5G TODAY AND INTO THE FUTURE

A TECHNICAL OVERVIEW OF R16, 17, 18 AND BEYOND

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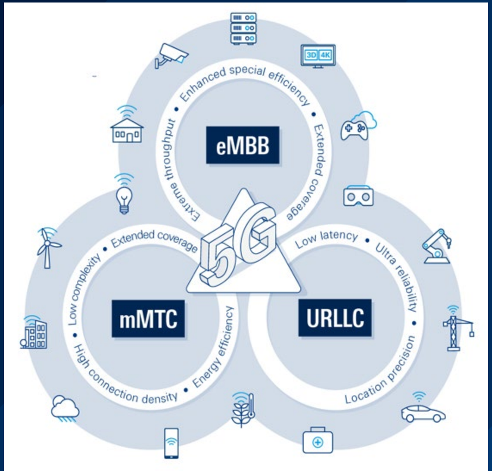


ROHDE&SCHWARZ

Make ideas real

5G NR TECHNOLOGY EVOLUTION

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

5GACIA

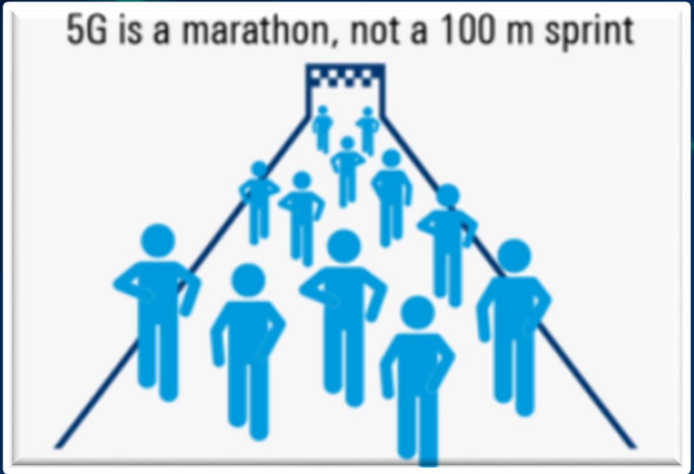
5GAA Automotive Association

| June 2022

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

| March 2024

3GPP Release 18 5G Advanced; focus: XR, AI, Energy Saving, …

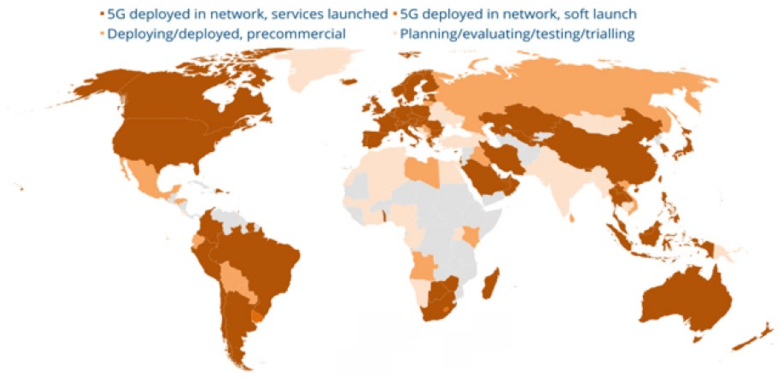


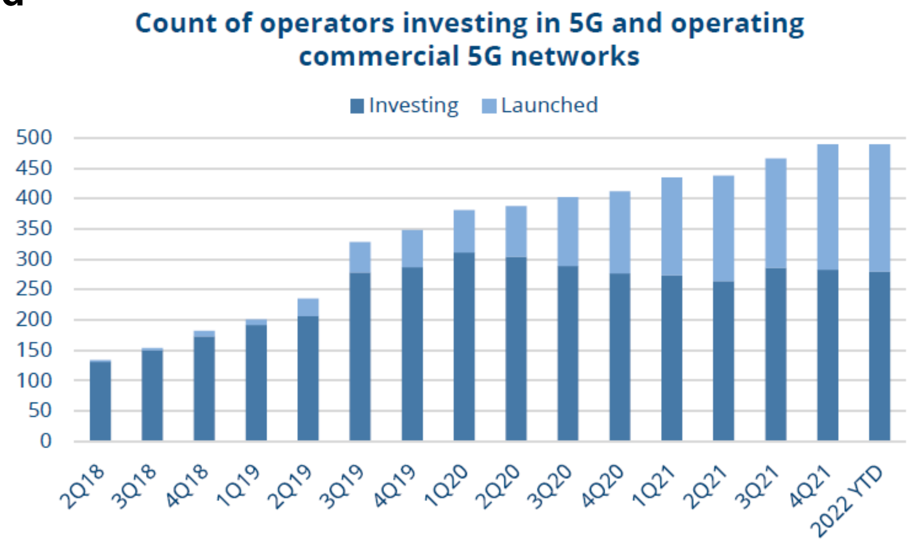
2018 2020 2022 2024 2026

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

5G NR TODAY
NETWORK NUMBERS INCREASE ONLY MODERATELY

- **491 operators** in **148 countries** / territories are **investing** in 5G (mobile or FWA).
- **211 operators** in **61 countries** / territories who have announced 3GPP-compatible 5G service launches (mobile or FWA).
- **23 operators** are understood to have **launched public 5G SA** networks (102 operators are identified as investing in 5G standalone)

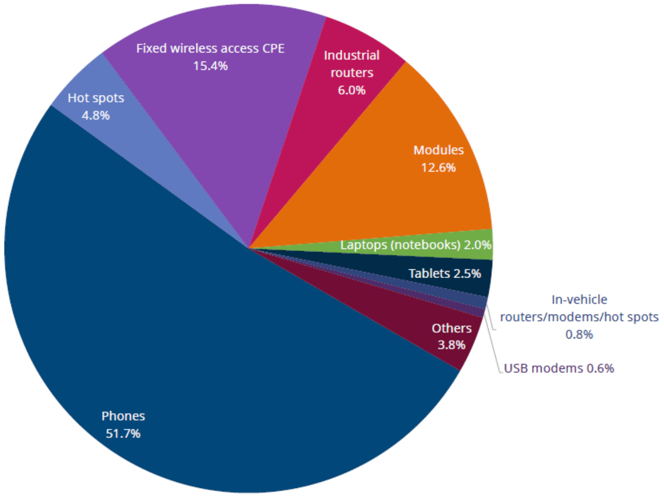


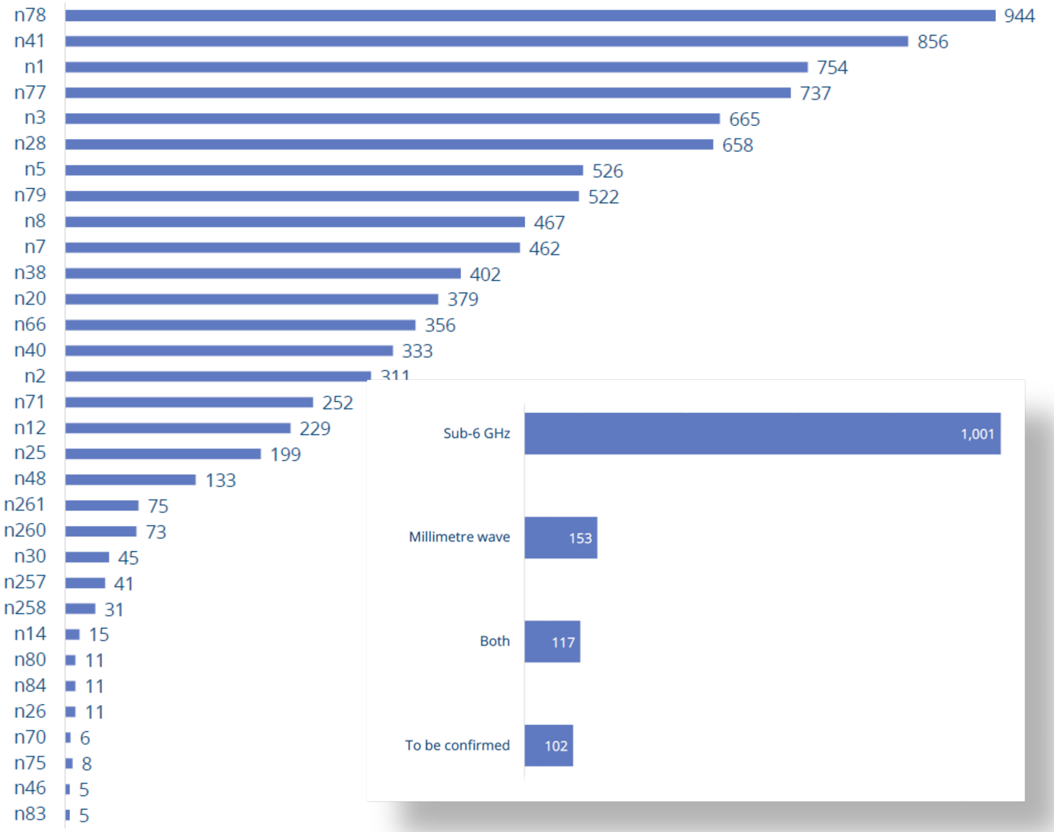


Source (GSA): Evolution from LTE to 5G, April 2022)

5G NR DEVICE NUMBERS INCREASE STEADILY

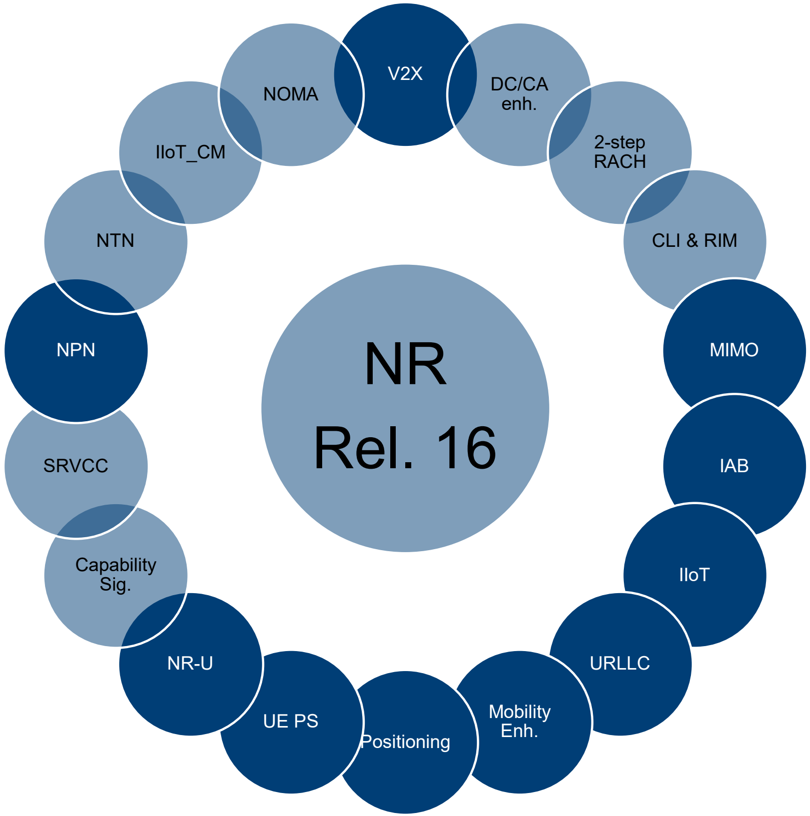
- ► **1373** announced devices including **1040** that are understood to be commercially available.
- ► **715** phones, at least **675** of which are now commercially available



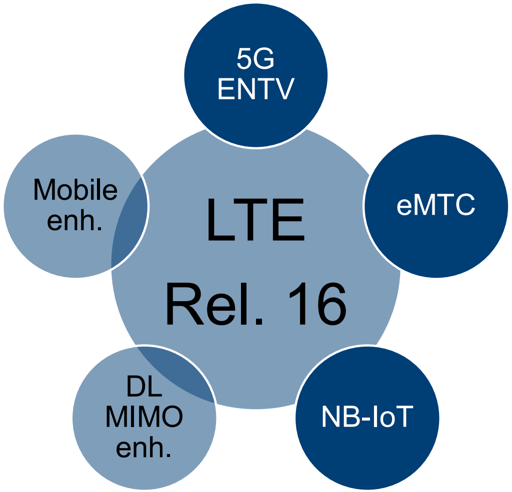


Source (GSA): 5G Device Ecosystem Member Report, May 2022)

LET'S GET MORE TECHNICAL:
3GPP REL. 16 TOPIC SUMMARY



Highlighted work items
= major new aspects

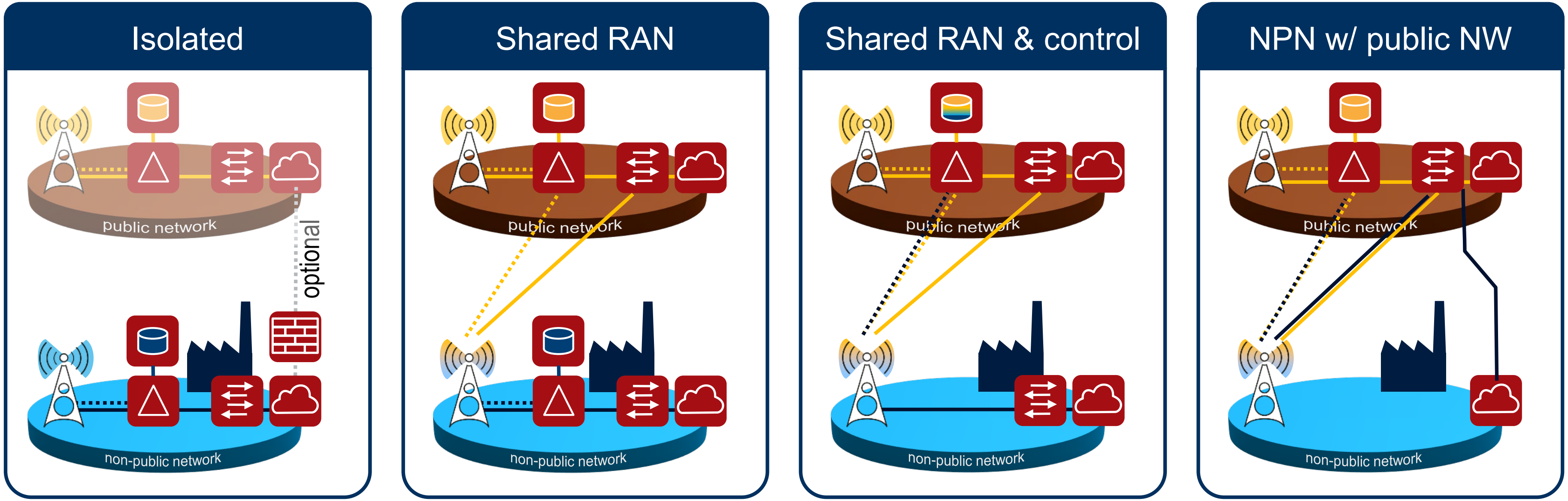


5G evolution, Releases 16

INDUSTRIAL IoT

INDUSTRY 4.0 SPECIFIC DEPLOYMENT SCENARIOS

5G-ACIA WP: 5G NON-PUBLIC NETWORKS (NPN) FOR INDUSTRIAL SCENARIOS

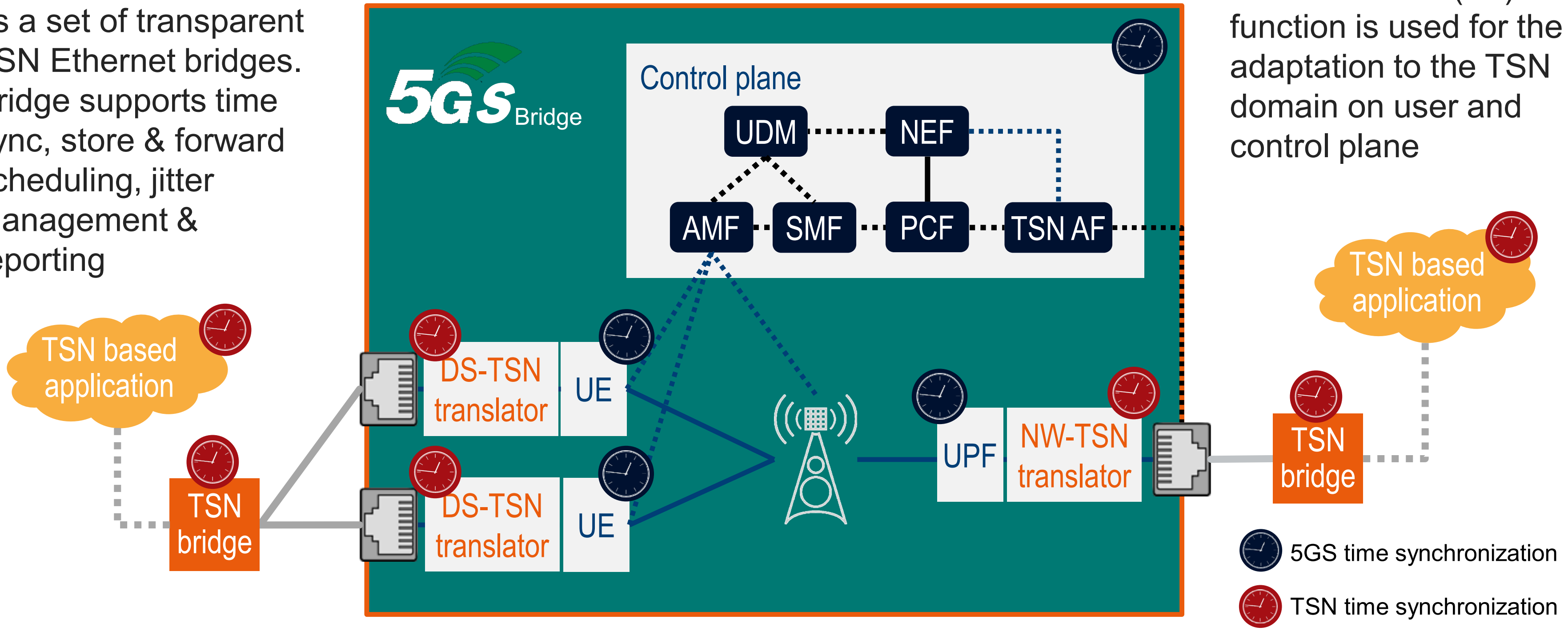


- Isolated NPN deployed on the organization’s defined premises, such as a campus or a factory, offer high reliability and operation flexibility

5G INTEGRATION INTO AN ETHERNET TSN ARCHITECTURE

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

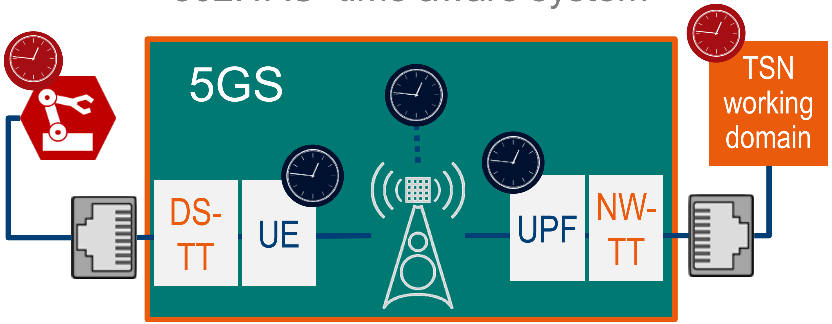
TSN translator (TT) function is used for the adaptation to the TSN domain on user and control plane



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

Time synchronization

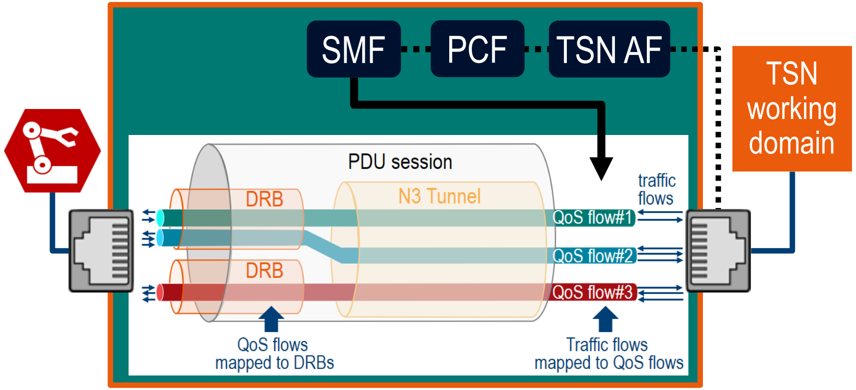
5GS can be considered as an IEEE 802.1AS "time aware system"



5GS calculates and adds the measured residence time between the TTs into the Correction Field (CF) of the synchronization packets of the TSN working domain (TS 23.501 - chapter 5.27.1).

gNB may signal 5G system time reference information to the UE using unicast or broadcast RRC signaling with a granularity of 10 ns

TSN traffic characteristic exchange

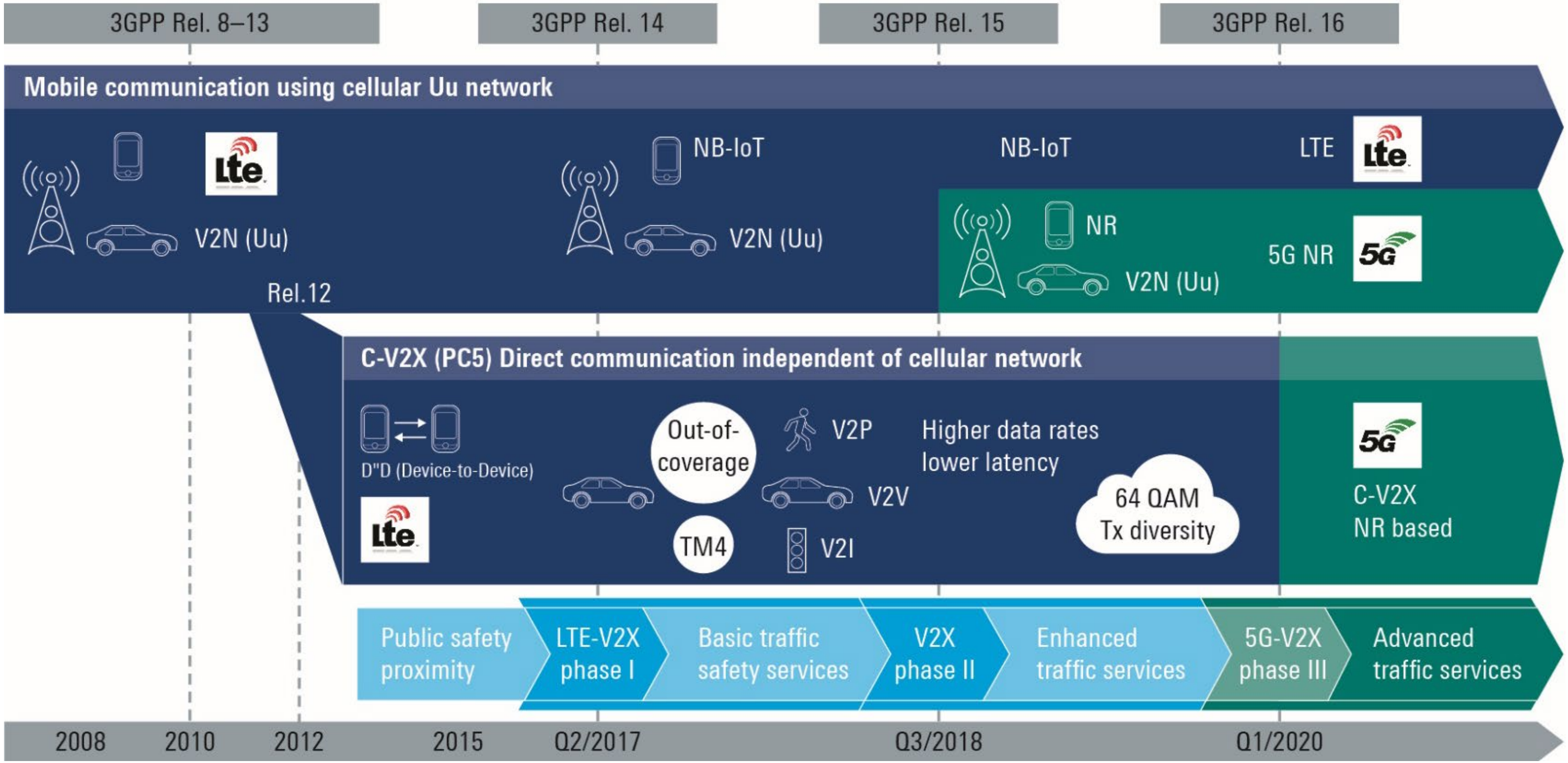


The knowledge of TSN traffic pattern is useful for the gNB to allow it to more efficiently schedule periodic, deterministic traffic flows either via Configured Grants, Semi-Persistent Scheduling or with dynamic grants.

5G evolution, Releases 16

NR-V2X

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

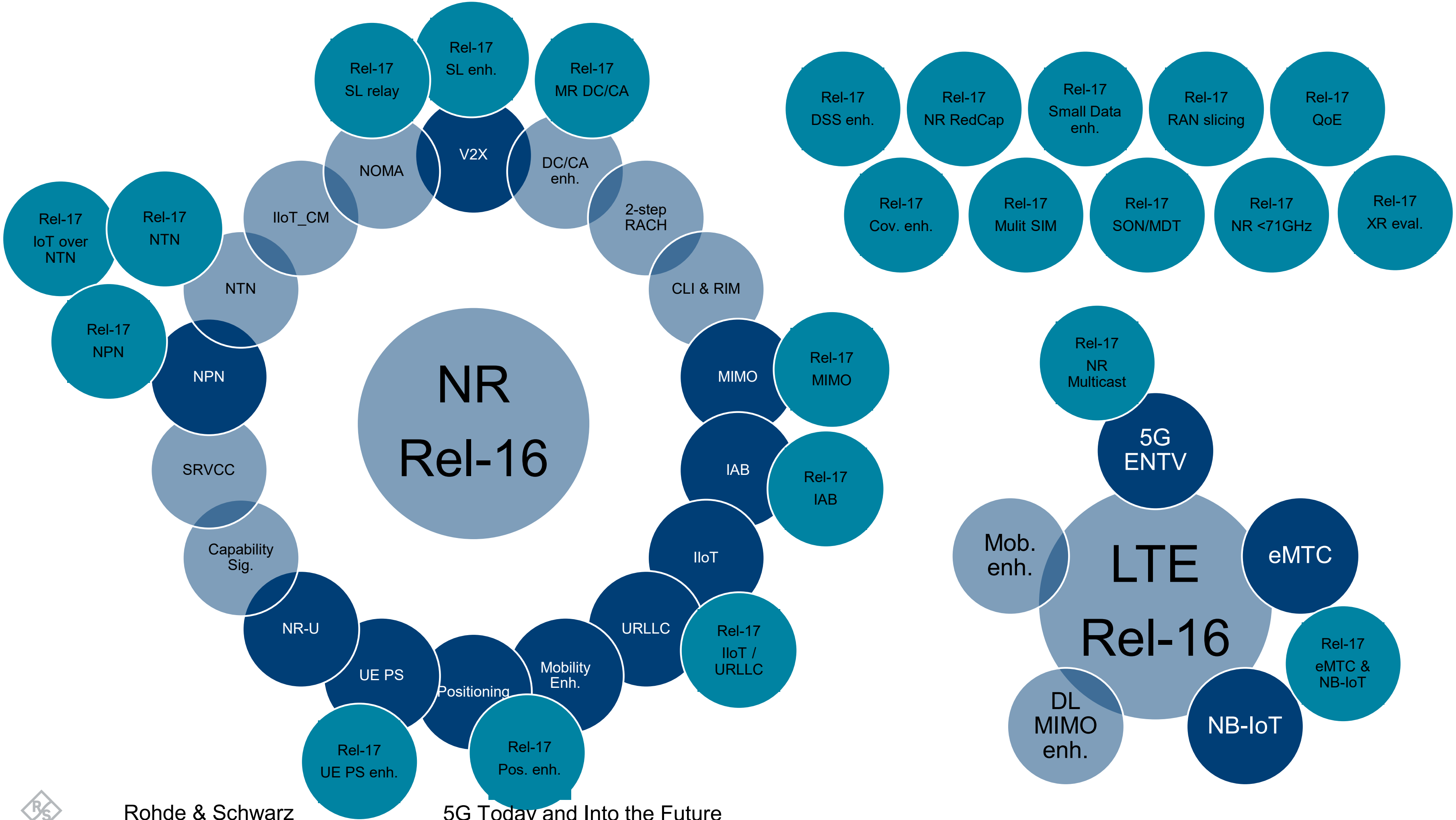


V2X PHYSICAL LAYER PARAMETERS

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 FR2
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, 64 QAM	QPSK, 16QAM, 64 QAM, 256 QAM
Channel coding	Turbo code	Turbo code	Turbo code	LPDC (data) + polar (signaling) codes
Time scheduling	1 subframe = 1 ms	1 subframe = 1 ms	1 subframe = 1 ms	1 slot, slot duration flexible, slot aggregation possible
# DMRS symbols/TTI	2 per subframe	4 per subframe	4 per subframe	2–4 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 (256 QAM)

3GPP RELEASE 17 OVERVIEW

- NR MIMO
- NR Sidelink enh.
- 52.6 - 71 GHz with existing waveform
- Dynamic Spectrum Sharing (DSS) enh.
- Industrial IoT / URLLC enh.
- IoT over Non Terrestrial Networks (NTN)
- NR over Non Terrestrial Networks (NTN)
- NR Positioning enh.
- Low complexity NR devices
- Power saving
- NR Coverage enh.
- NR eXtended Reality (XR)
- NB-IoT and LTE-MTC enh.
- 5G Multicast broadcast
- Multi-Radio DCCA enh.
- Multi SIM
- Integrated Access and Backhaul (IAB) enh.
- NR Sidelink relay
- RAN Slicing
- Enh. for small data
- SON / Minimization of drive tests (MDT) enh.
- NR Quality of Experience
- eNB architecture evolution, LTE C-plane / U-plane split
- Satellite components in the 5G architecture
- Non-Public Networks enh.
- Network Automation for 5G - phase 2
- Edge Computing in 5GC
- Proximity based Services in 5GS
- Network Slicing Phase 2
- Enh. V2x Services
- Advanced Interactive Services
- Access Traffic Steering, Switch and Splitting support in the 5G system architecture
- Unmanned Aerial Systems
- 5GC LoCation Services
- Multimedia Priority Service (MPS)
- 5G Wireless and Wireline Convergence
- 5G LAN-type services
- User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)


NR
Rel-16
V2X
NOMA
DC/CA enh.
IIoT_CM
2-step RACH
NTN
CLI & RIM
NPN
MIMO
SRVCC
IAB
Capability Sig.
IIoT
NR-U
URLLC
UE PS
Positioning
Mobility Enh.
Rel-17 SL relay
Rel-17 SL enh.
Rel-17 MR DC/CA
Rel-17 IoT over NTN
Rel-17 NTN
Rel-17 NPN
Rel-17 MIMO
Rel-17 IAB
Rel-17 IIoT / URLLC
Rel-17 UE PS enh.
Rel-17 Pos. enh.
Rel-17 DSS enh.
Rel-17 NR RedCap
Rel-17 Small Data enh.
Rel-17 RAN slicing
Rel-17 QoE
Rel-17 Cov. enh.
Rel-17 Mulit SIM
Rel-17 SON/MDT
Rel-17 NR <71GHz
Rel-17 XR eval.
Rel-17 NR Multicast
5G ENTV
LTE
Rel-16
Mob. enh.
eMTC
Rel-17 eMTC & NB-IoT
NB-IoT
DL MIMO enh.

