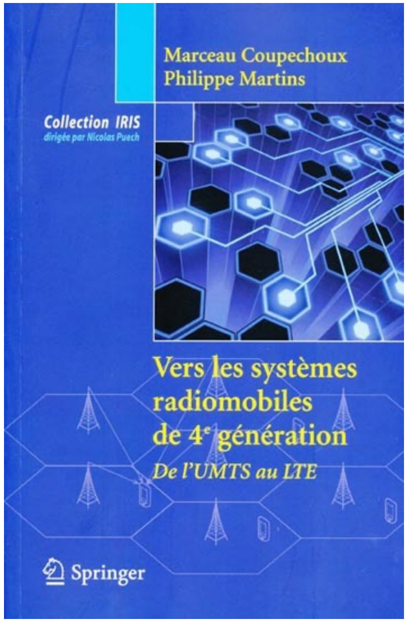
4 G:
LTE / LTE-A

References

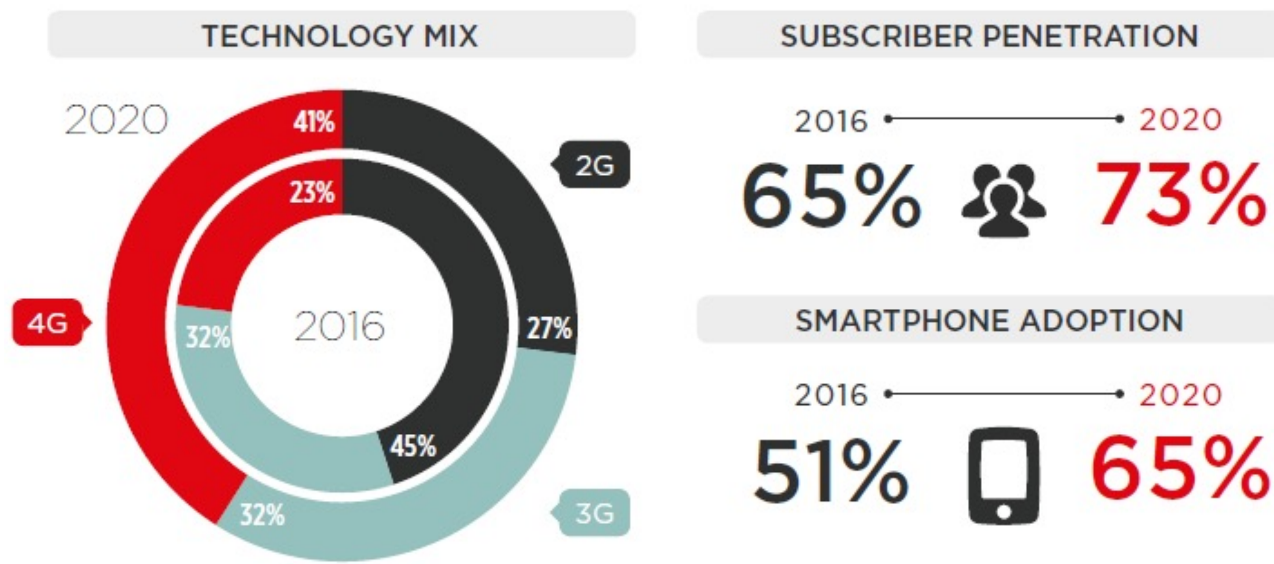
- J. G. Proakis, "Digital Communications", Mc Graw-Hill, 978-0-071138145
- M. Coupechoux, P. Martins, "Vers les systèmes radiomobiles de 4e génération", Springer, 978-2817800844
- 3GPP, http://www.3gpp.org/specifications
- http://wcnc2013.ieee-wcnc.org/WCNC.T1.Slides.pdf



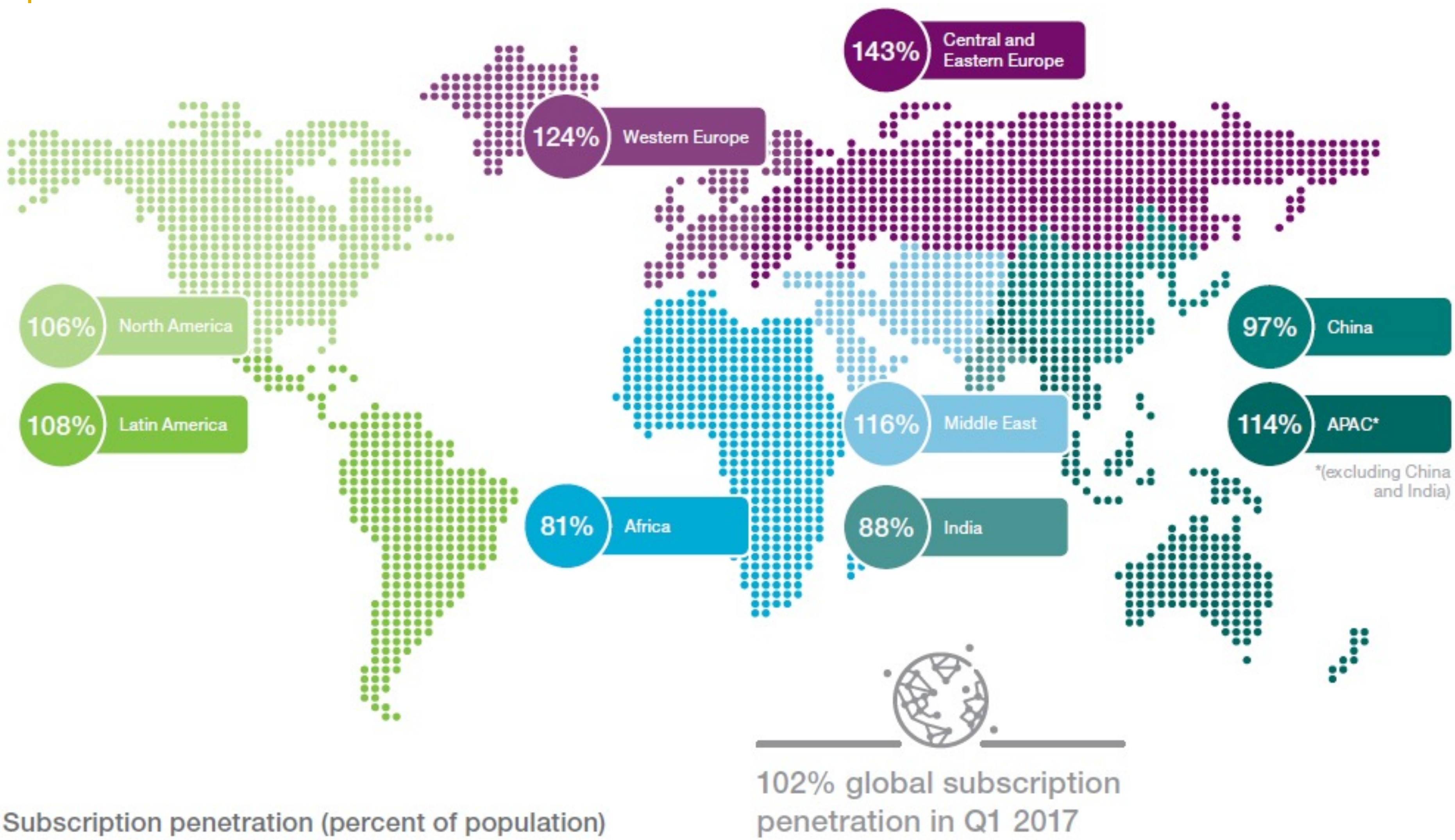
Outline

- LTE context
- LTE Architecture
- Multiple access in LTE : users multiplexing
- Radio Dimensioning and Planning
- Mobility in LTE
- LTE-A

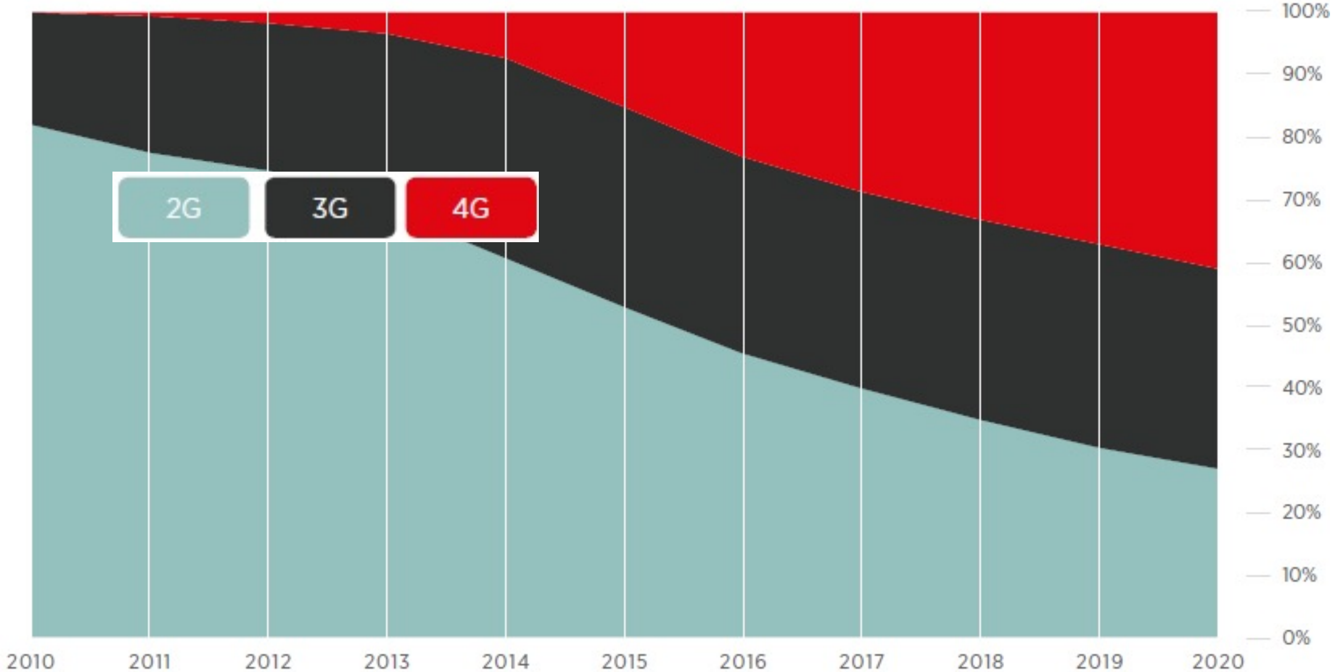
LTE Context


TECHNOLOGY MIX
2020
41%
23%
2G
4G
32%
2016
27%
45%
32%
3G
SUBSCRIBER PENETRATION
2016
2020
65%
73%
SMARTPHONE ADOPTION
2016
2020
51%
65%

Worldwide mobile networks 1/



Worldwide mobile networks 2/



5,08 BILLION

unique mobile subscribers

Cellular Network Generation		Maximum Downlink Data Rates	Latency	Current Coverage (1 Low – 5 High)
2G	GPRS	140.8 kbps	>500ms	★★★★★
	EDGE	473.6 kbps	150-200ms	★★★
3G	UMTS	384 kbps	200-250ms	★★★★
	HSPA	14.4 Mbps	50-100ms	★★★★
4G	HSPA+	42.2 Mbps	20-25ms	★★
	LTE	173 Mbps	5-10ms	★

LTE services

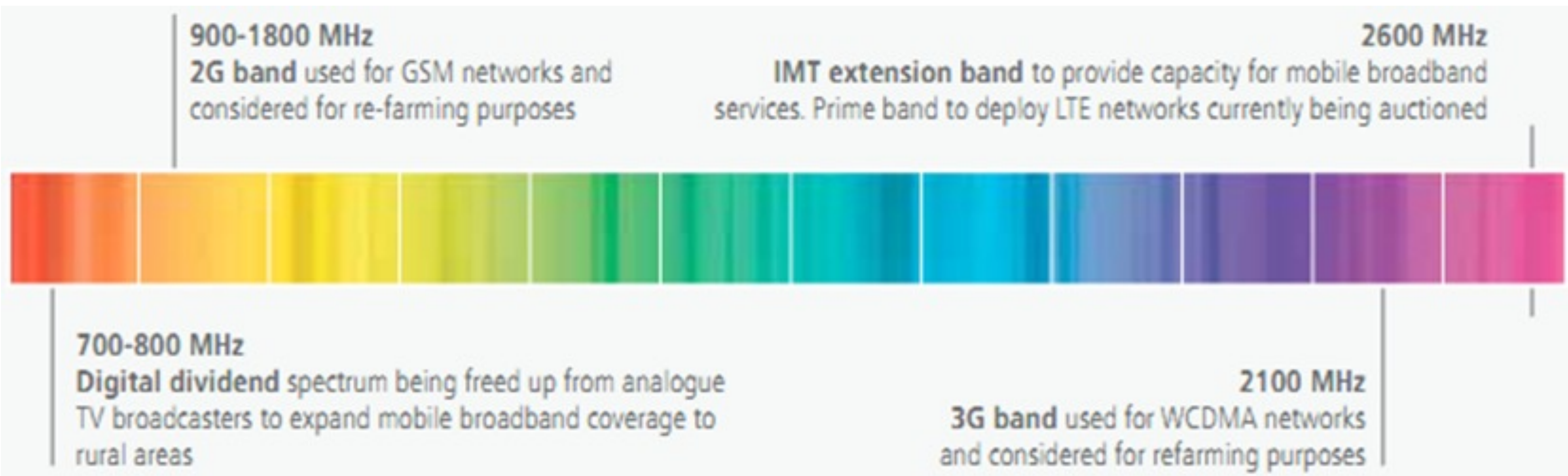
LTE standardisation

- **Long Term Evolution** standardized by 3GPP
  - LTE R8 finalized in 2008.
  - System Architecture Evolution: SAE finalized in 2009
- IMT-adv specifications:
  - 100 Mbps ↓, 50 Mbps ↑
  - Web-browsing, FTP, video-streaming, VoIP with same voice quality as in 2G/3G networks
- First launches:
  - 2009: Telia Sonera : Stockholm & Oslo (Ericsson)
    - NTT Docomo: « Xi » (Cross i), Dec. 2010
    - Verizon: Chicago, New York, San Francisco, Los Angeles, déc. 2010
  - End 2012: 146 networks
  - Nov. 2013: 245 networks / 92 countries

LTE networks commercial launches

Country	Operator	Launch
Norway	TeliaSonera (NetCom)	14.12.09
Sweden	TeliaSonera	14.12.09
Uzbekistan	MTS	28.07.10
Uzbekistan	UCell	09.08.10
Poland	Aero2 (LTE FDD and TDD)	07.09.10
USA	MetroPCS	21.09.10
Austria	A1 Telekom	05.11.10
Sweden	Telenor Sweden	15.11.10
Sweden	Tele2 Sweden	15.11.10
Hong Kong	CSL Limited	25.11.10
Finland	TeliaSonera	30.11.10
Germany	Vodafone	01.12.10
USA	Verizon Wireless	05.12.10
Finland	Elisa	08.12.10
Denmark	TeliaSonera	09.12.10
Estonia	EMT	17.12.10
Japan	NTT DoCoMo	24.12.10
Germany	Deutsche Telekom	05.04.11
Philippines	Smart Communications	16.04.11
Lithuania	Omnitel	28.04.11
Latvia	LMT	31.05.11
Singapore	M1	21.06.11
South Korea	SK Telecom	01.07.11
South Korea	LG U+	01.07.11
Germany	O2	01.07.11
Canada	Rogers Wireless	07.07.11
Austria	T-Mobile	28.07.11
USA	Mosaic Telecom	07. 2011
Canada	Bell Mobility	14.09.11
Saudi Arabia	Mobily (LTE TDD)	14.09.11
Saudi Arabia	STC (LTE TDD)	14.09.11
Saudi Arabia	Zain	14.09.11
USA	AT&T Mobility	18.09.11
UAE	Etisalat	25.09.11
Australia	Telstra	27.09.11
Denmark	TDC	10.10.11
Austria	3	18.11.11
Puerto Rico	AT&T Mobility	20.11.11
Puerto Rico	Claro	24.11.11
Kyrgyzstan	Saima Telecom	09.12.11
Brazil	Sky Brazil (LTE TDD)	13.12.11
Finland	DNA	13.12.11
Uruguay	Antel	13.12.11
USA	Cricket	21.12.11
Singapore	SingTel	22.12.11
Kuwait	Viva	27.12.11
Armenia	Vivacell-MTS	28.12.11
Bahrain	Viva Bahrain	01.01.12
Hungary	T Mobile	01.01.12
South Korea	KT	03.01.12
Russia	Yota	15.01.12
Canada	TELUS	10.02.12
USA	Peoples Telephone Co-op	14.02.12
Japan	Softbank Mobile XGP/LTE TDD	24.02.12
Portugal	TMN (Portugal Telecom)	12.03.12
Portugal	Vodafone Portugal	12.03.12
Portugal	Optimus	15.03.12
Japan	eAccess	15.03.12
USA	US Cellular	22.03.12
Croatia	T Mobile/T-Hrvatski Telekom	23.03.12
Croatia	VIPNet	23.03.12
USA	Panhandle (PTCI)	03. 2012
Australia	NBN Co (LTE TDD)	02.04.12
India	Bharti Airtel (LTE TDD)	10.04.12
Angola	Movicel	14.04.12
Puerto Rico	Open Mobile	19.04.12
Moldova	IDC	21.04.12
Sweden	3 (LTE FDD and TDD)	23.04.12
Hong Kong	China Mobile HK	25.04.12
Hong Kong	PCCW	25.04.12
USA	Cellcom	30.04.12
USA	Pioneer Cellular	30.04.12
Netherlands	Vodafone	01.05.12
Hong Kong	Hutchison 3 HK	02.05.12
Netherlands	Ziggo	03.05.12
Netherlands	Tele2	08.05.12
Netherlands	KPN	11.05.12
Netherlands	T-Mobile	11.05.12
Namibia	MTC	16.05.12
USA	BendBroadband	17.05.12
Tanzania	Smile	30.05.12
UAE	Du	12.06.12
Colombia	Une-UPM	14.06.12
Azerbaijan	Azercell	19.06.12
Czech Rep	Telefonica O2	19.06.12
Mauritius	Orange	21.06.12
UK	UK Broadband (LTE TDD)	28.06.12
Guam	IT&E	28.06.12
Hungary	Telenor Hungary	05.07.12
Dominican R.	Orange Dominicana	09.07.12
Slovenia	Si.mobil	12.07.12
USA	Sprint	15.07.12
Oman	Omantel (LTE TDD)	16.07.12
Australia	Optus	31.07.12
Mauritius	Emtel	July 2012
Slovak Rep	Telefonica O2	02.08.12
Hong Kong	Smartone	28.08.12
Russia	MTS (LTE TDD)	01.09.12
USA	C Spire Wireless	10.09.12
Singapore	StarHub	19.09.12
Japan	KDDI	21.09.12
Japan	Softbank Mobile	21.09.12
Canada	MTS	25.09.12
Denmark	3 Denmark	28.09.12
Philippines	Globe	28.09.12
Luxembourg	Tango	01.10.12
Guam	DoCoMo Pacific	04.10.12
Tajikistan	Babilon-Mobile	06.10.12
Norway	Telenor	10.10.12
South Africa	Vodacom	10.10.12
USA	Alaska Communications	12.10.12
Luxembourg	Orange	29.10.12
UK	EE (Everything Everywhere)	30.10.12

LTE carrier frequency bands 1/



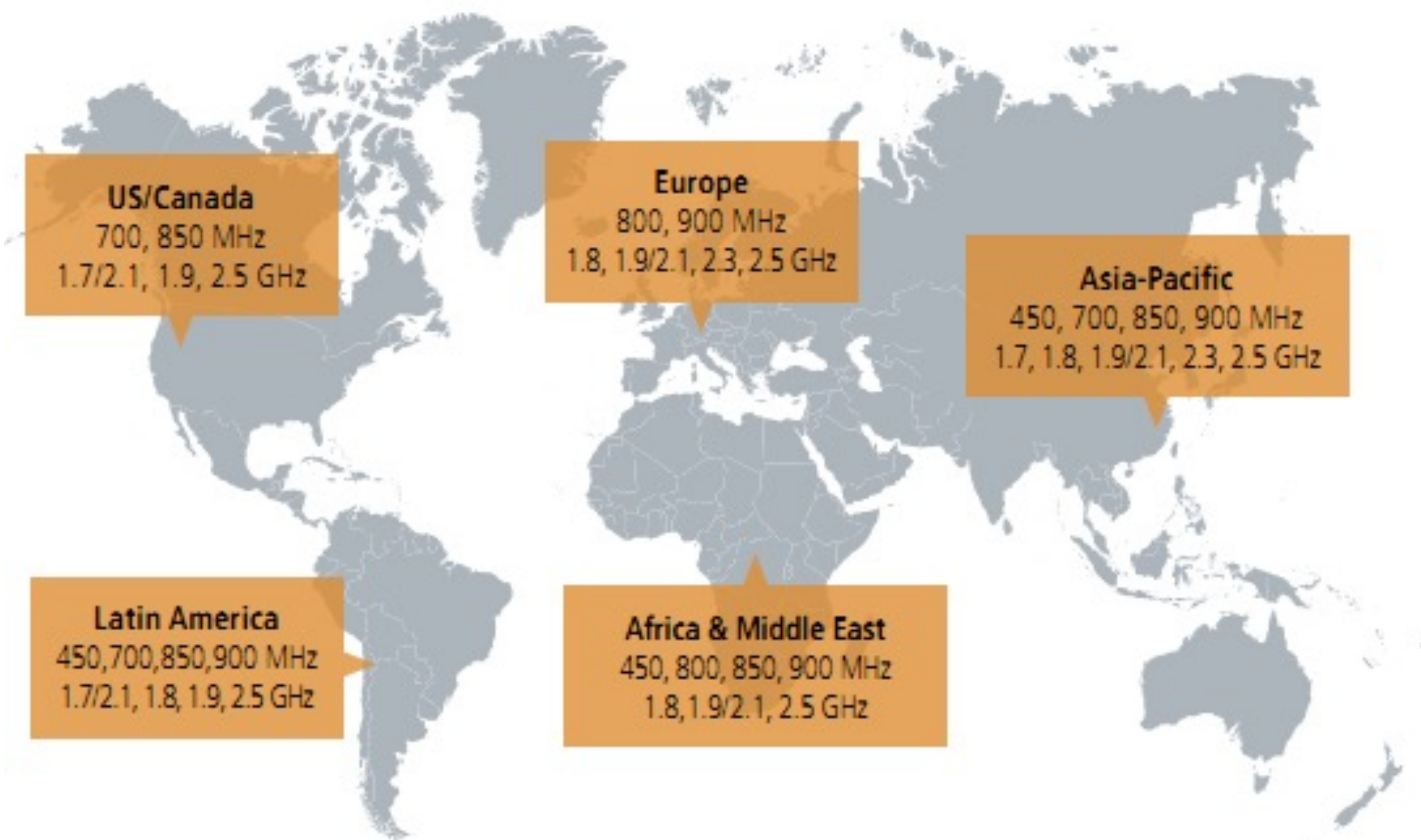
LTE carrier frequency bands 2/

- Licensed:
  - frequency carrier bands:
    - 700-800 MHz
    - 2,3 GHz
    - 2,5-2,6 GHz
  - more than 40 available bands!
  - existing systems reuse bands:
    - 900 MHz,
    - 1800 MHz,
    - 2100 MHz
- Duplexing:
  - FDD
  - TDD

