

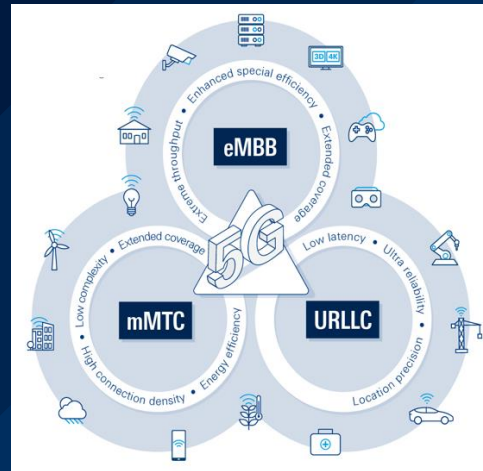
# 5G TODAY AND INTO THE FUTURE

## A TECHNICAL OVERVIEW OF R16, 17, 18 AND BEYOND

Reiner Stuhlfauth  
Technology Manager Wireless

**ROHDE & SCHWARZ**

Make ideas real



# 5G NR TECHNOLOGY EVOLUTION

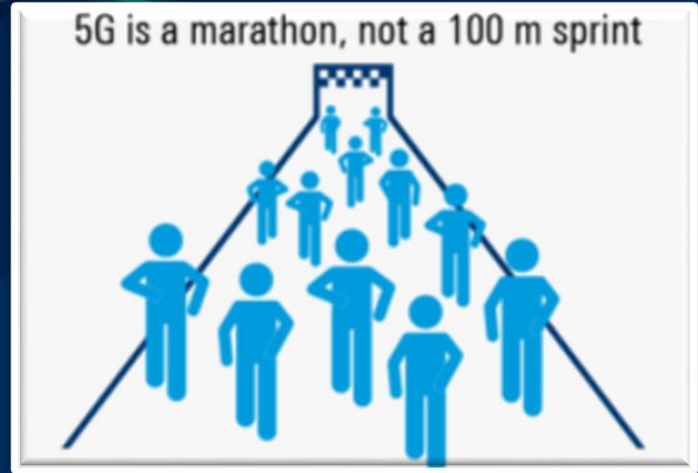
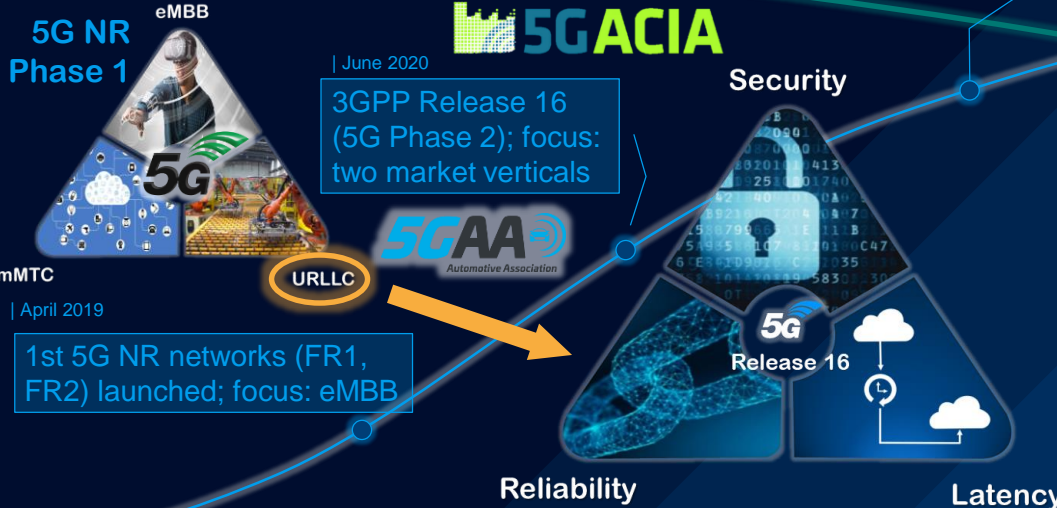
March 2024



