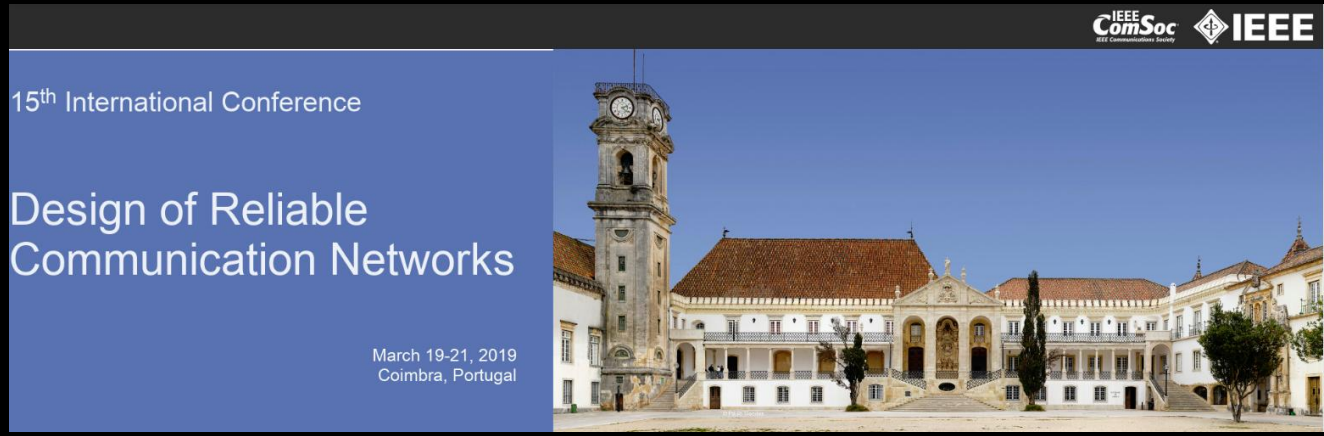

Challenges and contributions regarding reliability

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Altice Labs, S.A.

altice labs

Agenda

1. 5G definition
2. Reliability challenges
3. 5G reliability solutions
4. Final remarks

1. 5G definition
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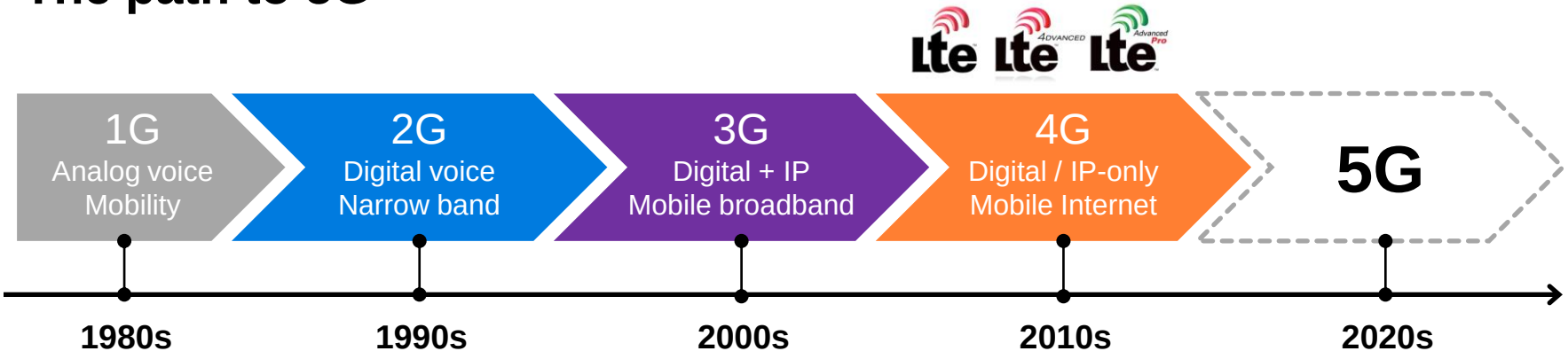
The path to 5G



ITU-R (*International Telecommunication Union*) defined IMT-2020 (5G) aspiration:

> "*Enabling a **seamlessly connected society** in the **2020 timeframe** and beyond that **brings together people along with things, data, applications, transport systems and cities** in a smart networked communications environment*"

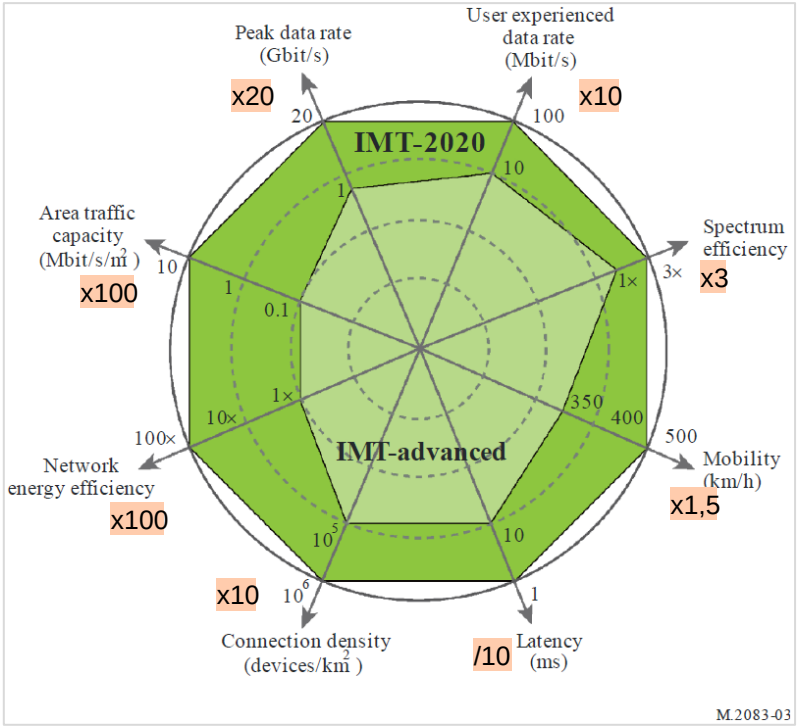
With **5G**, wireless/mobile communications will become a **GPT** (General Purpose Technology)

(IHS: "***GPTs lead to deep and sustained impacts accross a broad range of industries that often redefine economic competiveness and transform societies***")

5G performance improvement requirements

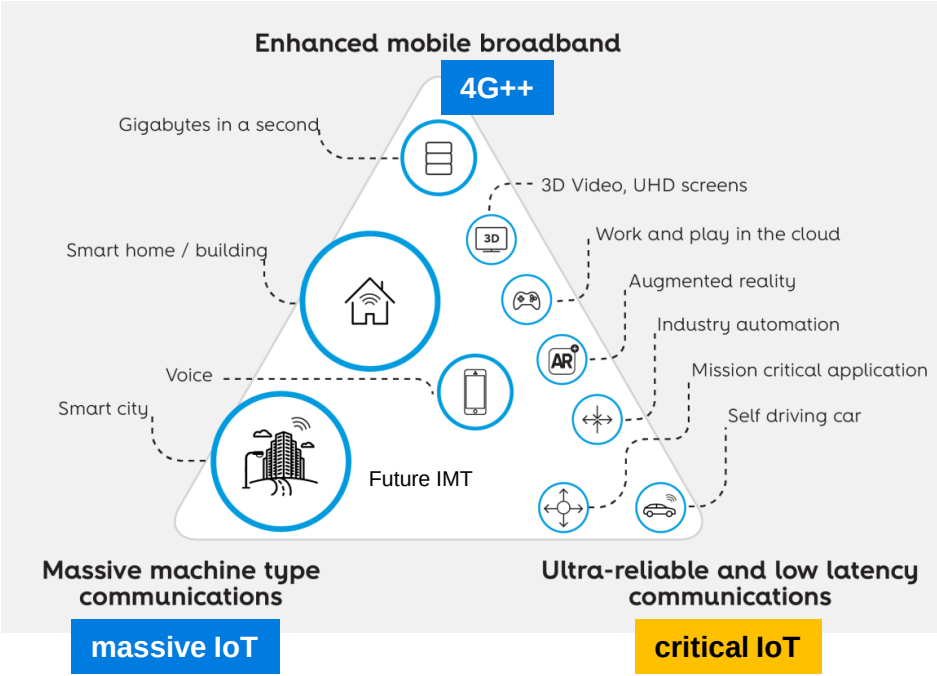
Metric	Requirement	Comments
Peak data rate	DL: 20 Gbit/s UL: 10 Gbit/s	assignable to a single mobile station
Peak spectral efficiency	DL: 30 bit/s/Hz UL: 15 bit/s/Hz	assignable to a single mobile station
User experienced data rate	DL: 100 Mbit/s UL: is 50 Mbit/s	5% point of the cumulative distribution function (CDF) of the user
Area traffic capacity	10 Mbit/s/m^2	indoor hotspot, eMBB
User plane latency	4 ms for eMBB 1 ms for URLLC	contribution of the radio network; one-way; small IP packets (0 byte payload + IP header), for UL and DL
Control plane latency	20 ms	transition time from Idle to Active state; eMBB and URLLC
Connection density	1 000 000 devs per km2	mMTC
Mobility	500 km/h	High speed vehicular, Rural – eMBB
Reliability	1-10^{-5}	32 bytes, L2 PDU, within 1 ms, 20 bytes application data + protocol overhead

ITU-R, "M.2410-0 - Minimum requirements related to technical performance for IMT-2020 radio interface(s)," 2017.



