Mestrado em

Engenharia Electrotécnica e de Computadores

Redes Móveis e Sem Fios

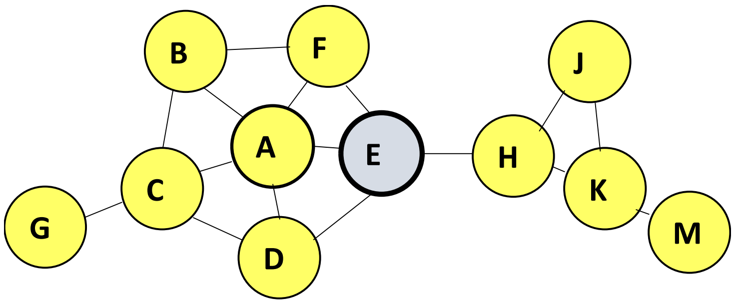
Exame – 2ª parte

7 de Julho de 2021

Duração 1h30

In order to avoid grading mistakes, please answer each question on a different page and keeping the order as much as possible.

1) Consider the OLSR routing protocol for mobile ad hoc networks.
   a) Classify OLSR as proactive or reactive. Justify. (1,0 val)
   b) OLSR employs two kind of control messages. Explain how those kinds of messages are used. (1,0 val)
   c) OLSR defines the concept of Multipoint Relay (MPR), which is not considered in simple link state protocols. Explain the advantage using MPRs. (1,0 val)
   d) In the following network topology, which should be the MPRs of node E. Justify. (2,0 val)



2) 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 DR4? (1,0 val)
   b) What is the maximum uplink packet rate (in packets per second) when using DR3, maximum packet size, no acknowledgements, and with 1% duty cycle? (1,0 val)
   c) Which entity of the LoRaWAN architecture is responsible for transmitting the acknowledgements? (1,0 val)
   d) Explain the difference between Class A, Class B and Class C devices. (1,0 val)
   e) Consider a LoRaWAN cell (network formed by a single gateway), where all the devices transmit packets with the same size and same period. If a single SF is used, which SF would you choose to maximize the number of devices supported in the cell? (1,0 val)

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

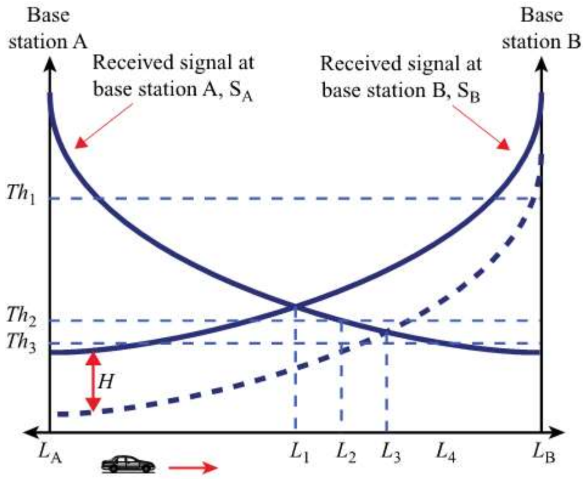
[1]-assumed that the acknowledgement frame has no payload and is transmitted using the same DR (i.e., best-case scenario)
[2]-assumed that RX2 is open with DR0 settings (the default setting according to [3])

3) Answer the following questions regarding the architecture and technologies of 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 threshold *Th3*. (1,0 val)

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



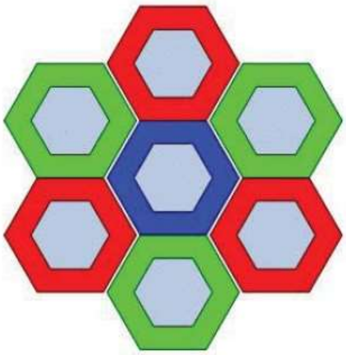
Car is moving from base station A at location L_A to base station B at L_B

b) Consider that an LTE network operator is covering an area with cells of radius $\boldsymbol{R = 500m}$. The total number of subcarriers owned by the operator is $\boldsymbol{N_f = 3600}$. 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 1200, and the respective reuse factor is 1/3. The remaining 2400 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 $\boldsymbol{A_p} = \frac{\boldsymbol{M}}{N_f^{cell}}\boldsymbol{A_t}$, where $\boldsymbol{M}$ is the number of frequencies used in the periphery of the cell, 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) Calculate the radius of the central hexagon of a cell. Justify. Note: in case that you were unable to solve b-i), present the result as a function of A_p. (1.0 val)

iii) 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.)