June 2022

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

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



2018

2020

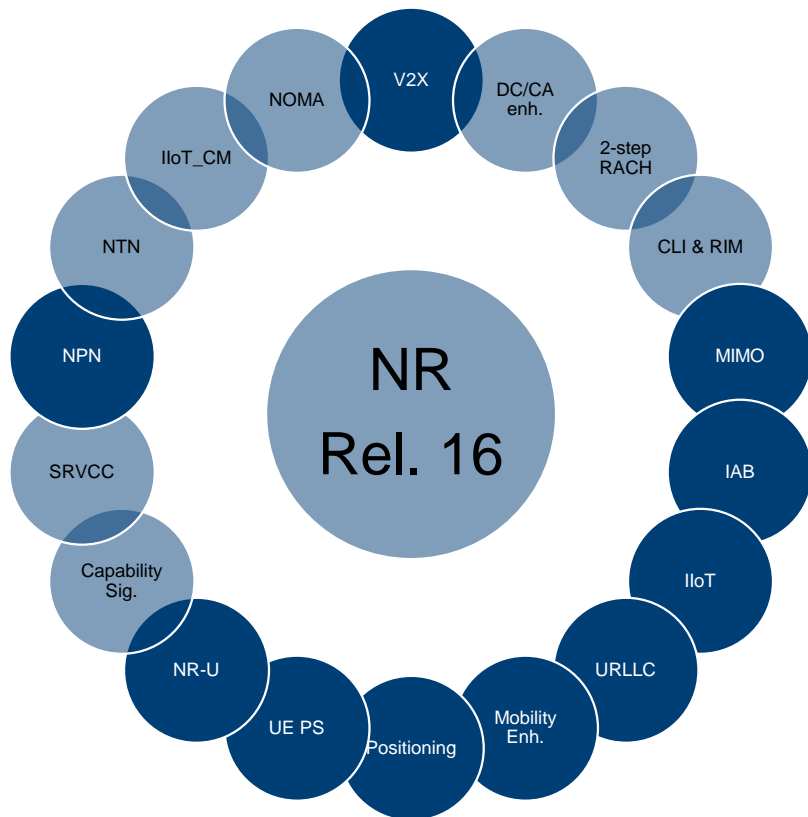
2022

2024

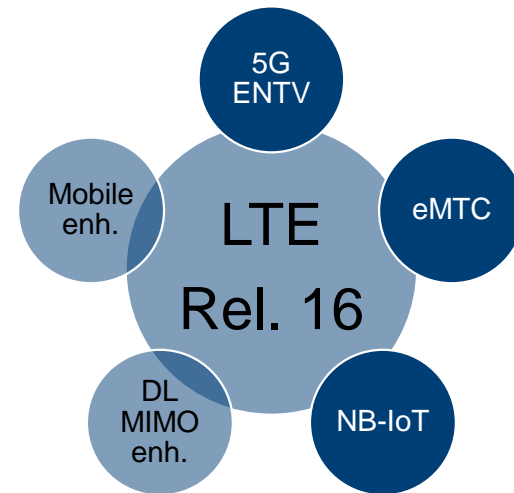
2026

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

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



Highlighted work items  
= major new aspects



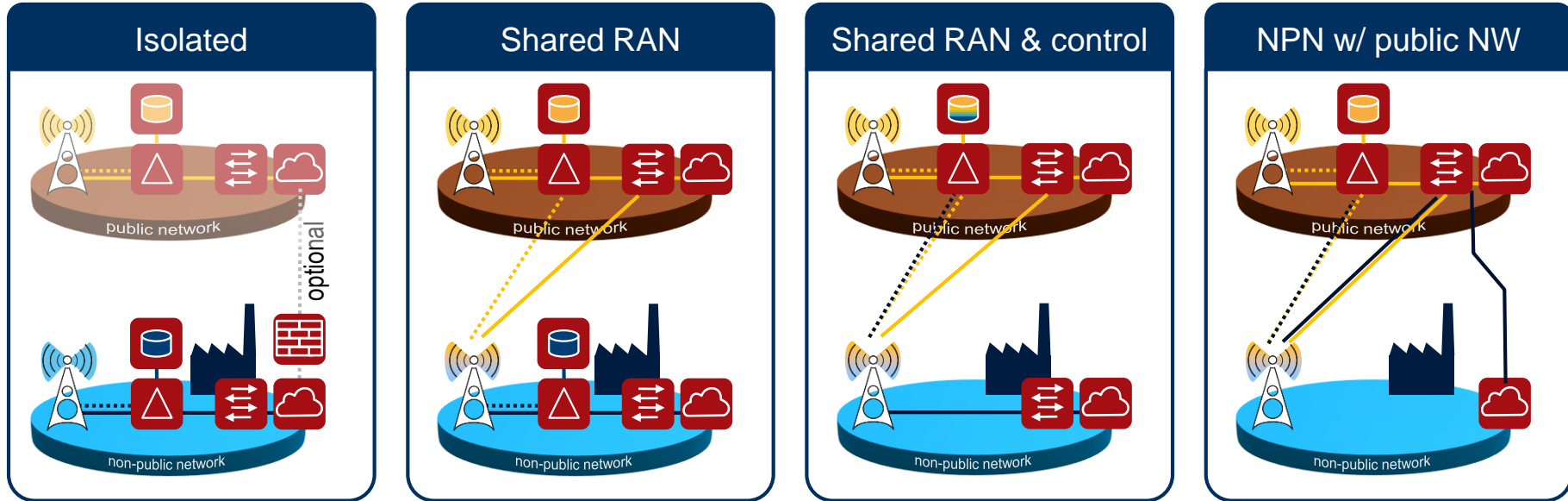


5G evolution, Releases 16

# INDUSTRIAL IoT

# INDUSTRY 4.0 SPECIFIC DEPLOYMENT SCENARIOS

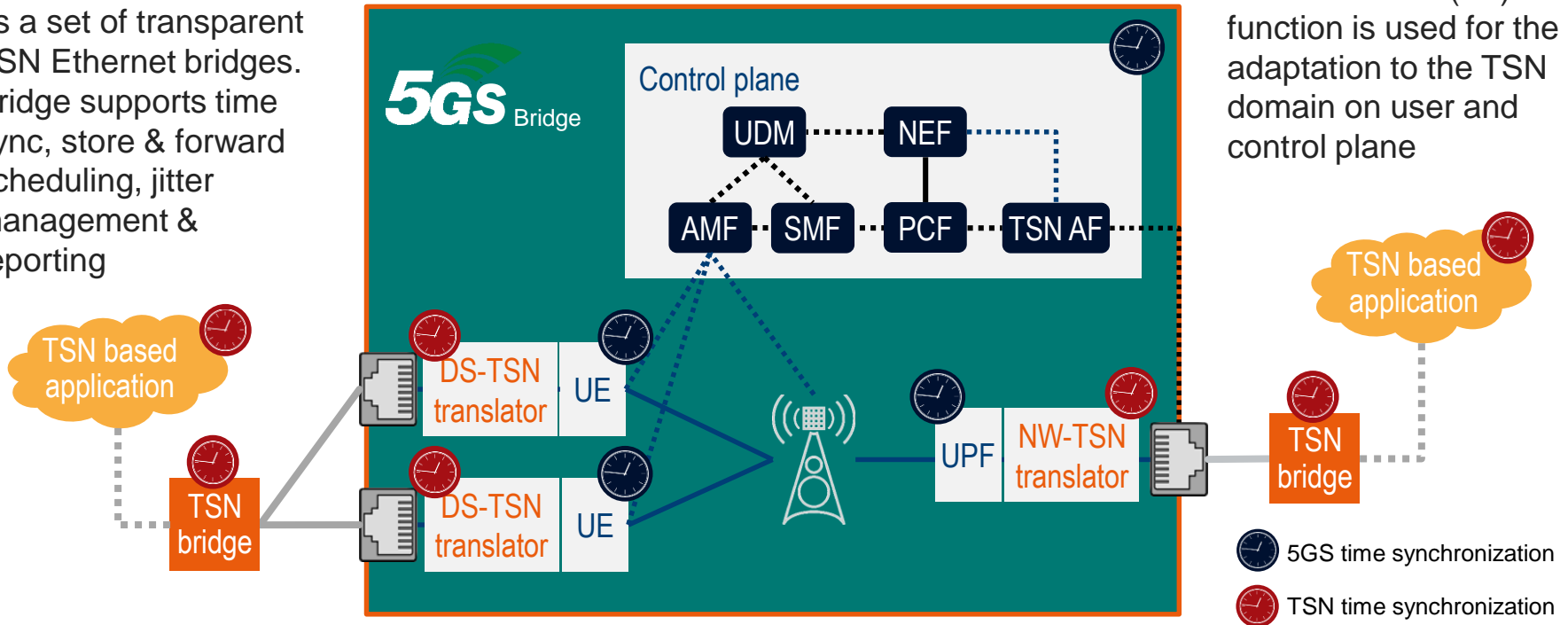
## 5G-ACIA WP: 5G NON-PUBLIC NETWORKS (NPN) FOR INDUSTRIAL SCENARIOS



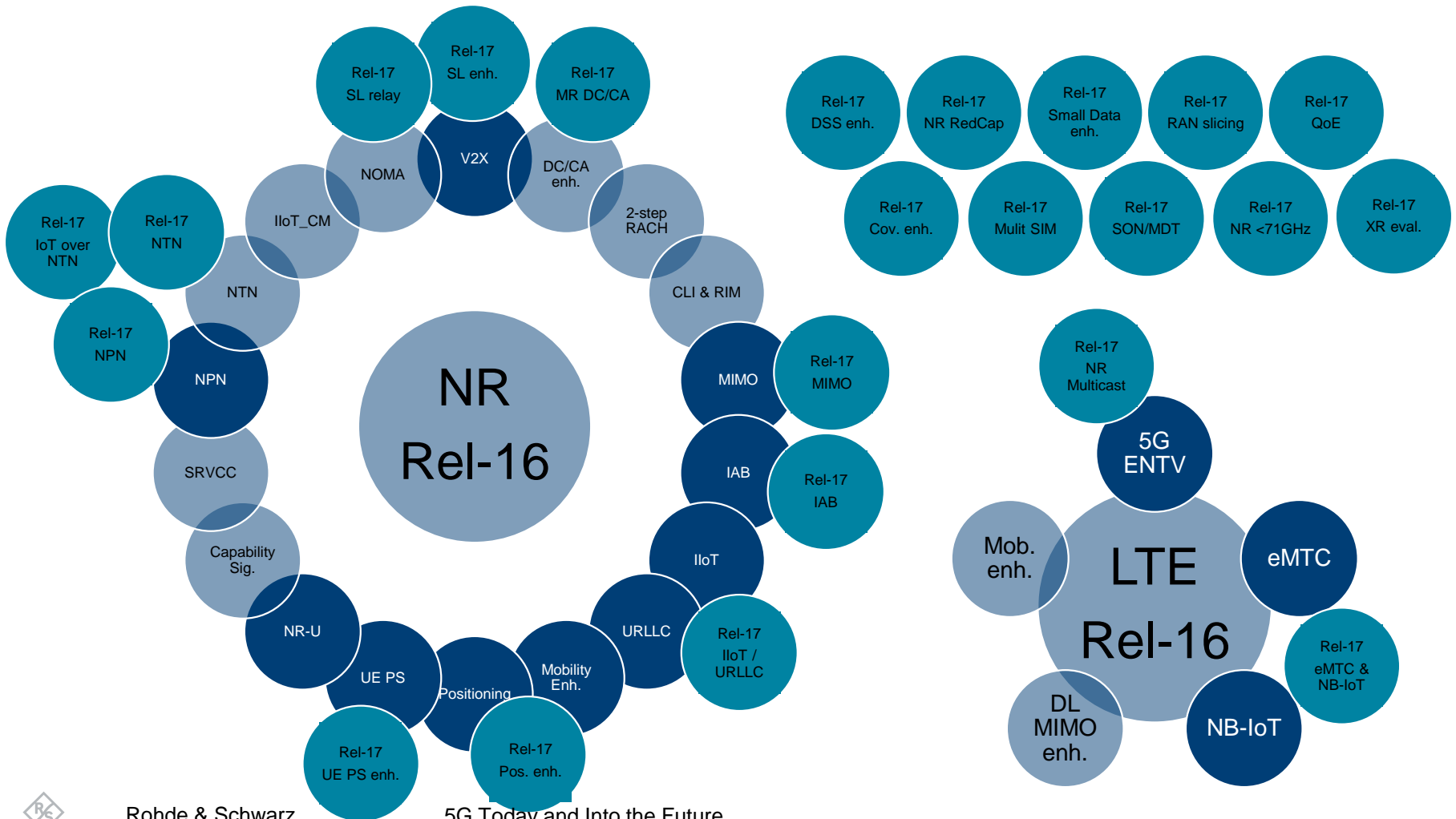
- Isolated NPN deployed on the organization's defined premises, such as a campus or a factory, offer high reliability and operation flexibility

