Hand-Offs

Introduction

In the lecture on frequency reuse, we developed the strategy of splitting the ground up into different radio cells with various frequencies allocated amongst the cells. Users who are closer to base station “A” will typically talk to that base station using its frequencies while users who are closer to base station “B” will do likewise with that cell. However a great advantage of mobile phones is that you can move around during a call (well, maybe this isn’t such a great advantage for highway safety). What happens if a mobile user “M” starts off a call in cell A and then moves into cell B? If base station A continues to try and handle the call, at some point due to the increasing distance the *S/N* and/or *S/I* will drop below a usable level. It would be more appropriate at that point for M to communicate through base station B. M could hang up and make a new call that would at this point presumably be handled by B, but that’s not a very convenient approach. Instead we’d like the cellular system to make this switch automatically without disrupting the call. This process of moving a call from one cell to another is called a “handoff” or a “handover.”

Basic Handoff Algorithm

For the most part, the handoff process involves monitoring signal strength at/from several base stations. When the signal at/from the “primary” base station (the one handling the call) gets too weak the call is switched to the adjacent base station with the largest signal. Presumably this will be the geographically closest base station.

Consider the situation shown in Figure 14.1. Here a mobile “M” moves between two cells while maintaining a call. We assume the call was in initially handled by base station B1. Eventually the link quality between B1 and M will get too poor to maintain the call. At some point M should be linked up with base station B2.

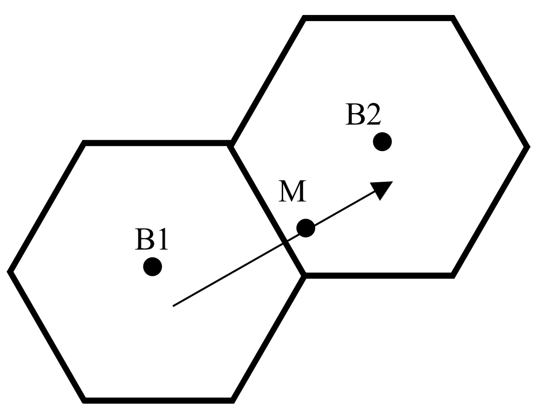

Figure 14.1: A mobile “M” moves between two cells served by base stations B1 and B2.

Using the model $P_r = P_0 - 10n\log(r/r_0)$ and assuming a distance of 4km between B1 and B2, we get the signal strengths shown in Figure 14.2. Here r is the distance from B1 and $4-r$ the distance from B2. (In this illustration we assume M moves along the line connecting B1 and B2.) As M moves along its path, P_1 decreases and P_2 increases. There will be some P_{min} that is the minimum usable signal. We cannot let the link signal fall below this level, so we have to take action before we reach this point. Typically we will specify some power level $P_{ho} > P_{\min}$ at which handoff is to take place. When $P_1 = P_{ho}$ we look at signals to/from other base stations. If the system is properly designed and functioning, one of these (at least) will be larger than P_1. In Figure 14.2 we will find that P_2 is larger. We would therefore switch the call over to B2 at a distance of about 2.5km, in this example.

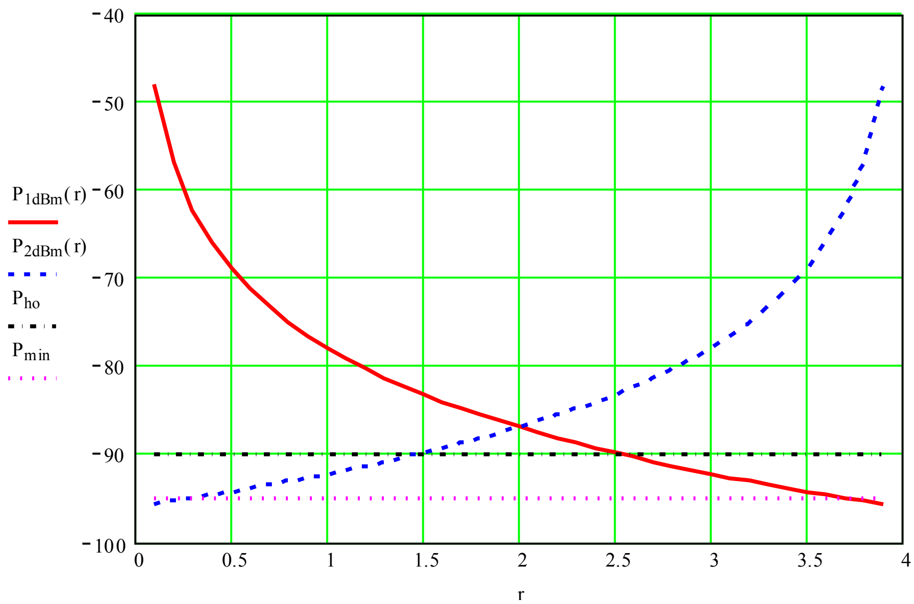

Figure 14.2: Simulated signal strengths for the situation in Figure 14.1. P_{1dBm} and P_{2dBm} are the received signals at/from B1 and B2. P_{ho} is the hand-off threshold while P_{min} is the minimum usable signal. Note that the horizontal axis has a linear scale while the vertical has a logarithmic scale.

