IMPERIAL COLLEGE LONDON

E4.03
AS5
SO10
ISE4.3

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2008

MSc and EEE/ISE PART IV: MEng and ACGI

MOBILE RADIO COMMUNICATION

Corrected Copy

Wednesday, 7 May 10:00 am

Time allowed: 3:00 hours

There are FOUR questions on this paper.

Answer THREE questions.

All questions carry equal marks. The maximum mark for each subquestion is shown in brackets.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : M.K. Gurcan

Second Marker(s) : K.K. Leung

Instructions to Candidates
Useful equations

$$0.5 \times \operatorname{erfc}(x) = 0.9 \Longrightarrow x = -1.282$$

The cut-off value γ_0 which is a solution for

$$1 = \frac{1}{\gamma_0} \exp\left(-\frac{\gamma_0}{10}\right) - \frac{1}{10} \int_{\frac{\gamma_0}{10}}^{\infty} \frac{\exp(-\gamma)}{\gamma} d\gamma$$

is

$$\gamma_0 = 0.7676$$

The cut-off value γ_0 which is a solution for

$$\frac{1}{10} \int_{\gamma_0}^{\infty} \exp\left(-\frac{\gamma}{10}\right) d\gamma = 0.95$$

is

$$\gamma_0 = 0.5129$$

For the cut-off value $\gamma_0 = 0.5129$ we have

$$\int_{\frac{\gamma_0}{10}}^{\infty} \frac{\exp(-\gamma)}{\gamma} d\gamma = 2.4437$$

1. Answer the following subquestions.

   (a) Under a free-space path loss model, find the transmitter signal power required to obtain a received signal power of 1 dBm for a wireless system with isotropic antennas ($G_l = 1$) and a carrier frequency $f = 5$ GHz, assuming a distance $d = 10$m. [3]

   (b) Consider a mobile radio receiver with noise power -160 dBm within the signal bandwidth of interest. Assume a simplified path-loss model with a reference $d_0 = 1$ m, constant K obtained from the free space path-loss formula with omnidirectional antennas and the carrier frequency $f_c = 1$ GHz, and the path loss exponent $\gamma = 4$. For a transmit power of $P_t = 10$ mW, find the maximum distance between the transmitter and receiver such that the received signal-to-noise power ratio is 20 dB. [6]

   (c) Using the indoor attenuation model, determine the required transmitter signal power for a desired received power of -110 dBm for a signal transmitted over 100 m that goes through 3 floors with attenuation 15 dB, 10 dB, and 6 dB, respectively, as well as 2 double plasterboard walls with the partition loss 3.4 dB. Assume a reference distance $d_0 = 1$, path loss exponent $\gamma = 4$ and constant $K = 0$ dB. [4]

   (d) Consider a cellular system operating at 900 MHz where propagation follows free-space path-loss with variations from log-normal shadowing with $\sigma = 6$ dB. Suppose that for an acceptable voice quality a signal-to-noise power ratio of 15 dB is required at the mobile. Assume that the base station transmits at 1 W and its antenna has a 3 dB gain. There is no antenna gain at the mobile and the receiver noise in the bandwidth of interest is -70 dBm. Find the maximum cell radius such that a mobile on the cell boundary will have an acceptable voice quality 90% of the time. [7]

2. Answer the following subquestions.

(a) Find a formula for the multipath delay spread T_m for a two-path channel model. Find a simplified formula when the transmitter-receiver separation, d, is relatively large. Compute T_m for a transmitter antenna height $h_t = 10$m, and a receiver antenna height $h_r = 4$m, and $d = 100$m. [3] [1] [1]

(b) Consider a two-path channel consisting of a direct ray plus a ground-reflected ray, where the transmitter is a fixed base station at height h and the receiver is mounted on a truck also at height h. The truck starts next to the base station and moves away at velocity v. Assume that the signal attenuation on each path follows a free-space path loss model. Find the time-varying channel impulse response at the receiver for the transmitter-receiver separation $d = vt$ which is sufficiently large for the length of the reflected ray to be approximated by $r + r' \approx d + 2h^2/d$. [4]

(c) Consider a time-invariant indoor wireless channel with a line-of-sight (LOS) component at delay 23 ns, a multipath component at delay 48 ns, and another multipath component at delay 67 ns. Find the delay spread assuming the demodulator synchronizes to

i. the LOS component, [2]

ii. the first multipath component. [1]

(d) Prove that for X and Y independent zero-mean Gaussian random variables with variance σ^2, the distribution of $Z = \sqrt{X^2 + Y^2}$ is Rayleigh distributed and the distribution of Z^2 is exponentially distributed. [4]

