Communication Systems Laboratory

Lab 5: Cross-Device OFDM Transmission

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1. Network configuration

A. Describe your network configuration that allows the computer to control two USRPs. You can describe the network configuration at your computer (IP & subnet mask) and the IP addresses you assign for the two USRPs.

To control two USRPs, we need to assign separate IP addresses to each of them. Figure 1.1 and Figure 1.2 represent the network configurations of USRP 1 (as transmitter) and USRP 2 (as receiver):

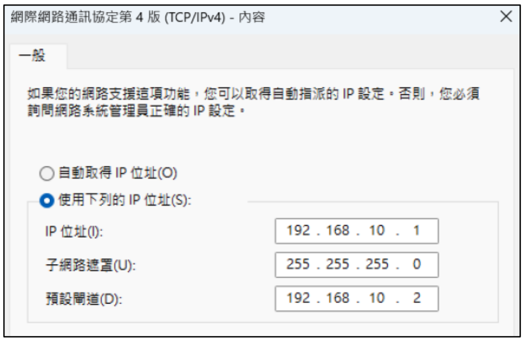

Figure 1.1 USRP 1 setting

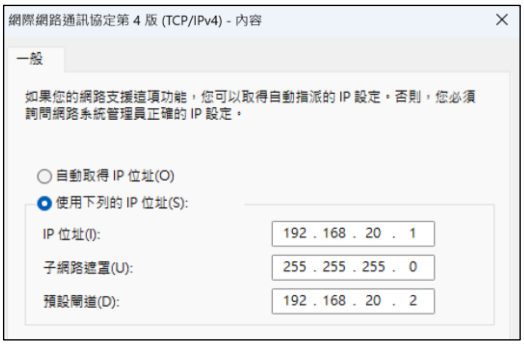

Figure 1.2 USRP 2 setting

We assign the IP address of USRP 1 to be 192.168.10.1, and the IP address of USRP 2 as 192.168.20.1. The subnet mask is set to 255.255.255.0, which indicates the first 3 entries of the IP address and the default gateway are the same.

B. Explain how the above network configuration allows the controlling of two USRPs from your computer.

After assigning different IP addresses to each USRP, we modified the IP address of the transmitter and the receiver of the MATLAB script used in Lab 4. Then, we used `findsdru` function to check the connectivity of each USRP device.

2. **Resolve cross-device synchronization issues**

A. Explain the strategy you develop to ensure complete capture of a whole frame at USRP 2.

In our experiment, we repeated the transmission of signal multiple times. Thus, we were able to locate the onset of the long training symbol. Then, we extend the parameter "Samples Per Frame" to 1.8 times of the original frame length. This value allows us to capture the whole frame at the receiver side.

B. 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.

The received signal at USRP 2 (as receiver) is plotted in Figure 2.1:

