

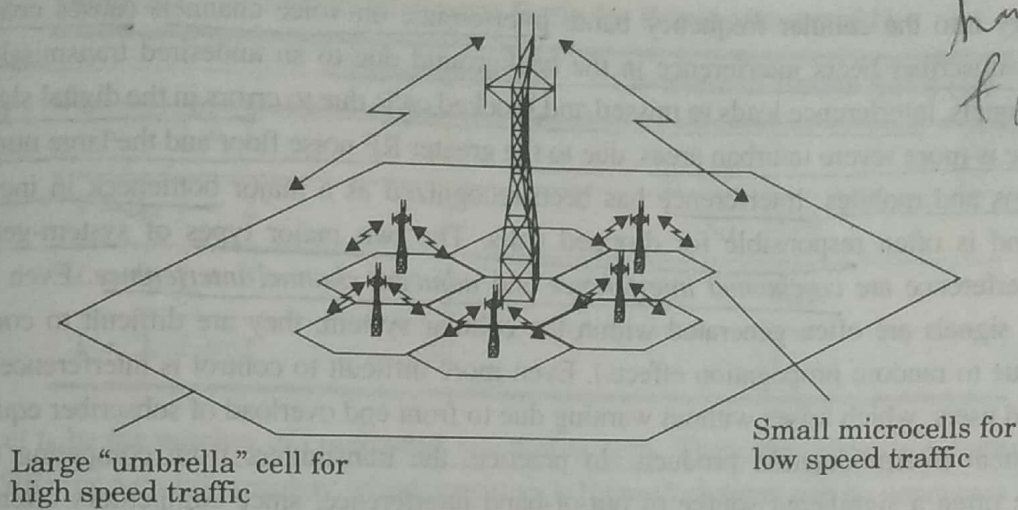
### 3.4.2 Practical Handoff Considerations

In practical cellular systems, several problems arise when attempting to design for a wide range of mobile velocities. High speed vehicles pass through the coverage region of a cell within a matter of seconds, whereas pedestrian users may never need a handoff during a call. Particularly with the addition of microcells to provide capacity, the MSC can quickly become burdened if high speed users are constantly being passed between very small cells. Several schemes have been devised to handle the simultaneous traffic of high speed and low speed users while minimizing the handoff intervention from the MSC. Another practical limitation is the ability to obtain new cell sites.

Although the cellular concept clearly provides additional capacity through the addition of cell sites, in practice it is difficult for cellular service providers to obtain new physical cell site locations in urban areas. Zoning laws, ordinances, and other nontechnical barriers often make it more attractive for a cellular provider to install additional channels and base stations at the same physical location of an existing cell, rather than find new site locations. By using different antenna heights (often on the same building or tower) and different power levels, it is possible to provide "large" and "small" cells which are co-located at a single location. This technique is called the *umbrella cell* approach and is used to provide large area coverage to high speed users while providing small area coverage to users traveling at low speeds. Figure 3.4 illustrates an umbrella cell which is co-located with some smaller microcells. The umbrella cell approach ensures that the number of handoffs is minimized for high speed users and provides additional microcell channels for pedestrian users. The speed of each user may be estimated by the base station or MSC by evaluating how rapidly the short-term average signal strength on the RVC changes over time, or more sophisticated algorithms may be used to evaluate and partition users [LiC93]. If a high speed user in the large umbrella cell is approaching the base station, and its velocity is rapidly decreasing, the base station may decide to hand the user into the co-located microcell, without MSC intervention.

Another practical handoff problem in microcell systems is known as *cell dragging*. Cell dragging results from pedestrian users that provide a very strong signal to the base station. Such a situation occurs in an urban environment when there is a line-of-sight (LOS) radio path between the subscriber and the base station. As the user travels away from the base station at a very slow speed, the average signal strength does not decay rapidly. Even when the user has traveled well beyond the designed range of the cell, the received signal at the base station may be above the handoff threshold, thus a handoff may not be made. This creates a potential interference and traffic management problem, since the user has meanwhile traveled deep within a neighboring cell. To solve the cell dragging problem, handoff thresholds and radio coverage parameters must be adjusted carefully.

