ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
School of Computer and Communication Sciences

Software-Defined Radio:	Midterm Exam
A Hands-On Course	November 9, 2016

Name:

Note:

- You have 2 hours to work at the exam.
- The exam is closed book, but your are allowed one sheet (one single-sided page) of handwritten notes. You are only allowed to use the workstations in the laboratory (not your own laptops). Resources from the internet as well as code written outside this exam are not allowed (unless the code is written on the sheet of handwritten notes).
- There is a `MATLAB` part and a paper-and-pencil part.
- You will start with the paper-and-pencil part for which you have up to 25 min. You are not allowed to use the computer for this part. After 25 min, or if you finish earlier, we will come to collect your answers and you can start the `MATLAB` part.
- The code will be evaluated according to the usual criteria, namely correctness, speed, form, and readability. Short comments that allow us to follow what you are doing will improve readability.
- Start by downloading from Moodle and unzipping the file `sdr_midterm_2016.zip`. The `MATLAB` files for Problem n, $n = 3, 4$, are found in subfolder pn.
- You will upload (to Moodle) your solution to the problems that require writing `MATLAB` code. Do so in a single archive.
- The problems can be solved in any order.

Problem 1. 6 p. (Paper and Pencil)

Let $p_{\mathcal{F}}(f)$ be a frequency-domain rectangular pulse defined by

$$p_{\mathcal{F}}(f) = \begin{cases} 1, & |f| \leq B \\ 0, & \text{otherwise.} \end{cases}$$

Answer the following questions. (You can answer the questions in any order.)

(a) Sketch the time-domain pulse $p(t)$ and label its maximum value and its zero-crossings.

(b) Let $\mathcal{E} = \int p^2(t)dt$. Specify the value of $\mathcal{E}$ as a function of B.

(c) Let $p_i = p(iT_s)$ for some sampling time T_s and $i \in \mathbb{Z}$, where $T_s < \frac{1}{2B}$. Express

$$\sum_{i \in \mathbb{Z}} p_i^2$$

as a function of $\mathcal{E}$ and T_s.

Problem 2. 6 p. (Paper and Pencil)

If you type `help rcosdesign` in `MATLAB` you obtain the following (abridged) response:

```
rcosdesign Raised cosine FIR filter design
    B = rcosdesign(BETA, SPAN, SPS) returns square root raised cosine FIR
    filter coefficients, B, with a rolloff factor of BETA. The filter is
    truncated to SPAN symbols and each symbol is represented by SPS
    samples. rcosdesign designs a symmetric filter. Therefore, the filter
    order, which is SPS*SPAN, must be even. The filter energy is one.
```

Suppose that you issue the commands

```
h=rcosdesign(0.5,4,3)
xc=xcorr(h,h)
[y,i]=max(xc) % where y and i are the value and the index of the max
```

Answer the following questions:

(a) Evaluate `y`.

(b) Evaluate `i`.
Hint: the command `length(h)` returns `13`.

(c) Assuming that you know `i`, give at least two indices where `xc` is essentially zero (exactly zero if `SPAN` is sufficiently large).

Problem 3. 9 p. (`MATLAB`)

The file `qamData.mat` contains a sequence of 4-QAM symbols which are affected by Doppler and by AWG noise. The symbol duration is $T_s = 10^{-6}$ [s]. Using the Fourier transform, find an estimate of the Doppler frequency with a resolution of exactly 50 Hz. Plot the Doppler-corrected complex constellation.

Hint: Note that raising a 4-QAM symbol to the power 4 eliminates the phase changes due to the 4-QAM modulation. After this operation your are left only with the effect of the Doppler frequency (and AWGN).

Problem 4. 9 p. (`MATLAB`)

Consider a transmitted sequence that consists of preambles and blocks of 4-QAM symbols. Specifically, before a block of 10^4 4-QAM symbols, there is a preamble of 1023 BPSK symbols. This pattern is repeated (with different 4-QAM symbols). In the file `r.mat`, you find a noisy chunk of the above signal. The noise-free preamble is stored in `p.mat`.

Find the first full preamble in the given sequence `r`, and extract and plot the noisy 4-QAM sequence (of length 10^4) which follows this preamble. Estimate the corresponding sequence of 4-QAM symbols and compute the symbol error rate (SER) with respect to the transmitted sequence, which is stored in `d.mat`.

Problem 5. 10 p. (`MATLAB`)

In this problem we consider a convolutional code with parameters `constraint_length = 3` and `generator = [5 7]`. An upperbound on the bit error rate (BER) is given by the following formula:

$$BER \leq \sum_{i=1}^{5} \sum_{d=1}^{9} i \cdot Q\left(\sqrt{d \cdot SNR_{dec}}\right) \cdot a(i,d)$$

where SNR_{dec} is the SNR in decimal, Q is the `qfunc` of `MATLAB` and, for our code

$$a(i,d) = \begin{cases} 2^{i-1}, & \text{if } d = i + 4 \\ 0, & \text{otherwise.} \end{cases}$$

(a) Compute the above BER upperbound for an SNR of 5dB without using loops.
Hint: Due to the form of $a(i,d)$, the double summation can be reduced to a single sum.

(b) Compute the BER for the same SNR by simulating a transmission chain. You will need to use the commands
`trellis = poly2trellis(constraint_length, generator)`,
`coded_bits = convenc(data, trellis)`,
`s_est = vitdec(rxData, trellis, trace_back_length, 'trunc', 'unquant')`
with the appropriate parameter values and using a traceback length of 15. You will need to use at least 10^7 bits in order to get a stable BER for the given SNR.