ITU-T, M.2083

5G ‘usage scenarios’ (ITU-R)



5G will power a **new generation of services and applications** in the areas of:

1. *enhanced Mobile BroadBand* (eMBB)
   Make it faster!
2. *massive Machine Type Communications* (mMTC)
   Make it massive!
3. *Ultra-Reliable, Low Latency Communications* (URLCC)
   Make it trustable and responsive!

All with a single, unified technology

Reinforce B2C

Embrace B2B

5G System

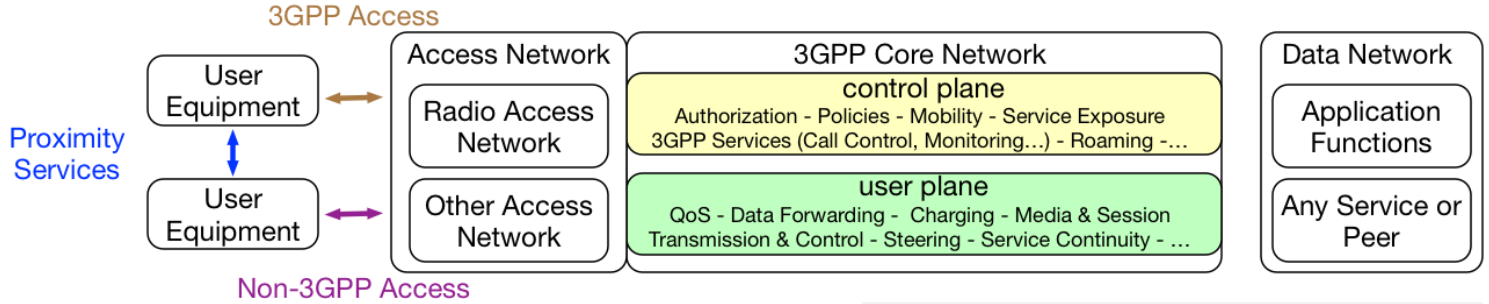
3GPP system consisting of a **5G Access Network** (AN), a **5G Core Network** and **UEs**

Based on a **new, unified, air interface**, able to "connect everything":
- 5G *New Radio:* ***5G-NR***

"You will be seeing 5G NR connectivity in your smartphones, cars, utility meters, wearables and much more" (Qualcomm)

Based in a **new architecture**, centred at a **common core**, able to "interconnect everything":
- *5G Core Network:* ***5GC***

"The new architecture shall support at least the new RAT(s), the Evolved E-UTRA, non-3GPP accesses and minimize access dependencies" (3GPP TR 23.799)

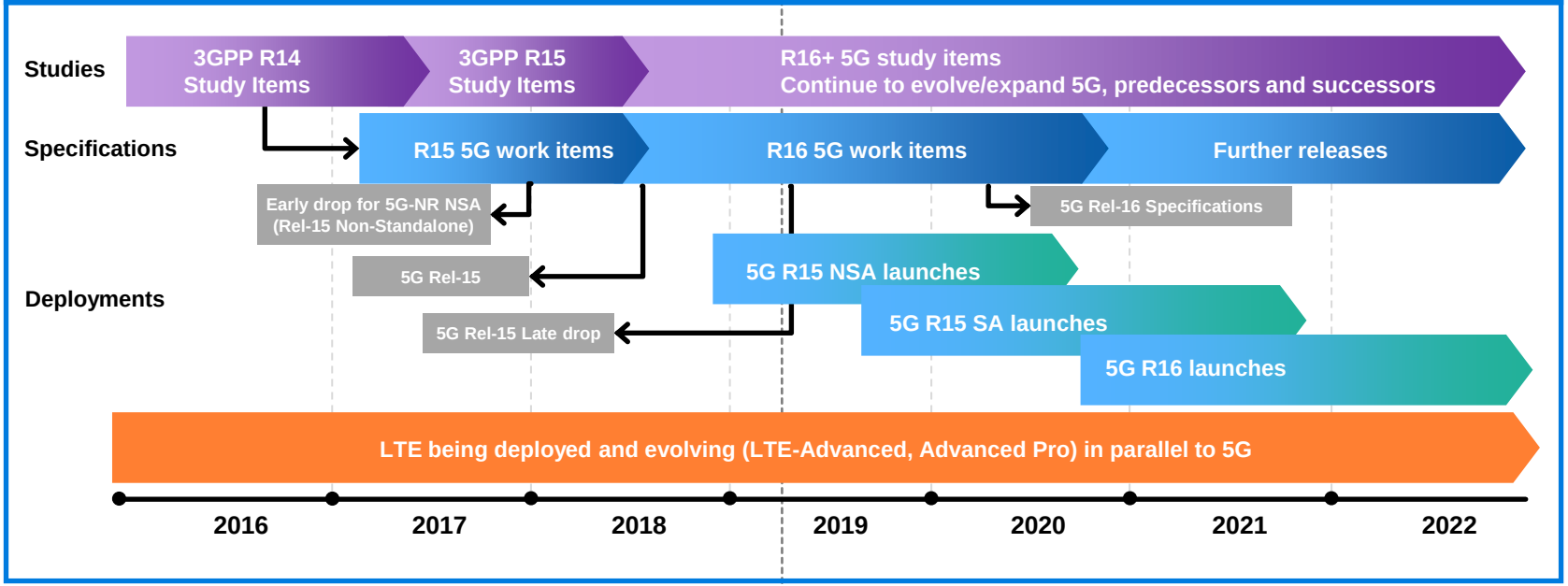


Workshop on 3GPP submission towards IMT-2020, Brussels, October 24/25, 2018
"System and Core Network Aspects"
Erik Guttman, 3GPP TSG SA Chairman, Samsung R&D Institute UK

3GPP 5G specifications calendar

5G phased specifications and deployments:

1. Rel-15 (Ph 1) focused in enhancing Mobile BroadBand (MBB) but significant support to all
2. Rel-16 (Ph 2) addressing the full range of use cases, improvements and extensions



Adapted from Qualcomm diagram

Functional freeze dates:
- Rel-14: Mar/17
- Rel-15: Jun/18
- Rel-16: Dec/19

1. 5G definition
2. **Reliability challenges**
3. 5G reliability solutions
4. Final remarks

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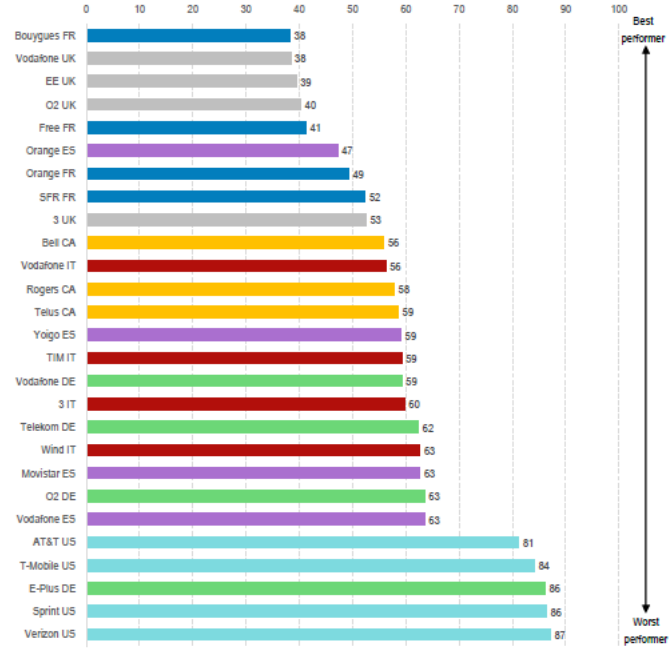
Real reliability in cellular networks

