CARLETON UNIVERSITY

Department of Systems and Computer Engineering

SYSC5608 – Wireless Communications Systems Engineering – Winter 2017

TERM EXAM SOLUTIONS **16 February 2017 – 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 = 110 mins.

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

Question	Mark	out of
1		50
2		50
3		50
4		50
TOTAL		200

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.

Q1 [50 pts] – Qualitative Questions

a) **[10 pts]** “User-in-the-loop: Spatial and temporal demand shaping for sustainable wireless networks” is the title of a paper published in the February 2014 issue of the IEEE Communications Magazine; this paper was discussed in the lectures. Briefly describe the UIL paradigm.

b) **[10 pts]** “The new frontier in RAN heterogeneity: Multi-tier drone-cells” is the title of a paper published in the November 2016 issue of the IEEE Communications Magazine; the drone-BS concept was discussed in the lectures. Given that the operational expenditure (OPEX) of a drone-BS is much higher than that of a terrestrial BS, explain why an operator may want to include drone-BSs in its RAN (other than in disaster scenarios where the terrestrial RAN is not operational).

c) **[10 pts]** In the 3GPP framework, to which releases the following standards correspond?:

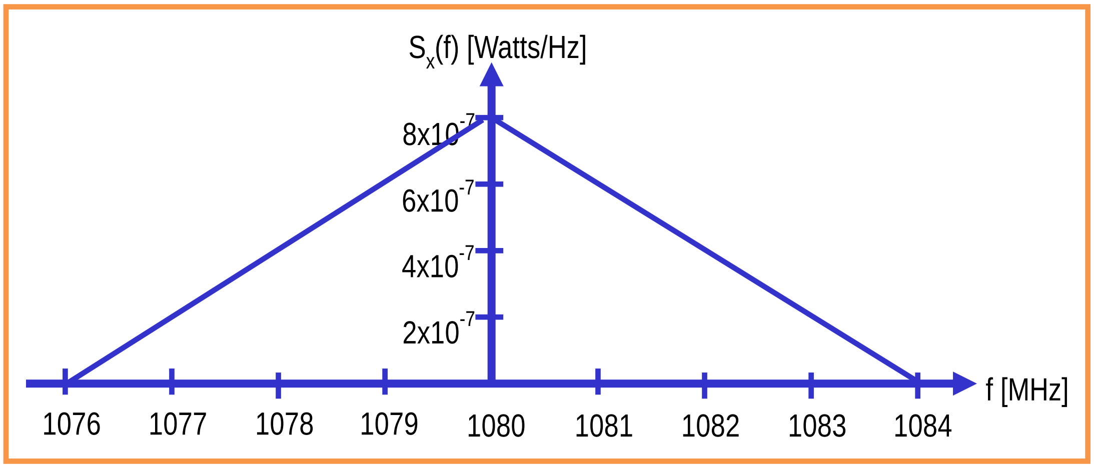
- 4G LTE: 3GPP Release-?
- 4G LTE-A: 3GPP Release-?
- 5G Phase 1: 3GPP Release-?
- 5G Phase 2: 3GPP Release-?

d) **[10 pts]** What does “HetHetNets” refer to?

e) **[10 pts]** What is the biggest (i.e., most profound) difference between 1G-4G and 5G?

Q2 [50 pts] – Power Spectral Density

The double-sided power spectral density, $S_x(f)$, for a digital signalling scheme is given below. PSD is symmetric with respect to the $f = 0$ Hz vertical axis; the left part is not shown.



a) Find the total power of this signalling scheme.

b) How much power does this signalling scheme has between 1082 MHz and 1083 MHz?

c) How much power does this signalling scheme has at 1083 MHz?

d) Find the absolute bandwidth of this signalling scheme.

e) $BW_{90\%}$ (90%-bandwidth) is defined as the frequency region in which 90% of the total power is confined to. Find $BW_{90\%}$ for this signalling scheme.

[*Extra space for Q2*]

Q3 [50 pts] – Spectral Efficiency vs SNR

Manipulate Shannon's channel capacity formula, $R = B * \log_2(1+SNR)$, to get an expression in the form of $f(SE) = E_b/N_0$, where f(.) means function of, and SE is spectral efficiency defined as R/B in b/s/Hz.

Sketch SE vs E_b/N_0 in a log-log scale; show (drive) asymptotes if there are any.

