Module 5

Broadcast Communication Networks

Lesson 9

Cellular Telephone Networks

Specific Instructional Objectives

At the end of this lesson, the student will be able to:

- Explain the operation of Cellular Telephone networks
- Explain the operation of the first generation cellular network - AMPS
- Distinguish between first generation and second-generation cellular networks
- Explain the operation of the second-generation cellular networks
- State the goals of 3G cellular networks

5.9.1 Introduction

In the early years of mobile radio systems, a large coverage was achieved by using a single high-powered transmitter with the antenna mounted on tall tower. Although a large coverage could be attained by this approach, it does not allow the reuse of the same radio frequencies due to interference. The *cellular* concept was invented in solving the spectral congestion and user capacity. Cellular telephony is a system-level concept, which replaces a single high power transmitter with a large number of low-power transmitters for communication between any two devices over a large geographic area. Primary goal of the cellular telephone network is to provide wireless communication between two moving devices, called *mobile stations* or between one mobile unit and a stationary unit, commonly referred to as *land-line* unit. To accommodate a large number of users over a large geographic area, the cellular telephone system uses a large number of low-power wireless transmitters to create *cells*. Variable power levels allow cells to be sized according to subscriber density and demand within a particular region. As mobile users travel from cell to cell, their conversations are handed off between *cells*. Channels (frequencies) used in one cell can be reused in another cell some distance away, which allows communication by a large number stations using a limited number of radio frequencies. To summarize, the basic concept of reuse allows a fixed number of channels to serve an arbitrarily large number of users.

The basic structure of the cellular telephone is discussed in Sec. 5.9.2. The principle of frequency reuse is elaborated in Sec. 5.9.3. Transmitting and receiving operations are explained in Sec. 5.9.4. Various issues of mobility management have been covered in Sec. 5.9.5. Channalization-based MACs, which are used in cellular telephone networks, is presented in 5.9.6. Section 5.9.7 presents the first generation cellular network – AMPS. Second generation cellular networks have been considered in Sec. 5.9.8. Finally, the key features of the third generation networks is highlighted in Sec. 5.9.9.

5.9.2 Cellular Telephone System

As shown in Fig. 5.9.1, a cellular system comprises the following basic components:

- **Mobile Stations (MS):** Mobile handsets, which is used by an user to communicate with another user
- **Cell**: Each cellular service area is divided into small regions called cell (5 to 20 Km)
- **Base Stations (BS):** Each cell contains an antenna, which is controlled by a small office.

- **Mobile Switching Center (MSC)**: Each base station is controlled by a switching office, called mobile switching center

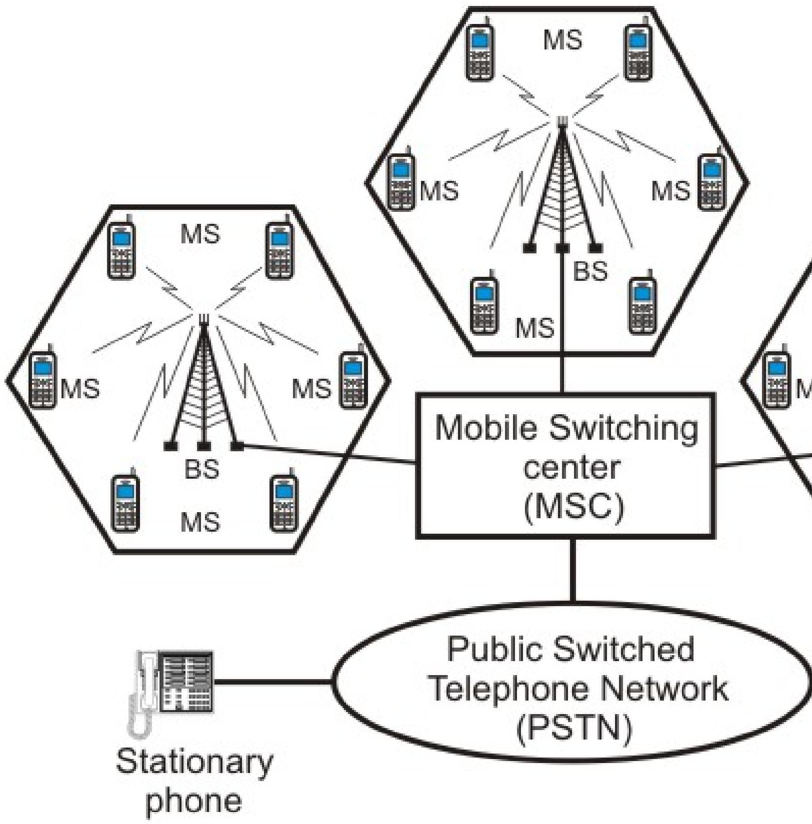
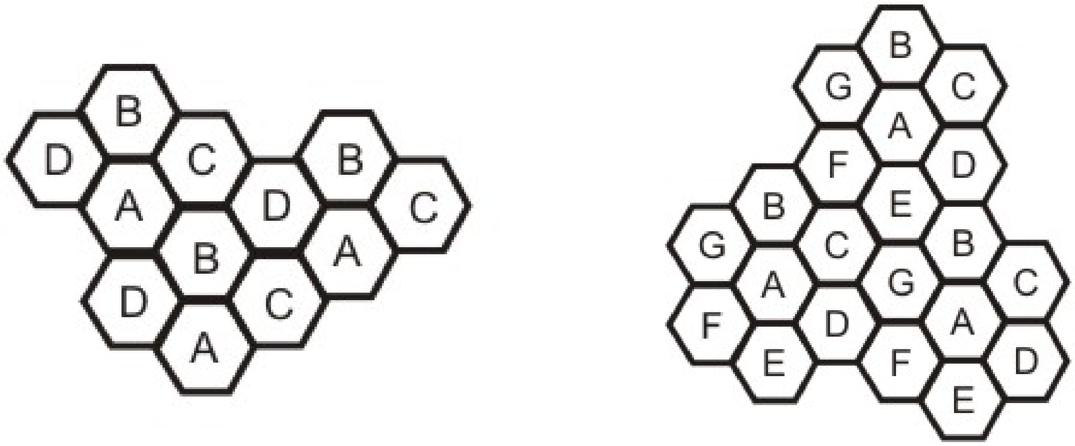