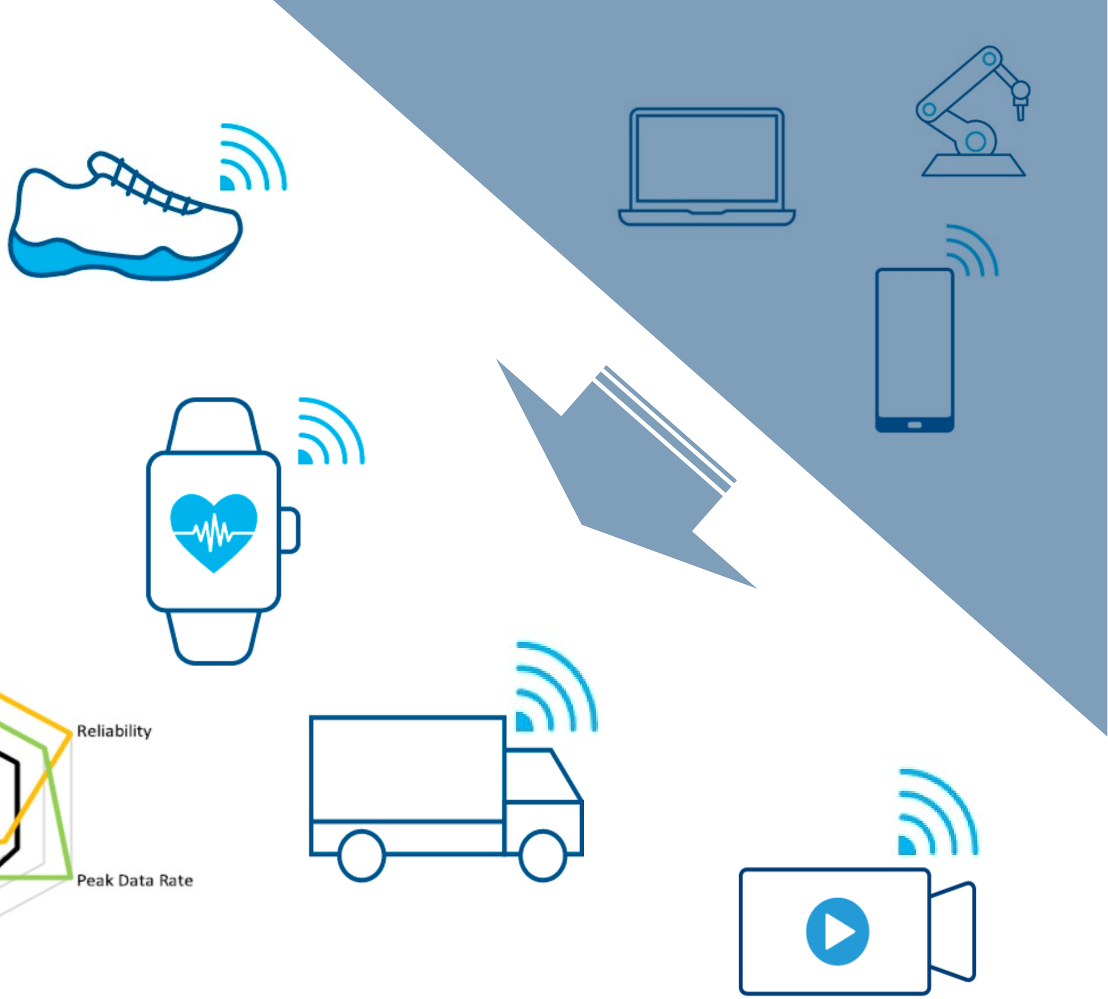
MULTI SIM SUPPORT
JUSTIFICATION AND GOAL

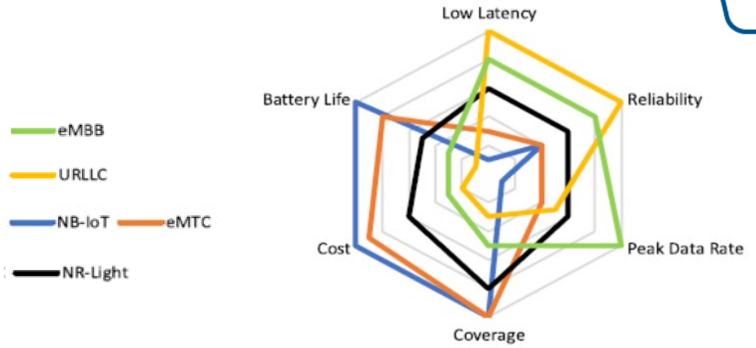
- MUSIM devices exist already since several years
  - So, why do we need a WI for that purpose?
- Realization is implementation specific → no specification exists
  - UE behavior is not predictable
  - Network may not be optimized
- Principal issue with the two networks (NWA and NWB) associated with the USIMS
  - Networks are not aware of each other

- Goal:
  - Enhancements to address the collision due to reception of paging when UE is in RRC IDLE/INACTIVE mode in both networks associated with the respective SIMs
- Mechanisms for UE to notify NWB that it does not want to switch → busy indicator

DEVICE OPTIMIZATION

► Reduced capability (RedCap)
  – 20 MHz (FR1), 100MHz (FR2)
  – 1 or 2 Rx
  – 256QAM optional
  – Half duplex FDD
  – Lower transmit power
  – Limited mobility/handovers

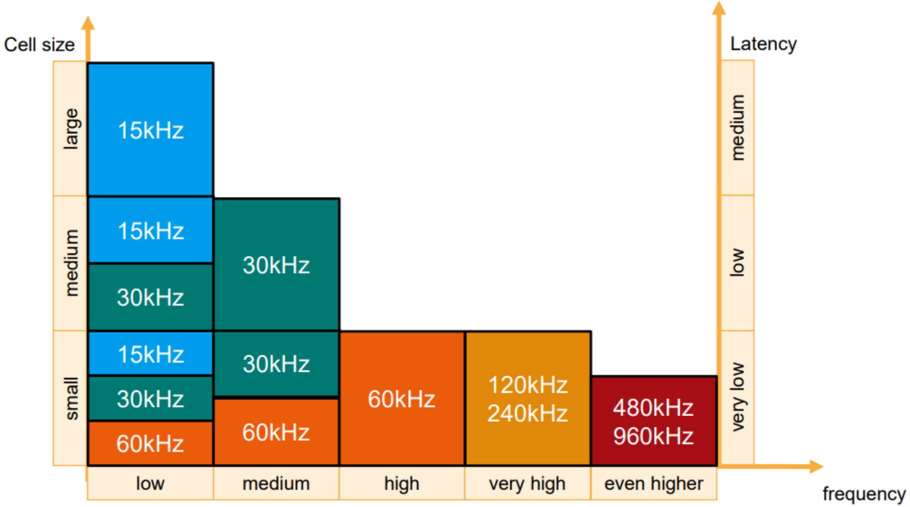




Source: Nokia

EXTENDING CURRENT NR OPERATION TO 71GHz

- In addition to 120kHz SCS, new SCS (480kHz and 960kHz) and wider bandwidth(s) are specified for operation in the extended frequency range.
- After some discussion the maximum bandwidth support is now **2GHz** (in addition to 100/400/1600 MHz).



Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
n263	57000 MHz	-	71000 MHz	57000 MHz	-	71000 MHz	TDD (Note)
[n264]	66000 MHz	-	71000 MHz	66000 MHz		71000 MHz	TDD (Note)
NOTE:	n263 unlicensed, n264 licensed						

NON-TERRESTRIAL-NETWORKS

Strong support from satellite industry players: ESA, Eutelsat, Globalstar, Intelsat, Inmarsat, Ligado Networks (former LightSquared), Sateliot, Thales, …

Goal: Global IoT operation & coverage beyond terrestrial deployments




Non-terrestrial networks refer to networks, or segments of networks, using an airborne or spaceborne vehicle for transmission

NON-TERRESTRIAL-NETWORKS
SPEC CHANGES

- Aspects related to **random access procedure/signals**
- Mechanisms for time/frequency adjustment including Timing Advance, and UL frequency compensation indication
- Timing offset related to scheduling and HARQ-ACK feedback
- Aspects related to HARQ operation
- General aspects related to timers (e.g. SR, DRX, etc.)
- RAN2 aspects related to idle mode and connected mode mobility
- RLF-based for NB-IoT
- Handover-based for eMTC
- System information enhancements
- Tracking area enhancements

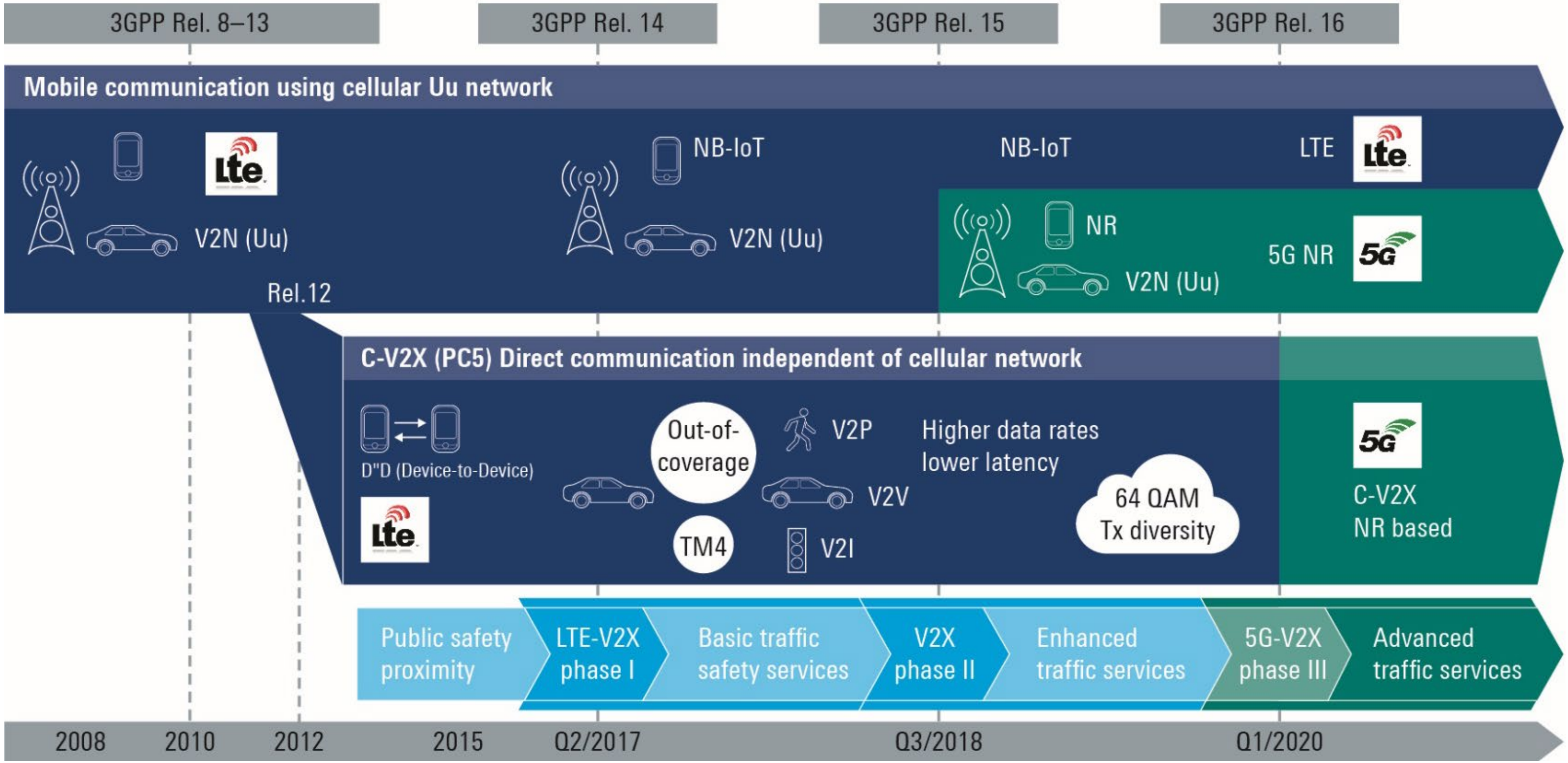
5G evolution, Releases 17

STRENGTHEN THE FOUNDATION AND IMPROVING VERTICALS

The ongoing evolution of 5G

NR-V2X: SIDELINK ENHANCEMENTS + RELAY

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

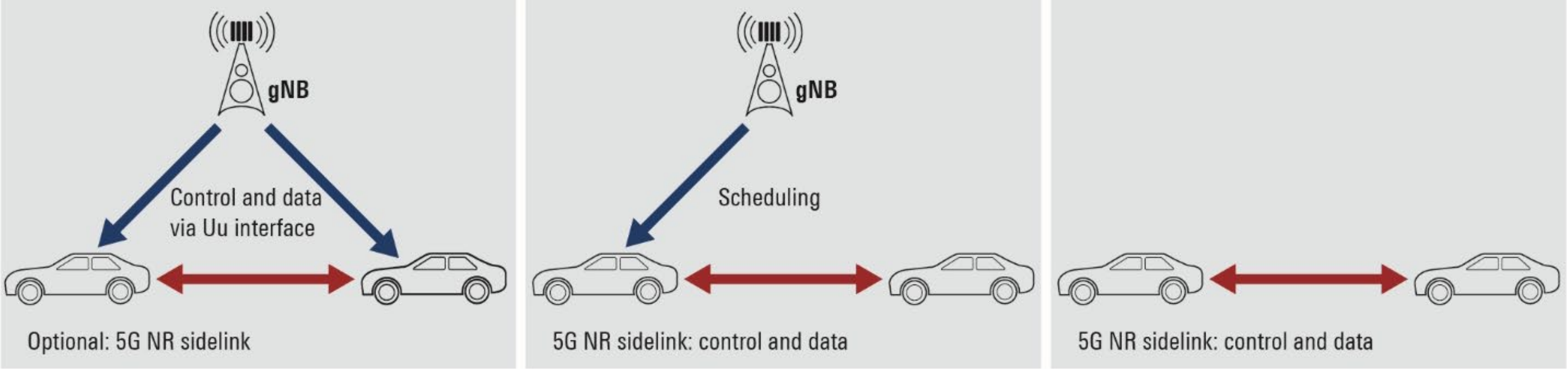


5G NR C-V2X COMMUNICATION MODES AT PHY LAYER

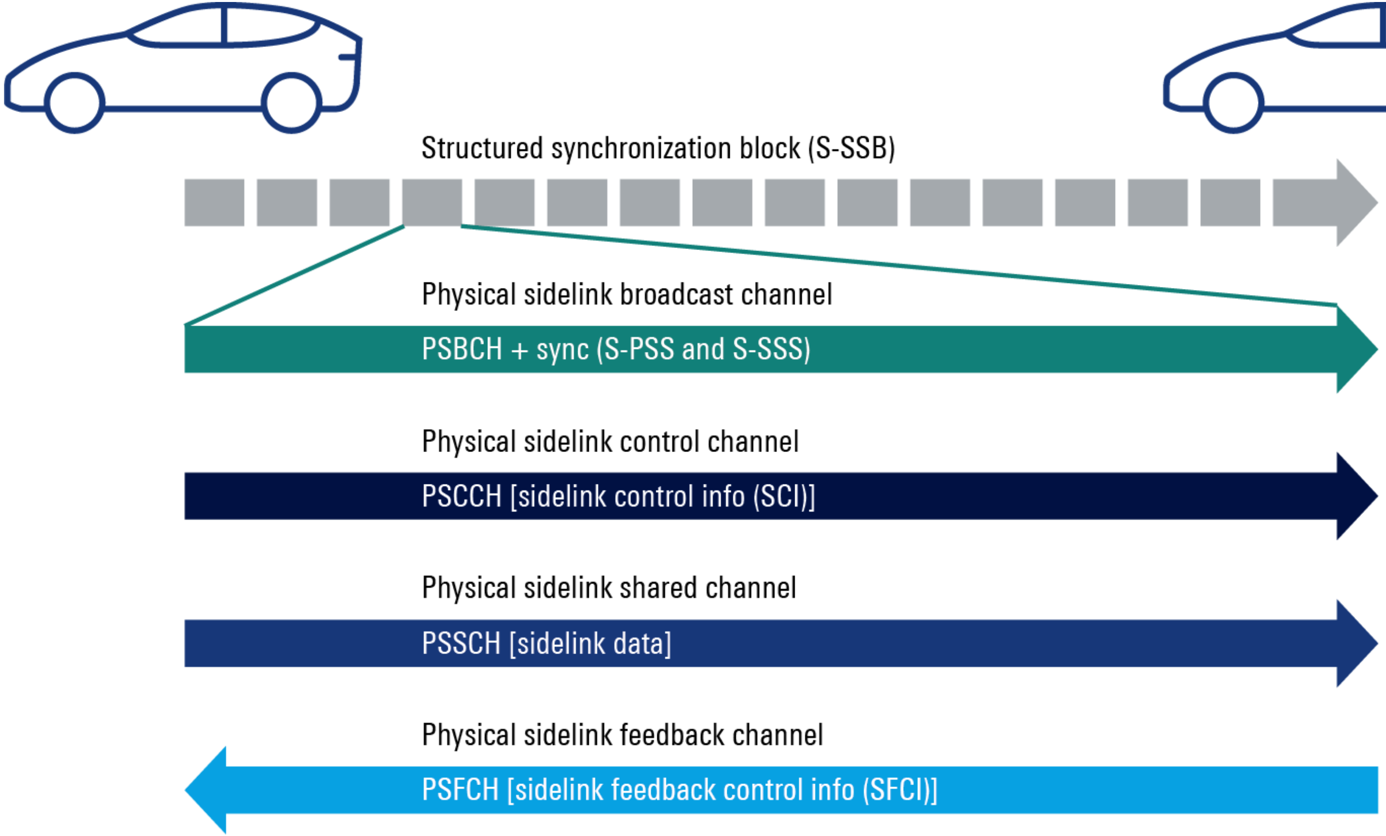
Uu based communication:
gNB optionally schedules sidelink,
data and control is sent over Uu-interface

5G NR sidelink mode 1:
gNB schedules sidelink resources,
data and control is sent over 5G NR sidelink

5G NR sidelink mode 2:
UEs autonomously select 5G NR sidelink resources
- Contention-based
- Channel structure required
- Synchronization aspects



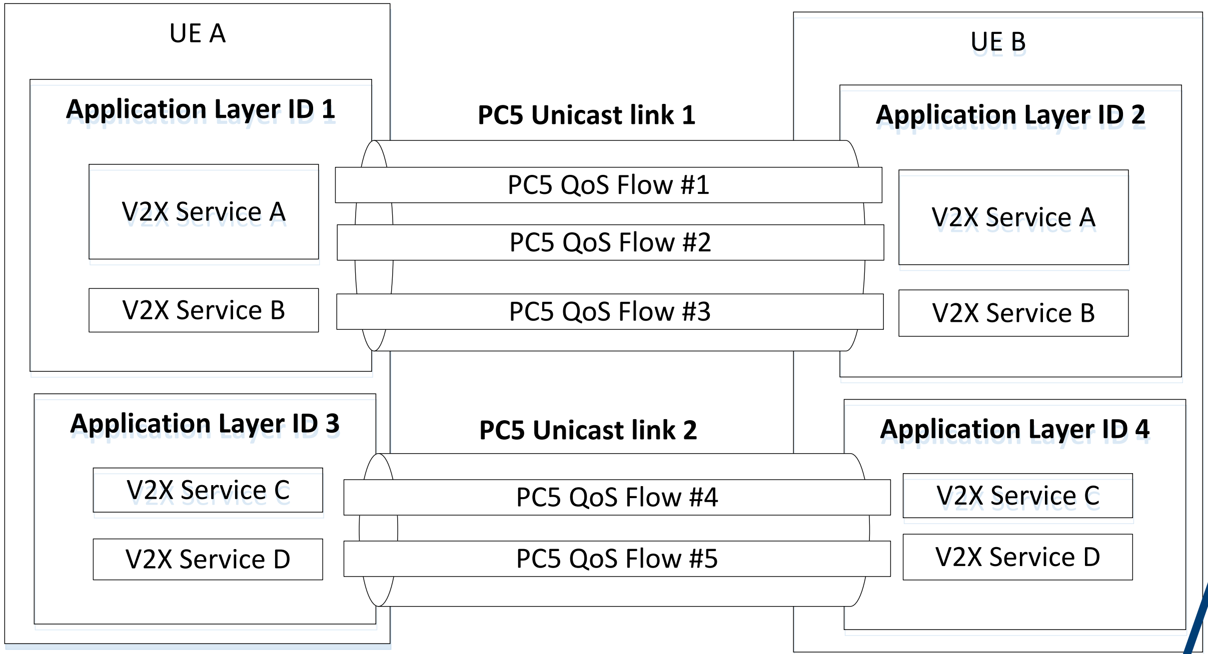
5G NR SIDELINK – CHANNEL STRUCTURE



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

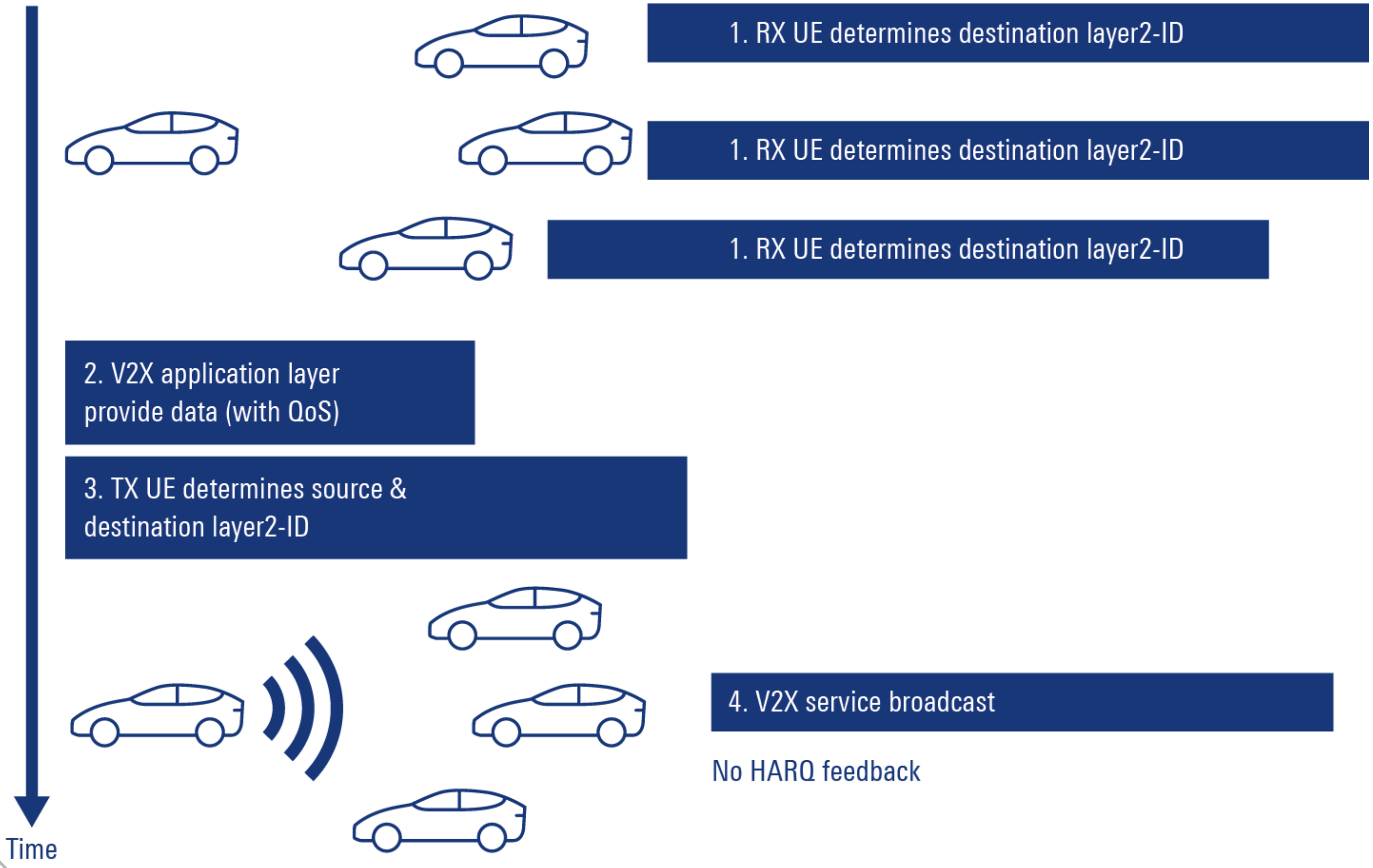


	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Service
21	GBR	3	20 ms	10^{-4}	1. N/A	2. 2000 ms	3. Platooning between UEs – Higher degree of automation; 4. Platooning between UE and RS – Higher degree of automation
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 automati
56		6	20 ms	10^{-1}	14. N/A	15. N/A	16. Platooning informative exchan – 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 automati
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 alignmen 35. Sensor sharin Higher degree of automation

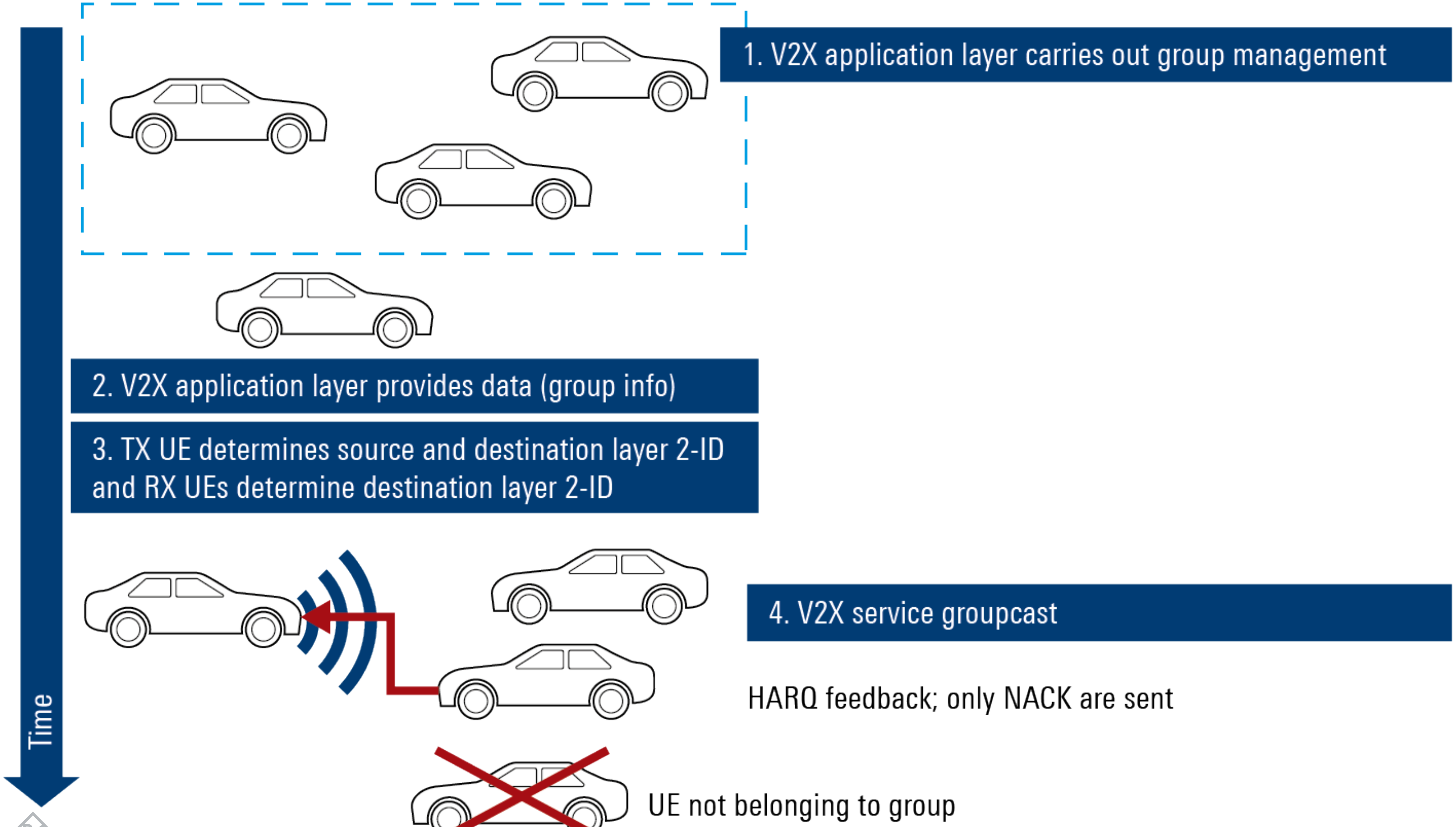
Not an eye chart ☺ but an example of the flexibility:

