SEMESTER 2 EXAMINATION 2018 - 2019

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION 150 MINS (2.5 Hours)

This paper contains 5 questions

Answer **THREE** questions out of **FIVE** questions.

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

This examination contributes 100% of the marks for the module.

Only University approved calculators MAY be used.

A foreign language dictionary is permitted ONLY IF it is a paper version of a direct Word to Word translation dictionary AND it contains no notes, additions or annotations.

10 page examination paper.

Question 1.

(a) Mobile radio channels can exhibit frequency dispersion.

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

(ii) What is the term used to denote the time-domain representation of this quantity?

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

(iv) Give the conditions that classify mobile 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.

[6 marks]

(b) Mobile radio channels can exhibit time dispersion.

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

(ii) What is the term used to denote the frequency-domain representation of this quantity?

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

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

[6 marks]

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

[6 marks]

(d) As an engineer in charge of designing a 4G mobile network, you decide to choose orthogonal frequency division multiplexing (OFDM).

Explain the purposes of the cyclic prefix at the beginning of each OFDM block or symbol.

[8 marks]

(e) The received signal power P_{Rx} at the receiver is related to the transmitted signal power P_{Tx} at the transmitter by the following equation

$$P_{Rx} \;=\; P_{Tx} \cdot h \cdot r^{-\alpha}$$

where h is the small-fading channel gain which is assumed to be a constant for all links, r is the distance from the transmitter to the receiver, and α is the pathloss exponent which is given by $\alpha = 2$.

The spatial locations of the source S, the destination D, and the potential relay R are illustrated in Figure 1. For the receiver to successfully detect the transmitted signal, the received signal power should be no less than the threshold P_{th}, i.e., $P_{Rx} \geq P_{th}$.

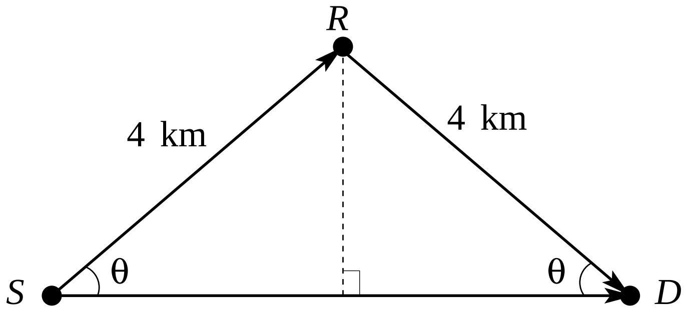

Figure 1

(i) Assume that $\theta = 30°$. In order to minimise the total required transmit power, should the source S directly transmit to the destination D? or should S transmit to the relay R and let R forward the signal to D? and why? (hint: $\cos 30° = \frac{\sqrt{3}}{2}$.)

(ii) What is the penalty, or cost paid, to achieve the minimum total required transmit power option derived in (i)?

[7 marks]

TURN OVER

Question 2.

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

[6 marks]

(b) With the aid of a clearly labelled block diagram and signal plots, describe the time-two clock recovery scheme for binary phase shift keying transmission.

[5 marks]

(c) Explain frequency division duplexing (FDD) and time division duplexing (TDD). In which of these two duplexing based systems, will the uplink channel and the downlink channel be reciprocal? Explain why.

[8 marks]

(d) With FDD or TDD, a mobile user requires two resource blocks (two frequency slots or two time slots) to achieve full duplexing. Name the duplexing scheme that is capable of achieving full duplexing with only a single resource block. Explain how this full duplexing scheme works with the aid of a system block diagram.

[9 marks]

(e) Consider the M-ary communication scheme with the constellation set

$$\mathcal{X} = \{\bar{x}_1, \bar{x}_2, \cdots, \bar{x}_M\},$$

where $M = 2^n$. At the transmitter, the constellation mapper maps every block of n bits into a symbol:

$$\{b_0, b_1, \cdots, b_{n-1}\} \rightarrow x \in \mathcal{X}.$$

At the receiver the detector outputs the received signal sample

$$y = g_0 x + \varepsilon$$

where g_0 is the known channel state information, and ε is the channel additive white Gaussian noise with power N_0.

(i) Express the log likelihood ratio (LLR) of the ith bit b_i using the optimal log-MAP demapper.

(ii) Calculate the LLR of the ith bit b_i according to the near optimal Max-log-MAP demapper.

[5 marks]

TURN OVER

Question 3.

(a) Specify and explain the two key performance measures for a modulation scheme.

[6 marks]

(b) Explain the three main parameters for designing a symbol constellation, using the square 16-quadrature amplitude modulation (16-QAM), star 16-QAM and 16-phase shift keying (16-PSK), as illustrations.

