Principles of Wireless Communications

Lab 3(c): *OFDM*

In this final part of Lab 3, you will transmit your OFDM signal through the wireless channel using USRPs. You should use the same steps as in Lab 1, but instead of QAM/QPSK data, you will transmit OFDM data through the USRP.

You should be able to start with the code you developed in Lab 3(b). Just before the call to the channel simulation function, you should write your data in the format that the USRP expects it. Then, you can transmit your data through the air, receive it on a different USRP and try to decode it, using the code you developed in Lab 3 (b) starting after the channel simulation function.

Your **base goal** is to transmit BPSK data with a bit-error rate of less than 0.001, and at a data rate of 1Mpbs at least.

A **stretch goal** would be to change your data to QPSK/QAM data and transmit it through the channel using OFDM.

Note that 802.11 WiFi uses BPSK at its lowest rate of 6 Mbps, i.e. when the channel conditions are just good enough to establish a minimal link. At the highest rates, it uses 64 QAM modulation.

What's different with hardware compared to the simulation?

Lot's of issues could show up in hardware which you did not encounter in the simulations. Here are a summary of some that may show up

1. The frequency response of the system will have significant roll-off on the edges. This is because the filters in the hardware are non-ideal and as such have significant roll-off. In wifi, this is handled by sacrificing 6 subcarriers on one edge and 5 subcarriers on the other edge. If you don't do fftshift in your code, this corresponds to subcarriers 28 – 38 being unused (you can stick zeros in them, or ignore them when calculating error). Additionally, subcarrier 0 is also not used as it will be mapped to the carrier frequency in the transmitted signal and the carrier cosine usually leaks into the transmitted signal in hardware

2. The OFDM signal is EXTREMELY sensitive to clipping. Clipping can occur either at the transmitter, receiver or both. It happens when the amplitude of the signal is too high for the amplifiers or A2D or D2A converters in the hardware. Before you transmit your signal, you should ensure that its magnitude is less than 0.5 (you can apply a scale factor to the signal before writing to file). This will ensure that your signal does not clip in the digital hardware of the transmitter. The signal could still clip if your gain (Tx gain, Rx gain or both) is too high.
One way to detect clipping is to transmit a cosine plot the fft of the received signal. If there is clipping, you will see additional peaks beyond a peak at the frequency of your cosine.

3. The carrier frequency offset between transmitter and receiver may change with time. In the simulation, the same carrier frequency offset was assumed for the entire transmission. In

reality, the carrier frequency offset will drift. One way to handle this is to use pilots. Pilots are subcarriers for which known data is transmitted. By comparing the phase difference between the received signal and the transmitted signal at these pilot subcarriers, you can apply a correction per OFDM symbol (i.e. block of 64 point FFTs). E.g., suppose you placed pilots at subcarriers 7, 21, 44 and 58, and their values were p1, p2, p3, p4. You can estimate the phase offset by finding an average phase offset by doing the following:

$$\hat{\phi} = \frac{1}{4}\left(\angle\frac{Y_7}{p_1} + \angle\frac{Y_{21}}{p_2} + \angle\frac{Y_{44}}{p_3} + \angle\frac{Y_{58}}{p_4}\right)$$

You can then apply a phase correction to the entire 64 point block after the FFT (note that you need to calculate a new $\hat{\phi}$ for each block of 64 points in the FFT. This is a simple approach to using the pilot for correcting for drift. There are other more sophisticated approaches, which hopefully, you won't need.

4. You should only need a few OFDM symbols for channel estimation (e.g. WiFi uses 2), so you could reduce your overhead significantly by cutting down on how much time you use for channel estimation. One benefit of this is that the carrier frequency offset will not drift as much compared to a case where you use a lot of your transmit samples for channel estimation.

What to turn in?

Please submit a final report including Lab 3a and 3b along with all your code and plots of your received, equalized signals (before you quantize it to +1 or -1 for the BPSK case) and please provide a plot of the magnitude of the channel frequency response. If you are doing QPSK/QAM, a constellation plot from a few of the subcarriers should be included.