3GPP defines ~10 different QoS flow profiles for the NR V2X sidelink

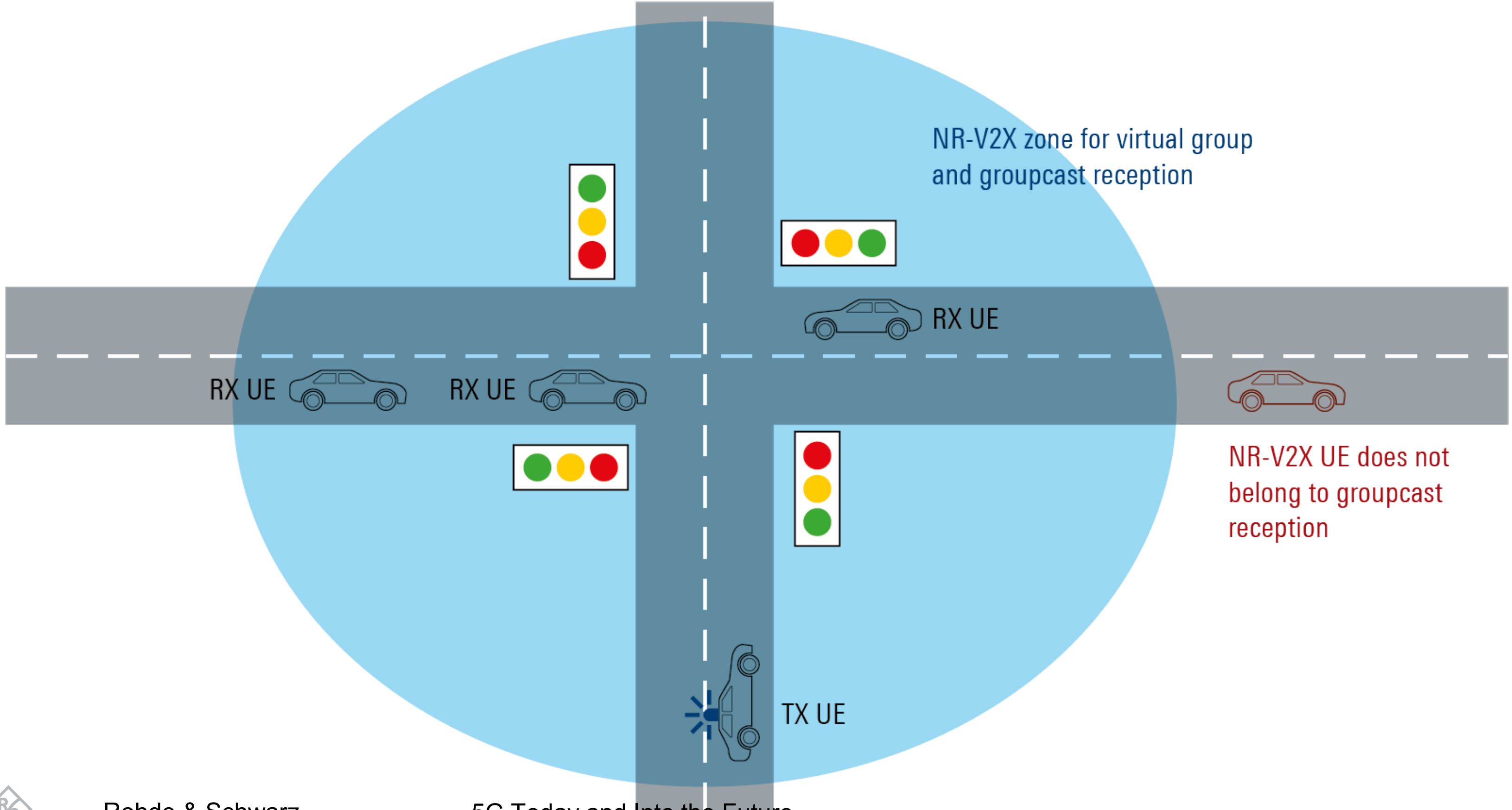
V2X PC5 INTERFACE PROCEDURE BROADCAST



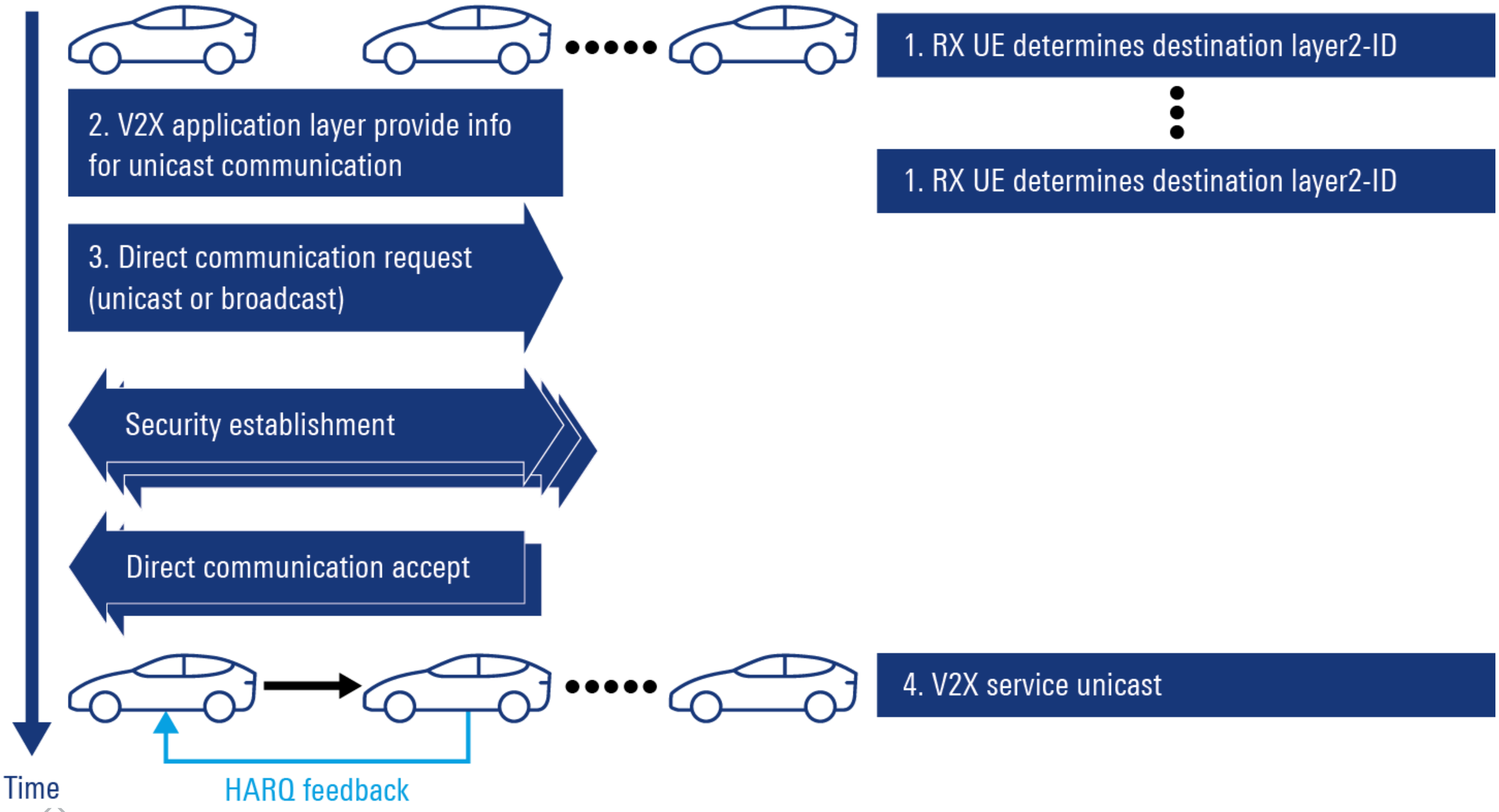
V2X PC5 INTERFACE PROCEDURE GROUPCAST



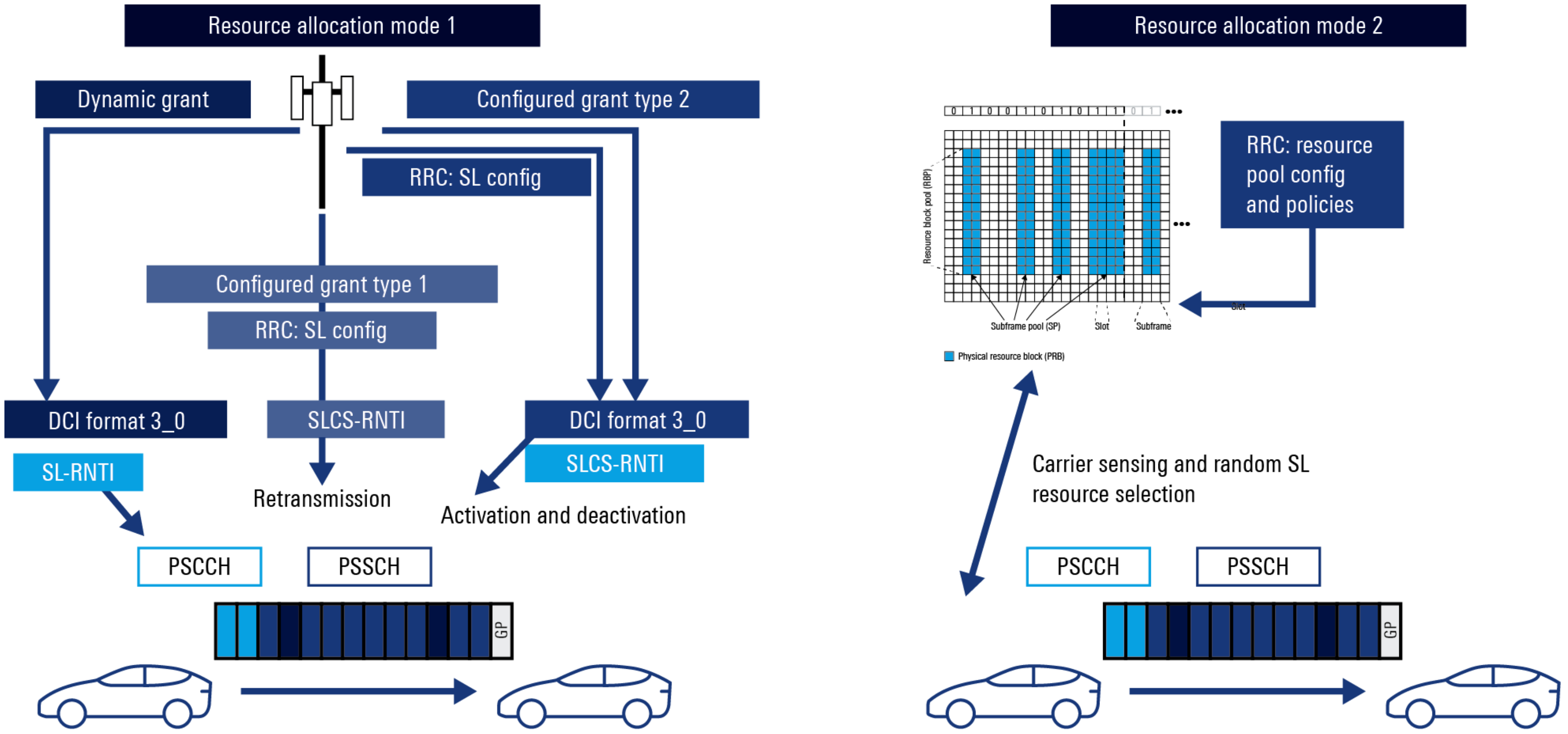
5G NR ZONE CONCEPT



V2X PC5 INTERFACE PROCEDURE UNICAST

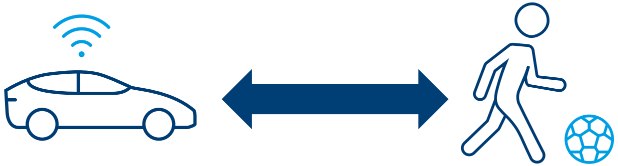


NR V2X SIDELINK RESOURCE SCHEDULING FLEXIBILITY

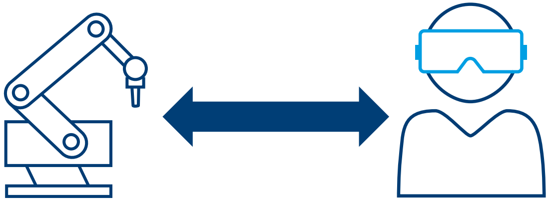


REL.17 NR SIDELINK ENHANCEMENTS

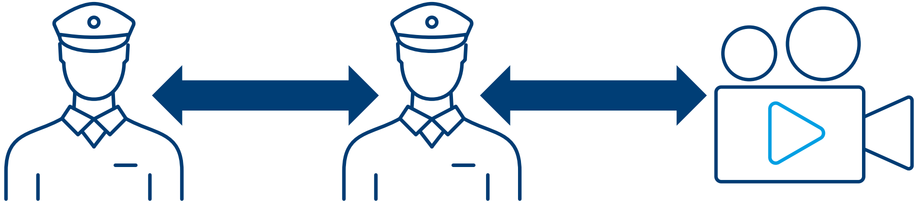
Release 16 sidelink with focus on automotive!



Release 17 sidelink with focus on battery consumption! (default resource pool allocation. TX side DTX & RX side DRX alignment, SL sensing)

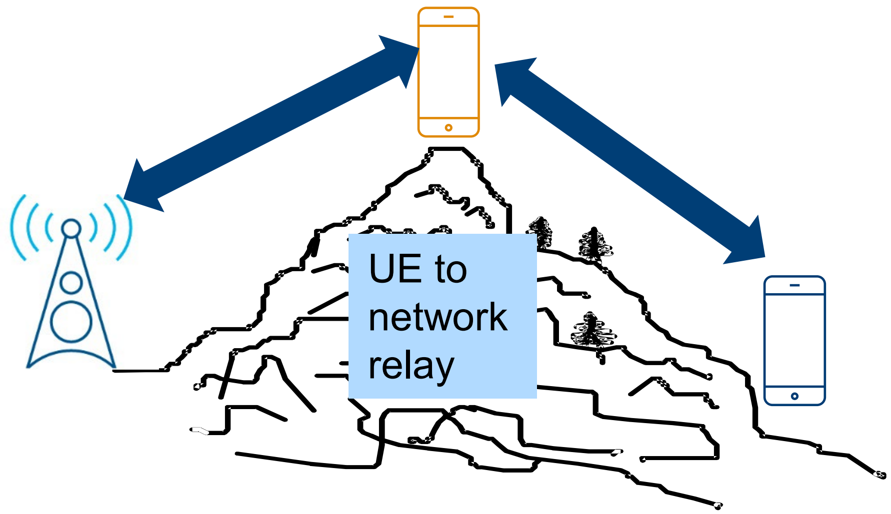


Release 17 sidelink with focus on uRLLC! (reliability & reduced latency, Inter-Ue coordination, new frequency bands: Uu and SL interface in licensed spectrum, SL operation geofencing)

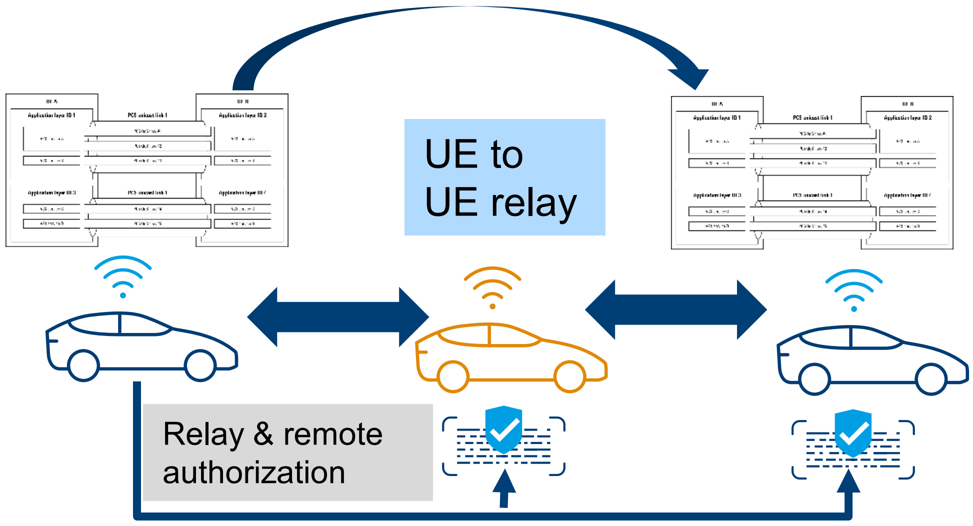


Release 17 sidelink with focus on ProSe! (network controlled interactive services, enhanced relay & coverage)

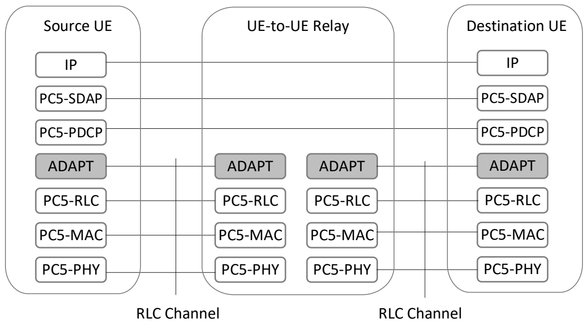
REL.17 NR RELAY

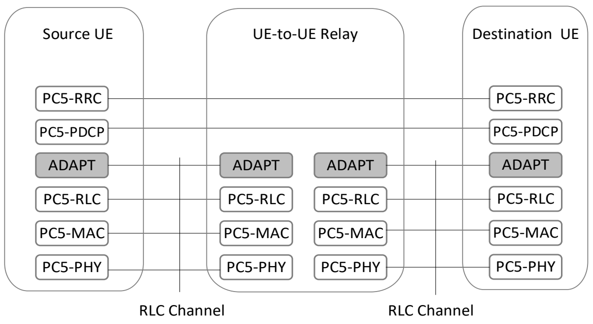


QoS mapping, e.g. new sidelink adaptation layer protocol



Procedures needed for: Discovery, QoS maintenance, C- and U-plane, authorization and service continuity



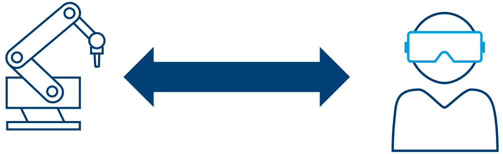


REL.17 NR SIDELINK ENHANCEMENTS

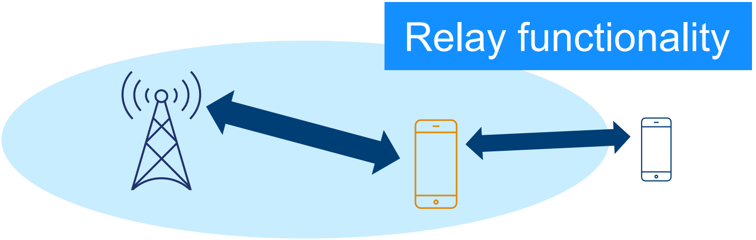
Release 16 sidelink with focus on automotive!

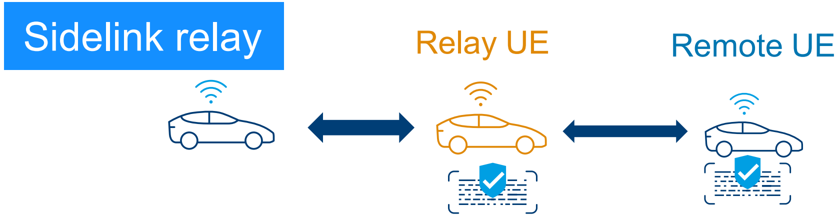
Release 17 sidelink with focus on battery consumption!

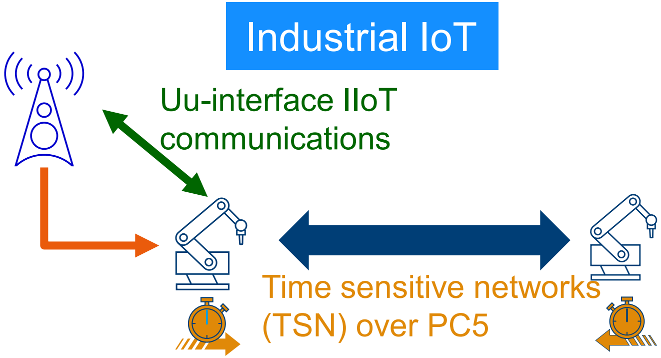
Release 17 sidelink with focus on uRLLC!



Release 17 sidelink with focus on public safety!



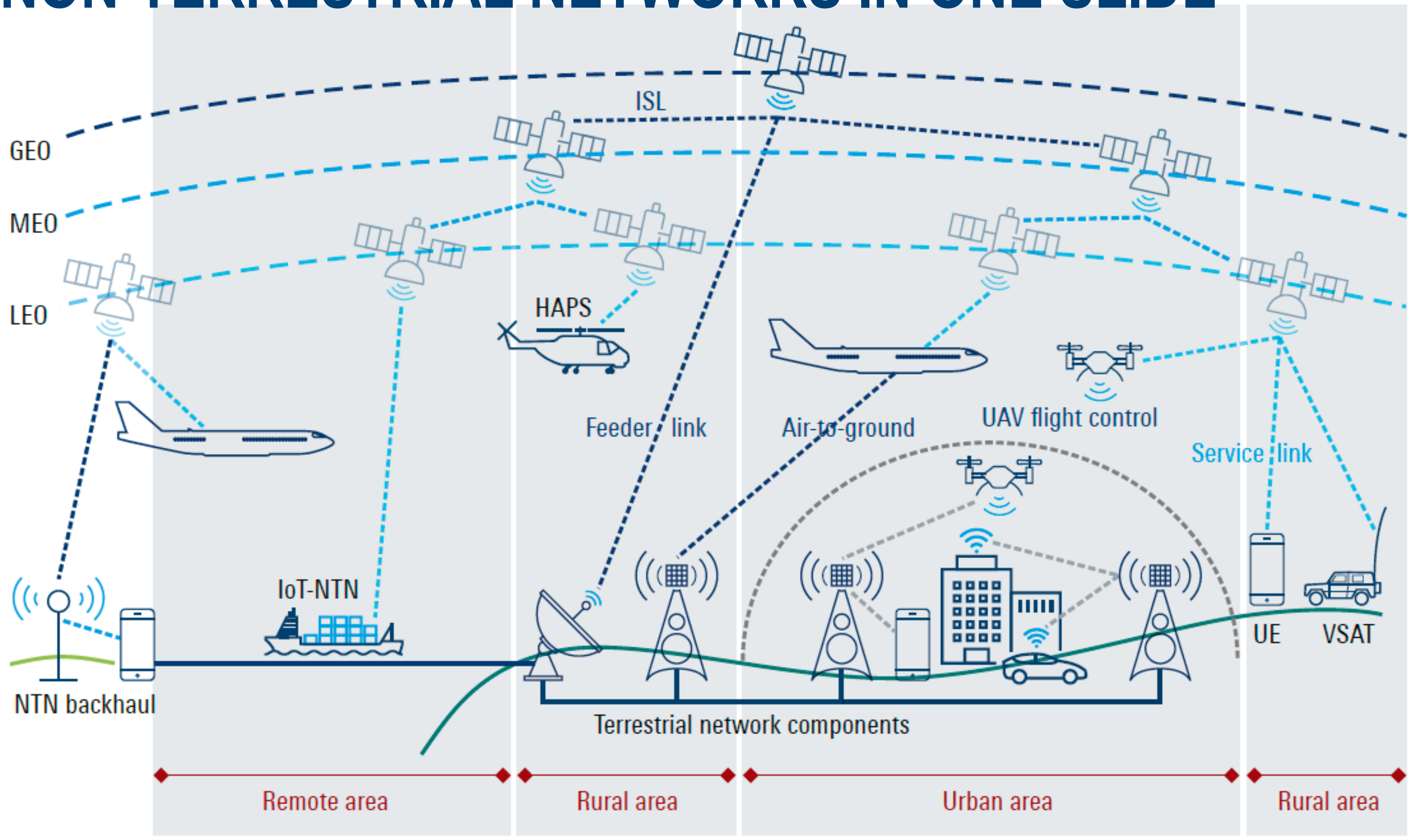




The ongoing evolution of 5G

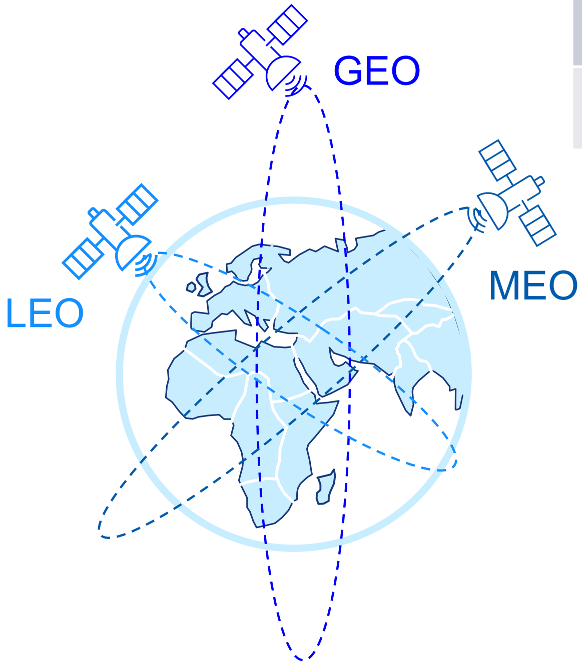
NON-TERRESTRIAL NETWORKS

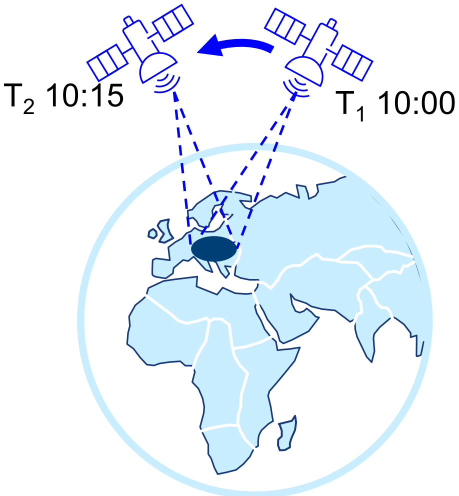
NON-TERRESTRIAL NETWORKS IN ONE SLIDE



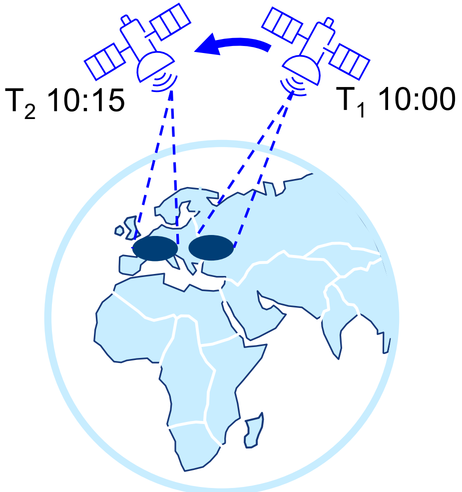
NTN: CONSTELLATION

Platform	Altitude	Orbit	Beam footprint
GEO	35786 km	Position fixed in elevation/azimuth to a given Earth point	200-3500 km
LEO	300-1500 km	Circular arount the Earth. Not stationary to a given Earth point	100 – 1000 km