Figure 5.9.1 Schematic diagram of a cellular telephone system

5.9.3 Frequency Reuse Principle

Cellular telephone systems rely on an intelligent allocation and reuse of channels. Each base station is given a group of radio channels to be used within a cell. Base stations in neighbouring cells are assigned completely different set of channel frequencies. By limiting the coverage areas, called *footprints*, within cell boundaries, the same set of channels may be used to cover different cells separated from one another by a distance large enough to keep interference level within tolerable limits as shown in Fig. 5.9.2. Cells with the same letter use the same set of frequencies, called *reusing cells*. N cells which collectively use the available frequencies (S = k.N) is known as cluster. If a cluster is replicated M times within a system, then total number duplex channels (capacity) is C = M.k.N= M.S.

Reuse factor: Fraction of total available channels assigned to each cell within a cluster is 1/N. Example showing reuse factor of ¼ is shown in Fig. 5.9.2 (a) and Fig. 5.9.2(b) shows reuse factor of 1/7.



(a) (b)

Figure 5.9.2 (a) Cells showing reuse factor of ¼, (b) Cells showing reuse factor of 1/7

As the demand increases in a particular region, the number of stations can be increased by replacing a cell with a cluster as shown in Fig. 5.9.3. Here cell C has been replaced with a cluster. However, this will be possible only by decreasing the transmitting power of the base stations to avoid interference.

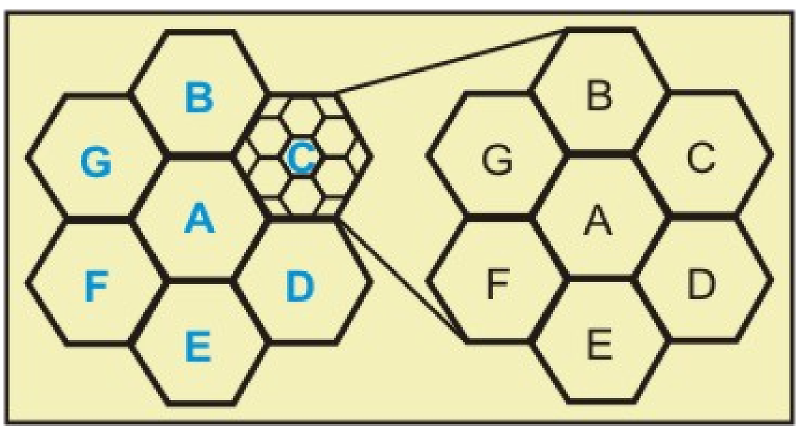


Figure 5.9.3 A cell is replaced by a cluster as demand increases

5.9.4 Transmitting and Receiving

Basic operations of transmitting and receiving in a cellular telephone network are discussed in this section.

Transmitting involves the following steps:

- A caller enters a 10-digit code (phone number) and presses the send button.
- The MS scans the band to select a free channel and sends a strong signal to send the number entered.
- The BS relays the number to the MSC.

- The MSC in turn dispatches the request to all the base stations in the cellular system.
- The Mobile Identification Number (MIN) is then broadcast over all the forward control channels throughout the cellular system. It is known as *paging*.
- The MS responds by identifying itself over the reverse control channel.
- The BS relays the acknowledgement sent by the mobile and informs the MSC about the handshake.
- The MSC assigns an unused voice channel to the call and call is established.

Receiving involves the following steps:

- All the idle mobile stations continuously listens to the paging signal to detect messages directed at them.
- When a call is placed to a mobile station, a packet is sent to the callee's home MSC to find out where it is.
- A packet is sent to the base station in its current cell, which then sends a broadcast on the paging channel.
- The callee MS responds on the control channel.
- In response, a voice channel is assigned and ringing starts at the MS.

5.9.5 Mobility Management

A MS is assigned a home network, commonly known as location area. When an MS migrates out of its current BS into the footprint of another, a procedure is performed to maintain service continuity, known as *Handoff management*. An agent in the home network, called *home agent*, keeps track of the current location of the MS. The procedure to keep track of the user's current location is referred to as *Location management*. Handoff management and location management together are referred to as *Mobility management*.

