1 CHAPTER

Introduction to Wireless Communication Systems

SYLLABUS

Introduction to Wireless Communication Systems: Evolution of mobile radio communications; examples of wireless communication systems; paging systems; Cordless telephone systems; overview of generations of cellular systems, comparison of various wireless systems.

Chapter Outline

- Evolution of Mobile Radio Communications
- Reasons for Developing a Wireless Mobile Telephone System
- Frequencies for Radio Transmission
- FCC Allocation for Mobile Radio Transmission
- Examples of Wireless Communication Systems
- Overview of Generations of Cellular Systems
- Cellular Mobile Communication : Important Terminologies used
- Comparison of Various Wireless Systems
- Advantages of Wireless Communications

1.1. EVOLUTION OF MOBILE RADIO COMMUNICATIONS

As a matter of fact, wireless communication system has been dominating the world of information technology by its simple maintenance technique. Wireless communication ensures its services even when people are on the move. Wireless communciations technology has had a huge impact on most of the developed world and a large number of developing countries. Wireless communications affects almost every aspect of our daily lives. From the ubiquitous cordless phone to automated counting of inventory in large retail stores to remote wireless sensors installed in locations that are difficult to access, wireless technologies play a role.

Furthermore, wireless communications technology, or simply wireless, is poised to continue expanding at a very fast pace.

Wireless communications is revolutionizing the way we live–just as personal computers in 1980s forever altered how we work, and the Internet in the 1990s dramatically changed how we acquire information. Using wireless communcations to send and receive messages, browse and Internet, and access corporate databases from any location in the world has already become commonplace. A wide array of devices ranging from computers to digital cameras, laser printers, and even refrigerators can already communicate without wires.

Users will soon be able to access the digital resources that they need at any time, no matter where they may find themselves. The IT industry and consumer marketplace are already seeing dramatic changes based on wireless technologies. It is truly becoming a wireless world.

In view of above, it is interesting to know about the history of a modern technology like wireless communications as under:

DO YOU KNOW?

In 1964, Bell Laboratories formed a mobile communication department after the U.S. Congress took away the satellite communications business from AT & T. The early wireless networks only concentrated on voice communication.

1. Radio and Television Communications

A renowned scientist Marconi, in 1874, conducted some experiments to send signals with the help of electromagnetic waves at short distances of only about 100 metres. Earlier, it was believed that electromagnetic (EM) waves could only be transmitted in a straight line and futher the primary obstacle to radio transmission was the curvature of the earth's surface. Marconi successfully conducted various experiments to prove that electromagnetic (EM) wave transmission was possible between two distant points-even through obstacles in between. Infact, this concept paved the way for wireless telegraphy which is also known as radio communications. Basically, the word 'radio' came from the term 'radiated energy'. Further, Marconi, in the year 1935, carried out some distance-based search experiments which eventually led to the invention of radar.

Marconi also carried out experiments on microwaves and early television technology. In the year 1927, Farnsworth gave the first public demonstration of the television system and developed several of the basic concepts of an electronic television system.

By the year 1939, widespread commerical electronic television broadcasting started in the United States. In the year 1941, the American Federal Communications Authority set the standards for broadcast television. Further, by the year 1970, television had become the primary information and entertainment medium in the world. Moreover, today, it has been estimated that there are more than a billion television set worldwide. But, still the standards for television broadcasting are not identical throughout the world. Infact, there are 15 different variations of broadcasting standards used around the world.

2. Radio Communcations

As a matter of fact, Radar has been recognised as one of the greatest scientific developments of the first half of the 20th century. Basically, the first practical radar system was produced in 1935 by the British physicist Robert Watson-Watt. By 1939, England had established a chain of radar stations along its southern and eastern coasts to detect aggressors in the air of on the sea. Radar is an active remote-sensing system that opearates on the principle of echoes. A radar display shows a map-like picture of the area being scanned. A Doppler radar is being used now-a-days by Meteorologists to locate tornados and microbursts, which are downdrafts of air traveling at very high speeds. Doppler radar is also used by law-enforcement agencies to locate speeding motorists.

3. Satellite Communcations

A satellite may be defined as an object that revolves around another object. As an illustrated example, the moon is a satellite of the earth and the earth is a satellite of the Sun. Also, man-made satellites provide communication capabilities around the world and thus transmitting television signals, telephone calls, faxes, computer communications, and weather information. Satellites can be sent into space with the help of a variety of launch vehicles. In the year 1720s, Newton illustrated how an artificial satellite could be launched from the Earth. In the year 1945, Arthur C Clarke, a science-fiction author, envisioned a network of communication satellites.

In the year 1964, an International organization known as Intelsat was formed. This organization launched a series of satellites with the objective of providing total earth coverage by satellite transmission. This had been achieved by the year 1969. Intelsat has lauched 19 satellites upto today. All these satellites are open to use by all Nations of the world. Infact, the great popularity of cellular telephones advanced the idea of always being connected everywhere on the Earth.

4. Wireless and Mobile (Cellular) Communcations

(i) Wireless communication is the fastest-growing part of the very dynamic field of electronic communication. It is an area with many jobs that go unfilled due to a shortage of knowledgeable people. Wireless communication began only a little later than the wired variety.

(ii) Morse's telegraph (1837) and Bell's telephone (1876) were soon followed by Hertz's first experiments with radio (1887). Hertz's system was a laboratory curiosity, but Marconi communicated across the English channel in 1899 and across the Atlantic Ocean in 1901. These successes led to the widespread use of radio for ship-to-ship and ship-to-shore communication using Morse code.

(iii) Early wireless systems used crude, through often quite powerful, spark gap transmitters, and were suitable only for radio telegraphy. The invention of the triode vacuum tube by De Forest in 1906 allowed for the modulation of a continuous-wave signal and made voice transmission practical. Commerical radio broadcasting in both the United States and Canada began in the year 1920.

(iv) After the World War II, two systems were developed that enhanced the development of modern wireless communication. AT&T introduced its improved Mobile Telephone Service (IMTS) in 1946, featuring automatic connection of mobile subscribers to the public switched telephone network (PSTN). This was an expensive service with limited capacity, but it did allow true mobile telephone service.

(v) The next year, in 1947, the American government setup the Citizens' Band (CB) radio service. This service was short-range, had no connection to the PSTN, and offered users no privacy, but it was cheap and easy to setup.

(vi) Meanwhile another rather humble-appearing appliance has become ubiquitous: the cordless phone. Usually, intended for very short-range communication, the system certainly lacked range and also it had connectivity with the PSTN.

(vii) Pagers were introduced in 1962. Though relatively limited in function, pagers remained very popular due to their low cost and small size.

(viii) The world's first cellular radio service was installed in Japan in 1979, followed in 1983 by North American Services. Cellular systems are quite different from previous radio-telephone services suchas IMTS in that, instead of using a single powerful transmitter located on a tall tower for wide coverage, the power of each transmitter is deliberately kept relatively small so that the coverage area, called a cell, will be small. Many small cells are used so that frequencies can be reused at short distances.

(ix) Infact, a portable or mobile telephone may move from one cell to another cell during the course of a conversation. Further, this handoff may occur several times during a conversation.

(x) Practical cellular systems had to await the development of computers fast enough and cheap enough to keep track of all this activity. Theoretically at least, the number of users in a cellular system can be increased indefinitely, simply by making the cells smaller.

On the other hand, mobile radio transmission cannot be applied at 10 GHz or above because severe propagation path loss, multipath fading, and rain activity make the medium improper for mobile communications.

Fortunately, 800 MHz was originally assigned to educational TV channels.

In addition, cable TV service became a big factor in the mid-70s and shared the load of providing TV channels.

In fact, this situation opened-up the 800 MHz band to some extent and the FCC allocated a 40 MHz system at 800 MHz to mobile radio cellular systems.

It may be noted that although 800 MHz is not the ideal transmission medium for mobile radio, it has been demonstrated that a cellular mobile radio system that does not go beyond this frequency band can be deployed.

Needless to say, the medium of transmitting an 800 MHz signal, although, it is workable, is already very difficult.

1.5. EXAMPLES OF WIRELESS COMMUNICATION SYSTEMS

In the examples of cellular, cordless and PCS systems each one of them has unique advantages and facilities with respect to mobile communication technology. Thus, the transition from analog mobile phones to digital mobile phones was made along a number of years and today digital cellular telephony is very popular worldwide due to its several technical advantages, including cellular coverage capability.

Examples of the cellular radio communication are as under:

1. Cellular telephone systems.
2. Cordless Telephone (CT) systems.
3. Paging systems.

These examples are given below:

DO YOU KNOW?

As of today, there is a need to have three spectral bands for GSM to roam in most areas of the world: 900 MHz and 1800 MHz operates in Europe and Asia, 1900 MHz in North and South America. Therefore, a triple-band handset is a solution today for International roaming.

1.5.1. Cellular Telephone Systems

The cellular telephone system mainly helps to connect a public switched telephone network (PSTN) and any distant/near user provided the user is available within the corresponding radio range. A basic cellular system is shown in figure 1.2. The mobile switching center or mobile telephone switching office (MTSO) connects the mobile units (called parties) to the PSTN. Every cell of the particular geographical area has its own base station with a transceiver, an antenna, and also a control circuitry.

The base stations are capable of handling many full duplex cellular communications. The mobile switching center can handle atleast 5000 telephonic conversation is at a time and 1,00,000 cellular users / subscribers in a network. The cellular communication is made possible between mobile units and the base stations with the help of common air interface (CAI), which specifies four channels.

They are :

(i) Forward Control Channels (FCC)
(ii) Reverse Control Channels (RCC)
(iii) Forward Voice Channels (FVC) and
(iv) Reverse Voice Channels (RVC).

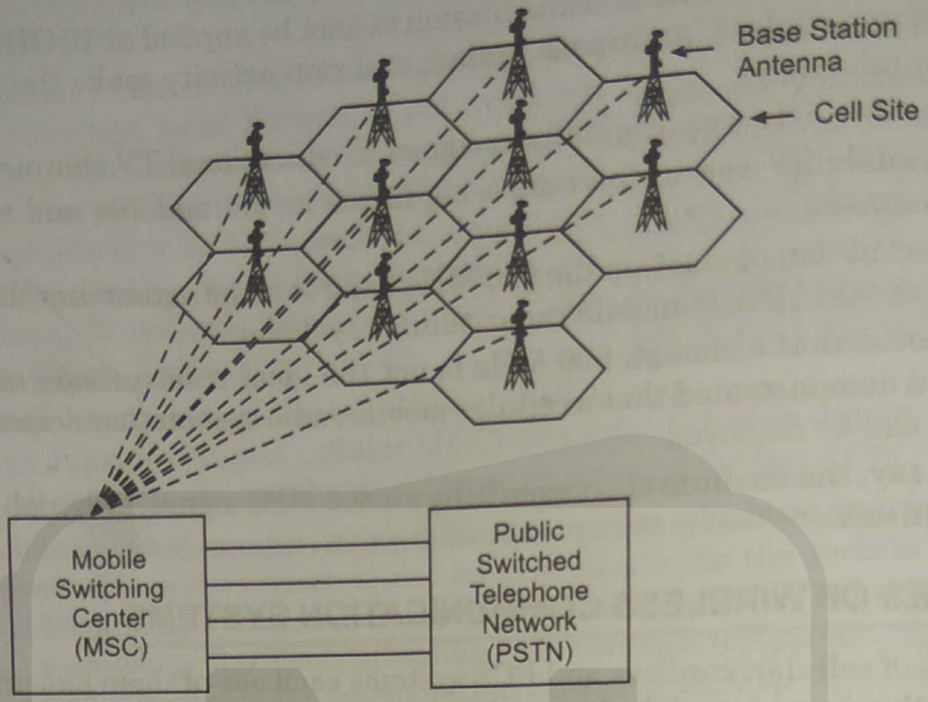


Fig. 1.2. Cellular Telephone System

The control channels mentioned here are also termed as setup channels. They will have calls that are in progress but they usually send and receive data messages carrying call initiation and requests for services.

The forward control channels (FCC) are also termed as "BEACONS" since they continuously broadcast the traffic request for the mobile units within the cellular system. As soon as the cell phone is switched on, it scans the control channels searching for the stronger signal of a base station. When the call progresses, the mobile switching center adjusts the power transmitted (P_T) of the mobile unit and alters the channel of the mobile unit and also the base station so as to maintain the call quality even though the mobile unit is non-stationary.

The call in the progress continues irrespective of the frequency changes from one base station to another base station. Such a call continued process without termination is called as **'Hand off' technique**. As the mobile moves and the signal strength reduces, when it is away from its base station of cell, the next base station of the neighbouring cell, where the mobile enters in, will take charge of the call. A relay like process thus takes place within several base stations of the entire cellular system simply to sustain the call developed between two subscribers.

Whenever a mobile originates a call, a request signal will be sent through reverse control channel. By seeing this request, the mobile unit will transmit its Mobile Identification Number (MIN), telephone number of its called subscriber, and the Electronic Serial Number (ESN). Then, the MSC will check the proper validity of the signals sent by the mobile and responds to its request by connecting the called subscribers through PSTN.

Key Point: The mobile communication establishes call, maintains it and terminates as the call is over. It enables communication eventhough the distance between subscriber is large.

1.5.2. Cordless Telephone (CT) Systems

The cordless telephone systems are full duplex systems and it is intended to link a portable handset to the dedicated base station which in turn is connected to a particular dedicated telephone line. For this, specific telephone number on public switched telephone network (PSTN) is used.

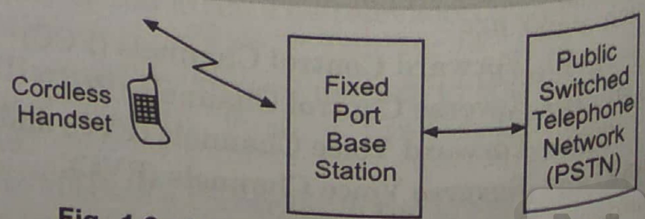


Fig. 1.3. Cordless Telephone (CT) system

The first generation (1G) cordless telephone systems came into existence in 1980's. But, the distance the system covered was only few meters.

Later in the second generation (2G) cordless systems, the distance was not a problem and the subscribers used cordless systems in mobile environment also. The system was good only if the subscriber availability was within the coverage of base station.

The cordless systems also work together with paging systems such that the roaming subscriber can first be paged and he or she can respond to it with the help of cordless telephone. In the simple cordless system shown in figure 1.3, it illustrates that the cordless handset is linked to PSTN through the base station (fixed port). The cordless handset has a wireless link with its dedicated base station. The cordless systems are divided into two namely : Analog CT and Digital CT.

In the early days these cordless systems were analog (Analog CT). They provided analog voice transmission and enabled mobility within a limited distances But, they had many demerits such as under :

(i) Poor call qualities

(ii) Interference

These problems urged the need for digital cordless (Digital CT) systems. They provided better voice quality similar to wired telephone system.

Example for digital cordless system is

CT2/ Common Air Interface (CAI)

Some of the main criteria of CT2 systems are as under:

(i) Voice signal is digitized through 32 kb/sec Adaptive Differential Pulse Code Modulation (ADPCM) technique.

(ii) Bit stream compression facility.

(iii) Final bit stream transmission at a rate of 72 kb/sec through Gaussian frequency shift keying (GFSK).

(iv) Immune to errors.

(v) It supports data transmissions effectively upto 32 kb/sec.