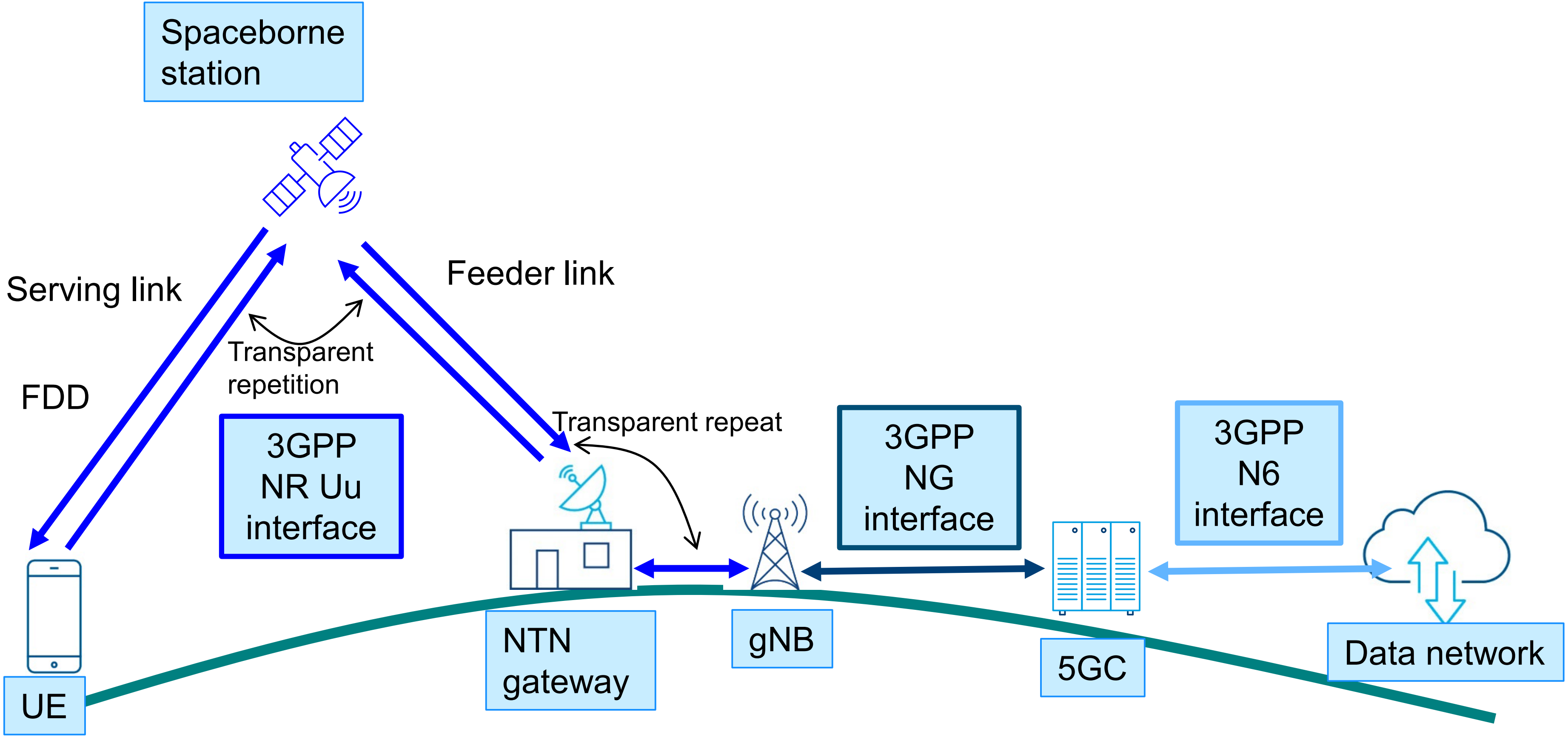


Steerable beams: Fixed with respect to Earth‘s surface

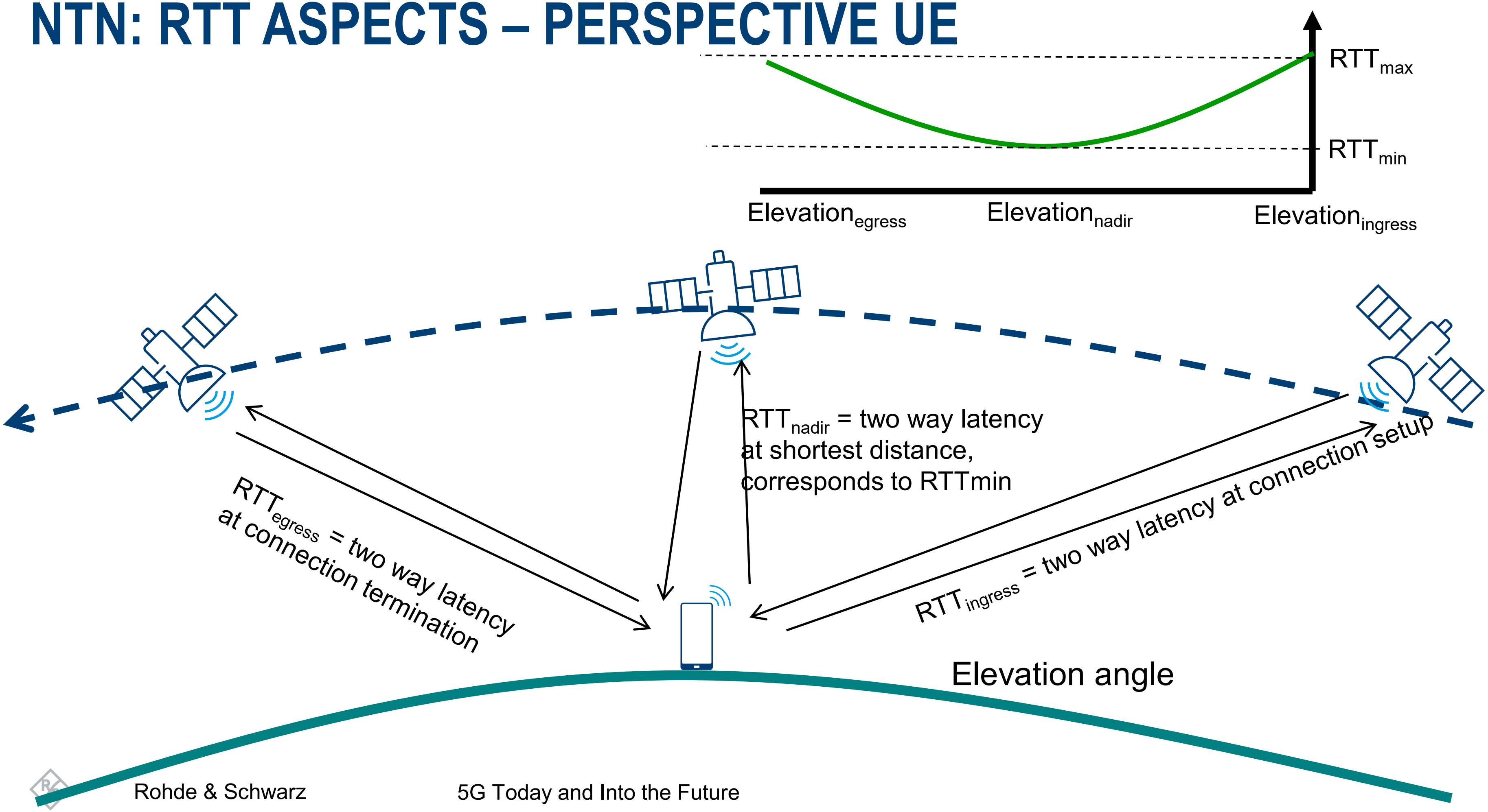


Fixed beams: Moving with respect to Earth‘s surface

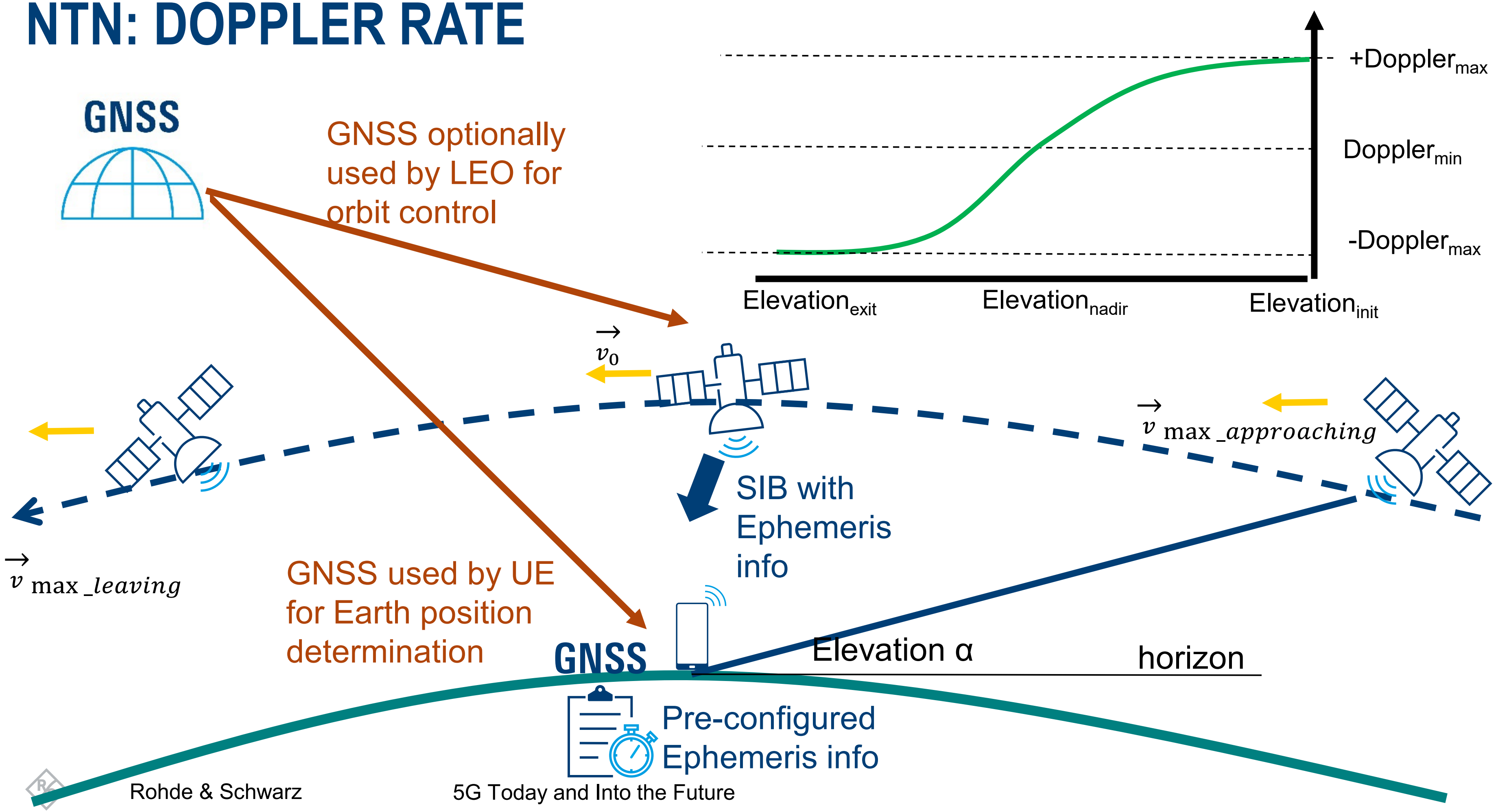
NTN: TRANSPARENT PAYLOAD ARCHITECTURE



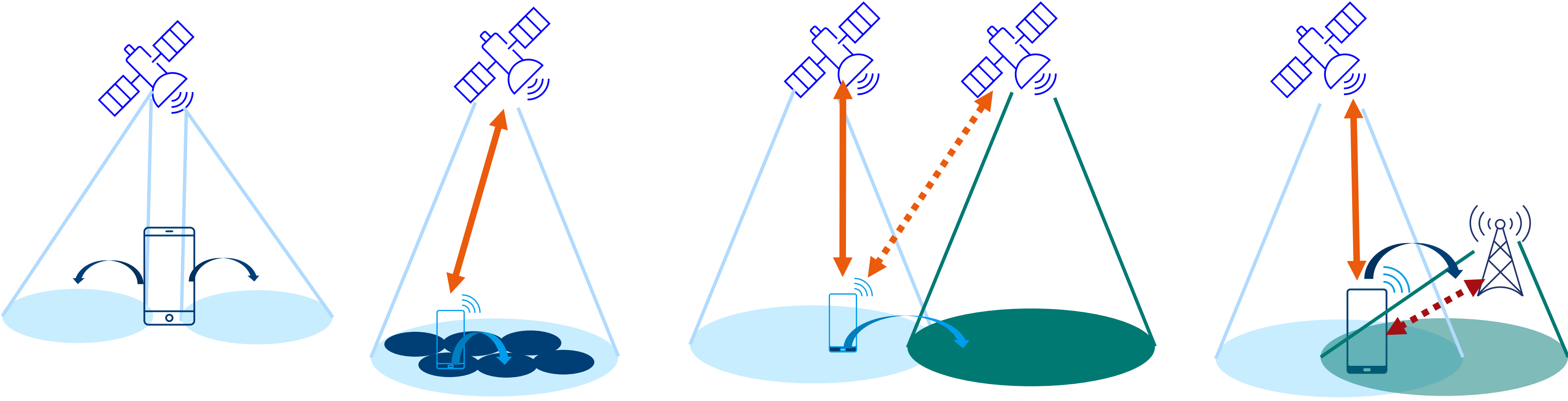
NTN: RTT ASPECTS – PERSPECTIVE UE



NTN: DOPPLER RATE



5G NTN MOBILITY SCENARIOS



Cell selection / cell re-selection

Intra-satellite / inter-beam handover

Inter-satellite handover/ inter-satellite DC

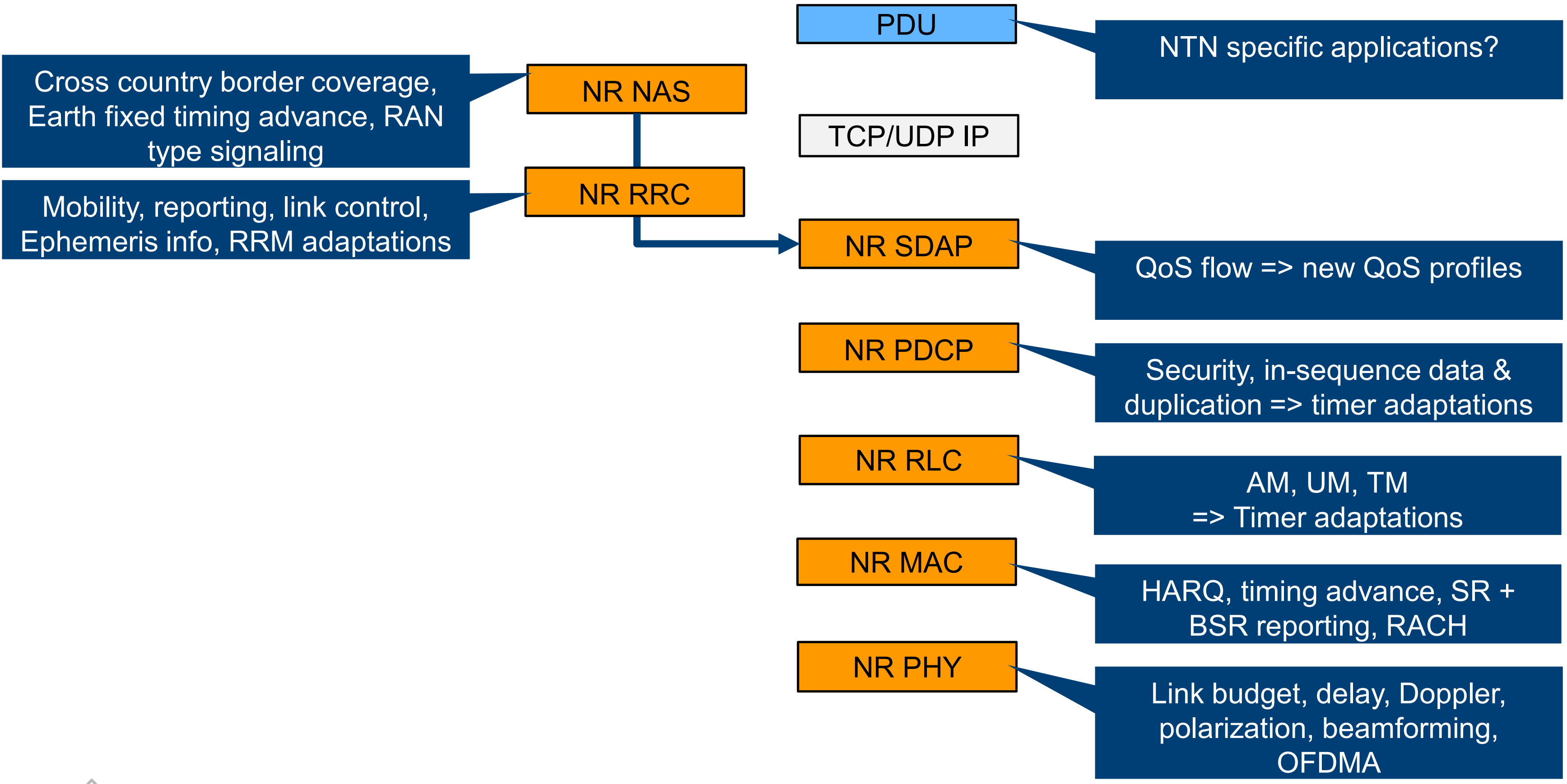
NTN - terrestrial handover / DC

NR-NTN connection

Future or dual connectivity NR-NTN connection

Future or dual connectivity terrestrial connection

NTN: PROTOCOL STACK



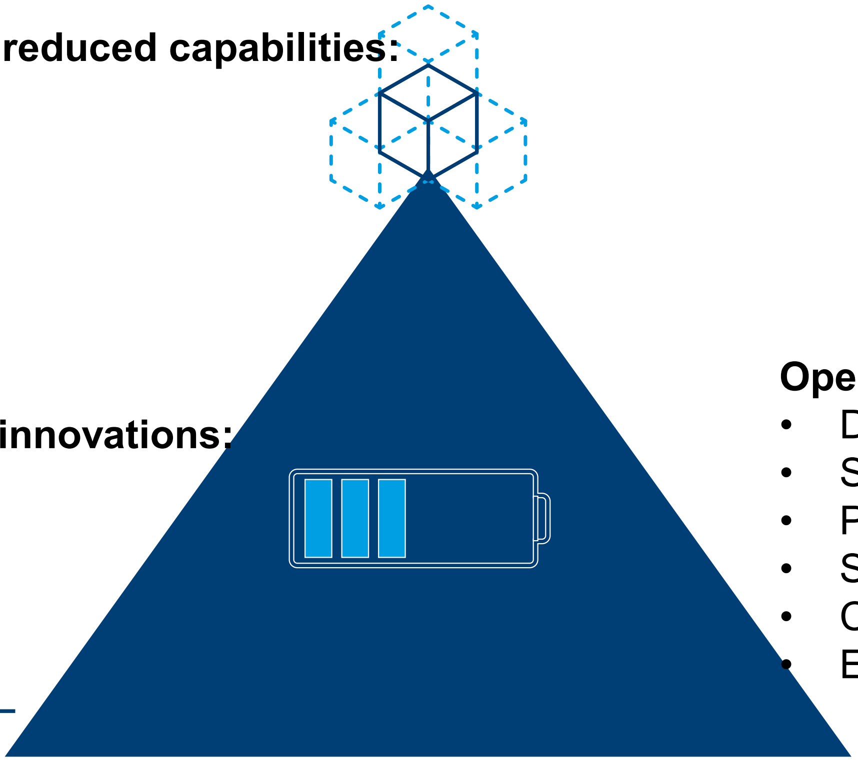
The ongoing evolution of 5G

REDUCED CAPABILITY (RedCap) + POWER SAVING

UE POWER SAVING OVERVIEW AS TRIANGLE

Hardware restrictions and reduced capabilities:

- Lower power class
- Single antenna
- Half-duplex operation
- Bandwidth restrictions
- Etc.



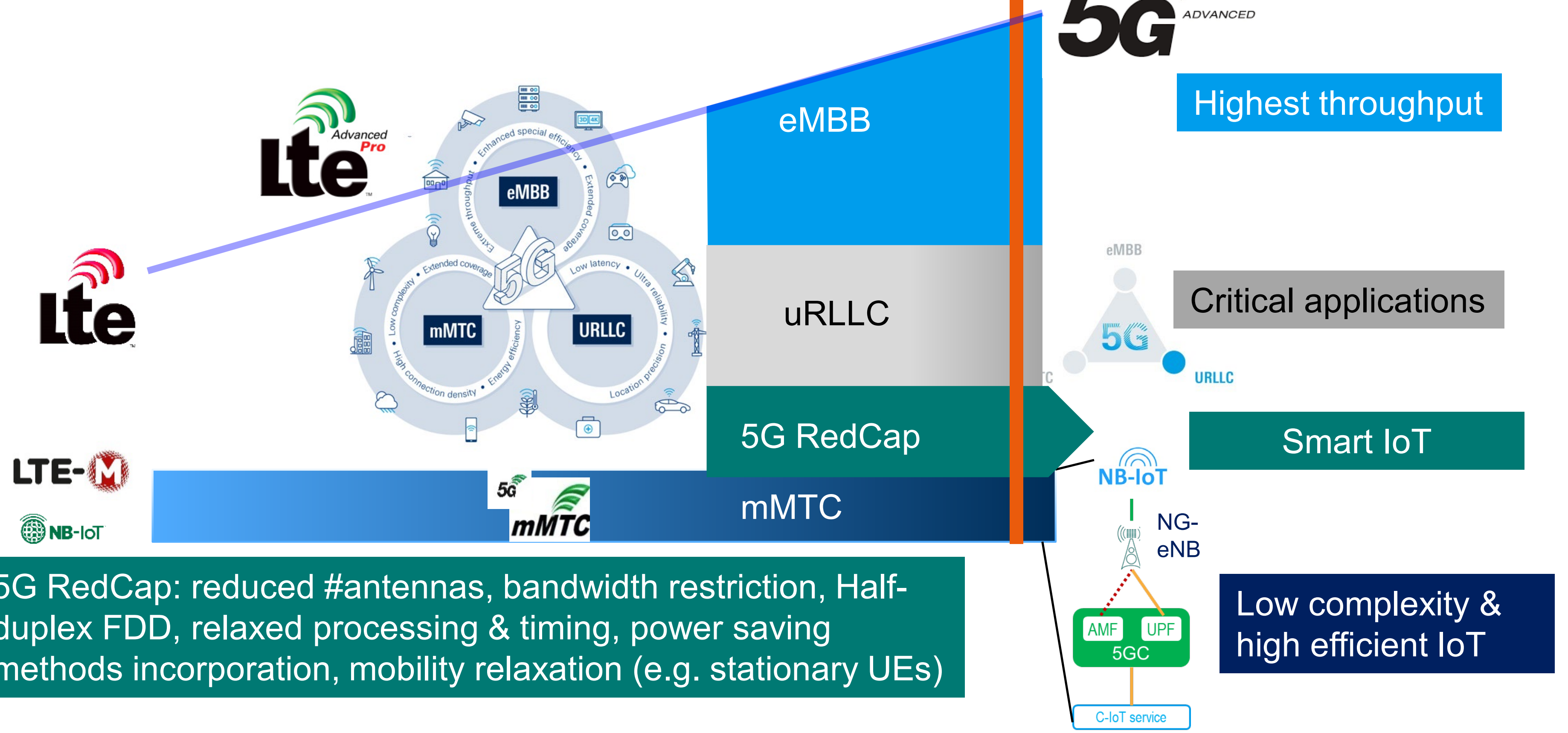
Enhanced mechanisms & innovations:

- Wake-up signals
- Relaxed measurements
- Adaptive bandwidth
- Etc.

Operational enhancements:

- Discontinuous reception (DRX)
- Sleep mode
- Power save mode (PSM)
- Signaling reduction, i.e. TAU
- Cross-slot scheduling
- Etc.

REL. 16 reduced capability (RedCap)



5G RedCap: reduced #antennas, bandwidth restriction, Half-duplex FDD, relaxed processing & timing, power saving methods incorporation, mobility relaxation (e.g. stationary UEs)

5G NR POWER SAVING ASPECTS – OVERVIEW

Bandwidth part (BWP= switching

Max of DL MIMO layers configurable per active BWP

Wake up signal introduction, scheduled by PDCCH

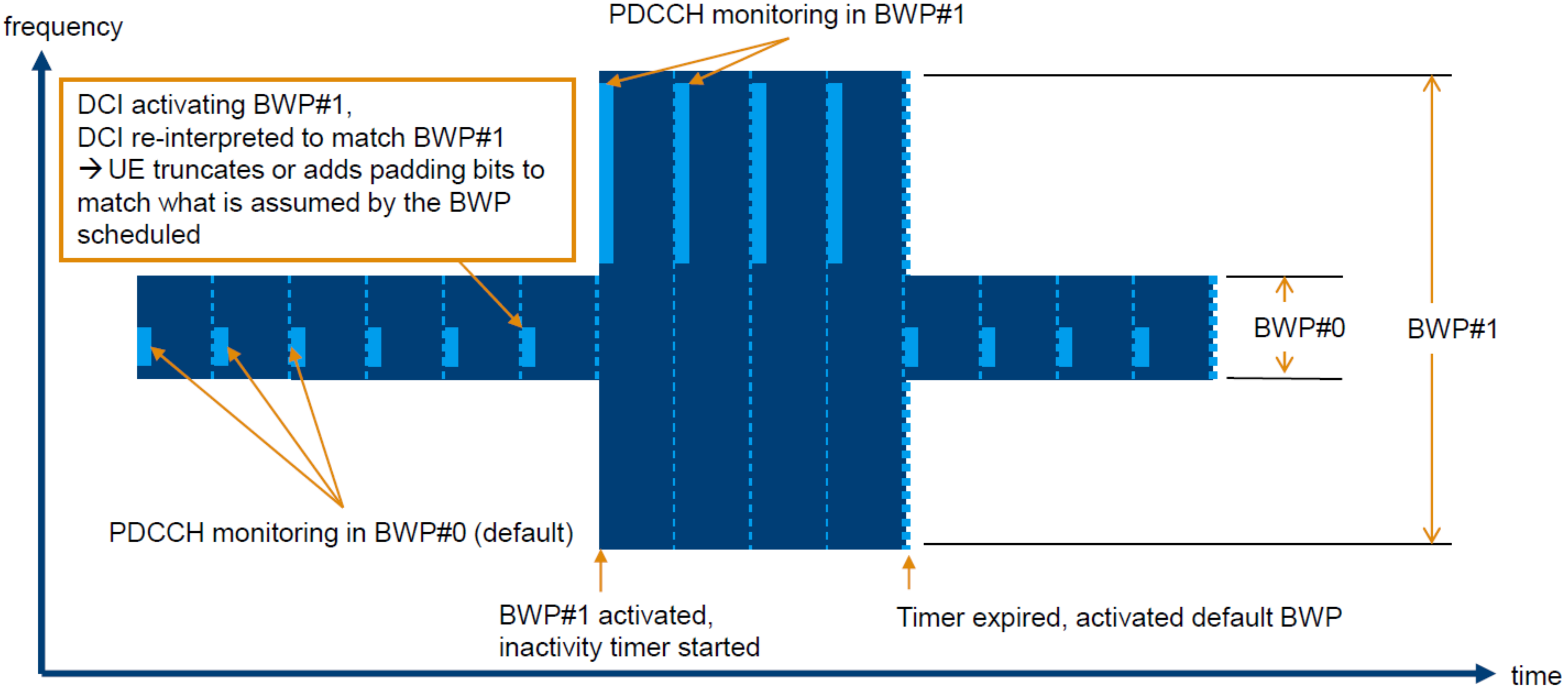
Cross-slot scheduling

UE assisted power saving methods

RRM measurement relaxation

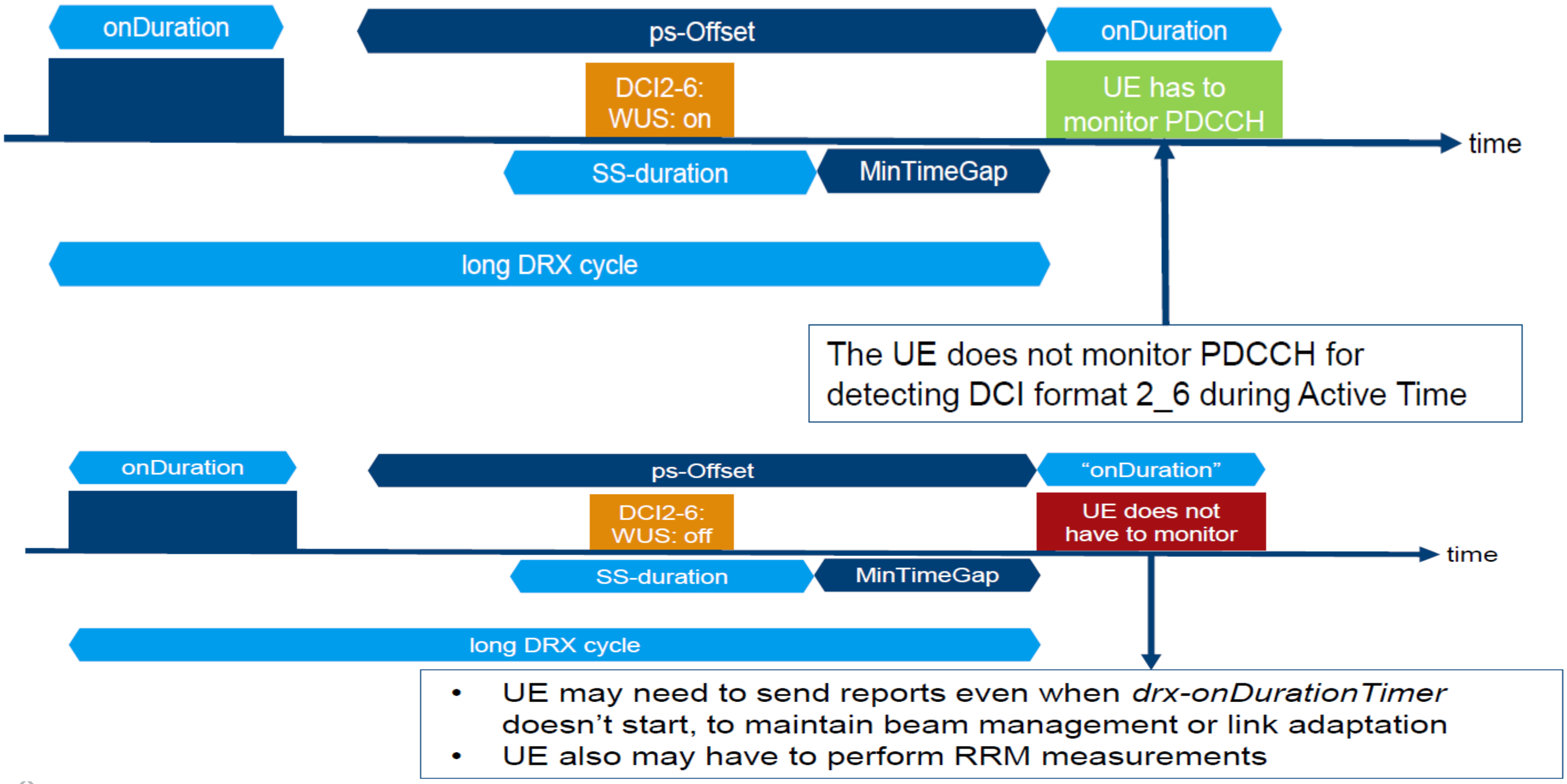
Rel. 16 ++ features: Several methodologies with respect to power saving are introduced

5G NR POWER SAVING ASPECTS – BWP SWITCHING

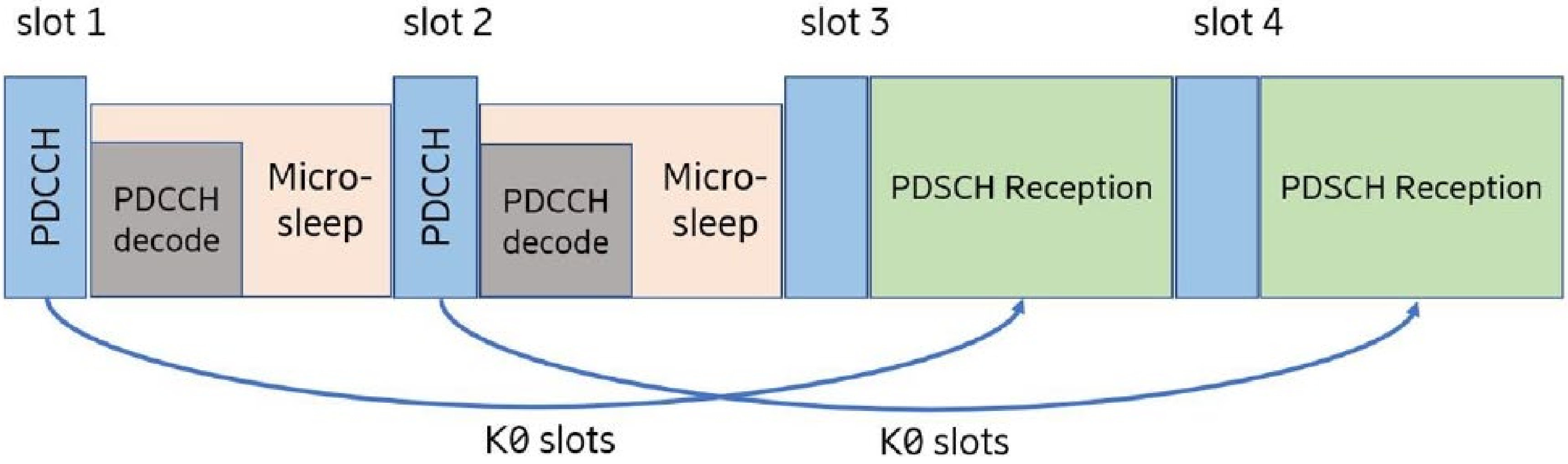


Rel. 15 feature: switching between different BWPs => goal to reduce energy

5G NR POWER SAVING ASPECTS – WAKE UP SIGNAL (WUS)