In first generation analog cellular systems, the typical time to make a handoff, once the signal level is deemed to be below the handoff threshold, is about 10 seconds. This requires that the value for  $\Delta$  be on the order of 6 dB to 12 dB. In digital cellular systems such as GSM, the mobile assists with the handoff procedure by determining the best handoff candidates, and the handoff, once the decision is made, typically requires only 1 or 2 seconds. Consequently,  $\Delta$  is



**Figure 3.4** The umbrella cell approach.

usually between 0 dB and 6 dB in modern cellular systems. The faster handoff process supports a much greater range of options for handling high speed and low speed users and provides the MSC with substantial time to “rescue” a call that is in need of handoff.

Another feature of newer cellular systems is the ability to make handoff decisions based on a wide range of metrics other than signal strength. The co-channel and adjacent channel interference levels may be measured at the base station or the mobile, and this information may be used with conventional signal strength data to provide a multi-dimensional algorithm for determining when a handoff is needed.

The IS-95 code division multiple access (CDMA) spread spectrum cellular system described in Chapter 11 and in [Lib99], [Kim00], and [Gar99], provides a unique handoff capability that cannot be provided with other wireless systems. Unlike channelized wireless systems that assign different radio channels during a handoff (called a hard handoff), spread spectrum mobiles share the same channel in every cell. Thus, the term *handoff* does not mean a physical change in the assigned channel, but rather that a different base station handles the radio communication task. By simultaneously evaluating the received signals from a single subscriber at several neighboring base stations, the MSC may actually decide which version of the user’s signal is best at any moment in time. This technique exploits macroscopic space diversity provided by the different physical locations of the base stations and allows the MSC to make a “soft” decision as to which version of the user’s signal to pass along to the PSTN at any instance [Pad94]. The ability to select between the instantaneous received signals from a variety of base stations is called soft handoff.

### 3.5 Interference and System Capacity

Interference is the major limiting factor in the performance of cellular radio systems. Sources of interference include another mobile in the same cell, a call in progress in a neighboring cell, other base stations operating in the same frequency band, or any noncellular system which inadvertently

leaks energy into the cellular frequency band. Interference on voice channels causes cross talk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked calls due to errors in the digital signaling. Interference is more severe in urban areas, due to the greater RF noise floor and the large number of base stations and mobiles. Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls. The two major types of system-generated cellular interference are *co-channel interference* and *adjacent channel interference*. Even though interfering signals are often generated within the cellular system, they are difficult to control in practice (due to random propagation effects). Even more difficult to control is interference due to out-of-band users, which arises without warning due to front end overload of subscriber equipment or intermittent intermodulation products. In practice, the transmitters from competing cellular carriers are often a significant source of out-of-band interference, since competitors often locate their base stations in close proximity to one another in order to provide comparable coverage to customers.

### 3.5.1 Co-channel Interference and System Capacity

Frequency reuse implies that in a given coverage area there are several cells that use the same set of frequencies. These cells are called *co-channel cells*, and the interference between signals from these cells is called *co-channel interference*. Unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter. This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells. To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

When the size of each cell is approximately the same and the base stations transmit the same power, the co-channel interference ratio is independent of the transmitted power and becomes a function of the radius of the cell ( $R$ ) and the distance between centers of the nearest co-channel cells ( $D$ ). By increasing the ratio of  $D/R$ , the spatial separation between co-channel cells relative to the coverage distance of a cell is increased. Thus, interference is reduced from improved isolation of RF energy from the co-channel cell. The parameter  $Q$ , called the *co-channel reuse ratio*, is related to the cluster size (see Table 3.1 and Equation (3.3)). For a hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N} \quad (3.4)$$

A small value of  $Q$  provides larger capacity since the cluster size  $N$  is small, whereas a large value of  $Q$  improves the transmission quality, due to a smaller level of co-channel interference. A trade-off must be made between these two objectives in actual cellular design.