(vi) Traffic can be separated with the Time Division Duplex (TDD) access technique.

Key Point: This CT2 standard does not provide for the mobility status and the later version CT2+ standard was used for this purpose.

1.5.3. Paging Systems

The paging systems are communication systems and they can transmit brief messages to subscribers. The message sent may be an alphanumeric message, numeric message or even voice data. Paging systems also include news headlines, faxes and store quotations. It may be sent to a particular paging subscriber through the paging system access number with a modem or a telephone keypad. Such a message is called as **page**.

In a technique called 'simultaneously', the wide paging systems send a page from each base station simultaneously.

The important performance metrics used in decision-making process under hand of situations (mobility management) are listed below:

DO YOU KNOW?

In 1995, the CDMA IS-95 was the first CDMA system (later called cdma One in 1988) using 1.25-MHz bandwidth. It was suggested by PacTel that the opertor could give up one tenth of the spectrum from analog spectrum to create a CDMA channel and generate at least twice the capacity of the entire analog system for voice.

(i) Probability of call blocking
(ii) Probability of call dropping.
(iii) Probability of call completion.
(iv) Handoff delay.
(v) Rate of handoff.
(vi) Probability of an incomplete handoff.
(vii) Probability of handoff blocking.
(viii) Interruption time duration.
(ix) Handoff probability.

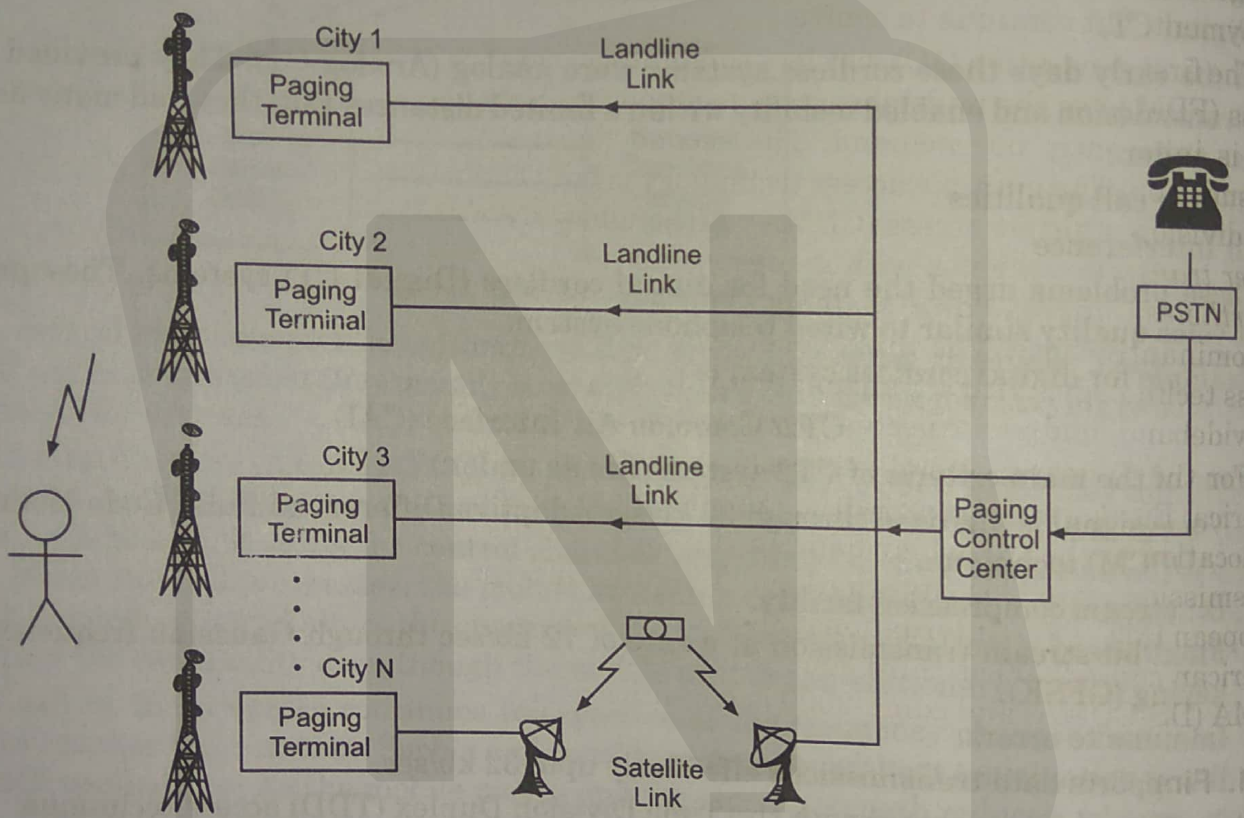


Fig. 1.4. A wide area paging system

Strategies used to calculate the instant of handoff are as under :

(i) Relative signal strength method.
(ii) Relative signal strength with hysteresis method.
(iii) Relative signal strength with threshold method.
(iv) Prediction techniques.

In a wide area paging system, a paging control center is available that connects the PSTN to different paging terminals.

Thus, paging systems enable communication with subscribers irrespective of their roaming state. But, the system requires large transmitter powers in the order of kilowatts and uses only low data rates for providing proper coverage.

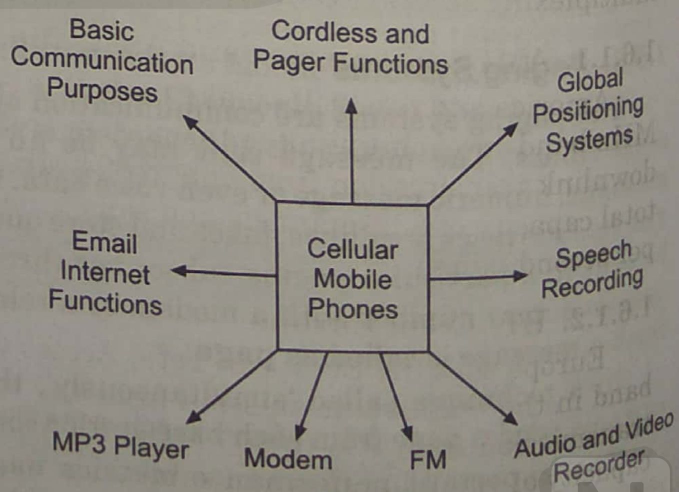


Fig. 1.5.

There are several functionalities possible with cellular mobile phones as shown in figure 1.5, which includes the pager functions too. It is helpful in sending short messages which are highly used by subscribers. The short message or page is sent to a subscriber, wherever he is, and it is the main advantage of these system in spite of low data rates and large transmitter power requirements.

1.6. OVERVIEW OF GENERATIONS OF CELLULAR SYSTEMS

Wireless communications systems that have been in deployment for sometime are those of the first generation and second generation. Third generation systems are also currently under deployment, but continue to evolve.

The first generation (1G) wireless communications systems use frequency division multiple access (FDMA) as the multiple access technology. FDMA is an analog transmission technique that is inherently narrowband. The second generation (2G) wireless systems use digital transmission. The multiple access technology is both time division multiple access (TDMA) and code division multiple access (CDMA). Although, the second generation wireless systems offer *higher transmission* rates with *greater flexibility* than the first generation systems, they are *nevertheless narrowband systems*. The service offered by both 1G and 2G systems is predominantly voice. The third generation (3G) standard is based on CDMA as the multiple access technology. With a transmission rate of up to *2 megabits per second* (Mbps), 3G systems are wideband, and are expected to support *multimedia services*.

For the first and second generations, the main initiatives have been originated in North America, Europe and Japan. Although all regions use similar technology, the systems differ in the location of the frequency band in the radio spectrum, the channel spacing, and the data transmission rate. ITU (International Telecommunications Union) has now adopted both the European IMT-2000 (International Mobile Telecommunications by the year 2000) and the North American cdma-2000 as third generation standards. IMT-2000 is a wideband direct-sequence CDMA (DS-CDMA) and cdma-2000 is a multicarrier CDMA (MC-CDMA) technology.

1.6.1. First Generation Cellular Systems

As a matter of fact, the first generation cellular systems make use of analog FM scheme for speech transmission. The individual calls use different frequencies and share the available spectrum through a particular multiple access technique known as frequency-division multiplexing access (FDMA).

1.6.1.1. AMPS in America and Australia

America and Australia make use of the Advanced Mobile Phone System (AMPS) with a 25 MHz band in each uplink transmission from 824 to 849 MHz, and a 25 MHz band in each downlink transmission from 869 to 894 MHz. AMPS uses a channel spacing of 30 kHz with a total capacity of 832 channels and sametimes supports a data transmission rate of 10 kilobits per second (kbps).

1.6.1.2. ETACS in Europe

Europe uses the European Total Access Communications System (ETACS) with a 25 MHz band in the uplink transmission from 890 to 915 MHz, and a 25 MHz band in the downlink, transmission from 935 to 960 MHz. ETACS uses a channel spacing of 25 kHz, with a total capacity of 1000 channels and sametimes supports a data transmission rate of 8 kbps.

1.6.1.3. NTT in Japan

The first generation cellular system is the Nippon Telephone and Telegraph (NTT) system which employs a 15 MHz band in the uplink transmission from 925 to 940 MHz, and a 15 MHz band in the downlink transmission from 870 to 885 MHz, with a channel spacing of 25 kHz. The NTT system has a total capacity of 600 channels and supports a data transmission rate of 0.3 kbps.

Later on, the NTT system was modified to enhance its capacity from 600 to 2400 channels. This enhancement was achieved by decreasing the channel spacing from 25 kHz to 6.25 kHz. Moreover, the data transmission rate of each channel was increased from 0.3 kbps to 2.40 kbps.

Table 1.2 lists the radio interface technology of the first generation wireless cellular systems i.e., AMPS in America, ETACS in Europe, and NTT in Japan.

From table 1.2, it may be observed that the three different systems differ in following parameters:

(i) location of the frequency bands,
(ii) channel spacing,
(iii) data rate,
(iv) spectral efficiency, and,
(v) system capacity.

Table 1.2. First Generation Analog Cellular Systems

Region	America	Europe	Japan
Parameter	AMPS	ETACS	NTT
Multiple access	FDMA	FDMA	FDMA
Duplexing	FDD	FDD	FDD
Forward channel	869-894 MHz	935-960 MHz	870-885 MHz
Reverse channel	824-849 MHz	890-915 MHz	925-940 MHz
Channel spacing	30 kHz	25 kHz	25 kHz
Data rate	10 kbps	8 kbps	0.3 kbps
Spectral efficiency	0.33 bps/Hz	0.33 bps/Hz	0.012 bps/Hz
Capacity	832 channels	1000 channels	600 channels

1.6.2. Second Generation Cellular Systems

The second generation cellular systems are completely digital. These cellular systems employ either TDMA or CDMA as the multiple access technology. The digital technology allows greater sharing of the radio hardware in the base station among the multiple users, and provides a larger capacity to support more users per base station per MHz of spectrum as compared to analog systems. As a matter of fact, digital systems offer a number of advantages over analog systems as under:

(i) digital systems provide natural integration with the evolving digital wireline network.
(ii) digital systems provide flexibility for supporting multimedia services.
(iii) digital systems provide flexibility for capacity expansion.
(iv) digital systems provide reduction in RF transmit power.

DO YOU KNOW?

Because each technology itself is advanced with time, we use time periods to classify the generations. Hence, analog systems are 1G, digital voice systems are 2G, digital voice data systems are B 2G, and broadband digital systems are 3G.

(v) digital systems provide encryption for communication privacy.

(vi) digital systems provide reduction in system complexity.

As discussed earlier, the second generation cellular systems use either TDMA or CDMA access technology. Code division multiple access (CDMA) standard is strictly North American in the form of IS-95 whereas TDMA deployment is regionally based (i.e., Europe, North america, or Japan). In Europe, it is the Pan-European GSM (Group Special Mobile or Global System for Mobile Communications) and DCS 1800 (Digital Cellular System). In North America, it is IS-54 and IS-136.

In Japan it is PDC (Personal Digital Cellular) systems. The different second generation standards have the following specifications:

1.6.2.1. GSM in Europe

The channel time in TDMA is partitioned into frames. Each frame consists of eight time-slots. Each time-slot is of 0.57 ms duration. Each user transmits periodically in every eighth slot and receives in the corresponding slot. The modulation scheme used is *Gaussian filtered minimum shift keying (GMSK).*

1.6.2.2. IS-54 in North America

In the frequency domain, the channel spacing is 30 kHz, the same as that of AMPS. The modulation scheme is p/4 shifted *Differential quadrature phase shift keying (DQPSK)* with a channel rate of 48.6 kbps. In the time domain, one TDMA frame consists of six time slots supporting three full-rate users or six half-rate users, each slot having a duration of approximately 6.67 ms. The speech codec rate is 7.95 kbps or 13 kbps with error protection. The capacity of each frequency channel is three times that of AMPS.

1.6.2.3. PDC in Japan

The **system is TDMA-based with three** slots multiplexed onto each carrier (similar to IS-54). In the frequency domain, the channel spacing is 25 kHz. The modulation scheme is p/4-shifted DQPSK with a transmission rate of 42 kbps. The speech codec operates at a full rate of 6.7 kbps or 11.2 kbps with error protection.

1.6.2.4. IS-95 in North America

IS-95 is a CDMA-based standard. Users share a common channel for transmission within a cell. Users in adjacent cells also use the same radio channel. In other words, the frequency spectrum is reused from cell to cell. The system is designed to be compatible with the existing analog system AMPS. The allocated frequency band is 824-849 MHz for the uplink using **offset quadrature phase shift** keying (OQPSK) and 869-894 MHz for downlink using QPSK. The spreading code chip rate is 1.2288 megachips per second (Mcps). The spreading factor is 128, with the maximum user data rate of 9.6 kbps. Forward and reverse links use different spreading processes. Rake receivers are used at both the base station and mobile station to resolve and to combine multipath components.

Table 1.3 lists the radio interface technology of the second generation digital.

In cellular communications, location management is critically important. IS-41, with two tiered network architecture for location management, is a companion standard to IS-54 in North America. GSM in Europe performs location management using MAP (Mobile Applications Port), which is also a two-wired network architecture.

Table 1.3. Second Generation Digital Cellular Systems

S. No.	Region Parameter	US IS-54	Europe GSM	Japan PDC	US IS-95
1.	Multiple access	TDMA/FDD	TDMA/FDD	TDMA/FDD	CDMA
2.	Modulation	π/4 DQPSK	GMSK	π/4 DQPSK	QPSK/OQPSK
3.	Forward channel	869-894 MHz	935-960 MHz	810-826 MHz	869-894 MHz
4.	Reverse channel	824-849 MHz	890-915 MHz	940-956 MHz	824-849 MHz
5.	Channel spacing	30 kHz	200 kHz	25 kHz	1.250 kHz
6.	Data chip rate	48.6 kbps	270.833 kbps	42 kbps	1.2288 Mcps
7.	Speech codec rate	7.95 kbps	13.4 kbps	6.7 kbps	1.2/2.4/4.8/ 9.6 kbps

1.6.3. Third Generation Wireless Communication Networks

Third generation standardization activities were initiated in Europe and in North America under the respective names IMT-2000 and cdma-2000. IMT-2000 is wideband direct-sequence code division multiple access (DS-CDMA), while cdma-2000 is multicarrier code division multiple access (MC-CDMA). ITU has adopted the recommendations of both IMT-2000 and cdma-2000 under the banner of Harmonized Global 3G (G3G). Both IMT-2000 and cdma-2000 use frequency division duplex (FDD) to support two-way transmissions with frequency isolation. TDD (time division duplex) has also been suggested as a third 3G mode. The gist of harmonization is that both ANSI-41 and GSM MAP based services should be fully supported in the Radio Access Network with all 3G CDMA modes.