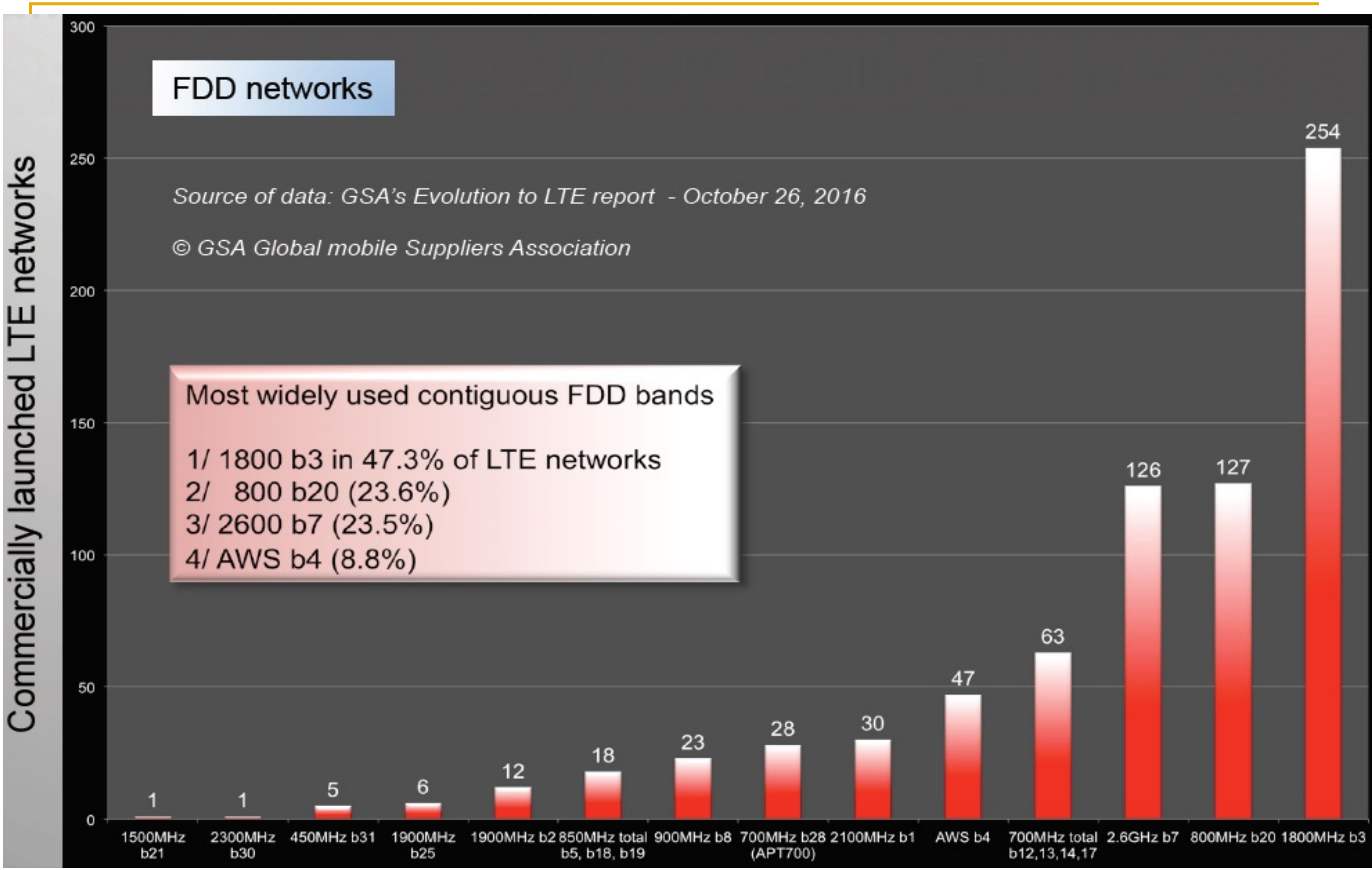
E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	$F_{UL\ low}$	–	$F_{UL\ high}$	$F_{DL\ low}$	–	$F_{DL\ high}$	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD

NOTE 1: Band 6 is not applicable

LTE worldwide spectrum availability



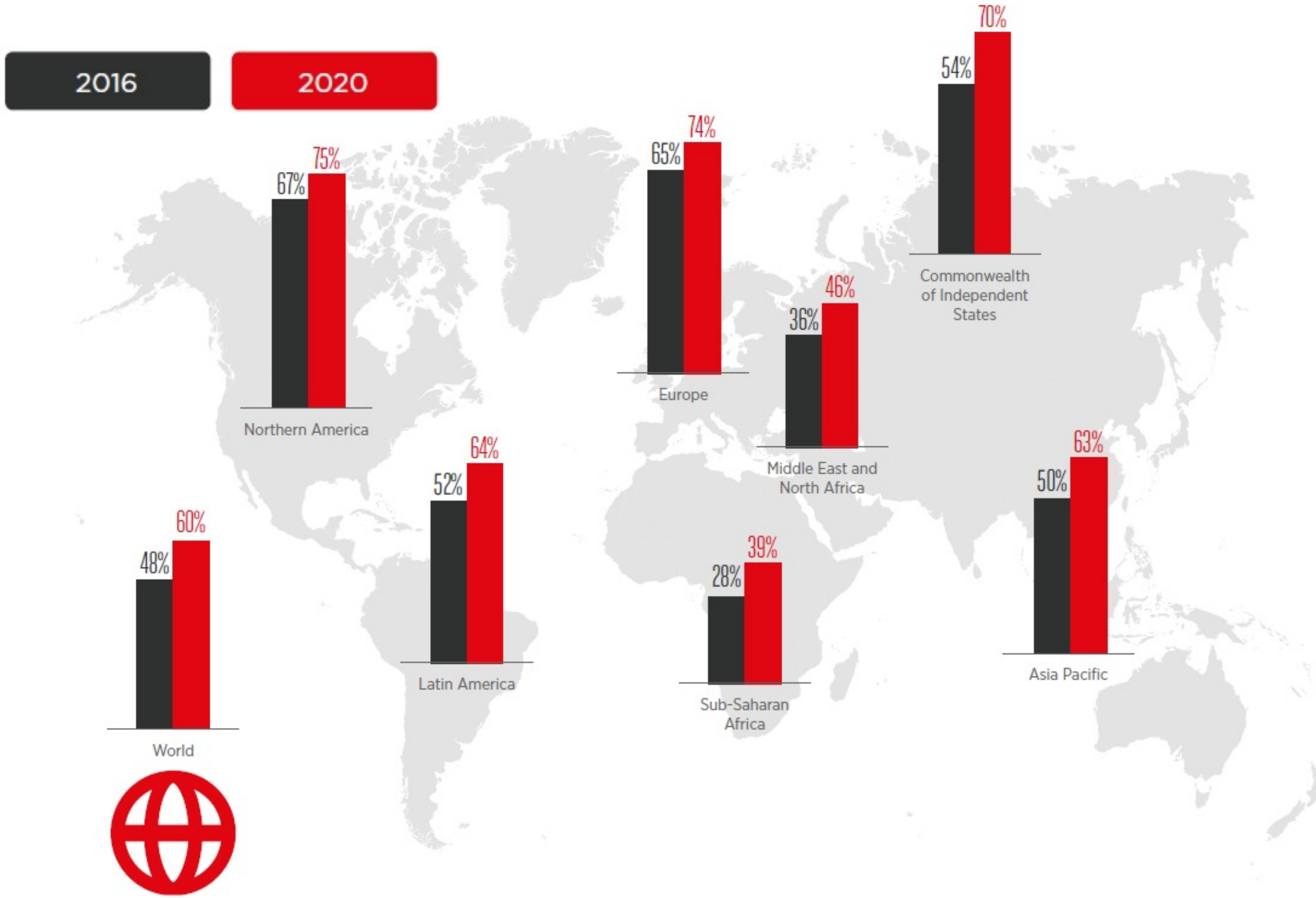
LTE carrier frequency bands deployed



LTE carrier frequency bands in France

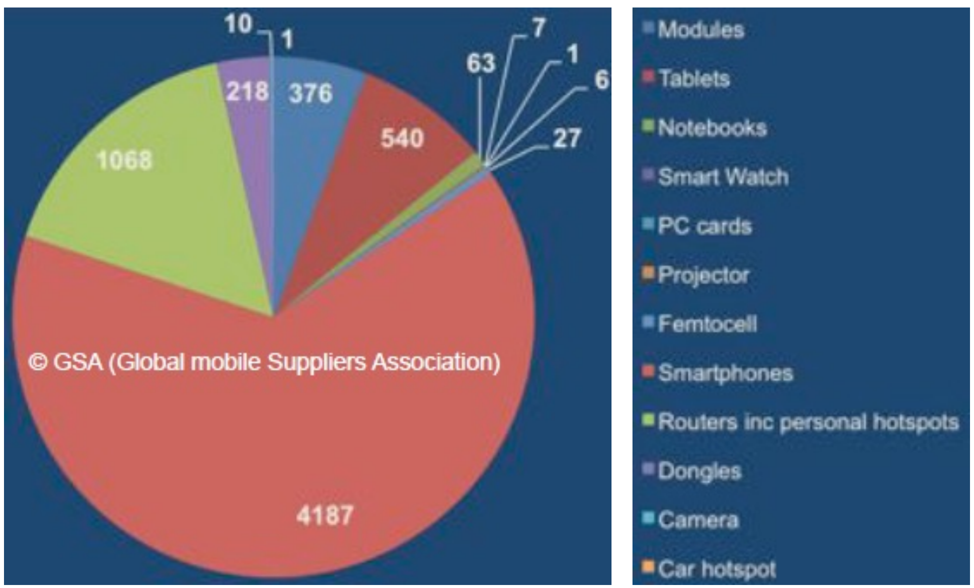
- Band 7 and 20 only ⇒ LTE FDD
- Band 7, around 2.6 GHz:
  - 2500 – 2570 MHz, 2620 – 2690 MHz
  - duplexing: 120 MHz
  - Bouygues Telecom, SFR : 2 x 15 MHz:
    - 2535 – 2550, 2655 – 2670 MHz
    - 2500 – 2515, 2620 – 2635 MHz
  - Free, Orange : 2 x 20 MHz:
    - 2550 – 2570 MHz, 2670 – 2690 MHz
    - 2515 – 2535 MHz, 2635 – 2655 MHz
- Bande 20, around 800 MHz :
  - 832 – 862 MHz, 791 – 821 MHz
  - duplexing : - 41 MHz
  - Bouygues Telecom, SFR, Orange : 2 x 10 MHz
  - Roaming agreement between Free and SFR

Mobile Internet Subscribers penetration



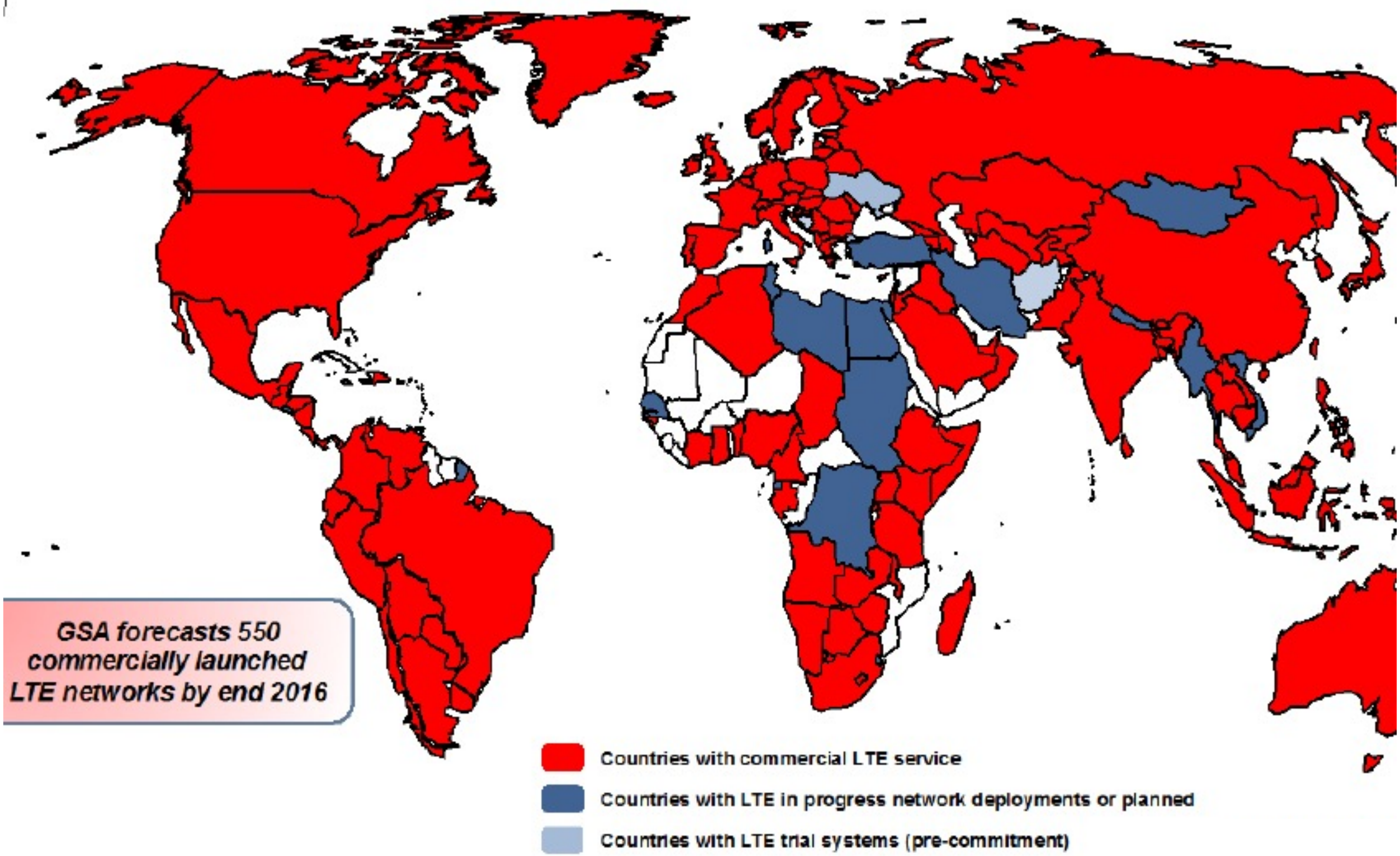
LTE markets 1/

- Dec 2013:
  - 500 operators (143 countries) are investing on LTE
  - 200 millions of subscribers (+350% over the past year!)
  - 1064 users devices
  - 111 equipments providers



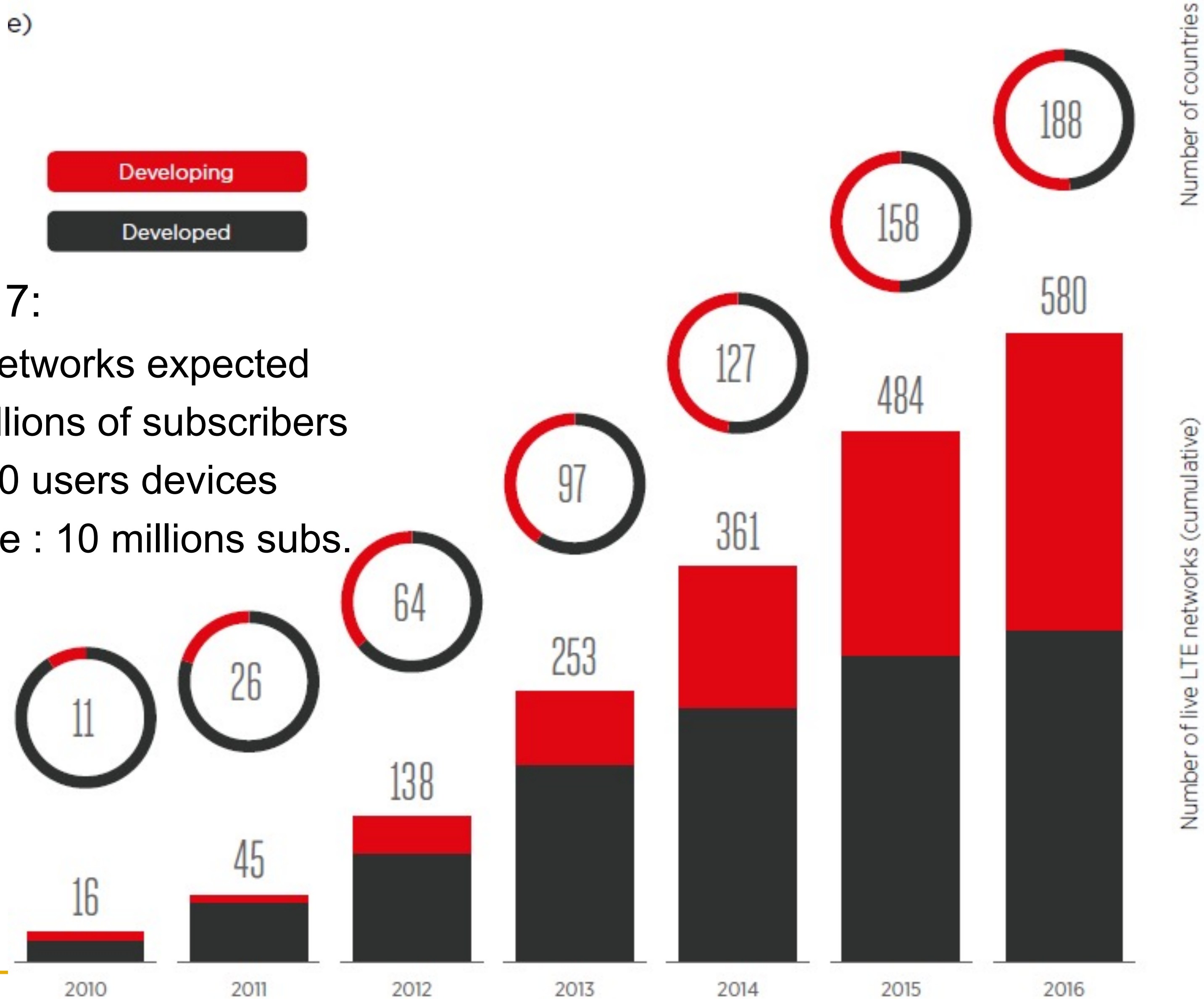
- Dec 2016:
  - 540 networks, 170 countries
  - 1,6 billions of subscribers
  - > 6000 users devices
  - France : 10 millions subs.

LTE markets 2/



LTE networks

- Dec 2017:
  - 635 networks expected
  - 1,4 billions of subscribers
  - > 7000 users devices
  - France : 10 millions subs.