4) Consider one of the orbital planes of a LEO satellite system operating in the 1 GHz frequency, with transmit power of 43 dBm. The angular speed is 0.824 mrad/s. The satellite and ground station antennas have similar characteristics. The received power is -82,28 dBm. The atmosphere introduces an additional attenuation of 10 dB.

a) Calculate the altitude of the orbit. (1,0 val)

b) Calculate the period of the orbit. (1,0 val)

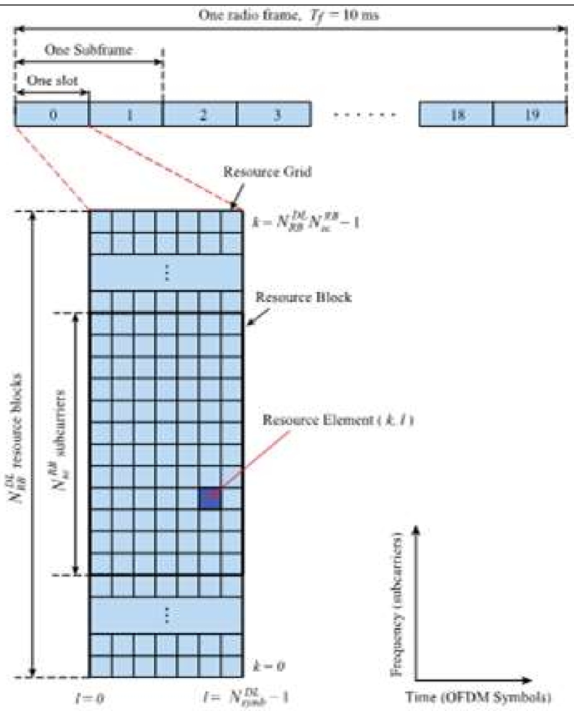
c) Calculate the gain of the antennas. (2, 0 val)

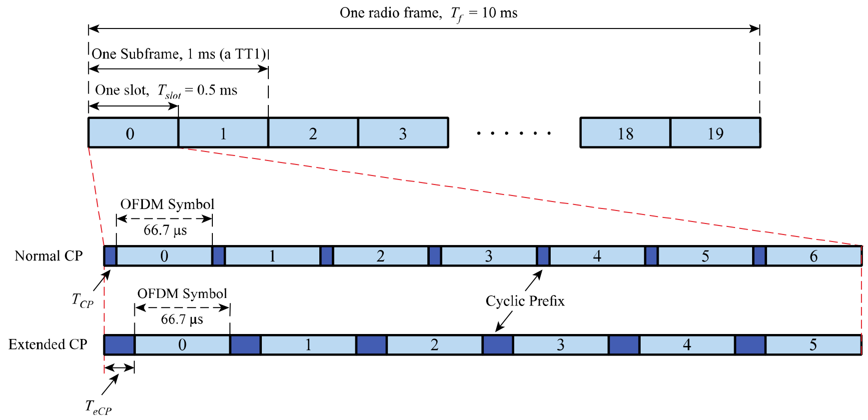
d) Calculate the beamwidth of the antennas. (1,0 val)

