Digital conference - The ongoing evolution of 5G - driven by test & measurement, October 7, 2020

THE ONGOING EVOLUTION OF 5G NEW RADIO RELEASES 16 AND 17

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Make ideas real

5G NR TECHNOLOGY EVOLUTION – THE NEXT PHASE

5G NR Phase 1

| April 2019

1st 5G NR networks (FR1, FR2) launched; focus: eMBB

| June 2020

3GPP Release 16 (5G Phase 2); focus: two market verticals

| Dec 2021

3GPP Release 17 (5G Phase 2+); focus: NTN, NR Light, FR2+

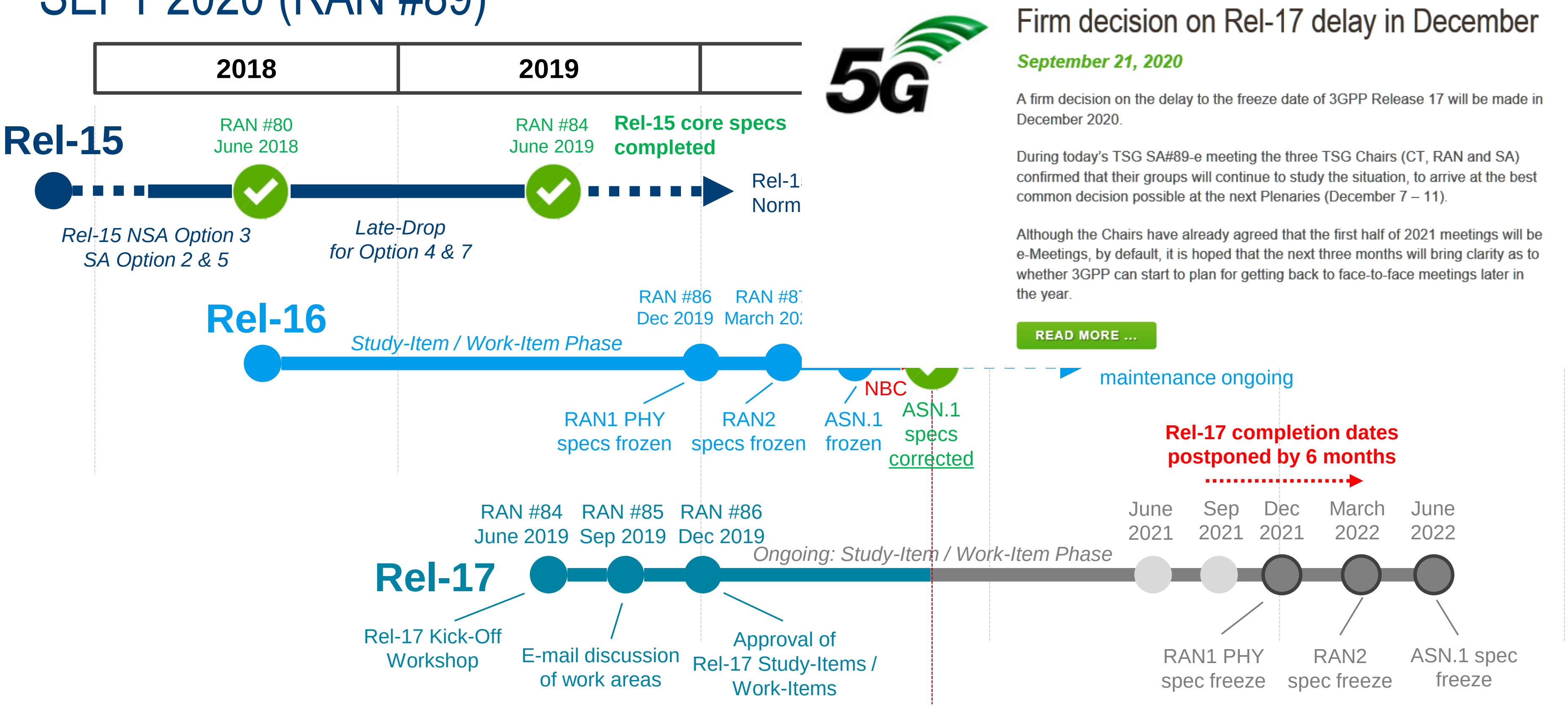
5G is a marathon, not a 100 m sprint…

2018 2020 2022 2024 2026

eMBB: enhanced Mobile Broadband
URLLC: Ultra-Reliable Low Latency Communication
mMTC: massive Machine Type Communication

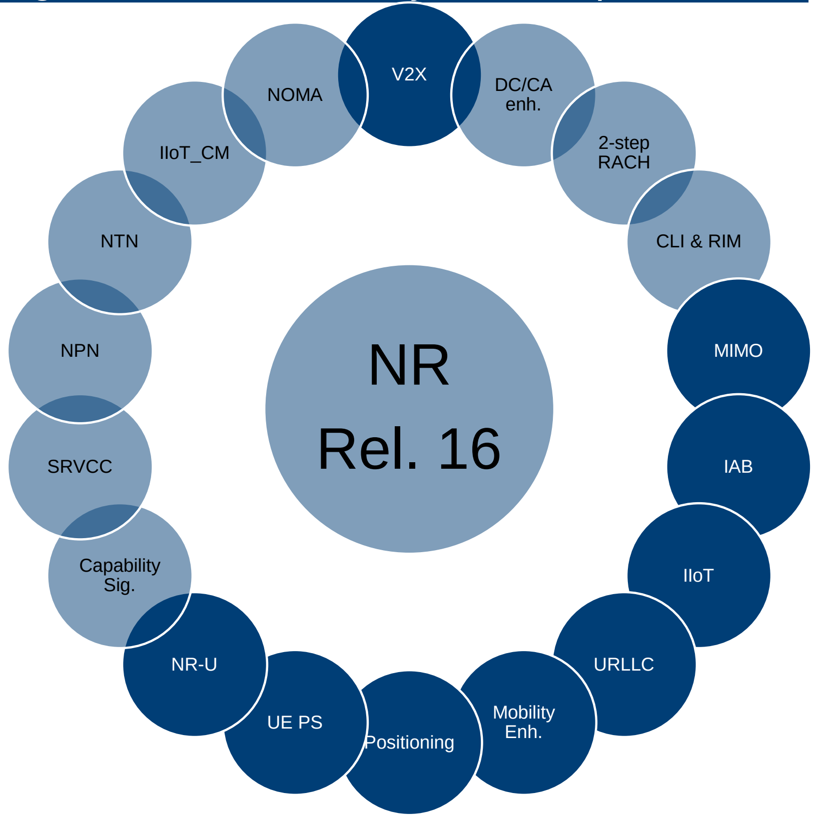
3GPP RAN STANDARDIZATION TIMELINE

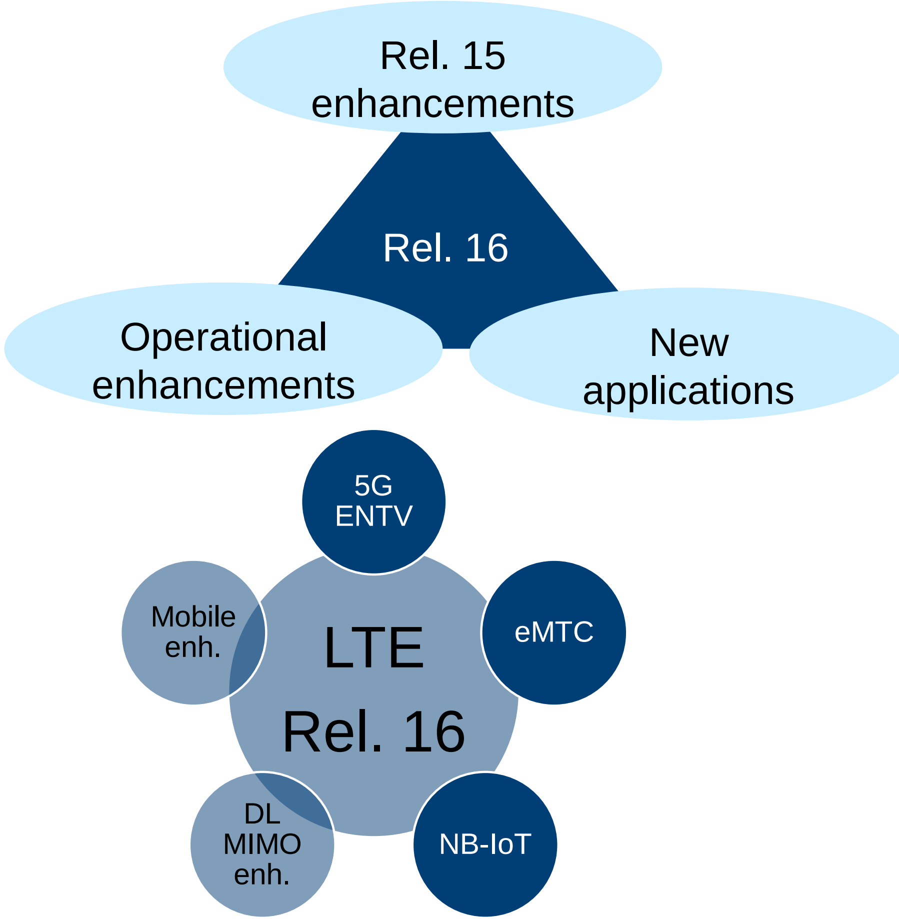
SEPT 2020 (RAN #89)



