CARLETON UNIVERSITY

Department of Systems and Computer Engineering

SYSC5608 – Wireless Communications Systems Engineering – Winter 2018

TERM EXAM **08 February 2018 – Prof. Halim Yanikomeroglu**

Closed-book exam. One-page aid-sheet is permitted.
No smart phones, no internet access.
Write answers in the space provided on the question sheet. If necessary, use both sides of a page.
Write legibly, and state any assumptions that you make.
Time = 100 mins.

Name: **Student No:**
Carleton or uOttawa?: **E-mail:**

Question	**Mark**	**out of**
1		**50**
2		**40**
3		**40**
4		**40**
TOTAL		**170**

USEFUL EXPRESSIONS:

Noise power: P_N = k T B F Watts (linear scale)
where k = 1.38 x 10^{-23} (Boltzmann's constant); T = 273+°C
Noise power: P_N = - 228.6 + $10\log_{10}$(273 + C°) + $10\log_{10}$(B) + F dBW (dB scale)
where °C: temp. in degrees centigrade; B: bandwidth in Hz; F: noise figure

SNR = P_{RX} - P_N (dB scale)
SNR in linear: P_{RX} /P_N (linear scale)

Question 1 [50 pts] – Short Questions

a) [10 pts] What is the maximum bit rate achievable when a polar coded 64-QAM scheme with a code rate of 2/3 is used in conjunction with raised-cosine pulses with a roll-off factor of 0.25, in a bandwidth of 20 MHz, in the presence of a 4x2 MIMO?

b) [10 pts] Consider a wireless channel with a bandwidth of 3 MHz. SNR at the receiver is 7 dB, the AWGN power spectral density is N_0 = -174 dBm/Hz, and the receiver noise figure is 8 dB. Find the received signal power, P_s, in Watts.

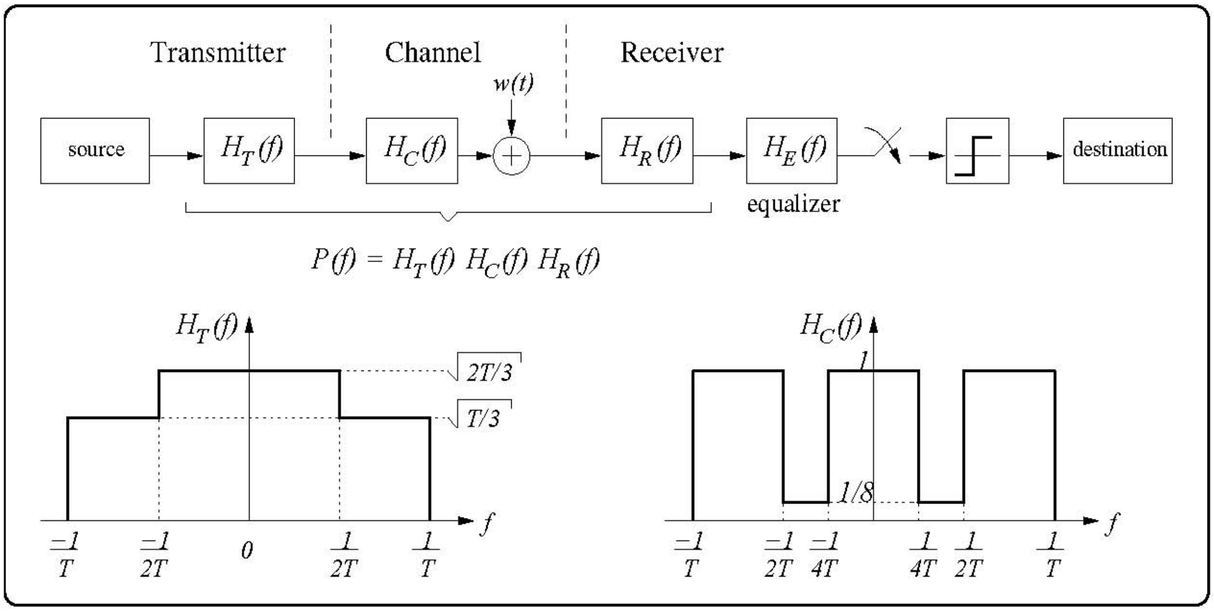
c) [10 pts] In a 5G wireless network, the target peak rate to be achieved is given as 40 Gbps. It is also given that there is a 16x8 multilayer MIMO system, and that the transmission bandwidth is 500 MHz. What is the minimum required SNR (in dB) to facilitate this peak rate?

d) [20 pts] In a binary signaling scheme, the bit error rate (BER) expression is given as a function of E_b/N_0 as follows: P_e = (1/2) e^{-E_b/N_o}. You are asked to compare the BER expressions for two different channels, AWGN channel and fading channel.