# 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 evolution, Releases 17

# STRENGTHEN THE FOUNDATION AND IMPROVING VERTICALS

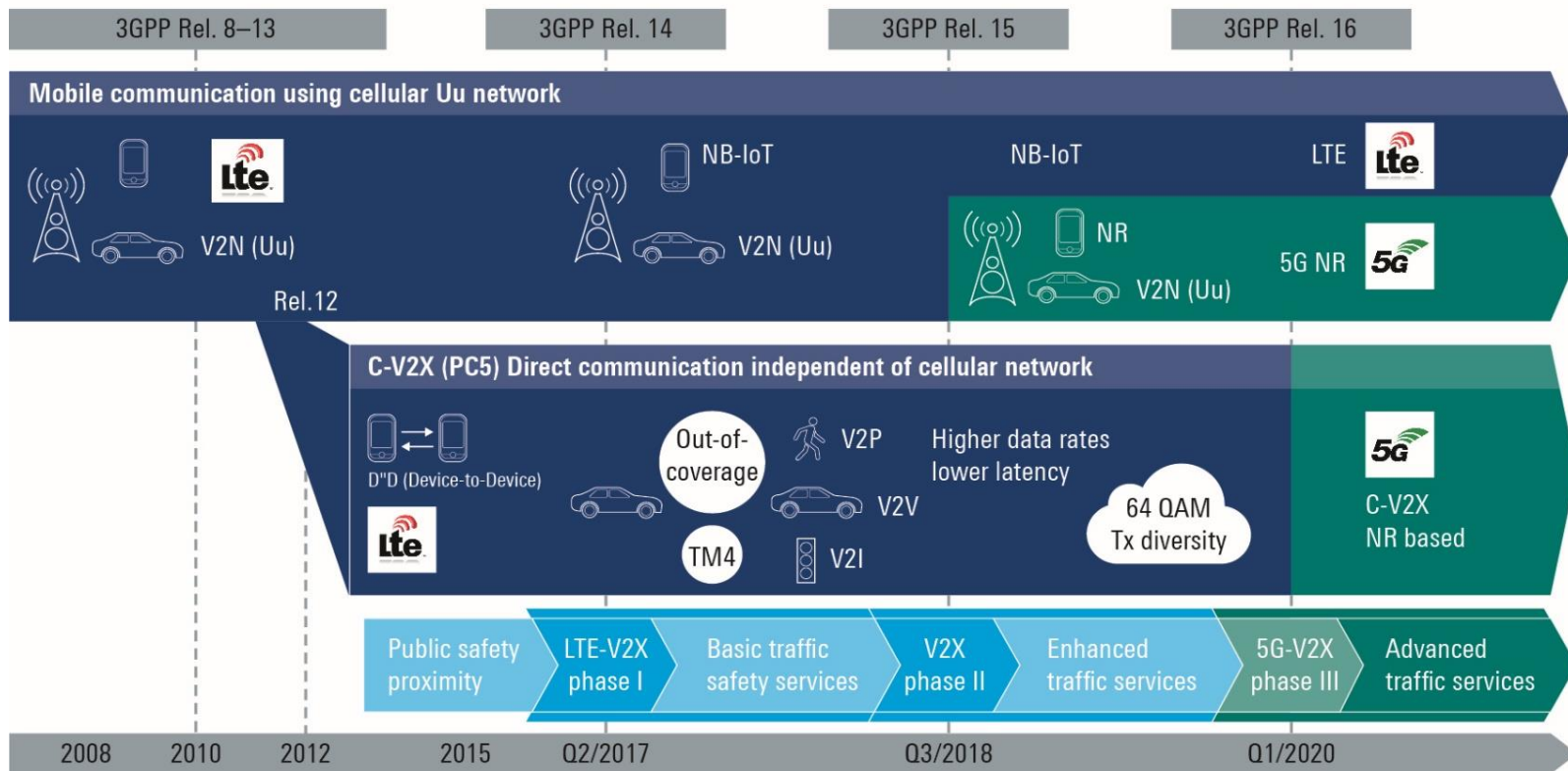




The ongoing evolution of 5G

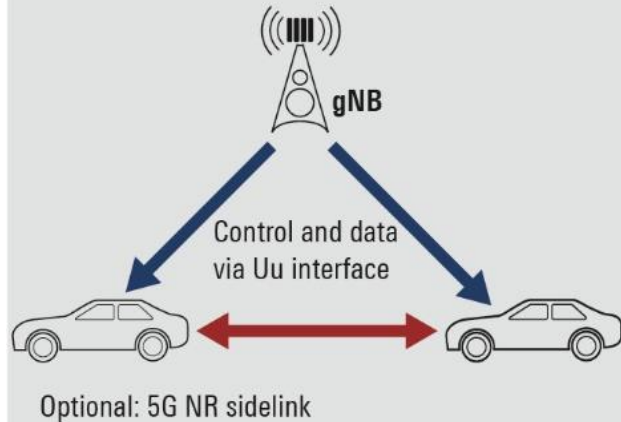
# NR-V2X: SIDELINK ENHANCEMENTS + RELAY

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

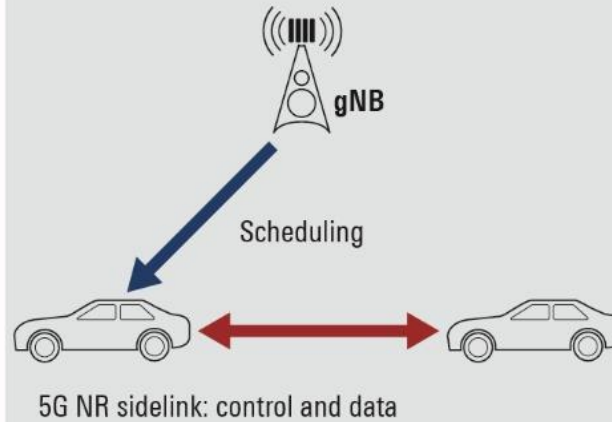


# 5G NR C-V2X COMMUNICATION MODES AT PHY LAYER

**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

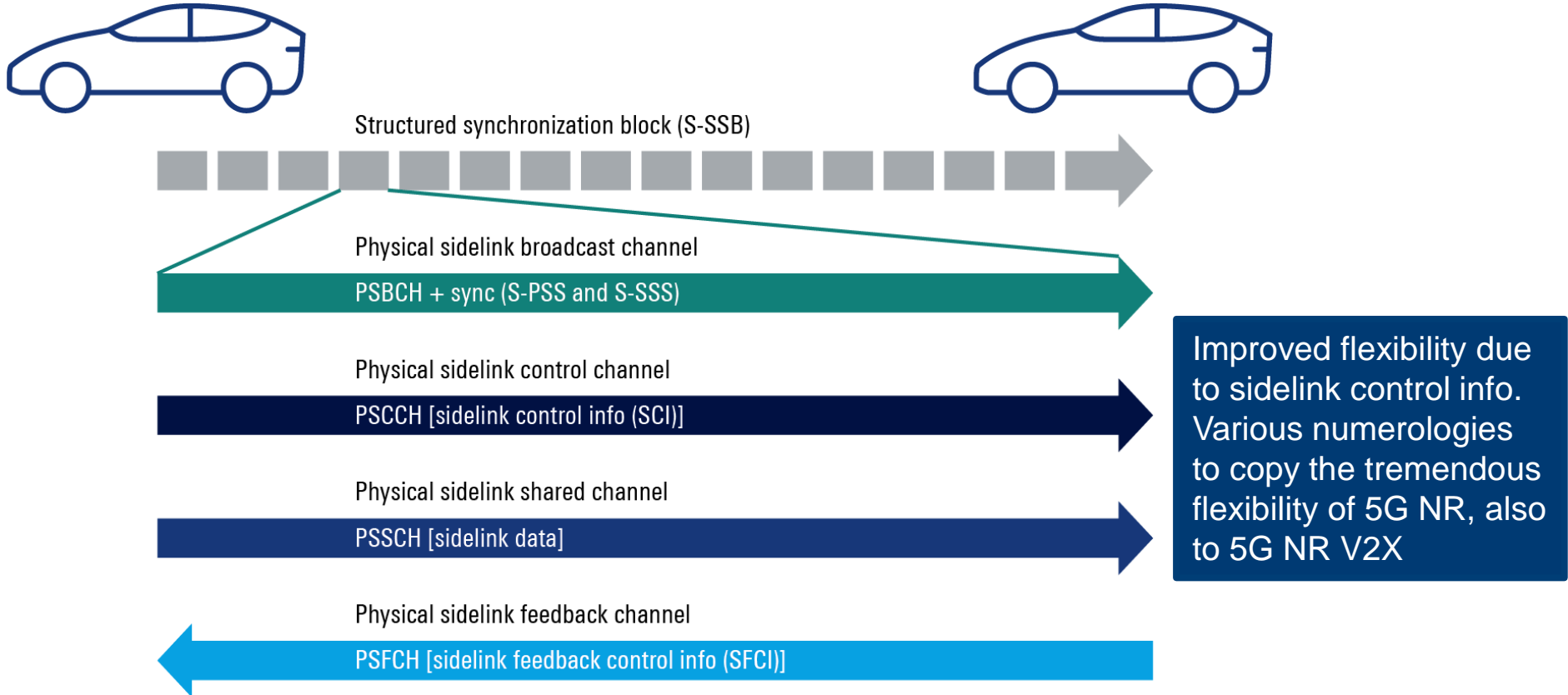


**5G NR sidelink mode 2:**  
UEs autonomously select 5G NR sidelink resources

- ▶ Contention-based
- ▶ Channel structure required
- ▶ Synchronization aspects



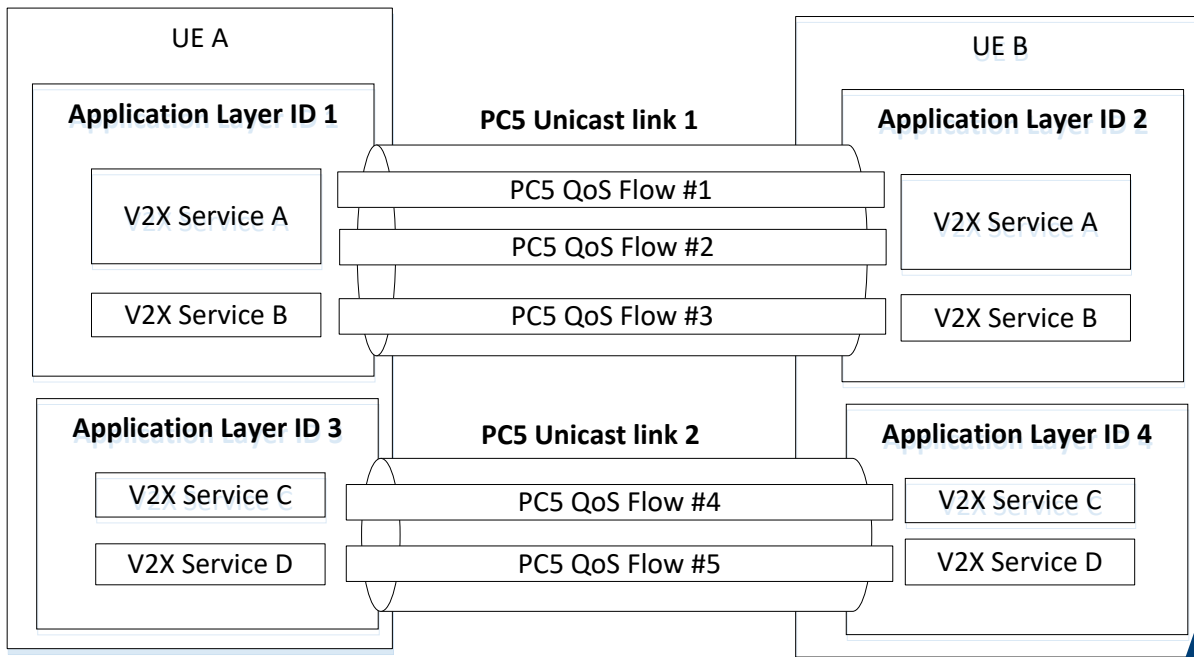
# 5G NR SIDELINK – CHANNEL STRUCTURE



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



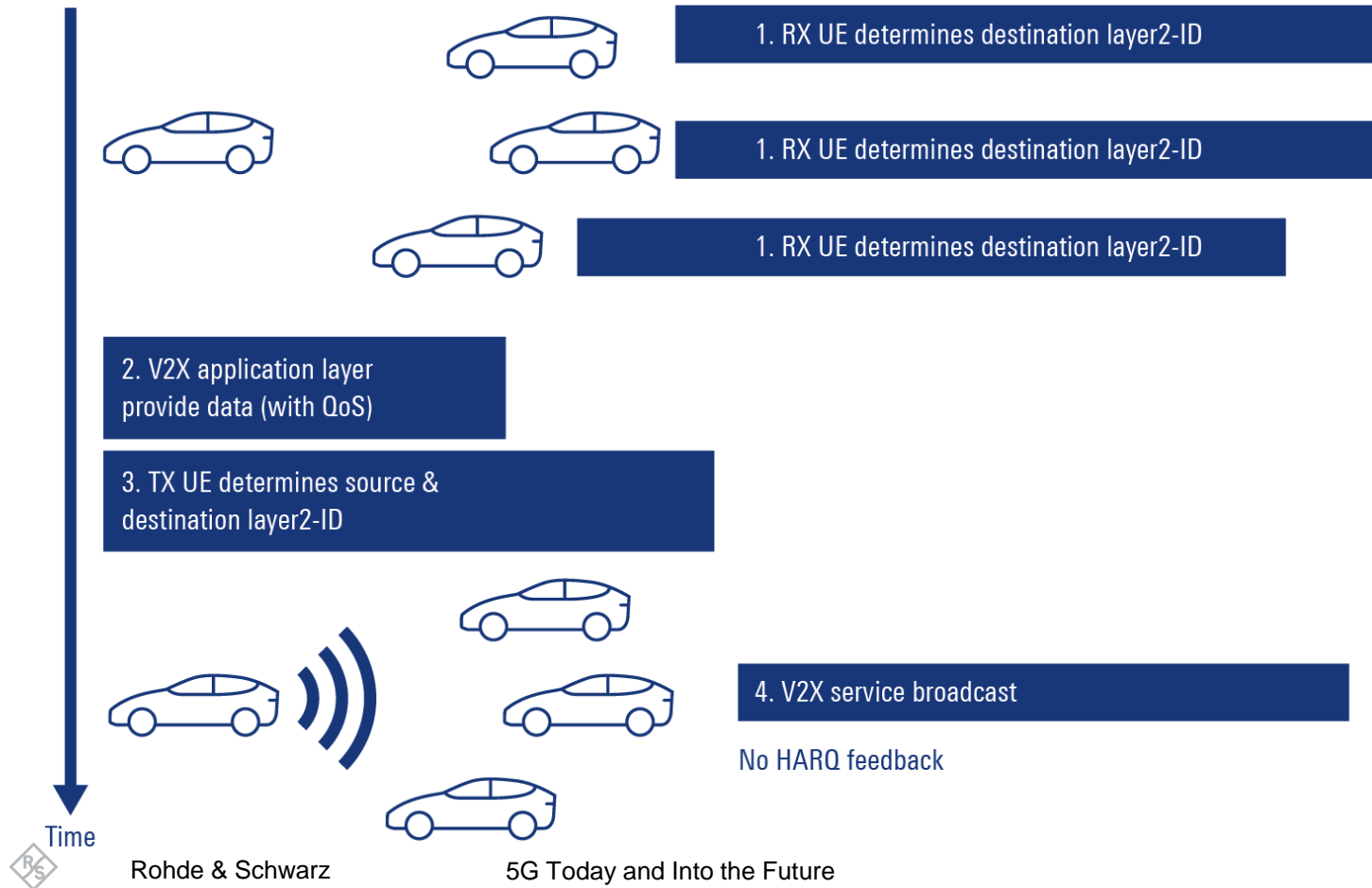
# NR V2X SIDELINK SUPPORTING QoS



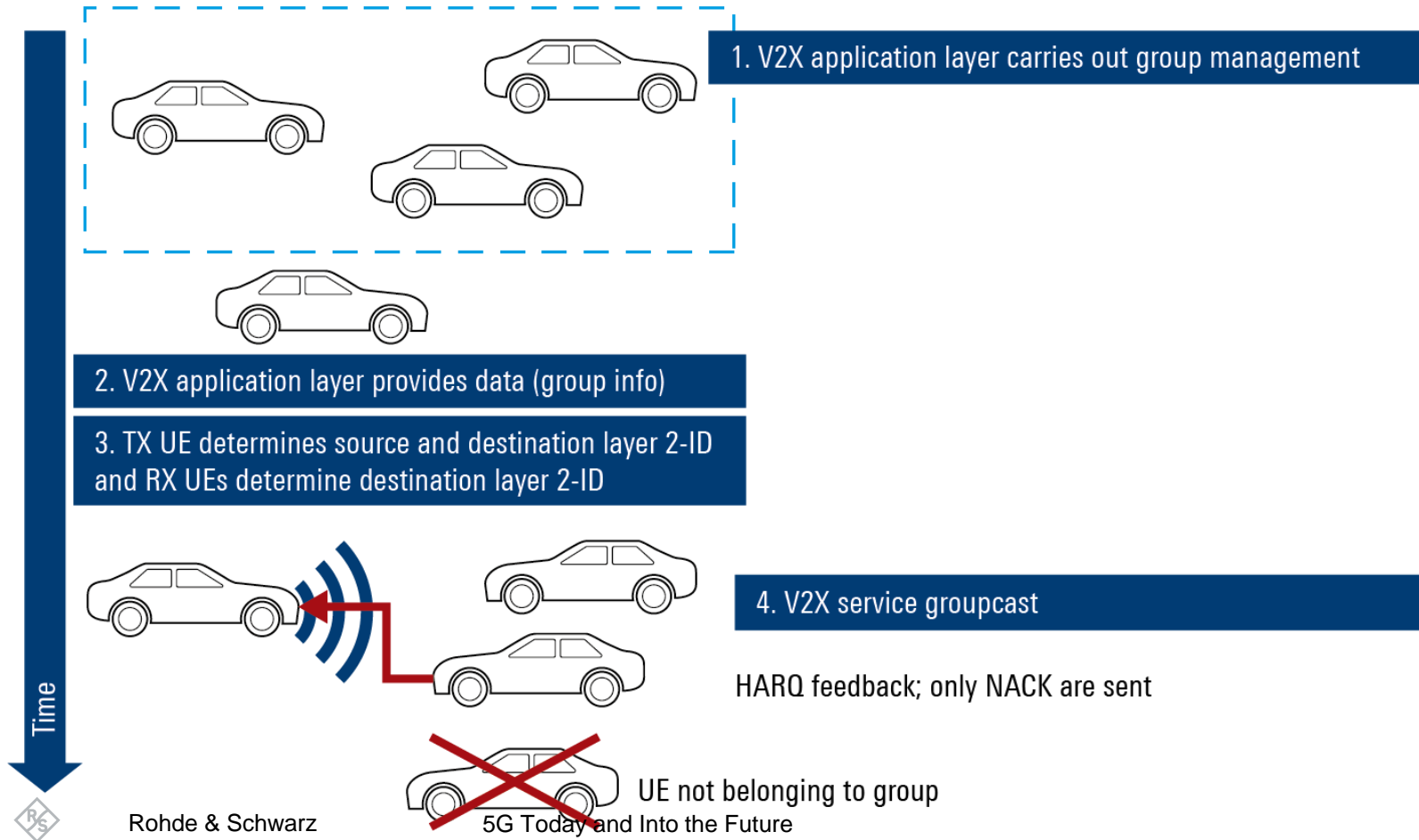
	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Service
21	GBR	3	20 ms	$10^{-4}$	1. N/A	2. 2000 ms	3. Platooning between UEs – Higher degree of automation;
22	(NOTE 1)	4	50 ms	$10^{-2}$	5. N/A	6. 2000 ms	4.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