Handoff: At any instant, each mobile station is logically in a cell and under the control of the cell's base station. When a mobile station moves out of a cell, the base station notices the MS's signal fading away and requests all the neighbouring BSs to report the strength they are receiving. The BS then transfers ownership to the cell getting the strongest signal and the MSC changes the channel carrying the call. The process is called *handoff*. There are two types of handoff; Hard Handoff and Soft Handoff. In a *hard handoff*, which was used in the early systems, a MS communicates with one BS. As a MS moves from cell A to cell B, the communication between the MS and base station of cell A is first broken before communication is started between the MS and the base station of B. As a consequence, the transition is not smooth. For smooth transition from one cell (say A) to another (say B), an MS continues to talk to both A and B. As the MS moves from cell A to cell B, at some point the communication is broken with the old base station of cell A. This is known as *soft handoff*.

Roaming: Two fundamental operations are associated with Location Management; *location update* and *paging*. When a Mobile Station (MS) enters a new Location Area, it performs a location updating procedure by making an association between the foreign agent and the home agent. One of the BSs, in the newly visited Location Area is informed and the home directory of the MS is updated with its current location. When the home agent receives a message destined for the MS, it forwards the message to the MS via the foreign agent. An authentication process is performed before forwarding the message.

5.9.6 Medium Access Control Techniques

Channelization is a multiple access method in which the available bandwidth of a link is shared in time, frequency or using code by a number of stations. Basic idea of these approaches can be explained in simple terms using the *cocktail party theory*. In a cocktail party people talk to each other using one of the following modes:
*FDMA***:** When all the people group in widely separated areas and talk within each group.
*TDMA***:** When all the people are in the middle of the room, but they take turn in speaking.
*CDMA***:** When all the people are in the middle of the room, but different pairs speak in different languages.
Basic principle of these approaches are briefly explained below:
FDMA: The bandwidth is divided into separate frequency bands. In case of bursty traffic, the efficiency can be improved in FDMA by using a dynamic sharing technique to access a particular frequency band; channels are assigned on demand as shown in Fig. 5.9.4

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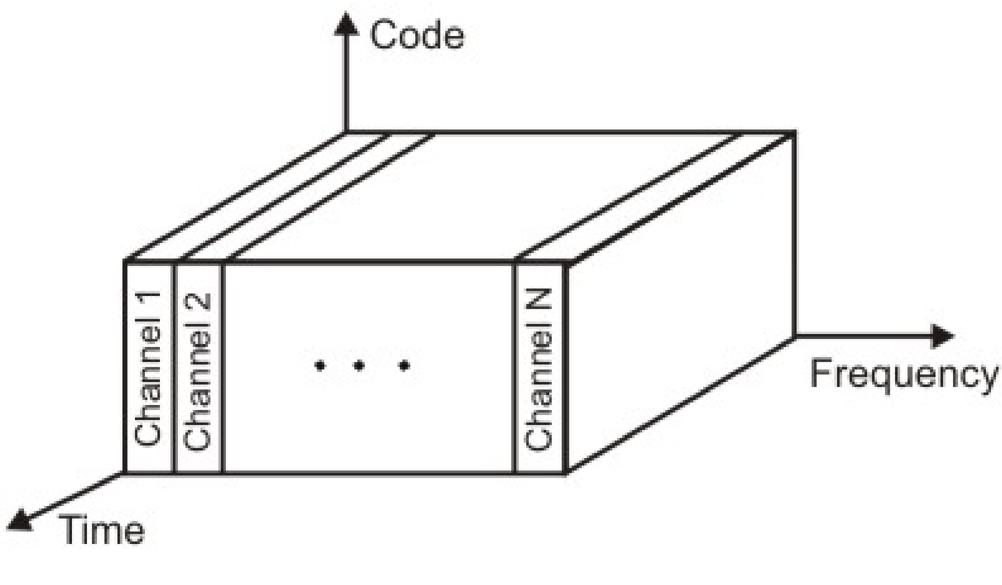

Figure 5.9.4 FDMA medium access control technique

TDMA: The bandwidth is timeshared as shown in Fig. 5.9.5. Channel allocation is done dynamically.

