CARLETON UNIVERSITY

Department of Systems and Computer Engineering

SYSC5608 – Wireless Communications Systems Engineering – Fall 2013

Term Exam

23 October 2013 – Prof. H. Yanikomeroglu

<u>Instructions:</u> Closed-book. One-page aid-sheet is permitted. Write answers in the spaces provided on the question sheet. If necessary, use both sides of a page. Duration: 80 minutes.

Name: **Student Number:** **E-mail:**

Question	Mark	out of
1.a		5
1.b		5
1.c		5
1.d		10
1.e		10
1.f		10
1.g		10
1.h		10
1.i		10
1.j		15
1 Total		90
2		60
3		50
Total		200

Question 1 – Short Questions [140 points]

a) [5 pts] If it takes 1 minute to download a movie using wired internet, how long will it take to download the same movie using wireless internet where the speed is one-tenth of the wired speed?

b) [5 pts] What is the wavelength if the carrier frequency is 1 GHz.

c) [5 pts] What is the unit for spectral efficiency?

d) [10 pts] State an interesting news item you have seen at the FierceWireless website.

e) [10 pts] What is the highest bit-rate achievable in a point-to-point system if

- SNR = 20 dB
- Number of transmit antennas = 6
- Number of receive antennas = 4
- Bandwidth = 20 MHz

f) [10 pts] It is often assumed that the white noise power spectral density is N_0 = -174 dBm/Hz. Show how this value is calculated? [Note that $P_{noise} = kTBF$ Watts, where k =1.38x10^{-23} joule/^{o}K]

g) [10 pts] Briefly explain the following concepts:

- Precoding

- Interference-limited system

h) [10 pts] Consider a wireless channel modelled as an LTI (linear, time-invariant) system with an impulse response $h(t) = a\delta(t-t_d) + a\delta(t-T/2-t_d)$, where a and t_d are constants accounting for attenuation and transmission delay, respectively. Let us assume that $x(t)$ is the transmitted signal representing one single bit; it is a rectangular function with amplitude 1 and duration [0, T]. Sketch the received signal $y(t)$.

i) [10 pts] The PSD (power spectral density), $S_X(f)$, of a signal $X(t)$ is given as

$$S_X(f) = \begin{cases} \beta, & -930MHz \le f \le -910MHz \\ \beta, & 910MHz \le f \le 930MHz \\ 0, & elsewhere \end{cases} .$$

- Find the bandwidth of $X(t)$.
- Find the total power of $X(t)$.

j) [15 pts] The average path loss in a wireless link is modeled as $\overline{PL} = \left(\frac{4\pi d_0}{\lambda}\right)^2 \left(\frac{d}{d_0}\right)^{3.3}$. When the carrier frequency is 900 MHz, it is observed that $\overline{PL}$=70 dB while the user is at a particular point. If the carrier frequency is increased from 900 MHz to 45 GHz, what will be $\overline{PL}$ at that same point?

Question 2 [60 points] – MMSE Estimation for the Path Loss Exponent

Three received power measurements were taken at distances 1 m, 10 m, and 100 m from a transmitter, as shown in the below table:

I	d_i [m]	$P_{RX,measured}$ [dBm]
0	1	-5
1	10	-40
2	100	-90

Based on these measurements, you are asked to develop an average received power model, in the form $\overline{P_{RX}}(d) = P_{RX}(d_0) + 10n\log(d_0/d)$. In your model, take the reference close-in distance as d_0 = 1 m. As a result, the measured and the predicted average values should be the same at this point; that is, $\overline{P_{RX}} = P_{RX,measured}$ at $d=d_0$.

(a) Find the minimum mean square error (MMSE) estimate for the path loss exponent, n.

(b) Next, lognormal shadowing is introduced in the model to account for the difference between the measured received power and the predicted average received power: $P_{RX}(d) = \overline{P_{RX}}(d) + X_\sigma$. Find the standard deviation of the random variable X.

[Space for Question 2]

Question 3 [50 points] – Outage in a Cellular Network

A cellular operator would like to cover as large a region as possible with a single BS; but it is concerned about the outage probability.

The user equipment (UE) sensitivity level is given as -100 dBm (that is, if the received signal power is below this level, the signal cannot be detected). The outage probability is defined as Pr_{out} = Prob(P_{RX} < -100 [dBm]).

The received signal power is modeled as P_{RX} [dBm] = 15 - 40log(d) + X, where X is a Gaussian random variable with 0-dB mean and 5-dB standard deviation.

Sketch Pr_{out} as a function of the BS-UE distance d for the range d=400 m to d=1000 m by calculating Pr_{out} at d = 400, 600, 800, 1000 m. Use the linear scale in both the vertical and horizontal axes in your graph.

Help: If u: G(μ, σ) → Prob $(u \geq z) = Q\left(\frac{z-\mu}{\sigma}\right)$. Also, $Q(t) = 1 - Q(-t)$.

t	*Q(t)*	*t*	*Q(t)*	*t*	*Q(t)*	*t*	*Q(t)*
0.0	0.50000	1.0	0.15866	2.0	0.02275	3.0	0.00135
0.1	0.46017	1.1	0.13567	2.1	0.01786	3.1	0.00097
0.2	0.42074	1.2	0.11507	2.2	0.01390	3.2	0.00069
0.3	0.38209	1.3	0.09680	2.3	0.01072	3.3	0.00048
0.4	0.34458	1.4	0.08076	2.4	0.00820	3.4	0.00034
0.5	0.30854	1.5	0.06681	2.5	0.00621	3.5	0.00023
0.6	0.27425	1.6	0.05480	2.6	0.00466	3.6	0.00016
0.7	0.24196	1.7	0.04457	2.7	0.00347	3.7	0.00011
0.8	0.21186	1.8	0.03593	2.8	0.00256	3.8	0.00007
0.9	0.18406	1.9	0.02872	2.9	0.00187	3.9	0.00005

[Space for Question 3]