CARLETON UNIVERSITY

Department of Systems and Computer Engineering

SYSC5608 – Wireless Communications Systems Engineering – Winter 2016

Term Exam I

11 February 2016 – Prof. H. Yanikomeroglu

Instructions: Closed-book. One-page aid-sheet is permitted. No smart phones.
Write answers in the spaces provided on the question sheet. If necessary, use both sides of a page. Write legibly, and state any assumptions that you make.

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

Question	Mark	out of
1		**30**
2		**50**
3		**60**
4		**30**
TOTAL		**170**

USEFUL EXPRESSIONS:

Received power: $P_{RX} = P_{TX} + G_{TX} – PL + G_{RX}$ (dB scale)
Received power: $P_{RX} = P_{TX}\, G_{TX}\, G_{RX} /PL$ (linear scale)

Noise power: $P_N = k\,T\,B\,F$ Watts (linear scale)
where $k = 1.38 \times 10^{-23}$ (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)

Free space path loss: $FSPL = (4\pi d/\lambda)^2$ (linear scale)
$FSPL = -147.6 + 20 \log_{10}(f) + 20 \log_{10}(d)$ (dB scale)
where frequency f is in Hz and distance d is in m.

PL is terrestrial radio links: $PL = A + 20 \log_{10}(f) + 10n \log_{10}(d)$
where n (>2) is the propagation exponent.

Question 1 [30 pts] – BER Calculation in a 2-Path Wireless Channel

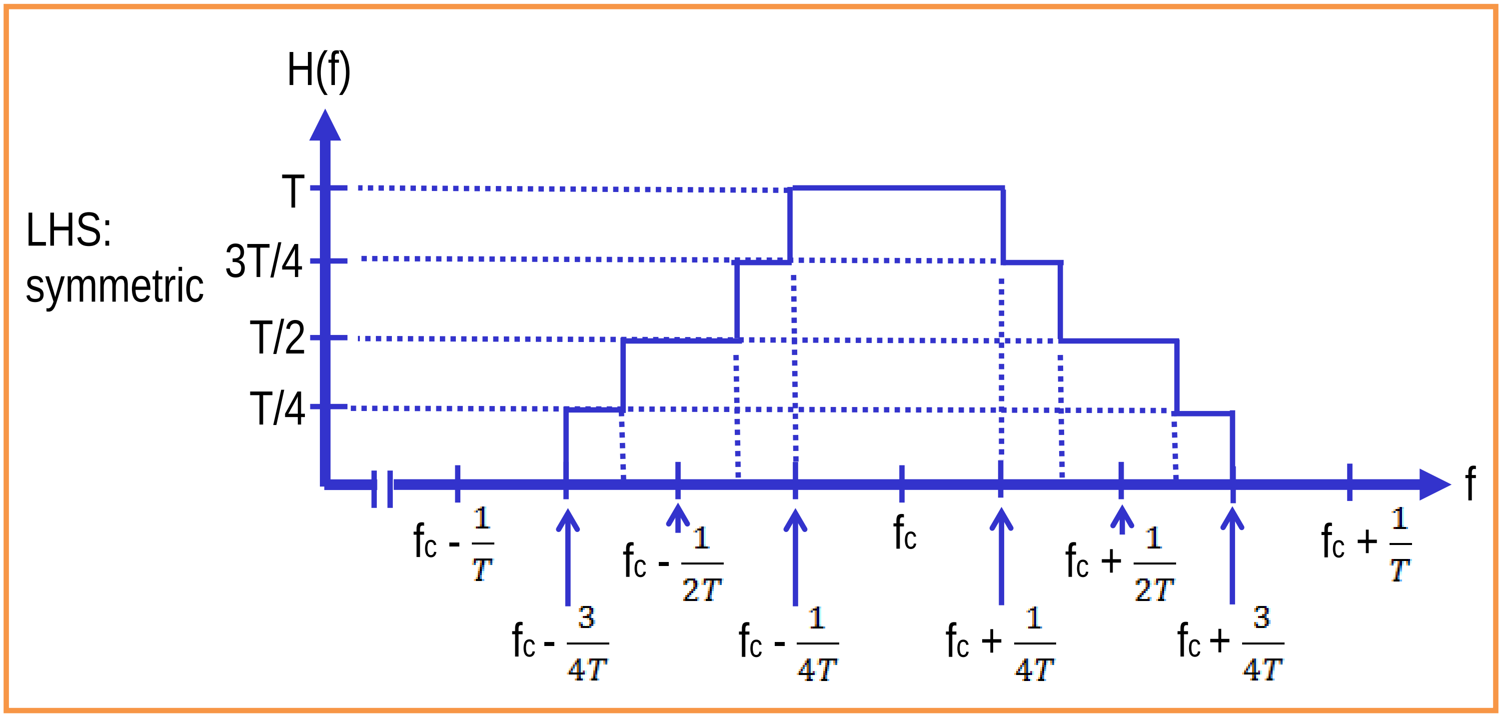
A large file composed of 0's and 1's is to be transmitted through a wireless channel. Binary 1 is represented by the rectangular function $x(t)$ with amplitude A and duration $[0, T]$; binary 0 is represented by $-x(t)$.