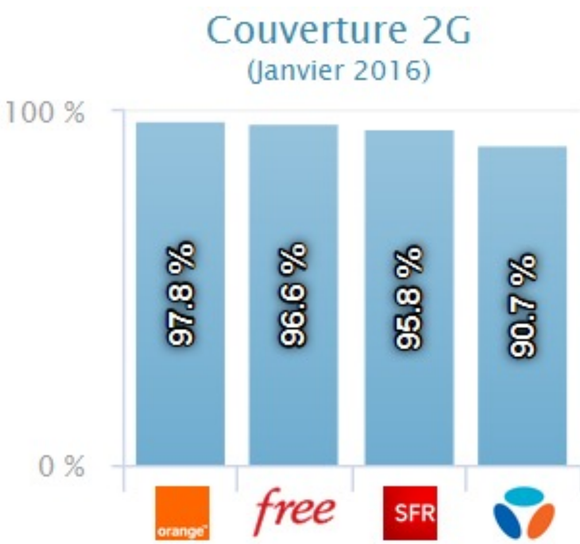


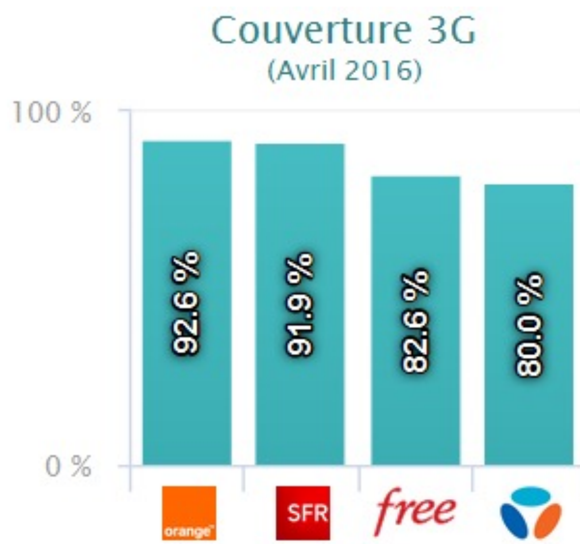
LTE networks in France

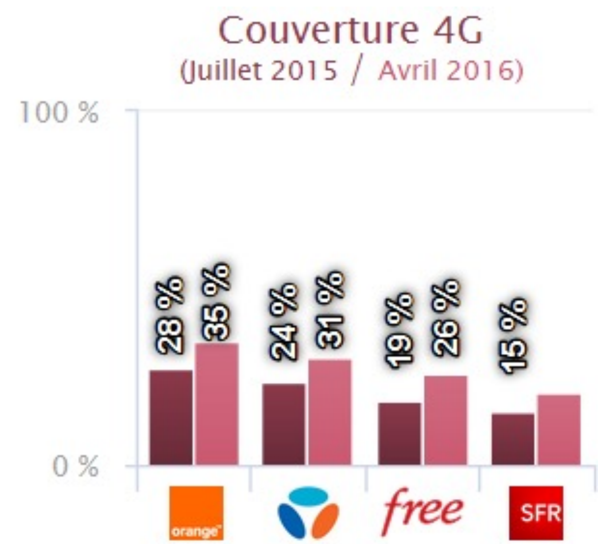
- Orange:
  - pilot network: Marseille, June 2012,
    ext. to: Lyon, Lille and Nantes
  - commercial launch: Paris in Feb. 2013
  - carrier frequencies : 800 MHz / 2.6 GHz
- SFR:
  - pilot network: Lyon, Nov. 2012
  - commercial launch: La Défense in Jan. 2013, and then Marseille
  - carrier frequencies : 800 MHz / 2.6 GHz
- Bouygues Telecom:
  - pilot network: Lyon, June 2012
  - commercial launch: Lyon, Strasbourg, Toulouse in May 2013
  - carrier frequencies : 800 MHz / 1800 MHz / 2.6 GHz
- Free Mobile:
  - commercial launch: Dec 2013
  - carrier frequencies : 2.6 GHz

LTE networks in France

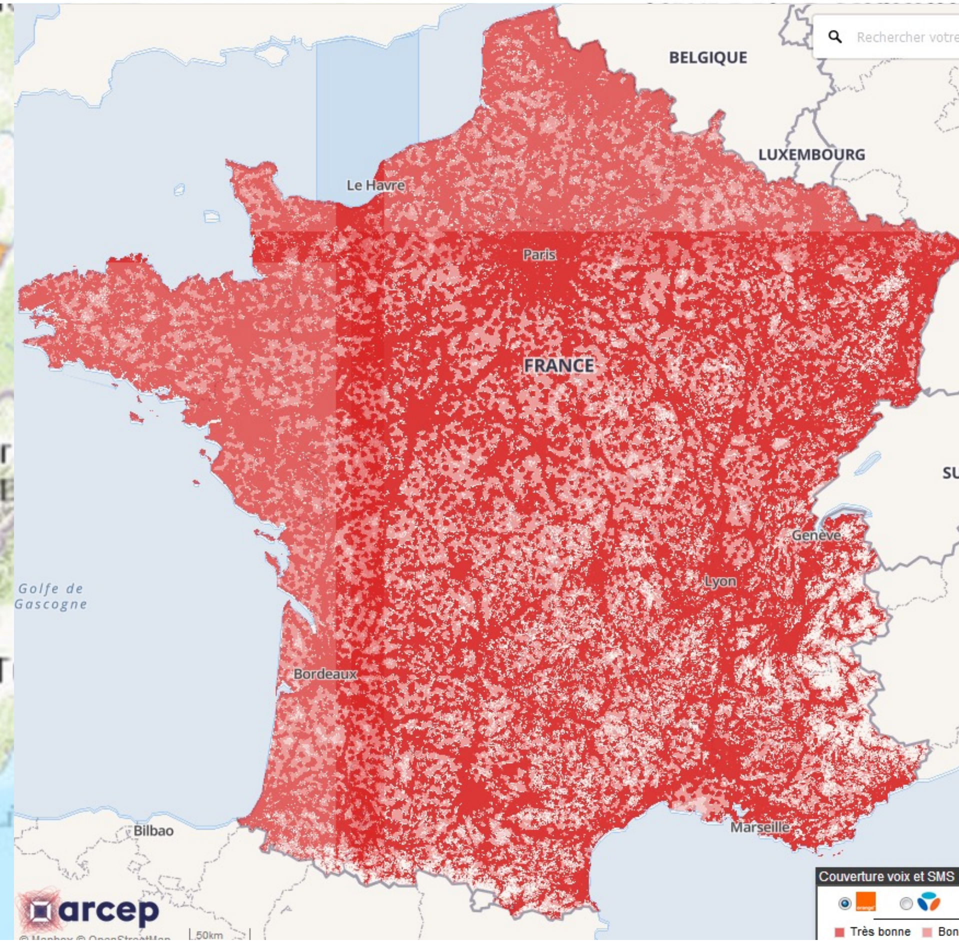
Dec 2017 radio access points	2G	3G	4G
Orange	20700	20300	13300
SFR	17100	17200	13500
Bouygues Telecom	14400	13000	13900
Free Mobile	-	6800	9100



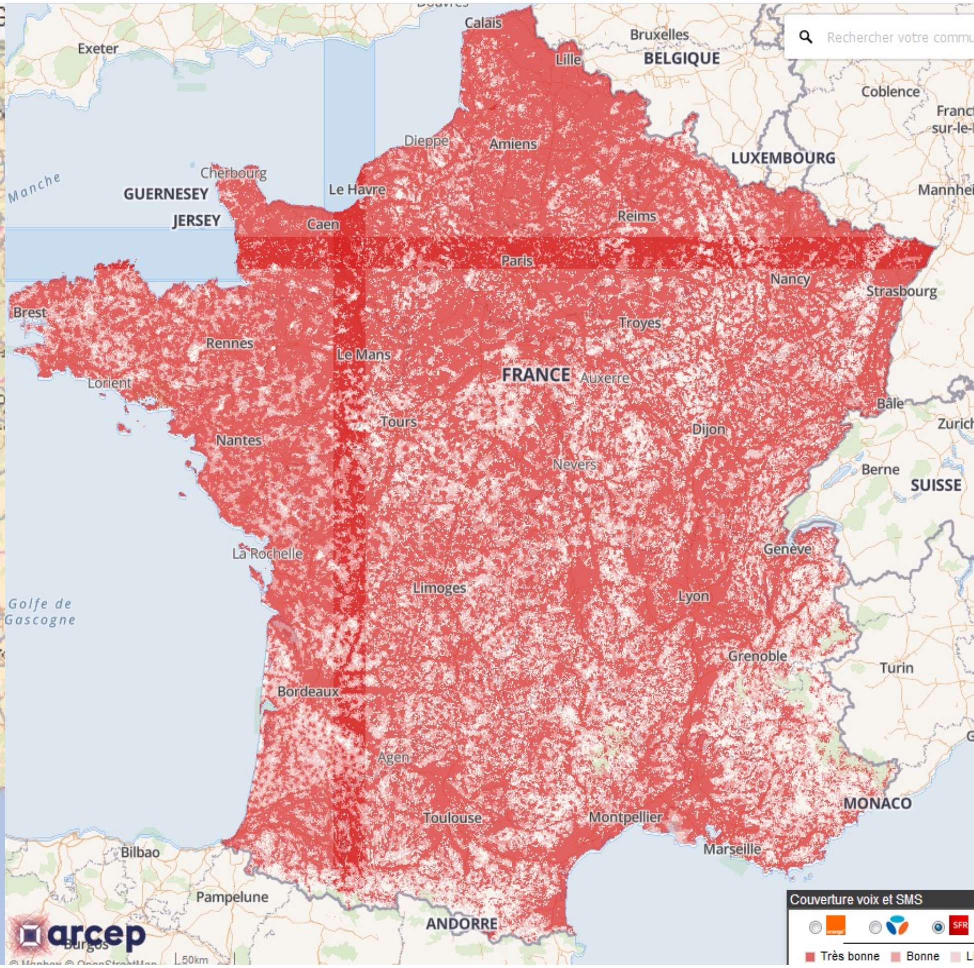




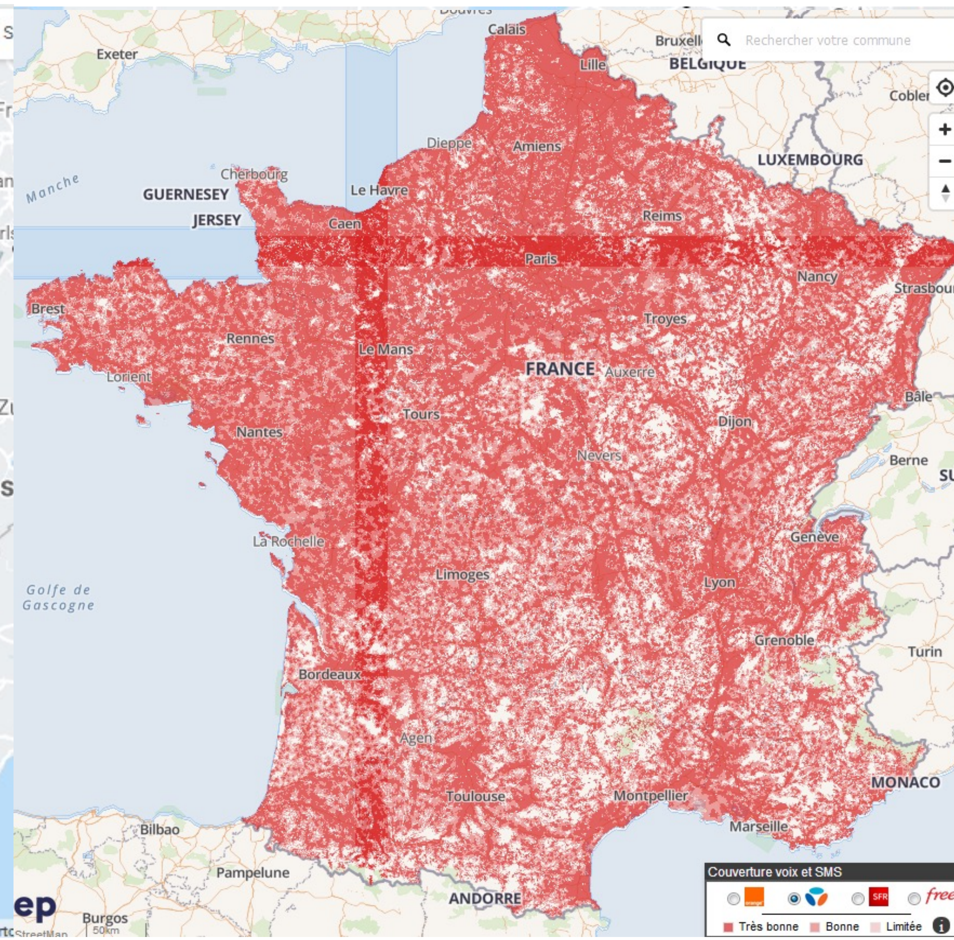
2G-3G/LTE coverage - Orange



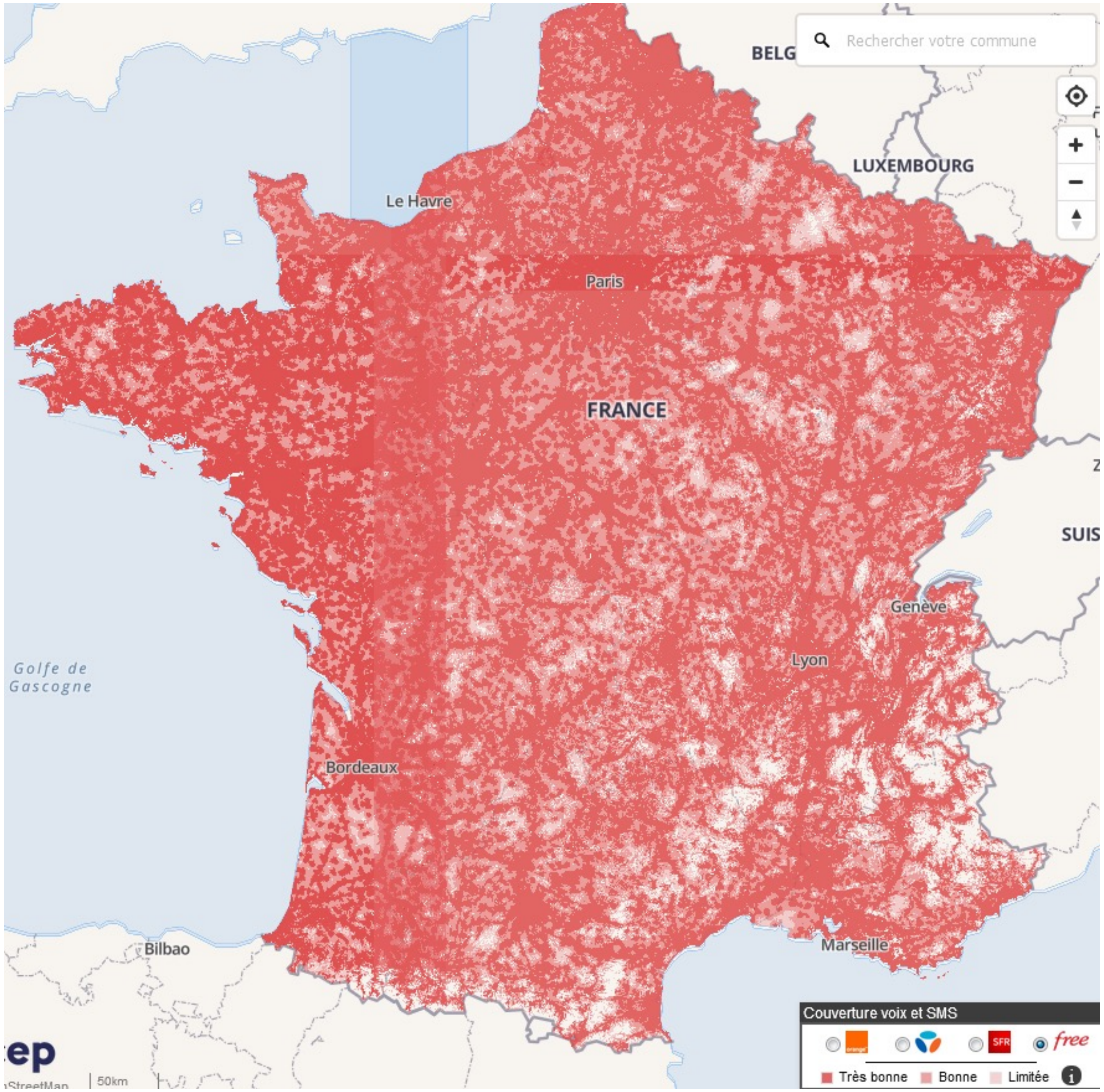
2G-3G/LTE coverage - SFR



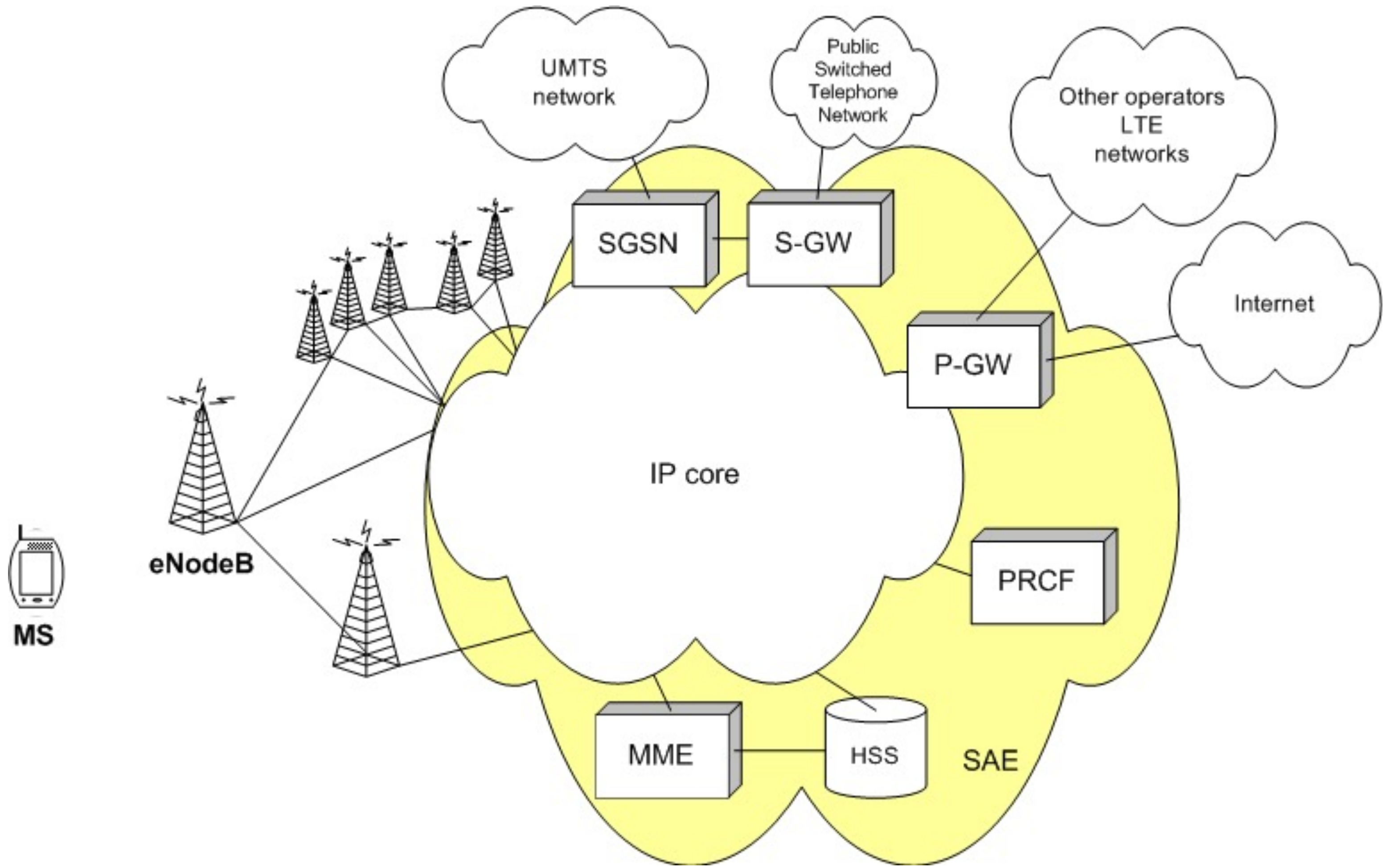
2G-3G/LTE coverage – Bouygues Tel.