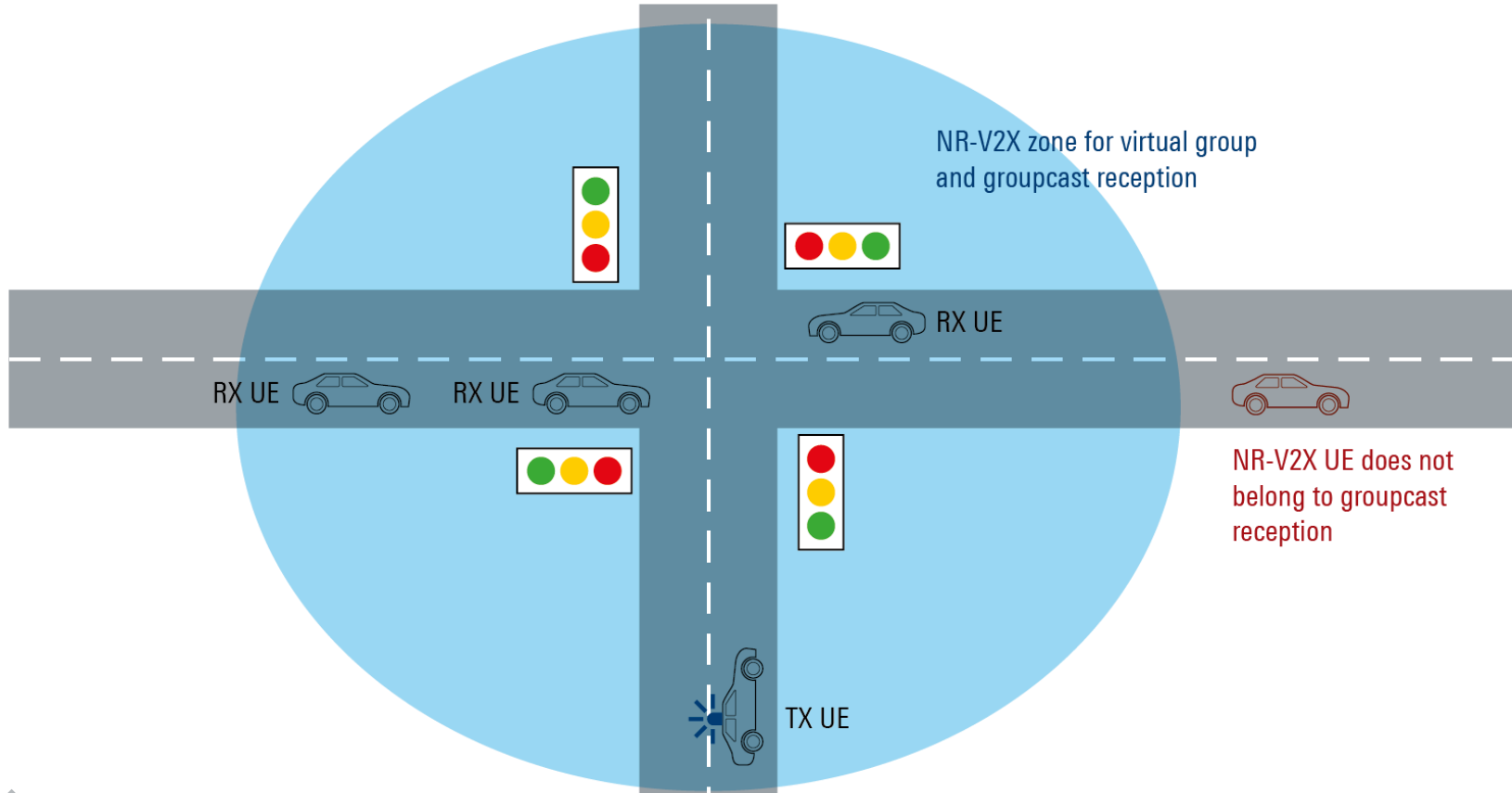
# V2X PC5 INTERFACE PROCEDURE BROADCAST



# V2X PC5 INTERFACE PROCEDURE GROUPCAST

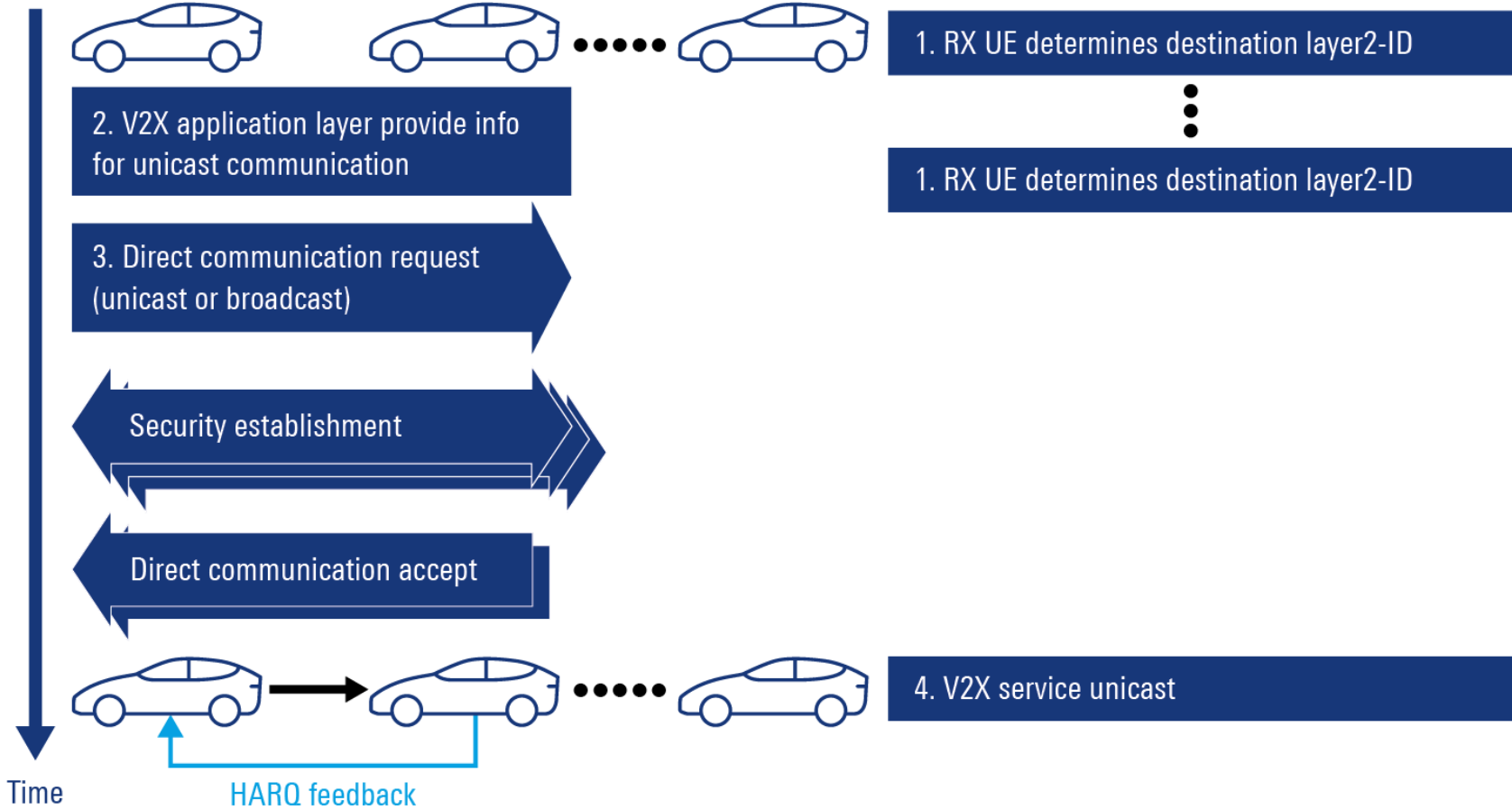


# 5G NR ZONE CONCEPT





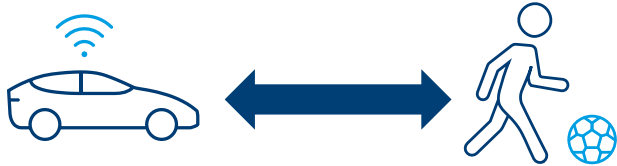
# V2X PC5 INTERFACE PROCEDURE UNICAST



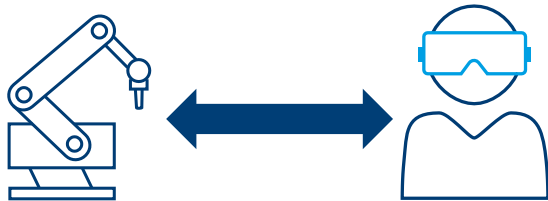
# REL.17 NR SIDELINK ENHANCEMENTS



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)

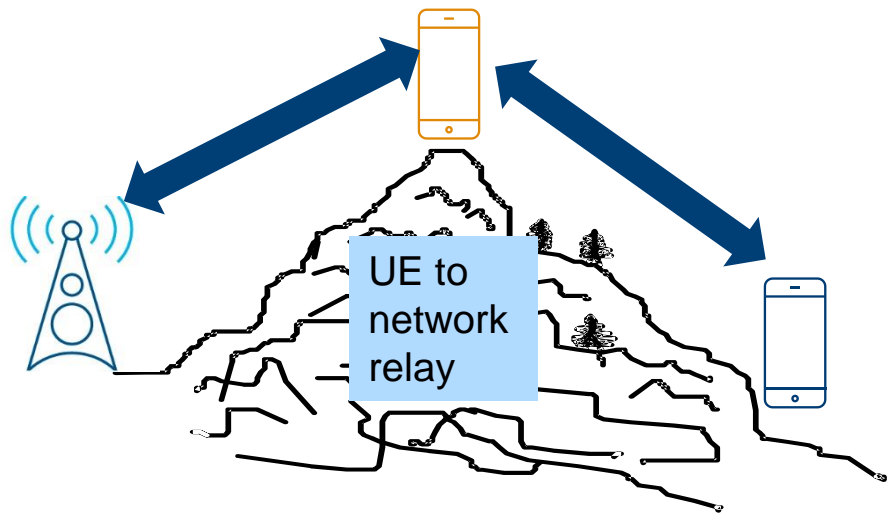


Release 17 sidelink with focus on uRLLC! (reliability & reduced latency, Inter-Ue coordination, new frequency bands: Uu and SL interface in licensed spectrum, SL operation geofencing)

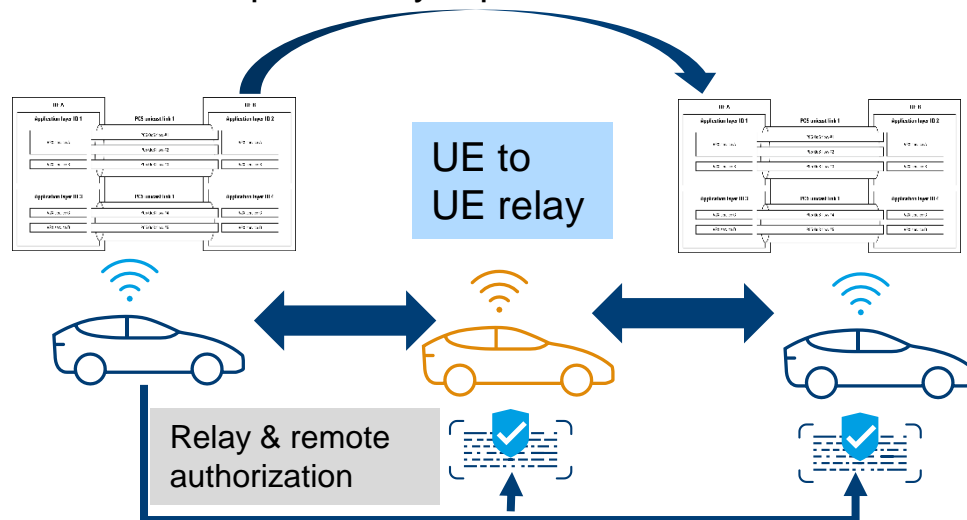


Release 17 sidelink with focus on ProSe! (network controlled interactive services, enhanced relay & coverage)

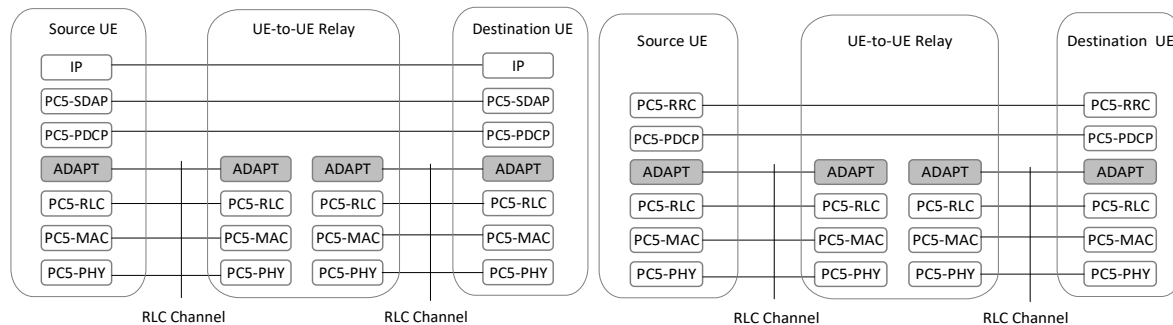
# REL.17 NR RELAY



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



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

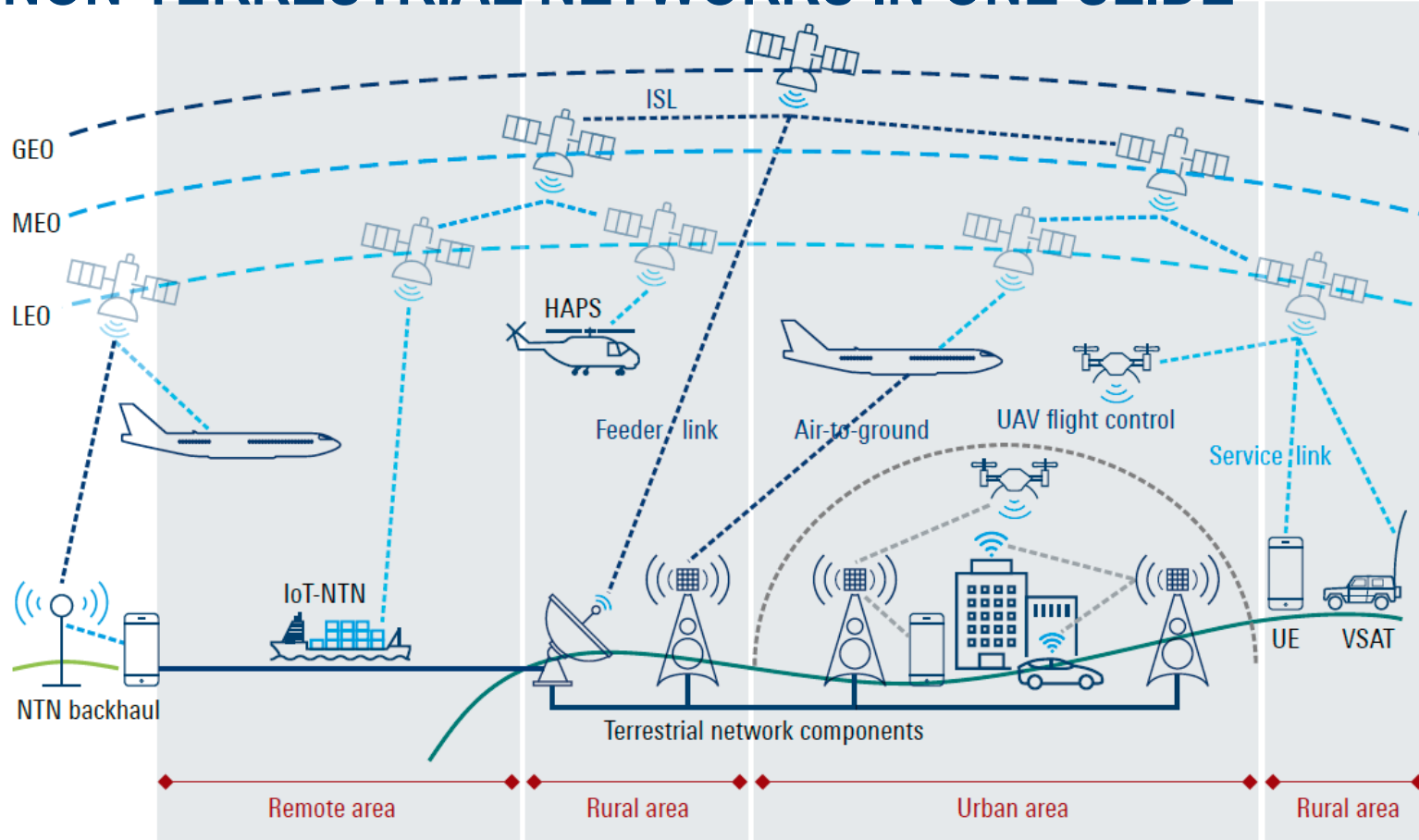




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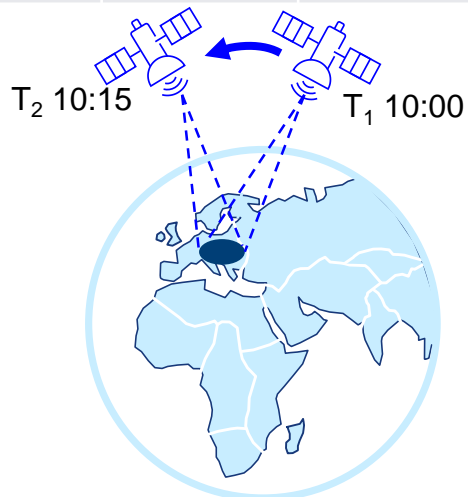
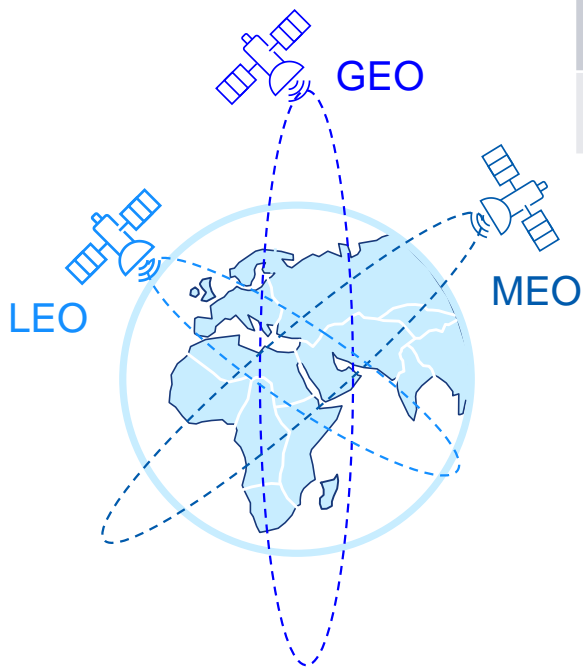
# NON-TERRESTRIAL NETWORKS

