used in the receiver to despread the receive signal which is synchronized to the PN sequence used to spread the transmitted signal in the transmitter.

A solution to synchronisation problem consists of two parts. They are:

(i) Acquisition

(ii) Tracking.

Acquisition: In acquisition (or) coarse synchronisation the two PN code are aligned to within a fraction of a chip in a short a time as possible.

Tracking: Once the incoming PN code has been acquired tracking (or) fine synchronisation takes place.

PN acquisition proceeds in two-steps:

First, the received signal is multiplied by a locally generated PN code to produce a measure of correlation between in and the PN code used in transmitter.

Secondly, An appropriate decision rule and strategy is used to process the measure of correlation so obtained to determine whether the two codes are in synchronism

As for tracking, it is accomplished using phase techniques very similar to those used for the local generation of coherent carrier references.

REVIEW QUESTIONS

1. A true random waveform has no DC term. Why is there a DC term in the power density of the PN code?
2. (a) What are the sequences generated by the polynomials $x^5 + x^4 + x^3 + x^2 + 1$ and $x^5 + x^4 + x^2 + x + 1$? Assume an initial conditions of (11111) in both cases.
   (b) Compute the plot the autocorrelation function for each sequence in part (a).
   (c) Compute and plot the cross-correlation function for the two sequences.
   (d) Draw the circuit diagram for generating each of the sequences.
3. A PN sequences is $12^{15} - 1$ in length. How many runs of four 1s would be expected?

❑❑❑

CHAPTER 18

Cellular and Mobile Communications

Inside this Chapter

18.1. Introduction

Although the concept of cellular communication was developed in 1947 in AT&T Bell laboratorie
USA, but the first tests were conducted to explore the possibility in commercial application
After that it then took another eight years when the Federal Communication Commission
USA, set aside new radio frequency for "Land Mobile communication". In this particular ye
(i.e., 1970), AT&T proposed to establish the very first high capacity cellular telephone system.
was then called as the advanced mobile phone service or AMPS.

Thus, in nineteen six*ies, more than half of the world cellular subscribers were using
AMPS system developed by AT&T. Now, the cellular carriers and equipment manufactures h
upgraded their system from analog to digital technology.

The idea behind this is to offer a higher quantity, higher capacity and more feature rich service for cellular users. Firstly, CTIA (Cellular Telecommunication Industry Association) adopted TDMA as its digital transmission standard in 1990 and then continued to support the system. The TDMA claims three times the transmission capacity of analog systems used previously. However, as a matter of fact, TDMA's strongest competitors is CDMA (*i.e.*, Code Division Multiple Access), a superior system developed by QUALCOMM., Inc. In fact, CDMA is based on spread spectrum technique which was originally developed for the military to scatter signals across a wide frequency band and hence making it difficult to intercept or jam it. In addition to its superior qualities, the most important feature of CDMA is that it offers at least 10 times the communication capacity of the present analog communication system.

One more digital transmission scheme, broadband CDMA, is being promoted by Intel corporation, Digital communication corporation which claims that B-CDMA, provides additional capacity to the network and also improves additional capacity to the network and improved voice quality. However, new equipment manufacturers today support all the major techniques, *i.e.*, AMPS, Narrow band AMPS, TDMA, CDMA and the GSM–the European digital standard. India selected GSM, though costly and yet to be field proven on a under scale. This digital system was proposed and developed by conference of European posts and Telecommunication (CEPT), with strong backing from European commission. The technical work in devising a common system has been co-ordinated by the CEPT's Groups Special Mobile (GSM) committee. Afterwards system has been renamed as Global system for Mobile communications. Now before discussing all this in detail, let us see the chart which illustrates the frequency allocated for different services. It has been illustrated in figure 18.1.

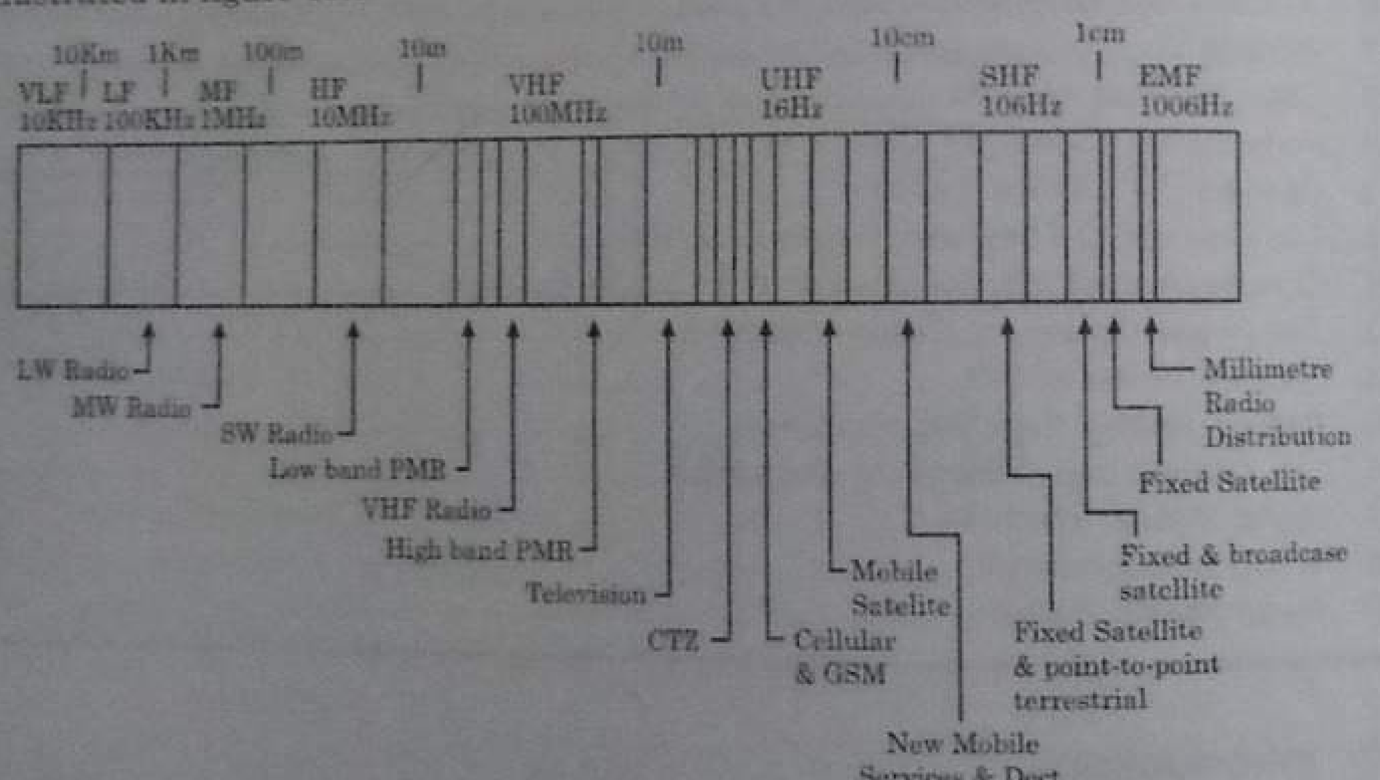


Fig. 18.1. *Chart showing the frequencies allocated for different services.*

18.2. Main Methods of Radio Transmission

Although there are several methods of radio transmission but mainly there are three methods of radio transmission listed as under:

(*i*) FDMA/SCPC (Frequency Division Multiple Access/ Single channel per carrier). Here each channel uses a separate carrier.

(*ii*) Wideband TDMA (Time Division Multiple Access). Here a single carrier is modulated to cover the whole band.

(*iii*) Narrowband TDMA (or FDM frequency division multiplex-TDMA). Here a number of carriers operate at different fr...

Speech is coded using a regular pulse excitation long term prediction linear predictive coder into a data stream of 13 kbit/s, although there is an option to halve the coding rate to double the spectrum efficiency and system capacity.

In terms of technology GSM is a most demanding system with the full range of digital techniques, *viz.*, equalisation, frequency hopping, sophisticated speech coding, error correction coding, echo cancellation block interleaving and advanced modulation provided to maximise the performance. The degree of processing is such that the battery current drain of the integrated circuits in the mobile is comparable with the current required to provide the RF power for the transmitter.

18.3. GSM Standards for Cellular Telephony

The GSM air interface provides the physical link between the mobile and the network. Some of the important characteristic of the air interface are given in Table 18.1. GSM is a digital system employing time division multiple access (TDMA) technique and operates at 900 MHz.

Table 18.1.

1.	Frequency band mobile-base	890-915 MHz
2.	Frequency band base-mobile	935-960 MHz
3.	124 radio carriers spaced by	200 MHz
4.	TDMA structure with 8 time slots per radio carrier	
5.	Gaussian minimum shift keying (GMSK) modulation with	BT = 0.3
6.	Slow frequency hopping at 217 hops per second	
7.	Block and combustion channel coding with interleaving	
8.	Down link and up line control	
9.	Discontinuous transmission and reception.	

The CEPT has made available two frequency bands in the GSM system: (*i*) 890 MHz for the mobile to base station (up, link), and (*ii*) 985 MHz to 960 MHz for the base station to mobile (down link).

These 25 MHz bands are divided into 124 pairs of carriers spaced by 200 MHz. Each of the carriers is divided into 8 TDMA time slots of 0.577 m sec length, such that the frame length is 4.615 m sec.

The recurrence of each time slot makes up one physical channel, such that each carrier can support eight physical channels, both in up link and down link directions. Figure 18.2 show features of GSM standard.

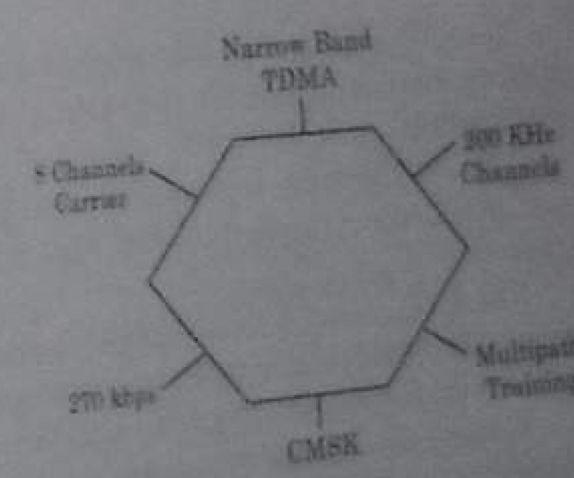


Fig. 18.2

18.4. Architecture of GSM

Although the basic architecture of different cellular standards are the same, their individual components and configuration may differ drastically. Basic components of GSM include, base transceiver station (BTS), base station controller (BSC), Mobile switching control (MSC) and a variety of registers and network management systems shown in figure 18.3.

The mobile station comprises a mobile equipment and a subscriber identity mobile (SIM) for security and authentication of subscriber. The BTS and BSC together constitute the base station sub-system (BSS) and perform all the functions related to the radio channel for speech, data signalling and frequency hopping control and power level control.

The MSC, VLR and HLR are concerned with mobility management functions. These include authentication and registration of a mobile customers, location updating, call setup and release.