LTE coverage – Free mobile



LTE networks architecture 1/



LTE networks architecture 2/

- Packet data **ONLY**: no more circuit services
- Devices maximum transmission power: 0.25 W (24 dBm)
- Access network:
  - connected eNodeB,
  - no controller
- SAE (System Architecture Evolution) defines an entirely new core network with a flatter all-IP architecture EPC (Evolved Packet Core) enabling:
  - higher data rate,
  - lower latency
  - packet-switched optimized system that supports multiple radio-access technologies, and all services $\Rightarrow$ VoIP

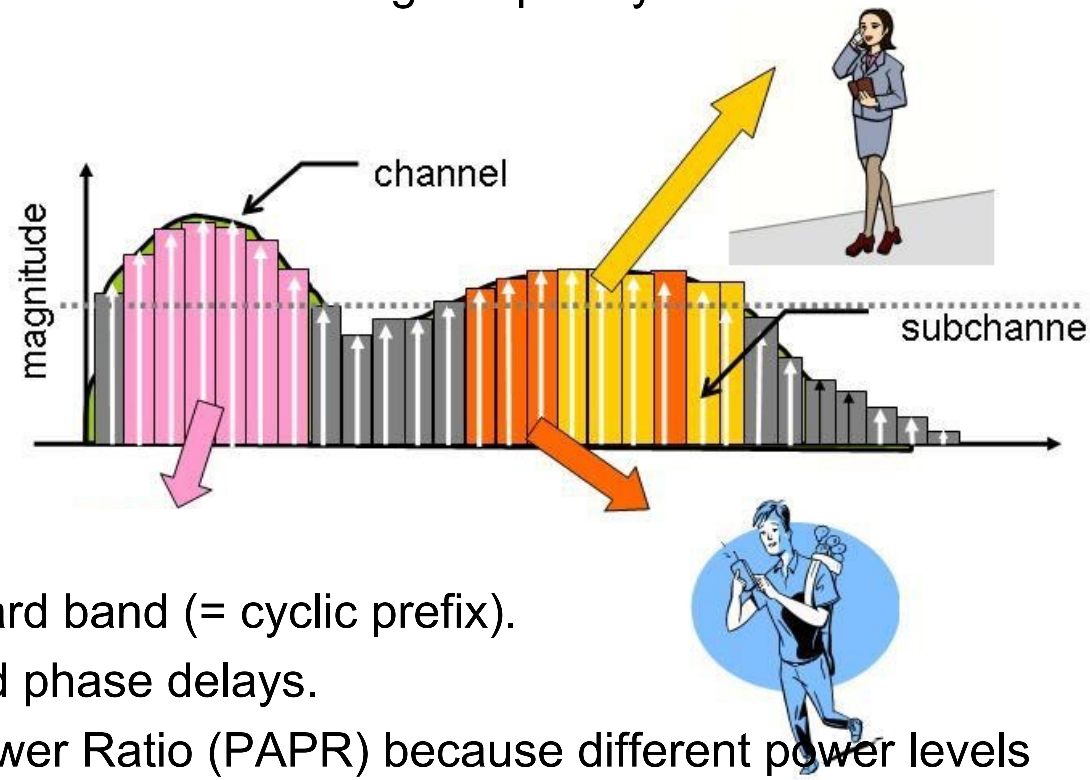
LTE networks architecture 3/

- EPC / for users data:
  - Serving-GW : interconnection with other 3GPP networks and RTCP
  - P-GW (PDN-GW): interconnection with internet
- EPC / for control:
  - HSS : Home Subscriber Server : Data Base
  - MME : Mobility Management Entity
    - Mobility management ⇒ HO, roaming, packets retransmisssion
    - Paging
    - Authentication with HSS
    - S-GW and P-GW selection
    - Link establishment
  - PCRF : Policy and Charging Rules Function :
    - Dynamic management, for each subscriber, of:
      - its sessions
      - its QoS information for the concerned P-GW
    - Charging policy of each packet in relation with the network's operator charging system

- Multiple access in LTE

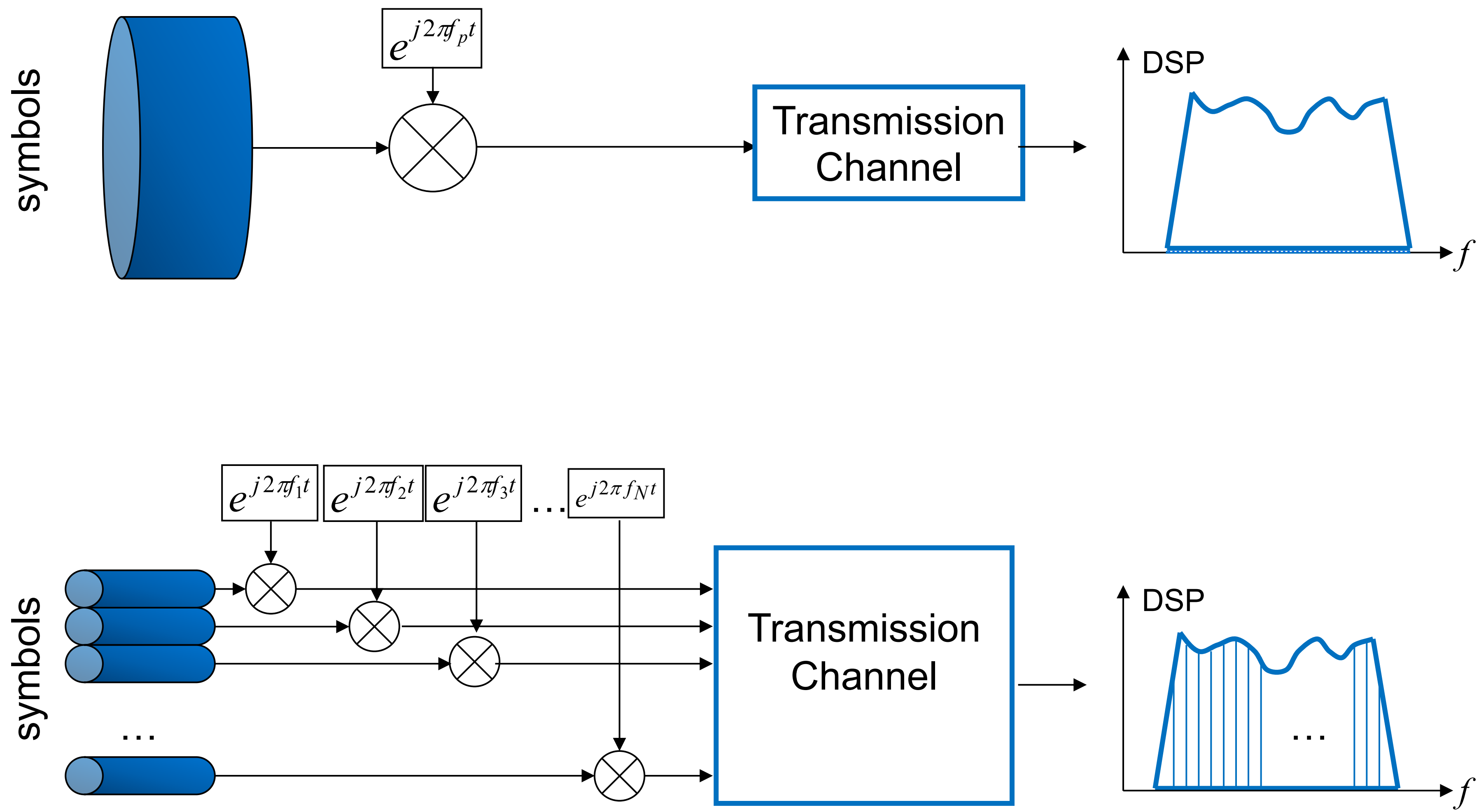
Multiple access: OFDMA principles

- Pros:
  - High flexibility in subcarrier allocation (to address users QoS constraints).
  - Each subcarrier is subject to a different fading: frequency and multi-user diversity
  - No intra-cell interference
  - Efficiency for frequency selectivechannels



- Cons:
  - Bandwidth loss due to guard band (= cyclic prefix).
  - Sensitive to frequency and phase delays.
  - High Peak-to-Average-Power Ratio (PAPR) because different power levels may be allocated to the subcarriers
    $\Rightarrow$ requires expensive power amplifiers at transmission.

OFDM principles 1/



OFDM principles 2/

- OFDM symbols are transmitted in subcarriers, with a low throughput:
  - channel can be considered as constant in each sub-carrier
    $\Rightarrow$ easier reception, without egalization
  - cyclical prefix > propagation delay
    $\Rightarrow$ resistance to multipaths effects $\uparrow$
  - « basic » modulations in each subcarrier : QAM

- Sub-carrier spacing Δf to ensure « orthogonality » between the subcarriers:
  (D_{frame} = symbol transmission duration in each subcarrier)
  => opération equivalente : FFT

$$\int_0^{D_{frame}} s_k \, e^{j2\pi f_1 t} e^{-j2\pi f_2 t} dt = 0$$

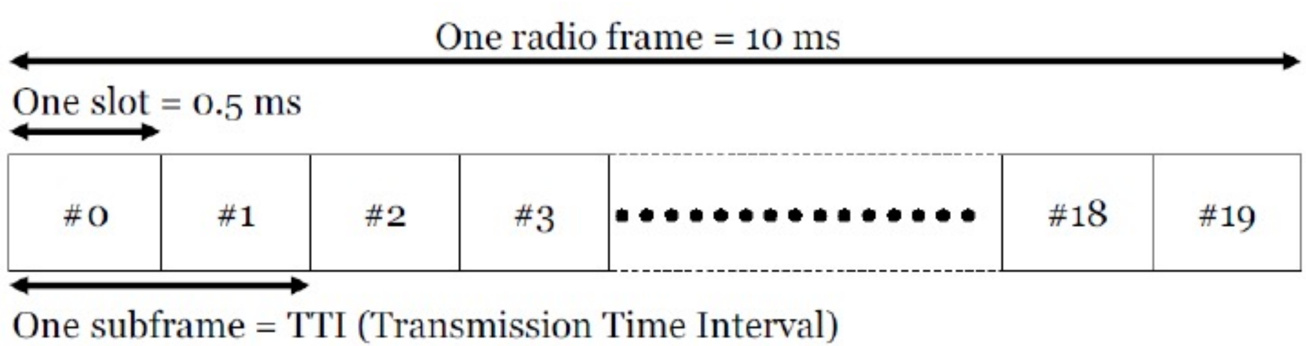
$$\boxed{\Delta f = \frac{1}{D_{frame}}}$$

- D_{frame} : OFDM frame duration:
  - T_S = necessary duration to create a symbol
  - N = number of OFDM subcarriers

$$D_{frame} \geq N \, T_S$$

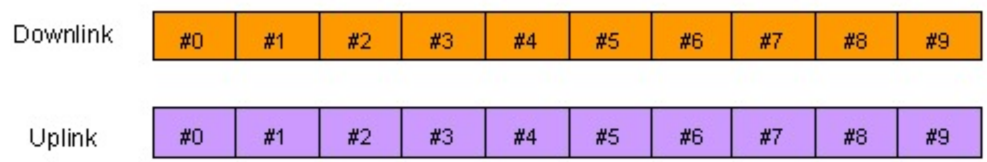
Radio frame structure 1/

- A radio frame has duration of 10 ms:
  - 20 slots
  - TTI: 1 ms
- A resource block (RB) spans:
  - 12 subcarriers; one subcarrier has bandwidth of 15 kHz, thus 180 kHz per RB
  - a slot duration of 0.5 ms, that tansmits 7 OFDM symbols in each subcarrier
- The allocation is replicated on the following 0.5 ms slot of the frame

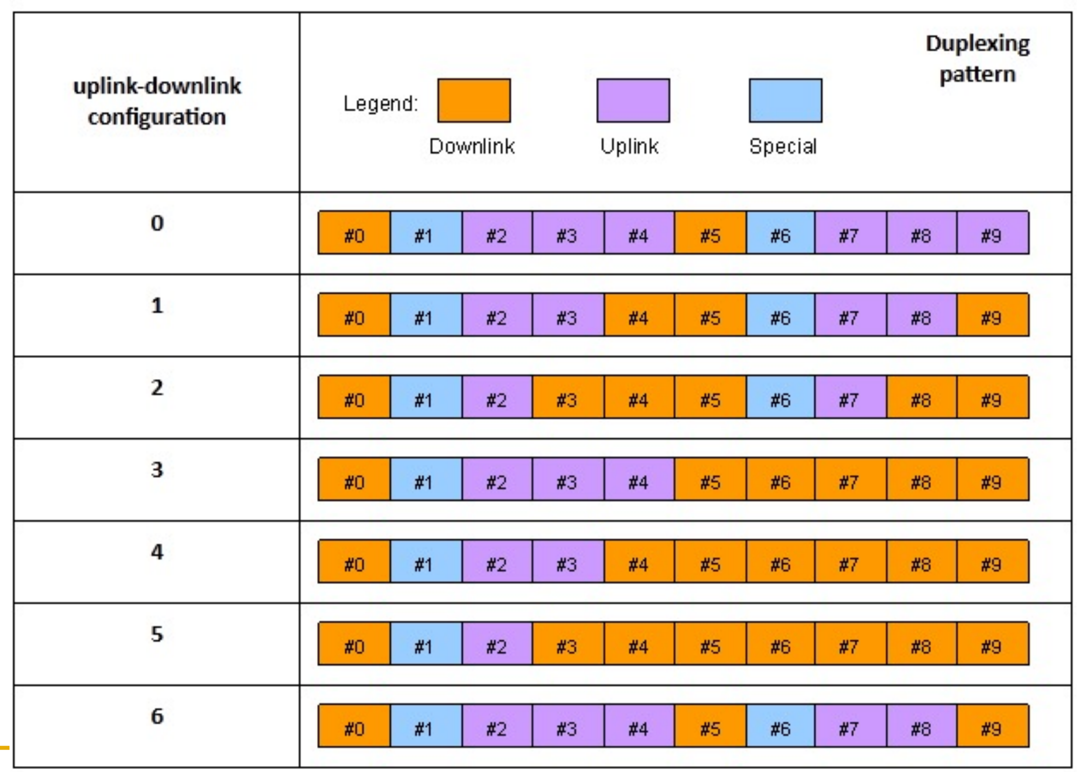


Radio frame structure 2/

- FDD mode



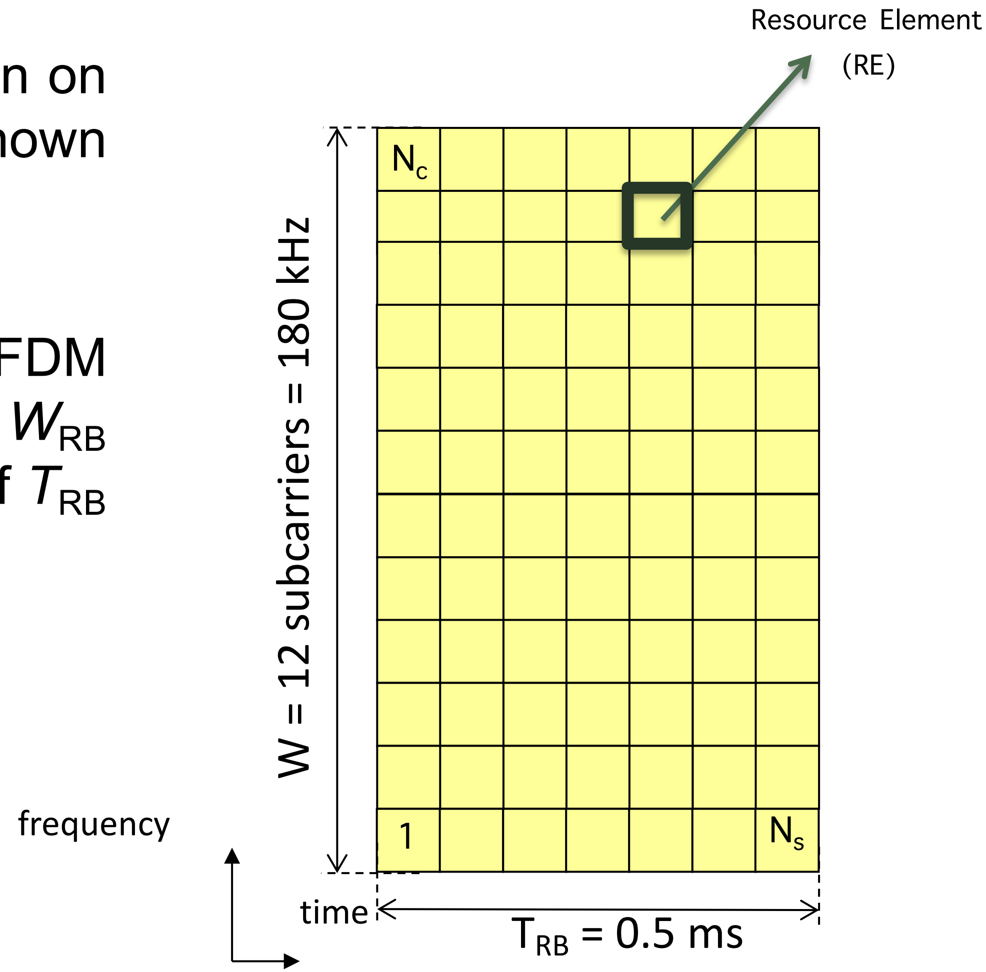
- TDD mode
  one or two switching points ↑↓ are predefined in each frame
  - At least four slots per frame for ↓



PHY Radio Resources in 4G

- The smallest unit of transmission on which the exchange occurs is known as radio Resource Block (RB).

- It consists of *Nc* = 12 OFDM subcarriers with total bandwidth W_{RB} = 180 kHz and with a duration of T_{RB} = 0.5 ms.

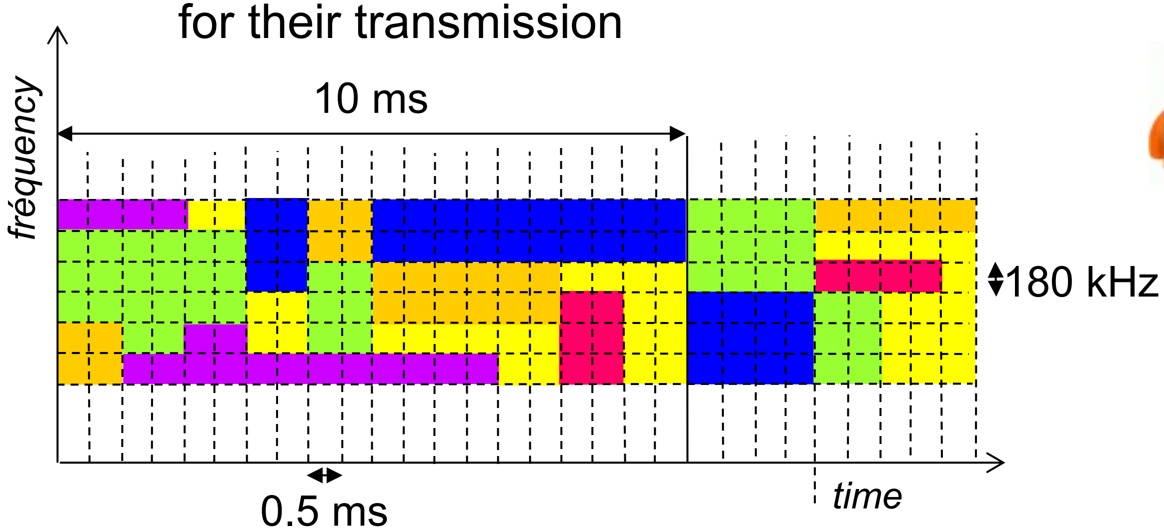


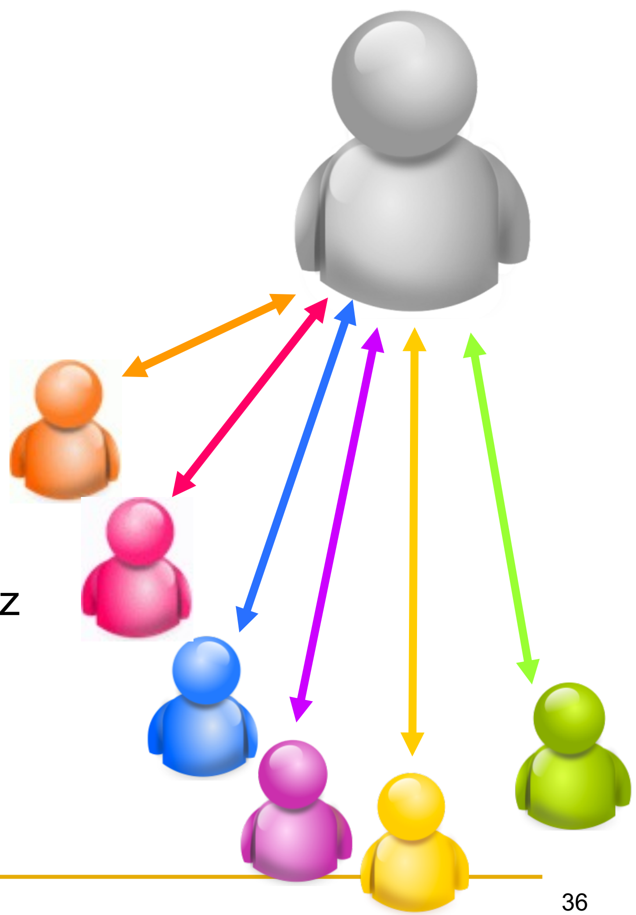
LTE Resource Blocks (RBs)

Bandwidth	Nb of available RBs
1,4 MHz	6
3 MHz	15
5 MHz	25
10 MHz	50
15 MHz	75
20 MHz	100

Multiple access: OFDMA 1/

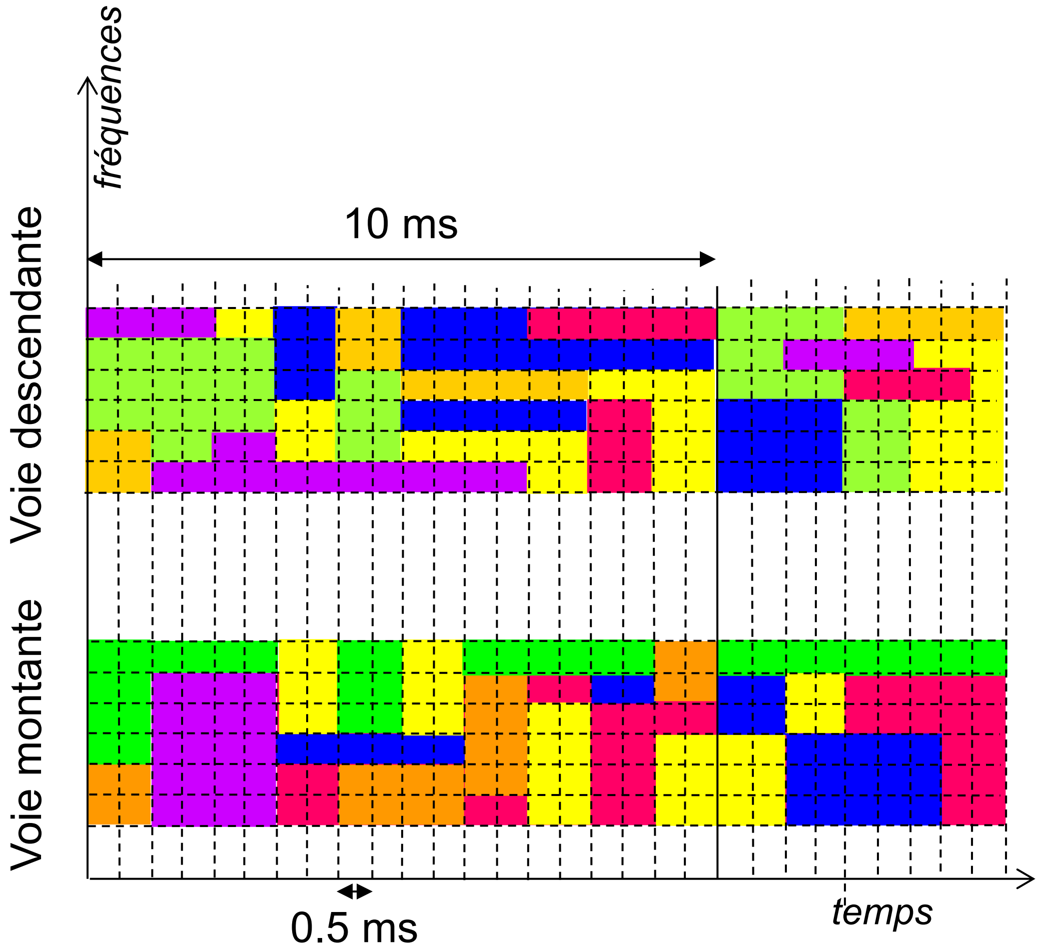
- OFDMA: transmitters use a selection of RBs, that varies dynamically as a function of the cell's load and the users radio channels conditions
  - flexibility
  - frequency diversity
- Adaptation on the uplink: SC-FDMA:
  - mobile users are allocated contiguous RBs for their transmission