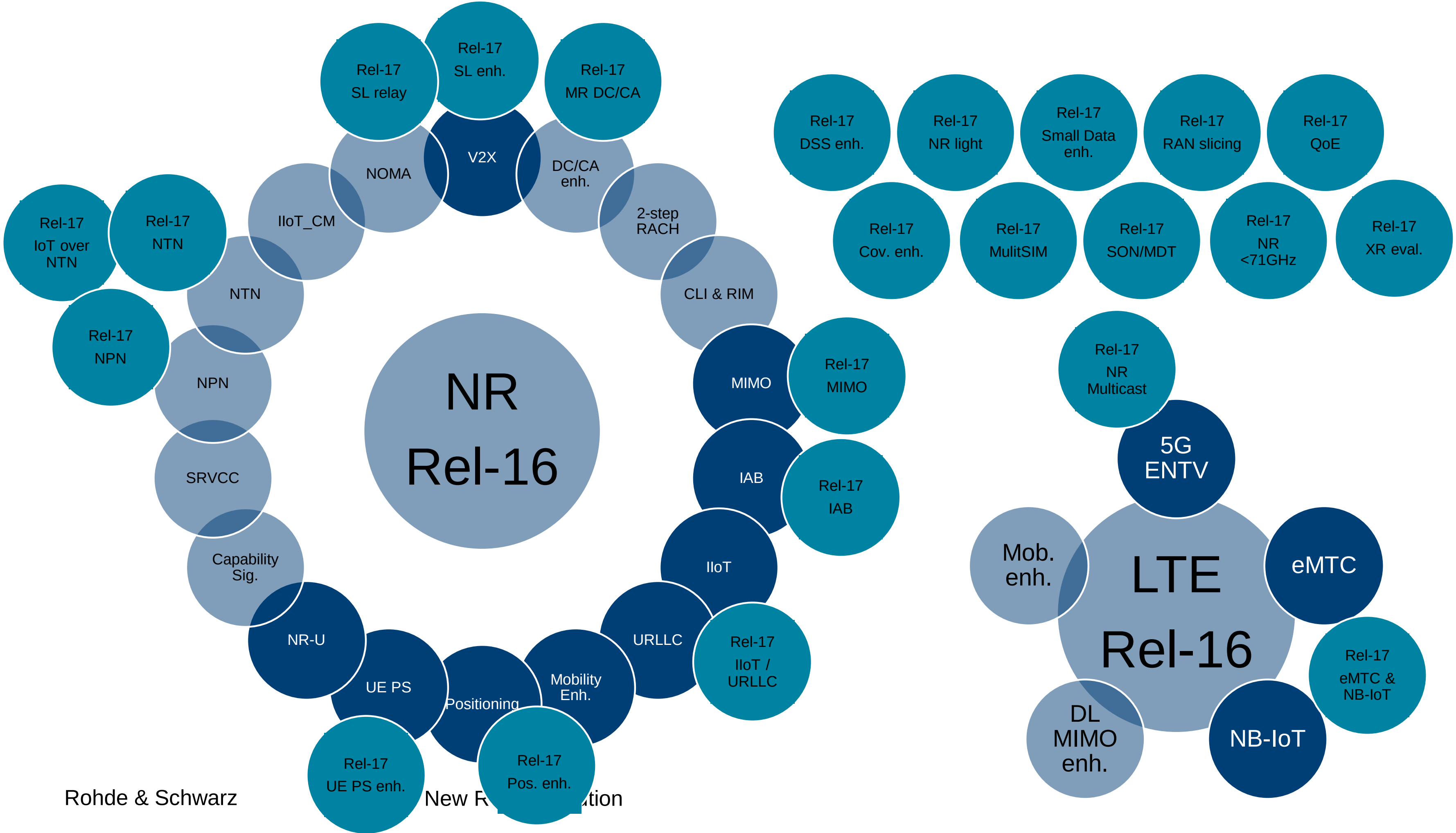
3GPP REL. 16 TOPIC SUMMARY

Highlighted work items: major new aspects





3GPP REL. 16 TOPICS AND REL. 17 FOLLOW-UPS



3GPP FR1 FREQUENCY BANDS

FDD | Supplemental downlink (SDL)
TDD | Supplemental uplink (SUL)

NR operating band	Uplink	Downlink	Duplex mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
n18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n29	N/A	717 MHz – 728 MHz	SDL
n30[3]	2305 Mhz – 2315 MHz	2350 MHz – 2360 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD[1]
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD

NR operating band	Uplink	Downlink	Duplex mode
n65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD[4]
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780 MHz	N/A	SUL
n89	824 MHz – 849 MHz	N/A	SUL
[n90]	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD[5]
n91	832 MHz – 862 MHz	1427 MHz – 1432 MHz	FDD
n92	832 MHz – 862 MHz	1432 MHz – 1517 MHz	FDD
n93	880 MHz – 915 MHz	1427 MHz – 1432 MHz	FDD
n94	880 MHz – 915 MHz	1432 MHz – 1517 MHz	FDD
n95	2010 MHz – 2025 MHz	N/A	SUL

Source: 3GPP TS 38.101-1

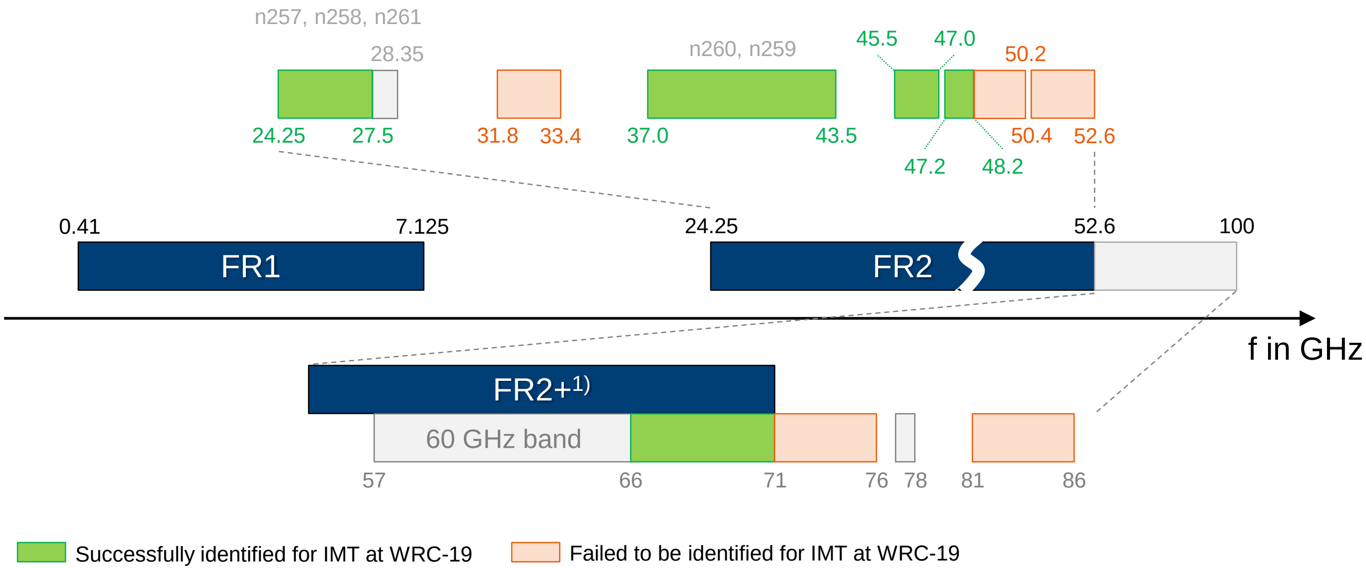
3GPP FR2 FREQUENCY BANDS

NR operating band	Uplink	Downlink	Duplex mode
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	27500 MHz – 28350 MHz	TDD
N262	47200 MHz – 48200 MHz	47200 MHz – 48200 MHz	TDD

Source: 3GPP TS 38.101-1

SPECTRUM FOR 5G NR

- FR1, FR2 frequency ranges defined for 3GPP Release 15
  - 3GPP Release 17 extends FR2 towards 71 GHz



Source: https://news.itu.int/wrc-19-agrees-to-identify-new-frequency-bands-for-5g/ [Nov 2019]   [1] Work Item (WI) for Rel-17 (RP-193229)

5G evolution, Releases 16 and 17

5G BROADCAST

5G BROADCAST TECHNOLOGY EVOLUTION

Traditional broadcast world

Rel. 14 FeMBMS

Rel. 15

Rel. 16 LTE-based 5G terrestrial broadcast

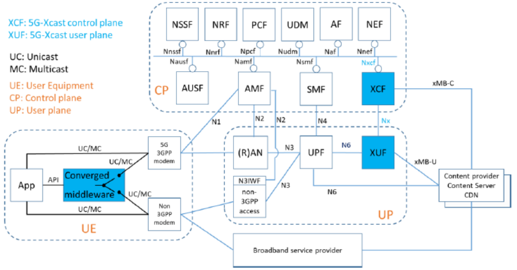
Rel. 15

Rel. 16

Rel. 17 Introduction of multicast + broadcast

Traditional cellular world

Converging worlds



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Impact on infrastructure to enable broadcast + multicast

5G New Radio evolution

	μ	Δ_f (Hz)	T_U (MS)	CP FRACTION	T_{CP} (MS)	T_S (MS)	SC_{RB}	ISD (km)
A	0	15000	66.67	~7%	4.7/5.1	0.07	12	1.4
B	0	15000	66.67	20%	16.67	0.08	12	5
C	-1	7500	133.33	20%	33.33	0.17	24	10
D	-2	3750	266.67	20%	66.67	0.33	48	20
E	-	2500	400.00	20%	100.00	0.50	72	30
F	-3	1875	533.33	20%	133.33	0.67	96	40
G	-	1250	800.00	20%	200.00	1.0	144	60
H	-	625	1600.00	20%	400.00	2.0	288	120
I	-	3333	300.00	10%	33.33	0.33	54	10
J	-	2045.45	488.88	2.22%	11.11	0.50	88	3.3
K	-	1022.72	977.78	2.22%	22.22	1.0	176	6.6
L	-	511.36	1955.56	2.22%	44.44	2.0	352	13.2
M	-	416.67	2400	4%	100	2.5	432	30
N	-	208.33	4800	4%	200	5.0	864	60
O	-	104.67	9600	4%	400	10.0	1728	120
P	-	217.39	4600	8%	400	5.0	828	120

5G Xcast: study on several numerologies to allow mix mode for several coverage scenarios

5G evolution, Releases 16 and 17

INDUSTRIAL IoT

How can we reduce network delays? 5G URLLC approach

Traffic prioritization by QoS and network virtualization

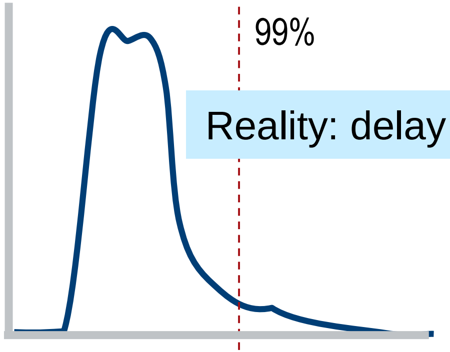
Short symbol times, min-slots, semi-persistent scheduling

High speed data connection leveraging more bandwidth

Local processing, by edge/fog computing, non-public networks

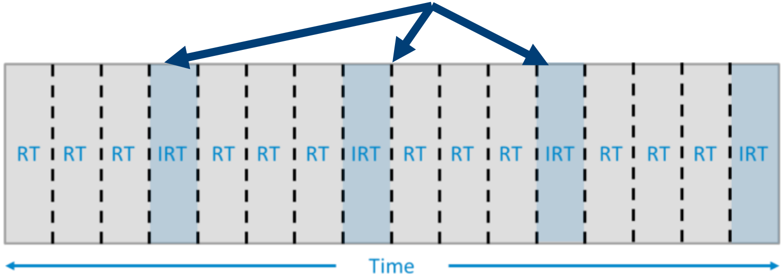
Buffer delay → Scheduling delay → Transmission delay → Propagation delay

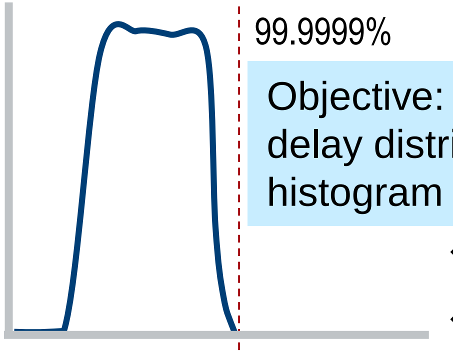
ASPECTS ABOUT LATENCY



Reality: delay distribution, histogram

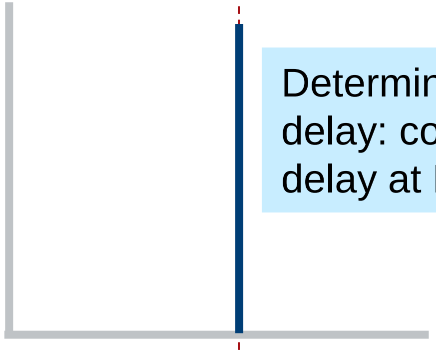
e.g. Ethernet: Isochronous real-time packets scheduling