It is likely that the third generation cellular systems will be equipped with the infrastructure to support Personal Communications Systems (PCS). The network infrastructure support will likely include the following :

(i) public land mobile networks (PLMNs),
(ii) mobile Internet Protocol (Mobile IP),
(iii) wireless asynchronous transfer mode (WATM) networks, and
(iv) low earth orbit (LEO) satellite networks.

1.6.3.1. High Transmission Rate

The most attractive features of 3G, compared with 2G, are as under

(i) *higher transmission rate,* and
(ii) support of *multimedia services.*

The higher transmission rate means that the bandwidth of the signal will be large compared with the coherence bandwidth of the propagation channel. When the signal bandwidth is large compared with the coherence bandwidth of the channel, different frequency components of the signal will experience different fading characteristics. Techniques to combat frequency selective fading need to be used in order to attain an acceptable error rate at the output of the cell-site receiver. A basic approach to combat frequency selective fading is to partition the signal into continuous frequency bands, each of which is narrow compared with the coherence bandwidth of the channel. Each of the signal components is then modulated onto a different subcarrier and the signal components are sent over the channel in parallel. In this way, each of the signal components will experience non-frequency-selective fading. i.e., the fading is uniform across a given component's frequency band. This can be achieved by converting the high rate serial data sequence into a number of lower rate parallel sequences and then modulating each onto a subcarrier. An effective method to achieve this is orthogonal frequency division multiplexing (OFDM).

Mobiles can be located anywhere within the footprint of a base station. If every mobile transmits at the same power level, the signal received at the cell-site receiver form the mobile(s) closest to it will be the strongest. This is known as the **near-far problem,** and the power levels need to be controlled to smooth out the near-far effect. Power control, rate allocation and service scheduling are radio resource management functions. The primary purpose in managing the radio resources is to maximize system utilization. Strategies to effectively mechanize these functions are challenging the research issues.

1.6.3.2. Capacity and Impact of User Mobility

The capacity of cellular systems is enlarged through efficient employment of the available bandwidth (i.e., frequency reuse). To support higher transmission rates in 3G systems, the limited bandwidth of the systems needs to be reused more.

Although decreasing the cell size allows for a higher degree of frequency reuse to increase system capacity, the tradeoff for this benefit is that mobile users tend to move in and out of cells much more frequently. To maintain service continuity, the connection of a mobile user must be handed off from the serving base station to base station of the target cell. Also, once handoff is complete, the mobile needs to identify its current location within the cellular array so that messages can be delivered to it in its new location. As a result, a reduction in the cell size translates to a larger overhead for mobility management (i.e., handoff management and location management) in the network.

(iii) Supports multi-function.

It is an excellent digital mobile radio system accepted worldwide. The satellite mobile systems incorporates good paging systems, data collection, global roaming and emergency communications. One such example is network of LEO satellites.

The fundamental technological developments has thus helped the wireless personal communication systems to grow rapidly and the demand it has is also high. The wireless networking will surely improve further to meet more requirements and additional features in wireless personal communication field.

1.8. COMPARISON OF VARIOUS WIRELESS SYSTEMS

Basically, wireless communication systems consist of a fixed-base transceiver station and a number of fixed/mobile subscriber transceiver equipments. The base station as well as the mobile subscribers of various types of mobile or portable wireless communication systems can be compared for the types of services, functionality, operating carrier frequency range, the level of infrastructure needed, configuration complexity, hardware cost, and radio coverage range. Table 1.4 presents a brief comparison of three most commonly used wireless communication systems. These are cellular telephone systems, cordless telephone systems and paging systems.

Table 1.4. Comparison of various wireless communication systems

S.No.	Service type	Functionality	Operating Freqeuncy	Level of Infra-structure	Complexity	Hardware cost	Range
1.	Paging systems	BS : Tx only MS : Rx only	<1 GHz	High	BS: High MS: Low	BS: High MS: Low	High
2.	Cordless telephone systems	Transceiver	1-3 GHz	Low	BS: Low MS: Medium	BS: Medium MS: Low	Low
3.	Cellular phone systems	Transceiver	<2 GHz	High	High	BS: High MS: Medium	High

Basically, all these wireless communication systems aim to connect a mobile subscriber (vehicle-installed or handheld or portable) to a fixed wireless base transceiver system having antennas mounted at reasonably high towers. Also, the user expectations vary widely among the type of services needed. Further, the infrastructure costs are dependent upon the required coverage area.

1.9. ADVANTAGES OF WIRELESS COMMUNICATIONS

As compared to wired networks, there are several advantages of using wireless communications. The advantages of wireless communications include mobility, ease of installation and lower cost, increased reliability, and more rapid disaster recovery.

1. Mobility

(i) The primary advantage of wireless mobile communication is that it gives the users freedom to move about without being tethered by wires while remaining connected with the network within its coverage area.

(ii) Many occupations, such as the police department, require its workers to be mobile instead of fixed at one location.

(iii) Wireless technology is also enabling many industries to shift toward an increasingly mobile workforce, whether they are in meetings, working on a hospital floor or conducting research. Notebook computers and other portable devices allow these employees added convenience, however, immediate access to the company network is an even greater convenience.

2. Easier Installation

(i) As a matter of fact, intalling network cabling in older buildings can be a difficult, slow and costly task. Facilities constructed prior to the mid 1980s were built without any thought given to running computer wiring in each room.

(ii) Wireless communcations and networks make it easier for any office to be modified with new cubicles or furniture without worrying about providing network connectivity through cables. There is no need to first consider the location of the computer jack in the wall when relocating furniture. Instead, the focus can be on creating the most effective work environment without any delay and hassles.

(iii) Also, the time required to install network cabling may take days or even weeks to complete, thereby disrupting the whole work. Using a wireless LAN eliminates such disruption.

3. Cost Effective Installation

(i) As a matter of fact, eliminating the need to install cabling and using wireless communication results in significant cost savings. Infact, installing network cabling in older buildings was an extremely difficult, slow and costly task. Now-a-days, in such cases, a wireless LAN is the ideal solution.

(ii) Historical buildings would be preserved, harmful asbestos would not be disturbed and difficult drilling could be avoided by using a wireless system.

4. Increased Reliability

The most common source of network problems is the failure of damage of network cables due to environmental conditions or erosion of metallic conductors. A cable splice that is done incorrectly can cause unexplainable errors and is very difficult to identify. Using wireless technology eliminates these types of cable failures and thus increases the overall reliability of the network.

5. Disaster Recovery

As a matter of fact, accidents may happen due to fires, tornados and floods at any possible location, and that also without any prior warning. Any organization that is not prepared to recover from such natural disasters will find itself quickly out of business. Now, since the computer network is a vital part of the daily operation of a business, the ability to have the network up and immediately working after a disaster is critical. Futher, a documented disaster recovery plan is essential.

2.3. PCS ARCHITECTURE

The PCS architecture consists of following two parts :

2.3.1. Radio Network

PCS users carry mobile stations (MS) to communicate with a BS in a PCS network. MS is also referred to as handset or mobile phone. The radio coverage of a base station is called cell. In GSM network, each cell is controlled by BSC which are connected to MS through BS. The BSC are connected to MSC by landlines.

2.3.2. Wireline Transport Network

An MSC is a telephone exchange configured specially for mobile applications. It interfaces the MSC (via BS) with PSTN. MSCs are also connected with mobility database to track the location of MS and roaming management. The databases are HLR and VLR. HLR contains the authentication information like IMSI (International Mobile Subscriber Identity), identification information like name, address of the subscriber, billing information like prepaid or postpaid, operator selection, denial of service to a susbscriber etc. VLR gives information about the location area of the subscriber while on roaming and power off status of the handset.

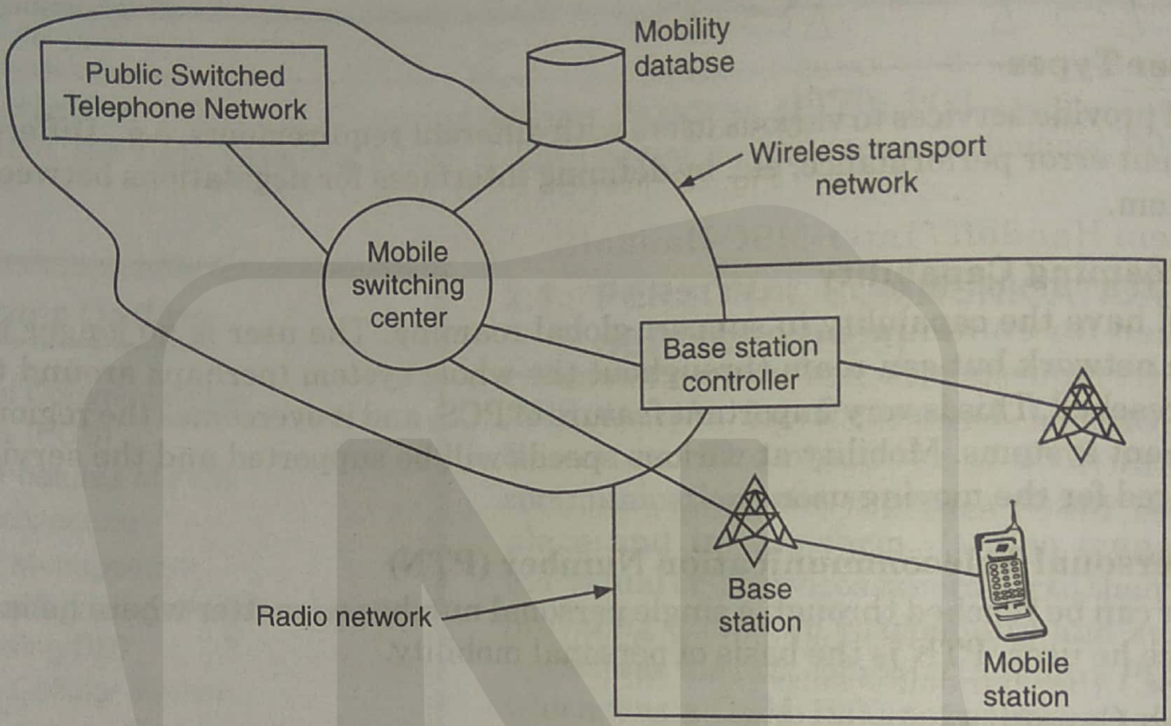


Fig. 2.1. PCS network architecture

2.4. MOBILITY MANAGEMENT

Mobility management function handles the function that arises due to mobility of the subscriber. Main objective of MM is location tracking and call setup. There are two aspects of mobility in a PCS network.

- **Handoff:** When a mobile user is engaged in conversation, the MS is connected to BS via radio link. If the user moves to the coverage area of the another BS, the radio link to old BS is disconnected and radio link to new BS is established to continue conversation. This process is called automatic link transfer or handoff.
- **Roaming:** When a mobile user moves from one PCS system to another, then the system should be informed of the current location of the user. Otherwise, it is impossible to deliver services.

2.4.1. Handoff

Depending on the mobility of MS, the handoff is divided into two categories:

Inter-BS Handoff / Inter Cell Handoff:

Here, MS usually moves from one BS to another BS under one MSC.

Action taken for communcation :

1. The MS momentarily suspends conversation and initiates the hand-off procedure by picking a channel in new BS. Then, it resumes the conversation in old BS.

2. When MSC receives that signal, he transfers the information to the new BS and setsup new conversation path to MS through that channel.
3. After MS has been transferred to new BS, it starts the conversation channel with new BS and then MSC disconnects the link with old BS.

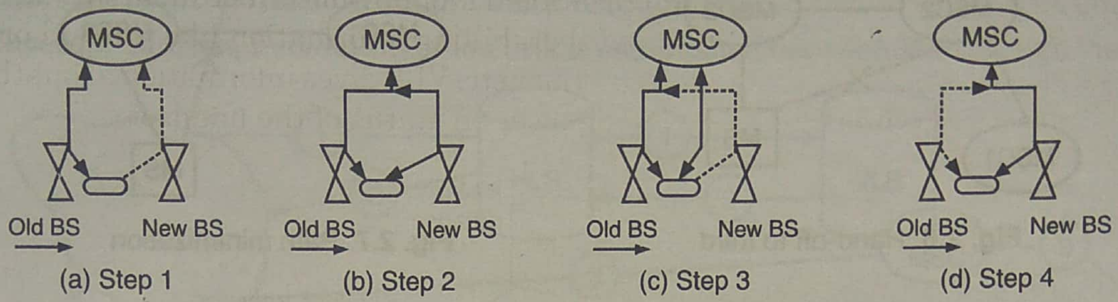


Fig. 2.2. Inter-BS link transfer

Inter-system Handoff / Inter-MSC Handoff

MS moves from one BS to another connected to two different MSCs.

Action taken for communication

1. MSC1 requests MSC2 to perform handoff measurement on the call in progress.
2. MSC2 then selects a BS by interrogating the signal quality and sends the information to MSC1
3. Then, MSC1 asks MSC2 to setup a voice channel.
4. Assuming that a voice channel is available in BS2, MSC2 instructs MSC1 to start radio link transfer.
5. MSC1 sends the MS a handoff order. Now, MS can access BS2 of MSC2. MSC2 informs MSC1 that handoff is successful. MSC1 than connects call path to MSC2.
6. In the intersystem handoff process, anchor MSC is always in call path before and after handoff.

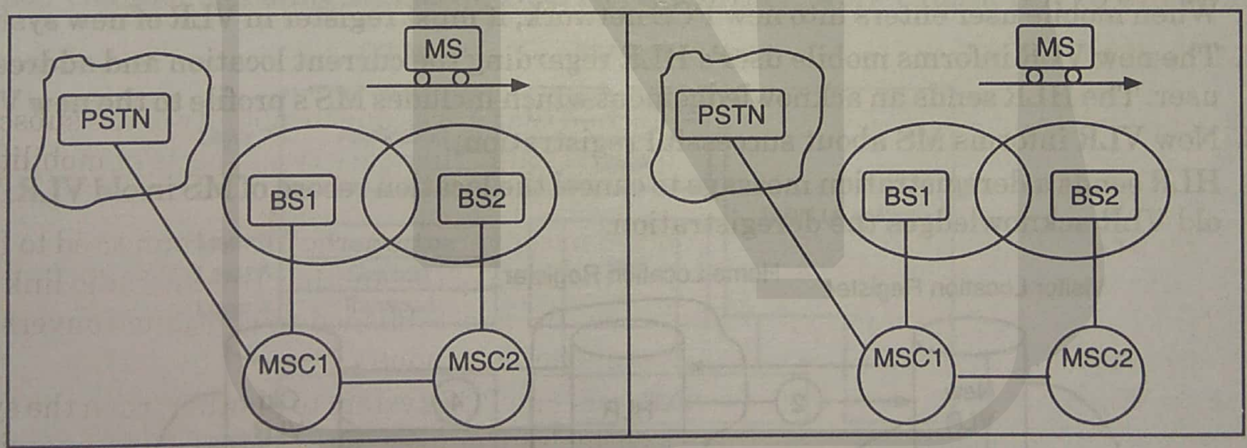


Fig. 2.3. Inter system handoff

Path Minimization

When MS moves to MSC3, MSC2 may be removed from the call path. The link between MSC1 and MSC2 is disconnected and MS connects to MSC3 directly. This process is called path minimization.