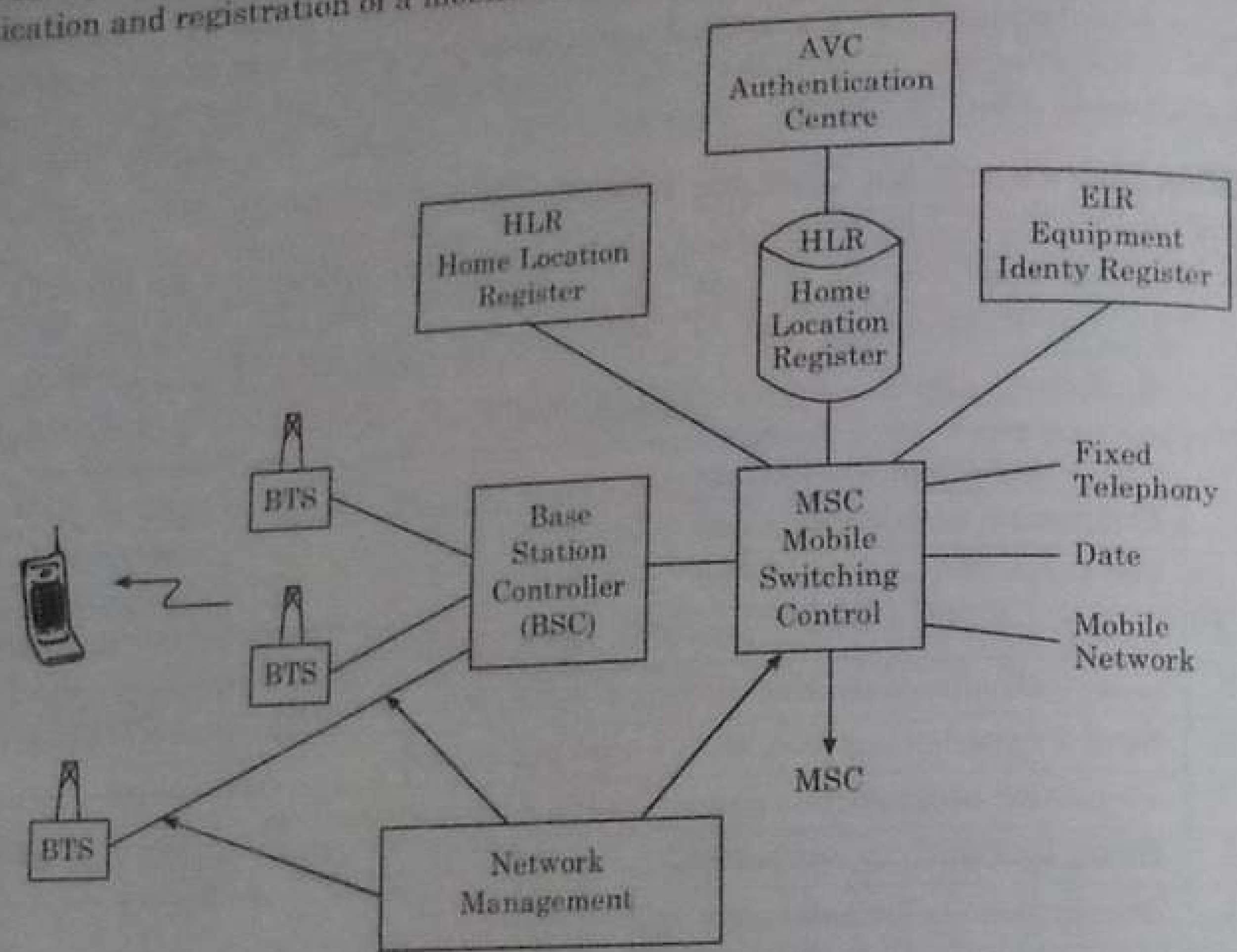


Fig. 18.3.

The HLR is the master subscriber data base and carrier information about individual subscriber numbers. Subscription levels, call restrictions, supplementary services and the most recent location of subscriber.

The VLR acts as a temporary subscriber data base for all subscribers and contains similar information as that in MLR VLR deviates a need of the MCS to access the HLR for energy transaction.

The authentication centre (AUC) works closely with the HLR and provides information to authenticated all cells in order to guard against fraud. The equipment identity register (EIR) is used for equipment security and validation of different types of mobile equipment.

Network management is used to monitor and control the major elements of the GSM Network. In particular it monitor and reports faults and performance data besides helping in reconfiguration of the network.

GSM also defines several interfaces which include the radio interface, the interface between MSC and BSC, interface the external data device and signalling interface that allows roaming between different GSM Network.

Features of GSM

The primary objective of GSM is to provide a full roaming mobile telephony service. Three broad categories of services provided by GSM are

(*i*) Teleservices,

(*ii*) Bearer services, and

(*iii*) Supplementary services.

(i) Teleservice

Teleservice are the services which are provided on a user terminal basis. Paramount teleservices include voice communication and facsimile transmission.

(ii) Bearer Services

For bearer services, the terminal equipment is provided by the user, the responsibility of the network service provide ending at the point connection. Data rates between 300 and 9600 bps fall into this category.

Supplementary services will be developed along the lines of ISDN services but will very from country to country. GSM uses the international standards organisation (ISO) and open systems interconnection (OSI) model. This model envisages structuring data communication on network in general.

OSI consists of seven layers. Figure 18.4 shows an OSI model for the mobile parts depicting the first three layers.

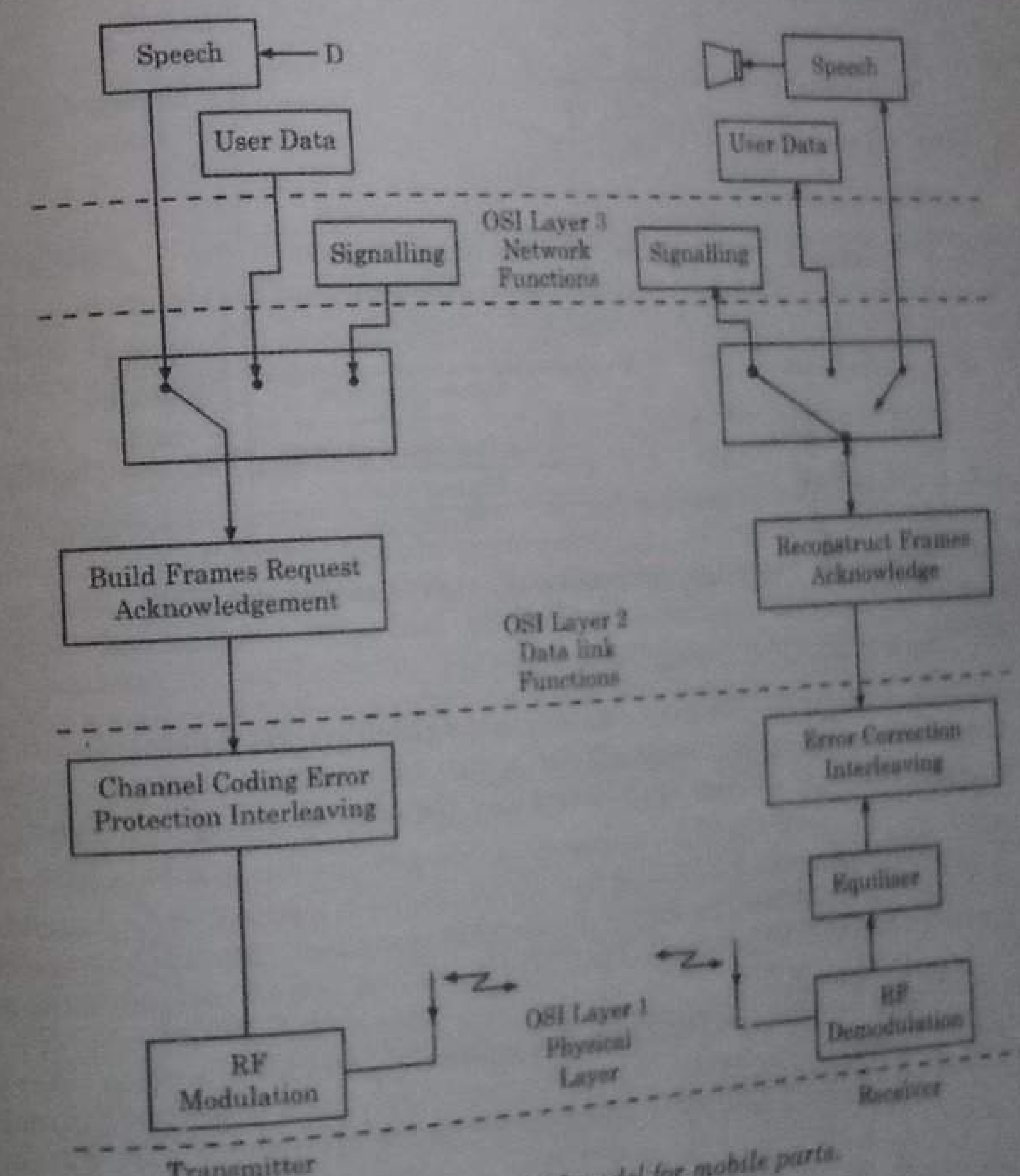


Fig. 18.4. *An OSI model for mobile parts.*

(iii) Supplementary Services

In the lowest layer 1, the physical characteristics of the transmission or radio path medi are special in reference to GSM radio link. These include frequencies, modulation, and elem of error protection coding.

Layer 2, the data link layer consists of element responsible for safe communication of messages or frames between radio stations.

Layer 3, the network layer, is responsible for managing calling and related activity of the radio network. Figure 18.5 shows the graphical representation of OSI model and GSM.

