Cellular Technologies

1/ List the functionalities of
1. Radio access network
2. Core network
3. Backbone network

2/ Explain and indicate the channels that are involved in the:
1. Cell selection
2. Handover
    a. Hard Handover
    b. Soft Handover
3. Roaming

3/ What is the difference between multiplexing and duplexing?

4/ What is the difference between baseband signal and modulated signal?
What is the difference between carrier frequency and the bandwidth?

5/ Terminology and standard parameters:
Complete the table with the missing fields

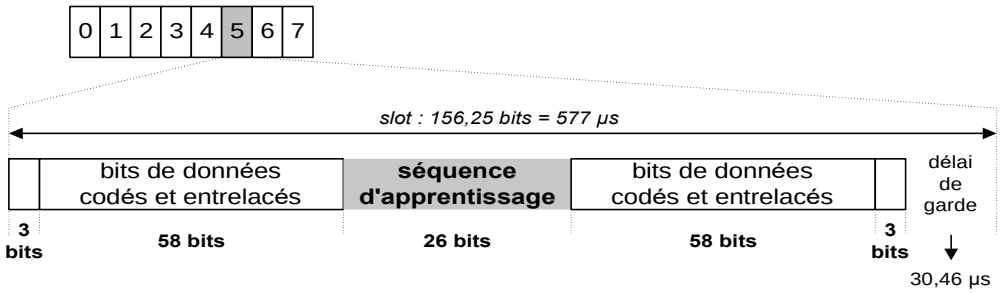
	2G	**3G**	**4G**	**5G**
Stations	BTS	Node B	eNB	g-NB eg-NB
Equipment	Mobile	UE	UE	UE
Radio Access Network	GERAN	UTRAN	EUTRAN	New Radio (5GRAN)
Core Network	NSS Network subsystem	PC	EPC	New Core
Backbone Network	Cable coaxial; Optical Fiber, Microwave transmission (Faisceaux Hertziens)			
Frequency	900 MHz	1800-2100 MHz	2.6 GHz	3.5 GHz
Radio resource	Time-frequency slot	Channelization code + scrambling code	12 Carrier frequencies + 7 time slots	12 Carrier frequencies + 7 time slots
Handover	Hard	Soft with FDD Hard with TDD	Hard	Hard
Switching	Circuit	Packet / Circuit	Packet	Packet
Voice service	Circuit switching	Circuit switching	VoIP (IMS) Switch to 3G	VoIP

Bandwidth per comm.	200 kHz	5 MHz	180 kHz	180, 360, 720 kHz
Slot per communication	4.615/8 ms	2/3 ms	2 x 0.5 ms	2 x (0.5, 0.25, 0.125) ms
Frame duration	26 Frames 120 ms	10 ms	10 ms	10, 5, 2.5, 1.25 ms
Number of slots	8 slots per frame = 4.615 ms	15 slots	20 slots (same allocation on 2 consecutive slots)	20 slots (same allocation on 2 consecutive slots)
Duplexing	FDD	FDD – TDD	FDD – TDD	TDD FDD
Multiplexing	T-FDMA	CDMA	OFDMA Spatial multiplexing	OFDMA Spatial multiplexing
User data rate	100 kb/s (EDGE)	4 Mb/s	30 Mb/s	100 Mb/s
End to end Latency	500 ms	100 ms	50 ms	1 ms

6/ Compared the time duration required to download the following applications:

Activity	**Typical Size**	**4G (30 Mb/s) Download Time**	**3G (4 Mb/s) Download Time**	**EDGE (0.1 Mb/s) Download Time**
Accessing typical web page	2 MB	0.5 seconds	4 seconds	3 minutes
Sending an e-mail without attachments	10 KB	<0.1 seconds	<0.1 seconds	1 second
Downloading high-quality photograph	2 MB	0.5 seconds	4 seconds	3 minutes
Downloading a music track (MP3)	5 MB	3 seconds	10 seconds	7 minutes
Downloading an application	30 MB	8 seconds	1 minute	40 minutes

7/ Time advance in cellular networks:
We recall the structure the slot in GSM:



In 2G network, a mobile is situated at the edge of a rural cell with radius R = 2 km. The length of the LOS path to reach the BS is 2 km and the most significant NLOS can go up to 10 km.
To establish a communication, the network attributes to this mobile the time-frequency slot number 5.

