Homework 1 (Due: before class in week 4)

Part A. Fading and Diversity
A key challenge with wireless channels is fading, in which the strength of the received signal falls sharply due to features of the RF environment as the receiver moves. If not addressed, fading will result in outages or periods in which the channel cannot be used. A key concept for combating fading is diversity, in which information is sent across multiple independent channels. Since it is unlikely that all channels will experience fades at the same time, outages can be reduced. This question asks you to explore fading and diversity using measured data from real 802.11 channels.

Do this work in Octave to familiarize yourself with that platform for the next homework. You are encouraged to work with a partner (teams of two people only) but only for this part of the homework. We recommend that you read an Octave/Matlab tutorial before starting. Note that all of our answers use very short scripts (of only a handful of lines each!).

Dataset: While a laptop is moved around the Allen center, we measured the strength of wireless signals received from one 802.11 AP. You are given a dataset of measurements that can be conveniently loaded into Octave as a multidimensional matrix. The command “load cse561.mat” will load a 12278x2x30 matrix into Octave as the variable M. The first index is the timestep in 4 ms intervals. At every timestep, measurements were recorded at each of two different antennas on the laptop: the second index is the antenna number. At every time and each antenna, measurements were recorded for the strength of the wireless signal for 30 sub-bands of the roughly 20 MHz of spectrum used for an 802.11 channel. The third index is the sub-band number. Each measurement is the strength of the received signal for the indicated sub-band, antenna and timestep. Signal strengths are power given in dBm and the threshold strengths needed to use the different possible modulations are given in the table below; the above load command also creates variables t_bpsk, t_qpsk, t_64qam, and t_64qam. If the strength is less than the threshold then the modulation cannot be reasonably decoded. Higher modulations carry more bits per symbol but require a stronger signal.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Bits/Symbol</th>
<th>Threshold (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>1</td>
<td>-91</td>
</tr>
<tr>
<td>QPSK</td>
<td>2</td>
<td>-88</td>
</tr>
<tr>
<td>16-QAM</td>
<td>4</td>
<td>-82</td>
</tr>
<tr>
<td>64-QAM</td>
<td>6</td>
<td>-76</td>
</tr>
</tbody>
</table>

Question 1. Fading and Outage: Hank Levy has commissioned the modern artist Y.R. Less to create a piece titled “1111101011011110” based on RF measurements. As Y.R. Less’s assistant, your job is to plot an actual RF fade over time and space along with its outage profile. You select the data from antenna 1 and sub-band 1. Turn in a plot of the signal strength (y-axis) over
all timesteps (x-axis). Include on this plot a line for each of the four modulations to show the timesteps for which the modulation can be used. Also compute and turn in a table of the outage probability and average bits/timestep (as a measure of capacity) for each of the four modulations over all timesteps. (The point of this question is to get you to look at fades. You may wish to visualize more data as you tackle the next questions.)

**Question 2. Coding Diversity:** In 802.11, information is coded (spread) across multiple sub-bands on the same antenna so that it can still be decoded even if some of the channels are in outage. This is a form of diversity. Let’s see how much it helps. Suppose you have a fabulous code in which redundancy is added to 25 sub-bands worth of information and the result is sent using 30 sub-bands such that the whole 25 sub-bands worth of information can be successfully received if any 25 (or more) sub-bands are not in outage; if more than 5 channels are in outage then no information is received. To assess the benefit of coding, we compare against the uncoded case in which 30 sub-bands worth of information is sent directly using 30 sub-bands. All 30 sub-bands must now not be in outage, or we will miss some information and lacking the complete packet will consider that no information was received.

Using the data for antenna 1, plot the same kind of graph as in the previous question for both the uncoded and coded signal and when the four modulations can be used. For the uncoded signal, plot the strength of the weakest sub-band, as this is the level that determines whether all 30 sub-bands can be received. For the coded signal, plot the strength of the 6th weakest sub-band, as 25 of 30 sub-bands are at or above this level so it determines whether a coded signal can be received. For both cases, also compute a table of the outage probability and the average bits/timestep/sub-band for each of the four modulations over all timesteps. Turn in both plots and tables. Briefly describe whether and how coding helps.

**Question 3. Antenna Diversity:** You are designing a new mobile phone. Coding, as used above, reduces the useful data rate because some channels must carry redundant information. A waste of good bandwidth! A different design is to use the diversity of another antenna and receive two copies of the signal. If either antenna has a strong signal then the sub-bands can be successfully decoded. The cost of this design is that another antenna and signal processing must be added to the mobile. You are evaluating two alternatives. The first alternative (select-antenna) is to select at each timestep the antenna that has the strongest signal totaled across all sub-bands. The hardware for this is simple. The second alternative (select-sub-band) is to select at each timestep and for each sub-band the antenna that has the strongest signal. The hardware for this is less simple. These designs should improve the situation compared to the basic setup of using a single antenna. Both kinds of selection can be used with coded or uncoded transmissions, giving four combinations for you to evaluate.
Plot the same kind of graph as in the previous question for all four signals showing when the four modulations can be used. You will have to compute how antenna diversity changes the received signal. For all four cases, also compute a table of the outage probability and average bits/ timestep/ sub-band for each of the four modulations over all timesteps. Turn in all plots and tables. Briefly say whether antenna diversity helps and how it compares to coding.

**Part B. Protocol Layering.**
Use the Wireshark tool to examine the packet trace in the supplied file (on the web site). The trace shows the TCP packets exchanged when a Web browser on the machine lorikeet.cs.washington.edu fetched the top-level page from the server www.cs.washington.edu. Your goal is to explore this trace and the protocol layering of the packets that are in it to see network traffic first hand and answer the question below. You will need to learn a little about the Wireshark tool to do this. There is much information at the Wireshark site [http://www.wireshark.org/](http://www.wireshark.org/). However, you simply might proceed as follows:

i. Launch Wireshark (on the CSE lab machines if you don’t want to install it)
ii. Open the trace file. The upper part of the window lists one line per packet. The lower part lets you look at protocols of the selected packet in detail (open the “+” areas).
iii. Look at the fields in each layer to see what kind of fields are there.
iv. You may sort the packets using the column headings to set the key.
v. You may enter a filter to look at a subset of the trace. (Click on “Expression” for help.)
vi. You may use the Statistics menu for some simple analyses, e.g., “Packet lengths”


b) Let’s see how much overhead protocols have. Consider the download direction from www.cs.washington.edu to lorikeet.cs.washington.edu and assume that the portion of packets up to and including the TCP header is “overhead”. The rest is “data”. Compute and turn in the percentage of the download bytes that is overhead. (Hint: sorting by packet length or using the Packet Length analysis will make it easy to get the numbers to add when you are ready.)

c) We only considered the download direction above, but the upload connection is mostly overhead. Would including the overhead of the upload direction significantly change your answer above?

**Part C. Textbook.**
1.10, 1.22, 2.3, 2.4, 2.46