).
- **1930s** First half duplex mobile communication systems were introduced in U.S.
- **1935** Invention of FM (Frequency Modulation).
- **1969** Nordic countries made an attempt to standardise the Telecommunication aspects of that countries.
- **1973** That group (NMT group) specifies a feature allowing mobile telephones to be located within different networks. This is the beginning of the roaming concept.
- **1979** The installation and testing of first cellular systems were authorised by FCC.
- **1981** The installation of first cellular systems in the world which was using an analog system called NMT (North Mobile Telephony).

Introduction of GSM

- **1981** A group of specialists was formed to determine a series of standards for Mobile communications by Conference of European Posts and Telecommunications (CEPT). This group was called Groupe Speciale Mobile.
- **The primitive aims of this comitee was as follows:**
  * Spectrum efficiency
  * International roaming
  * Low mobile and base stations costs
  * Good subjective voice quality
  * Compatibility with other systems such as ISDN (Integrated Services Digital Network)
- Ability to support new services
- **1989** The responsibility of GSM was passed from CEPT to ETSI(European Telecommunications Standards Institute).

1.5.2 The History Of GSM: 1982 to 2001

More than 700 GSM mobile networks have been established in Europe, the North America, South America, Iceland, Asia, Africa and Australia up until now, woven together by international roaming agreements and a common bond called the "Memorandum of Understanding" (MoU) which defines the GSM standards and the different phases of its world-wide implementation. GSMs pedigree derives from a 1982 proposal from Nordic Telecom and Netherlands PTT to the CEPT (Conference of European Post and Telecommunications) to develop a new digital cellular standard that would cope with the ever-burgeoning demands on European mobile networks. The European Commission (EC) issued a directive, which required member states to reserve frequencies in the 900 MHz band for GSM to allow for roaming. The European Telecommunications Standards Institute (ETSI) defined GSM as the internationally accepted digital cellular telephony standard. The proposal came to fruition in September 1987, when 13 operators and administrators in the CEPT GSM advisory group signed the charter GSM (Group Special Mobile) MoU "Club" agreement, with a launch date of

1 July 1991. The original French name was later changed to Global System for Mobile Communications, but the original GSM acronym stuck.

1982 - The Beginning

- Nordic Telecom and Netherlands PTT propose to CEPT (Conference of European Post and Telecommunications) the development of a new digital cellular standard that would cope with the ever a burgeoning demands on European mobile networks.
- The European Commission (EC) issues a directive which requires member states to reserve frequencies in the 900 MHz band for GSM to allow for roaming.

1986

- Main GSM radio transmission techniques are chosen.

1987

- September - 13 operators and administrators from 12 areas in the CEPT GSM advisory group sign the charter GSM (Group Special Mobile) MoU "Club" agreement, with a launch date of 1 July 1991.
- The original French name was later changed to, Global System for Mobile Communications but the original GSM acronym stuck.
- GSM spec drafted.

1989

- The European Telecommunications Standards Institute (ETSI) defined GSM as the internationally accepted digital cellular telephony standard.
- GSM becomes an ETSI technical committee.

1990

- Phase 1 GSM 900 specifications are frozen.
- DCS adaptation starts.
- Validation systems implemented.
- First GSM World congress in Rome with 650 Participants.

1991

- First GSM spec demonstrated.
- DCS specifications are frozen.
- GSM World Congress Nice has 690 Participants.

1992

- January - First GSM network operator is Oy Radiolinja Ab in Finland.
- December 1992 - 13 networks on air in 7 areas.
- GSM World Congress Berlin - 630 Participants.

1993

- GSM demonstrated for the first time in Africa at Telkom '93 in Cape Town.
- Roaming agreements between several operators established.
- December 1993 - 32 networks on air in 18 areas.
- GSM World Congress Lisbon with 760 Participants.
- Telecom '93 held in Cape Town. First GSM systems shown.

1994

- First GSM networks in Africa launched in South Africa.
- Phase 2 data/fax bearer services launched.
- Vodacom becomes first GSM network in the world to implement data/fax.
- GSM World Congress Athens with 780 Participants.
- December 1994 - 69 networks on air in 43 areas.

1995

- GSM MoU is formally registered as an Association registered in Switzerland - 156 members from 86 areas.
- GSM World Congress Madrid with 1400 Participants.
- December 1995 117 networks on air in 69 areas.
- Fax, data and SMS roaming started.
- GSM phase 2 standardization is completed, including adaptation for PCS 1900 (PCS).
- First PCS 1900 network live 'on air' in the USA.
- Telecom '95 Geneva - Nokia shows 33.6 kbps multimedia data via GSM.
- Namibia goes on-line.
- Ericsson 337 wins GSM phone of the year.
- US FCC auctions off PCS licenses.

1996

- GSM MoU is formally registered as an Association registered in Switzerland.
- December 1996 120 networks on air in 84 areas.
- GSM World Congress in Cannes.
- GSM MoU Plenary held in Atlanta GA, USA.
- 8K SIM launched.
- Pre-Paid GSM SIM Cards launched.
- Bundled billing introduced in South Africa.
- Libya goes on-line.
- Option International launches world's first GSM/Fixed-line modem.

1997

- Zimbabwe goes live.
- GSM World Congress Cannes 21/2/97.
- Mozambique goes live.
- Iridium birds launched.
- First dual-band GSM 900-1900 phone launched by Bosch.

1998

- Botswana GSM goes live.
- GSM World Congress Cannes (2/98).
- Vodacom Introduces Free Voicemail.
- MTN Gets Uganda Tender.
- GSM SIM Cracked in USA.
- Over 2m GSM 1900 users.
- MTN Gets Rwanda Tender.
- MTN follows with free voicemail.
- Rwanda GSM Live.
- First HSCSD trials in Singapore.
- Vodacom launches Yebo! Net 10/98.
- Iridium Live 11/98.
- First GSM Africa Conference (11/98).
- 125m GSM 900/1800/1900 users worldwide (12/98).
- Option International launches FirstFone.
- MTN launches Carryover minutes.

1999

- GSM Conference in Cannes 2/99.
- 165m GSM 900/1800/1900 users worldwide.
- GPRS trials begin and USA and Scandinavia 1/99.
- WAP trials in France and Italy 1/99.
- CellExpo Africa 5/99.
- Eight Bidders for Third SA Cell License.
- GSM MoU Joins 3GPP.
- MTN SA Head of GSM MoU.
- First GPRS networks go live.
- Blue tooth specification v1.0 released.

2000

- GSM Conference in Cannes 3/2000.
- By 12/2000 480m GSM 900/1800/1900 users worldwide.
- First GPRS networks roll out.
- Mobey Forum Launched.
- MeT Forum Launched.
- Location Interoperability Forum Launched.
- First GPRS terminals seen.
- Nokia releases Smart Messaging spec.
- SyncML spec released.

2001

- GSM Conference in Cannes 2/2001.
- By 5/2001 500m GSM 900/1800/1900 users worldwide.
- 16 billion SMS message sent in April 2001.
- 500 million people are GSM users (4/01).

2. MOBILE PHONES

2.1 OVERVIEW

Mobile phones may be thought of as cordless phones with elaborate portable and base units. High-power transmitters and elavated antennas that provide the radio carrier link over an area within 20 to 30 miles from the base station antenna, as well as the multiplexing, detecting, sorting and selecting features required to simultaneously service 60 subscribers per base station, are the major differences between cordless phones and mobile phones.

2.2 BASE UNIT

The base station can transmit and receive on several different frequencies simultaneously to provide several individual channels for use at the same time. The radio base station transmitter output power is typically 200-250 watts and the radiated power can be as high as 500 watts if the transmitting antenna gain is included. It covers a circular area of up to 30 milles in radius for clear reliable communications, but transmitters with the same frequence are not spacet closer than about 60 to 100 milles because of the noise interfrence levels.

The receiver contains filters, high-gain amplifiers, and demodulators to provide a usable voice signal to the phone line. The control terminal contains the necessary detector and timing and logic circuits to control the transmission link between the base unit and the mobile units. As a result, phone calls are coupled to and from the standard phone system just like calls that are carried completely over wired facilities. The control terminal has the necessary interface circuits so that a call initiated at a mobile unit is interconnected through the national or international phone system to the called party just as any other phone call.

The national and international phone system facilities are owned by the respective phone companies. The base units and mobile units may be owned by the phone company or by a separate company called a radio common carrier (RCC). When the mobile system is run by a RCC, the RCC is charged by the telephone company for the use of the standard phone system just like any other customer. The cost is then included in the charge by the RCC to the eventual user of the mobile units.

To subscribe to mobile phone service, a user has only to apply, and be accepted by the RCC or the phone company operating the system. When the application is accepted, the user can lease or purchase the mobile equipment.

2.3 MOBILE UNIT

The mobile unit in the user's vehicle consists of a receiver containing amplifiers, a mixer and a demodulator; a transmitter containing a modulator, carrier oscillators and amplifiers; the necessary control logic; a control unit with microphone, speaker, keypad and switches; antennas and the interconnecting cables. The control unit performs all of the functions associated with normal phone use. A modern control head with automatic functions is illustrated.

The mobile phone user with automatic control places and receives calls in the same manner as with an oridinary phone. When the handset is lifted to place a call, the radio unit automatically selects an available channel. If no channel is available, the busy light comes on, If a channel is found, the user hears the normal dial tone from the phone system, and can then dial the number and proceed as if the phone were direct wired. An incoming call to the mobile unit is signaled by a ringing tone and is answered simply by lifting the handset and talking. Thus, the automatic mobile phone is as easily used as a phone. The mobile phone combines the mobility of the radio link and the world-wide switched network of the existing phone system to provide a communication link to any other phone in the world.

2.4 DETAILED OPERATION

Different signalling techniques have to used in a mobile phone system in contrast with a wired facility. Since there are no wires connecting the telephone to the network, both speech and signalling must be transmitted via radio. For wireless operation, tones are used for those signaling functions, which are otherwise performed by voltage and current in hard-wired systems. This is accomplished by the use of special tones rather than applying a voltage level or detecting a current. The proper tone transmitted to the mobile unit will, for example, ring the mobile phone to indicate an incoming call just as with a standard phone different tone is used to indicate off-hook, busy, etc. The Improved Mobile Telephone System (IMTS) uses in band signalling tones from 1300 Hz to 2200 Hz. The older Mobile Phone System (MTS) had in band signalling tones in the 600 HZ to 1500 Hz range. Some systems use 2805 Hz as manual operation.