Objective: URLLC delay distribution, histogram

- Tactical Internet
- Deterministic delay
- Time sensitive networks (TSN)

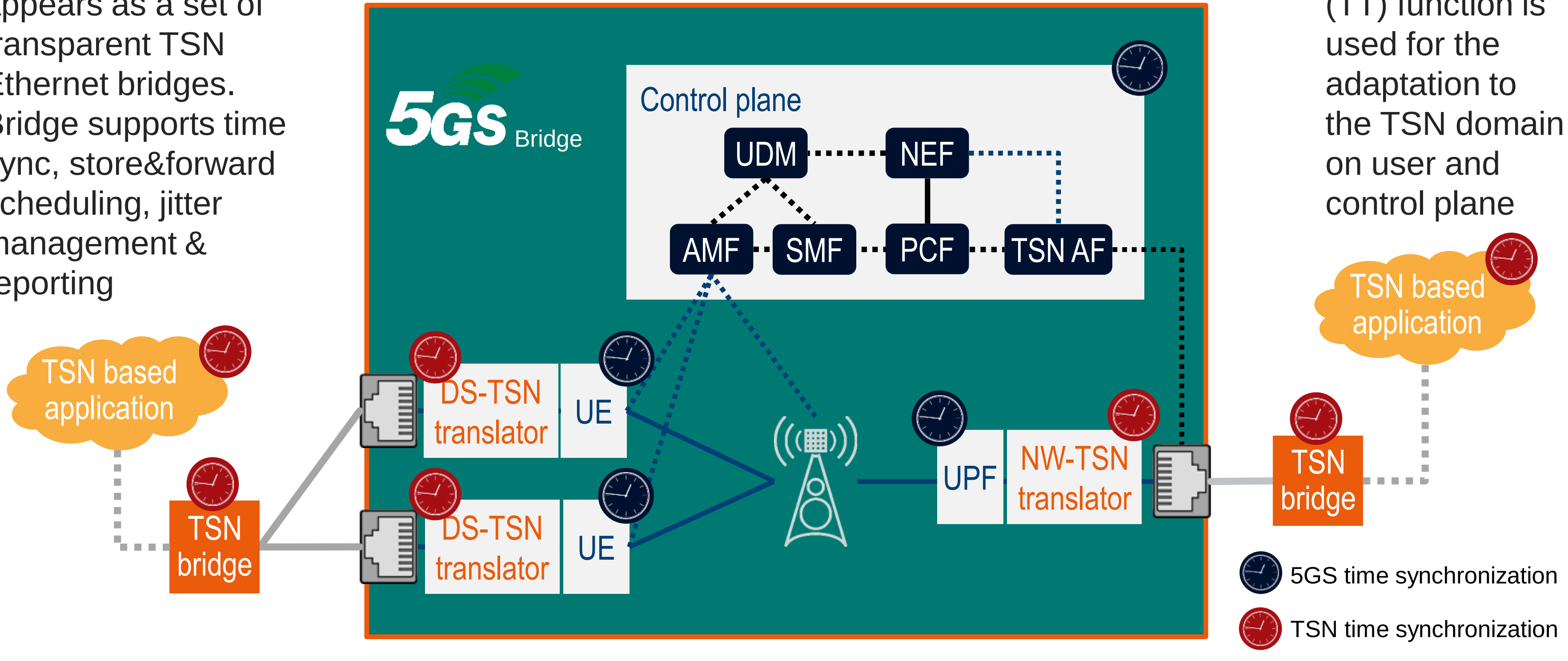


Deterministic delay: constant delay at RX entity

5G INTEGRATION INTO A ETHERNET TSN ARCHITECTURE
3GPP RELEASE 16 TECHNOLOGY COMPONENTS

- The 5G system appears as a set of transparent TSN Ethernet bridges.
- Bridge supports time sync, store&forward scheduling, jitter management & reporting

- TSN translator (TT) function is used for the adaptation to the TSN domain on user and control plane



5G evolution, Releases 16 and 17

5G EVOLUTION – POSITIONING, MIMO, MOBILITY, ETC.

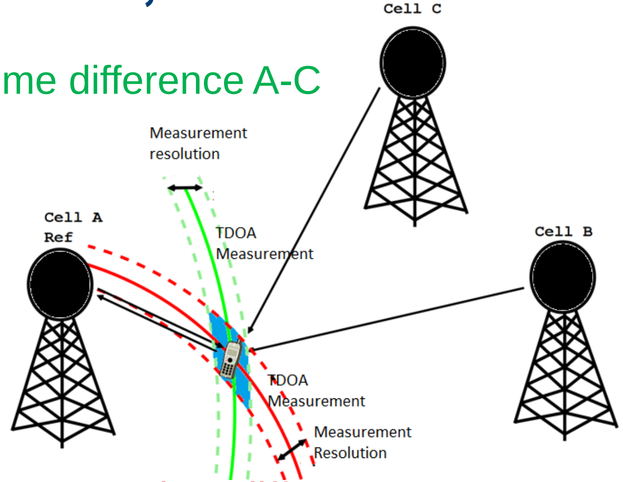
REL. 16: NR POSITIONING

Outlook: relative positioning methods, e.g. sidelink based

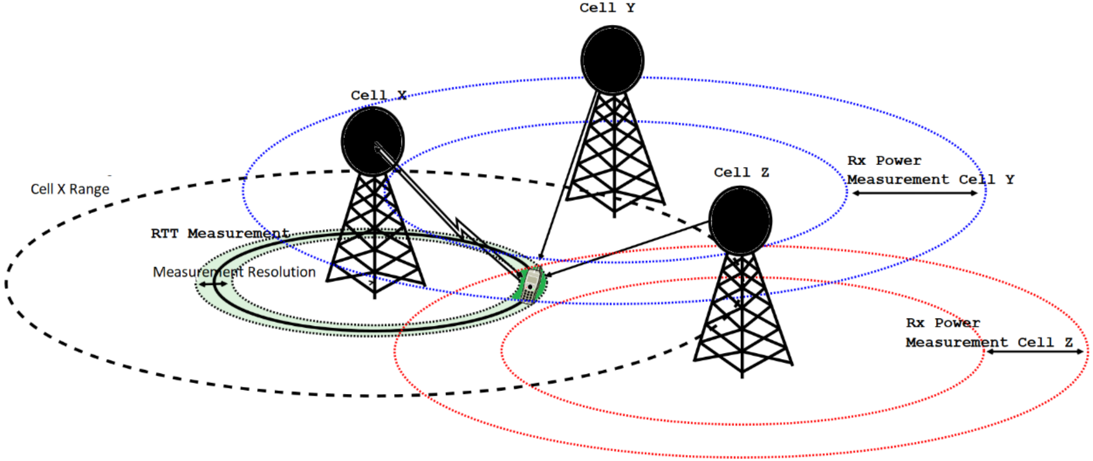
RAT independent methods	EUTRAN based methods	5G NR based methods
A-GNSS	OTDOA	NR E-CID
A-GNSS + RTK	E-CID	Multi-RTT
WLAN		DL AoD
Bluetooth		UL AoA
Terrestrial beacon system		DL TDOA
Sensor based methods (i.e. barometric)		UL-TDOA