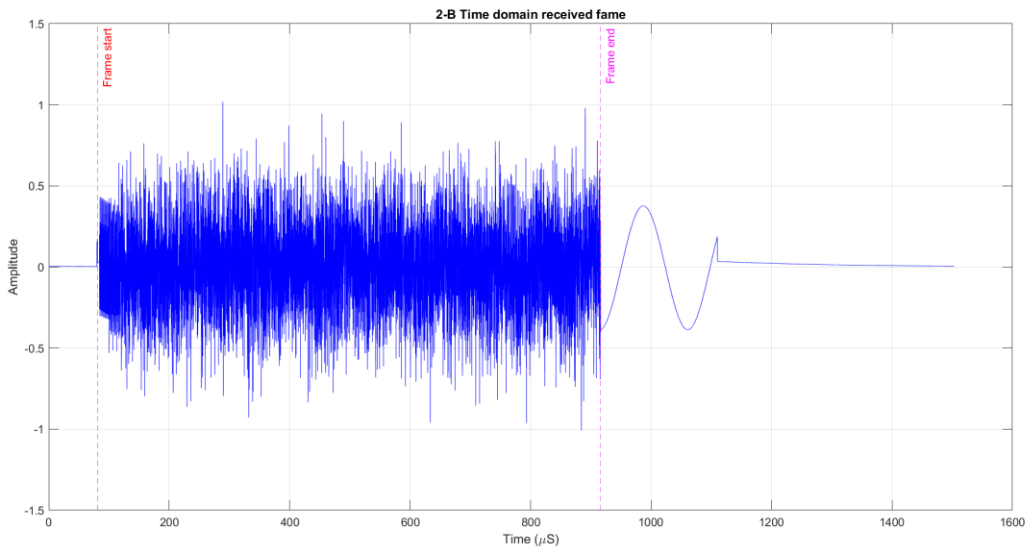

Figure 2.1 Received signal at USRP 2 in time domain

C. Plot (i) the magnitude and (ii) the phase of the estimated channel vs subcarrier. Describe and discuss the figure.

Figure 2.2 and Figure 2.3 depict the magnitude response and phase response of the estimated channel, respectively.

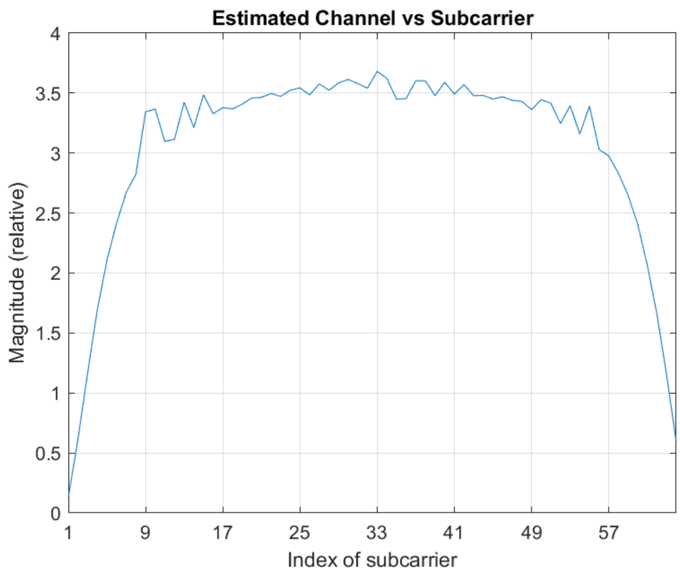

Figure 2.2 Magnitude response of estimated channel

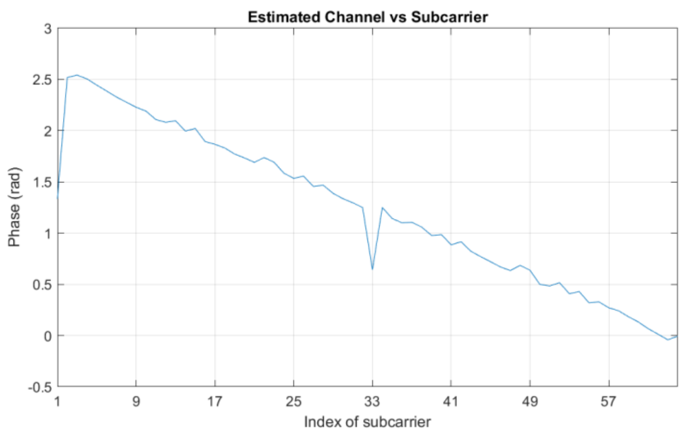

Figure 2.3 Phase response of estimated channel

In Figure 2.2, we observe that the magnitude response is lower in the first few carriers and the last few carriers. The frequency band of such carriers suffers is attenuated more by the filter because it is farther from the central frequency. Moreover, since applying inverse Fourier transform is equivalent to adding a window in the time domain, spectral leakage may influence edge subcarriers. Lastly, the power of subcarriers may be influenced by USRP, causing non-linear distortions.

As for Figure 2.3, which depicts the phase response of the estimated channel. We first observe that the phase response drops as the subcarrier index increases. This is because the accumulation of channel frequency offset (CFO) is different among each subcarrier. (Although we added an artificial CFO in the beginning of the simulation, such correction may not fully compensate for the offset of each carrier.)