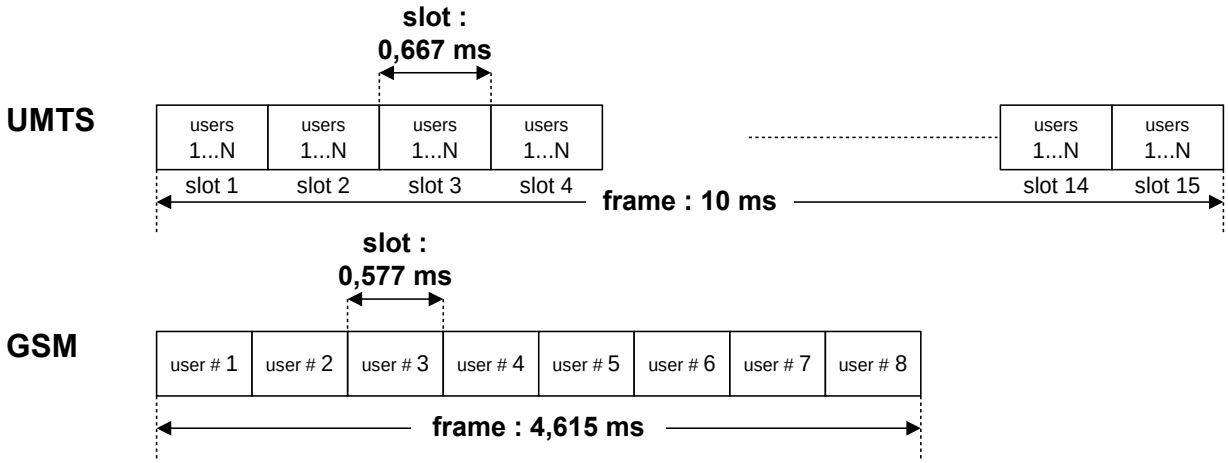
Explain what the time advance concept is. Indicate the starting time t_0 at the mobile side in the LOS and NLOS case.

8/ Explain what the roles of the Channelization code and the scrambling code in 3G are.

9/ 3G spreading factor and code allocation:

A bandwidth of 5 MHz is allocated to a 3G network operating in FDD mode. A QPSK constellation is used.
In UMTS, a roll-off coefficient of 0.22 is used. The chirp rate is fixed to 3.84 Mchirp/s.

The structure of 3G frame is illustrated below:



1. Find the bandwidth that is occupied by the CDMA signals.
2. Compute the QPSK symbol duration and indicate how many symbols are sent within the slot duration.
3. Find user data rate when no correcting code is used.
4. Find the data rate when a convolutional code with rate 1/2 is used.

Uplink: In HSUPA, it is possible to allocate multiple SF codes to a single user.

5. Complete the table to find the channel bit rates per user.

Channel bit rates	**Number of allocated spreading codes**	**Spreading factors N_i**
15 – 960 kbps	1	$N_i = 256 – 4$
1.92 Mbps	2	$N_i = 4$
3.84 Mbps	2	$N_i = 2$
5.76 Mbps	4	$2 \times \{N_i = 4\} + 2 \times \{N_i = 2\}$

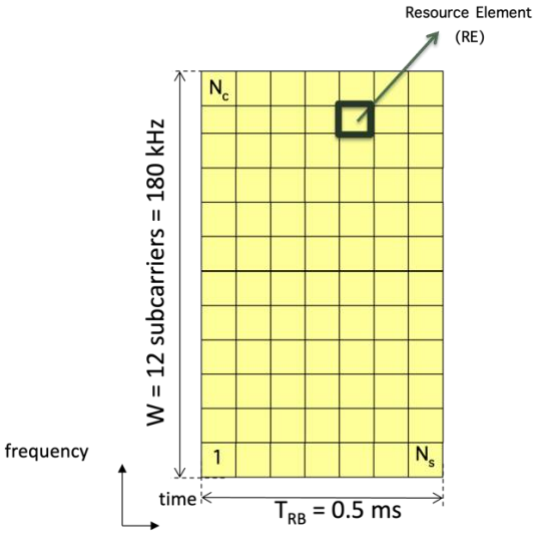
Uplink: In HSDPA, the SF is fixed to 16 and it is possible to allocate multiple spreading code to a single user.

6. Complete the table to find the channel bit rates per user.

Channel bit rates QPSK	**Channel bit rates 16 QAM**	**Spreading codes**	**Number of allocated spreading codes**
6 kbps – 1.872 Mbps		512 - 4	1
480 kbps	960 kbps	16	1
960 kbps	1.92 Mbps	16	2
…	…	…	…
7.2 Mbps	**14.4 Mbps**	16	15

10/ We consider a 3G network in which a user with high QoS transmits with a SF of 4. All the other UEs transmit with a SF of 128. Plot the Hadamard tree and compute the number of simultaneous users.

