# CARLETON UNIVERSITY

**Department of Systems and Computer Engineering**

## SYSC5608 – Wireless Communications Systems Engineering – Fall 2014

## Term Exam

## 08 October 2014 – Prof. H. Yanikomeroglu

Closed-book. One-page aid-sheet is permitted. No smart phones.

Instructions: 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. A blank page is provided after the last question.

**Name:**
**Carleton or uOttawa?:**
**Student Number:**

**E-mail:**

| Question | Mark | out of |
|---|---|---|
| 1a | | 35 |
| 1b | | 10 |
| 1c | | 15 |
| 1d | | 20 |
| 1e | | 15 |
| 1f | | 15 |
| 1 Total | | 110 |
| 2 | | 60 |
| TOTAL | | 170 |

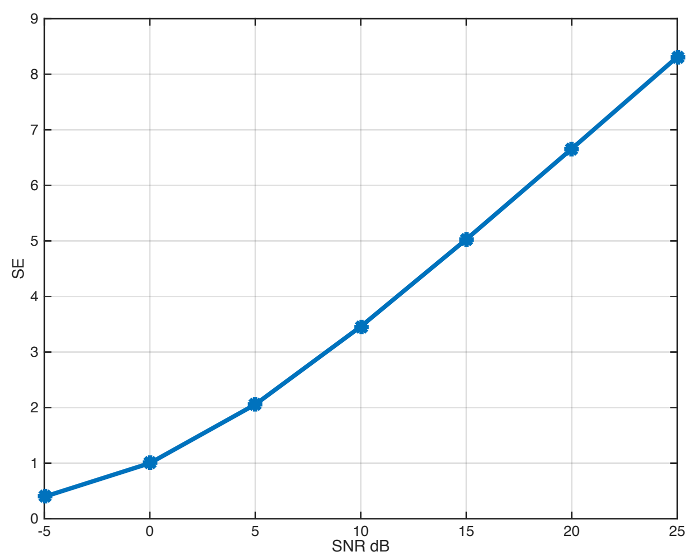
**Question 1 – Short Questions [110 points]**

**1-a)** **[35 pts]** In this question use the Shannon-Hartley-Nyquist limit for the spectral efficiency: SE $=\log_2(1+\text{SNR})$ bits/sec/Hz.

- Sketch SE as a function of $\text{SNR}_{\text{dB}}$ ($\text{SNR}_{\text{dB}}$: SNR represented in the dB form; for instance, SNR=2 → $\text{SNR}_{\text{dB}}$ = 3 dB). In your sketch, use the following values in the horizontal axis, $\text{SNR}_{\text{dB}}$ = -5 dB, 0 dB, 5 dB, 10 dB, 15 dB, 20 dB, 25 dB).

Solution (15pt)

| SNR [dB] | SNR [linear] | SE |
|---|---|---|
| -5 | 0.31 | 0.39 |
| 0 | 1 | 1 |
| 5 | 3.61 | 2.05 |
| 10 | 10 | 3.45 |
| 15 | 31.62 | 5.02 |
| 20 | 100 | 6.65 |
| 25 | 316.22 | 8.30 |



- Starting from the SE=$\log_2(1+SNR)$ expression, find a tight approximation for SE as a function of $SNR_{dB}$, when SNR is high. Is your answer consistent with the sketched values?

Solution (10pt):

SNR>>1 => SE = $\log_2(SNR)$ = $\log_2 (10^{(SNR\ [dB]/10)})$ = $\log_2(10)$*1/10*SNR [dB] = 0.33 *SNR [dB]

- Assume SE is high. In order to increase SE by 1 bits/sec/Hz, how much should $SNR_{dB}$ be increased?

Solution (10pt):

$$\Delta SE = 0.33 * \Delta[SNRdB]$$

$$if\, \Delta SE = 1 \Rightarrow \Delta[SNRdB] = 3.03$$

1-b) **[10 pts]** In a receiver, noise power is given as $P_N$ = -99 dBm. If $N_0$ = -174 dBm/Hz, and the noise figure as 8 dB. Find the signal BW.