5G NR POWER SAVING – CROSS-SLOT SCHEDULING



Rel. 16++ feature: Introduction of cross-slot scheduling functionality.
Idea: UE assumes 0ms scheduling transition: Via DCI and cross-slot scheduling a micro-sleep period can be introduced

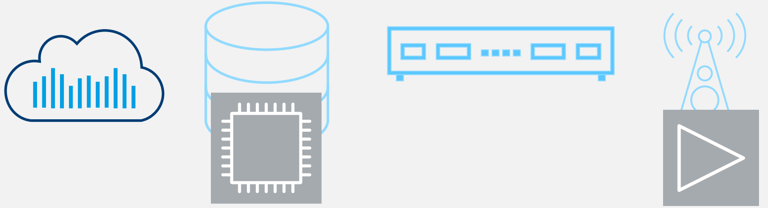
5G NR POWER SAVING – UE ASSISTED POWER SAVING

- **drx-Preference**: UE preference for C-DRX which includes: long/short DRX cycle, DRX inactivity timer, short DRX cycle timer
- **maxBW-Preference**: UE preference for maximum aggregated bandwidth of the cell group (CG)
- **maxCC-Preference**: UE preference for max number of SCellsof the CG
- **maxMIMO-LayerPreference**: UE preference for max number of MIMO layers of the CG
- **minSchedulingOffsetPreference**: UE preference for min offset for cross-slot scheduling of the CG
- **releasePreference**–This indicates whether the UE prefers to transition out of RRC_CONNECTED

Rel. 16++ feature: Introduction of UE assisted power saving methodologies

NETWORK ENERGY EFFICIENCY

Holistic approach: From cloud to component, energy saving methods in the entire 5G system



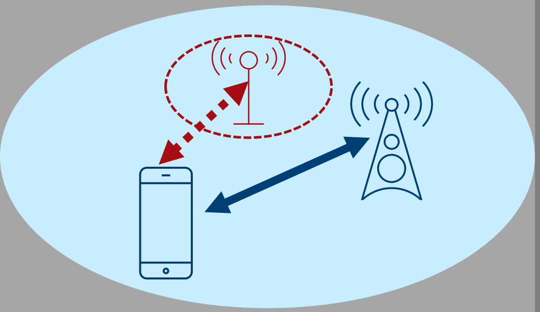
ETSI & 3GPP definition: Energy efficiency

$$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}}$$

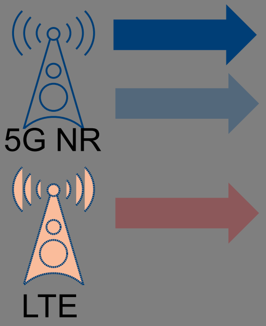
Data volume / energy consumption

$$EE_{MN,CoA} = \frac{CoA_{des.MN}}{EC_{MN}}$$

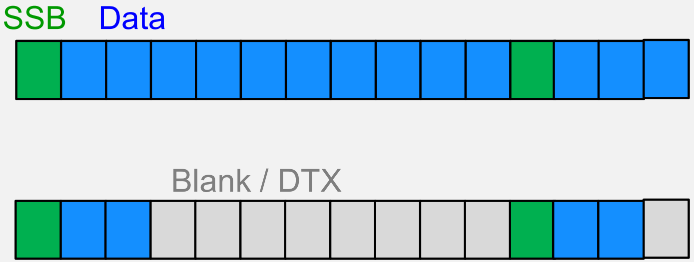
Designated coverage area / energy consumption



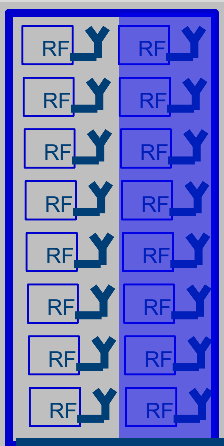
Turn on/off cells



Activate / de-activate carriers / RAT



Advanced sleep mode (ASM)



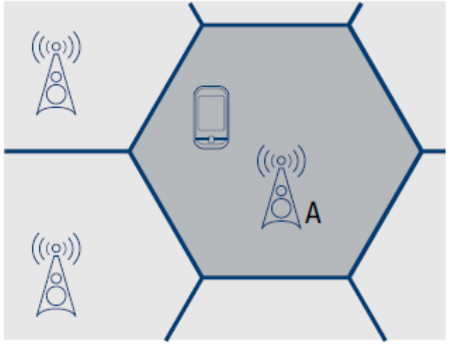
Turn on/off RF

The ongoing evolution of 5G

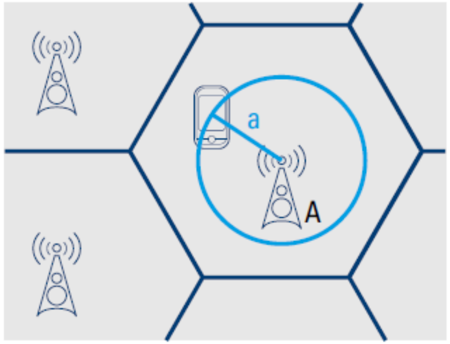
POSITIONING ENHANCEMENTS

5G NR POSITIONING: VARIOUS POSSIBILITIES

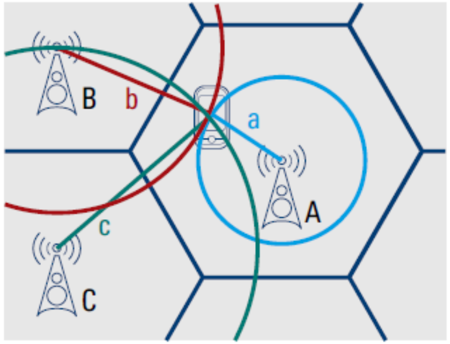
CID



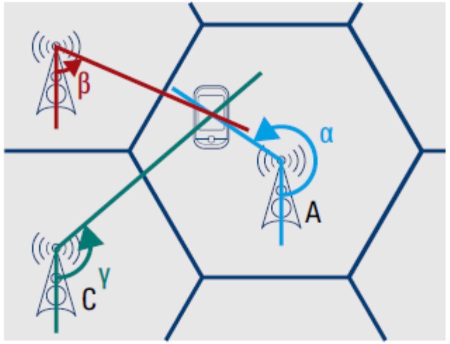
ECID (RSRP/TOA/TADV)



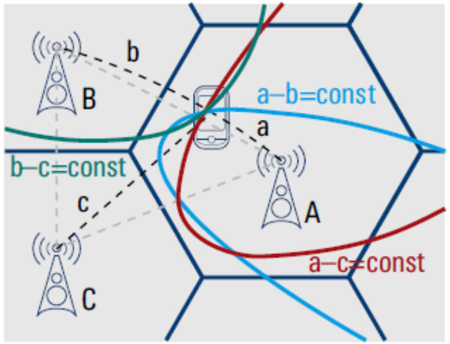
ECID (RSRP/TOA/TADV), (trilateration)



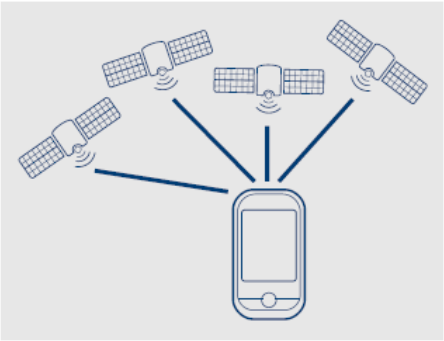
ECID (AOA), (triangulation)



Downlink/uplink (O/U-TDOA),
(multilateration)



GNSS based



LOCATION-BASED SERVICES IN REL. 17 - REQUIREMENTS

Ambitious objectives for Rel-17 target positioning requirements

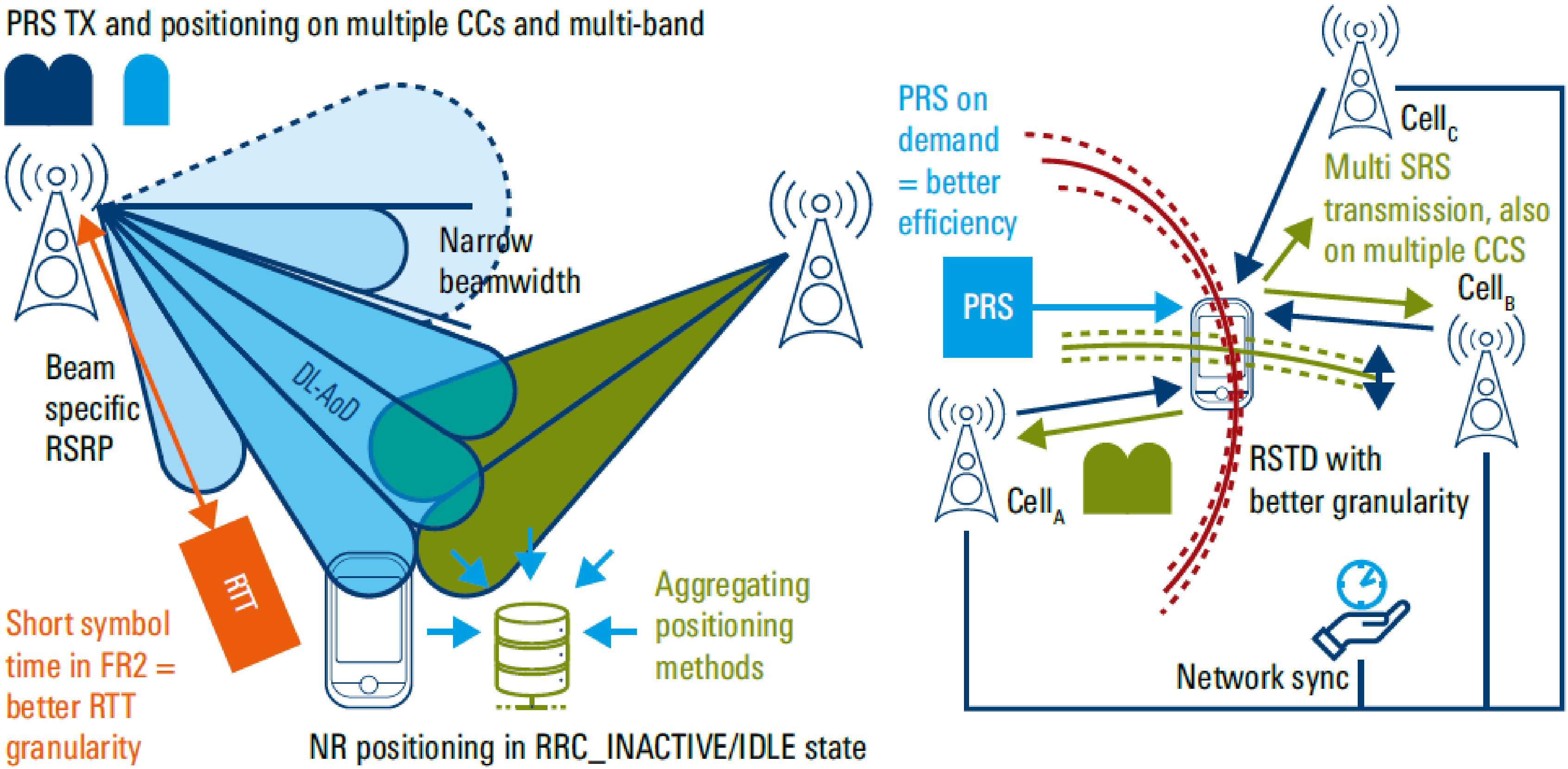
Commercial use cases:

- Horizontal position accuracy (< 1 m) for 90% of UEs
- Vertical position accuracy (< 3 m) for 90% of UEs
- End-to-end latency for position estimation of UE (< 100 ms)
- Physical layer latency for position estimation of UE (< 10 ms)

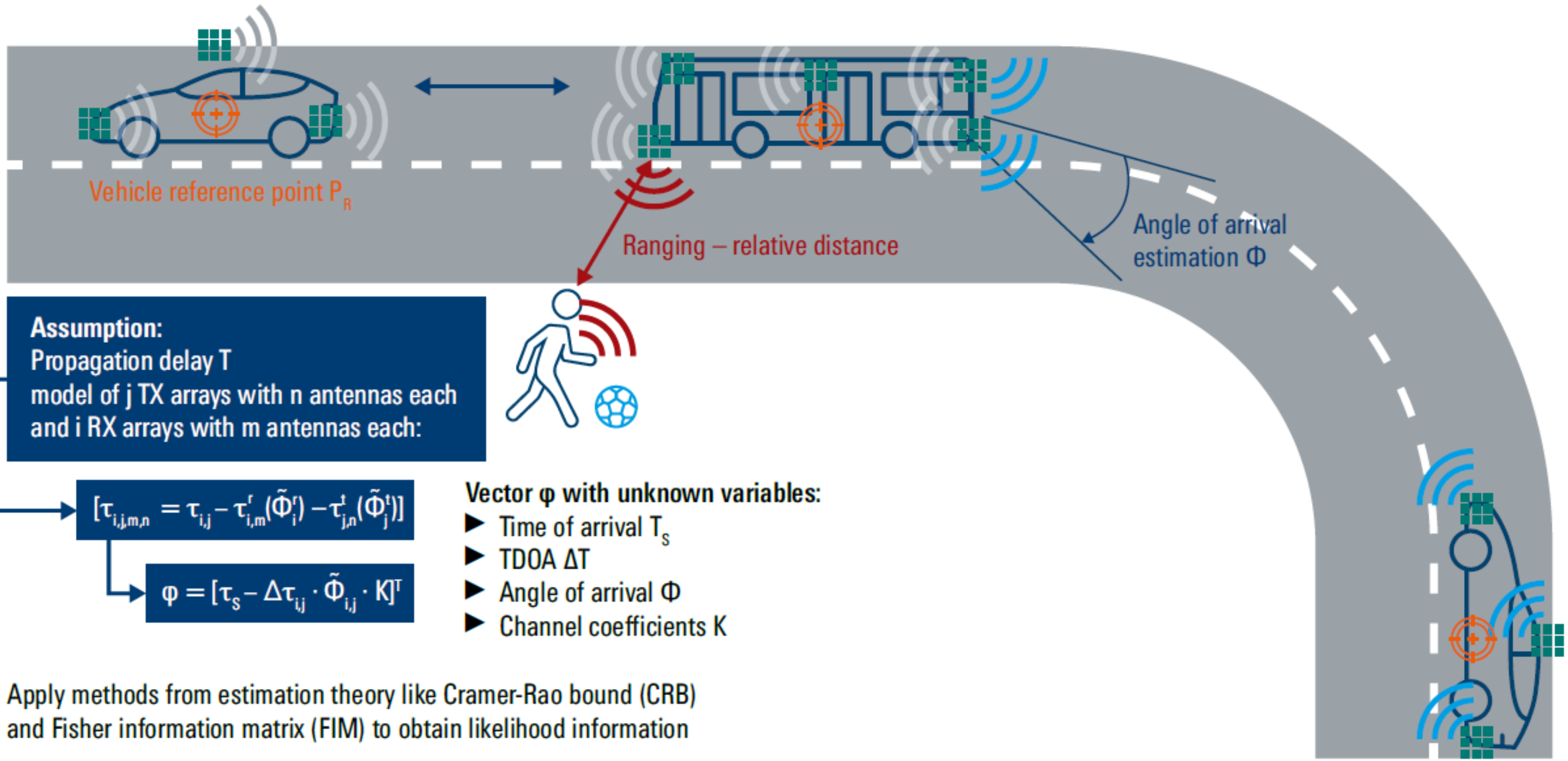
IIoT use cases:

- Horizontal position accuracy (< 0.2 m) for 90% of UEs
- Vertical position accuracy (< 1 m) for 90% of UEs
- End-to-end latency for position estimation of UE (< 100ms, in the order of 10 ms is desired)
- Physical layer latency for position estimation of UE (<10ms)

RELEASE 17 – POSITIONING ENHANCEMENTS



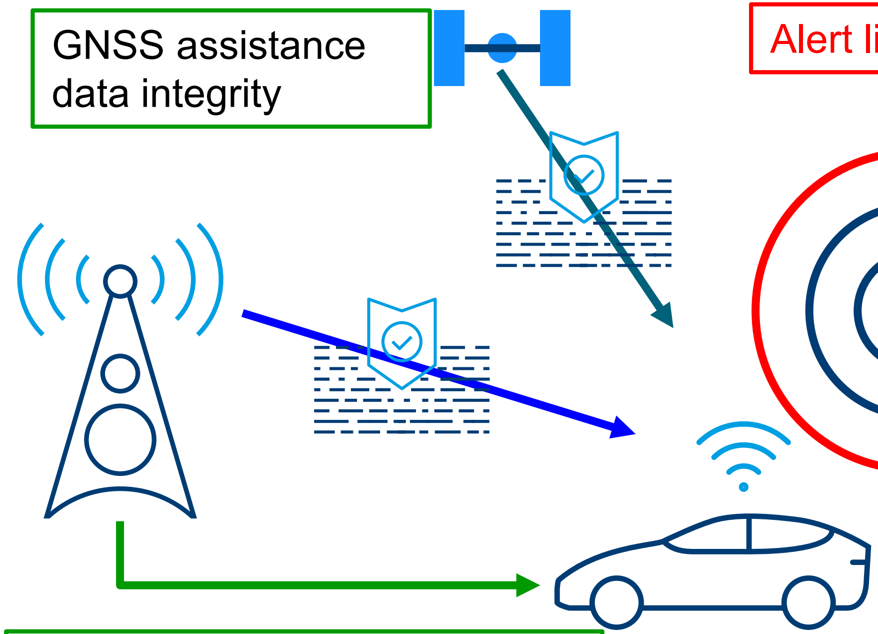
LBS IN RELEASE 18 – DIFFERENTIAL POSITIONING



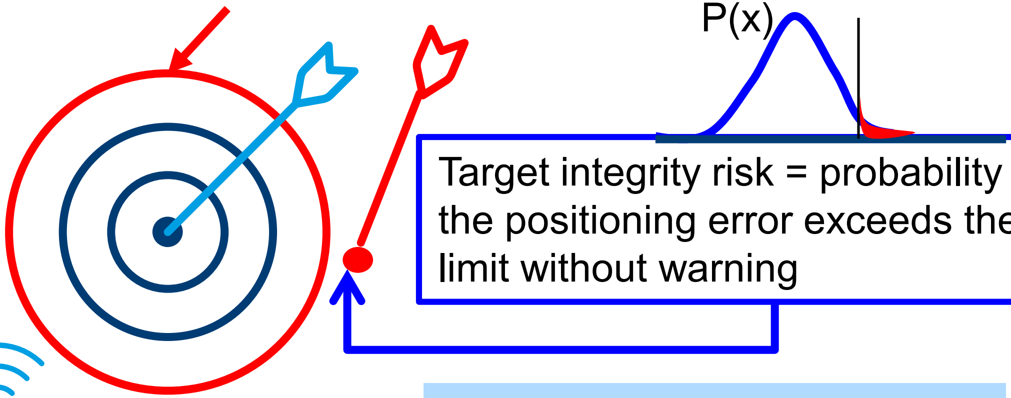
Apply methods from estimation theory like Cramer-Rao bound (CRB) and Fisher information matrix (FIM) to obtain likelihood information

LOCATION-BASED SERVICES IN RELEASE 17 - OUTLOOK

GNSS assistance data integrity



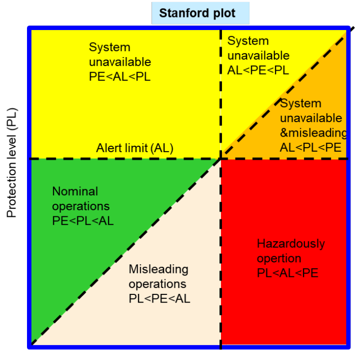
Alert limit = maximum allowable positioning error

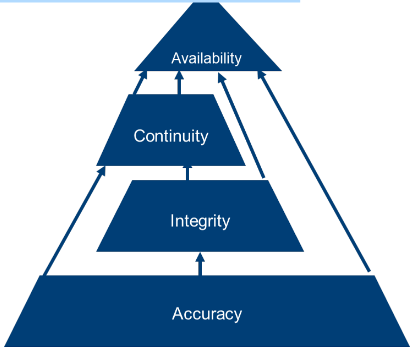


Target integrity risk = probability that the positioning error exceeds the alert limit without warning

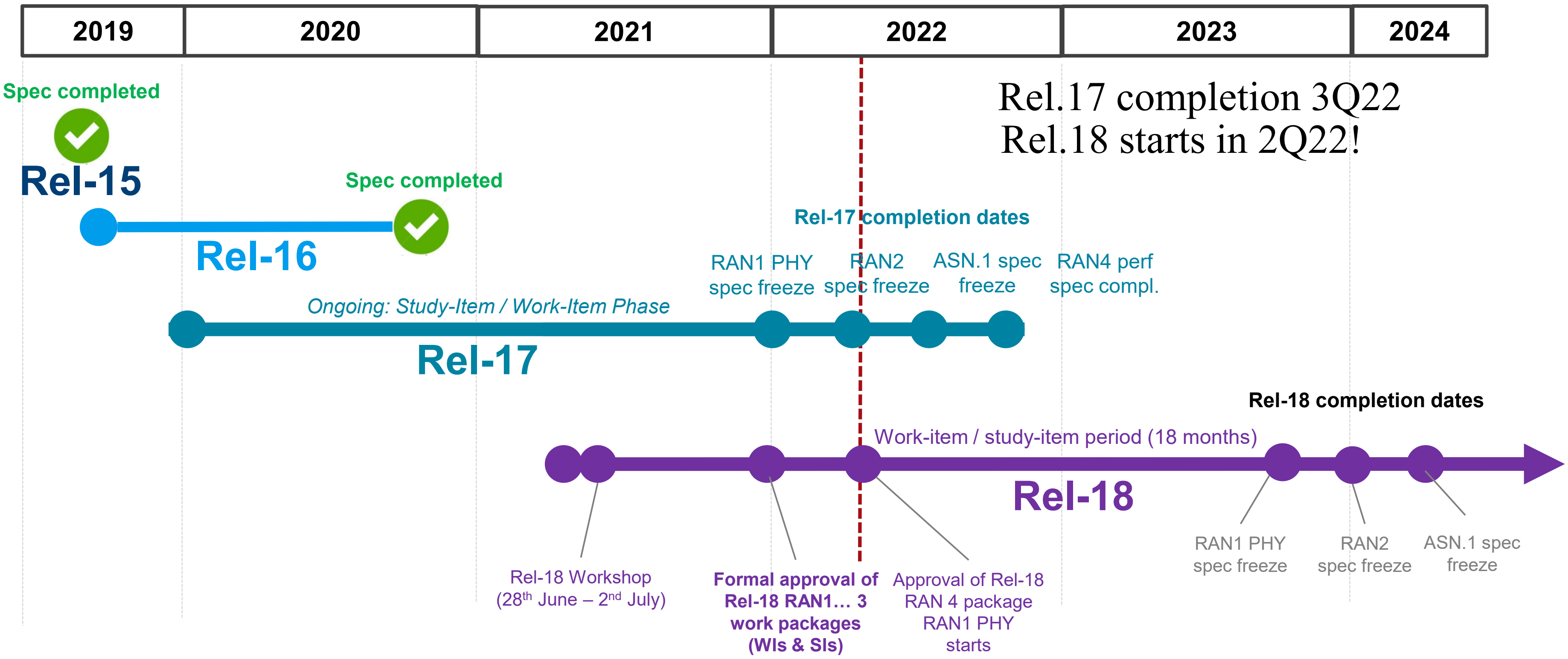
Idea to provide authentication and integrity data via 5G & perform data analytics within the device

Integrity model (Stanford plot)

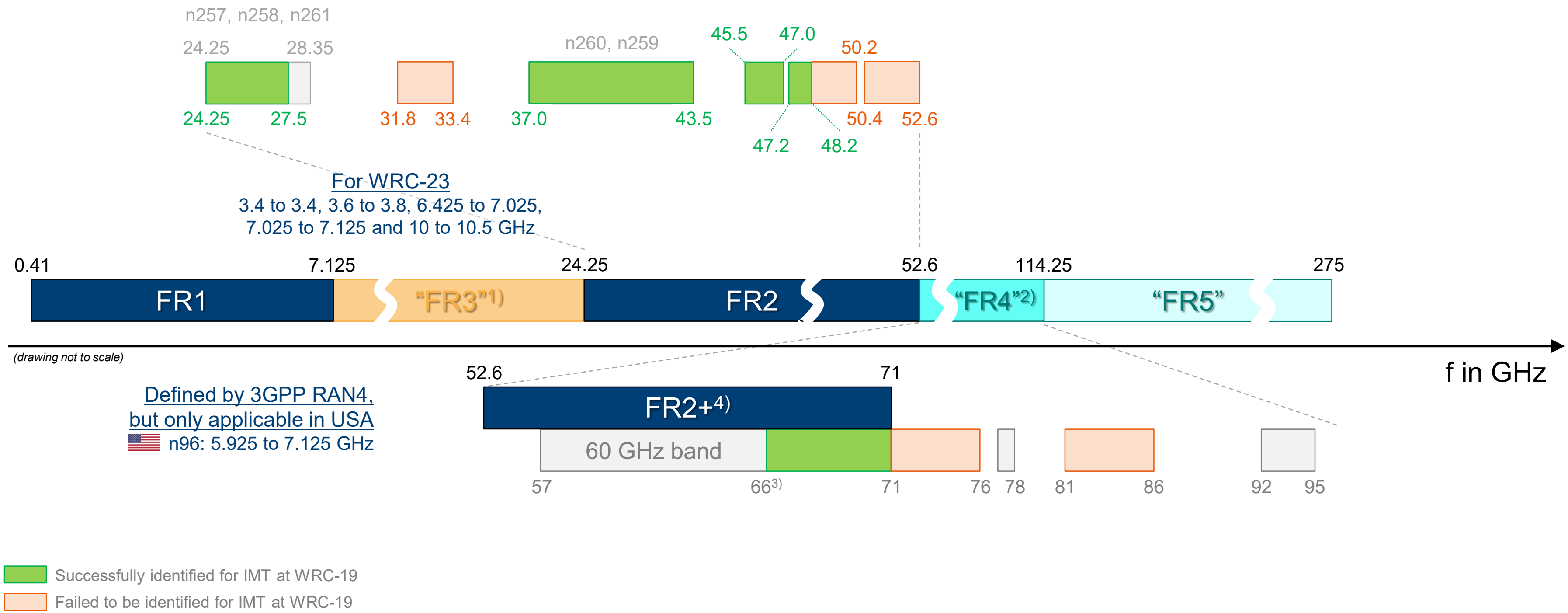




3GPP STANDARDIZATION TIMELINE DEC 2021



SPECTRUM FOR 5G NR AND 5G EVOLUTION



Source: https://news.itu.int/wrc-19-agrees-to-identify-new-frequency-bands-for-5g/

1) TR 38.820 V16.0.0 (2020-07)

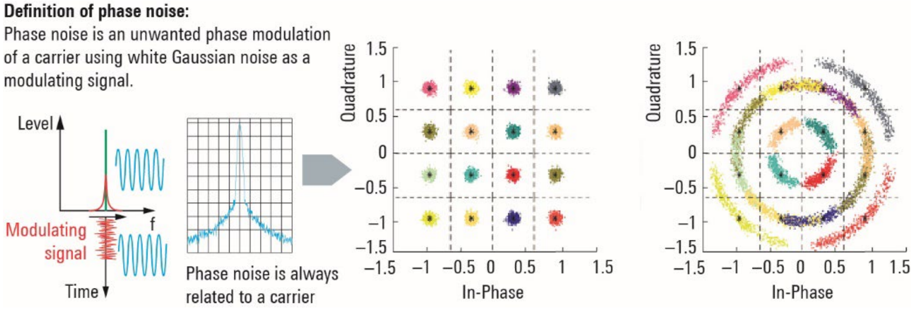
2) TR 38.807 V16.0.0 (2020-01)

3) 64 GHz in USA, Canada

4) TR 38.808 V0.0.1 (2020-06)

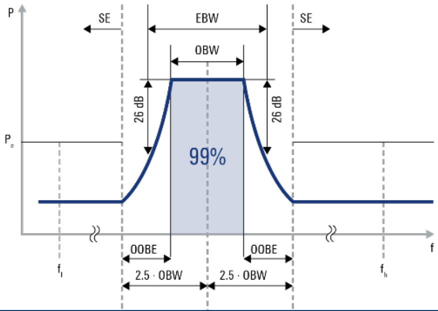
EXTENDING CURRENT NR OPERATION TO 71GHz - challenges

Higher phase noise



PA efficiency

Spectral efficiency



Friis equation => path attenuation

$$\frac{P_{Rx}}{P_{Tx}} = G_{antenna}\left(\frac{c}{4\pi f d}\right)^{\gamma}$$

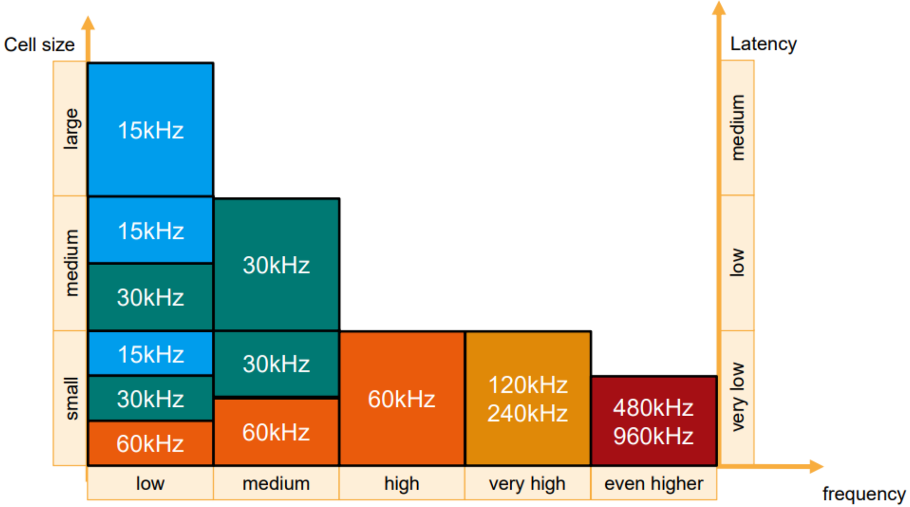
At higher frequencies: Free space path loss is high -> beamforming with high gain

Larger band size & bandwidth => Licensed & unlicensed bands

Available 5G band size

EXTENDING CURRENT NR OPERATION TO 71GHz

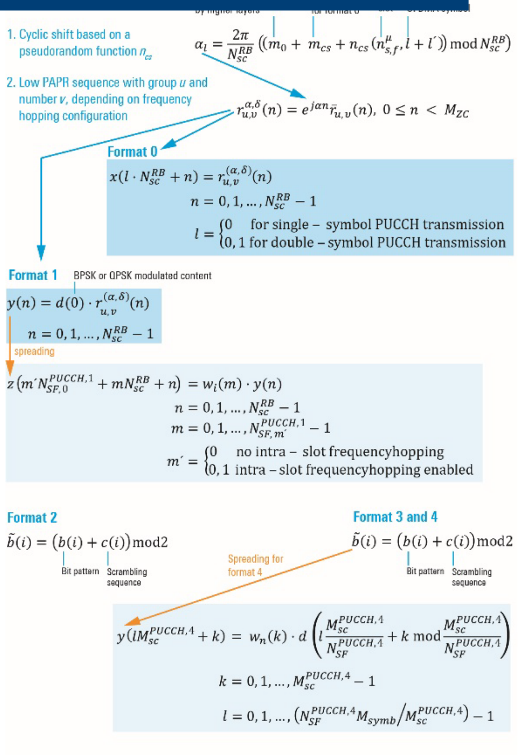
- In addition to 120kHz SCS, new SCS (480kHz and 960kHz) and wider bandwidth(s) are specified for operation in the extended frequency range.
- After some discussion the maximum bandwidth support is now **2GHz** (in addition to 100/400/1600 MHz).



