Radio Interface of 5G New Radio

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Why 5G ?

Some potential 5G applications :

Multimedia

- Ultra HD video
- Immersive and interactive experiences (AR/VR, virtual presence, tactile internet)
- Network games
- Live/streaming/on demand
- Collaborative productions, social networks
- Mobile and adaptive contents
- On demand networking (for temporary events)

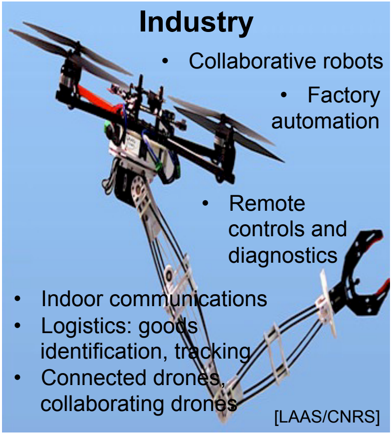
Health

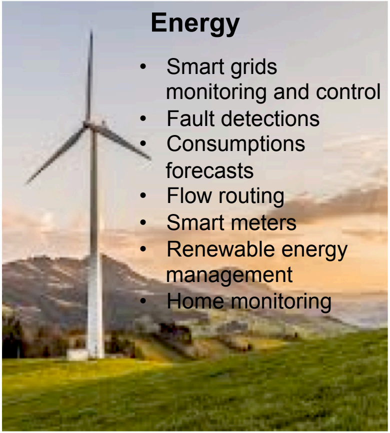
- Tele-surgery
- Bio-connectivity: monitoring, diagnosis, treatment

[Da Vinci]

- Wearable device communications
- Ambulance-hospital communications

Why 5G ?


Industry
• Collaborative robots
• Factory automation
• Remote controls and diagnostics
• Indoor communications
• Logistics: goods identification, tracking
• Connected drones, collaborating drones
[LAAS/CNRS]


Energy
• Smart grids monitoring and control
• Fault detections
• Consumptions forecasts
• Flow routing
• Smart meters
• Renewable energy management
• Home monitoring

Why 5G ?

Public services

- Public safety: operations of first responders in case of emergency or disaster; presence and localization of survivors; low network and terminal energy consumptions
- Public warning system
- Multimedia priority service for police, army, firemen
- Wide area sensor monitoring (forests, air and water quality)
- Private mobile radio (PMR)

Intelligent Transport Systems

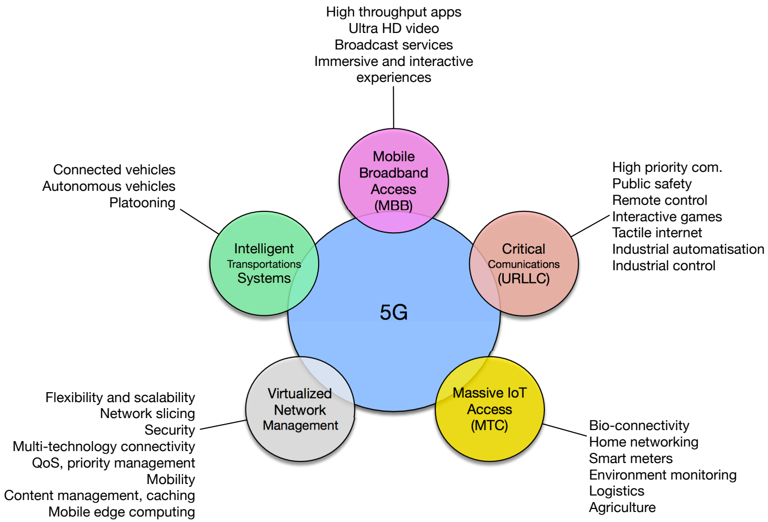
- Real-time control of vehicles
- Driver assistance
- Road traffic monitoring (floating car data)
- Accident prevention
- Remote vehicles diagnostics
- V2X communications
- Platooning
- Mobility support: high quality network access in buses, trains and airplanes

And many others that we don't even know today...
For more information and references : [3GPP 22.891, 2016]

Outlines

Outline

Use cases classification



Use cases classification

The three typical use cases envisioned for 5G :

- eMBB (Enhanced Mobile Broadband) : Low latency, higher spectral efficiency/throughput.
- mMTC (massive Machine Type Communications) : Improved link budget, low device complexity, long device battery life (low energy consumption), support high density device deployment.
- URLLC (Ultra Reliable Low Latency Communications) : High reliability (low packet error rate), low latency.

We can add :

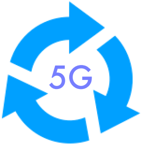
- eV2X (enhanced Vehicle to Everything) : High reliability, low latency, mobility.
- NETOP (network operation) : Flexibility, scalability, security, QoS, mobility.

Outline

Challenges

Mobile Broadband

Peak rate : 20 (DL)/10 (UL) Gbits/s
Peak spectral efficiency : 30/15 bits/s/Hz
5th percentile data rate : 100/50 Mbits/s
Average spectral efficiency : up to 9 bits/s/Hz/TRP
Capacity : 10 Mbits/s/m2
Mobility : up to 500 km/h



Massive Machine Type Communications

1 million connections/km2
(1 message/2hours/device)
Cost : <5€/chip
Energy : up to 10y battery lifetimes

Ultra Reliable and Low Latency Communications

Latency : 1-4 ms
Control plane latency : 10-20 ms
Reliability : 99,99999% success in 1 ms for a 32 bytes layer 2 packet

[source: IMT-2020 ITU-R M2410]

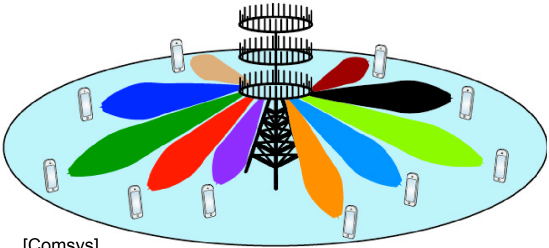
See [ITU-R M.2410, 2017] for the complete list of requirements.

Outline

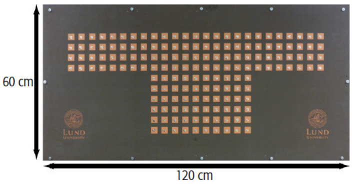
Massive MIMO

Massive MIMO = use >100 antennas to serve >10 users simultaneously on the same frequency. **Full Dimension MIMO** = beamform the signal in azimuth and elevation directions [Kammoun et al., 2019, Björnson et al., 2017, Marzetta, 2010].

- Advantages : high spectral and energy efficiency, simple linear precoding, the effects of noise and fading can be eliminated when the number of antennas is very large.
- Drawbacks/issues : antenna panel size, signalling for channel estimation, pilot contamination. Cell search, initial access and handovers requires a specific beam management.