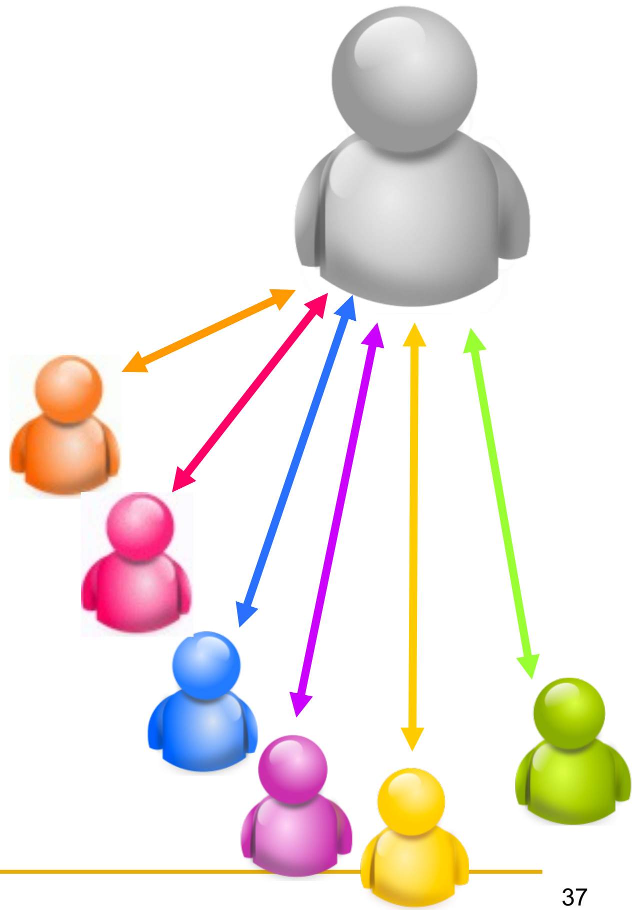




Multiple access: OFDMA 2/

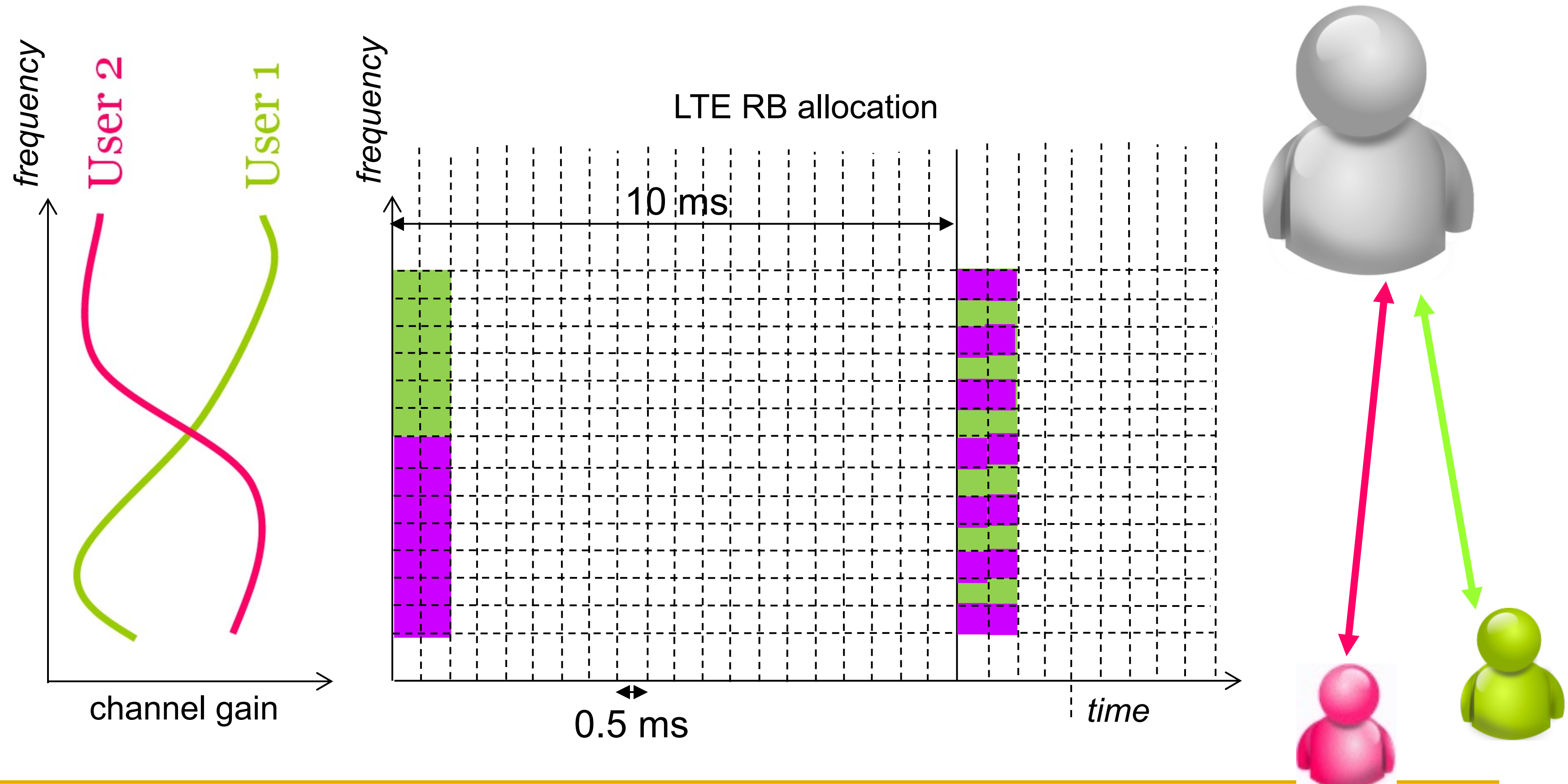
- RB allocation in FDD mode:





Channel-Dependent scheduling

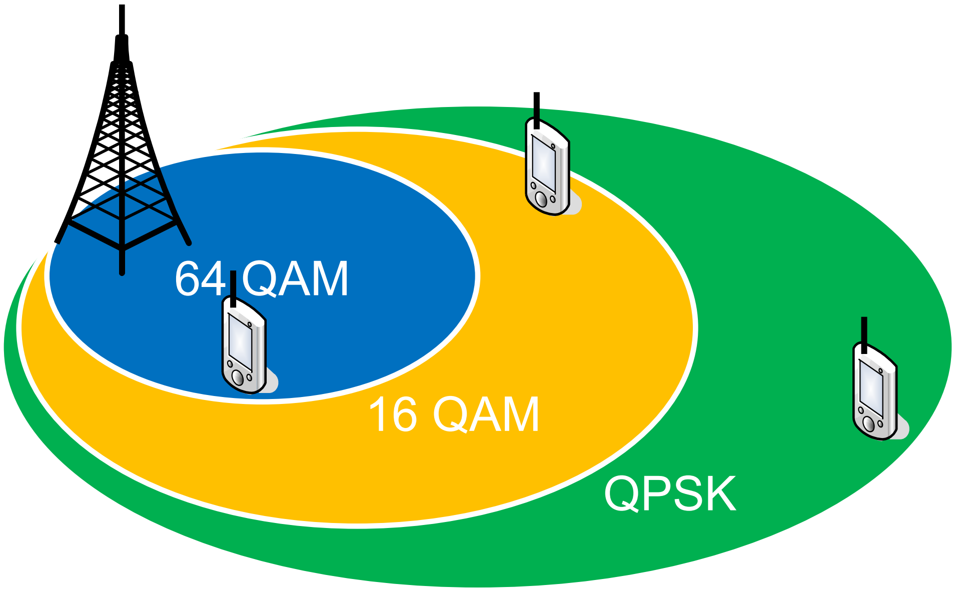
- Assign subcarriers to a user in good radio channel condition, for example:
  - Distributed allocation: Frequency diversity
  - Localized allocation: Frequency selective gain



Link Adaptation 1/

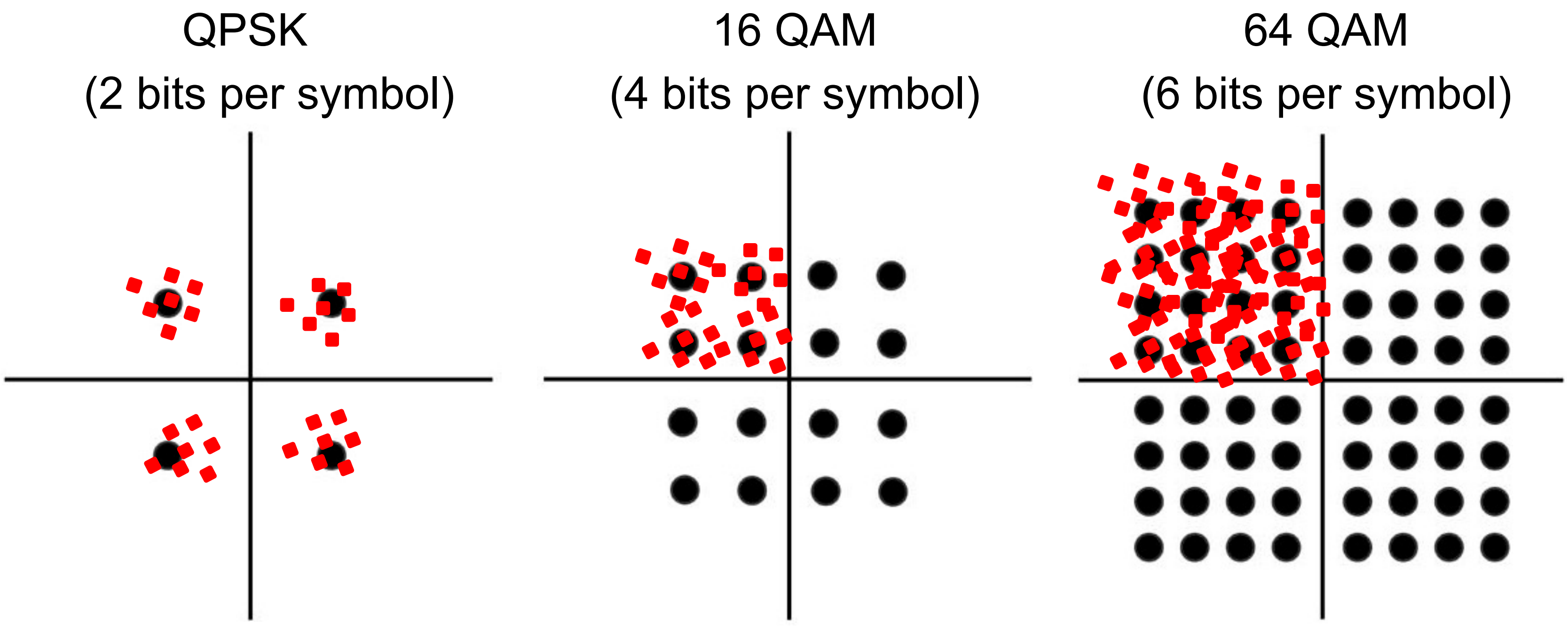
- Available modulations: QPSK, 16 QAM, 64 QAM
- Available coding schemes: 1/2, 2/3, 3/4

- ↓: 300 Mbps (20 MHz, 4x4 MIMO, 64-QAM)
- ↑: 75 Mbps (20 MHz, no MIMO, 64-QAM)



Link Adaptation 2/

- Determination of the spectral efficiency and requested minimum SINR for each LTE Modulation and Coding Scheme

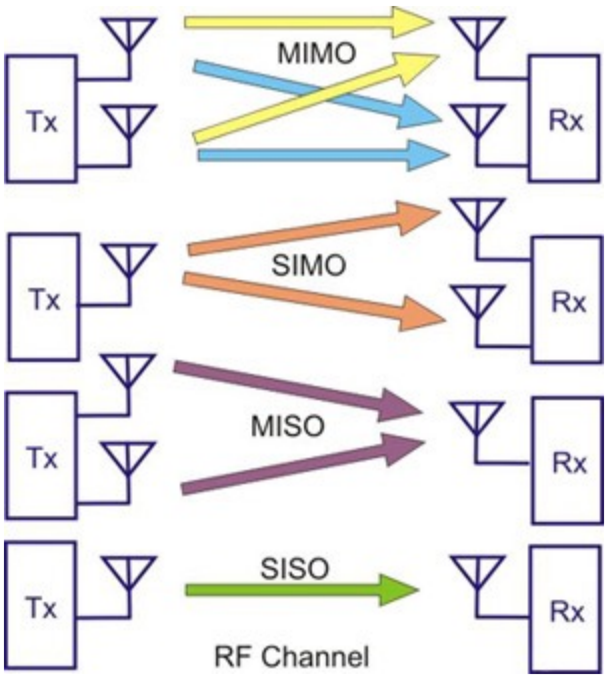


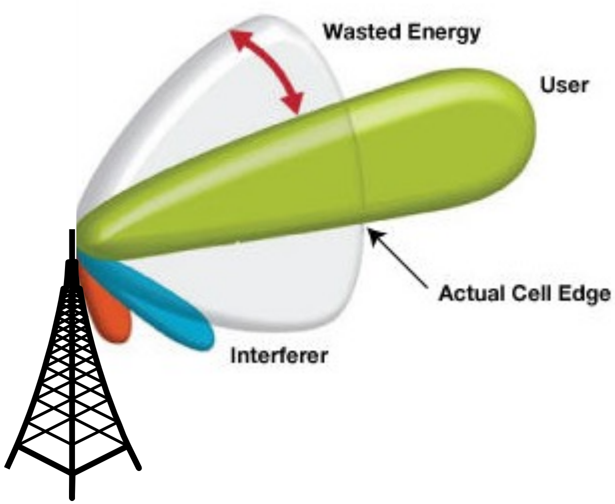
MIMO

- MIMO technique is used for:
  - Users multiplexing
    by use of multiple transmit antennas

  and/or
  - Individual user throughput increase / robustness
    by spatial transmit diversity

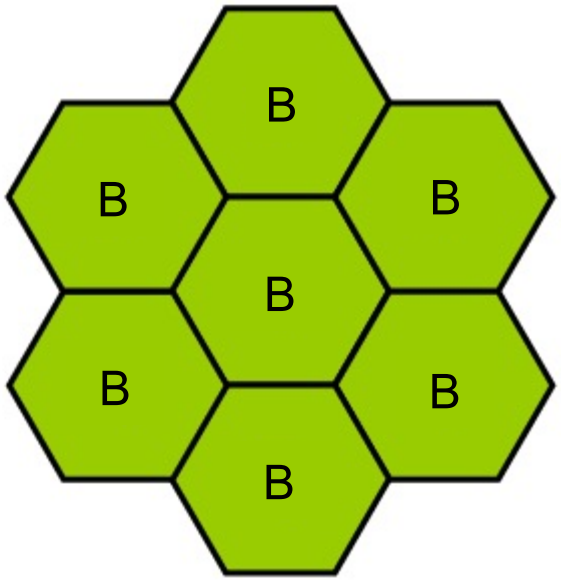
  and / or
  - Coverage
    by beamforming



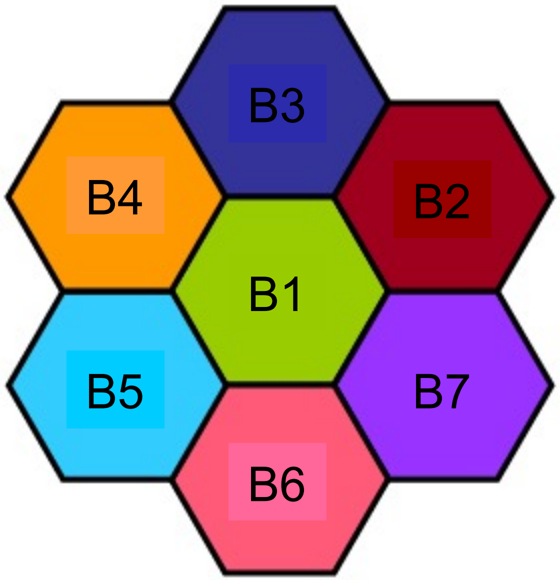


Frequency reuse

- frequency reuse



frequency reuse = 1

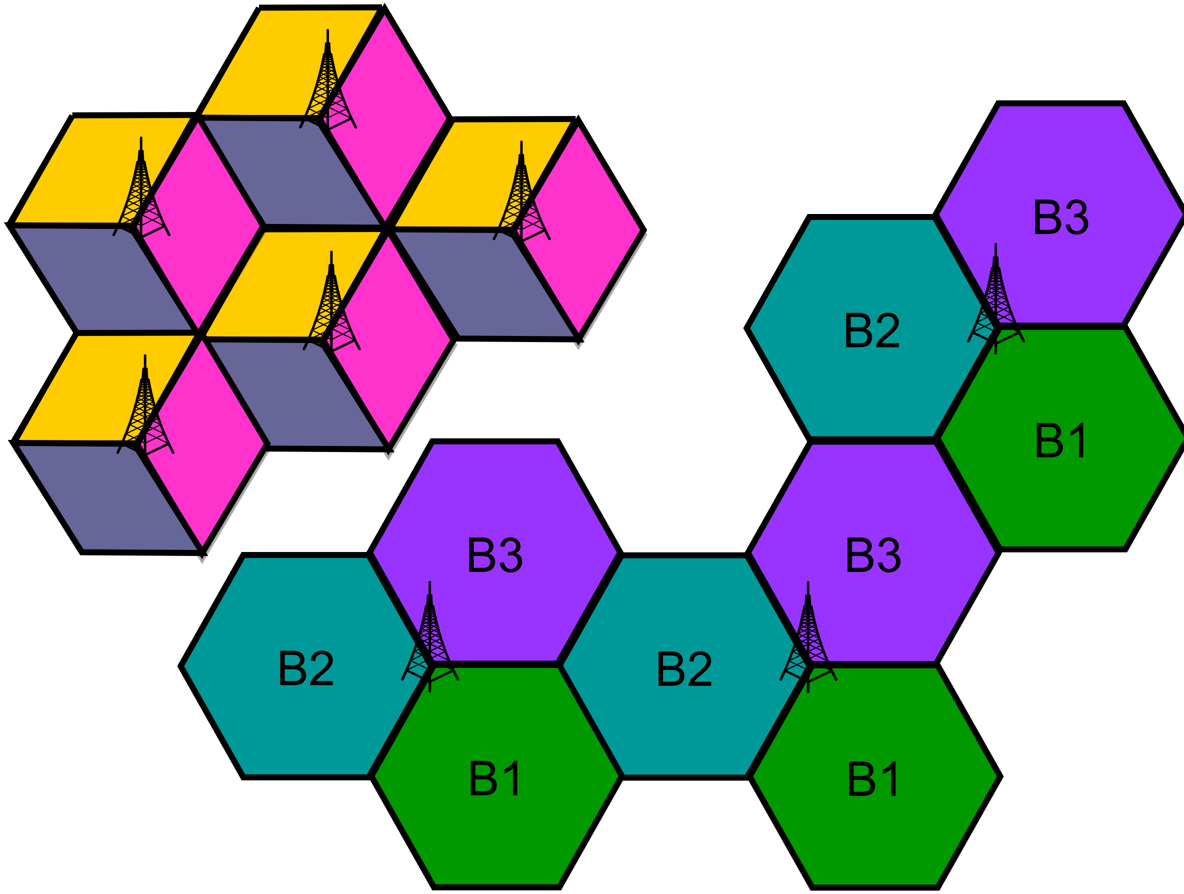


frequency reuse = 7

- Balance : spectral efficiency vs cell-edge users SINR

Ex. of usually adopted frequency reuse

frequency reuse = 3 with sectorized cells



Radio Dimensioning and Planning 1/

- Exercice on LTE radio dimensionning and cell capacity

Characteristic	unit	Uplink	Downlink
EIRP	dBm W	21 0.125	47 50
Rec. Thres. $_{QPSK}$	dBm W	-126.5 $2.2\ 10^{-16}$	-106.5 $2.2\ 10^{-14}$
PL $_{QPSK}$	dB	147.5 $\Rightarrow$ 144.5	153.5 $\Rightarrow$ 150.5
Rec. Thres. $_{16QAM}$	dBm W	-120 10^{-15}	-100 10^{-13}
PL $_{16QAM}$	dB	141 $\Rightarrow$ 138	147 $\Rightarrow$ 144
Rec. Thres. $_{64QAM}$	dBm W	-113 $5\ 10^{-15}$	-93 $5\ 10^{-13}$
PL $_{64QAM}$	dB	134 $\Rightarrow$ 131	140 $\Rightarrow$ 137

