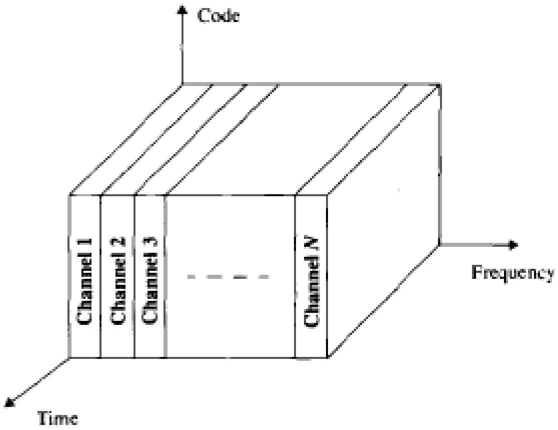
**Q.2 a. Explain the concept of TDMA and FDMA scheme. (8)**

**Answer:**

Concept of FDMA

Frequency Division Multiple Access (FDMA) Frequency division multiple access (FDMA) assigns individual channels to individual users. It can be seen that each user is allocated a unique frequency band or channel. These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same frequency band. In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel.



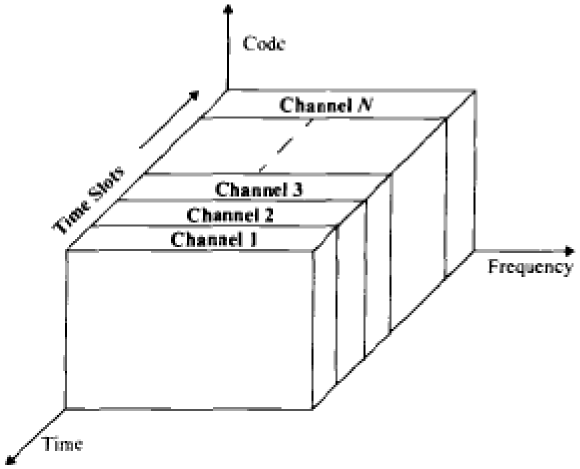
features of FDMA are.

- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.
- The bandwidths of FDMA channels are relatively narrow (30 kHz) as each channel supports only one circuit per carrier That is, FDMA is usually implemented in narrowband systems.
- The symbol time is large as compared to the average delay spread. This implies that the amount of intersymbol interference is low and, thus, little or no equalization is required in FDMA narrowband systems.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes as compared to TDMA.
- FDMA systems have higher cell site system costs as compared to TDMA sys-tems, because of the single channel per carrier design, and the need to use costly bandpass filters to eliminate spurious radiation at the base station.
- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time. This results in an increase in the cost of FDMA subscriber zmits and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

**Concept of FDMA**

Time Division Multiple Access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from Figure 8.3 that each user occupies a cyclically repeating time slot, so a channel may be thought of as particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is noncontiguous. This implies that, unlike in FDMA systems which accommodate analog FM,

Digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an infonnation message, and tail bits. In TDMAITDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels. In TDMAIFDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general, TDMAJFDD systems intentionally induce several time slots of delay between the forward and reverse time slots of a particular user, so that duplexers are not required in the subscriber unit.

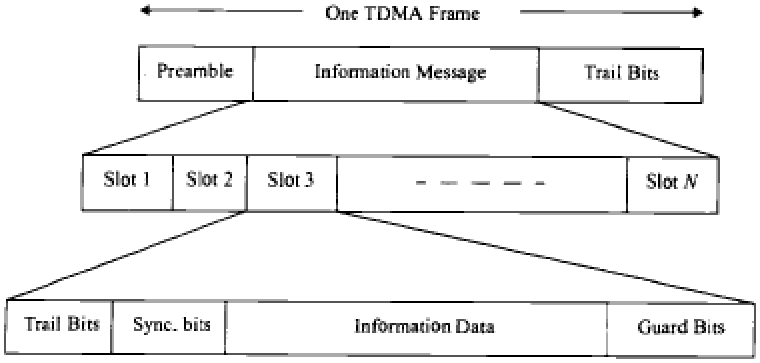


In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames.

The features of TDMA

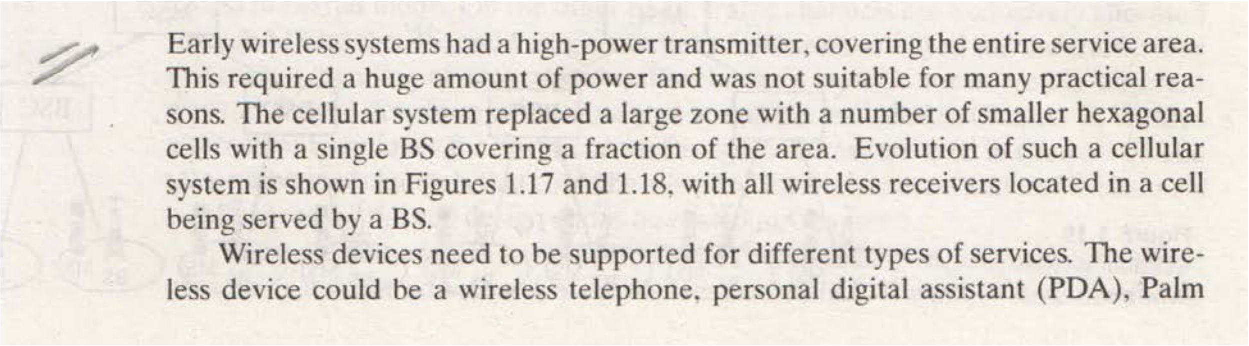
- TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots. The number of time slots per frame depends on several factors, such as modulation technique, available bandwidth, etc.

- Data transmission for users of a TDMA system is not continuous, but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots. An enhanced link control, such as that provided by mobile assisted handoff (MAHO) can be carried out by a subscriber by listening on an idle slot in the TDMA frame.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required. Even if FDD is used, a switch rather than a duplexer inside the subscriber unit is all that is required to switch between transmitter and receiver using TDMA.
- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized. If the transmitted signal at the edges of a time slot are suppressed sharply in order to shorten the guard time, the transmitted spectrum will expand and cause interference to adjacent channels.
- High synchronization overhead is required in TDMA systems because of burst transmissions. TDMA transmissions are slotted, and this requires the receivers to be synchronized for each data burst. In addition, guard slots are necessary to separate users, and this results in the TDMA systems having larger overheads as compared to FDMA.
- TDMA has an advantage in that it is possible to allocate different numbers of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by concatenating or reassigning time slots based on priority.



**b. Discuss basic Cellular System Infrastructure. Also explain call setup between MS and BS. (8)**

**Answer:**



Early wireless systems had a high-power transmitter, covering the entire service area. This required a huge amount of power and was not suitable for many practical reasons. The cellular system replaced a large zone with a number of smaller hexagonal cells with a single BS covering a fraction of the area. Evolution of such a cellular system is shown in Figures 1.17 and 1.18, with all wireless receivers located in a cell being served by a BS.

Wireless devices need to be supported for different types of services. The wireless device could be a wireless telephone, personal digital assistant (PDA), Palm

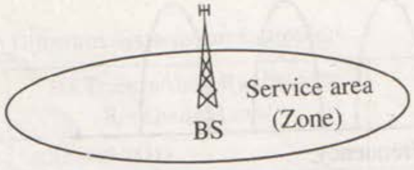


**Figure 1.17**
Early wireless system:
large zone.

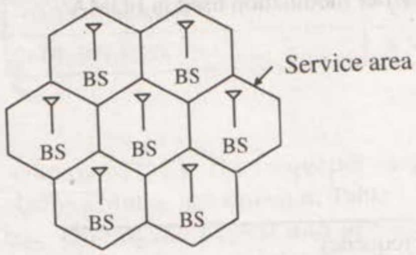


**Figure 1.18**
Cellular system:
small zone.

Pilot™, laptop with wireless card, or Web-enabled phone. For simplicity, it coul
be called a MS. The only underlying requirement is to maintain connectivity with th
world while moving, irrespective of the technology used to obtain ubiquitous acces
In a cellular structure, a MS needs to communicate with the BS of the cell where th
MS is currently located (Figure 1.6), and the BS acts as a gateway to the rest of th
world. Therefore, to provide a link, the MS needs to be in the area of one of th
cells (and hence a BS) so that mobility of the MS can be supported. Several BSs ar
connected through hard-wires and are controlled by a BS controller (BSC), which i
turn is connected to a mobile switching center (MSC). Several MSCs are intercon
nected to a PSTN (public switched telephone network) and the ATM (asynchronou
transfer mode) backbone. To provide a better perspective of wireless communica
tion technology, simplified system infrastructure for a cellular system is shown i
Figure 1.19.

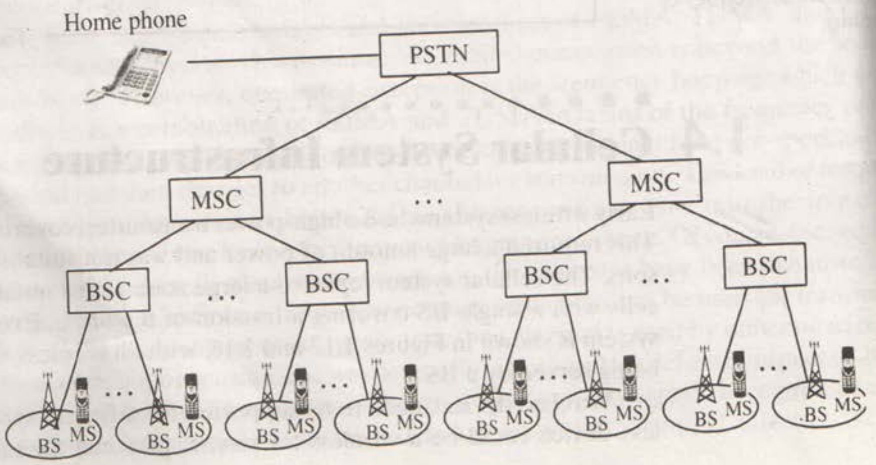


**Figure 1.19**
Cellular system
infrastructure.

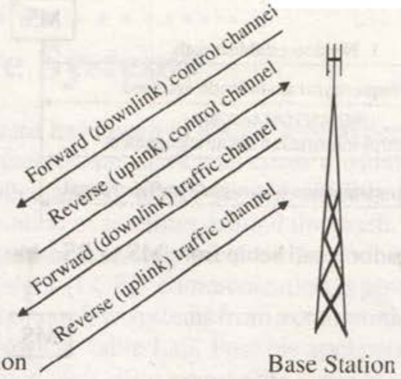


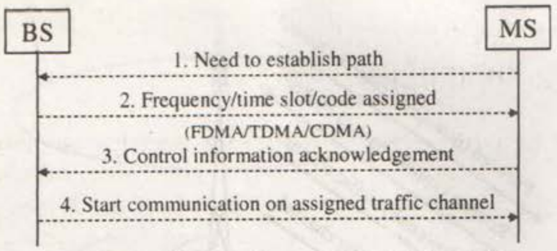
**Figure 1.20** Four simplex channels between BS and MS in a cell.

A BS consists of a base transceiver system (BTS) and a BSC. Both tower and antenna are a part of the BTS, while all associated electronics are contained in the BSC. The home location register (HLR) and visitor location register (VLR) are two sets of pointers that support mobility and enable the use of the same telephone numbers worldwide. HLR is located at the MSC where the MS is registered and where the initial home location for billing and access information is maintained. In simple words, any incoming call, based on the called number, is directed to HLR of the home MSC and then HLR redirects the call to the MSC (and the BS) where the MS is currently located. VLR basically contains information about all visiting MSs in that particular MSC area.

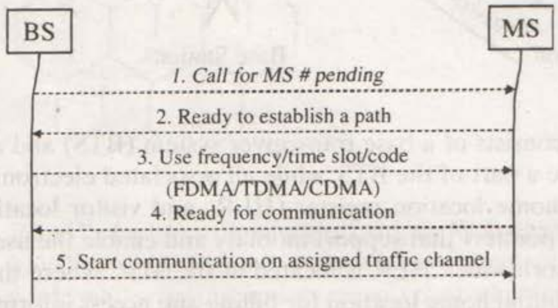
In any cellular (mobile) scheme, four simplex channels are needed to exchange synchronization and data between BS and MS, and such a simplified arrangement is shown in Figure 1.20. The control links are used to exchange control messages (such as authentication, subscriber information, call parameter negotiations) between the BS and MS, while traffic (or information) channels are used to transfer actual data between the two. The channels from BS to MS are known as *forward channels* (called downlinks outside the United States), and the term *reverse channels* (uplinks) is used for communication from MS to BS. Control information needs to be exchanged before actual data information transfer can take place. Simplified handshake steps for call setup using control channels are illustrated in Figure 1.21.

The control channels are used for a short duration for exchanging control information between the BS and each MS needing any service. Therefore, all MSs use just a few control channels to achieve this and hence have to compete for such access in shared mode. On the other hand, traffic channels are exclusively allocated to each MS by the BS, and a large number of channels are used for the traffic. For this reason, handing of control and traffic channels must be considered in different ways, and more details on control channel access are provided in Chapter 6. Various alternative techniques for traffic channel assignments are covered in Chapter 7. The total number of channels that could be allocated for both control and traffic channels is influenced by the cell design and is discussed in Chapter 5.

There are many issues involved in wireless communication, and extensive signal processing is required before any signals are transmitted. The major steps are shown



(a) Steps for a call setup from MS to BS



(b) Steps for a call setup from BS to MS

Figure 1.21
Handshake steps for a call setup between MS and BS using control channels.

*in Figure 1.22. Many of the signal processing operations are beyond the scope of this book, and we will concentrate primarily on the system aspect of wireless data communication.*

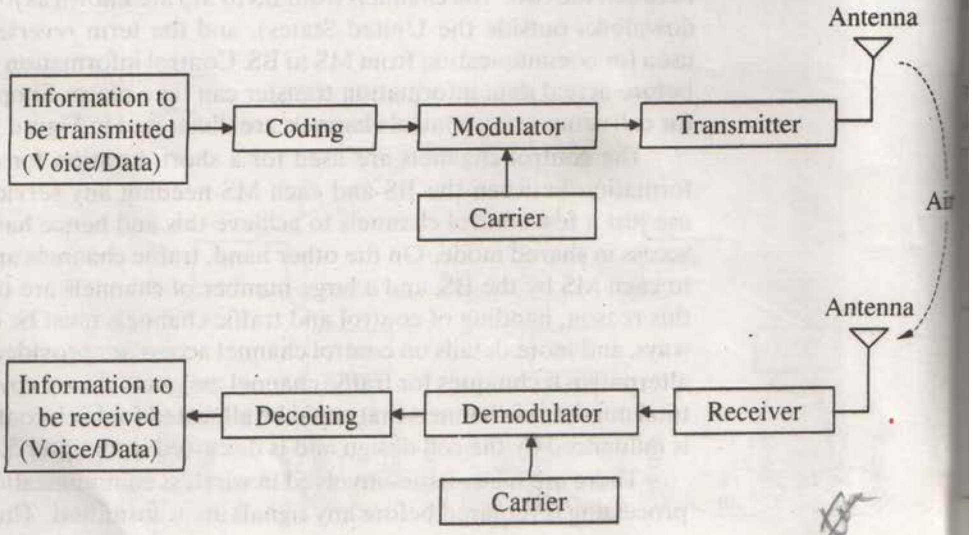


Figure 1.22
A simplified wireless *communication* system representation.

