Acoustic modem project

Session 4: OFDM transmission over a simulated acoustic channel

Paschalis Tsiaflakis, Hanne Deprez[1]

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Goal: Extending m-files *ofdm_mod.m* and *ofdm_demod.m* to obtain reliable OFDM transmission of an input image over a simulated acoustic channel with multipath fading and AWGN.

Requirements: Matlab in Windows.

Required files from DSP-CIS website: *main.m*, *imagetobitstream.m*, *bitstreamtoimage.m*, *image.bmp*.

Required files from previous sessions: *qam_mod.m*, *qam_demod.m*, *ber.m*, *ofdm_experiment.m*, *ofdm_mod.m*, *ofdm_demod.m*

Outcome: 3 m-files (+ 1 optional): *ofdm_demod*, *main.m* of Exercise 4-2, *main.m* of Exercise 4-3, *main.m* of Exercise 4-4 (optional)

Deliverables: 2 m-files (+ 1 optional): *milestone2a.m*, *milestone2b.m* and *ofdm_adapt_bitloading.m* (optional)

1 Exercise 4-1: Image to bitstream

In this session, we will start from a BMP image instead of a random bit sequence. The file *main.m* contains a communication chain where only a small part is implemented. This will be the main script of this session in which you have to add your own functions.

1. Download the files *main.m*, *imagetobitstream.m*, *bitstreamtoimage.m* and *image.bmp* from DSP-CIS website.
2. Run the *main.m* script and try to understand all components of this script.

2 Exercise 4-2: OFDM modulation over acoustic channel

1. Add your QAM modulator and demodulator from Exercise 3-1 to the *main.m* script to obtain a QAM symbol sequence. Check the BER to verify the correctness of your function.

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[1] For questions and remarks: `jeroen.verdyck@esat.kuleuven.be`

2. Add your OFDM modulator and demodulator from Exercise 3-2 to the *main.m* script to obtain an OFDM frame sequence. Check the BER to verify the correctness of your function.

3. Add AWGN to the received OFDM frame sequence and check the impact on the received image. Check the BER for different types of QAM constellations.

4. Set SNR=∞ dB and insert a channel with transfer function $H(z) = h_0 + h_1 z^{-1} + \ldots + h_L z^{-L}$ between the transmitter and receiver, with a user-defined channel order L. The channel coefficients can be random numbers, or you can choose them yourself.

5. Make sure the cyclic prefix is longer than the length of the channel impulse response. Check the BER.

6. In the function *ofdm_demod.m*, also scale the components of the FFT output with the inverse of the channel frequency response (this should be given as an extra input variable to the function). Check the BER. Explain what you observe.

7. Now use the acoustic channel impulse response as measured in Session 2. How long do you take the cyclic prefix now? Check the BER.

8. Add AWGN noise again and check the BER for different channel transfer functions $H(z)$ (including the channel impulse response measured in Session 2) and different SNRs.

3 Exercise 4-3: Reducing the BER with ON-OFF bit loading

For the measured acoustic channel impulse response and a small SNR, you can see a lot of errors in the received image. Can you observe any structure in the location of the errors and explain your findings? Inspect the attenuation of your channel at different frequencies. Which frequencies have a large attenuation? Can you exploit this knowledge to reduce the number of bit errors with ON-OFF bit loading, where only those frequency bins that have a good SNR are effectively used for the transmission?

4 Exercise 4-4 (Extra): Adaptive bit loading

Instead of considering a uniform M-ary QAM constellation for all frequency bins, one can also opt for an adaptive approach in which for each frequency bin a different constellation size is used as a function of its SNR (using the Shannon capacity formula). Assuming each OFDM tone (frequency bin) is modulated with unity average power, it can be shown that the optimal QAM choice is M-QAM, where $M = 2^{b(k)}$ with

$$b(k) = \left\lfloor \log_2 \left(1 + \frac{|H(k)|^2}{\Gamma P_n(k)} \right) \right\rfloor$$

where $\lfloor \cdot \rfloor$ is a flooring operator, k is the frequency bin or tone index, $H(k)$ is the channel frequency response, and $P_n(k)$ is the noise power[2]. Changing the value of Γ will change the BER. Choosing $\Gamma = 10$ yields a theoretical BER of approximately 10^{-6} per frequency bin if there is no channel coding. Apply this formula to obtain an optimal bit allocation to each tone.

5 Milestone demo

The second milestone demo takes place at the start of the fifth exercise session. You will be asked to show the following demo(s). Before the start of the fifth exercise session, e-mail the Matlab code of your demo(s) in one zip-package to

`jeroen.verdyck@esat.kuleuven.be`.

Make sure to mention your group number as well as the names of all group members in the name of the zip-file. Do not send additional files (only the files that are required to execute the demo).

- Demo 1: A single m-file named *milestone2a.m* to compute the BER vs SNR curves for different QAM constellation sizes plotted in one figure. For this you should use the *qam_experiment.m* file of Exercise 3-1.
- Demo 2: A single m-file named *milestone2b.m* that demonstrates the OFDM system starting from the script *main.m* of Exercise 4-2 for transmission of an image over the acoustic channel measured in Session 2. Also add ON-OFF bit loading of Exercise 4-3 and motivate your choice.
- Demo 3 (*Optional*): A single m-file named *ofdm_adapt_bitloading.m* that demonstrates the OFDM system starting from the script *main.m* of Exercise 4-2 for transmission of an image over the acoustic channel measured in Session 2, this time with adaptive bit loading.

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[2] Note that the per-frequency noise power $P_n(k)$ can be estimated using the received PSD and the channel transfer function $H(k)$ and that is not necessary constant over all frequency bins.