2.4 Handoff Strategies

When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station. This handoff operation not only involves identifying a new base station, but also requires that the voice and control signals be allocated to channels associated with the new base station.

Processing handoffs is an important task in any cellular radio system. Many handoff strategies prioritize handoff requests over call initiation requests when allocating unused channels in a cell site. Handoffs must be performed successfully and as infrequently as possible, and be imperceptible to the users. In order to meet these requirements, system designers must specify an optimum signal level at which to initiate a handoff. Once a particular signal level is specified as the minimum usable signal for acceptable voice quality at the base station receiver (normally taken as between –90 dBm and –100 dBm), a slightly stronger signal level is used as a threshold at which a handoff is made. This margin, given by $\Delta = P_{r\ handoff} - P_{r\ minimum\ usable}$, cannot be too large or too small. If Δ is too large, unnecessary handoffs which burden the MSC may occur, and if Δ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions. Therefore, Δ is chosen carefully to meet these conflicting requirements. Figure 2.3 illustrates a handoff situation. Figure 2.3(a) demonstrates the case where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active. This dropped call event can happen when there is an excessive delay by the MSC in assigning a handoff, or when the threshold Δ is set too small for the handoff time in the system. Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact that no channels are available on any of the nearby base stations (thus forcing the MSC to wait until a channel in a nearby cell becomes free).

In deciding when to handoff, it is important to ensure that the drop in the measured signal level is not due to momentary fading and that the mobile is actually moving away from the serving base station. In order to ensure this, the base station monitors the signal level for a certain period of time before a handoff is initiated. This running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided, while ensuring that necessary handoffs are completed before a call is terminated due to poor signal level. The length of time needed to decide if a handoff is necessary depends on the speed at which the vehicle is moving. If the slope of the short-term average received signal level in a given time interval is steep, the handoff should be made quickly. Information about the vehicle speed, which can be useful in handoff decisions, can also be computed from the statistics of the received short-term fading signal at the base station.

The time over which a call may be maintained within a cell, without handoff, is called the *dwell time* [Rap93b]. The dwell time of a particular user is governed by a number of factors, which include propagation, interference, distance between the subscriber and the base station, and other time varying effects. Chapter 4 shows that even when a mobile user is stationary, ambient motion in 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 2.4 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.

