EE 359 - Wireless Communications - Fall 2003

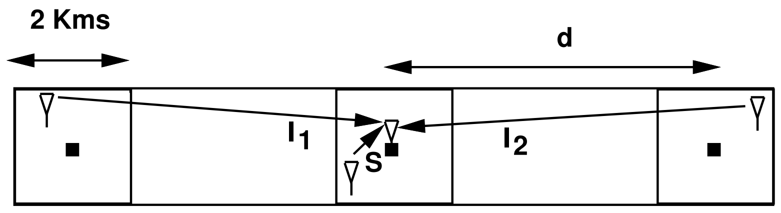
Homework 1: Due Thursday 10/9 (noon).

1. (20 pts.) This problem shows how different propagation models can lead to very different SNRs (and therefore different link performance) for a given system design. Consider a linear cellular system using frequency division, as might operate along a highway or rural road, as shown in the figure below. Each cell is allocated a certain band of frequencies, and these frequencies are reused in cells spaced a distance d away. Assume the system has square cells which are two kilometers per side, and that all mobiles transmit at the same power P. For the following propagation models, determine the minimum possible distance between the cells operating in the same frequency band should be spaced so that uplink SNR (the ratio of the minimum received signal-to-interference power (S/I) from mobiles to the base station) is greater than 20dB. You can ignore all interferers except from the neighboring two cells.

   (a) Propagation for both signal and interference follow a free-space model (Equation 2.3 of Chapter 2).

   (b) Propagation for both signal and interference follow the simplified path loss model (Equation 2.26 of Chapter 2), with $d_0 = 100$m, $K = 1$, and $\gamma = 3$.

   (c) Propagation for the signal follows the simplified path loss model with $d_0 = 100$m, $K = 1$, and $\gamma = 2$, while propagation of the interfererence follows the same model but with a path loss of $\gamma = 4$.



2. (20 pts) This problem illustrates some of the economic issues facing service providers as they migrate away from voice-only systems to mixed-media systems. Suppose you are a service provider in a cellular system. You have 120KHz of bandwidth which you must allocate between voice and data users. The voice users require 20Khz of bandwidth, and the data users require 60KHz of bandwidth. So, for example, you could allocate all of your bandwidth to voice users, resulting in 6 voice channels, or you could divide the bandwidth to have one data channel and three voice channels, etc. Suppose further that this is a time-division system, with timeslots of duration T. All voice and data call requests come in at the beginning of a timeslot and both types of calls last T seconds. There are six independent voice users in the system: each of these users requests a voice channel with probability .8 and pays \$.20 if his call is processed. There are two independent data users in the system: each of these users requests a data channel with probability .5 and pays \$1 if his call is processed. How should you allocate your bandwidth to maximize your expected revenue?

3. (20 pts) Cellular systems today are moving from large cells (macrocells) of radius around 1 mile to smaller microcells and picocells, of radius from 100 to 1000 feet. The reason for this migration is that smaller cells offer considerably more system capacity. The downside is that if cell size is smaller, more

cells are needed to cover a given city, resulting in greater expense (base station cost) and network complexity (more handoffs and routing is more difficult). This problem demonstrates the capacity increase as cell size decreases.

Consider a square city that is 100 square kilometers. Suppose you design a cellular system for this city with square cells, where every cell (regardless of cell size) has 100 channels so can support 100 active users (in practice the number of users that can be supported per cell is mostly independent of cell size as long as the propagation model and power scale appropriately).

(a) What is the total number of active users that your system can support for a cell size of 1 square kilometer?

(b) What cell size would you use if you require that your system support 250,000 active users?

Now we consider some financial implications based on the fact that users do not talk continuously. Assume that Friday from 5-6 pm is the busiest hour for cell phone users. During this time, the average user places a single call, and this call lasts two minutes. Your system should be designed such that the subscribers will tolerate no greater than a two percent blocking probability during this peak hour (Blocking probability is computed using the Erlang B model: $P_b = (A^C/C!)/(\sum_{k=1}^{C} A^k/k!)$, where C is the number of channels and $A = U\mu H$ for U the number of users, μ the average number of call requests per unit time, and H the average duration of a call. See Section 2.6 of Rappaport, EE276 notes, or any basic networks book for more details).

(c) How many total subscribers can be supported in the macrocell system (1 square Km cells) and in the microcell system (with cell size from part (b))?

(d) If a base station costs $500,000, what are the base station costs for each system?

(e) If users pay 50 dollars a month in both systems, what will be the montly revenue in each case. How long will it take to recoup the infrastructure (base station) cost for each system?

4. (20 pts.) Directional antennas are a powerful tool to reduce the effects of multipath as well as interference. In this problem we illustrate the multipath mitigation for the two-ray channel model (Section 2.3.1). Specifically, we will see that directional antennas along the LOS path for the two-ray model can reduce the attenuation affect of the ground wave cancellation. In this problem you will demonstrate this reduction by plotting the dB power ($10\log_{10} P_r$) versus log distance ($\log_{10} d$) for the two-ray model with the parameters $f = 900$MHz, R=-1, $h_t = 50$m, $h_r = 15$m, $G_l = 1$, and the following values for G_r: $G_r = 1, .316, .1$, and $.01$ (i.e. $G_r = 0, -5, -10$, and -20dB, respectively). Each of your 4 plots should range in distance from $d = 1$m to $d = 100,000$m. You should calculate and mark the critical distance $d_c = 4h_th_r/\lambda$ on each plot. Also normalize the plots to start at approximately 0dB. Finally, show the asymptotes $10\log_{10}(d^{-2})$ and $10\log_{10}(d^{-4})$ for $d \geq d_c$ starting at the value d_c. The reason we plot the power loss versus log distance is so that these asymptotes become straight lines with slopes 2 and 4, respectively, which makes it easy to see what the asymptotic power falloff is. *Note: the easiest way to generate these plots is using a computer program, however you can also approximate the plots by calculating several points by hand and using these to sketch the plots.*

5. (20 pts) Power Outage: Many PCS applications use the power outage probability as a performance measure, where the power outage probability is defined as the probability that the received power falls below some power threshold T_p. Typically, the bit error rate for received power below T_p is unacceptable for the desired application. The power outage is typically calculated based on log-normal shadowing, since an outage should only be declared when the channel is bad for a relatively long time period (as opposed to short power dips due to multipath fading). In this problem we will explore the impact of different log-normal shaodowing parameters on outage probability.

Consider a a cellular system where the received signal power is distributed according to a log-normal distribution with mean μ dB and standard deviation σ_ψ dB. Assume the received signal power must be above $T_p = 10$ dB for acceptable performance. For each of the problems below, you should first express the outage probability in terms of T_p, μ_ψ, and σ_ψ using Q functions, then substitute the numbers to get your solutions.

(a) What is the outage probability when the log-normal distribution has $\mu_\psi = 15$dB and $\sigma_\psi = 8$dB?

(b) For $\sigma_\psi = 4$dB, what value of μ_ψ is required such that the outage probability is less than 1%, a typical value for PCS systems?

(c) Repeat (b) for $\sigma_\psi = 12$dB.

(d) One proposed technique to reduce outage probability is to use macrodiversity, where a mobile unit's signal is received by multiple base stations and then combined. Explain why this might reduce outage probability.