(e) Answer the following parts

i. Summarize, in your own words, the main discussion points on flat fading and frequency selective fading. [2]

ii. Determine whether individual multipath rays are resolvable for two transmission bandwidths, 1.25 MHz, and 5 MHz when transmitting over a channel with a delay spread of [2]

A. 0.5 μs,

B. 1 μs and

C. 6 μs.

3. Answer the following subquestions.

(a) Assume a Rayleigh fading channel with 10MHz transmission bandwidth, where the transmitter and receiver have CSI and the distribution $p(\gamma)$ of the fading SNR is exponential $p(\gamma) = \frac{1}{10}\exp\left(-\frac{\gamma}{10}\right)$.

i. Find the cut-off value γ_0 and the corresponding power adaptation that achieves Shannon capacity on this channel. [2]

ii. Compute the Shannon capacity of this channel. [2]

iii. Compare your answer in part (a.ii.) with the channel capacity when operating over an additive white Gaussian noise (AWGN) channel with the same average SNR. [2]

iv. Compare your answer in part (a.ii.) with the Shannon capacity when only the receiver knows the received signal SNR γ. [2]

v. Compare your answer in part (a.ii.) with the zero-outage capacity and outage capacity with outage probability 0.05. [2]

vi. Repeat parts (a.ii, iii. and iv.), that is, when using the same average transmission power and the same fading distribution but with mean $\overline{\gamma}$= -5dB,

A. obtain the Shannon capacity for a system with perfect transmitter and receiver side information, [1]

B. obtain the Shannon capacity for a system with just receiver side information, and [1]

C. describe the circumstances under which a fading channel has a higher capacity than an AWGN channel with the same average SNR and explain why this behavior occurs. [1]

(b) Show, using Lagrangian techniques, that the optimal power allocation to maximize the capacity of a set of time-invariant block fading channels in parallel is given by the water filling formula as follows [7]

$$\frac{P(\gamma)}{\overline{P}} = \begin{cases} \dfrac{1}{\gamma_0} - \dfrac{1}{\gamma} & \gamma \geq \gamma_0 \\ 0 & \gamma < \gamma_0 \end{cases}$$

where γ_0 is the cut-off value and $P(\gamma)$ is the transmitted signal power as a function of the signal-to-noise-ratio γ and $\overline{P}$ is the average transmission power.

4. Answer the following subquestions.

(a) Consider the Core Network (CN) for the third generation wideband UTRAN/FDD radio system and describe

i. the functions undertaken by the serving GPRS support node (SGSN) and the gateway GPRS support node (GGSN), [2]

ii. the functions for the signalling protocol RANAP when using the control plane for the Iu PS interface which connects the UTRAN to the CN. [2]

(b) Consider the third generation UTRAN architecture and describe

i. the logical role of the Radio Network Controller (RNC), [2]

ii. the organization of the UMTS signalling plane between the User Equipment (UE) and the Serving Radio Network Controller (SRNC). [2]

(c) Consider the third generation WCDMA radio interface protocol architecture and describe

i. the main functions for the Radio Resource Controller (RRC) protocol, [2]

ii. how the RRC states operate. [2]

(d) A direct sequence spread spectrum system (DSSS) with the processing gain N =4 and the number of parallel channels $K = 4$ uses a spreading sequence matrix

$$\mathbb{S}=\begin{bmatrix} +0.5 & -0.5 & +0.5 & -0.5 \\ -0.5 & -0.5 & +0.5 & -0.5 \\ +0.5 & -0.5 & -0.5 & +0.5 \\ +0.5 & +0.5 & +0.5 & +0.5 \end{bmatrix}.$$

Find

i. the Gram matrix, [1]

ii. the correlation matrix $\mathbb{S}\mathbb{S}^T$. [1]

(e) A DSSS system with the processing gain $N = 2$ the number of codes $K = 4$ uses the $K \times N$ dimensional spreading sequence matrix

$$\mathbb{S}^H = \begin{bmatrix} 0.1968 - 0.9700i & -0.1239 - 0.0715i \\ 0.4752 + 0.1939i & -0.2992 - 0.8044i \\ 0.6720 + 0.1469i & -0.4231 + 0.5898i \\ 0.5329 & 0.8462 \end{bmatrix}.$$

Using the matrix $\mathbb{S}$

i. Show that the codes satisfy the Welch-Bound-equality conditions. [3]

ii. Assuming that the received total signal-to-noise ratio is $\frac{h \quad P_T}{\sigma^2} = 30$, calculate the signal-to-noise-ratio at the output of each receiver despreading unit when the transmission power is equally distributed. [2]

iii. Find the sum capacity for the system described in part e.ii. [1]