Communication Systems Laboratory
Lab 5: Cross-Device OFDM Transmission

Demo: May 7, 2025 (in class)
Report Due: 11:59 pm, May 9, 2025

The goal of this lab is cross-USRP transmission and reception. One homework submission per team. As before, please use the MATLAB live script (.mlx).

[Part 1] Cross-USRP Wi-Fi-Based OFDM transmission (60 points)

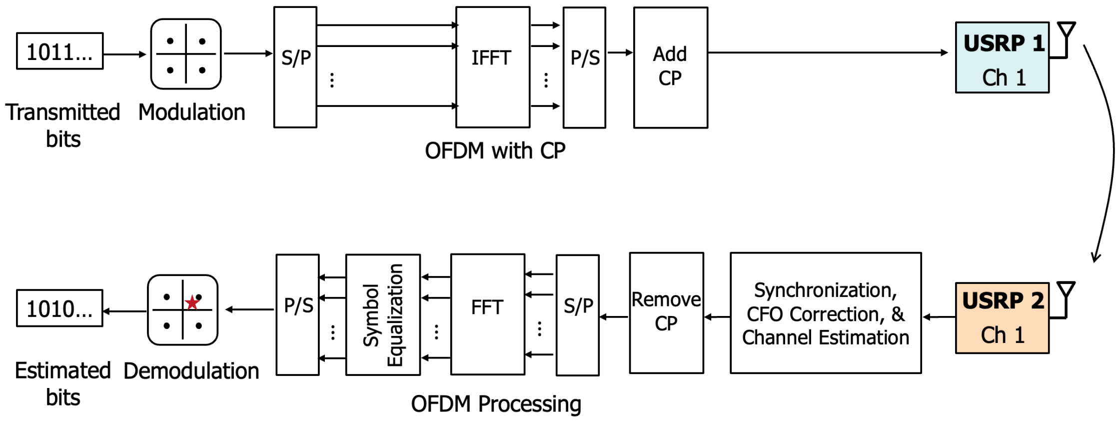

Figure 1. Signal generation and processing diagram.

While transmission and reception happen on the same USRP in Lab 4, different USRPs are used for transmission and reception in Lab 5. Since we have a limited number of USRPs, please share USRPs with other teams when testing your script. Please make sure the two USRPs have the same antenna configuration (i.e., operating at the same frequency range). USRP 1 is configured to have one transmit antenna, and USRP 2 is configured to have one receive antenna.

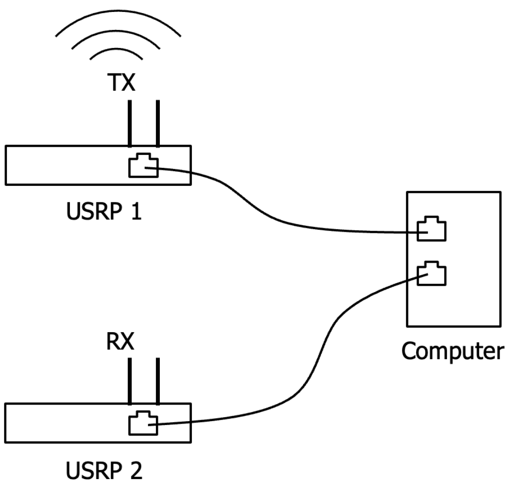

Figure 2. Connection to two USRPs.

Network Configuration

(1) Describe your network configuration that allows the computer to control two USRPs. More specifically, please describe the network configuration at your computer (IP & subnet mask) and the IP addresses you assign for the two USRPs.
(2) Explain how the above network configuration allows you to control two USRPs from your computer.

