Homework 2 (Due: before class in week 6)

Part A. 802.11 Receiver

We have now seen all the machinery used to send bits as wireless signals between 802.11 devices! In this part of the homework, you will build an 802.11 receiver in Octave. We will give you a signal with constellation points at each timestep, one symbol per subcarrier, and you will decode these points into bits. The processing is 802.11-like, rather than exactly 802.11, to avoid unnecessary details, and comes in several variations so that you can see for yourselves the effects of adding different processing.

You are encouraged to work with a partner (teams of two only) for this part of the homework, and to help each other with Octave questions (but not actual homework solutions) on the discussion board.

Our 802.11 design uses OFDM over 30 subcarriers, encoding QAM-16 symbols on each subcarrier to send 120 bits each timestep. The processing steps are shown in the figure below:

The shaded blocks are the ones you will develop. The blocks with asterisks (*) have optional processing that may or may not be present. Let’s go over them in detail:

1. Error coding takes in bits, adds redundancy using the code, and gives out coded bits. We use the Hamming 7, 4 code, a simplification of 802.11. For each 4 bits of input data, 7 bits of coded data are generated.

2. Interleaving spreads 120 bits at a time and groups them into 4-bit words, one for each subcarrier. In our transmitter, spreading is achieved in the following way: Number the words 0 to 29. The first bit is assigned to the most significant bit of word 0. The next bit is assigned to the most significant un-
filled bit of word \((X + 7) \mod 30\), where \(X\) is the number of the last word. This process will give each word exactly 4 bits, with each bit being appended to the end of the word.

If interleaving is not present, the first four bits will be assigned to word 0, the second four bits will be assigned to word 1, and so on.

3. Gray coding maps 30 4-bit words into 30 I/Q symbols for QAM-16 modulation. If there is no Gray coding, the words are mapped into symbols with the constellation numbered from 0 to 15 running left-to-right and top-to-bottom. We give you examples of both sets of constellations in the hw2.mat file.

4. The OFDM IDFT module implements 30 parallel OFDM subcarriers. It turns 30 I/Q symbols into a time-domain signal.

5. The Upconvert module shifts the signal up to a carrier frequency at which it is transmitted.

6. The Channel module implements a flat or frequency-selective fading channel, with (AWGN) noise.

7. The Downconvert module shifts the signal from a carrier frequency to baseband

8. The OFDM DFT module implements 30 parallel OFDM subcarriers. It turns the time domain signal into 30 I/Q symbols.

9. The Equalizer normalizes each symbol so that it sits in a constellation that looks like the transmitted one. (This involves amplifying weak signals and correcting for phase offsets that rotate the constellation.)

10. The Gray decoding maps 30 I/Q symbols into 30 4-bit words, reversing the procedure above.

11. The Deinterleave step de-spreads the 4-bit words into 120 bits, undoing the effects of interleaving above.

12. The Error decoding performs error correction. It takes 7 bits at a time and performs Hamming 7, 4 decoding to correct any bit errors, returning 4 bits of output at a time. The most-significant bit in the constellation is the first bit that should be passed to the Hamming decoder.

Dataset: We have given you a series of signals recorded after the Equalizer for a variety of transmitters: with and without Hamming coding, interleaving, and Gray coding; and with either a flat or frequency-selective fading channel. These signals can be loading from the hw2.mat file. See hw2.m for comments about the matrices found in hw2.mat (for example, what signals to use for which question), along with a few examples of how to work with the data.

The transmitted message is the same for all examples, and we give you raw bit-stream to compare against your results. There are lots of signals, but don’t despair – you only need the first set below to get started on the development of your receiver. The rest are for experiments.

1. No noise: We give you four signals without noise that you can use to test the three components of your system. One of the signals is just Hamming encoded, one is just Gray coded, one is just interleaved, and the last is Hamming and Gray coded and also interleaved.

2. Flat Fading: We give you four types of signals for a flat fading (i.e., AWGN) channel. 1) The signal is neither Hamming or Gray encoded, 2) only Hamming encoded, 3) only Gray encoded, or 4) both Hamming and Gray coded. For each of these four types of signals, we give you 5 versions, each having a different signal-to-noise ratio (SNR). The SNR for the channel is varied from 1 to 13 dB in 3 dB steps.
3. **Frequency Selective Fading**: To show the benefits of interleaving, we additionally give you signals that were passed through a frequency selective channel. The frequency-selective fading channel uses data you have analyze in Homework 1. We give you 4 signals in this case: 1) No Hamming, Gray coding, or interleaving, 2) Hamming and Gray Coded, 3) only interleaving with no coding of any type 4) with Hamming and Gray coding, and interleaving.

**Receiver Development**: Develop your receiver in steps as listed below and use the noise free signals we have given you to test each step. For each component, you can compare the original bit stream to the output when using your blocks to verify that it is working.

First, implement symbol decoding with Gray coding. We give you the Gray/non-gray coded constellations. You will need to read the I/Q symbols for each subcarrier, starting at subcarrier 0 and ending at subcarrier 29, and map them to the nearest constellation. At this point, you can answer Question 1.

Next, implement the Hamming decoder, and verify that it works using the noise-free, Hamming-only signal. Now, you can answer Question 2 below.

Last, implement de-interleaving and test it using the interleaved-only signal. You can then test all three components together. Now, you can answer Question 3 below.

**Question 1. Gray Coding**

a) For the AWGN signal that does not use any coding or interleaving and has an SNR of 7 dB, what is the received BER (Bit Error Rate) after your receiver decodes the bits? To calculate BER, compare the output of your receiver to the original bit-stream. The BER is just the ratio of the bits that were received incorrectly compared to the total number of bits.

b) How about the BER for the Gray coded version with the same SNR?

c) Now, looking at only the first 120 bits, what is the maximum and average number of errors in a row for the two cases? For each case, please show a 120 bit sequence with 1’s to indicate that the bit was received correctly and a 0 to indicate if it was received in error. The hw2.m file shows an example of how to generate this easily.

**Question 2. Hamming and Gray Coding in AWGN**

Now let’s see the impact of Hamming and Gray coding, and learn why 802.11 uses them both.

a) Plot SNR vs BER for the receiver processing the four flat-fading signals with variations of Hamming and Gray coding. The figure should have 4 lines to show the BER at each SNR for 1) the signal using no form of coding 2) with just Gray encoding 3) just Hamming encoding, or 4) both forms of coding.

b) You should find that the combination of Gray and Hamming coding is substantially better than using either one alone. Explain why this is likely the case.
Question 3. Interleaving in Frequency Selective Channels.
We have given you the signal power for each subcarrier across the frequency-selective channel; this data is taken from HW1.

a) By plotting the fading channel, tell us on what subcarriers you would expect to see bit errors given the -81 dBm threshold for QAM-16 (from HW1)? You do not need to turn in the plot, just list the subcarriers.

b) Now, looking at only the first 120 bits, compare the results of receiving the signal that has no coding or interleaving to that which has interleaving enabled. Turn in the sequence of 120 bits for both of these, with 1’s indicating that the bit was received correctly and a 0 meaning it was in error. Further tell us the average and maximum number of errors in a row for each of the two cases.

c) Finally, receive all of the four frequency-selective signals. Turn in a barplot that shows the BER for the signal that has 1) no coding or interleaving, 2) the version that is both Hamming and Gray coded, 3) the signal with just interleaving and 4) the signal with both forms of coding and interleaving.

Part B. Textbook.
3.10, 3.15, 3.16, 3.27, 4.10, 4.23, 4.27.