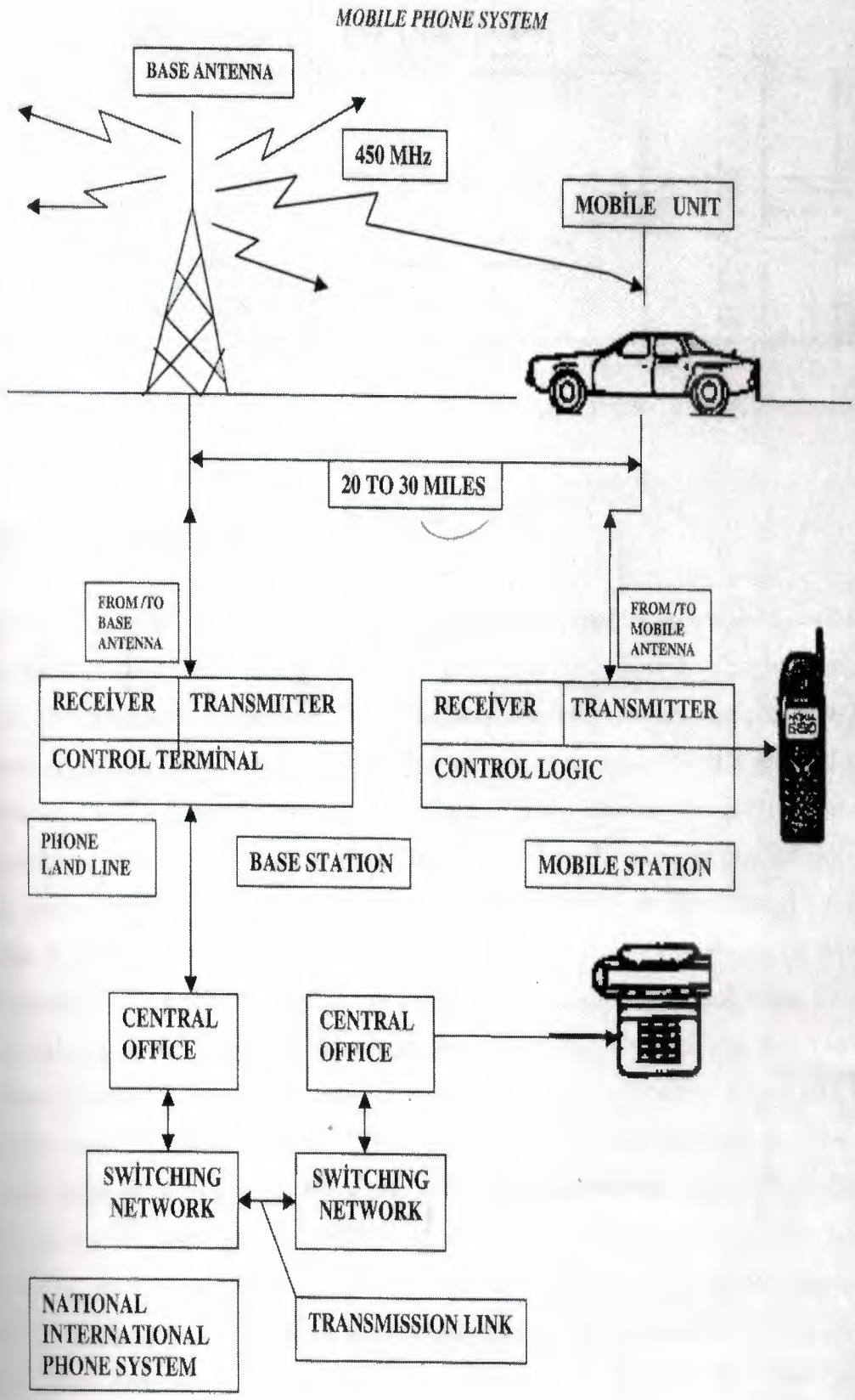


Figure 2.1 Mobile Phone System

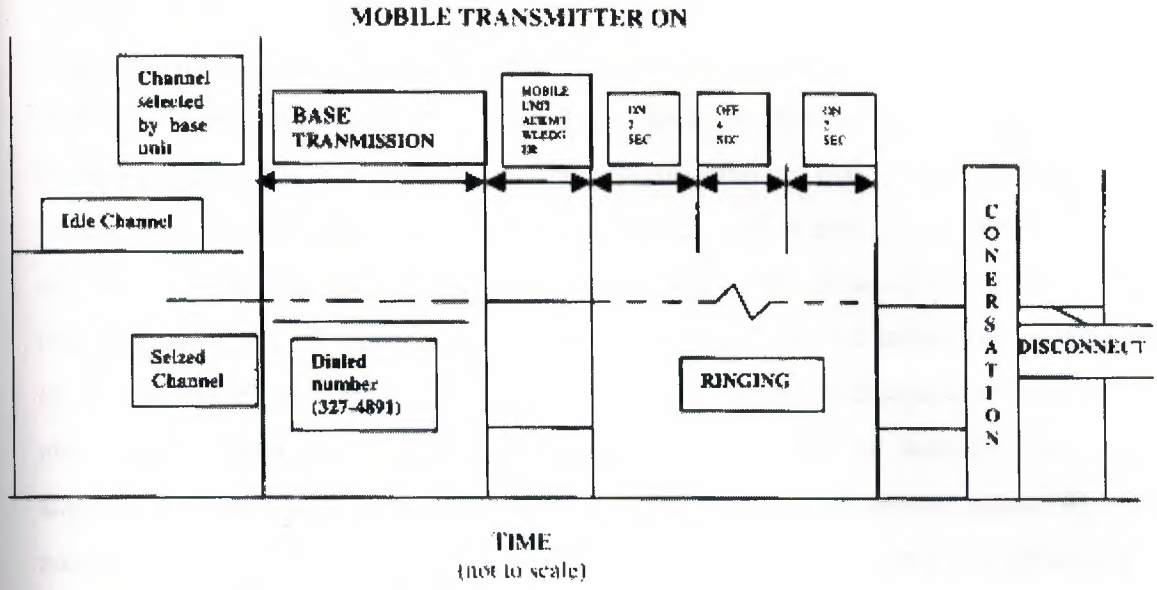


Figure 2.2 Mobile Transmitter ON

2.5 INCOMING CALL

To gain a better understanding of the system operation, consider an incoming call from a wire facility subscriber through the base unit to a mobile unit. The base station controls all activity on all channels. It selects only one idle channel and places a 2000 Hz idle tone (1).All on-hook mobile units that are turned on automatically search for the idle tone and lock on the idle channel because this is the channel over which the next call in either direction will be completed. After locking on the idle channel, all on-hook mobile units "listen" to their numbers on that channel. When an idle channel becomes busy for a call in either direction, the base station control terminal selects another unused channel and marks it with the idle tone. All on - hook mobile units then move to the new idle channel. This process is repeated each time and new call is initiated as long as unused channels are available. After the person calling the mobile subscriber dials the mobile units telephone number DD(2).The call is processed through the switched telephone network as in a normal landline call. Following the sequence. When the call reaches the control terminal, the terminal seizes the idle channel, and indicates seizure by removing the idle tone from that channel and applying the 1800Hz seize; tone ST(3). The ST prevents mobile units from seizing the channel to originate a call. The control terminal then out-pulses the mobile unit number MN(4). Over the base station transmitter at ten pulses per second, with idle-tone representing a mark and seize-tone representing a space. The others automatically abandon it and searches for the new idle

channel. When the mobile unit receives its correct seven-digit address, the mobile supervisory unit turns on the mobile transmitter and sends the acknovledgement signal Ack (5), using the 2150 Hz guard-tone, back to the control terminal. If this acknowledgement is not received by the control terminal within 3 seconds after out-pulsing the address, seize tone is removed and the call is abandoned. However, upon receipt of the mobile acknowledgement signal, the terminal sends standard repetitive ringing at a cycle of 2 seconds on, 4 seconds off, using idle and seize tones as before. If the mobile does not answer within 45 seconds, ringing (6), is discontinued and the call abandoned. When the mobile subscriber goes off-hook to answer, the mobile supervisory unit sends a burst of connect tone (1633 Hz) as an answer signal (8). Upon receipt of the answer signal, the control terminal stops the ringing and establishes a talking path between the calling circuit and the radio channel (7). When the subscriber hangs-up (8). At the end of call, the mobile supervisory unit sends disconnect signal (12. Alternating the disconnect tone (1336 Hz) and the guard tone. The mobile supervisory unit then turns of the mobile transmitter and begins searching for the market idle channel. Each on-hook mobile unit receiving the number transmission compares the received number to its unit number. Only the one mobile unit with a number match remains locked on that channel.

2.6 OUTGOING CALL

The sequence for a call originated by a mobile subscriber is illustrated. When the subscriber goes off-hook to place the call, the mobile unit must be locked on the marked-idle channel. If not, the hand set will be inoperative and the busy lamp on the control unit will light, indicating to the subscriber that no channel is available. If the mobile unit is locked on the marked idle channel, the mobile supervisory unit will turn on the mobile transmitter to initiate the acknowledgement or handshake sequence.

Then mobile unit transmits its own number so the control terminal can identify it as a subscriber and can charge the call to the number. The roaming functions, are similar to those. When a call is originated from the field, the mobile unit finds a marked idle channel and broadcasts an acknowledgement to the base by sending its identification. The mobile unit than completes a call in the usual manner by receiving a dial tone, then dialling the number and waiting for the called party to answer.

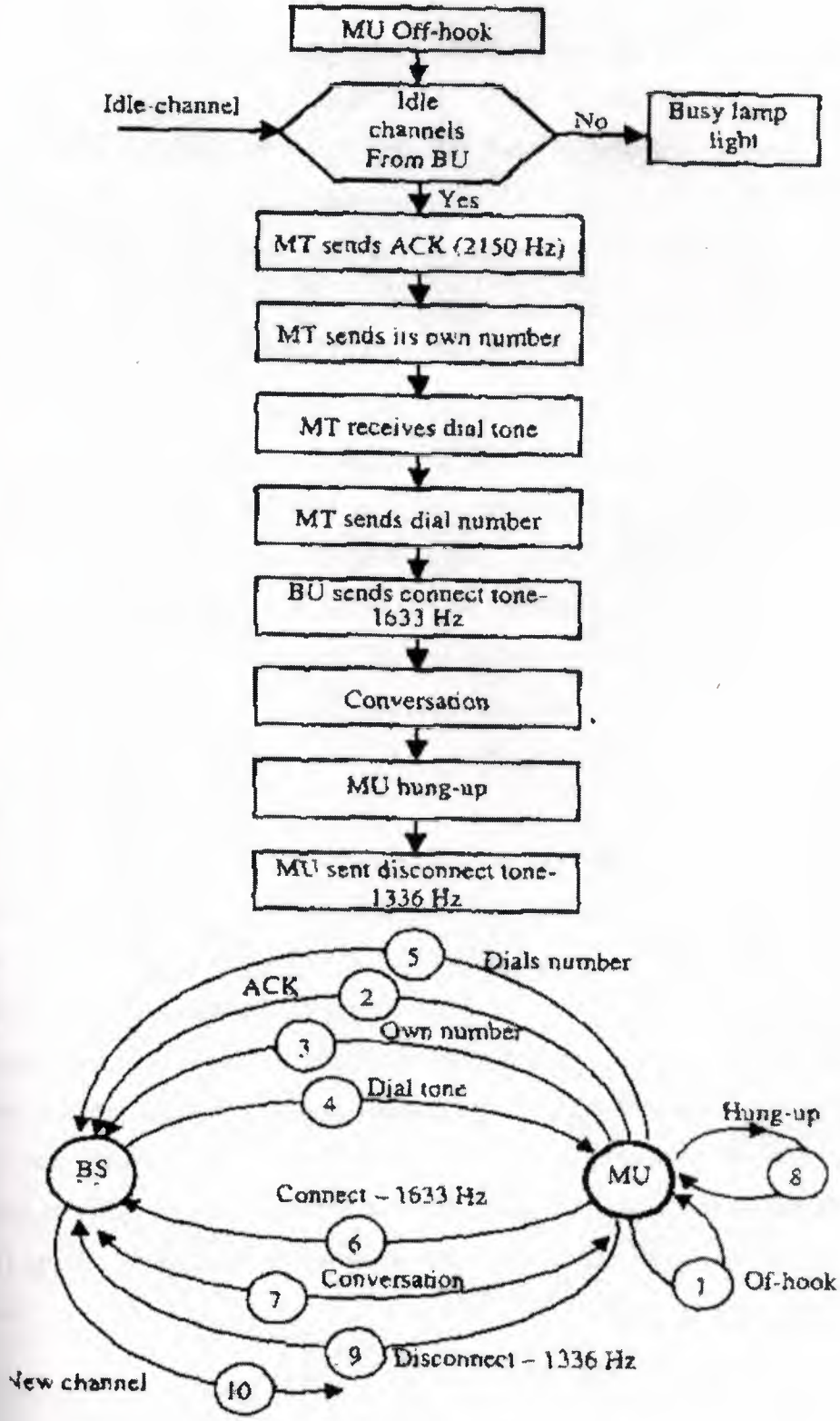


Figure 2.3 Mobile Outgoing Call

2.7 MOBILE STATION

A Mobile Station consists of two main elements: The Mobile Terminal (MT) and the Subscriber Identity Module (SIM). There are different types of terminals distinguished principally by their power and application. The fixed terminals are the ones installed in cars. Their maximum allowed output power is 20 W. The handheld terminals have experienced the biggest success thanks to their weight and volume, which are continuously decreasing. These terminals can emit up to 2 W. The evolution of technologies allows to decrease the maximum allowed power to 0.8 W.

2.8 MOBILE INTERNAL CALL(MIC)

The MSI sends the call setup information dialed by the mobile subscriber (MSISDN) to the MSG(1). The MSC request information about the celling mobile subscriber MS2 from the VLR (2). The MSG uses the dialling information (MSISDN) to establish the HLR and sets up signalling connection to it (3). The HLR sends a request to the VLR in whose are the called mobile subscriber MS2 is currently roaming (4). The VLR sends the requested MSRN back to the HLR. The HLR forwards the MSRN to the MSC(5). Steps (6) to (9) are the same as steps (6) to (9) traditional silicon in photovoltaic cells in space because of its supetior efficiency yielding about one-third more power for comparable cell areas.

A trio of phased-away antennas extends and points earthward to establish direct links over the 1.610-1.625-GHz band to Iridium subscribers. The Iridium constellation, with a company-projected price tag of $3.4 billion, is one of the most costly concepts ever devised for providing mobile communication services. Each satellite in the Iridium constellation will send out 48 pencil-thin spot-beams each of which can handle 230 simultaneous duplex conversations. Iridium satellites are distributed among six evenly spaced, near-polar orbits (86.4 degrees inclination) 780 km above the earth, sixty of the satellites provide overlapping global coverage, Polar regions included. The other six are in-orbit spares. Iridium subscriber equipment offer voice, data, paging, and facsimile services.

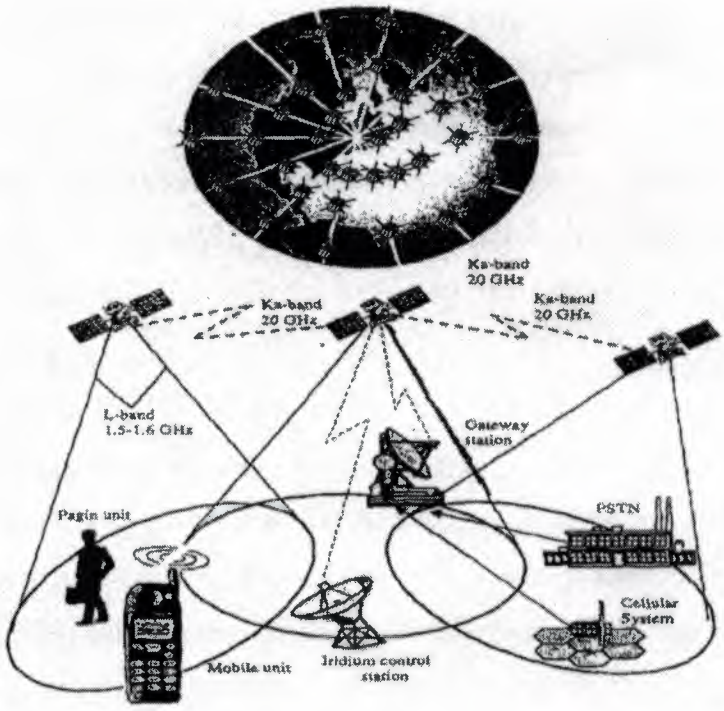


Figure 2.4 Mobile Internal Call

A call placed by an Iridium subscriber to another subscriber is transmitted directly by satellite to its destination worldwide, it is the only worldwide system to do this. If the call is to a party with a conventional fixed or mobile phone, it will be upconverted and transmitted by a feeder link from the satellite to a gateway. From there it is routed through the public switched phone network to its destination. Wheir an Iridium communicator is activated, the nearest satellite (working in concert with the ground-based Iridium network) ascertains the validity of that subscriber's account, then determines the location of the user. The system automatically checks to see if an inexpensive terrestrial link is available to handle the call. If not, the call is relayed through the nearest satellite and, if necessary, from satellite to satellite to its destination. If an Iridium subscriber is at a remote location, the call will be transmitted directly to the intended recipient. If the subscriber is in the vicinity of a land-based telecommunication system, conventional terrestrial communication channels will be

used instead. The satellite-to-satellite cross links, the satellite-to-Iridium gateway stations and downlinks connecting the iridium satellites with their ground-based system control stations are provided using Ka-band at 20 GHz. The transmission links connecting the hand-held communicators, the paging units, and the remote area phones will all be handled with the L-band frequencies between 1.5 and 1.6 GHz. Iridium employs CDMA modulations and TDMA architecture. This approach will require that a dedicated portion of the frequency spectrum be allocated to Iridium to provide interference-free operation. Iridium's transmission rates have been set at 4800 bps for voice, and both 4800 and 2400 bps for digital data transmissions.