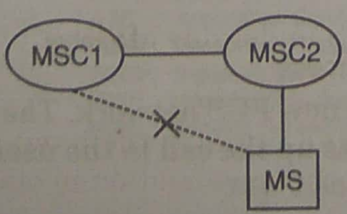


Fig. 2.4 Handoff forward

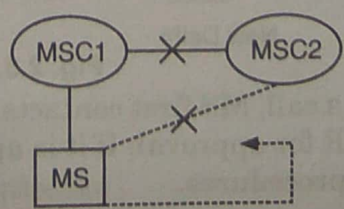


Fig. 2.5. Handoff backward

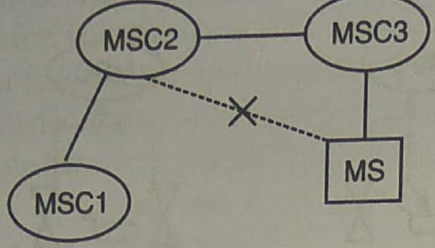


Fig. 2.6. Hand-off to third

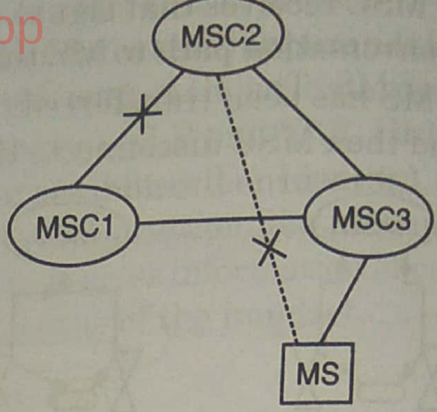


Fig. 2.7. Path minimization

2.4.2. Roaming Management

Two basic operations are performed under roaming management.

1. **Registration (location update):** Where MS informs the system its current location.
2. **Location tracking:** Process during which a system locates MS. Location tracking is required when network attempts to deliver call to a mobile user.

The roaming management follows a two level strategy where two tier systems of home and visited databases are used. When a user subscribes to the services of a network, a record is created in the system's database called HLR. This is referred to as home system of the mobile user. HLR is a network database, where MS's identity, profile, current location and validation period is stored.

When the mobile user visits a new network other than home system, a temporary record for the mobile user is created in the VLR of visited system. VLR temporarily stores information for visiting subscribers so that corresponding MSC can provide service.

Registration procedure includes following steps :

1. When mobile user enters into new PCS network, it must register in VLR of new system.
2. The new VLR informs mobile user's HLR regarding the current location and address of user. The HLR sends an acknowledgement which includes MS's profile to the new VLR.
3. New VLR informs MS about successful registration.
4. HLR sends a deregistration message to cancel the location record of MS in old VLR. The old VLR acknowledges the deregistration.

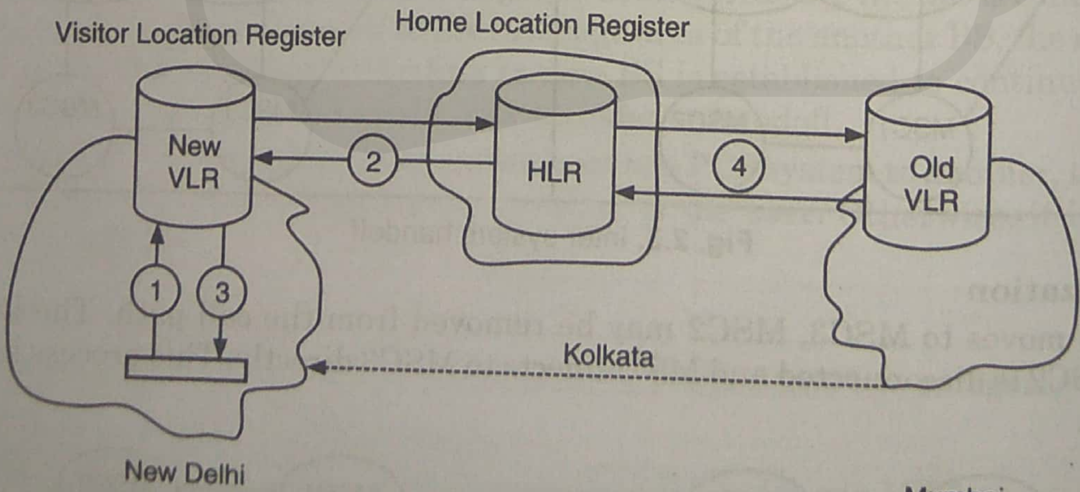


Fig. 2.8. MS registration process

To originate a call, MS first contacts with MSC in the new PCS network. The call request is forwarded to VLR for approval. If it is approved: MSC sets up the call to the user following the standard PSTN procedures.

1. If a wireline phone attempts to call a mobile subscriber, the call is forwarded to switch called the originating switch in PSTN. The switch makes a query to HLR to find current VLR of MS. The HLR queries the VLR in which MS resides to get a communicable address.
2. The VLR returns the address to switch through HLR.
3. Based on address, a communication link is established between MS through visited MSC.

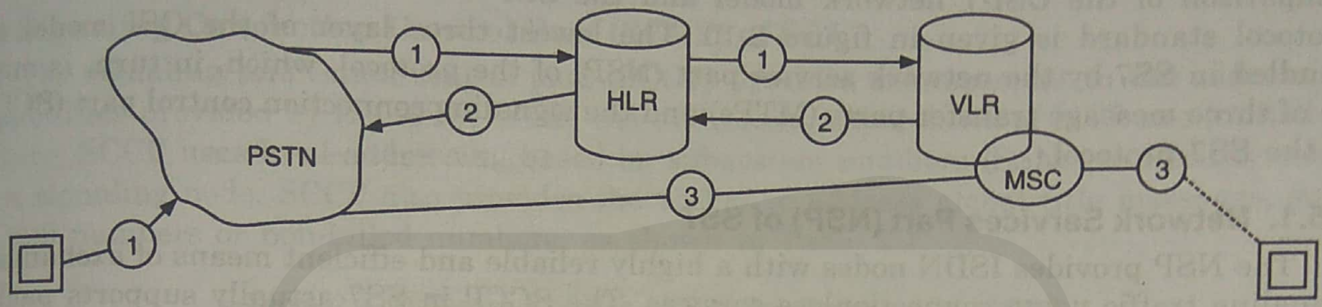


Fig. 2.9. PCS call delivery procedure

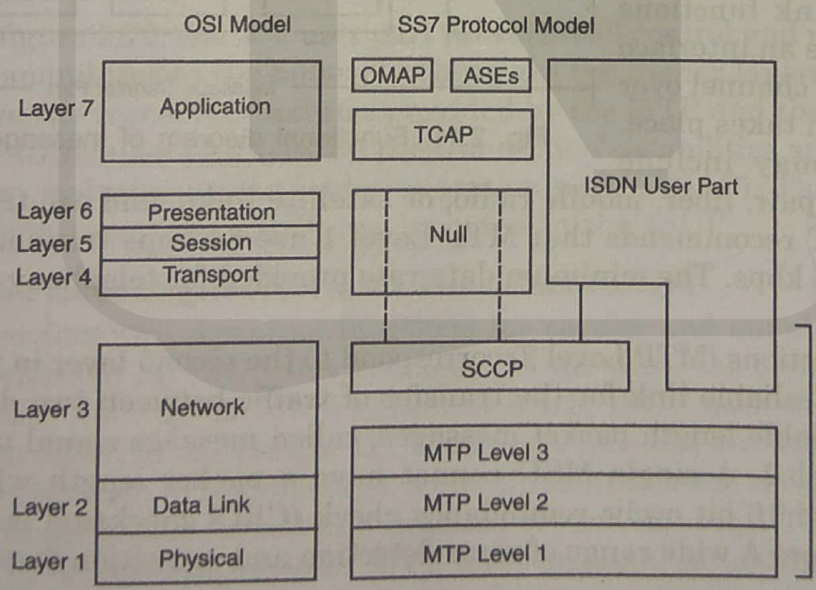
2.5. NETWORKS SIGNALING: PCS NETWORK SIGNALING USING SS7

(i) Basics

The SS7 signaling protocol is widely used for common channel signaling between interconnected networks. SS7 is used to interconnect most of the cellular MSCs throughout the US, and is the key factor in enabling autonomous registration and automated roaming in first generation cellular systems.

(ii) SS7 Protocol Architecture

SS7 is an outgrowth of the out-of-band signaling first developed by the CCITT under common channel signaling standard, CCS No. 6. Further, work caused SS7 to evolve analog



OMAP: Operations Maintenance and Administration Part
ASE : Application Service Element
TCAP: Transaction Capabilities Application Part
SCCP: Signaling Connection Control Part
MTP: Message Transfer Part
NSP: Network Service Part

Fig. 2.10. SS7 protocol architecture

the lines of the ISO-OSI seven layer network definition, where a highly layered structure (transparent from layer to layer) is used to provide network communications. Peer layers in the ISO model communicate with each other through a virtual (packed data) interface, and a hierarchical interface structure is established. A comparison of the OSI-7 network model and the SS7 protocol standard is given in figure 2.10. The lowest three layer of the OSI model are handled in SS7 by the network service part (NSP) of the protocol, which, in turn, is made up of three message transfer parts (MTPs) and the signaling connection control part (SCCP) of the SS7 protocol.

DO YOU KNOW?

The integrated services digital (ISDN) concept is designed to allow voice and data to be sent in the same way along the same

2.5.1. Network Services Part (NSP) of SS7

The NSP provides ISDN nodes with a highly reliable and efficient means of exchanging signaling traffic using connectionless services. The SCCP in SS7 actually supports packet data network interconnections as well as connection-oriented networking to virtual circuit networks. The NSP allows network nodes to communicate throughout the world without concern for the application or context of the signaling traffic.

(i) Message Transfer Part (MTP) of SS7

The function of the MTP is to ensure that signaling traffic can be transferred and delivered reliably between the end-users and the network. MTP is provided at three levels. Figure 2.11 shows the functionally of the various MTP levels.

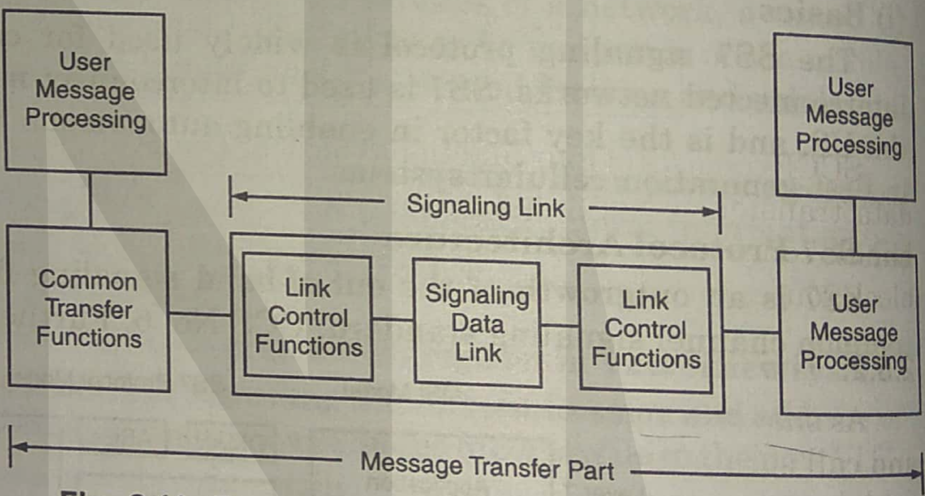


Fig. 2.11. Functional diagram of message transfer part

Signaling data link functions (MTP Level 1) provide an interface to the actual physical channel over which communication takes place. Physical channels may include copper wire, twisted pair, fiber, mobile radio, or satellite links, and are transparent to the higher layers. CCITT recommends that MTP Level 1 use 64 kbps transmissions, whereas ANSI recommends 56 kbps. The minimum data rate provided for telephony control operators is 4.8 kbps.

Signaling link functions (MTP Level 2) correspond to the second layer in the OSI reference model and provide a reliable link for the transfer of traffic between two directly connected signaling points. Variable length packet messages, called message signal units (MSUs), are defined in MTP Level 2. A single MSU cannot have a packet length which exceeds 272 octets, and a standard 16 bit cyclic redundancy check (CRC) checksum is included in each MSU for error detection. A wide range of error detection and correction features are provided in MTP Level 2.

MTP Level 2 also provides flow control data between two signaling points as a means of sensing like failure. If the receiving device does not respond to data transmission, MTP Level 2 uses a timer to detect link failure, and notifies the higher levels of the SS7 protocol which take appropriate actions to reconnect the link.

Signaling network functions (MTP Level 3) provide procedures that transfer messages between signaling nodes. As in ISDN, there are two types of MTP Level 3 functions: signaling message handling and signaling network management. Signaling message handling is used to provide routing, distribution, and traffic discrimination. Signaling network management allows the network to reconfigure in case of node failures, and has provisions to allocate alternate routing facilities in the case of congestion or blockage in parts of the network.

(ii) Signaling Connection Control Part (SCCP) of SS7

The signaling connection control part (SCCP) provides enhancement to the addressing capabilities provided by the MTP. While the addressing capabilities of MTP are limited in nature, SCCP uses local addressing based on subsystem numbers (SSNs) to identify users at a signaling node. SCCP also provides the ability to address global title messages, such as 800 numbers or non-billed numbers, as shown in Table 2.1.

Table 2.1. Different Classes of Service Provided by SCCP

Class of Service	Type of Service
Class 0	Basic connection class
Class 1	Sequenced (MTP) connectionless class
Class 2	Basic connection-oriented class
Class 3	Flow control connection-oriented class

SCCP consists of four functional blocks. The SCCP connection-oriented control block provides data transfer on signaling connections. The SCCP management block provides functions to handle congestion and failure conditions that cannot be handled at the MTP. The SCCP routing block routes forward messages received from MTP or other functional blocks.

2.5.2. The SS7 User Part

As shown in figure 2.11, the SS7 user part provides call control and management functions and call set-up capabilities to the network. These are the higher layers in the SS7 reference model, and utilize the transport facilities provided by the MTP and the SCCP. The SS7 user part includes the ISDN user part (ISUP), the transaction capabilities application part (TCAP) and the operation maintenance and administration part (OMAP). The telephone user part (TUP) and the data user part (DUP) are included in the ISUP.

(i) Integrated Services Digital Network User Part (ISUP)

The ISUP provides the signaling functions for carrier and supplementary services for voice, data and video in an ISDN environment. In the past, telephony requirements were lumped in the TUP, but this is now a subset of ISUP. ISUP uses the MTP for transfer of messages between different exchanges. ISUP message includes a routing label that indicates the source and destination of the message, a circuit identification code (CIC), and a message code that serves to define the format and function of each message. They have variable with a maximum of 272 octets that includes MTP level headers. In addition to the basic bearer services in an ISDN environment, the facilities of user-to--user signaling, closed user groups, calling line identification, and call forwarding are provided.

(ii) Transaction Capabilities Application Part (TCAP)

The transaction capabilities application part in SS7 refers to the application layer which invokes the services of the SCCP and the MTP in a hierarchical format. One application at a node is thus able to execute an application at another node and use these results. Thus, TCAP is concerned with remote operations.

