Lund University
Electrical and Information Technology

Exam in
Digital Communications, EITG05

August 20, 2018

Name: ______________________

Id Number: ______________________

Programme: __________

Nbr of sheets: __________

Mark with a cross the problems you solved.				
1	2	3	4	5

Signature: ______________________

Control protocol						
1	2	3	4	5	$\sum$	Grade

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- During this exam you are allowed to use a calculator, the compendium, a printout of the lecture slides, and Tefyma (or equivalent).
- Please use a new sheet of paper for each solution. Write your anonymized assessment code + a personal identifier on each paper.
- Solutions should clearly show the line of reasoning and follow the methods presented in the course. If you use results from the compendium or lecture slides, please add a reference in your solution.
- If any data is lacking, make reasonable assumptions.

Good luck!

Problem 1

Determine for each of the five statements below if it is true or false.
Give a motivation for each of your answers.

(a) Consider a conventional M-ary QAM system, using a pulse $g(t) = g_{rc}(t)$ with duration $T = T_s/2$.

"If the bandwidth efficiency is $4.21\,\mathrm{bps/Hz}$*,* M *= 256, then the 90% definition of bandwidth is used."*

(b) *"For 4-ary QAM with equally likely signal alternatives and a triangular pulse* $g(t) = g_{tri}(t)$ *with amplitude* A *and duration* $6T_s/10$ *the average signal power is* $2A^2/10$*."*

(c) *"With uncoded equally likely binary signals the bit error probability is always larger than* $2.5 \cdot 10^{-10}$ *if* E_b/N_0 *is* 13 *dB."*

(d) *"8-ary PPM and 8-ary FSK have the same energy efficiency."*

(e) Consider M-ary PAM signaling over an AWGN channel without multipath.

"In order to avoid inter-symbol interference (ISI), the symbol rate R_s *can never be larger than the inverse* $1/T$ *of the transmit pulse* $g(t)$ *duration* T*."*

(10p)

Problem 2

Consider a QAM signal constellation, with rectangular pulse shape of duration $T = T_s$,

$$s_\ell(t) = A_\ell \, g_{rec}(t) \, \cos(2\pi \, f_c \, t) - B_\ell \, g_{rec}(t) \, \sin(2\pi \, f_c \, t) \; , \quad \ell = 0, \ldots, 7 \; ,$$

for which the $M = 8$ possible amplitude pairs are given as follows:

$$(A_0, B_0) = (+2, 0) \; , \; (A_1, B_1) = (+1, +1) \; , \; (A_2, B_2) = (0, +2) \; , \; (A_3, B_3) = (-1, +1) \; ,$$

$$(A_4, B_4) = (-2, 0) \; , \; (A_5, B_5) = (-1, -1) \; , \; (A_6, B_6) = (0, -2) \; , \; (A_7, B_7) = (+1, -1) \; .$$

(a) For the carrier frequency $f_c = 2/T_s$, draw the transmit signal $s(t)$ corresponding to the message sequence $\mathbf{m} = (m[0] \; m[1] \; m[2] \; m[3]) = (0 \; 6 \; 2 \; 4)$ within the time interval $0 \leqslant t \leqslant 4\,T_s$.

(b) Draw the constellation diagrams for both conventional 8 PSK and for the QAM constellation defined above.

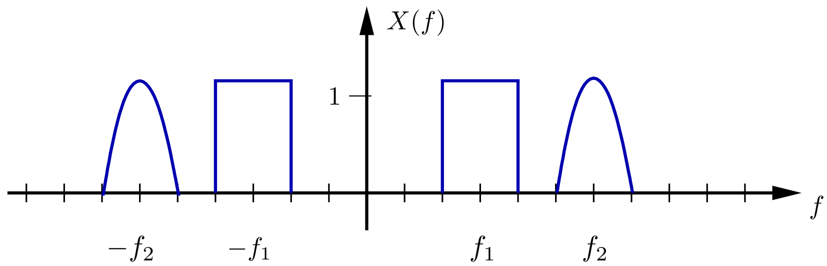
(c) For each constellation, find some Gray mapping to assign bits to the signal alternatives.

(d) You want to scale the amplitude of 8 PSK with some factor C to achieve equal average energy per bit $\mathcal{E}_b$ for both constellations. Determine the scaling factor C. Which constellation will then have a lower symbol error probability with an ML receiver (assuming a large signal-to-noise ratio)?

