UNIVERSITY OF SOUTHAMPTON ELEC6014W1

SEMESTER II EXAMINATIONS 2008/09

RADIO COMMUNICATION NETWORKS AND SYSTEMS

Duration: 120 mins

Answer THREE questions out of FIVE.

University approved calculators may be used.

An approximate marking scheme is indicated.

$$2\cos^2(\varphi) = 1 + \cos(2\varphi)$$
$$2\sin^2(\varphi) = 1 - \cos(2\varphi)$$
$$\sin(2\varphi) = 2\sin(\varphi)\cos(\varphi)$$
$$2\sin(\alpha)\cos(\beta) = \sin(\alpha+\beta) + \sin(\alpha-\beta)$$

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 $f_c = 2$ GHz, the transmitted signal bandwidth is $B_S = 200$ kHz, 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.

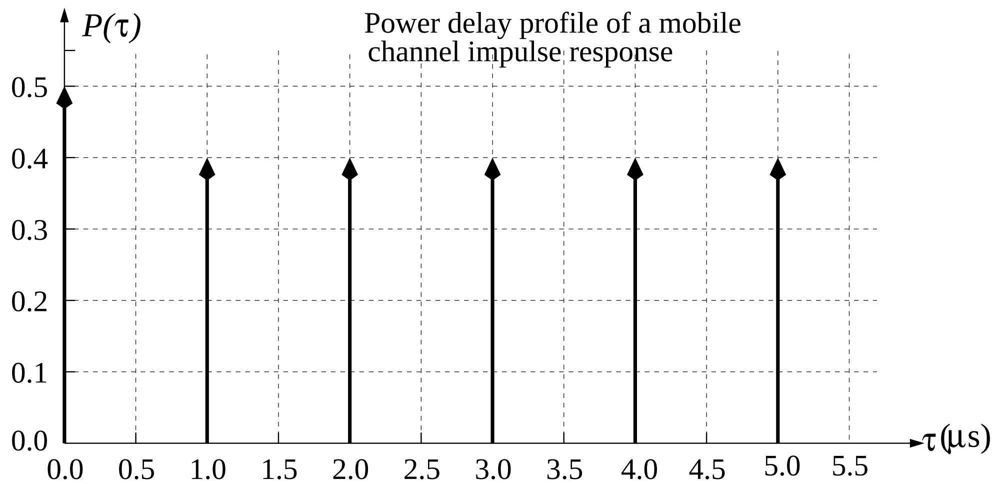

Figure 1

(i) Calculate the 50% coherence bandwidth of the channel, and decide whether an equaliser is required for this mobile communication system. (5 marks)

(ii) A mobile moves at a speed of 60 kmhr^{-1}. Estimate the Doppler spread of the corresponding channel, and determine whether the channel is slow or fast fading. (5 marks)

(iii) The symbol period of the system is $T_S = 10\ \mu$s. Calculate the normalised Doppler frequency of this fading channel. (3 marks)

Question 1 continued on the next page

b) Consider a Rayleigh fading multi-path environment. Given the relationship

$$\frac{d\cos^{-1}(x)}{dx} = -\frac{1}{\sqrt{1-x^2}}$$

and that the angle of arrival for the received waves is uniformly distributed, derive an expression for the Doppler power spectrum.

(6 marks)

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

(5 marks)

d) Classify various multiple-input multiple-output (MIMO) systems based on multiple-antenna techniques into three types and briefly discuss their main purposes.

(9 marks)

2.

a) Draw the block diagram of the times-two carrier recovery scheme for binary phase shift keying (BPSK) transmission, and explain the operation as well as the associated equations for this carrier recovery scheme.

(6 marks)

b) Describe the early-late clock recovery scheme designed for BPSK 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.

(14 marks)

d) Draw the block diagram of a baseband communication system for either the in-phase or quadrature-phase component and define the requirements of optimal transmitter and receiver filtering.

(7 marks)

3.

a) Using the square 16-QAM and star 16-QAM as illustrations, discuss the three main considerations or parameters when designing a symbol constellation.

(9 marks)

b) Consider the square 16-QAM constellation of Figure 2.