(iii) Operation Maintenance and Administration Part (OMAP)

The OMAP functions include monitoring, coordination, and control functions to ensure that trouble free communications are possible. OMAP supports diagnostics are known throughout the global network to determine loading and specific subnetwork behaviors.

2.5.3. Signaling Traffic in SS7

Call set-ups, inter-MSC Handoffs, and location updates are the main activities that generate the maximum signaling traffic in a network, and which are all handled under SS7. Setting up of a call requires exchange of information about the location of the calling subscriber (call origination, calling-party procedures) and information about the location of the called subscriber. Either or both, of the calling and the called subscribers can be mobile, and whenever any of the mobile subscribers switches MSCs under a handoff condition, it adds to the amount of information exchanged. Table 2.2 shows the amount of signaling traffic that is generated for call set-up in GSM. Location update records are updated in the network whenever a subscriber moves to a new location. The traffic required by the location up data process as a subscriber moves within and between VLR areas is shown in Table 2.3.

Table 2.2. Signaling Load for Call Set-up and Handoffs in GSM

Call originating from a Mobile	Load
Information on the originating MSC and the terminating switch	120 bytes
Information on the originating MSC and the associated VLR	550 bytes
Call Terminating at a Mobile	
Information on the switch and terminating MSC	120 bytes
Information on the originating MSC and the associated VLR	612 bytes
Information on the originating MSC switch and HLR	126 bytes
Inter MSC Handoffs	
Information on the new MSC and the associated VLR	148 bytes
Information on the new MSC and old MSC	383 bytes

Table 2.3. Signaling Load for Location Updating in GSM

Loading Updating	Load
Information on the current MSC and associated VLR	406 bytes
Information on the current VLR and HLR	55 bytes
Information on the new VLR and old VLR	406 bytes
Information on the new VLR and old VLR	213 bytes
Information on the old VLR and HLR	95 bytes
Information on the new VLR and HLR	182 bytes

2.5.4. SS7 Services

There are three main type of services offered by the SS7 network: the Touchstar, 800 services, and alternate billing services. These services are briefly explained below :

Touchstar: This kind of service is also known as CLASS and is a group of switch-controlled services that provide its users with certain call management capabilities. Services such as call return, call forwarding, repeat dialing, call block, call tracing, and caller ID are provided.

800 Services: These services were introduced by Bell System to provide toll-free access to the calling party to the services and database which is offered by the private parties. The costs associated with the processing of calls is paid by the service subscriber. The service is offered under two plans known as the 800-NXX plan, and the 800 Database plan. In the 800-NXX plan the first six digits of an 800 call are used to select the *interexchange carrier* (IXC). In the 800 Database plan, the call is looked up in a database to determine the appropriate carrier and routing information.

Alternate Billing Service and Line Information Database (ADB/LIDB): These services use the CCS network to enable the calling party to bill a call to personal number (third party number, calling card, or collect etc.) from any number.

2.5.5. Performance of SS7

The performance of the signaling network is studied by connection set-up time (response time) or the end-to-end signaling information transfer time. The delays in the signaling point (SP) and the STP depend on the specific hardware configuration and switching software implementation. The maximum limits for these delay times have been specified in the CCITT recommendations.

Congestion Control in SS7 Networks

With an increasing number of subscribers, it becomes important to avoid congestion in the signaling network under heavy traffic conditions. SS7 networking protocols provide several congestion control schemes, allowing traffic to avoid failed links and nodes.

Advantages of Common Channel Signaling over Conventional Signaling

CCS has several advantages over conventional signaling which have been outlined below:

(i) Faster Call Set-up

In CCS, high speed signaling networks are used for transferring the call set-up messages resulting in smaller delay times when compared to conventional signaling methods, such as multifrequency.

(ii) Greater Trunking (or Queuing) Efficiency

CCS has shorter call set-up and tear down times that result in less call-holding time, subsequently reducing the traffic on the network. In heavy traffic conditions, high trunking efficiency is obtained.

(iii) Information Transfer

CCS allows the transfer of additional information along with the signaling traffic providing facilities such as caller identification and voice or data identification.

2.6. A BASIC CELLULAR SYSTEM

Figure 2.12 shows a simr'ified basic cellular system that includes all the basic components necessary for cellular telephone communications. The figure shows a wireless radio network covering a set of geographical areas (cells) inside of which mobile two-way-radio units, such as cellular or PCS telephones, can communicate. The radio network is defined by a set of radio-frequency transceivers located within each of the cells. The locations of these radio-frequency transceivers are called *base stations*. A base station serves as central control for all users within that cell. Mobile units (such as automobiles and pedestrians) communicate directly with the base stations, and the base stations communicate directly with a *Mobile Telephone Switching*

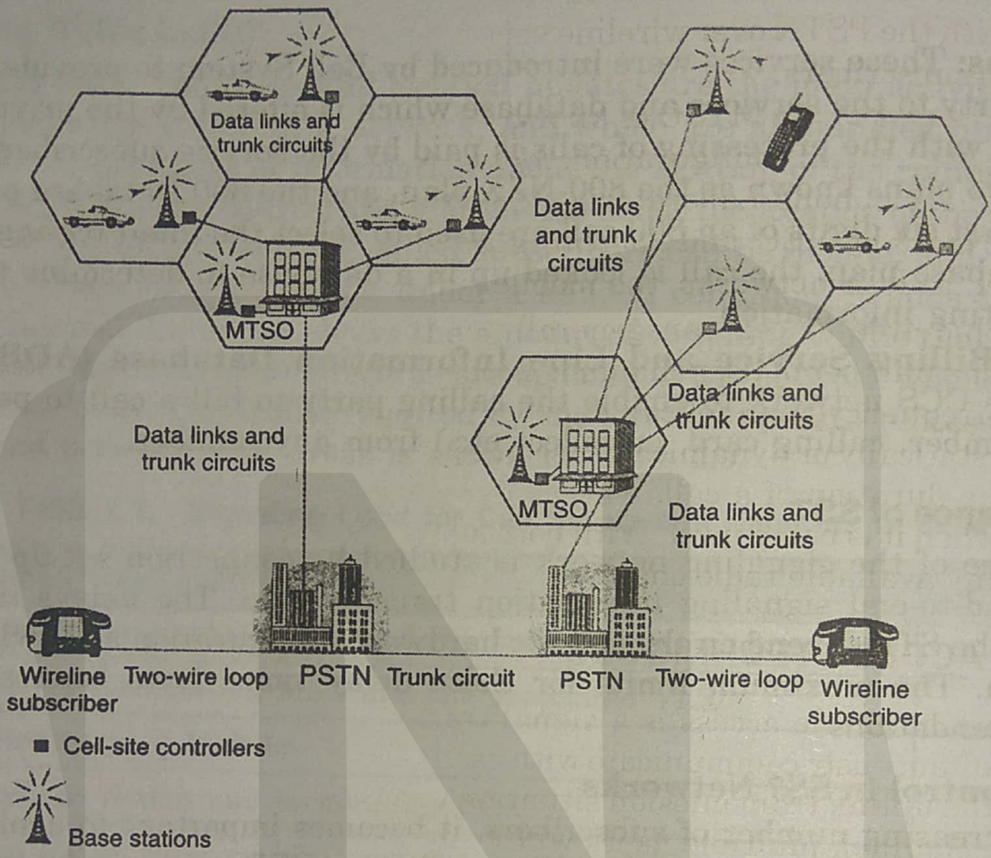


Fig. 2.12. A basic cellular system

Office (MTSO). An MTSO controls channel assignment, call processing, call setup, and call termination, which includes signaling switching, supervision, and allocating radio-frequency channels. The MTSO provides a centralized administration and maintenance point for the entire network and interfaces with the public telephone network over wireline voice trunks and data links. MTSOs are equivalent to class 4 toll offices, except smaller. Local loops (or the cellular equivalent) do not terminate in MTSOs. The only facilities that connect to an MTSO are trunk circuits. Most MTSOs are connected to the SS7 signaling network, which allows cellular telephones to operate outside their service area.

Base stations can improve the transmission quality, but they cannot increase the channel capacity within the fixed bandwidth of the network. Base stations are distributed over the area of system coverage and are managed and controlled by an on-site computerized *cell-site controller* that handles all cell-site control and switching functions. Base stations communicate not only directly with mobile units through the airways using control channels but also directly with the MTSO over dedicated data control links (usually four wire, full duplex). Figure 1.2 shows how trunk circuits interconnect cell-site controllers to MTSOs and MTSOs with exchange offices within the PSTN.

> **DO YOU KNOW?**
>
> The telecommunications standardization sector, called ITU-T, is responsible for both radio and wired telecommunication standardization. The former CCITT (Consultative committee on International Telegraph and Telephony) only made recommendations for devices in wired telecommunication networks.

The base station consists of a low-power radio transceiver, power amplifiers, a control unit (computer), and other hardware, depending on the system configuration. Cellular and PCS telephones use several moderately powered transceivers over a relatively wide service area. The function of the base station is to provide an interface between mobile telephone sets and the MTSO. Base stations communicate with the MTSO over dedicated data links, both metallic and non-metallic facilities, and with mobile units over the air waves using control channels. The MTSO provides a centralized administration and maintenance point for the entire network, and it interfaces with the PSTN over wireline voice trunks to honour services from conventional wireline telephone subscribers.

To complicate the issue, an MTSO is known by several different names, depending on the manufacturer and the system configuration. *Mobile Telephone Switching Office* (MTSO) is the name given by Bell Telephone Laboratories, *Electronic Mobile Xchange* (EMX) by Motorola, AEX by Ericsson, NEAX by NEC, and *Switching Mobile Center* (SMC) and *Master Mobile Center* (MMC) by Novatel. In PCS networks, the mobile switching center is called the MCS.

Each geographic area or cell can generally accommodate many different user channels simultaneously. The number of user channels depends on the accessing technique used. Within a cell, each radio-frequency channel can support up to 20 mobile telephone users at one time. Channels may be statically or dynamically assigned. Statically assigned channel are assigned a mobile unit for the duration of a call, wheras dynamically assigned channels are assigned a mobile unit only when it is being used. With both static and dynamic assignments, mobile units can be assigned any available radio channel.

2.7. MULTIPLE ACCESS TECHNIQUES

As a matter of fact, multiple access is a signal transmission situation in which two or more users wish to simultaneously communicate with each other using the same propagation channel. This is precisely the uplink transmission situation in a wireless communication system. In the uplink or reverse channel, multiple users will want to transmit information simultaneously. Without proper coordination among the transmitting users, collisions will occur when two or more users transmit simultaneously. Access methods that incur collision are referred to as random access and variants of random access. This chapter discusses the throughout characteristics of two popular random access methods: Aloha and carrier sense multiple access (CSMA).

Multiple access strategies based on orthogonality among the competing transmissions are collision-free. Orthogonality can be in the form of frequency division, time division or code division. Techniques with built-in conflict resolution capability presented in this chapter are frequency-division multiple access (FDMA), time-division multiple access (TDMA) and code-division multiple access (CDMA). Performance analysis and evaluation of these conflict free multiple access methods in terms of spectral efficiency and system capacity are described and discussed.

The radio spectrum is shared by the mobile users simultaneously. The sharing may be based on frequency, time, and code. The wireless telephony applies duplexing technique where talking and listening is enabled at a time. For example frequency division duplexing (FDD) offers two bands of frequencies for every user.

The simplex channel consists of a forward and a reverse channels and hence each duplex channel consists of one simplex channel.

These forward and reverse channels are separated with a frequency band in the entire system. On the other hand, time division duplexing known as TDD make use of time instead of frequency to have the same forward and reverse channels.

Both FDD and TDD schemes have advantages and disadvantages. The multiple access schemes with any one of these techniques are used for wireless communications.

2.7.1. Multiple Access in a Radio Cell

In each radio cell, the transmission from the base station in the downlink can be heard by each and every mobile user in the cell. For this reason, this mode of transmission is referred to as broadcasting. On the other hand, transmissions from the mobile users in the uplink to the base station is many-to-one, and is referred to as multiple access. Figure 2.13 illustrates the uplink/downlink transmission situations.

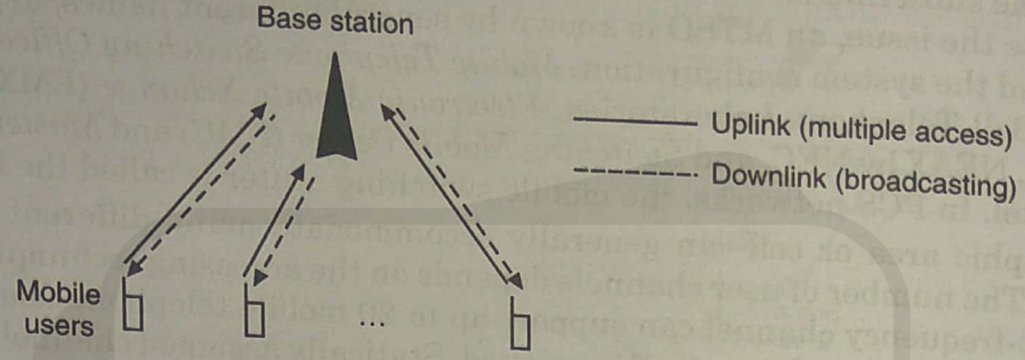


Fig. 2.13. The uplink and downlink transmissions

Transmission in the uplink mode have the following properties:

(i) Multiple mobile users want to access the common resource (base station) simultaneously;

(ii) If the transmission from two or more users arrive at the base station receiver at the same time, there will be destructive interference, unless the multiple arriving signals are mutually orthogonal;

(iii) Orthogonality between two signals x_i (t) and $x_j(t)$, $t \in [0, T]$, means that their inner product over the signaling interval vanishes. Mathematically, this means that

$$\int_0^T x_i(t)\, x_j(t)\, dt = 0. \quad \text{for} \quad i \neq j. \qquad \text{...(2.1)}$$

Key Point: The key element in multiple access is to make the transmitted signals from the different users orthogonal to each other. This raises the fundamental question of how this orthogonality condition should be mechanized.

2.8. DIFFERENT MULTIPLE ACCESS SCHEMES (TECHNIQUES)

The important multiple access schemes used are as under:

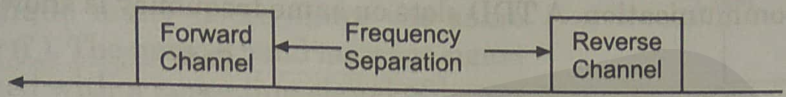
1. Frequency division multiple access (FDMA)
2. Time division multiple access (TDMA)
3. Code division multiple access (CDMA)

2.9. FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

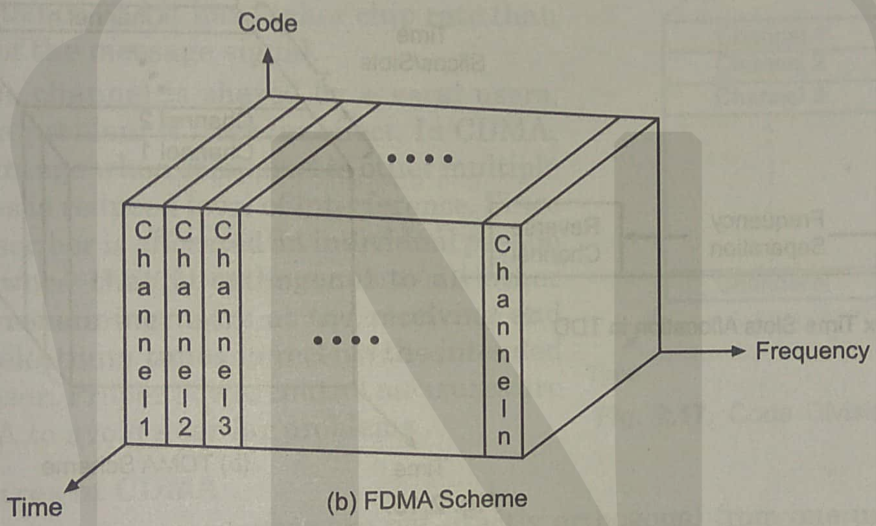
In wireless environment, individual users are allotted individual channels. The channels are frequency band is unique for each user/subscriber. The entire allowed radio spectrum is divided into many slices of frequency bands and each band or channel is allocated to each user. The allocation of radio channel can also be done on demand basis.

