5G Technology

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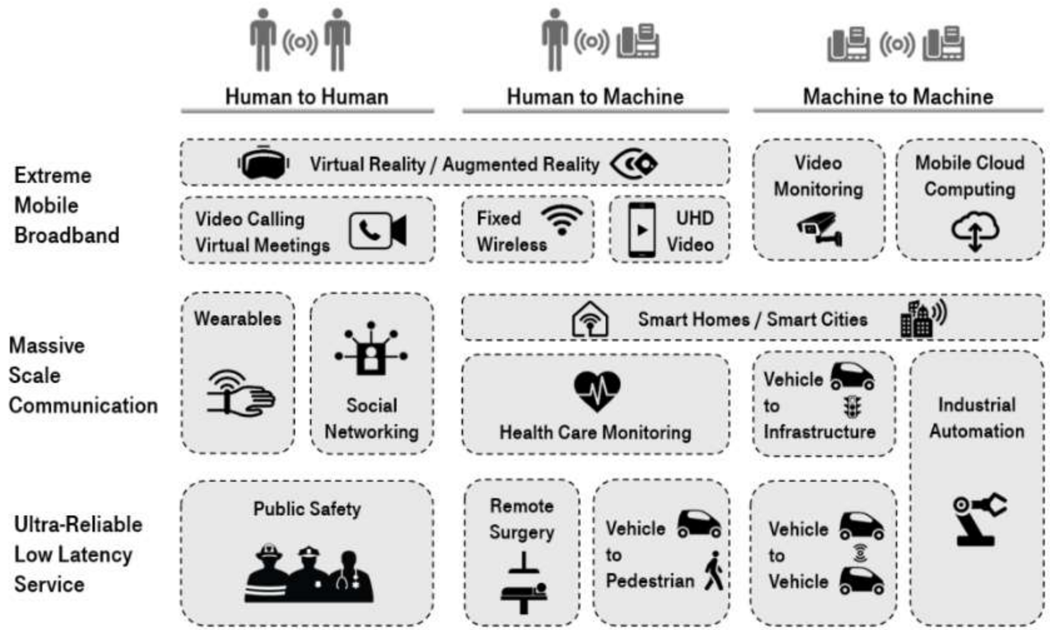
Why a new generation

New demanding services and applications

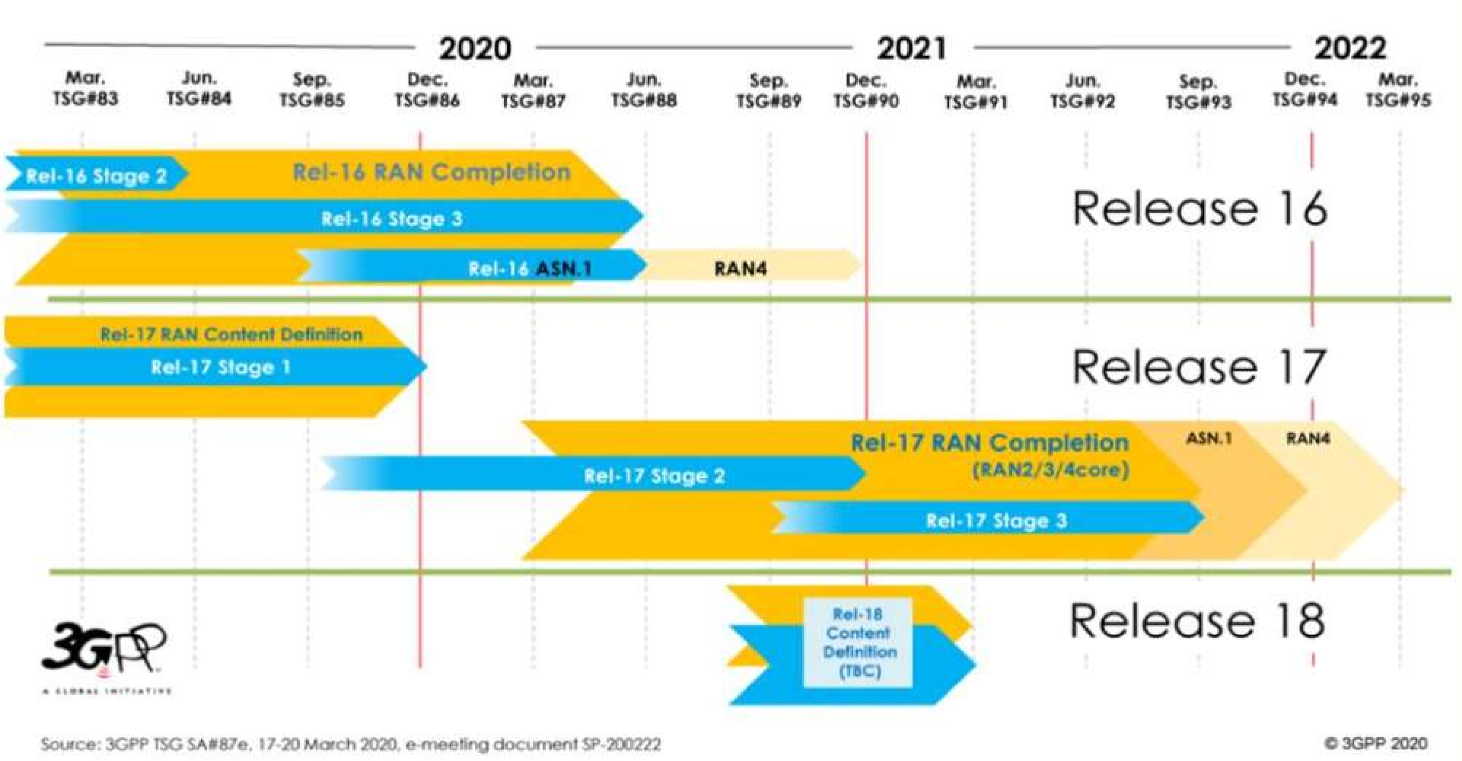
- Autonomous cars
- Smart cities
- IoT technology
- Immersive entertainment
- Communication and collaboration

