COMM.SYS.450

Multicarrier and Multiantenna Techniques

Exercise 4

Familiarizing with the task before attending the session is strongly recommended, and some work to finalize the code may be needed afterwards. For the exercise bonus, it is required to return the solution script to **Moodle** by the following Tuesday at 23:00. A model solution will be available on Moodle once the submission is closed. For any inquiries regarding the grading of the exercise returns please contact Karel Pärlin (karel.parlin@tuni.fi).

In this fourth exercise task, we are going to perform some channel estimation techniques that will allow us to exploit some knowledge to improve the system performance.

Having knowledge of the channel state information (CSI in LTE) is very important in mobile communications systems since it allows enhancing the performance of the system significantly. At the receiver side, it allows for instance, to perform channel equalization so that we can mitigate the effect of the frequency/time selectivity of the channel. If we have knowledge of the channel at the transmitter side, we can perform channel aware transmission, for example, we can apply beamforming, spatial multiplexing. We can also apply algorithms such as waterfilling (allocate different power to different subcarriers), or bit loading (that is, allocate a certain modulation and coding scheme on each subcarrier). It also enables the implementation of scheduler algorithms like maximum rate or proportional fair in OFDMA multiuser scenarios. However, the effectiveness of the above-mentioned techniques depends on how accurately the channel can be estimated. In the previous session, we assumed that we had perfect knowledge of the channel frequency response; therefore, the ZF equalizer was capable of perfectly suppressing the undesirable channel effect on the transmitted signal.

This time instead, we are going to implement a very simple channel estimation method based on reference signals. Reference signals are a set of symbols whose location at the resource grid and value are perfectly known by the receiver. In LTE this corresponds to the CRS signals for the DL. The receiver knows where those signals are transmitted (after obtaining the physical identity of the cell by means of the synchronization procedure based on PSS and SSS) so they can be used to obtain the channel state information.

Our reference signals are going to be a very basic sequence of BPSK symbols, whose location within the frame and value are known. We are going to build a four OFDM symbols frame (time-domain axis) of the following form. One BPSK symbol (this is going to be our pilot symbol) followed by three 16-QAM symbols (these are the actual symbols that are transmitting useful information). We are going to generate two frames, and hence, the time structure of our transmission is the following

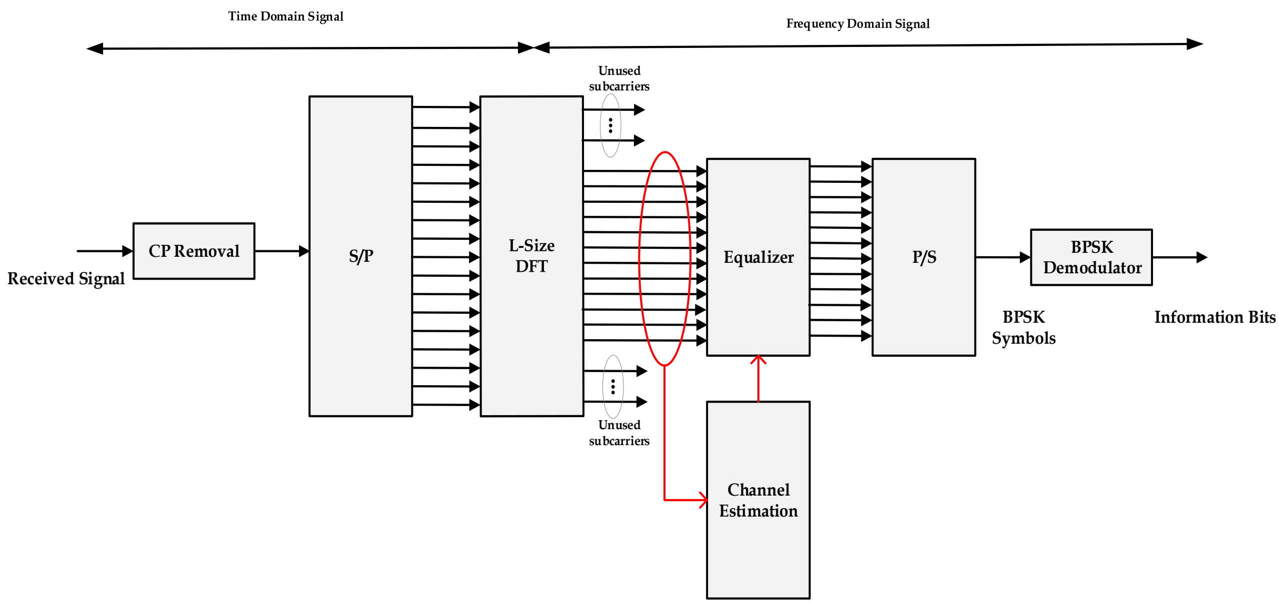
Pilot	Data	Data	Data	Pilot	Data	Data	Data
Channel realization 1				Channel realization 2			

We assume that the channel does not change within the frame duration, that is, the channel estimation will be valid across the whole frame. A second channel realization will be considered for the second frame, and therefore, the channel state information will need to be updated.

It is important to note that frame refers to time; therefore, each of those slots in the frame corresponds to an OFDM symbol that is, the output of the IFFT, which combines the different subcarrier signals.

In order to perform channel estimation, we are just going to modify a little bit the receiver structure so that we include such processing. The new receiver structure is depicted in the figure below

Where in order to perform the channel equalization, a channel state information acquisition stage is to be performed beforehand. The channel estimation will be done as it is explained in lectures 2 & 3 slides, where X_k is the BPSK pilot symbol at the k-th subcarrier while Y_k denotes the k-th FFT output signal. This technique is very simple and is not very robust in low SNR scenarios.



For the transmitter we consider an OFDM system with 20 active subcarriers, 15 kHz as subcarrier spacing, IFFT size of 32, and 16-QAM symbols will be used to transmit the information symbols while BPSK symbols are utilized as pilots. The CP has a length of ¼ of the OFDM symbol duration.

The OFDM link with channel estimation is to be implemented in the template script called **Ex4_ch_est.m**

Plot the estimated channel response and the actual channel response for different values of SNR. Plot the QAM constellation of the received symbols and the original transmitted symbols and compare it with the results obtained during the previous lab where we assumed perfect channel state information.

Waterfilling Algorithm

In the script **Ex4_water.m** you can find the implementation of the waterfilling algorithm for OFDM transmitters.

There is one parameter that you can change:

- Pt: total transmit power available at the transmitter.

Try with Pt = 15 and Pt = 50 and see how the plot changes. What is happening?

Calculate the channel capacity assuming that all subcarriers have the same allocated power, i.e, **subcarrier power = Pt/Active_subcarriers** and the channel capacity resulting after applying the waterfilling algorithm.

Use the expressions from the lecture notes of Prof. Renfors's 2020 Lecture 5.