In conventional telephonic systems, bidirectional communication is possible simultaneously and it is essential for cellular communication also. Such a simultaneous talk and listen facility is known as duplexing. Under frequency division multiplexing, duplexing is done using frequency and hence it is termed as frequency division duplexing (FDD).

In FDD, the duplex channel contains dual simplex channels namely forward and reverse channel as shown in figure 2.14 (a). The forward frequency band provides radio traffic from base station (BTS) to the mobile unit where as the reverse frequency radio band provides radio traffic from mobile unit to the base station. A duplexer device is kept in mobile unit and base station for enabling simultaneous conversation.



(a) Two Simplex Channels Allocation in FDD



(b) FDMA Scheme

Fig. 2.14.

Important Point : The separation in frequency between the forward and reverse channel is constant in the entire system for all the channels.

In figure 2.14 (b), the principle of FDMA multiplexing scheme is shown where the entire bandwidth is divided in frequency slices and assigned to every user.

Salient Features of FDMA Scheme

(i) FDMA requires proper filtering at receiver side to avoid adjacent channel interference (ACI).

(ii) In FDMA scheme, if a channel is not in use it will be idle and it will not be used by some other user. Hence, there is a chance of resource wastage.

(iii) FDMA channel can handle one phone circuit at a time.

(iv) Complexity is less.

(v) Narrow bandwidth.

(vi) If voice channel are assigned in FDMA, then, the mobile unit and base station start transmitting simultaneously.

Non-linear Effects in FDMA Scheme of Multiplexing

In this multiplexing scheme, the same antenna at base station is shared by several radio channels. The power amplifiers are operated near saturation region for getting maximum possible power efficiency and it is non-linear. These non-linearities cause spreading of signals over the entire frequency domain resulting in intermodulation (IM) frequency generation. It will enhance interferences in actual signal and intermodulation must be minimized.

2.10. TIME DIVISION MULTIPLE ACCESS (TDMA)

In time division duplexing utilizes time instead of frequency. Several users share the time slots of the entire time available. Each user is allocated a time slot in which it can access the channel.

Each duplex channel (TDD) has individual time slots for forward and reverse time slots to have bidirectional communication. A TDD slots on same frequency is shown in figure 2.15 (a).

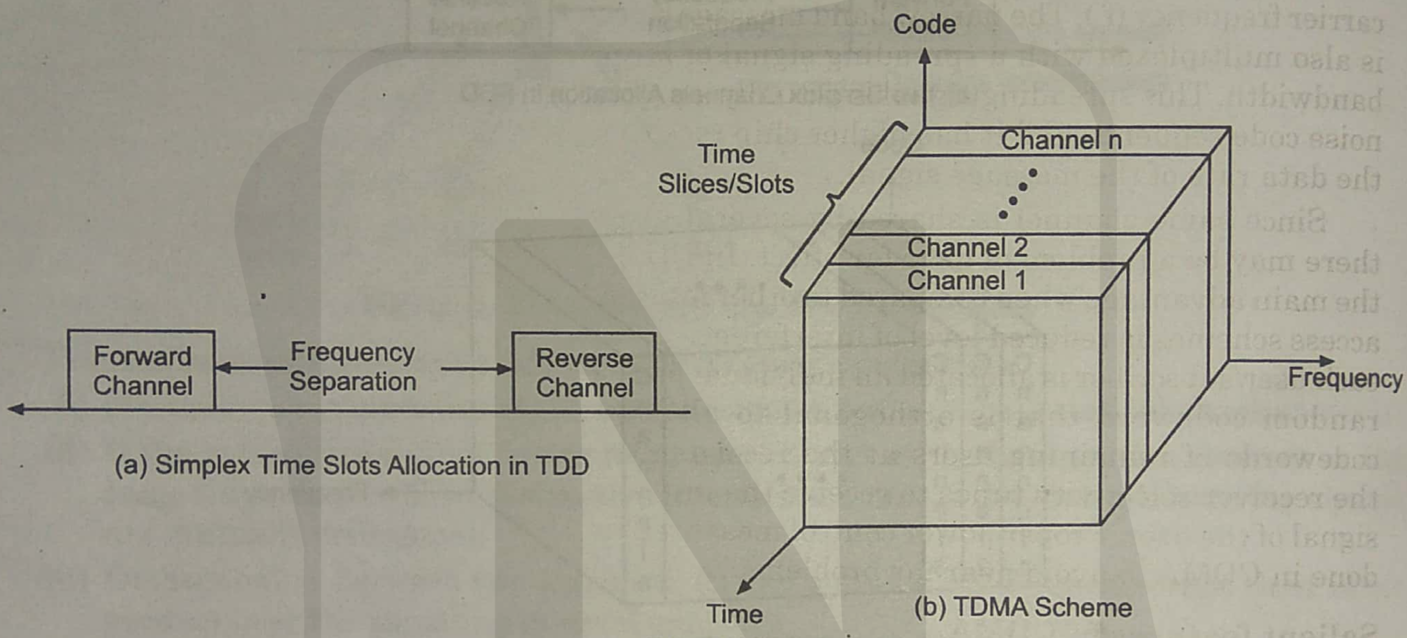


Fig. 2.15.

This TDD mode enables every transceiver (transmitter and receiver) to operate as a transmitter or receiver. The TDD mode is generally used in cordless phones. The principle of TDMA multiplexing scheme is shown in figure 2.15 (b). In TDMA system the entire radio spectrum is divided into time slots where a single user is allowed to use the radio channel in a time slot. In TDMA digital data transmission and digital modulation are allowed. Many users can access their channel in their respective time slots. The transmission from several users are interlaced into a single frame as shown in figure 2.16.

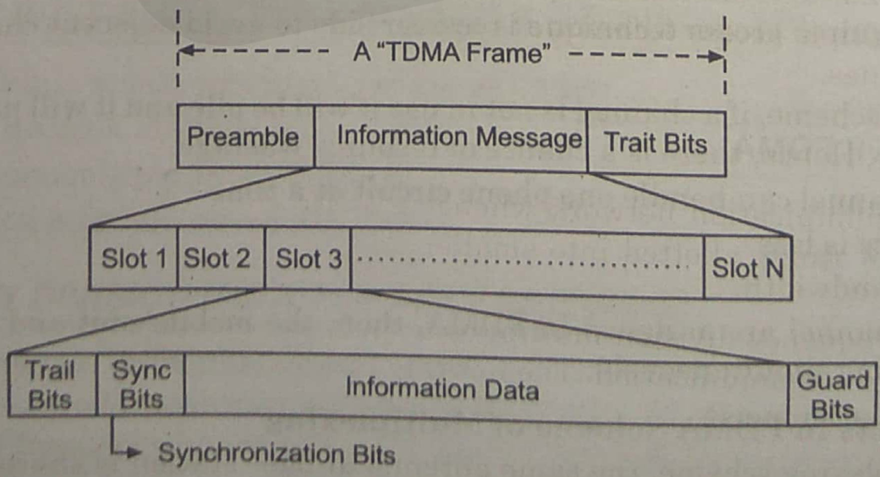


Fig. 2.16. TDMA frame format

In this format, the preamble field contains the synchronization and address informations. The guard bits are used to allow synchronization of the different receivers between various frames and time slots. It is assumed that there are 'N' number of time slots for 'N' number of users so that each user can access the channel in their allowed time slot.

Salient Features of TDMA

Each user in TDMA multiple access scheme shares same carrier frequency but with non overlapping time slots.

2.11. CODE DIVISION MULTIPLE ACCESS (CDMA)

In CDMA technique many users share the same carrier frequency (f_c). The narrow band message signal is also multiplexed with a spreading signal of larger bandwidth. This spreading signal is actually a pseudo noise code sequence and it has higher chip rate than the data rate of the message signal.

Since same channel is shared by several users, there may be a problem of near far effect. In CDMA, the main advantage when compared to other multiple access schemes is reduced level of interference. Since each user/subscriber is allocated an individual pseudo random codeword that is orthogonal to all other codewords of remaining users at the receiving end the receiver selectivity tunes to receive the intended signal of the user. Proper power control measures are done in CDMA to avoid near far problems.

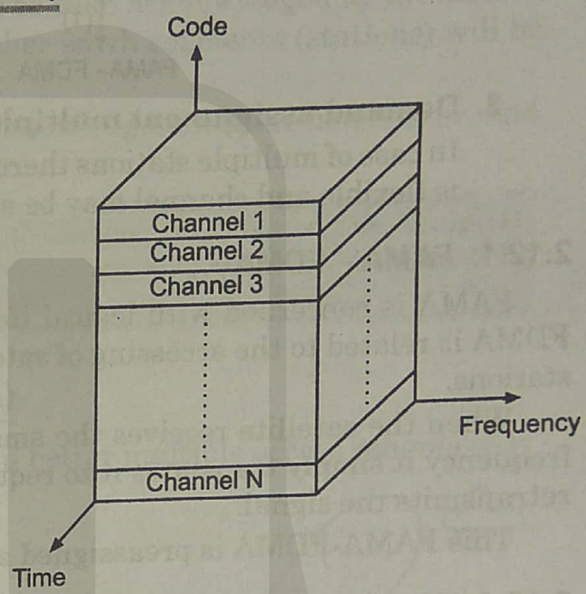


Fig. 2.17. Code Division Multiple Access

Salient features of CDMA

(i) If the spreading sequences are not exactly orthogonal from one user and to another user there may be a chance of self-jamming problem in CDMA. Hence this spreading sequence or pseudo random noise code has to be carefully planned and then it should be multiplied with the message signal.

(ii) Radio signal strength indicator (RSSI) is being used in CDMA to have better power control.

(iii) CDMA has better soft capacity limit than TDMA and FDMA methods.

(iv) CDMA has less interference problems due to allocation of unique codes to each use and this multiple access technique is applied for defence areas than other multiple access techniques.

2.12. TYPES OF FDMA

In satellite communication network whenever FDMA is applied it is possible to divide the entire frequency range allotted into smaller channels (slices) each of which uses frequency modulation.

Access of frequency division multiplexing is quite good with satellite networks which in turn helps mobile communication. The limiting factors of FDMA are thermal noise, cross talk and intermodulation noise.

3.7. FAST FADING WIRELESS CHANNEL MODELING

To design the communiction system, design engineer needs to estimate the effect of multipath fading or small scale fading, large scale fading and noise effect on the radio channel. The characteristics of the channel described by the power delay profile. The depth of the fading depends on the type of channel. The multipath fading channel can be divided on the basis of the distribution function of the instantneous power of the channel which depends on the radio environment. The types of fading multipath channel are as follows:

3.7.1. Additive White Gaussian Noise (AWGN) channel

In this channel, the received signal is degraded by thermal noise associated with physical channel itself and losses at transmitter and reciever. This AWGN channel gives accuracy in some cases (i.e., satellite communication, wire transmission through cables, analog communication etc.) But, for terrestrial wireless communication,AWGN channel is not suitable for radio channels.

3.7.2. Log-Normal Fading Channel

Propagation models have been developed to determine the path loss and these are known as large scale fading because they characterize the received signal strength by averaging the power level over large range of hunderds or thousands of metres distance between transmitter and reciever. But due to trees, foliage, rainfall and atmospheric condition, the gradual change in the local-mean power and this type of fading channel characterize by log-normal distribution function. The log-normal P.D.F. is given by

$$f_L(p_0) = \frac{1}{p_0\sigma\sqrt{2\pi}}\exp\left[\frac{ln(p_0)-m^2}{2\sigma^2}\right] \quad ...(3.3)$$

where,

p_0 = local mean power

σ = RMS valve of recived signal

m = mean of the received signal

3.7.3. Rayleigh Fading Channel

In Rayleigh fading channel, all mulitpath fades are independent and there is no line of sight (LOS). dominant path between transmitter and reciever. In the outdoor environment in urban areas, where direct line-of-sight (LOS) path is not available between transmitter and receiver, the Rayleigh fading channel is the only choice for communication engineers. In other words, when there is no line-of-sight (LOS) path available between transmitter and reciever, the received signals obey the Rayleigh distribution. Figure 3.13(a) shows the graphical represenation of Rayleigh Probability Density Function (P.D.F.). The P.D.F. of Rayleigh distribution is given by

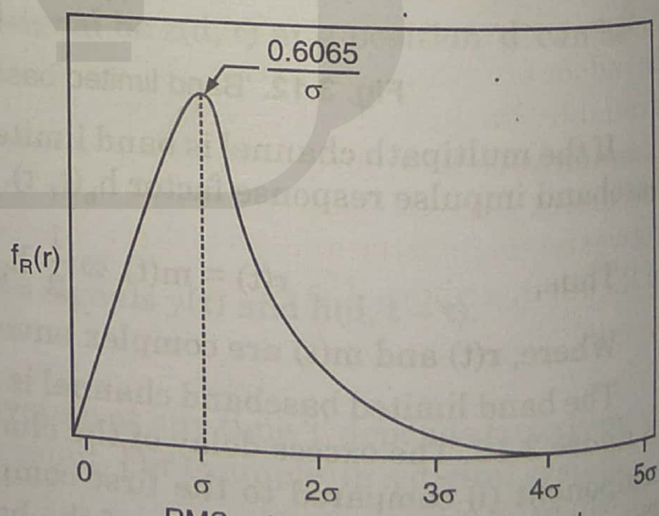


Fig. 3.13. (a) Rayleigh probability density function (PDF)

$$f_R(r) = \frac{1}{\sigma^2}\exp\left[-\frac{r^2}{2\sigma^2}\right], \quad \text{for } 0 \le r \le \infty$$

$$= 0, \quad \text{for } r < 0 \quad ...(3.4)$$

where, r = amplitude of received signal

σ^2 = average power of the received signal

Two-ray Rayleigh fading model

This fading model considers the multipath time delay factor. In today's digital communication that deals with higher data rates, it is important to model the effects of fading and multipath delay spread. An independent two-ray Rayleigh fading model for mobile channel has been shown in figure 3.13 (b).

