SEMESTER 2 EXAMINATIONS 2023 - 2024

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION 150 MINS (2.5 Hours)

This paper contains 4 questions

Answer all FOUR questions.

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

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.

7 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 (TD) representation of this quantity?

(iii) Provide the relationship between this physical quantity and its TD 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.

[4 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 (FD) representation of this quantity?

(iii) Provide the relationship between this physical quantity and its FD 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.

[4 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]

(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 $\alpha = 2$.

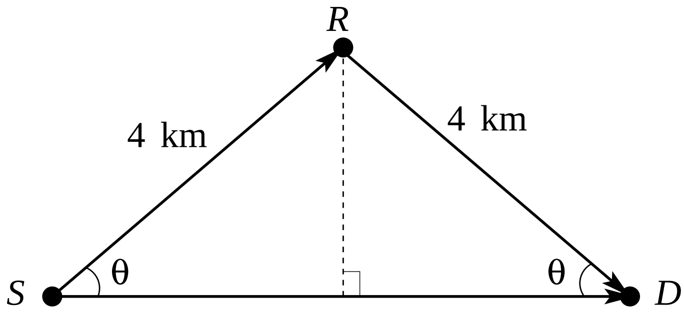

Figure Q1

The spatial locations of source S, destination D, and potential relay R are illustrated in Figure Q1. For the receiver to successfully detect the transmitted signal, the received signal power should be no less than the threshold P_{th}, i.e., $P_{Rx} \geq P_{th}$.

(i) Assume that $\theta = 60^\circ$. 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: $\cos 60^\circ = \frac{1}{2}$.)

(ii) If $\theta = 30^\circ$, repeat question (i) above. In this case, also calculate the ratio of the total required transmit power for $S \to D$ link to the total required transmit power for $S \to R \to D$ link. (hint: $\cos 30^\circ = \frac{\sqrt{3}}{2}$.)

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

[9 marks]

TURN OVER

Question 2.

(a) (i) Draw the block diagram of a baseband communication system and define the requirements of optimal transmitter and receiver filtering.

(ii) 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.

[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.

(iii) What will your modulation scheme design be if the channel in (ii) is an additive white Gaussian noise (AWGN) channel?

[8 marks]

(c) (i) With an appropriate diagram, describe the grant-based 4-step handshake multiple access procedure for a user device to access the fourth-generation (4G) network.

(ii) Will this 4-step handshake multiple access be suitable for massive machine type communications (mMTCs) and massive Internet of Things (mIoTs) connectivity? Explain why.

[9 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:

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

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.

[11 marks]

(c) With appropriate schematic diagrams, divide various transmit beamforming schemes into the three classes according to their hardware requirements and functions.

[6 marks]

TURN OVER

Question 4.

(a) In an MU-MIMO-OFDM system, K single-antenna users share the same N-subcarrier resources and communicate over frequency selective channels to the base station (BS), which is equipped with L receive antennas. At the BS, after cyclic prefix removal and N-point FFT processing, the frequency-domain (FD) receive signal vector $\underline{\mathbf{X}}_n \in \mathbb{C}^{L\times 1}$ on subcarrier n can be expressed as

$$\underline{\mathbf{X}}_n = \underline{\mathbf{H}}_n \, \underline{\mathbf{S}}_n + \underline{\mathbf{\Xi}}_n, \; 0 \le n \le N-1$$

where $\underline{\mathbf{H}}_n \in \mathbb{C}^{L\times K}$ is the FD channel matrix on subcarrier n,

$$\underline{\mathbf{S}}_n = [S_{1,n} \; S_{2,n} \cdots S_{K,n}]^{\mathrm{T}} \in \mathbb{C}^{K\times 1}$$

is the transmitted symbol vector of the K users on subcarrier n with $E\left[|S_{k,n}|^2\right] = \sigma_s^2$ for $1 \le k \le K$, and the transmitted data symbols take the values from the M-ary constellation set

$$S_{k,n} \in \mathcal{S} = \left\{\underline{S}^{(1)}, \underline{S}^{(2)}, \cdots, \underline{S}^{(M)}\right\},$$

while $\underline{\mathbf{\Xi}} = [\Xi_{1,n} \; \Xi_{2,n} \cdots \Xi_{L,n}]^{\mathrm{T}} \in \mathbb{C}^{L\times 1}$ is the FD Gaussian white noise vector on subcarrier n with $E\left[|\Xi_{l,n}|^2\right] = 2\sigma_\xi^2$ for $1 \le l \le L$.

Hence, given $\underline{\mathbf{H}}_n$, the multiuser detection (MUD) can be done on per subcarrier basis.

(i) Derive the maximum likelihood MUD solution of the transmitted symbol vector of the K users $\underline{\mathbf{S}}_n$ for $0 \le n \le N-1$.

(ii) Derive the linear minimum mean square error (MMSE) MUD solution of the transmitted symbol vector of the K users $\underline{\mathbf{S}}_n$ for $0 \le n \le N-1$.

(iii) Derive the linear zero-forcing (ZF) MUD solution of the transmitted symbol vector of the K users $\underline{\mathbf{S}}_n$ for $0 \le n \le N-1$.

[7 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.

[8 marks]

(c) Explain why it is inappropriate to apply carrier sense multiple access (CSMA) for wireless local area networks (LANs), and briefly describe the basic idea of the contention algorithm, multiple access with collision avoidance (MACA), for this type of wireless LANs.

[5 marks]

(d) Ad hoc networks have no central access points, and they rely on distributed access.

(i) Briefly explain how information can be transmitted from source to destination in ad hoc networks.

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

[5 marks]

END OF PAPER