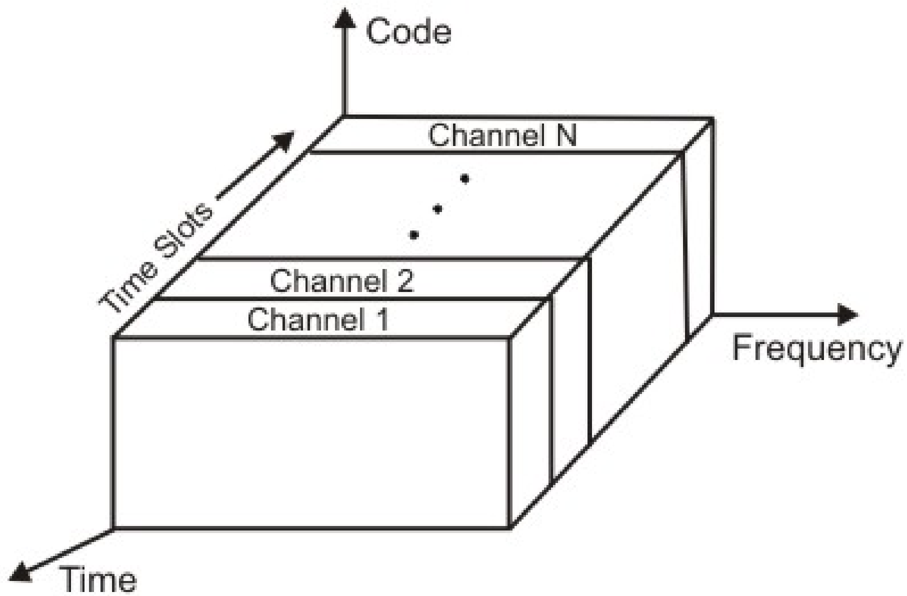

Figure 5.9.5 TDMA medium access control technique

CDMA: Data from all stations are transmitted simultaneously and are separated based on coding theory as shown in Fig. 5.9.6. In TDMA and FDMA the transmissions from different stations are clearly separated in either time or frequency. In case of CDMA, the transmission from different stations occupy the entire frequency band at the same time. Multiple simultaneous transmissions are separated by using coding theory. Each bit is assigned a unique m-bit code or chip sequence.

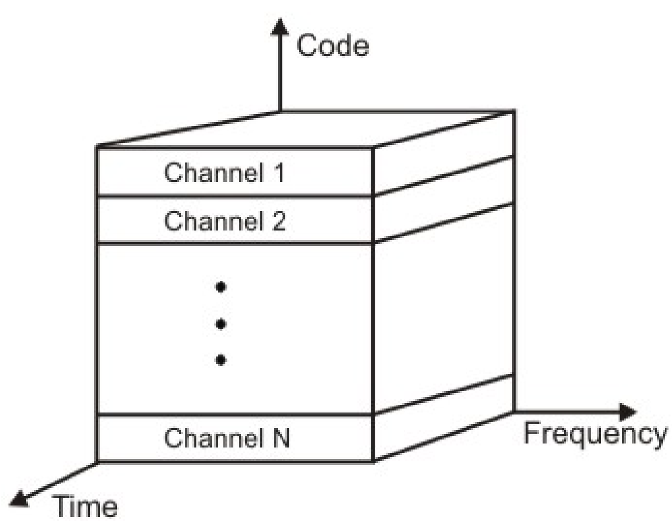

Figure 5.9.6 CDMA medium access control technique

Each station is assigned a unique m-bit code or chip sequence. These are not randomly chosen sequences. Let us use the symbol S_i to indicate the m-chip vector for station i. S_i is the complement of S_i. All chip sequences are pair-wise orthogonal, i.e. the normalized inner product of any two distinct codes is 0. For example: S_1 = {+1, -1, +1, -1} and S_2 = {+1, +1, -1, -1}, Now S_1 . S_2 = +1 -1 -1 +1 = 0. On the other hand S_1 . S_1 = +1 +1 +1 +1 = 4/m = 1 and S_1. S_1 = 0. The orthogonal property allows parallel transmission and subsequent recovery. Walsh table can be used to generate orthogonal sequences in an iterative manner. If the table for N sequences is known, the table for 2N sequences can be created. The multiplexing and demultiplexing operations are shown in Figs. 5.9.7.