Need for

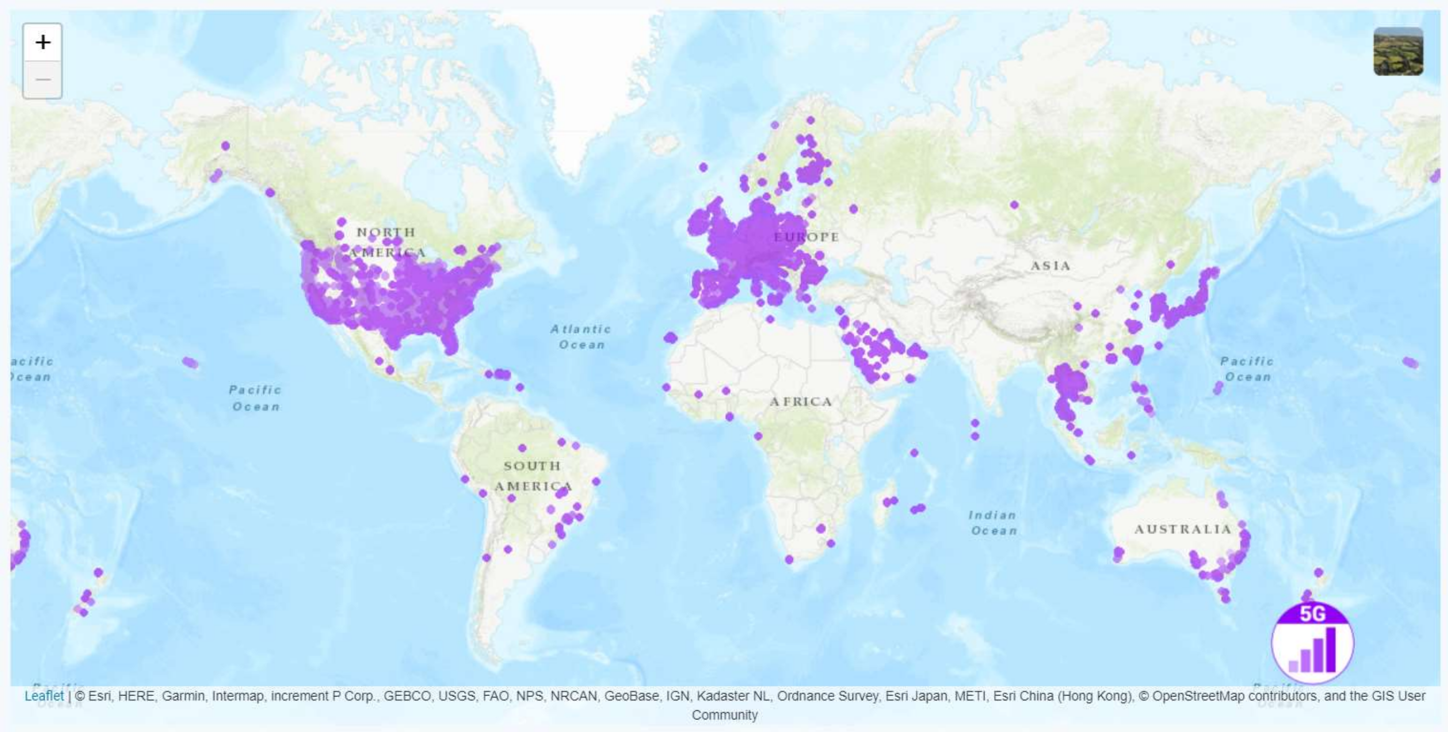
- Higher throughput (100 times the LTE throughput)
- Better spectral efficiency
- Better reactivity (latency of 4ms vs. 20ms f LTE)
- Better QoS management



