Simulation of a Wi-Fi Communication Chain

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1 General introduction

The objective of the project is to design and simulate a representative Wi-Fi transmission chain in Matlab. Orthogonal Frequency Division Multiplexing (OFDM), will be used, which efficiently deals with the channel memory introduced by the different path lengths of the channel. Your simulation will include the functionality usually found in a typical modem, and is built in three main steps:

- the reference OFDM communication chain over a multi-path channel;
- the synchronization architecture and algorithms supporting the OFDM communication;
- the multiple antenna technologies added to improve the reliability and capacity of the link.

A good understanding of the theory is necessary to start implementing the project. The project is organized in groups of 2 to 3 students. The deliverable is a written report of no more than 20 pages (ReportELEC401_your_names.pdf) and a .zip file of your Matlab code (CodeELEC401_your_names.zip). They have to be sent to *francois.horlin@ulb.be* before the study period preceeding the exam session. The report should focus on the presentation of the simulation results along with a clear explanation of the observations.

2 OFDM-based Communication Chain

The OFDM modulation is used in most wireless communication systems to efficiently deal with the multi-path channels. The principle of OFDM is to transmit independent data symbols on orthogonal narrow-band sub-carriers. Thus, the wide-band frequency selective channel is divided into a set of narrow-band frequency flat sub-channels, allowing us to individually equalize each part of the channel. The OFDM-based communication chain is depicted in Figure 1, and each block will be briefly explained.