Error rate[2]

Quantitative analysis

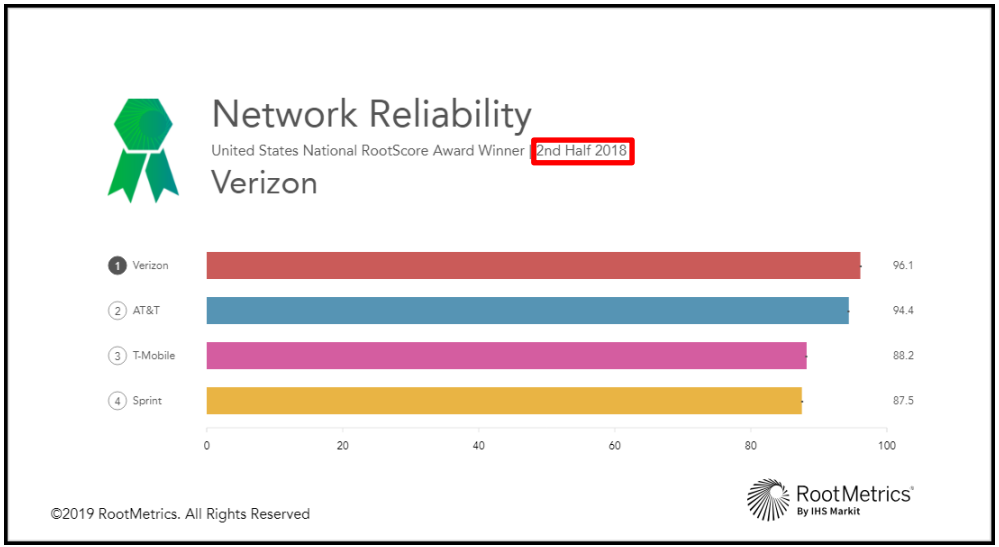
Figure 6: Major Western markets – error rate per 10,000 requests



Source: Apteligent, STL Partners

[2] A network reliability measure. The proportion of requests made by a customer using an application that experience an error. We assign scores based on the operator's error rate per 10,000 requests.

The typical block error rate (BLER) of 4G systems is 10^{-2} which can be achieved by channel coding (e.g. Turbo code) and re-transmission mechanisms (e.g. via HARQ)



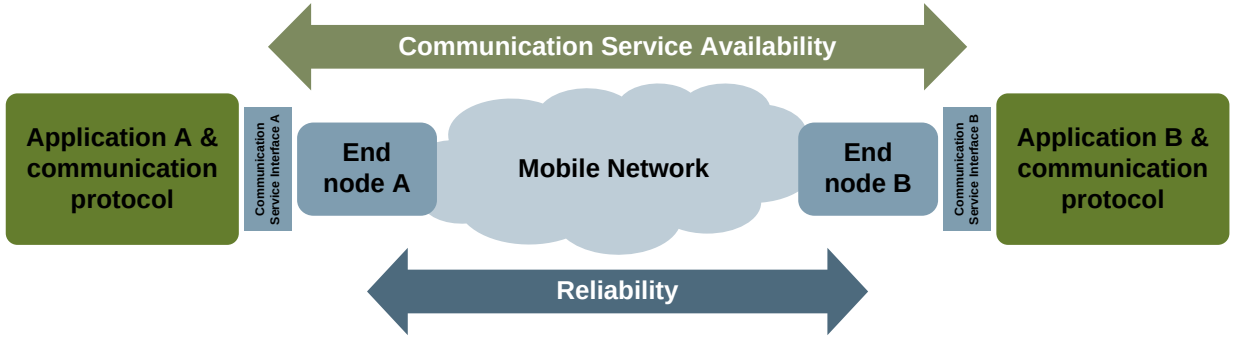
"Network Reliability Testing: A holistic look at reliability performance across data, call, and text testing"

Apteligent-STL-Mobile-Network-Experience-Index-Report-Q4-2015.pdf

Reliability and Availability definitions

Reliability (3GPP, TS 22.261):
Percentage value of the **amount of sent network layer packets** successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets.

Communication service availability (3GPP, TS 22.261):
Percentage value of the **amount of time** the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.



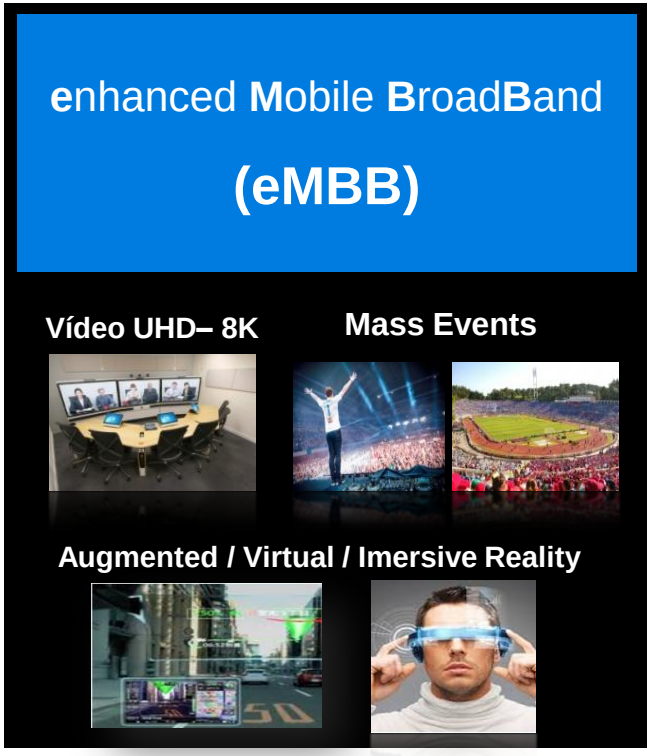
Reliability (ITU-R M.2083-0):
Capability to provide a given service with a **very high level of availability**.

5G: *enhanced Mobile Broadband* requirements

High bandwidth and mobility are mandatory
- Expand to higher frequencies (mmWave, >26GHz)

For interactive services and e.g. AR/VR from the edge, low latency is also relevant

Reliability increased at the cost of latency due to the use of longer blocklengths or through the use of retransmissions.
- e.g. Hybrid Automatic Repeat Request (HARQ)



5G: *massive MTC* requirements

massive **M**achine **T**ype **C**ommunications
(mMTC)

Logistic / Management

Wearables

Smart Meter

Smart Cities

Low Cost
- <5$ for the radio chip set
- up to 1$ per device per year (subscription fee)

Extended Coverage
- possibility to communicate with underground and inner buildings

Long Battery Life
- Battery life time around 10 years

Massive Number of Devices
- thousands of devices per cell

With no strong requirement on bandwidth (and latency), operation at lower frequencies is possible:
→ Higher coverage
→ Higher reliability

Layer 2 reliability mechanisms enable an application to rely on the network infrastructure to ensure delivery

Cellular IoT technologies:
- NB-IoT, LTE-M

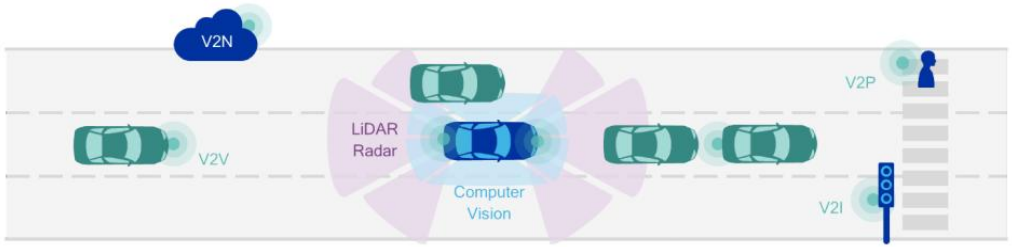
5G: *Critical IoT* requirements (Automotive)

http://5gaa.org/

"Develop, test and promote communications solutions, initiate their standardization and accelerate their commercial availability and global market penetration to address society's **connected mobility and road safety needs** with applications such as autonomous driving, ubiquitous access to services and integration into smart city and intelligent transportation"

Vehicle to anything (V2x) communications:

- Vehicle to Vehicle (V2V)
- Vehicle to Network (V2N)
- Vehicle to Infrastructure (V2I)
- Vehicle to Pedestrian (V2P)

