MATLAB Lab 7

OFDM Transceiver Design

Report due: 05/20/2016

1 Goal

In this lab exercise, we build a uncoded baseband OFDM transceiver with BPSK, 8PSK, and 16QAM modulations. Coded OFDM will be built in the next lab. We will observe the performance gain due to the ISI mitigation capability of OFDM. Note that in this lab, we leave the length of the Cyclic Prefix (CP), L, to your design. We are going to see that how the choice of L affects the performance of the overall system.

2 OFDM System

The block diagram of the OFDM system is depicted in Figure 1. Table 1 summarizes key system parameters.

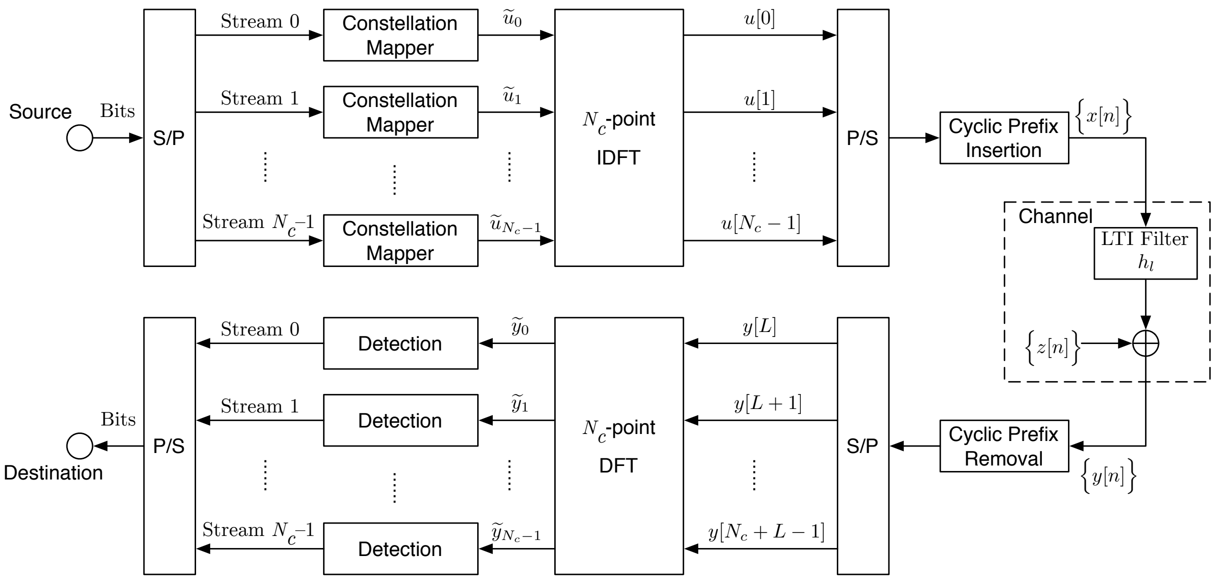

Figure 1: Baseband OFDM System

2.1 OFDM Transmitter

We discuss each component as follows:

Table 1: System Parameters

Parameter	Notation	Value
OFDM Symbol Length (DFT size)	N_c	128
Cyclic Prefix Length	L	By design
Number of OFDM Symbols	K	Depends on the length of bit streams
Total Number of Symbols to be Sent	N	$N_c \times K$

- **Serial-to-Parallel (S/P)**:

  The OFDM transmitter first parses the input bit stream into N_c parallel bit streams.

- **Constellation Mapper**:

  Each bit stream is then passed through a constellation mapper (modulator), such as PSK, QAM, etc. Note that different streams may use different kinds of constellations. We shall explore this in the next lab.

  For this lab, we shall use the same constellation for all streams. You should use BPSK, QPSK, and 16QAM respectively.

- **Inverse Discrete Fourier Transform (IDFT)**:

  The IDFT block converts the frequency-domain symbols into time domain. The size of the IDFT is N_c. You should implement this block **on your own**. You CANNOT use the existing functions in MATLAB, Simulink, etc. In particular, the input/output relationship of the IDFT block is the following:

$$u[n] = \frac{1}{\sqrt{N_c}} \sum_{k=0}^{N_c-1} \widetilde{u}_k e^{\frac{\mathrm{j}2\pi kn}{N_c}}, \quad n = 0, 1, \ldots, N_c - 1.$$

- **Parallel-to-Serial (P/S)**:

  The output of the IDFT (a parallel vector) is then converted into a serial sequence in time domain, which forms the data part of a OFDM symbol.

- **Cyclic Prefix Insertion**:

  To produce the actual time-domain sequence to be sent over the discrete-time baseband channel, a cyclic prefix needs to be added, as in Figure 2. This forms a **transmission block** of length $(N_c + L - 1)$. You should transmit in total K blocks, and hence the total transmitted symbols in time domain is $(N_c + L - 1) \times K$.