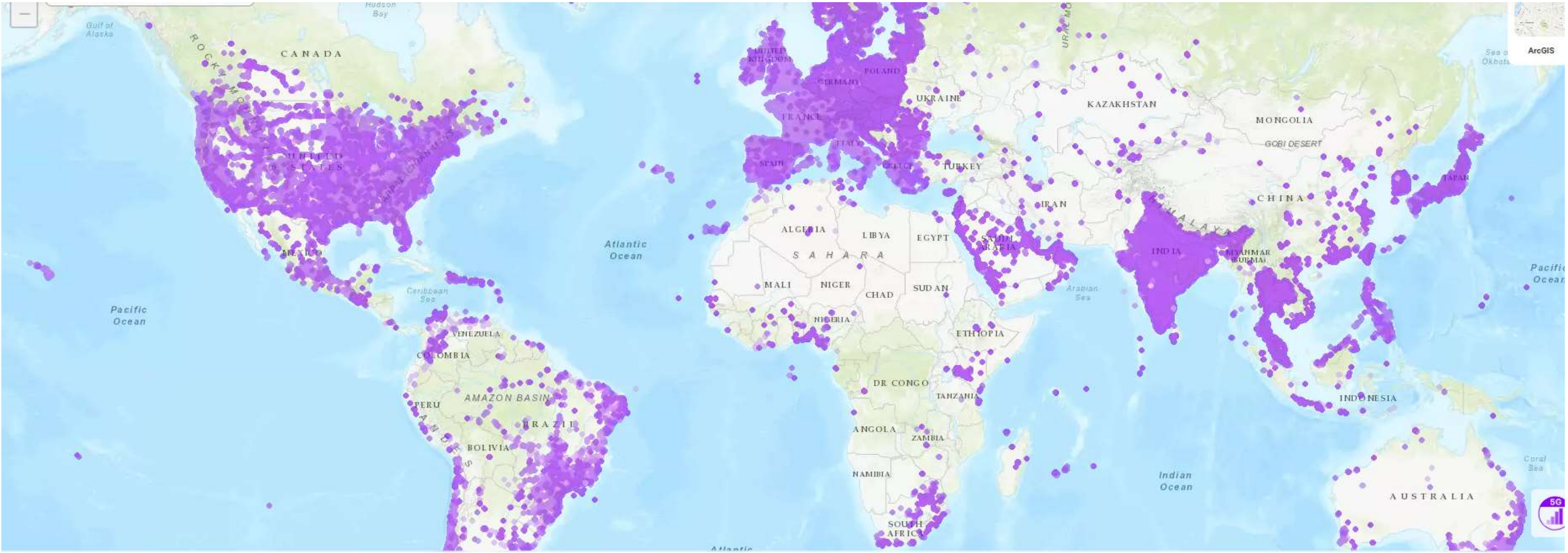
Current state



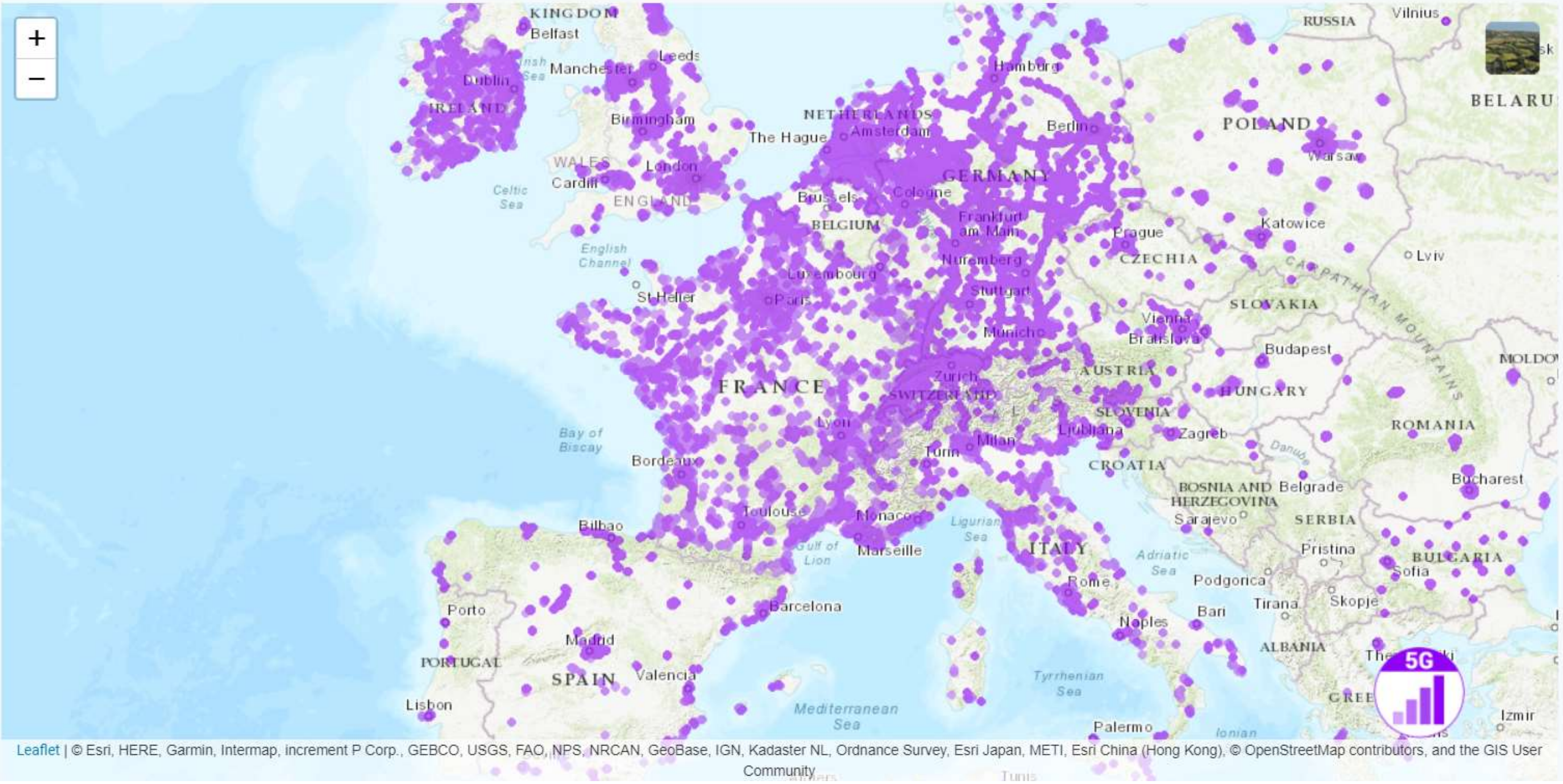
5G NR spreading (2022)



Current state(2024)



Current state



Current state – France

ARCEP delivered spectrum use authorization for the mobile operator at Nov, 12 2020 for frequency bande 3,4 – 3,8 GHz

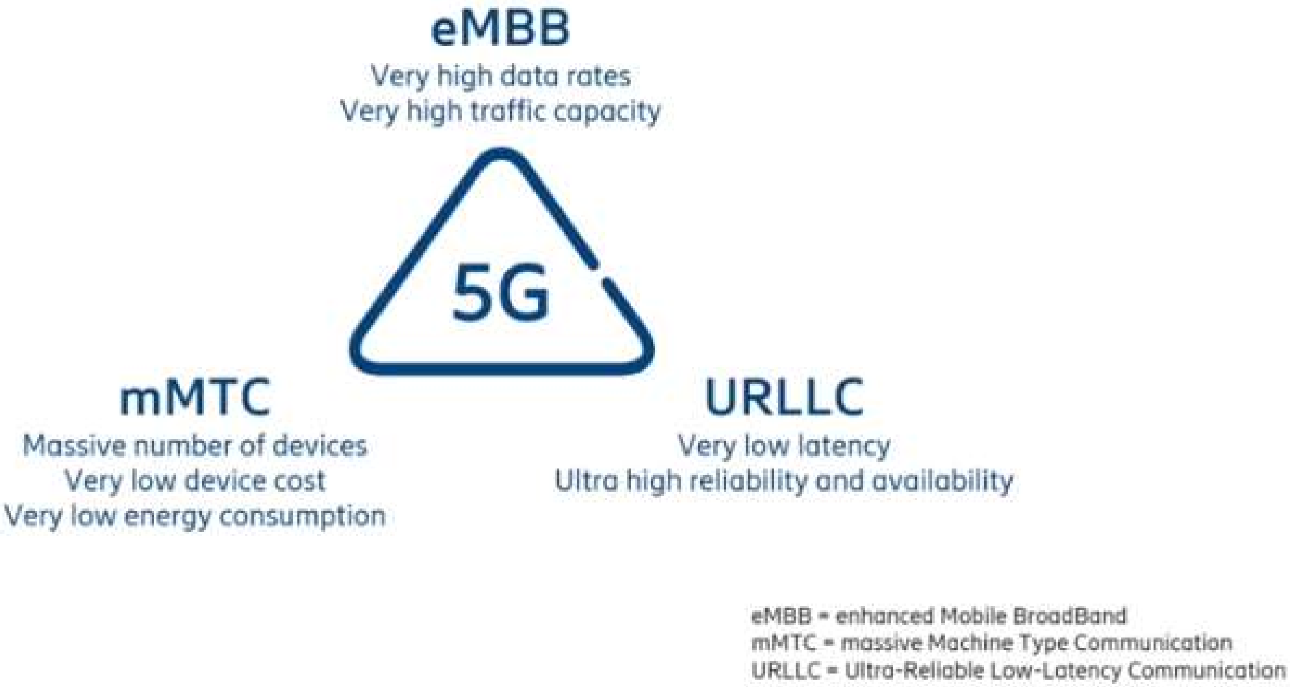
Candidat	Bouygues Telecom	Free Mobile	Orange	SFR	Total
Fréquences	3570 - 3640 MHz	3640 – 3710 MHz	3710 – 3800 MHz	3490 – 3570 MHz	-
Quantité de fréquences	70 MHz	70 MHz	90 MHz	80 MHz	310 MHz
Montant	602 000 000 €	605 096 245 €	854 000 000 €	728 000 000 €	2 789 096 245 €