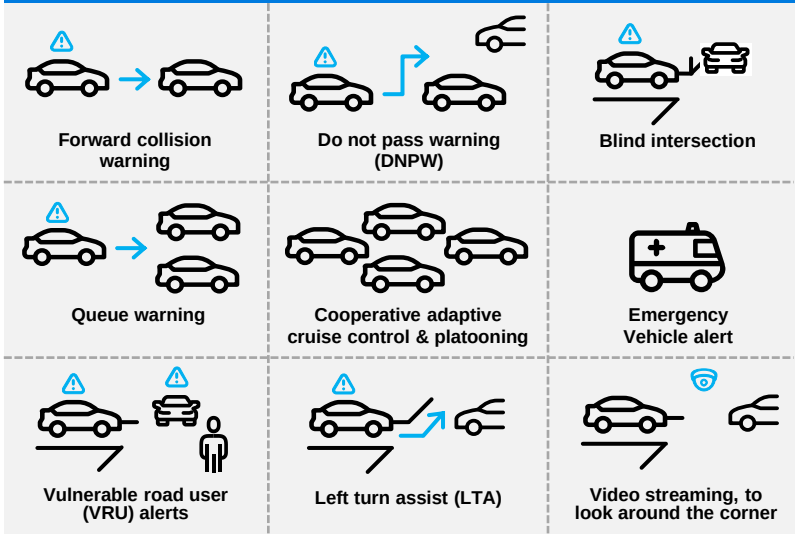


MEMBERS

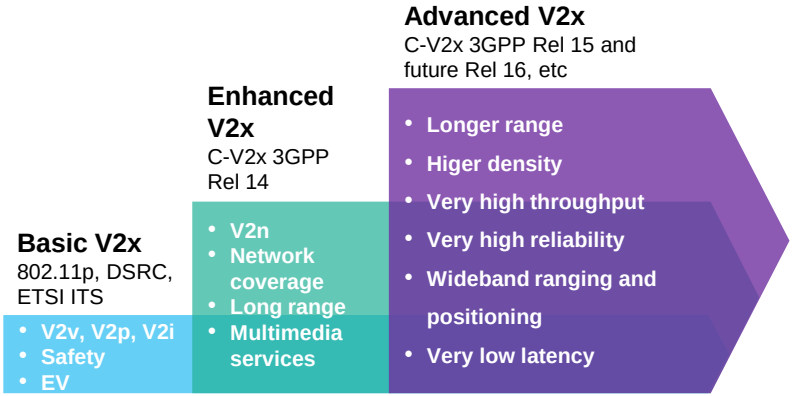
V2x Use Cases

Adapted from Qualcomm

V2x enables a broad set of use cases



3GPP V2x evolutionary support



Source: 5G Americas Whitepaper, "Cellular V2x Communications towards 5G", Mar'18

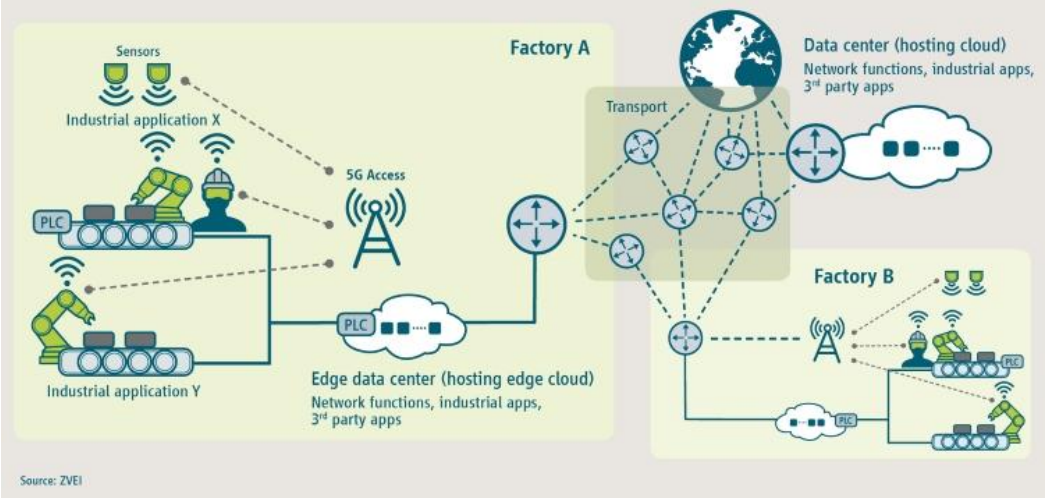
Communication scenario description	Max end-to-end latency (ms)	Reliability (%)
Information exchange between a UE supporting V2X application and a V2X Application Server	5	99.999
Cooperative driving for vehicle platooning Information exchange between a group of UEs supporting V2X application.	10	99.99
Emergency trajectory alignment between UEs supporting V2X application.	3	99.999
Sensor information sharing between UEs supporting V2X application	3	99.999

3GPP TS 22.186

5G: *Critical IoT* requirements (Industry)

https://www.5g-acia.org/

"5G-ACIA ensures the best possible applicability of 5G technology and 5G networks for the **manufacturing and process industries** by addressing, discussing and evaluating relevant technical, regulatory and business aspects."



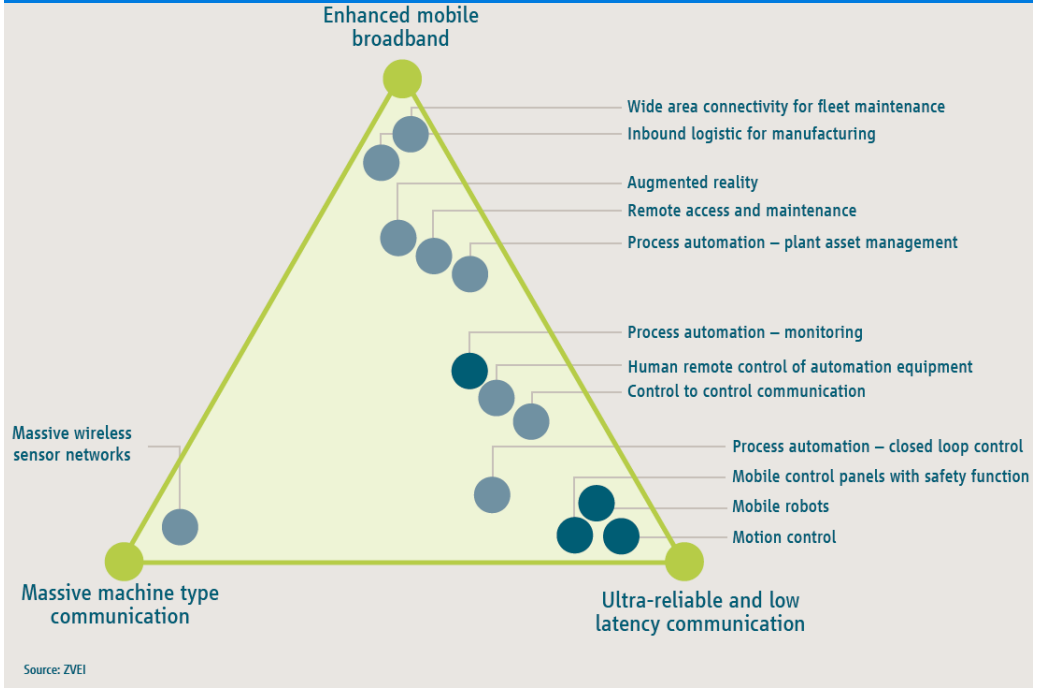
Source: 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, Apr'18

5G ACIA

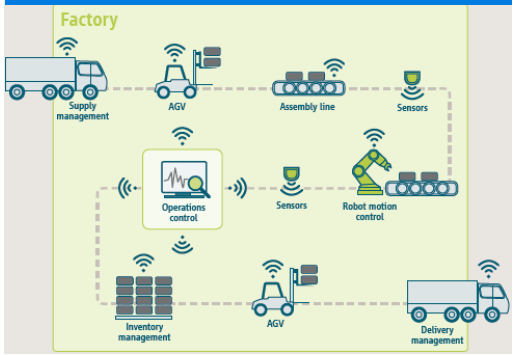
5G Alliance for Connected Industries and Automation

Industry use cases

Overview of selected industrial use cases and arrangement according to their basic service requirements (5G-ACIA)



Exemplary application areas of 5G in the factory of the future (5G-ACIA)