TDOA, RTT AND POWER BASED LBS TECHNOLOGIES

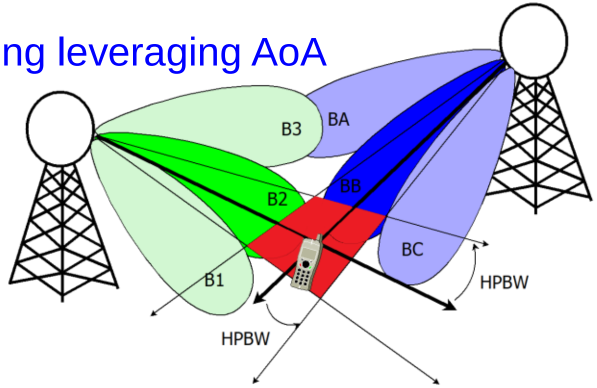
Time difference A-C

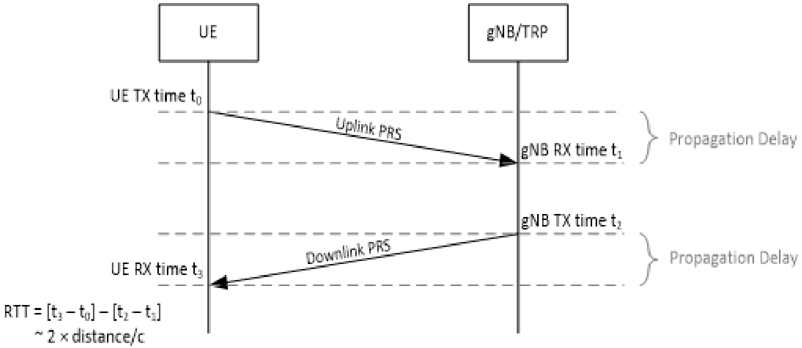


Time difference A-B



Beamforming leveraging AoA





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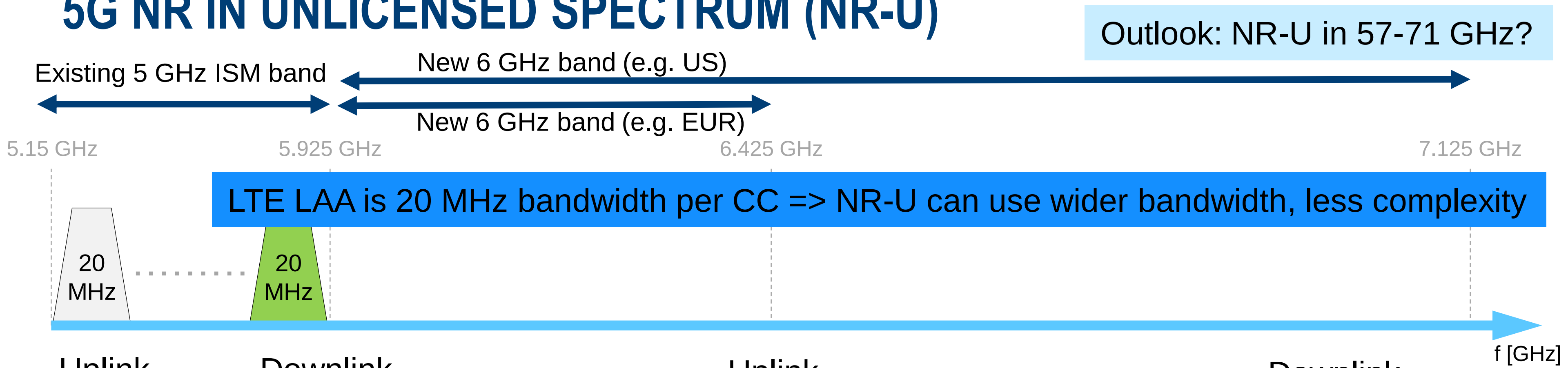
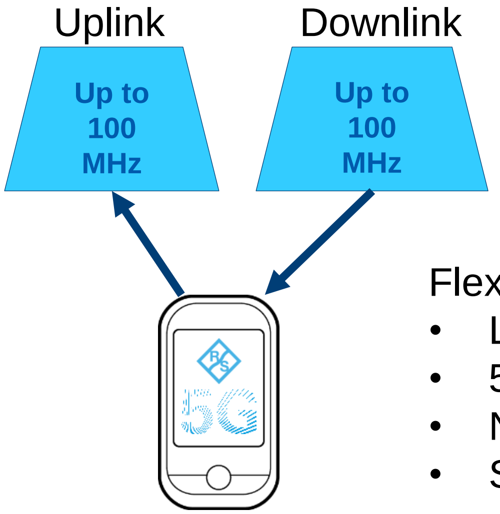
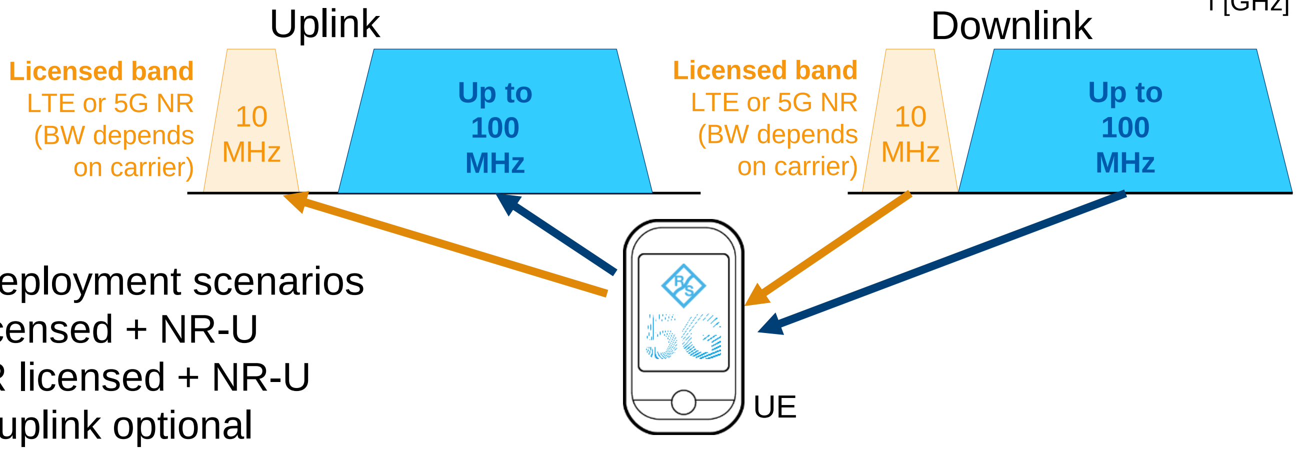
5G New Radio evolution

5G NR IN UNLICENSED SPECTRUM (NR-U)



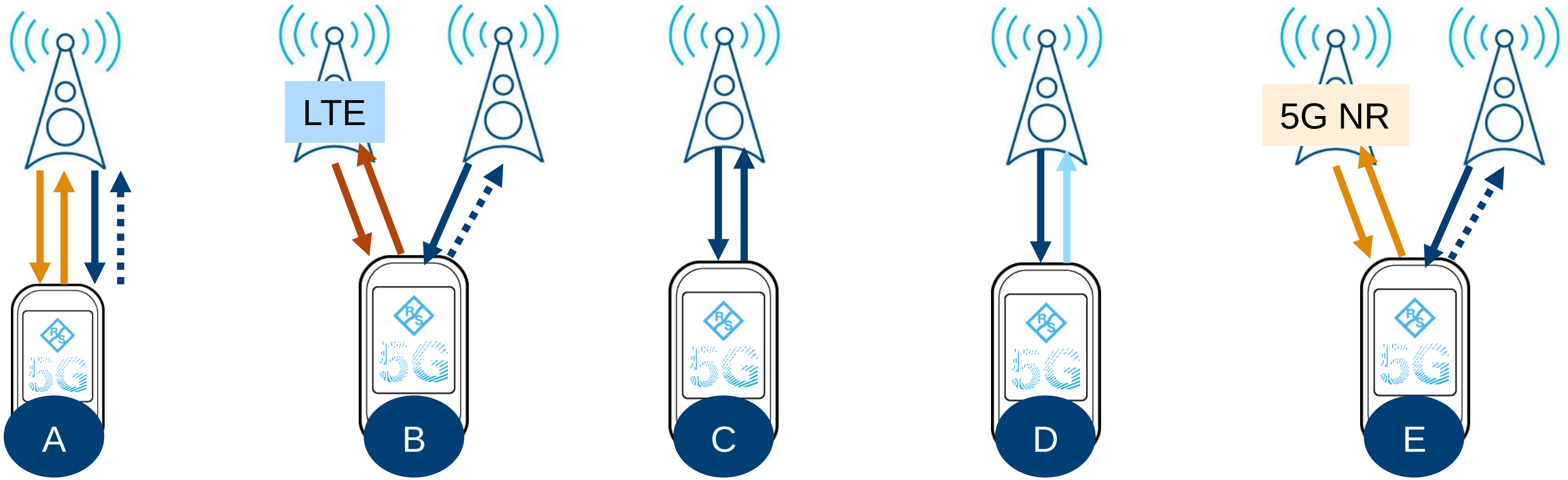




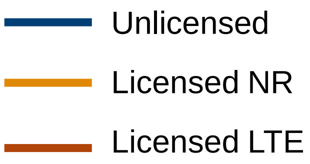
Flexible deployment scenarios

- LTE licensed + NR-U
- 5G NR licensed + NR-U
- NR-U uplink optional
- Standalone NR-U

REL. 16: NR ACCESS TO UNLICENSED SPECTRUM (NR-U)

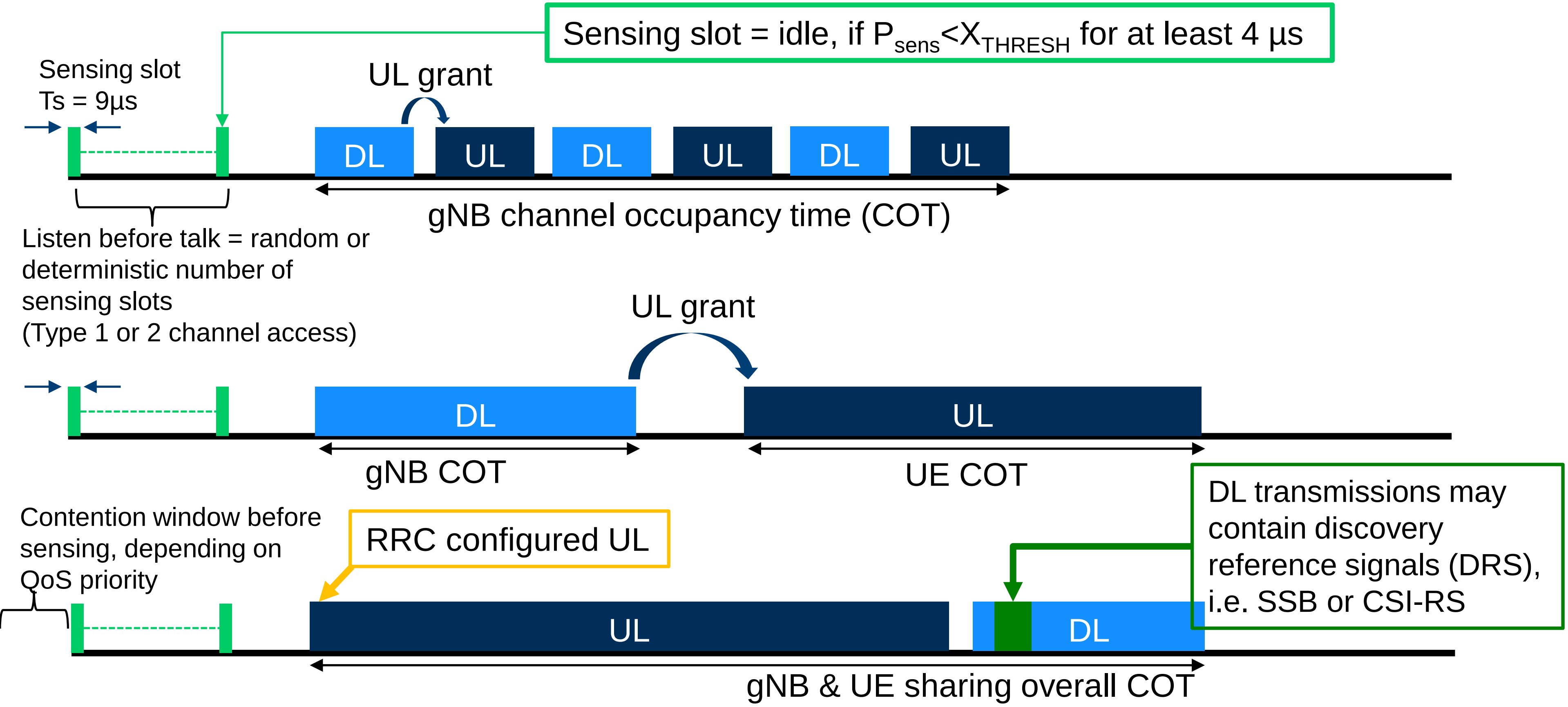


- Scenario A: Carrier aggregation between licensed band NR (PCell) and NR-U (SCell)
  - NR-U SCell may have both DL and UL, or DL-only
- Scenario B: Dual connectivity between licensed band LTE (PCell) and NR-U (PSCell)
- Scenario C: Stand-alone NR-U
- Scenario D: A stand-alone NR cell in unlicensed band and UL in licensed band
- Scenario E: Dual connectivity between licensed band NR and NR-U



Scenarios acc. TR 38.889

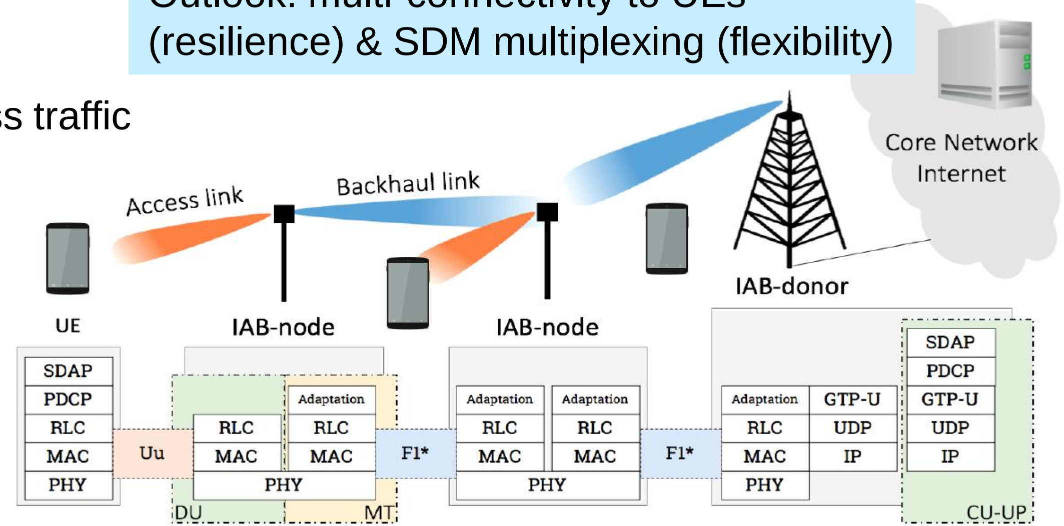
REL. 16: NR ACCESS TO UNLICENSED SPECTRUM (NR-U)