What’s new in 5G

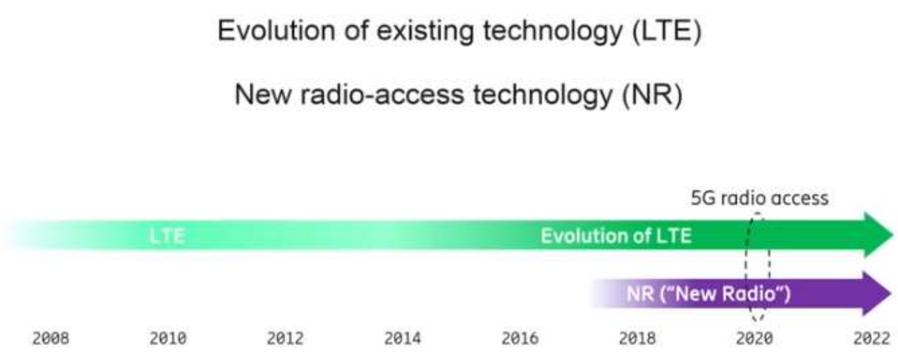
Starting from mid-2010s, telecom companies together with vendors jointly develop and test new technologies

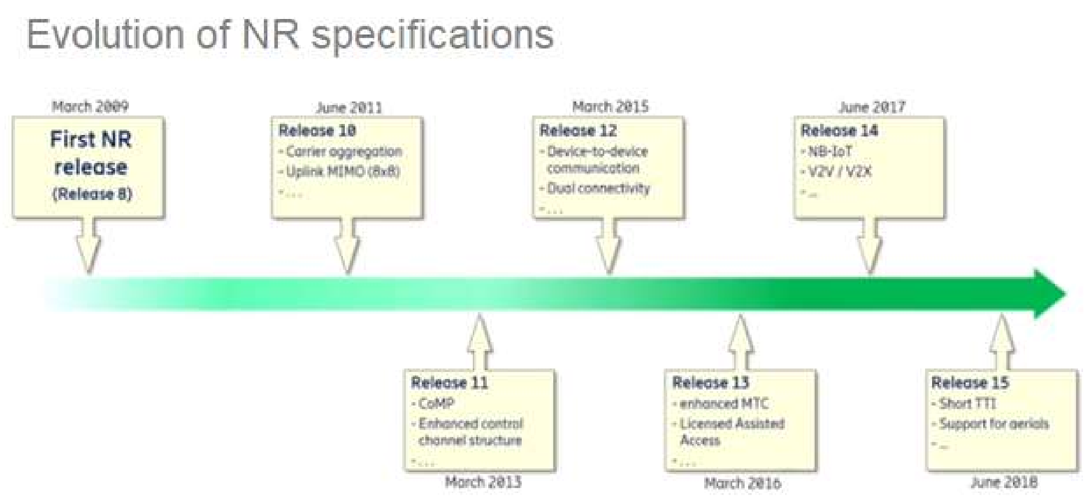
- 5G NR (New Radio) : the global standard of the air interface in 5G
- Frequency bands separated into two different frequency ranges :
  - Frequency Range 1 (FR1) of 6 GHz frequency bands
  - Frequency Range 2 (FR2) in the mmWave range (100Ghz-10THz).
- Nonorthogonal Multiple Access (NOMA)
- massive Multiple-In-Multiple-Out (MIMO)
- Internet of Things (IoT) and smart city technologies
- Industrial Internet of Things (IIoT)
- Machine-to-Machine (M2M)
- Device-to-Device (D2D)
- Vehicle-to-Vehicle (V2V)
- Vehicle-to-Everything (V2X) communications

Use cases applications



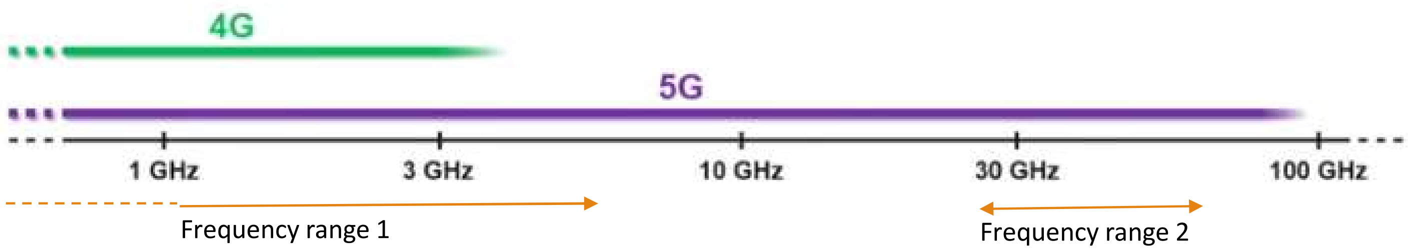
Parallel evolution of LTE (4G) and NR(5G) specifications