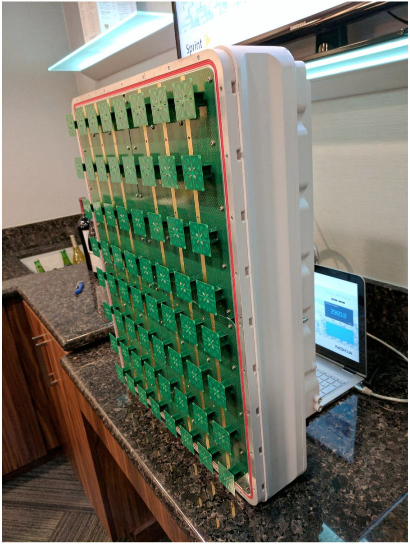


[Comsys]

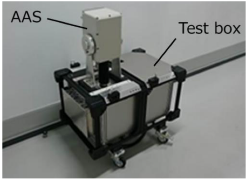


[Lund University: 160 antennes 3.5GHz]

Massive MIMO



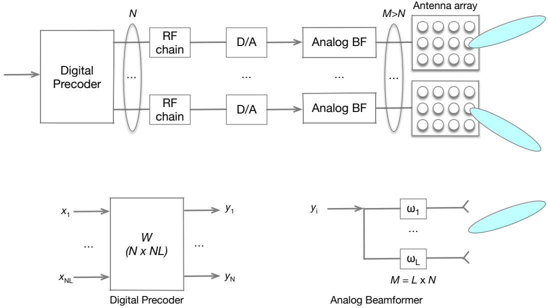
[Nokia: 128 antenna elements at 2.5GHz]



[NEC: 360 antenna elements at 28GHz, height=30cm]

Massive MIMO

Hybrid beamforming : It is still not practical to have fully digital precoder in mm waves because a dedicated RF chain is required per antenna element (space, cost issues).



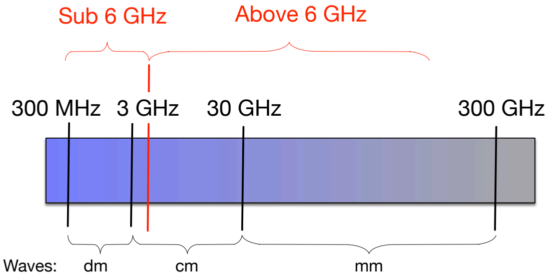
Typically :

- 3.5 GHz : 64 transceiver units, 128 antenna elements, mMIMO used for spatial multiplexing
- 28 GHz : 4 transceiver units, 512 or 1024 antenna elements, mMIMO used for beamforming

mmWaves

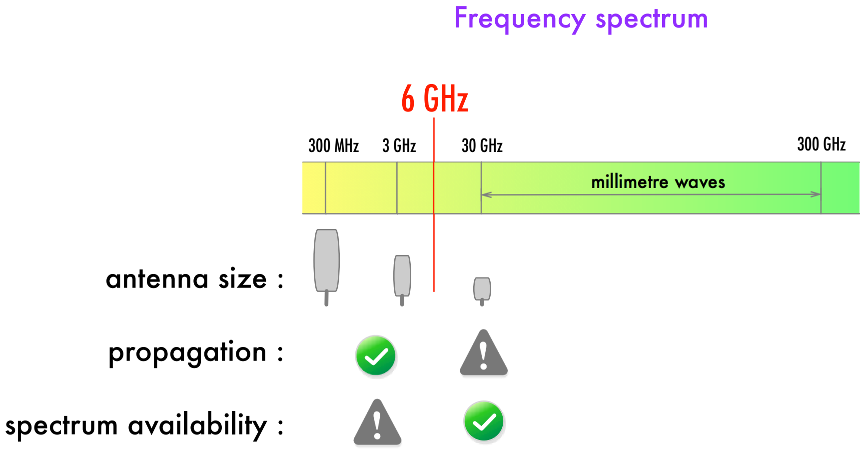
Millimeter Waves = use spectrum bands above 6 GHz.

- Advantages : above 6 GHz (26+41+66), around 11 GHz are available (vs 1.2GHz below), small antennas for massive MIMO, few co-channel interference, can provide both backhaul and access links.
- Drawbacks/issues : difficult propagation conditions (high attenuation, blockage, absorption), baseband and RF processing, modelling and performance.



mmWaves

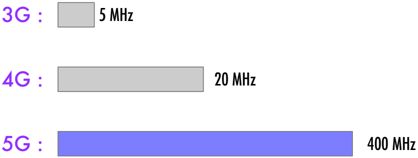
Large spectrum bands are available and antenna sizes are small (proportional to the wave length)



mmWaves

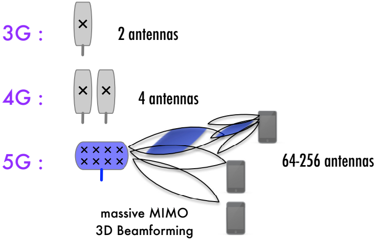
In mm waves, very large bandwidths are possible and the number of antennas can increase drastically

Bandwidth (W)



[NB: first versions of the standard]

Number of antennas (n_{ant})



mmWaves

Channel characteristics at 28 GHz for a cell range of 200 m [Pi and Khan, 2011, Rappaport et al., 2013, Akdeniz et al., 2014] :

- There is a 20-25 dB loss compared to traditional cellular frequencies.
- Rain attenuation and atmospheric absorption characteristics have little impact on the path-loss (less than 2 dB and 0.02 dB resp.).
- Outdoor materials like tinted glass or brick pillars have high penetration losses (30-40 dB), while indoor materials (clear glass and drywall) have moderate losses (4 to 7 dB).
- Outdoor, the average path-loss exponent is 2.55 in LOS and 5.76 in NLOS.
- In NLOS, there are several multipath components at different angles of arrivals (typically 2 to 4 clusters), which makes beam combining and spatial multiplexing feasible.
- Foliage may have a significant impact depending of its depth.

See also [ITU-R M.2376, 2017] for technical feasibility and [ITU-R M.2412, 2017] for channel modeling.

mmWaves

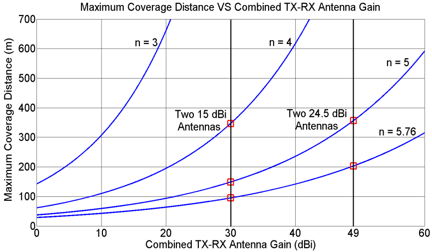


FIGURE 8. **Maximum coverage distance at 28 GHz with 119 dB maximum path loss dynamic range without antenna gains and 10 dB SNR, as a function of path loss exponent n.**

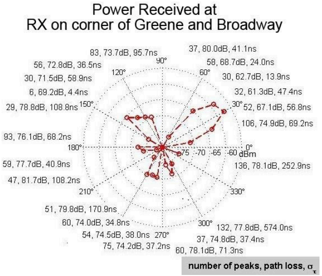
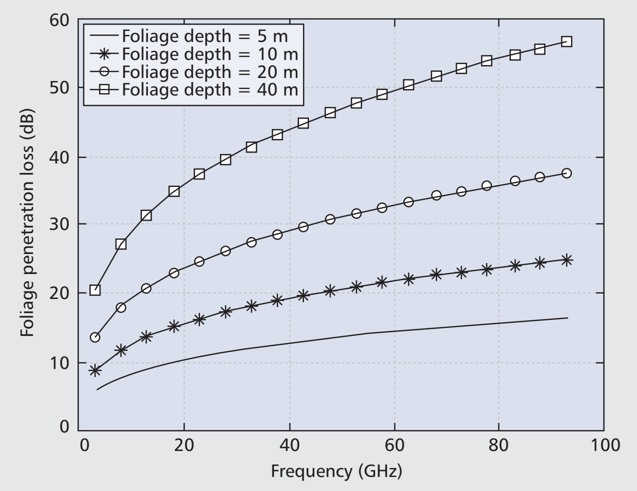


FIGURE 9. **Polar plot showing the received power at a NLOS location. This plot shows an AOA measurement at the RX on Greene and Broadway from the TX on the five-story Kaufman building (78 m T-R separation). The polar plot shows the received power in dBm, the number of resolvable multipath components, the path loss in dB with respect to the 5 m free space reference, and RMS delay spread with varying RX azimuth angles [31].**