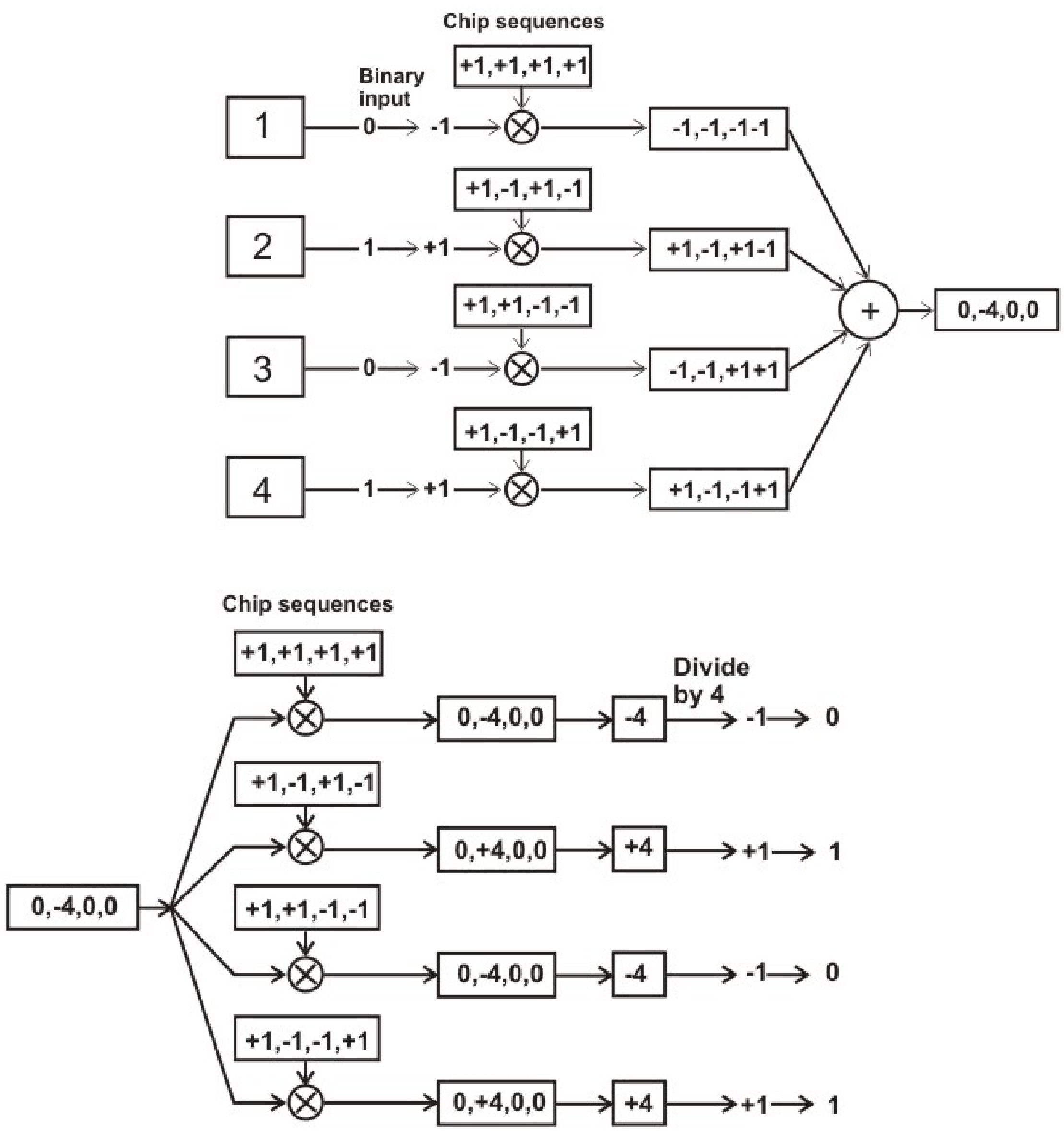

Figure 5.9.7 Multiplexing and demultiplexing operations in CDMA

5.9.7 First Generation System

The first generation was designed for voice communication. One example is Advanced Mobile Phone System (AMPS) used in North America. AMPS is an analog cellular phone system. It uses 800 MHz ISM band and two separate analog channels; forward and reverse analog channels. The band between 824 to 849 MHz is used for reverse communication from MS to BS. The band between 869 to 894 MHz is used for forward communication from BS to MS. Each band is divided in to 832 30-KHz channels as shown in Fig. 5.9.8. As each location area is shared by two service providers, each provider can have 416 channels, out of which 21 are used for control. AMPS uses Frequency Division Multiple Access (FDMA) to divide each 25-MHz band into 30-KHz channels as shown in Fig. 5.9.9.

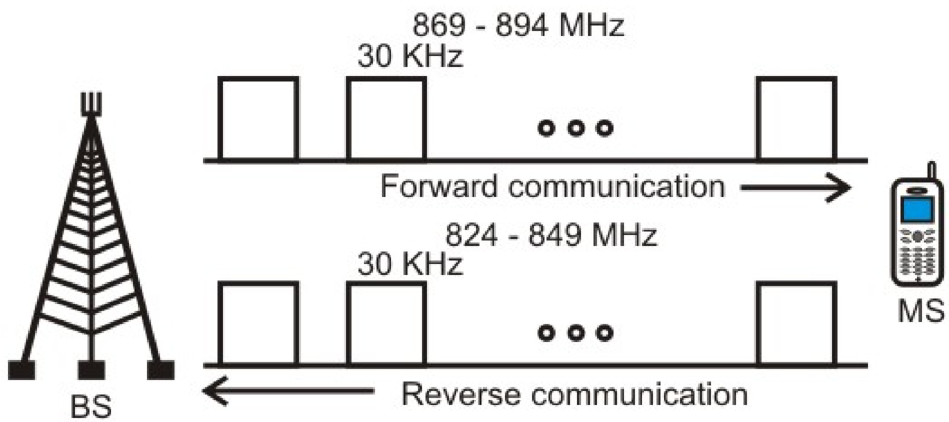

Figure 5.9.8 Frequency bands used in AMPS system

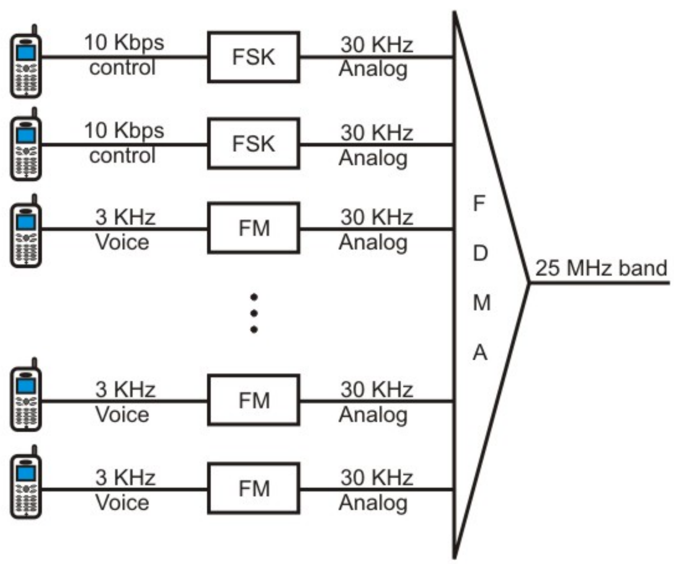

Figure 5.9.9 FDMA medium access control technique used in AMPS

5.9.8 Second Generation

The first generation cellular network was developed for analog voice communication. To provide better voice quality, the second generation was developed for digitized voice communication. Three major systems were evolved, as shown in Fig. 5.9.10.