5G NR spectrum

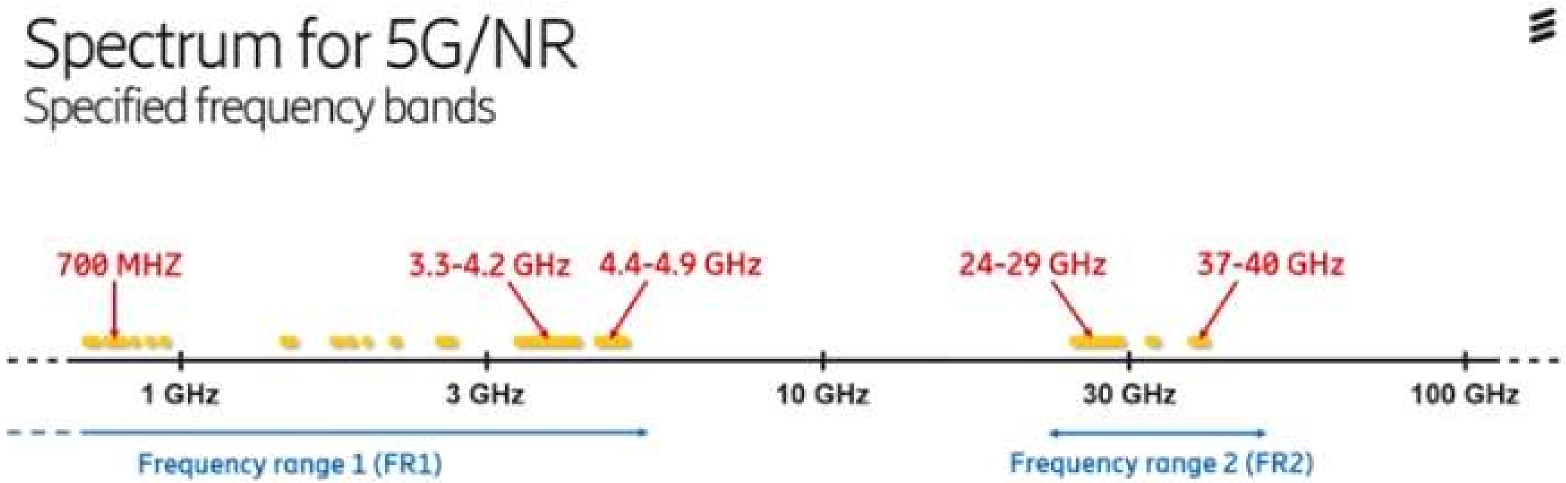
Extension to higher frequencies including millimeter-wave spectrum



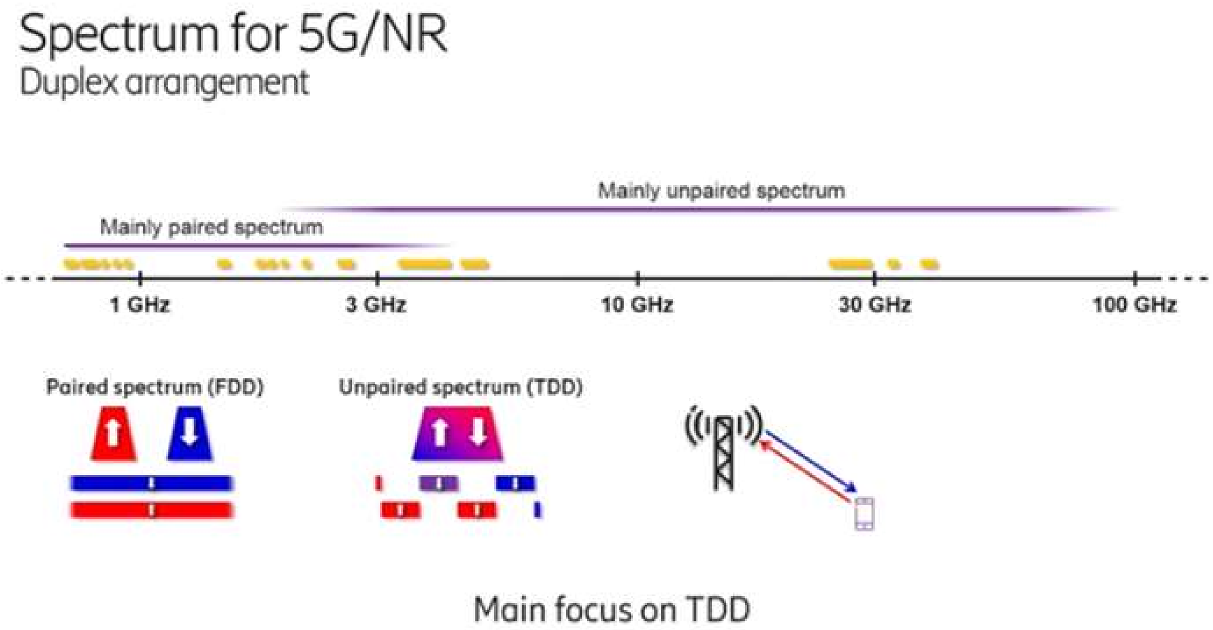
— Lower frequencies for wide-area coverage

— Higher frequencies for very high traffic capacity and very high data rates in dense deployments

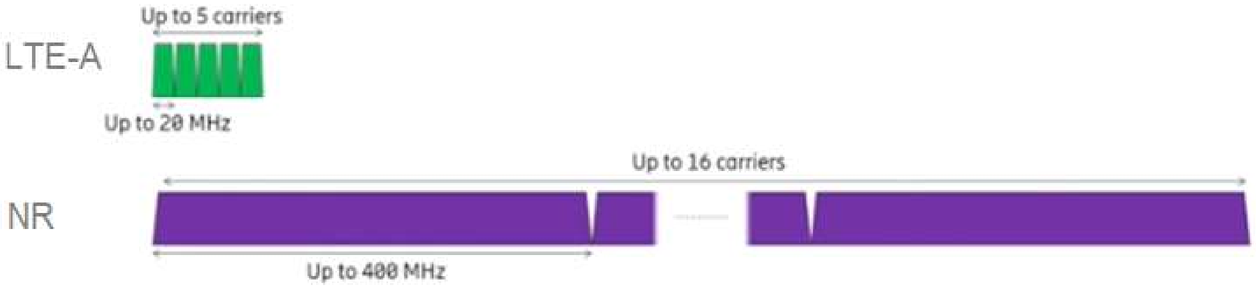
Spectrum use around the world



TDD vs. FDD mode



5G NR – radio carrier



LTE-A

- Per carrier bandwidth up to 20 MHz
  - Minimum carrier bandwidth: 1.25 MHz
- Carrier aggregation up to 5 carriers
  ➪ Maximum bandwidth: 100 MHz

NR

- Per-carrier bandwidth up to 400 MHz
  - Minimum carrier bandwidth: 5 MHz
- Carrier aggregation up to 16 carriers
  ➪ Maximum bandwidth: 6.4 GHz (!)