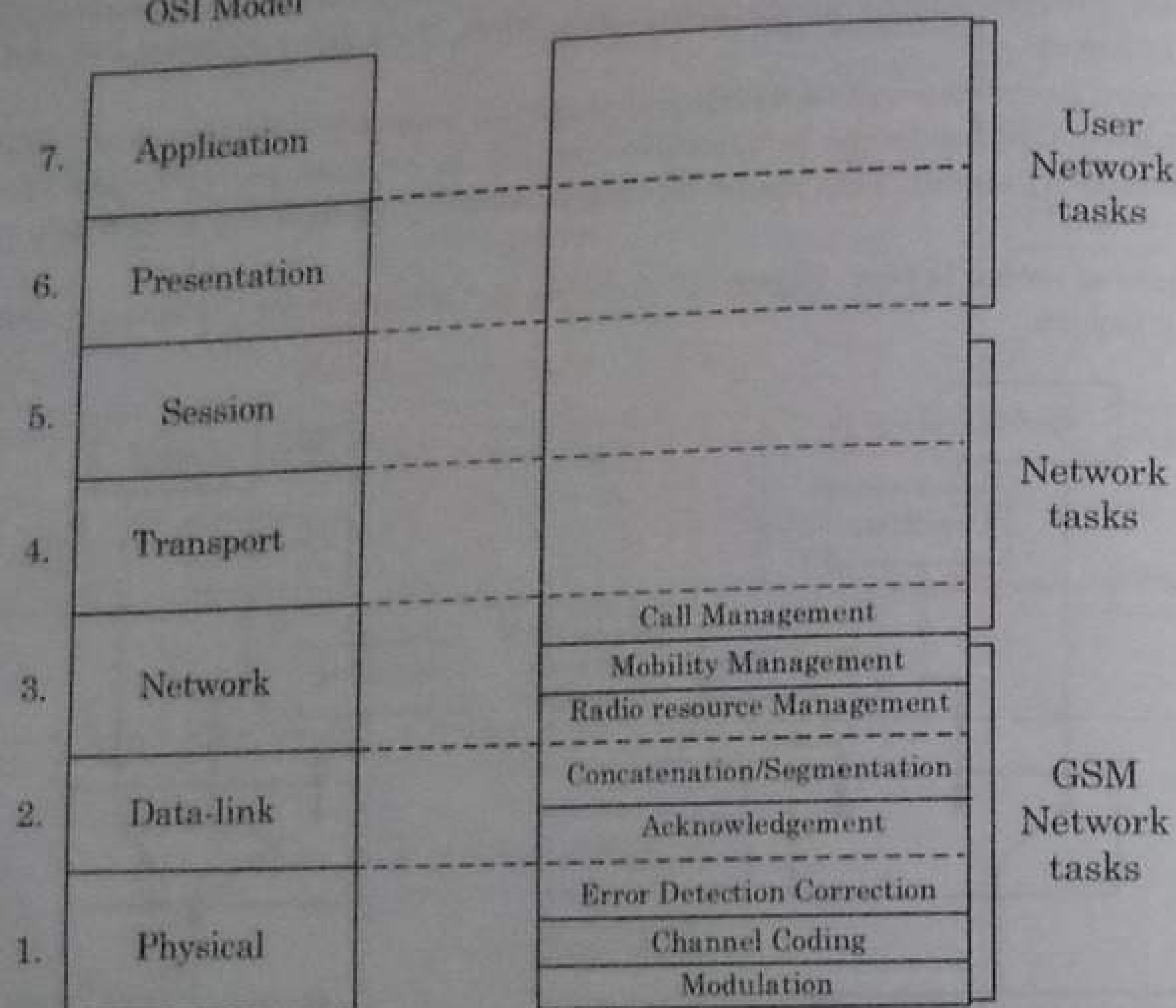
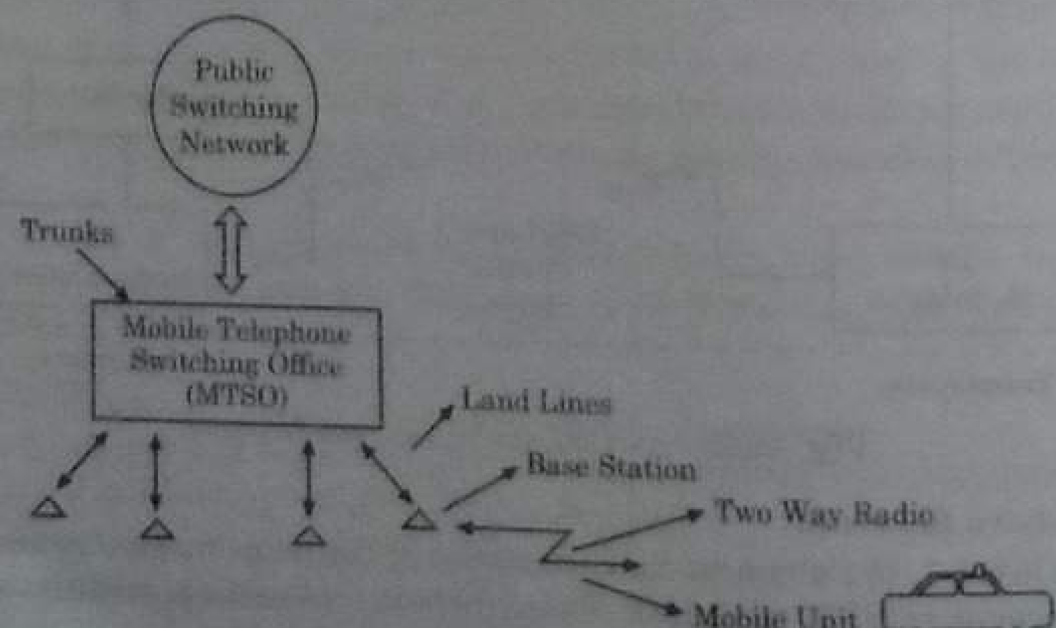


Fig. 18.5. *The graphical representation of OSI model and GSM*

18.5. The Cellular Mobile Radio Systems

Cellular mobile radio systems have come in a big way in the global market for providing telephone services to people on the move. The basic cellular mobile radio system shown in figure 18.6. These can be adopted for fixed cellular applications also, the principle being the same.



In cellular radio system, the geographical area under consideration is divided into a number of cells as shown in figure 18.7. These cells are usually hexagonal in shape and are organised into clusters with most cellular systems using seven cells cluster. The radio channels are allocated across the seven channels. The clusters are then repeated over and over again to cover the entire geographical area served by the system. Since cells using the same channels are separated from each other, and also since the transmitted signal power is low, interference is less likely. The shape of the cells need not always be hexagonal but depends on the terrain the radio propagation.

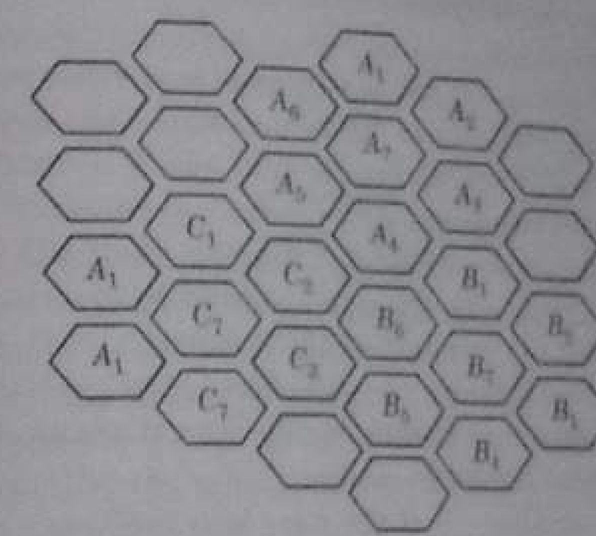


Fig. 18.7. *Cells in a cellular system permit frequency reuse without interference.*

Cellular systems provide an excellent breakthrough as they permit 'frequency reuse' in non-adjacent cells. That is, the same frequency channels can be used in different cells which are separated by a sufficient distance, without interference.

18.6. Structure of Cellophone

The compact cellphone is a very complex piece of digital engineering which has been made possible by advanced ICs and advancements in telecom technology. As a matter of fact the handset can be though to consist of two units–the mobile terminal (or the phone itself) and the Subscriber Identity Module (SIM). The SIM is a credit card-sized plastic module which fits into your mobile phone. This SIM is 'smart card', and consists of all the subscriber related information, like your cellular identification number and other preferences. It can also be used for storing messages and phone numbers.

It also enables charges to be automatically billed to the card-holder, regardless of who owns the phone. This means that if your handset is out of order, you can always use any other handset with your SIM card without affecting the other person's billing.

Functionally, the handset itself may be divided into three main parts. Terminal adaptations, radio modem and the radio frequency (RF) unit. Terminal adaptations comprise the human user interface elements (like the mic, speaker, display and keyboard), and interfaces to other equipment, such as a PC or a PCMCIA data card.

The radio modem is a digital processing unit which handles the conversion of data or speech signals into digital form. It interfaces between the terminal adaptations and the RF (radio frequency) unit. This RF unit handles the actual wireless communication by receiving and transmitting radio signals to the cellular network.

18.7. Working

When you dial a number on the keypad of the phone, the handset transmits the digits, with the help of a built-in radio transceiver, to a nearby radio base station (also called cell). A group of transceiver stations are controlled by a base station controller, which in turn is connected to a

Mobile Switching Centre (MSC). The MSC, in turn, is linked to other cellular and fixed line networks.

All the switching functions within a GSM network can be handled by the MSC, which is the intelligence of the network and performs all the functions like call routing, cell control, switching plus all accounting and charging activities.

Once a cell is forwarded to the MSC, it determines how to route the call and set up the required link to enable the conversation. If the call is destined for a fixed (or normal telephone) the MSC sends it to DOT's public telephone exchange, over a leased line, which then switches the call to the desired telephone set.

However, it may be noted that if the call is destined for another mobile phone, things become more complicated. Firstly, the MSC has to figure out where the desired mobile phone is, and then forward the call to the radio base station (or cell) which is nearest to it.

But how does the MSC figure out where a particular cell phone is? It is assisted by cellphone in this task. When the handset is powered on, it initializes itself and scan the control channels. These control channels are special radio frequencies used by the cell transmitter to send and receive control data. Based upon the strength of the received signal, the handset assigns itself to a specific cell. In this process, it informs the cell of its location so that it may be passed. The handset keeps monitoring the data that is sent on the control channel till its own ID is paged- and then puts itself into the receiving mode.

However, if the handset is mobile, *i.e.* if the user is travelling by a car while calling, the cellular system also needs to keep track of the phone and the call is progressed, so that it can automatically switch the call to another cell as the caller moves from one area to another. This process of switching calls between cells is user transparent, and is known as **cell handoff.**

Although as a user you never need to be actually aware of how the base station or the network and switching subsystems work, it helps to be knowledgeable about how they function so that you can take advantage of new services whenever they are offered by the service provider.

18.8. Other Services of GSM

One advantage of the GSM system is that it enables service providers to offer a number of new and useful value-added services. These include: Call forwarding (default, busy, no-answer, unconditional), call holding and retrieving, call acceptance, preferred language, priority access, remote facilities configuration, automatic reverse charging, selective call acceptance, etc.

Currently, all cellular operations provide the Calling Line Identification service which displays the incoming caller's number. This lets you decide if you want to take the call on your cellular, or call, back on your regular phone. Voice mail retrieval is another facility offered by some operators which allows users to retrieve voice message stored in the network. These messages are typically left by parties calling the user while the phone was in use, did not answer or had phone switched off.

The Short Message Service (SMS) is a service, currently available in Europe, which lets users send and receiver messages of up to 160 characters on their cell phones. The messages may be read on the display of the phone or a PC. SMS is a useful way to transmit data because the message can be sent or received even while a voice call is in progress.

Facsimile transmission (fax) has already entered the Indian market in a big way. Tough not many Indian companies are producing fax machines, they are keenly marketing the foreign products.

The latest buzz phrase that is luring the private and public telecom industries is the radio paging system. With their ability to alert the paged person by a beep, a buzz, a voice, a vibration or a text message, paging systems are half way to the kind of totally mobile telecom facilities that cellular or car telephones allow.

Radio paging systems include input devices such as telephones and computer keyboards through which the message is transmitted with a special code number of the person to be paged. This massage goes to the switching network station where it is incoded into a signalling format required by the pagers. Then the signal is transmitted using VHF/UHF radio frequencies by digital transmitters. Various kinds of pagers which can receive tone and voice, and allow numeric or alphanumeric display, being the message to the receiver.

18.9. Performance Criteria for Cellular Phones

There are three categories for specifying performance criteria of Mobile phones as under:

1. Voice quality,
2. Service quality,
3. Special features.

18.9.1. Voice Quality

Voice quality is very difficult to judge without subjective test from user's opinions. In this technical area engineers cannot decide how to build and systems without knowing the voice quality that twill satisfy the users. For as given chimerical communication system, the voice quality will be based upon the following criterion: a set value at which by per cent of customers rate the system voice quality (from transmitter to receiver) as good or excellent the top circuit merits (CM) of the five listed below.

Circuit Merits (CM)	*Score*	*The Quality scale*
CM5	5	Excellent (speech perfectly understandable
CM4	4	Good (speech easily understable, some noise)
CM3	3	Fair (speech understandable only with considerable effort frequentry repetitions needed)
CM2	2	Poor (speech understandable only with considerable effort frequently repetitions needed)
CM1	1	Unsatisfactory (speech not understandable)

As the per centage of customers choosing CM 4 + CM 5 increases, the cost of building the system rises.

The average of the CM scores obtained from all the listeners is known as **mean opinion score (MOS)**. Usually the toll-quality voice is around MOS ≥ 4.

