SEMESTER II EXAMINATIONS 2009/10

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.

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

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) 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)

c) 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)

Question 1 continued on the next page

d) With the aid of sketches, explain why orthogonal frequency division multiplexing (OFDM) is an effective technique for combating both time-domain fading and frequency selective channels.

(10 marks)

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

(6 marks)

b) 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)

c) Describe the early-late clock recovery scheme designed for BPSK with the aid of block diagrams.

(6 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.

(8 marks)

e) Draw the block diagram of the matched filter receiver and explain its operations with the aid of sketches.

(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.

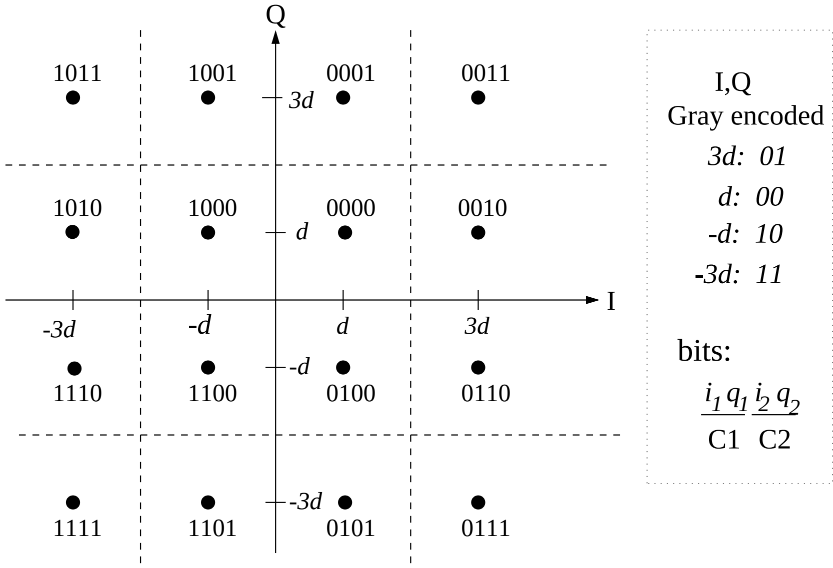

Figure 1

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.

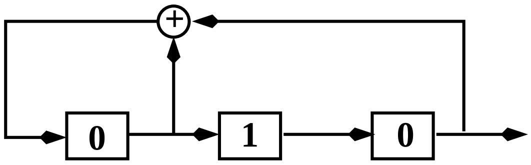

Figure 2

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 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) For this $BCH(7, 4, 3)$ system, 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 narrowband 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)

Question 4 continued on the next page

d) For a binary phase shift keying (BPSK) channel, the received signal sample is given by

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

where $s(k) \in \{\pm 1\}$ and $n(k)$ is a Gaussian white noise. Given the received signal sequence

$$r(1), r(2), \cdots, r(7) = 0.2, 0.5, -1.0, -0.7, 0.3, 1.1, 1.5\,,$$

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)

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) 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

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

where $\mathbf{H}$ 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 spatial filter.

Write down the MMSE solutions for the n_T spatial filters' weight vectors.

(5 marks)

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

(8 marks)

END OF PAPER