Selected use cases requirements (5G-ACIA)

Use case (high level)		Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2 ms	20 bytes	>100	100 m x 100 m x 30 m
	Machine tool	>99.9999%	< 0.5 ms	50 bytes	~20	15 m x 15 m x 3 m
	Packaging machine	>99.9999%	< 1 ms	40 bytes	~50	10 m x 5 m x 3 m
Mobile robots	Cooperative motion control	>99.9999%	1 ms	40-250 bytes	100	< 1 km²
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km²
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4-8 ms	40-250 bytes	4	10 m x 10 m
	Mobile cranes	>99.9999%	12 ms	40-250 bytes	2	40 m x 60 m
Process automation (process monitoring)		>99.99%	> 50 ms	Varies	10000 devices per km²	

No service 31,5s / Year

Pictures from: 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, Apr'18

Industrial communication protocols

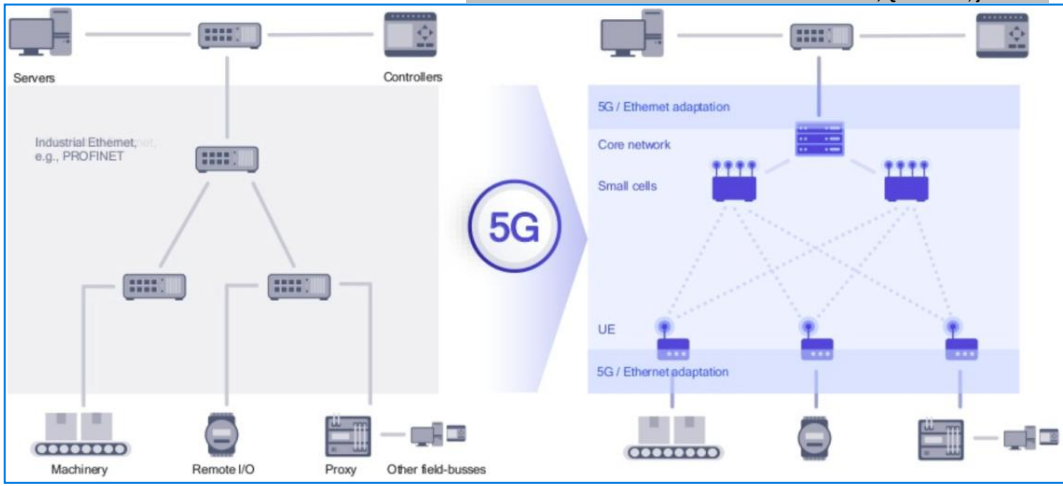
Industrial Ethernet

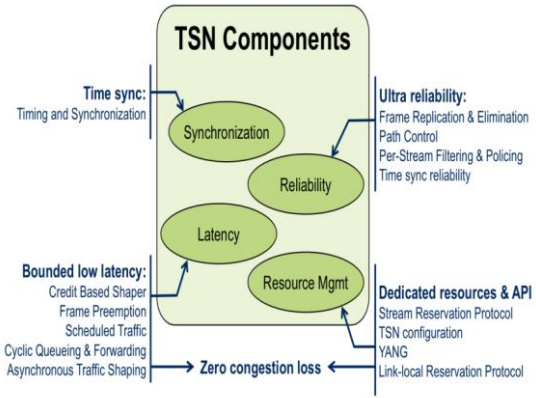
- Determinism is required. Data packets need to be sent and received at **specific times**, and they need a guarantee that **data will be delivered** each and every time (reliability)
- Physical infra-structure (cables and connectors) may also differ

Examples:

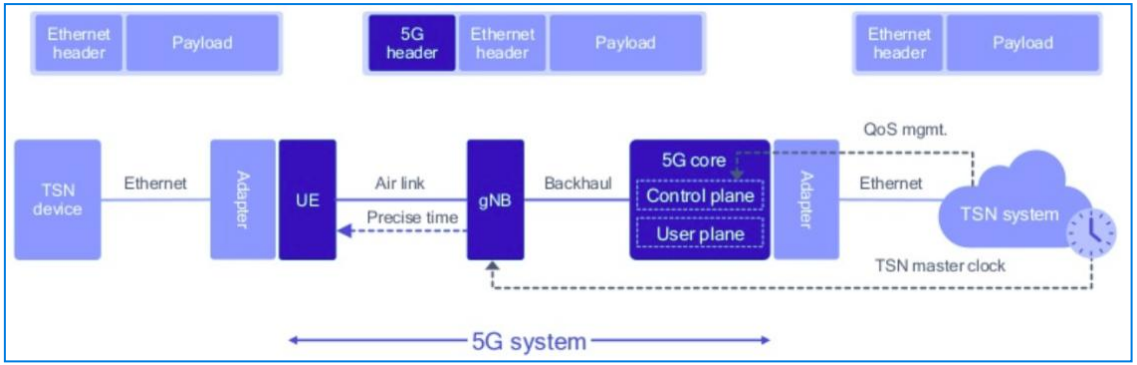
- PROFINET and EtherCAT
- TSN (*Time Sensitive Networking*)

Pictures from "How 5G Will Transform Industrial IoT", Qualcomm, jul/2018





Picture from "Time Sensitive Networking for 5G", Kasu Venkat Reddy, Cisco



Use cases and requirements considered for TSN requirements evaluation (3GPP TR 38.825)

Case	#UE	Communications service availability	Transmit period	Allowed E2E latency	Survival time	Packet size	Service area	Traffic periodicity	Use case
I	20	99,9999% to 99,999999%	0.5 ms	≤ Transmit period	Transmit period	50 bytes	15 m x 15 m x 3 m	Periodic	Motion control and control-to-control use cases
II	50	99,9999% to 99,999999%	1 ms	≤ Transmit period	Transmit period	40 bytes	10 m x 5 m x 3 m	Periodic	Motion control and control-to-control use cases
III	100	99,9999% to 99,999999%	2 ms	≤ Transmit period	Transmit period	20 bytes	100 m x 100 m x 30 m	Periodic	Motion control and control-to-control use cases

“Reliability targets going beyond 99.9999% can be achieved by higher layer redundancy (e.g. PDCP duplication) and it is not required to analyse whether those can be met on PHY layer”

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URLLC: The Ultra Reliability versus Low Latency challenge

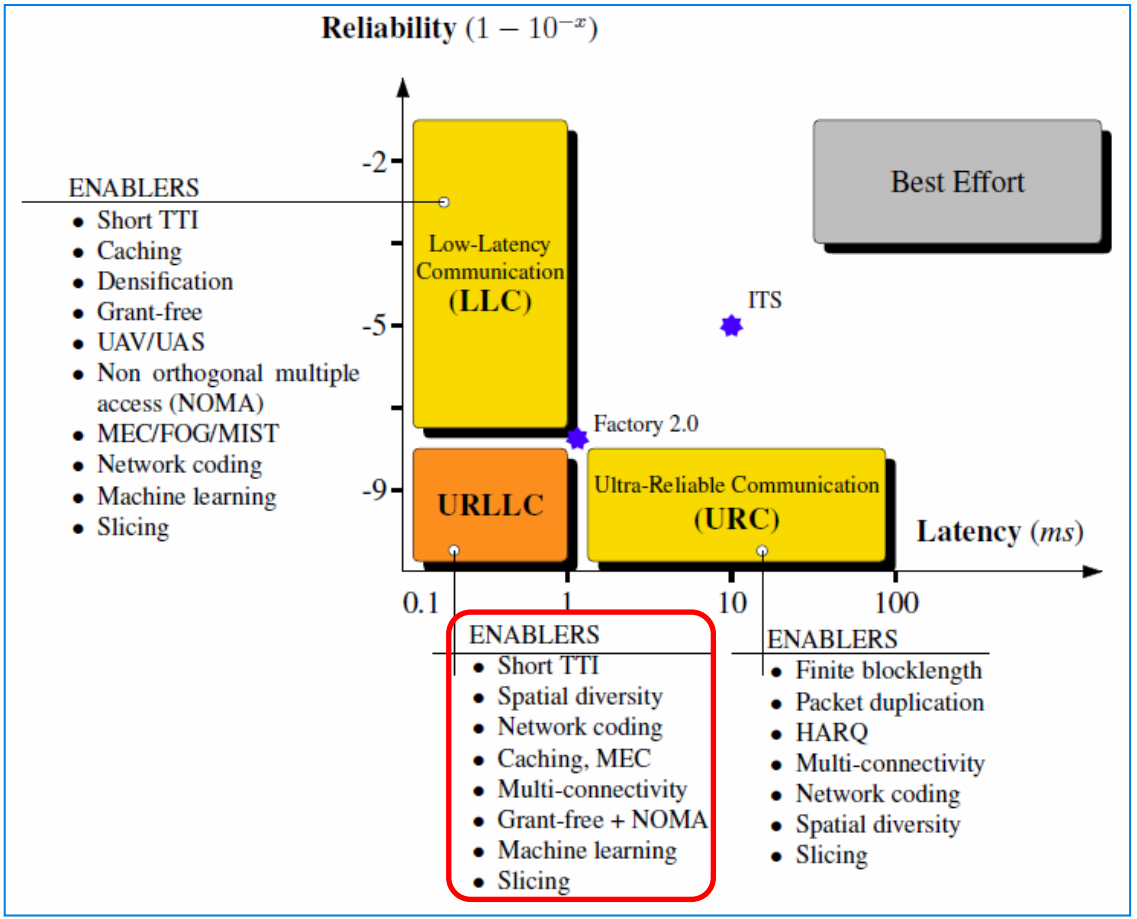
Answering two conflicting requirements:

- **Low latency and ultra-high reliability**

Release 16 objective:

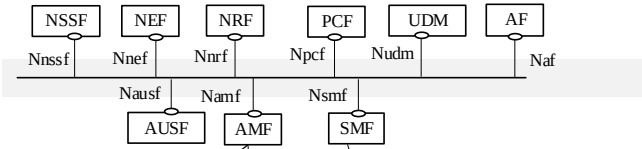
- **0.5-1ms one-way latency**
- **Reliability of up to 99.9999%**

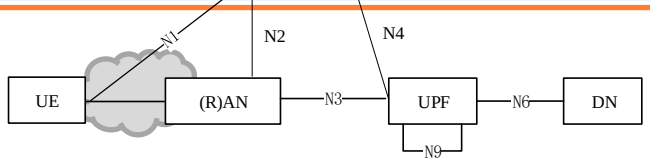
Retransmissions (e.g. HARQ) and packet duplications in time (e.g. PDCP duplications) are useless, considering the low latency budget



"Ultra-Reliable and Low-Latency Wireless Communication: Tail, Risk and Scale"
Mehdi Bennis, Senior Member IEEE, M'erouane Debbah, Fellow IEEE, and H. Vincent Poor, Fellow IEEE

3GPP 5G System: architectural contributions





Design principles:

- **Separate the User Plane (UP) functions from the Control Plane (CP) functions**
- **Modularize the function design**, e.g. to enable flexible and efficient network slicing
- **…**
- Support **"stateless" NFs**, where the "compute" resource is decoupled from the "storage" resource
- …

3GPP TS 23.501

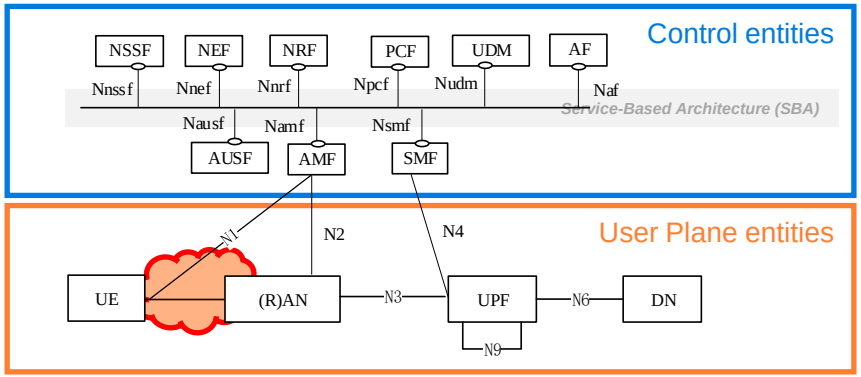
1. Network Slice Selection Function (NSSF)
2. Network Exposure Function (NEF)
3. NF Repository Function (NRF)
4. Policy Control Function (PCF)
5. Unified Data Management (UDM)
6. Application Function (AF)

7. Authentication Server Function (AUSF)
8. Access and Mobility Management Function (AMF)
9. Session Management Function (SMF)

10. Unified Data Repository (UDR)
11. Unstructured Data Storage Function (UDSF)
12. 5G-Equipment Identity Register (5G-EIR)
13. Security Edge Protection Proxy (SEPP)
14. Network Data Analytics Function (NWDAF)

1. User Equipment (UE)
2. (Radio) Access Network ((R)AN)
3. User Plane Function (UPF)
4. Data Network (DN)

5G-NR (*5G-New Radio*) characteristics



4G/LTE:

- **Turbo codes** for data channels
- **TBCCs** (tail-biting convolutional codes) for control channels.

LDPC (*Low-Density Parity-Check*):

- **Improved performance**: block error rate (BLER) around or below 10^{-5} for all code sizes and code rates
- Reduced decoding complexity and **improved decoding latency** (lower overall latency)
- Better **area throughput efficiency** and **higher peak throughput**

Operation from **low to very high bands**: 0.4 – 100Ghz
- Including standalone operation in unlicensed bands

Up to 400 MHz component-carrier bandwidth (20 MHz for LTE)
- Up to 100MHz in <6GHz
- Up to 400MHz in >6GHz

Up to 16 component carriers

Set of **different numerologies** (e.g. sub-carrier spacing and symbol time) for optimal operation in different frequency ranges

Native support for **Low Latency**
- E.g. shortened *Transmission Time Interval* (TTI)

Flexible and modular RAN architecture: split fronthaul, split control- and user-plane

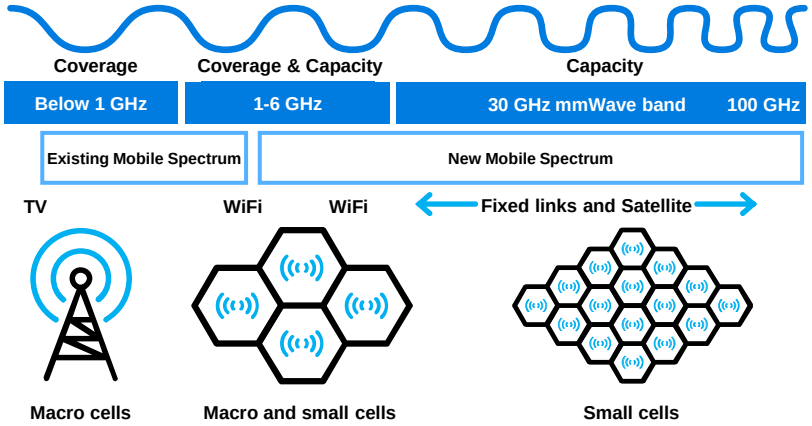
Support for **devices connecting directly**, with no network (**D2D, V2x**)

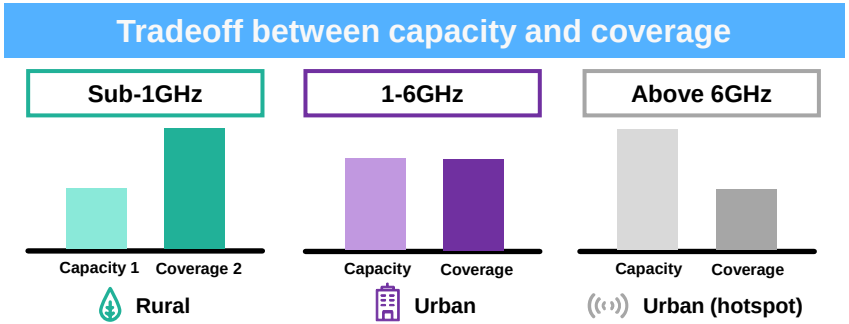
Native **end-to-end support for Network Slicing**

New channel coding
- LDPC for data channel, Polar coding for control channel

Multiple **diversity mechanisms** (for **Ultra Reliability**)