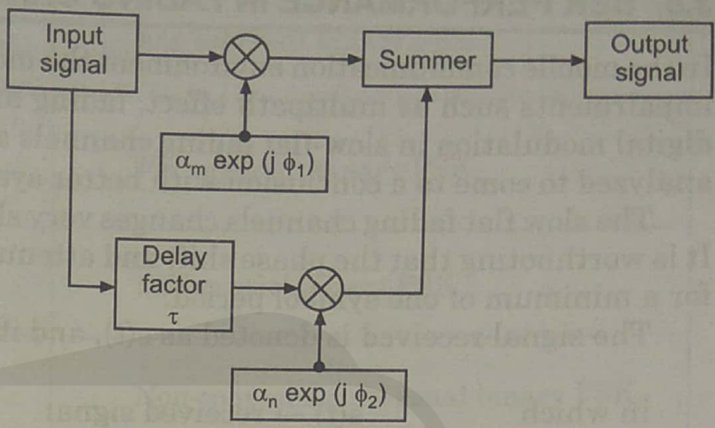


Fig. 3.13. (b) Two-ray Rayleigh fading model

The impulse response of the two-ray Rayleigh model can be given as under :

$$h(t) = \alpha_m \exp(j\phi_1)\,\delta(t) + \alpha_n \exp(j\phi_2)\,\delta(t-\tau)$$

in which the variable α_m and α_n are Rayleigh distributed, τ is the time delay factor and ϕ_1 and ϕ_2 are uniformly distributed over the range $(0, 2\pi)$. In case the value of α_n is equal to 0, a specific case of Rayleigh fading channel can be obtained as under :

$$h(t) = \alpha_m \exp(j\phi_1)\,\delta(t)$$

It is evident that the time delay factor 'τ' is varied, then, it is possible to obtain a wide range of frequency selective fading effects.

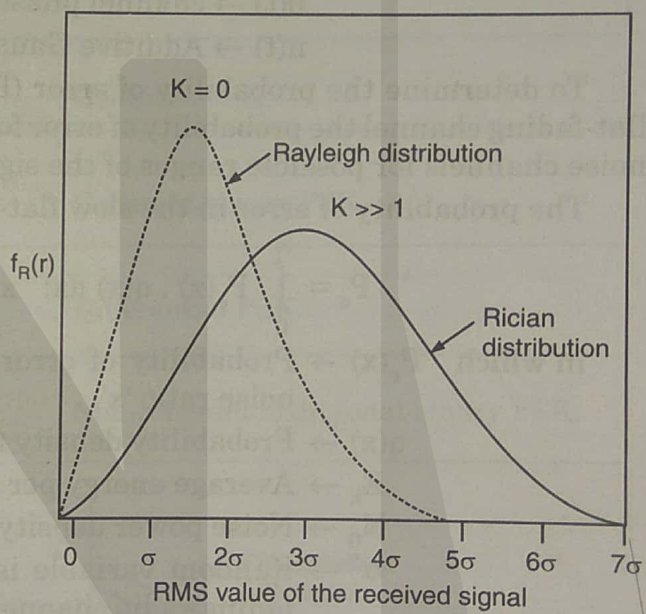


Fig. 3.14. Rician probability density function (PDF)

3.7.4. Rician Fading Channel

In the small scale fading, if the direct line-of-sight (LOS) path is dominant between transmitter and receiver, the fading is known as Rician fading. In indoor environment, where, direct LOS path is available, the Rician fading channel is suitable for communication engineer. In other words, when, the direct Line-of-Sight (LOS) path is available between transmitter and receiver, the received signal obey the Rician distribution. The P.D.F. of Rician distribution is given by

$$f_R(r) = \frac{r}{\sigma^2} \exp\left[-\frac{r^2+s^2}{2\sigma^2}\right] I_0\left(\frac{r^2}{\sigma^2}\right), \quad \text{for } s \geq 0 \text{ and } r \geq 0$$

$$= 0, \quad \text{for } r < 0 \qquad \text{...(3.5)}$$

where, s = peak value of the dominant signal

$I_0(\,)$ = modified Bessel function of the first kind and zero order

The Rician fading channels are more applicable in indoor and rural areas. Figure 3.14 shows the probability density function (PDF) for Rician fading. The Rician distribution is often described in terms of a parameter k which is defined as the ratio of the dominant LOS path power to the scattered path power as follows :

$$k = \frac{\text{power in dominant path}}{\text{power is scattered path}} = \frac{s^2}{2\sigma^2} \qquad \text{...(3.6)}$$

3.8. BER PERFORMANCE IN FADING CHANNELS

In the mobile communication environment the mobile radio channel has to meet several channel impairments such as multipath effect, fading and Doppler spread. Thus, the performance of digital modulation in slow-flat fading channels and in frequency selective channels have to be analyzed to come to a conclusion with better system performance.

The slow flat fading channels changes very slow when compared to the modulation applied. It is worthnoting that the phase shift and attenuation of the signal are assumed to be constant for a minimum of one symbol period.

The signal received is denoted as s(t), and it is $s(t) = \alpha(t) \exp(-j\,\theta(t))\, x(t) + n(t);\ 0 \le t \le T.$ ...(3.7)

in which
- $s(t) \rightarrow$ received signal
- $\alpha(t) \rightarrow$ channel gain
- $\theta(t) \rightarrow$ channel phase shift
- $n(t) \rightarrow$ Additive Gaussian Noise (AGN)

To determine the probability of error (P_e) of the digital modulation scheme used in slow flat-fading channel the probability of error for a specific modulation in additive white Gaussian noise channels for possible ranges of the signal strength, that is due to fading.

The probability of error in the slow flat-fading radio channel is given as under:

$$P_e = \int_0^\infty P_e(x) \cdot q(x)\, dx; \quad x = a^2 E_b/N_o \qquad \text{...(3.8)}$$

in which
- $P_e(x) \rightarrow$ Probability of error for modulation at particular value of signal to noise ratio 'x'.
- $q(x) \rightarrow$ Probability density function of 'x'.
- $E_b \rightarrow$ Average energy per bit.
- $N_0 \rightarrow$ Noise power density
- $\alpha^2 \rightarrow$ Random variable is used to express instantaneous power value of fading radio channel, corresponding to E_b/N_o.

For the Rayleigh fading channel case, α is the fading amplitudes that has Rayleigh distribution such that the fading power is α^2 and hence the value of x will have chi-square distribution.

$$p(x) = \frac{1}{\Gamma} \exp\left(\frac{-x}{\Gamma}\right);\ x \ge 0 \qquad \text{...(3.9)}$$

in which $\Gamma = \frac{E_b}{N_o} \cdot \overline{\alpha^2}$; $\overline{\alpha^2} \rightarrow$ instantaneous power value for unity gain fading channel.

and Γ now represents average value of the signal to noise ratio.

Let us consider $\overline{\alpha^2} = 1$ then in the case mentioned above

$\Gamma = \frac{E_b}{N_o}$, the Γ corresponds to the average $\frac{E_b}{N_o}$ for a fading channel.

From these considerations, the probability of error P_e for slow-flat fading channel can be [fo]und.

Table 3.1. Probability of error for different modulation techniques

Probability of error	Type of Modulation
$P_{e,\,FSK} = \frac{1}{2}\left[1-\sqrt{\frac{\Gamma}{2+\Gamma}}\right]$	For coherent binary FSK.
$P_{e,PSK} = \frac{1}{2}\left[1-\sqrt{\frac{\Gamma}{1+\Gamma}}\right]$	For coherent binary PSK.
$P_{e,DPSK} = \frac{1}{2(1+\Gamma)}$	Differential binary PSK.
$P_{e,NCFSK} = \frac{1}{2+\Gamma}$	Non-coherent orthogonal binary FSK.
For larger values of 'x', the P_e is rewritten as below:	
$P_{e,\,FSK} = \frac{1}{2\Gamma}$	Coherent FSK.
$P_{e,PSK} = \frac{1}{4\Gamma}$	Coherent binary PSK.
$P_{e,DPSK} = \frac{1}{2\Gamma}$	Differential PSK.
$P_{e,NCFSK} = \frac{1}{\Gamma}$	Non-coherent orthogonal binary FSK.

The bit error probability v_s E_b/N_o is shown in figure 3.15. The curves for AWGN and other modulation techniques vary in the graph. The P_e value for AWGN is high when E_b/N_o is very less. As E_b/N_o increases, this is a sudden drop in P_e. But, in other techniques, as E_b/N_o increases a smooth fall in P_e is observed.

Also, from the equations of probability of error P_e there is an inverse relation, which exists between the error rate and mean signal to noise ratio. But it is opposite with respect to AWGN channel where there is an exponential relationship observed between the error rate and signal to noise ratio. Finally, it is possible to improve bit error rate (BER) by using special techniques like error control coding, diversity techniques. They also help to minimize or even avoid deep fades in the signal in mobile communication.

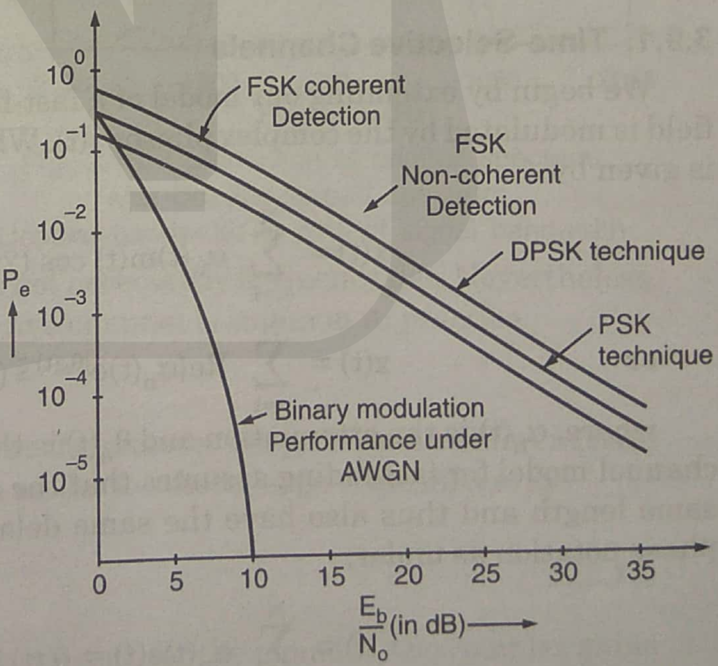


Fig. 3.15. BER performance of different digital modulation schemes under Rayleigh flat-fading channel compared to the performance curves under AWGN

3.12. DIVERSITY MODELING FOR WIRELESS COMMUNICATIONS

The diversity is a good technique applied in mobile communication receiver circuits where there is multipath environments. The diversity techniques use the nature of the propagation path characteristics for improving the sensitivity of receivers. It will improve the wireless links at less costs. It does not require prior training because a training sequence is not needed by a transmitter like an equalizer. Diversity technique finds a way of analyzing signal paths for multipath cellular environment. The diversity decisions made are at the receiver end and they are not known to the transmitter.

3.12.1. Diversity Concept

The simple concept of diversity is that even if a radio signal path experiences a deep fade, there will be another independent signal path available for analysis.

Let us consider figure 3.20. Here, a received signal is observed with many variations. Let us assume that two antennas with a specific separation between them are located on a terminal. They experience different fading levels as the mobile terminal moves. An example of received signal variations is represented in figure 3.20. The received signal levels differ with their corresponding fading levels. Hence, we select an antenna that possess higher signal level so that the probability of deep fading can be avoided.

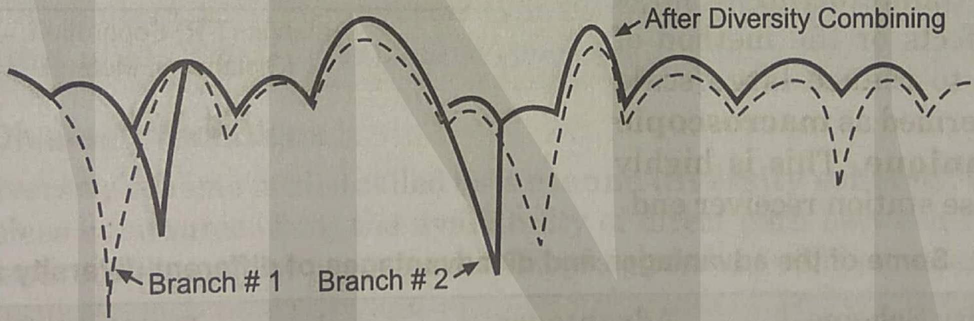


Fig. 3.20. Received signal level variations at various diversity branches

In figure 3.20, signal level of the antenna # 1 suffers fading whereas signal level of antenna #2 fades in seldom cases. Note that branch #1 is deeply faded whereas branch #2 is not highly faded.

3.12.2 Types of Fading

There are two types of fading as under:

(a) small-scale, and (b) large-scale fading.

(a) Small-scale fading

The small-scale fading are mainly characterized by rapid amplitude fluctuations and deep fades of less wavelengths (λ). The small-scale fading is due to signal fades caused by multiple path and reflections with respect to mobile movement.

(b) Large-scale fading

The large-scale fading is generated by shadowing effects which is due to changes in both the nature of surroundings and the terrain profile involved. The large scale fading is log-normally spreaded with particular standard deviation value of approximately 10 decibels in the urban area.

3.12.3. Types of Diversity

The two basic types of diversity are termed as under:

(i) Microscopic diversity, and

(ii) Macroscopic diversity.

(i) Microscopic diversity

To counteract small-signal fading that is to avoid deep fading in the signal received under small distances, fading can be minimized by this technique. It can prevent small signal fades in case of less antenna separations, if two antennas are used.

By choosing the signal of higher strength most of the time, the receiver can reduce the fading effects. Figure 3.21 shows that the small signal fades rapidly whereas large signal fades gradually with respect to an indoor environment.

(ii) Macroscopic diversity

In large signal fading, the signal strength reduces that is because of shadowing problems. By choosing a base station that is not shadowed when compared to other base stations, the mobile unit can acquire a better signal to noise ratio (SNR) in its forward path. Such a type of counteracting to large scale fading effects or the method of diversity used to reduce large scale signal fades is termed as **macroscopic diversity technique**. This is highly useful at the base station receiver end.

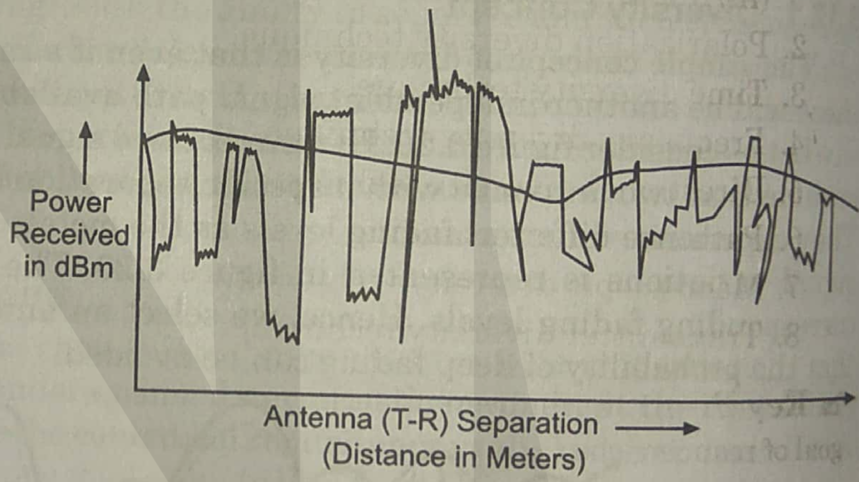


Fig. 3.21.

Table 3.2. Some of the advantages and disadvantages of different diversity schemes

S.No.	Diversity Scheme	Advantages	Disadvantages
1.	Polarization Diversity	No space and extra bandwidth is required.	(i) 3 dB extra power is a must (ii) Two branch diversity schemes is only possible.
2.	Space diversity	(i) Several diversity branches are allowed. (ii) It is also applicable to macroscopic diversity. (iii) No extra bandwidth or power is required.	(i) Large hardware size is required. (ii) Larger antenna spacing is a must for the microscopic diversity at the base station.
3.	Frequency diversity	Several diversity branches are allowed.	Relevant power level of frequency spectrum are important.