REL. 16: NR INTEGRATED ACCESS AND BACKHAUL (IAB)

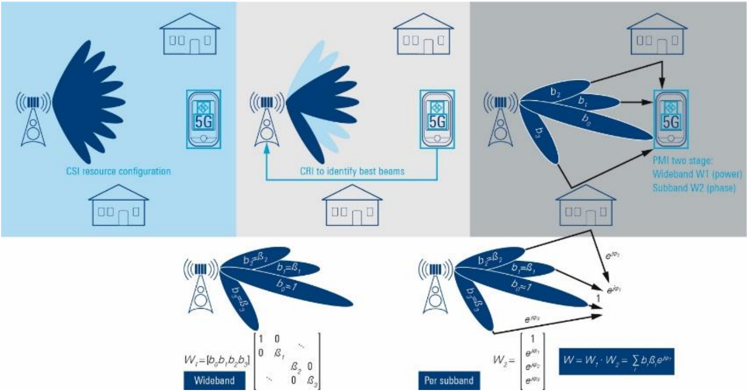
Outlook: multi-connectivity to UEs (resilience) & SDM multiplexing (flexibility)

- Wireless backhaul links to relay the access traffic
- Enabling flexible and ultra-dense cell deployments at lower cost, leverages coverage (not capacity)
- Multi-hops for the short range in mmWave

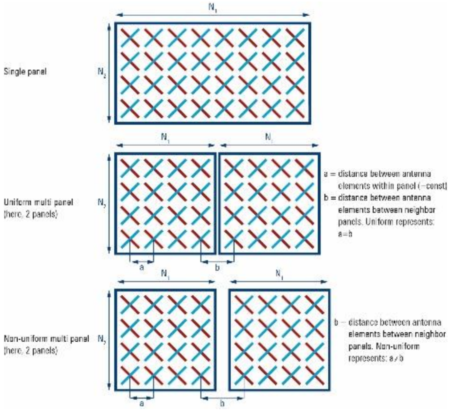


- Replaces the proprietary solutions in current (extensively used) wireless backhaul links (P2P, LOS)
- Motivated by larger bandwidths and native beamforming in NR (as opposed to LTE Rel-10 relays)
- Very beneficial for NR rollout and during the early phases of the initial growth

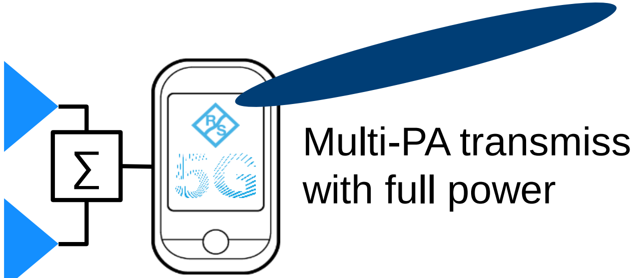
REL. 16: NR eNR-MIMO



CSI enhancements, e.g. type II to close gap to near-ideal CSI

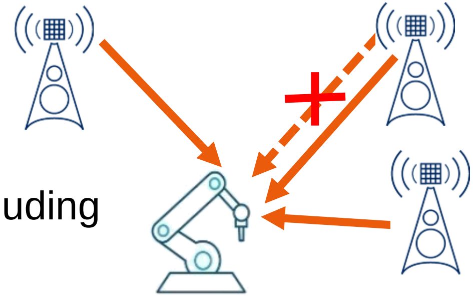


Allow larger size multi-TRP/panel



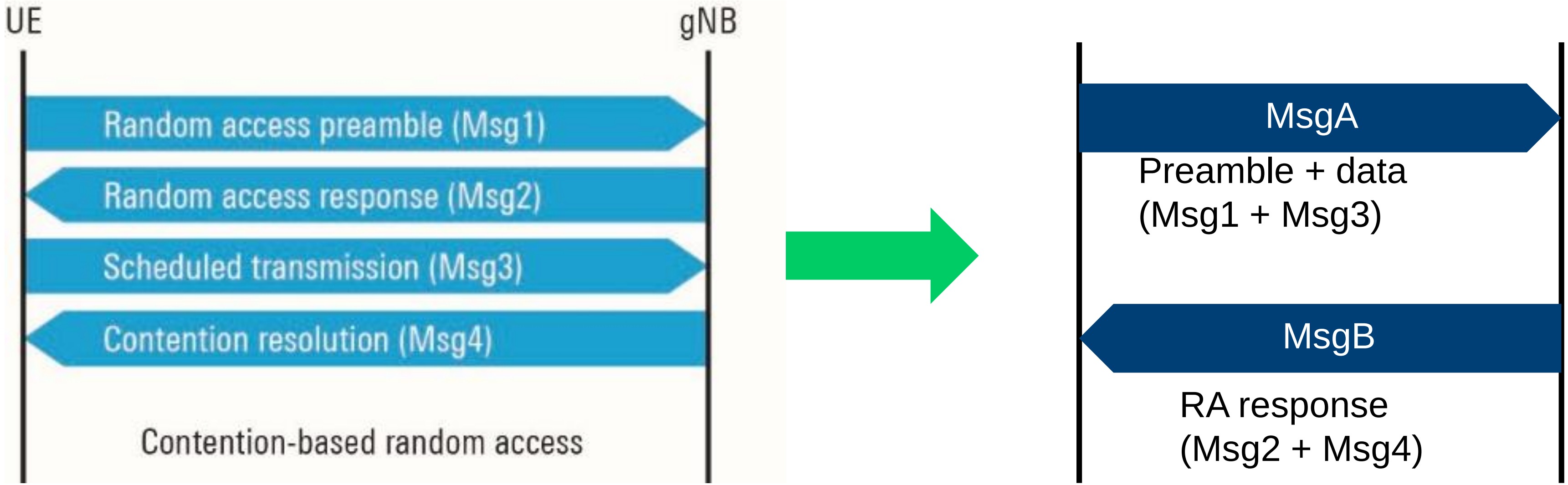
Multi-PA transmission with full power

Multi-beam operation, including beam failure recovery



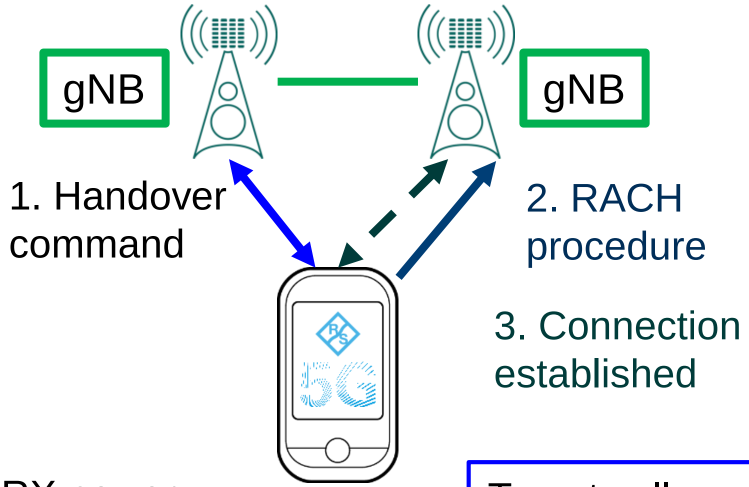
REL. 16: NR 2-STEP RACH

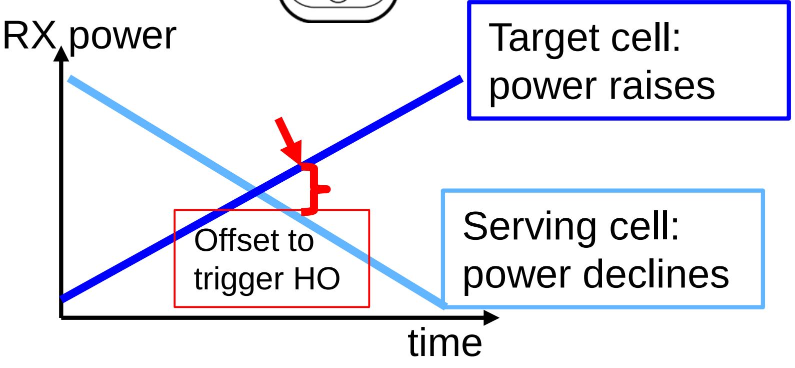
Idea: change legacy 4-step RACH into 2-step RACH
Motivation: reduce latency and control signaling overhead



5G NR MOBILITY ENHANCEMENTS

Rel. 15 mobility

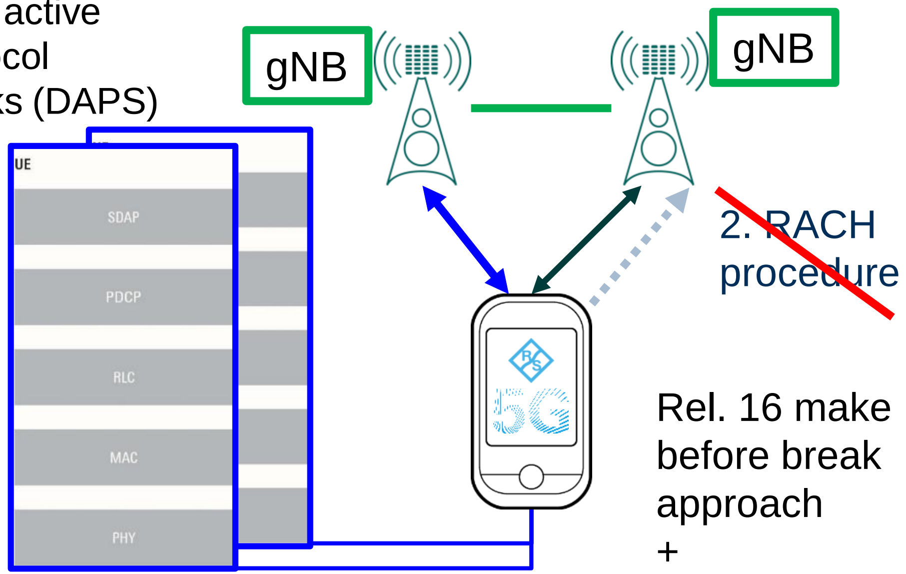




Idea: send HO command earlier, with some configuration info to trigger HO autonomously

