TÉCNICO LISBOA

Exam **A**

Mestrado em Engenharia Electrotécnica e de Computadores

Redes Móveis e Internet das Coisas

1st Exam

24th April 2023

Duration 2h00

Before starting to answer the questions, beware of the following:

i. **The exam question paper spans 4 pages.**
ii. **The duration of the exam is 2h00.**
iii. **The students are supposed to bring calculator, exam sheets and pen to the exam.**
iv. **The multiple choice questions are answered directly in the exam question paper. In the multiple choice questions, the wrong answers will be worth a penalty. In a question with N possible answers worth V points, the penalty is V/(N-1).**
v. **The exam has 4 versions: A, B, C e D.**
vi. **The students cannot consult any documents except the provided formulary.**
vii. **The students must place their identification document (student card) on the desk.**
viii. **All exam question paper sheets (see footer) and exam sheets must be identified with the following:**
   a) **Student Number;**
   b) **Name.**

1) In a radio network there are two mobile stations (A and B) and one base station. Multiple access is done based on CDMA. Chip modulation is BPSK. Station A has the following spreading code: +1, +1, -1, -1, +1, +1, -1, -1. Station B has the following spreading code: +1, -1, -1, +1, -1, +1, +1, -1. The decoding thresholds are ≤-3 and ≥+3, respectively for logical "0" and logical "1". At the time instant in question, impulsive noise from a nearby radar affects the base station only. The base station is transmitting simultaneously to Stations A and B with SF=4. The received sequence at A is 0, -3, +1, +2, 0, -2, +1, +2, and the received data bits at B are "10". Both signals arrive with a similar power level.

   a) What is the impulsive noise pattern at the base station? (1,0 val)

   i) 0,-1,+1,0,0,0,+1,0 ☐

   ii) +1,0,0,2,0,0,0,0 ☐

   iii) +1,-1,+1,+2,0,0,+1,0 ☐

   iv) Not enough data to know. ☐

   v) None of the above. ☐

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b) What is the data received by A? (1,0 val)

i) 0, 0 ☐

ii) 0, 1 ☐

iii) 1, 0 ☐

iv) 1, 1 ☐

v) None of the above. ☐

c) What is the noise pattern affecting reception at A? (1,0 val)

i) 0,-1,+1,0,0,0,+1,0 ☐

ii) +1,0,0,2,0,0,0,0 ☐

iii) +1,-1,+1,+2,0,0,+1,0 ☐

iv) Not enough data to know. ☐

v) None of the above. ☐

d) What is the noise pattern affecting reception at B? (1,0 val)

i) 0,-1,+1,0,0,0,+1,0 ☐

ii) +1,0,0,2,0,0,0,0 ☐

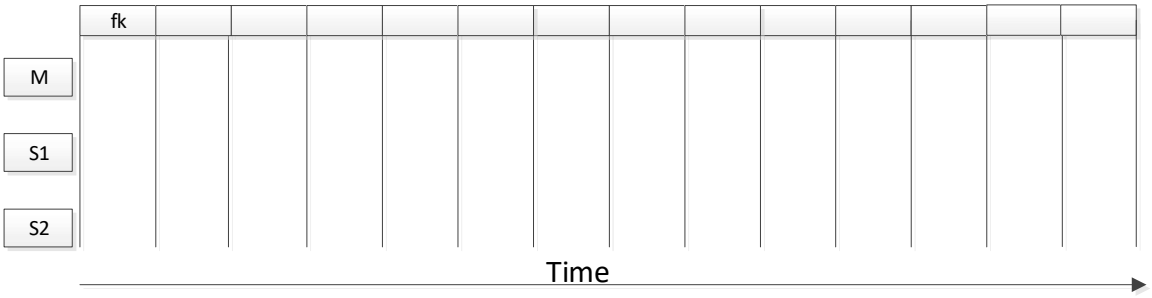
iii) +1,-1,+1,+2,0,0,+1,0 ☐

iv) Not enough data to know. ☐

v) None of the above. ☐

2) Consider a Bluetooth piconet, comprising one master and two slave devices (S1 and S2).

a) S1 has the following ACL packets in its transmission queue, which are ordered as follows (format is <higher level destination, packet>): <M, DH1>, <S2, DH3>, <M, DM1>. S2 has one packets in the queue: <M, DH5>. The master's polling policy is round-robin, starting by S1. Draw the timeline diagram of packet transmissions, clearly indicating **the timeslot assignment (for each packet, indicate the type, the occupied slots, the sender and the receiver), as well as the frequency in use in each slot. Also indicate which packets are POLL packets and indicate the acknowledgements (both standalone and piggybacked): e.g., ACK1 for an ACK directed to S1.** The diagram ends when the last ACL data packet is transmitted. **Note: the following figure is just an example of the table you have to fill.** (2,0 val)



b) Consider that a SCO session in in place between a Master a Slave using HV2 packets, and 30 kbit/s ACL traffic in the uplink direction. What is the maximum ACL data rate that would be supported in the downlink direction? (1,0 val)