Solution (10pt):

$P_N$ = [KT dB] + [B dB] + [F dB]

-99 = -174 + [B dB] + 8 => [B dB] = 10 ^(67/10) = 5.01 MHz

**1-c)** **[15 pts]** The main goal of 4G is to enable fast internet browsing (including video streaming) by smart phones, tablets, and laptops. How is 5G envisioned to be different? In other words, what else is 5G expected to offer?

Solution (15pt):

Main distinction is coming from accommodating very different application, such as IoT, health care, smart grids, smart cities, etc.

Partial marks for ubiquitous application coverage in cell, improved efficiency, interference coordination, seamless handover among different standards, higher MIMO, mm-wave, etc.

**1-d)** **[20 pts]** The impulse response of a two-path wireless channel is given as $h_{ch}(t) = \alpha\ \delta(t) - \alpha\ \delta(t-t_d)$. The distance between the direct path and the reflected path is denoted as $d$, and the corresponding time difference in arrival times is denoted by $t_d$. This system uses binary signalling with a bit-duration of $T$ seconds.

- We have two applications with transmission rates $R$ = 100 Kbps (VoIP) and 10 Mbps (high definition video streaming). For each application, for what d value, we will have $t_d = T$. For each case, comment whether this situation (i.e., $t_d = T$) will occur in indoors or outdoors.

- In the class, we computed the $P_e$ (probability of error) value for the case when $h_{ch}(t) = \alpha\ \delta(t) + \alpha\ \delta(t-T)$. Compute $P_e$ when $h_{ch}(t) = \alpha\ \delta(t) - \alpha\ \delta(t-T)$.

Solution (10pt+10pt):

$$d_2 - d_1 = d$$
$$d = c * t_d = c * T = c / R$$
$$R = 100kbps \to d = 3km \to outdoor$$
$$R = 10Mbps \to d = 30m \to indoor$$

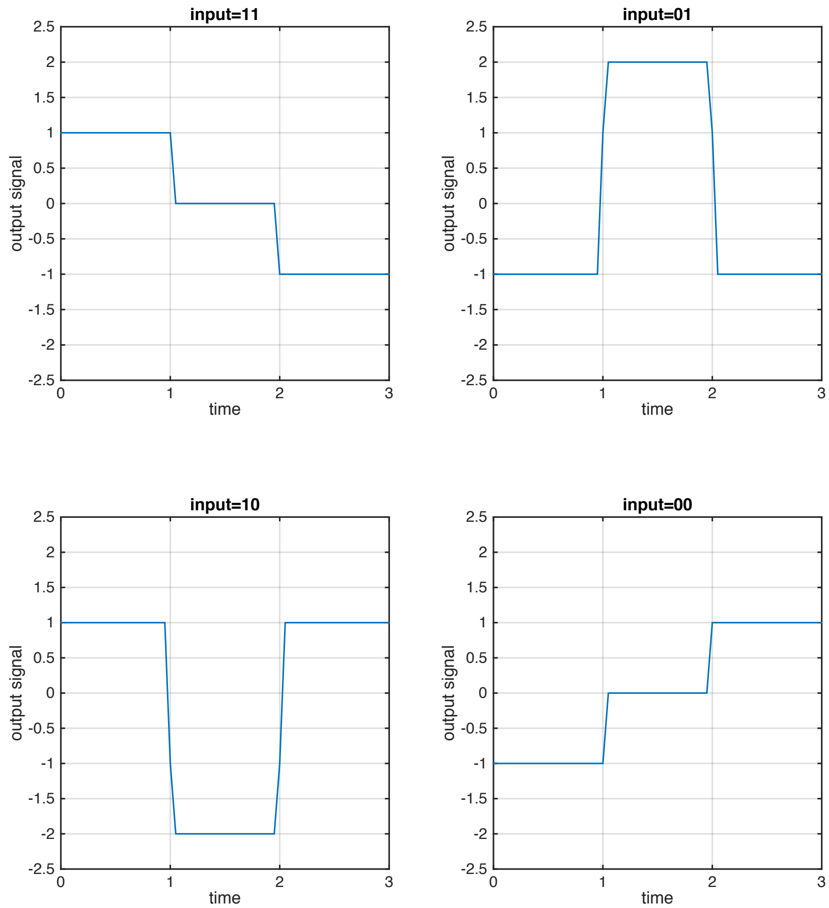
This problem was solved in class for $h_{ch}(t) = \alpha\ \delta(t) + \alpha\ \delta(t-T)$, the logic for $h_{ch}(t) = \alpha\ \delta(t) - \alpha\ \delta(t-T)$ is the same.