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

Assume that there is no background noise. Find the probability of bit error at the output of the receiver detector.

Question 2 [50 pts] – Transmission Through a Bandlimited Channel

A 4-ary bandpass communication system with zero-mean AWGN is shown in the below figure where T denotes the symbol duration. The channel is an ideal channel with $h_{CH}(t) = \delta(t)$. The transmitter and receiver filters, $h_{TX}(t)$ and $h_{RX}(t)$, constitute a matched filter pair; i.e., $|H_{TX}(f)| = |H_{RX}(f)|$. In the below figure the product $|H(f)| = |H_{TX}(f)||H_{CH}(t)||H_{RX}(f)|$ is shown.



(a) Does the above system comply with the Nyquist no-ISI criterion? Substantiate your answer with the help of a sketch.

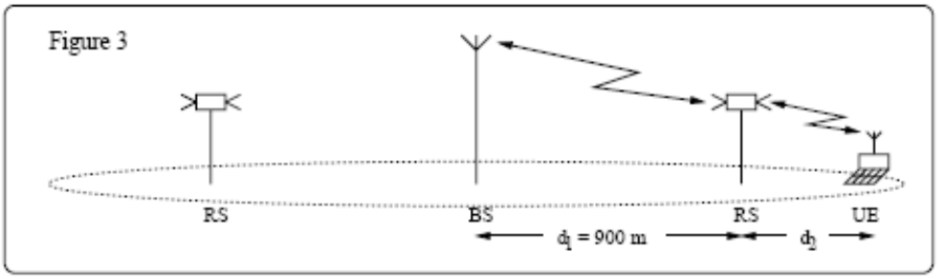
(b) If the total bandwidth 15 MHz, what is the maximum bit rate, R_b, of this system?

(c) If the bit rate has to be at least 80 Mbps, what constellation size has to be used instead of 4-ary? In other words, what would be M in the corresponding M-ary case?

(d) Sketch $|H_{TX}(f)| = |H_{RX}(f)|$.

Question 3 [60 pts] – Coverage in Analog Fixed-Relay Enhanced Cellular Networks

Consider a future cellular network operating at 2 GHz band in which the high data rate coverage region of each BS is enhanced through the use of fixed relays. One circular cell in such a network is shown in the below figure in which BS, RS, and UE denote base station, relay station, and user equipment, respectively.



Below we explain how the system works (please refer to the above figure):

• The BS transmits the signal at $P_{TX,BS}$ = 43 dBm. The path-loss (*PL*) in the first hop is modeled as

$PL_{BS\text{-}RS}$ [dB] = 28.92 + 30 log d_1 + X_1,

where X_1 is a Gaussian r.v. with 0 dB mean and 8 dB standard deviation capturing the shadowing effects. The distance between BS and RS is d_1 = 900 m.