In the AWGN channel, E_b/N_0 = 9 (linear scale). In the fading channel, E_b/N_0 is a random variable with the following histogram: E_b/N_0 = 6 (25% of the time), 9 (50% of the time), and 12 (25% of the time); all the E_b/N_0 values are in the linear scale. Note that the average E_b/N_0 in the fading channel is 9, which is equal to the E_b/N_0 value of the AWGN channel. In the fading case, assume that the channel changes slowly in comparison to the transmission rate.

Find $P_{e,AWGN}$ and $P_{e,fading}$. Discuss which channel results in a better performance and why.

Q2 [40 pts] – Inter-Symbol Interference (ISI)



In the above depicted wireless system, the transmitter and receiver filters, $h_T(t)$ and $h_R(t)$, constitute a matched filter pair; note that in such a case, $|H_R(f)| = |H_T(f)|$. Assume $H_R(f) = H_T(f)$.

(a) First, consider an ideal channel with $h_{C,i}(t) = \delta(t)$, where $\delta(t)$ denotes the Dirac delta function. Does $P(f) = H_T(f)H_{C,i}(t)H_R(f)$ result in ISI? Substantiate your results.

(b) Now, consider a more realistic channel, $H_c(f)$, as depicted in the above figure. Does $P(f) = H_T(f)H_C(t)H_R(f)$ result in ISI? Substantiate your results.

(c) An equalizer is used to combat against ISI. The equalizer chosen for this system is a "zero-forcing" filter. The goal of the "zero-forcing" equalization is to remove all the ISI completely; that is, $H_E(f)$ should be designed in such a way to force $P(f)H_E(f)$ to obey Nyquist's zero-ISI criterion. Sketch $H_E(f)$.

(d) Do you predict a potential problem in the error rate performance due to the zero-forcing equalization used in this system (in the presence of background noise)? Explain.

[*Extra space for Q2*]

Q3 [40 pts] – BER Calculation in a 3-Path Wireless Channel

A large file composed of 0's and 1's is to be transmitted through a wireless channel. Binary 1 is represented by the rectangular function $x(t)$ with amplitude A and duration $[0, T]$; binary 0 is represented by $-x(t)$.

Consider a wireless channel modelled as an LTI (linear, time-invariant) system with a normalized impulse response $h(t) = a\delta(t) + a\delta(t-T) + a\delta(t-2T)$, where $a = 1/\sqrt{3}$ is and T is the bit duration.

Assume that there is no background noise. Find the probability of bit error at the receiver (substantiate your result).

Q4 [40 pts] – Scheduling

Consider a single-cell wireless network with 3 users (UE_1, UE_2, UE_3) and 6 resource blocks (RB_1, …, RB_6), where UE means user equipment and RB means resource block. Each RB is 200 KHz in bandwidth. The below table shows the spectral efficiency (bits/sec/Hz) achieved for each RB-to-UE assignment possibility:

	RB_1	RB_2	RB_3	RB_4	RB_5	RB_6
UE_1	6	5	2	1	3	4
UE_4	5	3	1	6	2	4
UE_3	1	2	5	3	4	6

In this question, we will explore various scheduling (assignment) schemes: $\{RB_i \rightarrow UE_j\}$, i=1,..,6, and j=1, 2, 3. Note that an RB cannot be assigned to more than one UE. Let R_j denote the rate of UE_j after the RB assignments, and $R_T = \sum_j R_j$.

a) Find the scheduling scheme that will maximize the aggregate cell rate R_T (substantiate your answer). Indicate the resulting R_1, R_2, R_3, and R_T.

b) Consider a more realistic situation in which the number of UEs and RBs are both high (for instance, 50 UEs and 100 RBs). Step-by-step, write the scheduling algorithm that will maximize R_T (this is called a pseudo-code).

c) Consider next a resource-fair scheduling scheme in which each UE gets an equal number of RBs. Find the resource-fair scheduling scheme which will maximize the aggregate cell rate R_T (substantiate your answer). Indicate the resulting R_1, R_2, R_3, and R_T.

[*Extra space for Q4*]