**Q.3 a. List the advantages and disadvantages of DS-SS. (6)**

**Answer:**

DSSS has the advantage of providing higher capacities than FHSS, but it is a very sensitive technology, influenced by many environment factors (mainly reflections). The best way to minimize such influences is to use the technology in either (i) point to multipoint, short distances applications or (ii) long distance applications, but point to point topologies. In both cases the systems can take advantage of the high capacity offered by DSSS technology, without paying the price of being disturbed by the effect of reflections. As so, typical DSSS applications include indoor wireless LAN in offices (i), building to building links (ii), Point of Presence to Base Station links (in cellular deployment systems) (ii), etc.

**b. What do you mean by small scale fading? Explain it. (6)**

**Answer:**

The term fading, or, small-scale fading, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. This might be so severe that large scale radio propagation loss effects might be ignored

**Types of Small-Scale Fading**

The type of fading experienced by the signal through a mobile channel depends on the relation between the signal parameters (bandwidth, symbol period) and the channel parameters (rms delay spread and Doppler spread). Hence we have four different types of time dispersive nature of the channel.

Fading Effects due to Multipath Time Delay Spread

**Flat Fading**

Suchtypesoffadingoccurswhenthebandwidthofthetransmittedsignalislessthan the coherence bandwidth of the channel. Equivalently if the symbol period of the signal is more than the rms delay spread of the channel, then the fading is flat fading.

So we can say that flat fading occurs when

Types of Small-Scale Fading

The type of fading experienced by the signal through a mobile channel depends on the relation between the signal parameters (bandwidth, symbol period) and the channel parameters (rms delay spread and Doppler spread). Hence we have four different types of time dispersive nature of the channel.

$$B_S \ll B_C$$

where BS is the signal bandwidth and BC is the coherence bandwidth. Also

$$T_S \gg \sigma_\tau$$

where TS is the symbol period and στ is the rms delay spread. And in such a case, mobile channel has a constant gain and linear phase response over its bandwidth.

**Frequency Selective Fading**

Frequency selective fading occurs when the signal bandwidth is more than the coherence bandwidth of the mobile radio channel or equivalently the symbols duration of the signal is less than the rms delay spread.

$B_S \gg B_C$ and

$$T_S \ll \sigma_\tau$$

At the receiver, we obtain multiple copies of the transmitted signal, all attenuated and delayed in time. The channel introduces inter symbol interference. A rule of thumb for a channel to have flat fading is if

$$\frac{\sigma_\tau}{T_S} \leq 0.1$$

**Fading Effects due to Doppler Spread**

Fast Fading

In a fast fading channel, the channel impulse response changes rapidly within the symbol duration of the signal. Due to Doppler spreading, signal undergoes frequency dispersion leading to distortion. Therefore a signal undergoes fast fading if

$T_S \gg T_C$ where TC is the coherence time and

$B_S \gg B_D$

where BD is the Doppler spread. Transmission involving very low data rates suffer from fast fadin

Slow Fading

In such a channel, the rate of the change of the channel impulse response is much less than the transmitted signal. We can consider a slow faded channel a channel in which channel is almost constant over at least one symbol duration. Hence

$T_S \ll T_C$

and

$B_S \gg B_D$

**c. Explain Doppler Effect.** **(4)**

**Answer:**

The Doppler effect (or Doppler shift) is the change in frequency of a wave for an observer moving relative to the source of the wave. In classical physics (waves in a medium), the relationship between the observed frequency f and the emitted frequency fo is given by:

$$f = \left(\frac{v \pm v_r}{v \pm v_s}\right) f_0$$

where v is the velocity of waves in the medium, v is the velocity of the source relative to the medium and vrs is the velocity of the receiver relative to the medium.

In mobile communication, the above equation can be slightly changed according to our convenience since the source (BS) is fixed and located at a remote elevated level from ground.

**Q.4 a. Discuss the Slotted ALOHA and Pure ALOHA.** **(8)**

**Answer:**

**Pure ALOHA**

The pure ALOHA protocol is a random access protocol used for data transfer. A user accesses a channel as soon as a message is ready to be transmitted. After a transmission, the user waits for an acknowledgment on either the same channel or a separate feedback channel. In case of collisions, the terminal waits for a random period of time and retransmits the message. As the number of users increase, a greater delay occurs because the probability of collision increases. For the ALOHA protocol, the vulnerable period is double the packet duration. Thus, the probability of no collision during the interval of 2τ is found by evaluating Pr (n) given as

$$Pr(n) = \frac{(2R)^n e^{-2R}}{n!} \text{ at } n = 0$$

One may evaluate the mean of equation (8.10) to determine the average number of packets sent during 2t The probability of no collision is Pr (0) = e-2R. The throughput of the ALOHA protocol is found by using this Equation

$$T = Re^{-2R}$$

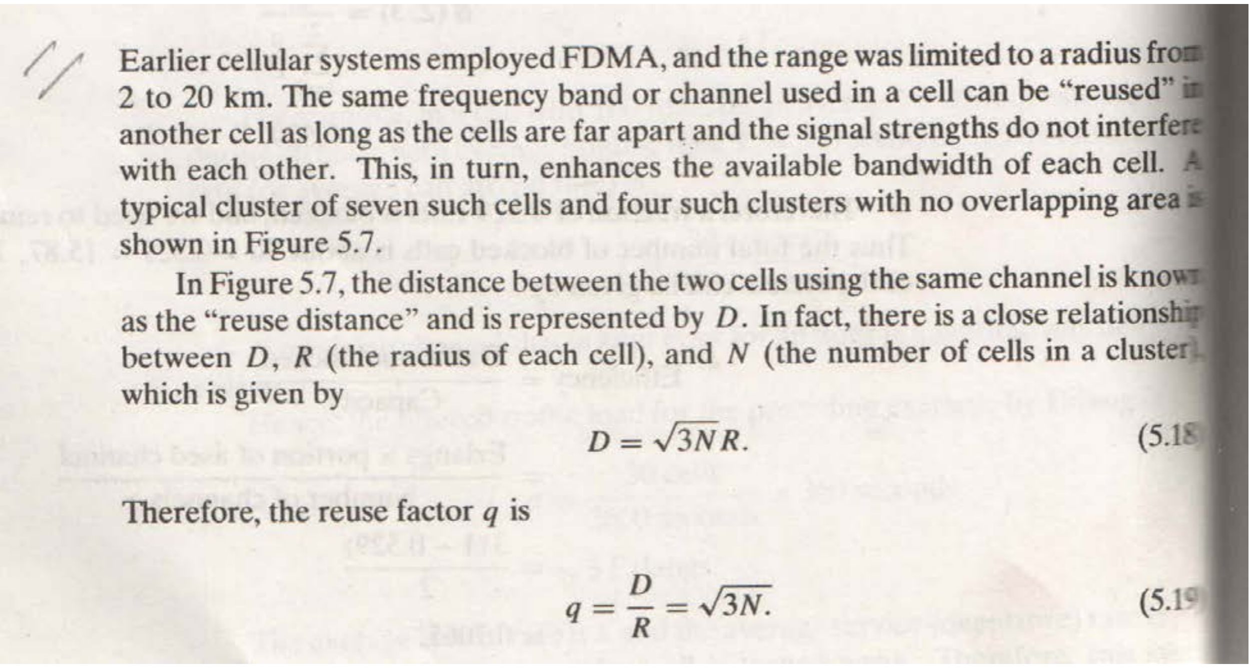
**Slotted ALOHA**

In slotted ALOHA, time is divided into equal time slots of length greater than the packet duration τ. The subscribers each have synchronized clocks and transmit a message only at the beginning of a new time slot, thus resulting in a discrete distribution of packets. This prevents partial collisions, where one packet collides with a portion of another As the number of users increase, a greater delay will occur due to complete collisions and the resulting repeated transmissions of those packets originally lost. The number of slots which a transmitter waits prior to retransmitting also determines the delay characteristics of the traffic. The vulnerable period for slotted ALOHA is only one packet duration, since partial collisions are prevented through synchronization. The probability that no other packets will be generated during the vulnerable period is $e^{-R}$ The throughput for the case of slotted ALOHA is thus given by

$$T = Re^{-R}$$

**b. What is frequency reuse? How cell splitting & sectoring increase cellular capacity? (8)**

**Answer:**



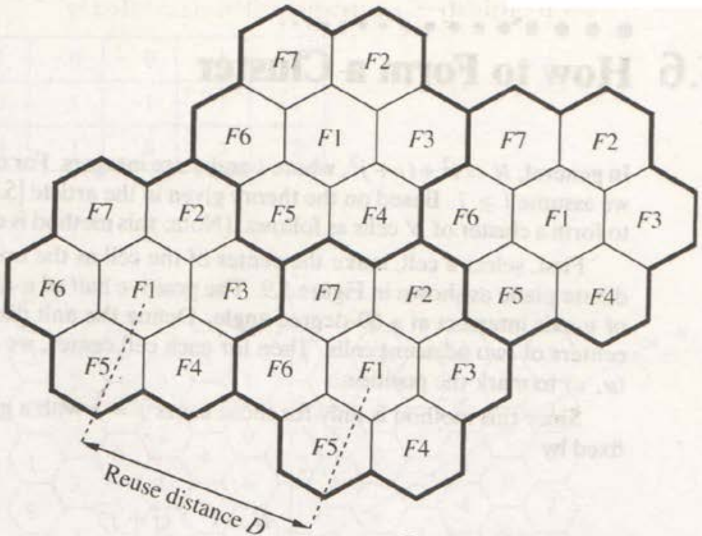
Earlier cellular systems employed FDMA, and the range was limited to a radius from 2 to 20 km. The same frequency band or channel used in a cell can be "reused" in another cell as long as the cells are far apart and the signal strengths do not interfere with each other. This, in turn, enhances the available bandwidth of each cell. A typical cluster of seven such cells and four such clusters with no overlapping area is shown in Figure 5.7.

In Figure 5.7, the distance between the two cells using the same channel is known as the "reuse distance" and is represented by $D$. In fact, there is a close relationship between $D$, $R$ (the radius of each cell), and $N$ (the number of cells in a cluster), which is given by

$$D = \sqrt{3N}R. \quad (5.18)$$

Therefore, the reuse factor $q$ is

$$q = \frac{D}{R} = \sqrt{3N}. \quad (5.19)$$



Fx: A set of frequency bands

**Figure 5.7**
Illustration of frequency reuse.

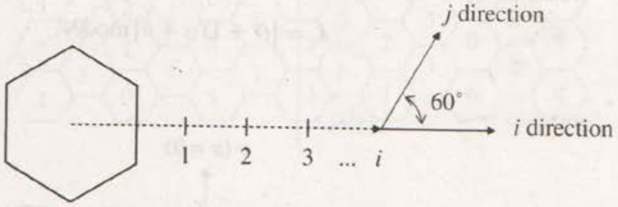
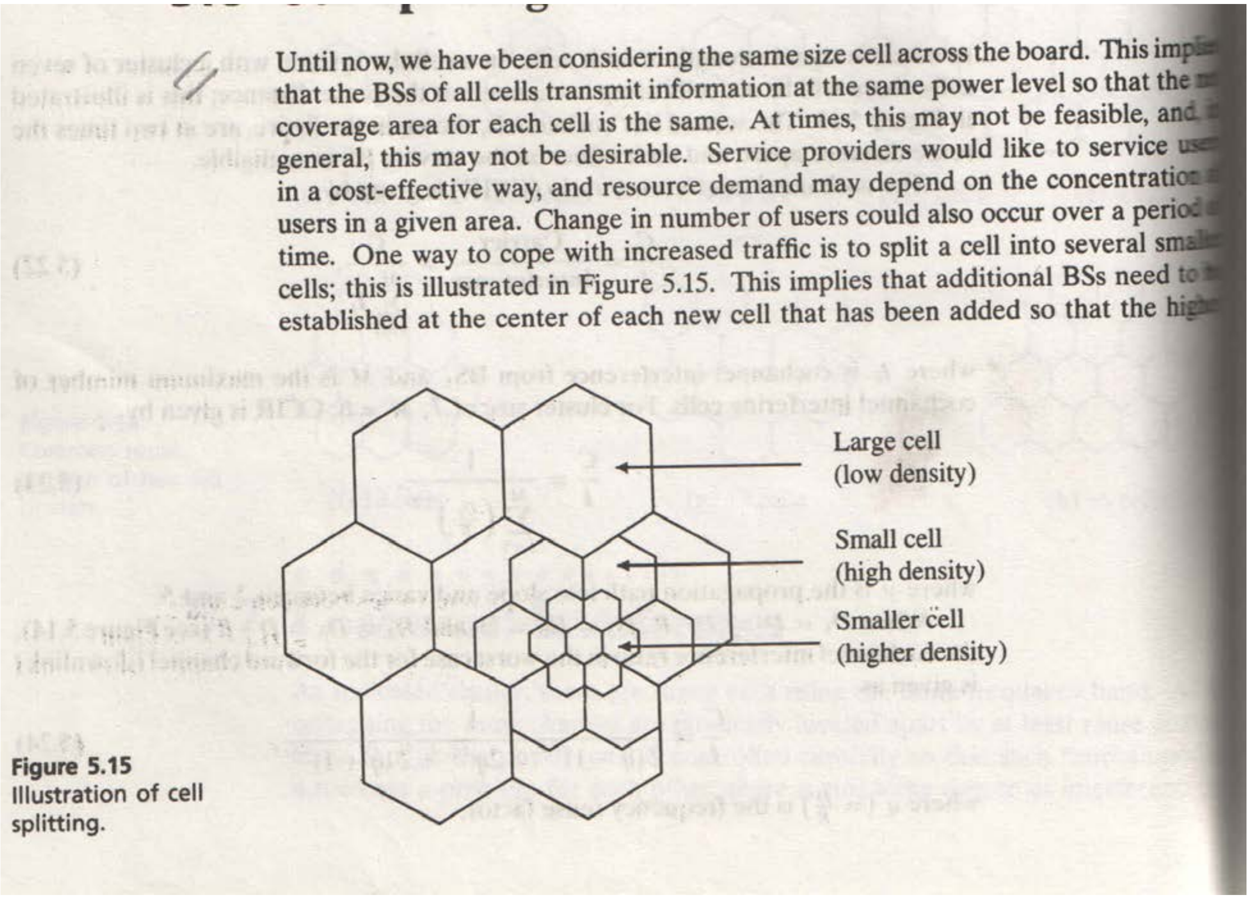


