UNIVERSITY OF SOUTHAMPTON ELEC6014W1

SEMESTER 2 EXAMINATIONS 2012-2013

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) In a mobile cellular system, the mobile station (MS) antenna height $h_{MS} = 1$ m, the base station (BS) antenna height $h_{BS} = 100$ m, the carrier frequency $f = 1$ GHz, and the cell radius $R = 500$ m. The propagation pathloss of the mobile channel can be calculated using the urban Hata model given by

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

with the small/medium city correction factor of

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

In the Hata model, the carrier frequency f is given in (MHz), the heights of the BS and MS antennas, h_{BS} and h_{MS}, are given in (m), and the BS-to-MS distance d is given in (km).

Assume that the 2% slow fading overload margin is $L_{\text{slow}} = 14$ dB, and the 2% fast fading overload margin is $L_{\text{fast}} = 7$ dB. Further assume that the BS's receiver sensitivity is -111 dBm. Calculate the transmitter power required for a MS if the MS is at the cell edge.

(6 marks)

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

(6 marks)

Question 1 continued on the next page

d) The power delay profile of a mobile radio channel is given in Figure 1. The system's carrier frequency is $f_c = 2$ GHz, and the transmitted signal bandwidth is $B_S = 200$ kHz. The 50% coherence bandwidth is defined as

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

with the root mean square delay spread given by

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

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

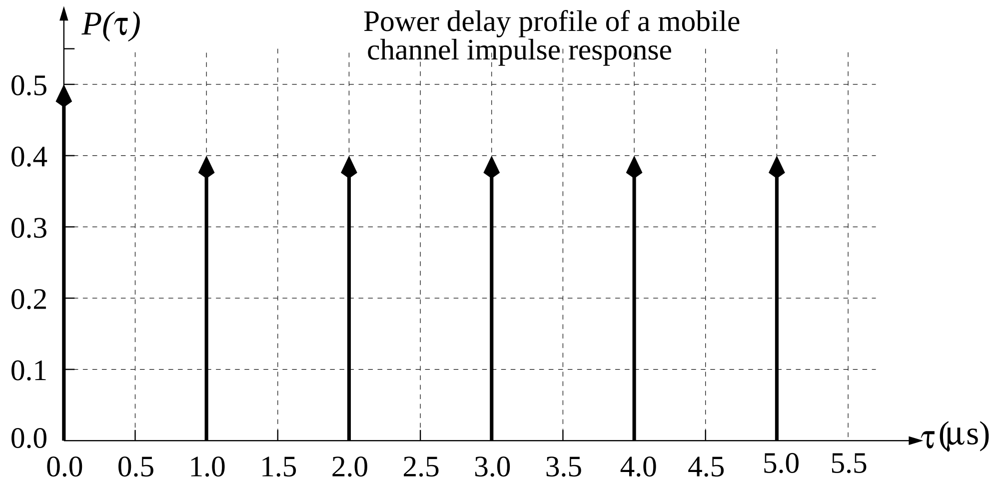

Figure 1

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

(6 marks)

e) With the aid of clearly labelled block diagram, briefly describe the operations of the coherent space-time shift-keying transmitter.

(9 marks)

2.

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

(6 marks)

b) Describe the time-two clock recovery scheme designed for BPSK transmission, with the aid of clearly labelled block diagrams and signal plots.

(6 marks)

c) 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)

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

(6 marks)

e) i) State the famous Shannon-Hartley channel capacity formula, clearly defining each variable in the formula.

(2 marks)

ii) According to the Shannon-Hartley channel capacity formula, what are the two basic resources for digital communications? Discuss how you can trade off these two resources to achieve the required channel capacity.

(4 marks)

3.

a) Draw the block diagram of the correlation 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 Gray labelled 4-ary pulse amplitude modulation (4-PAM) constellation of Figure 2.

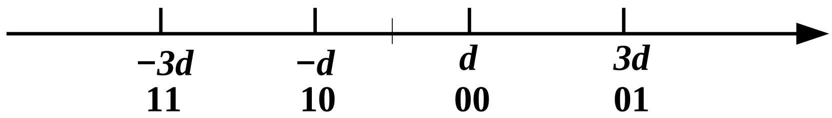

Figure 2

Derive the corresponding error probability equations for the class one and class two sub-channels under additive white Gaussian noise (AWGN). The two 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 two-sided power spectral density of the noise.

(7 marks)

c) Repeat b) for the Gray labelled square 16-quadrature amplitude modulation (16-QAM) constellation.

(4 marks)

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

(6 marks)

Question 3 continued on the next page

TURN OVER

e) i) Write down the average error probability of the 4-QAM scheme over the AWGN channel.

(2 marks)

ii) Based on the result of i), derive the average error probability of the 4-QAM scheme over the Rayleigh fading channel, whose 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. You may find the integration formula

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

useful.

(5 marks)

iii) Comment on the effect of fading to the achievable system performance, and suggest a counter fading measure.

(2 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 soft sequence is given by

$$+0.8, -1.2, +0.6, -2.2, -0.4, -1.3, -0.9$$

where the left most value corresponds to the left-most position of the trellis, a positive value for the soft decision represents how likely or probable the corresponding bit is **1**, and a negative value for the soft decision represents how likely the corresponding bit is **0**. The soft-input hard-output Viterbi algorithm is used for decoding.

Draw the associated trellis diagram for decoding, clearly marking all the transitions and the associated branch metrics. Find the most likely transmitted information sequence.

(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.

(8 marks)

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

(10 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 $r(k)$ 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 complex-valued data 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 is given by

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

where d is referred to as the equaliser's decision delay.

i) Explain how the decision delay is related to the channel. Under what condition will the decision delay be $d = 0$? (4 marks)

ii) 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 Toeplitz matrix $\mathbf{C}$ in terms of the channel impulse response taps $c_0, c_1, \cdots, c_h$. (2 marks)

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

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

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

Question 5 continued on the next page

b) Give the expression of the cost function used by the blind equalisation algorithm known as the constant modulus algorithm (CMA), and describe the weight updating equation of the CMA.

(6 marks)

c) For 4th generation (4G) and beyond 4G (B4G) high-speed broadband applications, with data rates in tens of Mbps transmitted over the wireless channels of typical delay spread in microseconds, the intersymbol interference (ISI) spans tens or even hundreds of symbols. Applying the time-domain equalisation to these 4G and B4G systems leads to impractically long equaliser, excessively slow convergence and poor performance.

With the aid of the baseband system diagram, explain the operations of the single-carrier (SC) block transmission system with frequency-domain equalisation (FDE) and, therefore, explain why the SC-FDE offers an attractive alternative for mitigating ISI for these broadband systems.

(11 marks)

END OF PAPER