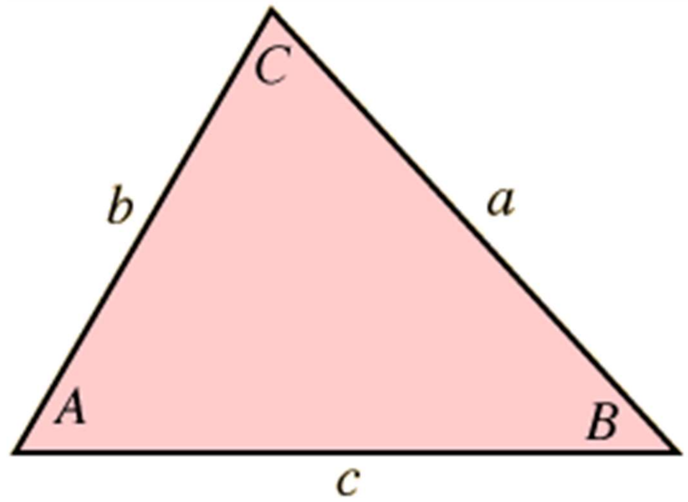
LoRaWAN
Symbol Rate: $$Rs = \frac{BW}{2^{SF}}$$
Chirp Rate: $$Rc = BW \times Rs = \frac{BW^2}{2^{SF}}$$
Net Bit Rate: $$Rb = SF \times Rs \times CR$$ CR=Code Rate (k/n of the error correcting code)
Bit Error Rate (empirical approximation): $$BER = Q\left(\frac{log_{12}(SF)}{\sqrt{2}} \cdot \frac{E_b}{N_0}\right)$$

Cellular Networks and Traffic Engineering	
Hexagonal cell area: $A_{cell} = 1.5 \times R^2 \times \sqrt{3}$	Distance between hexagonal cell centers: $d = \sqrt{3} \times R$
Frequency reuse factor: $RF = \frac{1}{G}$	Cell cluster sizes: $G = I^2 + J^2 + (I \times J)\ st\ I, J = 0, 1, 2, etc.$
Reuse distance vs cell Radius and cluster size: $\frac{D}{R} = \sqrt{3G}$	Reuse distance vs distance between adjacent cell centers, cell radius and cluster size: $D^2 = d^2 I^2 + d^2 J^2 - 2(dI \times dJ)\cos(120^{\circ}) = d^2\left(I^2 + J^2 + (I \times J)\right) = 3R^2\left(I^2 + J^2 + (I \times J)\right)$
Traffic intensity: $A = \lambda \cdot h$	Traffic intensity: $A = \rho \cdot N$
Grade of service for ∞ sources LCC: $P = \frac{\frac{A^N}{N!}}{\sum_{x=0}^{N} \frac{A^x}{x!}}$	Capacity of blocking system: $C = A(1 - P)$
Law of cosines: see above.	

CQI Index	Modulation	Code Rate × 1024	Efficiency
0	Out of Range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

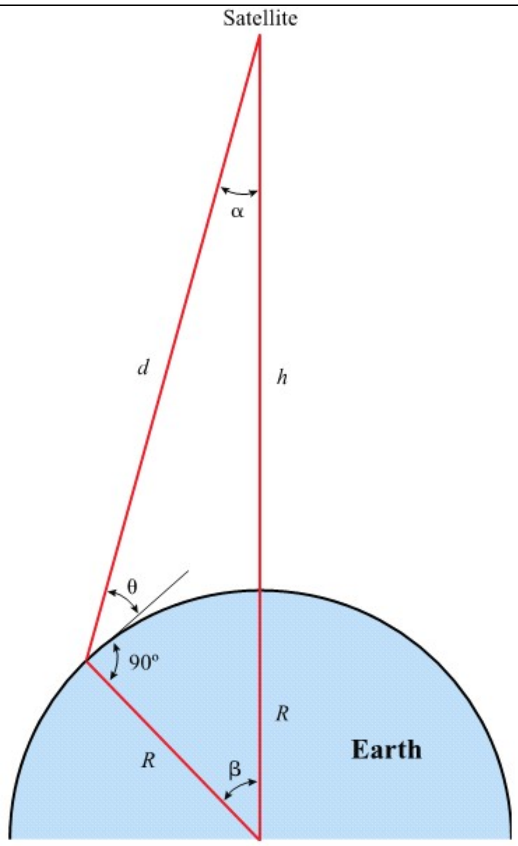




Useful Trigonometry	
	
Law of cosines: $c^2 = a^2 + b^2 - 2ab \cdot cos(C)$ $b^2 = a^2 + c^2 - 2ac \cdot cos(B)$ $a^2 = b^2 + c^2 - 2bc \cdot cos(A)$	Law of sines: $\frac{a}{sin(A)} = \frac{b}{sin(B)} = \frac{c}{sin(C)}$