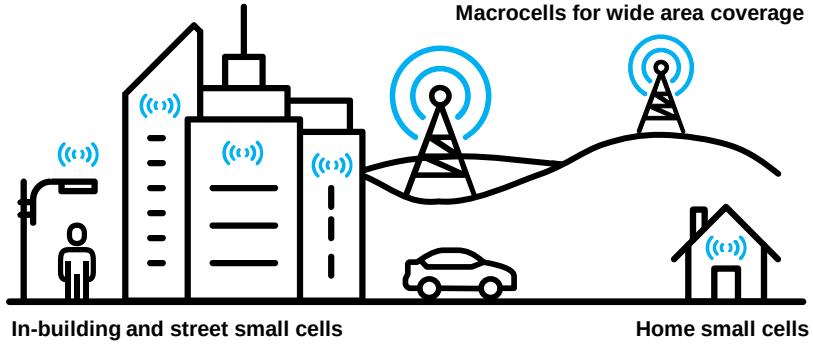
Larger spectrum for all applications





Technology to operate on all frequencies

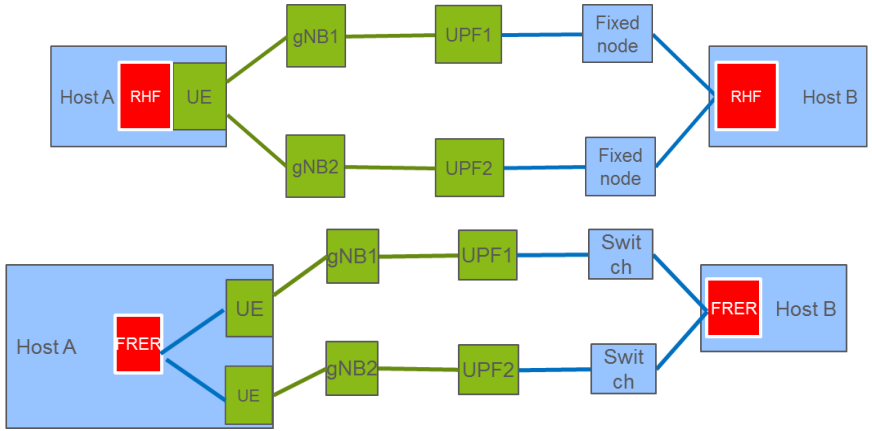
- Expanding to lower ones for reliability and coverage
- Expanding to higher oner for capacity and latency



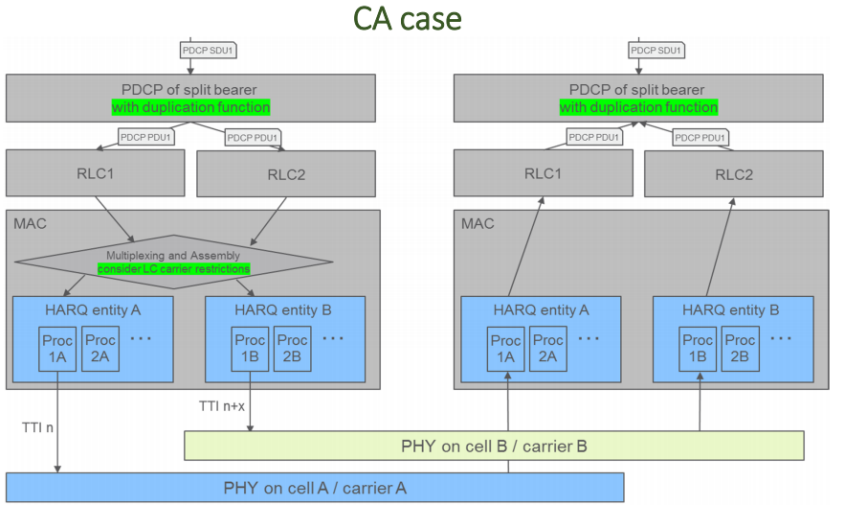
Data duplication and multi-connectivity (Rel-16)

Support PDCP duplication enhancement with up to 4 copies
- Duplication applies in case of multi-connectivity and carrier aggregation (CA)

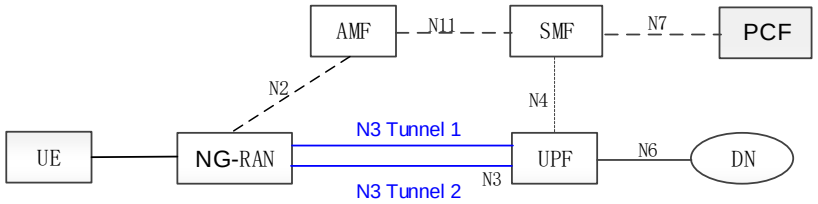
Redundant transmission paths to ensure high reliability, hard to achieve with a single path
- Dual-Connectivity (DC)
- End-to-end or inside the 5G System (xHaul and transport)



3GPP TR 23.725



"5G NR User Plane Protocol , What's new Over LTE in 5G NR", Teckplayon



3GPP TR 23.725

RHF: *Redundancy Handling Function*
FRER: *Frame Replication and Elimination for Reliability*

5G and virtualization

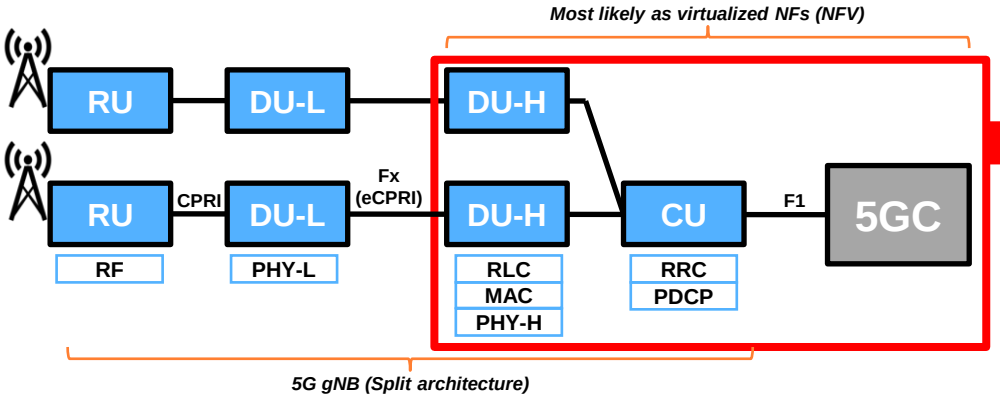
5G to be deployed heavily with virtualization (NFV)

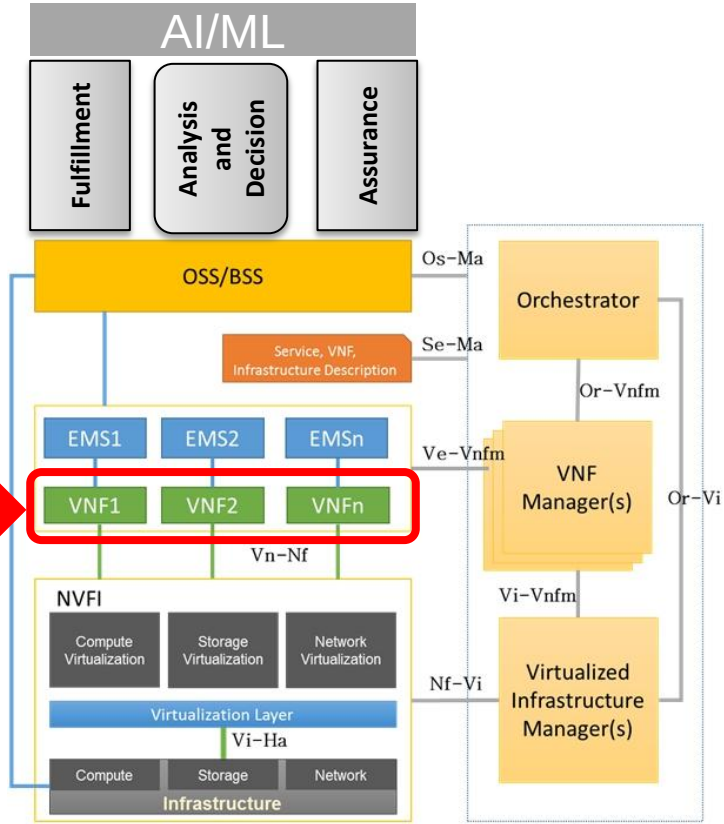
- Lifecycle Management to create backup/load balancing units and fast recovery

→ Supporting HW, SW and overall conditions (HVAC, power, etc.) must contribute/guarantee to the required reliability

Artificial Intelligence / Machine Learning

- Associated to NFV, automate service degradation correction or failures recovery