18.9.2. Service Quality

Three items are required for service quality. With ratio coverage, however

1. *Coverage:* The system must serve an area as large as possible. it is usually not practical to cover 100 per cent of the because of irregular terrain configurations, it is usually not practical to illuminate weak spots with sufficient area for two reasons:

(i) The transmitted power would have to be very high to illuminate weak spots with sufficient reception, a significant cost factor.

(ii) The higher the transmitted power, the harder it becomes to control interference.

Therefore, systems usually try to cover 90 per cent of an area in flat terrain and 75 percent are in hilly terrain. The combined voice quality and coverage criteria in AMPS cellular system state that 75 per cent of users rate the voice quality between good an excellent in 90 per cent of the served area, which is generally flat terrain. The voice quality and coverage criteria would be adjusted as per decided various terrain conditions. In hilly terrain, 90 per cent of users must rate voice quality good or excellent in 75 per cent of the served area. A system operator can lower the per centage values stated above for a low-performance an blow-cost system.

2. *Required grade of service:* For a normal start-up system the grade of service is specified for a blocking probability of 02 for initiating calls at the bust hour. This is average value. However, the blocking probability at each cell site will be different. At the busy hour, near freeway, automobile traffic is usually heavy, so the blocking probability at certain cell sites may be higher than 2 per cent, especially when car accidents occur. The decrease the blocking probability requires a good system plan and a sufficient number of radio channels.

3. *Number of dropped calls:* During Q calls in an hour, if a call is dropped and $Q-1$ calls are completed, then the call drop rate is $1/Q$. This drop rate must be kept low. A high drop rate could be caused by either coverage problems or hand off problems related to inadequate channel availability. How to estimate the number of dropped calls will be described in Chapter 9.

18.9.3. Special Features

A system would like to provide as many special features as possible, such as call forwarding, call waiting, voice stored (VSR) box, automatic roaming, or navigation services. However, sometimes the customers may not be willing to pay extra charges the these special services.

18.10. Operation of Cellular Systems

In this article, let us describe the operation of the cellular mobile system from a customer's perception without touching on the design parameters. The operation can be divided into four parts and a hand off procedure.

Mobile unit initialization: When a user sitting in a car activates the receiver of the mobile unit, the receiver scans 21 set-up channels which are designated among the 416 channels. It then selects the strongest and locks on for a certain time. Since each site is assigned a different set-up channel, locking onto the strongest set-up channel usually means selecting, the nearest cell site. This self location scheme is used in the idle stage and is user-independent. It has a great advantage because it eliminates the load on the transmission at the cell site for locating the mobile unit. The disadvantage of the self-location scheme is that no location information of idle mobile units appears at each cell site. Therefore, when the call initiates from the land line to a mobile unit, the paging process is longer. Since a large per centage of calls originates at the mobile unit, the use of self-location schemes is justified. After 60's the self-location procedure is repeated. In the future, when land line originated calls increase, feature called "registration" can be used.

Mobile originated call: The user places the called number into an originating register in the mobile unit, checks to see that the number is correct, and pushes the "send" button. A request for service is sent on a selected set-up channel obtained from self-locations scheme. The cell site receives it, and in directional cell sites, selects the best directive antenna for the voice channel to use. At the same time the cell site sends requisite to the mobile telephone switching office (MTSO) via a high-speed data link. The MTSO selects an appropriate voice channel for the call, and the cell site acts on it through the best directive antenna to link the mobile unit. The MTSO also connects the wire-line party through the telephone company zone office.

Network originated call: A landline party dials a mobile unit number. The telephone company zero office recognize that the number is mobile and forward the cell to the MTSO. The MTSO sends a paging message to certain cell sites based on the mobile unit number and the search algorithm. Each cell site transmits the page on its own set-up channel, locks onto it, and responds to the cell site. The mobile unit also follows the instruction to tune to an assigned voice channel and initiate user alert.

Call termination: When the mobile user turns off the transmitter, a particular signal (signalling tone) transmits to the cell site, and both sides free the voice channel. The mobile unit resumes monitoring pages through the strongest set-up channel.

Handoff procedure: During the call, two parties are on a voice channel. When the mobile unit moves out of the coverage area of a particular cell site, the reception becomes weak. The present cell site requests a handoff. The system switches the call to a new frequency channel in a new cell site without either interrupting the call or alerting the near. The call continues as long as the user is talking. The user does not notice the handoff occurrences. *Handoff* was first used by the AMPS system, them renamed *handover* by the European systems because the different meanings in English and American English.

18.11. The Concept of Frequency Reuse Channels

A radio channel consists of a pair of frequencies, one for each direction of transmission which may be used for full-duplex operation. A particular radio channel, say F_1, used in one geographic zone to call a call, say C_1, with a coverage radius R can be used in another cell with the same coverage radius at a distance D away.

Frequency reuse in the core concept of the cellular mobile radio system. In this frequency reuse system, users in different geographic locations (different cells may simultaneously use the same.

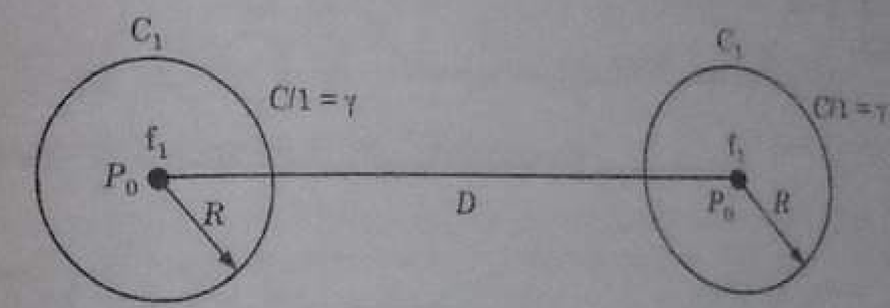


Fig. 18.8. *The ratio of D/R.*

Frequency channel (figure 18.8). The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur. Interference due to the common use of the same channel is called ***cochannel interference*** and is our major concern in the concept of frequency reuse.

18.11.1. Frequency Reuse Schemes

The frequency reuse concept may be utilized in the time domain and the space domain. Frequency reuse in the time domain results in the occupation of the same frequency in different time slots. It is known as ***time-division multiplexing (TDM)***. Frequency reuse in the space domain can be divided into two categories.

(*i*) Same frequency assigned in two different geographic area, such as AM or FM radio stations using the same frequency in different cities.

(*ii*) Same frequency repeatedly used in a same generally area in one system–the scheme is used in cellular systems. There are many cochannel cells in the system. The total frequency spectrum allocation is divided into K frequency reuse patterns, as illustrated in Fig. 2.3 for $k = 4, 7, 12$ and 19.

18.11.2. The Frequency Reuse Distance

The minimum distance which allows the same frequency to be reused will depend upon several factors, such as the number of cochannel cells in the vicinity of the centre cell, the type of geographic terrain contour, the antenna height, and the transmitted power at each cell site.

The frequency reuse distance D may be found from the expression

$$D = \sqrt{3K}\,R$$

where K is frequency reuse pattern shown in figure 18.9, then

$$D = \begin{cases} 3.46R & K = 4 \\ 4.6R & K = 7 \\ 6R & K = 12 \\ 7.55R & K = 19 \end{cases}$$

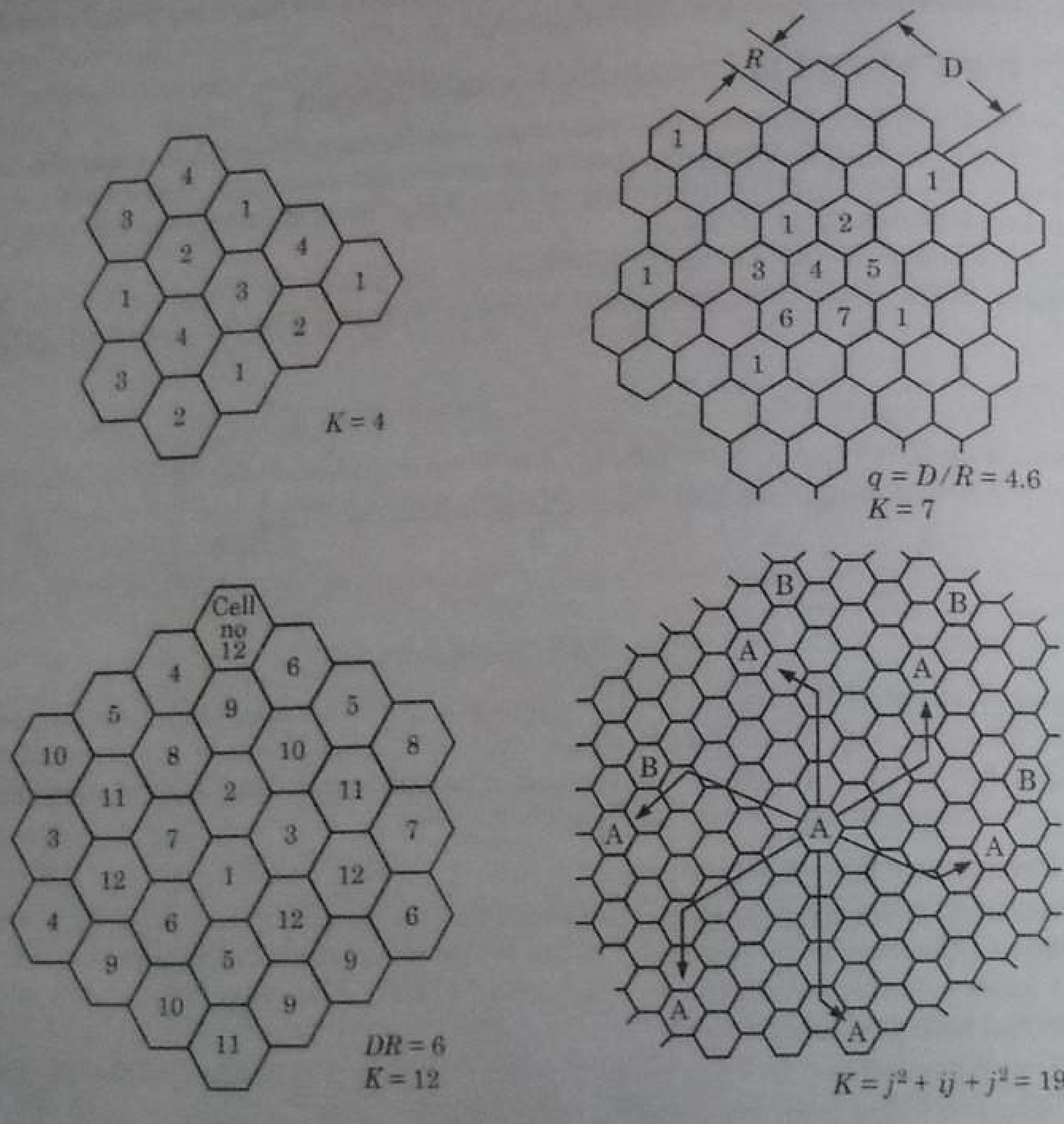


Fig. 18.9. *N-Cell reuse pattern.*

18.12. Consideration of the Components in a Cellular Systems

The elements of cellular mobile radio system design have been mentioned in the previous sections. Here we must also consider the components of cellular systems, like mobile radios, antennas, cell-site controller, and MTSO. Infact, they will affect our system design if we do not choose the right one. The general view of the cellular system is shown in figure 18.10. Even though the EIA (Electronic Industries Association) and the FCC have specified standards for radio equipment at the cell sites and the mobile sites, we still need to be concerned about that equipment. The issues affecting choice of antennas, switching equipment, and data links are briefly described here.