# NON-TERRESTRIAL NETWORKS IN ONE SLIDE

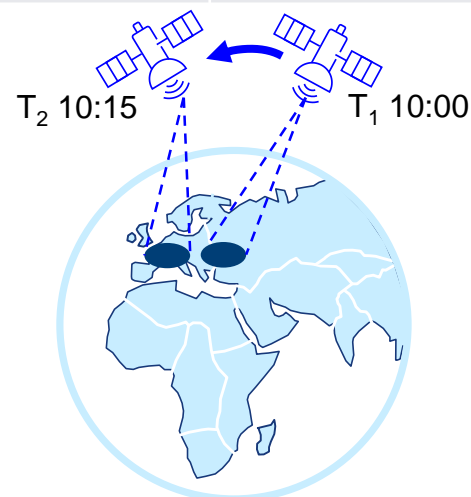


# NTN: CONSTELLATION

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 around the Earth. Not stationary to a given Earth point	100 – 1000 km

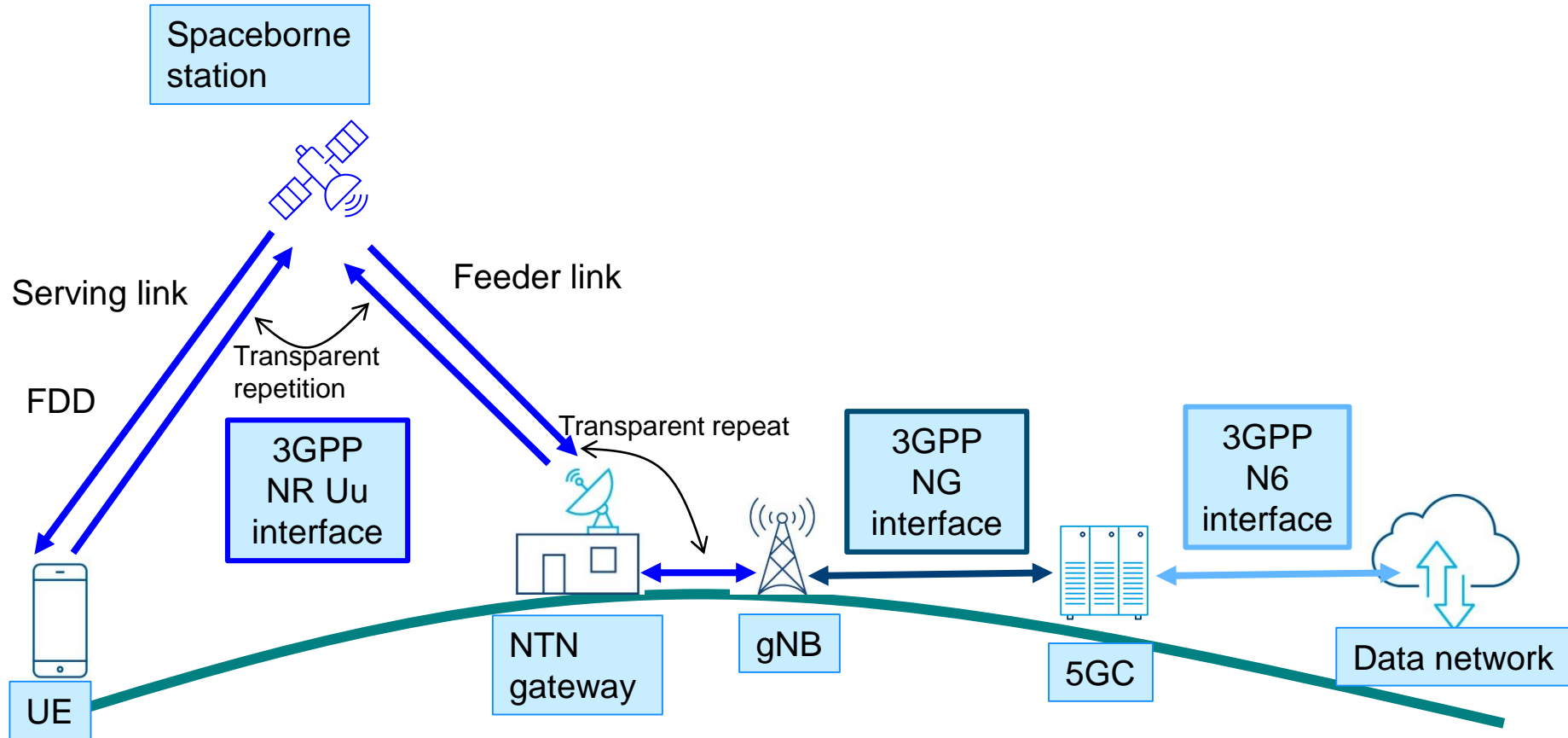


Steerable beams: Fixed with respect to Earth's surface

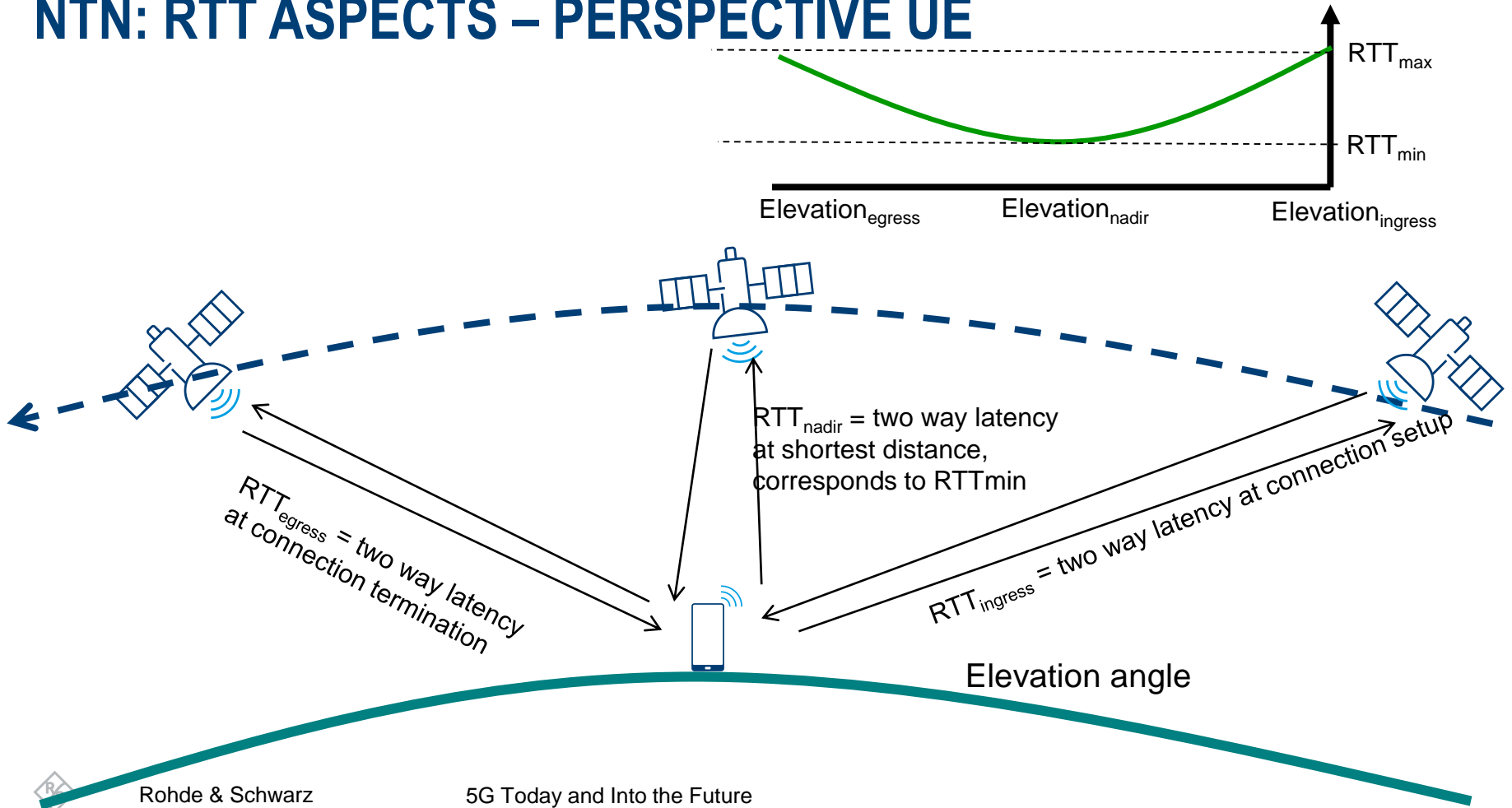


Fixed beams: Moving with respect to Earth's surface

# NTN: TRANSPARENT PAYLOAD ARCHITECTURE

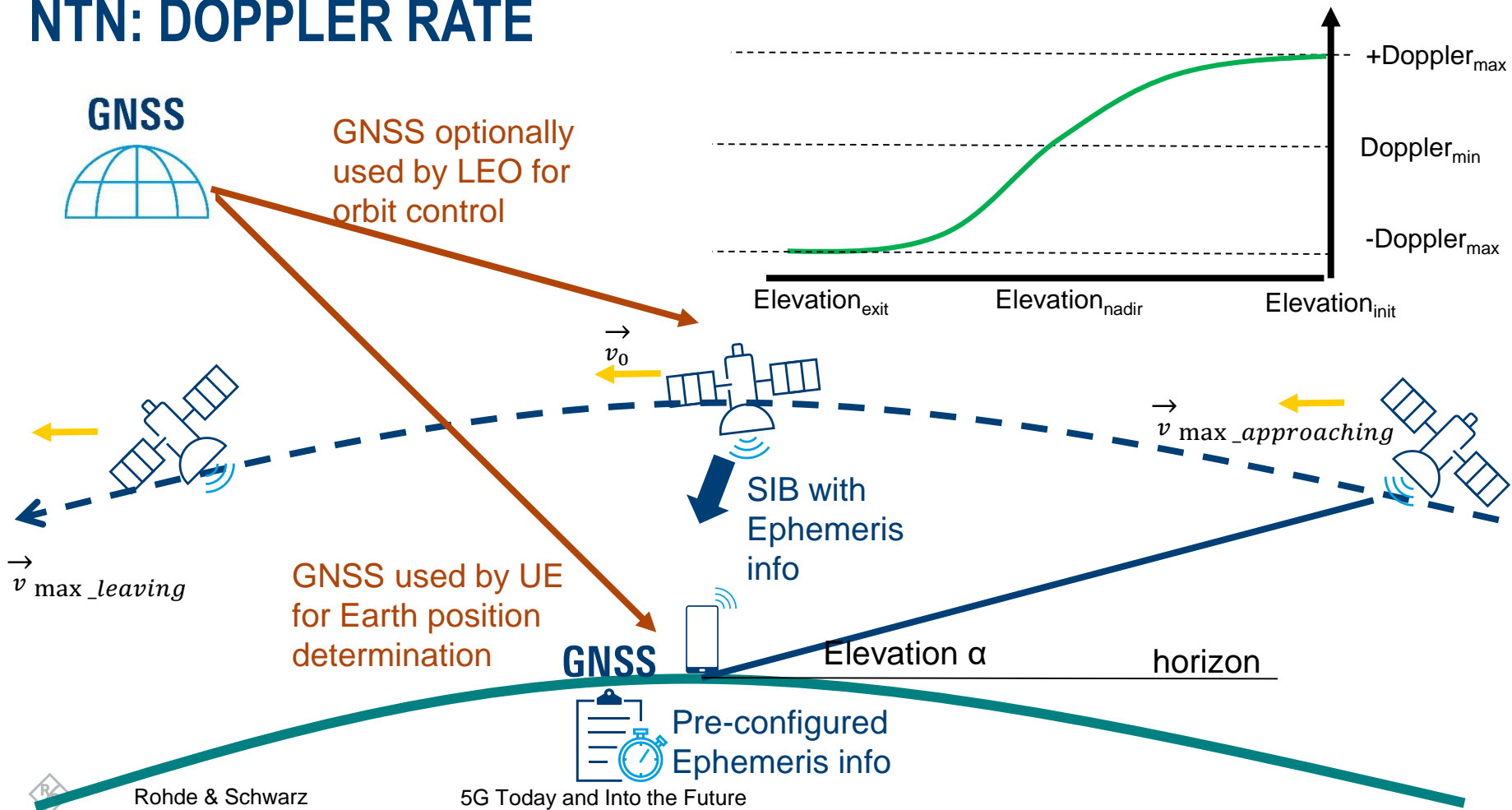


# NTN: RTT ASPECTS – PERSPECTIVE UE

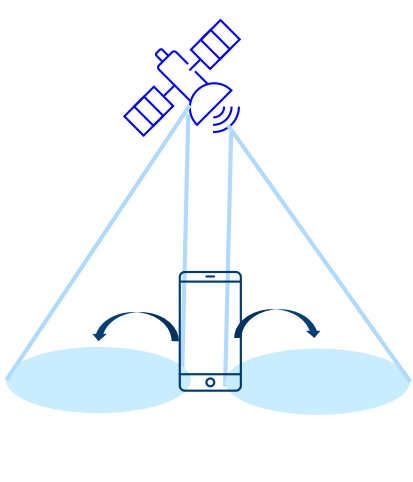




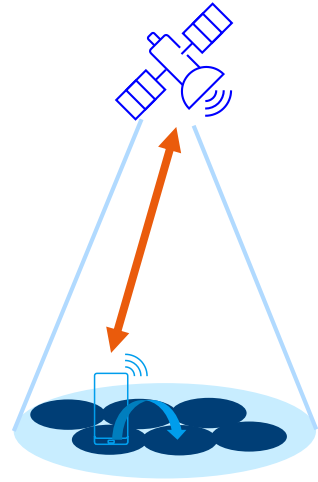
# NTN: DOPPLER RATE



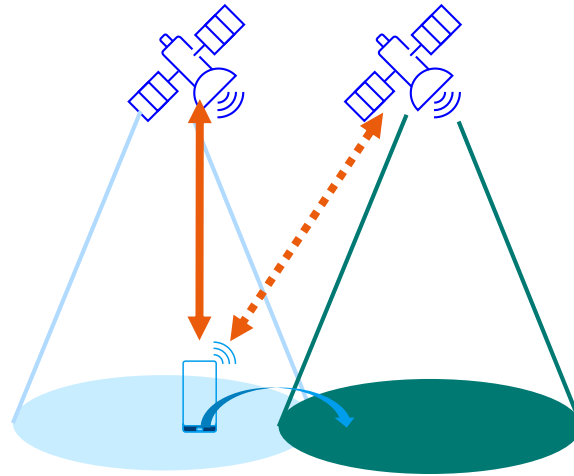
# 5G NTN MOBILITY SCENARIOS



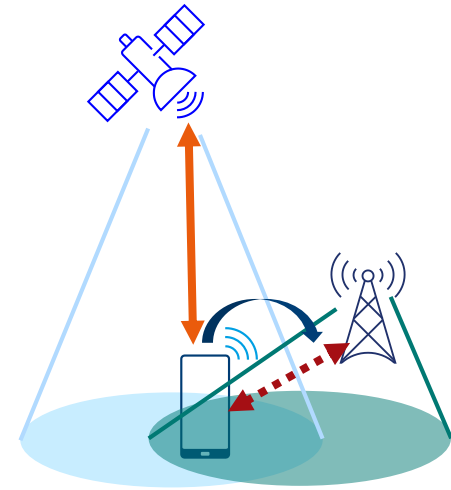
Cell selection /  
cell re-selection



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



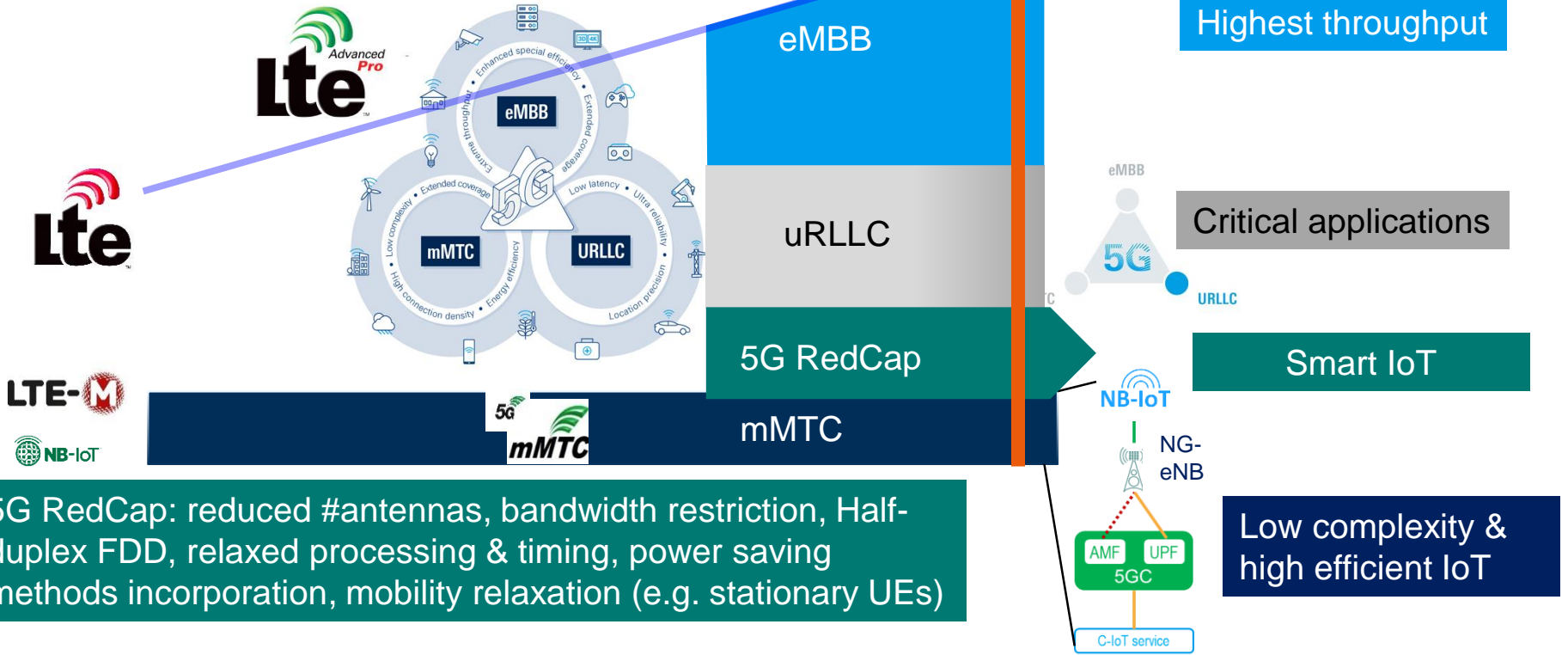




