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GSM CELL PLANNING

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IN THE NAME OF ALLAH, MOST GRACIOUS, MOST MERCIFUL.

I wish to express my deepest appreciation to my god who stood beside me all the time,who supported me in all my achievements and who has given me the power and patience to finish my college studies successfully.

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Last but not least i dedicate my work and my success to my father **Ahmad Zayed**, my mother, my brother, my sisters and my friends who provided me the encouragement and assistance that have made the completion of this work possible and I hope them success and happiness in life.

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ABSTRACT

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 GSM technical specifications define the different entities that form the GSM network by defining their functions and interface requirements.

Each mobile uses a separate, temporary radio channel to talk to the cell site. The cell site talks to many mobiles at once, using one channel per mobile. Channels use a pair of frequencies for communication one frequency (the forward link) for transmitting from the cell site and one frequency (the reverse link) for the cell site to receive calls from the users. Radio energy dissipates over distance, so mobiles must stay near the base station to maintain communications. The basic structure of mobile networks includes telephone systems and radio services. Where mobile radio service operates in a closed network and has no access to the telephone system, mobile telephone service allows interconnection to the telephone network.

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INTRODUCTION

The future is mobile on the one hand more and more people will spend much of their time on the road whether working or during vacation. People want access to the telecommunication services in any place at any time. On the other hand, more and more communication devices are portable, such as pagers, mobile phones, personal digital assistants (PDAs), laptops, and palmtops. The development of wireless communications takes these facts into account. New technologies and services are continuing to come forth. The number of subscribers to mobile services is tremendously growing worldwide. Therefore the proper design of mobile networks, in order to meet the increases in demand, is of utmost importance.

The aim of this project is to give an introduction to basic GSM concepts, specifications, networks, services and the aim with indoor cell planning is, as for "traditional" cell planning, to plan for good coverage and capacity and at the same time interfere as little as possible. How this can be achieved is briefly described here. The focus is on antenna and RBS system, RF design and antenna configuration but also frequency planning, capacity issues and traffic control are described. The project consists of introduction, four chapters and conclusion.

Chapter one provides an introduction to basic GSM concepts, specifications, networks, and services. A short history of network evolution is provided in order set the context for understanding GSM.

Chapter two provides the functional architecture of a GSM system can be divided into the Mobile Station (MS), the Base Station (BS), and the Network Subsystem (NS). The MS is carried by the subscriber, the BS subsystem controls the radio link with the MS and the NS performs the switching of calls between the mobile and other fixed or mobile network users as well as mobility management. The MS and the BS subsystem communicate across the Um interface also known as radio link.

Chapter three discusses the basics of radiotelephony systems, including both analog and digital systems. The advantages of digital cellular technologies over analog cellular networks include increased capacity and security. Technology options such as TDMA and CDMA offer more channels in the same analog cellular bandwidth and encrypted voice and data.

Chapter four discusses the aim with indoor cell planning, as for "traditional" cell planning, to plan for good coverage and capacity and at the same time interfere as little as possible. And focus on antenna and RBS system; RF design and antenna configuration but also frequency planning, capacity issues and traffic control are described. The tools for indoor cell planning, TEMS Prediction, TEMS Light and TEMS Transmitter, are also described with focus on how to use them in the planning process.

1. INTRODUCTION TO GLOBAL SYSTEM FOR MOBILE COMMUNICATION (GSM)

1.1 Overview

This chapter provides an introduction to basic GSM concepts, specifications, networks, and services. A short history of network evolution is provided in order set the context for understanding GSM.

1.2 The Evolution of Mobile Telephone Systems

Cellular is one of the fastest growing and most demanding telecommunications applications. Today, it represents a continuously increasing percentage of all new telephone subscriptions around the world. Currently there are more than 45 million cellular subscribers worldwide, and nearly 50 percent of those subscribers are located in the United States. It is forecasted that cellular systems using a digital technology will become the universal method of telecommunications. By the year 2005, forecasters predict that there will be more than 100 million cellular subscribers worldwide. It has

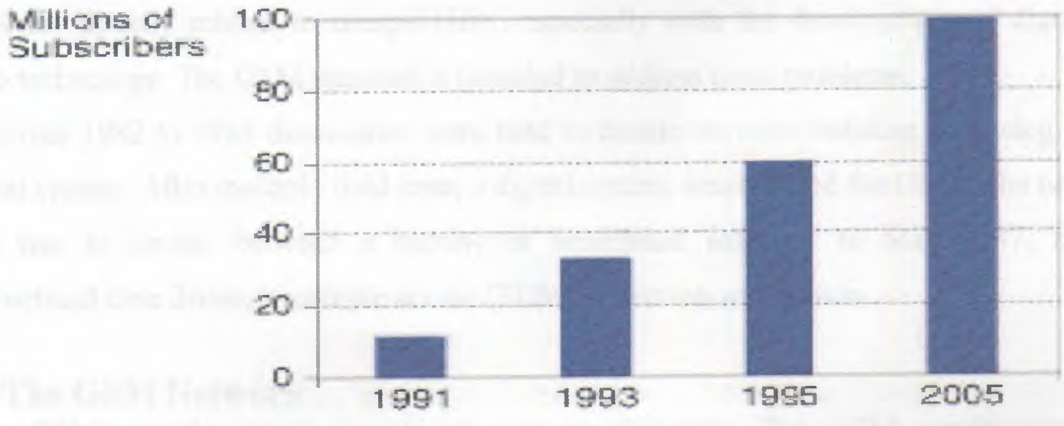

Figure 1.1: Cellular Subscriber Growth Worldwide

Even been estimated that some countries may have more mobile phones than fixed phones by the year 2000 as show in (Figure1.1).

The concept of cellular service is the use of low-power transmitters where frequencies can be reused within a geographic area. The idea of cell-based mobile radio service was formulated in the United States at Bell Labs in the early 1970s. However, the Nordic countries were the first to introduce cellular services for commercial use with the introduction of the Nordic Mobile Telephone (NMT) in 1981.

Cellular systems began in the United States with the release of the advanced mobile phone service (AMPS) system in 1983. Asia, Latin America, and Oceanic countries adopted the AMPS standard, creating the largest potential market in the world for cellular. In the early 1980s, most mobile telephone systems were analog rather than digital, like today's newer systems. One challenge facing analog systems was the inability to handle the growing capacity needs in a cost-efficient manner. As a result, digital technology was welcomed. The advantages of digital systems over analog systems include ease of signaling, lower levels of interference, integration of transmission and switching, increased ability to meet capacity demands, and technology options such as TDMA and CDMA.

1.3 GSM

Throughout the evolution of cellular telecommunications, various systems have been developed without the benefit of standardized specifications. This presented many problems directly related to compatibility, especially with the development of digital radio technology. The GSM standard is intended to address these problems.

From 1982 to 1985 discussions were held to decide between building an analog or digital system. After multiple field tests, a digital system was adopted for GSM. The next task was to decide between a narrow or broadband solution. In May 1987, the narrowband time division multiple access (TDMA) solution was chosen.

1.4 The GSM Network

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 Figure1.2.

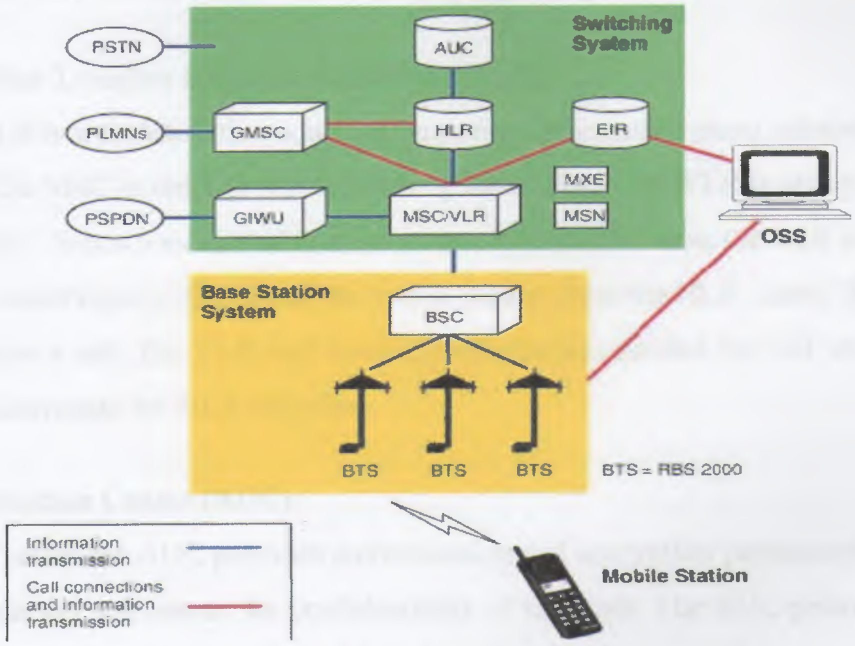

Figure1.2: GSM Network Element

1.4.1 The Switching System

The switching system (SS) is responsible for performing call processing and subscriber-related functions. The switching system includes the following functional units:

1.4.1.1 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.

1.4.1.2 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.

1.4.1.3 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 would 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.

1. 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.

2. 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.

1.4.2 The Base Station System (BSS)

All radio-related functions are performed in the BSS, which consists of base station controllers (BSCs) and the base transceiver stations (BTSs):

1.4.2.1 BSC

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.

1.4.2.2 BTS

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.

1.4.3 The Operation and Support System

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

1.4.4 Additional Functional Elements

Other functional elements shown in (Figure 1.2) are as follows:

1.4.4.1 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.

1.4.4.2 Mobile Service Node (MSN)

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

1.4.4.3 Gateway Mobile Services Switching Center (GMSC)

A gateway is a node used to interconnect two networks. The gateway is often implemented in an MSC. The MSC is then referred to as the GMSC.

1.4.4.4 GSM Inter Working 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.

1.5 GSM Network Areas

The GSM network is made up of geographic areas. As shown in (Figure 1.3), these areas include cells, location areas (LAs), MSC/VLR service areas, and public land mobile network (PLMN) areas.

The cell is the area given radio coverage by one base transceiver station. The GSM network identifies each cell via the cell global identity (CGI) number assigned to each cell. The location area is a group of cells. It is the area in which the subscriber is paged. Each LA is served by one or more base station controllers, yet only by a single MSC (Figure 1.4) Each LA is assigned a location area identity (LAI) number

An MSC/VLR service area represents the part of the GSM network that is covered by one MSC and which is reachable, as it is registered in the VLR of the MSC (Figure 1.5).

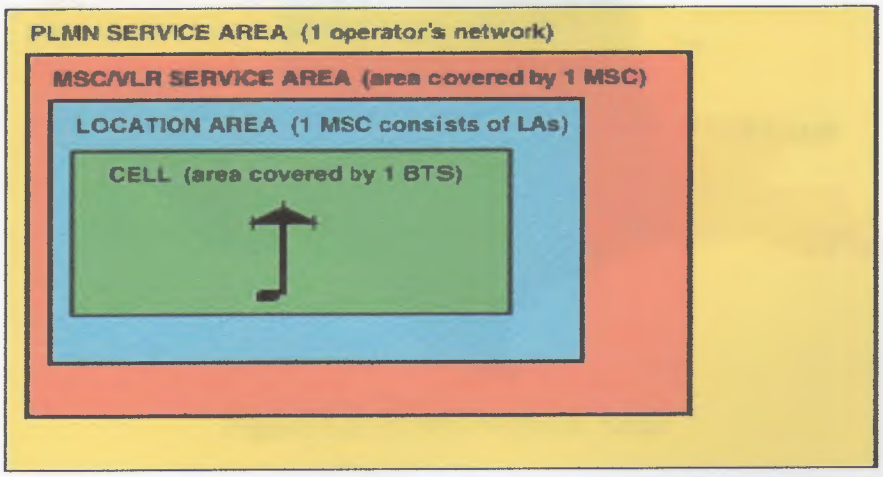

Figure 1.3: Network Areas

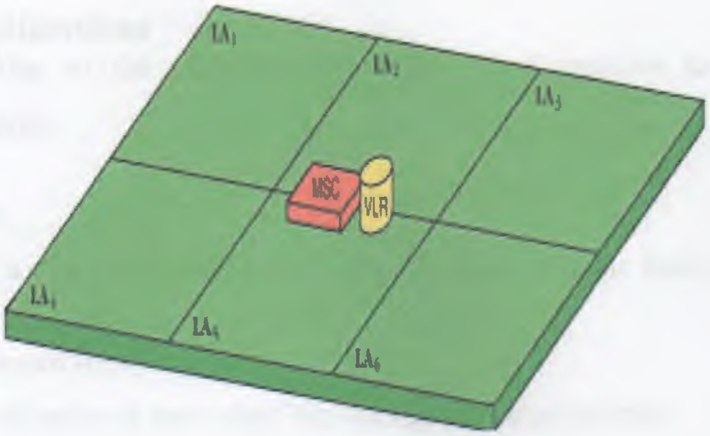

Figure 1.4: Location Areas

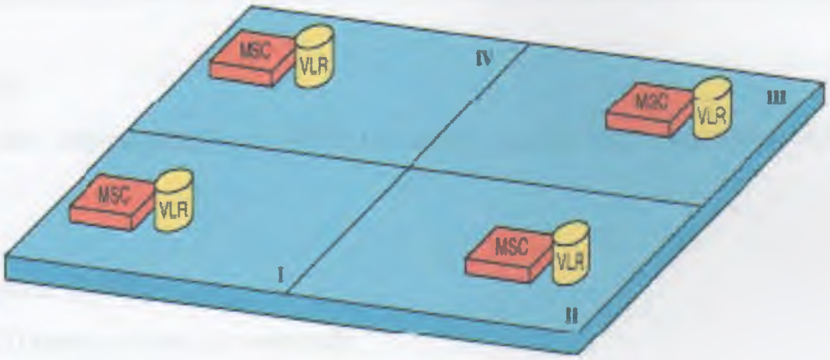

Figure 1.5: MSC/VLR Service Areas

Figure 1.6: PLMN Network Areas

The PLMN service area is an area served by one network operator (Figure 1.6).

1.6 GSM Specifications

Before looking at the GSM specifications, it is important to understand the following basic terms:

1.6.1 Bandwidth

The range of a channel's limits; the broader the bandwidth, the faster data can be sent

1.6.2 Bits Per Second (bps)

A single on-off pulse of data; eight bits are equivalent to one byte

1.6.3 Frequency

The number of cycles per unit of time; frequency is measured in hertz (Hz).

1.6.4 Kilo (k)

Kilo is the designation for 1,000; the abbreviation kbps represents 1,000 bits per second.

1.6.5 Megahertz (MHz)

1,000,000 hertz (cycles per second).

1.9.6 Milliseconds (ms)

One-thousandth of a second.

1.6.7 Watt (W)

A measure of power of a transmitter. Specifications for different personal communication services (PCS) systems vary among the different PCS networks. Listed below is a description of the specifications and characteristics for GSM.

1.6.8 Frequency Band

The frequency range specified for GSM is 1,850 to 1,990 MHz (mobile station to base station).

1.6.9 Duplex Distance

The duplex distance is 80 MHz. Duplex distance is the distance between the uplink and downlink frequencies. A channel has two frequencies, 80 MHz apart.

1.6.10 Channel Separation

The separation between adjacent carrier frequencies. In GSM, this is 200 kHz.

1.6.11 Modulation

Modulation is the process of sending a signal by changing the characteristics of a carrier frequency. This is done in GSM via Gaussian minimum shift keying (GMSK).

1.6.12 Transmission Rate

GSM is a digital system with an over-the-air bit rate of 270 kbps.

1.6.13 Access Method

GSM utilizes the time division multiple access (TDMA) concept. TDMA is a technique in which several different calls may share the same carrier. Each call is assigned a particular time slot.

1.6.14 Speech Coder

GSM uses linear predictive coding (LPC). The purpose of LPC is to reduce the bit rate. The LPC provides parameters for a filter that mimics the vocal tract. The signal passes through this filter, leaving behind a residual signal. Speech is encoded at 13 kbps.

1.7 GSM Subscriber Services

There are two basic types of services offered through GSM: telephony (also referred to as teleservices) and data (also referred to as bearer services). Telephony services are mainly voice services that provide subscribers with the complete capability (including necessary terminal equipment) to communicate with other subscribers. Data services provide the capacity necessary to transmit appropriate data signals between two access points creating an interface to the network. In addition to normal telephony and emergency calling, the following subscriber services are supported by GSM:

1.7.1 Dual-Tone Multi frequency (DTMF)

DTMF is a tone-signaling scheme often used for various control purposes via the telephone network, such as remote control of an answering machine. GSM supports full-originating DTMF.

1.7.2 Facsimile Group III

GSM supports CCITT Group 3 facsimile. As standard fax machines are designed to be connected to a telephone using analog signals, a special fax converter connected to the exchange is used in the GSM system. This enables a GSM–connected fax to communicate with any analog fax in the network.

1.7.3 Short Message Services

A convenient facility of the GSM network is the short message service. A message consisting of a maximum of 160 alphanumeric characters can be sent to or from a mobile station. This service can be viewed as an advanced form of alphanumeric paging with a number of advantages. If the subscriber's mobile unit is powered off or has left the coverage area, the message is stored and offered back to the subscriber when the mobile is powered on or has reentered the coverage area of the network. This function ensures that the message will be received.

1.7.4 Cell Broadcast

A variation of the short message service is the cell broadcast facility. A message of a maximum of 93 characters can be broadcast to all mobile subscribers in a certain geographic area. Typical applications include traffic congestion warnings and reports on accidents.

1.7.5 Voice Mail

This service is actually an answering machine within the network, which is controlled by the subscriber. Calls can be forwarded to the subscriber's voice-mail box and the subscriber checks for messages via a personal security code.

1.7.6 Fax Mail

With this service, the subscriber can receive fax messages at any fax machine. The messages are stored in a service center from which the subscriber via a personal security code to the desired fax number can retrieve them.

1.8 Supplementary Services

GSM supports a comprehensive set of supplementary services that can complement and support both telephony and data services. Supplementary services are defined by GSM and are characterized as revenue-generating features. A partial listing of supplementary services follows:

1.8.1 Call Forwarding

This service gives the subscriber the ability to forward incoming calls to another number if the called mobile unit is not reachable, if it is busy, if there is no reply, or if call forwarding is allowed unconditionally.

1.8.2 Barring Of Outgoing Calls

This service makes it possible for a mobile subscriber to prevent all outgoing calls.

1.8.3 Barring Of Incoming Calls

This function allows the subscriber to prevent incoming calls. The following two conditions for incoming call barring exist: baring of all incoming calls and barring of incoming calls when roaming outside the home PLMN.