i) 86.4 kbit/s ☐

ii) 54.4 kbit/s ☐

iii) 387.2 kbit/s ☐

iv) 30.0 kbit/s ☐

v) None of the above. ☐

c) Consider the uplink direction of an L2CAP session whose traffic is being shaped by a Token Bucket mechanism. There is no traffic in the downlink direction. The negotiated uplink flow spec for the connection is <Token Rate, Token Bucket Size> = <30000 Byte/s, 400 Byte>. The amount of tokens in the token bucket at $\boldsymbol{t = 0}$ is 300. What will be the amount of tokens in the token bucket at the end of the next 6 slots, if one full DM1 packet is transmitted during the second slot of the period? **Note: Assume that the consumed tokens are subtracted just before packet transmission.** (1,0 val)

i) 412.5 ☐

ii) 400 ☐

iii) 395,5 ☐

iv) 300 ☐

v) None of the above. ☐

3) Consider a point-to-point radio link operating in a 4.1 MHz wide frequency range centered at 5 GHz. Within that frequency range, FDD is employed with bandwidth divided equally among the two directions, with a guard band of 100 kHz between directions. The link connects two buildings of the same company in a city, which are located 6 km apart. Propagation is free space up to 100 m from the receiver. Beyond that distance, a path loss exponent is 4 was estimated. The endpoint antennas stand 2 m high at the top of the buildings, featuring gains of 20 dBi in both cases. The employed radio technology has four modes of operation achieved with different combinations of channel coding and modulation, whose bitrates and respective sensitivities are the following: <1 Mbit/s, -95 dBm>, <2 Mbit/s, -93 dBm>, <3 Mbit/s, -91 dBm>, <4 Mbit/s, -89 dBm>. The transmit power is 300 mW. The noise power spectral density is -170 dBm/Hz.

a) What is the maximum spectral efficiency that can be achieved with the given transmission modes? Justify. (1,0 val)

b) Assuming that the endpoints communicate at the maximum possible bitrate, what is that bitrate? (2,0 val)

c) Assuming a roll-off factor of 0, and QPSK modulation, calculate the code rate of the FEC code being used in the 3 Mbit/s transmission mode. (1,0 val)

4) LoRaWAN is a Low Power Wide Area Network (LPWAN) technology, which is currently considered very promising from the point of view of Internet of Things (IoT) implementation. Consider the tables below and answer the following questions:

a) What is the number of bits per symbol when operating at DR3? (1,0 val)

b) What is the maximum uplink packet rate (in packets per second) when using DR4, maximum packet size, no acknowledgements, and 1% duty cycle? **Note: Assume that there is no downlink traffic.** (1,0 val)

c) Which entity of the LoRaWAN architecture is responsible for receiving and processing the data from the devices? (1,0 val)

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d) Consider a LoRaWAN cell (network formed by a single gateway), where all the devices (class A) transmit packets with the same size and same period, ignoring duty cycle limitations. If a single SF is used, which SF should be used to minimize the probability of collision? Justify. (1,0 val)

e)

Table I. LoRaWAN data rates settings and frames characteristics

Data rate (DR)	SF	Band width, kHz	Modu-lation	maximum MACPayload size, bytes	Maximum FRMPayload size[1], bytes	Shortest downlink frame ToA, s	Longest downlink frame ToA, s	Shortest uplink frame ToA, s	Longest uplink frame ToA, s
0	12	125	LoRa	59	51	0.991	2.793	1.155	2.793
1	11	125	LoRa	59	51	0.578	1.479	0.578	1.561
2	10	125	LoRa	59	51	0.289	0.698	0.289	0.698
3	9	125	LoRa	123	115	0.144	0.677	0.144	0.677
4	8	125	LoRa	250	242	0.072	0.697	0.082	0.707
5	7	125	LoRa	250	242	0.041	0.394	0.041	0.400
6	7	250	LoRa	250	242	0.021	0.197	0.021	0.200
7	n/a	150	GFSK	250	242	0.0032	0.0421	0.0035	0.0424

[1]- given that $FHDR_{OPTS}$=0

Table II. LoRaWAN ED performance for the different data rates

Data rate (DR)	No RX slots				ACK in RX1[1]				No ACK in RX2[2]			
	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %
0	2.7935	183.3	146.1	100	4.78	107.0	85.3	58.4	5.0	103.3	82.3	56.4
1	1.5606	328.1	261.4	100	3.14	163.2	130.0	49.7	3.7	137.5	109.5	41.9
2	0.6984	733.1	584.2	100	1.99	257.7	205.3	35.1	2.9	178.9	142.5	24.4
3	0.6769	1 512.9	1 359.2	100	1.82	562.3	505.1	37.2	2.8	360.5	323.9	23.8
4	0.7071	2 885.1	2 738.1	100	1.78	1 146.5	1 088.1	39.7	2.9	710.6	674.4	24.6
5	0.3996	5 104.9	4 844.7	100	1.44	1 415.8	1 343.7	27.7	2.6	795.8	755.2	15.6
6	0.1998	10 209.8	9 689.3	100	1.22	1 671.6	1 586.3	16.4	2.4	863.1	819.1	8.5
7	0.0424	48 113.2	45 660.4	100	1.05	1 951.0	1 851.6	4.1	2.0	998.2	947.3	2.1