Satellite Systems	
$F_g = m \cdot g \cdot (R/r)^2$ $g = 9.81 m/s^2$ (gravitational acceleration) $R = 6370\ km$ (radius of the Earth)	$F_c = m \cdot r \cdot \omega^2$
$L = \left(\frac{4 \cdot \pi \cdot d \cdot f}{c}\right)^2$	$Footprint\ Diameter = 2 \times \alpha \times h$
$G_{(1plane)} = 2\pi/(2 \times \alpha)$	$A_{eff} = \eta \cdot A_{phy} = \frac{\lambda^2}{4\pi} G$
$P_r(dBm) = P_t(dBm) + 10 \cdot log_{10}\left(\frac{G_t \cdot G_r \cdot \lambda^2}{(4 \cdot \pi \cdot d)^2}\right) - At$	

$$P_r(dBm) = P_t(dBm) - 10 \cdot log_{10}\left(\frac{4 \cdot Footprint}{\pi^2 \cdot A_{eff}}\right) - At$$



$$\frac{R}{R+h} = \frac{sin(\alpha)}{sin\left(\theta + \frac{\pi}{2}\right)} =$$

$$\frac{sin\left(\frac{\pi}{2} - \beta - \theta\right)}{sin\left(\theta + \frac{\pi}{2}\right)} = \frac{cos(\beta + \theta)}{cos(\theta)}$$

$$\frac{d}{R+h} = \frac{sin(\beta)}{sin\left(\theta + \frac{\pi}{2}\right)} =$$

$$= \frac{sin(\beta)}{cos(\theta)}$$

$$d = \frac{(R+h) \cdot sin(\beta)}{cos(\theta)} = \frac{R \cdot sin(\beta)}{sin(\alpha)}$$

Mestrado em
Engenharia Electrotécnica e de Computadores

Redes Móveis e Sem Fios

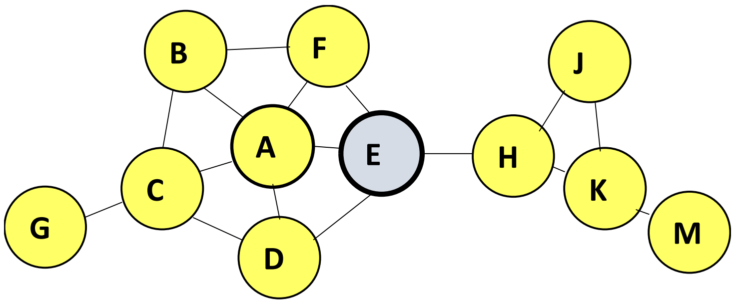
Exame – 2ª parte

7 de Julho de 2021

Duração 1h30

In order to avoid grading mistakes, please answer each question <u>on a different page</u> and keeping the order as much as possible.

1) Consider the OLSR routing protocol for mobile ad hoc networks.
   a) Classify OLSR as proactive or reactive. Justify. (1,0 val)
   b) OLSR employs two kind of control messages. Explain how those kinds of messages are used. (1,0 val)
   c) OLSR defines the concept of Multipoint Relay (MPR), which is not considered in simple link state protocols. Explain the advantage using MPRs. (1,0 val)
   d) In the following network topology, which should be the MPRs of node E. Justify. (2,0 val)



2) 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 DR4? (1,0 val)
   b) What is the maximum uplink packet rate (in packets per second) when using DR3, maximum packet size, no acknowledgements, and with 1% duty cycle? (1,0 val)
   c) Which entity of the LoRaWAN architecture is responsible for transmitting the acknowledgements? (1,0 val)
   d) Explain the difference between Class A, Class B and Class C devices. (1,0 val)
   e) Consider a LoRaWAN cell (network formed by a single gateway), where all the devices transmit packets with the same size and same period. If a single SF is used, which SF would you choose to maximize the number of devices supported in the cell? (1,0 val)