In an NLOS dense urban environment, a coverage range of 200 m is possible provided that the net antenna gain is 49 dBi [Rappaport et al., 2013].

mmWaves

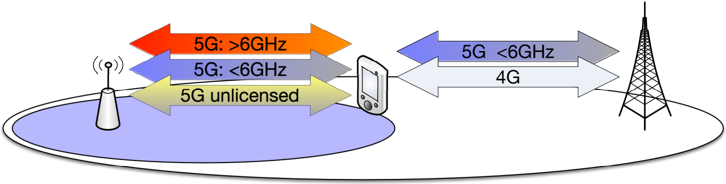


[Pi and Khan, 2011]

Spectrum aggregation and unlicensed bands

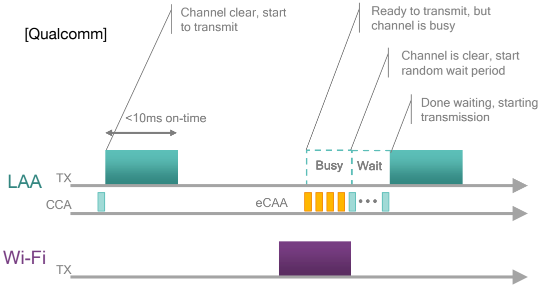
Spectrum aggregation = aggregate carriers and technologies from both licensed and unlicensed spectrum. **Multi-RAT dual connectivity** = connect to different technologies from different nodes. Variants : intraband (contiguous or not), inter-band, only DL or both links.

- Advantages : high data rates when channel conditions are bad and MIMO is not efficient ; smooth integration with existing technologies ; better use of fragmented spectrum (truncking gain) ; load balancing.
- Drawbacks/issues : complex signalling and protocol aspects, tight cooperation between cells (joint scheduling) ; coexistence with other technologies, no QoS guarantee, regulatory requirements in unlicensed bands.



Spectrum aggregation and unlicensed bands

Channel Clear Assesment (CCA) and Listen-Before-Talk (LBT) operation :



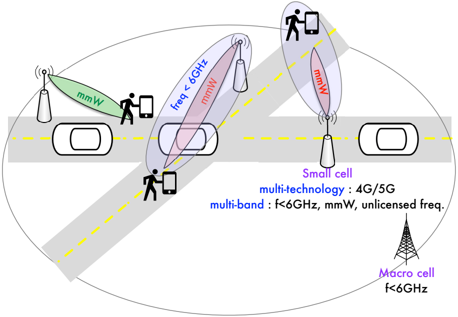
Remarks :

- LTE-U (R12) : only DL ; Licensed Assisted Access (LAA, R13) : only DL+LBT ; eLAA (R14) :UL+DL ; MulteFIRE : stand-alone LTE in unlicensed bands
- New Radio Unlicensed (NR-U) : foreseen for R16, priority on 5GHz and 60GHz bands, stand-alone operation

Heterogeneous networks

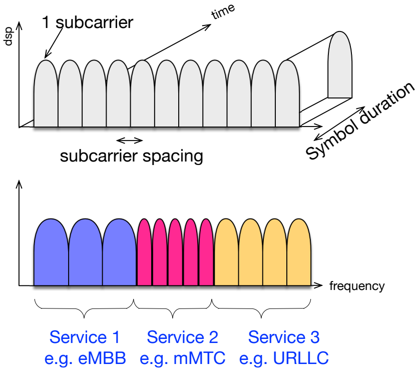
Heterogenous networks = small cells, femto cells, relays complement the macro cell layer. They use multiple bands (incl. unlicensed) and multiple technologies.

- Advantages : increase network capacity (network densification), good channel conditions and low user sharing for high data rates.
- Drawbacks/issues : increase of interference, load balancing ; site planning, sharing ; regulation rules (EM exposure) ; backhaul availability ; maintenance costs.



Flexible numerology

New waveform = CP-OFDM with flexible subcarrier spacing (SCS) and symbol duration.



Flexible numerology

Why again OFDM ?

- High spectral efficiency.
- Low cost, low complexity, efficient equalization.
- Easy use of MIMO techniques because of its robustness wrt inter-symbol interference (ISI).
- Flexibility : it can support various services by appropriately designing subcarrier spacing, cyclic prefix length, user multiplexing.

Flexible numerology

However...

- OFDM has high PAPR, which implies a loss of power efficiency (not good for UL coverage and low cost small base stations). SC-FDMA has lower PAPR (implying 1-2 dB gain at reception) but is less flexible for scheduling, requires more complex MIMO receivers.
- OFDM is prone to inter-carrier interference (ICI) caused by [Zaidi et al., 2016] :
  - Doppler : the shift is increasing with carrier frequency and speed but decreases with subcarrier spacing. ICI power is proportional to the square of the normalized Doppler shift.

$$W_d = \frac{f_c v}{\Delta f \times c}, \quad (1)$$

    where f_c is the carrier frequency, v is the terminal speed, Δf is the subcarrier spacing and c is the speed of light.
  - Phase noise : a random perturbation of the phase of the oscillator. It can be partly compensated by pilots. Related ICI power increases with carrier frequency but decreases with subcarrier spacing.

Flexible numerology

- The cyclic prefix represents a loss of efficiency. The delay spread is almost frequency independent (from less than 1 μs in small cells, to a few μs in urban areas). If we want to maintain a constant proportion of CP and still absorb the delay spread, we have an upper limit on the subcarrier spacing.
- Modulation/demodulation complexity increases with FFT size.

Flexible numerology

- URLLC : requires short symbols for low latency $\Rightarrow$ large SCS
- eMBB : uses large bandwidths, requires not too large FFT $\Rightarrow$ large SCS
- mmW : uses large bandwidths, inter-carrier interference increases with frequency but decreases with SCS $\Rightarrow$ large SCS
- mMTC and sub-6GHz : smaller bandwidths and larger cells (more inter-symbol interference) $\Rightarrow$ short SCS

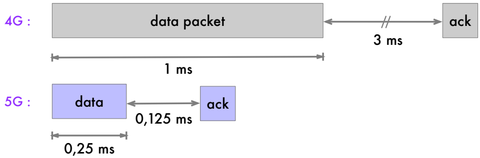
Table – Waveform design principles

	URLLC	eMBB	mMTC	mmW	Freq.<6GHz
Large SCS	✓	✓		✓	
Short SCS			✓		✓

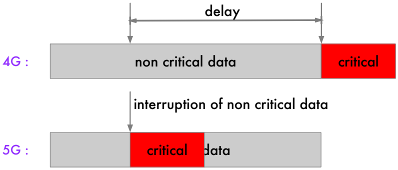
Mini-slots and dynamic TDD

Low latency = no fixed timing relations, dynamic TDD, self-contained slots, semi-persistent scheduling and grant free transmission, DL preemption of the ressources.

Very low latency



Ressource preemption



Mini-slots and dynamic TDD

Dynamic TDD = a transmission can start at any OFDM symbol (this is the notion of "mini-slot" transmission).

- Advantages : allows very flexible scheduling, very fast ACK/NACK feedback, very low latencies. The flexible starting time is useful when listen-before-talk is used in unlicensed bands.
- Drawbacks/issues : may require additional signalling, creates new co-channel inter-cell interference issues.

D	D	D	D	D	D	D	D	D	D	D	D	D	D
U	U	U	U	U	U	U	U	U	U	U	U	U	U
X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	D	D	D	D	D	D	D	D	D	D	D	D	X
D	D	D	D	D	D	D	D	D	D	D	D	X	X

...