Distributed cloud: Edge Computing and 5G

Distributed, small data centres (NFV powered), placed close to the network edge

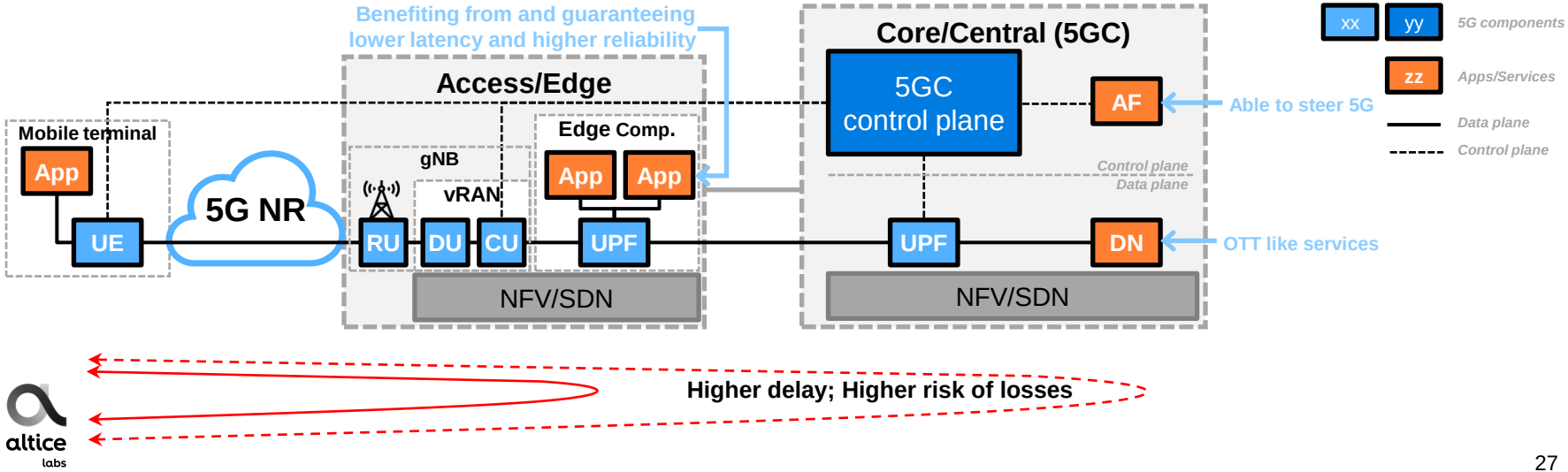
Mandatory for 5G, to enable low latency services (faster retransmissions, reaction time, etc)

- Operator and 3rd-party Applications, can be hosted at the ‘edge’

Take benefit of NFV for lifecycle management (LCM) of VNF:

- 5G RAN (CU/DU)
- 5G use plane VNF (UPF)
- Edge Applications

5G provides native support to *(Multi-access) Edge Computing*



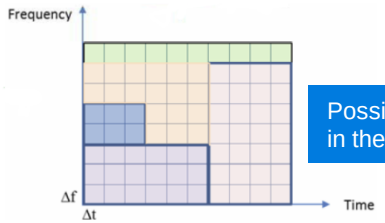
5G Slicing

Slicing enables the creation of distinct logical networks:
- Of the same type (different businesses)
- Providing differentiated behaviour (different services)

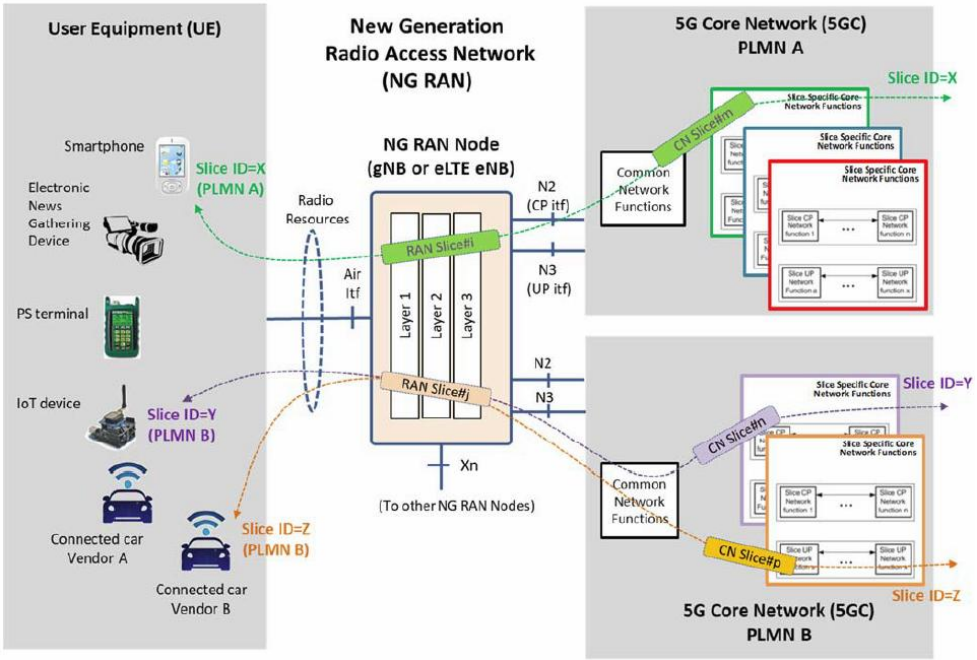
5G supports end-to-end slicing (radio and core)
- Resources isolation between services
- Customized functions and/or capacities, according to SLA

Each terminal (UE) may connect simultaneously to max 8 slices (no limit for the number of slices in the core)

Takes benefit of NVF to easy slices creation and management (LCM)



Possible resources allocation in the RAN for 5 slices



5G Americas, *NetWork Slicing for 5G networks & services*, Nov/16
On 5G Radio Access Network Slicing: Radio Interface Protocol Features and Configuration, R. Ferrús

Network Slice definition (TR 23.799): *complete logical network (providing Telecommunication Services and Network Capabilities) including AN and CN.*

1. 5G definition
2. Reliability challenges
3. 5G reliability solutions
4. **Final remarks**

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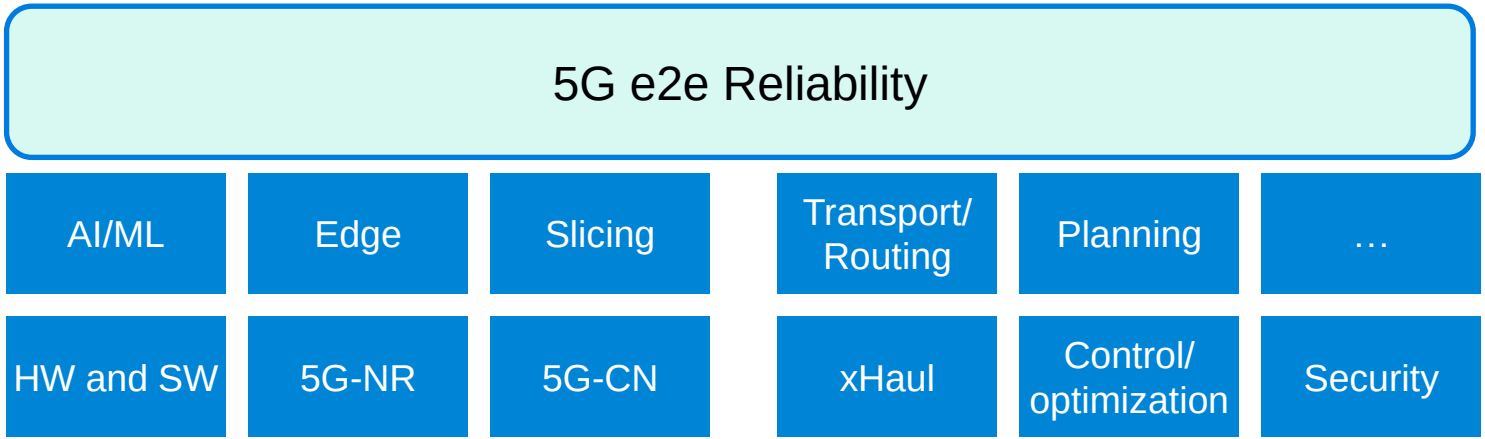
So, reliability is much more than just radio!



Conclusions

5G will be an universal wireless connectivity technology

- 5G will be in all sort of terminals (e.g. smart phones, computers, sensors and cars)

5G has the potential to be disruptive

- Strong social and economic impact

Several vertical sectors with high reliability demands

- URLLC as the main differentiator of 5G (B2B)

Increased reliability, associated to very low latency requirements, is a multi-dimensional challenge

5G-NR contributes significantly to the technology high reliability

- But 5G architecture and related technologies are significant to achieve the target improvements (including e2e reliability!)

Challenges and contributions regarding reliability

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