SEMESTER 2 EXAMINATION 2021 - 2022

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION 150 MINS (2.5 Hours)

This paper contains ?? questions

Answer All the Four 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.

?? page examination paper.

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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.

[5 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.

[5 marks]

(c) 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]

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(d) (i) Discuss the use cases or application areas offered by the fifth generation (5G) mobile network.

(ii) Explain why MIMO, particularly massive MIMO, offers a promising technology for 5G.

[7 marks]

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Question 2.

(a) (i) With a clearly labeled block diagram, explain the operation of the time-two carrier recovery scheme.

What carrier modulation communication system is this carrier recovery scheme suitable for?

(ii) You are designing a quadrature amplitude modulation (QAM) based carrier communication system. Can you apply the time-two carrier recovery scheme for carrier recovery? Explain why.

Draw the block diagram of the carrier recovery scheme that can be used for QAM transmission, and briefly explain its operation.

[8 marks]

(b) (i) 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.

(ii) A fading communication channel has a passband bandwidth $B_p = 220$ MHz. The combined transfer function of the transmit and receive filters has a raised-cosine characteristic with a roll-off factor of 0.1. Design an appropriate modulation scheme so that you can transmit at the bit rate of $R_b = 800$ Mbits/s over this fading channel reliably.

[7 marks]

(c) In a spatial-domain non-orthogonal access system, the base station (BS) equipped with M antennas serves K $(K < M)$ single-antenna mobiles with the same resource block 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 does the BS need 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.

[10 marks]

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Question 3.

(a) 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.

(iii) If the *a priori* LLRs of b_i for $0 \leq i \leq n-1$ are given, how can you calculate the *a posteriori* LLRs of b_i?

(iv) The LLRs derived in (ii) are in fact the *a posteriori* LLRs under what assumption?

(v) Discuss the reason for calculating the LLRs of bits rather than using the hard detected bits.

[8 marks]

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

[12 marks]

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(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

$$G_2 = \left[\begin{array}{cc} x_1 & x_2 \\ -x_2^* & x_1^* \end{array} \right].$$

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. Is Alamouti's G_2 space-time block code an orthogonal space-time block code?

[5 marks]

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Question 4.

(a) In a multiuser multiple-input multiple-output (MU-MIMO) system, n_T single-antenna transmitters communicate over flat fading channels to the base station (BS) which is equipped with n_R receiving antennas. The MU-MIMO system is described by the following model

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

where $\boldsymbol{H}$ is the $n_R \times n_T$ channel matrix, $\boldsymbol{s}(k) = [s_1(k) \cdots s_{n_T}(k)]^{\mathrm{T}}$ is the transmitted symbol vector of the n_T users with $E\left[|s_m(k)|^2\right] = \sigma_s^2$ for $1 \le m \le n_T$, and the transmitted data symbols take the values from the M-ary constellation set

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

while $\boldsymbol{x}(k) = [x_1(k) \cdots x_{n_R}(k)]^{\mathrm{T}}$ denotes the received signal vector at the BS, and $\boldsymbol{n}(k) = [n_1(k) \cdots n_{n_R}(k)]^{\mathrm{T}}$ is the complex-valued Gaussian white noise vector associated with the MIMO channels with $E\left[\boldsymbol{n}(k)\boldsymbol{n}^{\mathrm{H}}(k)\right] = 2\sigma_n^2 \boldsymbol{I}_{n_R}$.

(i) How can you acquire the channel matrix $\boldsymbol{H}$? Design an estimation scheme to obtain an estimate of $\boldsymbol{H}$.

(ii) Given the channel matrix $\boldsymbol{H}$, the transmission power σ_s^2 and the channel noise statistic σ_n^2, determine the minimum mean square error (MMSE) detection of the transmitted symbol vector $\boldsymbol{s}(k)$.

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

[8 marks]

(b) With the aid of a clearly labeled block diagram and well-defined equations, briefly describe the operations of the spatial modulation transmitter and receiver.

[7 marks]

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(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.

(ii) With FDD or TDD, a mobile user requires two resource blocks (two frequency slots or two time slots) to achieve full duplexing, namely, one resource block for transmitting and the other for receiving. 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.

[10 marks]

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