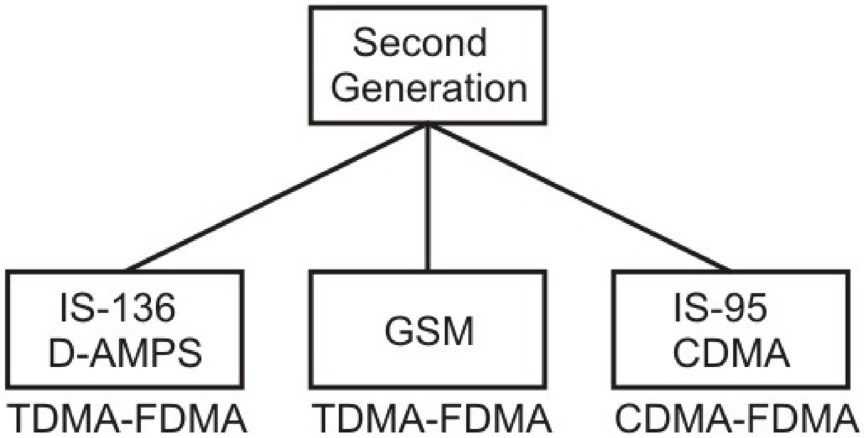

Figure 5.9.10 FDMA medium access control technique used in AMPS

D-AMPS: D-AMPS is essentially a digital version of AMPS and it is backward compatible with AMPS. It uses the same bands and channels and uses the frequency reuse factor of 1/7. 25 frames per second each of 1994 bits, divided in 6 slots shared by three channels. Each slot has 324 bits-159 data, 64 control, 101 error-correction as shown in Fig. 5.9.11. As shown in the figure, it uses both TDMA and FDMA medium access control techniques.

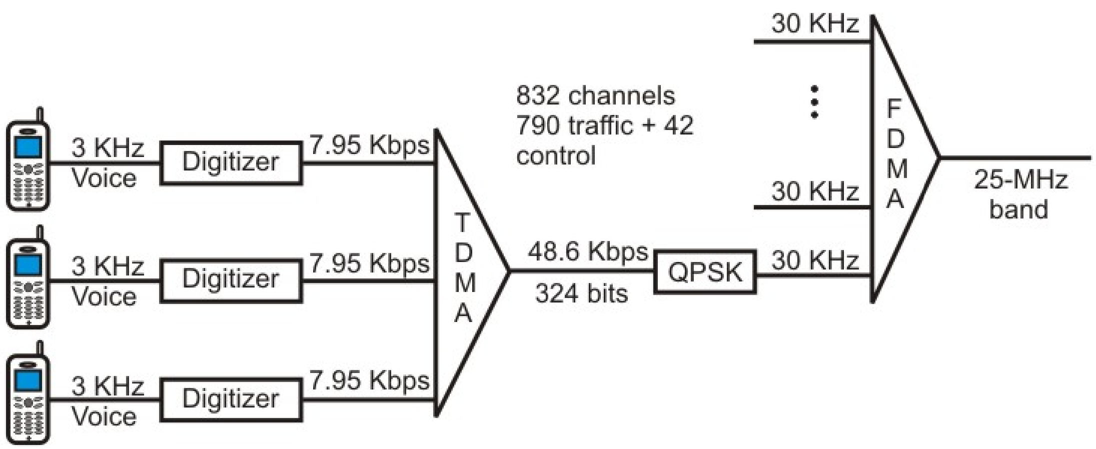

Figure 5.9.11 D-AMPS

GSM: The Global System for Mobile (GSM) communication is a European standard developed to replace the first generation technology. Uses two bands for duplex communication. Each voice channel is digitized and compressed to a 13Kbps digital signal. Each slot carries 156.25 bits, 8 slots are multiplexed together creating a FDM frame, 26 frames are combined to form a multiframe, as shown in Fig. 5.9.12. For medium access control, GSM combines both TDMA and FDMA. There is large amount of overhead in TDMA, 114 bits are generated by adding extra bits for error correction. Because of complex error correction, it allows a reuse factor as low as 1/3.

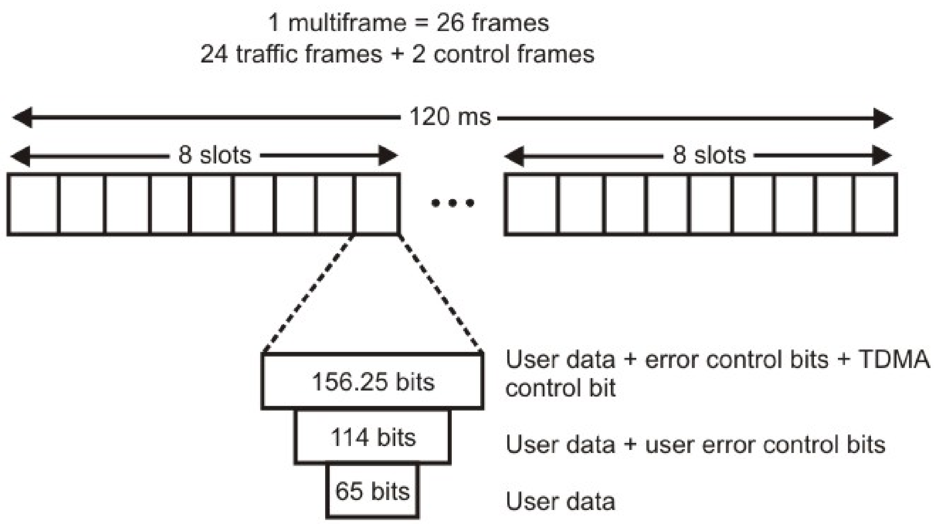

Figure 5.9.12 Multiframe components

IS-95 CDMA: IS-95 is based on CDMA/DSSS and FDMA medium access control technique. The forward and backward transmissions are shown in Fig. 5.9.13 and Fig. 5.9.14, respectively.