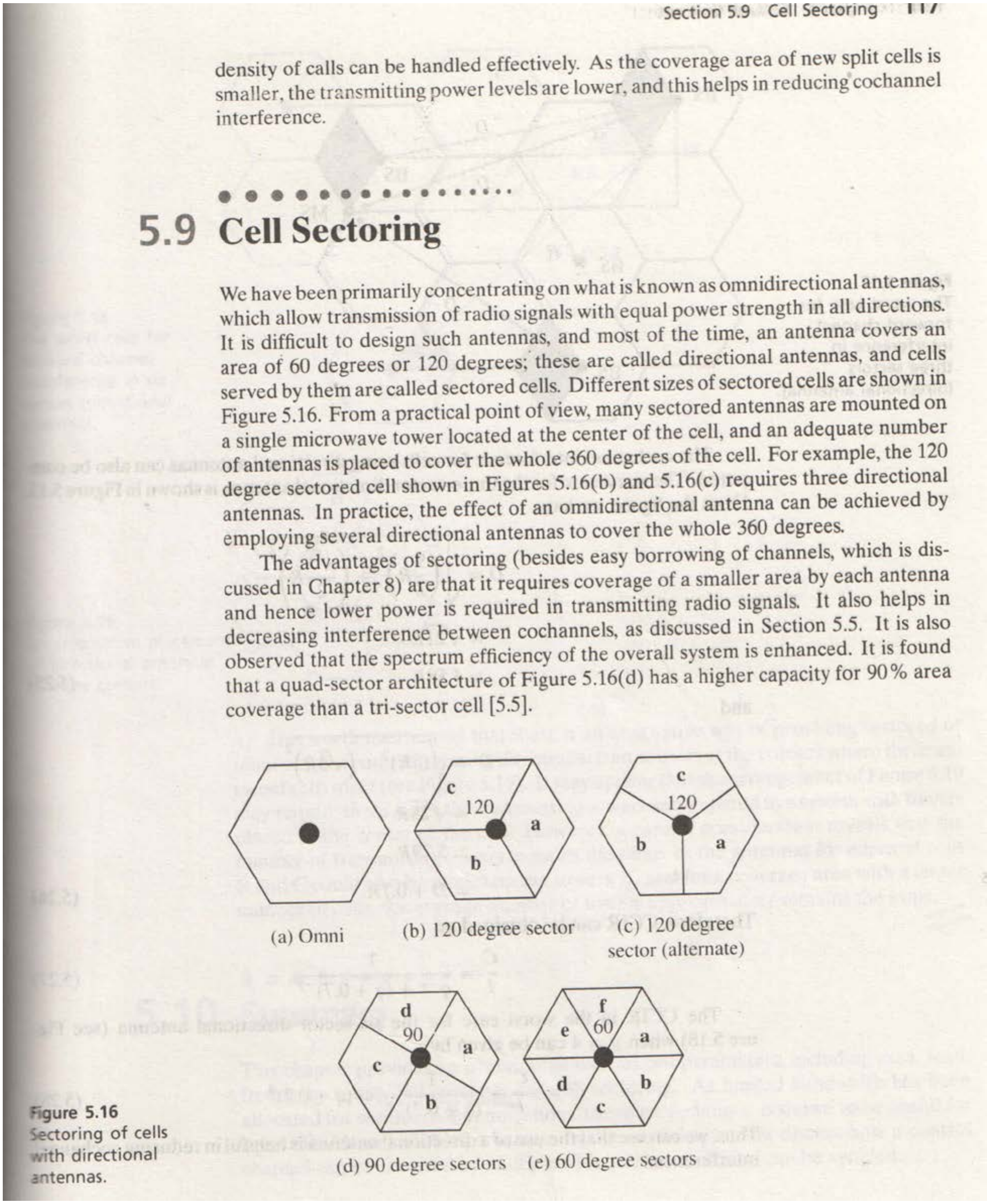
**Figure 5.8**
Finding the center of an adjacent cluster using integers i and j (directions of i and j can be interchanged).

Another popular cluster size is with $N = 4$. In fact, the arguments made in selecting a rectangular versus hexagonal shape of the cell are also applicable to the size of the hex cell clusters such that multiple copies of such clusters should fit well with each other, just like a puzzle. Additional areas can be covered by additional clusters without having any overlapped area. In general, the number of cells $N$ per cluster is given by $N = i^2 + ij + j^2$. Here $i$ represents the number of cells to be traversed along direction $i$, starting from the center of a cell, and $j$ represents the number of cells in a direction 60° to the direction of $i$. Substituting different values of $i$ and $j$ leads to $N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, \ldots$: the most popular values are 7 and 4. Finding the center of all clusters around a reference cell for some selected values of $N$, is illustrated in Figure 5.8. Repeating this for all six sides of the reference cell leads to the center for all adjacent clusters. Unless specified, a cluster of size 7 is assumed throughout this book.



Until now, we have been considering the same size cell across the board. This impl that the BSs of all cells transmit information at the same power level so that the coverage area for each cell is the same. At times, this may not be feasible, and, general, this may not be desirable. Service providers would like to service use in a cost-effective way, and resource demand may depend on the concentratio users in a given area. Change in number of users could also occur over a period time. One way to cope with increased traffic is to split a cell into several smal cells; this is illustrated in Figure 5.15. This implies that additional BSs need to established at the center of each new cell that has been added so that the high

**Figure 5.15**
Illustration of cell splitting.



density of calls can be handled effectively. As the coverage area of new split cells is smaller, the transmitting power levels are lower, and this helps in reducing cochannel interference.

## 5.9 Cell Sectoring

We have been primarily concentrating on what is known as omnidirectional antennas, which allow transmission of radio signals with equal power strength in all directions. It is difficult to design such antennas, and most of the time, an antenna covers an area of 60 degrees or 120 degrees; these are called directional antennas, and cells served by them are called sectored cells. Different sizes of sectored cells are shown in Figure 5.16. From a practical point of view, many sectored antennas are mounted on a single microwave tower located at the center of the cell, and an adequate number of antennas is placed to cover the whole 360 degrees of the cell. For example, the 120 degree sectored cell shown in Figures 5.16(b) and 5.16(c) requires three directional antennas. In practice, the effect of an omnidirectional antenna can be achieved by employing several directional antennas to cover the whole 360 degrees.

The advantages of sectoring (besides easy borrowing of channels, which is discussed in Chapter 8) are that it requires coverage of a smaller area by each antenna and hence lower power is required in transmitting radio signals. It also helps in decreasing interference between cochannels, as discussed in Section 5.5. It is also observed that the spectrum efficiency of the overall system is enhanced. It is found that a quad-sector architecture of Figure 5.16(d) has a higher capacity for 90% area coverage than a tri-sector cell [5.5].

(a) Omni (b) 120 degree sector (c) 120 degree sector (alternate)

(d) 90 degree sectors (e) 60 degree sectors

**Figure 5.16** Sectoring of cells with directional antennas.

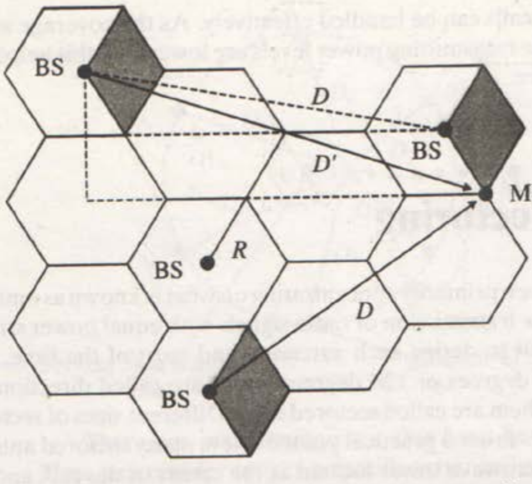


**Figure 5.17** The worst case for forward channel interference in three sectors (directional antenna).

The cochannel interference for cells using directional antennas can also be computed. The worst case for the three-sector directional antenna is shown in Figure 5.17. From the figure, we have

$$D = \sqrt{\left(\frac{9}{2}R\right)^2 + \left(\frac{\sqrt{3}}{2}R\right)^2}$$
$$= \sqrt{21}R$$
$$\simeq 4.58R \qquad (5.25)$$

and

$$D' = \sqrt{(5R)^2 + \left(\sqrt{3}R\right)^2}$$
$$= \sqrt{28}R$$
$$\simeq 5.29R$$
$$= D + 0.7R. \qquad (5.26)$$

Therefore, CCIR can be obtained as

$$\frac{C}{I} = \frac{1}{q^{-\gamma} + (q + 0.7)^{-\gamma}}. \qquad (5.27)$$

The CCIR in the worst case for the six-sector directional antenna (see Figure 5.18) when $\gamma = 4$ can be given by

$$\frac{C}{I} = \frac{1}{(q + 0.7)^{-\gamma}} = (q + 0.7)^4 \qquad (5.28)$$

Thus, we can see that the use of a directional antenna is helpful in reducing cochanne interference.

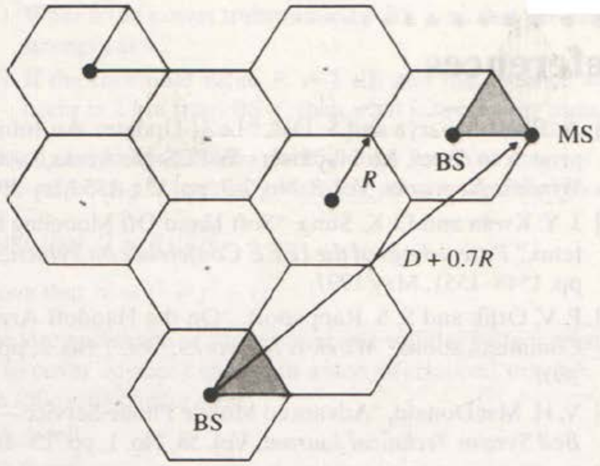


**Figure 5.18** The worst case for forward channel interference in six sectors (directional antenna).

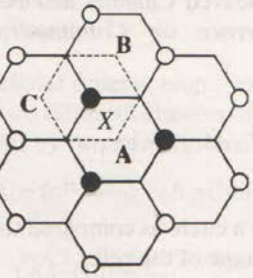


**Figure 5.19** An alternative placement of directional antennas at three corners.

It is worth mentioning that there is an alternative way of providing sectored or omni-cell coverage, by placing directional transmitters at the corners where three adjacent cells meet (see Figure 5.19). It may appear that the arrangement of Figure 5.19 may require three times the transmitting towers as compared to a system with towers placed at the center of the cell. However, a careful consideration reveals that the number of transmitting towers remains the same, as the antennas for adjacent cells B and C could also be placed on the towers $X$, and for a coverage area with a larger number of cells, the average number of towers approximately remains the same.

**Q.5 a. Discuss various types of satellite systems. (8)**

**Answer:**

Satellites have been put in space for various purposes [11.1], and their placement in space and orbiting shapes have been determined as per their specific requirements. Four different types of satellite orbits have been identified:

1. GEO (geostationary earth orbit) at about 36,000 km above the earth's surface
2. LEO (low earth orbit) at about 500–1500 km above the earth's surface
3. MEO (medium earth orbit) or ICO (intermediate circular orbit) at about 6000–20,000 km above the earth's surface
4. HEO (highly elliptical orbit)

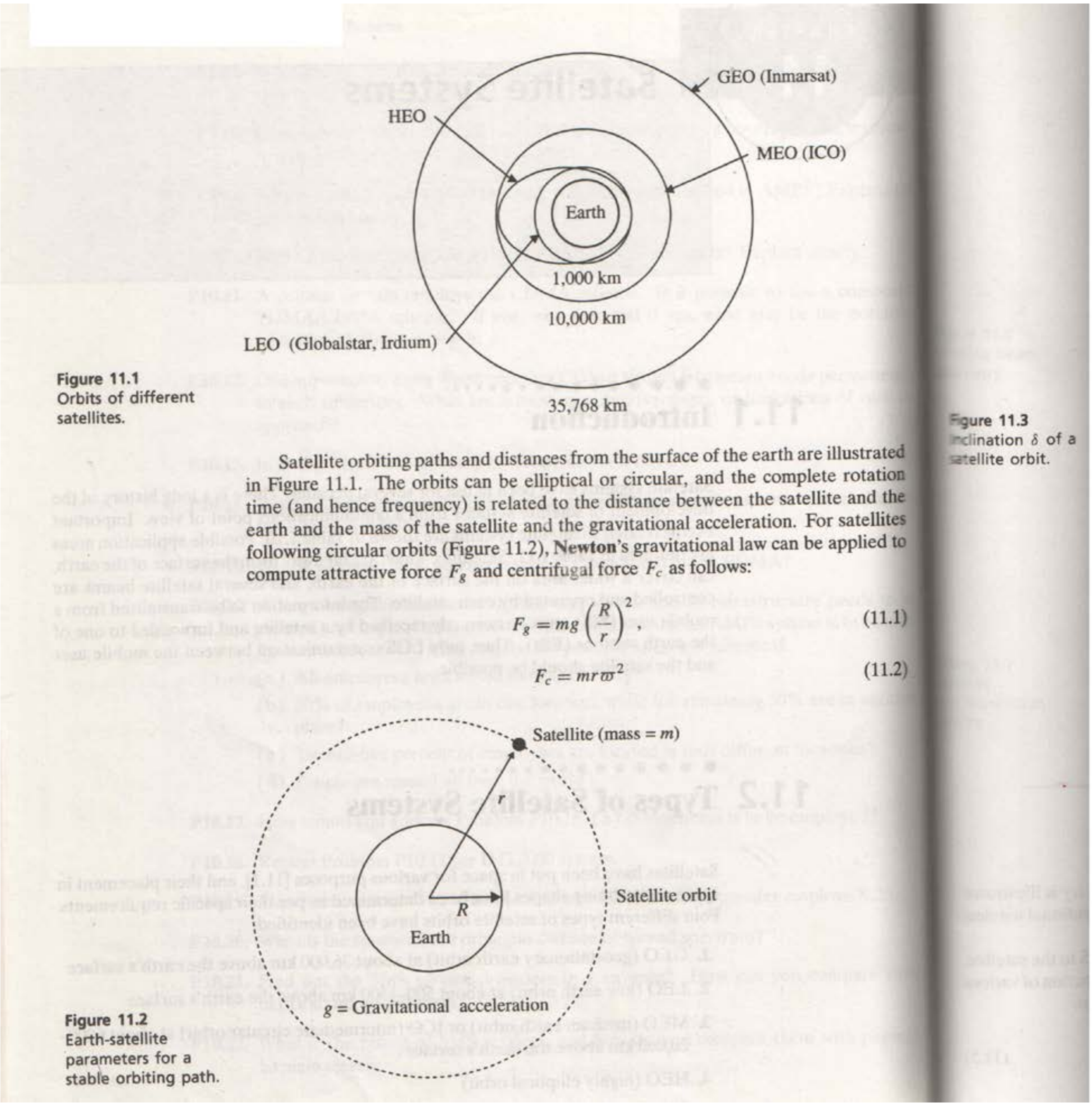


**Figure 11.1**
Orbits of different satellites.

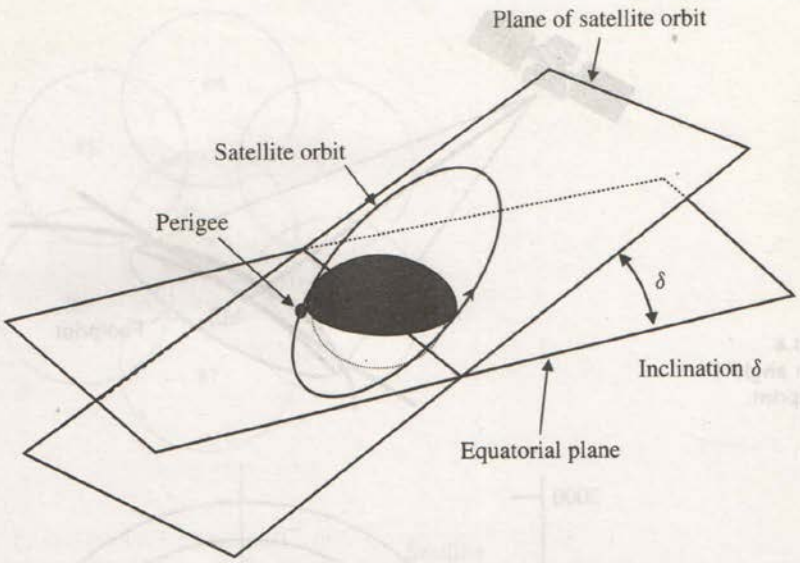
Figure 11.3
Inclination δ of a satellite orbit.