D	D	D	D	D	X	U	D	D	D	D	D	X	U

...

A slot is made of 14 OFDM symbols.

Mini-slots and dynamic TDD

Examples of slot formats (source :Ericsson) :

(a) Heavy downlink transmission with uplink feedback : a "self-contained" sub-frame.

(b) Heavy uplink transmission with downlink feedback.

(c) Very short time critical downlink transmission with immediate uplink ack (no need to wait for a slot boundary) or transmission in unlicensed band (transmit asap the channel is free) or in mmWaves (few symbols may carry sufficient volume of data).

(d) Slot aggregation for heavy downlink transmission.

(a)	D	D	D	D	D	D	D	D	D	D	D	D	X	U														
(b)	D	X	U	U	U	U	U	U	U	U	U	U	U	U														
(c)	X	X	X	X	D	D	X	U	X	X	X	X	X	X														
(d)	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	X	U

Mini-slots and dynamic TDD

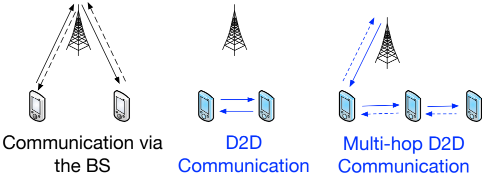
The slot format has an impact on several performance and planning aspects :

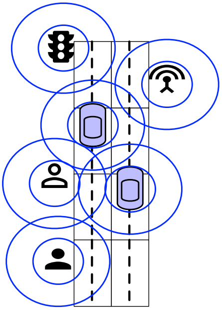
- DL/UL ratio : related to the amount of traffic in both directions.
- # of DL/UL switching points : more frequent switching points means lower latency, better channel estimation (positive impact, especially at high speed) and fast HARQ feedback. However, more guard periods are required and so more resources are lost.
- Coverage : large cells require long guard periods at every switching point.
- Coexistence : In France, the first deployment of 5G will be in the 3.5 GHz band. In order to avoid adjacent channel interference with LTE-TDD, slot format should be aligned between the two technologies.

Device-to-Device communications

Device to device = direct communications between terminals.

- Advantages : increase network capacity, low latency, good channel conditions for high data rates.
- Drawbacks/issues : increase of interference, resource management, signalling and synchronization.



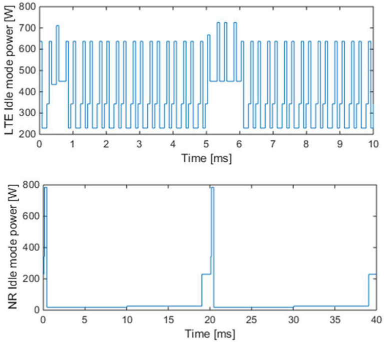


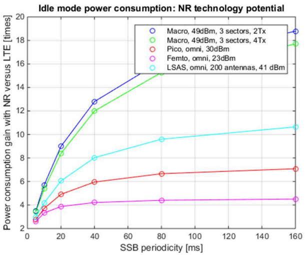
Lean design

Lean design = minimize "always on" transmission

- Advantages : forward compatibility, energy saving.
- Drawbacks/issues : delays, loss of synchronization.

In LTE, there are always on signals like reference signals, synchronization signals, broadcast of system information. In NR : reference signals are sent only when needed, longer periodicity, new sleep modes, improved dependence on load [Frenger and Tano, 2019].

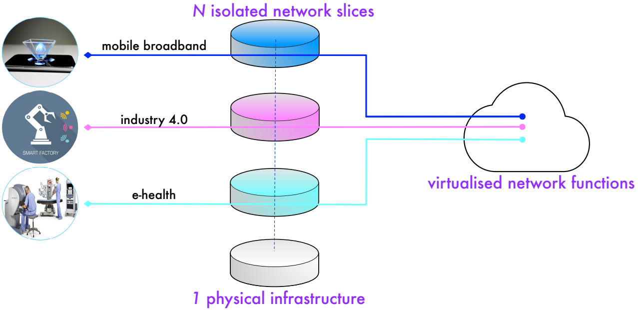




Virtualization

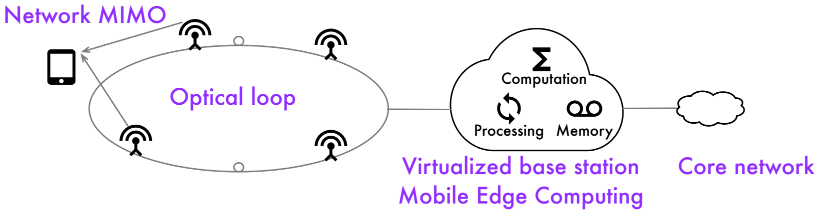
Virtualization = network functions are not anymore associated to a specific hardware, there are in programmable in software and located in a cloud made of generic hardware. Virtualization allows **network slicing** and **mobile edge computing**.
Network slice = a collection of network functions that support the communication requirements of particular uses case(s).

- Advantages : flexibility, scalability, isolation between slices.
- Drawbacks/issues : delays, security issues.



Virtualization

Mobile Edge Computing = signal processing, CPU and memory-intensive applications, caching is performed in an edge cloud ; radio signal is carried over fiber to simple radio heads ; coordination between antennas is made easier.



Outline

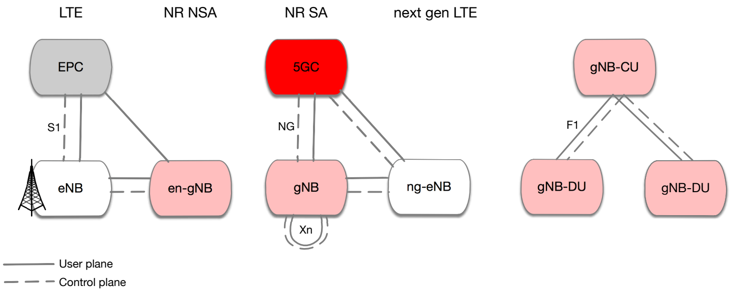
Typical peak data rates in 5G

Peak data rates in DL (first deployments) :

Band Duplex	Bandwidth in MHz	LTE (4G) MIMO 2×2	LTE (4G) MIMO 4×4	NR (5G) MIMO 2×2	NR (5G) MIMO 4×4
700MHz FDD	5	49.0	-	53.5	-
	10	**97.9**	-	**111.3**	-
	15	149.8	-	169.1	-
	20	195.8	-	226.9	-
2.6GHz FDD	5	49.0	98.0	53.5	107.0
	10	97.9	195.8	111.3	222.6
	15	149.8	299.9	169.1	338.1
	20	195.8	391.7	226.9	453.7
3.5 GHz TDD	**70**	-	-	**598.6**	**1197.3**
	90	-	-	**776.0**	**1552.0**

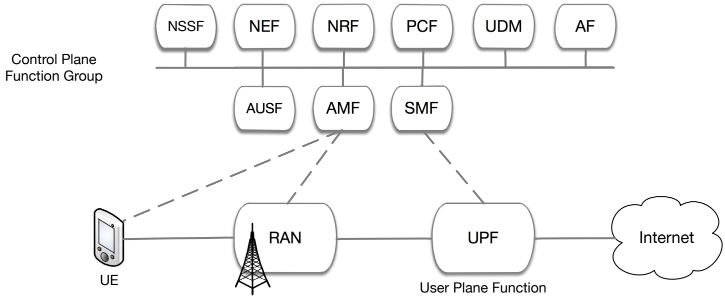
Outline

Architecture



- Non Stand Alone (NSA) : Initial deployments, dual connectivity with LTE
- Stand Alone (SA) : After R16
- For more information : [3GPP 38.401, 2018]