[6 marks]

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

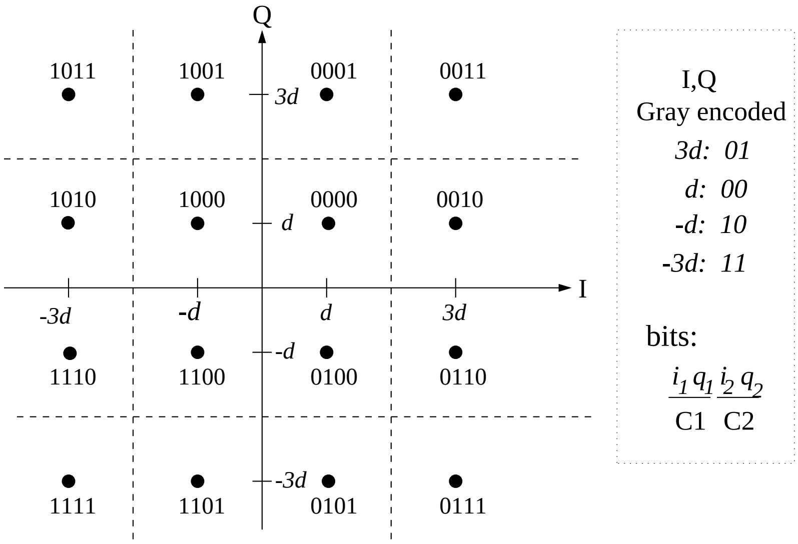

Figure 2

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. The two error probabilities should be expressed as functions of the channel's signal to noise ratio 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]

(d) In a multiple-input multiple-output (MIMO) system, the base station (BS) equipped with M antennas serves K single-antenna mobiles based on the time division duplexing (TDD) protocol.

(i) In uplink reception, what does the BS need in order to perform multi-user detection (MUD)? Describe how the BS obtains this information and give an MUD scheme based on this information.

(ii) In downlink transmission, what the BS needs in order to carry out multi-user transmission (MUT) precoding? Describe how the BS obtains this information and provide an MUT precoding scheme based on this information.

[11 marks]

(e) The desired signal to interference plus noise power ratio achieved by a MIMO system is SINR, and the system's bandwidth is W [Hz]. What is the achievable capacity of this MIMO system in terms of bits per second? [3 marks]

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Question 4.

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

[6 marks]

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

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

The complex-valued received signal sample $r(k)$ 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. Given the received signal sequence

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

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.

[8 marks]

(c) With the aid of clearly labelled block diagrams for two-stage turbo transmitter and receiver, briefly explain how iterative turbo detection and decoding operates.

[13 marks]

(d) Explain why it is inappropriate to apply carrier sense multiple access (CSMA) for wireless ad hoc LANs, and briefly describe the basic idea of the contention algorithm, multiple access with collision avoidance (MACA), for this type of wireless LANs. [6 marks]

Question 5.

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

$$\boldsymbol{x}(k) = \boldsymbol{H}\,\boldsymbol{s}(k) + \boldsymbol{n}(k)\,, \qquad \text{(Eq. 5.1)}$$

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

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

are used to detect the transmitted symbols $s_m(k)$ for $1 \le m \le n_T$, where $\boldsymbol{w}_m$ 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

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

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

(ii) What are the necessary and sufficient conditions for a detector weight vector $\widehat{\boldsymbol{w}}_m$ to be a minimum point of the MSE?

(iii) From these conditions, determine the minimum MSE (MMSE) solution $\widehat{\boldsymbol{w}}_m$ of the m-th detector's weight vector.

[11 marks]

(b) Consider the MIMO system described by (Eq. 5.1) in (a). The transmitted data symbols take the values from the M-ary constellation set

$$s_m(k) \in \mathcal{S} = \left\{\bar{s}^{(1)}, \bar{s}^{(2)}, \cdots, \bar{s}^{(M)}\right\}$$

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(i) Assume that the MIMO channel matrix $\boldsymbol{H}$ is known at the receiver. Write down the expression of the maximum likelihood (ML) solution for the optimal detection of the transmitted symbol vector $\boldsymbol{s}(k)$.

(ii) During the training period, the receiver has the training data

$$\boldsymbol{X} = \left[\boldsymbol{x}(1)\ \boldsymbol{x}(2) \cdots \boldsymbol{x}(K)\right],\ \boldsymbol{S} = \left[\boldsymbol{s}(1)\ \boldsymbol{s}(2) \cdots \boldsymbol{s}(K)\right]$$

Write down the expression of the least squares (LS) estimate for the MIMO channel matrix.

[8 marks]

(c) With the aid of a clearly labelled block diagram and well-defined equations, briefly describe the operations of the coherent space-time shift-keying transmitter and receiver.

[14 marks]

END OF PAPER