Satellite orbiting paths and distances from the surface of the earth are illustrated in Figure 11.1. The orbits can be elliptical or circular, and the complete rotation time (and hence frequency) is related to the distance between the satellite and the earth and the mass of the satellite and the gravitational acceleration. For satellites following circular orbits (Figure 11.2), **Newton**'s gravitational law can be applied to compute attractive force $F_g$ and centrifugal force $F_c$ as follows:

$$F_g = mg\left(\frac{R}{r}\right)^2, \tag{11.1}$$

$$F_c = mr\varpi^2 \tag{11.2}$$

**Figure 11.2**
Earth-satellite parameters for a stable orbiting path.



**gure 11.3**
clination δ of a
atellite orbit.

with

$$\varpi = 2\pi f_r, \tag{11.3}$$

where $m$ is the mass of the satellite, $g$ is the gravitational acceleration of the earth ($g = 9.81\ \text{m/s}^2$), $R$ is the radius of the earth ($R = 6370$ km), $r$ is the distance of the satellite from the center of the earth, $\varpi$ is the angular velocity of the satellite, and $f_r$ is the rotational frequency.

For the orbit of the satellite to be stable, we need to equate the two forces, giving

$$r = \sqrt[3]{\frac{gR^2}{(2\pi f_r)^2}}. \tag{11.4}$$

The plane of the satellite orbit with respect to the earth is shown in Figure 11.3. The plane of the satellite orbit will primarily dictate part of the earth that is covered, by the satellite beam in each rotation. The elevation angle between the satellite beam and the surface of the earth has an impact on the illuminated area (known as the footprint) and is shown in Figure 11.4. The elevation angle $\theta$ of the satellite beam governs the distance of the satellite with respect to the MS. The intensity level of a footprint is given in Figure 11.5, with a circle corresponding to 0 dB intensity clearly marked. The area inside this circle is considered to be an isoflux region and this constant intensity area is usually taken as the footprint of a beam. A satellite consists

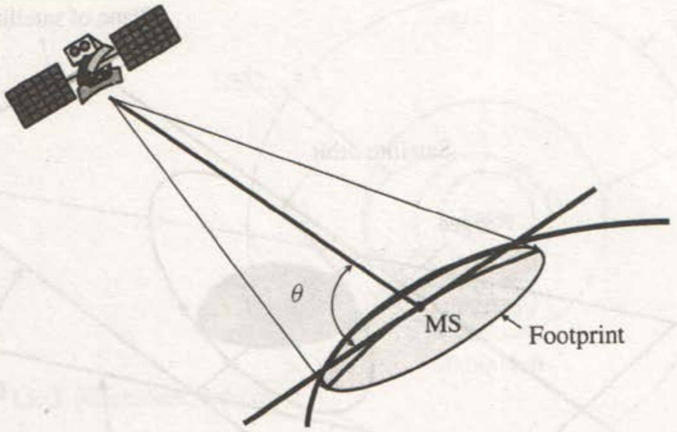


**Figure 11.4**
Elevation angle θ and footprint.

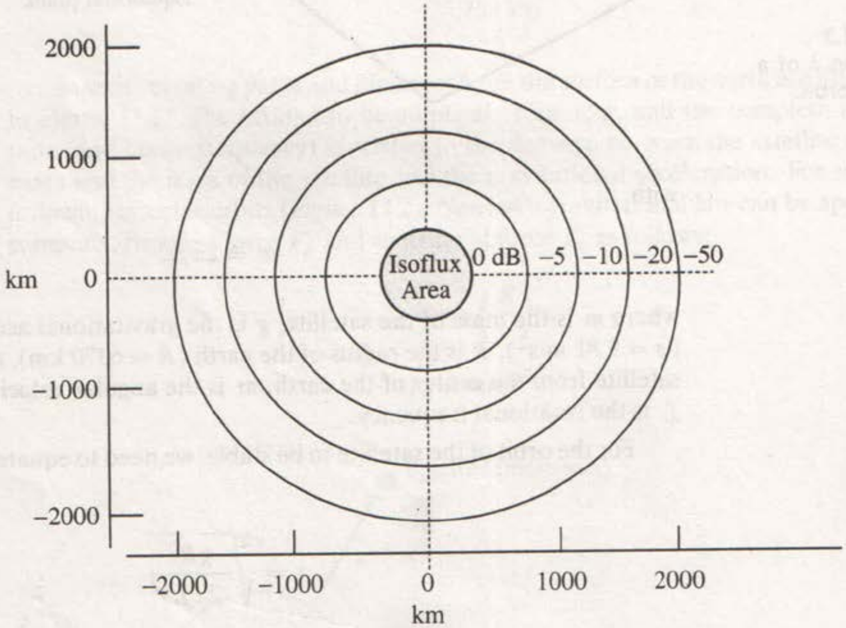


**Figure 11.5**
GEO satellite beam footprint.

of several illuminated beams, and one such example of beam geometry is illustrated in Figure 11.6. These beams could be considered as cells of the conventional wireless system.

Figure 11.7 shows the path $d$ taken for communication from a MS to the satellite. The time delay for the signal to travel from the satellite to a MS is a function of various parameters and can be obtained using the geometry of Figure 11.7 as:

$$\text{Delay} = \frac{d}{c} = \frac{1}{c}\left[\sqrt{(R+h)^2 - R^2\cos^2\theta} - R\sin\theta\right]. \tag{11.5}$$

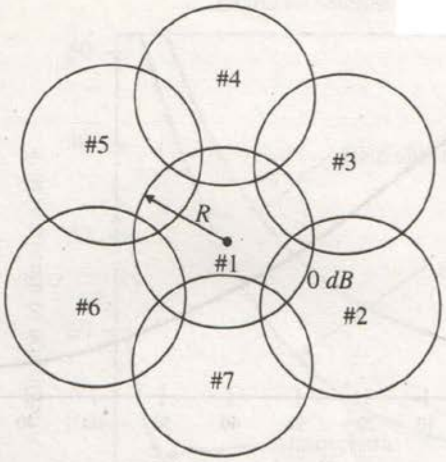


**Figure 11.6**
Satellite beam geometry.

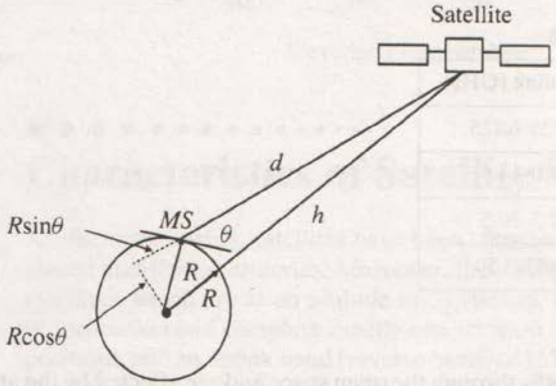


**Figure 11.7**
Satellite communication delay.

where $R$ is the radius of the earth (6370 km), $h$ is the orbital altitude, $\theta$ is the satellite elevation angle, and $c$ is the speed of light.

Figure 11.8 shows the variation of delay as a function of the elevation angle $\theta$ of a MS when a satellite is at an elevation of 10,355 km. The satellites operate at different frequencies for the uplink (MS to satellite) and downlink (satellite to MS). The frequency bands used for most satellite systems are shown in Table 11.1.

C band frequencies have been used in first-generation satellites. This band has become overcrowded because of terrestrial microwave networks that employ these frequencies. The Ku and Ka bands are becoming more popular even though rain causes a high level of attenuation. Satellites receive signals at very low power levels, typically less than 100 picowatts, which is one to two orders of magnitude lower than terrestrial receivers (typical range 1 to 100 microwatts). Signals from the satellite

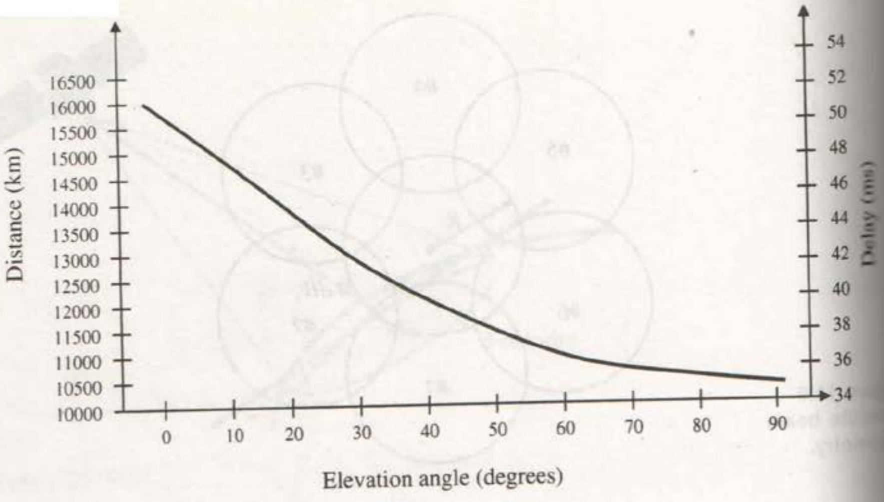


**Figure 11.8**
Variation of delay in MS as a function of elevation angle.

**Table 11.1:** ▶
Frequency Range for Different Bands

| Band | Uplink (GHz) | Downlink (GHz) |
|---|---|---|
| C | 3.7–4.2 | 5.925–6.425 |
| Ku | 11.7–12.2 | 14.0–14.5 |
| Ka | 17.7–21.7 | 27.5–30.5 |
| LIS | 1.610–1.625 | 2.483–2.50 |

travel to MSs through the open space and are affected by the atmospheric conditions. The received power is determined by the following four parameters:

- Transmitting power
- Gain of the transmitting antenna
- Distance between the satellite transmitter and the receiver
- Gain of the receiving antenna

Atmospheric conditions cause attenuation of the transmitted signal, and the los $L$ at the MS is given by a generic relationship

$$L = \left(\frac{4\pi r f_c}{c}\right)^2 . \qquad (11.6$$

where $f_c$ is the carrier frequency and $r$ is the distance between the transmitter an the receiver. The impact of rain on the signal attenuation is illustrated in Figure 11.9

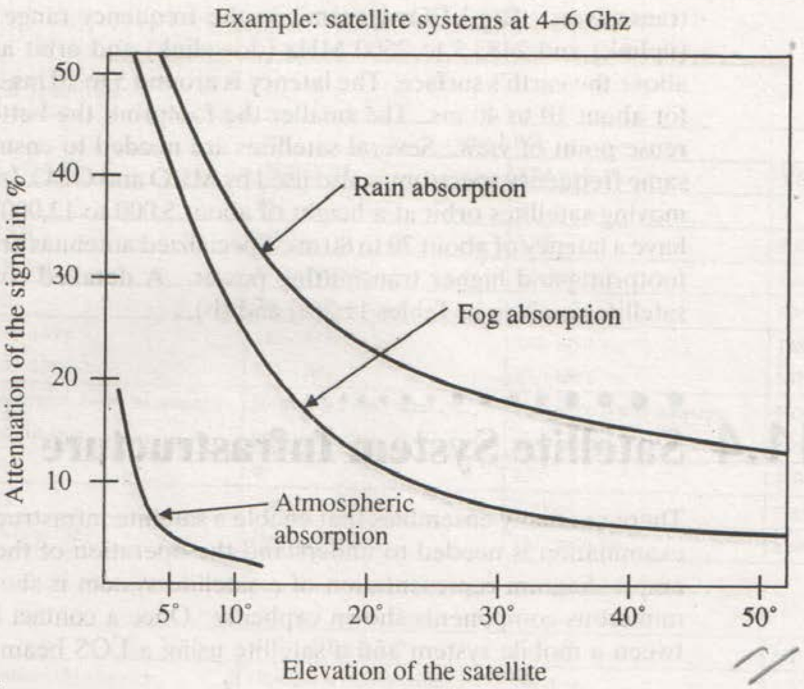


**Figure 11.9**
Atmospheric attenuation.

**b. How is roaming supported in cellular mobile systems? Explain with diagrams.(8)**

**Answer:**

In earlier sections, emphasis has been on allocating channels to different calls
handoff can be efficiently supported as much as possible and blocking probab
both originating and handoff calls can be minimized. We do need to worry
what happens when channel and hence radio contact is changed from one
another for successful handoff. As discussed in Chapter 1, a number of cells
controlled by a MSC, and depending on the destination, the signals go throu
backbone network, interconnecting MSCs with the PSTN, which serves as a
infrastructure between MSs and existing home or commercial telecommun
systems. The hardwired network is primarily supported by ultra-high-speed
optic cables, and information transfer is in terms of packet scheduling, reflecting
bandwidth allocation to different users.

The MSCs are connected to the backbone network via different gateways. Th
fore, with mobility support, the real problem in routing becomes that of m
packets to appropriate endpoints of the backbone network. Various possible
off scenarios are illustrated in Figure 9.8.

