Data Provided: Q-Function on Page 5

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (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. What is the primary objective of a communication system? Explain why this objective is not fully achievable in practice.

In a digital communication system, what is the purpose of:

i. Multiple-access;
ii. Data detection in the receiver? **(4)**

b. What is the Doppler frequency shift? Derive an expression for the Doppler frequency shift in a typical mobile cellular geometry.

A mobile located at 5 km from a radio base station transmitting on a radio carrier frequency of 2 GHz experiences a Doppler shift of 5Hz. What is the angle of incidence of the received radio wave if the mobile is traveling at 50 km/h? **(4)**

c. Why is it important to include the ground plane in the radio propagation model for a cellular mobile system?

Prove that the far field pathloss for the ground plane radio propagation model is approximated by:

$$P_L = \frac{d^4}{G_t G_r (h_t h_r)^2}$$

where d, G_t, G_r, h_t, h_r have their normal meanings.

Now determine the critical distance for the cellular mobile system of Part 1(b) when $h_t = 15\text{m}$ and $h_r = 1.5\text{m}$. **(6)**

d. In a cellular mobile system, shadow fading obeys a log-normal distribution. What is the log-normal distribution?

The cellular mobile system in Part 1(b) is required to achieve an outage rate due to shadow fading of 5%. Determine the minimum transmit power needed at the base station assuming an allowed minimum received power of -102 dBm. Use a shadow fading standard deviation of 8 dB, isotropic transmit & receive antennas, and the ground plane propagation model with $h_t = 15\text{m}$ and $h_r = 1.5\text{m}$. **(6)**

2. **a.** What is the difference between narrowband and wideband multipath fading?

In narrowband fading, the received signal is given by:

$$r(t) = Re\left\{\left(\sum_{l}^{L(t)-1} \alpha_l(t) e^{-j\varphi_l(t)}\right) e^{j2\pi f_c t}\right\}$$

where $L(t), \alpha_l(t)\ and\ \varphi_l(t)$ denote the number of multipaths, *l*-th path amplitude and *l*-th path phase at time *t*, respectively. Give expressions for the In-phase (I) and Quadrature-phase (Q) components of the received signal and explain the role of the Central limit theorem when modelling the I and Q signals. **(5)**

b. Based on Clarke's uniform scattering environment, prove that the autocorrelation function of the I signal is given by:

$$A_I(\tau) = \frac{P_r}{2\pi} \int cos\left(2\pi \frac{v\tau}{\lambda} \cos(\theta)\right)\, d\theta$$

What is the significance of this equation at the first autocorrelation null? **(5)**

c. For the uniform scattering environment described in Part 2(b), what is the probability distribution function of the received signal envelope? Explain how the variance of this distribution depends on the average received envelope power.

For binary digital transmission, determine the minimum received envelope power as a fraction of the average envelope power to achieve a bit error rate of 5% assuming the system experiences single bit error events per fade. **(5)**

d. The average data rate of the system in Part 2(c) is given by:

$$R_b = \frac{\rho f_D \sqrt{2\pi}}{e^{\rho^2} - 1}$$

where ρ denotes the ratio of received envelope power to average envelope power. Use this expression to determine the average fading rate of the system in Part 2(c) for a mobile moving at 35 km/h in a 1.8 GHz cellular mobile system. **(5)**

3. **a.** The channel impulse response of a time-invariant multipath channel is given by $h(\tau) = h_0\delta(\tau) + h_1\delta(\tau - T_s)$, where $h_0 = 1 - j$ and $h_1 = 3 + 2j$ are the complex channel amplitudes, $\delta(\cdot)$ is the Dirac delta function and $T_s = 1$ s is the sample period.

Sketch the power delay profile of this channel, clearly labelling all of the pertinent points. **(3)**

b. Calculate the mean delay and *rms* delay spread of the channel in Part 3(a).

What is meant by the coherence bandwidth of a frequency selective channel and determine the 50% coherence bandwidth of the channel in Part 3(a)? **(7)**

c. Determine the optimum capacity of the channel in Part 3(a) when viewed as a two-block frequency selective channel when h_0 and h_1 are known at the transmitter as well as at the receiver. Assume a maximum transmit power of 1 W, a signal bandwidth of $1/T_s$ and an one-sided noise power spectral density $N_0 = 1$ W/Hz at the receiver.

What are the optimal power allocations that achieve the optimum capacity?

[Hint: the DFT is given by $X[i] = \frac{1}{\sqrt{2}}\sum_{n=0}^{N-1} x[n]e^{-j2\pi ni/N}, i = 0,1,\dots N$] **(7)**

d. By calculating the Shannon capacity for an additive white Gaussian noise (AWGN) channel under the same signalling constraints, how would you expect your answer in Part 3(c) to compare with the AWGN Shannon bound and explain your expectation? **(3)**

4. **a.** What is the purpose of the Cyclic Prefix (CP) in an Orthogonal Frequency Division Multiplexed (OFDM) system and how is it formed?

Consider a time-invariant multipath channel given by $h(\tau) = h_0\delta(\tau) + h_1\delta(\tau - T_s)$, where $h_0 = 1$ and $h_1 = j$ are the complex channel amplitudes, $\delta(\cdot)$ is the Dirac delta function and $T_s = 1$ s is the sample period. What length of CP would you use in an OFDM system to avoid ISI between OFDM symbols. **(3)**

b. 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 BPSK constellation format is used to transmit "all ones" I-data, then for the multipath channel in Part 4(a) determine:

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

Mention any particular difficulty the receiver detector would encounter in case iii. **(7)**

c. Why is the binary sequence {1,1,1,-1} particularly suitable as a spreading sequence in a Direct Sequence Spread Spectrum (DSSS) wireless communication system subject to frequency selective multipath fading? **(3)**

d. How does a RAKE receiver in a DSSS system exploit a frequency selective multipath channel?

Design a RAKE receiver using post-correlator maximal ratio combining for the channel impulse response in Part 4(a) when the spreading sequence in Part 4(c) is used (i.e. chip period $T_c = T_s = 1$ s).

Now determine the peak magnitude of the correlator output for your RAKE receiver. **(7)**

TOF/GGC

EQUATION SHEET

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

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

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