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**REDUCED CAPABILITY (RedCap) + POWER SAVING**

# 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)



# 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.



# 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

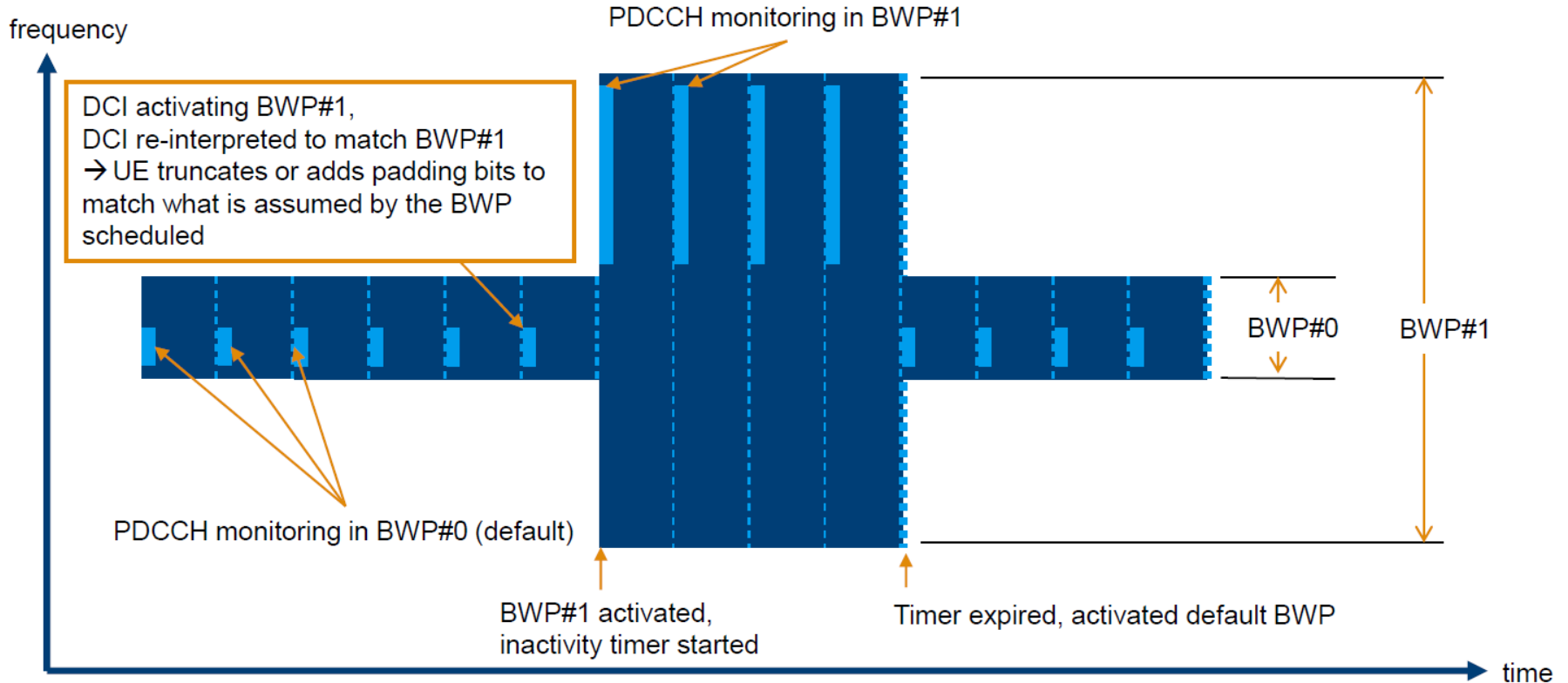
UE assisted power saving methods

RRM measurement relaxation

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



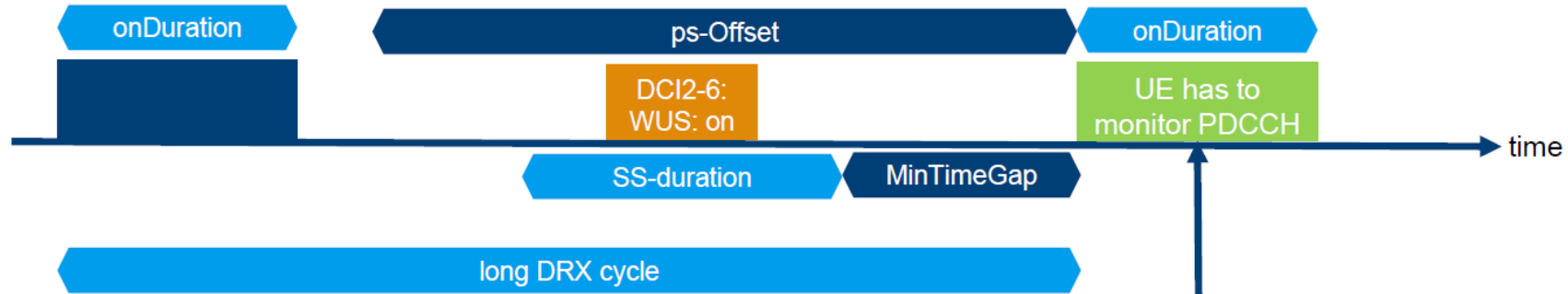
# 5G NR POWER SAVING ASPECTS – BWP SWITCHING



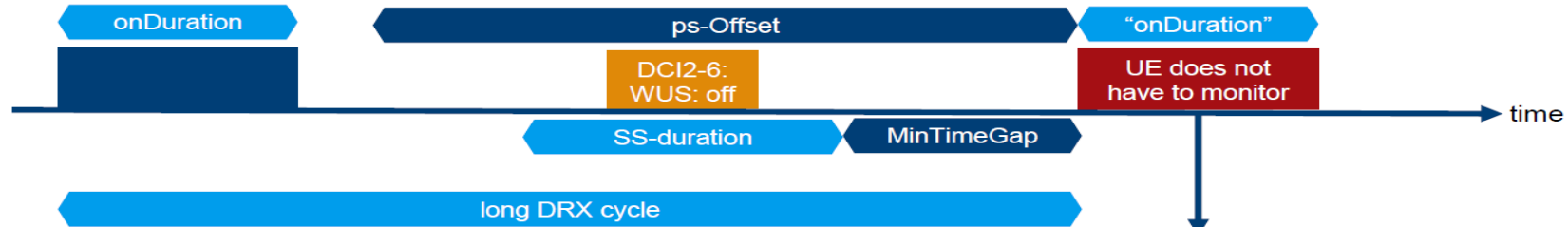
Rel. 15 feature: switching between different BWPs => goal to reduce energy



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

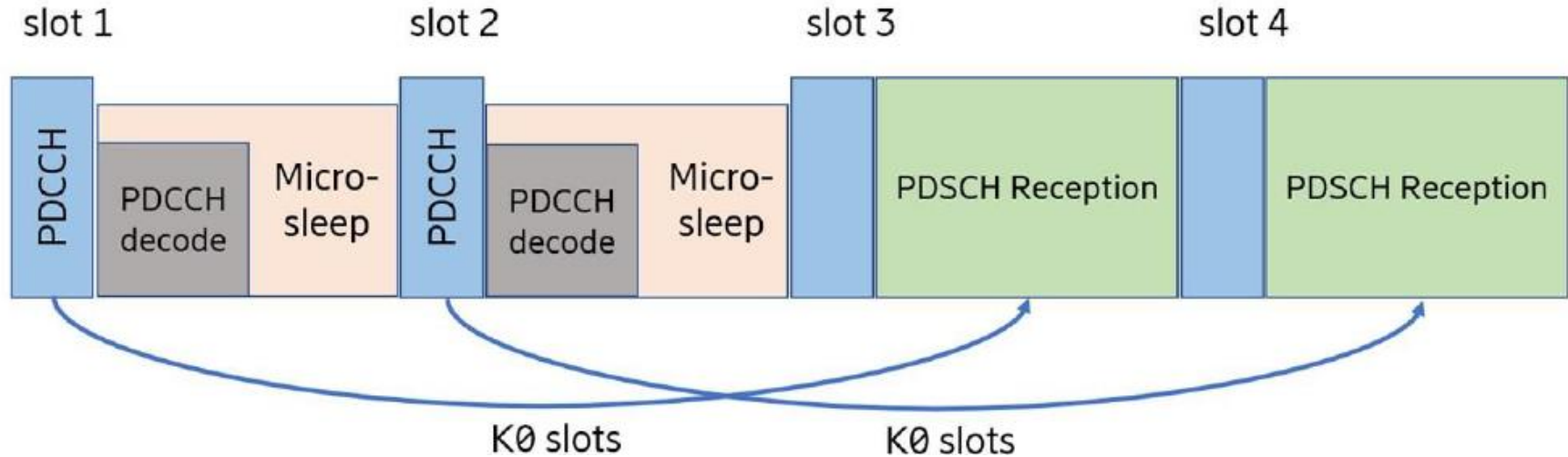


The UE does not monitor PDCCH for detecting DCI format 2\_6 during Active Time



- UE may need to send reports even when *drx-onDurationTimer* doesn't start, to maintain beam management or link adaptation
- UE also may have to perform RRM measurements