### 3.5.3 Adjacent Channel Interference

Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference. Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband. The problem can be particularly serious if an adjacent channel user is transmitting in very close range to a subscriber's receiver, while the receiver attempts to receive a base station on the desired channel. This is referred to as the near-far effect, where a nearby transmitter (which may or may not be of the same type as that used by the cellular system) captures the receiver of the subscriber. Alternatively, the near-far effect occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile. The base station may have difficulty in discriminating the desired mobile user from the "bleedover" caused by the close adjacent channel mobile.

Adjacent channel interference can be minimized through careful filtering and channel assignments. Since each cell is given only a fraction of the available channels, a cell need not be assigned channels which are all adjacent in frequency. By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference may be reduced considerably. Thus instead of assigning channels which form a contiguous band of frequencies within a particular cell, channels are allocated such that the frequency separation between channels in a given cell is maximized. By sequentially assigning successive channels in the frequency band to different cells, many channel allocation schemes are able to separate adjacent channels in a cell by as many as  $N$  channel bandwidths, where  $N$  is the cluster size. Some channel allocation schemes also prevent a secondary source of adjacent channel interference by avoiding the use of adjacent channels in neighboring cell sites.

### 3.7 Improving Coverage and Capacity in Cellular Systems

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users. At this point, cellular design techniques are needed to provide more channels per unit coverage area. Techniques such as cell splitting, sectoring, and coverage zone approaches are used in practice to expand the capacity of cellular systems. Cell splitting allows an orderly growth of the cellular system. Sectoring uses directional antennas to further control the interference and frequency reuse of channels. The zone microcell concept distributes the coverage of a cell and extends the cell boundary to hard-to-reach places. While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station to oversee all handoff chores related to the microcells, thus reducing the computational load at the MSC. These popular capacity improvement techniques will be explained in detail.

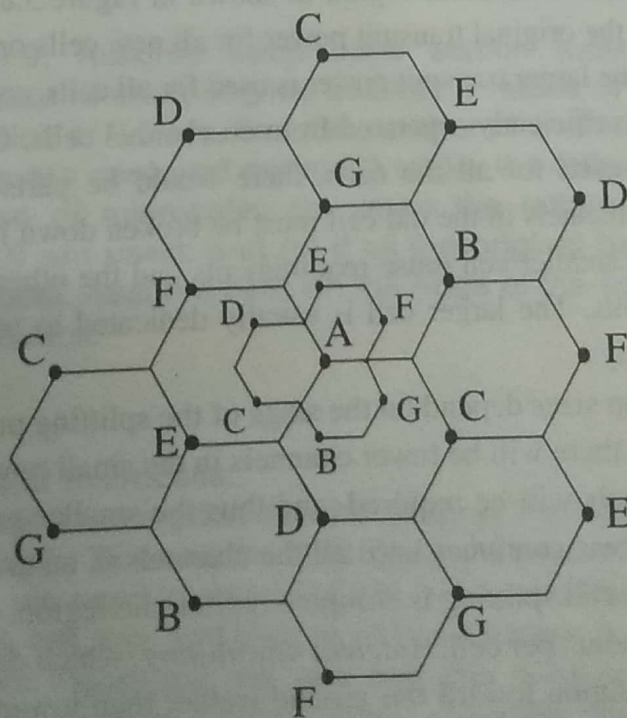
#### 3.7.1 Cell Splitting

Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power. Cell splitting increases the capacity of a cellular system since it increases the number of times that chan-

cells are reused. By defining new cells which have a smaller radius than the original cells and by installing these smaller cells (called *microcells*) between the existing cells, capacity increases due to the additional number of channels per unit area.

Imagine if every cell in Figure 3.1 were reduced in such a way that the radius of every cell was cut in half. In order to cover the entire service area with smaller cells, approximately four times as many cells would be required. This can be easily shown by considering a circle with radius  $R$ . The area covered by such a circle is four times as large as the area covered by a circle with radius  $R/2$ . The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and thus capacity, in the coverage area. Cell splitting allows a system to grow by replacing large cells with smaller cells, while not upsetting the channel allocation scheme required to maintain the minimum co-channel reuse ratio  $Q$  (see Equation (3.4)) between co-channel cells.