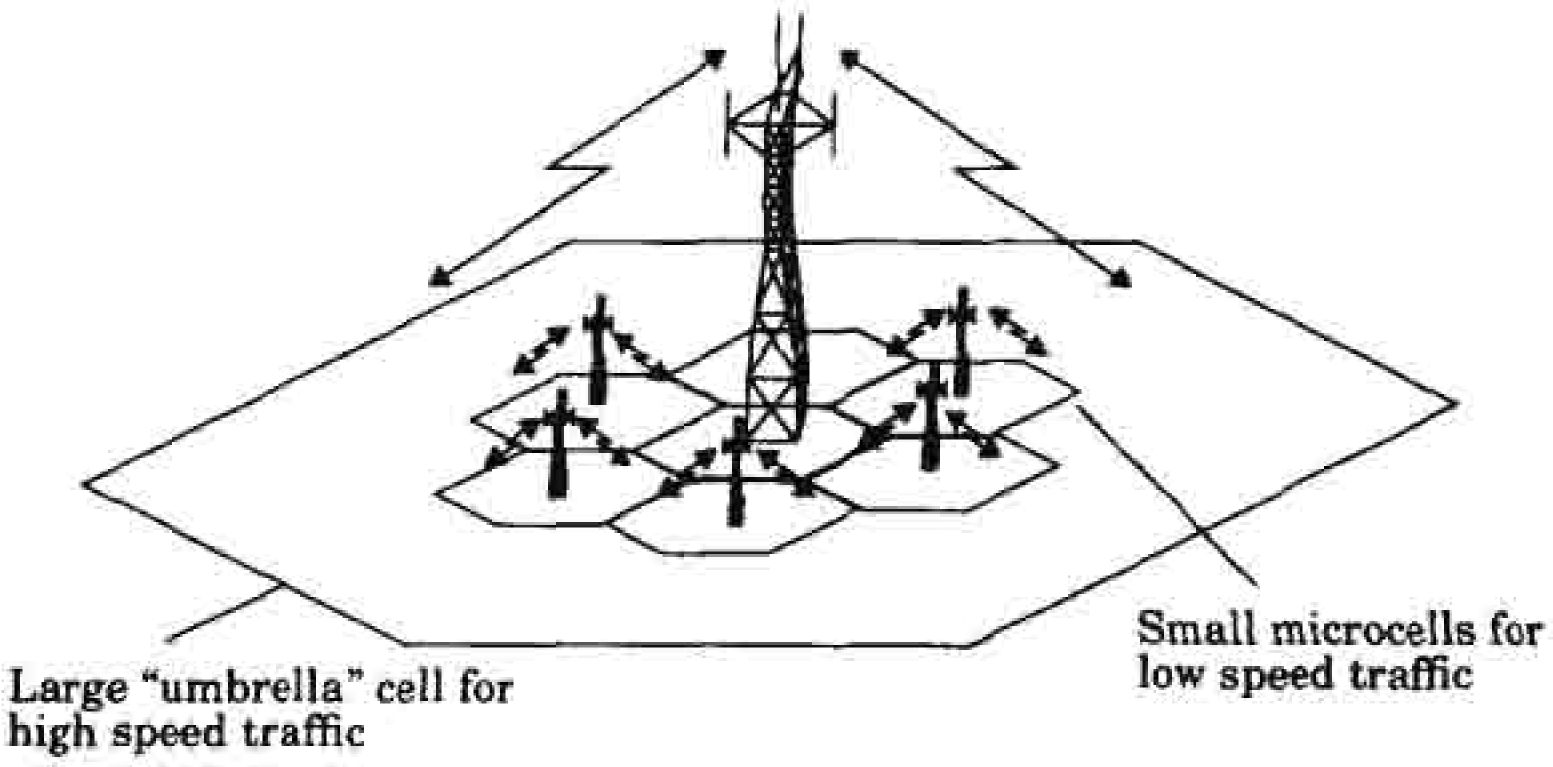

Figure 2.4
The umbrella cell approach.

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 sta-

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}} \tag{2.11}$$

For $N = 7$, the co-channel reuse ratio Q is 4.6, and the worst case S/I is approximated as 49.56 (17 dB) using equation (2.11), whereas an exact solution using equation (2.8) yields 17.8 dB [Jac94]. Hence for a 7-cell cluster, the S/I ratio is slightly less than 18 dB for the worst case. To design the cellular system for proper performance in the worst case , it would be necessary to increase N to the next largest size, which from equation (2.3) is found to be 12 (corresponding to $i = j = 2$). This obviously entails a significant decrease in capacity, since 12-cell reuse offers a spectrum utilization of 1/12 within each cell, whereas 7-cell reuse offers a spectrum utilization of 1/7. In practice, a capacity reduction of 7/12 would not be tolerable to accommodate for the worst case situation which rarely occurs. From the above discussion it is clear that co-channel interference determines link performance, which in turn dictates the frequency reuse plan and the overall capacity of cellular systems.

Example 2.2

If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) $n = 4$, (b) $n = 3$? Assume that there are 6 co-channels cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

Solution to Example 2.2

(a) $n = 4$

First, let us consider a 7-cell reuse pattern.
Using equation (2.4), the co-channel reuse ratio $D/R = 4.583$.
Using equation (2.9), the signal-to-noise interference ratio is given by
$S/I = (1/6) \times (4.583)^4 = 75.3 = 18.66$ dB.
Since this is greater than the minimum required S/I, $N = 7$ can be used.

b) $n = 3$

First, let us consider a 7-cell reuse pattern.
Using equation (2.9), the signal-to-interference ratio is given by
$S/I = (1/6) \times (4.583)^3 = 16.04 = 12.05$ dB.
Since this is less than the minimum required S/I, we need to use a larger N.
Using equation (2.3), the next possible value of N is 12, ($i = j = 2$).
The corresponding co-channel ratio is given by equation (2.4) as
$D/R = 6.0$.

Using equation (2.3) the signal-to-interference ratio is given by
$S/I = (1/6) \times (6)^3 = 36 = 15.56$ dB.

2.5.2 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.

If the frequency reuse factor is small, the separation between adjacent channels may not be sufficient to keep the adjacent channel interference level within tolerable limits. For example, if a mobile is 20 times as close to the base station as another mobile and has energy spill out of its passband, the signal-to-interference ratio for the weak mobile (before receiver filtering) is approximately

$$\frac{S}{I} = (20)^{-n} \qquad (2.12)$$

For a path loss exponent $n = 4$, this is equal to -52 dB. If the intermediate frequency (IF) filter of the base station receiver has a slope of 20 dB/octave, then an adjacent channel interferer must be displaced by at least six times the passband bandwidth from the center of the receiver frequency passband to achieve 52 dB attenuation. Here, a separation of approximately six channel bandwidths is required for typical filters in order to provide 0 dB SIR from a close-in adjacent channel user. This implies that a channel separation greater than six is needed to bring the adjacent channel interference to an acceptable level, or tighter base station filters are needed when close-in and distant users share the same cell. In practice, each base station receiver is preceeded by a high Q cavity filter in order to reject adjacent channel interference.