UNIVERSITY OF SOUTHAMPTON ELEC6014W1

SEMESTER II EXAMINATIONS 2007/08

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) Provide a simple formula for the power budget calculation of mobile radio cellular systems and justify the terms with the aid of a sketch.

(4 marks)

b) Assume that the propagation pathloss of a mobile channel can be calculated using the typical urban Hata model given by

$$L_{Hu} = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_{BS} - a(h_{MS})$$
$$+(44.9 - 6.55 \log_{10} h_{BS}) \log_{10} d \quad \text{(dB)}$$

with the small/medium city correction factor of

$$a(h_{MS}) = (1.1 \log_{10} f - 0.7) h_{MS} - (1.56 \log_{10} f - 0.8),$$

where f is the carrier frequency (MHz), h_{BS} and h_{MS} are the heights (m) of the BS and MS antenna, respectively, and d is the BS-to-MS distance (km).

The mobile antenna height $h_{MS} = 1$ m, the base antenna height $h_{BS} = 100$ m, the carrier frequency $f = 1$ GHz, and the cell radius $d = 500$ m. Further assume that the 2% slow fading overload margin $L_{\text{slow}} = 14$ dB, and the 2% fast fading overload margin $L_{\text{fast}} = 7$ dB. If the receiver sensitivity is -111 dBm, calculate the transmitter power required.

(4 marks)

c) 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)

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)

Question 1 continued on the next page

e) Mobile radio channels can exhibit frequency dispersion.

i) What is the physical quantity that is used to measure the frequency dispersion of channel?

ii) What is the time-domain representation of this quantity called?

iii) Give the relationship between this physical quantity and its time-domain representation.

iv) Give the conditions that classify mobile radio channels into fast-fading and slow-fading ones, respectively, assuming that the signal bandwidth is B_S and the signal symbol period is T_S.

(5 marks)

f) Mobile radio channels can exhibit time dispersion.

i) What is the physical quantity that is used to measure the time dispersion of channel?

ii) What is the frequency-domain representation of this quantity called?

iii) Give the relationship between this physical quantity and its frequency-domain representation.

iv) Give the conditions that classify mobile radio channels into frequency-selective and flat ones, respectively, assuming that the signal bandwidth is B_S and the signal symbol period is T_S.

(5 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 the 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 1.

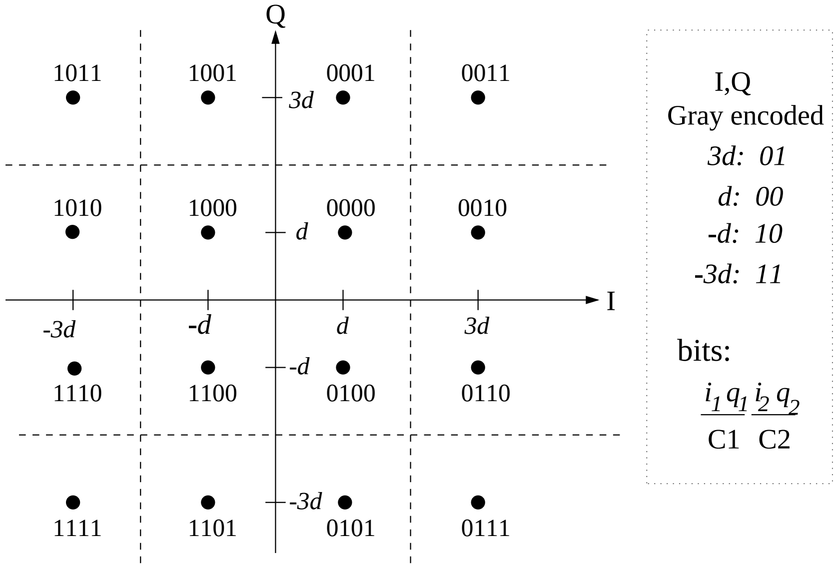

Figure 1

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 shift register feedback circuit for the generating polynomial $g(x) = 1 + x^2 + x^3$ is given in Figure 2, where the numbers in the register blocks denote the initial values of the registers.

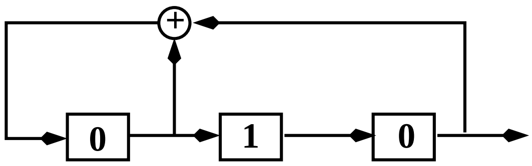

Figure 2

Write down a period of the m-sequence generated by this circuit and verify the autocorrelation function of this m-sequence is given by

$$R_{aa}(k) = \begin{cases} 1, & k = 0 \\ -\frac{1}{N}, & 1 \leq k \leq N-1 \end{cases}$$

where N is the period of the m-sequence.

(7 marks)

4.

a) For the systematic 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, construct and draw the state-transition diagram, marking explicitly all the states and state-transitions, labelled by the associated encoded bits.

(7 marks)

b) Assume that the received sequence is $010010000000 \cdots 00$, 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.

(7 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.

(8 marks)

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

(11 marks)

5.

a) Draw the schematic diagram of symbol-by-symbol-decision adaptive channel equalisation. Explain the two operational modes of the adaptive equaliser.

(6 marks)

b) A real-valued filter is defined by

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

where $r(k)$ 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 data symbol with the mean square value σ_s^2, and the additive white Gaussian noise (AWGN) $n(k)$ has a variance σ_n^2. During training, the error signal used for filter weight updating is $e(k) = s(k-d) - y(k)$.

(i) Given $\mathbf{s}(k) = [s(k) \; s(k-1) \cdots s(k-m-h)]^T$ 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 system impulse response taps $c_0, c_1, \cdots, c_h$. (2 marks)

(ii) Given the mean square error expression $J(\mathbf{w}) = E\left[|e(k)|^2\right]$, what are the necessary and sufficient conditions for a filter weight vector $\hat{\mathbf{w}}$ to be a minimum point of the mean square error? (4 marks)

(iii) From these conditions, determine the minimum mean square error (MMSE) solution $\hat{\mathbf{w}}$ of the filter's weight vector. You should express the MMSE solution in terms of the system's parameters $\mathbf{C}$, σ_n^2 and σ_s^2. (2 marks)

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

Question 5 continued on the next page

c) For the BPSK modulation scheme, namely $s(k) \in \{-1, \ +1\}$, write down the weight adaptation equation of the least bit error (LBER) algorithm.

(3 marks)

d) For a BPSK channel, the received signal sample is given by

$$r(k) = 0.5s(k) + 1.0s(k-1) + 0.5s(k-2) + n(k)\,,$$

where $s(k) \in \{-1, +1\}$. Given the received signal sequence

$$r(1), r(2), \cdots, r(7) = 0.2, 0.5, -1.0, -0.7, 0.3, 1.2, 1.4\,,$$

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.

(8 marks)

e) For the general quadrature amplitude modulation (QAM) scheme, 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)

END OF PAPER