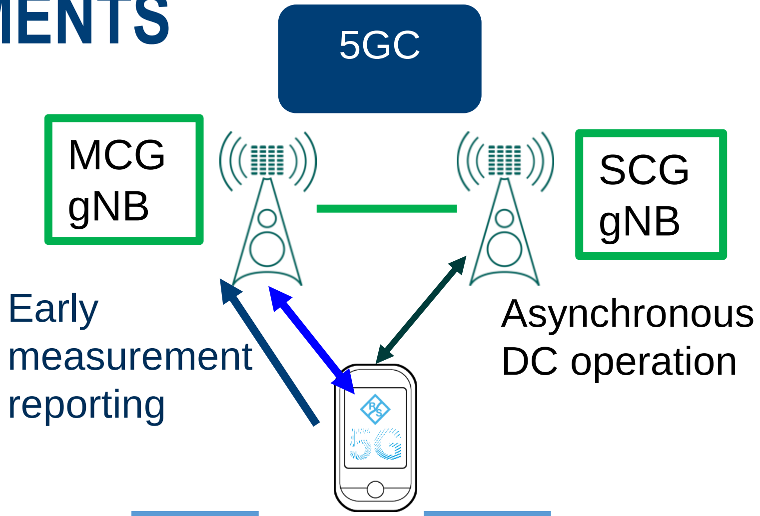
Rel. 16 mobility

Dual active protocol stacks (DAPS)

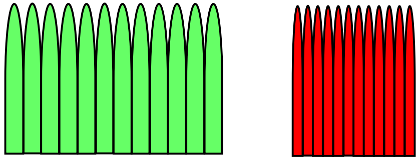


Rel. 16 make before break approach
+
RACH less handover procedure

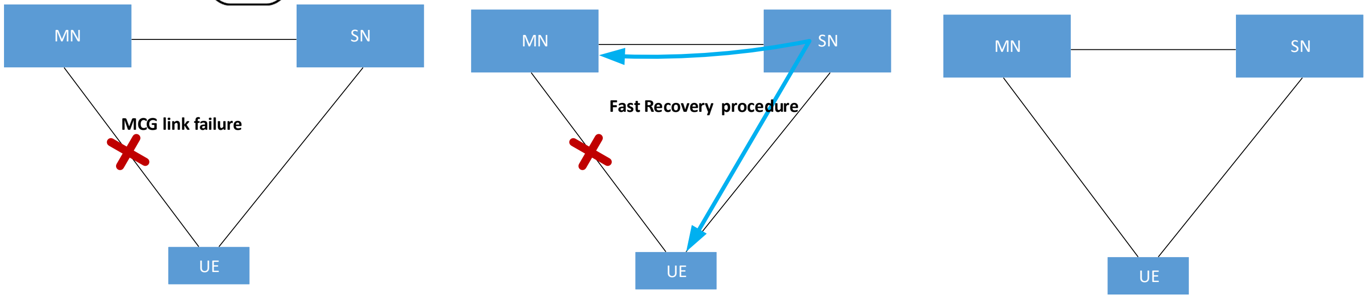
5G NR DUAL CONNECTIVITY AND CARRIER AGGREGATION ENHANCEMENTS



Cross-carrier scheduling of different numerologies



Fast recovery procedure



a. MCG link failure

b. MCG link fast Recovery procedure on SCG link

c. MCG link recovery

Das Bildelement mit der Beziehungs-ID rId2 wurde in der Datei nicht gefunden.

NB-IoT radio interface
=> integration into 5GC

LTE-M

DL + UL transmission efficiency and/or

Stand-alone deployment (without LTE carrier)

UE power consumption
DL: (EDT, WUS)
UL: (Predefined UL resources, PUR)

Connection to 5G core

Scheduling enhancement (Multiple UL/DL TBs)

Coexistence with NR

Extreme coverage for non-BL UEs

Mobility enhancement

NB-IoT

DL + UL transmission efficiency

Improved multi-carrier operation

UE power consumption DL: (EDT, WUS)
UL: (PUR)

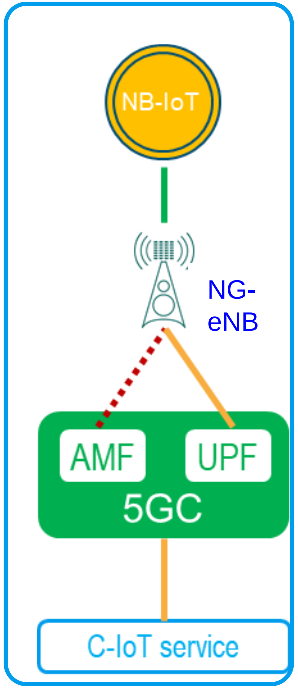
Mobility enhancement

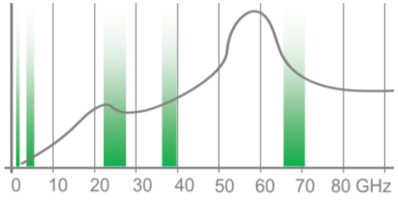
Scheduling enhancement (Multiple UL/DL TBs)

Coexistence with NR

Network management tool enhancement

Connection to 5GC





Surveillance camera

- Video with 2 to 4 Mbps, high end with 7.5 to 25 Mbps
- Latency <500 ms and reliability 99 to 99.9%
- Traffic is heavy in UL

Industrial wireless sensor

- Service availability 99.99%
- End-to-end latency < 100 ms (Critical device with 5 ms to 10 ms)
- Stationary device with < 2 Mbps
- Years of battery life