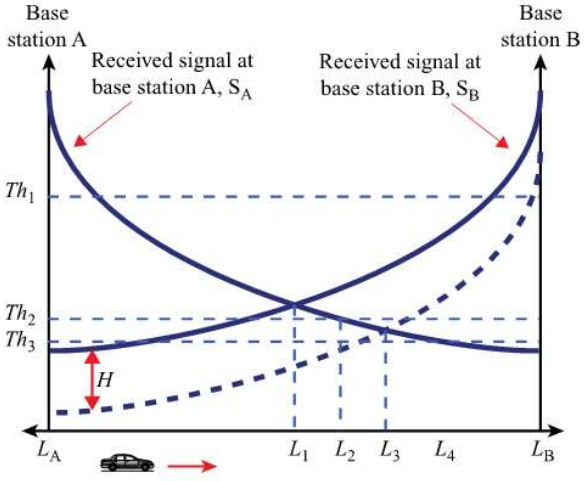
[1]-assumed that the acknowledgement frame has no payload and is transmitted using the same DR (i.e., best-case scenario)
[2]-assumed that RX2 is open with DR0 settings (the default setting according to [3])

5) Answer the following questions regarding the LTE mobile cellular systems.

a) A mobile terminal is currently connected with Base Station A, and approaching Base Station B, as depicted in the following picture. Which handoff locations (L_A, L_1, L_2, L_3, L_4, L_B) result from the following handover strategies:

i) Relative Signal Strength with Hysteresis. (1,0 val)

ii) Relative Signal Strength with threshold *Th2*. (1,0 val)



Car is moving from base station A at location L_A to base station B at L_B

b) There are four User Equipments (UEs) sharing resources in a cell using LTE FDD. In this implementation, the downlink physical resource blocks (RBs) are allocated in slices with the same number of RBs, where all RBs

of a slice are adjacent in the frequency domain. Consider that there are four such RB slices (S1, S2, S3, and S4) with the same number of subcarriers, where the measured signal-to-interference-plus-noise-ratio (SINR) levels are given by the following table. Assume that each UE is able to fully use up to four RB slices, given its category and the amount of traffic that is currently being generated. Which UE should be given ownership of which RB slice by the LTE scheduler, if the objective is to maximize the total throughput? (1,0 val.)

i) S1:UE1, S2:UE3, S3:UE4, S4:UE8 ☐

ii) S1:UE1, S2:UE3, S3:UE4, S4:UE1 ☐

iii) S1:UE3, S2:UE2, S3:UE2, S4:UE4 ☐

iv) S1:UE2, S2:UE1, S3:UE4, S4:UE3 ☐

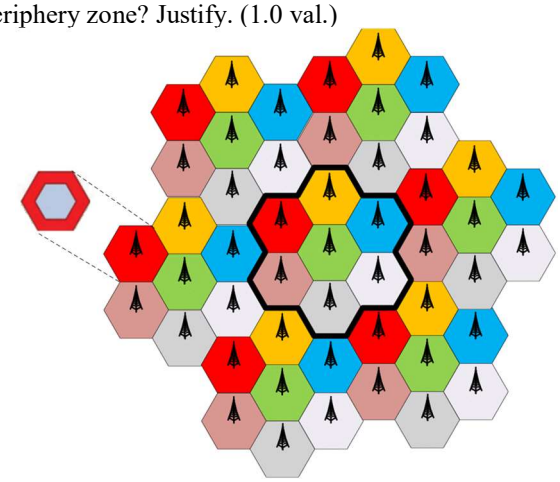
v) None of the above. ☐

UE	SINR (dB)			
	S1	S2	S3	S4
UE1	11	8	10	12
UE2	10	-5	1	6
UE3	-6	14	10	8
UE4	8	6	11	-2

c) Consider that an LTE network operator is covering an area with cells of radius $\boldsymbol{R = 400m}$. The operator owns one channel of 5 MHz (only 4.5 MHz are usable), and the total number of subcarriers is represented by $\boldsymbol{N_f}$. In order to avoid interference between neighbor cells, the latter use different subcarriers in their periphery zones. The total number of subcarriers reserved for use in the periphery zones of the cells is 200, and the respective reuse factor is 1/7. The remaining subcarriers (always the same) are used in the central zones of all cells, hence the respective reuse factor is 1. The periphery zone of each cell is defined as the area ($\boldsymbol{A_p}$) outside of the central hexagon (see figure), and we have that $\boldsymbol{A_p = \frac{M}{N_f^{cell}} A_t}$, where $\boldsymbol{M}$ is the number of frequencies used in the periphery of the cell, $\boldsymbol{N_f^{cell}}$ is the total number of frequencies used in the cell and $\boldsymbol{A_t}$ is the total area of the cell.

i) Calculate $\boldsymbol{A_p}$. Justify. (1,0 val)

ii) What is the distance between the center of one cell and the center of the closest cell that reuses the same subcarriers in the periphery zone? Justify. (1.0 val.)



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