Multiple access technology

LTE

— Downlink: Conventional OFDM

— Uplink: SC-FDMA

— A single numerology with 15 kHz sub-carrier spacing

NR

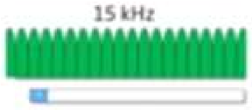
— Downlink: Conventional OFDM

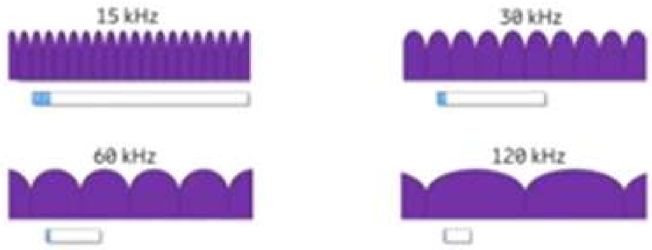
— Uplink: Conventional OFDM or SC-FDMA

— Flexible/scalable numerology

— 15 kHz, 30 kHz, 60 kHz, 120 kHz

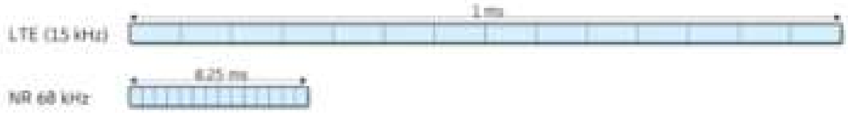
— Correspondingly scaled symbol length





Latency in 5G NR

- Higher numerology ➪ Shorter slots
  - 1 ms at 15 kHz ➪ 0.25 ms at 60 kHz



- Possibility for sub-slot transmission
  - Transmissions not confined to slots

- Faster retransmissions
  - Enabled by enhancements in processing capabilities

Enables more than 10X lower radio-interface latency compared to LTE

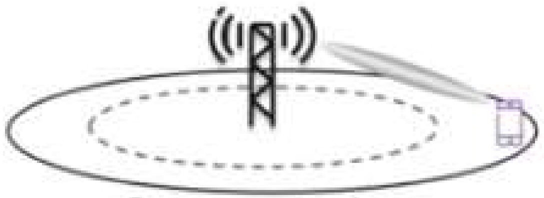
Smart antenna and Beam forming

— Use of antenna array with many antenna elements to focus transmitted energy in desired direction

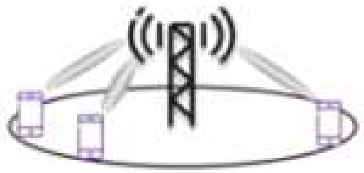
— More energy reaching target receiver ⇨ Extended coverage

— Less interference to other links ⇨ Higher system capacity

  — Reuse of the same resources within one cell ("multi-user MIMO")



Coverage extension



Spatial reuse

LTE and 5G NR cohabitation

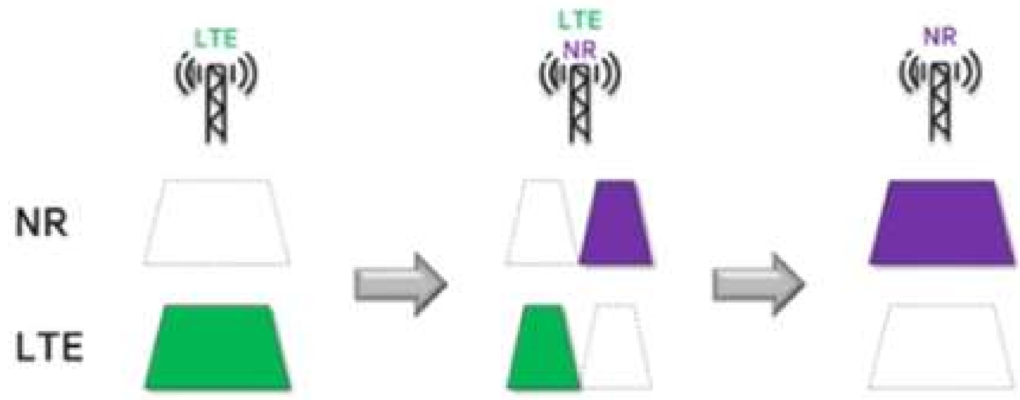
— NR will often be deployed in new spectrum at high frequencies (e.g. 28 GHz)

— NR will also often be deployed in lower-frequency spectrum (as low as 700 MHz)

  — Spectrum often already used by LTE

⇨ *Spectrum migration* or *spectrum co-existence*

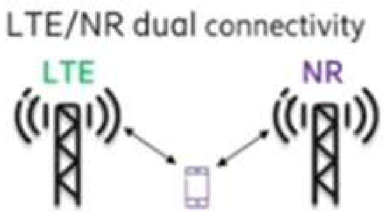
5G NR deployment

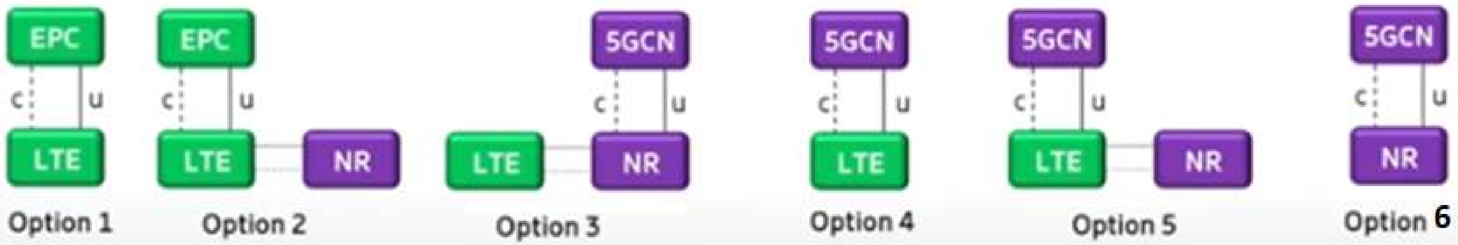


— Loss of LTE capacity and data rates when introducing NR
— Limited NR data rates during migration
— Long time until full NR deployment

Core network

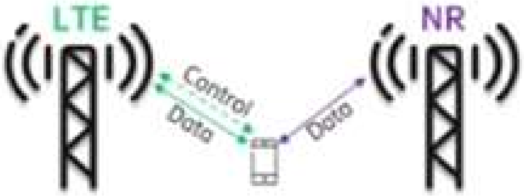
- In addition to NR, 3GPP is also developing a new core network – 5GCN
- Different RAT/CN combinations/options
  - NR alone or in dual-connectivity with LTE
  - EPC or 5GCN
  - Master/slave relation