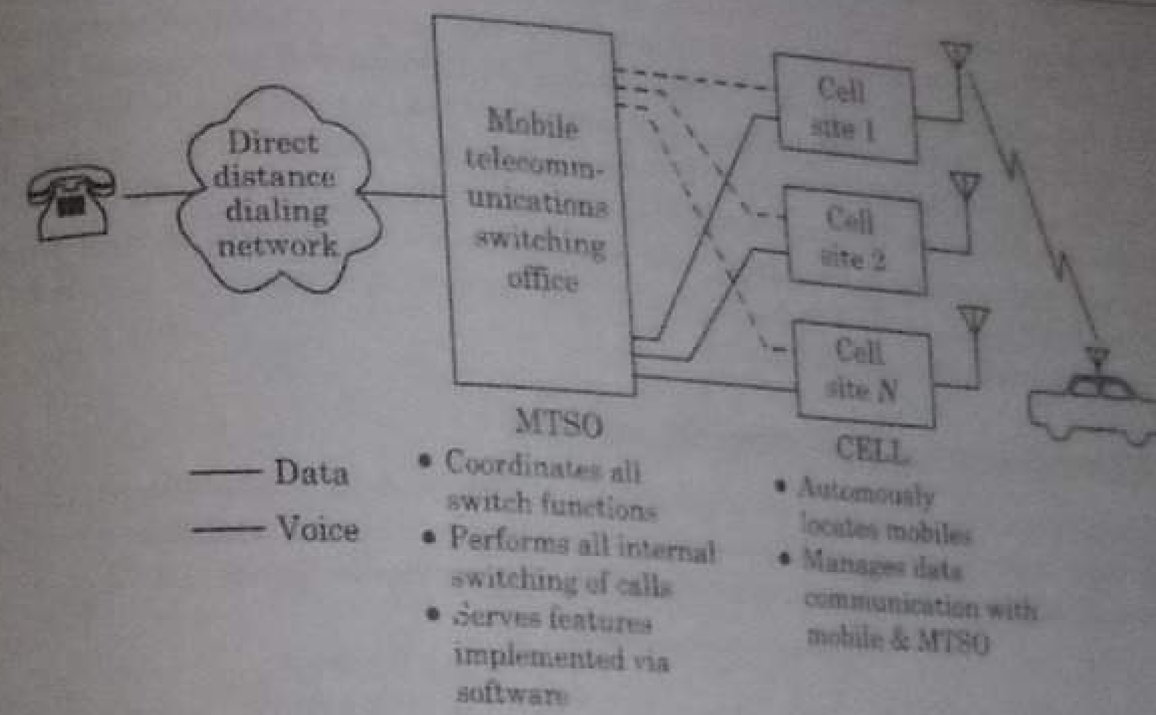


Fig. 18.10. *A general view of cellular telecommunications systems.*

18.13. The Power Control for Cellular Systems

The power level can be controlled only by the mobile transmitted switching office (MTSO), not by the mobile units, and there can be only limited power control by the cell sites as a result of system limitations.

The reasons are as under:

The mobile transmitted power level assignment must be controlled by the MTSO or the cell site, not the mobile unit. Or, alternatively, the mobile unit can lower the power level but cannot arbitrarily increase it. This is because the MTSO is capable of monitoring the performance of the whole system and can increase or decrease the transmitted power level of those mobile units to render optimum performance. The MTSO will also optimize performance for any particular mobile unit unless a special arrangement is made.

18.14. Function of the MTSO

The MTSO controls the transmitted power levels at both the cell sites and the mobile units. The advantages the having the MSTO control the power levels are as under:

(i) Control of the mobile transmitted power levels. When the mobile unit is approaching the cell site, the mobile unit power level must be reduced for the following factors:

(a) Reducing the chance of generating intermodulation products from a saturated receiving amplifier.

(b) Lowering the power level is equivalent to reducing the chance of interfering with other channel cell sites.

(c) Reducing the near-end-far and interference ratio.

(ii) Control of the cell-site transmitted power level. When the signal received from the mobile unit at the cell site is quite strong, then MTSO must reduce the transmitted power level of that particular radio at the cell site and also at the same time, lower the transmitted power level at the mobile unit. The advantages are as under:

(a) For a particular radio channel, the cell size decreases significantly, the cochannel reuse distance increase, and the cochannel interference is further reduced. In other words, cell size and cochannel interferences inversely proportional to cochannel reuse distance

(b) The adjacent channel interference in the system is also reduced. However, in most cellular systems, it is not possible to reduce only one or a few channel power levels at the cell site due to of the design limitation of the combiner. The channel isolation in the combiner is 18 dB. If the transmitted power level of one channel is lower, the channel having high transmitted design an unequal-power combiner for the system operator so that the power level of each channel can be controlled at the cell site.

3. The power transmitted from a small cell is always reduced, and so is that from a mobile unit. The MTSO can facilitate adjustment of the transmitted power of the mobile units as soon as they enter the cell boundary.

18.15. Cellular Analog Switching Equipment

Most analog switching equipment consists of processors, memory, switching network, trunk circuitry and miscellaneous service circuitry. The control is usually centralized, and there is always some degree of redundancy. A common control system has been shown in figure 18.11.

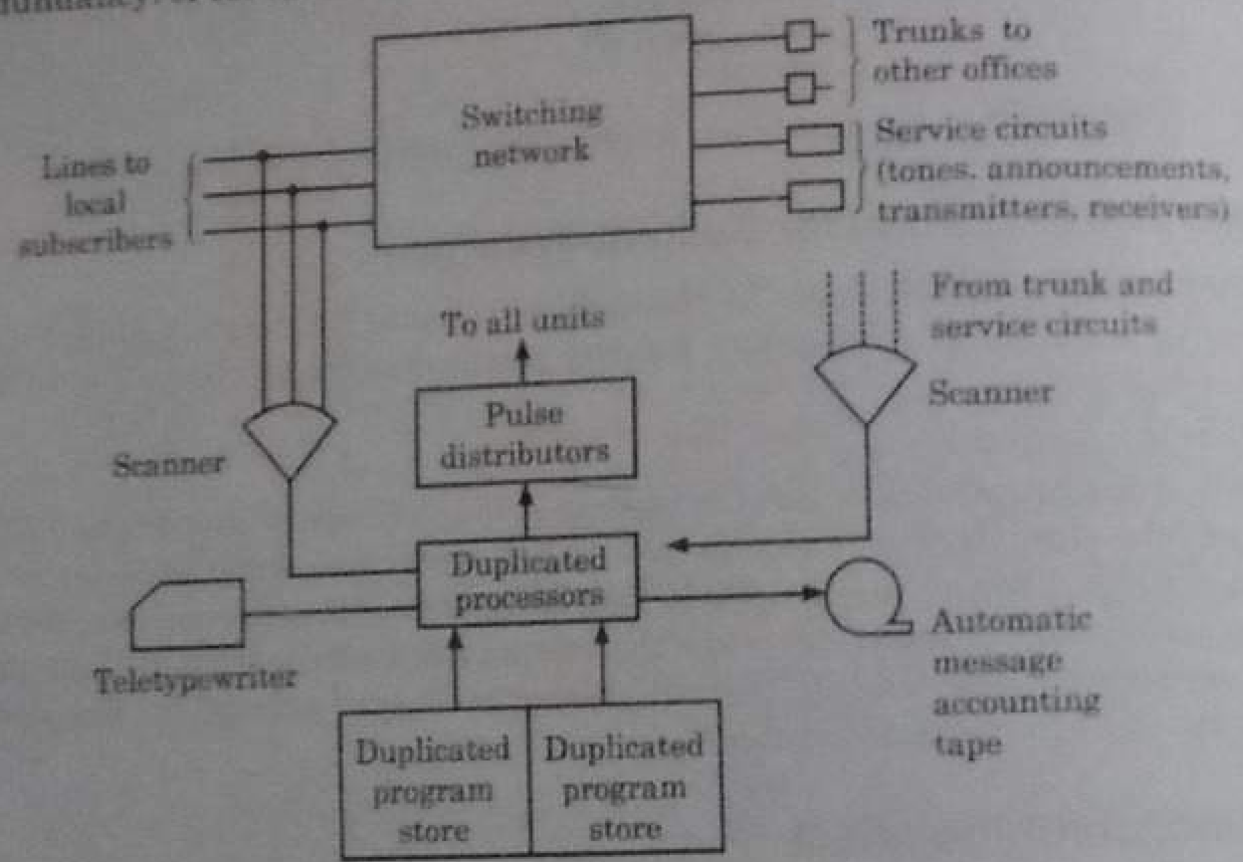


Fig. 18.11. *A typical analog switching system.*

The programs are stored in the memory which provides the logic for controlling telephone calls. The processor and the memory for programming and calls are duplicated. The switching network provides a means for interconnecting the local lines and trunks. The scanners are read under the control of the central processor. The changes in every connection at the line side and at the trunk side are also controlled by the processor. The central processor sends the order to all the units (switching network, trunk, service circuits) through pulse distributions. The automatic message accounting (AMA) tapes are used for recording the call usage. Three programmes are stored in most switching equipment (1) call processing (set, up, hand off, or disconnect a call), (2) hardware maintenance (diagnose failed or suspected failed units), and (3) administration (collect customer recorder, truck records, building data, and traffic count).

18.15.1. Modified Analog Switching Equipment

The local line side has to change to the trunk side as illustrated in figure 18.12, since the mobile unit does not have a fixed frequency channel. Hence, the mobile unit itself acts as a trunk line. In addition, the processors have to be modified to handle cellular call processing, the locating algorithm, the handoff algorithm, the special disconnect algorithm, billing (air time and wire line), and diagnosis (radio, switching, and other hardware failure).

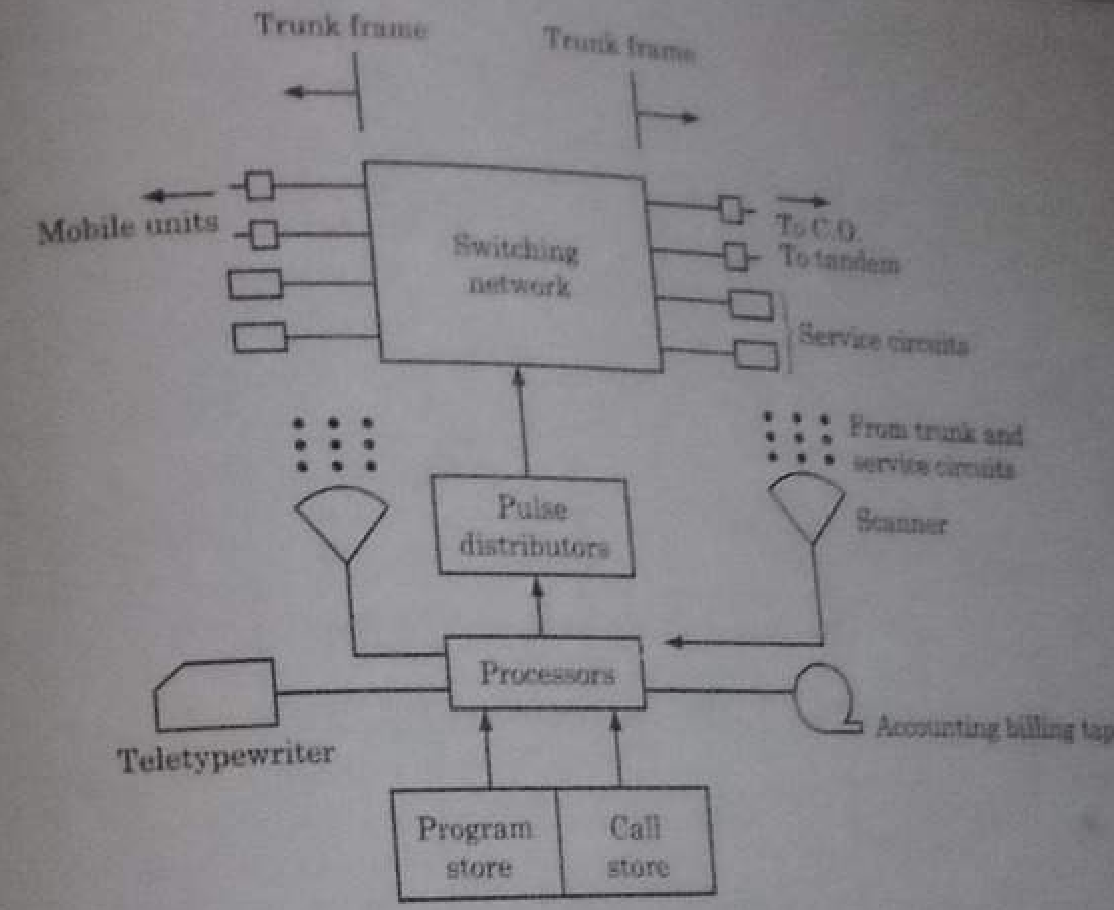


Fig. 18.12. *Illustration of a modified analog switching system for cellular mobile systems.*