Assuming $MSC_1$ to be the home of the MS for registration, billing, authen
tion, and all access information, when the handoff is from location "a" to loc
"b," the routing of messages meant for the MS can be performed by $MSC_1$
However, when the handoff occurs from location "b" to location "c," then bi
tional pointers are set up to link the HLR of $MSC_1$ to the VLR of $MSC_2$ so
information can be routed to the cell where the MS is currently located (Figure
The call in progress can be routed by HLR of $MSC_1$ to VLR of $MSC_2$ and to
corresponding BS to eventually reach the MS at location "c."

The situation is different and slightly more complicated when handoff oc
at locations "d" and "e" in Figure 9.8, and routing of information using simply
HLR–VLR pair of pointers may not be adequate. The paging area (PA) is the
covered by one or several MSCs in order to find the current location of the
[9.2]. This concept is similar to the Internet network routing area [9.3][9.4], and
understand how the connection is established and maintained, let us concentra

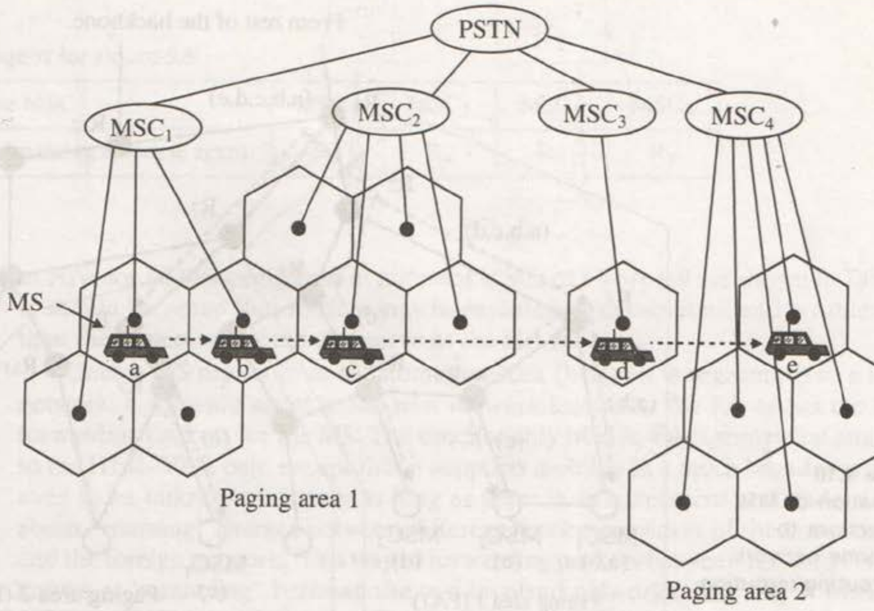


Figure 9.8
Handoff scenarios with different degrees of mobility.

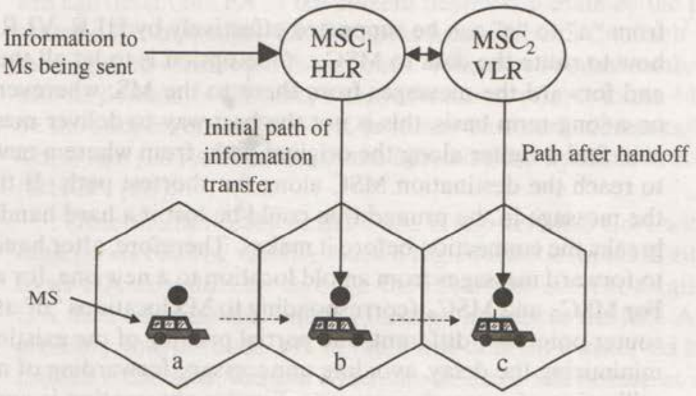


Figure 9.9
Information transmission path when MS hands off from "b" to "c."

an example backbone network that interconnects various MSCs to the Internet and the rest of the world. For illustration, only a small portion of the backbone is shown in Figure 9.10.

Basically, there are two issues involved. One determines the path along the shortest path, and the second ascertains the path according to the current location of the MS. Selecting a new path and making changes to an existing path of the MS would largely depend on the topolcgy of the backbone network. A part of connections between two MSCs is shown in Figure 9.10. Assume that an incoming call is being routed to the backbone along a link as shown in Figure 9.10. Paths needed to reach different backbone networks, and MSCs to be used are shown by the dotted lines for different MS locations and the controlling MSCs. The movement

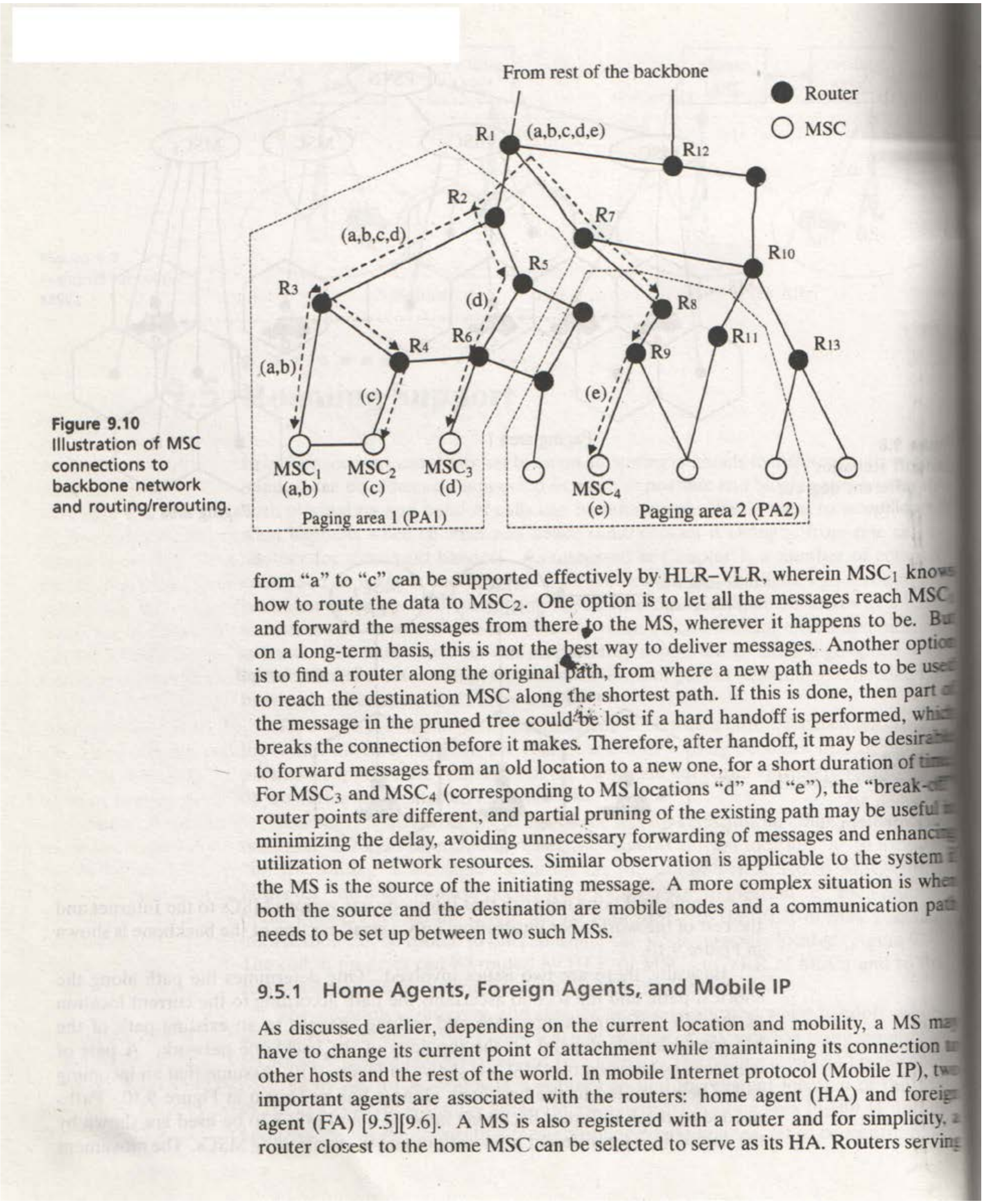


**Figure 9.10** Illustration of MSC connections to backbone network and routing/rerouting.

from "a" to "c" can be supported effectively by HLR–VLR, wherein $MSC_1$ knows how to route the data to $MSC_2$. One option is to let all the messages reach MSC and forward the messages from there to the MS, wherever it happens to be. Bu on a long-term basis, this is not the best way to deliver messages. Another optio is to find a router along the original path, from where a new path needs to be use to reach the destination MSC along the shortest path. If this is done, then part o the message in the pruned tree could be lost if a hard handoff is performed, whic breaks the connection before it makes. Therefore, after handoff, it may be desira to forward messages from an old location to a new one, for a short duration of tim For $MSC_3$ and $MSC_4$ (corresponding to MS locations "d" and "e"), the "break-o router points are different, and partial pruning of the existing path may be useful i minimizing the delay, avoiding unnecessary forwarding of messages and enhancin utilization of network resources. Similar observation is applicable to the system i the MS is the source of the initiating message. A more complex situation is whe both the source and the destination are mobile nodes and a communication pat needs to be set up between two such MSs.

### 9.5.1 Home Agents, Foreign Agents, and Mobile IP

As discussed earlier, depending on the current location and mobility, a MS ma have to change its current point of attachment while maintaining its connection t other hosts and the rest of the world. In mobile Internet protocol (Mobile IP), tw important agents are associated with the routers: home agent (HA) and foreig agent (FA) [9.5][9.6]. A MS is also registered with a router and for simplicity, a router closest to the home MSC can be selected to serve as its HA. Routers serving

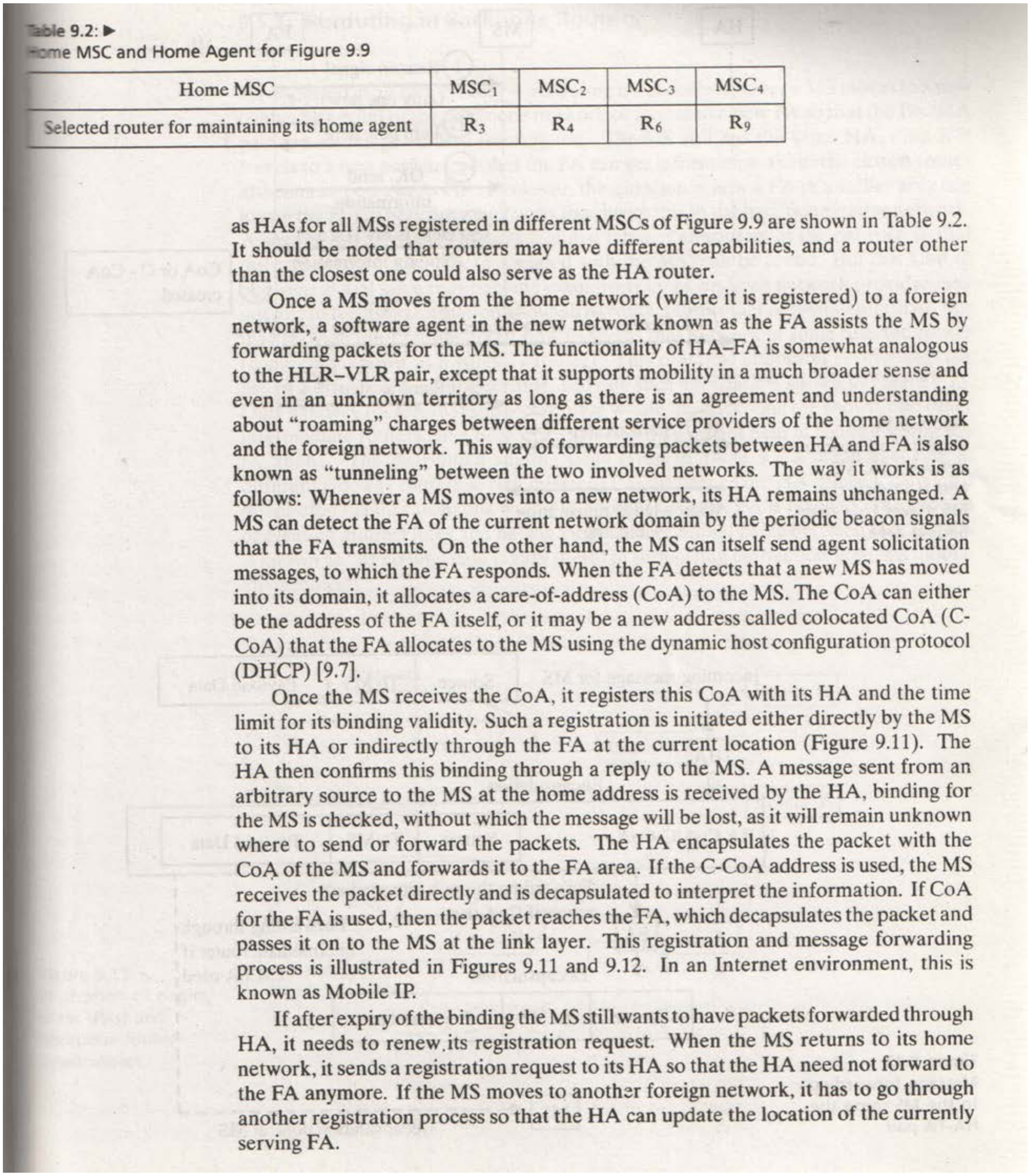


Table 9.2: ▶
Home MSC and Home Agent for Figure 9.9

| Home MSC | $MSC_1$ | $MSC_2$ | $MSC_3$ | $MSC_4$ |
|---|---|---|---|---|
| Selected router for maintaining its home agent | $R_3$ | $R_4$ | $R_6$ | $R_9$ |

as HAs for all MSs registered in different MSCs of Figure 9.9 are shown in Table 9.2. It should be noted that routers may have different capabilities, and a router other than the closest one could also serve as the HA router.

Once a MS moves from the home network (where it is registered) to a foreign network, a software agent in the new network known as the FA assists the MS by forwarding packets for the MS. The functionality of HA–FA is somewhat analogous to the HLR–VLR pair, except that it supports mobility in a much broader sense and even in an unknown territory as long as there is an agreement and understanding about "roaming" charges between different service providers of the home network and the foreign network. This way of forwarding packets between HA and FA is also known as "tunneling" between the two involved networks. The way it works is as follows: Whenever a MS moves into a new network, its HA remains unchanged. A MS can detect the FA of the current network domain by the periodic beacon signals that the FA transmits. On the other hand, the MS can itself send agent solicitation messages, to which the FA responds. When the FA detects that a new MS has moved into its domain, it allocates a care-of-address (CoA) to the MS. The CoA can either be the address of the FA itself, or it may be a new address called colocated CoA (C-CoA) that the FA allocates to the MS using the dynamic host configuration protocol (DHCP) [9.7].