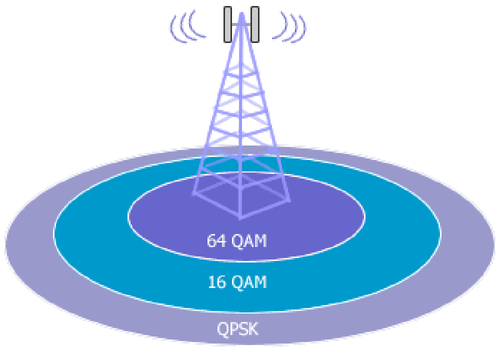
Show the attainable and unattainable regions.

Roughly locate a signaling scheme that uses 16-QAM with rate-3/4 turbo codes.

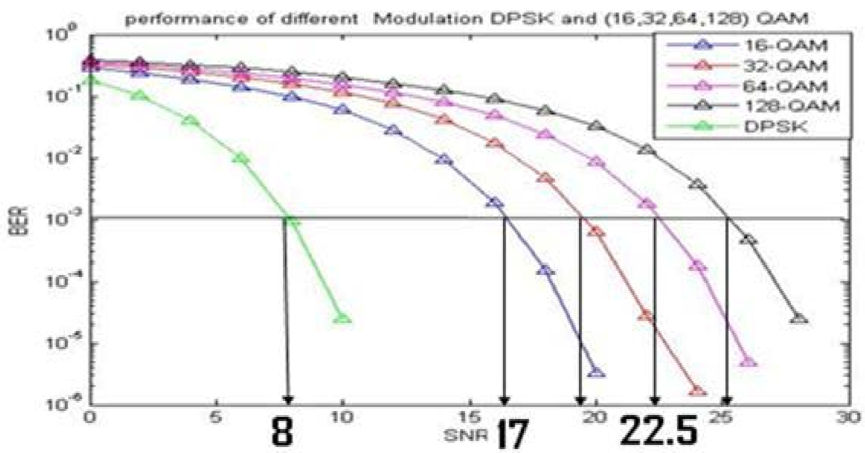
Q4 [50 marks] – Adaptive Modulation

Consider a cell with a path-loss expression of PL = 28+ 32log(d), where d is given in metres. In order to enable simple calculations, the path-loss expression does not involve shadowing. Cochannel interference is also assumed to be negligible. SNR at d=50 m is measured as 27 dB.

A UE (user equipment) close to BS uses a higher order modulation scheme in comparison to the further away ones, due to the fact that further away UEs experience lower SNR values; refer to the conceptual sketch below:



The allowed modulation levels are DPSK (a type of 2-PSK), 16-QAM, 32-QAM, 64-QAM, and 128-QAM. The acceptable BER threshold for the considered application is given as 10^{-3}; also, the lowest allowed modulation level is given as DPSK. The below BER vs SNR figure shows the performance of the considered modulation levels:



performance of modulation schemes

a) Determine the radii of the concentric circles for each modulation level.

Ex: $r_a < d < r_b$ → 16-QAM.

b) Determine the radius of the cell.

c) If the average UE density is 1 per 500 m^2, calculate the average spectral efficiency for this cell.

a) Modulation levels

$PL(d) = 28 + 32 \log(d)$

$SNR(d) = P_{RX}(d) – P_N = P_{TX} – PL(d) – P_N = (P_{TX} – P_N) – PL(d)$

$SNR(50) = (P_{TX} – P_N) – PL(50) = 27$
$P_{TX} – P_N = PL(50) + 27$

$SNR(d) = (PL(50) + 27) – PL(d) = (28 + 32 \log(50) + 27) – (28 + 32 \log(d))$
$SNR(d) = 32 \log(50) + 27 – 32 \log(d)$

$d = 10^{[32\log(50)+27-SNR(d)]/32}$

QAM:		DPSK		16-QAM		32-QAM		64-QAM		128-QAM
SE [b/s/Hz]:	0	|	2	|	4	|	5	|	6	| 7
SNR [dB]:		8		17		19		22.5		25
r [m]:		196.21		102.68		88.91		69.12		57.74
		r_2		r_4		r_5		r_6		r_7

b) Cell radius: $r_2 = 196.21$ m

c) Total no of UEs in the cell = $\pi r_2^2/500$

No of UEs using DPSK = $\pi(r_2^2 – r_4^2)/500$

<u>SE</u> = $([2\pi(r_2^2 – r_4^2)/500] + [4\pi(r_4^2 – r_5^2)/500] + \ldots + [7\pi r_7^2/500])/(\pi r_2^2/500)$

<u>SE</u> = $[2(r_2^2 – r_4^2) + 4(r_4^2 – r_5^2) + 5(r_5^2 – r_6^2) + 6(r_6^2 – r_7^2) + 7r_7^2]/r_2^2$

<u>SE</u> = 2.96 b/s/Hz