18.15.2. Cell-Site Controllers and Hardware

Mobile telephone switching office (MTSO) system manufacturers designed their own c... site controllers and transceivers (radios). Cell-site equipment is shown in figure 18... The cell site can be rendered "smarter", that is, programmed to handle many semiautonom... functions under the direction of the MTSO. Cell-site equipment consists of two basic frame... under:

1. **Data frame—consists of controller and both data and locating radios**
   (a) Providing RF radiation, reception, and distribution.
   (b) Providing data communication with MTSO and with the mobile units.
   (c) Locating mobile units.
   (d) Data communication over voice channels.
2. **Maintenance and test frame**
   (a) Testing each transmitting channel for:
   (i) Incident and reflected power to and from the antenna.
   (ii) Transmitter frequency and its deviation.
   (iii) Modulation quality.
   (b) Testing each receiving channel for:
   (i) Sensitivity.
   (ii) Audio quality.

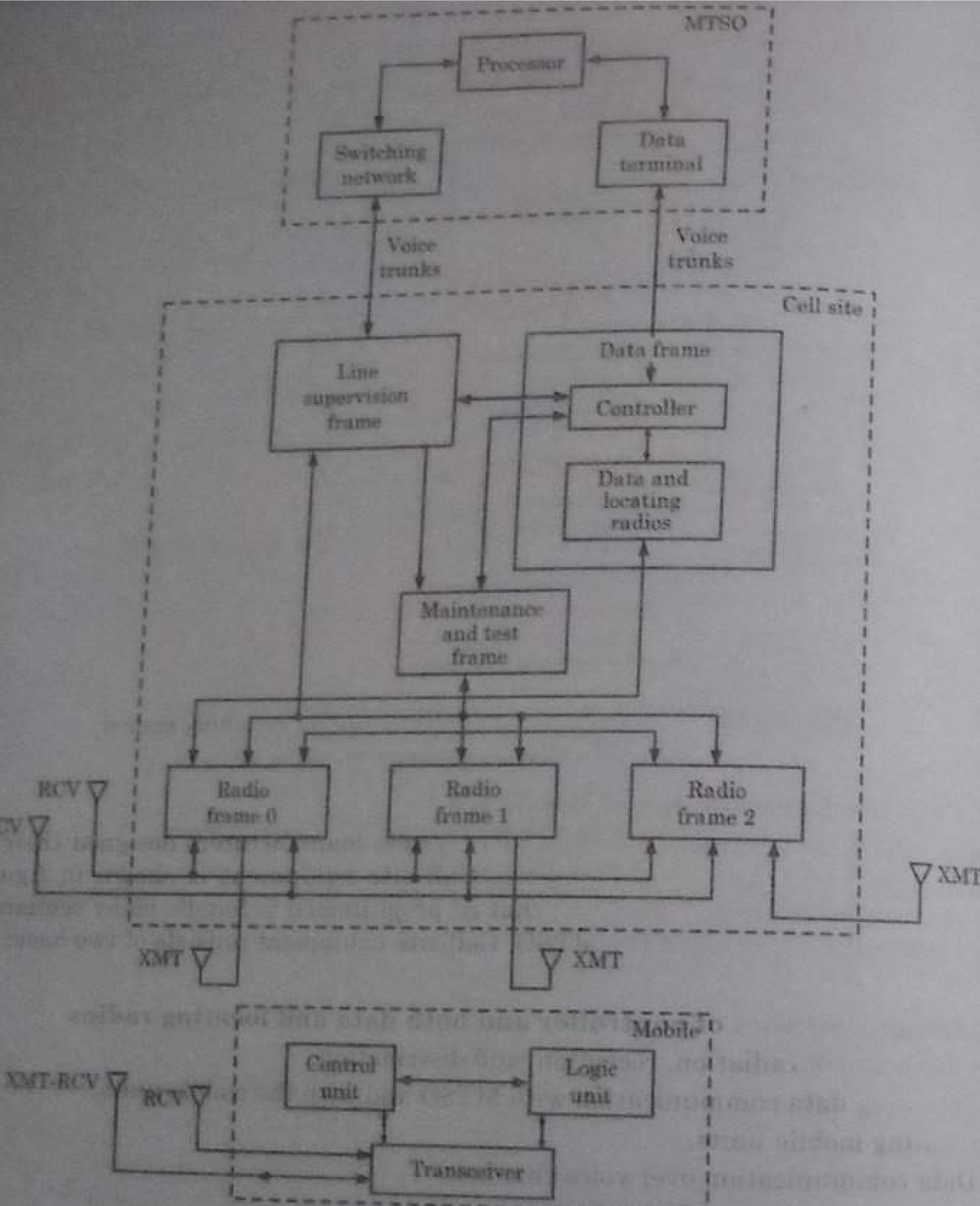


Fig. 18.13. Illustration of Cellular mobile major systems.

6. The Cellular Digital Switching Equipment

1. General Concept

e digital switching, which is usually the message switch, handles the digitized message alog switch, which is the circuit switch, must hold a call throughout the entire duration of . The digital (message) switch can send and message or transmit the voice in digital from: it can break a message into small pieces and send it at a fast rate. Thus, the digital switch rnate between ON the OFF modes periodically during a call. During the OFF mode, the an handle other calls. Hence, the call-processing efficiency of digital switching is higher t of analog switching.

The further digital switch may be a switching packed which would send digital information in a non-periodic fashion on request. There are several other advantages to digital switching besides its greater efficiency. Digital switches are always quite small, consume less power, require less human effort to operate, and are easier to maintain. Digital switching is also flexible and can grow medullary. Digital switching equipment can be either centralized or decentralized. A centralized system of a digital system has an architecture similar to that of an analog system: Motorola's EMX2500, Ericession's AXE-10, and Northern Telecom incarnation's DMS-MTXM are large centralized digital system. A decentralized system is described here.

A decentralized system is slightly different from a remote-control switching system. In the remote-control switching system, a main switch is used to control a remote secondary switch. In a decentralized system, all the switches are treated equally, i.e., there is no main switch.

18.16.2. Elements of Switching

One decentralized switching system can be introduced here for illustration. It is the American Telephone and Telegraph (AT&T) Autoplex 1000, which consists of an executive cellular processor (ECP), digital cellular switching (DCS), an interprocess message switch (IMS), RPC (ring peripheral control), and nodes.

1. ECP transports messages from the one processor to another.
2. IMS attached to token ring (IMS uses a token ring technology provides interfaces between ECP, DCS, cell sites, and other network. The RPC attached to the ring permits direct communication among all the elements through the ring.
3. DCS, which are digital cellular switches, function is modules to allow the systems to grow. Of these coders, LPC is attractive because of its performance and degree of complexity.

18.17. Digital Mobile Telephony

Because voice communication is the key service in cellular mobile systems, when we think of the digital systems, we must think of a digital voice.

In present-day mobile cellular systems, transmission of a digital voice in a multipath fading environment is a challenging job. The major considerations in implementing digital voice in cellular mobile systems are discussed below, along with a tentatively recommended transmission rate for the cellular mobile system.

Digital Voice in the Mobile Radio Environment

1. The criterion the judge, a good digital voice through a wire line is employed in three existing digital voice schemes:
   (a) In a continuously variable step delta (CVSD) modulation scheme, the present transmission rate is 16 kbps. This is not toll-quality voice transmission and is commonly used by the military.
   (b) In a LPC scheme, the present transmission rate of .4 kbps provides a synthetic quality voice, but a rate of .8 kbps using vector quantization may proved a communications quality voice. A rate of 16 kbps can provide a toll-quality voice.
   (c) In a pulse code modulation (PCM) scheme, the present transmission rates of 32 kbps and 64 kbps is used commercially. Of the three schemes, LPC seems most attractive because if its low transmission rate. However, LPC is more vulnerable in terms of distortion to the mobile fading environment.
2. Digital voice has to be processed in real time, which imposes constraints on the digital processing time. This adversely affects LPC but not CVSD.
3. When sending a digital stream (voice) through a radio channel in a fading environment, in general an LPC scheme needs more code protection than CVSD scheme does because LPC is not implemented in a continuous waveform in either the frequency domain or the time domain while CVSD is implemente' in a continuous waveform in the time domain.

4. Because the mobile unit is moving, sometimes rapidly, sometimes slowly, insertion of extra synchronization bits is needed in the normal digital stream.

onsiderations for a digital voice transmission in cellular mobile systems

The following factors are significant which are to be considered:

Digital Transmission Rate

(a) Present cellular signalling rate: The present signalling format is designed on the sumption that the mobile unit moves at an average of 30 mi/h and that the transmission rate 10 kbps. The 21 synchronization bits (10 synchronization bits and 11 frame bits) occur in front every code word of 48 bits ensure that the bits are not falling out of synchrony before the ynchronization takes place.

(b) Considerations of LPC scheme: If a rate of 4.8 kbps using LPC for a communications ality voice is accepted its rate is almost half of the present transmission rate, and at this nsmission rate a 48-bit word would be acceptable in a fading environment. The resynchronization eme for a mobile receiver should take place in front of every code work of 48 bits (21 synchronization s) + (a code word of 48 bits = 69 bits). The number of synchronization bits is almost half the nber of bits in a code word. Therefore, the transmission rate would be approximately (4.8 × = 7.2 kbps.

(c) Redundancy of transmission: The protection of synchronization in a mobile radio ronment is not sufficient. If the digital stream were to occur in a signal fade, partial or whole words would be lost. In order to prevent fading, redundancy of transmission is often used would take a minimum redundancy scheme; for example, we would transmit the same message hree times and take a "2-out -of-3 majority vote" on each bit to minimize the fading impairment e message bits. For LPC of 4.8 kbps, an RF transmission rate of (4.8 kbps × 1.5)3 = 21.6 kbps eded. It is reasonable for a 30-kHz channel to carry a transmission rate of 21.6 kbps over a r fading medium. When an RF transmission rate of 21.6 kbps over a severe fading medium n an RF transmission rate is given, the channel bandwidth can be narrower with a trade-off smitted powers.

d) Modulation, diversity coding, ARQ, and scrambling: Diversity and modulation can in reducing the RF transmission rate for the digital voice. However ARQ schemes, fancy g schemes, and complicated scrambling schemes cannot be implemented for voice transmission is because the digital voice must be processed in real time, and these three schemes usual. re be processed in real time, and these three schemes usually require a fair amount of time rocessing. These schemes can be used for data transmission.

