SEMESTER 2 EXAMINATIONS 2017-2018

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION: 150 MINS (2.5 Hours)

This paper contains 5 (FIVE) questions.

Answer THREE questions out of FIVE questions.

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.

1.

a) Consider a Rayleigh fading multi-path environment. Given that the angle of arrival for the received waves is uniformly distributed, derive an expression for the Doppler power spectrum. [6 marks]

You may find the following relationship useful.

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

b) Classify various multiple-input multiple-output (MIMO) systems based on multiple-antenna techniques into three types and briefly discuss their main purposes. [6 marks]

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

i) With the aid of sketches, explain to your boss why OFDM is an effective technique for combating both time-domain fading and frequency selective channels. [6 marks]

ii) Explain to your boss the purposes of the cyclic prefix at the beginning of each OFDM block or symbol. [8 marks]

d) The received signal power P_{Rx} at receiver is related to the transmitted signal power P_{Tx} at 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 $\alpha = 2$.

Question 1 d) continued on the next page

Question 1 d) continues ...

The spatial locations of source S, destination D, and 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., $P_{Rx} \geq P_{th}$.

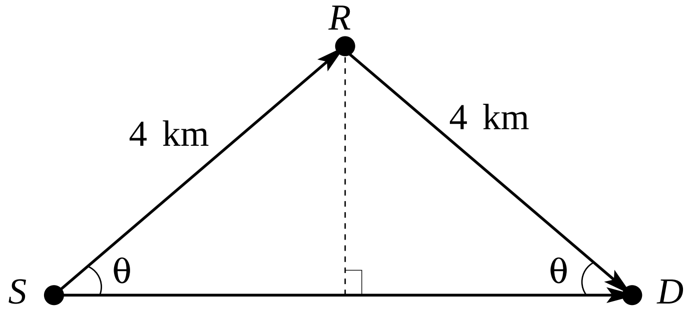

Figure 1

i) Assume that $\theta = 30^\circ$. In order to minimise the total required transmit power, should source S directly transmit to destination D? or should S transmit to relay R and let R forward the signal to D? and why? (hint: $\cos 30^\circ = \frac{\sqrt{3}}{2}$.) [4 marks]

ii) What is the penalty, or cost paid, to achieve the minimum total required transmit power option derived in i)? [3 marks]

TURN OVER

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 early-late clock recovery scheme for binary phase shift keying transmission. [5 marks]

c) i) Explain the 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]

ii) 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 single resource block. Explain how this full duplexing scheme works with the aid of a system block diagram. [8 marks]

d) 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 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 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. [4 marks]

ii) Calculate the LLR of the ith bit b_i according to the near optimal Max-log-MAP demapper. [2 marks]

3.

a) 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.

[7 marks]

b) Consider the 4-QAM communication system.

i) Derive the average error probability of the 4-QAM scheme over the additive white Gaussian noise (AWGN) channel, expressed as a function 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-side power spectral density of the noise. [4 marks]

ii) Based on the result of question i) above, 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 following integration formula useful.

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

[3 marks]

iii) Comment on the effect of fading to the achievable system performance, and suggest a counter fading measure. [2 marks]

Question 3 continued on the next page

TURN OVER

Question 3 continues ...

c) 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]

d) In traditional networks with distributed access, such as ad hoc networks, there are no central access points.

   i) Briefly explain how information can be transmitted from source to destination in traditional ad hoc networks. [3 marks]

   ii) What does the communication strategy you outlined in i) rely on? [2 marks]

   iii) In emerging networks known as delay tolerance networks, can the communication strategy you outlined in i) still be applied? and why? [2 marks]

   iv) Explain briefly the new communication strategy or paradigm for delay tolerance networks. [4 marks]

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

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

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. [10 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. [6 marks]

Question 4 continued on the next page

TURN OVER

Question 4 continues ...

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 the BS needs in order to perform multi-user detection (MUD)? Describe how the BS obtains this information and give an MUD scheme based on this information.

[5 marks]

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. [6 marks]

5.

a) A multiple-input multiple-output (MIMO) system, consisting of n_T transmit antennas and n_R receive 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, $\boldsymbol{s}(k) = [s_1(k)\ s_2(k) \cdots s_{n_T}(k)]^T$ is the transmitted symbol vector of the n_T transmitters with $E\left[|s_m(k)|^2\right] = \sigma_s^2$ for $1 \leq m \leq n_T$, $\boldsymbol{x}(k) = [x_1(k)\ x_2(k) \cdots x_{n_R}(k)]^T$ is the received signal vector, and $\boldsymbol{n}(k) = [n_1(k)\ n_2(k) \cdots n_{n_R}(k)]^T$ is the complex-valued Gaussian white noise vector associated with the MIMO channels with $E\left[\boldsymbol{n}(k)\boldsymbol{n}^H(k)\right] = 2\sigma_n^2 \boldsymbol{I}_{n_R}$. A bank of the spatial filters

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

are used to detect the transmitted symbols $s_m(k)$ for $1 \leq m \leq n_T$, 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) Give the mean square error (MSE) expression, $J(\mathbf{w}_m) = E\left[|\varepsilon_m(k)|^2\right]$, for the m-th detector. You should express the MSE in terms of the MIMO system's parameters $\boldsymbol{H}$, σ_n^2 and σ_s^2. [6 marks]

ii) What are the necessary and sufficient conditions for a detector weight vector $\widehat{\boldsymbol{w}}_m$ to be a minimum point of the mean square error? [4 marks]

iii) From these conditions, determine the minimum mean square error (MMSE) solution $\widehat{\boldsymbol{w}}_m$ of the m-th detector's weight vector. [2 marks]

Question 5 continued on the next page

TURN OVER

Question 5 continues ...

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

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

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 $\boldsymbol{s}(k)$.
[4 marks]

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

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

Write down the expression of the least squares (LS) estimate for the MIMO channel matrix. [4 marks]

c) With the aid of clearly labelled block diagram and well-defined equations, briefly describe the operations of the coherent space-time shift-keying transmitter and receiver. [13 marks]

END OF PAPER