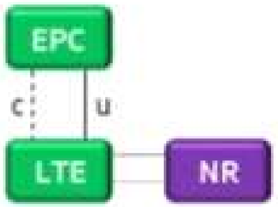




Non-stand-alone NR

- December release limited to NR *non-stand-alone* operation
- LTE/NR dual-connectivity
  - LTE providing all control-plane functionality
  - NR provides complementary user-plane capacity
- Core network based on EPC (option 3)
  - 5GCN not yet available
- Will remain an important deployment option also for the future





NOMA vs. OFDMA

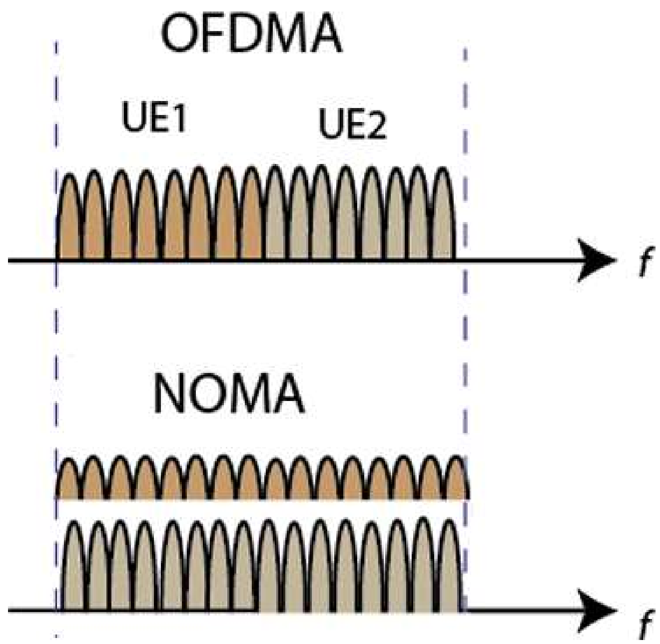
Advantages

- increased spectral efficiency (about 20%)
- increased total throughput (50%)
- no near-far effect

Drawbacks

- complex receiver design
- early stage of NOMA development

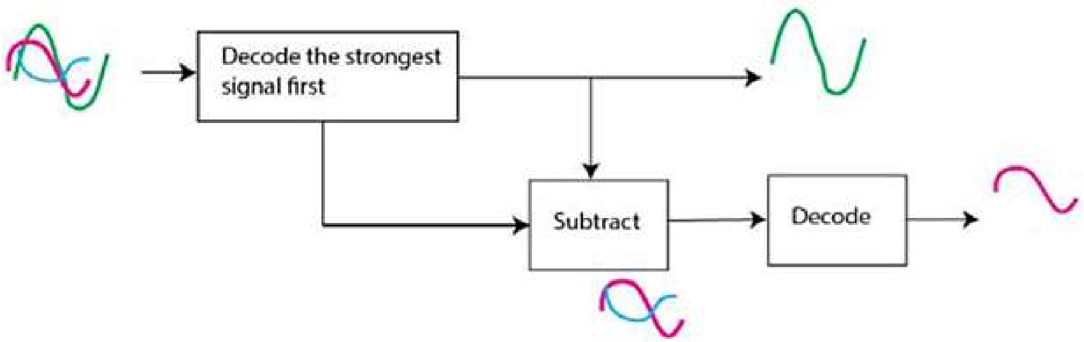
It is proposed for long-term evolution advanced (LTE-A) standard



NOMA operation scheme

Two main mechanisms:

- Superposition coding at transmitter of different data streams (waveforms): use of different power for each data stream
- Successive Interference Cancellation (SIC) to decode the different streams consecutively from the strongest waveform to the weakest



NOMA in Downlink

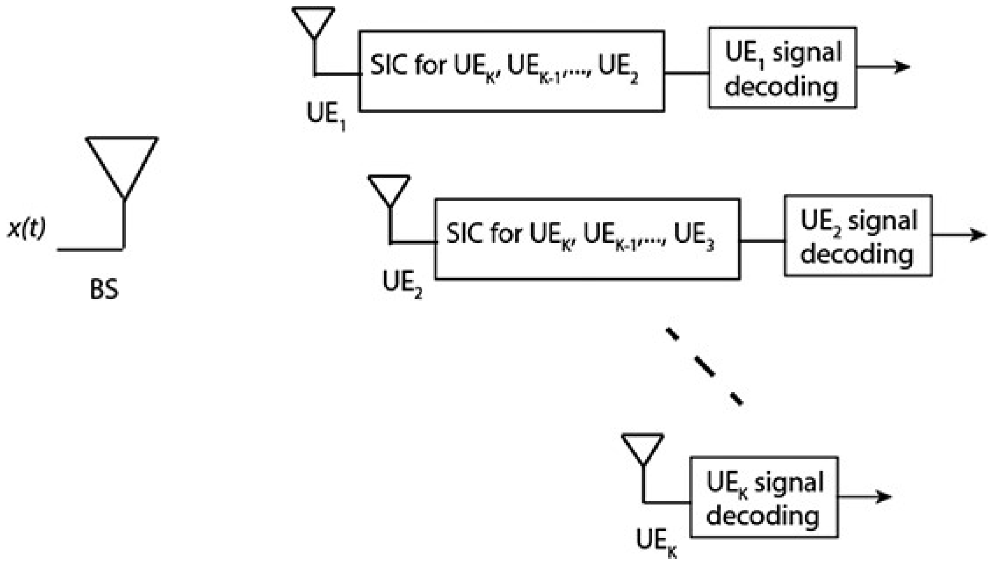
The base station superimposes the information waveforms for its serviced users.

Each user equipment (UE) employs SIC to detect their own signals.