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

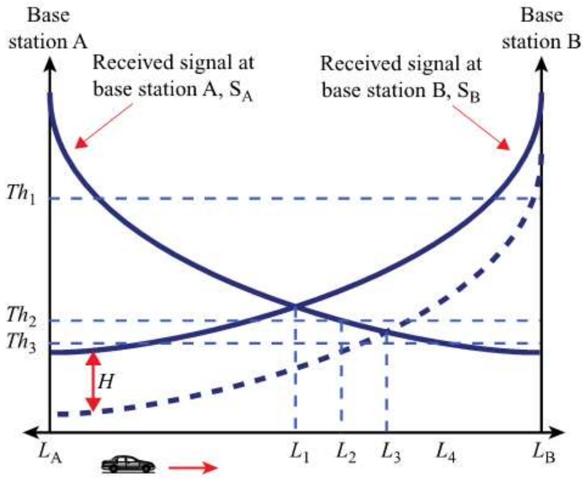
[1]-assumed that the acknowledgement frame has no payload and is transmitted using the same DR (i.e., best-case scenario)
[2]-assumed that RX2 is open with DR0 settings (the default setting according to [3])

3) Answer the following questions regarding the architecture and technologies of 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 threshold *Th3*. (1,0 val)

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



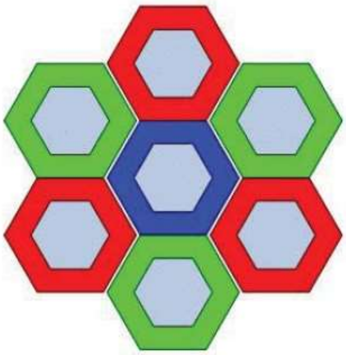
Car is moving from base station A at location L_A to base station B at L_B

b) Consider that an LTE network operator is covering an area with cells of radius $\boldsymbol{R = 500m}$. The total number of subcarriers owned by the operator is $\boldsymbol{N_f = 3600}$. 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 1200, and the respective reuse factor is 1/3. The remaining 2400 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 $\boldsymbol{A_p} = \frac{\boldsymbol{M}}{N_f^{cell}}\boldsymbol{A_t}$, where $\boldsymbol{M}$ is the number of frequencies used in the periphery of the cell, 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) Calculate the radius of the central hexagon of a cell. Justify. Note: in case that you were unable to solve b-i), present the result as a function of $\boldsymbol{A_p}$. (1.0 val)

iii) 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.)



4) Consider one of the orbital planes of a LEO satellite system operating in the 1 GHz frequency, with transmit power of 43 dBm. The angular speed is 0.824 mrad/s. The satellite and ground station antennas have similar characteristics. The received power is -82,28 dBm. The atmosphere introduces an additional attenuation of 10 dB.

a) Calculate the altitude of the orbit. (1,0 val)

b) Calculate the period of the orbit. (1,0 val)

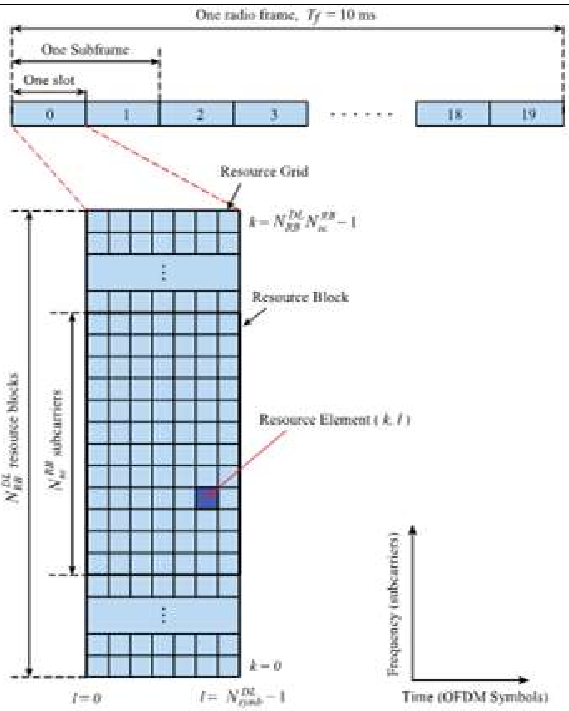
c) Calculate the gain of the antennas. (2, 0 val)