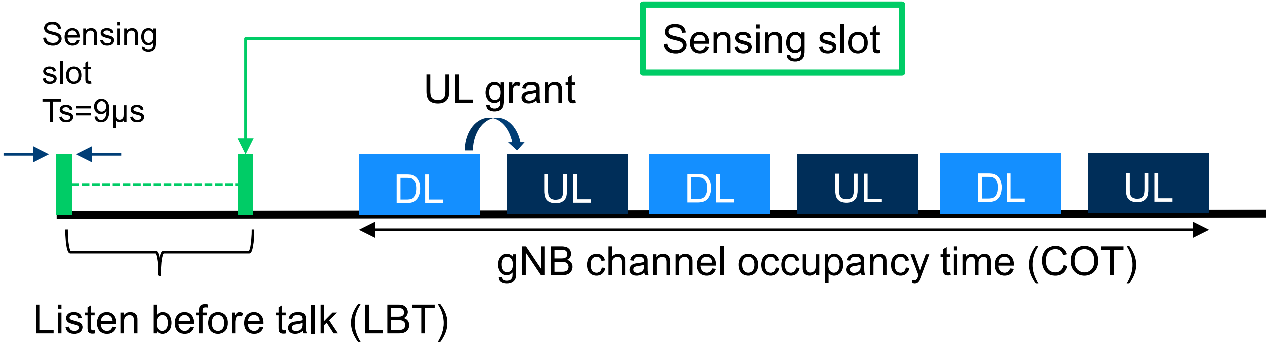
Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
n263	57000 MHz	-	71000 MHz	57000 MHz	-	71000 MHz	TDD (Note)
[n264]	66000 MHz	-	71000 MHz	66000 MHz		71000 MHz	TDD (Note)
NOTE:	n263 unlicensed, n264 licensed						

EXTENDING NR OPERATION TO 71GHz – some details

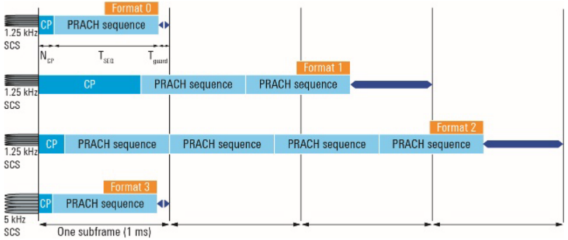
PUCCH format updates



FR2-2 unlicensed: only dynamic shared mode + LBT



FR2-2 PRACH: longer sequences for better efficiency

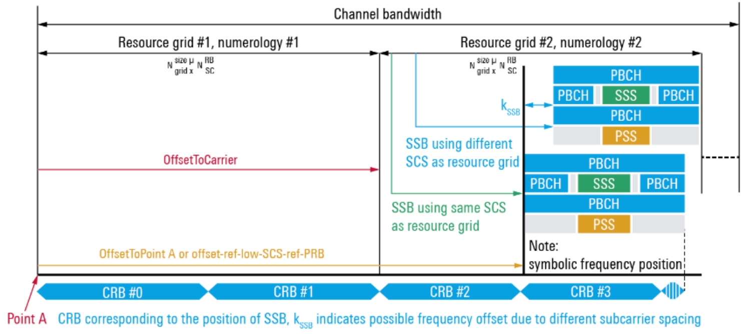


EXTENDING NR OPERATION TO 71GHz – some details

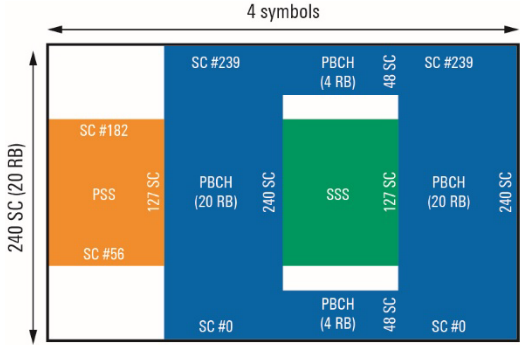
FR2-2 study phase: discussions

Subcarrier spacing [kHz]	Minimum bandwidths [MHz]	Maximum bandwidths [MHz]
120	50, 400 (Note)	400
480	200	1600
960	400, 2160 (Note)	1600, 2000, 2160, 3200 (Note)

SSB mixed numerology possible and offset signaling via k_{SSB}

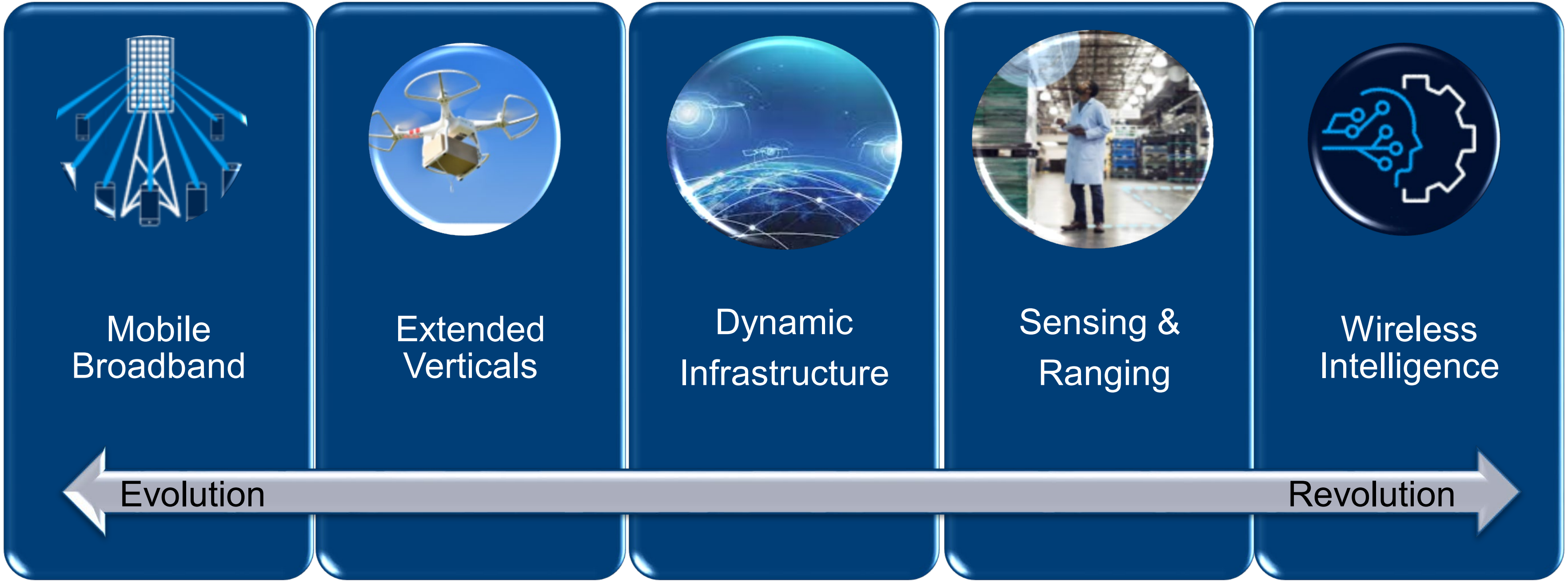


FR2-2: SSB with wider subcarrier spacing



- Wider SCS with SSB => reception performance is weaker
- Mixed numerology allowed
- Potential SSB and COREST0 offset

“5G ADVANCED” EVOLUTION AND REVOLUTION



EVOLUTION MOBILE BROADBAND

5G NR | Release 15

5G NR | Release 16

5G NR | Release 17

5G NR Advanced
Release 18

Mobile Broadband

"real and urgent demands for improving UL performance needed by many operators/UE for commercialization of networks (i.e.CPE)"

Evolution of MIMO
(DL Multi Panel)

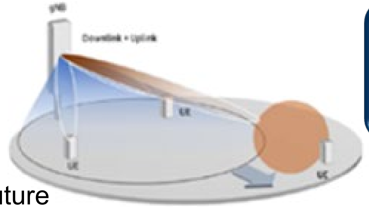
Evolution of MIMO
(UL Multi Panel , up to 8 TX)

FR1-FR2
(up to 52.6 GHz)

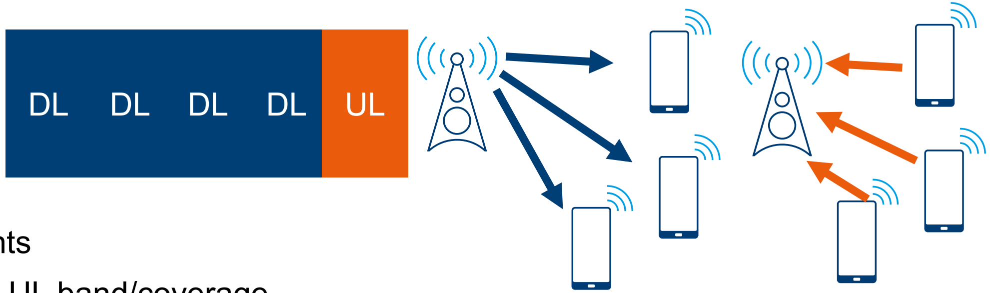
Higher Frequency
(FR2-2 up to 71 GHz)

UL coverage

Full Duplex
(NW Side)



REL-18 FULL DUPLEX

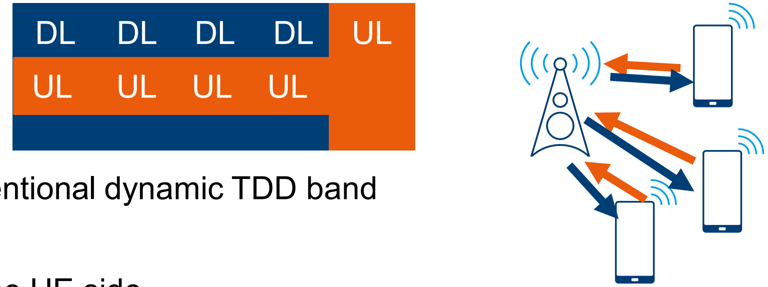


Justification :

- TDD is widely used in commercial NR deployments
- TDD limited time duration in UL , implies reduced UL band/coverage

& increased latency.

- CLI handling and RIM for NR were introduced in Rel-16



Objectives :

- Subband non-overlapping full duplex at the gNB side within a conventional dynamic TDD band
- Conditions :
  - Duplex enhancement at the gNB side, Half duplex operation at the UE side
  - No restriction on frequency ranges
- Cross-link interference (CLI) handling : inter-gNB , Inter-UE , intra/inter subband , inter operator
- Co-existence in co-channel and adjacent channels with legacy system
- Impact in antenna/RF design (antenna isolation, TX IM suppression in the RX part, filtering, interference suppression)

EXTENDED VERTICALS

5G NR Advanced
Release 18

5G NR
| Release 17

5G NR
| Release 16

5G NR
| Release 15

Extended Verticals

URLLC/IIOT
(Ultra Reliable, Low latency)

Extended Reality

Reduced Capabilities

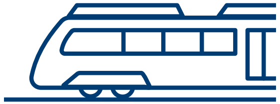
eRedCap for Smart Grid/Energy Harvesting

Drones/Uncrewed aerial vehicles

Broacast for critical situations & public safety

REDUCED CAPABILITIES IN REL. 18

RedCap evolution	5G eMBB	Rel. 17	Rel. 18
Bandwidth	100 MHz	20 MHz	5 MHz
Peak rate	2 Gbps	100 Mbps	10 Mbps
Cost assessment	100%	-60%	-71%



Future railway mobile communications system (FRMCS)
- 2*5.6 MHz FDD (874.4 – 880 MHz / 919.4 – 925 MHz
- Parallel operation: GSM-R and NR
- ~3.6 MHz available for NR

Public protection and disaster relief (PPDR)
- 2*3 MHz FDD in band n28

EVOLUTION IN 5G INFRASTRUCTURE

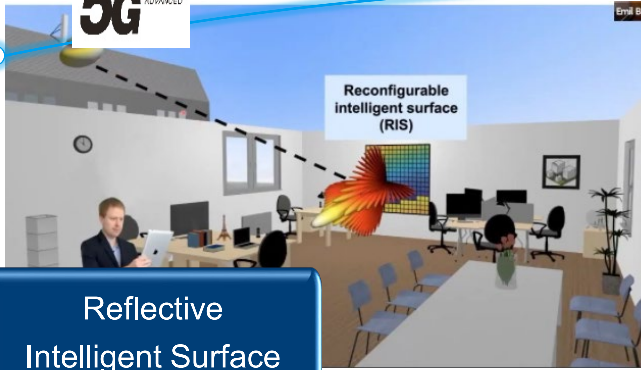
Smart Infrastructure

5G NR
| Release 15

5G NR
| Release 16

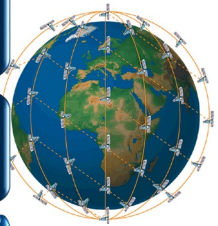
5G NR
| Release 17

5G NR Advanced
Release 18



Reflective Intelligent Surface

Wireless Access Backhaul (IAB)



Non Terrestrial / Satellite

UE Power Saving

Network Energy Saving

REVOLUTION IN SENSING & RANGING

Sensing & Ranging

5G NR
| Release 15

5G NR
| Release 16

5G NR
| Release 17

5G NR Advanced
Release 18

Sidelink
V2X/Automotive

Sidelink/Relay for
IIOT/Personal Network
FR2/CA/NR-U

Sidelink
for sensing and ranging
(Positioning)

AI/ML FOR NR AIR INTERFACE – WIRELESS INTELLIGENCE

Justification: Identify benefits of augmenting the air-interface with features enabling support of AI/ML based algorithms for enhanced performance and/or reduced complexity/overhead.

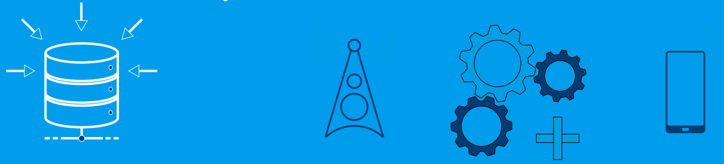
Usecases definition

Pilot cases for framework definition
i.e. Beam management

AI/ML Framework

Data, Model , Lifecycle

Collaboration UE and gNB



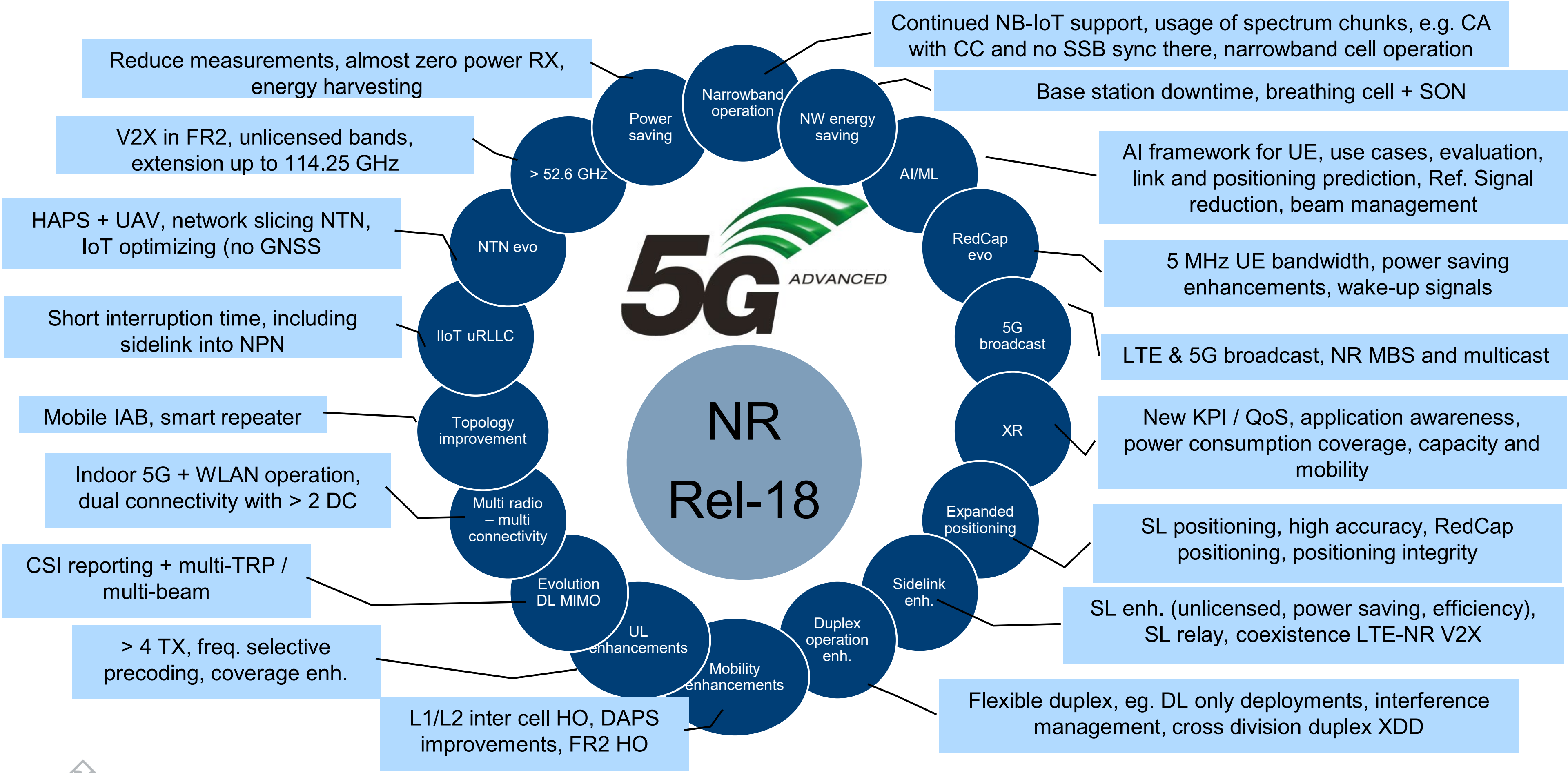
i.e. Field Data vs Simulation Data
i.e.Online vs Offline Training

Wireless Intelligence

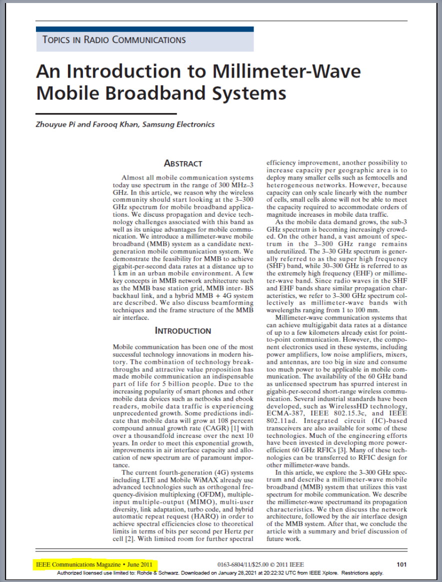
Evaluation & Testability

“assessing performance in comparison with traditional methods”
KPI, Evaluation Methodology, Testability and interoperability

3GPP RELEASE 18 KICK-OFF PROPOSALS



ARE WE GETTING AHEAD OF OURSELVES? NO!


Topics in Radio Communications

An Introduction to Millimeter-Wave Mobile Broadband Systems

Zhouyue Pi and Farooq Khan, Samsung Electronics

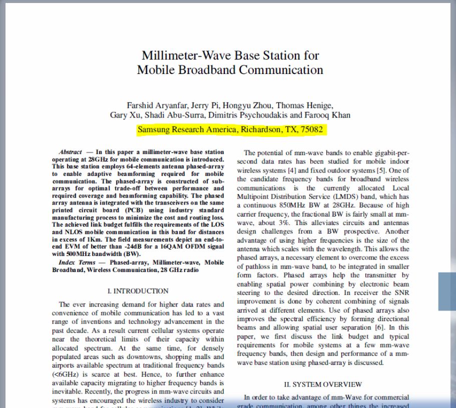
Abstract

Introduction

IEEE Communications Magazine • June 2011 0163-6804/11/$25.00 © 2011 IEEE 101

The support of mmWave was one of the revolutionary elements in 5G!

~4 years

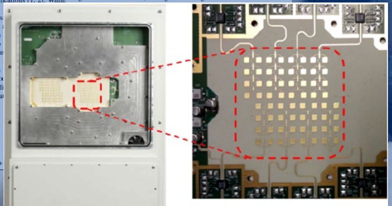

Millimeter-Wave Base Station for Mobile Broadband Communication

Farshid Aryanfar, Jerry Pi, Hongyu Zhou, Thomas Henige, Gary Xu, Shadi Abu-Surra, Dimitris Psychoudakis and Farooq Khan

Samsung Research America, Richardson, TX, 75082

I. Introduction

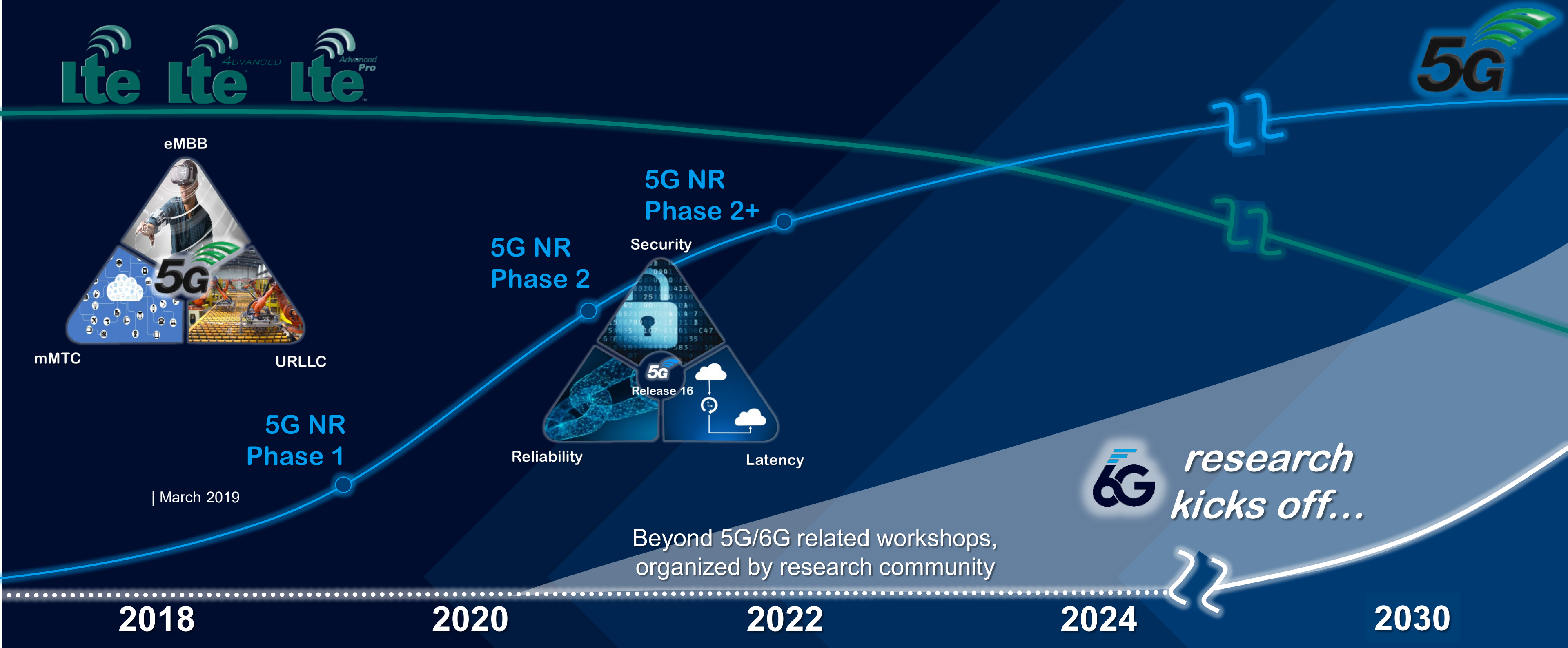
II. System Overview


28 GHz base station with 64-element antenna array

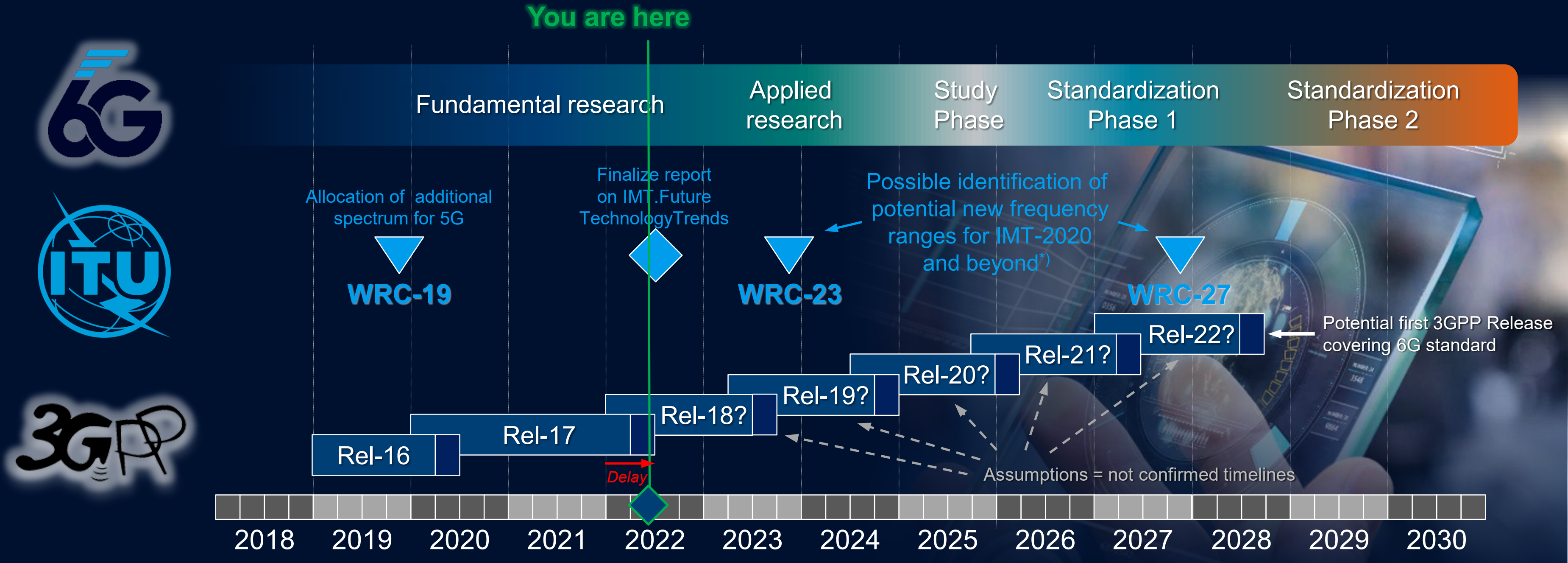
~4+ years

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5783993 (June 2011)
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7166778&tag=1 (June 2015)

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



FUTURE STANDARDIZATION AND REGULATORY ROADMAP



*) *IMT-2020 systems are usually called 5G. The ITU has already started a new report to prepare the work on IMT-2020 and beyond that is likely to become 6G*