Once the MS receives the CoA, it registers this CoA with its HA and the time limit for its binding validity. Such a registration is initiated either directly by the MS to its HA or indirectly through the FA at the current location (Figure 9.11). The HA then confirms this binding through a reply to the MS. A message sent from an arbitrary source to the MS at the home address is received by the HA, binding for the MS is checked, without which the message will be lost, as it will remain unknown where to send or forward the packets. The HA encapsulates the packet with the CoA of the MS and forwards it to the FA area. If the C-CoA address is used, the MS receives the packet directly and is decapsulated to interpret the information. If CoA for the FA is used, then the packet reaches the FA, which decapsulates the packet and passes it on to the MS at the link layer. This registration and message forwarding process is illustrated in Figures 9.11 and 9.12. In an Internet environment, this is known as Mobile IP.

If after expiry of the binding the MS still wants to have packets forwarded through HA, it needs to renew its registration request. When the MS returns to its home network, it sends a registration request to its HA so that the HA need not forward to the FA anymore. If the MS moves to another foreign network, it has to go through another registration process so that the HA can update the location of the currently serving FA.

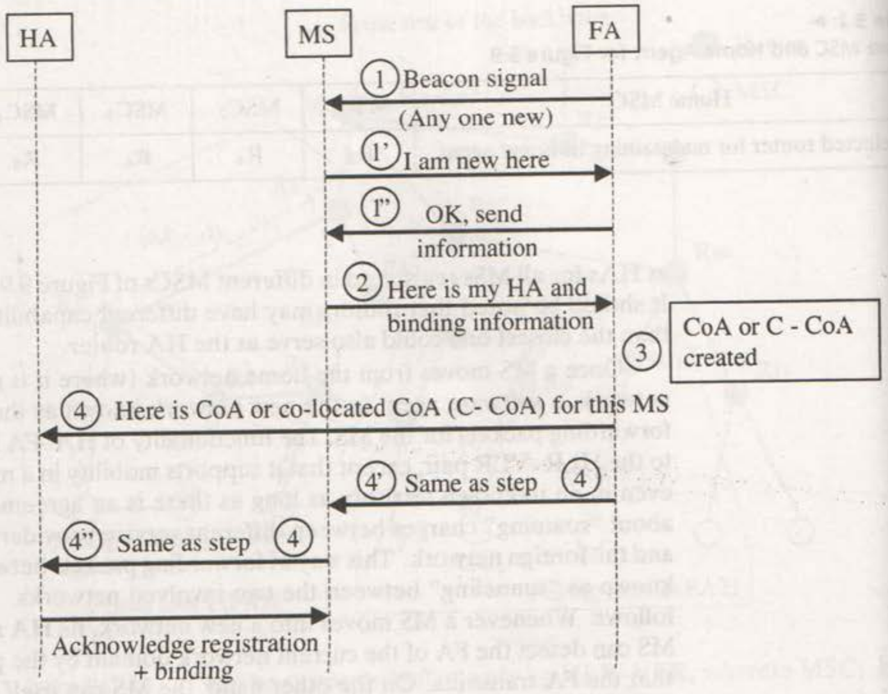


**Figure 9.11**
Registration process between FA, MS, and HA when the MS moves to a new paging area.

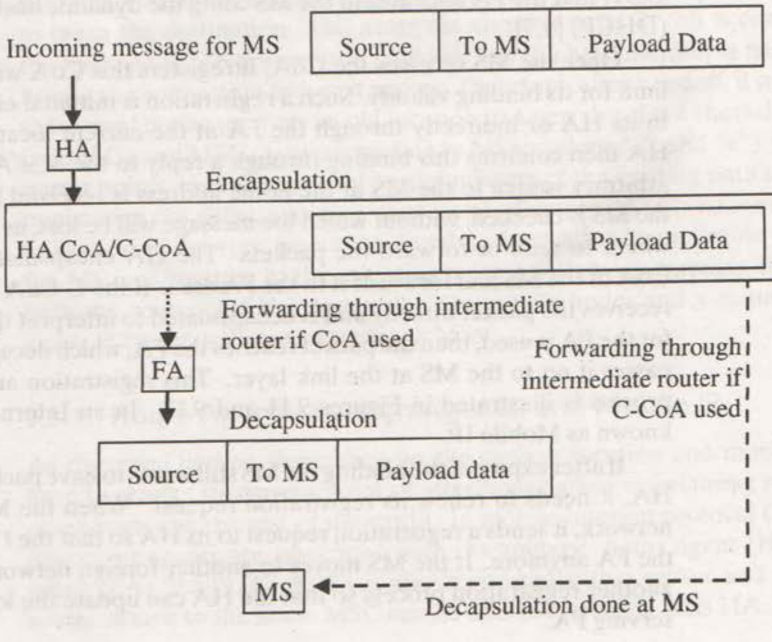
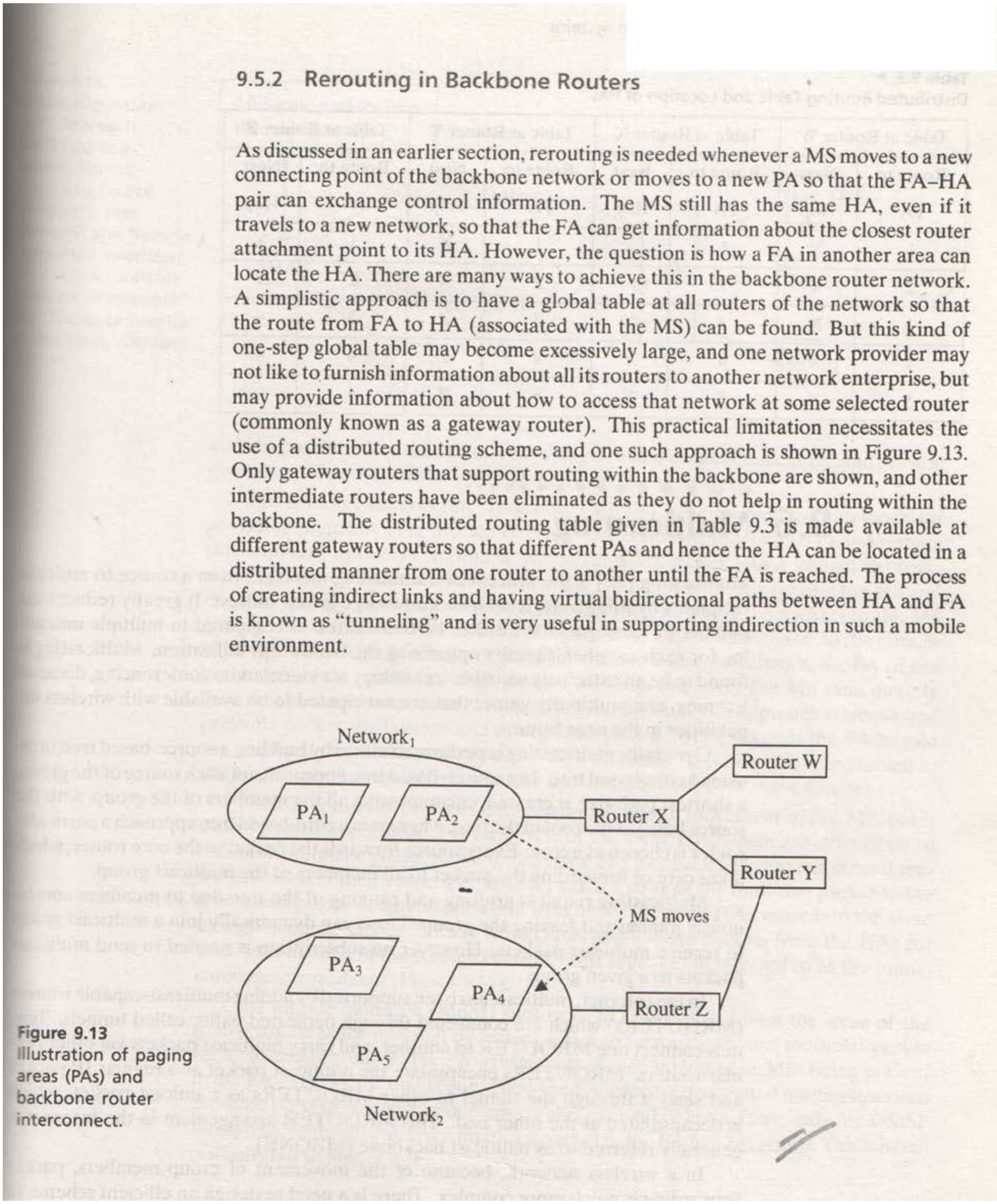


**Figure 9.12**
Message forwarding to the MS using the HA–FA pair.



### 9.5.2 Rerouting in Backbone Routers

As discussed in an earlier section, rerouting is needed whenever a MS moves to a new connecting point of the backbone network or moves to a new PA so that the FA–HA pair can exchange control information. The MS still has the same HA, even if it travels to a new network, so that the FA can get information about the closest router attachment point to its HA. However, the question is how a FA in another area can locate the HA. There are many ways to achieve this in the backbone router network. A simplistic approach is to have a global table at all routers of the network so that the route from FA to HA (associated with the MS) can be found. But this kind of one-step global table may become excessively large, and one network provider may not like to furnish information about all its routers to another network enterprise, but may provide information about how to access that network at some selected router (commonly known as a gateway router). This practical limitation necessitates the use of a distributed routing scheme, and one such approach is shown in Figure 9.13. Only gateway routers that support routing within the backbone are shown, and other intermediate routers have been eliminated as they do not help in routing within the backbone. The distributed routing table given in Table 9.3 is made available at different gateway routers so that different PAs and hence the HA can be located in a distributed manner from one router to another until the FA is reached. The process of creating indirect links and having virtual bidirectional paths between HA and FA is known as "tunneling" and is very useful in supporting indirection in such a mobile environment.

**Figure 9.13** Illustration of paging areas (PAs) and backbone router interconnect.

**Q.6 a. Explain GSM architecture. (10)**

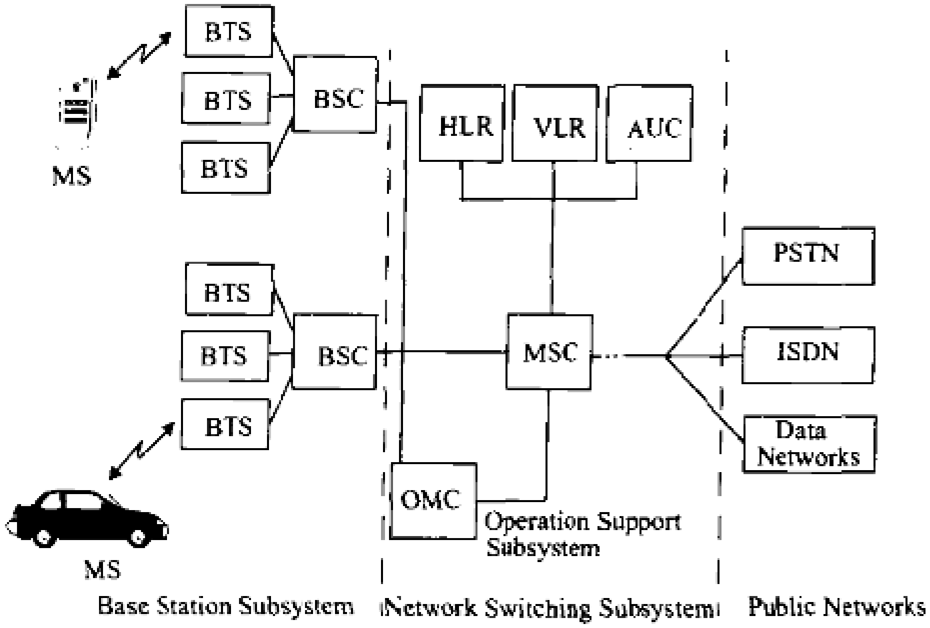
**Answer:**

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

The BSS, also known as the radio subsystem, provides and manages radio transmission paths between the mobile stations and the Mobile Switching Center (MSC). The BSS also manages the radio interface between the mobile stations and all other subsystems of GSM. Each BSS consists of many Base Station

Controllers (BSCs) which connect the MS to the NSS via the MSCs. The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the PSTN and ISDN. The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose, and troubleshoot all aspects of the GSM system. This subsystem interacts with the other GSM subsystems, and is provided solely for the staff of the GSM operating company which provides service facilities for the network. Figure shows the block diagram of the GSM system architecture.

The Mobile Stations (MS) communicate with the Base Station Subsystem (BSS) over the radio air interface. The BSS consists of many BSCs which connect to a single MSC, and each BSC typically controls up to several hundred Base Transceiver Stations (BTSs). Some of the BTSs maybe co-located at the BSC, and others may be remotely distributed and physically connected to the BSC by microwave link or dedicated leased lines. Mobile handoffs between two BTSs under the control of the same BSC are handled by the BSC, and not the MSC. This greatly reduces the switching burden of the MSC



The NSS handles the switching of GSM calls between external networks and the BSCs in the radio subsystem and is also responsible for managing and providing external access to several customer databases. The MSC is the central unit in the NSS and controls the traffic among all of the BSCs. In the NSS, there are three different databases called the Home Location Register (HLR), Visitor Location Register (VLR), and the Authentication Center (AUC). The HLR is database which contains subscriber information and location information for each user who resides in the same city as the MSC. Each subscriber in GSM market is assigned a unique International Mobile Subscrther (IMSI), and this number is used to identify each home a particular Identity user. The VLR is a database which temporarily stores the IMSI and customer information roaming subscriber who is visiting the coverage VLR is linked between several adjoining MSCs in graphic region and contains subscription information of for each area of a particular MSC. The particular market or geo- area. Once a roaming mobile is logged in the VLR, the MSC sends the every visiting user in the necessary information to the visiting subscriber. The Authentication Center is a strongly protected database which handles the authentication and encryption keys for every single subscriber in the HLR and VLR. The Authentication Center contains a register called the Equipment Identity Register (EIR) which identifies stolen or fraudulently altered phones that transmit identity data that does not match with information contained in either the HLR or VLR.

**b. Explain feature of 3G network. (6)**

**Answer:**

3G is the third generation of mobile phone standards and technology, superseding 2.5G. It is based on the International Telecommunication Union (ITU) family of standards under the International Mobile Telecommunications-2000 (IMT-2000). ITU launched IMT-2000 program, which, together with the main industry and standardization bodies worldwide, targets to implement a global frequency band that would support a single, ubiquitous wireless communication standard for all countries, to provide the framework for the definition of the 3G mobile systems. Several radio access technologies have been accepted by ITU as part of the IMT-2000 framework.

3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. Services include wide-area wireless voice telephony, video calls, and broadband wireless data, all in a mobile environment. Additional features also include HSPA data transmission capabilities able to deliver speeds up to 14.4Mbit/s on the down link and 5.8Mbit/s on the uplink.