The closest UE to the base station (BS) obtains the minimum power while the farthest obtains the maximum power

The farthest UE extract its data earlier (few iterations of SIC)

The closest UE extracts its data after many iterations of SIC



NOMA in Downlink

The transmitted signal by the BS is:

$$x(t) = \sum_{k=1}^{K} \sqrt{\alpha_k P_T} x_k(t)$$

Where :

$x_k(t)$ is the individual symbol waveform,

α_k is the power allocation coefficient for the UE_k,

P_T is the total available power at the BS

The power allocated to each UE_k is :

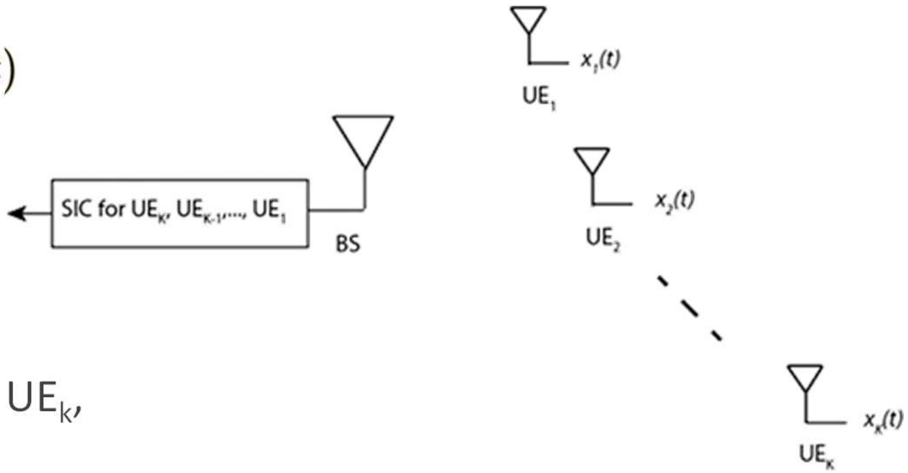
$$P_k = \alpha_k * P_T$$

The received signal at the UE_k is $y_k(t) = x(t) g_k + w_k(t)$

NOMA in Uplink

The transmitted signal by the UE depends on its distance from the antenna

$$y(t) = \sum_{k=1}^{K} x_k(t)\, g_k + w(t)$$



Where :

$x_k(t)$ is the individual symbol waveform received from UE_k,

g_k is the power attenuation of the signal received from the UE_k,

W(t) is the white nose

The SIC decode the signal from the nearest UE first

Device to Device technology

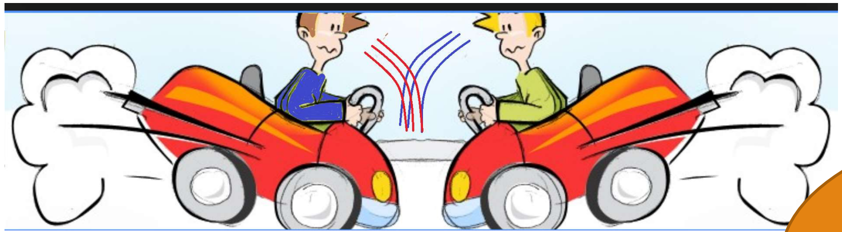
Presents three main benefits:

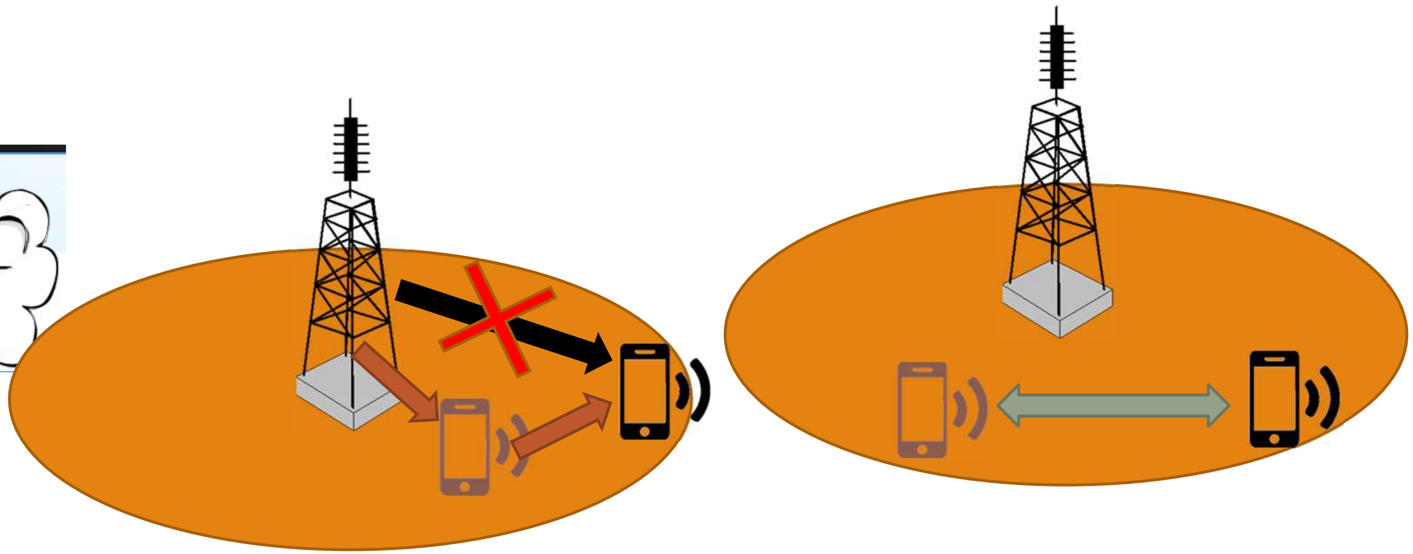
- New applications specially in safe-driving technology (V2V, V2P, V2N, V2X)
- Use the UEs as relays for users near the edge of the cell
- Direct communications without need for the 5G infrastructure (latency reduction)

Device to Device technology

D2D challenges

- Security issues: the data are relayed by a third part
- Energy issues: the UEs near the antenna may be overused reducing the duration of their batteries





Edge computing

Edge Computing is new computer architecture presenting an alternative to the Cloud Computing.

Rather than transferring data collected by IoT objects to a distant cloud, data are sent to local cloud (micro data center).

Advantages:

- The transmission of the increasing amount of collected data to a distant cloud is unrealistic
- Actors in field of health, manufacturing, telecommunication and financial require the processing of more data in faster way

Edge computing

Advantages:

- IoT objects have a limited throughput which leads to long periods of communication with the Cloud (communication latency). Use of local cloud reduces the problem.
- Latency reduction is very important for applications such as safe driving, financial, etc.

Edge Computing is one of major objectives of 5G technology. A micro data center will be attached to each 5G antenna.