Word Error Rate: In the multipath fading environment, the bit error rate P_e is not the concept for voice-quality measurement; the word error rate P_w is also important and varies vehicle speed. However, information on the word error rate for transmission of digital voice a mobile radio environment only appears in two extreme. Assume that we know the required d P_w. We can covert P_e and P_w to a required carrier-to-noise ratio C/N. If a two-branch sity scheme has been used, the bit error rate of 10^{-3} in a relatively slow fading case requires / level of approximately 15 dB. The C/N level, a word error rate of a 4-bit word is about In general, if the work error rate is the same as or lower than the bit error rate for a given he C/N level is acceptable. In our case, P_w and P_e are the same at C/N = 15; therefore, the 15 dB is justified.

Relationship between C/N and E_b/N_0: The relationship between the carrier-to-noise /N, the energy-per-bit-noise-per-hertz ratio E_b/N_0, the transmission rate R, and the bandwidth be expressed as

$$\frac{C}{N} = \frac{E_b}{N_0}\frac{R}{B}$$

When the number of levels C/N increases, the bandwidth decreases. Keeping E_b/N_0 constant, we see that when the bandwidth decreases, the required carrier-to-noise ratio C/N increases. Previously we calculated that C/N = 15 dB words for a two-level (binary) system. If the number of levels increases, the C/N will be higher than 15 dB.

Example 18.1. Let E_b/N_0 = 15 dB for a two-level system and R_0 and B_0 be the transmission rate and transmission bandwidth, respectively, of the two-level system. Now if we reduce the bandwidth $B_1 = 0.5\ B_0$, then

$$\left(\frac{C}{N}\right) = (31.6)\frac{R_0}{0.5B_0} = 2\left(\frac{C}{N}\right)_0 = \left(\frac{C}{N}\right) + 3\text{dB}$$

This means that the power increases by 3 dB. If the transmitted power was 50 W, now it is 100 W.

18.18. MTSO Interconnection

18.18.1. Connection to Wire-Line Network

The MTSO operates on a truck-to-truck basis. The MTSO interconnection arrangement is similar to a private-branch exchange (PBX) or a class 5 central office (a tandem connection) see figure 18.14. The MTSO has three types of interconnection links.

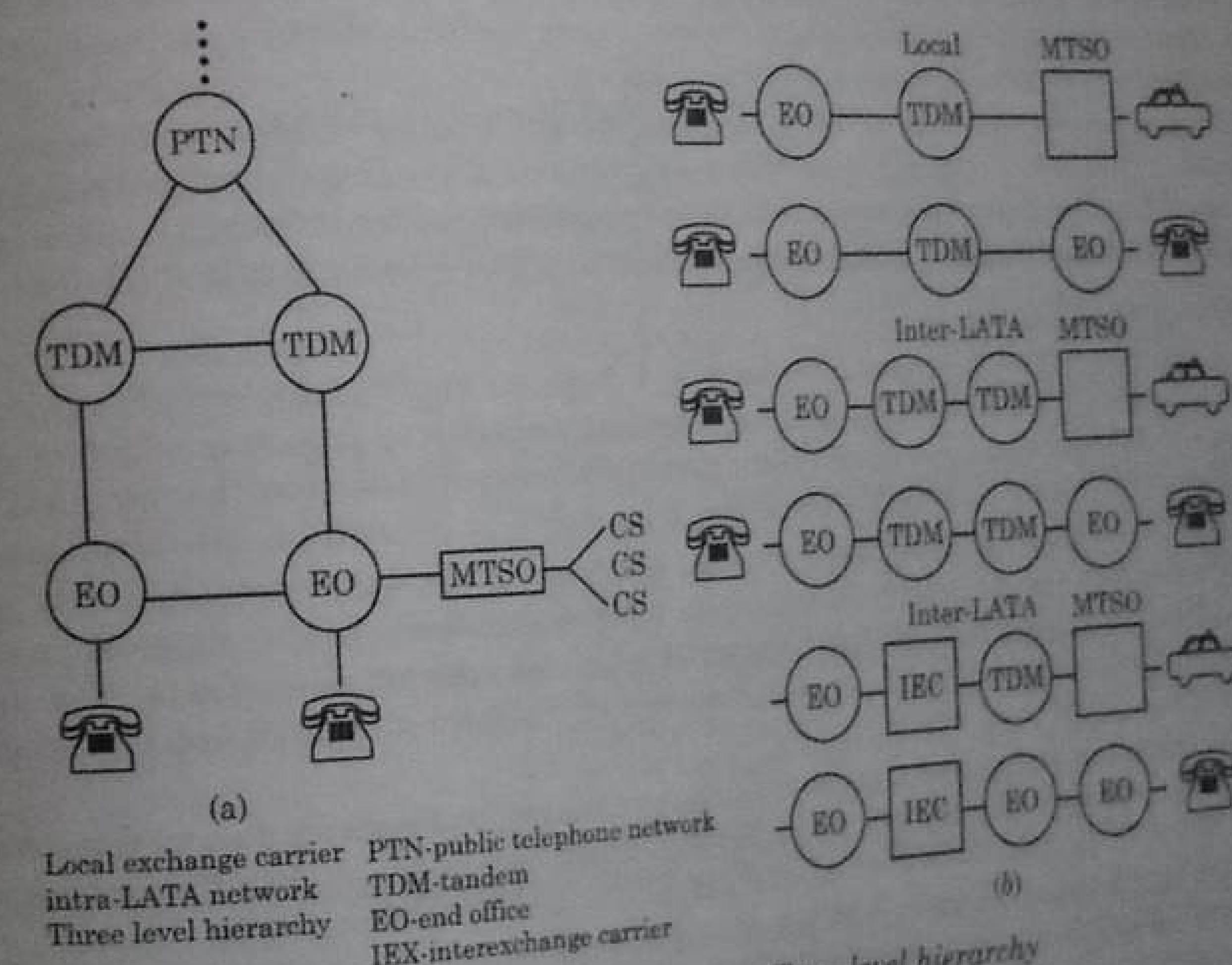


Fig. 18.14. *Illustration of Three-level hierarchy (a) Interconnection of MTSO: (b) three types of call.*

Type 1—interconnects a MTSO to a local-exchange carrier (LEC) end office.

Type 2A—interconnects an LEC tandem office.

Type 2B—interconnects to an LEC end office in conjunction with type 2A on a high-usage alternate-routing basis.

The three-level hierarchy of a public telephones network is shown in figure 18.15. With this diagram, we can illustrate the three types of calls: (1) a local call, (2) an intra-LATA (local access and transport area) call, and (3) an inter-LATA call.

18.18.3. Connection to a Cell Site

Two types of facility are used as under:

1. Cell site trunks provide a voice communication path. Each trunk is physically connected to a cell-site voice radio. The number of trunks is decided on the basis of the traffic and the desired blocking probability (grade of service).
2. The cell site acts as a traffic concentrator for the MTSO. For instance, we may design an average busy hour radio channel occupancy of [illegible] for high-traffic cells.

Both T1 carrier cables and microwave links are used. The duplication is needed for reliability.

18.19. Radio Paging Systems

As a matter of fact, two persons are required for any form of human communication, however for good communication everyone needs to be contactable. Mobile radio is for communication, with people on the move. Paging is a simple land mobile radio system to solve the all times, all-places, all-people communication problems.

With very economic use of the radio spectrum, paging systems can keep thousands of people in touch, with a small, light-weight, unobtrusive, body-worn equipment. Present day paging developments are available with several innovative features and powerful message capabilities and are supported by nation-wide and international transmitting and control facilities. Even in India, a sophisticated modern paging system with many useful features is being planned for Mumbai and other metropolitans too.

This article reviews the basic paging concepts, on site paging history, wide area paging developments, operation of a public paging system, constituents of a paging control and transmitting system, anatomy of miniaturised pager unit, innovative features/facilities of an alive modern system, user's multiple benefits, numerous beneficiaries, global growth rate and future trends.

18.19.1. Concept of Paging

Paging literally means to summon by sending a page (i.e., attendant) to call someone by name. As a matter of fact, Radio paging is fundamentally a one-way personal selective calling system and relies on the availability of wire line telephone network to support the communication process. The user is always in contact even through he mobile or away from his telephone set.

When the call is sent out on a paging system, the pager (radio bell) carried by the person required immediately sounds a deep or gives a distinctive alert tone. In the simplest case, the person receiving the tone alert signal has to contact back to take the actual message. Now pagers are available with additional facility of displaying messages in the form of numeric and alphanumeric form or conveying direct voice messages.

In earlier days, it was common practice to use public address systems for paging the required people instantly, whether in a big office or a factory. That was a simple beginning of paging. Later, such direct audio systems were replaced and improved by radio methods.

Radio paging emerged as a useful method of communication via radio in the mid-1950s. The problem of calling doctors/nursing staff silently without distressing patients was addressed by the radio technology of the day. In 1956, the first paging system used low frequencies like 30-50 kHz and its range was restricted to below 500 metres due to the use of inductive loop techniques. Inductive loop systems have the advantage of excellent spectrum conservation properties. However, the cost of installation, extension and coverage predictions makes such a system less attractive in relation to its radio alternatives.

During 1960s and 1970s on-site paging expanded rapidly with frequency allocation of 27-41 [M]Hz and 470 MHz bands. Both amplitude and frequency modulations were used. The signalling systems were based on sequential tones in the audio frequency band of 300 MHz to 3 kHz. Paging service was initially limited to tone alert operation.

In the early 1970s, digital signalling methods became popular and paging became [illegible]. In the early 1980s digital code formats were improved to permit paging of numeric, alphanumeric display and voice messages. Now there are many different proprietary digital signalling systems commercially available giving rise to the problem of non-compatibility between different manufacturers.

On-site paging provides service within a private or professional organisation. With a typical range of less than 2 kms, on-site paging grew as an extension of the internal telephone, public address and intercom system business. However, applications for the facilities offered in the on-site situations were soon found for much wider area systems requiring longer ranges. Fireman's call-out and medical answering services are best examples. The early system required [illegible] receiver capability but excellent sensitivity to achieve wider range. Because of low capacity, they had to be simple and less costly. The early wide area paging systems, unlike on-site systems, were run as an extension of mobile radio business.

The significant milestones in the growth of the wide area paging are shown in figure 18.15. Bell Boy was first introduced in North America in 1963, followed by Eurocall in Europe in 1967 and Pocket Bell in Japan in 1968. The early systems used sequential tone signalling. They can be generally classified as 2-tone and 5-tone signalling methods. The EIA/Motorola 5-tone system is notable.

