UNIVERSITY OF SOUTHAMPTON ELEC6014W1

SEMESTER 2 EXAMINATIONS 2011-2012

RADIO COMMUNICATION NETWORKS AND SYSTEMS

DURATION: 120 MINS (2 Hours)

This paper contains 5 (FIVE) questions.

Answer THREE questions out of FIVE.

An outline marking scheme is indicated in brackets to the right of each question.

Only University approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains **no** notes, additions or annotations.

 Number of pages: 9

1.

a) The power delay profile of a mobile radio channel is given in Figure 1. The system's carrier frequency is $f_c = 1.5$ GHz, the transmitted signal bandwidth is $B_S = 200$ kHz, the symbol period of the system is $T_S = 5\ \mu$s, and the propagation speed is $c = 3 \times 10^8\ \mathrm{ms}^{-1}$.

The 50% coherence bandwidth is defined as

$$B_C = \frac{1}{5\sigma_\tau}$$

with the root mean square delay spread given by

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}\,,$$

where $\bar{\tau}$ and $\overline{\tau^2}$ are the first and second moments of the channel's power delay profile, respectively.

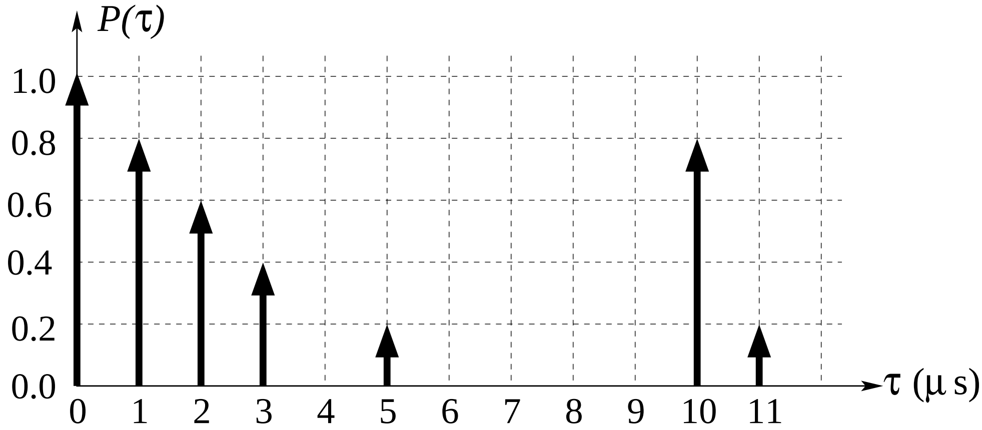

Figure 1

i) Calculate the 50% coherence bandwidth of the channel, and decide whether an equaliser is required for this mobile communication system.

(6 marks)

ii) You are making a mobile call at a high-speed train travelling at a speed of 360 kmhr^{-1}. Estimate the Doppler spread of the corresponding channel, and calculate the normalised Doppler frequency of this fading channel.

(6 marks)

Question 1 continued on the next page

b) As an engineer in charge of designing a fourth generation mobile communication system, you decide to choose orthogonal frequency division multiplexing (OFDM).

i) With the aid of sketches, explain to your boss why OFDM is an effective technique for combating both time-domain fading and frequency selective channels.

(9 marks)

ii) Explain to your boss the purposes of the cyclic prefix at the beginning of each OFDM block or symbol.

(8 marks)

c) In mobile wireless systems, the channel interleaver and deinterleaver are often employed at transmitter and receiver, respectively. Briefly describe the purpose of using them.

(4 marks)

2.

a) Explain why the times-two carrier recovery circuit is not suitable for the quadrature amplitude modulation (QAM) signalling scheme. Draw the block diagram of the times-four carrier recovery scheme for QAM transmission, and explain its operation.

(6 marks)

b) Describe the early-late clock recovery scheme designed for binary phase shift keying, with the aid of block diagrams.

(6 marks)

c) Use 16-QAM as an example to explain why the above early-late clock recovery scheme does not work for multi-level modulation schemes, and describe briefly the modified early-late clock recovery scheme that is capable of operating in high-order QAM systems.

(12 marks)

d) Explain with the aid of key equations how the differential phase shift keying based non-coherent receiver works. Compare the non-coherent and coherent receivers in terms of performance and implementation complexity.