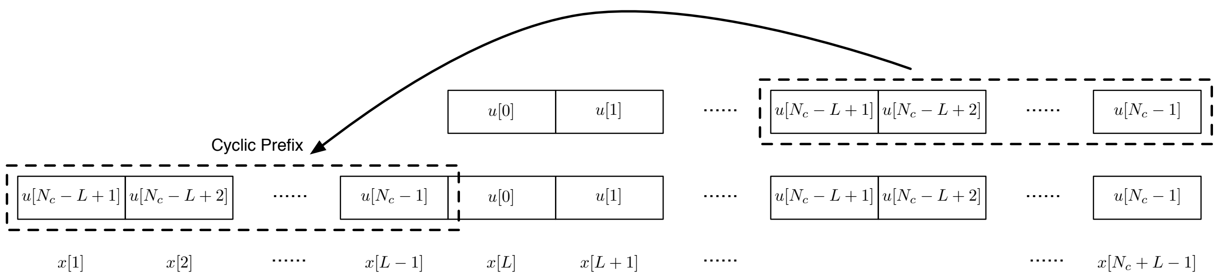

Figure 2: Cyclic Prefix Insertion

2.2 LTI Filter Channel

Please load the file `LTI.mat` to obtain the LTI filter channel. The array starts at index 0, and ends at index `length(h)-1`. Recall that the input/output relationship of the channel is described as follows:

$$y[n] = \sum_{l \geq 0} h_l x[n-l] + z[n].$$

2.3 OFDM Receiver

The receiver comprises the following components:

- **Cyclic Prefix Removal**: In each of the K blocks, remove the first $(L-1)$ received symbols.
- **S/P and DFT**: After removing CP, the sequence is first transposed to a parallel N_c-dimensional vector, and then passed through a N_c-point DFT, resulting in a length-N_c sequence in frequency domain. In particular, the input/output relationship of the DFT block is the following:

$$\widetilde{y}_k = \frac{1}{\sqrt{N_c}} \sum_{n=0}^{N_c-1} y[n] e^{\frac{-\mathrm{j}2\pi kn}{N_c}}, \quad k = 0, 1, \ldots, N_c - 1.$$

- **Detection**: For each of the N_c streams of symbols, the receiver detect the symbols and convert them into bits. Note that for the purpose of detection, you need to consider the equivalent end-to-end channel of each stream, which depends on the time-domain channel $\{h_l\}$. In particular, the k-th stream has a equivalent (complex) channel gain $\widetilde{h}_k$ where

$$\widetilde{h}_k := \sum_{l \geq 0} h_l e^{\frac{-\mathrm{j}2\pi kl}{N_c}}, \quad k = 0, 1, \ldots, N_c - 1.$$

- **P/S**: Finally, the parallel streams of bits are resembled back to the original stream.

3 Exercises

1. Simulate your OFDM system with CP length $L = 30$ and BPSK, 8PSK, and 16QAM modulations respectively. Plot in the same figure of the overall BER versus $\frac{E_b}{N_0}$ curves for the OFDM system built above. $\frac{E_b}{N_0}$ should be from 0 dB all the way to the $\frac{E_b}{N_0}$ that generates the BER of 10^{-5}.

2. Calculate the peak-to-average power ratio (PAPR) in the above simulation.

3. Simulate uncoded BPSK, 8PSK, and 16QAM over the LTI filter channel **without** OFDM, by reusing the codes you developed in Lab 5 or Lab 6. You can use the simple successive interference cancellation to slightly boost its performance. Compare the BER curves with those in 1. and show the performance gain due to the ISI mitigation capability of OFDM.

4. Repeat 1. for $L = 10$ and $L = 20$. Find the gain in $\frac{E_b}{N_0}$ in the BER curves from $L = 10$, $L = 20$, to $L = 30$.

5. Simulate the system from $L = 1$ to $L = 40$ at a fixed $\frac{E_b}{N_0} = 10$ dB. Since the larger the L is, the larger the overhead is, how would you choose the length of the CP when operating at $\frac{E_b}{N_0} = 10$ dB?

4 Lab Report

In this lab, you are supposed to work with your partner. Only one report is needed for each group. Only one person needs to submit the report on CEIBA. Please specify your group members in the report.

There is no format requirements for your lab report. In the report, you should address the results of the exercises mentioned above. You should also include your simulation program in the appendix of the report. Include whatever discussions about the new findings during the lab exercise, or the problems encountered and how are those solved. Do not limit yourself to the exercises specified here. You are highly encouraged to play around with your simulation program on self-initiated extra lab exercises/discussions. Extra points are usually given by TA when grading those reports.