An example of cell splitting is shown in Figure 3.8. In Figure 3.8, the base stations are placed at corners of the cells, and the area served by base station A is assumed to be saturated with traffic (i.e., the blocking of base station A exceeds acceptable rates). New base stations are therefore needed in the region to increase the number of channels in the area and to reduce the area served by the single base station. Note in the figure that the original base station A has been surrounded by six new microcells. In the example shown in Figure 3.8, the smaller cells were added in such a way as to preserve the frequency reuse plan of the system. For example, the microcell base station labeled G was placed half way between two larger stations utilizing the same channel set G. This is also the case for the other microcells in the figure. As can be seen from Figure 3.8, cell splitting merely scales the geometry of the cluster. In this case, the radius of each new microcell is half that of the original cell.



- Increase no. of channels
- Rescaling
- $D/R$  unchanged
- ↓
- Need not to upset channel Allocation scheme

Figure 3.8 Illustration of cell splitting.

### 3.7.2 Sectoring

As shown in Section 3.7.1, cell splitting achieves capacity improvement by essentially rescaling the system. By decreasing the cell radius  $R$  and keeping the co-channel reuse ratio  $D/R$  unchanged, cell splitting increases the number of channels per unit area.

However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease the  $D/R$  ratio. As we now show, sectoring increases SIR so that the cluster size may be reduced. In this approach, first the SIR is improved using directional antennas, then capacity improvement is achieved by reducing the number of cells in a cluster, thus increasing the frequency reuse. However, in order to do this successfully, it is necessary to reduce the relative interference without decreasing the transmit power.

The co-channel interference in a cellular system may be decreased by replacing a single omnidirectional antenna at the base station by several directional antennas, each radiating within a specified sector. By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells. The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called sectoring. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three  $120^\circ$  sectors or six  $60^\circ$  sectors as shown in Figure 3.10(a) and (b).

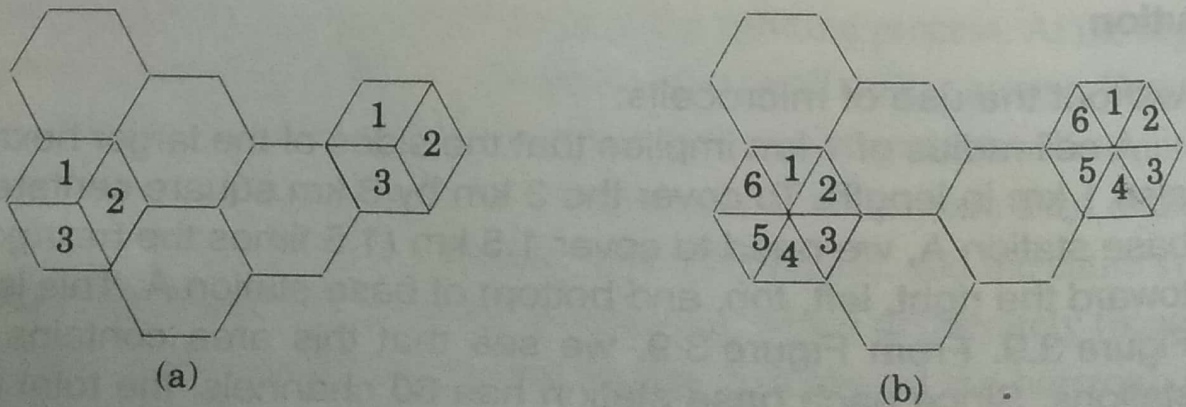
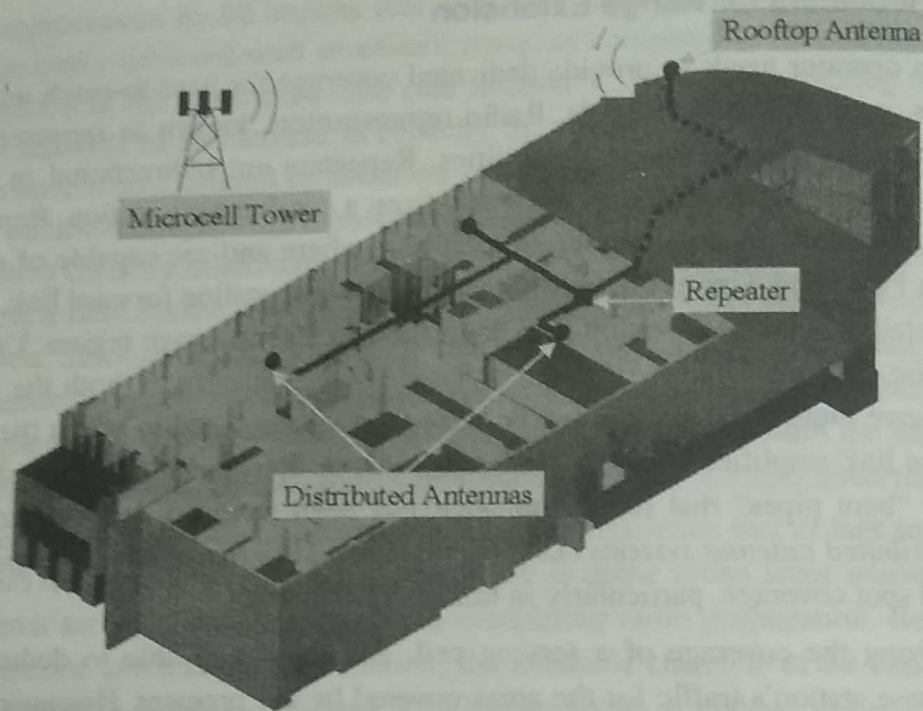