2.9 MOBILE AND PORTABLE PHONE UNITS

Mobile and portable units are essentially the same things. The only difference is that the portable units have a lower output power and a less efficient antenna. Each mobile phone unit consists of a control unit, a radio transceiver, a logic unit, and a mobile antenna. The control unit houses all the user interfaces, including a handset. The transceiver uses a frequency synthesiser to tune into any designated cellular system channel. The logic unit interrupts subscriber actions and system commands and manages the transceiver and control units.

2.10 WIRELINE-TO-MOBILE CALLS

The cellular system's switching centre receives a from a wireline party through a dedicated interconnect line from the public switched phone network. The switch translates the received dialling digits and determines whether the mobile unit to which the call is destined is on or off hook (busy). If the mobile unit is available, the switch pages the mobile subscriber. Following a page response from the mobile unit, the switch assigns an idle channel and instructs the mobile unit to time into that channel. The mobile unit sends a verification of channel tuning the controller in the cell site and then sends an audible call progress tone to the subscriber's mobile phone. Causing it to ring. The switch terminates the call progress tones when it receives positive indication that the subscriber has answered the phone the conversation between the two parties has begun.

2.11 MOBILE-TO-WIRELINE CALLS

A mobile subscriber who desires to call a wireline party first enters the called number into the unit's memory using Touch-Tone buttons or a dial on the phone unit. The subscriber then presses a send key, which transmits the called number as well as the mobile subscriber's identification number to the switch. If the identification number is valid, the switch routes the call over a leased wireline interconnection to the public phone network, which completes the connection to the wireline party. Using the cell-site controller, the switch assigns the mobile unit a nonbusy user channel and instructs the mobile unit to tune into that channel. After the switch receive verification that the mobile unit is tuned to the assigned channel. The mobile subscriber receives an audible call progress tone from the switch. After the called party picks up the phone, the switch terminates the call progress tones and the conversation can begin.

2.12 MOBILE-TO-MOBILE CALLS

Calls between two mobile units are also possible in the cellular radio system. To originate a call to another mobile unit, the calling party enters the called number into the unit's memory via the touchpad on the telephone set and the presses the send key. The switch receives the caller's identification number and the called number and then determines if the called unit is free to receive a call. The switch sends a page command to all cell-site controllers, and the called party (who may be anywhere in the service area) receives a page. Following a positive page from the called party, the switch assigns each party an idle user channel and instruct each party to tune into the respective user channel. Then the called party's phone rings. When the system receives notice that the called party has answered the phone, the switch terminates the call progress tone, and the conversation may begin between the two mobile units. If a mobile subscriber wishes to initiate a call and all user channels are busy, the switch sends a directed retry command instructing the subscriber to reattempt the call through a neighbouring cell. If the system cannot allocates a user channel through the neighbouring cell, the switch transmits a intercept message to the calling mobile unit over the control channel. Whenever the called party is off look, the calling party receives busy signal. Also, if the called is invalid, the system either sends a record message via the control channel or provides and an announcement that the call cannot be processed.

2.13 ADVANCED MOBILE PHONE SERVICE

Cell-Site Hardware

The hardware facilities of the AMPS cell-site connect the mobile radio customer to the land phone network and perform actions necessary for RF radiation, caption, and distribution; voice and data communications and processing; equipment easting, control, and reconfigration; and call set-up, supervision, and termination. Cell-site operational control is achieved partially through wired logic and partially through programmable controllers. This part describes the cell-site functional groups, their physical characteristics and designed, and the ways they inter/ace with the rest of the AMPS system.

INTRODUCTION

Lyn the AMPS system, the interface between the land phone network and the radio paths to the mobiles occurs at the cell sites. In addition to performing unction needed for trunk termination and for radio transmission and reception, the cell site handles many semiautonomous functions under the general direction of the Mobile Phone Switching Office (MTSO).

Cell sites have facilities to:

- Provide RF radiation, reception, and distribution.
- Provide data communications with the MTSO and mobiles.
- Locate mobiles.
- Perform remotely ordered equipment testing.
- Perform equipment control and reconfiguration functions.
- Perform voice-processing functions.
- Perform, call setup, call supervision, and call termination.
- Handoff or receive from another cell site any mobile which has moved out of the normal service area of the cell site carrying the call. Programmable controllers control cell-site operations partially by wired logic and partially. Control functions are redundant and can be a configured as needed to overcome a localised failure. A battery plant assures maintenance of service in case of commercial power outage.

Facilities dependent upon traffic requirements in each cell coverage area are modular so those additional units may be installed as needed to match busy-hour traffic levels.

This will ensure that plant investment can grow sensibly as a function of anticipated revenues 48 voice channels. The precise number if a frame at each site is a function of the voice channels requirements for that site. There are four frame codes, and the smallest size cell site requires one of each code. Each radio frame has a maximum capacity of 16 radius. When the number of voice radius grows beyond 16, another radio frame must be added. Each line supervision frame (LSF) can handle 48 voice channels and, when this number is exceeded, another LSF is added. A single data frame (DF) and a single maintenance test frame (MTF) are necessary regardless if the number of voice radius in the cell site. The maximum size of a cell site is 144 voice radius, which would require a total of 14 frames; nine radio frames, three line supervision frames, one data frame, and one maintenance test frame.

2.14 DATA FRAME

The data frame contains the equipment for major cell-site control functions, which include communication with the MTSO, control of voice and data communication with mobiles, and communication with the controller in the maintenance test frame communication between controllers is necessary for requesting performance of specific tests and for receiving results. The DF contains both hardware logic and programmable controllers. Only one set of hardware logic and one controller is needed per cell site regardless of the number if voice radius. Because of the critical functions performed in the DF, redundancy if all subassemblies is provided to assure continuation of service in the presence of a failure. The OF can reconfigure itself under the direction of the MTSO, which maintains service by permitting any malfunctioning subassembly to be replaced with an off-line redunant unit. The data frame contains five major subsystems.

2.15 CENTRAL CONTROL AND MONITORING SITE

Illustrates the system design of the CCM, which is based on an pH 2100 microprocessor data- acquisition system. Through software, it emulates radio plan control functions performed by an ess, supervises data gathering and recording and automatically

calibrates and monitors the performance of all the Cellular Test Bed's land-based radio components. The CCM interrogates and instructs the mobile unit via telemetry link and the cell sites via specially, conditioned landlines. Operator intervention, if needed is also available. The cell site control message formats, as in the AMPS design, include seven parity bits to ensure high reliability ofdata transmission. The CCM software requests data retransmissions whenever errors occur. The CCM also contains the calibrated audio facilities necessary to conduct voice quality tests.

2.16 THE TELEMETRY SITE

The telemetry site (TM) incorporates the radio transceiver facilities, which permit the CCM to reliably instruct and interrogate the MCL. Anywhere within the CTB test probe area. To meet the transmit/receive path reliability requirements of this important radio link, the TM site is centrally located within the probe area and uses a high-gain transmits and diversity-receive antenna system elevated 230 feet above the local street surface. The TM site also incnipcirates voice communication facilities to administer test operations.

2.17 MOBILE COMMUNICATIONS LABORATORY

The interior of the MCL. Contains radio, logic. Miniprocessor, and data-recording facilities. The RF/analog subsystem which consists of five measurement channels driven by two electronically selectable RF preamplifiers fed from two receive antennas appropriately paced for diversity reception, is illustrated. The same antennas and preamplifiers also feed the AMPS mobile radio used to evaluate the performance of the voice and signalling subsystems.

The main measurement receiver uses a computer-controlled agile local oscillator, which mixes the RF signals down to three intermediate frequencies. Each of these frequencies feeds into two highly selective channels that use logaithmic detectors. Two channels (one high-gain, one low-gain) service each IF signal to achieve an instantaneous dynamic range that is linear from –150 to –30 dBm. The two channels are adjusted to maintain a 20-dB overlap centred at –90 dBm. The measurements for calculating real-time average values are selected using either the high-gain measurement or by, accepting the low-gain result it exceeds a threshold approximately in the middle of the Overlap region.

Environmental noise is monitored on one antenna by a single logia-rhythmic detector with a linear range from –150 to –10 dBm. The output of the diversity switch in the mobile radio is measured by an eighth logarithmic detector having a linear range from –120 to –40 dBm, with the useful range extending nearly 10 dB more at each end.

Instantaneous data sampled from these receivers are processed to obtain a true incident power by a stored program reference tabulation, this processing translates the output from a 10-bit analog-to-digital converter to a number proportional to the corresponding instantaneous input signal power.The instantaneous signal power samples are summed over one-half second of real-time to calculate average values.

The MCL is also wquipped with a gyroscopic-bearing and distance-tracking system so that all system status and measurement information recorded each one-half second are tagged with true vehicle position.

2.18 CTB Calibration and Performance Monitoring

The calibration and performance-monitoring equipment in the CTB's hardware and software designs and the subsequent off-line statistical processing of the measurement data can precisely control and qualify the field experiments to obtain results comparable in resolution and reliability to those achieved in the laboratory. Examples of the call-ration and performance monitoring subsystems incorporated within the central and interferer cell sites the MCL uses a similar calibration and monitoring system.

The cell sites transmit calibration and monitoring subsystem monitors, via precision coupler and temperature-compensated detection circuits the RF power incident to and reflected from each antenna/cable assembly. The detected voltages, sampled and processed by the PROCON, are sent to the CCM, where they are monitored and recorded (on-line) to insure the integrity of the cell site transmit function.

The type of calibration and monitoring subsystem used in the cell site receivers is illustrated. In practice, the test generator is set, under CCM control, to a reference power level. The CCM then (via land lines and the PROCON) automatically steps a programmable, precision attenuator to supply the input reference signals necessary to calibrate the cell site instrument level, 1000 samples are taken and averaged to generate stored program reference tabulations which, during real-time data acquisition, are used to determine the true instantaneous signal strength incident at the terminals of the receive antenna. The test generator also furnishes a reference signal to each antenna and

cable subsystem. The instrumentation receiver monitors the forward and reflected power to ensure that antenna system returns requirements are met. As shown, the test generator subsystem also furnishes the reference signal necessary to establish the FM quieting performance of the AMPS radius. Calibration of the CTB's transmit-and-receive subsystems is maintained within $\pm \frac{1}{2}$ dB during each field evaluation sequence. The calibrations are performed at least before and after each test sequence and are hardcopies as part of the data package.

2.19 CONTROL/RECORDING ARCHITECTURE

This section describes the system control and data-recording structures of the CTB that perform the AMPS emulation and data-acquisition functions. As noted previously, an extensive data of transmission parameters is established at the CCM every data frame. The algorithmic software module accesses the appropriate cell site transmission data are communicated to cell site and implemented by the operating system. The following paragraphs discuss the communication, control, measurement, and data-recording aspects of CTB operation.

2.20 CTB DATA COMMUNICATION

As described earlier, the CTB, which is linked with cell, sites by data lines and to the MCL by a full-duplex telemetry channel. These interconnections, together with powerful processing capability at each remote site, form a comprehensive data communications structure.

Basically, three types of message are used for are used for data communications within this field configuration: First, control messages, such as signalling requests to cell sites, permit the execution of system-level operations. Second special data acquisition requests and data messages to and from cell sites and the MCL permit the acquisition of data at the CCM.

Third, CTB operational-control messages permit the automatic calibration ofcell sites, synchronise the data-acquisition frame at each cell site status information onthe proper performance of the system. The last category of messages allows direct CCM instructions to the mobile logic unit via telemetry link and also permits the MCL and CCM operators to request test pauses.

The land-line messages are transmitted at a rate of 2400b/s, while the MCL data transfer rate is 1800b/s. All messages are formatted into 32-bit blocks with seven bits devoted to error control. The data are encoded in a shortened (127,120) Bose-Chaudhuri-Hocquenghem(BCH) code, which is used in an error-detection mode with retranmission.

System Control

The CTB configuration must be properly initialised to start data acquisition. First, the interferer transmitters and the main cell site instrumentation receivers must be tuned to the serving channel. Then the test can start by synchronising the data-acquisition frames at each cell site and the MCL with the CCM system clock. From that point on microscopic data measurement at the MCL and cell sites depend on their local clocks. The CCM data-collection subsystem initiates each frame with "request-for-data" messages to the cell sites and the MCL. The data received are checked and formatted by a CCM software module and placed in a buffer to the system-control algorithmic module. This module is coded so that it can access data variable to the AMPS control algorithms only at the proper time interval. The output of the module by requires a system reconfiguration, which is accomplished by the CCM with appropriate data-link messages. All system decisions, requests for action, and actions, are recorded with the underlying data for later analysis.

2.21 Measurement of RF transmissions parameters

Radio transmissions parameters are measured at each of the cell sites and at the MCL. Each cell site instrumentation receiver switches sequentially to each of eight RF channels for sampling the mobile carrier level as received on each of two omnidirectional and three pairs of directional antennas. The data-sampling rate is 512 Hz enabling the acquisition system to make 64 measurement per channels each data frame. The samples are processed through a calibration stored-program reference tabulation to generate quantities proportional to the RS signal as receiver at the antenna terminals.

The cell site programmable controller than forms eight averages from these samples every data frame. If we assume an underlying Rayleigh distribution, these averages estimate the local means within a 95% confidence interval of approximately 1

dB. They are eight averages together with the final eight instantaneous samples from the RF parameter list, which is transmitted to the CCM, every data frame and recorded on digital tape in the formatted.

MCL activities

The MCL is a highly sophisticated data acquisition facility. Its five basic measurement channels are alternately switched to two diversity-receiving antennas. Further, measurement are made on both the high-and-low-gain if channels with the MCL computer selecting the proper value in real-time. Measurements are made on setup, voice, interferer and noise channels. In addition, the AMPS diversity signal and peak-noise distributions are measured.

3. GSM RADIO INTERFACE

3.1 OVERVIEW

The Radio interface is the interface between the mobile stations and the fixed infrastructure. It is one of the most important interfaces of the GSM system. One of the main objectives of GSM is roaming. Therefore, in order to obtain a complete compatibility between mobile stations and networks of different manufacturers and operators, the radio interface must be completely defined. The spectrum efficiency depends on the radio interface and the transmission, more particularly in aspects such as the capacity of the system and the techniques used in order to decrease the interference and to improve the frequency reuse scheme. The specification of the radio interface has then an important influence on the spectrum efficiency.