Note that if the mobile is traveling at some velocity v, then $r = vt$ and Figure 14.2 also corresponds to signal strengths vs. time. The amount of time between $P_1 = P_{ho}$ and $P_1 = P_{\min}$ is the amount of time the system has to complete the handoff. If it cannot achieve the handoff in this time then the call is "dropped."

Example 14.1

If $P_r = P_0 - 10n\log(r/r_0)$ and $r = vt$ with a v of 100 km/hr and an n of 3, and if P_{ho} and P_{min} are -90dBm and -95dBm, how long do you have to complete a hand off? Assume a distance of 1 km.

$\frac{dP_r}{dt} = \frac{dP_r}{dr}\frac{dr}{dt} = -\frac{10nv}{\ln(10)r}$. Plugging in the numbers we find a value of -0.36dB/sec. We have to complete the handoff by the time P_r drops by 5 dB. This will happen in about 14 seconds.

Small-scale fading introduces a complication. In practice the signal strength vs. distance/time plot will not look like 14.2. Instead there will be superimposed Rayleigh fading as in Figure 9.1. It would be disastrous to initiate a handoff every time a fade dropped the signal below P_{ho}. For that reason we need to monitor the *time-averaged* signal.

Another detail is that the handoff does not occur at the boundary between the cells ($r = 2$ in the figure) but a little farther out ($r = 2.5$ in this example). To see why this is so, imagine that you set P_{ho} so that handoff occurs right at the cell boundary. The two base stations ideally have the same signal strength at this point and with even a little bit of variation in the signals you could end up trying to handoff back and forth several times. Moreover with two signals of the same strength it you don't gain much by the handoff. Therefore, we set P_{ho} so that we are well into the other cell before handoff occurs. Now, imagine the mobile turned around and headed back towards B1 after being handed off to B2. Handoff to B1 would now occur well inside B1's cell ($r = 1.5$ in this example) on a circular boundary centered on B2. This is a type of "handoff hysteresis." It defines a circular contour outside the hexagonal cell boundary and a more-or-less six-sided, piecewise-circular "contour" inside the hexagonal cell boundary, as shown in Figure 14.3.

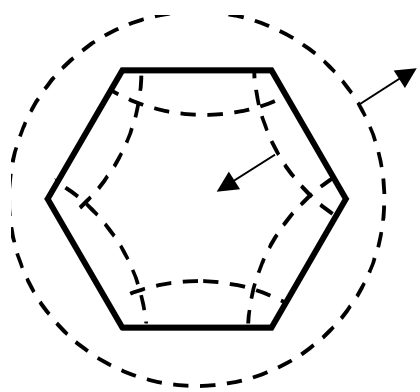

Figure 14.3: Hand-off "hysteresis" effect. When leaving the cell, hand off occurs (ideally) at outer circle. When entering the cell, hand off occurs at the inner "contour."

The hexagonal boundary defines those points at which *initiated* calls will be assigned to that cell's base station. The outer circle defines where outwardly traveling mobiles will be handed off *from* this cell. The inner contour more-or-less defines where inwardly traveling mobiles will be handed off *to* this cell (you can come up with situations where this will not be the case). In the real world propagation effects due to the terrain will distort these boundaries, but the essential idea will still apply.

Note that in order for a handoff to occur, the new base station must have an available channel. If all its channels are being used then a handoff cannot occur. In some systems a fraction of each base station's channels are reserved for hand off.

1G Approach to Handoff

The "First Generation" (1G) cellular system in the US is the AMPS (Advanced Mobile Phone System). This analog FM cellular system got its start in 1983. At that time "smarts" in the form of embedded controllers and microprocessors were considerably more expensive and power hungry, so as much as possible, algorithmic computation is assigned to the base stations. The base station monitors the uplink signal strength from the mobile. When the mobile needs to be handed off, the Mobile Switching Center (MSC) tells adjacent base stations to monitor and report the signal strength of that mobile. In this way the MSC determines which base station the mobile should be handed off to and coordinates the handoff between the two base stations.

2G Approach to Handoff

There are three types of "Second Generation" (2G) systems in the US, usually referred to as: TDMA, GSM, and CDMA. At the time these systems were standardized, it was feasible to include more "brains" in the handsets. Therefore TDMA and GSM systems use Mobile Assisted Handoff (MAHO). In MAHO, the mobile monitors the signals of the serving and adjacent base stations. When it finds that the signal from an adjacent base station is preferable, it alters its serving base station so a handoff can be initiated. This reduces the network overhead needed to monitor and initiate handoffs and allows them to be completed in a shorter time. We will cover this is more detail when we discuss these particular systems.

All of the handoffs we have considered here are so-called "hard" handoffs in which a mobile is assigned to only a single base station at a time. CDMA systems can employ "soft" handoffs in which signals simultaneously received at two base stations are optimally combined. We will study this in a future lecture.

References

1. Rappaport, T. S., *Wireless Communications: Principles and Practice*, Prentice Hall, 1996, ISBN 0-13-375536-3.

2. Garg, V. K. and J. E. Wilkes, *Wireless and Personal Communications Systems,* Prentice Hall, 1996, ISBN 0-13-234626-5.