Homework 1
Due: February 12, 2018

1. 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 (see Figure 1). 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, 2 km per side, and that all mobiles transmit at the same power P. For the following propagation models, determine the minimum distance that the cells operating in the same frequency band must be spaced so that uplink SNR (the ratio of the minimum received signal-to-interference or S/I power from mobiles to the base station) is greater than 20 dB. You can ignore all interferers except those from the two nearest cells operating at the same frequency.

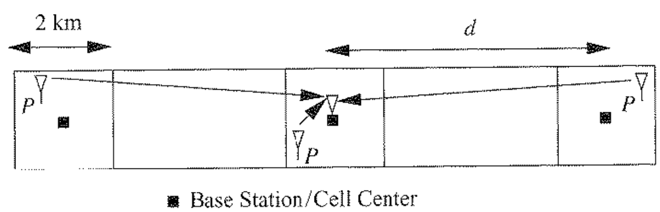

Figure 1: Linear cellular system for problem 1

   (a) Propagation for both signal and interference follow a free-space model.

   (b) Propagation for both signal and interference follow the simplified path-loss model with $d_o = 100$ m, $K = 1$, and $\gamma = 3$.

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

2. Assume that local average signal strength field measurements were made inside a building, and post processing revealed that the measured data fit a distant-dependent mean power law model having a log-normal distribution about the mean. Assume the mean power law was found to be $P_r(d) \propto d^{-3.5}$. If a signal of 1 mW was received at $d_0 = 1$ m from the transmitter, and at a distance of 10 m, 10% of the measurements were stronger than -25 dBm, define the standard deviation, $\sigma_{\psi_{dB}}$, for the path loss model at $d = 10$ m.

3. Suppose that a mobile station is moving along a straight line between base stations BS1 and BS2, as shown in Figure 2. The distance between the base stations is $D = 1600$ m. The received power (in dBm) at base station i, from the mobile station, is modeled as (reverse link)

$$P_{r,i}(d) = P_0 - 10n\log_{10}(d_i/d_0) + \psi_i, \quad (dBm), \quad i = 1, 2. \tag{1}$$

where d_i is the distance between the mobile and base station i, in meters, P_0 is the received power at distance d_0 from the mobile antenna, and n is the path loss exponent. The term $P_0 - 10\gamma\log_{10}(d_i/d_0)$ is usually called local area mean power. The terms ψ_i are zero-mean Gaussian random variables with

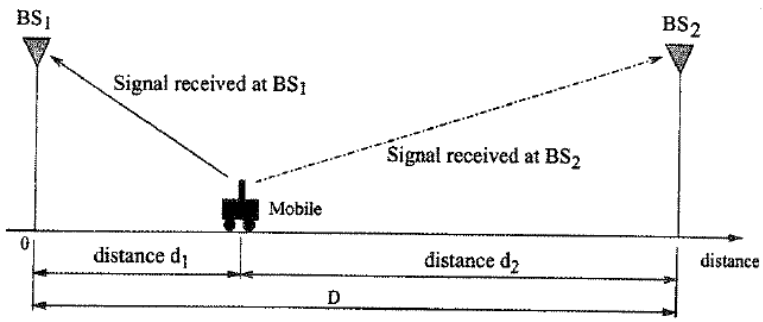

Figure 2: Mobile moving along straight line between BS1 and BS2.

standard deviation σ, in dB, that model the variation of the received signals due to shadowing. Assume that the random components ψ_i of the signals received at different base stations are independent of each other. n is the path loss exponent.

The minimum usable signal for acceptable voice quality at the base station receiver is $P_{r,min}$, and the threshold level for handoff initiation is $P_{r,HO}$, both in dBm.

Assume that the mobile is currently connected to BS1. A handoff occurs when the received signal at the base station BS1, from the mobile, drops below threshold $P_{r,HO}$, and the signal received at candidate base station BS2 is greater than the minimum acceptable level $P_{r,min}$.

Using the parameters in Figure 3, determine:

Parameter	Value
n	4
σ	6 dB
P_0	0 dBm
d_0	1 m
$P_{r,min}$	–118 dBm
$P_{r,HO}$	–112 dBm

Figure 3: Parameters for Problem 3

(a) The probability that a handoff occurs (Pr[handoff]), as a function of the distance between the mobile and its serving base station. Show your result in a plot Pr[handoff] vs. distance d_1.

(b) The distance d_{ho} between base station BS1 and the mobile, such that the probability that a handoff occurs is equal to 80%.

4. A transmitter provides 15 W to an antenna having 12 dB gain. The receiver antenna has a gain of 3 dB and the receiver bandwidth is 30 kHz. If the receiver system noise figure is 8 dB and the carrier frequency is 1800 MHz, find the maximum T-R separation that will ensure that a SNR of 20 dB is provided for 95% of the time. Assume $\gamma = 4$, $\sigma_{\psi_{dB}} = 8$ dB, and $d_0 = 1$ km. Note: The noise factor, F, is defined as the ratio of the output noise power, N, of a device to the portion thereof attributable to thermal noise in the input termination at standard noise temperature T_0 (usually 290 K). The

following equation might be useful: $N = FBKT_0$, where B is the input signal bandwidth and K is Boltzmann's constant. The relation between noise figure and noise factor is $Noisefigure = 10 \log F$.

5. Four received power measurements were taken at distances of 100 m, 200 m, 1 km, and 2 km from a transmitter. The measured values at these distances are -0 dBm, -25 dBm, -35 dBm, and -38 dBm, respectively. It is assumed that the path loss for these measurements follows the model

$$PL(d)[dB] = \overline{PL}(d) + \psi_{dB} = \overline{PL}(d_0) + 10\gamma \log_{10}(d/d_0) + \psi_{dB} \tag{2}$$

where $d_0 = 100$ m.

(a) Find the minimum mean square error (MMSE) estimate for the path loss exponent γ. You can use the matlab function fmincon to perform this optimization.

(b) Calculate the standard deviation of shadowing about the mean value.

(c) Estimate the received power at $d = 2$ km using the resulting model.

(d) Predict the likelihood that the received signal level at 2 km will be greater than -35 dBm. Express your answer as a Q-function.

6. **WiFi on Steroid:** This question is based on the paper "WiFi on Steroid: 802.11ac and 802.11ad" by Verma, L.; Fakharzadeh, M.; and Sunghyun Choi. For each discussion point, please provide a short paragraph or list to illustrate the point. Summarize the technologies and features in 802.11 ac & ad systems. In particular discuss the following aspects:

o The operating frequency. Comment on the channel characteristics in that range.

o Channel BW.

o Number of antennas used in MIMO.

o The highest modulation technique.

o Any other advanced transmission techniques.

o The maximum data rate.

o Comment on this data rate: Is it peak or sustainable? Is it for a single user in the whole system? Does it account for interference from other users or systems in the same frequency band?

7. **mmWave for 5G cellular:** This question is based on the paper "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!" by Rappaport, T.S.; Shu Sun; Mayzus, R.; Hang Zhao; Azar, Y.; Wang, K.; Wong, G.N.; Schulz, J.K.; Samimi, M.; and Gutierrez, F. For each discussion point, please provide a short paragraph or list to illustrate the point.

o What is the main aim of this article?

o Describe the setup of the measurement campaign. Be specific about the antenna settings and how measurements are taken (resolutions in time, freq, space ...).

o What are the main characteristics of propagation at 28 GHz? Be specific about pathloss, shadowing, multipath profile.

o What is the propagation range for 28 GHz signals, specify Tx and Rx power. Is it feasible for cellular communications?

o Discuss differences between 28 GHz and 38 GHz propagations.