The University Of Sheffield.

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DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (2.0 hours)

EEE6431 Broadband Wireless Techniques

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. a. Draw a schematic block diagram of a generalised digital communication system and label each constituent block.

Briefly explain how the following channel characteristics affect the propagation of signals:

I. Path loss;
II. Bandwidth limitation. **(6)**

b. What is meant by the free-space path loss in a wireless communication system?

A mobile is located 3 km from a base station transmitting at 40 W with a radio carrier frequency of 2.1 GHz. Show that the power in dBW at the mobile assuming free space propagation and the use of isotropic antennas is -92.4 dBW. **(5)**

c. Explain the key differences between the 2-ray path loss model and the free-space path loss model in a terrestrial wireless communication system?

The basic dB path loss formula for the 2-ray ground propagation path loss model is given by:

$$P_L(dB) = 40\log(d) - 20\log(h_t) - 20\log(h_r) - 10\log(G_t) - 10\log(G_r)$$

where d, h_t, h_r, G_t and G_r take their normal meanings. Calculate the path loss predicted by this formula when applied to a wireless communication system operating at 2.1 GHz for the following parameters:

$$h_t = 15 \text{ m}, h_r = 1.5 \text{ m}, G_t = G_r = 1, d = 3 \text{ km}.$$

What transmit power in watts should the base station in Part 1(b) use to achieve the same receive power at the mobile when the 2-ray path loss model is used? **(7)**

d. What are the causes of shadow fading in a wireless communication system?

Find the outage probability due to shadow fading at a range of 3 km for the 2-ray path loss channel in Part(c) assuming a base station transmit power of 40 W, a mobile minimum power requirement of -128 dBW and a shadow fading standard deviation of 8 dB. **(7)**

2. **a.** How does multipath propagation cause fading in radio waves? Use your answer to explain the difference between narrowband and wideband multipath channels. **(5)**

b. Consider a radio channel subject to narrowband Rayleigh fading. The *pdf* of the Rayleigh distributed envelope r is given by:

$$P_R(r) = \frac{2r}{\bar{P}_r} e^{(-r^2/\bar{P}_r)}$$

where $\bar{P}_r$, the average received signal power, is equal to 0 dBm. Find the probability that the received power P_R falls below -10 dBm. **(8)**

c. Why is it important to know the average fade duration in a digital radio communication system?

In a narrowband Rayleigh fading channel, the average fade duration is given by:

$$\bar{t}_R = \frac{e^{\rho^2} - 1}{\rho f_d \sqrt{2\pi}}$$

where $\rho = \sqrt{P_R/\bar{P}_r}$ and f_D is the maximum Doppler shift. In a certain digital radio system, subject to narrowband Rayleigh fading, the data bits are not reliably recovered should the instantaneous received signal power fall below one tenth of the average signal power. Determine the feasible range of Doppler frequencies such that the average time duration when data is in outage is less than 10 ms. **(7)**

d. For the system in Part 2(c), find the average fading rate that corresponds to the average fade duration of 10 ms.

Comment on your answer. **(5)**

3. **a.** An expression for the time invariant discrete channel impulse response (CIR) of an RF channel is given by:

$$h(\tau) = \sum_{l=0}^{L-1} h_l \delta(\tau - \tau_l).$$

Briefly explain the meaning of the terms in h_l, τ_l and L. **(5)**

b. For the time invariant discrete CIR shown in the Table below, calculate the:

I. mean excess delay;
II. *rms* delay spread; and
III. 90% coherence bandwidth.

Time Invariant Discrete CIR	
Excess Delay (μs)	Path Power (dBr)
0	-3
1	0
5	0
10	-3

Time invariant discrete CIR **(7)**

c. With the aid of a schematic diagram, explain the meaning of “time invariant block frequency selective fading”.

How does this type of time invariant discrete CIR benefit a broadband wireless communication system? **(6)**

d. A time invariant block frequency selective fading channel has five sub-channels each of bandwidth B = 1 MHz. The frequency responses associated with each sub-channel are $\{H_1, H_2, H_3, H_4, H_5\} = \{1,2,3,2,1\}$, respectively. The transmit power constraint is fixed by P = 5 mW and the noise 1-sided power spectral density N_0 is 10^{-9} W/Hz.

I. What is the Shannon capacity of this channel?
II. What are the optimal power allocations that achieve this capacity? **(7)**

4. **a.** Draw a schematic diagram of a multicarrier transceiver and label its constituent components.

Briefly explain why multicarrier modulation is used in wideband frequency selective channels? **(6)**

b. A wireless OFDM multicarrier system operates in a frequency selective channel with a coherence bandwidth of 31.25 kHz. The system uses a sub-channel symbol period $T_n = 10T_m$, where T_m denotes the channel *rms* delay spread.

I. What does setting $T_n = 10T_m$ achieve in the OFDM system?
II. What is the total bandwidth of the OFDM system using overlapping sub-carriers separated by $1/T_n$ if $n = 64$ sub-channels?

Assume the use of raised cosine pulses with roll-off factor $\beta = 1$ and an additional bandwidth factor $\varepsilon = 0.1$ for time limiting purposes. **(6)**

c. What is the consequence of an insufficiently long Cyclic Prefix (CP) in an Orthogonal Frequency Division Multiplexed (OFDM) system?

Consider a time invariant discrete CIR given by:

$$h(\tau) = j \cdot \delta(\tau) + \delta(\tau - 1) - 0.5j \cdot \delta(\tau - 2),$$

where $\delta(\cdot)$ is the Dirac delta function and the sample period $T_s = 1$ s.

For this channel, what length of CP would you use in an OFDM system to avoid ISI between OFDM symbols? **(5)**

d. The inverse-FFT at the transmitter of an OFDM system using four subcarriers can be expressed in matrix form $\boldsymbol{x} = \boldsymbol{M} \cdot \boldsymbol{X}$ as:

$$\boldsymbol{M} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

where $\boldsymbol{x}$ and $\boldsymbol{X}$ denote time and frequency domain symbol column vectors, respectively. If a QPSK constellation format is used to transmit "all ones" I&Q-symbols, then for the multipath channel in Part 4(c) determine:

i. The transmitted OFDM symbol including the CP;
ii. The received OFDM symbol after removal of the CP; and
iii. The received QPSK symbols after zero-forcing equalisation.

Describe any difficulty the receiver's detector could encounter in case iii. **(8)**

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EQUATION SHEET

- **Gaussian *pfd* and graphical *Q*-Function:**

$$P_r(X \geq x_1) = \int_{x_1}^{\infty} p(x)\,dx$$

$$P_r(X \geq x_1) = Q\left(\frac{x_1 - m}{\sigma}\right)$$