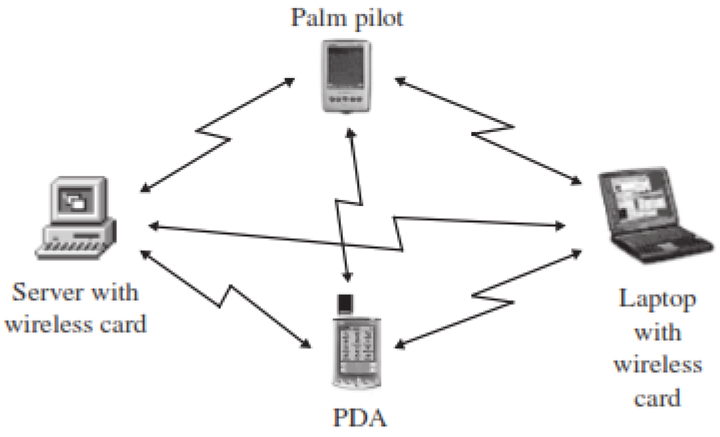
3G networks are wide area cellular telephone networks which evolved to incorporate high-speed internet access and video telephony. IMT-2000 defines a set of technical requirements for the realization of such targets, which can be summarized as follows:

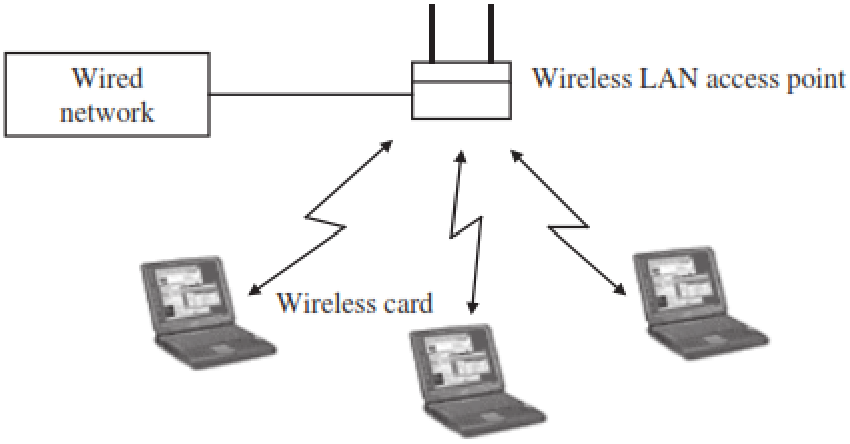
- high data rates: 144 kbps in all environments and 2 Mbps in low-mobility and indoor environments
- symmetrical and asymmetrical data transmission circuit-switched and packet-switched-based services
- speech quality comparable to wire-line quality
- improved spectral e_ciency
- several simultaneous services to end users for multimedia services
- seamless incorporation of second-generation cellular systems
- global roaming
- open architecture for the rapid introduction of new services and technology.

**Q.7 a. Explain 802.11 protocol in detail. (8)**

**Answer:**

The IEEE, ETSI have been involved in developing standards for the WLAN.This physical layer and MAC standard specifies carrier frequencies in the 2.4 GHz range bandwidths with data rate of 1 or 2 Mbps, protocols, power levels, modulation schemes
User demand for higher bit rates and international availability of the 2.4 GHz ISM band has resulted in development of a high-speed standard in the same carrier frequency range. This standard, called the IEEE 802.11b (popularly known as Wi-Fi), specifies a PHY layer providing a basic rate of 11 Mbps and a fallback rate of 5.5 Mbps.
To meet such demands, the IEEE 802.11 group has added another layer in the 5.2 GHz band, utilizing OFDM to provide data rates up to 54 Mbps. This standard, known as the IEEE 802.11a, became the first to use OFDM in packet-based communication The IEEE 802.11 and IEEE 802.11b standards could be used to provide communication between a number of terminals as an ad hoc network using peer-to-peer mode, or as a client/server wireless configuration





The key behind all these networks consists of the wireless cards and WLAN access point
The IEEE standards allow two types of transmissions: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). FHSS is primarily used for low-power, low-range applications and DSSS is popular in providing Ethernet-like data rates.

In the ad hoc network mode, as there is no central controller, the wireless access cards use the CSMA/CA protocol to resolve shared access of the channel.

In then client/server configuration, many PCs and laptops, physically close to each other can be linked to a central hub that serves as a bridge between them and the wired network. The wireless access cards provide the interface between the PCs and the antenna, while the AP serves as the WLAN hub. The AP is usually placed at the ceiling or high on the wall and supports
a number of users receiving, buffering, and transmitting data between
the WLAN and the wired network. The AP can also be programmed to select
one of the hopping sequences, and the WLAN cards tune in to the corresponding
sequence.
The aim of IEEE 802.11 is to provide wireless network connection for fixed, portable, and moving stations within tens to hundreds of meters with one medium access control (MAC) and several physical layer.

**IEEE 802.11a**
IEEE 802.11a operates on 5GHz. As compared to other IEEE 802.11 standards, such as IEEE 802.11b/g, it has less interference, since the 2.4GHz band is heavily used. The modulation of IEEE 802.11a uses orthogonal frequency-division multiplexing (OFDM) with 52 subcarriers spanning over a 20MHz spectrum. Each subcarrier can be modulated with BPSK, QPSK, 16-QAM, or 64-QAM, depending on the wireless environment.

**IEEE 802.11b**
IEEE 802.11b operates on 2.4GHz band with throughput of up to 11Mbps and was marketed under the name Wi-Fi. IEEE 802.11b uses a direct extension of direct-sequence spread spectrum DSSS on the PHY layer. DSSS uses a continuous string of pseudonoise (PN) code symbols to module information, which allows multiple transmitters to share the same channel with orthogonal PN codes

**IEEE 802.11g**
IEEE 802.11g,is the third modulation standard for WLAN. It operates on 2.4G like IEEE 802.11b. The PHY layer can use either DSSS or OFDM. Due to its heritage of PHY technology from IEEE 802.11a, IEEE 802.11g can achieve higher throughput of up to 54Mbps.

**IEEE 802.11n**

IEEE 802.11n is the recent amendment that incorporates multiple-input multiple output (MIMO) technology. The bandwidth in IEEE 802.11n can be 40MHz, and the maximum PHY layer data rate is raised from 54Mbps to an objective of up to 600Mbps. MIMO improves communication performance with the use of multiple antennas at both the transmitter and receiver for multiple transmitted data streams. IEEE 802.11n can operate on 2.4GHz and 5GHz. It uses either DSSS or OFDM for PHY layer modulation

**b. Explain the basic functions of smart antenna with a Diagram. (8)**
**Answer:**

Simultaneous transmission by a MS requires smart antennas equipped with spatial multiplexing and demultiplexing capability. Beamforming is a technique whereby the gain pattern of an adaptive array is steered to a desired direction through either beam-steering or null-steering signal-processing algorithms, allowing the antenna system to focus the maxima of the antenna pattern toward the desired user while minimizing the impact of noise, interference, and other effects from undesired users that can degrade signal quality. Smart antennas are implemented as an array of omnidirectional antenna elements, each of which is fed with the signal, with an appropriate change in its gain and phase. This array of complex quantities constitutes a steering vector and allows the resultant beam to form the main lobe and nulls in certain directions. With an $L$-element array, it is possible to specify ($L$ - 1) maximas and minimas in desired directions by using constrained optimization techniques when determining the beamforming weights. This flexibility of an $L$-element array to be able to fix the pattern at ($L$ - 1) places is known as the degree of freedom of the array . Smart antennas can be classified into two groups, both systems using an array of antenna elements: switched beam and adaptive beamforming antenna systems.

**Switched Beam**

A switched-beam system consists of a set of predefined beams, of which the one that best receives the signal from a particular desired user is selected. The beams have a narrow main lobe and small side lobes so that signals arriving from directions other than that of the desired main lobe direction are significantly attenuated. A linear RF network called a fixed beamforming network (FBN) is used that combines $M$ antenna elements to form up to $M$ directional beams.

**Adaptive Beam**

Adaptive antenna arrays, on the other hand, rely on beamforming algorithms to steer the main lobe of the beam in the direction of the desired user and simultaneously place nulls in the direction of the interfering users' signals. An adaptive antenna array has the ability to change its antenna pattern dynamically to adjust to noise, interference, and multipath. It consists of several antenna elements whose signals are processed adaptively by a combining network; the signals received at different antenna elements are multiplied with complex weights and then summed to create a steerable radiation pattern. Popular beamforming algorithms use a training sequence to obtain the desired beam pattern, while blind beamforming methods such as the constant modulus algorithm (CMA) do not impose such a requirement.

**Q.8 a. Define MSK. Write the advantages of MSK over QPSK. (8)**

**Answer:**

Minimum shift keying (MSK) is a special type of continuous phase. Frequency shift keying (CPFSK) wherein the peak frequency deviation is equal to 1/4 the bit rate.

1. In QPSK the phase changes by 90degree or 180 degree .This creates abrupt amplitude variations in the waveform, Therefore bandwidth requirement of QPSK is more filters of other methods overcome these problems , but they have other side effects.

2. MSK overcomes those problems. In MSK the output waveform is continuous in phase hence there are no abrupt changes in amplitude.

**b. Explain cyclic Coding and CRC code. (8)**

An advantage of cyclic codes over most other types of codes is that they are relatively easy to encode and decode.

Thus, block codes used for forward error correction (FEC) systems are most cyclic codes wherein encoding or decoding is performed with a shift register. A mathematical expression in a polynomial form can be used because shift of a code generates another code. The code word with *n* bits can be expressed as

$$c(x) = c_1x^{n-1} + c_2x^{n-2} + \cdots + c_n,$$

Where the coefficients *ci* (*i* = 1, 2,...,*n*) take the value either 0 or 1.

The code word can be expressed by the data polynomial *m*(*x*) and the check polynomial *cp* (*x*).

Thus, we have

$$c(x) = m(x)x^{n-k} + c_p(x),$$

Where the check polynomial $c_p(x)$ is the remainder from dividing $m(x)x^{n-k}$ by the generator polynomial *g*(*x*)—that is,

$$s(x) = \text{rem}\left[\frac{c(x) + e(x)}{g(x)}\right]$$

If there is no error, we have $s(x) = 0$.A (*n*, *k*) code can easily be generated with a *n* - *k* linear feedback shift register. The syndrome *s*(*x*) can be obtained by the same feedback shift register

**Cyclic Redundancy Check**

Cyclic redundancy code (CRC) is an error-checking code that is widely used in data communications systems and other serial data transmission systems. Using this technique, the transmitter appends an extra *n*-bit sequence to every frame. The Additional bit sequence is called a frame check sequence (FCS). The FCS holds redundant information about the frame that helps the receivers detect errors in the frame. CRC is based on polynomial manipulations using modulo arithmetic. The algorithm treats blocks of input bits as coefficient sets for polynomials. For example, binary 10100 implies the polynomial:

$$1 \cdot x^4 + 0 \cdot x^3 + 1 \cdot x^2 + 0 \cdot x^1$$

This is the message polynomial. A second polynomial with constant coefficients is called the generator polynomial. This is divided into the message polynomial, giving quotient and remainder. The coefficients of the remainder form the bits of the final CRC. We define the following parameters as:

*Q* — *k* bits long frame to be transmitted
*F* —FCS of *n* - *k* bits, which would be added to *Q*
*J* — The result after cascading *Q* and *F*
*P* — The CRC-generating polynomial

CRC-16 and CRC-CCITT transmit 8 bits and generate 16-bit FCS. CRC-32 provides more protection by generating 32-bit FCS. Few Department of Defense (DoD) applications use CRC-32, whereas most user applications in Europe and the United States use either CRC-16 or CRC-CCITT.

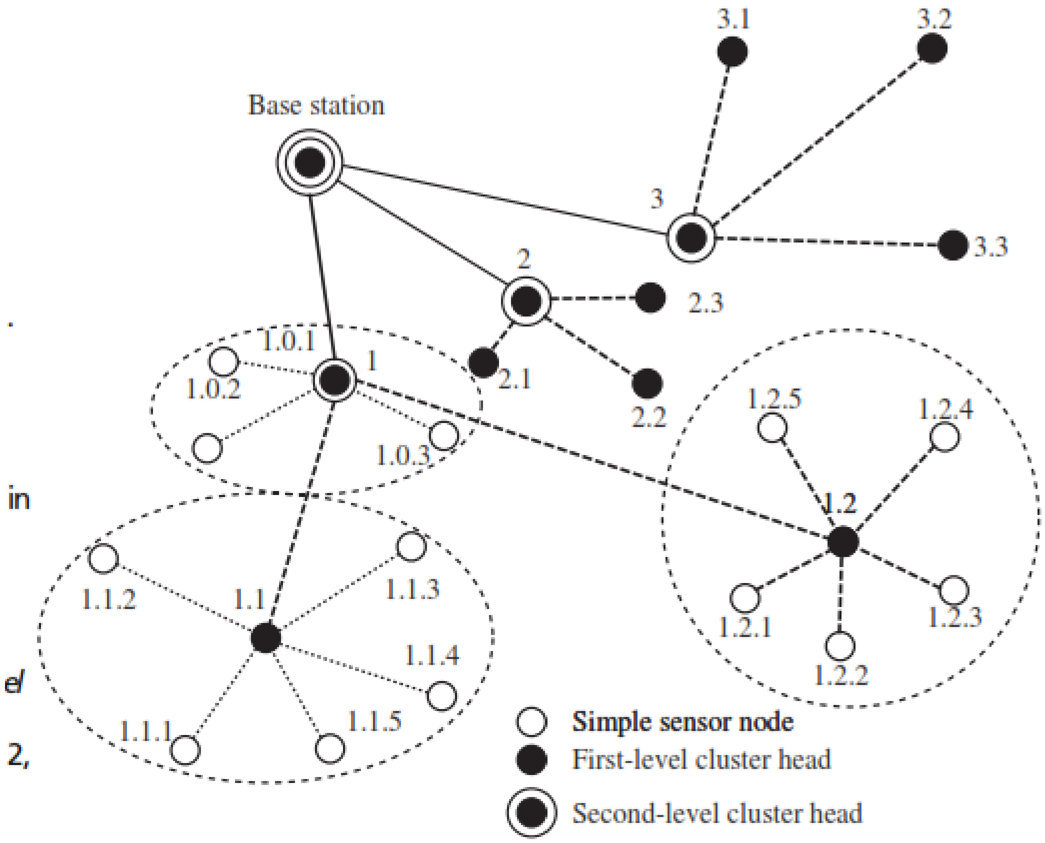
**Q.9 a. What is a wireless sensor network? Explain hierarchical routing in sensor network with an example. (8)**

**Answer:**

A wireless sensor network (WSN) are spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location