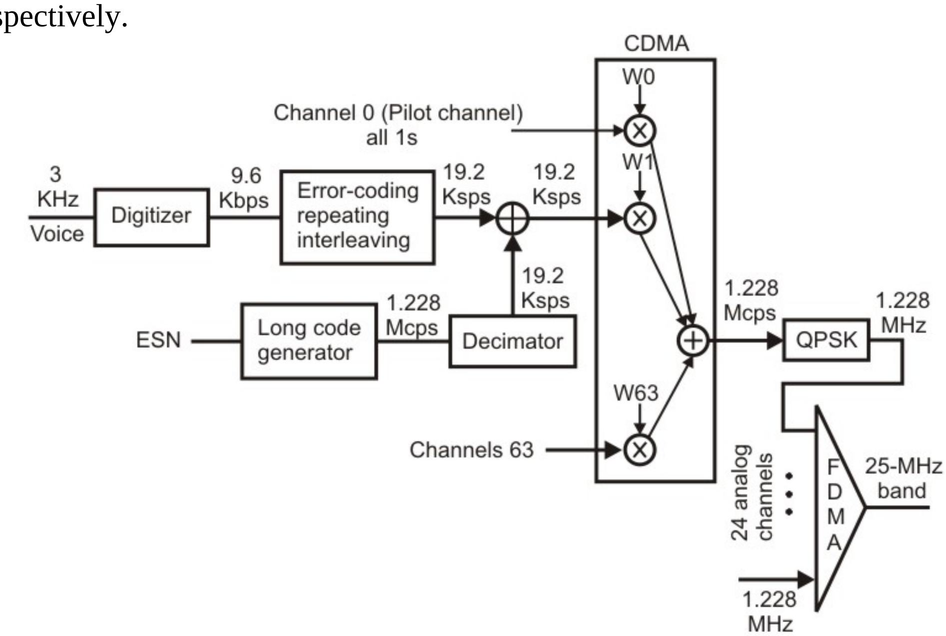

Figure 5.9.13 Forward transmission in IS-95 CDMA

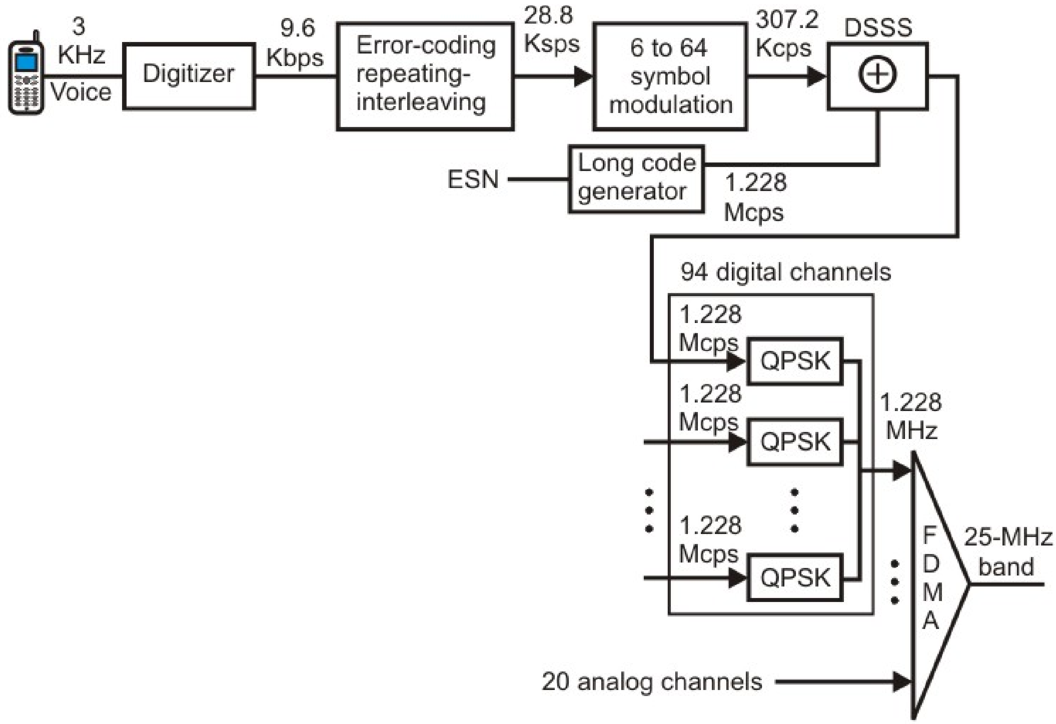

Figure 5.9.14 Backward transmission in IS-95 CDMA

5.9.9 Third Generation

We are presently using the second generation technologies and the development of the third generation technologies are in progress. Goals of the third generation (3G) technologies are mentioned below:

- Allow both digital data and voice communication.
- To facilitate universal personnel communication.
- Listen music, watch movie, access internet, video conference, etc.