11/ The structure of 4G radio resource is illustrated in the Figure below. In LTE, the carrier spacing is fixed to Δf = 15 kHz.



a. Complete the table with the sampling frequency and the OFDM symbol duration:

Bandwidth	Nb of available RBs	Sampling Frequency	OFDM symbol duration	FFT size
1,4 MHz	6	1.92 MHz		128
3 MHz	15			256
5 MHz	25			512
10 MHz	50			1024
15 MHz	75			1536
20 MHz	100			2048

In the downlink, the modulation and coding scheme (MCS) that can be transmitted on each radio resource depends on the value of the SINR as indicated in the table below.

b. Considering a SISO network and a bandwidth of 20MHz, complete the table:

SINR (dB)	MCS	Maximal cell data rate	1 RB per UE Data rate
-0.75	QPSK-1/3		
1.5	QPSK-1/2		
3.5	QPSK-2/3		
7	16QAM-1/2		

9.5	16QAM-2/3		
11.5	16QAM-4/5		
12	64QAM-1/2		
14.7	64QAM-2/3		

In LTE-Advanced, it is possible to use 8X8 MIMO configuration and to aggregate up to 5 carriers of 20 MHz each.

c. Compute the maximal and minimal aggregate data rate in the cell.

The 8x8 MIMO configuration can be used either to multiplex multiple streams towards a single user or to multiplex multiple users on the same radio resource. This is known as multi-user system.

d. Assuming the scheduling policy limits the number of RR to one per user, compute the maximal data rate attributed to a user in the case of single user transmission.

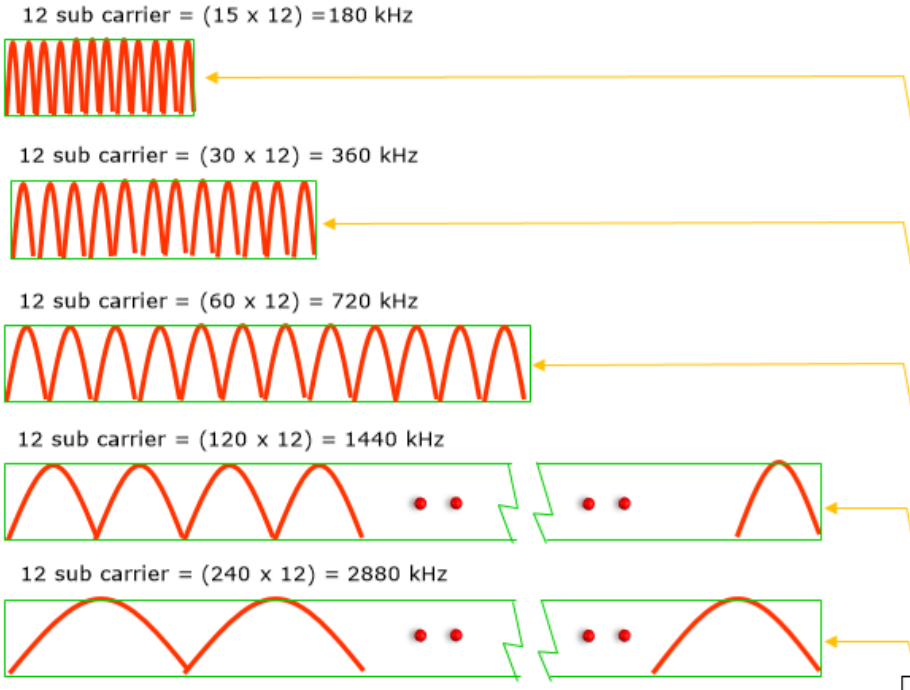
e. Assuming the scheduling policy limits the number of RR to one per user, compute the maximal number of users that can be scheduled in LTE-A networks.

12/ What is the advantage of the TDD compared to FDD when considering the pattern 0, 4, 5 and 6 of LTE

uplink-downlink configuration	Legend: Downlink, Uplink, Special — Duplexing pattern
0	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
1	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
2	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
3	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
4	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
5	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9
6	#0 #1 #2 #3 #4 #5 #6 #7 #8 #9

13/ Numerology in 5G:

Explain how the numerology reduces the delay in 5G.



μ	$\Delta f = 2^{\mu} \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

38.211 Table 4.2-1

NOTE : In LTE, there is only type of subcarrier spacing (15 Khz), whereas in NR multiple types of subcarrier spacing are available. This is the biggest difference between LTE and NR numerology

12/ Resource allocation:

Activity	Required Download Speed	3G	4G
Skype/WhatsApp phone call	0.1 Mbit/s		
Skype video call	0.5 Mbit/s		
Skype video call (HD)	1.5 Mbit/s		
Listening to online radio	0.2 Mbit/s		
Watching YouTube videos (basic quality)	0.5 Mbit/s		
Watching YouTube videos (720p HD quality)	2.5 Mbit/s		
Watching YouTube videos (1080p HD quality)	4 Mbit/s		
Watching Netflix (standard definition)	1.5 Mbit/s		
Watching Netflix (high definition)	5 Mbit/s		
Watching iPlayer/Netflix (4K UHD)	25 Mbit/s		

4/ Allocation de basse bande pour l'UL en 2G et haute bande pour le DL

5/ Rate adaptation in LTE

7/ Calcul du debit en UMTS et allocation de ressources différent SF

8/ /Calcul du debit en 4G et allocation de ressources

9/ Numérologie en 5G

10/ Beamforming in massive MIMO

11/ Virtualisation des fonctionalités en 5G