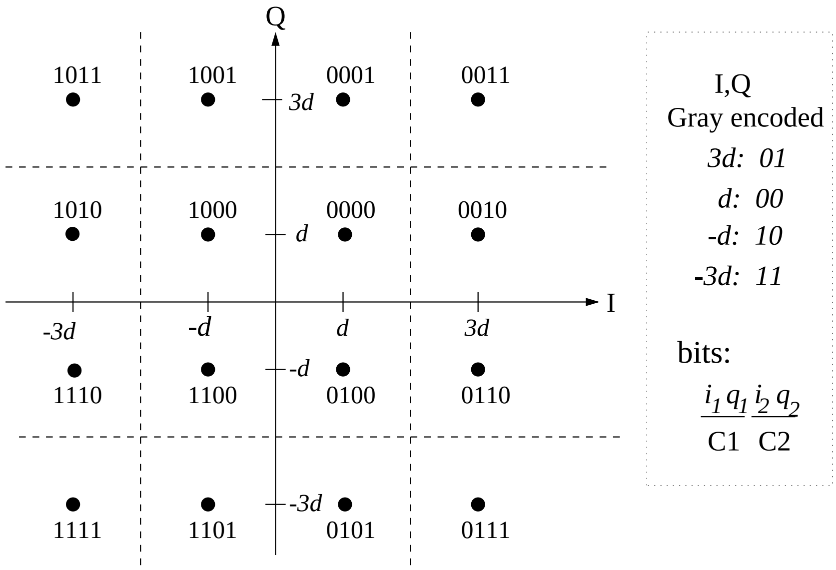

Figure 2

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.

(10 marks)

Question 3 continued on the next page

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.

(7 marks)

d) The Walsh codes are generated by applying the Hadamard transform of:

$$\mathbf{H}_1 = [0] \quad \mathbf{H}_{2n} = \left[\begin{array}{cc} \mathbf{H}_n & \mathbf{H}_n \\ \mathbf{H}_n & \overline{\mathbf{H}}_n \end{array} \right].$$

Write down the code matrix $\mathbf{H}_8$ and verify that the eight columns of this code matrix form a set of eight orthogonal codes.

(7 marks)

4.

a) For the binary Bose-Chaudhuri-Hocquenhem code $BCH(7, 4, 3)$ described by the generator polynomial $g(x) = 1 + x + x^3$, draw the encoder circuit, construct and draw the state-transition diagram and the state diagram, marking explicitly all the states and state-transitions, labelled by the associated output bit. (8 marks)

b) Assume that the received sequence is 1100001, where the left-most bit is at the left-most position of the trellis. The hard-decision Viterbi algorithm is used for decoding. 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.

(8 marks)

c) 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.

(9 marks)

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

(8 marks)

5.

a) A complex-valued equaliser is defined by

$$y(k) = w_0^* r(k) + w_1^* r(k-1) + \cdots + w_m^* r(k-m) = \mathbf{w}^H \mathbf{r}(k) \, ,$$

where w_i^* denotes the conjugate of the weight w_i, $r(k)$ is the received signal at sample k given by

$$r(k) = c_0 s(k) + c_1 s(k-1) + \cdots + c_h s(k-h) + n(k) \, ,$$

$s(k)$ is the transmitted quadrature amplitude modulation (QAM) symbol with the mean square value σ_s^2, and $n(k)$ is the channel additive white Gaussian noise (AWGN) with $E[|n(k)|^2] = 2\sigma_n^2$.

During training, the error signal used for equaliser weight updating is

$$e(k) = s(k-d) - y(k) \, .$$

(i) With the definition of $\mathbf{s}(k) = [s(k) \; s(k-1) \cdots s(k-m-h)]^T$ and the expression of the received signal vector

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

express the $(m+1) \times (m+h+1)$ dimensional system Toepitz matrix $\mathbf{C}$ in terms of the channel impulse response taps $c_0, c_1, \cdots, c_h$. (2 marks)

(ii) Give the expression for the mean square error (MSE) $J(\mathbf{w}) = E\left[|e(k)|^2\right]$. You should express the MSE in terms of the system's parameters $\mathbf{C}$, σ_n^2 and σ_s^2. (4 marks)

(iii) What are the necessary and sufficient conditions for an equaliser weight vector $\hat{\mathbf{w}}$ to be a minimum point of the mean square error? (4 marks)

(iv) From these conditions, determine the minimum mean square error (MMSE) solution $\hat{\mathbf{w}}$ of the equaliser's weight vector. (2 marks)

Question 5 continued on the next page

b) For the complex-valued equaliser

$$y(k) = \mathbf{w}^H \mathbf{r}(k)$$

defined in a):

(i) Write down the weight adaptation equation of the least mean square (LMS) algorithm. (2 marks)

(ii) Give the expression of the cost function used by the blind equalisation algorithm called the constant modulus algorithm (CMA), and describe the weight updation equation of the CMA. (6 marks)

c) Draw the schematic diagram of the orthogonal frequency division multiplexing (OFDM) transceiver and explain its operations.

(13 marks)

END OF PAPER