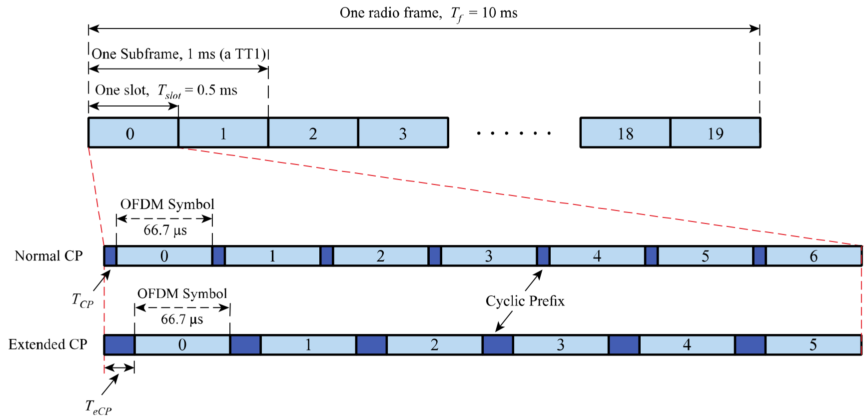
d) Calculate the beamwidth of the antennas. (1,0 val)

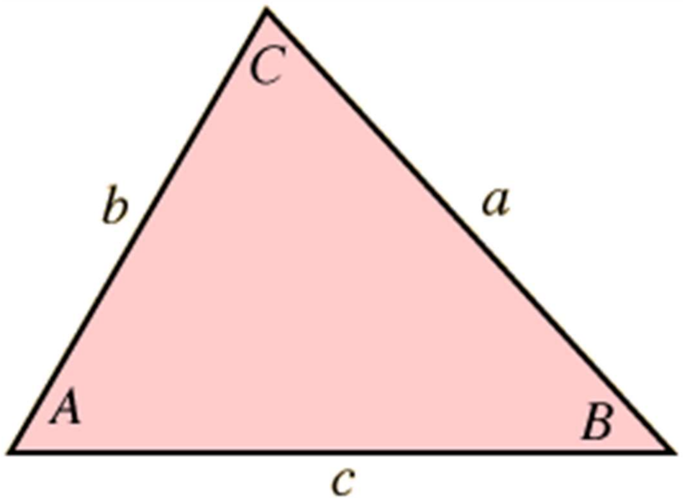
LoRaWAN
Symbol Rate: $$\boldsymbol{Rs = \frac{BW}{2^{SF}}}$$
Chirp Rate: $$\boldsymbol{Rc = BW \times Rs = \frac{BW^2}{2^{SF}}}$$
Net Bit Rate: $$\boldsymbol{Rb = SF \times Rs \times CR}$$ CR=Code Rate (k/n of the error correcting code)
Bit Error Rate (empirical approximation): $$\boldsymbol{BER = Q\left(\frac{log_{12}(SF)}{\sqrt{2}} \cdot \frac{E_b}{N_0}\right)}$$

Cellular Networks and Traffic Engineering	
Hexagonal cell area: $A_{cell} = 1.5 \times R^2 \times \sqrt{3}$	Distance between hexagonal cell centers: $d = \sqrt{3} \times R$
Frequency reuse factor: $RF = \frac{1}{G}$	Cell cluster sizes: $G = I^2 + J^2 + (I \times J)\ st\ I, J = 0,\ 1,\ 2,\ etc.$
Reuse distance vs cell Radius and cluster size: $\frac{D}{R} = \sqrt{3G}$	Reuse distance vs distance between adjacent cell centers, cell radius and cluster size: $D^2 = d^2 I^2 + d^2 J^2 - 2(dI \times dJ)\cos(120^{\circ}) = d^2\left(I^2 + J^2 + (I \times J)\right) = 3R^2\left(I^2 + J^2 + (I \times J)\right)$
Traffic intensity: $A = \lambda \cdot h$	Traffic intensity: $A = \rho \cdot N$
Grade of service for ∞ sources LCC: $P = \frac{\frac{A^N}{N!}}{\sum_{x=0}^{N} \frac{A^x}{x!}}$	Capacity of blocking system: $C = A(1 - P)$
Law of cosines: see above.	