Wearables

- Bitrate approx. 150 Mbps/50 Mbps.
- Days of battery

LTE-M

NB-IoT

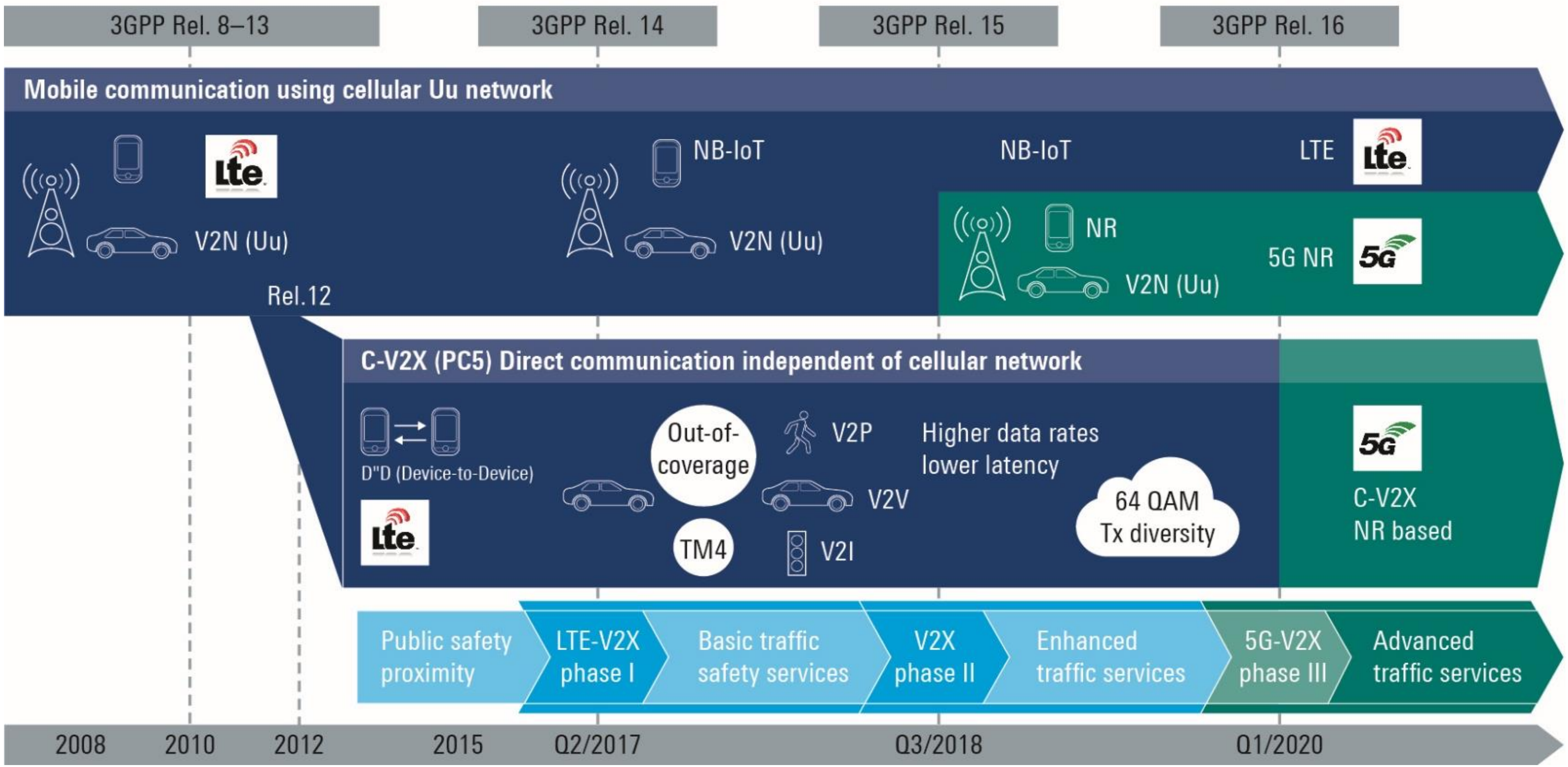
Rel. 17 5G NR light

- Throughput
- Cost
- Size
- Coverage

5G evolution, Releases 16 and 17

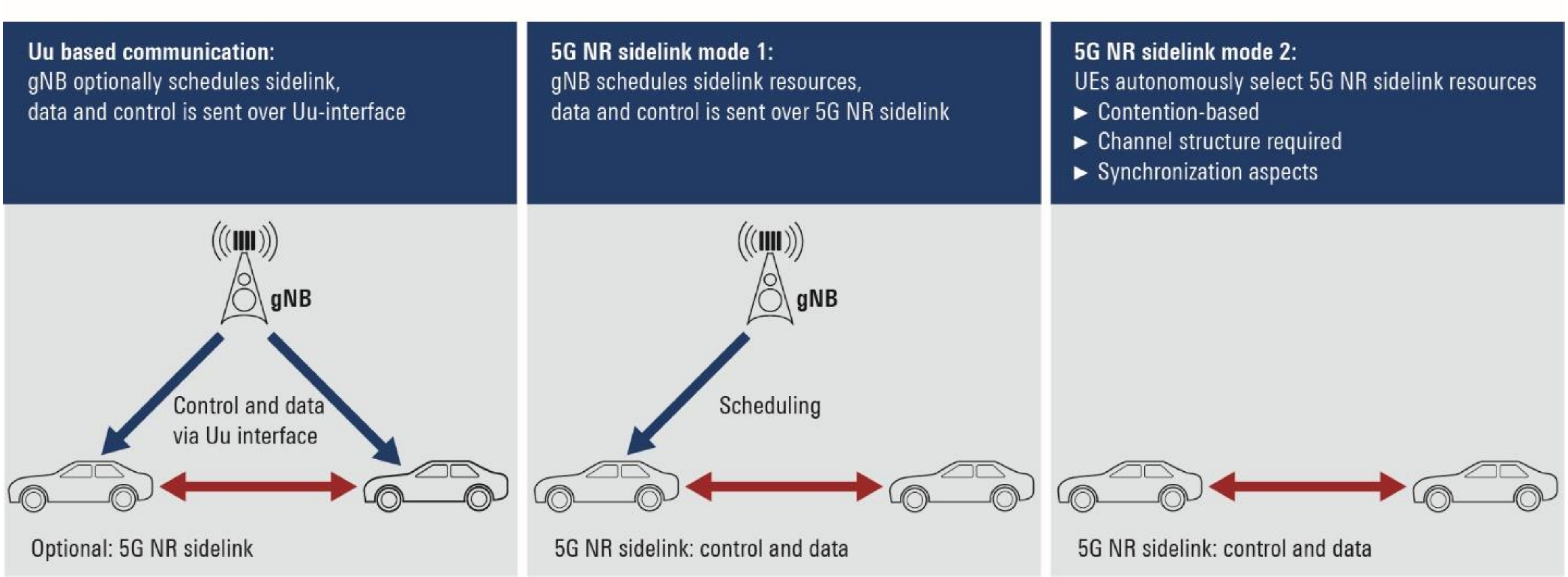
NR-V2X

EVOLUTION OF 3GPP MOBILE COMMUNICATIONS STANDARD RELEASES 12 TO 16 FF RELEVANT FOR AUTOMOTIVE



Rohde & Schwarz 5G New Radio evolution

5G NR C-V2X COMMUNICATION MODES AT PHY LAYER

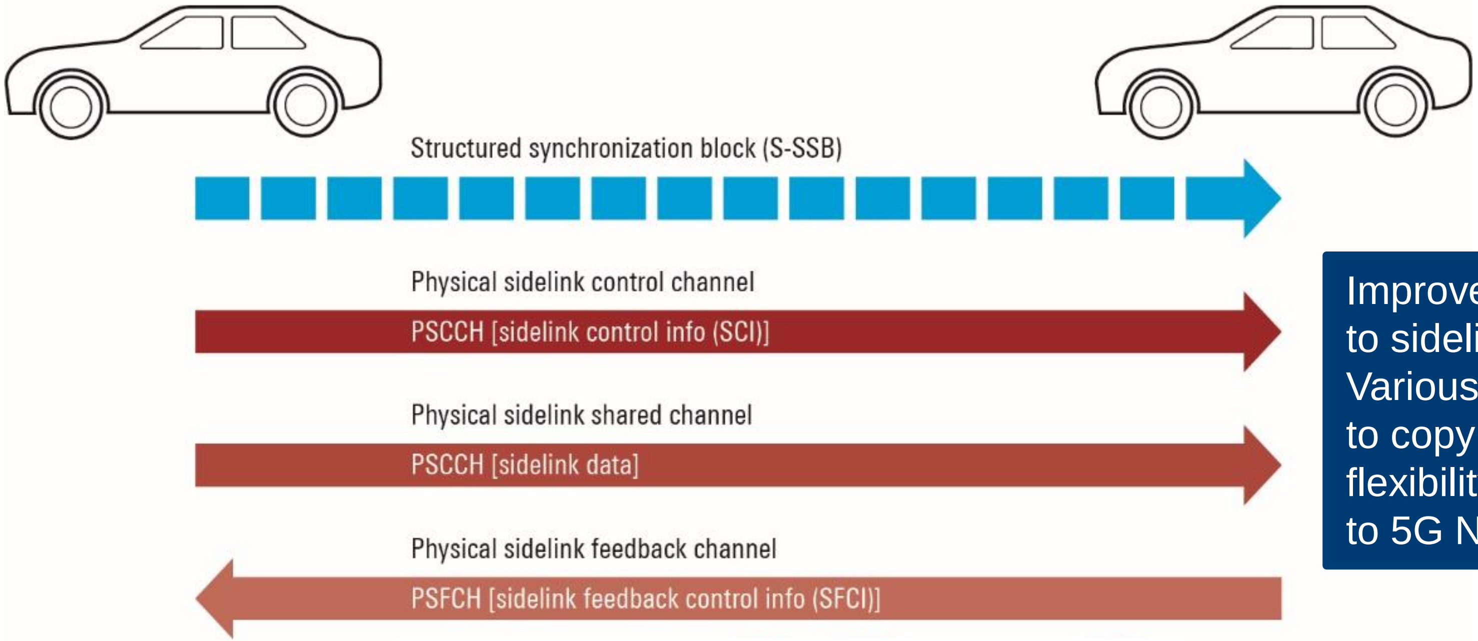


Note: eNB can schedule NR or LTE sidelink. gNB can schedule NR or LTE sidelink

V2X PHYSICAL LAYER PARAMETERS

Parameter	LTE D2D (Rel. 12)	LTE V2X (Rel. 14)	LTE V2X (Rel. 15)	5G NR V2X (Rel. 16/17)
Frequency	All bands possible (e.g. FirstNet 700 MHz)	Target 5.9 GHz	Target 5.9 GHz	Target 5.9 GHz FR1 but also FR 2 possible
Waveform	DFT-s-OFDM	DFT-s-OFDM	DFT-s-OFDM	CP-OFDM
Subcarrier spacing	15 kHz	15 kHz	15 kHz	NR numerologies 15/30/60/120 kHz
Cyclic prefix	Normal + extended	Normal	Normal	Normal + extended (only 60 kHz SCS)
Modulation	QPSK, 16QAM	QPSK, 16QAM	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM, 256QAM
Channel coding	Turbo code	Turbo code	Turbo code	LDPC (data) + Polar (signaling) codes
Time scheduling	1 subframe = 1 ms	1 subframe = 1ms	1 subframe = 1ms	1 slot flexible duration, slot aggregation possible
# DMRS symbols /TTI	2 per subframe	4 per subframe	4 per subframe	2 to 4 per slot
Data/control multiplex	TDM	FDM	FDM	TDM+FDM
HARQ	NA	NA	NA	RX UE reports to TX UE, TX UE reports to gNB
MIMO	Single layer	Single layer	TX + RX diversity	Up to 2 layers
Retransmissions	4 by default	Up to 2	Up to 2	Up to 32 (configurable + resource reservation)
Communication type	Groupcast, broadcast	Broadcast only	Broadcast only	Unicast, groupcast + broadcast
Carrier aggregation	No	No	Up to 8 CCs	No
Peak throughput	~7 Mbps	~32 Mbps	~72 Mbps	~200 Mbps (256QAM)

5G NR SIDELINK – CHANNEL STRUCTURE

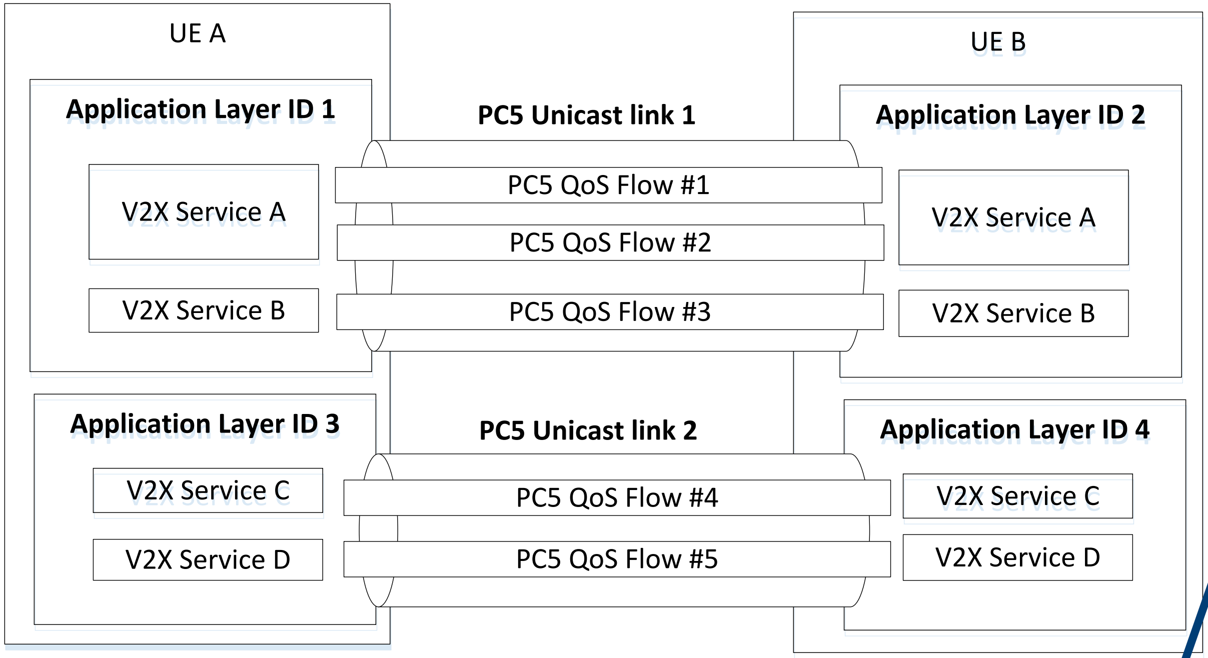


Unicast containing ACK / NACK, groupcast only NACK

Improved flexibility due to sidelink control info. Various numerologies to copy the tremendous flexibility of 5G NR, also to 5G NR V2X

Technology of PC5 direct communications (5G)

NR V2X SIDELINK SUPPORTING QoS



	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Service
21	GBR	3	20 ms	10^{-4}	1. N/A	2. 2000 ms	3. Platooning between UEs – Higher degree of automation; 4. Platooning between UE and RS – Higher degree of automation
22	(NOTE 1)	4	50 ms	10^{-2}	5. N/A	6. 2000 ms	7. Sensor sharin higher degree of automation
23		3	100 ms	10^{-4}	8. N/A	9. 2000 ms	10. Information sharing for automat driving – between UEs or UE and RSU higher degree of automation
55	Non-GBR	3	10 ms	10^{-4}	11. N/A	12. N/A	13. Cooperative la change – higher degree of automatio
56		6	20 ms	10^{-1}	14. N/A	15. N/A	16. Platooning informative exchang – low degree of automation; 17. Platooning – information sharing with RSU
57		5	25 ms	10^{-1}	18. N/A	19. N/A	20. Cooperative la change – lower degree of automatio
58		4	100 ms	10^{-2}	21. N/A	22. N/A	23. Sensor information sharing lower degree of automation
59		6	500 ms	10^{-1}	24. N/A	25. N/A	26. Platooning – reporting to an RSU
90	Delay Critical GBR	3	10 ms	10^{-4}	27. 2000 bytes	28. 2000 ms	29. Cooperative collision avoidance; 30. Sensor sharin Higher degree of automation; 31. Video sharing higher degree of automation
91	(NOTE 1)	2	3 ms	10^{-5}	32. 2000 bytes	33. 2000 ms	34. Emergency trajectory alignment 35. Sensor sharin Higher degree of automation

Not an eye test ☺ but an example of the flexibility:
3GPP defines ~10 different QoS flow profiles for the NR V2X sidelink

THE 7 PILLARS OF 5G NR-C-V2X

1. CP-OFDM with multiple numerologies
2. Greater flexibility & higher throughput
3. Low latency slot structure (self-contained)
4. Broadcast, multicast and unicast
5. QoS management policy
6. Beamforming support
7. Channel structure: reliability + flexibility

5G evolution, Releases 16 and 17

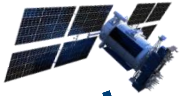
NON-TERRESTRIAL NETWORKS

NON TERRESTRIAL NETWORK APPLICATIONS

ETSI TR 103 612: Mobile/fixed communication network in the frequency range 6425 to 7125 MHz

