SEMESTER 2 EXAMINATION 2020 - 2021

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION 24×60 MINS (24 Hours)

This paper contains 4 questions

Answer All the Four questions.

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

This is an open book assessment and contributes 100% of the marks for the module.

Ignore the following instruction

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.

9 page examination paper.

Question 1.

(a) A mobile radio channel has the power delay profile given in **Figure Q1-1**. The system's carrier frequency is $f_c = 3$ GHz, the transmitted signal bandwidth is $B_S = 200$ kHz, the symbol period of the system is $T_S = 5\,\mu\text{s}$, and the propagation speed is $c = 3 \times 10^8\,\text{ms}^{-1}$.

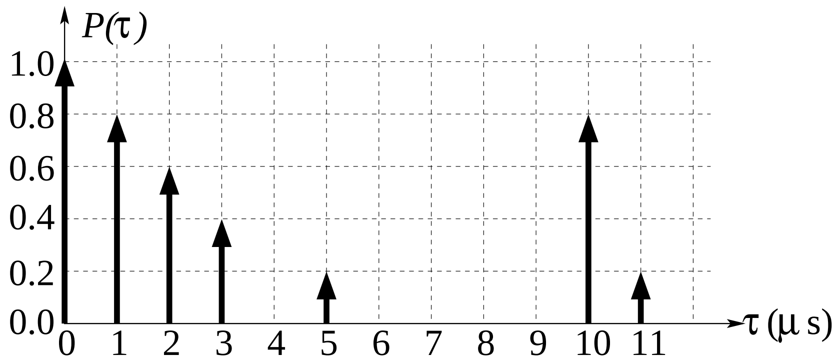

Figure Q1-1

(i) Calculate the root mean square delay spread and the 50% coherence bandwidth of the channel, and decide whether an equaliser is required for this mobile communication system.

(ii) You are making a mobile call using this mobile system at a high-speed train travelling at a speed of 360 km/hr. Estimate the Doppler spread of the corresponding channel, and calculate the normalised Doppler frequency of this fading channel.

[6 marks]

(b) The fourth generation (4G) mobile network adopts the orthogonal frequency division multiplexing (OFDM) transmission technique in order to support high-rate broadband applications.

(i) Explain why. You should provide your explanation based on the characteristics of mobile channel.

(ii) With appropriate block diagrams, briefly describe the operations of the OFDM transceiver. Clearly explain the purposes of the cyclic prefix at the beginning of each OFDM block or symbol.

(iii) What is the main drawback of OFDM transmission technique? You should explain this drawback from the characteristics of OFDM transmission signal.

[11 marks]

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

[3 marks]

(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.

[5 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 carrier recovery scheme that can be used for QAM transmission, and briefly explain its operation.

[4 marks]

(b) A fading communication channel has a passband bandwidth $B_p = 110$ 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 $R_b = 400$ Mbits/s over this fading channel reliably.

[5 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]

(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.

(ii) What does the communication strategy you outlined in (i) rely on?

(iii) In emerging networks known as delay tolerance networks, can the communication strategy you outlined in (i) still be applied? and why? Explain briefly the new communication strategy or paradigm for delay tolerance networks.

[6 marks]

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?

[6 marks]

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

[11 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.

[3 marks]

(d) 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 OSTBC?

[5 marks]

TURN OVER

Question 4.

(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

$$\boldsymbol{x}(k) = \boldsymbol{H}\,\boldsymbol{s}(k) + \boldsymbol{n}(k)\,, \tag{Eq. 4.1}$$

where $\boldsymbol{H}$ is the $n_R \times n_T$ channel matrix, $\boldsymbol{s}(k) = [s_1(k) \cdots s_{n_T}(k)]^{\mathrm{T}}$ denotes the transmitted symbol vector of the n_T transmitters with $E\left[|s_m(k)|^2\right] = \sigma_s^2$ for $1 \le m \le n_T$, $\boldsymbol{x}(k) = [x_1(k) \cdots x_{n_R}(k)]^{\mathrm{T}}$ is the received signal vector, 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 $E\left[\boldsymbol{n}(k)\boldsymbol{n}^{\mathrm{H}}(k)\right] = 2\sigma_n^2 \boldsymbol{I}_{n_R}$. 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. The m-th error signal for the m-th detector is defined by

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

(i) Derive 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.

[5 marks]

(b) Consider the MIMO system described by (Eq. 4.1) in (a). The transmitted data symbols take the values from the M-ary constellation set

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

(i) 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 $\boldsymbol{s}(k)$.

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

[5 marks]

(c) Explain why it is inappropriate to apply carrier sense multiple access (CSMA) for wireless ad hoc LANs, and describe the basic contention algorithm suitable for this type of wireless LANs.

[4 marks]

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

(ii) Discuss the advantages and disadvantages of STSK transmission scheme, compared with the spatial modulation.

[11 marks]

END OF PAPER