(9 marks)

3.

a) Draw the block diagram of the matched filter receiver and explain its operations with the aid of sketches. What is the common principle that different receiver detectors, such as the threshold detector, matched filter detector and correlation detector, is based on?

(7 marks)

b) Consider the square 16-quadrature amplitude modulation (QAM) constellation of Figure 2.

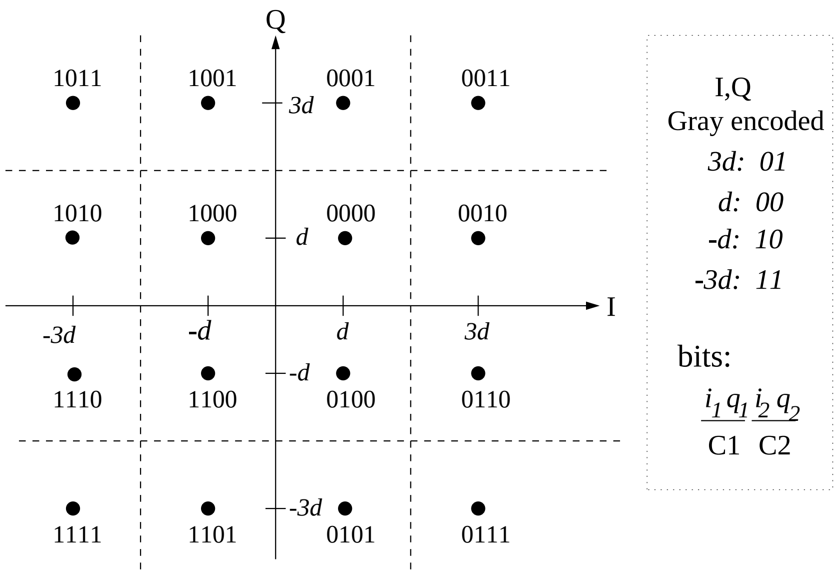

Figure 2

Using Bayes' decision theory and the Gaussian Q-function of:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{y^2}{2}} d\,y\,,$$

derive the corresponding error probability equations for the class one and class two sub-channels under additive white Gaussian noise (AWGN). The final error probabilities should be expressed as functions of the channel's signal to noise ratio (SNR) E_s/N_0, where E_s is the average symbol energy and $N_0/2$ is the power spectral density of the noise.

(8 marks)

Question 3 continued on the next page

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c) The Rayleigh fading envelope α has the probability density function

$$p(\alpha) = \frac{\alpha}{\alpha_0^2} e^{-\frac{\alpha^2}{2\alpha_0^2}}, \ \alpha \geq 0,$$

where α_0^2 is the second moment of the Rayleigh distribution. With the aid of the integration formula

$$\int_0^{\infty} 2Q\left(\sqrt{2}\beta x\right) e^{-\mu x^2} x \, dx = \frac{1}{2\mu}\left(1 - \frac{\beta}{\sqrt{\mu + \beta^2}}\right),$$

derive the average error probability of the 4-QAM scheme over this Rayleigh fading channel.

(6 marks)

d) The channel capacity for the AWGN channel is given by

$$C = B_p \log_2(1 + \text{SNR}) \ \ [\text{bps}]$$

where B_p is the channel bandwidth in Hz.

i) Specify the two key performance measures for a modulation scheme.

(4 marks)

ii) With the aid of the above channel capacity formula, determine the required channel SNR for supporting 4-QAM, 16-QAM, and 64-QAM, respectively, assuming the roll-off factor $\gamma = 0$.

(4 marks)

iii) Then explain how you can trade off the two performance measures of d.i) by varying the modulation size M of the square M-QAM.

(4 marks)

4.

a) For the half-rate constraint-length 2 convolutional code $CC(2, 1, 2)$ described by the generator polynomials $g_0(x) = 1$ and $g_1(x) = 1 + x + x^2$, draw the encoder circuit and construct the state-transition diagram, marking explicitly all the states and state-transitions, labelled by the associated encoded bits.

(7 marks)

b) The hard-decision Viterbi algorithm is used to decode the received sequence $010010000000 \cdots 00$, where the left-most bit is at the left-most position of the trellis. Draw the associated trellis diagram for decoding, clearly marking all the transitions and the associated bits. Find the most likely transmitted information sequence. Furthermore, assuming that the decoding is error-free, state the number of transmission errors inflicted by the channel.