1.8.4 Advice of Charge (AoC)

The AoC service provides the mobile subscriber with an estimate of the call charges. There are two types of AoC information: one that provides the subscriber with an estimate of the bill and one that can be used for immediate charging purposes. AoC for data calls is provided on the basis of time measurements.

1.8.5 Call Hold

This service enables the subscriber to interrupt an ongoing call and then subsequently reestablish the call. The call holds service is only applicable to normal telephony.

1.8.6 Call Waiting

This service enables the mobile subscriber to be notified of an incoming call during a conversation. The subscriber can answer, reject, or ignore the incoming call. Call waiting is applicable to all GSM telecommunications services using a circuit-switched connection.

1.8.7 Multiparty Service

The multiparty service enables a mobile subscriber to establish a multiparty conversation that is, a simultaneous conversation between three and six subscribers. This service is only applicable to normal telephony

1.8.8 Calling Line Identification Presentation/Restriction

These services supply the called party with the integrated services digital network (ISDN) number of the calling party. The restriction service enables the calling party to restrict the presentation. The restriction overrides the presentation.

1.8.9 Closed User Groups (CUGs)

CUGs are generally comparable to a PBX. They are a group of subscribers who are capable of only calling themselves and certain numbers.

1.9 SUMMARY

Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard that would formulate specifications for a pan-European mobile cellular radio system operating at 900 Mhz. It is estimated that many countries outside of Europe will join the GSM partnership.

2. ARCHITECTURE OF GSM

2.1 Overview

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. 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 a very limited market for each type of equipment, so economies of scale, and the subsequent savings, could not be realized.

In 1981 a joint Franco German study was initiated to develop a common approach, which, it was hoped, would become a standard for Europe. Soon after, in 1982 a 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. Then a study group formed 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:

1. Good subjective speech quality.
2. Low terminal and service cost.
3. Support for international roaming.
4. Ability to support handheld terminals.
5. Support for range of new services and facilities.
6. Spectral efficiency.
7. ISDN compatibility.

In 1989, GSM responsibility was transferred to the European Telecommunication Standards Institute (ETSI), and phase I of the GSM specifications was published in 1990. Commercial service was started in mid-1991, and by 1993 there were 36 GSM networks in 22 countries. 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 networking 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 original French name was later changed to Global System for Mobile Communications, but the original GSM acronym stuck.

Global System for Mobile communications is a digital cellular communications system. It was developed in order to create a common European mobile telephone standard but it has been rapidly accepted worldwide. GSM was designed to be compatible with ISDN services.

The Global System for Mobile communications (GSM) is a digital cellular communications system initially developed in an European context which has rapidly gained acceptance and market share worldwide. It was designed to be compatible with ISDN systems and the services provided by GSM are a subset of the standard ISDN services (speech is the most basic).

The functional architecture of a GSM system can be divided into the Mobile Station (MS), the Base Station (BS), and the Network Subsystem (NS). The MS is carried by the subscriber, the BS subsystem controls the radio link with the MS and the NS performs the switching of calls between the mobile and other fixed or mobile network users as well as mobility management. The MS and the BS subsystem communicate across the Um interface also known as radio link.

2.2 History of the Cellular Mobile Radio and GSM

The idea of cell-based mobile radio systems appeared at Bell Laboratories (in USA) in the early 1970s. However, mobile cellular systems were not introduced for commercial use until the 1980s. During the early 1980s, analog cellular telephone systems experienced a very rapid growth in Europe, particularly in Scandinavia and the United Kingdom. Today cellular systems still represent one of the fastest growing telecommunications systems, but in the beginnings of cellular systems, each country developed its own system, which was an undesirable situation for the following reasons:

1. The equipment was limited to operate only within the boundaries of each country.
2. The market for each mobile equipment was limited.

In order to overcome these problems, the Conference of European Posts and Telecommunications (CEPT) formed, in 1982, the Group Special Mobile (GSM) in order to develop a pan-European mobile cellular radio system (the GSM acronym became later the acronym for Global System for Mobile communications). The standardized system had to meet certain criteria:

1. Spectrum efficiency
2. International roaming
3. Low mobile and base stations costs
4. Good subjective voice quality
5. Compatibility with other systems such as ISDN (Integrated Services Digital Network)
6. Ability to support new services

Unlike the existing cellular systems, which were developed using an analog technology, the GSM system was developed using a digital technology. The reasons for this choice are explained.

In 1989 the responsibility for the GSM specifications passed from the CEPT to the European Telecommunications Standards Institute (ETSI). The aim of the GSM specifications is to describe the functionality and the interface for each component of the system, and to provide guidance on the design of the system. These specifications will then standardize the system in order to guarantee the proper networking between the different elements of the GSM system. In 1990, the phase I of the GSM specifications was published but the commercial use of GSM did not start until mid 1991.

The most important events in the development of the GSM system are presented in the table 2.1

Table 2.1 Events in the development of GSM

Year	Events
1982	CEPT establishes a GSM group in order to develop the standards for a pan-European cellular mobile system
1985	Adoption of a list of recommendations to be generated by the group
1986	Field tests were performed in order to test the different radio techniques proposed for the air interface
1987	TDMA is chosen as access method (in fact, it will be used with FDMA) Initial Memorandum of Understanding (MoU) signed by telecommunication operators (representing 12 countries)
1988	Validation of the GSM system
1989	The responsibility of the GSM specifications is passed to the ETSI
1990	Appearance of the phase 1 of the GSM specifications
1991	Commercial launch of the GSM service
1992	Enlargement of the countries that signed the GSM- MoU> Coverage of larger cities/airports
1993	Coverage of main roads GSM services start outside Europe
1995	Phase 2 of the GSM specifications Coverage of rural areas

From the evolution of GSM, it is clear that GSM is not anymore only a European standard. GSM networks are operational or planned in over 80 countries around the world. The rapid and increasing acceptance of the GSM system is illustrated with the following figures:

1. 1.3 million GSM subscribers worldwide in the beginning of 1994.

2. Over 5 million GSM subscribers worldwide in the beginning of 1995.

3. Over 10 million GSM subscribers only in Europe by December 1995.

Since the appearance of GSM, other digital mobile systems have been developed. The table 2.2 charts the different mobile cellular systems developed since the commercial launch of cellular systems.

Table 2.2 Mobile cellular systems

Year	Mobile Cellular System
1981	Nordic Mobile Telephony (NMT), 450>
1983	American Mobile Phone System (AMPS)
1985	Total Access Communication System (TACS) Radiocom 2000 C-Netz
1986	Nordic Mobile Telephony (NMT), 900>
1991	Global System for Mobile communications> North American Digital Cellular (NADC)
1992	Digital Cellular System (DCS) 1800
1994	Personal Digital Cellular (PDC) or Japanese Digital Cellular (JDC)
1995	Personal Communications Systems (PCS) 1900- Canada>
1996	PCS-United States of America>

2.3 Architecture of the GSM Network

The GSM network is composed of several functional entities, whose functions and interfaces are defined. The GSM network can be divided into four 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, performs the switching of calls between the mobile and other fixed or mobile network users, as well as management of mobile services, such as authentication. With the Operations and Maintenance center, which oversees the proper operation and setup of the network. And the operational and support subsystem. The Mobile Station and the Base Station Subsystem communicate across the Um interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile service Switching Center.

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:

1. The Mobile Station (MS).
2. The Base Station Subsystem (BSS).
3. The Network and Switching Subsystem (NSS).
4. The Operation and Support Subsystem (OSS).

The architecture of the GSM network is presented in (Figure 2.1).

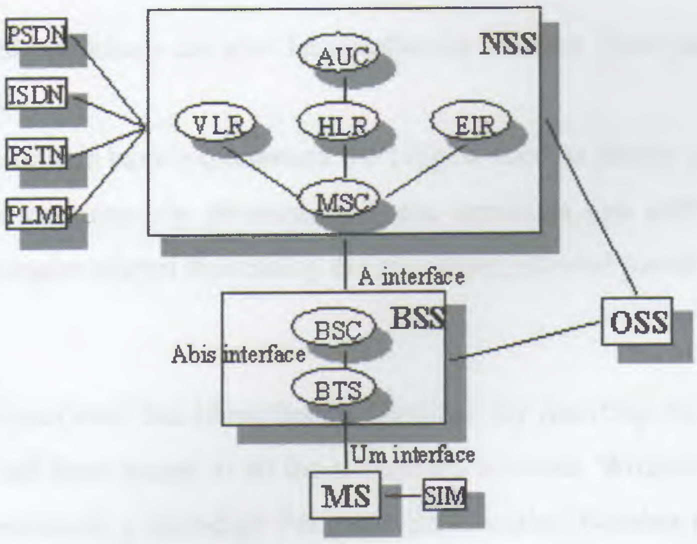

Figure 2.1: Architecture of the GSM network

2.3.1 Mobile Station

The mobile station (MS) consists of the physical equipment, such as the radio transceiver, display and digital signal processors, and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to all subscribed services irrespective of both the location of the terminal and the use of a specific terminal. By inserting the SIM card into another GSM cellular phone, the user is able to receive calls at that phone, make calls from that phone, or 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), identifying the subscriber, a secret key for authentication, and other user information. The IMEI and the IMSI are independent, thereby providing personal mobility. The SIM card may be protected against unauthorized use by a password or personal identity number.

2.3.1.1 The Terminal

There are different types of terminals distinguished principally by their power and application:

1. The fixed terminals are the ones installed in cars. Their maximum allowed output power is 20 W.
2. The GSM portable terminals can also be installed in vehicles. Their maximum allowed output power is 8W.
3. 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 decreasing the maximum allowed power to 0.8 W.

2.3.1.2 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 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.

2.3.2 The Base Station Subsystem

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

The BTS 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. The requirements for a BTS are ruggedness, reliability, portability, and minimum cost. BTS is responsible for providing layers 1 and 2 of the radio interface, that is, an error-corrected data path. Each BTS has at least one of its radio channels assigned to carry control signals in addition to traffic.

The BSC manages the radio resources for one or more BTSs. It is responsible for the management of the radio resource within a region. Its main functions are to allocate and control traffic channels, control frequency hopping, undertake handovers (except to cells outside its region) and provide radio performance measurements. Once the mobile has accessed, and synchronized with, a BTS the BSC will allocate it a dedicated bi-directional signaling channel and will set up a route to the Mobile services 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.

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:

2.3.2.1 The Base Transceiver Station

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.

2.3.2.2 The Base Station Controller

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.

2.3.3 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 in addition 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 public fixed network (PSTN or ISDN), and signaling between functional entities uses the ITUT Signaling System Number 7 (SS7), used 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 (possibly international) 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. It also contains a *unique authentication key and associated challenge/response generators.*

The current location of the mobile is in the form of a Mobile Station Roaming Number (MSRN), which is a regular ISDN number used to route a call to the MSC where the mobile is currently located. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

The 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, most manufacturers of switching equipment implement one VLR together with one MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR, 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

Mobile Equipment Identity (IMEI). An IMEI is marked as invalid if it has been reported stolen or is not type approved. The Authentication Canter 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 ciphering of the radio channel.

The 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.

2.3.3.1 The Mobile services Switching Center (MSC)

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

2.3.3.2 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.

2.3.3.3 Home Location Register (HLR)

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

2.3.3.4 Visitor Location Register (VLR)

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.

2.3.3.5 The Authentication Center (AuC)

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.

2.3.3.6 The Equipment Identity Register (EIR)

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).

2.3.3.7 The GSM Interlocking Unit (GIWU)

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

2.3.4 The Operation and Support Subsystem (OSS)

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 transferred to the BTS. This transfer decreases considerably the costs of the maintenance of the system.

2.4 The Geographical Areas of The GSM Network

The (figure 2.2) presents the different areas that form a GSM network.

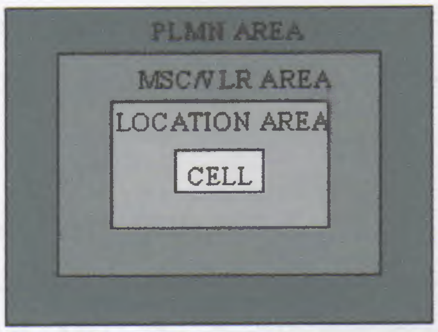

Figure 2.2: GSM network areas

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

2.5 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:

1. Transmission.
2. Radio Resources management (RR).
3. Mobility Management (MM).
4. Communication Management (CM).
5. Operations, Administration and Maintenance (OAM).

2.5.1 Transmission

The transmission function includes two sub-functions:

1. The first one is related to the means needed for the transmission of user information.
2. 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.

2.5.2 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:

1. Channel assignment, change and release.
2. Handover.
3. Frequency hopping.
4. Power-level control.
5. Discontinuous transmission and reception.
6. Timing advance.

Handover, which represents one of the most important responsibilities of the RR, will Be described:

2.5.2.1 Handover:

Movements can produce the need to change the channel or cell, especially 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:

1. Handover of channels in the same cell.
2. Handover of cells controlled by the same BSC.
3. Handover of cells belonging to the same MSC but controlled by different BSCs.
4. 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 deciding which is the best cell in order to maintain the quality of the communication link. Two basic algorithms are used for the handover:

2.5.2.2 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.

2.5.2.3 The power budget algorithm.

This algorithm performs a handover, instead of continuously increasing the power level, in order to obtain a good communication quality.

2.5.3 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.

2.5.3.1 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.

2.5.3.2 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.

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2.5.4 Communication Management (CM)

The CM function is responsible for:

a. Call control.

b. Supplementary Services management.

c. Short Message Services management.

2.5.4.1 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 dials the Mobile Subscriber ISDN (MSISDN) number, which includes:

a. A country code

b. A national destination code identifying the subscriber's operator

c. 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.

2.5.4.2 Supplementary Services Management

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

2.5.4.3 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:

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

2.5.5 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 as it is shown in the following examples:

1. 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 analyzing it and control the network.
2. The self-test tasks, usually incorporated in the components of the BSS and NSS, also contribute to the OAM functions.
3. The BSC, in charge of controlling several BTSs, is another example of an OAM function performed outside the OSS.

2.6 How Does It Work

2.6.1 Make Call

When the mobile user initiates a call, his equipment will search for a local base station, i.e. The BSS. Once the mobile has accessed, and synchronized with, a BTS the BSC will allocate it a dedicated bi-directional signaling channel and will set up a route to the Mobile services Switching Center (MSC).

2.6.2 Call Initialization

When a mobile requests access to the system it has to supply its IMEI (International Mobile Equipment Identity). This is a unique number, which will allow the system to initiate a process to confirm that the subscriber is allowed to access it. This process is called authentication. Before it can do this, however, it has to find where the subscriber is based. Every subscriber is allocated to a home network, associated with an MSC within that network. This is achieved by making an entry in the Home Location Register (HLR), which contains information about the services the subscriber is allowed.

Whenever a mobile is switched on and at intervals thereafter, it will register with the system; this allows its location in the network to be established and its location area to be updated in the HLR. A location area is a geographically defined group of cells. On first registering, the local MSC will use the IMSI to interrogate the subscriber's HLR and will add the subscriber data to its associated Visitor Location Register (VLR). The VLR now contains the address of the subscriber's HLR and the authentication request is routed back through the HLR to the subscriber's Authentication Centre (AC). This generates a challenge/response pair, which is used by the local network to challenge the mobile. In addition, some operators also plan to check the mobile equipment against an Equipment Identity Register (EIR), in order to control stolen, fraudulent or faulty equipment.

2.6.3 Authentication

The authentication process is very powerful and is based on advanced cryptographic principles. It especially protects the network operators from fraudulent use of their services. It does not however protect the user from eavesdropping. The Time Division Multiple Access (TDMA) nature of GSM coupled with its frequency hopping facility will make it very difficult for an eavesdropper to lock onto the correct signal however and thus there is a much higher degree of inherent security in the system than is found in today's analogue systems. Nevertheless for users who need assurance of a secure transmission, GSM offers encryption over the air interface. This is based on a public key encryption principle and provides very high security.

2.6.4 Call Set-up

Once the network accepts the user and his equipment, the mobile must define the type of service it requires (voice, data, supplementary services etc.) and the destination number. At this point a traffic channel with the relevant capacity will be allocated and the MSC will route the call to the destination. Note that the network may delay assigning the traffic channel until the connection is made with the called number. This is known as off-air call set-up, and it can reduce the radio channel occupancy of any one call thus increasing the system traffic capacity.

2.7 SUMMARY

The developers of GSM chose digital system, as opposed to the 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. GSM was designed to be compatible with ISDN services.

3. Mobile Communications System

3.1 Overview

This chapter discusses the basics of radiotelephony systems, including both analog and digital systems. The advantages of digital cellular technologies over analog cellular networks include increased capacity and security. Technology options such as TDMA and CDMA offer more channels in the same analog cellular bandwidth and encrypted voice and data.

3.2 Mobile Communications Principles

Each mobile uses a separate, temporary radio channel to talk to the cell site. The cell site talks to many mobiles at once, using one channel per mobile. Channels use a pair of frequencies for communication one frequency, the forward link, for transmitting from the cell site, and one frequency, the reverse link, for the cell site to receive calls from the users. Radio energy dissipates over distance, so mobiles must stay near the base station to maintain communications. The basic structure of mobile networks includes telephone systems and radio services. Where mobile radio service operates in a closed network and has no access to the telephone system, mobile telephone service allows interconnection to the telephone network (Figure 3.1).

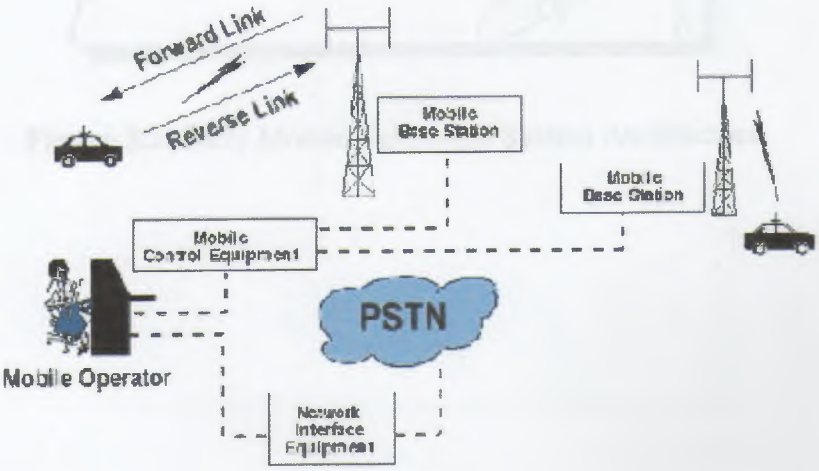

Figure 3.1: Basic Mobile Telephone Service Network

3.2.1 Early Mobile Telephone System Architecture

Traditional mobile service was structured similar to television broadcasting: One very Powerful transmitter located at the highest spot in an area would broadcast in a radius of up to fifty kilometers. The cellular concept" structured the mobile telephone network in a different way. Instead of using one powerful transmitter, many low-power transmitters were placed throughout a coverage area. For example, by dividing a metropolitan region into one hundred different areas (cells) with low-power transmitters using twelve conversations (channels) each, the system capacity theoretically could be increased from twelve conversations or voice channels using one powerful transmitter to twelve hundred conversations (channels) using one hundred low-power transmitters. (Figure 3.2) shows a metropolitan area configured as a traditional mobile telephone network with one high-power transmitter.