Architecture



- A service based architecture.
- AMF : Access and Mobility, SMF : Session Mgt, PCF : Policy Control, NEF : Network Exposure, NRF : Network Repository, UDM : Unified Data Mgt, AUSF : Authentication Server, AF : Application Function, NSSF : Network Slice Selection
- For more information : [3GPP 23.501, 2018]

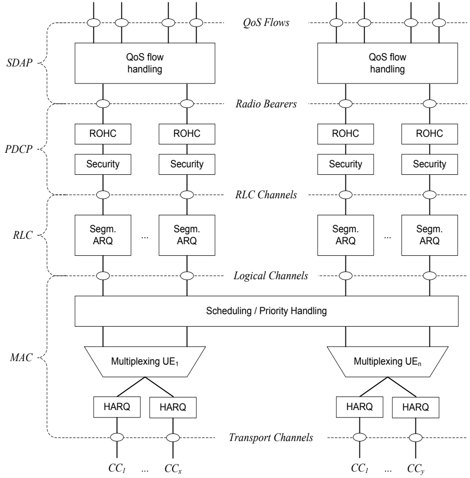
Protocol Stack

SDAP services and functions
- Mapping bw a QoS flow and a RB
- Marking QoS flow ID in DL and UL packets

PDCP services and functions
- Sequence numbering
- Header compression
- Reordering
- Retransmissions
- Ciphering and integrity

RLC services and functions
- Transparent Mode (TM): Transfer of PDUs
- Unacknowledged Mode (UM): TM+Sequence numbering, SDU segmentation/reassembly
- Acknowledge Mode (AM): UM+ARQ

MAC services and functions
- Mux/demux of MAC SDU
- HARQ
- Priority handling bw UEs
- Priority handling bw logical channels



Frequency bands

Two *frequency bands* are defined :

Table – NR Frequency bands and channel bandwidths

Designation	**Frequency range**
FR1	450 MHz - 6 GHz
FR2	24,25 GHz – 52,6 GHz

- FR1 is the classical frequency range for mobile communications (sub-6GHz band)
- FR2 is sometimes called mmWave (even if it is also dm wave)

Frequency bands and channel bandwidths

- There is a list of possible *operating bands*. Each operating band is characterized by a frequency range (FR1 or FR2), a UL/DL band, a duplex mode, applicable SCS and BS/UE bandwidths.
- Examples of operating bands in FR1 :

Designation	FR	UL [MHz]	DL [MHz]	Duplex mode
n66	FR1	1710 – 1780	2110 – 2200	FDD
n78	FR1	3300 – 3800	3300 – 3800	TDD
n261	FR2	27500-28350		TDD

- Examples : In n66, subcarrier spacings 15, 30, and 60 kHz are applicable and BS/UE bandwidth are at most 40 MHz. In n78, same subcarrier spacings, BS/UE bandwidth up to 100 MHz. In n261, subcarrier spacing of 60 or 120 kHz, BS/UE bandwidth from 50 to 400 MHz.
- For more information : [3GPP 38.101, 2019, 3GPP 38.104, 2019]

Frequency bands and channel bandwidths

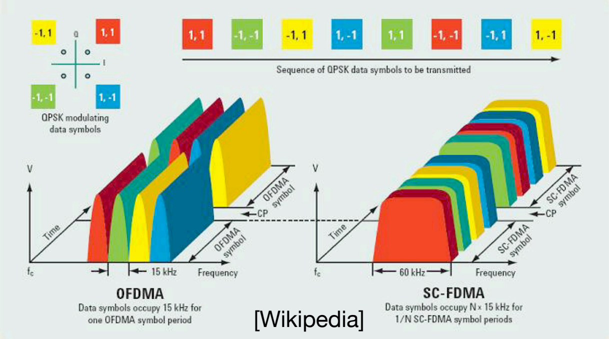
Although the standard defined a very wide range of possible bands, some are of particular interest (european perspective) :

- 700 MHz with maximum bandwidth of 20 MHz for coverage and/or machine-type communications.
- 1400 MHz only for downlink as a supplementary carrier for enhancing capacity.
- 3.4-3.8 GHz with maximum bandwidth of 100 MHz for capacity. The "core" band for 5G in early phases.
- 26 GHz with maximum bandwidth of 400 MHz for hot spots and small cells.
- Later : 42 GHz and 66-71 GHz.

Below 6 GHz, around 1.2 GHz may be available for mobile communications ; above 6 GHz (26+41+66), around 11 GHz are available.

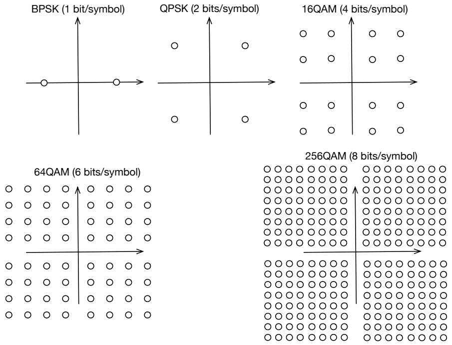
Duplexing and multiplexing

- **Duplexing** will be mainly FDD below 6 GHz and TDD above. Small/isolated cell can adopt dynamic TDD, while macro cells semi-static TDD or FDD.
- **Multiplexing** is OFDMA for DL and UL with SC-FDMA as an option for UL (for coverage limited scenarios). OFDMA is preferred for higher order modulations and uplink massive MIMO, while SC-FDMA is a fall back when the channel is quality is not sufficient for multi-stream MIMO.



Modulations

- **Modulations** : up to 256QAM (in both DL and UL) ; $\pi/2$-BPSK in UL for reduced PAPR and better amplifier efficiency at low data rates for IoT.



Coding

- Control channels : Reed-Muller block codes and CRC assisted polar codes [Arikan, 2009] (vs. tail-bitting convolutional codes in LTE).
- **Data channels** use rate compatible (for IR-HARQ) quasi-cyclic Low-Density Parity Check Codes (LDPC vs. Turbo codes in 3G, 4G).
- LDPC has been invented by Gallager in the 60's [Gallager, 1962], ignored for a long time and rediscovered in the 90's [MacKay and Neal, 1997].
- Already adopted in WiFi, DVB or ATSC.
- Compared to Turbo codes :
  - LDPC have usually similar performance but higher performance at high code rates
  - LDPC encoding and decoding is less complex
  - LDPC allow for a greater parallelism and thus lower decoding delay

[Richardson and Kudekar, 2018, Hui et al., 2018]

Coding

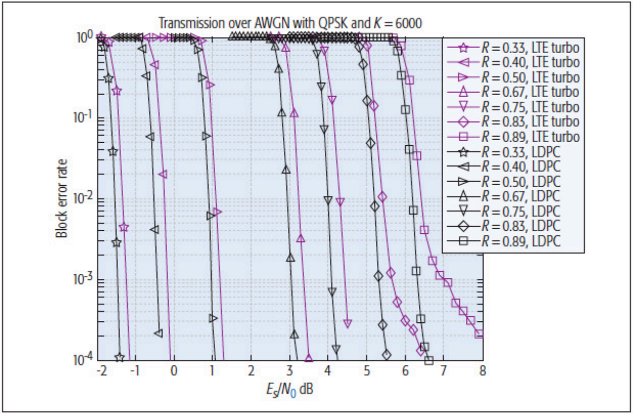
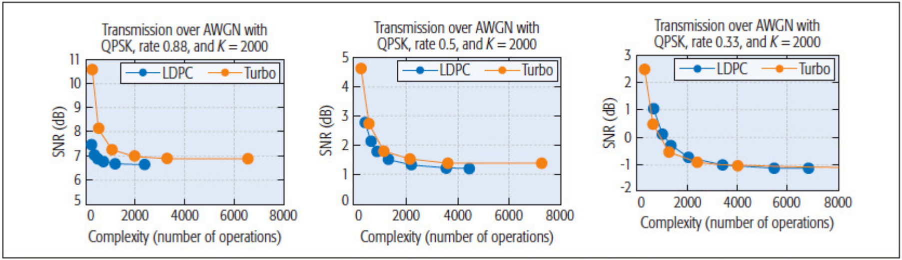