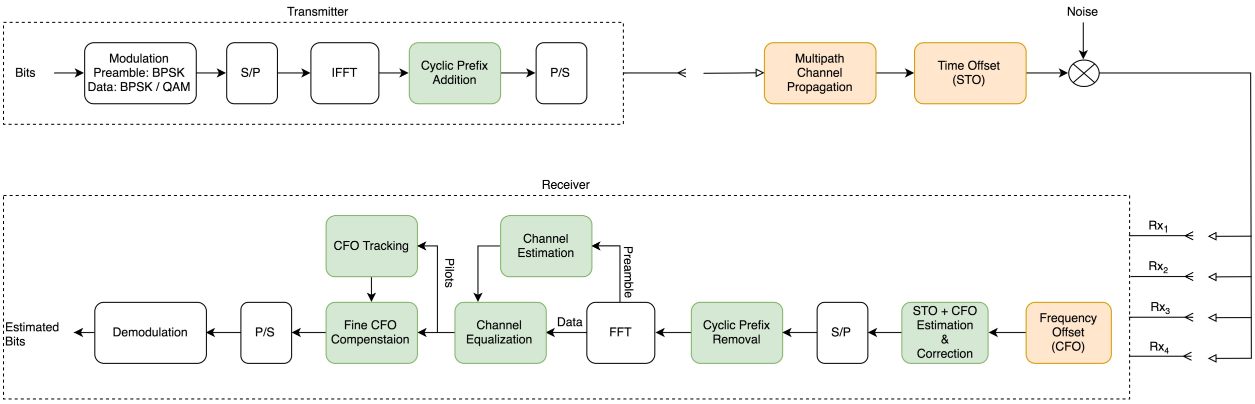

Figure 1: OFDM-based Communication Chain

First stage of the OFDM chain is to map the information bits in PSK or QAM symbols, directly in the frequency domain. Each frequency domain symbol is transmitted on a different sub-carrier of the OFDM spectrum. To do so, the serial symbol stream is reshaped to a matrix composed of parallel blocks, where the number of parallel blocks is the number of OFDM symbols, and the length of one block is the number of sub-carriers, Q. Then, these parallel blocks are transformed into time-domain with Q-point IFFT. Afterwards, the Cyclic Prefix (CP) is added in front of each parallel block. This is done by copying the last L samples of each block, to the front. Addition of CP makes the OFDM symbols appear to be periodic to ensure the orthogonality between sub-carriers. It also allows us to avoid Inter-Symbol Interference. Finally, at the transmitter side, the matrix is reshaped into a vector/symbol-stream for sequential sample transmission.
When the signal is on-air, the channel memory is introduced by the multi-path propagation, which is the first unwanted element of the communication chain. Afterwards, since the receiver does not have the knowledge of the transmission time, there exists a time shift called the Sampling Time Offset (STO) between the two devices, which is the second unwanted element. Finally, the noise is added to the signal, just before the receiving antenna(s).
At the receiver side, the third unwanted element is introduced, which is the Carrier Frequency Offset (CF0) caused by the use of different local oscillators in the two devices. The receiver is designed to progressively compensate for these three unwanted effects. It first roughly estimate and compensate for the STO and CFO. STO compensation allows us to find the beginning of each OFDM frame, while rough CFO correction allows us to make sure that the sub-carriers are still orthogonal for the later frequency-domain processing. Serial-to-Parallel conversion is applied for block processing. Cyclic Prefix removal is performed to get the Q time-domain samples. FFT is computed on each block, to get the frequency-domain samples. The OFDM frame is separated into two parts. From the known Preamble, the Channel Estimation is performed. By using the resulting channel estimate, the effect of frequency selectivity on the data, introduced by the multi-path propagation, is equalized. Since the there remains an error at the output of the rough CFO compensation and because the local oscillators (LO) may not be stable during one OFDM frame, an additional CFO tracking and compensation is performed over the pilot sub-carriers. Finally, the blocks are reshaped into a vector, and each frequency-domain symbol is demodulated separately.
The main parameters to be considered are provided in Table 1. They are chosen according to the IEEE 802.11ax amendment of the standard.

Parameters	Values
Bandwidth [MHz]	160
Number of sub-carriers [samples]	2048
CP length [samples]	256
Preamble length [OFDM symbols]	2
Data length, Comm. Mode [OFDM symbols]	30
Carrier frequency [GHz]	5
SNR [dB]	-5:5:30

Table 1: Parameters

3 Steps to be followed

3.1 OFDM modulation

- Implement the OFDM transceiver (IFFT/FFT, cyclic prefix addition and removal), check the orthogonality among the sub-carriers;
- Assess the bit error rate (BER) performance of the OFDM transceiver in the presence of additive white Gaussian noise (AWGN) only for a varying signal-to-noise ratio (SNR);
- Assess the performance degradation caused by a second propagation path of random coefficient/delay and show that low-complexity frequency-domain channel equalization can help coping with it;
- Discuss the choice of the modulation parameters (OFDM symbol dimension, cyclic prefix length).

Note that the SNR is often computed at the input of the receiver and averaged over the channel realizations. Other definitions of the SNR may change the conclusions.

3.2 Channel estimation

- Form the preamble typically composed of known BPSK or QPSK symbols and implement the channel estimation (both frequency-domain and time-domain channel estimation methods);
- Assess the channel estimation accuracy for both methods by evaluating the channel estimate mean square error (MSE) as a function of the SNR;
- Form the overall frame, including the preamble and the data blocks, and assess the BER performance degradation due to channel estimation errors.

3.3 Time acquisition

- Add the uncertainty on the received signal time-of-arrival in the simulation and evaluate its impact; check that a time shift can be seen as an additional delay included in the channel impulse response, making the OFDM system robust to sufficiently small time synchronization errors;
- Form the two-times repetitive preamble and implement the time acquisition based on the auto-correlation algorithm;

- Evaluate the time-acquisition accuracy by computing the time-of-arrival estimate MSE as a function of the SNR;
- Update the overall frame to include the repetitive preamble and demonstrate that it can be decoded even when its time-of-arrival is estimated.

3.4 Frequency acquisition and tracking

- Add the CFO on the received signal in the simulation and evaluate its impact for different sizes of the OFDM symbol;
- Implement the rough frequency acquisition by averaging the phase shift due to the CFO between the two repetitive parts of the preamble;
- Evaluate the CFO estimation accuracy by computing the CFO estimate MSE as a function of the SNR;
- Replace a few symbols with pilots within the data blocks and implement the fine frequency tracking achieved by observing the remaining common phase shift on the pilot sub-carriers.
- Demonstrate that the overall data frame can be decoded in the presence of CFO and discuss the affordable CFO range.

3.5 Maximum ratio combining

- Update the synchronisation structure implemented at the receiver when it is equipped with multiple antennas: the channel estimation, time acquisition, frequency acquisition and tracking are first performed independently per antenna; the estimates of the time and frequency offsets can afterwards be averaged over the antennas to improve the robustness to the noise;
- Implement the Maximum Ratio Combining (MRC) receiver and evaluate the diversity and array gains obtained as a function of the number of antennas;