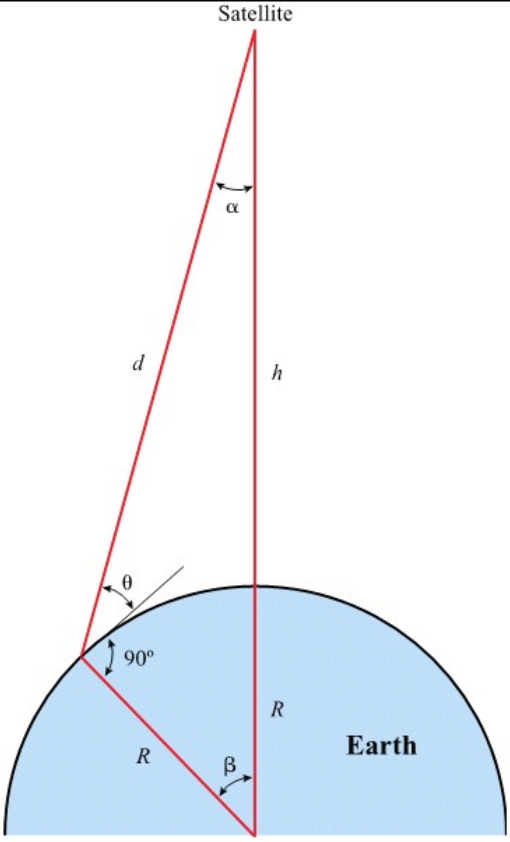
CQI Index	Modulation	Code Rate × 1024	Efficiency
0	Out of Range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547





Useful Trigonometry	
	
Law of cosines: $c^2 = a^2 + b^2 - 2ab \cdot cos(C)$ $b^2 = a^2 + c^2 - 2ac \cdot cos(B)$ $a^2 = b^2 + c^2 - 2bc \cdot cos(A)$	Law of sines: $\frac{a}{sin(A)} = \frac{b}{sin(B)} = \frac{c}{sin(C)}$

Satellite Systems	
$F_g = m \cdot g \cdot (R/r)^2$ $g = 9.81 m/s^2$ (gravitational acceleration) $R = 6370\ km$ (radius of the Earth)	$F_c = m \cdot r \cdot \omega^2$
$L = \left(\frac{4 \cdot \pi \cdot d \cdot f}{c}\right)^2$	$Footprint\ Diameter = 2 \times \alpha \times h$
$G_{(1plane)} = 2\pi/(2 \times \alpha)$	$A_{eff} = \eta \cdot A_{phy} = \frac{\lambda^2}{4\pi} G$
$P_r(dBm) = P_t(dBm) + 10 \cdot log_{10}\left(\frac{G_t \cdot G_r \cdot \lambda^2}{(4 \cdot \pi \cdot d)^2}\right) - At$	

$$P_r(dBm) = P_t(dBm) - 10 \cdot log_{10}\left(\frac{4 \cdot Footprint}{\pi^2 \cdot A_{eff}}\right) - At$$	
 	$$\frac{R}{R+h} = \frac{sin(\alpha)}{sin\left(\theta+\frac{\pi}{2}\right)} =$$ $$\frac{sin\left(\frac{\pi}{2}-\beta-\theta\right)}{sin\left(\theta+\frac{\pi}{2}\right)} = \frac{cos(\beta+\theta)}{cos(\theta)}$$ $$\frac{d}{R+h} = \frac{sin(\beta)}{sin\left(\theta+\frac{\pi}{2}\right)} =$$ $$= \frac{sin(\beta)}{cos(\theta)}$$ $$d = \frac{(R+h)\cdot sin(\beta)}{cos(\theta)} = \frac{R\cdot sin(\beta)}{sin(\alpha)}$$