Figure 1. Performance comparison between LDPC with sum-product (SP) decoding and LTE turbo with log-MAP decoding. Both are decoded using their optimal decoders with sufficiently large number of iterations. The plot highlights the fundamental differences in the code structure itself.

from [Richardson and Kudekar, 2018]

Coding



from [Richardson and Kudekar, 2018]

Numerology

- NR supports different subcarrier spacings to support different kinds of services.
- Different numerologies are derived from a base by a scaling factor. They are time aligned and the number of OFDM symbols per subframe is constant.
- The cyclic prefix overhead is approximately constant (about 6%), except for an extended prefix configuration at 60 kHz subcarrier spacing.
- It may be possible to multiplex different numerologies on the same carrier.
- Configurations :
  - $f_c < 6$ GHz : $\mu \in \{0, 1, 2\}$ and bandwidth is from 5 MHz to 100 MHz
  - $f_c > 6$ GHz : $\mu \in \{2, 3\}$ and bandwidth is from 50 MHz to 400 MHz

Numerology

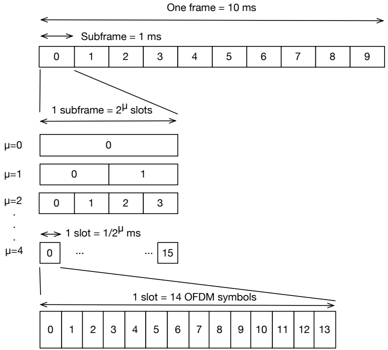
Table – Numerology

Subcarrier spacing config μ	0	1	2	3	4
Subcarrier spacing [kHz]	15	30	60	120	240
Symbol duration [μs]	66.7	33.3	16.6	8.33	4.17
Nominal cyclic prefix [μs]	4.7	2.41	1.205	0.6	0.3
Nominal max bandwidth [MHz]	49.5	99	188	396	397.4
Max FFT size	4096	4096	4096	4096	2048
Nb of symb/slot	14	14	14	14	14
Slot duration [ms]	1	0.5	0.25	0.125	0.0625
Frequency range	FR1	FR1	FR1/2	FR2	Only SSB

$\mu \in \{0, 1, 3, 4\}$ for PSS, SSS and PBCH, $\mu \in \{0, 1, 2, 3\}$ for other channels.
[3GPP 38.211, 2018]

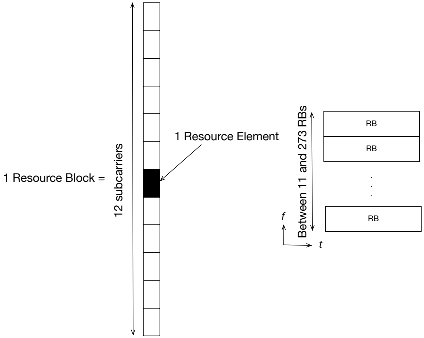
Frame Structure

- Regardless of the numerology, subframe and frame durations are constant (all numerologies align in time at subframe boundaries).
- The number of OFDM symbols per slot is always 14 for the normal prefix.



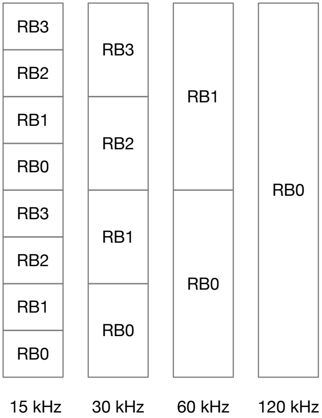
Resource Blocks and Resource Elements

- Resource Blocks are defined in the frequency domain as 12 consecutive subcarriers. There are bw 11 and 273 RBs (depending on the signal bandwidth).
- 1 RB during 1 OFDM symbol is called a Resource Element Group (REG).
- A Resource Element is defined as 1 subcarrier during 1 OFDM symbol on 1 antenna port for 1 subcarrier spacing configuration.



Resource Blocks and Resource Elements

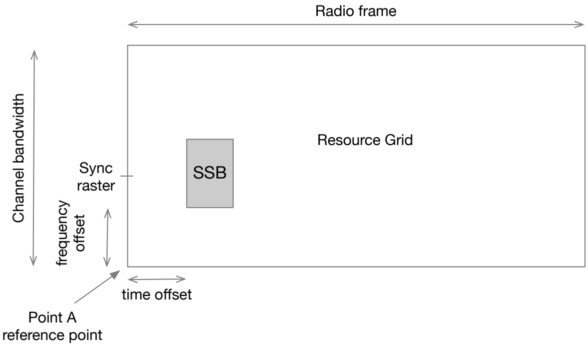
RB alignment across subcarrier spacings :



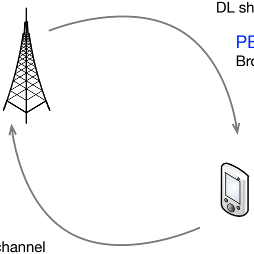
Resource Blocks and Resource Elements

Frequency domain resource organization

- There is one resource grid per subcarrier spacing and antenna port.
- *Point A* is a reference point for all resource grids. Its location is signalled in SIB1.
- There are *common resource blocks* and *physical resource blocks* for every subcarrier spacing. CRB are a common reference ; PRB are effectively used for transmissions in the bandwidth part.



Physical Channels



PDSCH
DL shared channel

PBCH
Broadcast channel

PDCCH
DL control channel

DL Physical Signals
Demodulation Reference Signals
Phase-tracking RS
Channel State Information RS
Primary Sync PSS
Secondary Sync SSS

PUSCH
UL shared channel

PUCCH
UL control channel

PRACH
Random access channel

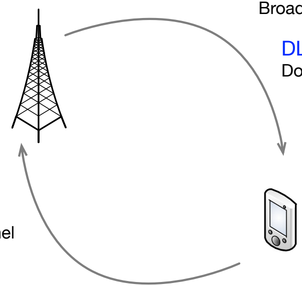
UL Physical Signals
Demodulation RS
Phase-tracking RS
Sounding RS