(10p)

Problem 3

A communication system can serve two users simultaneously, at carrier frequencies $f_1 = 300\,\mathrm{MHz}$ and $f_2 = 600\,\mathrm{MHz}$, respectively. The frequency spectrum $X(f)$ of the combined bandpass signal $x(t) = x_1(t) + x_2(t)$ is given in the figure below:



(a) Describe how the receiver can reconstruct the (real-valued) baseband signal $s_2(t)$ of the second user, using a multiplier and a low-pass filter.

(b) Draw the spectrum of the converted signal *before* the filtering.

Consider now a 2-ray multi-path channel with impulse response

$$h(t) = \sum_{i=1}^{2} \alpha_i \, \delta(t - \tau_i) \; , \quad \text{where } \alpha_1 = 1, \alpha_2 = -0.5, \; \tau_1 = 0\,\mu\mathrm{s}, \tau_2 = 1.5\,\mu\mathrm{s} \; .$$

A binary PAM signal with rectangular pulse $g_{rec}(t)$ of duration $T = T_s = 3\,\mu\mathrm{s}$ and amplitude A is transmitted over this channel, namely

$$s(t) = \sum_{n=-\infty}^{\infty} A[n] \, g(t - nT_s) \quad \text{where} \quad A[-1] = 0, A[1] = +1, A[2] = -1, A[3] = +1 \; .$$

(c) Draw the signal $z(t)$ at the output of the multi-path channel within the time interval $0 \leqslant t \leqslant 3\,T_s$.

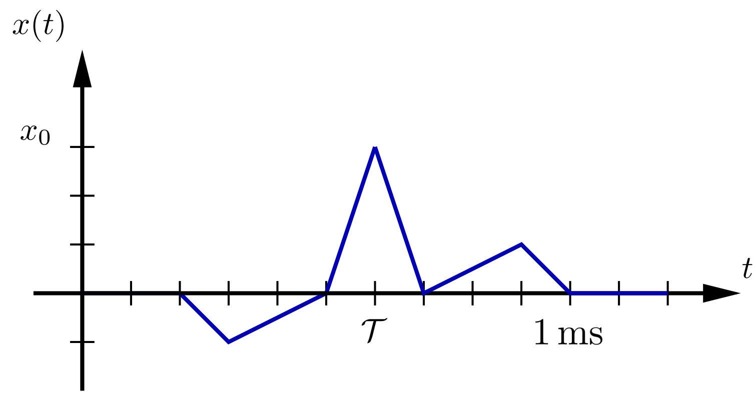
(d) What happens in this scenario, if an ML receiver is used that was designed for a channel without multipath? Which modifications to the transmitter/receiver can be done to guarantee the same error probability as for the case $h(t) = \delta(t)$?

Remark: Part (c) and (d) can be solved independently from (a) or (b).

(10p)

Problem 4

Assume a communication system employing 4 PAM modulation with equally likely signal alternatives. The combination of the transmit pulse $g(t)$, channel filter $h(t)$, and receiver filter $v(t)$ can be written as $x(t) = g(t) * h(t) * v(t)$. The signal is sampled in the receiver at time instants $\mathcal{T} + i\,T_s$, $i = 0, 1, 2, \ldots$.



(a) What is the maximum possible bitrate for ISI-free reception?

(b) Let us now assume that we can tolerate some ISI. You are allowed to choose either $T_s = 200\,\mu\text{s}$ or $T_s = 300\,\mu\text{s}$. Draw the discrete impulse response $x[i]$ of the system for both cases.

(c) Determine which of the two cases is better, by comparing their worst case intersymbol interference ISI_{wc}. What bitrate can be achieved with your selection?

(d) Give an example of an information sequence $A[i]$ for which the worst case ISI occurs. Is there a risk for erroneous decisions?

(10p)

Problem 5

Your task is to specify a 8-PSK communication link that will be used to replace an existing 8-FSK system with a target symbol error rate of $P_s \leqslant 2 \cdot 10^{-6}$. The power at the receiver is equal to $P_z = 10^{-13}\,W$. The parameter of the additive white Gaussian noise is equal to $N_0 = 5 \cdot 10^{-20}$ [W/Hz] and the propagation attenuation is $\alpha = 0.02 \cdot d^{-1}$.

(a) Determine the maximum bit rate R_b that can be achieved by the 8-FSK system.

(b) The current distance between transmitter and receiver is $d = 100\,\mathrm{m}$. Your aim is to achieve the same P_s and R_b with 8-PSK modulation without increasing the transmit power. What is the maximum value of d under these conditions?

(c) Compare the required bandwidth of the two solutions, assuming in both cases a rectangular pulse of duration $T = T_s$. The frequency separation of the FSK system is $f_\Delta = R_s$.

(d) Describe some advantages and disadvantages of FSK modulation and of PSK modulation.

(10p)