Radio Dimensioning and Planning 2/

- Considered propagation model: COST 231 extension to Hata's model
  - in dense urban area
  - for 30 m high base stations

$$L_{dB}(d) = 28.8 + 33.9 \times log_{10}(f) + 35.22 \times log_{10}(d)$$

- This general formula results in:
  - with f = 2.6 GHz : $L_{dB}(d) = 144.7 + 35.22 \times log_{10}(d)$
  - with f = 1.8 GHz : $L_{dB}(d) = 139.2 + 35.22 \times log_{10}(d)$
  - with f = 800 MHz : $L_{dB}(d) = 127.3 + 35.22 \times log_{10}(d)$
  - with f = 700 MHz : $L_{dB}(d) = 125.3 + 35.22 \times log_{10}(d)$

Radio Dimensioning and Planning 2/

- Max. Tx/Rx distance when no traffic is considered:

Characteristic	unit	f = 700 MHz	f = 800 MHz	f = 1.8 GHz	f = 2.6 GHz
PL_{QPSK}	dB	144.5			
d_{max}	m	**3500**	**3100**	**1400**	**990**
PL_{16QAM}	dB	138			
d_{max}	m	**2300**	**2000**	**920**	**650**
PL_{64QAM}	dB	131			
d_{max}	m	**1450**	**1300**	**585**	**410**

Radio Dimensioning and Planning 3/

- 25 active MS, f = 2.6 GHz
  - Uplink: 1 RB per MS
  - Downlink: 1 RB per MS

Characteristic	unit	Uplink	Downlink	d_{max} (m)
EIRP	dBm W	21 0.125	33 2	
Rec. Thres. $_{QPSK}$	dBm W	-126.5 $2.2\ 10^{-16}$	-106.5 $2.2\ 10^{-14}$	585 m
PL $_{QPSK}$	dB	144.5	139.5 $\Rightarrow$ 136.5	
Rec. Thres. 16QAM	dBm W	-120 10^{-15}	-100 10^{-13}	380 m
PL $_{16QAM}$	dB	138	133 $\Rightarrow$ 130	
Rec. Thres. 64QAM	dBm W	-113 $5\ 10^{-15}$	-93 $5\ 10^{-13}$	240 m
PL $_{64QAM}$	dB	131	126 $\Rightarrow$ 123	

Radio Dimensioning and Planning 4/

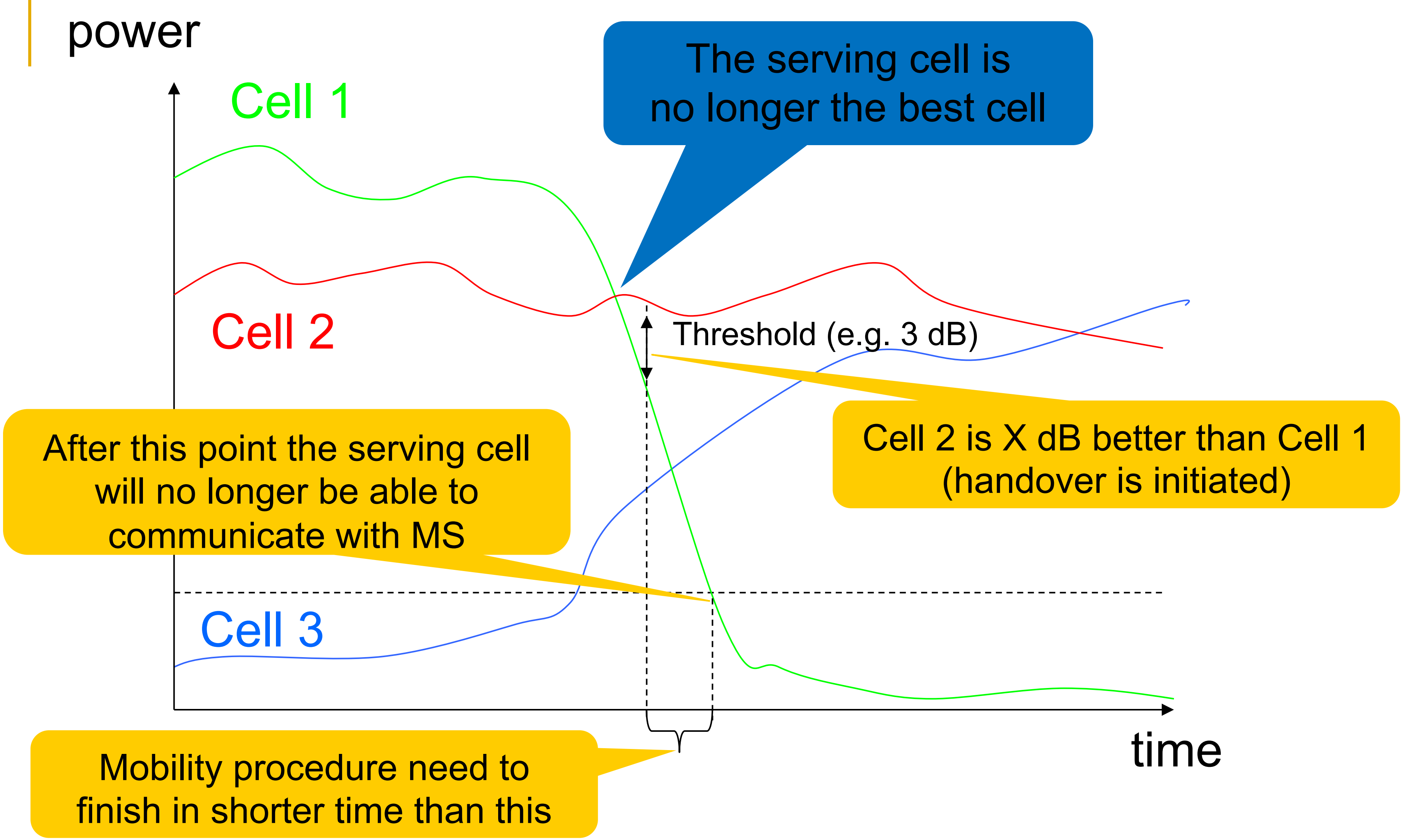
- 5 active MS, f = 2.6 GHz
  - Uplink: 5 RB per MS
  - Downlink: 25 active RB

Characteristic	unit	Uplink	Downlink	d_{max} (m)
EIRP	dBm W	14 0.025	33 2	
Rec. Thres. $_{QPSK}$	dBm W	-126.5 $2.2\ 10^{-16}$	-106.5 $2.2\ 10^{-14}$	585 m
PL $_{QPSK}$	dB	140.5 $\Rightarrow$ 137.5	136.5	
Rec. Thres. $_{16QAM}$	dBm W	-120 10^{-15}	-100 10^{-13}	380 m
PL $_{16QAM}$	dB	134 $\Rightarrow$ 131	130	
Rec. Thres. $_{64QAM}$	dBm W	-113 $5\ 10^{-15}$	-93 $5\ 10^{-13}$	240 m
PL $_{64QAM}$	dB	127 $\Rightarrow$ 124	123	

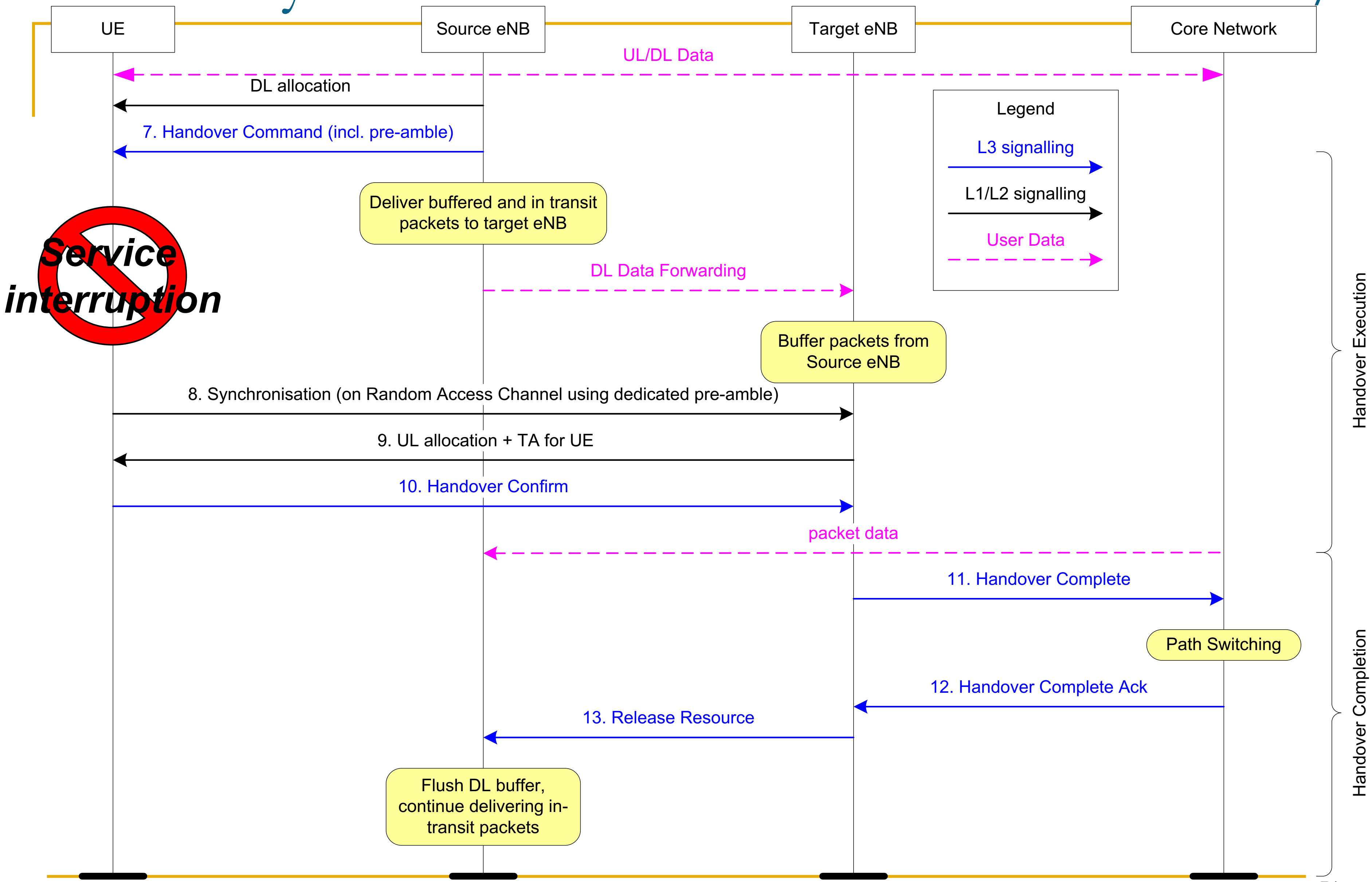
Mobility 1/

- Services today do not have strong requirements for interruption during HO:
  - Voice works with < 200 ms
  - TCP/IP should probably cope with 100 ms interruption as long as there are not packet losses
  - Play out buffers for streaming would probably be much larger than 200 ms
- Requirements for future services are unknown
- No soft HO
- Potential frequency reuse equal to 1

Mobility 2/


power
Cell 1
The serving cell is no longer the best cell
Cell 2
Threshold (e.g. 3 dB)
Cell 2 is X dB better than Cell 1 (handover is initiated)
After this point the serving cell will no longer be able to communicate with MS
Cell 3
time
Mobility procedure need to finish in shorter time than this

Mobility 3/


UE
Source eNB
Target eNB
Core Network
UL/DL Data
DL allocation
7. Handover Command (incl. pre-amble)
Legend
L3 signalling
L1/L2 signalling
User Data
Deliver buffered and in transit packets to target eNB
Service interruption
DL Data Forwarding
Buffer packets from Source eNB
8. Synchronisation (on Random Access Channel using dedicated pre-amble)
9. UL allocation + TA for UE
10. Handover Confirm
packet data
11. Handover Complete
Path Switching
12. Handover Complete Ack
13. Release Resource
Flush DL buffer, continue delivering in-transit packets
Handover Execution
Handover Completion

Mobility 4/

- Service interruption is around 20 ms

- In case UE looses contact with source cell it will select a new cell and send a recovery request message (including UE identity and "shared secret")

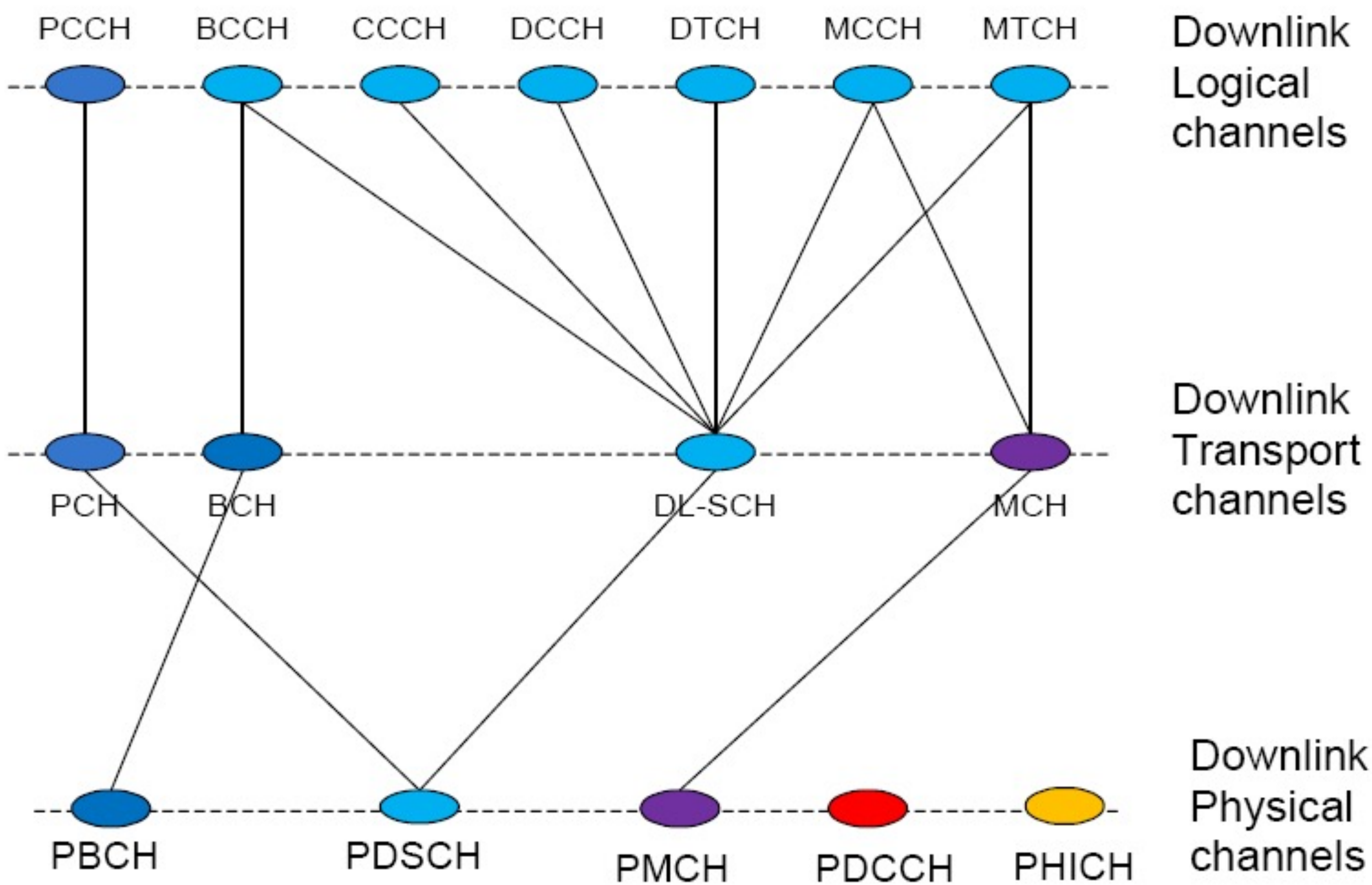
- In case the serving eNB looses contact with the UE, it can prepare neighbor eNBs about the potential arrival of the UE

LTE logical/trans/phys channels

- The physical, logical and transport channels all link to different areas of the stack. By organising them in this way, the LTE system is able to route the data to the required area.
- ***Physical channels:*** These are transmission channels that carry user data and control messages.
- ***Logical channels:*** Provide services for the Medium Access Control (MAC) layer within the LTE protocol structure.
- ***Transport channels:*** The physical layer transport channels offer information transfer to Medium Access Control (MAC) and higher layers.

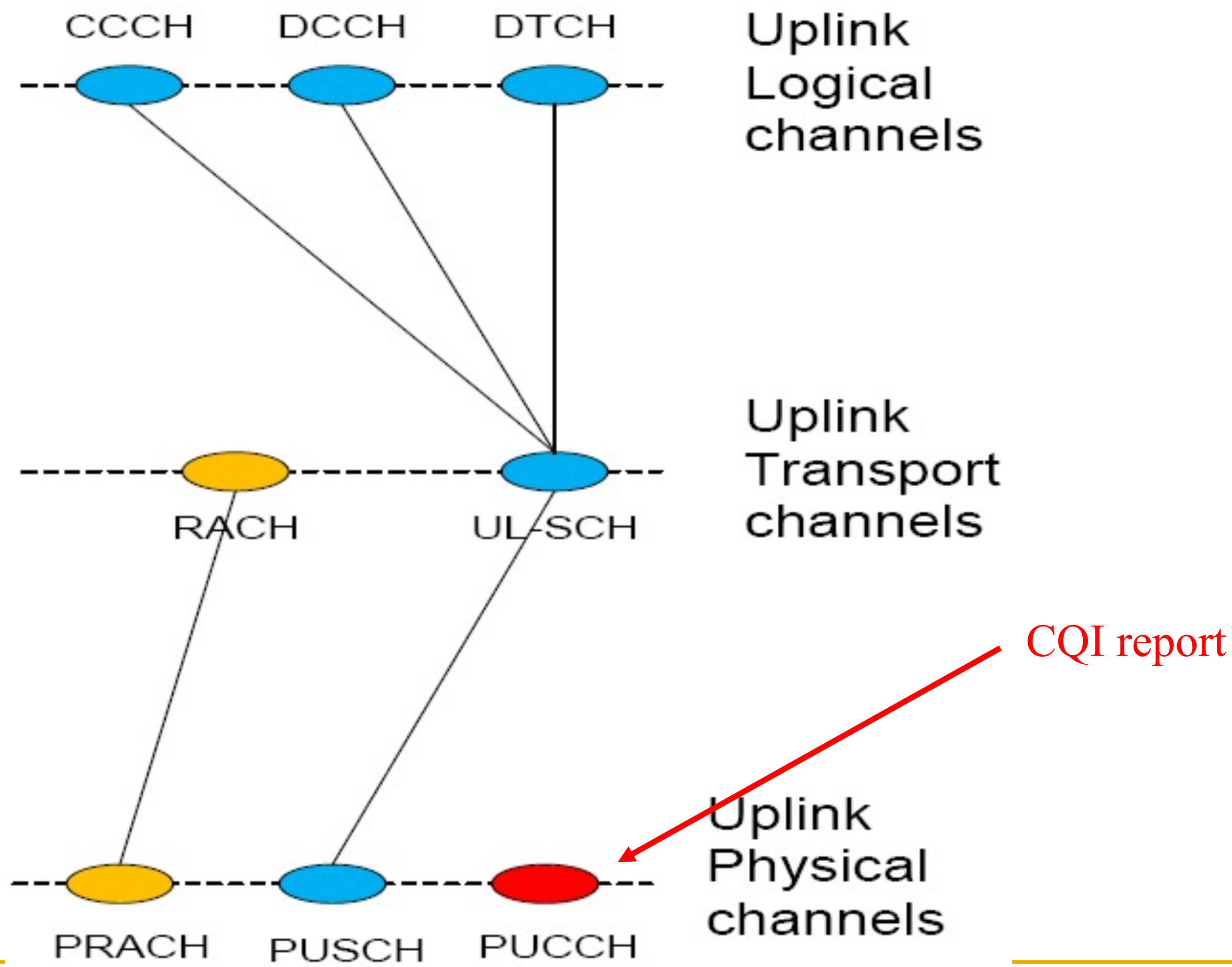
LTE logical/trans/phys channels 1/

- Downlink:



LTE logical/trans/phys channels 2/

- Uplink:



LTE Downlink Logical Channels

Paging Control Channel (PCCH)	• A downlink channel that transfers paging information and system information change notifications. • This channel is used for paging when the network does not know the location cell of the UE.
Broadcast Control Channel (BCCH)	• A downlink channel for broadcasting system control information.
Common Control Channel (CCCH)	• Channel for transmitting control information between UEs and network. • This channel is used for UEs having no RRC connection with the network.