Figure 3.2: Early Mobile Telephone System Architecture

3.3 Mobile Telephone System Using the Cellular Concept

Interference problems caused by mobile units using the same channel in adjacent areas proved that all channels could not be reused in every cell. Areas had to be skipped before the same channel could be reused. Even though this affected the efficiency of the original concept, frequency reuse was still a viable solution to the problems of mobile telephony systems.

Engineers discovered that the interference effects were not due to the distance between areas, but to the ratio of the distance between areas to the transmitter power (radius) of the areas. By reducing the radius of an area by fifty percent, service providers could increase the number of potential customers in an area fourfold. Systems based on areas with a one-kilometer radius would have one hundred times more channels than systems with areas ten kilometers in radius. Speculation led to the conclusion that by reducing the radius of areas to a few hundred meters, millions of calls could be served.

The cellular concept employs variable low-power levels, which allows cells to be sized according to the subscriber density and demand of a given area. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between cells (Figure 3.3).

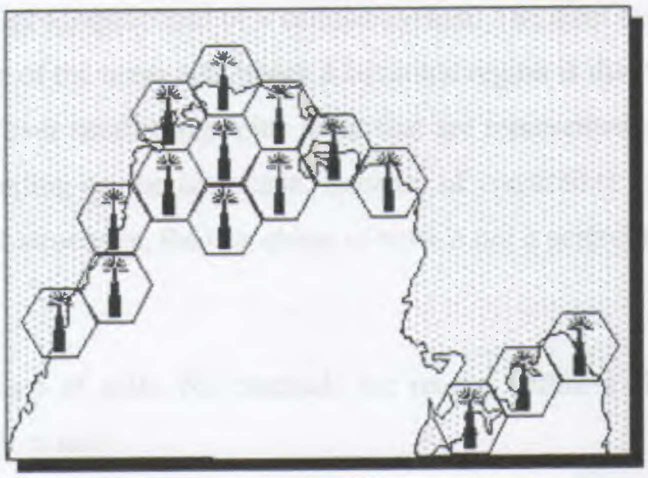

Figure 3.3: Mobile Telephone System Using a Cellular Architecture

The cellular radio equipment (base station) can communicate with mobiles as long as they are within range. Radio energy dissipates over distance, so the mobiles must be within the operating range of the base station. Like the early mobile radio system, the base station communicates with mobiles via a channel. The channel is made of two frequencies, one for transmitting to the base station and one to receive information from the base station.

3.4 Cellular System Architecture

Increases in demand and the poor quality of existing service led mobile service providers to research ways to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular use was limited, efficient use of the required frequencies was needed for mobile cellular coverage. In modern cellular telephony, rural and urban regions are divided into areas according to specific provisioning guidelines. Engineers experienced in cellular system architecture determine deployment parameters, such as amount of cell-splitting and cell sizes.

Provisioning for each region is planned according to an engineering plan that includes cells, clusters, frequency reuse, and handovers.

3.4.1 Cells

A cell is the basic geographic unit of a cellular system. The term *cellular* comes from the honeycomb shape of the areas into which a coverage region is divided. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending on the landscape. Because of constraints imposed by natural terrain and man-made structures, the true shape of cells is not a perfect hexagon.

3.4.2 Clusters

A cluster is a group of cells. No channels are reused within a cluster. (Figure3.4) Illustrates a seven-cell cluster.

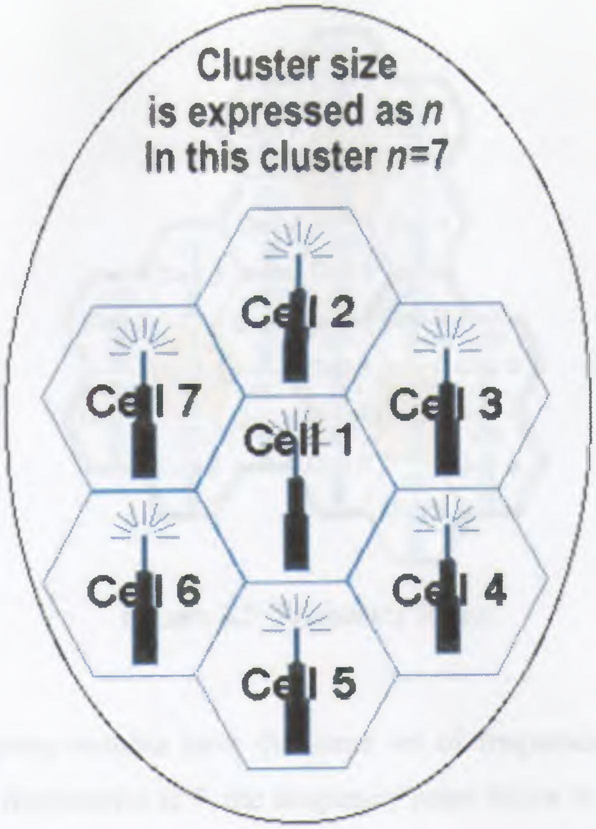

Figure3.4: A Seven-Cell Cluster

3.4.3 Frequency Reuse

Because only a small number of radio channel frequencies were available for mobile systems, engineers had to find a way to reuse radio channels in order to carry more than one conversation at a time. The solution the industry adopted was called frequency planning or frequency reuse. Frequency reuse was implemented by restructuring the mobile telephone system architecture into the cellular concept.

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned a group of channels that is completely different from neighboring cells. The coverage area of cells is called the footprint. This footprint is limited by a boundary so that the same group of channels can be used in different cells that are far enough away from each other so that their frequencies do not interfere (Figure 3.5).

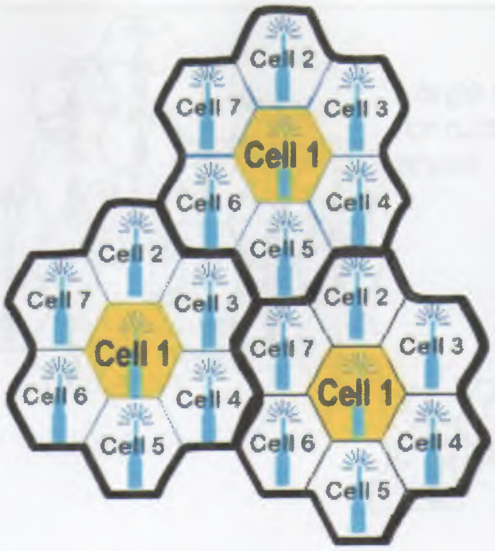

Figure 3.5: Frequency Reuse

Cells with the same number have the same set of frequencies. Here, because the number of available frequencies is 7, the frequency reuse factor is 1/7. That is, each cell is using 1/7 of available cellular channels.

3.4.4 Cell Splitting

Unfortunately, economic considerations made the concept of creating full systems with many small areas impractical. To overcome this difficulty, system operators developed the idea of cell splitting. As a service area becomes full of users, this approach is used to split a single area into smaller ones. In this way, urban centers can be split into as many areas as necessary in order to provide acceptable service levels in heavy-traffic regions, while larger, less expensive cells can be used to cover remote rural regions (Figure 3.6).

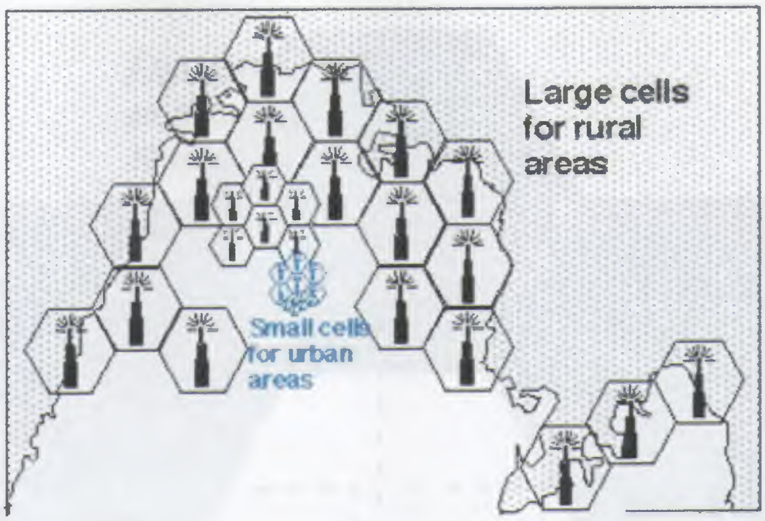

Figure 3.6: Cell Splitting

3.4.5 Handoff

The final obstacle in the development of the cellular network involved the problem created when a mobile subscriber traveled from one cell to another during a call. As adjacent areas do not use the same radio channels, a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells. Because dropping the call is unacceptable, the process of handoff was created. Handoff occurs when the mobile telephone network automatically transfers a call from radio channel to radio channel as a mobile crosses adjacent cells (Figure 3.7).

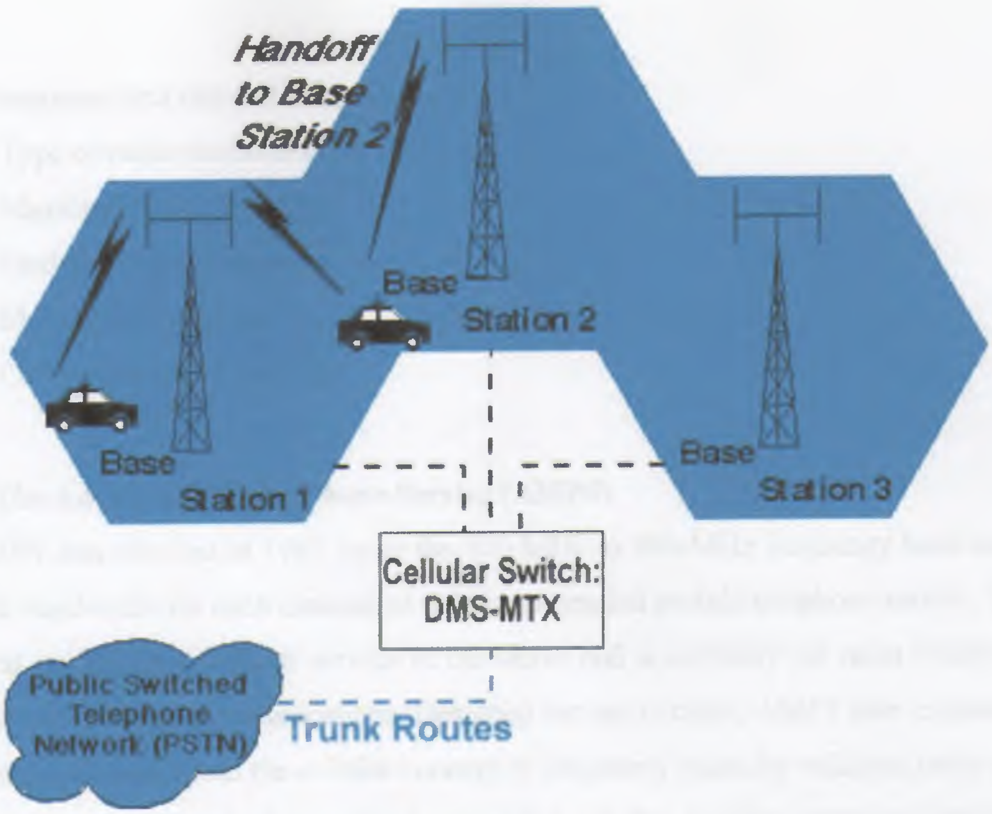

Figure 3.7: Handoff between Adjacent Cells

During a call, two parties are on one voice channel. When the mobile unit moves out of the coverage area of a given cell site, the reception becomes weak. At this point, the cell site in use requests a handoff. The system switches the call to a stronger-frequency channel in a new site without interrupting the call or alerting the user. The call continues as long as the user is talking, and the user does not notice the handoff at all.

3.5 North American Analog Cellular Systems

Originally devised in the late 1970s to early 1980s, analog systems have been revised somewhat since that time and operate in the 800-MHz range. A group of government, Telco, and equipment manufacturers worked together as a committee to develop a set of rules (protocols) that govern how cellular subscriber units (mobiles) communicate with the "cellular system." System development takes into consideration many different, and often opposing, requirements for the system, and often a compromise between conflicting requirements results. Cellular development involves some basic topics:

1. Frequency and channel assignments
2. Type of radio modulation
3. Maximum power levels
4. Modulation parameters
5. Messaging protocols
6. Call-processing sequences

3.5.1 The Advanced Mobile Phone Service (AMPS)

AMPS was released in 1983 using the 800-MHz to 900-MHz frequency band and the 30 kHz bandwidth for each channel as a fully automated mobile telephone service. It was the first standardized cellular service in the world and is currently the most widely used standard for cellular communications. Designed for use in cities, AMPS later expanded to rural areas. It maximized the cellular concept of frequency reuse by reducing radio power output. The AMPS telephones (or handsets) have the familiar telephone-style user interface and are compatible with any AMPS base station. This makes mobility between service providers (roaming) simpler for subscribers. Limitations associated with AMPS include:

1. Low calling capacity
2. Limited spectrum
3. No room for spectrum growth
4. Poor data communications
5. Minimal privacy
6. Inadequate fraud protection

AMPS is used throughout the world and is particularly popular in the United States, South America, China, and Australia. AMPS uses frequency modulation (FM) for radio transmission. In the United States, transmissions from mobile to cell site use separate frequencies from the base station to the mobile subscriber.

3.5.2 Narrowband Analog Mobile Phone Service (NAMPS)

Since analog cellular was developed, systems have been implemented extensively throughout the world as first-generation cellular technology. In the second generation of analog cellular systems, NAMPS was designed to solve the problem of low calling capacity. NAMPS is now operational in 35 U.S. and overseas markets and NAMPS was introduced as an interim solution to capacity problems. NAMPS is a U.S. cellular radio system that combines existing voice processing with digital signaling, tripling the capacity of today's AMPS systems. The NAMPS concept uses frequency division to get three channels in the AMPS 30-kHz single channel bandwidth. NAMPS provides three users in an AMPS channel by dividing the 30-kHz AMPS bandwidth into three 10-kHz channels. This increases the possibility of interference because channel bandwidth is reduced.

1.6 Cellular System Components

The cellular system offers mobile and portable telephone stations the same service provided fixed stations over conventional wired loops. It has the capacity to serve tens of thousands of subscribers in a major metropolitan area. The cellular communications system consists of the following four major components that work together to provide mobile service to subscribers (Figure 3.8):

1. Public switched telephone network (PSTN)
2. Mobile telephone switching office (MTSO)
3. Cell site with antenna system
4. Mobile subscriber unit (MSU)

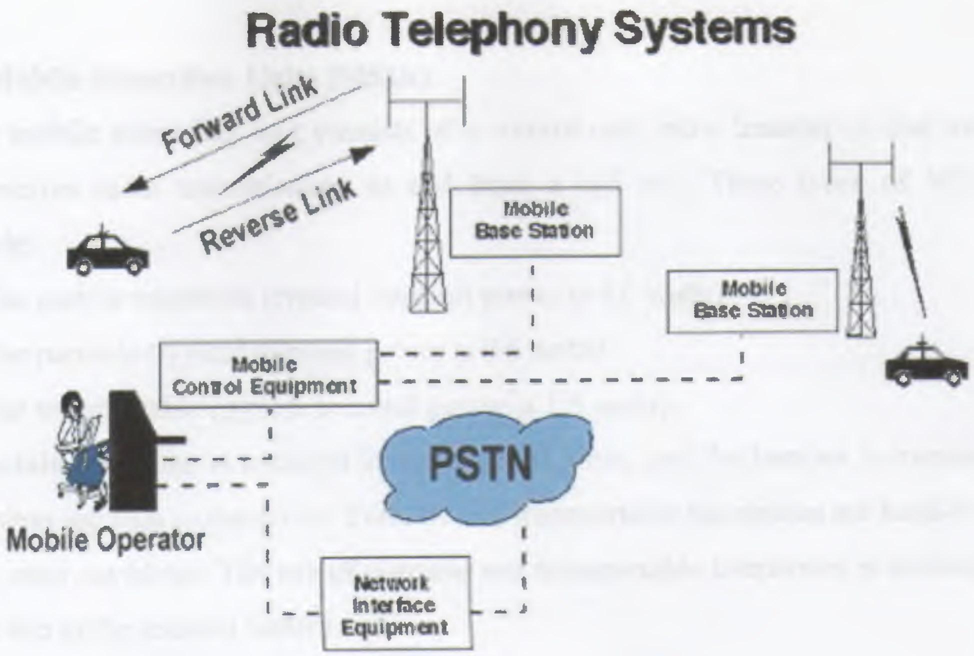

Figure 3.8: Cellular System Components

3.6.1 PSTN

The PSTN is made up of local networks, the exchange area networks, and the long-haul network that interconnect telephones and other communication devices on a worldwide basis.

3.6.2 Mobile Telephone Switching Office (MTSO)

The MTSO is the central office for mobile switching. It houses the mobile switching center (MSC), field monitoring and relay stations for switching calls from cell sites to wire line central offices (PSTN). In analog cellular networks, the MSC controls the system operation. The MSC controls calls, tracks billing information, and locates cellular subscribers.

3.6.3 The Cell Site

The term cell site is used to refer to the physical location of radio equipment that provides coverage within a cell. A list of hardware located at a cell site includes power sources, interface equipment, radio frequency transmitters and receivers, and antenna systems.

3.6.4 Mobile Subscriber Units (MSUs)

The mobile subscriber unit consists of a control unit and a transceiver that transmits and receives radio transmissions to and from a cell site. Three types of MSUs are available:

1. The mobile telephone (typical transmit power is 4.0 watts)
2. The portable (typical transmit power is 0.6 watts)
3. The transportable (typical transmit power is 1.6 watts)

The mobile telephone is installed in the trunk of a car, and the handset is installed in a convenient location to the driver. Portable and transportable telephones are hand-held and can be used anywhere. The use of portable and transportable telephones is limited to the charge life of the internal battery.