Transport Channels

BCH
Broadcast channel

DL-SCH
Downlink shared channel

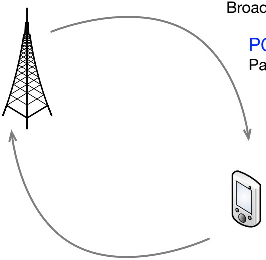
PCH
Paging channel



UL-SCH
Uplink shared channel

RACH
Random access channel

Logical Channels



BCCH
Broadcast control channel

PCCH
Paging control channel

CCCH
Common control channel

DCCH
Dedicated control channel

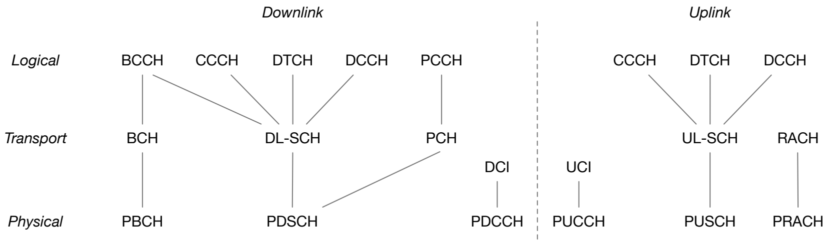
DTCH
Dedicated traffic channel

CCCH
Common control channel

DCCH
Dedicated control channel

DTCH
Dedicated traffic channel

Channel Mapping



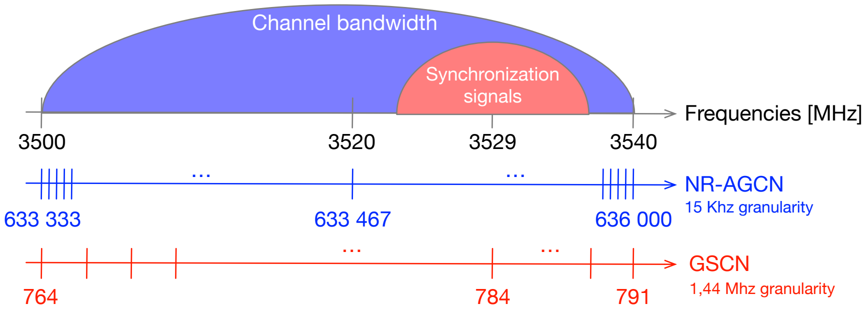
Cell search

Goal : acquiring time and frequency synchronisation, cell ID and system information

1. Find SSB in the synchronization raster
2. Get relative position of the SSB in the carrier bandwidth from PBCH
3. Get timing/beam index of the SSB from PBCH
4. Get initial CORESET from PBCH
5. Get SIB1 scheduling from CORESET

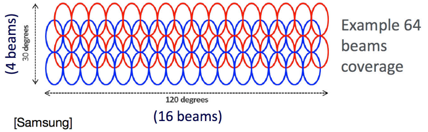
Cell search

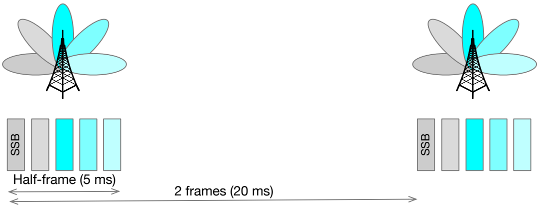
Example of channel and synchronization raster values around 3.5 GHz :

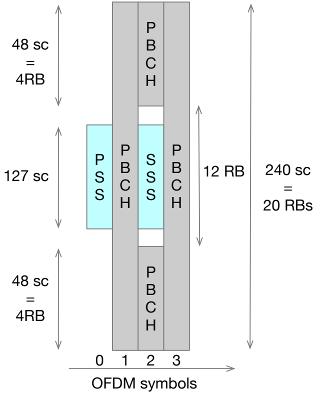


Cell search

Synchronization blocks :

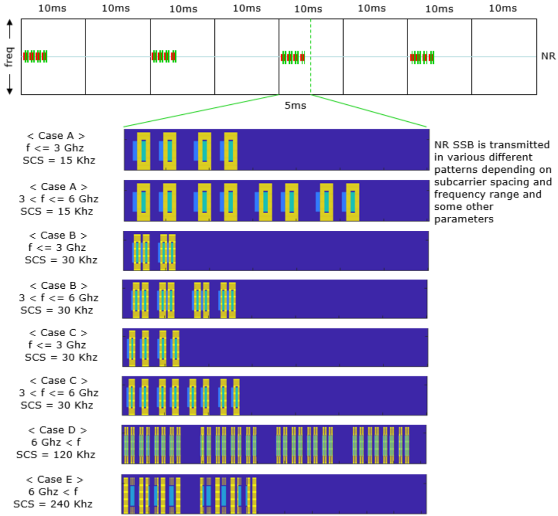






- PSS, SSS and PBCH are transmitted within a 'SS block' (SSB). SSBs are sent by bursts of up to 8 blocks (for FR1) or 64 blocks (FR2) within a half-frame of 5 ms and every 5 to 160 ms (ty pical : 20 ms).

Cell Search



[source : ShareTechnote.com]

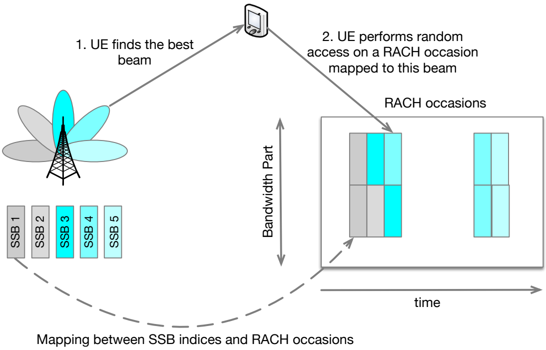
Cell search

SS/PBCH :

- PSS is used for initial symbol boundary synchronization, PSS/SSS for the detection of the cell ID. PSS broadcasts 1 out 3 sequences and SSS one out of 336. There are in total 1008 possible cell IDs.
- Cell ID is required to decode PBCH and find DMRS locations.
- Subcarrier spacing for SSB can be higher than for data, e.g. 120/240 kHz iso 60/120 kHz in FR2 to reduce beam sweeping latency and overhead.
- MIB includes : SSB index (identifies this SSB in the SS burst set), half-frame indication, SFN, common subcarrier spacing, frequency offset bw this SSB and the overall resource block grid, info for decoding PDCCH/SIB1 (bandwidth, CORESET, common search space, PDCCH parameters).
- PBCH has its own reference signals DMRS.

Random access

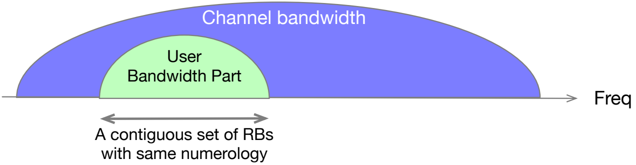
- The PRACH resources and the preamble format to be used are provided to the UE in the system information.
- Open loop power control and power ramping are applied.



Data transmission : BWP

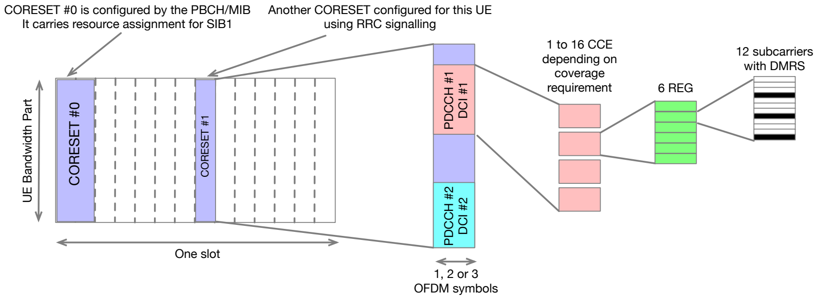
Bandwidth Parts (BWP) : "Stay in the box" !

- A UE can be active only on a narrow part of the NR carrier bandwidth (e.g. to reduce energy consumption or for low-end devices).
- With bandwidth adaptation, the receive and transmit bandwidth of a UE can be adjusted :
  - the width (e.g. the BWP can shrink in case of low activity to save power)
  - the location (to increase scheduling flexibility)
  - the subcarrier spacing (to adapt to different services)
- BWPs are configured at the UE. The network can inform the UE to dynamically change its active BWP.