• The RS amplifies the received signal power by G_{RS} = 100 dB (we omit the noise amplification) and then transmits it to the UE. The path-loss in this second hop is modeled as

$PL_{RS\text{-}UE}$ [dB] = 31.31 + 35 log d_2 + X_2,

where X_2 is a Gaussian r.v. with 0 dB mean and 8 dB standard deviation, once again, capturing the shadowing effects. The distance between RS and UE is d_2 m.

• The UE receives signal only from the RS; i.e., the UE does not receive any signal from the BS.

• The BS, RS, and UE, all have unity-gain antennas (or one may assume that $P_{TX,BS}$ and G_{RS} incorporate the antenna gains).

• The interference and background noise picked up at the UE have a total power of P_{I+N} = 2.5 × 10^{-13} Watts.

• The QoS (quality of service) constraint dictates that the average signal-to-interference-plus-noise ratio (SINR) at the UE, γ_{UE}, has to be greater than 4 dB at least 92% of the time at the cell edge (since the constraint is on the average SINR, we do not include the effects of multipath fading).

(a) Determine the propagation exponents n_1 & n_2, and the reference distances d_{01} & d_{02} used in above given the path-loss model between the BS and RS, and RS and UE. Compare {d_{01}, n_1} and {d_{02}, n_2} and comment on why they are not the same.

Help 1: Propagation model: $P_{RX} = P_{TX}\left(\frac{\lambda}{4\pi d_0}\right)^2\left(\frac{d_0}{d}\right)^n 10^{x/10}$

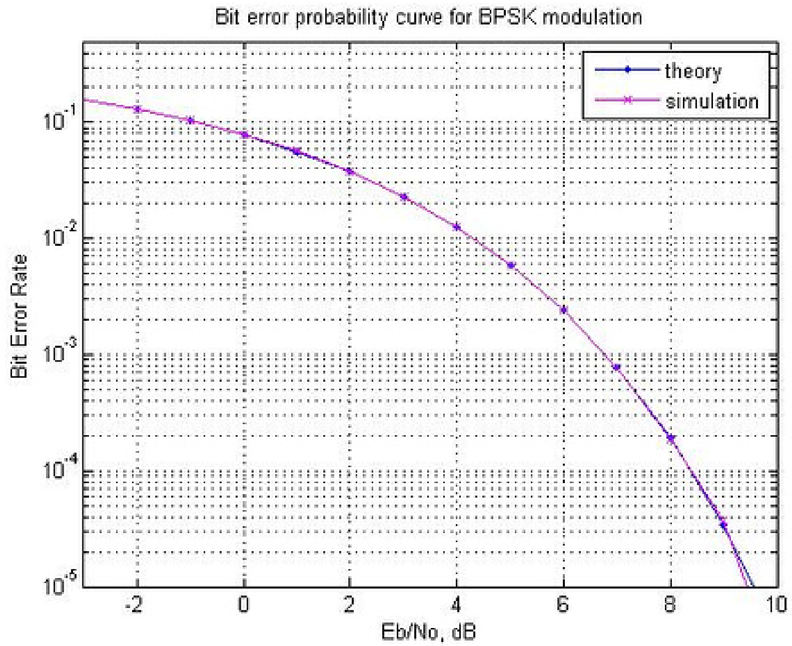
(b) Determine the maximum cell size (900+d_2) taking the QoS constraint into account.

Help 2: If u: $G(\mu,\sigma)$ → $\Pr(u \geq z) = Q\left(\frac{z-\mu}{\sigma}\right)$. Also, $Q(z) = 1 - Q(-z)$.

Note: Part (a) can be solved without solving Part (b); likewise, Part (b) can be solved without solving Part (a).

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

Question 4 [30 pts] – Power Calculations: In the 4G LTE wireless networks, the bandwidth is assigned to applications in terms of "resource blocks (RBs)". The bandwidth of one RB is 200 KHz.



Consider an LTE application that uses BPSK modulation; the corresponding BER versus SNR (E_b/N_0) relation is given in the above figure. This application requires a BER of 10^{-4} and it is assigned one RB.

The AWGN power spectral density is N_0 = -174 dBm/Hz, and the receiver noise figure is 6 dB. Find the necessary received signal power, P_s, in Watts.