In Figure 2.3, the phase response is lower in index 33, which represents the central frequency. This is due to the mechanism of OFDM. Subcarriers of frequency near the center interfere more significantly, which decreases the phase of the central frequency component. Also, waves of different frequency may have different phase velocities, such delay in phase may also result in interference.

D. Apply CFO correction and perform equalization to the received signal by USRP 2. Plot the received constellation.

Continuing from Lab 4, we applied an artificial CFO to correct the received signal. Figure 2.4 depicts the received constellation at USRP 2 (as receiver side) after applying CFO correction and performing equalization. The result is very similar to what we obtained in Lab 4.

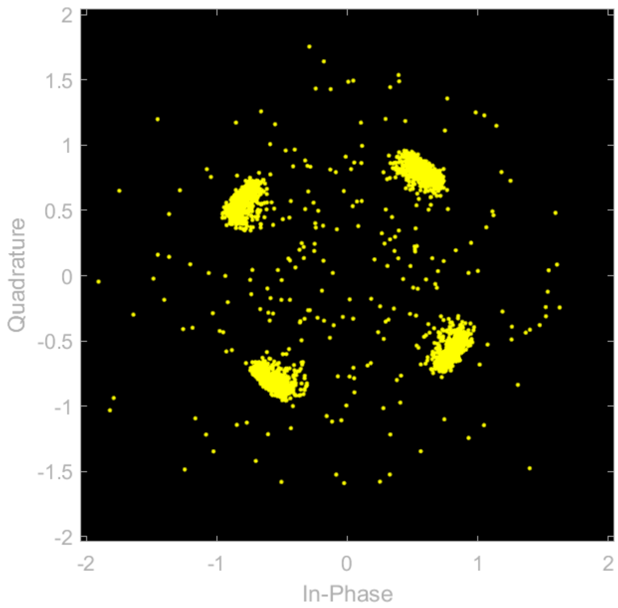

Figure 2.4 Corrected received signal constellation modulated in 4-QAM

E. 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.

   The bit-error rate varies from simulation to simulation due to different channel quality. In one estimation, we obtained a BER of 0.005859, which is very close to zero.

F. Change the modulation to 16-QAM and repeat the experiment. Plot the CFO corrected and equalized constellation at USRP 2.

   We simply change the modulation order from 4 to 16. Figure 2.5 depicts the CFO corrected and equalized constellation of the received signal at USRP 2.

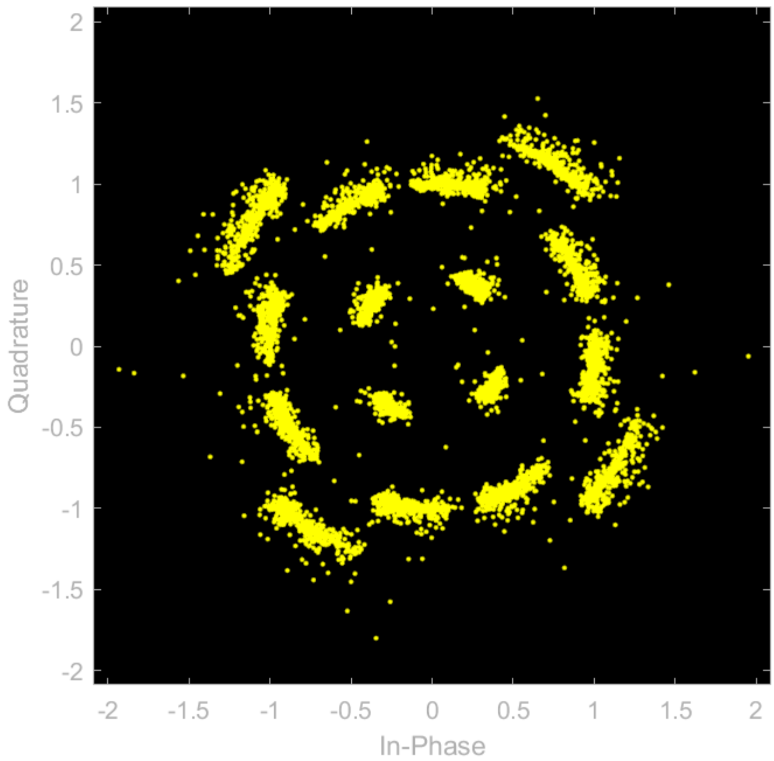

Figure 2.5 Corrected received signal constellation modulated in 16-QAM

3. Framework to transmit multiple frames

Expanding your framework to transmitting multiple frames, each with different random bits. Transmit and receive 100 frames, each with 100 OFDM symbols using 16-QAM modulation.