Data transmission : DL control

Control Resource Sets (CORESETs) :

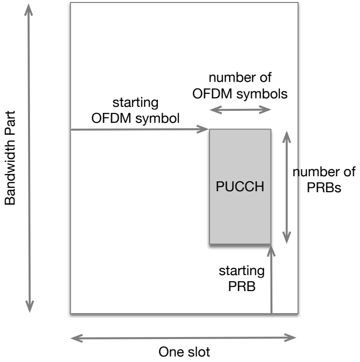


- A CORESET is a time-frequency resource where control channels PDCCH may be located. Contrary to LTE, it does not span the entire bandwidth.
- The location and the size of the CORESETs are semi-statically configured by RRC. CORESET0 is given in the MIB. Rather at the beginning of the slot but not necessary (for ultra low latency).
- Different code rates are available by aggregating CCEs.

Data transmission : UL control

PUCCH :

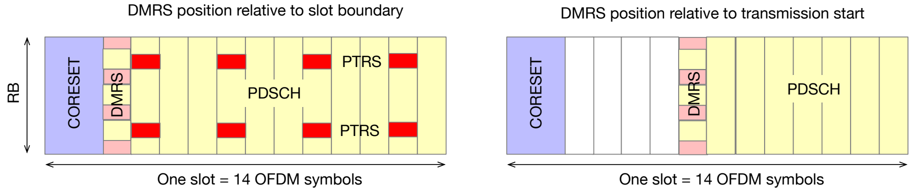
- Localization is flexible in time and frequency : either predefined formats are signalled by SIB1 or defined by RRC messages.
- UCI includes CSI (Channel State Information = CQI, RI, PMI, Reference Signal Received Power, index of the SSB, index of the CSI-RS), ACK/NACK and scheduling requests.



Reference Signals

Demodulation Reference Signals (DMRS) for coherent demodulation.

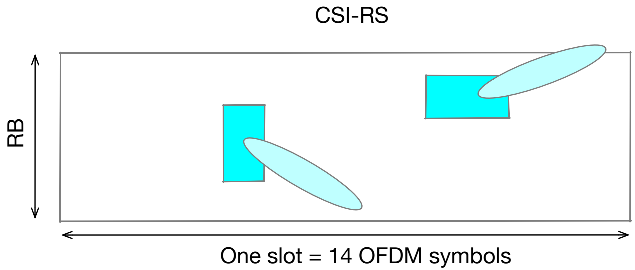
- Support variable nb. of antenna ports, very short transmissions, high-speed scenarios
- Front-loaded : the receiver can decode on the fly for lower latency
- DMRS at the beginning of the slot : PDSCH occupies most of the slot
- DMRS at the beginning of the transmission : PDSCH short transmissions ("mini-slot" approach).



Reference Signals

Channel State Information Reference Signals (CSI-RS) for channel sounding on the DL

- Configured on a per-UE basis to avoid "always on" signals.
- Several UEs share the same set of CSI-RS.
- CSI-RS for different antenna ports are multiplexed in time, frequency or code
- Periodic, semi-persistent (may desactivated) or aperiodic (the UE is informed)



Reference Signals

Other reference signals :

- PTRS are used for tracking the phase of the local oscillator at transmitter and receiver. This is used to compensate for phase noise and it is particularly important at high carrier frequencies.
- SRS are used for UL sounding and to allow UL frequency domain scheduling.

Some words on future releases

R16 frozen in mid-2020 :

- V2X : platooning, extended sensors, automated driving, remote driving.
- IIoT and URLLC : for factory automation with the goal of replacing wired Ethernet
- Unlicensed bands : LAA and standalone operation
- eMBB enhancements : positioning, MIMO, power consumption, dual connectivity, SON, interference mitigation, mobility, etc.
- Integrated Access and Backhaul.

[3GPP 21.916, 2019, Balazs Bertenyi, 2019]

Some words on future releases

R17 expected for end of 2021. Some potential work areas :

- NR light for mid-tier devices
- NR above 52.6GHz up to 114GHz with decision on waveform
- Multi-SIM operation
- NR multicast and broadcast mainly for V2X and public safety
- NR for non terrestrial networks
- Data collection to enable AI and SON
- Enhancements in small data transfer, D2D, coverage, IoT, URLLC, MIMO.

[Balazs Bertenyi, 2019]

Outline

Towards 6G ?

Some possible hot topics to imagine 6G :

- THz communications
- Visible light communications
- Cell-less architectures
- Intelligent meta-surfaces
- Zero-battery devices and wireless transfer
- ML physical layer design
- ML based resource allocation
- AI based network optimization

6G for what ? Telepresence ? What about energy consumption ?

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Acronyms I

5GC	5G Core Network
ACK	Acknowledgment
AI	Artificial Intelligence
AM	ARQ Acknowledged Mode
ARFCN	Absolute Radio Frequency Channel Number
AR/VR	Augmented/Virtual Reality
ATSC	Advanced Television Systems Committee
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BS	Base Station
BWP	Bandwidth Part
CCA	Channel Clear Assessment
CCCH	Common Control Channel
CCE	Control Channel Element
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRB	Common Resource Block
CSI	Channel State Information
CU	Central Unit
D2D	Device to Device
DMRS	Demodulation Reference Signal
DCCH	Dedicated Control Channel
DCI	Downlink Control Information
DL	Downlink
DL-SCH	Downlink Shared Channel
DTCH	Dedicated Traffic Channel
DU	Distributed Unit
DVB	Digital Video Broadcasting

Acronyms II

EM	Electromagnetic
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
GSCN	Global Synchronization Channel Number
HARQ	Hybrid Automatic Repeat on Request
ICI	Inter-Carrier Interference
IIoT	Industrial IoT
IoT	Internet of Things
IR	Incremental Redundancy
ISI	Inter-Symbol Interference
LAA	Licensed Assisted Access
LBT	Listen Before Talk
LDPC	Low Density Parity Check
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MBB	Mobile Broadband
MIMO	Multiple Input Multiple Output
ML	Machine Learning
mmW	Millimeter Waves
MTC	Machine-Type Communications
NACK	Negative Acknowledgment
NB	Node-B
NLOS	Non Line of Sight
NR	New Radio
NSA	Non Stand Alone
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access

Acronyms III

PAPR	Peak to Average Power Ratio
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCH	Paging Channel
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PMR	Professional Mobile Radio
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PSS	Primary Synchronization Signal
PTRS	Phase Tracking Reference Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Qadrature Amplitude Modulation
QoS	Quality of Service
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RE	Resource Element
REG	Resource Element Group
RLC	Radio Link Control
ROHC	Robust Header Compression
RRC	Radio Resource Control
RS	Reference Signal
SA	Stand Alone
SC-FDMA	Single Carrier Frequency Division Multiple Access

Acronyms IV

SCS	Subcarrier Spacing
SDAP	Service Data Adaptation Protocol
SDU	Service Data Unit
SIB	System Information Block
SON	Self-Organized Networks
SRS	Sounding Reference Signal
SSB	Synchronization Signal Block
SSS	Secondary Synchronization Signal
TCP	Transport Control Protocol
TDD	Time Division Duplex
TM	ARQ Transparent Mode
TTI	Transmission Time Interval
UCI	Uplink Control Information
UE	User Equipment
UM	ARQ Unacknowledged Mode
UL	Uplink
UL-SCH	Uplink Shared Channel
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communications
V2X	Vehicle to Everything