Assume background noise is negligible, and assume equal probable input sequence:
$\Pr(00) = \Pr(11) = \Pr(10) = \Pr(01) = 0.25$, then

$$\Pr(Error) = 0.25 * (\Pr(Error\,|\,00) + \Pr(Error\,|\,11) + \Pr(Error\,|\,10) + \Pr(Error\,|\,01))$$

By inspection,
- if the preceding bit has the opposite polarity, there will be enforcement and constructive interference.
- if, however, the preceding bit has the same polarity, there will be cancellation and destructive interference (refer to the figures next page)

Therefore
$$= 0.25(0 + 0 + 0.5 + 0.5) = 0.25$$




[The figure is based on assumption of alpha=1 and T=1].

**1-e)** **[15 pts]** Suppose that you are involved in the design of a next-generation WLAN standard, say 802.11hy, that operates in the millimeter wave. The target downlink peak rate is 100 Gbps. Choose some appropriate

- bandwidth,
- spectral efficiency, and
- number of antennas (for MIMO gain)

values for this network.

Solution (5pt for formula, 2*5 pt for two items out of three):
R= n * B * SE
mm-wave => fc around 30-300 GHz, (such as 60 GHz in WiGig)
We assume and the bandwidth 3GHz @ 60 GHz.
Take n= 10 antenna.
Then SE = 10 / 3.

Many other possibilities will also work.

**1-f)** **[15 pts]** 4G promises rates up to 1 Gbps. On the other hand, the rates wireless users experiences are substantially less. Describe the two main reasons for this situation.

Solution (2*7.5):
Shared rate among the entire users in cell.
Path-loss and interference especially in cell edge (much lower SE than peak SE)

- **Question 2 [60 marks] – Adaptive Modulation in Wireless Communications**

In a WLAN system, the adaptive modulation scheme operates based on the following look-up table:

| | | |
|---|---|---|
| | SNR < 0 dB | → SE = 0 |
| 0 dB ≤ | SNR < 4.77 dB | → SE = 1 bits/sec/Hz |
| 4.77 dB ≤ | SNR < 8.45 dB | → SE = 2 bits/sec/Hz |
| 8.45 dB ≤ | SNR < 11.76 dB | → SE = 3 bits/sec/Hz |
| 11.76 dB ≤ | SNR < 14.91 dB | → SE = 4 bits/sec/Hz |
| 14.91 dB ≤ | SNR | → SE = 5 bits/sec/Hz |

The distance-dependent SNR between an access point and a user which is $d$ meters away is given as SNR = 81.16 – 36 log($d$) + $X_\sigma$, where $X_\sigma$: G($\mu$=0 dB; $\sigma$=8 dB) captures the shadow fading.

- If the user is 100 m away from the AP, what is the likelihood that the spectral efficiency is 3?
- If the user is 500 m away from the AP, what is the likelihood that it will still have the connection?

**Help**: If $u$: G($\mu$, $\sigma$) → $\text{Prob}\,(u \geq z) = Q\left(\dfrac{z-\mu}{\sigma}\right)$. 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 |

Solution (30pt):

$$P(SE=3) = P(8.45 < 81.16 - 36 * \log(100) + X < 11.76)$$
$$= P(8.45 < 9.16 + X < 11.76) = P(-0.71 < X) - P(2.6 < X)$$
$$= 1 - Q(0.71/8) - Q(2.6/8) \approx 1 - 0.47 - 0.38 \approx 0.15$$

Solution (30pt):

$$P(SE \neq 0) = P(81.16 - 36\log(500) + X > 0) = P(-16 + X > 0)$$
$$= Q(2) = 0.02275$$