(Contd...)

4.	Time diversity	(i) Hardware is simple. (ii) Several diversity branches are allowed.	(i) Larger buffer memory is a must when diversity frequency is small. (ii) More frequency spectrum is necessary according to the number of diversity branches.
5.	Angle Diversity	Doppler spread can be reduced.	Diversity gain will depend on the number of obstacles available around the terminal.
6.	Path Diversity	(i) No space is required. (ii) No extra bandwidth and power are required.	The diversity gain will depend on the delay status.

3.12.4. Few Important Diversity Techniques

The important diversity techniques are discussed in the following ways:

Types of Diversity Techniques:

1. Space diversity technique.
   (i) Selection diversity
   (ii) Feedback diversity
   (iii) Maximal ratio combining method.
   (iv) Equal gain combining.
2. Polarization diversity technique.
3. Time diversity technique.
4. Frequency diversity technique.
5. Directional diversity technique.
6. Path diversity technique.
7. Macroscopic diversity technique.
8. Transmitter diversity technique.

Key Point: Each diversity technique is unique in its functionality but aims towards a common goal of reducing the fading effects in multipath receiver circuit.

3.12.5. Space Diversity Technique

The space diversity scheme is also called as **'antenna diversity scheme'**. In conventional methods of wireless communication, the availability of direct path between transmitter and receiver is not assured. Hence, the occurrence of Rayleigh fading will be present.

But, the antenna space diversity can achieve independent fading changes by applying spatially separated antennas.

In the space diversity scheme, the receiver configuration is quite simple. Several number of diversity branches are selectable. For producing diversity reception at each and every cell site, multiple base station receiving antennas are used effectively. It is important to note that main scattering takes place in ground which is in the vicinity of the mobile unit, and hence, to attain decorrelation the antennas at base station have to be placed with necessary separation distances. This separation distance can be in order of tens of wavelength (λ) value with respect to base station. Generally, the space diversity technique can be used at base station or mobile or at both ends.

Also, in case the antenna spacing is greater than $\frac{\lambda}{2}$, then it is sufficient to obtain low fading correlation between the diversity branches, and antenna spacing of 50 λ to 100 λ is a must at the base station end.

A general schematic of space diversity is shown in figure 3.22. There are 'n' branches with separate gain values namely G_1 G_2 ... G_n and a set of demodulators to generate required output.

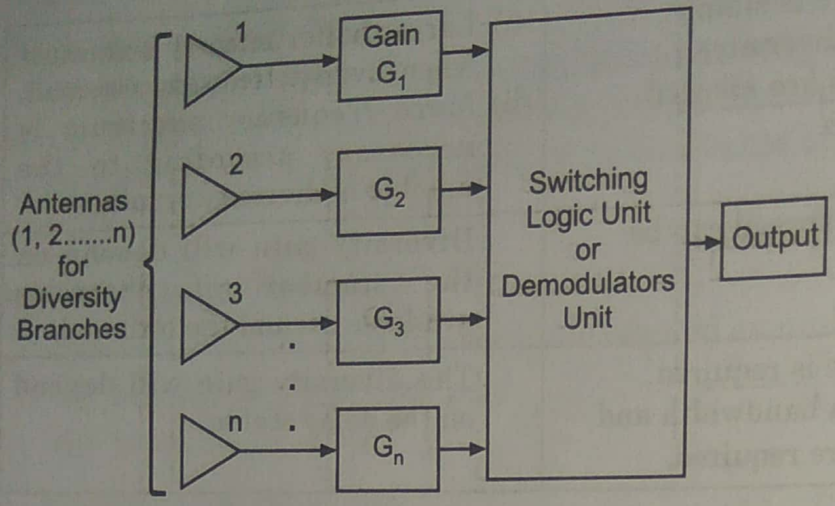


Fig. 3.22. Simple block diagram of space diversity technique

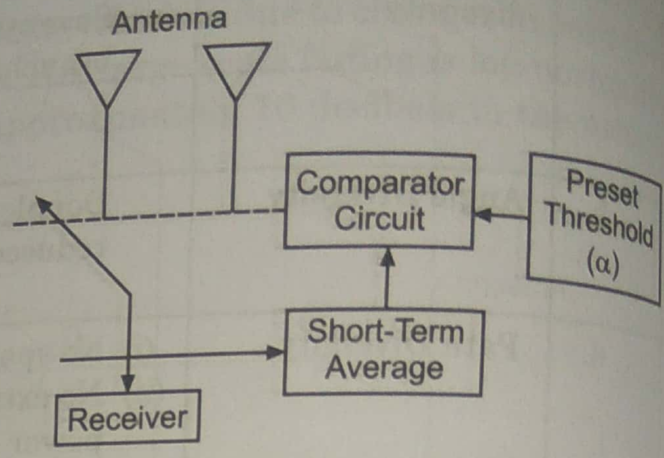


Fig. 3.23. Feedback diversity technique

3.12.6. Combining Methods: Space Diversity Combining Schemes

(i) Selective Diversity Combining

In selective diversity combining, the branches having the strongest received signal will be selected. In selective diversity method, 'n' number of demodulators are used and their gains can be adjusted to give mean signal to noise ratio (SNR) for every diversity branch. Then, the antenna signals will be sampled. Finally, the best signal that possess good signal strength will be sent to a demodulator. It is also seen that practical diversity system has to be designed carefully such that reciprocal of the mobile signal fading rate is longer than the internal time constant values of selection diversity circuitry.

(ii) Switched Combining Technique: Feedback Diversity

The feedback diversity technique is also known as **scanning diversity**. In this method the 'n' signals are scanned in a proper sequence and monitored to pick a signal in the sequence which is above the preset threshold value say 'α'. Then, scanning process will be initiated for the received signals. But, the demerit of this method is that the fading level reduction is less than the other diversity techniques. In this method, for the received signals (m), the best signal of better strength is measured by comparing every signal with a preset threshold value 'α' as shown in figure 3.20. One of the merit of feedback diversity is its easier implementation than other methods.

(iii) Maximal Ratio Combining Technique

The concept of this method is that all the branch signals [N] are combined coherently with necessary weighting coefficients for every diversity branch signal, so that the reduction of fading will be better leading to overall improvement of system performance. Unlike selection diversity, the signals are cophased before addition process and for this, individual receiver and phasing circuit is a must for all the antenna elements. Figure 3.24 shows that the output signal of maximal ratio combiner will be such that the sum of individual signal to noise ratio (SNR) values will be equal to the SNR of output signal measured.

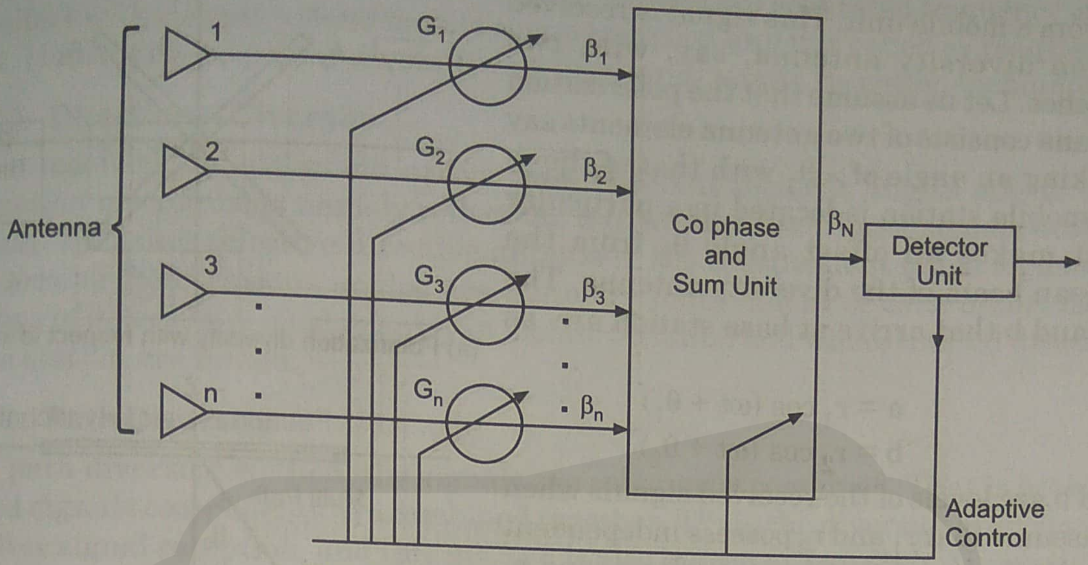


Fig. 3.24. Maximal ratio combiner technique

Advantages

(i) Maximal ratio combiner generates an acceptable SNR value.

(ii) Accuracy is high.

(iii) Produces best reduction of fading.

(iv) Equal Gain Combiner Technique

In the equal gain combining, all the diversity branches are coherently added with a same weighting factor. On the other hand, this scheme also cophases all the diversity branches and finally adds them up. As the signals are cophased from all branches, they provide an equal gain factor. When compared to maximal ratio combining, the configuration of this method is simple. By applying equal gain combining, it is convenient for the receiver to get back the signals.

One of the demerits of this method is that it degrades the SNR value by 0.5 dB at the output of combiner if two branches are involved. If ten branches are involved in the reception, then the SNR degradation would be roughly upto 1 dB value.

3.12.7. Polarization Diversity

In polarization diversity, both horizontal and vertical polarization are involved. In case, if a signal is transmitted by a pair of polarized antennas and it is received by another pair of antennas, then two uncorrelated fading signals will be received because different fading variations are experienced by horizontal and vertical polarizations and due to different reflection coefficient values of the tall building walls.

The measured vertical and horizontal polarization signal paths between base station and mobile is found to be uncorrelated. Also, the decorrelation in vertical and horizontal polarization for signals is due to multiple reflections in the radio channel between base stations and mobile antennas. There will be an amount of dependence of received polarization on transmitted polarization.

It is interesting to note that whenever the radio path meets an obstacle, the polarization diversity is observed as to decrease the multipath delay spread with decreasing the power received.

Model for polarization diversity

Now, let us consider that the signal is being transmitted with horizontal or vertical polarization from a mobile unit. This signal is received by polarization diversity antenna, say, with two diversity branches. Let us assume that the polarization diversity antenna consists of two antenna elements say A_1 and A_2 making an angle of $\pm\theta_1$ with that of the y-axis. Then, a mobile station is located in a particular direction that makes an offset angle θ_2 from the direction of mean beam of the diversity antenna. The two signals a and b that arrive at base station are as under:

$$a = r_1 \cos(\omega t + \theta_1)$$
$$b = r_2 \cos(\omega t + \theta_2)$$

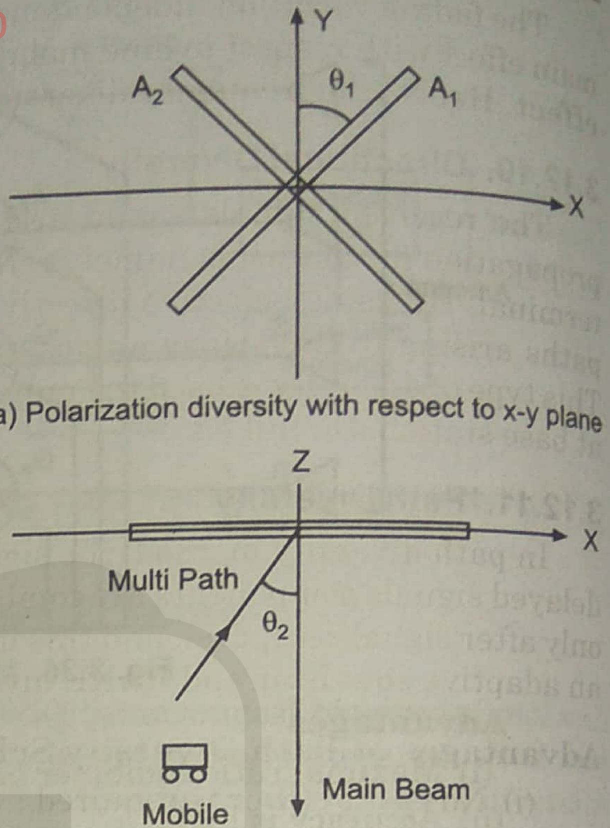
in which a and b are levels of the received signals when $\theta_2 = 0$. Let us assume that r_1 and r_2 possess independent Rayleigh distributions and the phase angles ϕ_1 and ϕ_2 have independent uniform distribution values. The correlation coefficient of the signals received at A_1 and A_2 can be determined by three factors:

They are as under:

(i) Polarization angle.

(ii) Cross polarization discrimination.

(iii) Offset angle from that of the main beam direction of diversity antenna setup.



(a) Polarization diversity with respect to x-y plane

(b) Polarization diversity with respect to x-z plane

Fig. 3.25. Model for the base station polarization diversity

By these factors, the value of correlation coefficient can be determined.

Important Point : As the offset angle 'θ_2' grows higher, the correlation coefficient also becomes higher value.

Thus, polarization diversity is one of the best technique in diversity reception and it can be applied for mobile unit and the base station.

3.12.8. Time Diversity

In time diversity method, the information is transmitted repeatedly at specific time spacings that would exceed the coherence time of the mobile channel, and this will lead to repetition of signals for several times; irrespective of fading conditions. Thus, when an identical information is sent for different time slots, it is possible to obtain diversity branch signals. The time diversity technique is well suited for spread spectrum CDMA system in which RAKE receiver is used for reception.

3.12.9. Frequency Diversity

In this method of frequency diversity, the information is transmitted on many carrier frequencies. The idea behind this is that if the frequencies are separated by more than that of the coherence bandwidth of the mobile channel, these would be uncorrelated with each other and hence would not experience same fading status. Also, under channels of uncorrelated situations, the occurrence of fading will be multiple of the individual fading probability (occurrences).

The frequency diversity scheme is applied in microwave fields whenever line of sight (LOS) links is used. That is in LOS links they may carry many channels in the frequency division multiplex mode (FDM). There are chances of deep fades in frequency diversity due to tropospheric propagations and the resulting refractions of the signal.

The fading variation independence factor between the separated frequency components is a main effect with respect to land mobile communication and it is called as **frequency diversity effect**. Hence, the frequency diversity is a popular diversity reception technique.

3.12.10. Directional Diversity

The received signals would arrive from different incident angles due to any one of the propagation mechanisms namely reflection, diffraction or scattered signals around the mobile terminal. By using selective directive antennas, the independent faded signals (since all the paths arising from various angles are mutually independent of each other) can be received. This type of diversity is used to apply in mobile terminal end where limited directions of signals at base station are linked.

3.12.11. Path Diversity

In path diversity method, the signals are coherently combined. That is both the direct and delayed signals components are combined together. Thus, the diversity branches are generated only after signal reception, and this method is also known as **Implicit diversity**. For example, an adaptive equalizer and RAKE diversity are also categorized as path diversity schemes.

Advantages of Path Diversity Schemes

(i) No extra power is required

(ii) No extra antennas are required and

(iii) No extra frequency spectrum is required.

Demerit of path diversity scheme

This diversity method is very sensitive to Rayleigh fading conditions, and therefore, the propagation path conditions has to be given more attention.