SEMESTER 2 EXAMINATION 2022 - 2023

ADVANCED WIRELESS COMMUNICATIONS NETWORKS AND SYSTEMS

DURATION 150 MINS (2.5 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 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.

8 page examination paper.

Question 1.

(a) The power delay profile of a mobile channel is given in Figure Q1.1. The system's carrier frequency is $f_c = 3$ GHz, the transmitted signal bandwidth is $B_S = 2$ MHz, the symbol period of the system is $T_S = 0.5\,\mu\text{s}$, and the propagation speed is $c = 3 \times 10^8\,\text{ms}^{-1}$.

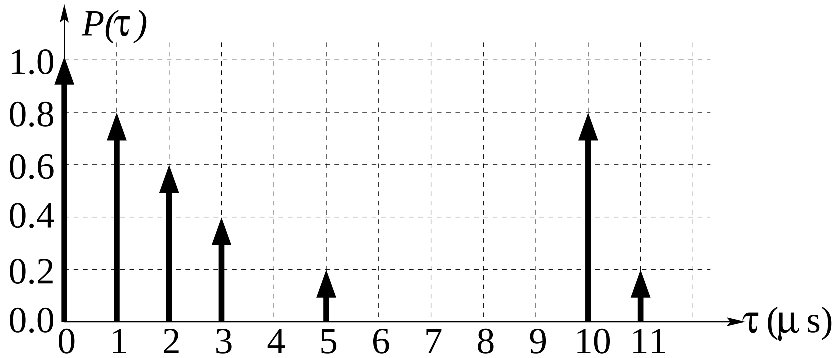

Figure Q1.1

The root mean square delay spread is defined as $\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$, where $\bar{\tau}$ and $\overline{\tau^2}$ are the first and second moments of the channel's power delay profile, respectively, and the 50% coherence bandwidth is defined by $B_C = \frac{1}{5\sigma_\tau}$.

(i) Calculate 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 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.

[8 marks]

(b) 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 $\alpha = 2$.

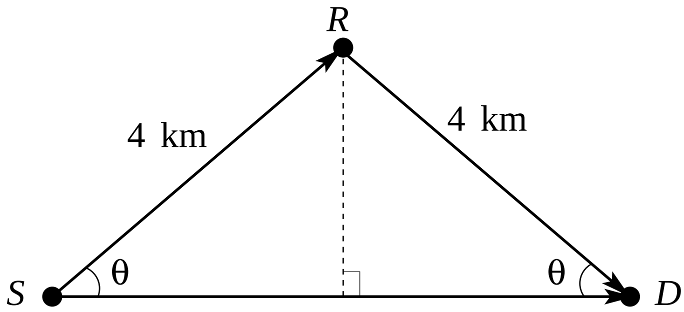

Figure Q1.2

The spatial locations of source S, destination D, and potential relay R are illustrated in Figure Q1.2. 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: $\cos 30^\circ = \frac{\sqrt{3}}{2}$.)

[9 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]

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) 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?

(iii) 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.

[12 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) With an appropriate diagram, describe the 4-step handshake multiple access procedure for user device to access the fourth-generation (4G) network.

[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?

(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]

TURN OVER

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

[6 marks]

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 $\underline{\mathbf{\Xi}} = \left[\Xi_{1,n} \; \Xi_{2,n} \cdots \Xi_{L,n}\right]^{\mathrm{T}} \in \mathbb{C}^{L\times 1}$ 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]

TURN OVER

(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) 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) above rely on?

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

(iv) Explain briefly the new communication strategy or paradigm for delay tolerance networks.

[10 marks]

END OF PAPER