Criteria for 3G Technologies are:

- Voice quality: Same as present PSTN network.
- Data rate: 144Kbps (car), 384 (pedestrians) and 2Mbps (stationary).
- Support for packet-switched and circuit-switched data services.
- Bandwidth of 2 MHz.
- Interface to the internet.

ITU developed a blueprint called Internet Mobile Communication for year 2000 (IMT-2000). All five Radio Interfaces adopted by IMT-2000 evolved from the second generation technologies as shown in Fig. 5.9.15.

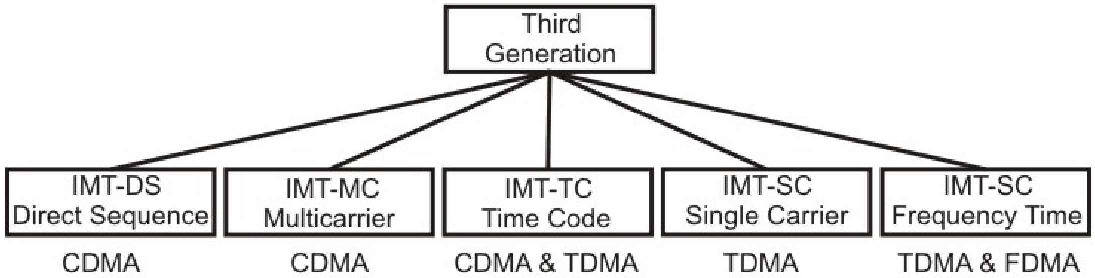

Figure 5.9.15 Third generation cellular technologies

Review Questions

1. What is the relationship between a base station and a mobile switching center?
Ans: A number of BSs are under the control of a single MSC. A base station is equipped with a transmitter/receiver for transmission and reception with the MSs in its footprint. On the other hand, the MSC coordinates communication among the base stations and the PSTN network. It is a computer-controlled system responsible for connecting calls, recording call information and billing.

2. What is reuse factor? Explain whether a low or a high reuse factor is better?
Ans: Fraction of total available channels assigned to each cell within a cluster (1/N) is known as the reuse factor. Capacity (total number of channels available for communication) of a cellular telephone system depends on the reuse factor.

3. What is AMPS and in what way it differs from D-AMPS?
Ans: AMPS is a purely analog cellular telephone system developed by Bell Labs and use North America and other countries. On the other hand D-AMPS is a backward compatible digital version of AMPS.

4. What is mobility management?
Ans: Mobility management deals with two important aspects; Handoff management and location management. Handoff management maintains service continuity when an MS migrates out of its current BS into the footprint of another BS. To do this it is necessary to keep track of the user's current location. The procedure performed for this purpose is known as Location management.

5. What is the maximum number of callers in each cell in a GSM?
Ans: In a multiframe 8 users can transmit in 8 slots. As there are 124 such channels are sent simultaneously using TDMA, total number of callers in a cluster is 124X8. As reuse factor is 7 in GSM, maximum number of callers in a cell is (124X8)%7 = 141.

6. Distinguish between soft and hard handoff.
Ans: In hard handoff a mobile station communicates with one base station at a time. So, when it moves out from one base station to another, first it breaks connection connection with the existing one before establishing connection with a new base station. On the other hand in soft handoff a mobile station can communicate with two base stations simultaneously.

7. In what way FDM differs from FDMA?
Ans: In FDM, channels are statically assigned to different stations, which is inefficient in case of bursty traffic. On the other hand, channels can be allocated on demand. The efficiency is improved in FDMA by using a dynamic sharing technique to access a particular frequency band.

8. In what way CDMA differs from FDMA?
Ans: In FDMA, the transmissions from different stations are separated in frequency. On the contrary, in CDMA the transmission from different stations occupy the entire frequency band at the same time and multiple simultaneous transmissions are separated by coding theory.

9. What happens when multiple signals collide in CDMA?
Ans: As multiple signals collide in CDMA, they are added to form a new sequence, which is used at the receiving end to demultiplex the the sent data.

10. What is an inner product?
Ans: If two code sequences are multiplied, element by element, and the results are added, we get a number called inner product.
Example: Let there are two code sequences S_1 = {+1, -1, +1, -1} and S_2 = {+1, +1, -1, -1}, Now $S_1 . S_2$ = +1 -1 -1 +1 = 0. So, the inner product is 0. On the other hand $S_1 . S_1$ = +1 +1 +1 +1 = 4. So inner product is 4 = 1. Similarly, the inner product for $S_1 . S_1$ is 0.

11. Compare and contrast FDMA, TDMA and CDMA techniques.
Ans: In case of FDMA the bandwidth is divided into separate frequency bands. In case of TDMA the bandwidth is timeshared. On the other hand in case of CDMA data from all stations are transmitted simultaneously and are separated based on coding theory. Unlike FDMA, CDMA has soft capacity, which means that there is no hard limit on the number of users. Capacity of FDMA and TDMA is bandwidth limited, whereas the bandwidth of CDMA is interference limited. CDMA offers high capacity in comparison to FDMA and TDMA. CDMA also help to combat multipath fading.