A. Calculate the BER for each of the 100 frames. Plot BER per frame vs frame number.

We first placed the two USRPs on the top of a table, but the BER of transmission became abnormally high, sometimes even higher than 50%. Therefore, we chose to replace the two USRPs in the drawer. The metallic surface of the drawer can reduce the noise from the environment, and the BER decreased to less than 1 %.

As for the simulation, we decided to manually run our program 100 times. Such a decision comes from our concern about the difficulty of debugging. Although writing a loop to automate the simulation is feasible, program execution may encounter errors halfway, and it won't be significantly faster than manual repetition.

We measured that each transmission takes around 12 seconds. Figure 3.1 lists the BER of each transmission.

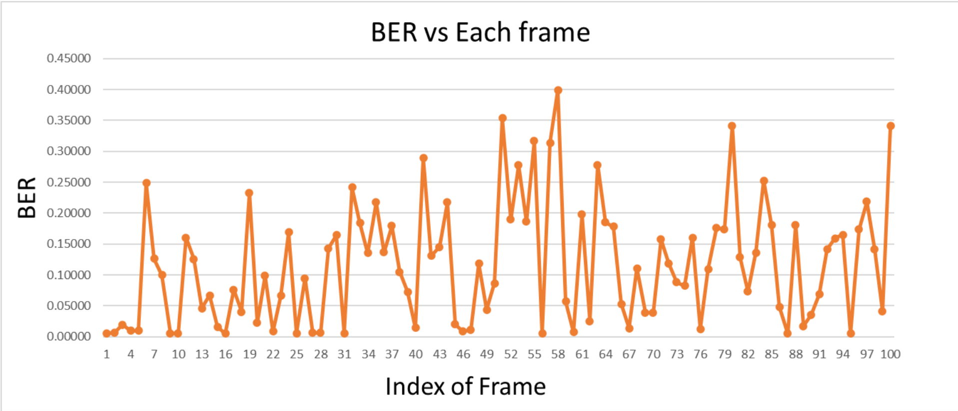

Figure 3.5 BER of each transmitted frame

The mean BER of the entire transmission is 0.11624, the variance is 0.00095, and the standard deviation is 0.09745. From Figure 3.5, we can see that BER varies in each transmission. We also plotted the distribution of BER of the entire transmission in Figure 3.6.

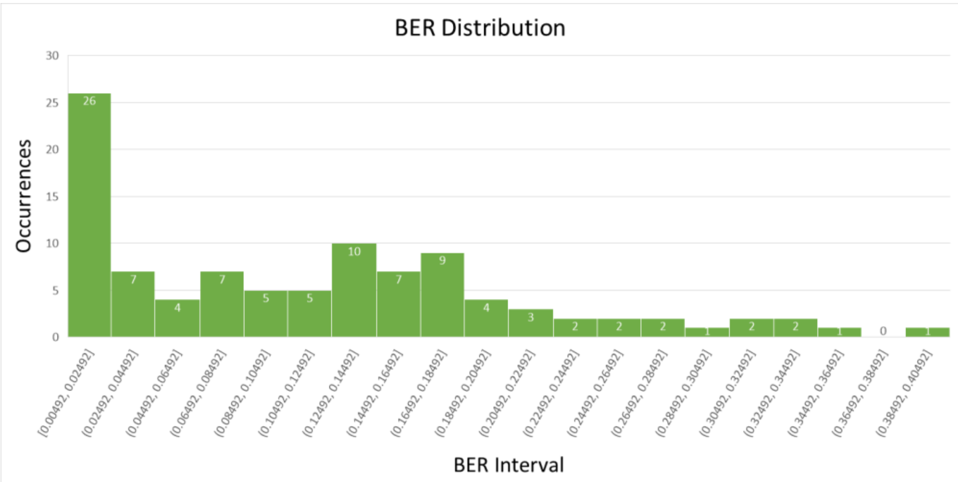

Figure 3.6 Distribution of BER in the transmission

B. Calculate the BER per subcarrier based on the received 100 frames. Plot BER vs subcarrier. Describe and analyze the BER figure you obtain.