6G RESEARCH AREAS

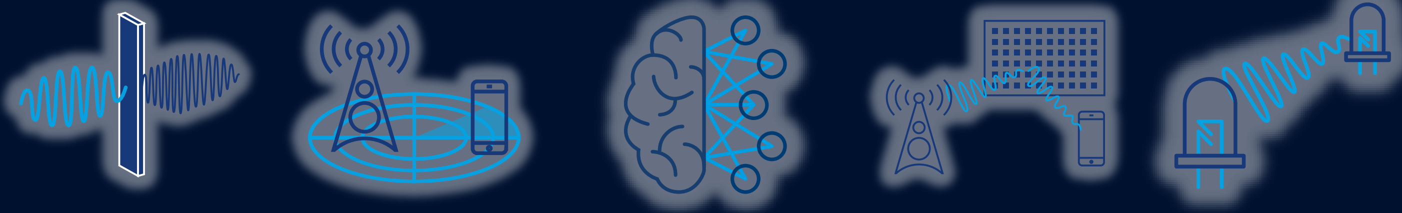
THz communication

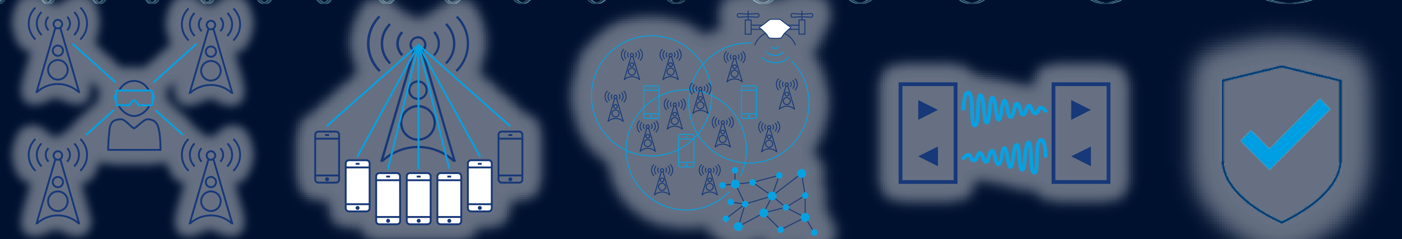
Joint communication & sensing

Artificial Intelligence and Machine Learning

Reconfigurable Intelligent Surfaces

Photonics, Visible Light Communication





Multiple access, new waveforms, channel coding

Ultra-massive MIMO

New network topologies, distributed computing

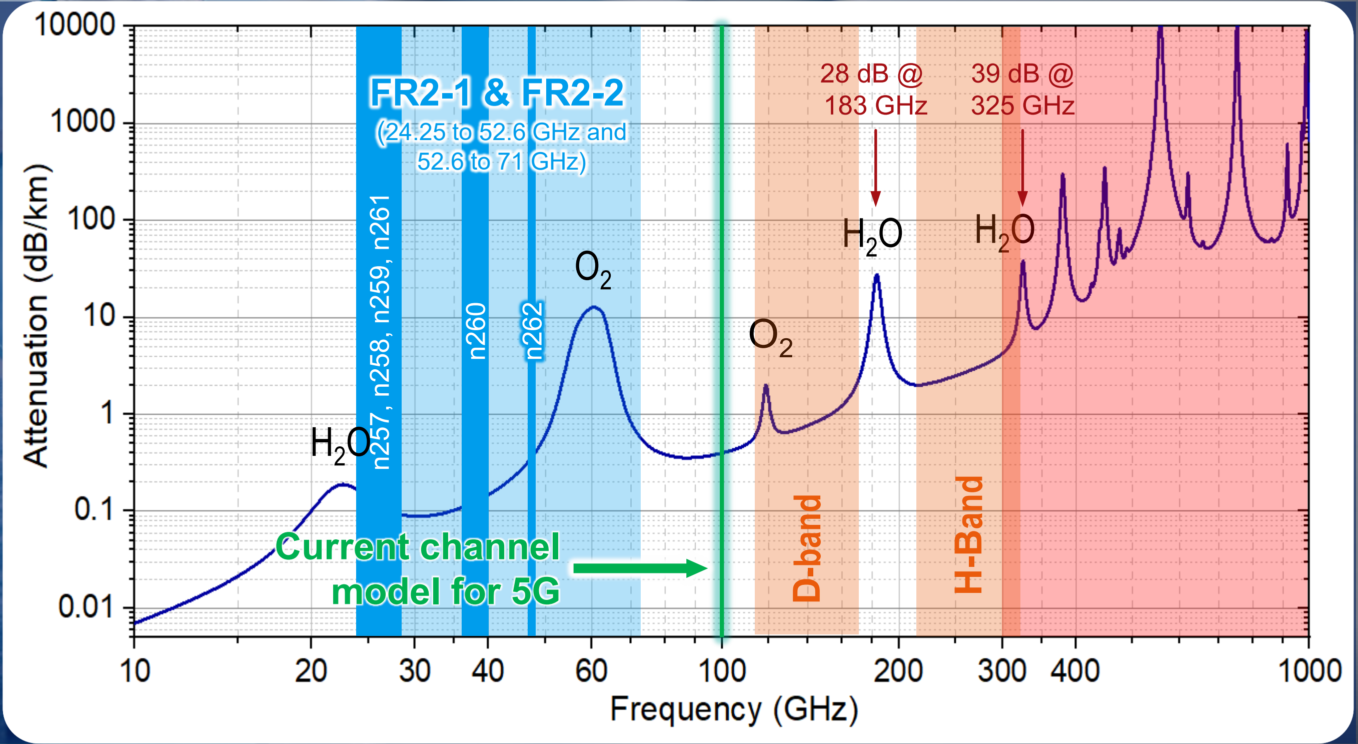
Full-duplex communication

Security & Trustworthiness

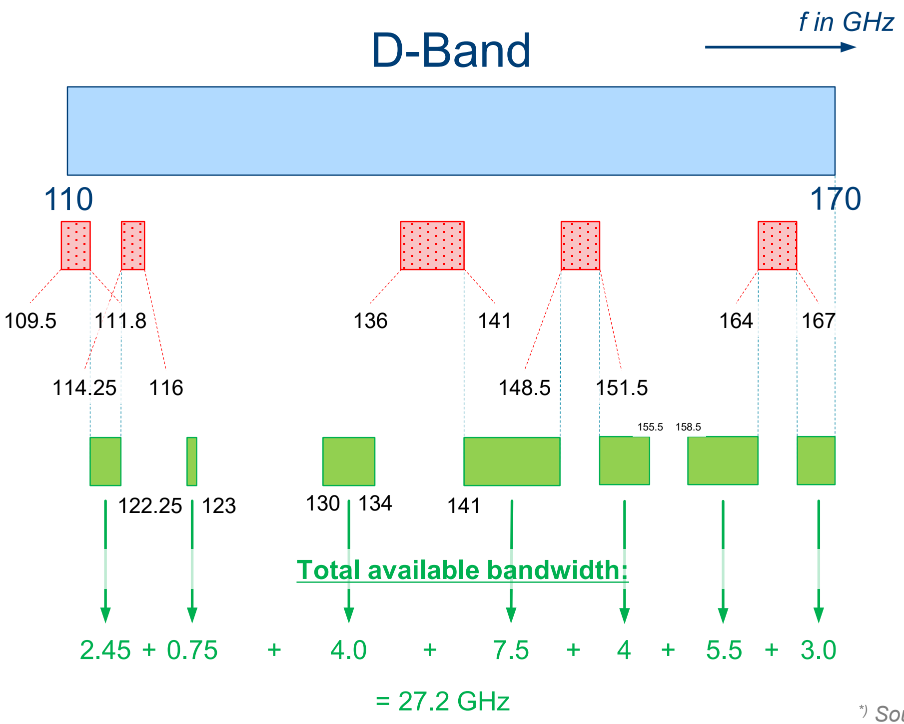
A high-level overview on all these research areas is provided in one of our #THINKSIX video. Don't miss it!

THE PROPERTIES OF A (SUB-)THz SIGNALS DEFINE THE ACTUAL RANGE OF APPLICATIONS

- **Energy / frequency region of molecular rotational transitions** of gas molecules and vibrational transitions of weak bonds.
- **Low energy: does not initiate changes in chemical structure.**
- **Terahertz waves can penetrate** through materials opaque to other parts of the EM spectrum.



EARLY 6G RESEARCH FOCUSSES ON D-BAND (110 – 170 GHz)



- ▶ According to ITU regulation (RR 5.340) all radio emissions are prohibited in the [red dotted] marked frequency ranges; but there is more:

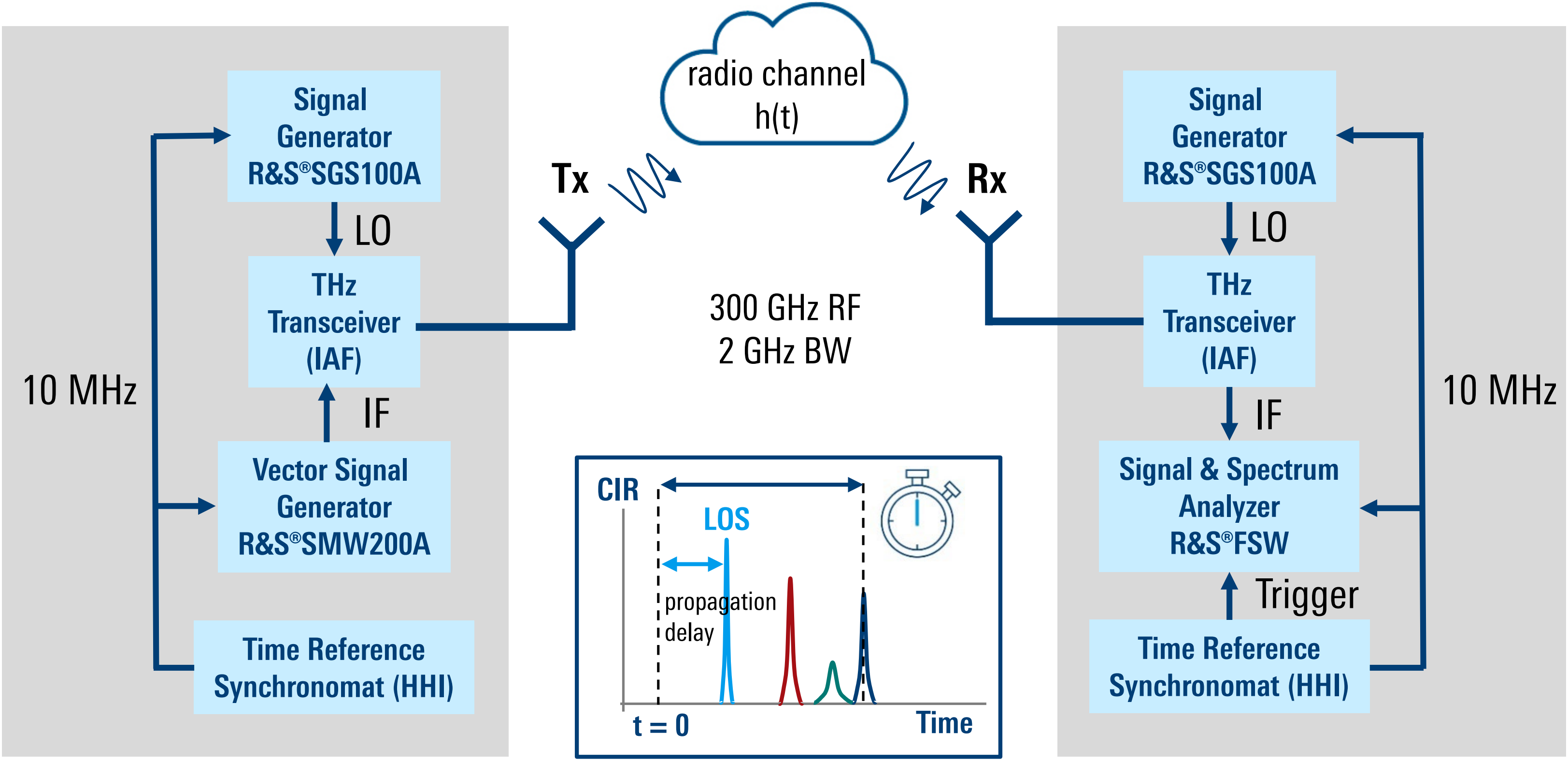
Service	Radio Regulations*)	Frequency range
Earth exploration satellite (passive), radio astronomy, space research (passive),Inter-satellite	RR 5.340, RR 5.341 RR 5.138, RR 5.149 US246, US 211, US 342	109.5 to 111.8, 114.25 to 116, 116 to 119.98, 119.98 to 122.25, 136 to 141, 148.5 to 151.5, 155.5 to 158.5, 164 to 167 GHz
Fixed-Satellite, Mobile-Satellite, Radio Navigation	RR 5.149, RR 5.554 US211, US342	123 to 130 GHz
Amateur satellite	Amateur radio	134 to 136 GHz

- ▶ Frequency ranges that are marked [green] are accessible by Fixed Services (FS), i.e. for wireless backhaul, and Mobile Services (MS)

*) Source: https://www.ntia.doc.gov/files/ntia/publications/ntia_manual_september_2017_revision.pdf

Time domain channel sounding setup at 300 GHz

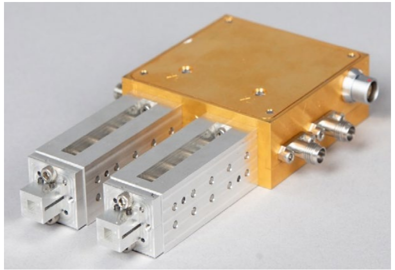
Propagation delay measurement between transmitter and receiver



Research cooperation with Fraunhofer IAF and HHI at THz frequencies

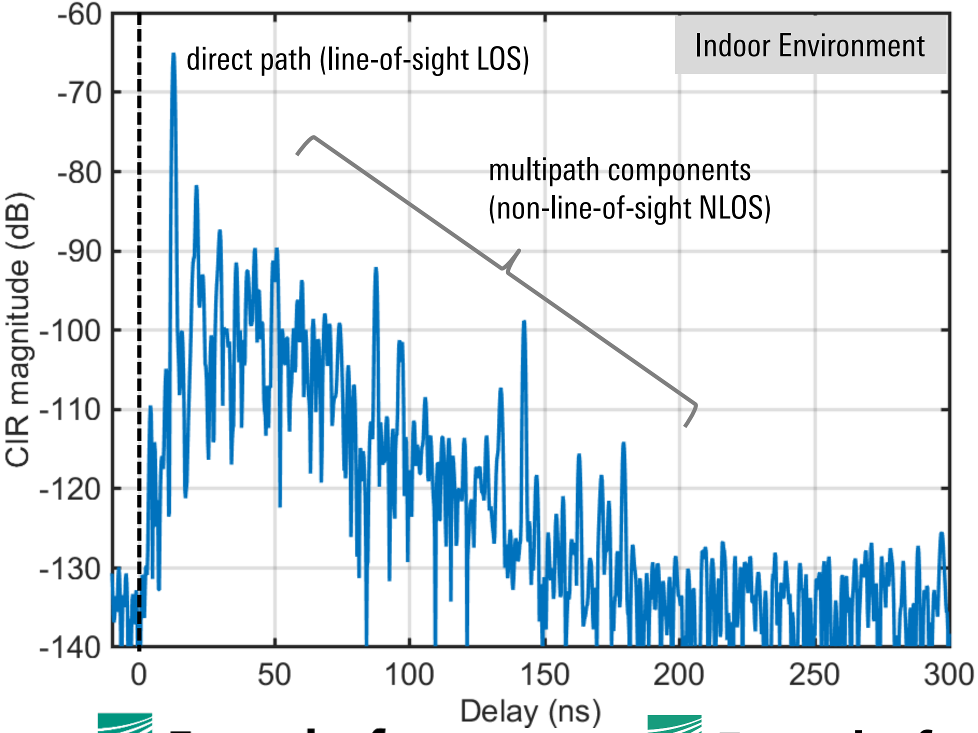
Channel impulse response CIR of indoor environment at 300 GHz

- Fraunhofer IAF InGaAs mHEMT technology: extremely low-noise and broadband applications at room temperature
- Signal generation Tx and analysis Rx at 275–325 GHz operating frequency
- Signals can be arbitrary modulated for transmission experiments with Beyond 5G candidate waveforms for THz communication or for channel propagation measurements.



„THz Channel Sounding: Design and Validation of a High Performance Channel Sounder at 300 GHz" (IEEE WCNC2020) https://ieeexplore.ieee.org/document/9124887

An electromagnetic wave travels approx. 30 cm in 1ns !



Fraunhofer IAF

Fraunhofer HHI

ADJUST THE CHANNEL – ALONG WITH THE SIGNAL

$$r(t) = h(t)s(t) + n(t)$$

Classical approach to maximise reception quality:
Adapt s(t) transmission scheme to target channel h(t),
e.g. CP-OFDM for multipath channel, carrier frequency and bandwidth, pre-coding/equalization, modulation and coding schemes etc.

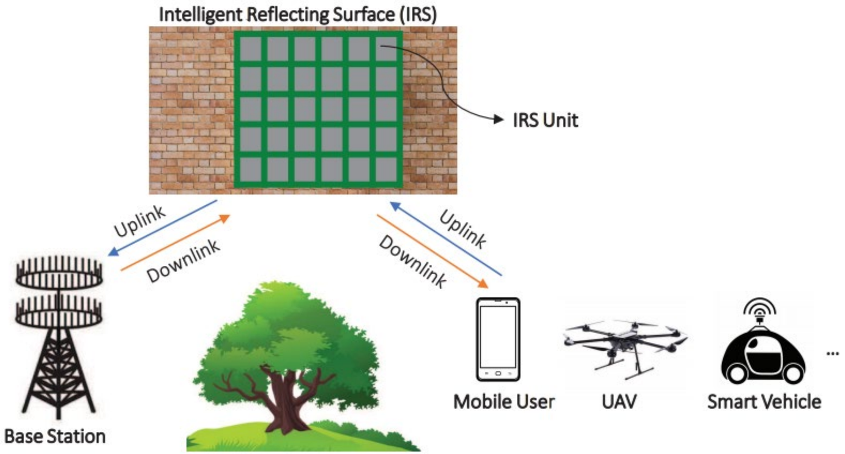
IRS offers adaptation of channel h(t) in addition, in order to maximise reception quality.

INTELLIGENT REFLECTING SURFACES (IRS)
PROMISING TECHNOLOGY FOR 6G WIRELESS COMMUNICATIONS

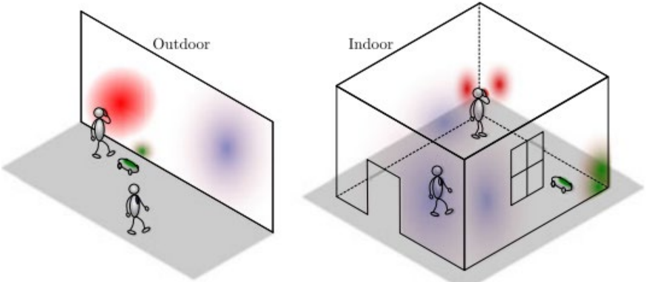
- Intelligent reflecting surfaces (IRSs) **tune wireless environments** to increase spectrum and energy efficiencies
  - Reconfigurable reflect arrays
  - Liquid crystal meta-surfaces
  - Programmable meta-materials

"man-made structures become more and more electronically active, with integrated electronics and wireless communication making the entire environment intelligent"

Source: IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 66, NO. 10, MAY 15, 2018

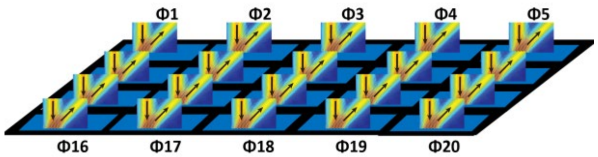


IRS-aided wireless communications

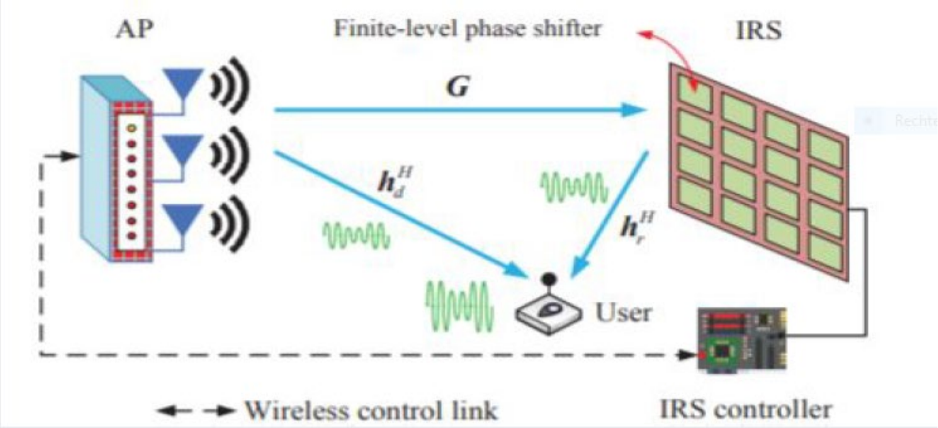


IRS-based wireless communications

IRS



- Intelligent reflecting surface (IRS) is a cost-effective solution for achieving high spectrum and energy efficiency.
- It consists of massive low-cost passive elements that are able to reflect the signals with adjustable phase shifts.
- It minimize the transmit power at the access point (AP).
- SNR is maximized by passive beamforming through the IRS.



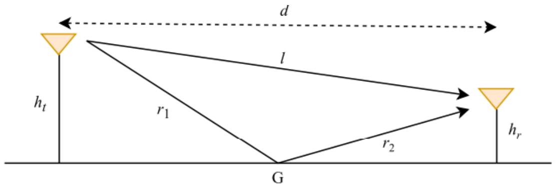
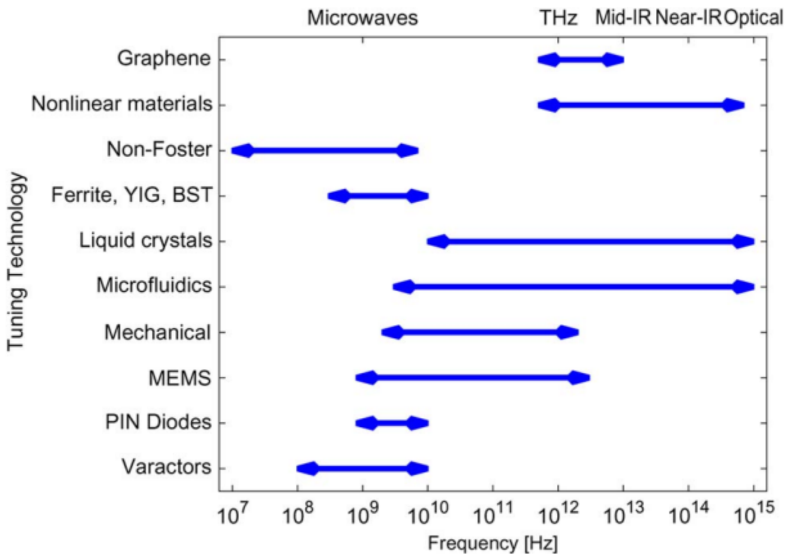


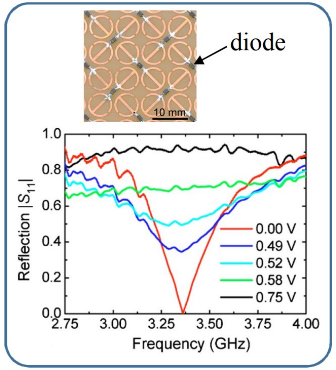
FIGURE 1. Two-ray propagation model with a LOS ray and a ground-reflected ray.

Source: IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 66, NO. 10, MAY 15, 2018

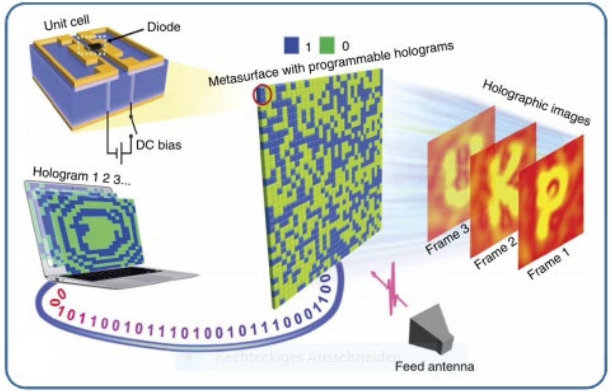
META-MATERIALS REVIEW



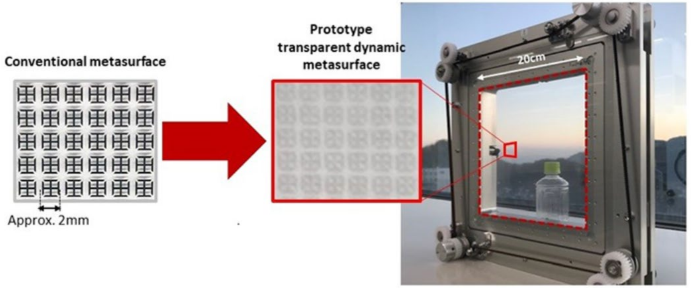
Tuning Technologies for reconfigurable meta-materials vs. operation frequency



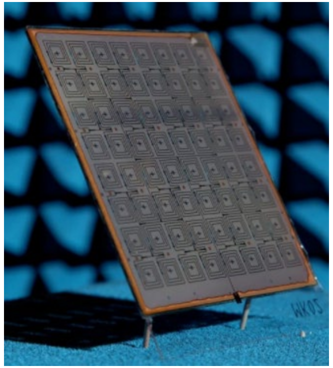
Reflection control with varactors



Dynamic hologram creation



Prototype of transparent dynamic metasurface

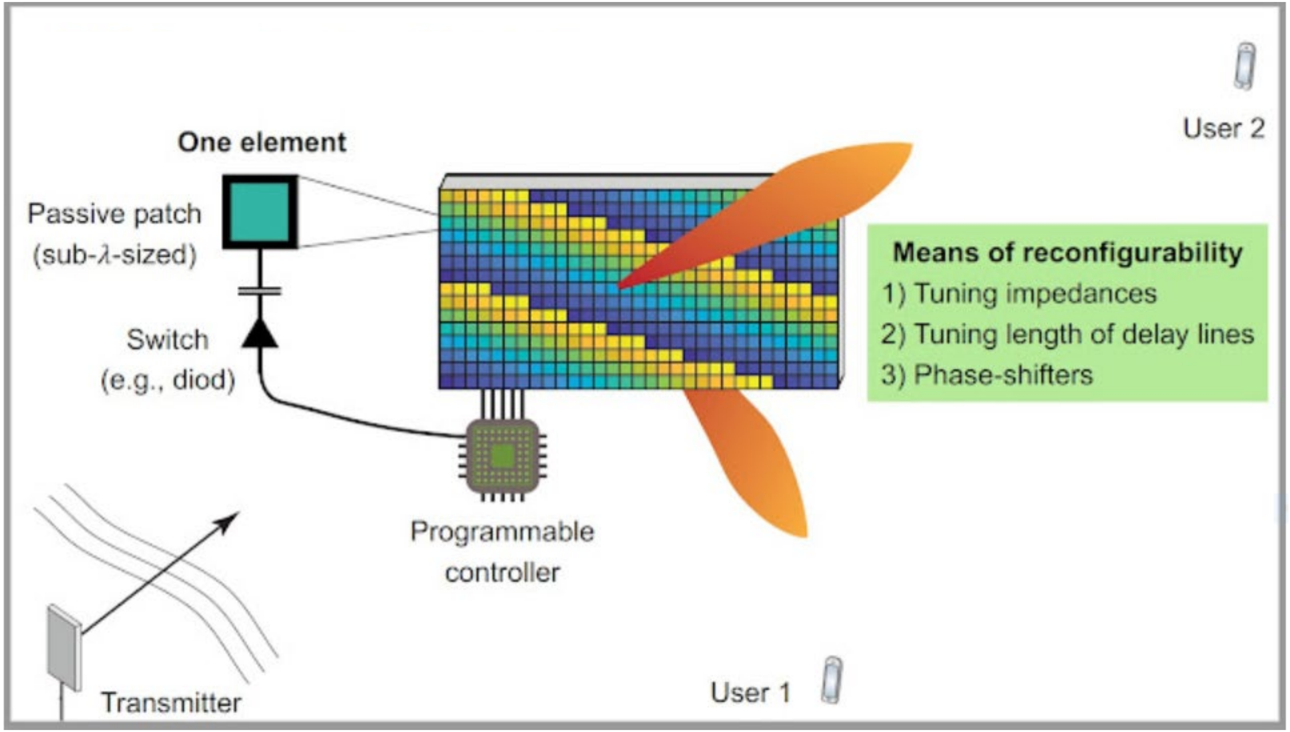


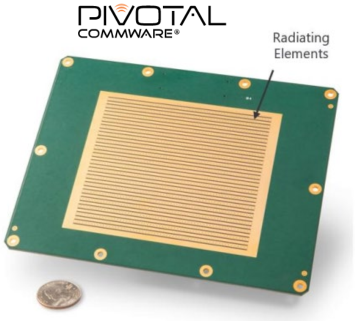
ALCAN Systems liquid crystal-based phased-array antenna

- VARACTORs (variable capacitors, e.g. used in VCOs or frequency multipliers)
- microelectromechanical systems (MEMS)

Source:Oliveri et al.: Reconfigurable Electromagnetics Through MetamaterialsVA Review, Proceedings of the IEEE | Vol. 103, No. 7, July 2015

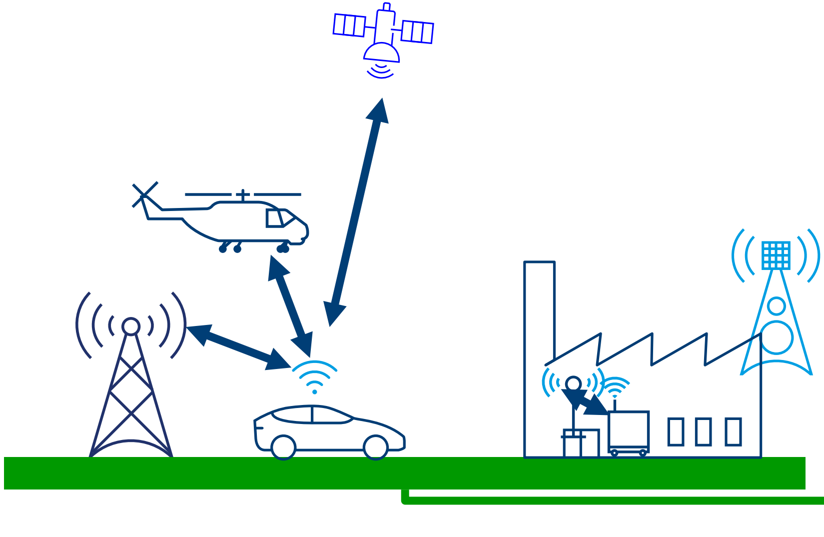
IRS OPERATION IN A NUTSHELL

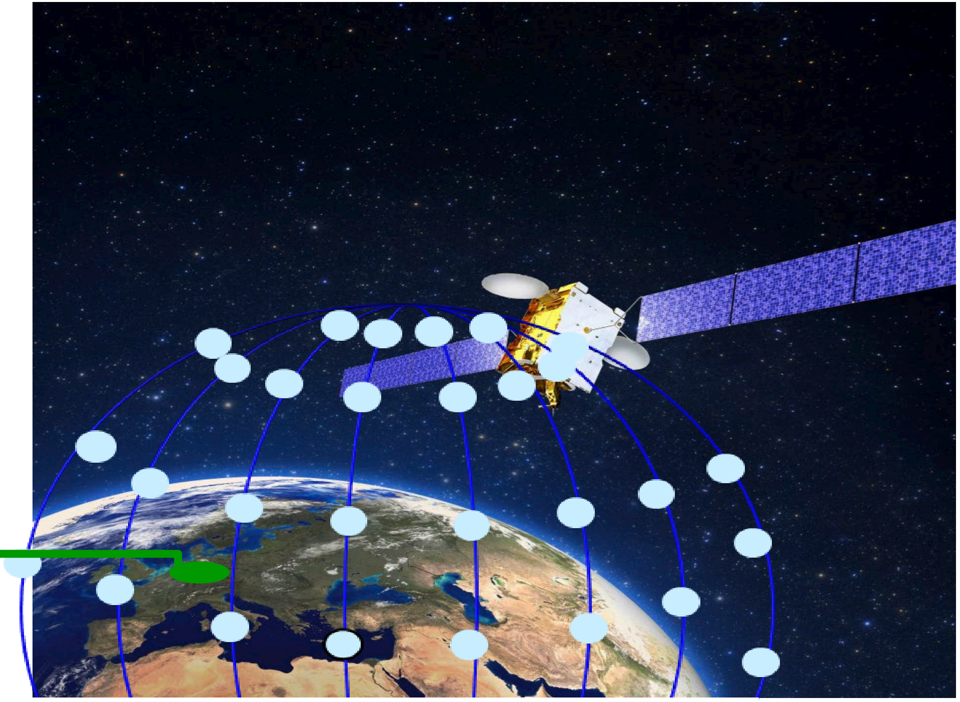




Sources: https://www.free6gtraining.com/2020/12/communications-using-intelligent.html and https://www.youtube.com/watch?v=9cBn5piI9Ms