# 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

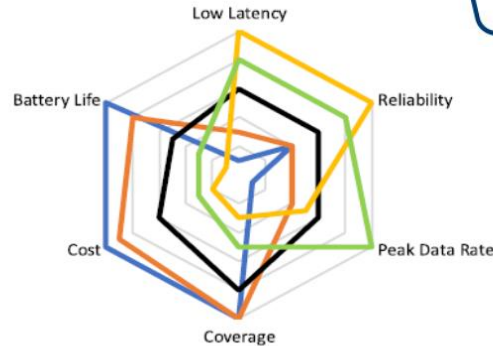
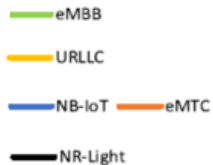
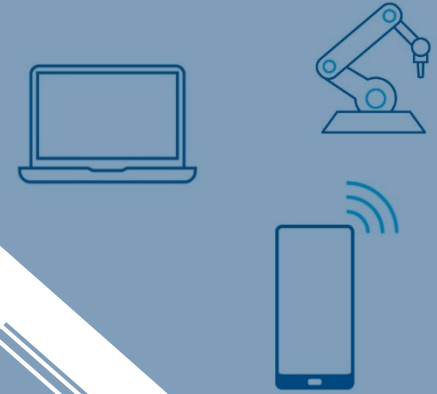
- ▶ **drx-Preference:** UE preference for C-DRX which includes: long/short DRX cycle, DRX inactivity timer, short DRX cycle timer
- ▶ **maxBW-Preference:** UE preference for maximum aggregated bandwidth of the cell group (CG)
- ▶ **maxCC-Preference:** UE preference for max number of SCells of the CG
- ▶ **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

# DEVICE OPTIMIZATION

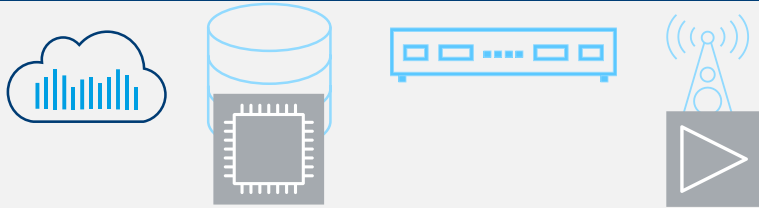
## ► Reduced capability (RedCap)

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



# NETWORK ENERGY EFFICIENCY

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



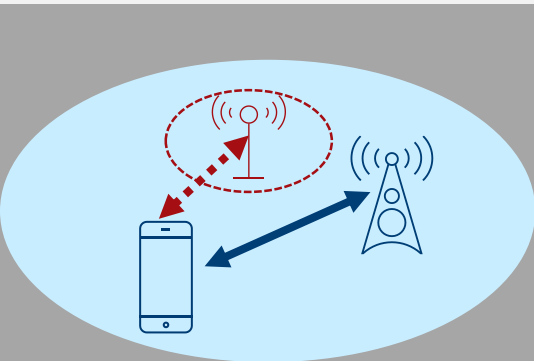
ETSI & 3GPP definition: Energy efficiency

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

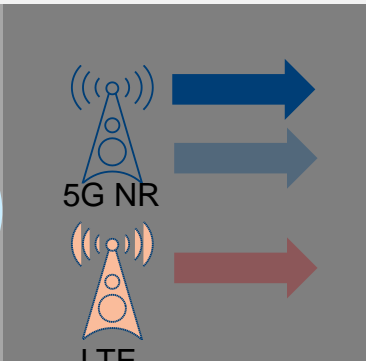
Data volume /  
energy consumption

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

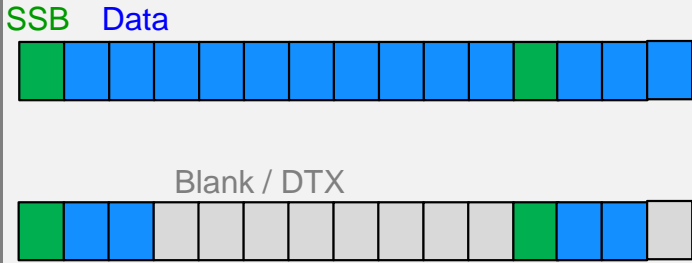
Designated coverage area /  
energy consumption



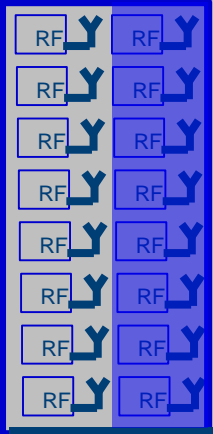
Turn on/off cells



Activate / de-activate  
carriers / RAT



Advanced sleep  
mode (ASM)



Turn  
on/off RF

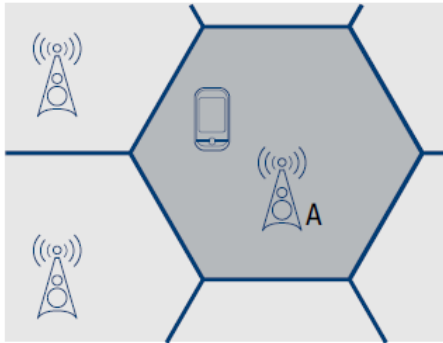
A woman with long dark hair, wearing a light-colored sleeveless top, stands on a balcony at night. She is looking down at her smartphone. The balcony has a glass railing. In the background, there are several tall buildings with lights, including one with a prominent grid of red and white lights. The sky is dark.

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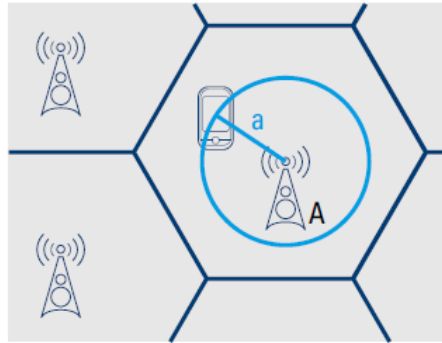
# POSITIONING ENHANCEMENTS

# 5G NR POSITIONING: VARIOUS POSSIBILITIES

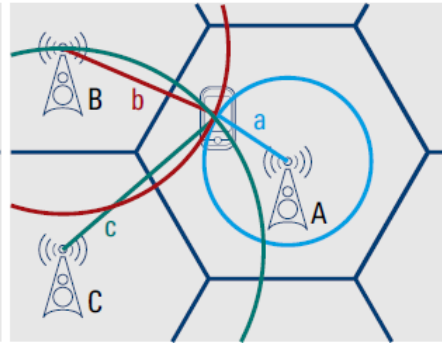
CID



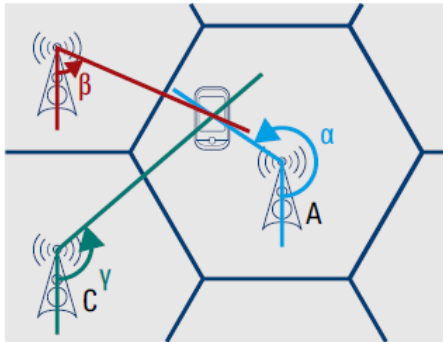
ECID (RSRP/TOA/TADV)



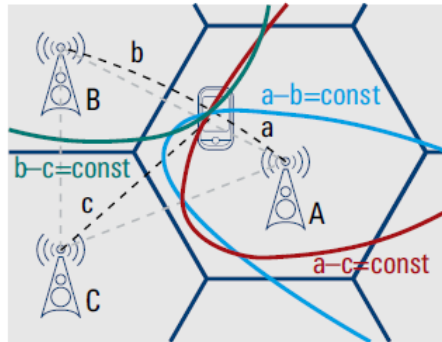
ECID (RSRP/TOA/TADV), (trilateration)



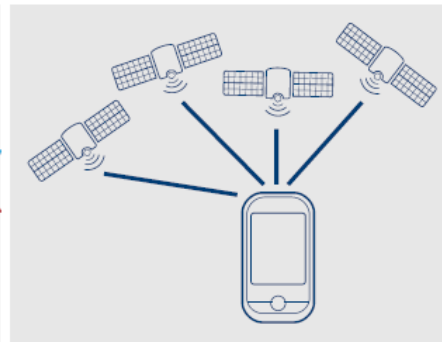
ECID (AOA), (triangulation)



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)

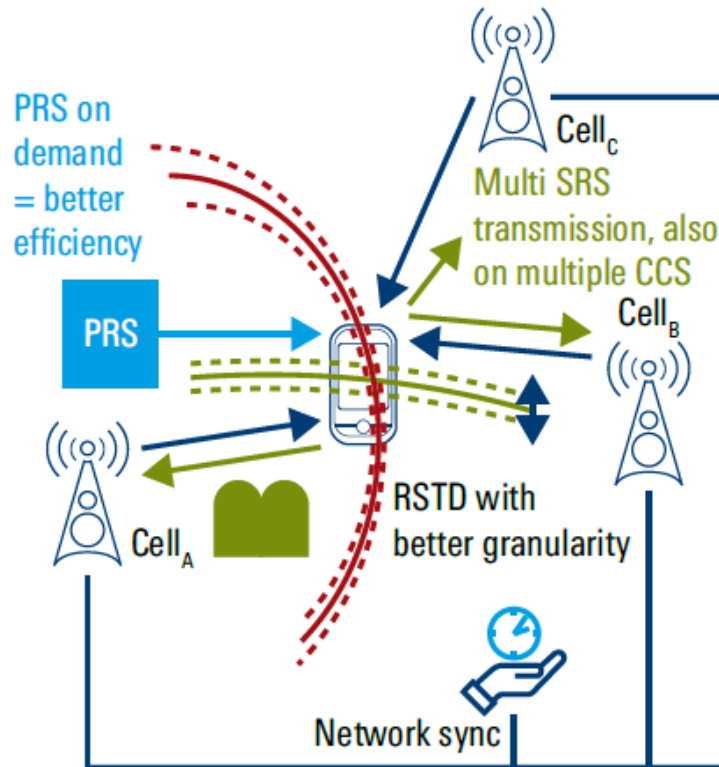
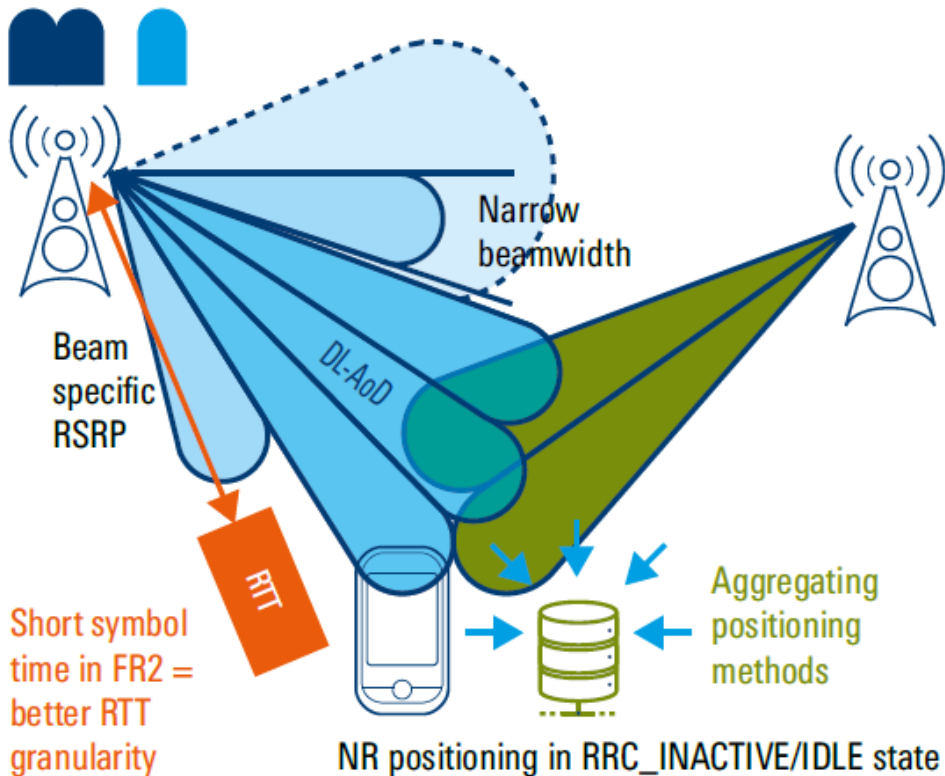
### IIoT use cases:

- 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 ( $< 100$ ms, in the order of 10 ms is desired)
- Physical layer latency for position estimation of UE ( $< 10$ ms)