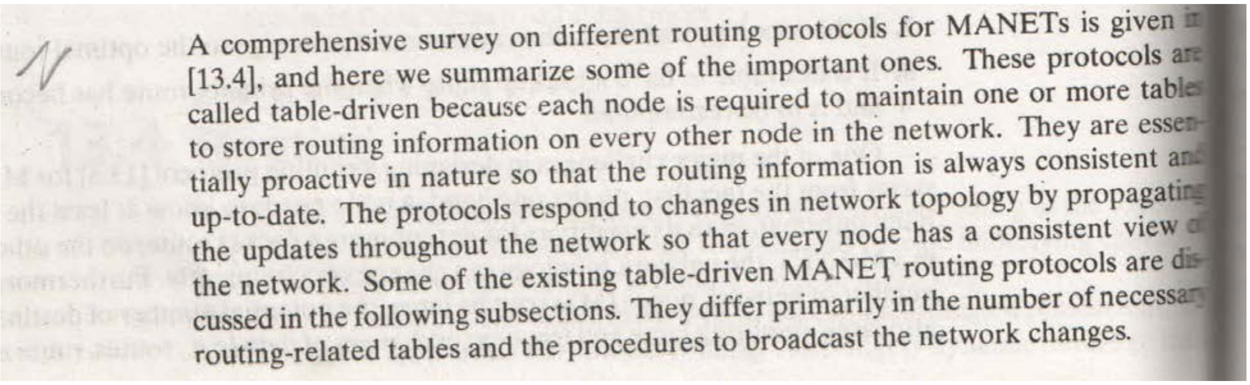
Some authors suggest that a hierarchical clustering scheme is the most suitable for wireless sensor networks, as this model enables us to take advantage of all the features that are specific to sensor networks. The network is assumed to consist of a BS, away from the nodes, through which the end user can access data from the sensor network. All the nodes in the network are homogeneous and begin with the same initial energy. The BS, however, has a constant power supply and so has no energy constraints. It can transmit with high power to all the nodes, and there is no need for routing from the BS to any specific node. However, the nodes cannot always reply to the BS directly due to their power constraints, resulting in asymmetric communication. The BS can also be used as a database to hold data. Consider the partial network structure shown in Figure 14.7. Each cluster has a CH that collects data from its cluster members, aggregates it, and sends it to the BS or an upper-level CH. For example, nodes 1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, and 1.1 form a cluster with node 1.1 as the CH. Similarly, there exist other CHs, such as 1.2. These CHs, in turn, form a cluster with node 1 as their CH. Therefore, node 1 becomes a second-level CH as well. This pattern is repeated to form a hierarchy of clusters, with the uppermost level cluster nodes reporting directly to the BS. The BS forms the root of this hierarchy and supervises the entire network. The main features of this architecture are as follows:

- All the nodes transmit only to their immediate CH, thus saving energy.
- Only the CH needs to perform additional computations on the data, such as aggregation. Therefore, energy is again conserved.
- The cluster members are mostly adjacent to each other and have similar data.Since the CHs aggregate similar data, aggregation is said to be more effective.
- CHs at increasing levels in the hierarchy need to transmit data over relatively longer distances. As they need to perform extra computations, they end up consuming energy faster than the other lower-level nodes. In order to distribute this consumption evenly, all the nodes take turns, becoming the CH for a time interval *T*, called the cluster period.
- Since only the CHs need to know how to route the data toward their own CH or BS, complexity in data routing is reduced.



**b. Discuss various table driven routing protocols. (8)**

**Answer:**


A comprehensive survey on different routing protocols for MANETs is given in [13.4], and here we summarize some of the important ones. These protocols are called table-driven because each node is required to maintain one or more tables to store routing information on every other node in the network. They are essentially proactive in nature so that the routing information is always consistent and up-to-date. The protocols respond to changes in network topology by propagating the updates throughout the network so that every node has a consistent view of the network. Some of the existing table-driven MANET routing protocols are discussed in the following subsections. They differ primarily in the number of necessary routing-related tables and the procedures to broadcast the network changes.

### 13.5.1 Destination-Sequenced Distance-Vector Routing

The destination-sequenced distance-vector (DSDV) [13.8] routing protocol is a table-driven routing protocol based on the classic Bellman-Ford routing algorithm discussed in Chapter 12. The algorithm works correctly, even in the presence of loops in the routing tables. As stated above, each mobile node maintains a routing table with a route to every possible destination in the network and the number of hops to the destination. Each such entry in the table is marked with a sequence number assigned by the destination node. The sequence numbers allow the mobile node to distinguish stale routes from new ones, and help avoid formation of routing loops.

A new route broadcast contains:

- The destination address.
- The number of hops required to reach the destination.
- The sequence number of the information received about the destination and a new sequence number unique to the broadcast.

If multiple routes are available for the same destination, the route with the most recent sequence number is used. If two updates have the same sequence number, the route with the smaller metric (e.g., hops) is used to optimize the routing. Further, if the routes fluctuate frequently, that may lead to large network traffic as broadcasts need to be sent each time a better route is discovered. To avoid such broadcasts, the mobile nodes keep track of the settling time of routes or the weighted average time before the route with best metric is discovered. The nodes can now delay the update broadcasts by settling time, during which a better route may be discovered, thus reducing network traffic.

Any updates in the routing tables are periodically broadcasted in the network to maintain table consistency. The amount of traffic generated by these updates can be huge. To alleviate this problem, the updates are done through two types of packets. The first is called a full dump [13.8]. A full dump packet carries all the available routing information and can require multiple network protocol data units (NPDUs). When there is only occasional movement, these packets are used rarely. Instead, smaller incremental packets are used to relay only the change in information since the last full dump. The incremental packets fit into a standard NPDU and hence decrease the amount of traffic generated. The nodes maintain a separate table in which they maintain all the information sent in the incremental routing information packets.

### 13.5.2 Cluster Head Gateway Switch Routing

The cluster head (CH) gateway switch routing (CGSR)protocol [13.9] is different from the previous protocol in the type of addressing and the network organization scheme employed. Instead of a flat network, CGSR uses CHs which control a group of ad hoc nodes and hence achieve a hierarchical framework for code separation among clusters, channel access, routing, and bandwidth allocation (Figure 13.2). Identification of appropriate clusters and selection of CHs is quite complex. Once clusters have been defined, it is desirable to use a distributed algorithm within the cluster to elect a node as the CH. The disadvantage of using a CH scheme is that

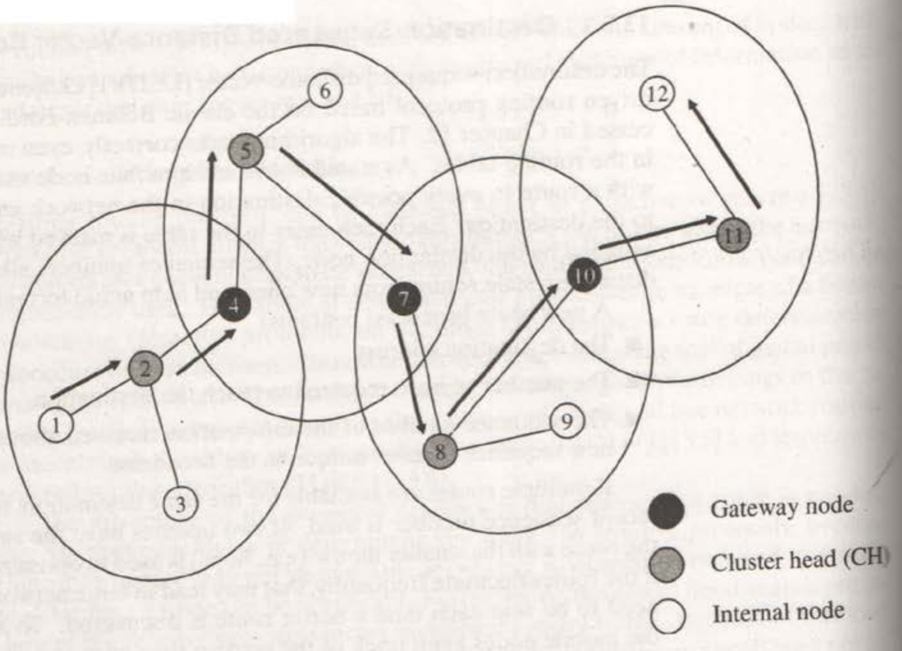
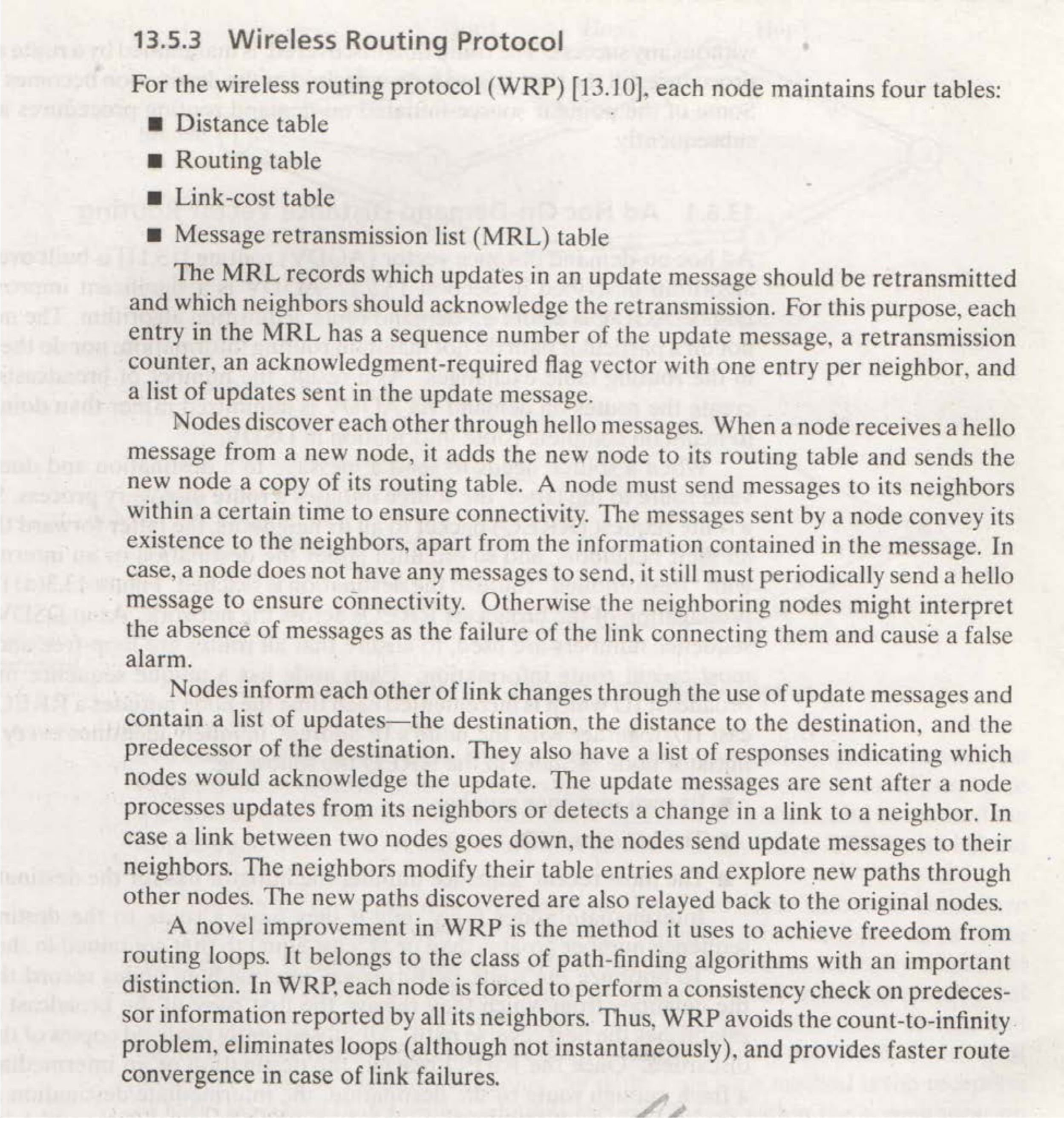


**Figure 13.2** Routing in CGSR from node 1 to node 12.

frequent changes adversely affect performance as nodes spend more time selecting a CH rather than relaying packets. Hence, the Least Cluster Change (LCC) clustering algorithm is used rather than CH selection every time the cluster membership changes. Using LCC, CHs only change when two CHs come into contact, or when a node moves out of contact with all other CHs.

CGSR uses DSDV as the underlying routing scheme and shares the overhead with the same. However, it modifies DSDV to use a hierarchical cluster-head-to-gateway routing approach. Gateway nodes are those within communication range of two or more CHs. A packet sent by a node is first transmitted to its CH. From there it is routed to the gateway node, then to another CH and so on till the packet reaches the CH of the destination. The packet is then transmitted to the destination as illustrated in Figure 13.2. To use this routing scheme, each node must maintain a cluster member table (CMT), which stores the destination CH for each node in the network. The CMTs are broadcast periodically by the nodes using the DSDV algorithm. When a node receives such a table from a neighbor, it can update its own information.

As expected, each node also maintains a routing table to determine the next hop required to reach any destination. While transmitting a packet, the node looks up the CMT and the routing table to determine the nearest CH along the route to the destination, and the next hop required to reach this CH. It then relays the packet to this node.



### 13.5.3 Wireless Routing Protocol

For the wireless routing protocol (WRP) [13.10], each node maintains four tables:

- Distance table
- Routing table
- Link-cost table
- Message retransmission list (MRL) table

The MRL records which updates in an update message should be retransmitted and which neighbors should acknowledge the retransmission. For this purpose, each entry in the MRL has a sequence number of the update message, a retransmission counter, an acknowledgment-required flag vector with one entry per neighbor, and a list of updates sent in the update message.

Nodes discover each other through hello messages. When a node receives a hello message from a new node, it adds the new node to its routing table and sends the new node a copy of its routing table. A node must send messages to its neighbors within a certain time to ensure connectivity. The messages sent by a node convey its existence to the neighbors, apart from the information contained in the message. In case, a node does not have any messages to send, it still must periodically send a hello message to ensure connectivity. Otherwise the neighboring nodes might interpret the absence of messages as the failure of the link connecting them and cause a false alarm.

Nodes inform each other of link changes through the use of update messages and contain a list of updates—the destination, the distance to the destination, and the predecessor of the destination. They also have a list of responses indicating which nodes would acknowledge the update. The update messages are sent after a node processes updates from its neighbors or detects a change in a link to a neighbor. In case a link between two nodes goes down, the nodes send update messages to their neighbors. The neighbors modify their table entries and explore new paths through other nodes. The new paths discovered are also relayed back to the original nodes.

A novel improvement in WRP is the method it uses to achieve freedom from routing loops. It belongs to the class of path-finding algorithms with an important distinction. In WRP, each node is forced to perform a consistency check on predecessor information reported by all its neighbors. Thus, WRP avoids the count-to-infinity problem, eliminates loops (although not instantaneously), and provides faster route convergence in case of link failures.

**Text Book**

**Introduction to Wireless and Mobile Systems, second Edition (2007), Dharma Prakash Agrawal and Qing An Zeng, Thomson India Edition.**