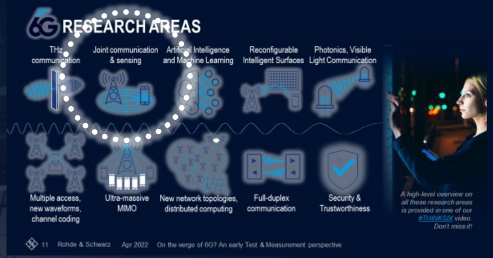
THE PATH OF NTN TOWARDS 6G -> UNIFIED 3D NETWORKS



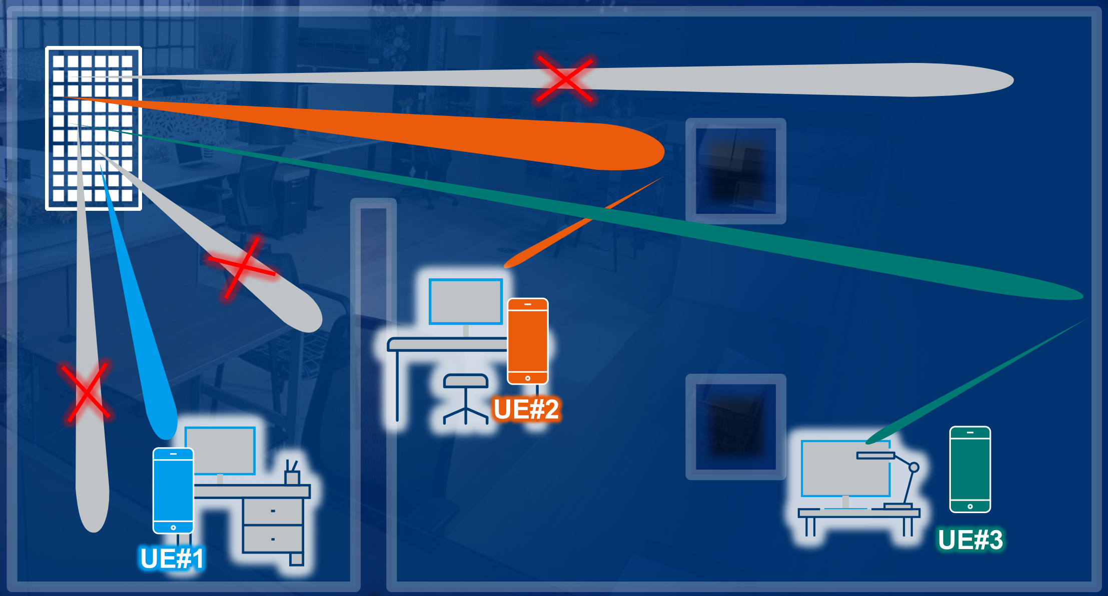


Beyond cellular – 3D unified networks
- Dynamic, self-configuring
- Resilient & intelligent
- Autonomous & infrastructure agnostic

COMBINING TWO WORLDS
JOINT COMMUNICATION AND SENSING

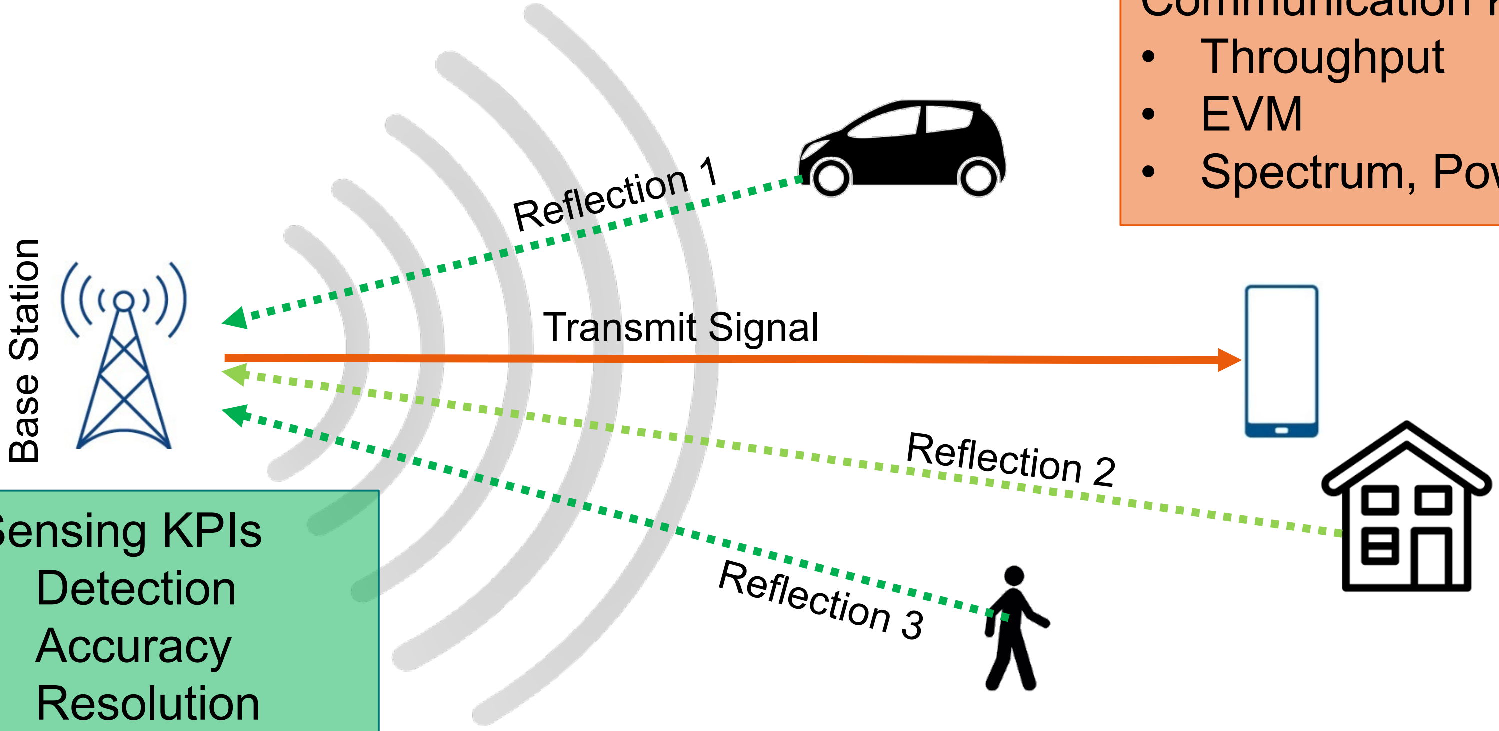


- Design communication signal that can be used for objection detection, tracking, recognition, localization and imaging
- Sensing-assisted communication by utilizing sensed information to aid beam management/alignment, CSI acquisition, medium-aware links, interference mitigation etc.
- Research challenges
  - What frequency / bandwidth?
  - Waveform design (e.g. PAPR)?
  - …
- T&M challenge
  - How to test efficiently?



TEST CAPABILITIES DEMONSTRATED IN THE EXHIBITION
MEET OUR EXPERTS TO DISCUSS

Communication KPIs
- Throughput
- EVM
- Spectrum, Power

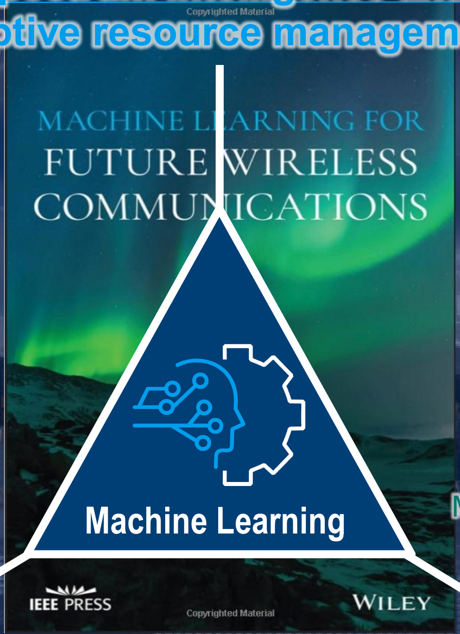


Sensing KPIs
- Detection
- Accuracy
- Resolution

WHAT ROLE WILL MACHINE LEARNING PLAY IN 6G?

Spectrum intelligence and adaptive resource management

- Spectrum sharing & access
- Optimal resource allocation
- Coverage & capacity optimization
- Traffic & mobility prediction
- Data transfer mobile crowd sensing
- Energy efficiency optimization



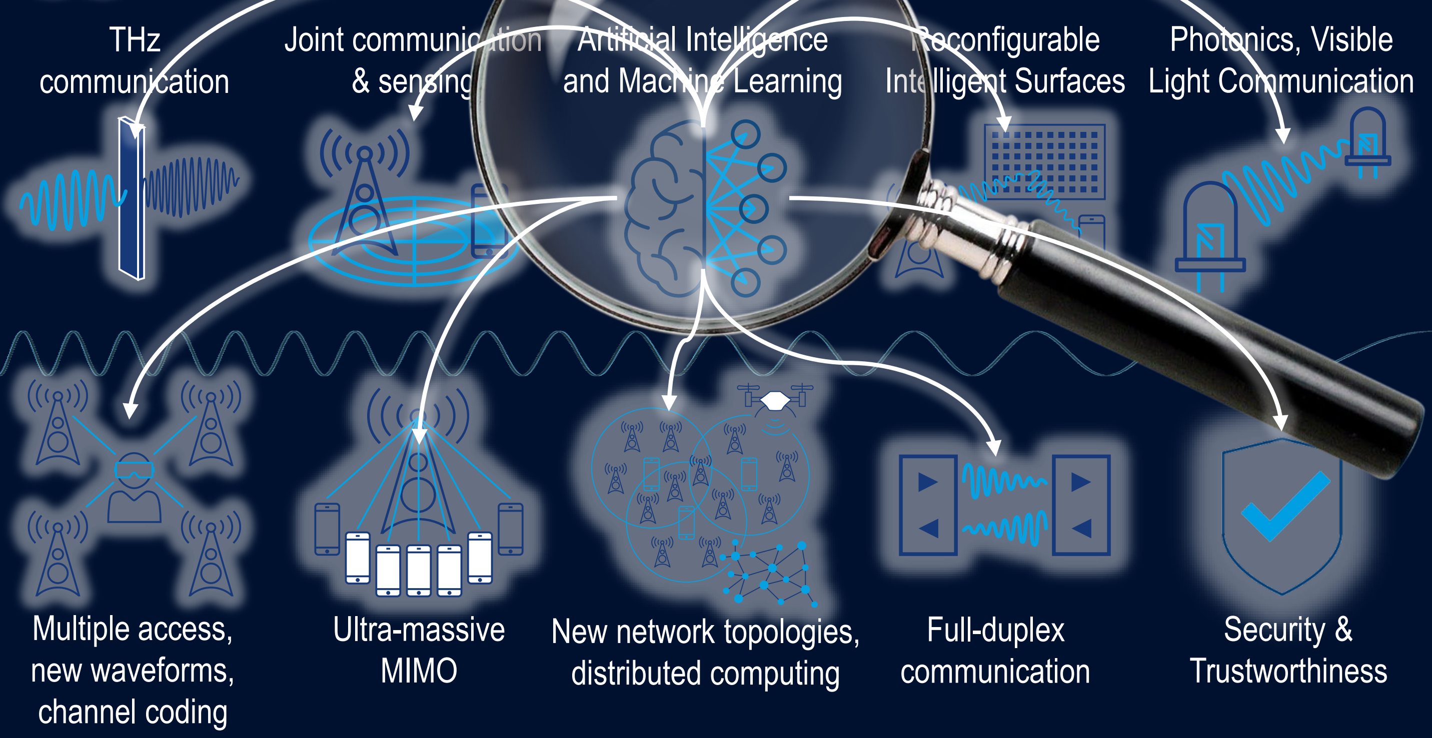
Network Intelligence and adaptive system optimization

- Cooperative Edge Caching
- Self-interference cancellation
- Location Verification
- Context-aware cross-layer optimization
- Digital Frontend

Transmission Intelligence and adaptive baseband processing

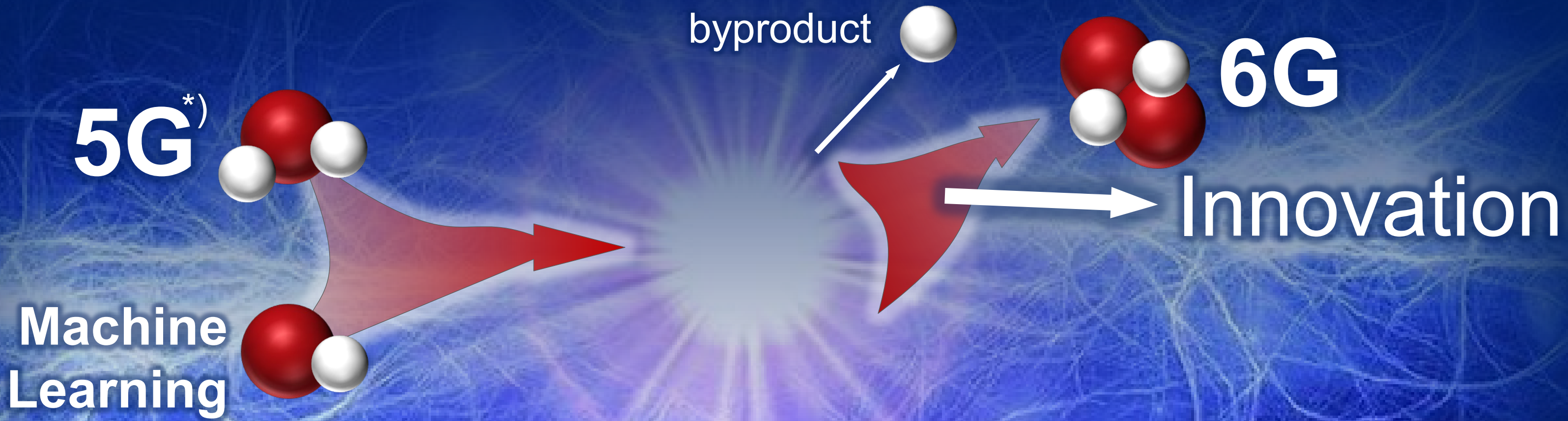
- Adaptive Modulation & Coding based on ML
- Channel decoding
- Non-linear MIMO detector
- Channel equalization & signal detection
- Channel prediction

6G RESEARCH AREAS



A high-level overview on all these research areas is provided in one of our [#THINKSIX](#) video. Don't miss it!

SO WHAT ROLE WILL MACHINE LEARNING PLAY IN 6G?
(MACHINE LEARNING), LIFE, THE UNIVERSE AND EVERYTHING



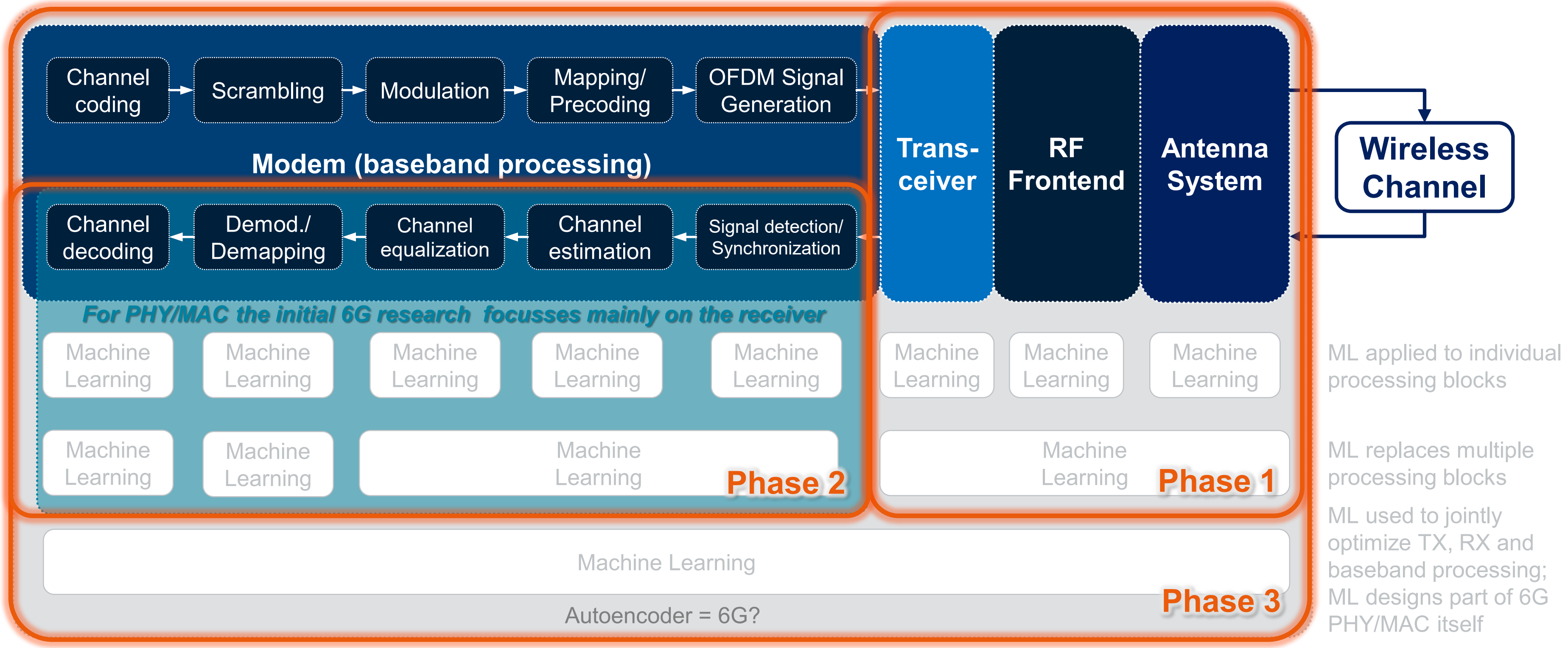
…and the answer may not be 42

*) *First study item in 3GPP Release 18*

The current status of the fundamental research for an AI-native air interface for 6G

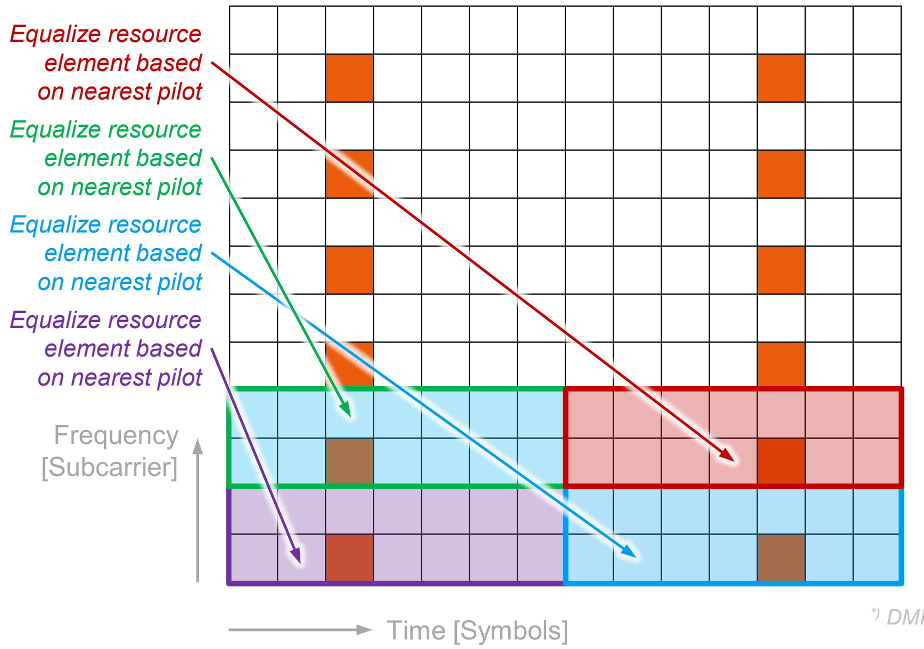
HOW TO APPLY MACHINE LEARNING FOR 6G PHY?

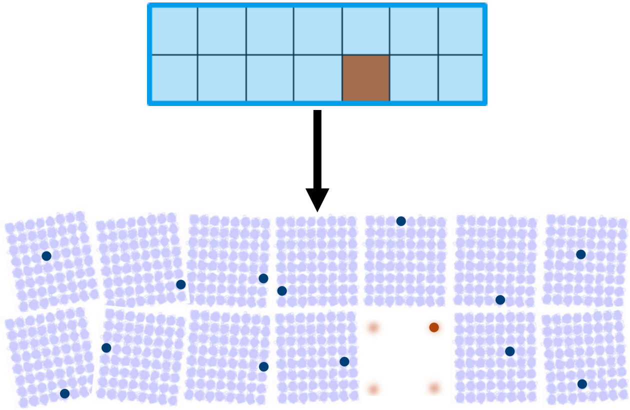
WE THINK THREE MIGHT BE THREE PHASES



WHY IS THERE ROOM FOR ML TO BE APPLIED IN WIRELESS?

- 5G: there is a zoo of reference signals*) to allow the receiver to estimate the channel properties and ultimately equalize resource elements for the propagation effects

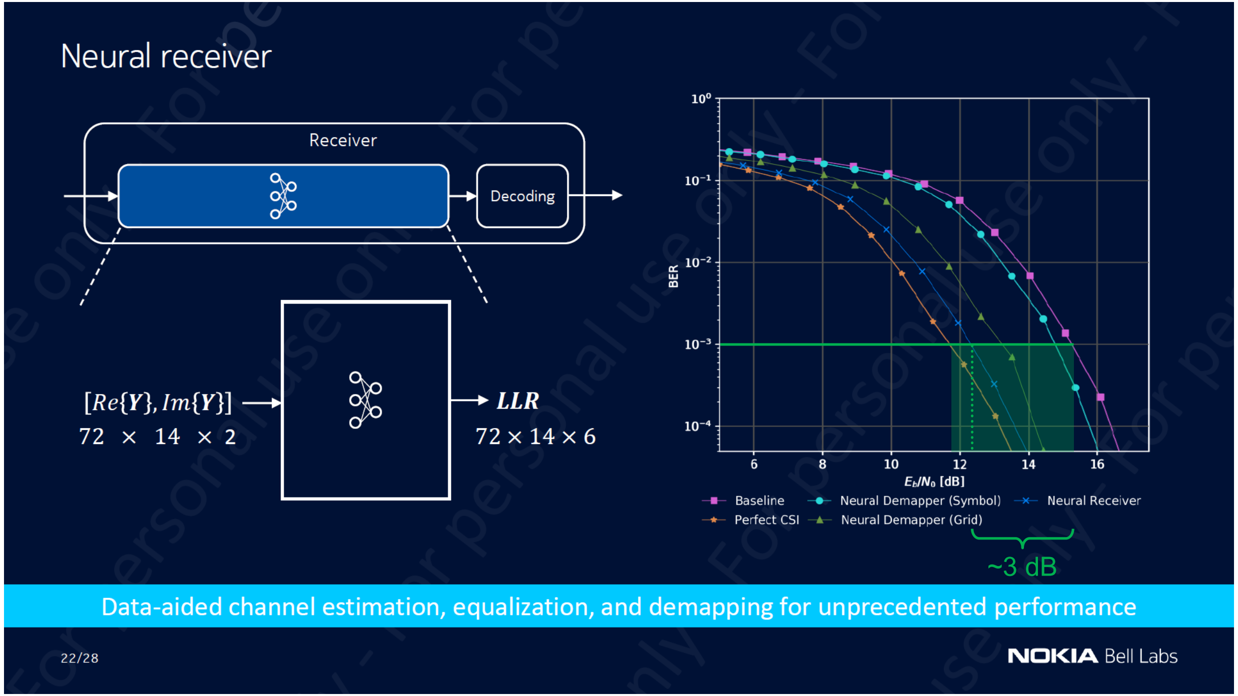




Imperfect channel estimation and channel aging leads to SNR degradation and mismatched computation and thus equalization errors → Machine Learning can be used to overcome this mismatch

*) DMRS for each physical channel in DL and UL direction, PTRS; DL: CSI-RS, TRS, PRS; UL: SRS

APPROACHING PERFORMANCE CLOSE TO PERFECT CHANNEL KNOWLEDGE



Source: https://aiforgood.itu.int/events/the-road-towards-an-ai-native-air-interface-for-6g/ [Nov 2020]

SUMMARY

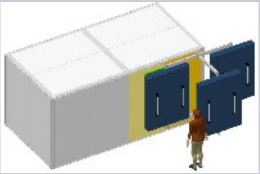
- Deployment of 5G networks is in full swing! Clear evolution path provided by the industry's standardization organization. Some of the 6G research items scatter back into 5G Advanced.
- Academia and key industry players are exploring the boundaries and started looking into next generation of wireless communication aka 6G
- Revolutionary aspects require early engagement from a T&M perspective to provide reliable and repeatable feedback on - potentially different – technical approaches
- Rohde & Schwarz is actively engaged in this phase of fundamental research, providing our expertise in test and measurement to make ideas real


"If you want to go fast, go alone.
If you want to go far, go together!"
African proverb
www.rohde-schwarz.com/5G

ATS1800C – CATR CONFORMANCE CHAMBER

- Compact and moveable 3GPP compliant high end CATR chamber
- High performance CATR reflector provides 30cm QZ size
- Supports OOB measurement with optional feed switcher from 6GHz to 90GHz
- Optional temperature test solution with 3D measurement support available
- Positioner can hold heavy devices as well as head or hand phantoms (CTIA mmW OTA device test requirement)

R&S FR2 OTA IFF CATR SOLUTIONS OVERVIEW

	ATS800B	ATS800R	ATS1800C	ATS1800M	ATS1800XL
					
WxDxH [m]	1.2 x 0.6 x 0.8	0.6 x 1.2 x 2.0	0.9 x 1.5 x 2.0	~3.5 x 1.5 x 2.0	~ 4.2 x 2.2 x 2.1
Application	Benchtop R&D, academia, research institutes	R&D, pre-conformance (RF, LBS, Netop, PCT, PQA)	R&D, Conformance & pre-conformance (RF, LBS, Netop, PCT, PQA)	R&D, Conformance & pre-conformance RRM multiple AoA	R&D, Conformance & pre-conformance gNB and big UE
Type	Black box CATR	Black box CATR	Black box CATR	Black box CATR	Black box CATR
Freq. Range	20 - 50 GHz	20 - 50 GHz	(6) 23 - 90 GHz	(6) 23 - 90 GHz	(6) ~15 - 90 GHz
Supported freq. Range	Full range	Full range	Full range (feed switcher)	Full range (multiple feeds)	Full range (feed switcher)
Quiet zone	Ø 20 cm	Ø 20 cm	Ø 30 cm	4x Ø 30cm	Ø 60cm
Positioner	2D positioner (opt.)	3D Az over El (opt.)	3D Az over El	3D Az over El	3D GCC
Shielding Eff.	N/A	>60dB	>90 dB	>70dB	>70dB
Extreme Temp.	N/A	1D	3D	3D	3D

5G NR SIGNALING SETUPS

Minimum Footprint Setup

Extended Setup (CMWflexx)

CMX500 OBT (One Box Tester)

5G NR RADIO COMMUNICATION TESTER

CMX500 5G NR Signaling Tester

- Future proof 5G NR signaling test platform
- Independent Operating System (Linux)
- Modular and scalable HW-Architecture
- LTE and FR1 multiband capabilities up to 8 Ghz
- FR2 Multiband Remote Radio Support (24 – 50GHz)
- 20 Gbps+ End-to-End IP Data Performance capability
- Single Web-based GUI for RF, Protocol and App Tests
- Extensive IP and Application Test feature set onboard
- LTE Anchor support for up to 8CC LTE

ADDITIONAL RESOURCES AND WHITEPAPER RELATED TO THE CONTENT OF TODAY'S PRESENTATIONS:

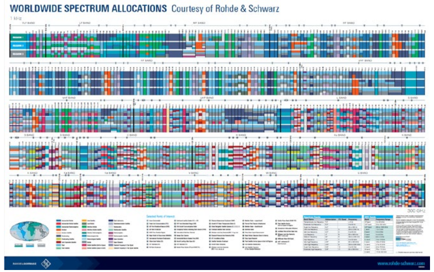
5G technology book oline version (>1000 pages on 5G technology): www.rohde-schwarz.com/5G

5G Voice over New Radio (VoNR) | Rohde & Schwarz (rohde-schwarz.com)

5G Non-terrestrial Networks | Technology Update | Rohde & Schwarz (rohde-schwarz.com)

5G in Automotive | Rohde & Schwarz (rohde-schwarz.com)

White paper: Positioning in 5G NR | Rohde & Schwarz (rohde-schwarz.com)



Additional Resources

- Worldwide Spectrum Allocation Poster (2020)
- Free "Demystifying 5G NR" poster | Rohde & Schwarz (rohde-schwarz.com)