3.7 Digital Systems

As demand for mobile telephone service has increased, service providers found that basic engineering assumptions borrowed from wire line (landline) networks did not hold true in mobile systems. While the average landline phone call lasts at least ten minutes, mobile calls usually run ninety seconds. Engineers who expected to assign fifty or more mobile phones to the same radio channel found that by doing so they increased the probability that a user would not get dial tone—this is known as call-blocking probability. As a consequence, the early systems quickly became saturated, and the quality of service decreased rapidly. The critical problem was capacity. The general characteristics of TDMA, GSM, PCS1900, and CDMA promise to significantly increase the efficiency of cellular telephone systems to allow a greater number of simultaneous conversations. (Figure 3.9) shows the components of a typical digital cellular system.

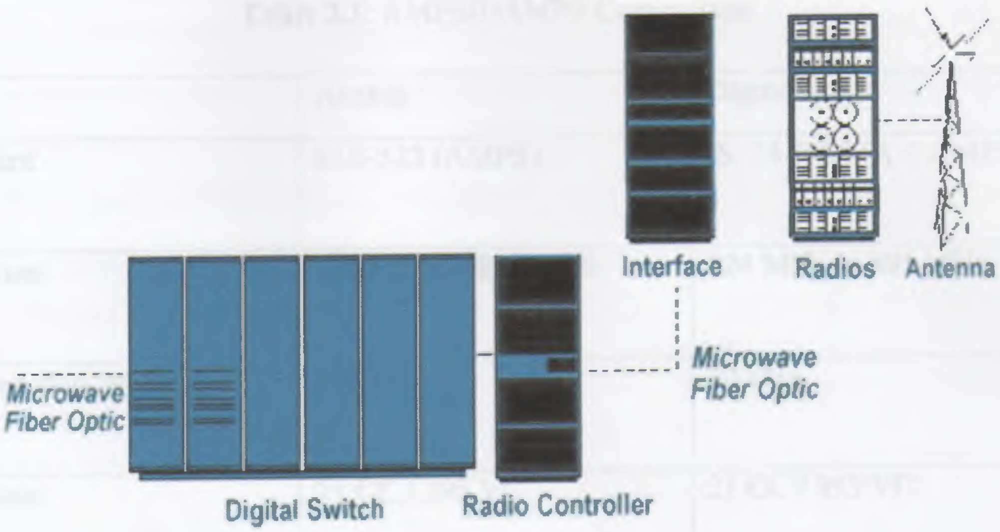

Figure 3.9: Digital Cellular System

The advantages of digital cellular technologies over analog cellular networks include increased capacity and security. Technology options such as TDMA and CDMA offer more channels in the same analog cellular bandwidth and encrypted voice and data. Because of the enormous amount of money that service providers have invested in AMPS hardware and software, providers look for a migration from AMPS to DAMPS by overlaying their existing networks with TDMA architectures.

Table 3.1: AMPS/DAMPS Comparison

	Analog	Digital
Standard	EIA-533 (AMPS)	IS–54 (TDMA + AMPS
Spectrum	824 MHz to 891 MHz	824 MHz to 891 MHz
Channel Bandwidth	30 kHz	30 kHz
Channels	21 CC / 395 VC	21 CC / 395 VC
Conversations per Channel	1	3 or 6
Subscriber Capacity	40 to 50 Conversations per cell	125 to 300 Conversations per cell
TX/RCV Type	Continuous	Time-shared bursts
Carrier Type	Constant phase Variable frequency	Constant frequency Variable phase
Mobile/Base Relation ship	Mobile slaved to base	Authority shared cooperatively
Privacy	Poor	Better—easily scrambled
Noise Immunity	Poor	High
Fraud Detection	ESN plus optional password (PIN)	ESN plus optional password (PIN)

3.7.1 Time Division Multiple Access (TDMA)

North American digital cellular (NADC) is called DAMPS and TDMA. Because AMPS preceded digital cellular systems, DAMPS uses the same setup protocols as analog AMPS. TDMA has the following characteristics:

1. IS–54 standard specifies traffic on digital voice channels
2. Initial implementation triples the calling capacity of AMPS systems
3. Capacity improvements of 6 to 15 times that of AMPS are possible
4. Uses many blocks of spectrum in 800 MHz and 1900 MHz
5. All transmissions are digital
6. TDMA/FDMA application 7. 3 callers per radio carrier (6 callers on half rate later), providing three times the AMPS capacity.

TDMA is one of several technologies used in wireless communications. TDMA provides each call with time slots so that several calls can occupy one bandwidth. Each caller is assigned a specific time slot. In some cellular systems, digital packets of information are sent during each time slot and reassembled by the receiving equipment into the original voice components. TDMA uses the same frequency band and channel allocations as AMPS. Like NAMPS, TDMA provides three to six time channels in the same bandwidth as a single AMPS channel. Unlike NAMPS, digital systems have the means to compress the spectrum used to transmit voice information by compressing idle time and redundancy of normal speech. TDMA is the digital standard and has 30-kHz bandwidth. Using digital voice encoders, TDMA is able to use up to six channels in the same bandwidth where AMPS uses one channel.

3.7.2 Extended Time Division Multiple Access (E– TDMA)

The extended TDMA (E–TDMA) standard claims a capacity of fifteen times that of analog cellular systems. This capacity is achieved by compressing quiet time during conversations. E–TDMA divides the finite number of cellular frequencies into more time slots than TDMA. This allows the system to support more simultaneous cellular calls.

3.7.3 Fixed Wireless Access (FWA)

Fixed wireless access (FWA) is a radio-based local exchange service in which telephone service is provided by common carriers (Figure 3.10). It is primarily a rural application that is, it reduces the cost of conventional wireline. FWA extends telephone service to rural areas by replacing a wire line local loop with radio communications. Other labels for wireless access include fixed loop, fixed radio access, wireless telephony, radio loop, fixed wireless, radio access, and Ionica. FWA systems employ TDMA or CDMA access technologies.

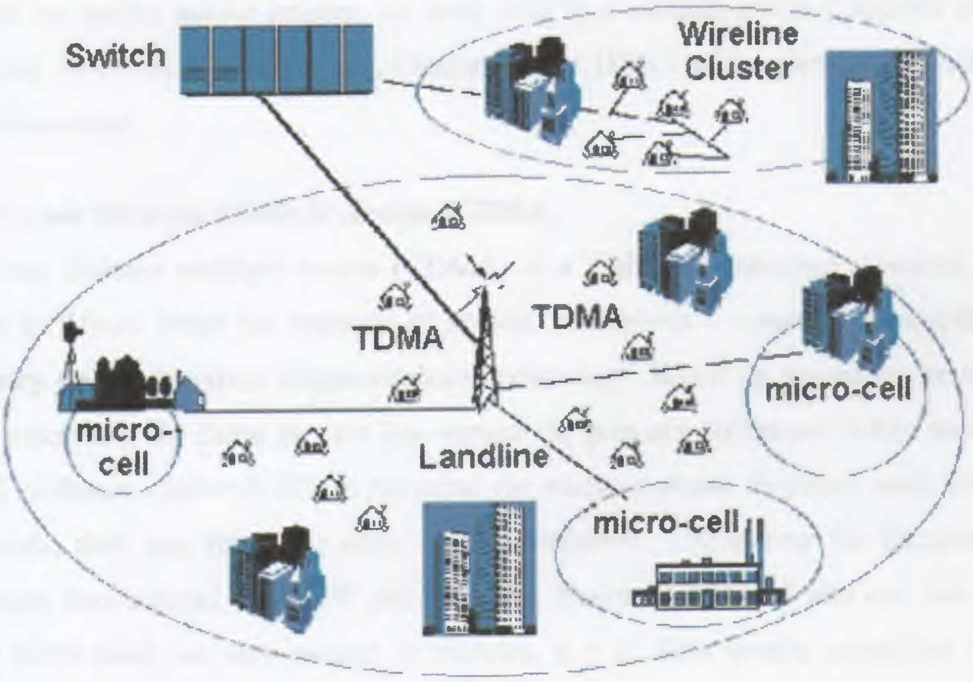

Figure 3.10: Fixed Wireless Access

3.7.4 Personal Communications Services (PCS)

The future of telecommunications includes personal communications services. PCS at 1900 MHz (PCS1900) is the North American implementation of DCS1800 (Global System for Mobile communications, or GSM). Trial networks were operational in the United States by 1993, and in 1994 the Federal Communications Commission (FCC) began spectrum auctions. As of 1995, the FCC auctioned commercial licenses. In the PCS frequency spectrum the operator's authorized frequency block contains a definite number of channels. The frequency plan assigns specific channels to specific cells, following a reuse pattern, which restarts with each *n*th cell. The uplink and downlink bands are paired mirror images. As with AMPS, a channel number implies one uplink and one downlink frequency: e.g., Channel 512 = 1850.2 MHz uplink paired with 1930.2 MHz downlink.

3.7.5 Code Division Multiple Access (CDMA)

Code division multiple access (CDMA) is a digital air interface standard, claiming eight to fifteen times the capacity of analog. It employs a commercial adaptation of military spread-spectrum single-sideband technology. Based on spread spectrum theory, it is essentially the same as wire line service the primary difference is that access to the local exchange carrier (LEC) is provided via wireless phone. Because users are isolated by code, they can share the same carrier frequency, eliminating the frequency reuse problem encountered in AMPS and DAMPS. Every CDMA cell site can use the same 1.25 MHz band, so with respect to clusters, n = 1. This greatly simplifies frequency planning in a fully CDMA environment.

CDMA is an interference-limited system. Unlike AMPS/TDMA, CDMA has a soft capacity limit; however, each user is a noise source on the shared channel and the noise contributed by users accumulates. This creates a practical limit to how many users a system will sustain. Mobiles that transmit excessive power increase interference to other mobiles. For CDMA, precise power control of mobiles is critical in maximizing the system's capacity and increasing battery life of the mobiles. The goal is to keep each mobile at the absolute minimum power level that is necessary to ensure acceptable service quality. Ideally, the power received at the base station from each mobile should be the same (minimum signal to interference).

3.8 SUMMARY

A mobile communications system uses a large number of low-power wireless transmitters to create cells the basic geographic service area of a wireless communications system. Variable power levels allow cells to be sized according to the subscriber density and demand within a particular region. As mobile users travel from cell to cell, their conversations are "handed off" between cells in order to maintain seamless service. Channels (frequencies) used in one cell can be reused in another cell some distance away. Cells can be added to accommodate growth, creating new cells in unserved areas or overlaying cells in existing areas.

4. GSM CELL PLANNING

4.1 Overview

An indoor system can be built for deferens reasons. If the coverage is poor form cells outside the building, leading to bad quality, a solution can be to build an indoor system. Buildings generating a high traffic load, like conference center and airports, may need indoor system to take care of the traffic. A different application is the business indoor system with the aim to complement or replace the fixed telephony network.

The aim with indoor cell planning is, as for "traditional" cell planning, to plan for good coverage and capacity and at the same time interfere as little as possible. How this can be achieved is briefly described here. The focus is on antenna and RBS system, RF design and antenna configuration but also frequency planning, capacity issues and traffic control are described

The tools for indoor cell planning, TEMS Prediction, TEMS Light and TEMS Transmitter, are also described with focus on how to use them in the planning process.

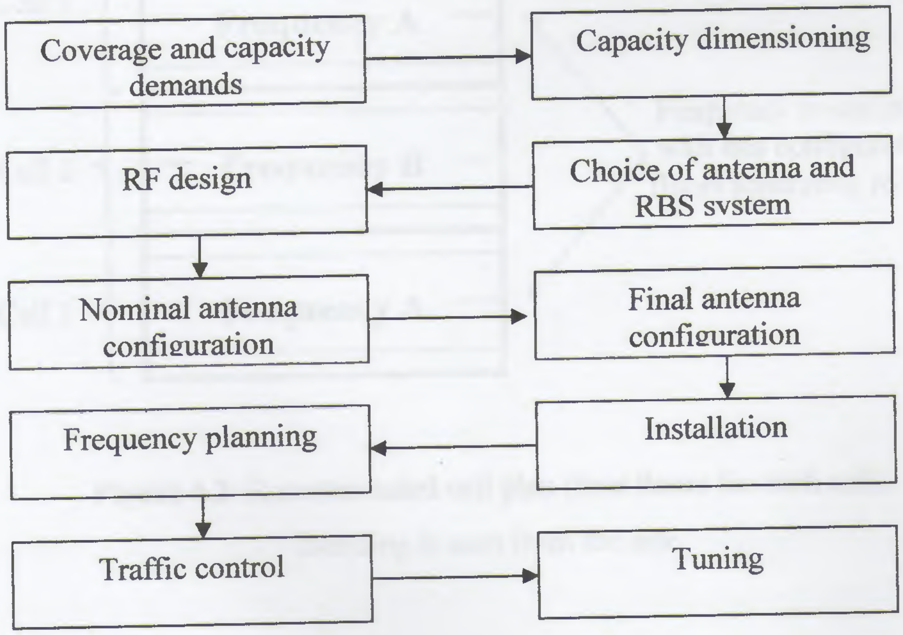

Figure 4.1: The workflow of indoor cell planning

4.2 Capacity Dimensioning

When dimensioning the capacity of an indoor cell, one must take its application into account. Two different categories of indoor cells can be identified:

1. Public indoors cells. Indoor cells which cover public buildings such as shopping centers and airport terminals.

2. Business indoors cells. Indoor cells covering areas such as offices. In some applications the coverage, capacity and quality demands in business indoor cells may be considerably higher than in public indoor cells, and the GOS must probably be very low.

4.2.1 Dividing One Cell into Several Cells

A way of increasing the capacity is to split the "one cell building" into more cells. This should only be considered when the building is large and the traffic demand is high. The splitting should be done into at least three cells to allow frequency re-use in the building, and the split should preferable be performed vertically. Horizontal splitting should be avoided, at least concerning frequency re-use, but may be necessary in low and long buildings.

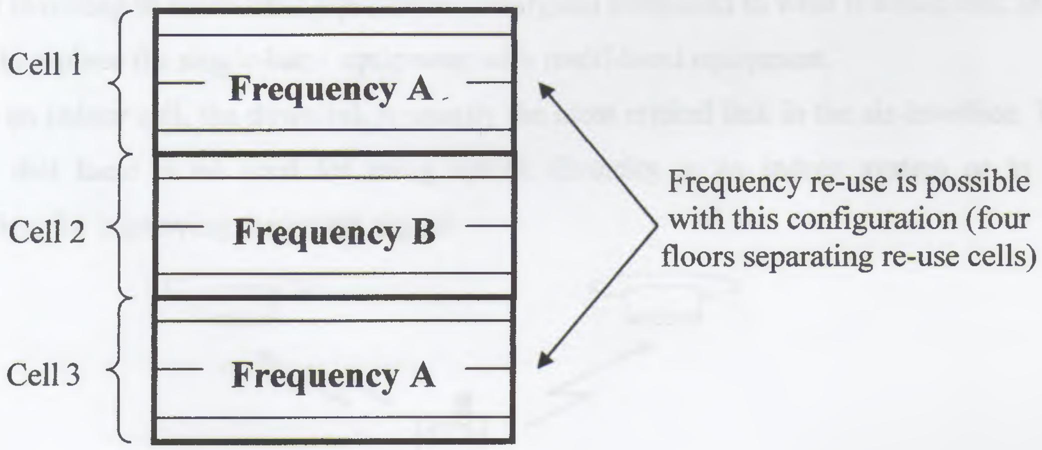

Figure 4.2: Recommended cell plan (four floors for each cell).
Building is seen from the side.

The cell size, for the separating cell, makes the re-use distance. The recommended separating distance is around four floors, depending on the leakage between the co-channel cells.

4.3 Antenna and RBS Systems

When designing an indoor system, the ambition is (note! this is not a requirement) to get the antenna network as symmetric as possible in order to provide each single antenna within the system with the same output power. It is desirable to place the RBS somewhere in the middle of the building in order to minimize feeder distance to the antennas.

Preparation for any future extension of the indoor system, both from a coverage point of view and from a capacity point of view, shall always be considered before the installation. The RF-link budget shall be calculated so that there is a possibility to add power splitters, hybrid couplers, etc. to the antenna system in case of further extension of the antenna network.

Although if the intention is, when planning an indoor system, to be operating on a GSM frequency single-band, it is better to prepare the antenna network for multi-band. The cost of investing in multi-band equipment is marginal compared to what it would cost in the future to replace the single-band equipment with multi-band equipment.

In an indoor cell, the downlink is usually the most critical link in the air-interface. This means that there is no need for using uplink diversity in an indoor system or to use amplifiers for improving the uplink signal.

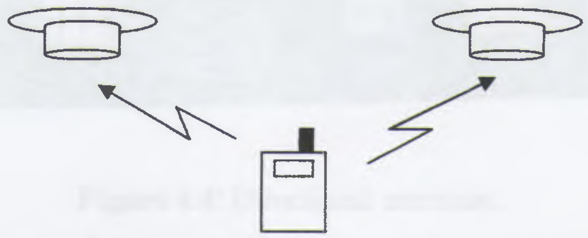

Figure 4.3: Reception of the uplink signal via several antennas

However, multi-antenna indoor systems are using a sort of uplink diversity, which will improve the uplink signal since it is received by several antennas, as depicted in Figure 4.3.

4.4 Antenna System

4.4.1 Antennas

The antenna configurations for indoor applications can be divided into four categories:

1. Integrated antennas, i.e. antennas integrated in the base station (possible only for RBS 2302).
2. Distributed antennas using a coax feeder network.
3. Leaking cable.
4. Distributed antennas using a fiber-optical feeder network.

Please notice that a single antenna is here considered to be a special case of distributed antennas.

There are several types of antennas that are suitable for indoor applications. The two most commonly used antenna types are the directional antenna (Figure 4.4) and the omni-directional antenna.