3.2 FREQUENCY ALLOCATION

Two frequency bands, of 25 MHz each one, have been allocated for the GSM system:

- The band 890-915 MHz has been allocated for the uplink direction (transmitting from the mobile station to the base station).
- The band 935-960 MHz has been allocated for the downlink direction (transmitting from the base station to the mobile station).

These bands were allocated by the ITU (International Telecom Union) who are responsible for allocating radio spectrum on an international basis. Although these bands were (and still are) used by analog systems in the early 1980's, the top 10 MHz were reserved for the already emerging GSM Network by the CEPT (European Conference of Posts and Telecommunications: translated from French). But not all the countries can use the whole GSM frequency bands. This is due principally to military reasons and to the existence of previous analog systems using part of the two 25 Mhz frequency bands.

3.3 MULTIPLE ACCESS SCHEME

The multiple access scheme defines how different simultaneous communications, between different mobile stations situated in different cells, share the GSM radio spectrum. A mix of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), combined with frequency hopping, has been adopted as the multiple access scheme for GSM.

It is hoped that eventually the GSM network will use the entire bandwidth. It is apparent from this that the bandwidth you use on a day-to-day basis to operate your mobile phone is limited. It would seem that only a certain number of users can operate on the bandwidth simultaneously. However GSM has devised a method to maximize the bandwidth available. They use a combination of Time and Frequency Division Multiple Access (TDMA/FDMA).

a) **FDMA:** Using FDMA, a frequency is assigned to a user. So the larger the number of users in a FDMA system, the larger the number of available frequencies must be. The limited available radio spectrum and the fact that a user will not free its assigned frequency until he does not need it anymore, explain why the number of users in a FDMA system can be "quickly" limited.

This is the division of the bandwidth in to 124 carrier frequencies each of 200 kHz. At least one of these is assigned to each base station.

b) **TDMA:** TDMA allows several users to share the same channel. Each of the users, sharing the common channel, is assigned their own burst within a group of bursts called a frame. Usually TDMA is used with a FDMA structure.

The carrier frequencies are then divided again into 8 time slots. This prevents mobiles from transmitting and receiving calls at the same time as they are allocated separate time slots

In GSM, a 25 Mhz frequency band is divided, using a FDMA scheme, into 124 carrier frequencies spaced one from each other by a 200 kHz frequency band. Normally a 25 Mhz frequency band can provide 125 carrier frequencies but the first carrier frequency is used as a guard band between GSM and other services working on lower frequencies.

Each carrier frequency is then divided in time using a TDMA scheme. This scheme splits the radio channel, with a width of 200 kHz, into 8 bursts. A burst is the unit of time in a TDMA system, and it lasts approximately 0.577 ms. A TDMA frame is formed with 8 bursts and lasts, consequently, 4.615 ms. Each of the eight bursts, that form a TDMA frame, are then assigned to a single user.

3.4 CHANNEL STRUCTURE

A channel corresponds to the recurrence of one burst every frame. It is defined by its frequency and the position of its corresponding burst within a TDMA frame. In GSM there are two types of channels:

- The traffic channels used to transport speech and data information.
- The control channels used for network management messages and some channel maintenance tasks.

Since radio spectrum is a limited resource shared by all users, a method must be devised to divide up the bandwidth among as many users as possible. The method chosen by GSM is a combination of Time- and Frequency-Division Multiple Access (TDMA/FDMA). The FDMA part involves the division by frequency of the (maximum) 25 MHz bandwidth into 124 carrier frequencies spaced 200 kHz apart. One or more carrier frequencies are assigned to each base station. Each of these carrier frequencies is then divided in time, using a TDMA scheme. The fundamental unit of time in this TDMA scheme is called a burst period and it lasts 15/26 ms (or approx. 0.577 ms). Eight burst periods are grouped into a TDMA frame (120/26 ms, or approx. 4.615 ms), which forms the basic unit for the definition of logical channels. One physical channel is one burst period per TDMA frame. The number and position of their corresponding burst periods define channels. All these definitions are cyclic, and the entire pattern repeats approximately every 3 hours. Channels can be divided into dedicated channels, which are allocated to a mobile station, and common channels, which are used by mobile stations in idle mode.

3.4.1 Traffic Channels

A traffic channel (TCH) is used to carry speech and data traffic. Traffic channels are defined using a 26-frame multi frame, or group of 26 TDMA frames. The length of a 26-frame multi frame is 120 ms, which is how the length of a burst period is defined (120 ms divided by 26 frames divided by 8 burst periods per frame). Out of the 26 frames, 24 are used for traffic, 1 is used for the Slow Associated Control Channel (SACCH) and 1 is currently unused (see Figure 3.1). TCHs for the uplink and downlink are separated in time by 3 burst periods, so that the mobile station does not have to transmit and receive simultaneously, thus simplifying the electronics. In addition to these full-rate TCHs, there are also half-rate TCHs defined, although they are not yet implemented.

Half-rate TCHs will effectively double the capacity of a system once half-rate speech coders are specified (i.e., speech coding at around 7 kbps, instead of 13 kbps). Eighth-rate TCHs are also specified, and are used for signaling. In the recommendations, they are called Stand-alone Dedicated Control Channels (SDCCH). Full-rate traffic channels (TCH/F) are defined using a group of 26 TDMA frames called a 26-Multiframe. The 26-Multiframe lasts consequently 120 ms. In this 26-Multiframe structure; the traffic channels for the downlink and uplink are separated by 3 bursts. As a consequence, the mobiles will not need to transmit and receive at the same time, which simplifies considerably the electronics of the system. The frames that form the 26-Multiframe structure have different functions:

- 24 frames are reserved to traffic.
- 1 frame is used for the Slow Associated Control Channel (SACCH).
- The last frame is unused. This idle frame allows the mobile station to perform other functions, such as measuring the signal strength of neighboring cells.

Half-rate traffic channels (TCH/H), which double the capacity of the system, are also grouped in a 26-Multiframe but the internal structure is different.

3.4.2 Control Channels

According to their functions, four different classes of control channels are defined:

- Broadcast channels.
- Common control channels.
- Dedicated control channels.
- Associated control channels.

Common channels can be accessed both by idle mode and dedicated mode mobiles. Idle mode mobiles to exchange the signalling information required to change to dedicated mode use the common channels. Mobiles already in dedicated mode monitor the surrounding base stations for handover and other information. The common channels are defined within a 51-frame multiframe, so that dedicated mobiles using the 26-frame multiframe TCH structure can still monitor control channels. The common channels include:

a) Broadcast Control Channel (BCCH)

The base station, to provide the mobile station with the sufficient information it needs to synchronize with the network, uses the BCH channels. Three different types of BCHs can be distinguished:

- The Broadcast Control Channel (BCCH), which gives to the mobile station the parameters needed in order to identify and access the network.
- The Synchronization Channel (SCH), which gives to the mobile station the training sequence needed in order to demodulate the information transmitted by the base station.
- The Frequency-Correction Channel (FCCH), which supplies the mobile station with the frequency reference of the system in order to synchronize it with the network Continually broadcasts, on the downlink, information including base station identity, frequency allocations, and frequency-hopping sequences.

b) Common Control Channels (CCCH)

The CCCH channels help to establish the calls from the mobile station or the network. Three different types of CCCH can be defined:

- The Paging Channel (PCH). It is used to alert the mobile station of an incoming call.
- The Random Access Channel (RACH), which is used by the mobile station to request access to the network.
- The Access Grant Channel (AGCH). The base station, to inform the mobile station about which channel it should use, uses it. This channel is the answer of a base station to a RACH from the mobile station.

c) Frequency Correction Channel (FCCH) and Synchronization Channel (SCH)

Used to synchronize the mobile to the time slot structure of a cell by defining the boundaries of burst periods, and the time slot numbering. Every cell in a GSM network broadcasts exactly one FCCH and one SCH, which are by definition on time slot number 0 (within a TDMA frame).

d) Dedicated Control Channels (DCCH)

The DCCH channels are used for message exchange between several mobiles or a mobile and the network. Two different types of DCCH can be defined:

- The Standalone Dedicated Control Channel (SDCCH), which is used in order to exchange signaling information in the downlink and uplink directions.
- The Slow Associated Control Channel (SACCH). It is used for channel maintenance and channel control.

e) Associated Control Channels

The Fast Associated Control Channels (FACCH) replace all or part of a traffic channel when urgent signaling information must be transmitted. The FACCH channels carry the same information as the SDCCH channels.

f) Random Access Channel (RACH)

Slotted Aloha channel used by the mobile to request access to the network.

g) Paging Channel (PCH)

Used to alert the mobile station of an incoming call.

h) Access Grant Channel (AGCH)

Used to allocate an SDCCH to a mobile for signaling (in order to obtain a dedicated channel), following a request on the RACH.

3.4.3 Burst Structure

There are four different types of bursts used for transmission in GSM. The normal burst is used to carry data and most signaling. It has a total length of 156.25 bits, made up of two 57 bit information bits, a 26 bit training sequence used for equalization, 1 stealing bit for each information block (used for FACCH), 3 tail bits at each end, and an 8.25 bit guard sequence, as shown in Figure 3.1. The 156.25 bits are transmitted in 0.577 ms, giving a gross bit rate of 270.833 kbps. The F burst, used on the FCCH, and the S burst, used on the SCH, have the same length as a normal burst, but a different internal structure, which differentiates them from normal bursts (thus allowing synchronization). The access burst is shorter than the normal burst, and is used only on the RACH. As it has been stated before, the burst is the unit in time of a TDMA system. Four different types of bursts can be distinguished in GSM:

- The frequency-correction burst is used on the FCCH. It has the same length as the normal burst but a different structure.

- The synchronization burst is used on the SCH. It has the same length as the normal burst but a different structure.
- The random access burst is used on the RACH and is shorter than the normal burst.
- The normal burst is used to carry speech or data information. It lasts approximately 0.577 ms and has a length of 156.25 bits.

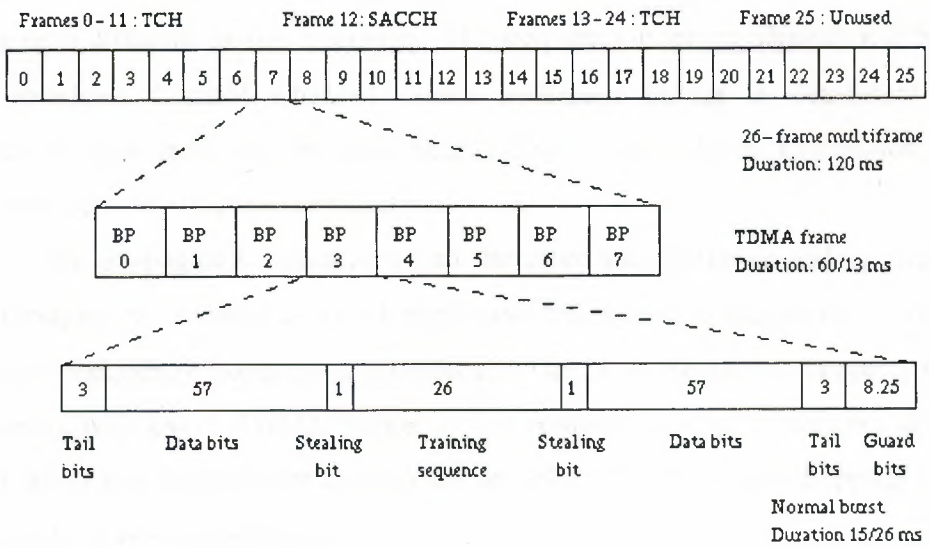


Figure 3.1 Structure of the 26-Multiframe, the TDMA frame and the normal burst

The tail bits (T) are a group of three bits set to zero and placed at the beginning and the end of a burst. They are used to cover the periods of ramping up and down of the mobile's power. The coded data bits correspond to two groups, of 57 bits each, containing signaling or user data.

The stealing flags (S) indicate, to the receiver, whether the information carried by a burst corresponds to traffic or signaling data. The training sequence has a length of 26 bits. It is used to synchronize the receiver with the incoming information, avoiding then the negative effects produced by a multipath propagation. The guard period (GP), with a length of 8.25 bits, is used to avoid a possible overlap of two mobiles during the ramping time.

3.4.4 Frequency Hopping

The mobile station already has to be frequency agile, meaning it can move between a transmit, receive, and monitor time slot within one TDMA frame, which normally are on different frequencies. GSM makes use of this inherent frequency agility
to implement slow frequency hopping, where the mobile and BTS transmit each TDMA frame on a different carrier frequency. The frequency-hopping algorithm is broadcast on the Broadcast Control Channel. Since multipath fading is dependent on carrier frequency, slow frequency hopping helps alleviate the problem. In addition, co-channel interference is in effect randomized.

The propagation conditions and therefore the multipath fading depend on the radio frequency. In order to avoid important differences in the quality of the channels, the slow frequency hopping is introduced. The slow frequency hopping changes the frequency with every TDMA frame. A fast frequency hopping changes the frequency many times per frame but it is not used in GSM. The frequency hopping also reduces the effects of co-channel interference.

There are different types of frequency hopping algorithms. The algorithm selected is sent through the Broadcast Control Channels.

Even if frequency hopping can be very useful for the system, a base station does not have to support it necessarily On the other hand, a mobile station has to accept frequency hopping when a base station decides to use it.

3.5 From source information to radio waves

The figure 3.2 presents the different operations that have to be performed in order to pass from the speech source to radio waves and vice versa. If the source of information is data and not speech, the speech coding will not be performed.