LTE Downlink Logical Channels

Dedicated Control Channel (DCCH)	• A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. • Used by UEs having an RRC connection.
Dedicated Traffic Channel (DTCH)	• A point-to-point channel, dedicated to one UE, for the transfer of user information. • A DTCH can exist in both uplink and downlink.
Multicast Control Channel (MCCH)	• A point-to-multipoint downlink channel used for transmitting MBMS control information from the network to the UE, for one or several MTCHs. • This channel is only used by UEs that receive MBMS.
Multicast Traffic Channel (MTCH)	• A point-to-multipoint downlink channel for transmitting traffic data from the network to the UE. • This channel is only used by UEs that receive MBMS.

LTE Downlink Transport Channel

Paging Channel (PCH)	• Supports UE discontinuous reception (DRX) to enable UE power saving • Broadcasts in the entire coverage area of the cell; • Mapped to physical resources which can be used dynamically also for traffic/other control channels.
Broadcast Channel (BCH)	• Fixed, pre-defined transport format • Broadcast in the entire coverage area of the cell
Multicast Channel (MCH)	• Broadcasts in the entire coverage area of the cell; • Supports MBSFN combining of MBMS transmission on multiple cells; • Supports semi-static resource allocation e.g. with a time frame of a long cyclic prefix.

LTE Downlink Transport Channel

Downlink Shared Channel (DL-SCH)

- Supports Hybrid ARQ
- Supports dynamic link adaptation by varying the modulation, coding and transmit power
- Optionally supports broadcast in the entire cell;
- Optionally supports beam forming
- Supports both dynamic and semi-static resource allocation
- Supports UE discontinuous reception (DRX) to enable UE power saving
- Supports MBMS transmission

LTE Downlink Physical Channels

Physical Downlink Shared Channel (PDSCH)	• Carries the DL-SCH and PCH • QPSK, 16-QAM, and 64-QAM Modulation
Physical Downlink Control Channel (PDCCH)	• Informs the UE about the resource allocation of PCH and DL-SCH, and Hybrid ARQ information related to DL-SCH • Carries the uplink scheduling grant • QPSK Modulation
Physical Hybrid ARQ Indicator Channel (PHICH)	• Carries Hybrid ARQ ACK/NAKs in response to uplink transmissions. • QPSK Modulation

LTE Downlink Physical Channels

Physical Broadcast Channel (PBCH)

- The coded BCH transport block is mapped to four sub-frames within a 40 ms interval. 40 ms timing is blindly detected, i.e. there is no explicit signalling indicating 40 ms timing
- Each sub-frame is assumed to be self-decodable, i.e. the BCH can be decoded from a single reception, assuming sufficiently good channel conditions.
- QPSK Modulation

Physical Multicast Channel (PMCH)

- Carries the MCH
- QPSK, 16-QAM, and 64-QAM Modulation

LTE Uplink Logical Channels

Common Control Channel (CCCH)	• Channel for transmitting control information between UEs and network. • This channel is used for UEs having no RRC connection with the network.
Dedicated Control Channel (DCCH)	• A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. • Used by UEs having an RRC connection.
Dedicated Traffic Channel (DTCH)	• A point-to-point channel, dedicated to one UE, for the transfer of user information. • A DTCH can exist in both uplink and downlink.

LTE Uplink Transport Channel

Random Access Channel (RACH)

- Channel carries minimal information
- Transmissions on the channel may be lost due to collisions

Uplink Shared Channel (UL-SCH)

- Optional support for beam forming
- Supports dynamic link adaptation by varying the transmit power and potentially modulation and coding
- Supports Hybrid ARQ
- Supports dynamic and semi-static resource allocation

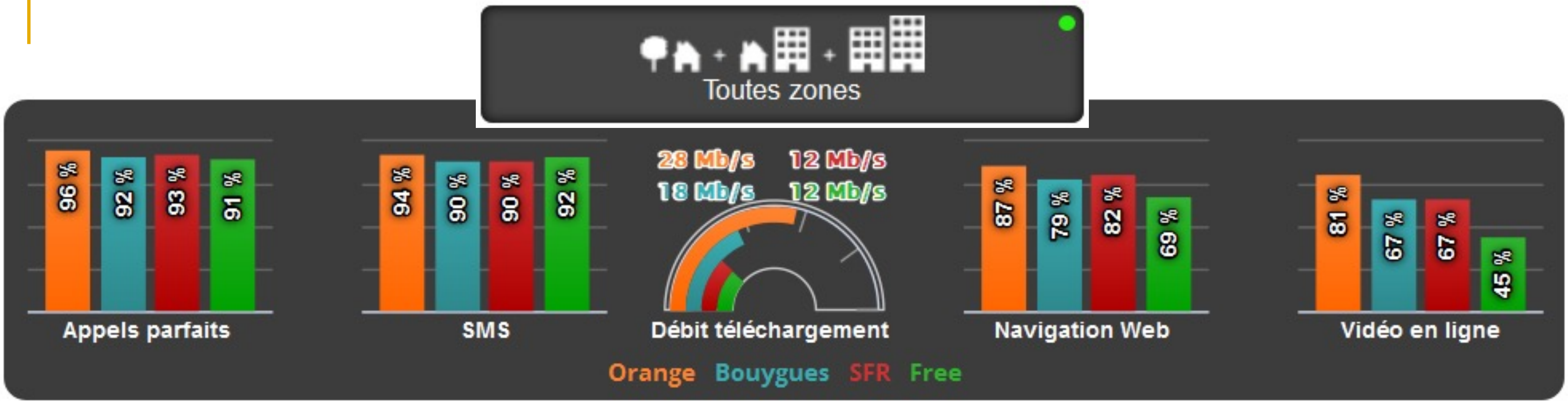
LTE Uplink Physical Channels

Physical Radio Access Channel (PRACH)	• Carries the random access preamble • The random access preambles are generated from Zadoff-Chu sequences with zero correlation zone, generated from one or several root Zadoff-Chu sequences.
Physical Uplink Shared Channel (PUSCH)	• Carries the UL-SCH • QPSK, 16-QAM, and 64-QAM Modulation
Packet Uplink Control Channel (PUCCH)	• Carries Hybrid ARQ ACK/NAKs in response to downlink transmission • Carries Scheduling Request (SR) • Carries CQI reports • BPSK and QPSK Modulation

LTE – Conclusion 1/

- Efficient technology
- Low loaded networks (for the moment!)
- New services

- In France, Free mobile emergence
  1. subscriptions fees 3G ↓ ⇒ accelerated 4G networks roll-out for technology differentiation
  2. subscriptions fees 4G = subscriptions fees 3G ⇒ VAS, commodotization?

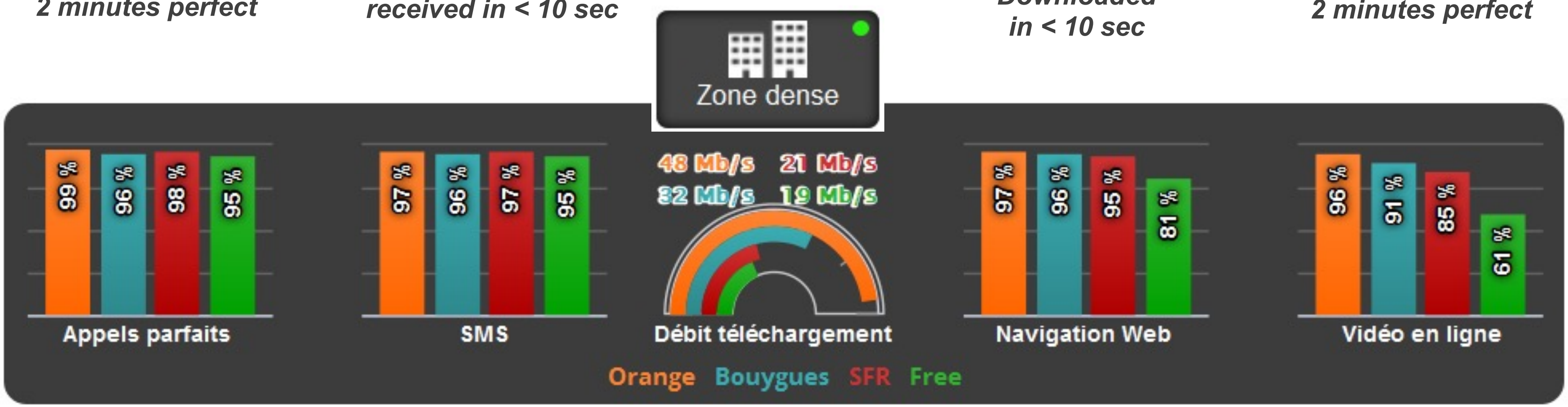


2 minutes perfect

received in < 10 sec

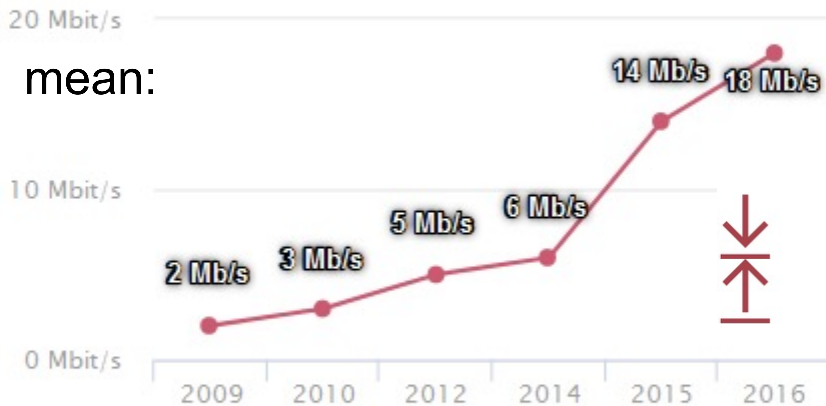
Downloaded in < 10 sec

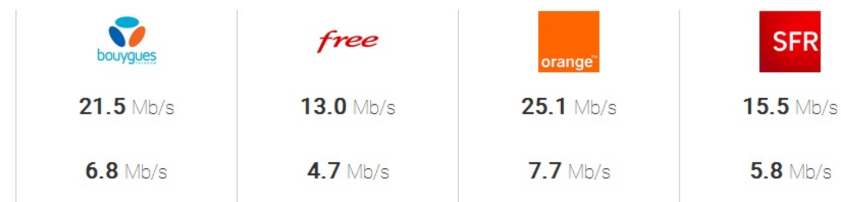
2 minutes perfect

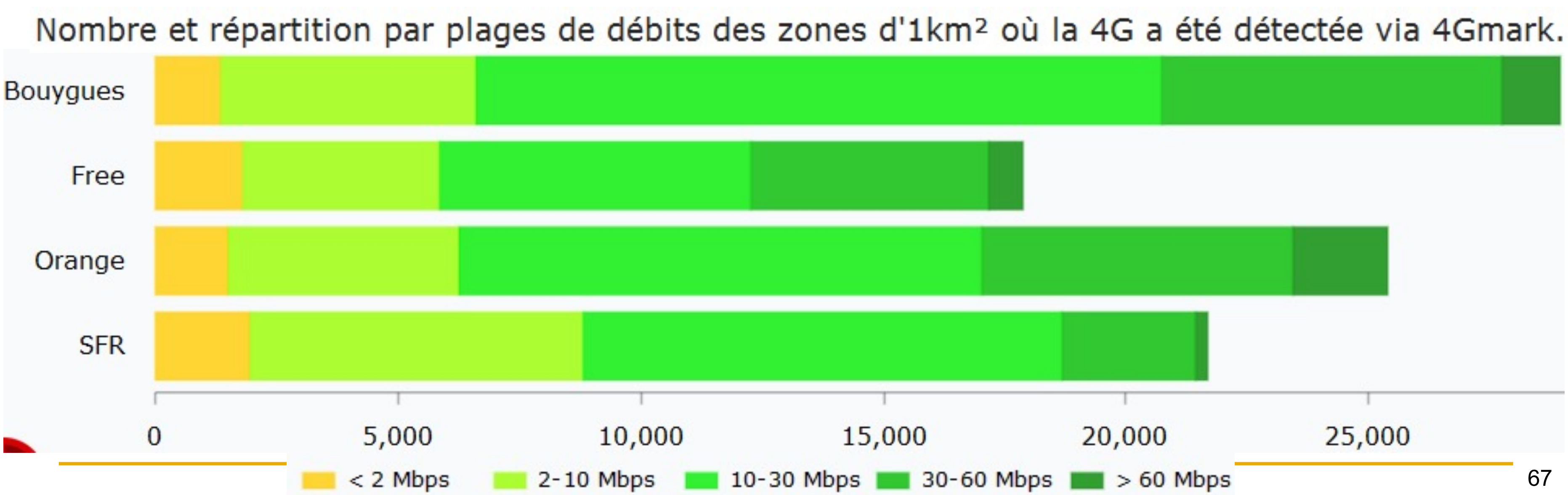


LTE – Conclusion 3/

- Monitored throughputs with a 4G terminal:
  - mean:



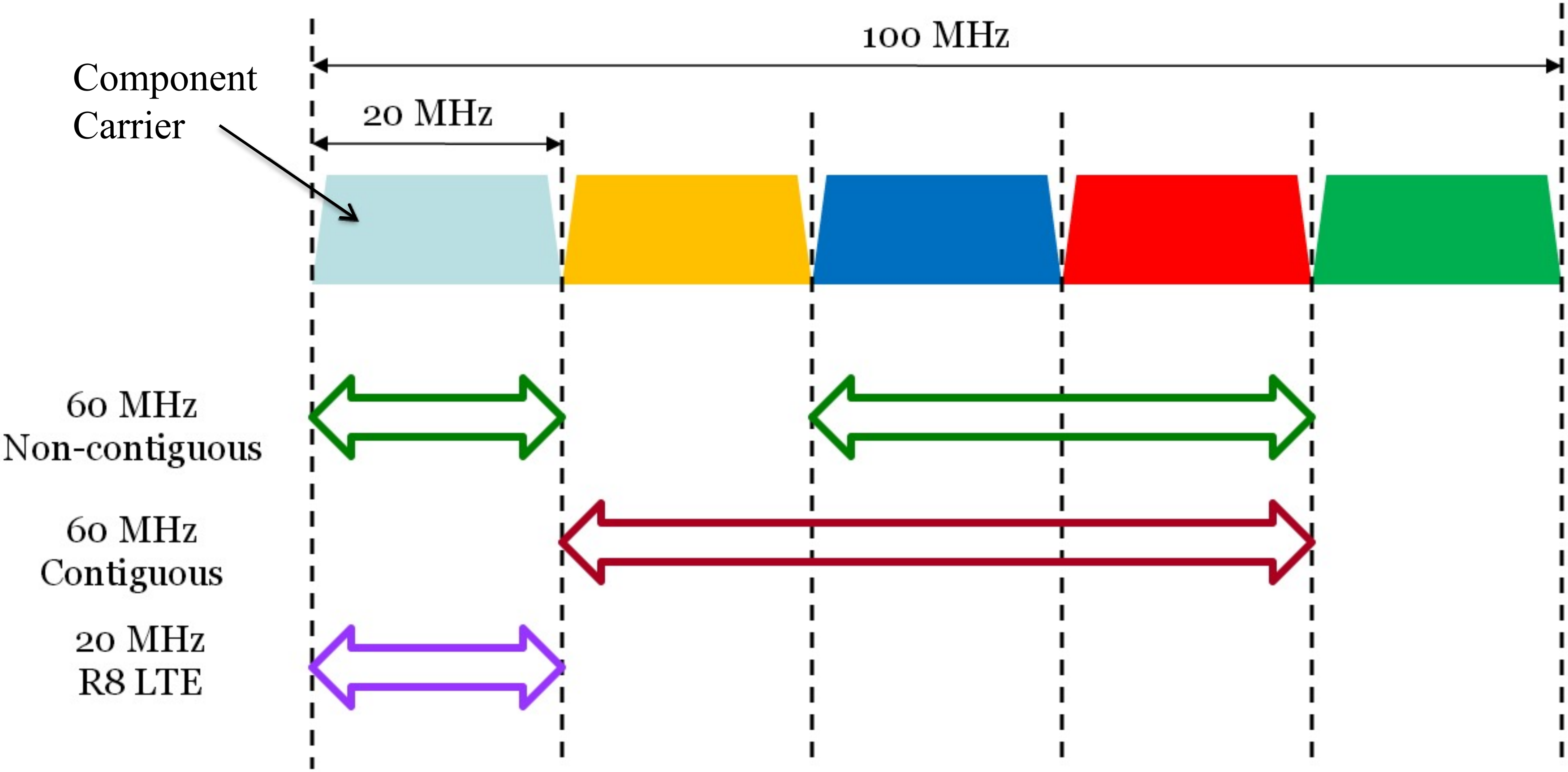




LTE - Advanced

- Maximum throughputs with LTE: 300 Mbits/s ↓, 150 Mbits/s ↑
- In 2008, UTI specified constraints for a « 4G » standard (« IMT-advanced ») :
  - Throughput ↓ and ↑ from 100 Mbits/s to 1 Gbits/s! ⇒ LTE : '3.9 G'
- Goals :
  - Specification of a new standard, fulfilling « 4G » requirements
  - LTE evolutions:
    - improve existing networks and ensuring compatibility between LTE and LTE-Advanced equipments
    - extend bandwidth to 100 MHz, by « carrier aggregation »
    - introduce relays
  - Release 10 finalised mid-2011: LTE-Advanced
    - R11 in 2013, R12 in 2014

Carrier Aggregation 1/



Carrier Aggregation 2/

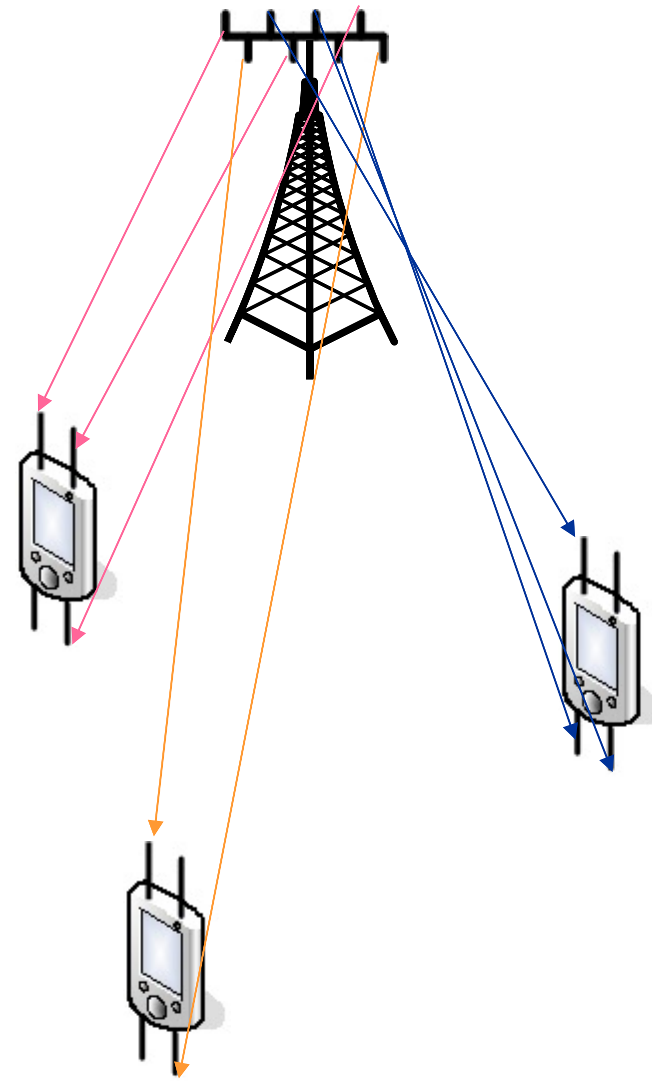
- Spectrum aggregation scenarios:
  - Intra-band adjacent
  - Intra-band non adjacent
  - Inter-band

- Asymmetric bandwidth for FDD
  - Number of DL Component Carriers > Number of UL Component Carriers

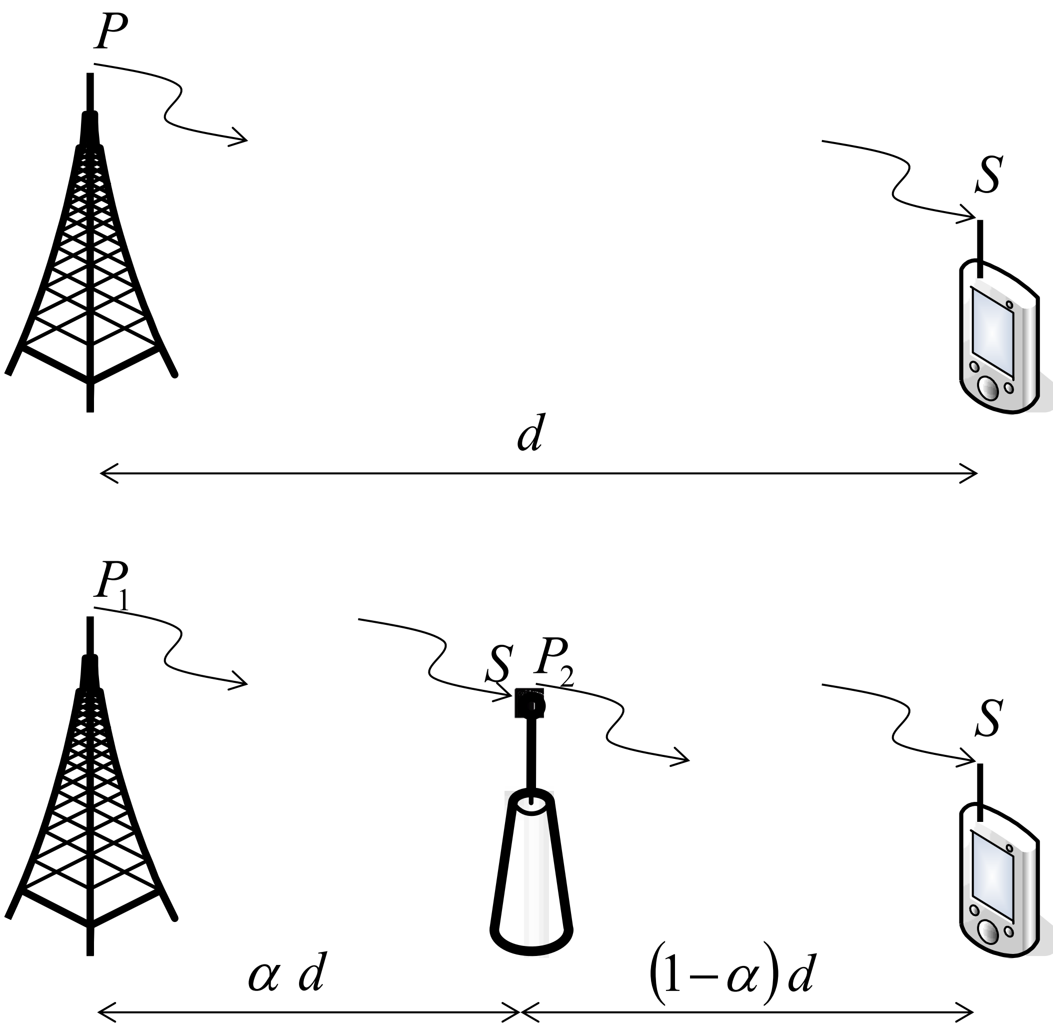
Enhanced MIMO

- Downlink MIMO
  - Up to 8x8 configuration
  - Support for MU-MIMO
  - Enhancements to CSI feedback