Figure 3.10 (a)  $120^\circ$  sectoring; (b)  $60^\circ$  sectoring.

### 3.7.4 A Microcell Zone Concept

The increased number of handoffs required when sectoring is employed results in an increased load on the switching and control link elements of the mobile system. A solution to this problem was presented by Lee [Lee91b]. This proposal is based on a microcell concept for seven cell reuse, as illustrated in Figure 3.13. In this scheme, each of the three (or possibly more) zone sites



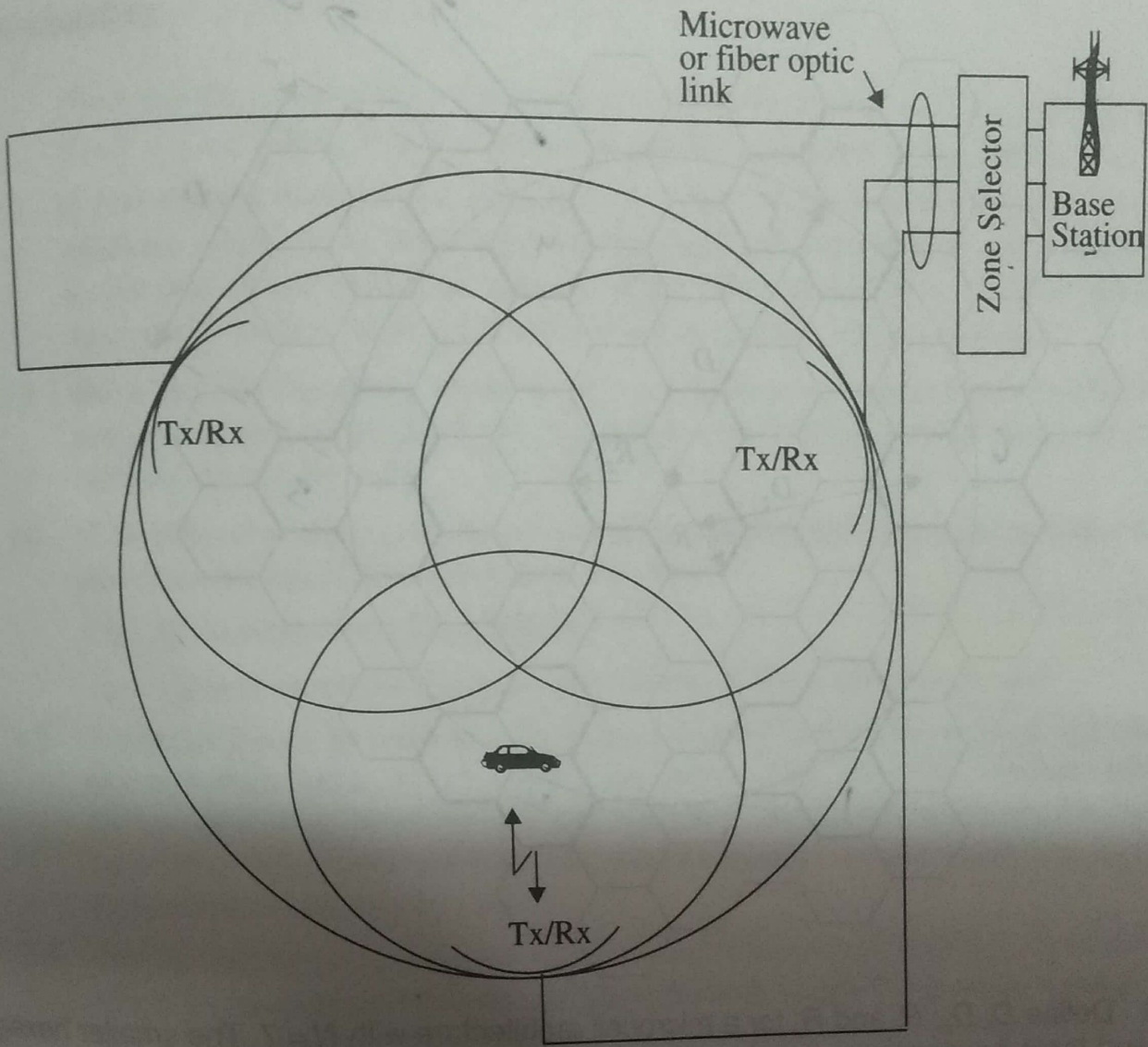


**Figure 3.12** Illustration of how a distributed antenna system (DAS) may be used inside a building. Figure produced in SitePlanner®. (Courtesy of Wireless Valley Communications Inc.)

(represented as Tx/Rx in Figure 3.13) are connected to a single base station and share the same radio equipment. The zones are connected by coaxial cable, fiberoptic cable, or microwave link to the base station. Multiple zones and a single base station make up a cell. As a mobile travels within the cell, it is served by the zone with the strongest signal. This approach is superior to sectoring since antennas are placed at the outer edges of the cell, and any base station channel may be assigned to any zone by the base station.

As a mobile travels from one zone to another within the cell, it retains the same channel. Thus, unlike in sectoring, a handoff is not required at the MSC when the mobile travels between zones within the cell. The base station simply switches the channel to a different zone site. In this way, a given channel is active only in the particular zone in which the mobile is traveling, and hence the base station radiation is localized and interference is reduced. The channels are distributed in time and space by all three zones and are also reused in co-channel cells in the normal fashion. This technique is particularly useful along highways or along urban traffic corridors.

The advantage of the zone cell technique is that while the cell maintains a particular coverage radius, the co-channel interference in the cellular system is reduced since a large central base station is replaced by several lower powered transmitters (zone transmitters) on the edges of the cell. Decreased co-channel interference improves the signal quality and also leads to an increase in capacity without the degradation in trunking efficiency caused by sectoring. As mentioned earlier, an  $S/I$  of 18 dB is typically required for satisfactory system performance in narrowband FM. For a system with  $N = 7$ , a  $D/R$  of 4.6 was shown to achieve this. With respect to



**Figure 3.13** The microcell concept [adapted from [Lee91b] © IEEE].