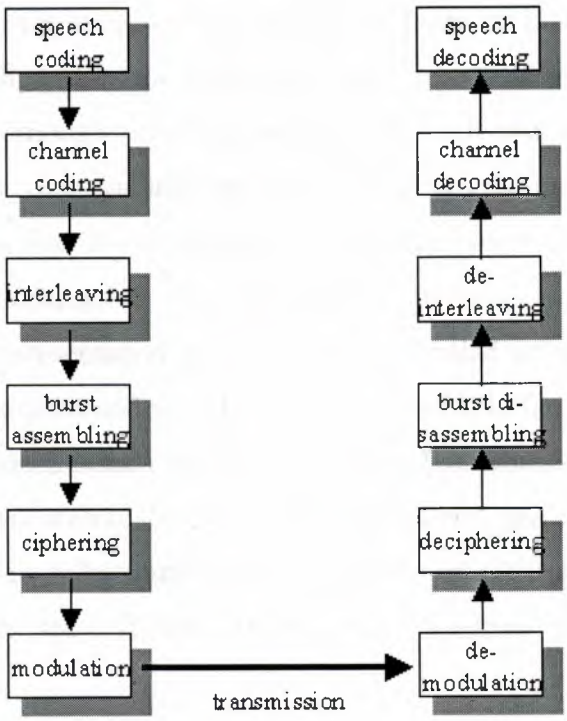


Figure 3.2 From speech source to radio waves

3.5.1 Speech Coding

The transmission of speech is, at the moment, the most important service of a mobile cellular system. The GSM speech coder, which will transform the analog signal (voice) into a digital representation, has to meet the following criterias:

- A good speech quality, at least as good as the one obtained with previous cellular systems.
- To reduce the redundancy in the sounds of the voice. This reduction is essential due to the limited capacity of transmission of a radio channel.
- The speech coder must not be very complex because complexity is equivalent to high costs.

The final choice for the GSM speech coder is a coder named RPE-LTP (Regular Pulse Excitation Long-Term Prediction). This coder uses the information from previous samples (this information does not change very quickly) in order to predict the current sample. The speech signal is divided into blocks of 20 ms. These blocks are then passed to the speech coder, which has a rate of 13 kbps, in order to obtain blocks of 260 bits. Obviously the most important aspect of the GSM Network is speech transmission. Although other services are now offered, voice telephony is still the most popular service available and hence generates the most revenue for the various companies. The device that transforms the human voice into a stream of digital data, suitable for transmission over the radio interface and which regenerates an audible analog representation of received data is called a Speech CODEC (speech transcoder or speech coder/decoder). The full-rate speech CODEC used in GSM is known as RPE-LTP, which stands for "Regular Pulse Excitation - Long Term Prediction". It is hoped there will eventually be a standardized full speech CODEC which will half the amount of data to be transmitted and so will enable twice as many customers to use the same slot in the TDMA frame. The diagram below shows audio signal processing

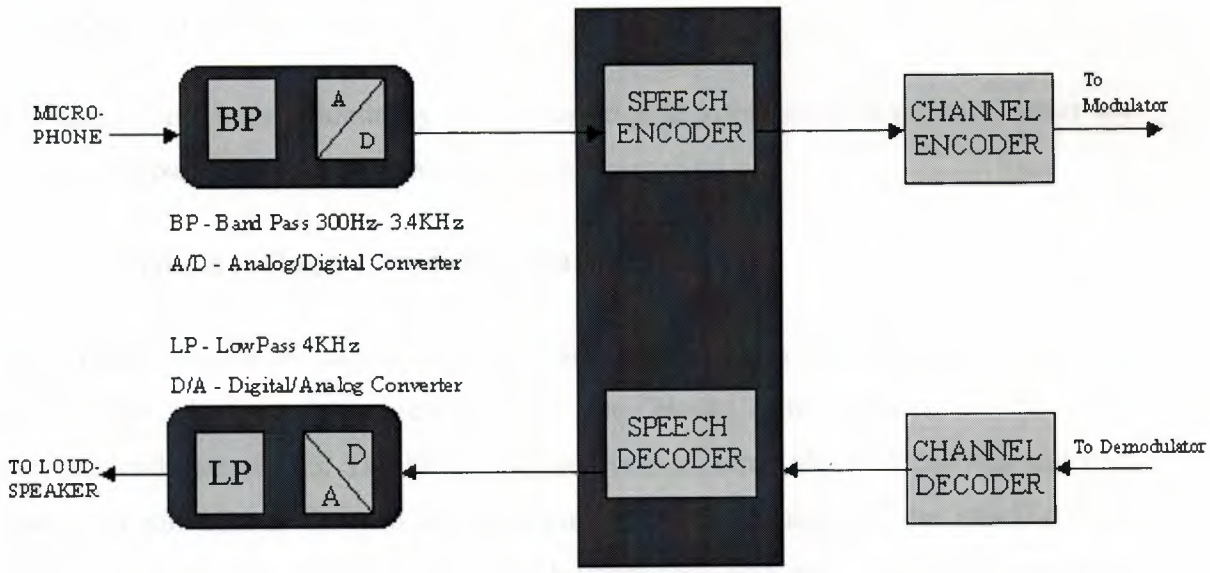


Figure 3.3 Audio Signal Processing

GSM is a digital system, so speech which is inherently analog, has to be digitized. The method employed by ISDN, and by current telephone systems for

multiplexing voice lines over high-speed trunks and optical fiber lines, is Pulse Coded Modulation (PCM). The output stream from PCM is 64 kbps, too high a rate to be feasible over a radio link. The 64 kbps signal, although simple to implement, contains much redundancy. The GSM group studied several speech coding algorithms on the basis of subjective speech quality and complexity (which is related to cost, processing delay, and power consumption once implemented) before arriving at the choice of a Regular Pulse Excited Linear Predictive Coder (RPE-LPC) with a Long Term Predictor loop. Basically, information from previous samples, which does not change.

Very quickly, is used to predict the current sample. The coefficients of the linear combination of the previous samples, plus an encoded form of the residual, the difference between the predicted and actual sample, represent the signal. Speech is divided into 20 millisecond samples, each of which is encoded as 260 bits, giving a total bit rate of 13 kbps. This is the so-called Full-Rate speech coding. Recently, some North American GSM1900 operators have implemented an Enhanced Full-Rate (EFR) speech-coding algorithm. This is said to provide improved speech quality using the existing 13 kbps bit rate.

3.5.2 Channel coding

Channel coding adds redundancy bits to the original information in order to detect and correct, if possible, errors occurred during the transmission.

a) Channel coding for the GSM data TCH channels

The channel coding is performed using two codes: a block code and a convolutional code. The block code corresponds to the block code defined in the GSM Recommendations 05.03. The block code receives an input block of 240 bits and adds four zero tail bits at the end of the input block. The output of the block code is consequently a block of 244 bits. A convolutional code adds redundancy bits in order to protect the information. A convolutional encoder contains memory. This property differentiates a convolutional code from a block code. A convolutional code can be defined by three variables: n, k and K. The value n corresponds to the number of bits at the output of the encoder, k to the number of bits at the input of the block and K to the memory of the encoder. The ratio, R, of the code is defined as follows: $R = k/n$. Let's

consider a convolutional code with the following values: k is equal to 1, n to 2 and K to 5. This convolutional code uses then a rate of R = 1/2 and a delay of K = 5, which

Means that it will add a redundant bit for each input bit. The convolutional code uses 5 consecutive bits in order to compute the redundancy bit. As the convolutional code is a 1/2 rate convolutional code, a block of 488 bits is generated. These 488 bits are punctured in order to produce a block of 456 bits. Thirty-two bits, obtained as follows, are not transmitted:

C (11 + 15 j) for j = 0, 1,..., 31

The block of 456 bits produced by the convolutional code is then passed to the interleaver.

b) Channel coding for the GSM speech channels

Before applying the channel coding, the 260 bits of a GSM speech frame are divided in three different classes according to their function and importance. The most important class is the class Ia containing 50 bits. Next in importance is the class Ib, which contains 132 bits. The least important is the class II, which contains the remaining 78 bits. The different classes are coded differently. First of all, the class Ia bits are block-coded. Three parity bits, used for error detection, are added to the 50 class Ia bits. The resultant 53 bits are added to the class Ib bits. Four zero bits are added to this block of 185 bits (50+3+132). A convolutional code, with r = 1/2 and K = 5, is then applied, obtaining an output block of 378 bits. The class II bits are added, without any protection, to the output block of the convolutional coder. An output block of 456 bits is finally obtained.

c) Channel coding for the GSM control channels

In GSM the signaling information is just contained in 184 bits. Forty parity bits, obtained using a fire code, and four zero bits are added to the 184 bits before applying the convolutional code (r = 1/2 and K = 5). The output of the convolutional code is then a block of 456 bits, which does not need to be punctured.

Electromagnetic interference can disrupt encoded speech and data transmitted over the GSM Network. Because of this this complicated encoding and block

interleaving is used to protect the Network. Speech and data rates use different algorithms. Radio emissions too can cause interference if they occur outside of the allotted bandwidth and must be strictly controlled to allow for both GSM and older analog systems to co-exist. Because of natural and man-made electromagnetic interference, the encoded speech or data signal transmitted over the radio interface must be protected from errors. GSM uses convolutional encoding and block interleaving to achieve this protection. The exact algorithms used differ for speech and for different data rates. The method used for speech blocks will be described below. Recall that the speech coder produces a 260-bit block for every 20 ms speech sample. From subjective testing, it was found that some bits of this block were more important for perceived speech quality than others. The bits are thus divided into three classes:

- **Class Ia** 50 bits - most sensitive to bit errors.
- **Class Ib** 132 bits - moderately sensitive to bit errors.
- **Class II** 78 bits - least sensitive to bit errors.

Class Ia bits have a 3 bit Cyclic Redundancy Code added for error detection. If an error is detected, the frame is judged too damaged to be comprehensible and it is discarded. It is replaced by a slightly attenuated version of the previous correctly received frame. These 53 bits, together with the 132 Class Ib bits and a 4-bit tail sequence (a total of 189 bits), are input into a 1/2 rate convolutional encoder of constraint length 4. Each input bit is encoded as two output bits, based on a combination of the previous 4 input bits. The convolutional encoder thus outputs 378 bits, to which are added the 78 remaining Class II bits, which are unprotected. Thus every 20 ms speech sample is encoded as 456 bits, giving a bit rate of 22.8 kbps. To further protect against the burst errors common to the radio interface, each sample is interleaved. The 456 bits output by the convolutional encoder are divided into 8 blocks of 57 bits, and these blocks are transmitted in eight consecutive time-slot bursts. Since each time-slot burst can carry two 57-bit blocks, each burst carries traffic from two different speech samples. Recall that each time-slot burst is transmitted at a gross bit rate of 270.833 kbps. This digital signal is modulated onto the analog carrier frequency using Gaussian-filtered Minimum Shift Keying (GMSK). GMSK was selected over other modulation schemes as a compromise between spectral efficiency, complexity of the transmitter, and limited spurious emissions. The complexity of the transmitter is related to power consumption, which

should be minimized for the mobile station. The spurious radio emissions, outside of the allotted bandwidth, must be strictly controlled so as to limit adjacent channel interference, and allow for the co-existence of GSM and the older analog systems (at least for the time being).

3.5.3 Interleaving

An interleaving rearranges a group of bits in a particular way. It is used in combination with FEC codes in order to improve the performance of the error correction mechanisms. The interleaving decreases the possibility of losing whole bursts during the transmission, by dispersing the errors. Being the errors less concentrated, it is then easier to correct them.

a) Interleaving for the GSM control channels

A burst in GSM transmits two blocks of 57 data bits each. Therefore the 456 bits corresponding to the output of the channel coder fit into four bursts (4x114 = 456). The 456 bits are divided into eight blocks of 57 bits. The first block of 57 bits contains the bit numbers (0, 8, 16,....., 448), the second one the bit numbers (1, 9, 17, ...,449), etc. The last block of 57 bits will then contain the bit numbers (7, 15,....., 455). The first four blocks of 57 bits are placed in the even-numbered bits of four bursts. The other four blocks of 57 bits are placed in the odd-numbered bits of the same four bursts. Therefore the interleaving depth of the GSM interleaving for control channels is four and a new data block starts every four bursts. The interleaver for control channels is called a block rectangular interleaver.

b) Interleaving for the GSM speech Channels

The block of 456 bits, obtained after the channel coding, is then divided in eight blocks of 57 bits in the same way as it is explained in the previous paragraph. But these eight blocks of 57 bits are distributed differently. The first four blocks of 57 bits are placed in the even-numbered bits of four consecutive bursts. The other four blocks of 57 bits are placed in the odd-numbered bits of the next four bursts. The interleaving depth of the GSM interleaving for speech channels is then eight. A new data block also starts every four bursts. The interleaver for speech channels is called a block diagonal interleaver.

c) Interleaving for the GSM data TCH channels

A particular interleaving scheme, with an interleaving depth equal to 22, is applied to the block of 456 bits obtained after the channel coding. The block is divided into 16 blocks of 24 bits each, 2 blocks of 18 bits each, 2 blocks of 12 bits each and 2 blocks of 6 bits each. It is spread over 22 bursts in the following way:

- The first and the twenty-second bursts carry one block of 6 bits each.
- The second and the twenty-first bursts carry one block of 12 bits each.
- The third and the twentieth bursts carry one block of 18 bits each.
- From the fourth to the nineteenth burst, a block of 24 bits is placed in each burst.

A burst will then carry information from five or six consecutive data blocks. The data blocks are said to be interleaved diagonally. A new data block starts every four bursts.

3.5.4 Burst Assembling

The burst assembling procedure is in charge of grouping the bits into bursts. Section 3.4.3. presents the different bursts structures and describes in detail the structure of the normal burst.

3.5.5 Ciphering

Ciphering is used to protect signaling and user data. First of all, a ciphering key is computed using the algorithm A8 stored on the SIM card, the subscriber key and a random number delivered by the network (this random number is the same as the one used for the authentication procedure). Secondly, a 114-bit sequence is produced using the ciphering key, an algorithm called A5 and the burst numbers. This bit sequence is then XORed with the two 57 bit blocks of data included in a normal burst. In order to decipher correctly, the receiver has to use the same algorithm A5 for the deciphering procedure.

3.5.6 Modulation

The modulation chosen for the GSM system is the Gaussian Minimum Shift Keying (GMSK). The aim of this section is not to describe precisely the GMSK modulation as it is too long and it implies the presentation of too many mathematical concepts. Therefore, only brief aspects of the GMSK modulation are presented in this section. The GMSK modulation has been chosen as a compromise between spectrum efficiency, complexity and low spurious radiations (that reduce the possibilities of adjacent channel interference). The GMSK modulation has a rate of 270 5/6 kbauds and a BT product equal to 0.3. Figure 3.4. presents the principle of a GMSK modulator.