Note that the result varies in each simulation. Figure 3.2 and Figure 3.3 depict results of 2 transmissions:

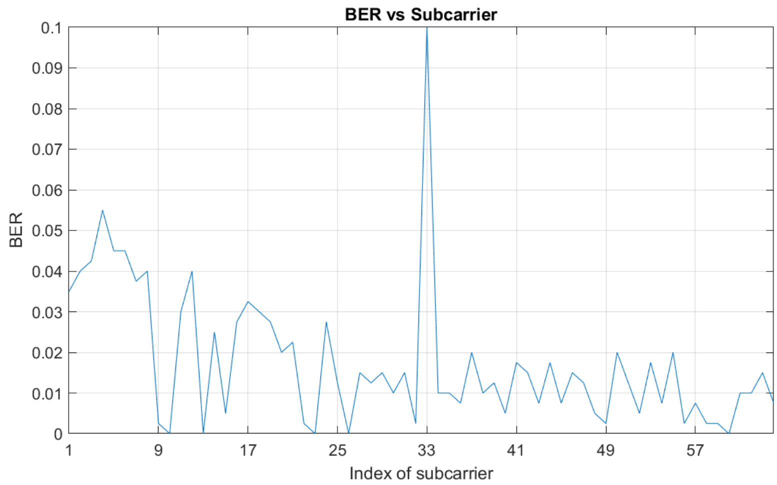

Figure 3.2 BER to subcarrier, Result 1

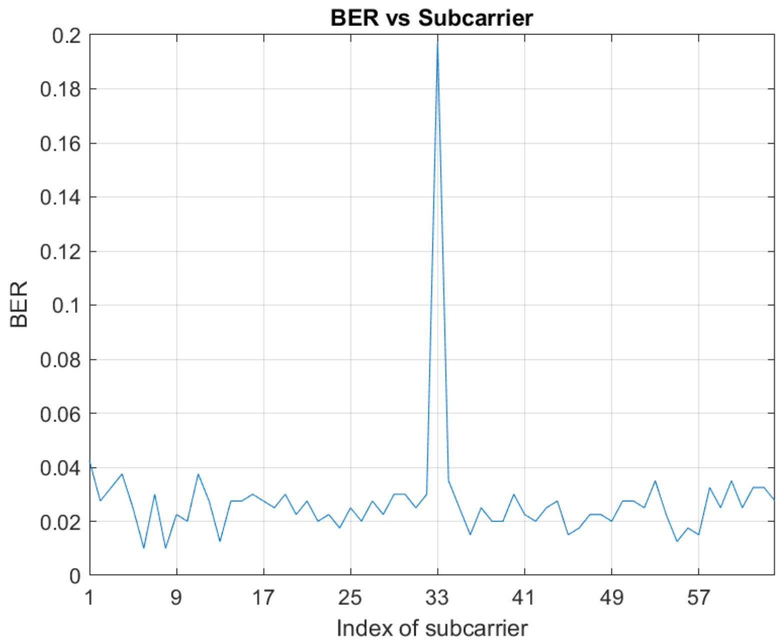

Figure 3.3 BER to subcarrier, Result 2

We can observe that the BER is higher in the beginning due to synchronization and other initialization issues. The most notable part in Figure 3.2 is that the BER is the highest in subcarrier 33, which is the middle of the frequency band. Near the central frequency, the signals from the subcarriers share components of the central frequency. Also, waves of different frequency may have different phase velocities, the delay may contribute to inter-symbol interference. The mechanism of OFDM and shifts in phase velocity contribute to more interference, hence the bit-error rate increases.