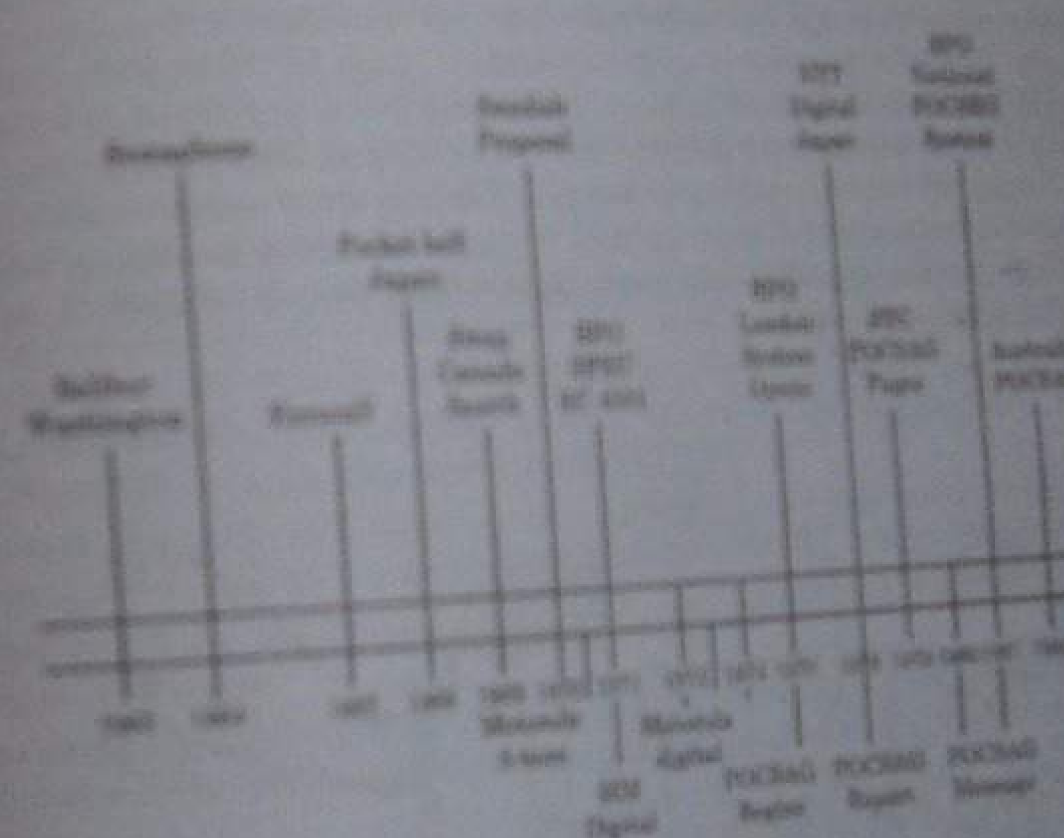


Fig. 18.15. *Illustration of Paging milestones*

The later developments were in digital signalling. The first truly binary digital paging sys[tem] was introduced in 1970 in Canada and subsequently aroused great interest in such metho[d] signalling. During the mid-1970s digital paging systems were developed by some of the m[ajor] companies like the Swedish PTT and NTT, Japan.

However, during this period, one of the most adventurous single channel national pa[ging] system in the word was designed and planned in the UK by BPO (British Post Office). Sy[stem] wide area paging (SWAP) was initially proposed in which numerous proprietary digital pa[ging] codes could be accommodated by computer control. Such a system was commissioned in L[ondon] in 1976. However, the BPO realised that it was necessary to have a transmission system capa[ble] both simultaneous and sequential techniques to optimise traffic handling for a nation-wide ro[ll-out] while it was also important to standardise a paging code and a signalling format for [illegible] channel utilisation and occupancy.

Thus, in December 1975, the Post Office Code Standardisation Advisory Group (POCSAG) was established. A code structure and format originally proposed by Philips Research Laboratories was finally accepted with some modifications. POCSAG paging code, published in 1978, satisfied ideal code properties for large national use, with an address capacity of eight million and pager capacity of two million. The credit for evolving an international paging code goes to British Post Officer.

In addition to the POCSAG (a British code in real sense), three other notable and rival codes which are in wide use are as under:

(i) GSC (Golay sequential code) is essentially of Americal origin. It is supported by the largest manufactures with a full range of products and is in volume service, notable in the USA.

(ii) NTT code is in high volume service in Japan and also sold by NEC in other countries.

(iii) MBS code is in use exclusively in Sweden.

18.19.2. The Components of a Paging System

The block diagram in figure 18.16 illustrates how a typical wide area public paging system works. The radio paging system basically consists of paging control terminal (PCT), radio base stations (subscriber units). PCT is usually installed in the centralised exchange premises for public paging. Radio transmitters are installed at suitable sites to take the advantage of antenna height and better radio coverage. Normally more than one transmitter is used to cover a wide area in a big city. Typical high power transmitter outputs range for 50 to 1000 watts for public wide area paging, while 5 watts is the maximum transmitter power permitted in India for private paging. Frequency bands available for paging cover both VHF and UHF ranges (30, 70, 150, 400 and 900 MHz bands). RF channel spacing is just kHz like any other single voice channel radio system. Paging broadcasts are received selectivey by the subscribers pssessing pager units. A typical PCT mainly contains of central processor, input-output processor (coders, storage units, queuing units etc.) and peripherals.

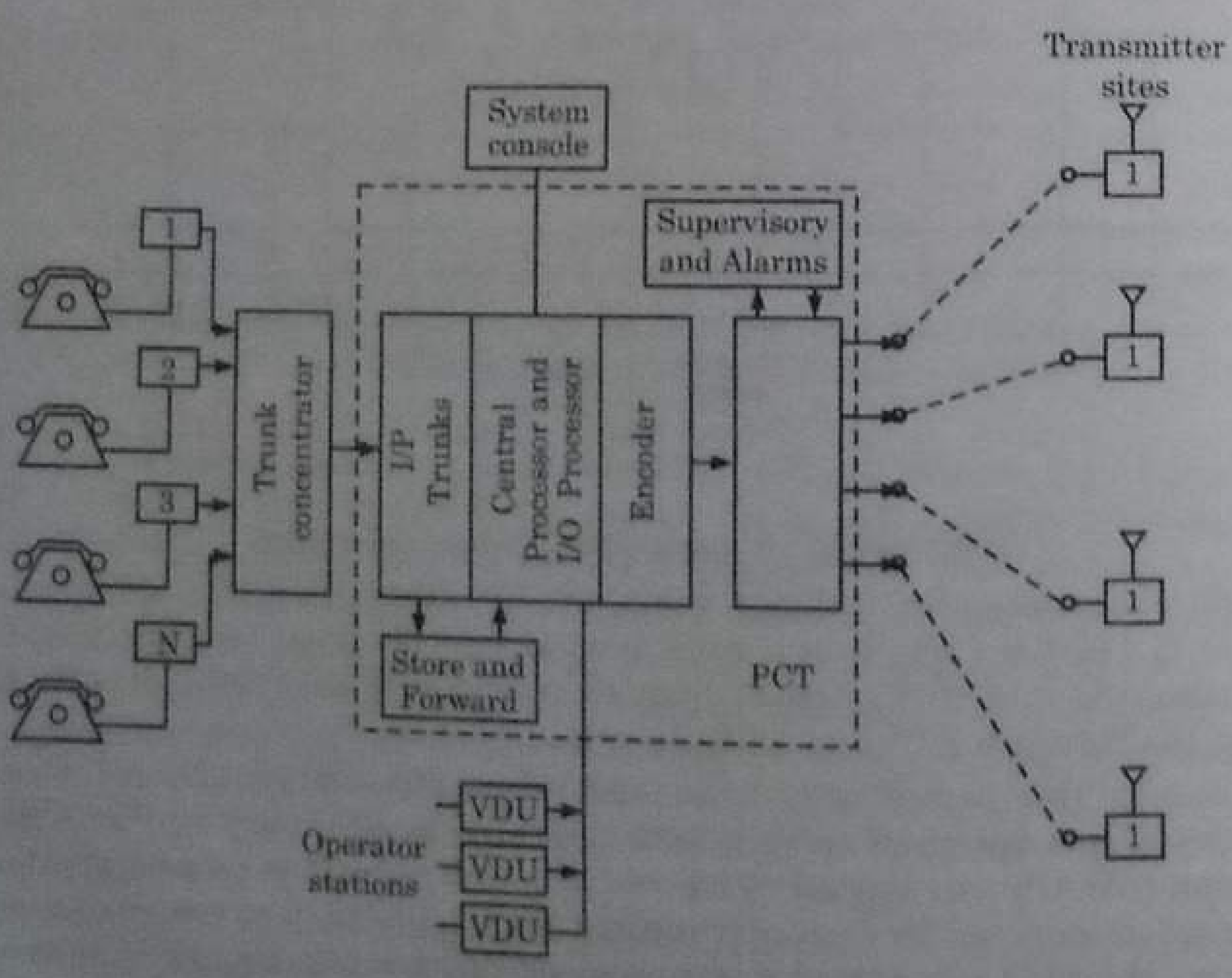


Fig. 18.16. *Illustration of wide area public system.*

Since PCT is the heat of the paging system, generally it is configured with full dynamic redundancy with auto change over facility to increase system reliability. Dynamic redundancy includes redundancy by of central processor and input-output processor with associated RAM and disc drives. For smaller and less important places redundant protection can be reduced from 1 + 1 mode (full redundancy on unit by unit basis) to 1 + 1 mode (one unit is redundant for N working units) or non-redundant configuration may resorted to for simplicity and economy.

PCT also provides centralised remote supervision, fault diagnosis, online testing, remote control, traffic analysis, billing etc. It generally has facilities for digital paging (numeric and alphanumeric messages). Some PCTs have facility for voice messages too. PCT is capable of being operated manually (through an operator control) or automatically when interfaced with the existing PSTN (public switching telephone network).

18.19.3. Operational Features of a Paging System

When a subscriber dials a pager number form any telephone with an intention of sending a message, PCT first receives call from the PSTN through various exchanges directly or through a trunk concentrator. PCT feeds back either a suitable tone or a voice announcement to the calling subscriber to indicate that the call is being processed. After decoding and recognising the pager number as that of a valid paging subscriber, the system returns a go-ahead signal to the calling subscriber to enter the actual message. Store and forward facility will record messages when the system is busy and then transmits as soon as it becomes free. Completion of message transmission is also conveyed to the caller.

The encoded data is distributed through a zone controller and is carried to multiple transmitter sites on VF (voice frequency) channel either by wire-line or radio. The electrical path lengths of these links should be properly equalised for compensating data delays. After modulation (generally FM is used), the transmitters broadcast the RF signals. In multiple transmitter zones, a single radio frequency channel is preferred so as to avoid multichannel recoveries. The transmitters can operate either sequentially or simultaneously. To avoid null zones between individual transmitter service areas, very high stability of RF carrier must be maintained.

PCT has facilities for group calling, priority paging, secure paging, repeat paging, greeting messages, canned messages, message retrieval etc.

Group call. In a group call, a page (same message) is sent simultaneously to multiple subscribers. Thus it is possible to call at a time several subscribers having common interest.

Priority page. By assigning priority status to any subscriber, his page will be transmitted before nonpriority pages.

Secure page. Secure paging is applicable to operator control systems. Each operator is assigned an identification code and password to gain access to the system, to protect unauthorised access to the system.

Repeat page. In repeat paging, repetition of the same message is done more than once for special subscribers requiring extra reliability to ensure that the message has successfully been received. For example, if a paging subscriber is inside a basement, due to penetration losses the pager would be out-of-range. As a first step, the pager provides an indication/warning. All messages transimitted during such times may be lost and repeat paging at programmed intervals will increase the probability of reception.

Greetings. With greeting facility, the caller can be greeted by prerecorded voice greetings. These greetings can be programmed by the subscriber.

Canned messages. Canned or predefined messages can be sent by dialling unique numbers for each message, on the lines of telegraphic greetings.

Message retrieval. Messages can be retrieved from the paging system by disclosing a password for identification, to verify messages or find out missing messages, if any.