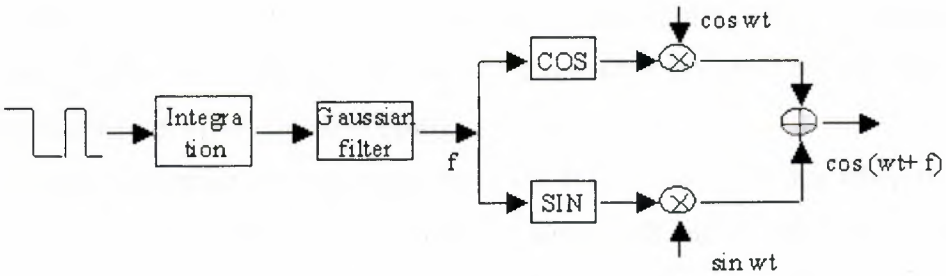


Figure 3.4 GMSK Modulator

3.6 DISCONTINUOUS TRANSMISSION (DTX)

Minimizing co-channel interference is a goal in any cellular system, since it allows better service for a given cell size, or the use of smaller cells, thus increasing the overall capacity of the system. Discontinuous transmission (DTX) is a method that takes advantage of the fact that a person speaks less that 40 percent of the time in normal conversation, by turning the transmitter off during silence periods. An added benefit of DTX is that power is conserved at the mobile unit. The most important component of DTX is, of course, Voice Activity Detection. It must distinguish between voice and noise inputs, a task that is not as trivial as it appears, considering background noise. If a

voice signal is misinterpreted as noise, the transmitter is turned off and a very annoying effect called clipping is heard at the receiving end. If, on the other hand, noise is misinterpreted as a voice signal too often, the efficiency of DTX is dramatically decreased. Another factor to consider is that when the transmitter is turned off, there is total silence heard at the receiving end, due to the digital nature of GSM. To assure the receiver that the connection is not dead, comfort noise is created at the receiving end by trying to match the characteristics of the transmitting end's background noise. This is another aspect of GSM that could have been included as one of the requirements of the GSM speech coder. The function of the DTX is to suspend the radio transmission during the silence periods. This can become quite interesting if we take into consideration the fact that a person speaks less than 40 or 50 percent during a conversation. The DTX helps then to reduce interference between different cells and to increase the capacity of the system. It also extends the life of a mobile's battery. The DTX function is performed thanks to two main features:

- The Voice Activity Detection (VAD), which has to determine whether the sound represents speech or noise, even if the background noise is very important. If the voice signal is considered as noise, the transmitter is turned off producing then, an unpleasant effect called clipping.
- The comfort noise. An inconvenient of the DTX function is that when the signal is considered as noise, the transmitter is turned off and therefore, a total silence is heard at the receiver. This can be very annoying to the user at the reception because it seems that the connection is dead. In order to overcome this problem, the receiver creates a minimum of background noise called comfort noise. The comfort noise eliminates the impression that the connection is dead.

3.7 TIMING ADVANCE

The timing of the bursts transmissions is very important. Mobiles are at different distances from the base stations. Their delay depends, consequently, on their distance. The aim of the timing advance is that the signals coming from the different mobile stations arrive to the base station at the right time. The base station measures the timing delay of the mobile stations. If the bursts corresponding to a mobile station arrive too

late and overlap with other bursts, the base station tells, this mobile, to advance the transmission of its bursts.

3.8 POWER CONTROL

There are five classes of mobile stations defined, according to their peak transmitter power, rated at 20, 8, 5, 2, and 0.8 watts. To minimize co-channel interference and to conserve power, both the mobiles and the Base Transceiver Stations operate at the lowest power level that will maintain an acceptable signal quality. Power levels can be stepped up or down in steps of 2 dB from the peak power for the class down to a minimum of 13 dBm (20 milli watts). The mobile station measures the signal strength or signal quality (based on the Bit Error Ratio), and passes the information to the Base Station Controller, which ultimately decides if and when the power level should be changed. Power control should be handled carefully, since there is the possibility of instability. This arises from having mobiles in co-channel cells alternatingly increase their power in response to increased co-channel interference caused by the other mobile increasing its power. This in unlikely to occur in practice but it is (or was as of 1991) under study. At the same time the base stations perform the timing measurements, they also perform measurements on the power level of the different mobile stations. These power levels are adjusted so that the power is nearly the same for each burst. A base station also controls its power level. The mobile station measures the strength and the quality of the signal between itself and the base station. If the mobile station does not receive correctly the signal, the base station changes its power level.

3.9 DISCONTINUOUS RECEPTION

Another method used to conserve power at the mobile station is discontinuous reception. The paging channel, used by the base station to signal an incoming call, is structured into sub-channels. Each mobile station needs to listen only to its own sub-channel. In the time between successive paging sub-channels, the mobile can go into sleep mode, when almost no power is used. It is a method used to conserve the mobile station's power. The paging channel is divided into sub channels corresponding to single mobile stations. Each mobile station will then only 'listen' to its sub channel and will stay in the sleep mode during the other sub channels of the paging channel.

3.10 MULTIPATH AND EQUALIZATION

At the GSM frequency bands, radio waves reflect from buildings, cars, hills, etc. So not only the 'right' signal (the output signal of the emitter) is received by an antenna, but also many reflected signals, which corrupt the information, with different phases. An equalizer is in charge of extracting the 'right' signal from the received signal. It estimates the channel impulse response of the GSM system and then constructs an inverse filter. The receiver knows which training sequence it must wait for. The equalizer will then, comparing the received training sequence with the training sequence it was expecting, compute the coefficients of the channel impulse response. In order to extract the 'right' signal, the received signal is passed through the inverse filter. At the 900 MHz range, radio waves bounce off everything - buildings, hills, cars, airplanes, etc. Thus many reflected signals, each with a different phase, can reach an antenna. Equalization is used to extract the desired signal from the unwanted reflections. It works by finding out how a known transmitted signal is modified by multipath fading, and constructing an inverse filter to extract the rest of the desired signal. This known signal is the 26-bit training sequence transmitted in the middle of every time-slot burst. The actual implementation of the equalizer is not specified in the GSM specifications.

4. GSM ARCHITECTURE

4.1 OVERVIEW

The increasing demand for data services leads to the internet growing and the World Wide Web has grown from 130 mostly educational sites in mid-1993 to 650,000 largely commercial sites at the beginning of 1997. There are now estimated to be well in excess of 50 million individual subscribers with internet access. This development can be divided into two periods. First generation wireless networks evolve from specialized proprietary protocols or national standards. Wireless voice and data networks operate independently or, at best, are loosely coupled. Over the last decade a second-generation fully digital mobile communication network, now called the Global System for Mobil communications (GSM), with integrated voice and data capabilities has been created and deployed. GSM has three spectral variants: GSM 900, DCS1800 and PCS 1900 operating respectively in the 900MHz, 1.8 GHz and 1.9 GHz bands. GSM has matured to be adopted by around 200 operators in 100 countries. The success of GSM has produced a market led evolution. The GSM system was originally deployed in phase 1 as a basic voice and circuit data service and then additional supplementary services were added in the pre-planned phase 2. GSM is now in "phase 2+", which allows for the ongoing introduction of new services and which should eventually migrate to a third generation system known as the Universal Mobile Telecommunications System (UMTS). A rich collection of new data services is currently being defined under phase 2+. These services when combined with existing data services will provide greater choices and improved bandwidth. The GSM system architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The subsystems are the Base Station Subsystem (BSS), Network and Switching Subsystem (NSS), and the Operation Support subsystem (OSS). The Mobile Station (MS) is also a subsystem, but is usually considered to be part of the BSS for architecture purposes. Equipment and services are designed within GSM to support one or more of these specific subsystems.

- The BSS provides and manages radio transmission paths between the mobile stations and the Mobile Switching Center (MSC). It also manages the radio interface. Each BSS consists of many Base Station Controllers (BSCs) which connect the MS to the NSS via the MSCs.
- The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the PSTN and ISDN.
- The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose, and troubleshoot all aspects of the GSM system. This subsystem interacts with the other GSM subsystems, and is provided solely for the staff of the GSM operating company, which provides service facilities for the network.

One goal of the GSM is to achieve separation between the NSS and BSS, so that other wireless technologies could be used, such as digital enhanced cordless telecommunications (DECT) and the satellite systems. The GSM air interface between the mobile stations and other subsystems of GSM combines both time division multiple access (TDMA) and frequency division multiple access (FDMA) with optional frequency hopping.

4.2 ARCHITECTURE OF THE GSM NETWORK

The GSM technical specifications define the different entities that form the GSM network by defining their functions and interface requirements. The GSM network can be divided into four main parts:

- The Mobile Station (MS).
- The Base Station Subsystem (BSS).
- The Network and Switching Subsystem (NSS).
- The Operation and Support Subsystem (OSS).

The architecture of the GSM network is presented in figure 4.1

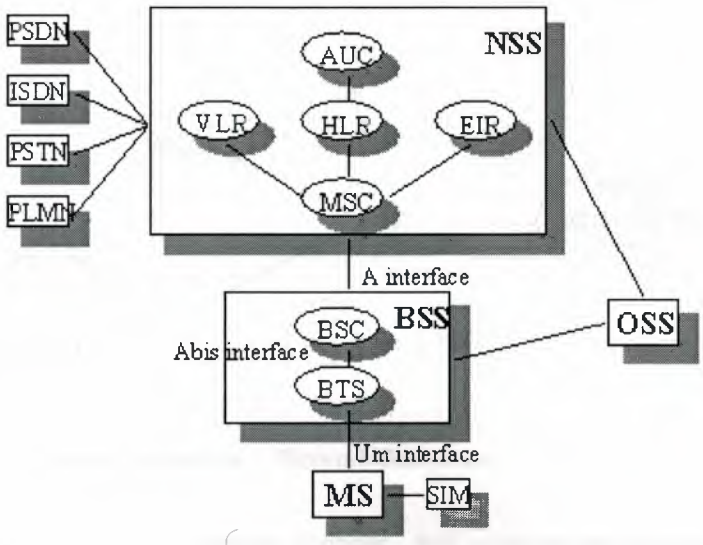
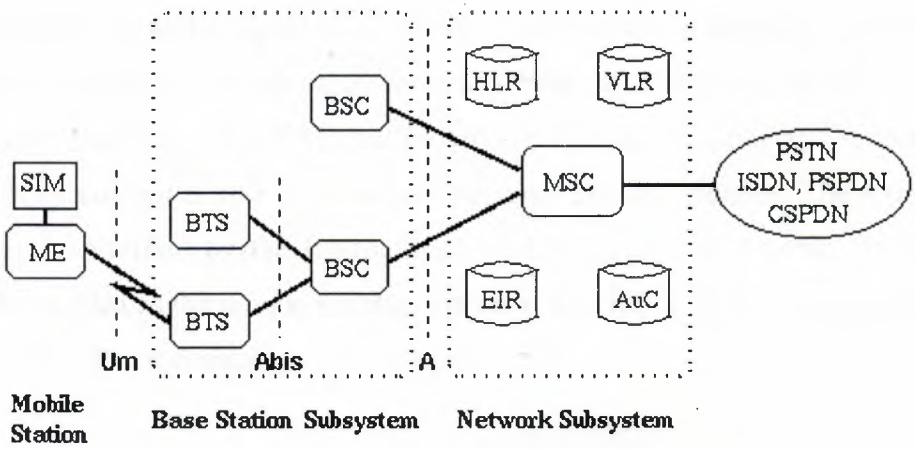


Figure 4.1 Architecture of the GSM network

A GSM network is composed of several functional entities, whose functions and interfaces are specified. Figure 4.1 shows the layout of a generic GSM network. The GSM network can be divided into three broad parts. The subscriber carries the Mobile Station. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which is the Mobile services Switching Center (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations. Not shown is the Operations and Maintenance Center, which oversees the proper operation and setup of the network. The Mobile Station and the Base Station Subsystem communicate across the U_m interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile Services Switching Center across the A interface. GSM provides recommendations, not requirements. The GSM specifications define the functions and interface requirements.

In detail but do not address the hardware. The reason for this is to limit the designers as little as possible but still to make it possible for the operators to buy equipment from different suppliers. The GSM network is divided into three major systems: the switching system (SS), the base station system (BSS), and the operation and support system (OSS). The basic GSM network elements are shown in Figure 4.2



SIM Subscriber Identity Module
ME Mobile Equipment
BTS Base Transceiver Station
BSC Base Station Controller
HLR Home Location Register
VLR Visitor Location Register
MSC Mobile services Switching Center
EIR Equipment Identity Register
AuC Authentication Center

Figure 4.2 General architecture of a GSM network

4.2.1 Mobile Station

The mobile station (MS) consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another GSM terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services.

The International Mobile Equipment Identity (IMEI) uniquely identifies the mobile equipment. The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information.

The IMEI and the IMSI are independent, thereby allowing personal mobility. The SIM card may be protected against unauthorized use by a password or personal identity number.

The mobile station is the formal name for what represents, for most people, their actual cell-phone and a smart card called the Subscriber Identity Module (SIM). Other examples of mobile stations are car-phones and transportable units. The SIM card can be regarded as separate from the actual terminal as a user can insert the card into another terminal, receive calls from there, and reap the full access of other subscribed services. The SIM card provides for greater security and renders theft futile as it may contain a user password or personal identity number. The terminal itself is uniquely identified by the International Mobile Equipment Identity (IMEI), which is similar in idea as the unique number a printer, say, has as a part of a computer network. A Mobile Station consists of two main elements:

- The mobile equipment or terminal.
- The Subscriber Identity Module (SIM).

a) The Terminal

There are different types of terminals distinguished principally by their power and application: The `fixed' terminals are the ones installed in cars. Their maximum allowed output power is 20 W. The GSM portable terminals can also be installed in vehicles. Their maximum allowed output power is 8W.