(7 marks)

c) With the aid of a diagram, explain the operations of orthogonal space-time block codes (OSTBCs). Clearly indicate what OSTBCs aim to achieve and their associated drawbacks.

(9 marks)

d) Alamouti's G_2 space-time block code using two transmitter antennas and one receiver antenna is defined by the 2×2 transmission matrix

$$G_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}.$$

Assume that the antenna spacing is sufficiently large so that the two narrow-band channels are independently faded. Further assume that the fading is sufficiently slow such that during two time slots the channels are unchanged.

Derive the maximum likelihood solution for decoding x_1 and x_2 with the aid of the system block diagram. Is Alamouti's G_2 space-time block code an OSTBC?

(10 marks)

5.

a) A multiple-input multiple-output (MIMO) system, consisting of n_T transmitters and n_R receivers, communicates over flat channels. The system is described by the following MIMO model

$$\mathbf{x}(k) = \mathbf{C}\,\mathbf{s}(k) + \mathbf{n}(k)\,,$$

where $\mathbf{C}$ is the $n_R \times n_T$ channel matrix, $\mathbf{s}(k) = [s_1(k)\ s_2(k) \cdots s_{n_T}(k)]^T$ is the transmitted symbols vector of the n_T transmitters with the symbol energy given by $E\left[|s_m(k)|^2\right] = \sigma_s^2$ for $1 \le m \le n_T$, $\mathbf{x}(k) = [x_1(k)\, x_2(k) \cdots x_{n_R}(k)]^T$ is the received signal vector, and $\mathbf{n}(k) = [n_1(k)\ n_2(k) \cdots n_{n_R}(k)]^T$ is the complex-valued Gaussian white noise vector associated with the MIMO channels with $E\left[\mathbf{n}(k)\mathbf{n}^H(k)\right] = 2\sigma_n^2 \mathbf{I}_{n_R}$. A bank of the spatial filters

$$y_m(k) = \mathbf{w}_m^H \mathbf{x}(k),\ 1 \le m \le n_T,$$

are used to detect the transmitted symbols $s_m(k)$ for $1 \le m \le n_T$, where $\mathbf{w}_m$ is the n_R-dimensional complex-valued weight vector of the m-th detector. During training, the m-th error signal for updating the m-th detector's weight vector is given by

$$e_m(k) = s_m(k) - y_m(k)\,.$$

i) Give the mean square error (MSE) expression, $J(\mathbf{w}_m) = E\left[|e_m(k)|^2\right]$, for the m-th detector. You should express the MSE in terms of the MIMO system's parameters $\mathbf{C}$, σ_n^2 and σ_s^2.

(6 marks)

ii) What are the necessary and sufficient conditions for a detector weight vector $\hat{\mathbf{w}}_m$ to be a minimum point of the mean square error?

(4 marks)

iii) From these conditions, determine the minimum mean square error (MMSE) solution $\hat{\mathbf{w}}_m$ of the m-th detector's weight vector.

(2 marks)

Question 5 continued on the next page

iv) For the detector $y_m(k) = \mathbf{w}_m^H \mathbf{x}(k)$, write down the weight adaptation equation of the least mean square (LMS) algorithm.

(3 marks)

b) In a communication system, the transmitted symbol $s(k)$ takes the value from the 4-QAM symbol set

$$s(k) \in \{1+\text{j}, 1-\text{j}, -1+\text{j}, -1-\text{j}\} .$$

The complex-valued received signal sample is given by

$$r(k) = 1.0s(k) + 0.5s(k-1) + n(k) ,$$

where $n(k)$ is a complex-valued Gaussian white noise process. Note that the channel is real-valued with two taps $h_0 = 1.0$ and $h_1 = 0.5$.

Given the received signal sequence

$$\begin{aligned} r(1), r(2), \cdots, r(7) \;\; = \;\; & 0.2-1.1\text{j}, 0.5+0.4\text{j}, -1.0+0.6\text{j}, -0.7-0.8\text{j}, \\ & 0.3+0.3\text{j}, 1.1-\text{j}, 1.5+0.7\text{j} , \end{aligned}$$

find the maximum likelihood sequence estimate $\hat{s}(1), \hat{s}(2), \cdots, \hat{s}(7)$ using the Viterbi algorithm. Sketch the trellis diagram, clearly showing the development of the winning path.

(14 marks)

c) Briefly describe the four basic wireless access (multiuser access) techniques.

(4 marks)

END OF PAPER