Resolve Cross-Device Synchronization Issues

Transmit a frame with 100 OFDM data symbols with 4-QAM modulation using USRP 1. Receive the frame with USRP 2. Develop a strategy that allows complete capture of a whole frame at USRP 2. For example, you can try:

- Append/prepend zeros to the transmit frame to make the beginning and the end of the frame visually apparent.
- Capture a longer range in the time domain than the transmitted frame.
- Retransmission scheme with ACK/NAK from USRP 2.
- …

(3) Explain the strategy you employ to ensure complete capture of a whole frame at USRP 2.
(4) Using the above proposed strategy, plot the received signal in the time domain at USRP 2. Mark the beginning and the end of the frame to show a successful capture of a whole frame.
(5) Without CFO correction, plot the received constellation (only the data tones). Do you observe the constellation rotating?
(6) Estimate the CFO of the received frame. What is the estimated CFO? Also, please explain your CFO estimation process. For instance, whether the CFO is estimated from STS, LTS, or both.
(7) Apply CFO correction to the received frame and then estimate the channel. Plot (i) the magnitude and (ii) the phase of the estimated channel vs subcarrier, with zero subcarrier in the middle. Describe and discuss the figure.
(8) Perform equalization on the received frame. Plot the CFO-corrected and equalized received constellation (only the data tones). Do you still observe the constellation rotating?
(9) Use the four pilot tones to track the residual CFO and further correct the data tones accordingly. With the assistance of the pilot tones, plot the received constellation (only the data tones). What do you observe?
(10) Demodulate the received signal at USRP 2 and calculate the bit error rate for this single frame. What is the BER? The goal is to obtain no (or very few) bit errors.
(11) Change the modulation to 16-QAM and repeat the experiment. Plot the CFO corrected, equalized, and pilot-assisted constellations as in (9).
(12) Following (11), what is the BER using 16-QAM modulation? How does it compare to the BER using 4-QAM in (10)?

Establish a Framework to Transmit Multiple Frames

Expanding your framework to transmit multiple frames, each with different random bits.

(13) Transmit and receive 20 frames, each with 100 OFDM symbols using 16-QAM modulation. Calculate the BER for each of the 20 frames. Plot BER per frame vs frame number, and provide the total BER for the 20 frames. The goal is to show that your transmission framework is robust enough that you can consistently collect usable experimental data. Thus, the BER

should be rather consistent across different frames.

(14) Calculate the BER per subcarrier based on the received 20 frames. Plot BER vs subcarrier. Describe and analyze the BER figure you obtain. Is there frequency-dependent BER behavior? If some subcarriers experience higher bit errors, what do you think is the reason?

(15) Please select three (or more) transmission distances (please measure the distance). At each distance, transmit and receive 20 frames, each with 100 OFDM symbols using 16-QAM modulation as in (13). Plot the total BER vs transmission distance, showing that the BER increases with distance.

[Part 2] Demo (40 points, no report needed)

There are two options for the demo:

1. Demo on May 7 in class.
2. Demo on May 14 in class with a 20% penalty (i.e., 0.8*original score).

If some part of your demo is not successful on May 7, you may demo again on May 14. The part you successfully demonstrated on May 7 will get full points without penalty.

(1) **(5 points)** Show that the two USRPs can be controlled from one computer.

(2) Show successful cross-device transmission of a frame with 100 OFDM symbols using 4-QAM modulation. Please show:
   - a) **(5 points) Received time domain signal**. Please mark the beginning and the end of the frame detected by your synchronization method, showing a correct detection of the transmitted frame.
   - b) **(5 points) CFO**. Please show the constellation before CFO correction, and the estimated CFO value.
   - c) **(5 points) Channel**. Please plot the estimated channel vs subcarrier (amplitude and phase).
   - d) **(5 points) Equalization**. Please plot the received constellation after CFO correction and equalization.
   - e) **(5 points) BER**. Please show that the BER is close to zero.
   - f) **(10 points) Repeatable**. Please repeat (a) to (e) once more to show that your system is robust enough. That is, (a) to (e) should be successful every time you test it.

Grading:

- 4 points for each problem. 60 points in total for 15 questions.
- 40 points for the class demo.