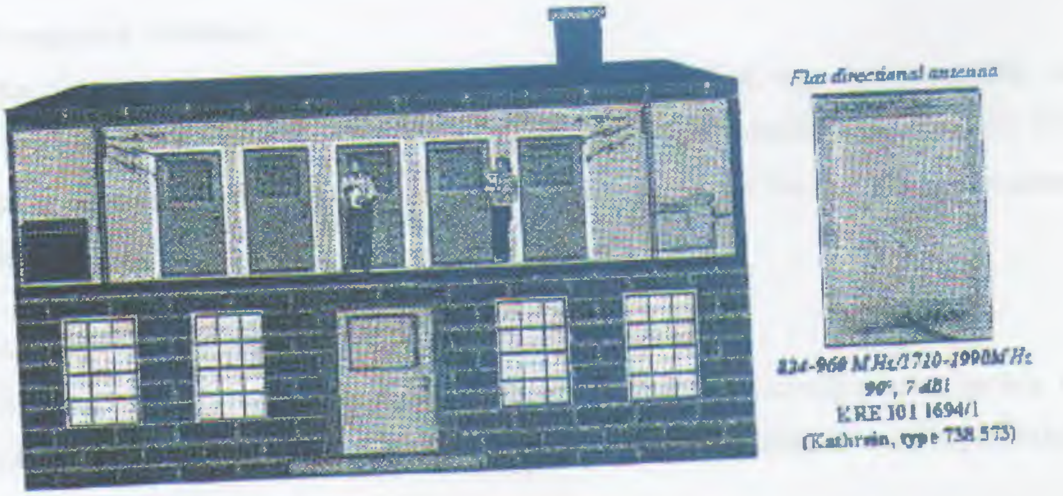

Figure 4.4: Directional antennas.

Two commonly used types of omni-directional antennas are the so called "Mexican hat" antenna and the so called "rod" or "tubular mast" antenna, Figure 4.5. Both types of antennas are attached to the ceiling where they are hard to spot among other equipment like smoke detectors. Comparing these two types of antennas, the "Mexican hat" is to prefer since it has a more stable construction than the "tubular mast".

Figure 4.5: Omni-directional antennas.

The "Mexican hat" is usually mounted without a jumper cable. The feeder is bent down into a drilled hole through the ceiling and connected to the antenna. When the antenna has been connected to the feeder, it is attached to the ceiling.

4.4.2 Integrated Antennas

An indoor area that could be covered from one location, e.g. open premises, and where it is possible to have the RBS mounted on a wall is a suitable application for RBS 2302 using the integrated antennas. Examples of applications are for instance sports arenas and railway stations.

4.4.3 Antennas Distributed via a Coax Feeder Network

Antennas distributed via a coax feeder network are the configuration having the widest range of applications. The attractive features of the configuration could explain this:

1. Low cost.
2. Flexibility in the design when shaping the coverage area:
   - Using unequally distributed power splitters can control power distribution.
   - Additional antennas are inexpensive and easy to add on.

3. Robust and well proven technique:

- No active devices in the antenna system requiring local power supply or supervision.

4.4.3.1 Coaxial Cable

The most suitable dimensions of coaxial feeder for indoor systems are listed (including typical feeder loss values) . The N connector is suitable for all the listed coaxial cables except for the 7/8" coaxial cable. The 7/8" coaxial cable, which is hard to install due to its inflexibility, should be used together with 7/16 connectors.

Table 4.1: Typical feeder loss values

Feeder type	Feeder loss, dB/100 m		Comments
	800-900MHz	1800-900MHz	
CF 1/4"	13.5	20.5	
LCF 3/8"	10	14.5	
1/2" Super flex	11	16.5	Suitable to use between hybrid couplers ets
LCF 1/2"	7	10.5	
LCF 7/8"	4	6.5	Conceivable but not recommended for indoor application

4.4.3.2 Power Splitters

Power splitters are used for splitting up the antenna feeder network. There are two types of power splitters:

1. Equally distributed

   The equally distributed power splitters divide the power equally over the output ports which mean that a two-way power splitter has an attenuation of 3 dB, a three-way power splitter 5 dB and so forth. This is shown in Figure 4.6.

2. Unequally distributed

   The unequally distributed power splitters distribute the power unequally over the output ports as shown in Figure 4.6 .

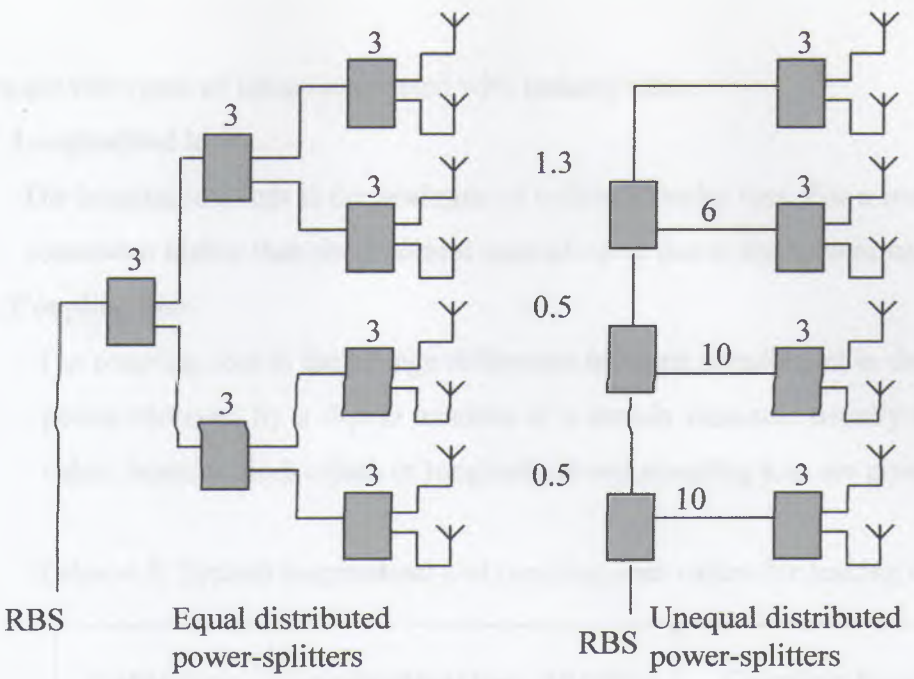

Figure 4.6: Power splitters. Comparison of typical antenna

Network structures using equally distributed power splitters and unequally distributed power splitters. The figures in the antenna networks represent the attenuation (dB) in the power splitters.

4.4.4 Leaking Cable

Leaking cable could be an alternative to distributed antennas in some applications such as car or train tunnels. Leaking cable is also conceivable in indoor applications. Compared to distribute antennas (coaxial) leaking cable is generally a more expensive alternative both in terms of equipment and installation cost.

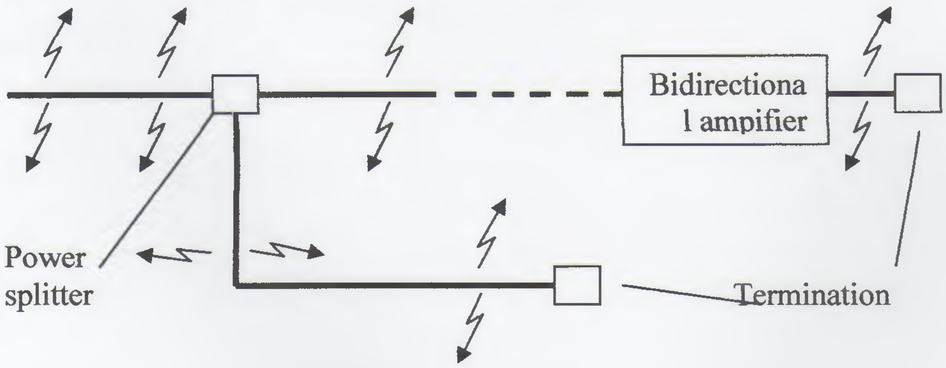

Figure 4.7: Leaking cable.

There are two types of losses associated with leaking cable:

1. Longitudinal loss

   The longitudinal loss is the analogue of ordinary feeder loss. For a leaking cable it is somewhat higher than for a normal coaxial cable due to the intentional leakage

2. Coupling loss

   The coupling loss is the avenge difference between signal level in the cable and the power received by a dipole antenna at a certain distance, usually 6 m, from the cable. Some typical values of longitudinal and coupling loss are given in Table 4.2

Table 4.2: Typical longitudinal and coupling loss values for leaking cables.

Cable type	**Longitudinal loss, dB/100m**		**Coupling loss, dB**	
	800-900 MHz	1800-900 MHz	8000-900 MHz	1800-900 MHz
1/4"	23 - 32	32 - 52	69	71
3/8"	12 – 14	18 - 21	68	74
1/2"	9.5 - 11	13 - 18	68	73
7/8"	5.5 - 6	8 - 11	69	72

4.4.5 Antennas Distributed via a Fiber-optical Network

There are different solutions based on fiber-optics that can be used for indoor systems. The main purpose is to overcome losses in long coaxial feeder cable. One disadvantage of using a fiber-optical network is that each antenna terminal need local power supply and alarm handling.

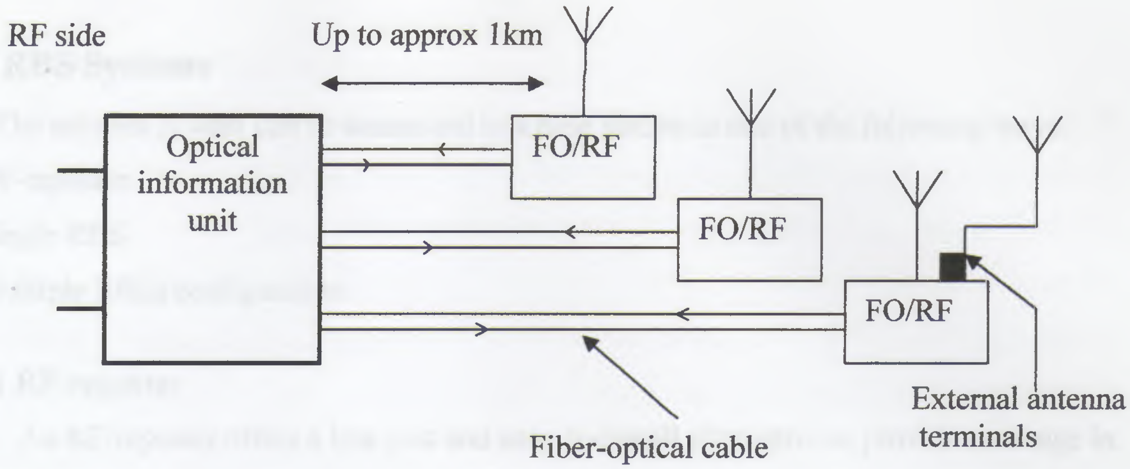

Figure 4.8: Antennas distributed via a fiber-optical network.

Note that as the configuration is depicted in Figure 4.8, an additional fiber-optical antenna entails installation of two additional transmitter/receiver-fibers all the way from the optical interface unit to the location of the antenna. Ordinary antennas could however be connected to the external antenna terminal on the fiber-optical antenna.

The main features of the antenna systems are summarized in Table 4.3

Table 4.3: Antenna system summary

Antenna system	Comments
Integrated antennas	+ Easy and quick installation + Low cost - Limited coverage
Distributed antennas (coax)	+ Low cost + Flexible design - Robust and well proven technique
Leaking cable	+ Flexible design - Expensive
Distributed antennas (fiber)	+ Low attenuation + Easy installation - Expensive - Limited design Flexibility - Power supply of antenna units

4.5 RBS Systems

The antenna system can be connected to a base station in one of the following ways:

1. RF-repeater
2. Single RBS
3. Multiple RBSs configuration

4.5.1 RF-repeater

An RF-repeater offers a low cost and easy-to-install alternative to provide coverage in a building. The macro cell surrounding the building, termed donor cell, must however have spare capacity. When the capacity demand in the building increases and becomes higher than what the donor cell can offer, the RF-repeater may be replaced by an ordinary RBS (plus transmission). The indoor antenna system, originally designed for the RF-repeater, should in large parts be possible to keep. The RE-repeater can thus partly be viewed as a temporary solution for instance when there is doubt if the potential traffic in a building will motivate an ordinary indoor system.

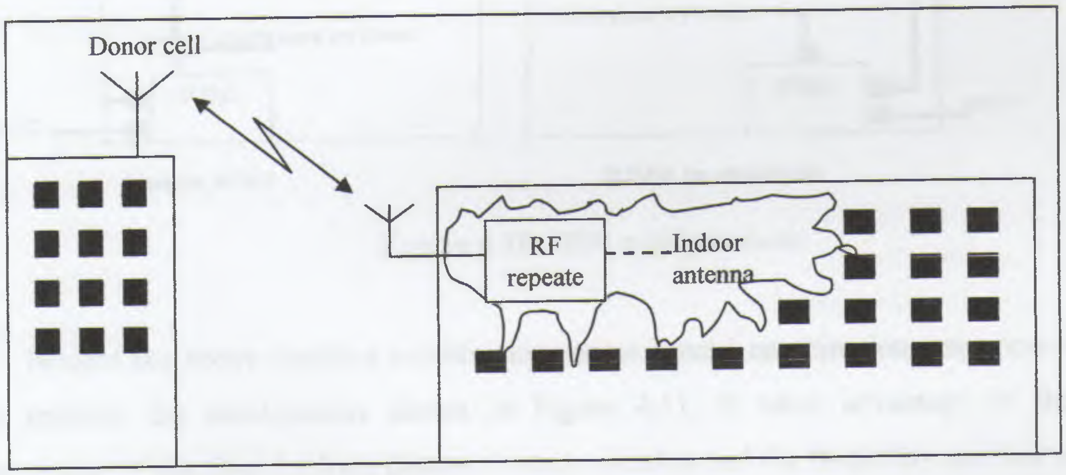

Figure 4.9: RF-repeater

4.5.2 Single and Multiple RBS

A single RBS is the most straightforward way to configure the RBS system in an indoor application. It is more trucking efficient than using multiple RBSs. However, in large buildings where large areas are to be covered, high feeder loss values limit the applicability of a single RBS. In this case multiple RBSs, i.e. RBSs distributed over the building, is a better choice. The obvious reason for this is that in a multiple RBS system the RBSs may be placed closer to the antennas as compared to a single RBS system, and thereby the feeder losses are reduced.

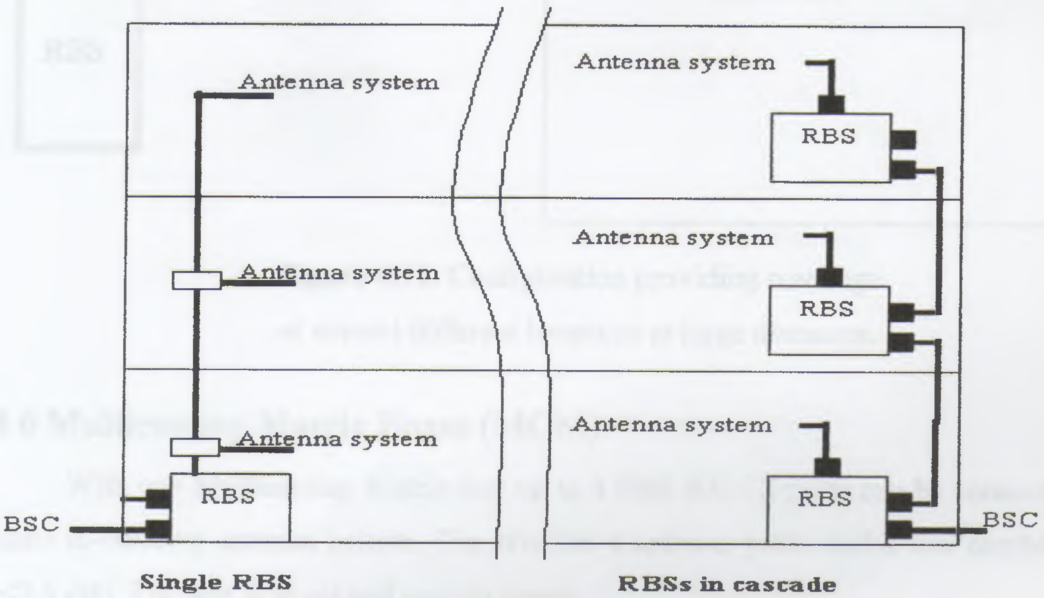

Figure 4.10: BBS configurations

Besides the above depicted combinations some special combinations are conceivable, for instance the combination shown in Figure 4.11. It takes advantage of the low attenuation of the fiber for long distance communication and the flexibility and low cost of the ordinary coax distributed antennas for the actual antenna system.

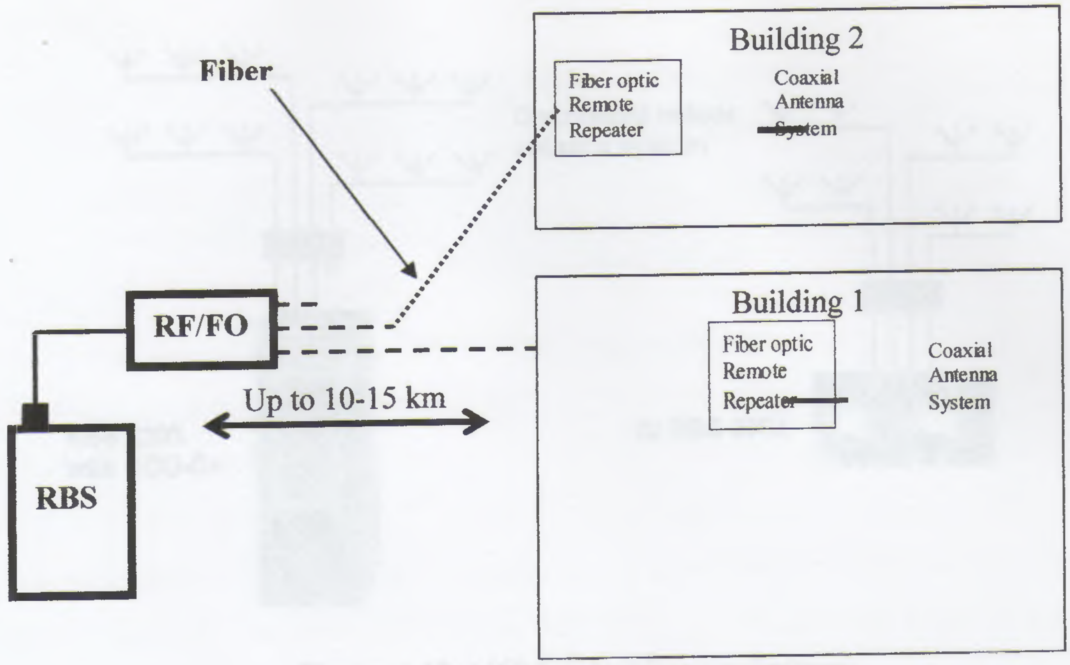

Figure 4.11: Configuration providing coverage at several different locations at large distances.

4.6 Multicasting Matrix Boxes (MCM)

With one Multicasting Matrix box up to 4 RBS RX/TX ports can be connected to the same in-building antenna system. The box has 4 antenna ports, and a low combining loss (<0.5 dB). The box is small and easy to install.