3GPP: NR over NTN
5G NR air interface adopted to NTN
GEO, LEO, HAPS -> air to ground
Fixed or moving terrestrial cells
UE support GNSS + NTN
Business case: „human“: eMBB

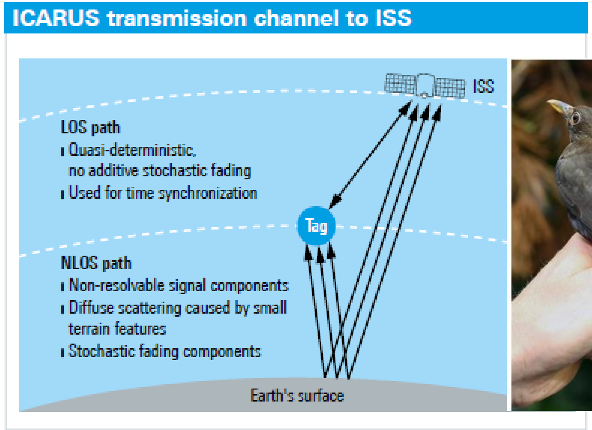
3GPP: IoT over NTN
NB-IoT & LTE-M adopted to NTN
GEO, LEO, HAPS -> air to ground
Business case: „IoT“
e.g. ICARUS: Internet of animals @400MHz



Remote areas

Public safety

Temporary hotspots



Rohde & Schwarz

5G New Radio evolution

NON TERRESTRIAL NETWORK IN ONE SLIDE

Non-terrestrial networks refer to networks, or segments of networks, using an airborne or spaceborne vehicle for transmission (part of Rel. 17):

Scenario:

- Device :
  - Low speed, pedestrian/ship, VSAT
  - Medium/high speed vehicle/train
  - Very high speed aerial
  - Unmanned aerial system UAS

- Base station
  - Spaceborne: satellite systems like GEO, MEO or LEO
  - Airborne: aerial vehicles (8 to 50 km)
  - Air 2 ground (A2G) system
  - High altitude platform station (HAPS)
  - Terrestrial

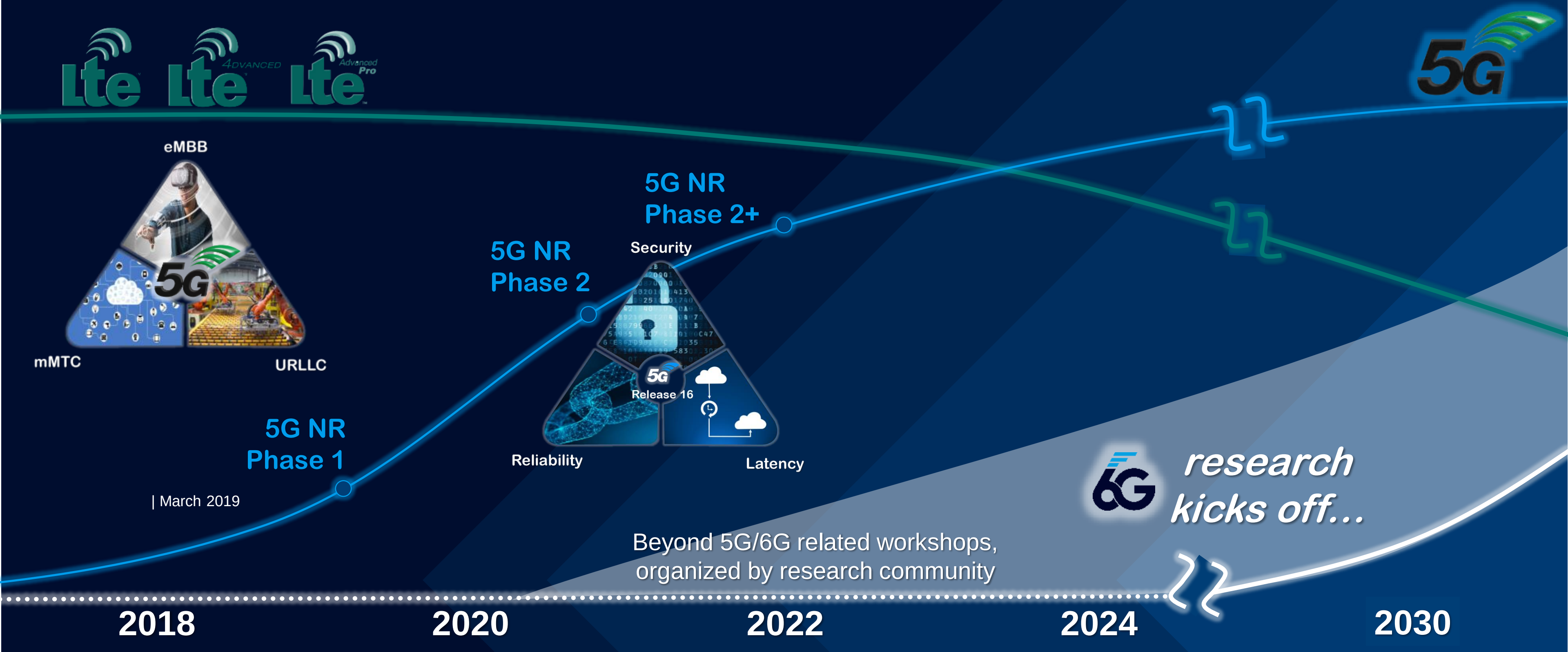
Deployment:

- Rural, suburban, isolated areas
- Internet access rural areas (MBB), MTC/IoT
- Cataclysm/disaster relief, public safety
- **Discussion to operate in S and Ka-band**

5G evolution, Releases 16 and 17

BEYOND 5G

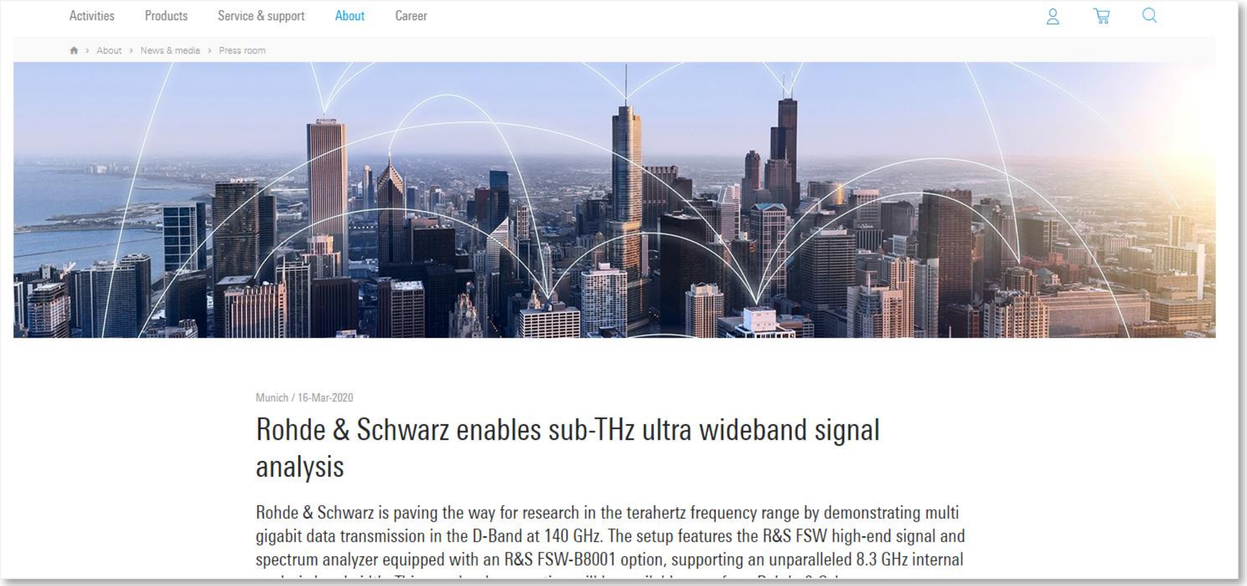
FROM 5G NR PHASE 2 AND 2+ TOWARDS BEYOND 5G & 6G



eMBB: enhanced Mobile Broadband
URLLC: Ultra-Reliable Low Latency Communication
mMTC: massive Machine Type Communication

TRENDS TO HIGHER FREQUENCIES AND WIDER BANDWIDTHS WILL CONTINUE

Bandwidth extension for FSW signal and spectrum analyzer up to 8.3 GHz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About > News & media > Press room

Munich / 16-Mar-2020

Rohde & Schwarz enables sub-THz ultra wideband signal analysis

Rohde & Schwarz is paving the way for research in the terahertz frequency range by demonstrating multi gigabit data transmission in the D-Band at 140 GHz. The setup features the R&S FSW high-end signal and spectrum analyzer equipped with an R&S FSW-B8001 option, supporting an unparalleled 8.3 GHz internal

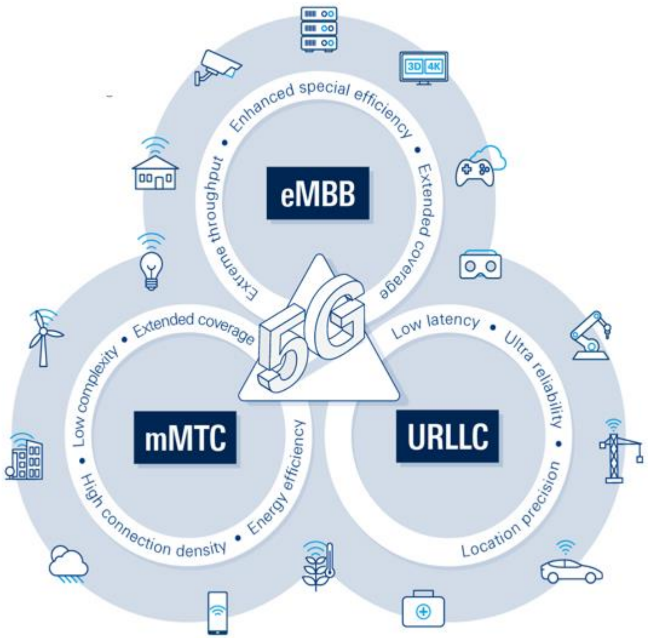
Source: https://www.rohde-schwarz.com/us/about/news-press/all-news/rohde-schwarz-enables-sub-thz-ultra-wideband-signal-analysis-press-release-detailpage_229356-793512.html

5G IS A MARATHON, NOT A 100M SPRINT

- ► First 5G NR network are being deployment based on Non-standalone (NSA) mode (Option 3X) using FR1 and FR2 frequencies
  - Not yet mature, optimization ongoing
  - Standalone (SA) rollout started

- ► Initial 5G deployments focus on enhanced mobile broadband (eMBB), upcoming releases of the standard will focus on URLLC use cases to address the two market verticals Industrial IoT (IIoT) and automotive

- ► Rohde & Schwarz helps the industry to pave the way with innovative test solutions for 5G



THE ONGOING EVOLUTION OF 5G NEW RADIO RELEASES 16 AND 17

q&a

Thank you for listening.

For any questions please contact me via chat in the expert lounge area the next 30 minutes.