The handheld terminals have experienced the biggest success thanks to their weight and volume, which are continuously decreasing. These terminals can emit up to 2 W. The evolution of technologies allows to decrease the maximum allowed power to 0.8 W.

b) The SIM

The SIM is a smart card that identifies the terminal. By inserting the SIM card into the terminal, the user can have access to all the subscribed services. Without the SIM card, the terminal is not operational. A four-digit Personal Identification Number (PIN)

protects the SIM card. In order to identify the subscriber to the system, the SIM card contains some parameters of the user such as its International Mobile Subscriber

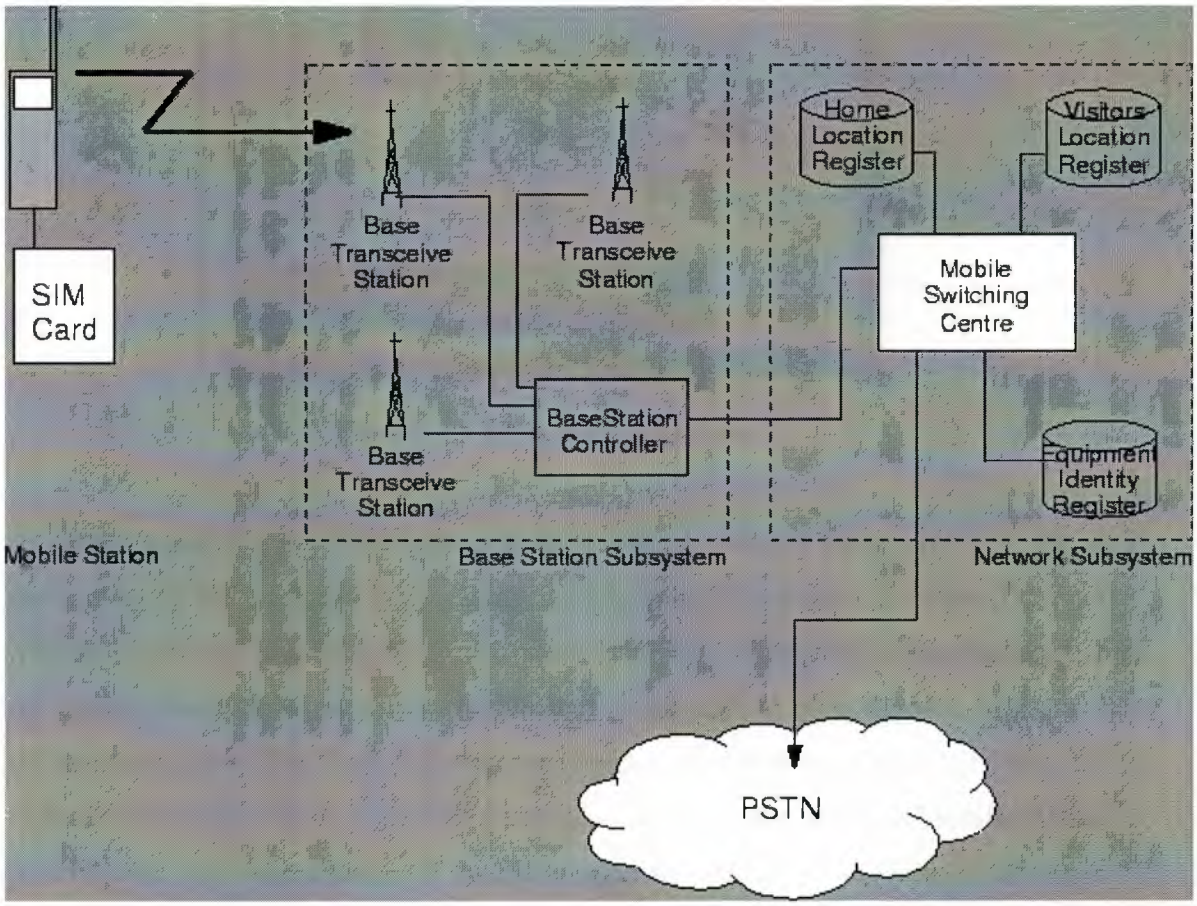


Figure 4.3 Overview of a GSM Mobile Network

Identity (IMSI). Another advantage of the SIM card is the mobility of the users. In fact, the only element that personalizes a terminal is the SIM card. Therefore, the user can have access to its subscribed services in any terminal using its SIM card.

4.2.2 The Base Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). These communicate across the standardized Abis interface, allowing (as in the rest of the system) operation between components made by different suppliers.

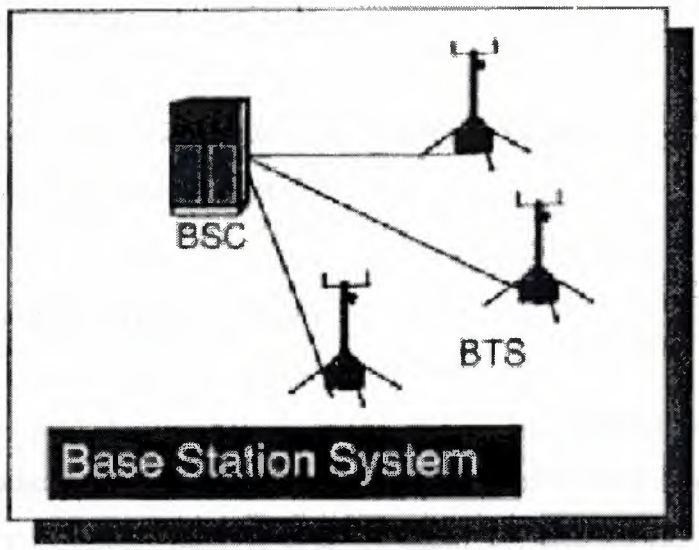


Figure 4.3 Base Station System

When a call is made from a mobile, the terminal searches for a local base station to connect to. A Base Station Sub-system is made up of two parts – the Base Transceiver Station (BTS) and the Base Station Controller (BSC). They both communicate across the standardized Abis interface, which allows a network to be composed of parts from different suppliers. The Base-Transceiver Stations provide for one or more channels per radio cell. Its main job is to handle the radio-link protocols with the Mobile Station. It provides the two lowest layers of the radio interface, and so provides an error-corrected data path. At least one of the channels is used to carry control signals, which insure that the data arrives correctly at the destination. The Base Station Controller manages the radio resources for one or more BTSs and operates within a particular region. Its main functions are to handle radio-channel setup, control frequency hopping, undertake handovers (except to cells outside its region) and provide radio performance measurements. The BSC is the connection between the mobile station and the Mobile Services Switching Center (MSC). Once the mobile has been successfully connected to a BTS, the BSC will set up a bi-directional signaling channel specifically for itself and it will connect it on to the MSC. All radio-related functions are performed in the BSS, which consists of base station controllers (BSCs) and the base transceiver stations (BTSs).

The BSS connects the Mobile Station and the NSS. It is in charge of the transmission and reception.

The BSS can be divided into two parts:

- The Base Transceiver Station (BTS) or Base Station.
- The Base Station Controller (BSC).

a) The Base Transceiver Station

The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Station. In a large urban area, there will potentially be a large number of BTSs deployed, thus the requirements for a BTS are ruggedness, reliability, portability, and minimum cost.

The BTS handles the radio interface to the mobile station. The BTS is the radio equipment (transceivers and antennas) needed to service each cell in the network. A group of BTSs are controlled by a BSC.

The BTS corresponds to the transceivers and antennas used in each cell of the network. A BTS is usually placed in the center of a cell. Its transmitting power defines the size of a cell. Each BTS has between one and sixteen transceivers depending on the density of users in the cell.

b) The Base Station Controller

The Base Station Controller manages the radio resources for one or more BTSs. It handles radio-channel setup, frequency hopping, and handovers, as described below. The BSC is the connection between the mobile station and the Mobile service Switching Center (MSC).

The BSC also translates the 13 kbps voice channel used over the radio link to the standard 64 kbps channel used by the Public Switched Telephone Network or ISDN.
The BSC provides all the control functions and physical links between the MSC and BTS. It is a high-capacity switch that provides functions such as handover, cell configuration data, and control of radio frequency (RF) power levels in base transceiver stations. A number of BSCs are served by an MSC.

The BSC controls a group of BTS and manages their radio resources. A BSC is principally in charge of handovers, frequency hopping, exchange functions and control of the radio frequency power levels of the BTSs.

4.2.3 The Network and Switching Subsystem

The central component of the Network Subsystem is the Mobile services Switching Center (MSC). It acts like a normal switching node of the PSTN or ISDN, and additionally provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. These services are provided in conjunction with several functional entities, which together form the Network Subsystem. The MSC provides the connection to the fixed networks (such as the PSTN or ISDN). Signaling between functional entities in the Network Subsystem uses Signaling System Number 7 (SS7), used for trunk signaling in ISDN and widely used in current public networks.

The Home Location Register (HLR) and Visitor Location Register (VLR), together with the MSC, provide the call-routing and roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The location of the mobile is typically in the form of the signaling address of the VLR associated with the mobile station. The actual routing procedure will be described later. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

The Visitor Location Register (VLR) contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. Although each functional entity can be implemented as an independent unit, all manufacturers of switching equipment to date implement the VLR together with the MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR, thus simplifying the signaling required. Note that the MSC contains no information about particular mobile stations; this information is stored in the location registers.

The other two registers are used for authentication and security purposes. The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile equipment on the network, where its International Mobile Equipment Identity (IMEI) identifies each mobile station. An IMEI is marked as invalid if it has been reported stolen or is not type approved. The Authentication Center (AuC) is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, which is used for authentication and encryption over the radio channel.

The NSS handles the switching of GSM calls between external networks and the BSCs in the radio subsystem and is also responsible for managing and providing external access to several customer databases. The MSC is the central unit in the NSS and controls the traffic among all of the BSCs. In the NSS, there are three different databases called the Home Location Register (HLR), Visitor Location Register (VLR), and the Authentication Center (AuC). The HLR is a database, which contains subscriber information and location information for each user who resides in the same city as the MSC. Each subscriber in a particular GSM market is assigned a unique International Mobil Subscriber Identity (IMSI), and this number is used to identify each home user. The VLR is a database, which temporarily stores the IMSI and customer information for each roaming subscriber who is visiting the coverage area of a particular MSC. The Authentication Center is a strongly protected database, which handles the authentication and encryption keys for every single subscriber in the HLR and VLR. The OSS supports one or several Operation Maintenance Centers (OMC), which are used to monitor and maintain the performance of each MS, BS, BSC, and MSC within a GSM system. The switching system (SS) is responsible for performing call processing and subscriber-related functions. The switching system includes the following functional units. The main component of the Network Subsystem is the Mobile services Switching Center (MSC). It is made up of a usual trunk ISDN exchange but additionally provides all the functionality needed to handle a mobile user such as registration, authentification, checking the whereabouts of the user, handovers and call routing. The MSC provides the connection to the fixed networks, such as PSTN or ISDN. The Home Location Register (HLR) and the Visitor Location Register (VLR) handle call routing and roaming. There is more information on Roaming in the GSM Network as a separate project on this ICT site.

The HLR contains all the necessary information about the user and the current location of the mobile. This location is usually in the form of the signaling address of the VLR associated with the mobile station. The Equipment Identity Register (EIR) contains a list of all the mobile equipment (identified by their IMEI) on the network. Authentification: If the mobile user attempts to access the system, it is asked for its International Mobile Subscriber Identity (IMSI). This unique number is checked and validated by the system.

Its main role is to manage the communications between the mobile users and other users, such as mobile users, ISDN users, fixed telephony users, etc. It also includes data bases needed in order to store information about the subscribers and to manage their mobility. The different components of the NSS are described below.

a) The Mobile services Switching Center (MSC)

The MSC performs the telephony switching functions of the system. It controls calls to and from other telephone and data systems. It also performs such functions as toll ticketing, network interfacing, common channel signaling, and others

It is the central component of the NSS. The MSC performs the switching functions of the network. It also provides connection to other networks.

b) The Gateway Mobile services Switching Center (GMSC)

A gateway is a node interconnecting two networks. The GMSC is the interface between the mobile cellular network and the PSTN. It is in charge of routing calls from the fixed network towards a GSM user. The GMSC is often implemented in the same machines as the MSC.

c) Home Location Register (HLR)

The HLR is a database used for storage and management of subscriptions. The HLR is considered the most important database, as it stores permanent data about subscribers, including a subscriber's service profile, location information, and activity status. When an individual buys a subscription from one of the PCS operators, he or she is registered

in the HLR of that operator. The HLR is considered as a very important database that stores information of the subscribers belonging to the covering area of a MSC. It also stores the current location of these subscribers and the services to which they have access. The location of the subscriber corresponds to the SS7 address of the Visitor Location Register (VLR) associated to the terminal.

d) Visitor Location Register (VLR)

The VLR is a database that contains temporary information about subscribers that is needed by the MSC in order to service visiting subscribers. The VLR is always integrated with the MSC. When a mobile station roams into a new MSC area, the VLR connected to that MSC will request data about the mobile station from the HLR. Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogate the HLR each time.

The VLR contains information from a subscriber's HLR necessary in order to provide the subscribed services to visiting users. When a subscriber enters the covering area of a new MSC, the VLR associated to this MSC will request information about the new subscriber to its corresponding HLR. The VLR will then have enough information in order to assure the subscribed services without needing to ask the HLR each time a communication is established.

The VLR is always implemented together with a MSC; so the area under control of the MSC is also the area under control of the VLR.

e) The Authentication Center (AuC)

A unit called the AuC provides authentication and encryption parameters that verify the user's identity and ensure the confidentiality of each call. The AuC protects network operators from different types of fraud found in today's cellular world.

The Authentification Center (AuC) is the network sub-system register, which contains all the password numbers in the customer's SIM card, which is used for authentification and security over the network. One of the main reasons why cell-phones can be so small and still have enough power to remain on standby for so long is that they use a receiving method known as Discontinuous Receive (DRX). This allows the mobile to only listen

to paging signals when they are emitted by a known paging cycle of the network. The phones are not continuously checking for signals and use one tenth of the power requirements they would need therefore.

The AuC register is used for security purposes. It provides the parameters needed for authentication and encryption functions. These parameters help to verify the user's identity.

f) The Equipment Identity Register (EIR)

The EIR is a database that contains information about the identity of mobile equipment that prevents calls from stolen, unauthorized, or defective mobile stations. The AUC and EIR are implemented as stand-alone nodes or as a combined AUC/EIR node.