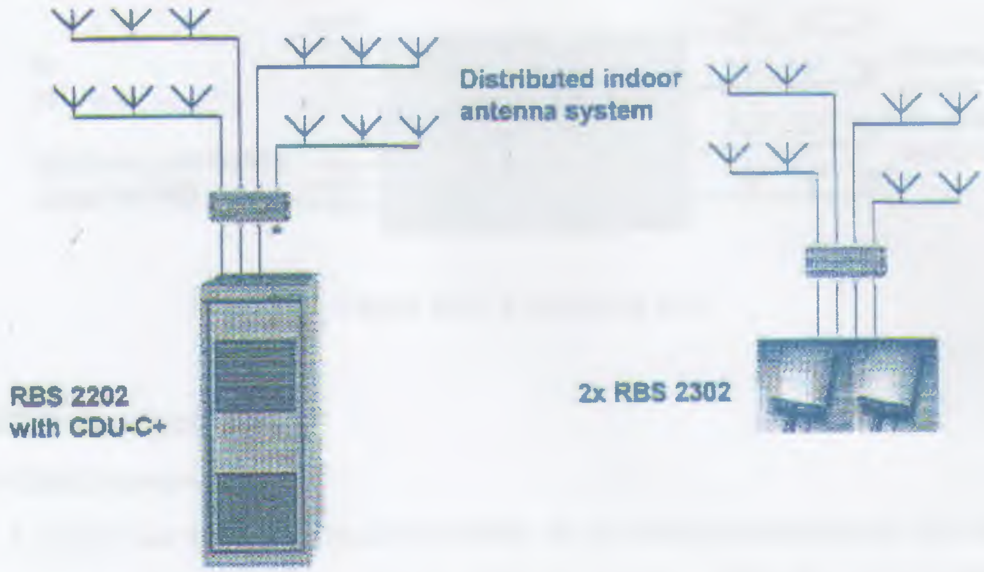

Figure 4.12: MCM in-building applications

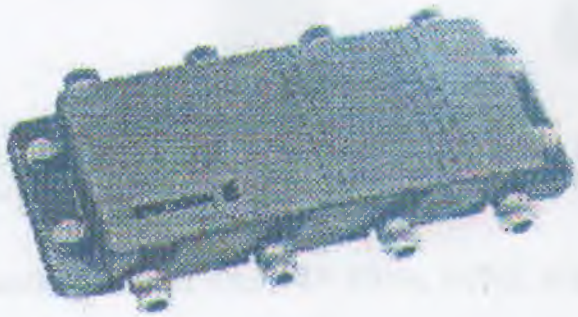

Figure 4.13: Multicasting Matrix Box

4.7 Combining Box

The Combining box combines a multi-operator system and/or a multi-system to a single indoor antenna system. Up to 4800/900 MHz systems can be combined with up to 4 1800/1900 MHz systems. The box has 4 antenna ports and a low combining loss (<1 dB).

Figure 4.14: Combining Box

4.8 RBS Products

4.8.1 RBS Overview

Ericsson has three base stations suitable for in-building applications, the micro base station RBS 2302, the macro base station RBS 2202 and the office base station RBS 2401. Each base station is given a short description in this section.

Figure 4.15: RBS 2302, RBS 2202 and RBS 2401.

All RBSs are prepared for data services 14.4 kBit/s, GPRS, HSCSD and Support of Localized Service Area (SoLSA).

All RBSs can be operated from the common operation and maintenance system OSS , the two charts in Figure 4.16 and Figure 4.17 show the output power and the level of traffic for different types of radio units in a 900 MHz system and an 1800 MHz system.

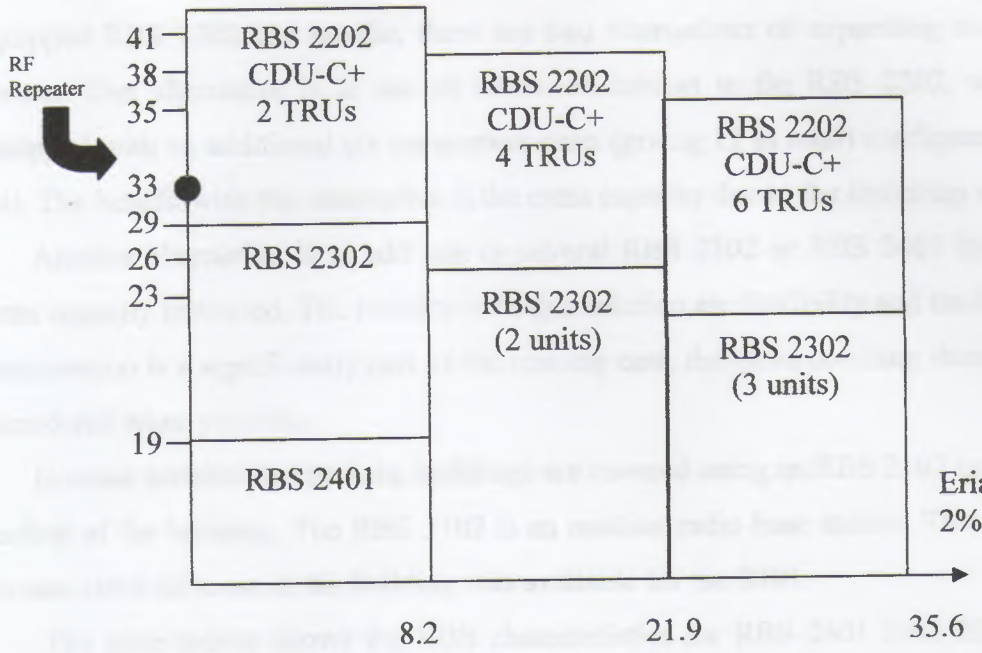

Figure 4.16: Selection of radio unit in a GSM 900 system.

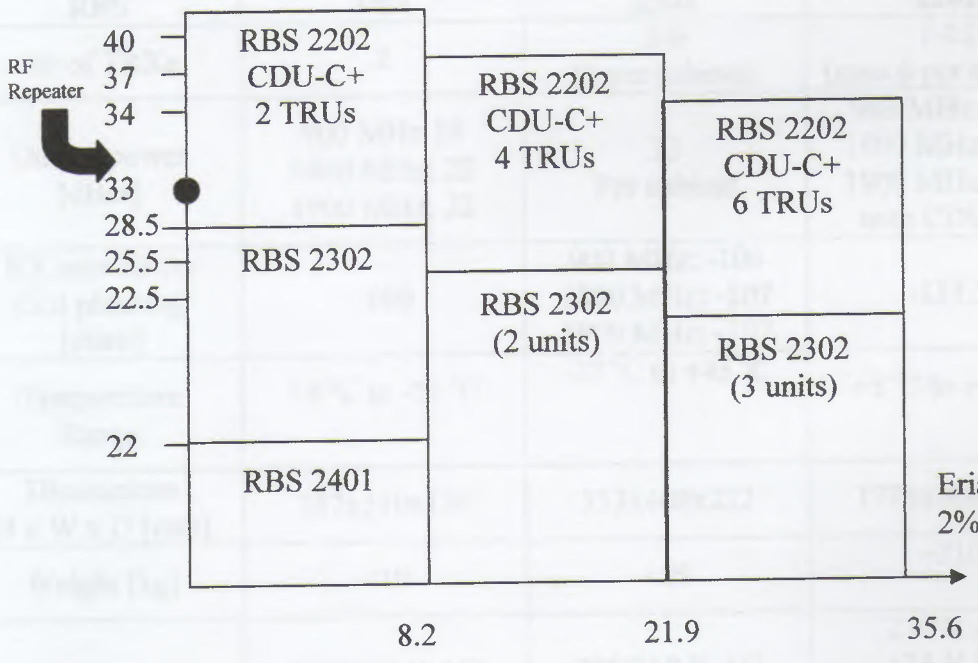

Figure 4.17: Selection of radio unit in a GSM 1800 system.

If the estimated traffic of the in-building system exceeds the maximum traffic a fully equipped RBS 2202 can handle, there are two alternatives of expanding the in-building system. One alternative is to use an extension cabinet to the RBS 2202, which can be equipped with an additional six transceiver units (giving 12 in total) configured as a single cell. The benefit with this alternative is the extra capacity due to the trouncing effects.

Another alternative is to add one or several RBS 2302 or RBS 2401 in areas where extra capacity is needed. The benefits with this solution are flexibility and the low cost. The transmission is a significantly part of the running cost, therefore co-siting should always be considered when possible.

In some installations in Asia, buildings are covered using an RBS 2102 installed on the rooftop of the building. The RBS 2102 is an outdoor radio base station. This solution was chosen, since no room in the building was available for the RBS.

The table below shows the RBS characteristics for RBS 2401 RBS 2302 and RBS 2202

Table 4.4: RBS characteristics

RBS	**2401**	**2302**	**2202**
No of TRXs	2	2-6 (2 per cabinet)	1-12 (max 6 per cabinet)
Output power [dBm]	900 MHz:19 1800 MHz: 22 1900 MHz: 22	33 Per cabinet	900 MHz: 41.0 1800 MHz: 40.0 1900 MHz: 40.0 with CDU-C+
RX senstitivity Cell planning [dBm]	-100	900 MHz: -106 1800 MHz: -107 1900 MHz: -107	-111.5
Temperature Range	+5 °C to -35 °C	-33 °C to +45 °C	+5 °C to +40 °C
Dimensions H x W x D [mm]	387x510x126	353x408x222	1775x600x400
Weight [kg]	<19	<29	~210
Power system	230/110 V AC Nom 65 VA	230/110 V AC Nom 150 VA	230 V AC +24 V DC -48 V DC Type: 1.0-1.2 kVA

4.8.2 RBS 2401

The RBS 2401 is a high quality small radio base station, designed for indoor mounting and applications. RBS 2401 is in itself a complete RBS, including transmission interface and integrated power supply. The product is designed for maximum efficiency in all situations, like office in-building solutions and public hot spot in-building applications.

RBS 2401 is a two TRX unit and is available for GSM 900 and GSM 1800. RBS 2401 will be available for GSM 1900 in the beginning of year 2000. G.703 transmission with long haul and multi drop functionality is supported; optional HDSL modem will be available.

No acoustic noise is generated since no active cooling components are used. For power back up an UPS could be installed.

The RBS 2401 can only be used with external antenna systems. The cabinet will have two external feeder interfaces. Both antenna ports contain the same signals since the RBS has a built in multicasting box (hybrid combiner).

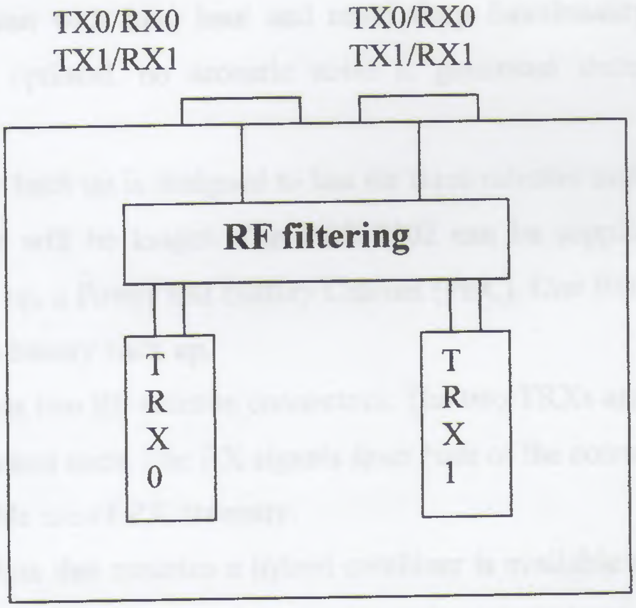

Figure 4.18: RBS 2401 antenna pads.

The RSB 2401 supports a flexible antenna system configuration. One or two antenna branches is possible to connect to the RF connectors. Each antenna can be used to give extra coverage, no overlapping coverage is necessary.

This easy-to-install, high-quality unit for indoor coverage also supports Ethernet connection to the corporate Local Area Network (LAN) via an external interface unit.

4.8.3 ABS 2302

RBS 2302 is a complete BTS site, including transmission interface, integrated power supply, and optionally integrated antennas. The product is designed for maximum efficiency in range different situations, like micro cells and in-building applications. This together with flexible transmission solutions and antenna configurations, with integrated or external antennas, give efficient medium to high capacity solutions.

RBS 2302 is available for GSM 900, GSM 1800 and GSM 1900 MHz.The RBS is a two TRX unit with expansion possibilities. Each cell can have up to 6 TRXs, and this is achieved by using three cabinets.

G.703 transmission with long haul and multi drop functionality is supported, and integrated HDSL is optional. no acoustic noise is generated since no active cooling components are used.

A built-in battery back up is designed to last for three minutes under high load; typical battery back up time will be longer. The RBS 2302 can be supplied with an optional external battery back up, a Power and Battery Cabinet (PBC). One PBC can supply up to 2 hours and 45 minutes battery back up.

The RBS 2302 has two RF antenna connectors. The two TRXs are transmitting on one of the antenna connectors each. The RX signals from both of the connectors are split to the two TRXs fora possible use of RX diversity.

A multi casting box that contains a hybrid combiner is available as option. The use of the multicasting box allows for one or two antenna branch systems. RX diversity is not supported when the multicasting box is used.

4.8.4 RBS 2202

The RBS 2202 is a high quality, high capacity radio base station, designed for indoor mounting. In in-building applications the main usage is in large multicasting systems.

RBS 2202 is available for GSM 900, GSM 1800 and GSM 1900 MHz.

RBS 2202 can be equipped with 6 TRUs in one cabinet; two cabinets can form a 12 TRU cell.

For RBS 2202 battery backup is available in an external cabinet, with the same size as the RBS 2202 cabinet, providing 1 .8 hours of backup.

The RBS 2202 is used with external antenna systems.

4.9 RF Design

4.9.1 Link Budget

The link budget for an indoor cell can be determined in a way similar to the link budget for macro cells.

4.9.1.1 Required Signal Strength

To be able to perform a call in a real-life situation some margins have to be added to the MS sensitivity level to compensate for Raleigh fading, interference and body loss. This obtained signal strength will be referred to as SSreq and can be expressed as:

$$SS_{req} = MS_{sens} + RF_{marg} + IF_{marg} + BL \qquad (4.1)$$

Where

MS_{sens} = MS sensitivity (-104 dB m)

RF_{marg} = Raleigh fading margin (3 dB no frequency hopping[2] .0 dB frequency hopping)

IF_{marg} = Interference margin (Depends on the environment, see Table 4.4).

BL = Body loss (5 dB 900 MHz, 3 dB 1800/1900MHz)

4.9.1.2 Design level

In the design phase, an extra margin must be added to SSreq to handle the log-normal fading. The obtained signal strength is what should be used when planning the system according to the Keenan-Motley model and will be referred to as the design level, SSdes.

$$SS_{des} = SS_{req} + LNF_{marg} \quad (4.2)$$

Where

LNF_{marg} = The indoor log normal fading (5 dB can be used as an estimate).

4.9.1.3 BTS Output Power

The required **BTS** output power can be calculated by adding the losses in the antenna network to the design level. That is:

$$P_{outBTS} = SS_{des} + L_p + G_a + L_f + L_{ps} + L_c \quad (4.3)$$

Where

P_{outBTS} = BTS output power at antenna connector.

L_p = Path loss from antenna to MS at the cell border.

G_a = BTS antenna gain, MS antenna gain assumed to be 0dB.

L_f = Feeder loss

L_{ps} = Loss in power splitters.

L_c = Loss in external combiners, duplexers, diplexers etc. Note that the loss in the CDUs is not part of Lc, since the reference point for BTS output power is at the antenna connector.

4.9.2 Design Levels

In areas with a high level of interference the required interference margin has to be higher, and in areas with low interference it has to be lower.

In order to avoid the complex matter of measuring the level of interference and from these data calculate **SSdes.** a simplified design procedure is proposed. The idea is that by studying the surrounding radio environment it should be possible to classify the level of interference in the cell as low, medium or high and from this classification say what the required signal strength should be. In Table 4.5, proposed values of SSdes are given for each of the mentioned interference levels. Note that these values must be regarded as rules of thumb.

Table 4.5: Design levels and required signal strengths in areas of different interference.

NOTE: The proposed values must be regarded as rules of thumb.

Level of interference	Design level (SS_{des})	Required level (SS_{req})
Low	-85 dBm	-90 dBm
Medium	-75 dBm	-80 dBm
High	-65 dBm	-70 dBm

The cell should be designed so tat SSdes is obtained at the cell border when designing the cells according to the Keenan-Motley model. In the verification measurements it is of course not necessary to measure SSreq. Then SSreq is enough since the lognormal fading dips are included in the measurements.

4.10 Antenna Configuration

When the requirements on received signal strength and coverage are defined,, an antenna configuration must be chosen. Coverage measurements take a lot of time and should be used primarily to decide if a nominal configuration gives the anticipated coverage.

It becomes more and more important to plan for reduced interference towards surrounding cells. The requirement on low interference towards other cells implies that:

1. Several antennas should be used. This lowers the necessary output power at each antenna. It is furthermore not'expensive to add antennas to a distributed antenna system.
2. Do not place antennas close to windows.

4.10.1 Work Flow

The purpose of this process is to create an antenna plan which works "on paper". An antenna plan includes antenna locations and types as well as design of the feeder network.

Some antenna locations may be unsuitable from an implementation point of view and may have to be adjusted. If major changes are needed a creation of a new nominal antenna plan is required.

Since predictions inside buildings contain uncertainties such as wall losses it is necessary to control the actual coverage from the nominal antenna.When the nominal antenna plan has been decided, the system is implemented.