- Uplink MIMO
  - Introduction of UL transmit diversity
  - Introduction of up to 4x4 SU-MIMO



Relaying Issue 1/



$$S \propto \frac{P}{d^{\gamma}}$$

Objective:

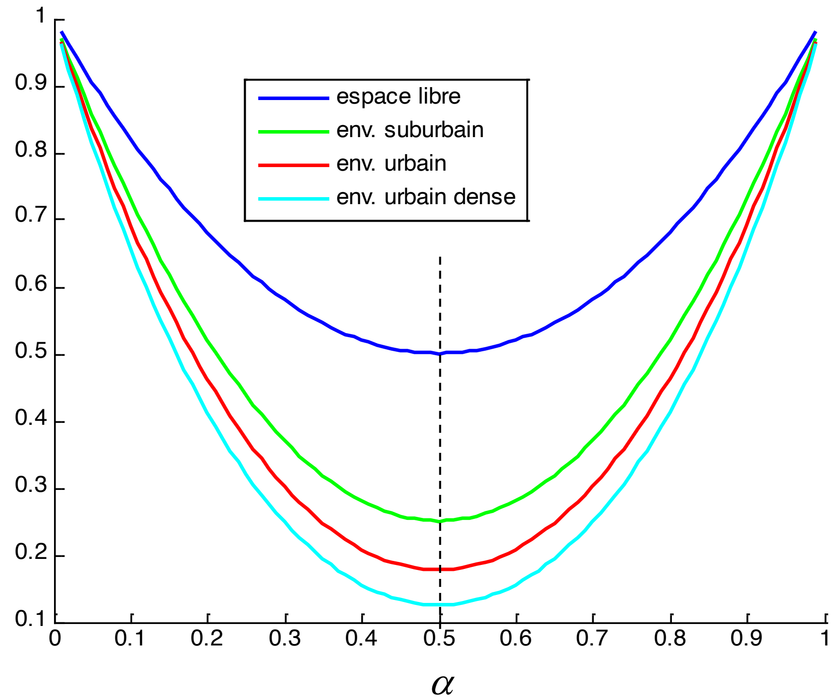
$$\boxed{P_1 + P_2 < P}$$

$$S \propto \frac{P_1}{(\alpha\, d)^{\gamma}} = \frac{P_2}{((1-\alpha)\, d)^{\gamma}}$$

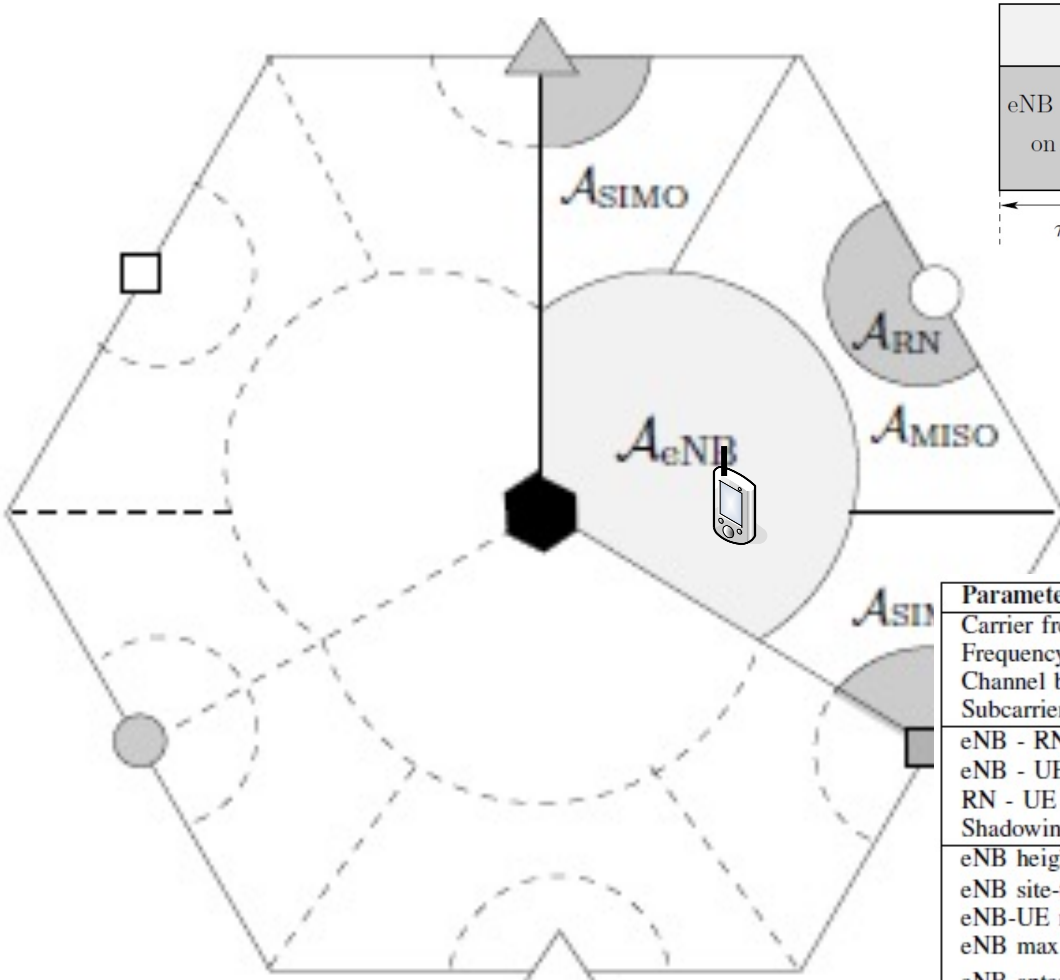
Relaying Issue 2/

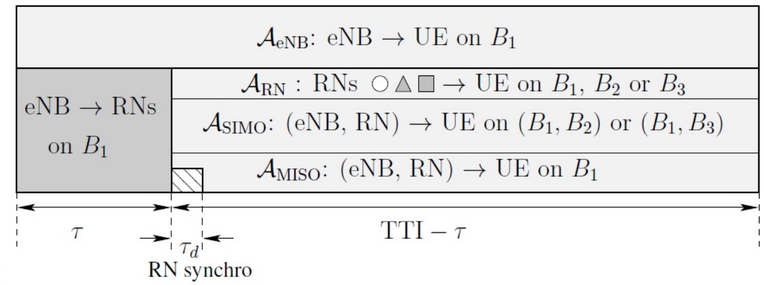
$$P_1 + P_2 < P \;\Rightarrow \alpha^{\gamma} + (1-\alpha)^{\gamma} < 1$$

- Conclusion, where relays and MS have the same sensitivity:
  - Relay must be situated at the middle of the eNB-MS distance
  - Relaying is more benefic in dense environnements
  - Network capacity is divided by 2 with an half-duplex relay



One Relaying strategy… 1/



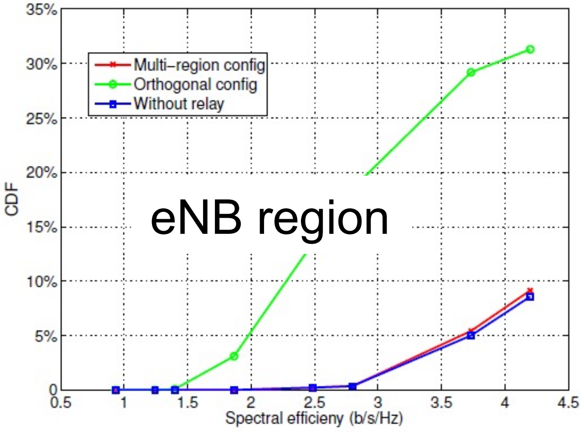


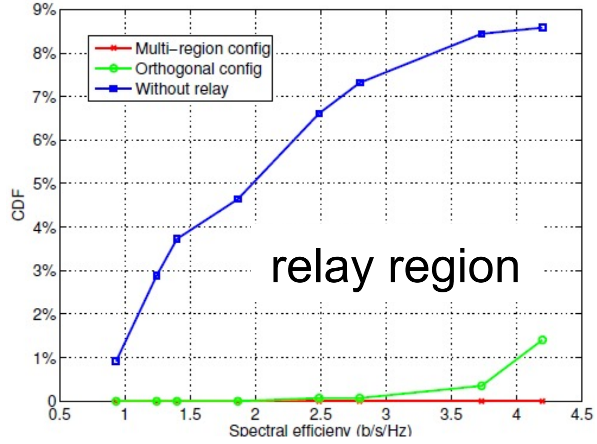
Parameter	Value
Carrier frequency	2.6 GHz
Frequency reuse pattern	$1 \times 3 \times 1$
Channel bandwidth	10 MHz
Subcarrier bandwidth	B = 15 KHz
eNB - RN propagation (LOS)	$\alpha = 10^{-10.2}$, $\gamma = 2.2$
eNB - UE propagation (NLOS)	$\alpha = 10^{-13.9}$, $\gamma = 3.9$
RN - UE Propagation (NLOS)	$\alpha = 10^{-14.3}$, $\gamma = 3.95$
Shadowing deviation	σ_s = 6 dB
eNB height	25 m (above rooftop)
eNB site-to-site distance	$d = 2\sqrt{3}$ km
eNB-UE minimal distance	$d_{\text{min}} = 30$m
eNB max Tx power per sector	46 dBm
eNB antenna pattern (dBi)	$G_{\text{eNB}}(\theta^{\circ}) = 17 - \min\left(12\frac{\theta^2}{70^2}, 20\right)$
RN height	20 m (above rooftop)
RN-UE minimal distance	$d_{\text{min}} = 30$m
RN max Tx power	36 dBm
RN antenna pattern (dBi)	$G_{\text{RN}} = 7$ (omnidirectional)

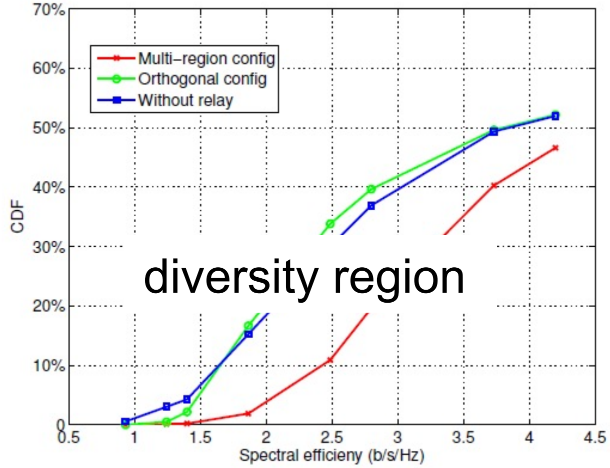
One Relaying strategy… 2/

- Conclusion, when eNB-relay LOS propagation is considered:
  - Spectral efficiency ↑
  - Average cell capacity ↑
  - Transmit energy dissipation ↓

	No relay	Multi-region
Cell throughput C(Mbps)	24.75	24.96
eNB reg throughput $\bar{C}_{\mathrm{eNB}}$(Mbps)	-	8.53
Energy (Joules)	0.0398	0.0394

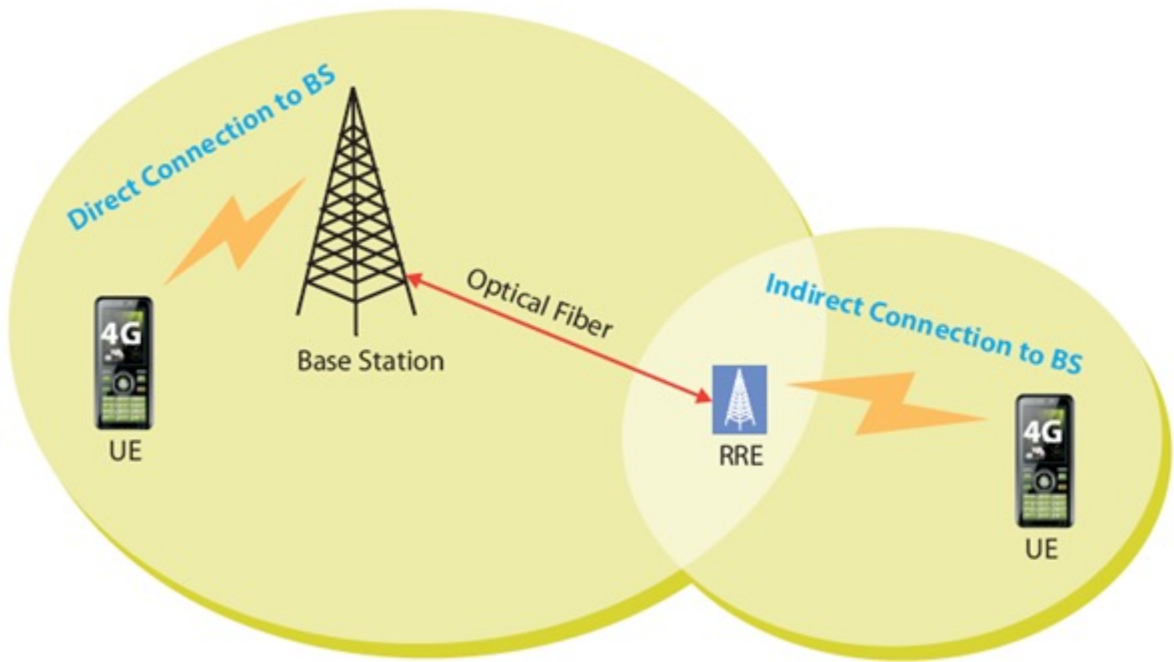






Remote Radio Heads

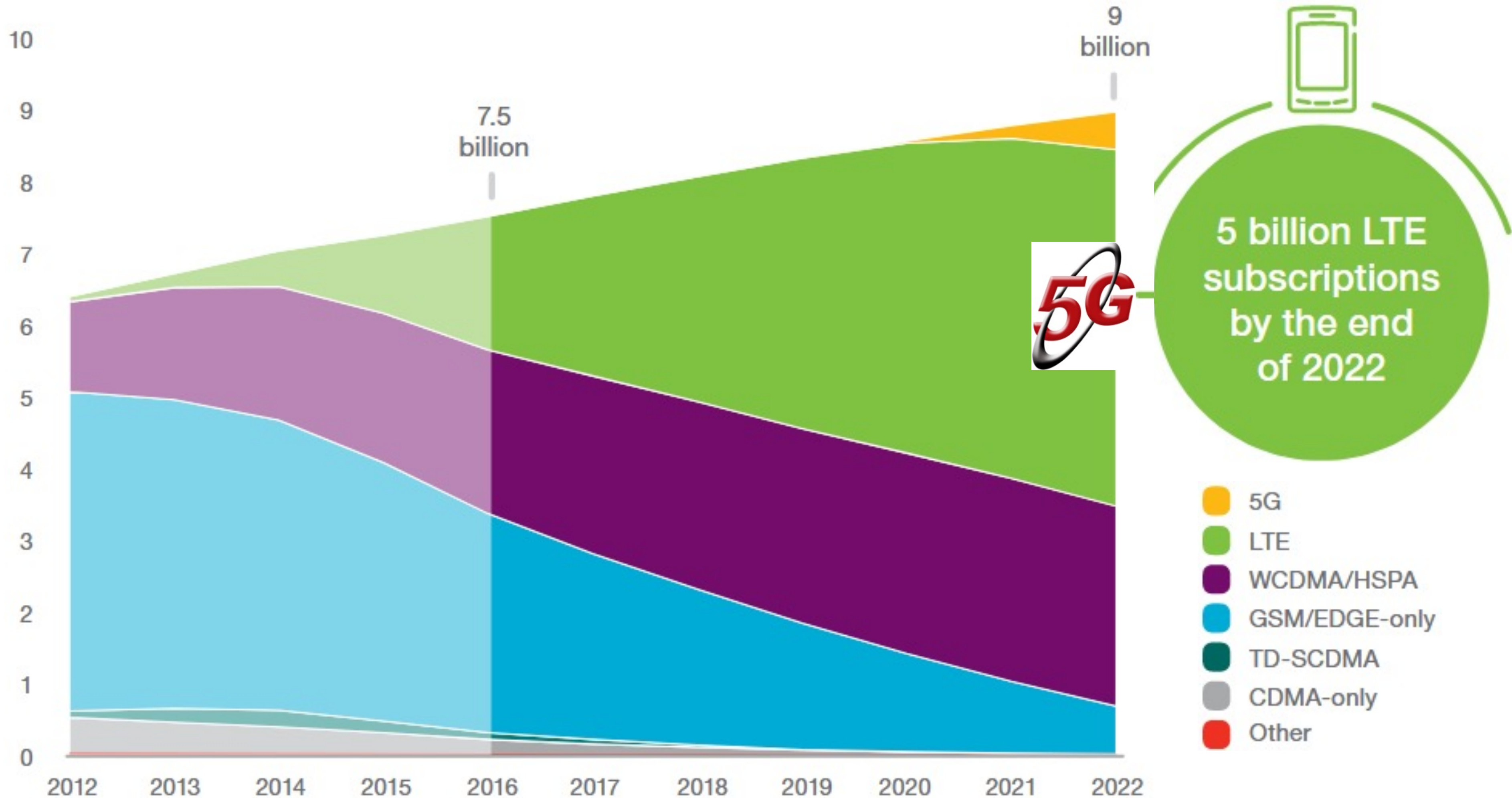
- Enhanced techniques to extend coverage area using optical fiber should be used as effective technique to extend cell coverage



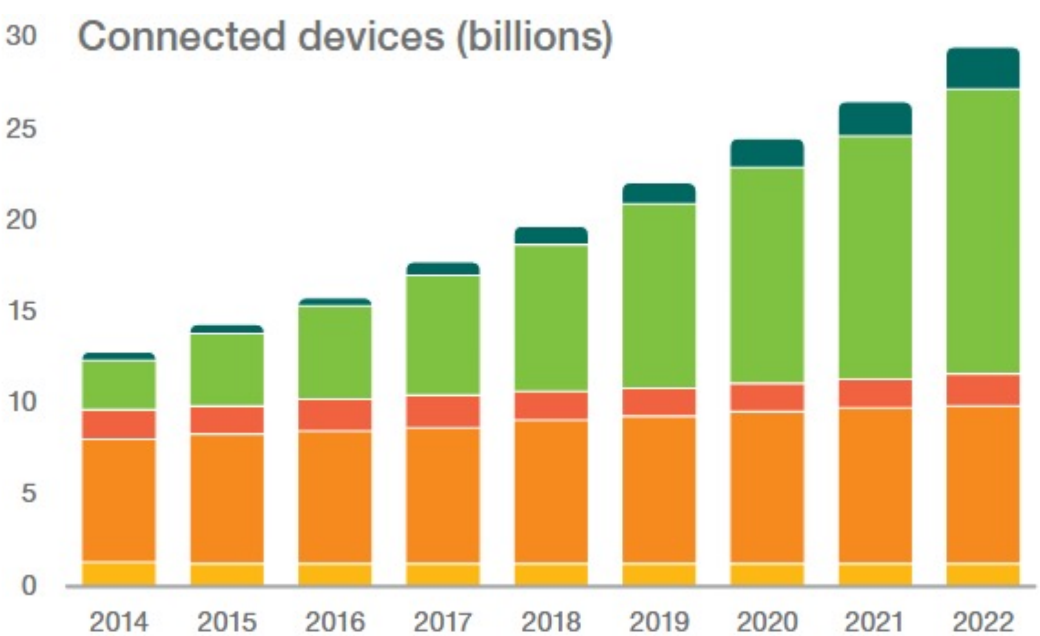
General Conclusion

8,3 BILLION

mobile subscriptions, including M2M
(year to year: + 4.7%)



General Conclusion



	2016	2022
Wide-area IoT	0.4	2.1
Short-range IoT	5.2	15.5
PC/laptop/tablet	1.6	1.7
Mobile phones	7.3	8.6
Fixed phones	1.4	1.3
	16 billion	29 billion

Potential 5G use cases