The EIR is also used for security purposes. It is a register containing information about the mobile equipments. More particularly, it contains a list of all valid terminals. Its International Mobile Equipment Identity (IMEI) identifies a terminal. The EIR allows then to forbid calls from stolen or unauthorized terminals (e.g., a terminal which does not respect the specifications concerning the output RF power).

g) The GSM Interworking Unit (GIWU)

The GIWU consists of both hardware and software that provides an interface to various networks for data communications. Through the GIWU, users can alternate between speech and data during the same call. The GIWU hardware equipment is physically located at the MSC/VLR.

The GIWU corresponds to an interface to various networks for data communications. During these communications, the transmission of speech and data can be alternated.

h) Message center (MXE)

The MXE is a node that provides integrated voice, fax, and data messaging. Specifically, the MXE handles short message service, cell broadcast, voice mail, fax mail, e-mail, and notification.

i) Mobile service node (MSN)

The MSN is the node that handles the mobile intelligent network (IN) services.

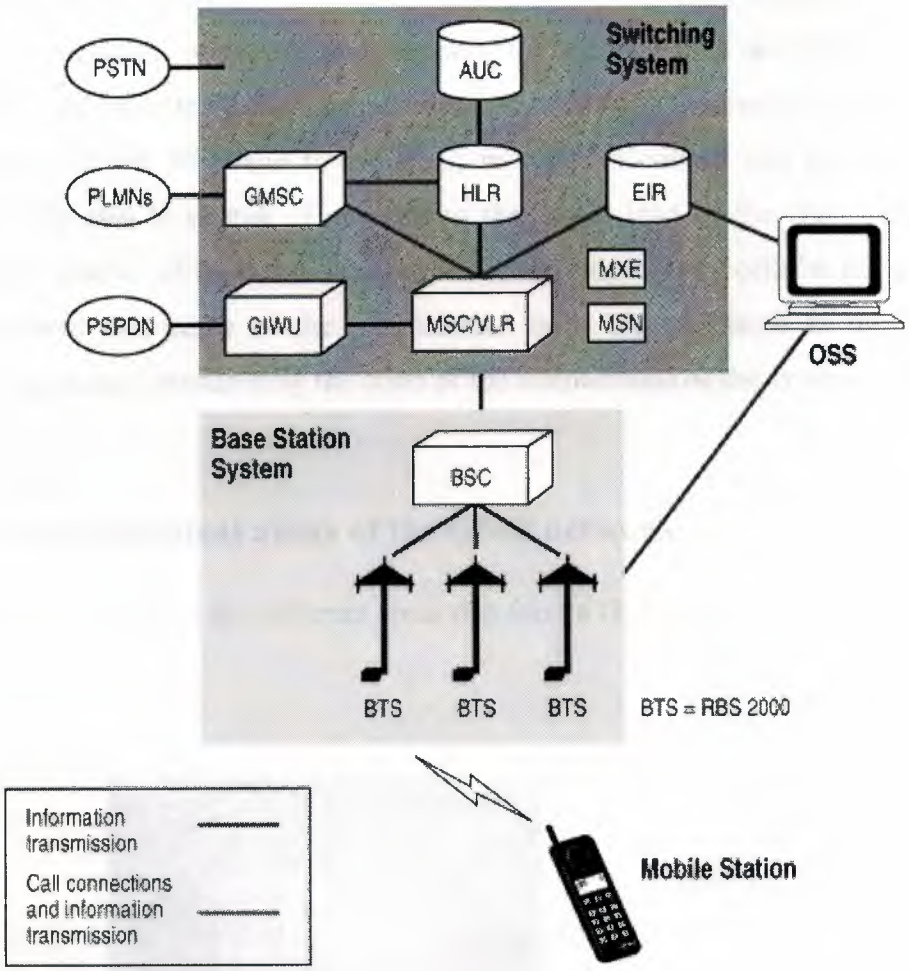


Figure 4.4 GSM Network Elements

4.2.4 The Operation and Support Subsystem (OSS)

The operations and maintenance center (OMC) is connected to all equipment in the switching system and to the BSC. The implementation of OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional, and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organizations. The OSS is connected to the different components of the NSS and to the BSC, in order to control and monitor the GSM system. It is also in charge of controlling the traffic load of the BSS. However, the increasing number of base stations, due to the development of cellular radio networks, has provoked that some of the maintenance tasks are transfered to the BTS. This transfer decreases considerably the costs of the maintenance of the system.

4.3 The geographical areas of the GSM network

The figure 4.5 presents the different areas that form a GSM network.

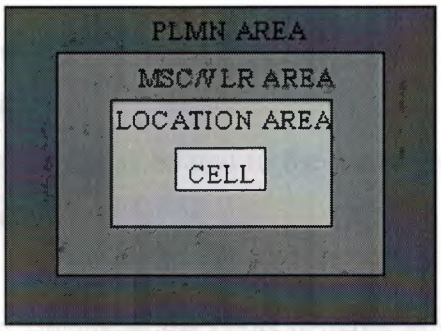


Figure 4.5 GSM Network Areas

As it has already been explained a cell, identified by its Cell Global Identity number (CGI), corresponds to the radio coverage of a base transceiver station. A Location Area (LA), identified by its Location Area Identity (LAI) number, is a group of cells served by a single MSC/VLR. A group of location areas under the control of the same MSC/VLR defines the MSC/VLR area. A Public Land Mobile Network (PLMN) is the area served by one network operator.

4.4 THE GSM FUNCTIONS

In this paragraph, the description of the GSM network is focused on the different functions to fulfill by the network and not on its physical components. In GSM, five main functions can be defined:

- Transmission.
- Radio Resources management (RR).
- Mobility Management (MM).
- Communication Management (CM).
- Operation, Administration and Maintenance (OAM).

4.4.1 Transmission

The transmission function includes two sub-functions:

- The first one is related to the means needed for the transmission of user information.
- The second one is related to the means needed for the transmission of signaling information.

Not all the components of the GSM network are strongly related with the transmission functions. The MS, the BTS and the BSC, among others, are deeply concerned with transmission. But other components, such as the registers HLR, VLR or EIR, are only concerned with the transmission for their signaling needs with other components of the GSM network.

4.4.2 Radio Resources Management (RR)

The role of the RR function is to establish, maintain and release communication links between mobile stations and the MSC. The elements that are mainly concerned with the RR function are the mobile station and the base station. However, as the RR function is also in charge of maintaining a connection even if the user moves from one cell to another, the MSC, in charge of handovers, is also concerned with the RR functions.

The RR is also responsible for the management of the frequency spectrum and the reaction of the network to changing radio environment conditions. Some of the main RR procedures that assure its responsibilities are:

- Channel assignment, change and release.
- Handover.
- Frequency hopping.
- Power-level control.
- Discontinuous transmission and reception.
- Timing advance.

Some of these procedures are described in section 5. In this paragraph only the handover, which represents one of the most important responsibilities of the RR, is described.

Handover

The user movements can produce the need to change the channel or cell, specially when the quality of the communication is decreasing. This procedure of changing the resources is called handover. Four different types of handovers can be distinguished:

- Handover of channels in the same cell.
- Handover of cells controlled by the same BSC.
- Handover of cells belonging to the same MSC but controlled by different BSCs.
- Handover of cells controlled by different MSCs.

- Handovers are mainly controlled by the MSC. However in order to avoid unnecessary signaling information, the first two types of handovers are managed by the concerned BSC (in this case, the MSC is only notified of the handover).

The mobile station is the active participant in this procedure. In order to perform the handover, the mobile station controls continuously its own signal strength and the signal strength of the neighboring cells. The base station gives the list of cells that must be monitored by the mobile station. The power measurements allow to decide which is the best cell in order to maintain the quality of the communication link. Two basic algorithms are used for the handover:

- The `minimum acceptable performance' algorithm. When the quality of the transmission decreases (i.e. the signal is deteriorated), the power level of the mobile is increased. This is done until the increase of the power level has no effect on the quality of the signal. When this happens, a handover is performed.
- The `power budget' algorithm. This algorithm performs a handover, instead of continuously increasing the power level, in order to obtain a good communication quality.

4.4.3 Mobility Management

The MM function is in charge of all the aspects related with the mobility of the user, specially the location management and the authentication and security.

a) Location Management

When a mobile station is powered on, it performs a location update procedure by indicating its IMSI to the network. The first location update procedure is called the IMSI attach procedure.

The mobile station also performs location updating, in order to indicate its current location, when it moves to a new Location Area or a different PLMN. This location-updating message is sent to the new MSC/VLR, which gives the location information to the subscriber's HLR. If the mobile station is authorized in the new MSC/VLR, the subscriber's HLR cancels the registration of the mobile station with the old MSC/VLR.

A location updating is also performed periodically. If after the updating time period, the mobile station has not registered, it is then deregistered.
When a mobile station is powered off, it performs an IMSI detach procedure in order to tell the network that it is no longer connected.

b) Authentication and Security

The authentication procedure involves the SIM card and the Authentication Center. A secret key, stored in the SIM card and the AuC, and a ciphering algorithm called A3 are used in order to verify the authenticity of the user. The mobile station and the AuC compute a SRES using the secret key, the algorithm A3 and a random number generated by the AuC. If the two computed SRES are the same, the subscriber is authenticated. The different services to which the subscriber has access are also checked.
Another security procedure is to check the equipment identity. If the IMEI number of the mobile is authorized in the EIR, the mobile station is allowed to connect the network. In order to assure user confidentiality, the user is registered with a Temporary Mobile Subscriber Identity (TMSI) after its first location update procedure.

4.4.4 Communication Management (CM)

The CM function is responsible for:

- Call control.
- Supplementary Services management.
- Short Message Services management.

a) Call Control (CC)

The CC is responsible for call establishing, maintaining and releasing as well as for selecting the type of service. One of the most important functions of the CC is the call routing. In order to reach a mobile subscriber, a user diales the Mobile Subscriber ISDN (MSISDN) number which includes:

- A country code.
- A national destination code identifying the subscriber's operator.
- A code corresponding to the subscriber's HLR.

The call is then passed to the GMSC (if the call is originated from a fixed network), which knows the HLR corresponding to a certain MISDN number. The GMSC asks the HLR for information helping to the call routing. The HLR requests this information from the subscriber's current VLR. This VLR allocates temporarily a Mobile Station Roaming Number (MSRN) for the call. The MSRN number is the information returned by the HLR to the GMSC. Thanks to the MSRN number, the call is routed to subscriber's current MSC/VLR. In the subscriber's current LA, the mobile is paged.

b) Supplementary Services Management

The mobile station and the HLR are the only components of the GSM network involved with this function

c) Short Message Services Management

In order to support these services, a GSM network is in contact with a Short Message Service Center through the two following interfaces:

- The SMS-GMSC for Mobile Terminating Short Messages (SMS-MT/PP). It has the same role as the GMSC.
- The SMS-IWMSC for Mobile Originating Short Messages (SMS-MO/PP).

4.4.5 Operation, Administration and Maintenance (OAM)

The OAM function allows the operator to monitor and control the system as well as to modify the configuration of the elements of the system. Not only the OSS is part of the OAM, also the BSS and NSS participate in its functions.

The components of the BSS and NSS provide the operator with all the information it needs. This information is then passed to the OSS, which is in charge of analize it and control the network.

The self-test tasks, usually incorporated in the components of the BSS and NSS, also contribute to the OAM functions.

CONCLUSION

The first cellular radio system in Europe was installed in Scandinavia in 1981 and it served initially only a few thousand subscribers. But now days from 1981 to 2001 we are seeing that a few thousand subscribers reached to 500 million subscribers.

A general objective of the GSM system is to provide a wide range of services and facilities, both voice and data, that are compatible with the existing fixed Public Switched Telephone Network (PSTN), Public Switched Data Networks (PSDN), Public Land Mobile Network (PLMN) and Integrated Services Digital Networks (ISDN). Another objective is to give compatibility considered mobile subscriber the access to any mobile subscriber in any country, which operates the system, and provides facilities for automatic roaming, locating and updating the mobile subscriber's status.

The Radio Interface is the interface between the mobile stations and the fixed infrastructure. It is one of the most important interfaces of the GSM system. One of the main objectives of GSM is Roaming. Therefore, in order to obtain a complete compatibility between mobile stations and networks of different manufacturers and operates, the radio interface must be completely defined.

GSM as the modern telecommunication system is a complex object. Its implementation and operation are not simple task, neither easy its describtion.

In this Graduation Project I have tried to give an explanations of the GSM, Mobile Phones, Radio Interface and most weighted about GSM Architecture. As with any explanations, there are many details missing. I believe, however, that gave the brief explanations in each chapters.

REFERENCES

[1] Mamedov F. S., Telecommunications, Lecture notes, Near East University Press, Lefkoşa, 2000.

[2] Vijay K. Garg, Joseph E. Wilkes, Wireless and Personal Communications Systems, Feher/Prentice Hall Digital and Wireless Communications Series,AT&T Bell Labs., Holmdel, New Jersey, 1996.

[3] GSM Specification Series 1.02-1.06, "GSM Overview, Glossary, Abbreviations, Service Phases."

[4] GSM Specification Series 3.01-3.88, "GSM PLMN Functions, Architecture, Numbering and Addressing, Procedures."

[5] Padgett, Jay E., Gunther, Christoph G., Hattori, Takeshi, " Overview of Wireless Personal Communications". IEEE Communications Magazine, V33, n1, January, 1995:28, 14 pages.

[6] Lee, W. C. Y., Mobile Cellular Telecommunications Systems, New York: McGraw-Hill, 1989.

[7] Hans Lobensommer and Helmut Mahner. GSM – a European mobile radio standard for the world market. Telcom Report International, 15(3-4), 1992.

[8] Mouly, M, and Poutet, M, "The GSM System for Mobile Communications", Palaiseau, France, 1992.

[9] Vijay K. Garg, Willowbrook, Illinois Joseph E. Wilkes, "Principles and Applications of GSM" Red Bank, New Jersey, 1999.

[10] David M. Bolston. The pan-European system: GSM. In David M. Bolston and R.C.V. Macario, editors, cellular Radio Systems. Artech House, Boston, 1993.

[11] Javier Gozalvez Sempere Research Engineer in Mobile Communications "An Overview of the GSM System" University of Strothclyde Glasgow, Scotland.

[12] John Scourios (University of Waterloo). "Overview of the Global System for Mobile Communications".
"http://ccnga.uwaterloo.ca/~jscouria/GSM/gsmreport.html"