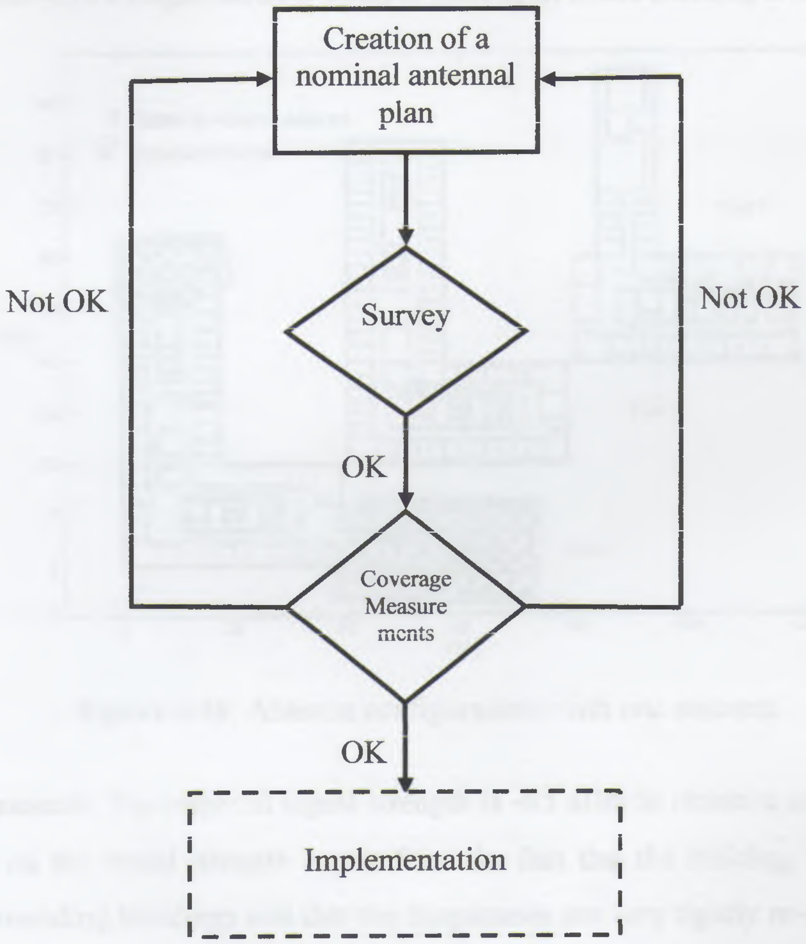

Figure 4.19 Antenna configuration work flow.

4.10.2 Nominal Antenna Plan

A nominal cell plan is made in two steps:

1. Studies of different indoor configurations with desired performance regarding public or business, interference situation and building types. The purpose of this is to gain a feeling for indoor antenna configurations.
2. Path loss estimations. This can be done with paper and pen or by using a prediction tool such as TEMS Prediction.

4.10.2.1 Antenna Configuration, Examples

4.10.2.1.1 Single Antenna in an Office Building

In Figure 4.20 a single antenna solution used in an office building is shown.

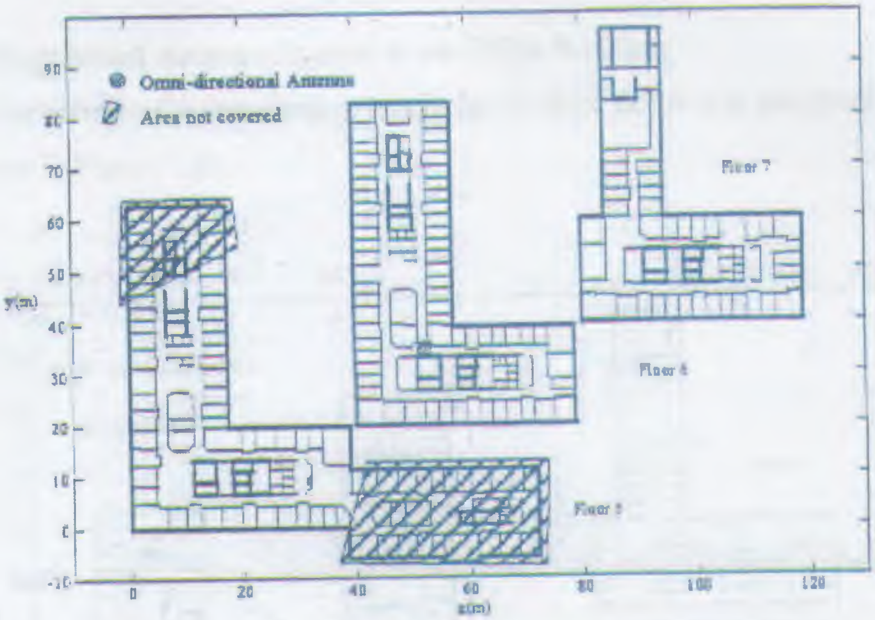

Figure 4.20: Antenna configurations with one antenna.

Requirements: The required signal strength is -65 dBm to obtain a sufficient C/I The requirement on the signal strength comes from the fact that the building is tall compared with the surrounding buildings and that the frequencies are very tightly re-used in the area, giving high interference into the building.

Solution: An omni-directional antenna was placed in the middle of the area intended to be covered. The antenna was fed with 30 dBm, the maximum power with the coax net and base station used.

Result: floors 6 and 7 were fully covered, but floor 5 was not covered in the shadowed areas marked in Figure 4.20. The cell borders were not possible to control. The cell extended several floors outside the intended area. The signal strength was also varying significantly in the cell, and was very high in the vicinity of the antenna (approximately-25 dBm).

Conclusions:

1. The equipment and installation cost is slightly lower than with a distributed antenna
2. There may be difficulties in obtaining coverage.
3. The higher interference towards other cells may prevent tight re-use.
4. The cell borders may be hard to control.

4.10.2.1.2 Distributed Antenna System in an Office Building

Another solution for providing coverage on the three floors is to use several antennas. This is shown in Figure 4.21.

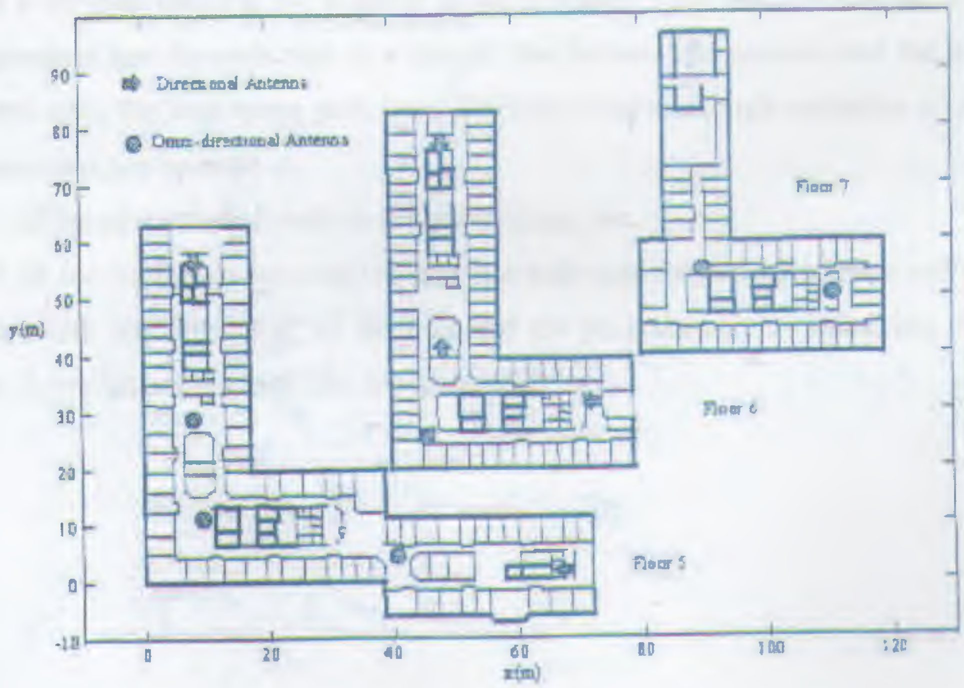

Figure 4.21: Antenna configuration with 11 antennas

Requirements: The same as in the preceding example.

Solution:A distributed antenna system consisting of 11 antennas, both directional and omni-directional antennas. The power fed into the antennas was 6 dBm. No antennas are mounted in rooms next to the outer wall.

Result: Full coverage. Evenly distributed signal strength and a low amount of radiated power to the surroundings.

Conclusions:A distributed antenna system can be used to control the cell borders, giving high coverage and lower interference than with a single antenna. This is especially desired in business applications where buildings tend to be high and excellent quality is required. It is especially important to use many antennas and low EIRP high up in a building with line-of-sight to other cells. This decreases the risk of interfering other cells.

4.10.2.2 Coverage Predictions

In the same way that the Okumura-Hata model has been developed semi-empirically for macrocell coverage predictions, the Keenan-Motley model has been developed for indoor wave propagation predictions. This model has been accepted by COST 231, and contains a 3D term which is not possible to see in Figure 4.22. The tool calculates the wall type dependent loss for each wall in a straight line between the antenna and the prediction point, and adds the free space path loss. The following are rough estimates of wall loss parameters that can be used:

1. 2 dB for plasterboard walls in office buildings, etc.
2. 5 dB for reinforced concrete walls in stairwells and car parks Antennas and/or BTS + feeder network are distributed by the user and the program quickly calculates the signal strength. A prediction can look like in Figure 4.22:

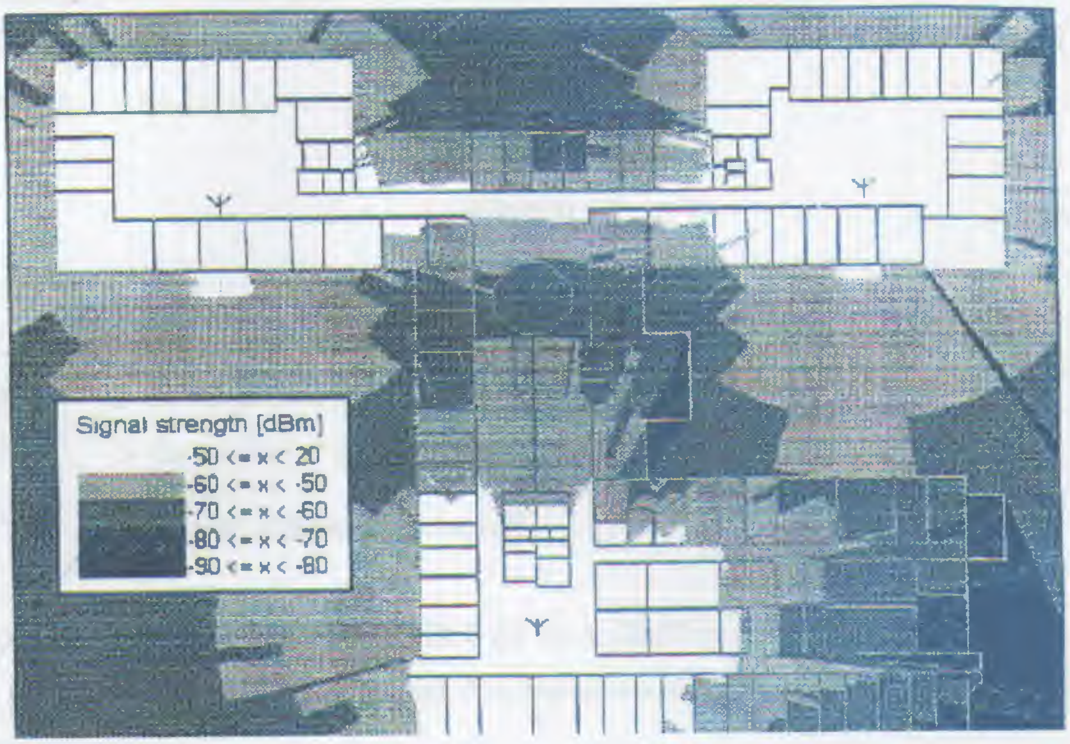

Figure 4.22: Example of signal strength prediction made by TEMS Prediction Omni antennas with 10 dBm EIRP am used

The model underestimates the signal strength in certain locations. This may be seen in rooms in the end of corridors, far from an antenna. The underestimation of the signal strength is due to tat the model assumes tat the signal passes through several walls, while in reality it will be reflected and diffracted along the corridor. This will lead to higher signal strength than expected in these locations.

The floor plan used in TEMS predictions is drawn by hand on a scanned background image or is imported from a vectorizing program. The manual procedure is not too time consuming in case a good map without too much text can be found.

4.10.2.3 Estimate Path Loss Manually

In a simplified form the Keenan-Motley model can be written in the following way for 900 MHz.

$$L = 31.5 + 20\log(d) + N_W \bullet W \qquad (4.4)$$

where

L	is the path loss between isotropic antennas (dB).
d	is the transmitter-receiver separation (m)
N_W	is the number of walls passed by the direct ray.
W	is the wall attenuation factor (dB).

The free space path loss increases with 6 dB for 1800 MHz in the equation above, a figure that can be used for 1900 MHz as well. The free space path loss is shown in Figure 5.23 for different distances.

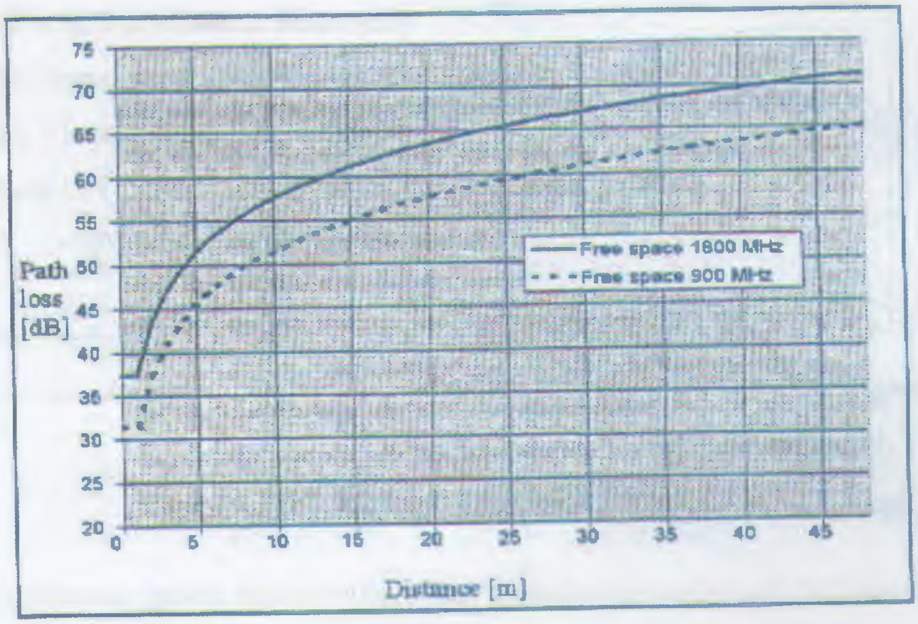

Figure 4.23: Free space loss as a function of transmitter-receiver distance

The total wall loss is given by counting the number of walls between the antenna and estimated location and multiplying by the wall attenuation factor.

Indoor Propagation

Modified Keenan-Motley Model

$$L = 31.5 + 20 \bullet \log f + 20 \bullet \log d + k \bullet F(k) + p \bullet W(k) + D(d - d_b)$$

Free-space formula

L= path loss (dB)

f= frequency (MHz)

d = transmitter to receiver separation (km)

k = number of floors traversed by the direct wave

F = floor attenuation factor (dB)

P = number of walls traversed by the direct wave

W = wall attenuation factor (dB)

D= linear attenuation factor (dB/m) (note 1)

db = indoor breakpoint (in) (note 1)

Note 1: For distances above the breakpoint add typically 0.2 dB/m.

Typical breakpoint = 65m.

Figure 4.24: Loss in free space plus loss in walls.

A more elaborate model take also floor loss as well as an additional distance dependent loss, due to diffraction, scattering, obstructive objects and destructive interference, which is added after a breakpoint distance, into account (Figure 4.24).

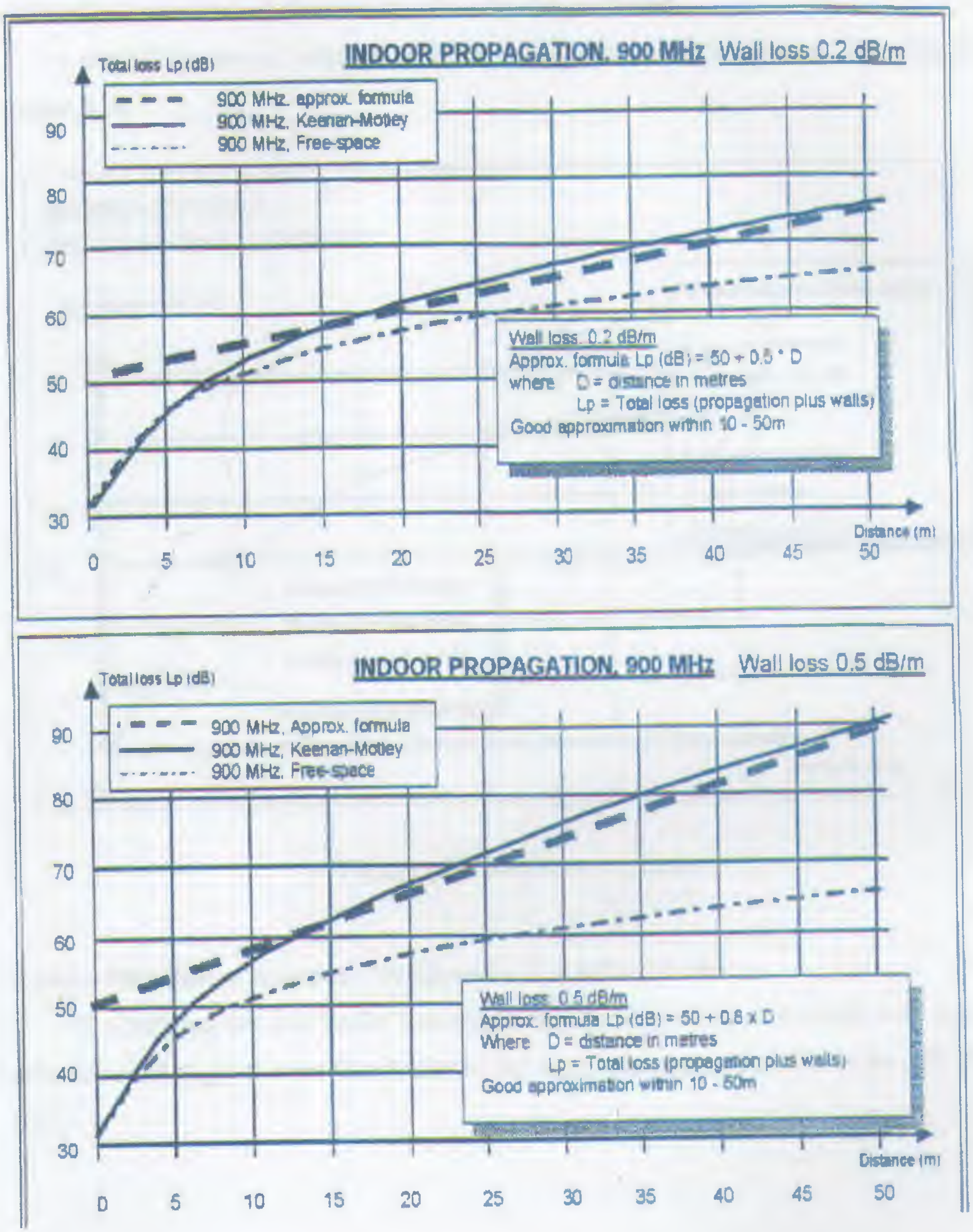

Figure 4.25:diagrams showing approximate indoor propagation loss at 900MHz for a wall Attenuation of 0.2 & 0.5 dB/m.At 1800MHz the loss is 6dB higher, thus change the 50 to 56 in the formula

In the previous diagram (Figure 4.25), the total wall loss (for the estimated distance) is divided by the estimated distance to get a wall loss per meter.

A simplified way of estimating the loss between floors is shown in the diagram in Figure 4.26

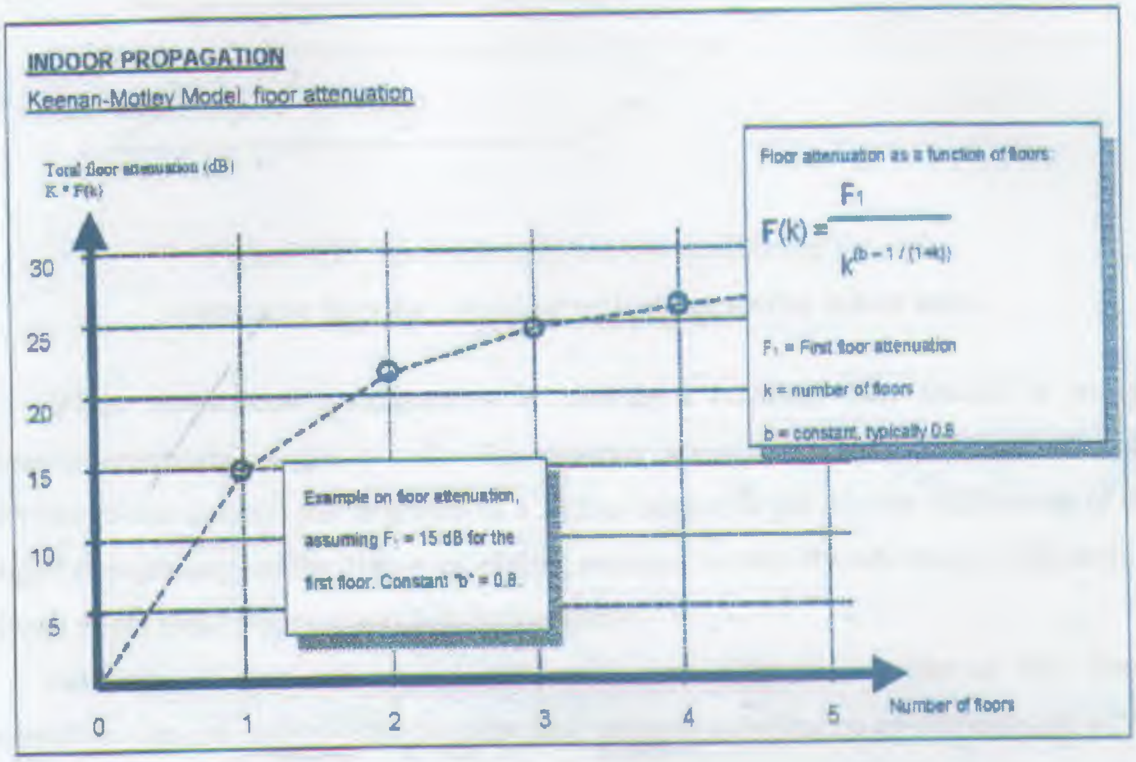

Figure 4.26: loss between floors

4.10.2.4 Distributed Antenna Configuration for Indoor Cells

If a building wit low traffic concentration is to be planned as a single cell, antennas are positioned to get as even distribution of the signal strength as possible in the cell, Figure 4.27.

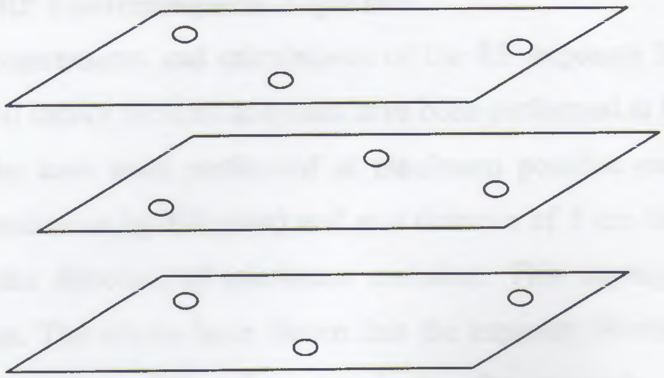

Figure 4.27: Recommended antenna positioning for each consecutive floor for a building with one or several indoor cells.

When "several-cell" configuration is used for a building, there should be enough distance separating co-channel cells. This distance is round four floors. The antennas can wit this re-use distance still is placed in a zigzag manner to get as even distribution of the signal strength as possible. However, placing antennas on top of each other as Figure 4.28 shows might make planning and installation easier.

Buildings divided into several cells with very tight re-use (one or two floors separation) are recommended to have the same antenna positions on co-channel cells to get as good C/I as possible. Such tight re-use is however not recommended for business indoor systems.

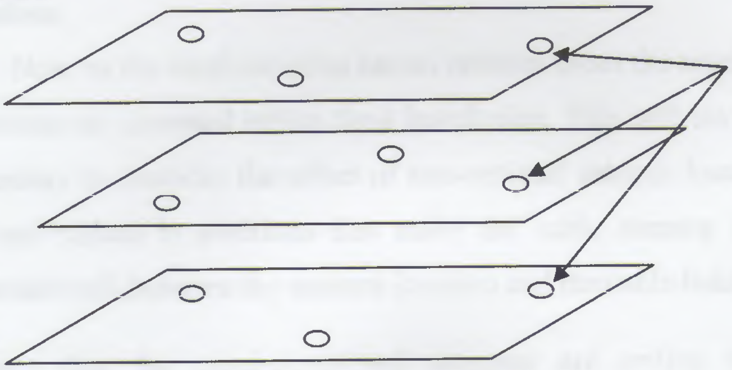

Figure 4.28: Recommended antenna positioning for each consecutive floor, for a building with several indoor cells with very tight re-use.

4.10.2.5 RF Electromagnetic Exposure

Measurements and calculations of the RF exposure levels from unidirectional and directional indoor picocell antennas have been performed at Ericsson, both at 900 and 1800 MHz. The tests were performed at maximum possible output power (according to the recommendations by Ericsson) and at a distance of *5* cm from the surface of the antenna unit, in the direction of maximum emission. This corresponds to worst case exposure conditions. The results have shown that the exposure levels are below the general public and occupational RF safety standards, for example those published by WHO, IRPA/ICNIRP, CENELEC, IEEE/ANSI and FCC.

Therefore, there is no need of any special RF exposure safety instructions for these antennas. Installation and maintenance people can work close to the antennas in operation without any risk of RF exposure exceeding the safety limits. It is however always advisable to place the antennas in such a way that people can not easily touch them or stay close to them, which could affect the performance. A discretely placed antenna will also reduce the risk of unnecessary public concern about the RF exposure.

4.11 Survey

The nominal configuration may not be suitable for the building. Reasons for this can be tat the suggested locations are too close to where people sit, tat there are obstacles deteriorating the radiation pattern or tat there are problems mounting the antennas at these locations.

Note tat the landlord often has an opinion about the antenna locations. Ensure tat these locations are accepted before final installation. This will save unnecessary work. It is also necessary to consider the effect of non-optimal antenna locations.See to that the antennas are not placed in positions that make the cable running difficult, for example with a concrete wall between the antenna location and the cable ladder.

Note: that the omni-directional antennas are ceiling mounted and the directional antennas are wall mounted in general.

4.12 Coverage Measurements

Coverage measurements are performed to verify the antenna configuration so that it provides a sufficient coverage. The antenna locations that are determined are then tested one or several at a time. A test transmitter is connected to the antenna and the signal strength is measured with a mobile receiver. In Figure 4.29 the measurement configuration is shown.

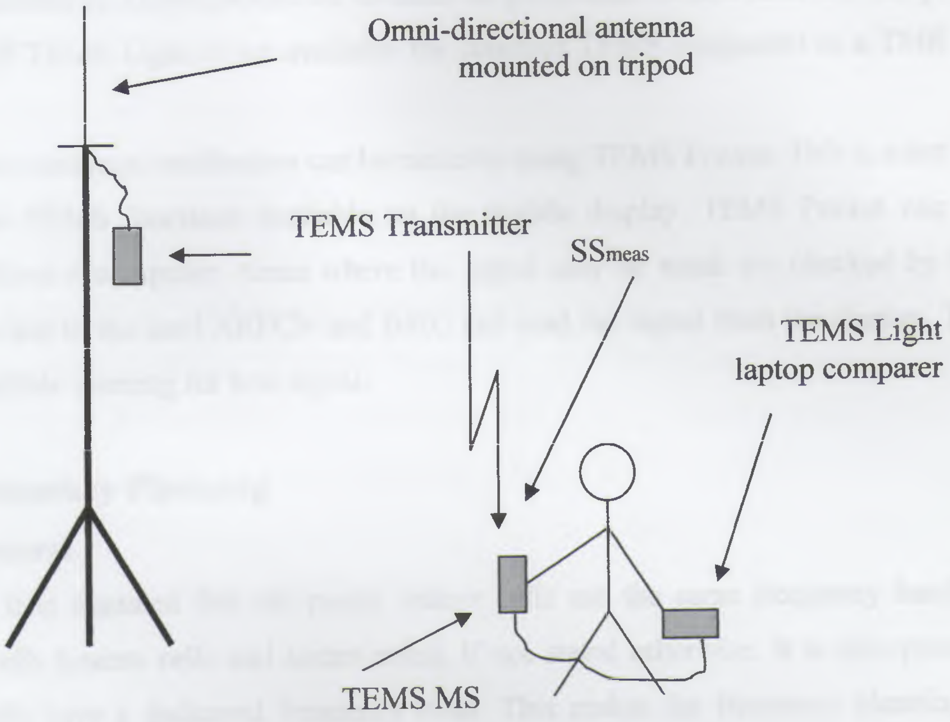

Figure 4.29: Measurement configuration

4.12.1 Transmitter Equipment

For the generation of test signals it is suitable to use one or several TEMS Transmitters. The TEMS Transmitter is a small unit that transmits in the GSM downlink band. The output power is adjustable between 20 and 27dBm (GSM 900/1900) or 22 and 27 dBm (GSM 1800). Using two optional attenuators the output power can be varied between 2 and 27 dBm (GSM 900/1900) or 4 and 27 dBm (GSM 1800). A complete editable BCCH is transmitted while the other 7 time slots contain an unmediated carrier.

4.12.2 Receiver Equipment

The recommended receiver is a TEMS Light equipment. This is a TEMS mobile connected to a small pen-operated PC. The TEMS light program is a reduced version of the standard TEMS

PC software but with the possibility to log fix points by marking with the pen on a scanned map. The information in the log files is displayed on the scanned map as color marks, associated to a window with more information concerning each mark. These measurements can be exported to TEMS prediction to calibrate prediction models used for that particular building. If TEMS Light is not available the standard TEMS equipment or a TMR can be used.

A faster coverage verification can be made by using TEMS Pocket. This is a test mobile with some TEMS functions available on the mobile display. TEMS Pocket can not be operated from a computer. Areas where the signal may be weak are checked by locking TEMS Pocket to the used ARFCN and BSIC and read the signal from the display. There is also an audible warning for low signal.

4.13 Frequency Planning

4.13.1 General

Here it is assumed that the public indoor cells use the same frequency band as the outdoor cells (macro cells and micro cells), if not stated otherwise. It is also possible tat indoor cells have a dedicated frequency band. This makes the frequency planning much easier.

The business indoor cells should be planned in the same way as public indoor cells in the beginning. Separate band is recommended later on for quality and capacity reasons, easy frequency planning and O&M handing. Especially if a tight MRP is applied for the macro cells.

If only one cell is used within a building, no frequency plan is needed for that cell other than consideration taken for outdoor cells. When a building is divided into more than one cell, co-channels should be planned as far apart as possible.

4.13.2 Planning Rules With Re-use of Outdoor Frequencies

The frequency planning is performed manually, selecting suitable frequencies by studying the operators frequency plan.

1. Exclude frequencies in nearby cells, likely to interfere significantly with the indoor system, and adjacent frequencies to those.

2. From the remaining frequencies, choose the ones most likely not to cause interference. The BCCH frequencies should be the least disturbed of them. Hop on several frequencies to smooth out the interference.

The following need to be considered if too few acceptable frequencies exist:

1. Increase signal strength for indoor cell.
2. Allocate dedicated frequencies for indoor cells. Start with frequencies for BCCH.
3. Redesign the frequency plan.

4.13.3 Planning Rules With Dedicated the Frequencies

Dedicated frequencies for public indoor is useful when there are several of indoor systems at rather low height in the buildings, i.e. mostly shopping malls, gallerias and subway stations. It is then recommended to use a group of 4-6 frequencies and re-use them in all buildings. The importance is that at least one best server outdoor cell must separate the public indoor cells geographically (Figure 4.25).

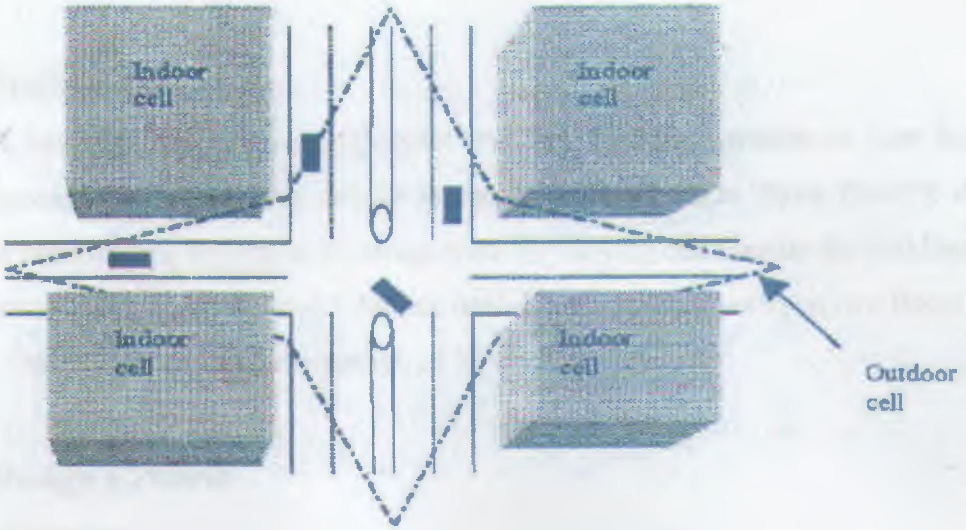

Figure 4.30: Outdoor cell separating indoor cells.

Dedicated frequencies for business indoor should be considered when several of high buildings in a close area will be planned. The need for dedicated indoor cells when one cell needed is rather low and general method of re-using outdoor frequencies should be applied.

4.13.4 High Buildings and Skyscrapers

The business indoor cells will in several cases be located in high buildings. One way to plan is by using the standard method described above for the lower part of the building and use dedicated frequencies for higher parts of the building. The quality could then be good even for high buildings. There need to be several high buildings with indoor systems if the dedicated frequencies for indoor approach should be spectrum efficient

4.13.5 Traffic Control

In many situations it is necessary to control the traffic flow in the indoor cell. For example it is often desired to direct the traffic from the nearby macro cells to the indoor cell, and make it stay there, in order to off-load the macro cell. Another requirement may be that only certain subscribers should be allowed to access the cell. This can be achieved with appropriate use of the radio network features: Hierarchical cell structures, Idle mode offsets and Differential channel allocation.

4.14 Study Case

A building (e.g. the training center in Kista, Sweden) consists of four floors, each approximately 70 meters long and 18 meters wide (see section "floor Plans"). All indoor areas in this building have poor coverage from the serving cell outside the building.

Indoor walls have a loss of 5 dB per wall. Floors/ceilings between two floors attenuate 25 dB. Outer walls have an attenuation of 18 dB.

4.15 Design Criteria

4.15.1 Coverage

Good coverage, SSdesign> *-85* dBm.

4.15.2 Capacity

The capacity demand is 200 subscribers, with traffic of 30 mE/subscriber in the busy hour.the grade of service is 2%.

4.15.3 System Balance

Balance towards the most common class of MS.

4.15.4 Hardware

BTS, antennas, cables, etc. in accordance with data given previously in this chapter.

4.15.5 Task

Make the design based on the information provided previously. Present block diagram, signal level diagram, material list and floor plans with material positions marked.

4.15.6 Floor Plans

Floors one through four must have coverage according to the previous specification above.

4.16 SUMMARY

This chapter discussed the fundamentals and basic techniques of cell planning, the elements of cellular system design were considered which, include the frequency reuse concept, traffic engineering, hand off mechanisms, and cell splitting techniques, the cellular system design objectives were also specified

CONCLUSION

GSM, the Global System for Mobile communications, is a digital cellular communications system, which has rapidly gained acceptance and market share worldwide, although it was initially developed in a European context. In addition to digital transmission, GSM incorporates many advanced services and features, including ISDN compatibility and worldwide roaming in other GSM networks. In GSM system, security mechanism is good enough. Security feature should be compatible with signaling system, so the consequence is on the distance of security information movement on GSM system. Therefore, the extra connection must be reduced for security purposes. Operator has independency to offer and do some security aspects in its network, but if doing this feature selection, it has to be done exactly or take every security features, so there will not a problem in future.

The GSM system, and its sibling systems operating at 1.8 GHz (called DCS1800) and 1.9 GHz (called GSM1900 or PCS1900, and operating in North America), are a first approach at a true personal communication system. The SIM card is a novel approach that implements personal mobility in addition to terminal mobility. Together with international roaming, and support for a variety of services such as telephony, data transfer, fax, Short Message Service, and supplementary services, GSM comes close to fulfilling the requirements for a personal communication system: close enough that it is being used as a basis for the next generation of mobile communication technology in Europe, the Universal Mobile Telecommunication System (UMTS). Another point where GSM has shown its commitment to openness, standards and interoperability is the compatibility with the Integrated Services Digital Network (ISDN) that is evolving in most industrialized countries and Europe in particular (the so-called Euro-ISDN). GSM is also the first system to make extensive use of the Intelligent Networking concept, in which services like 800 numbers are concentrated and handled from a few centralized service centers, instead of being distributed over every switch in the country. This is the concept behind the use of the various registers such as the HLR. GSM is a very complex standard, but that is probably the price that must be paid to achieve the level of integrated service and quality offered while subject to the rather severe restrictions imposed by the radio environment.

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