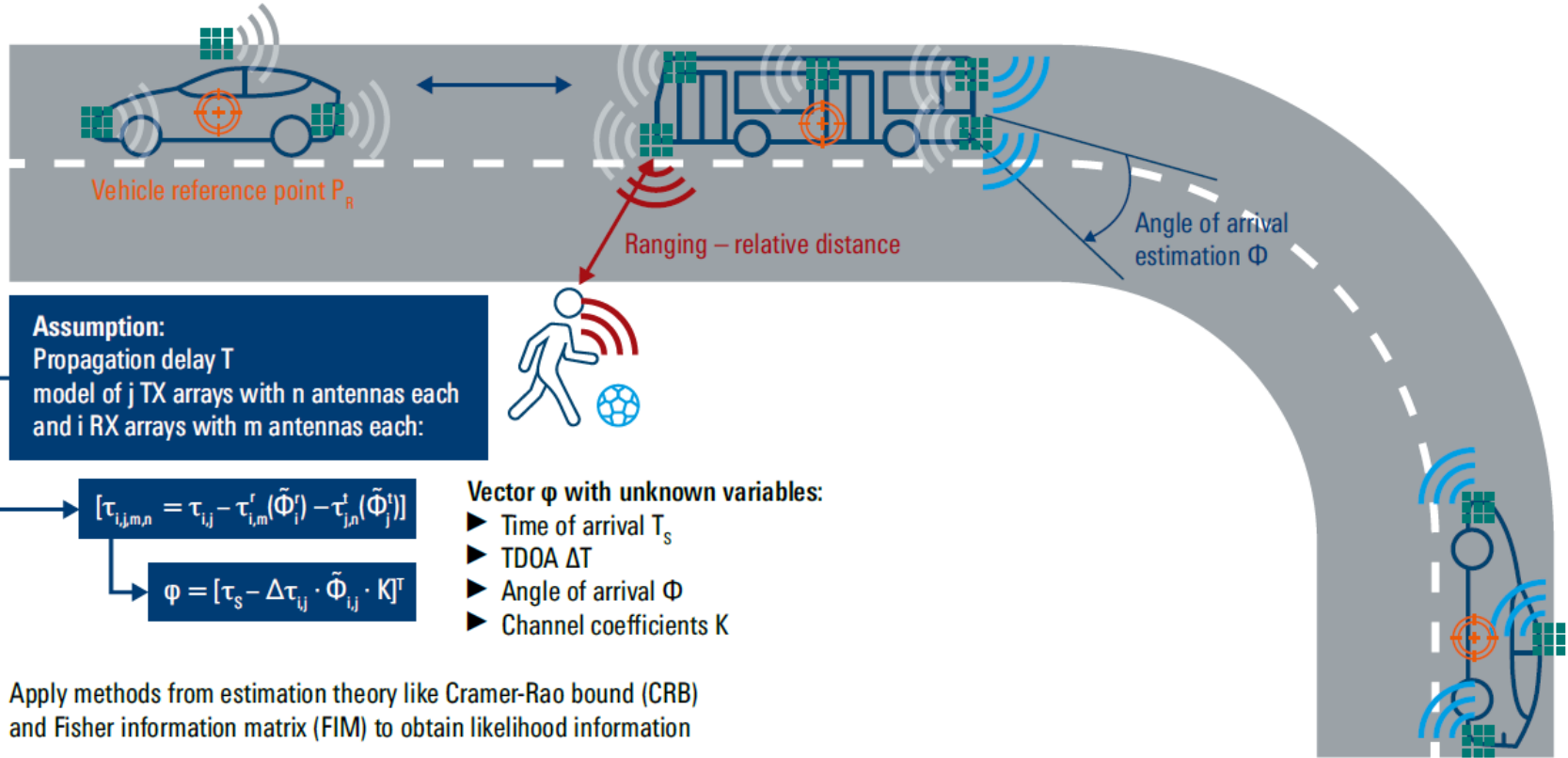


# RELEASE 17 – POSITIONING ENHANCEMENTS

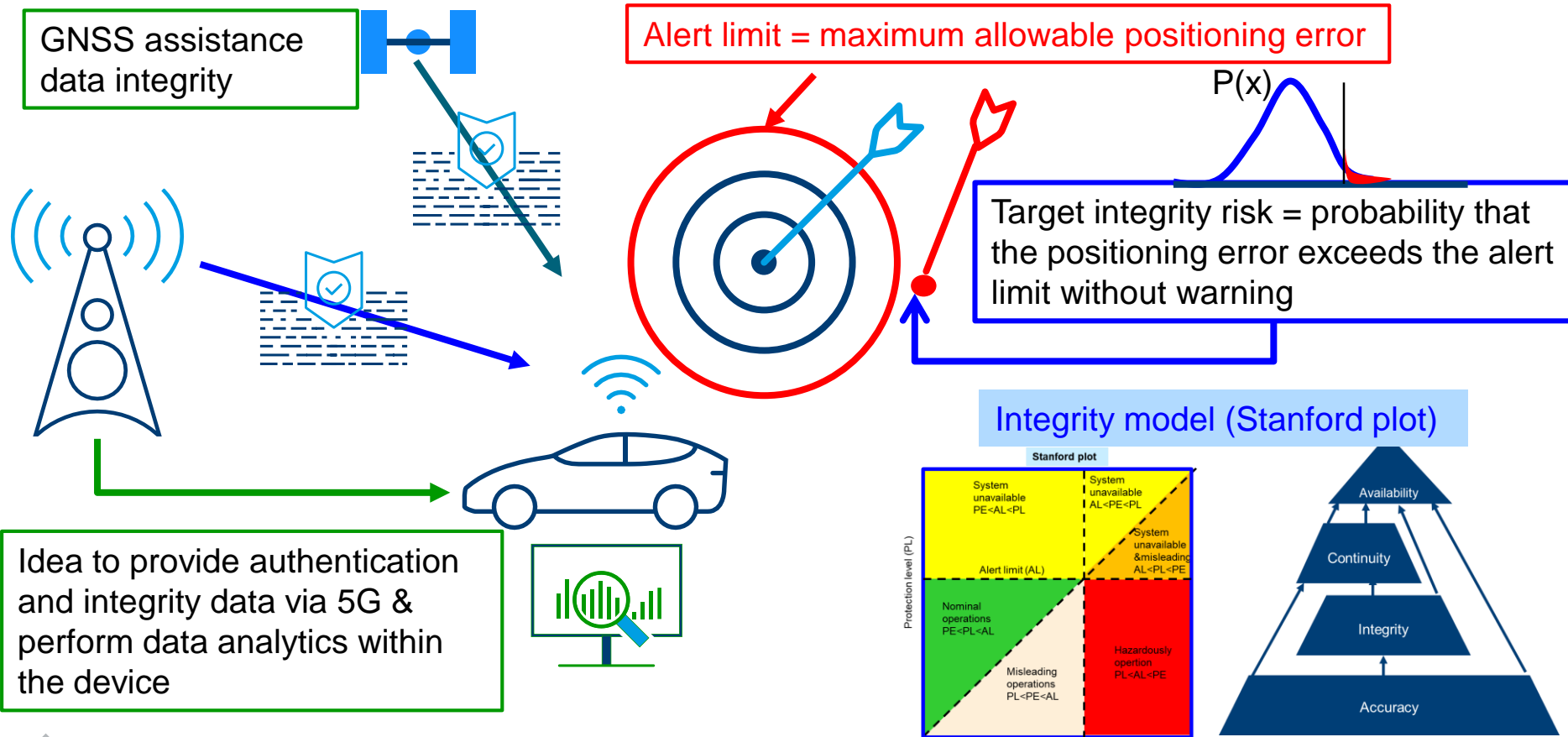
PRS TX and positioning on multiple CCs and multi-band



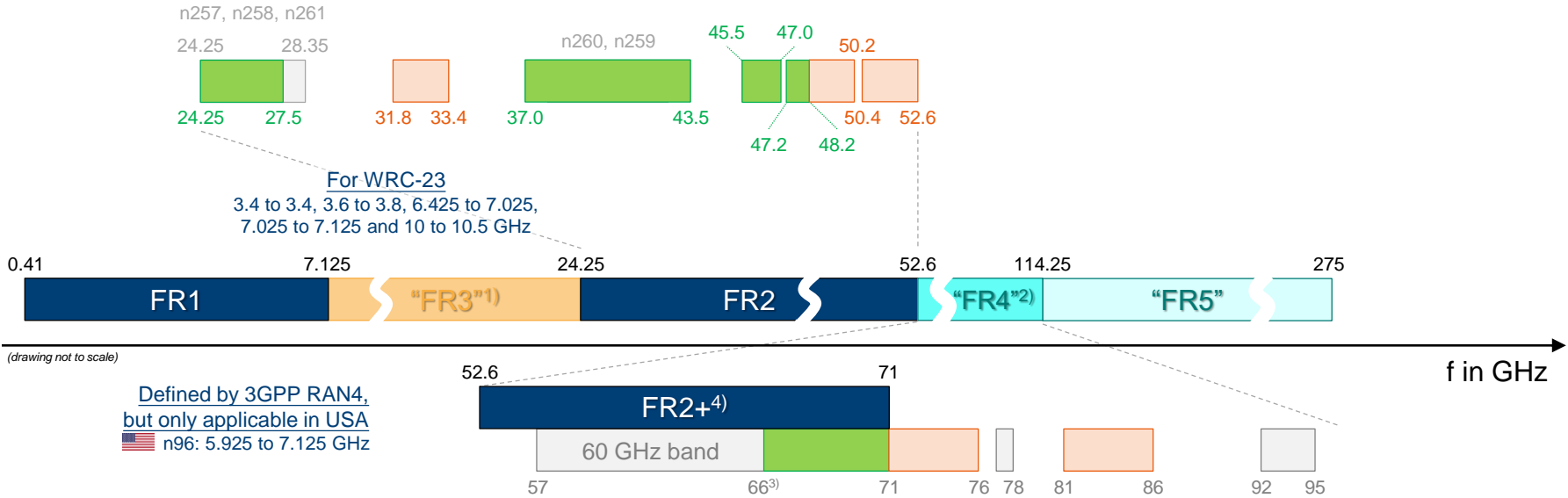
# LBS IN RELEASE 18 – DIFFERENTIAL POSITIONING



# LOCATION-BASED SERVICES IN RELEASE 17 - OUTLOOK



# SPECTRUM FOR 5G NR AND 5G EVOLUTION



■ Successfully identified for IMT at WRC-19  
■ Failed to be identified for IMT at WRC-19

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

<sup>1)</sup> [TR 38.820 V16.0.0 \(2020-07\)](#)

<sup>2)</sup> [TR 38.807 V16.0.0 \(2020-01\)](#)

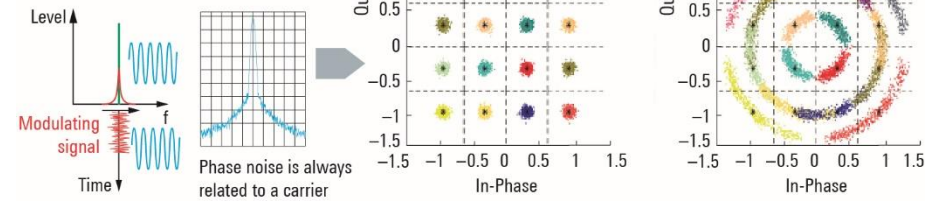
<sup>3)</sup> 64 GHz in USA, Canada

<sup>4)</sup> [TR 38.808 V0.0.1 \(2020-06\)](#)

# EXTENDING CURRENT NR OPERATION TO 71GHz - challenges

## Higher phase noise

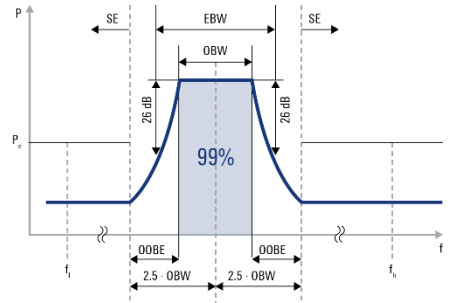
**Definition of phase noise:**  
Phase noise is an unwanted phase modulation of a carrier using white Gaussian noise as a modulating signal.



## PA efficiency



## Spectral efficiency

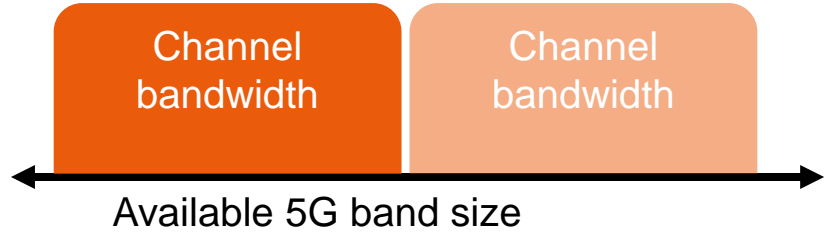


## Friis equation => path attenuation

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

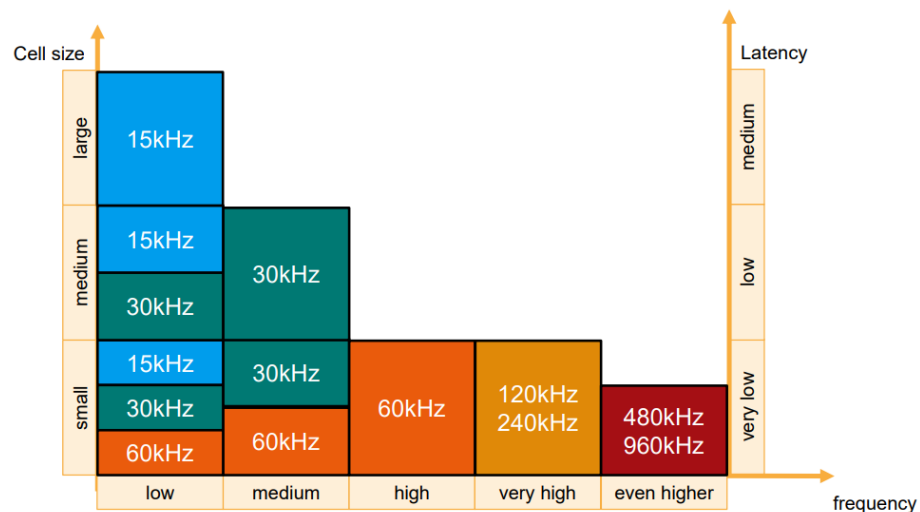
At higher frequencies: Free space path loss is high -> beamforming with high gain

## Larger band size & bandwidth => Licensed & unlicensed bands



# 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

1. Cyclic shift based on a pseudorandom function  $\eta_u$

$$\alpha_l = \frac{2\pi}{N_{SC}^{RB}} ((m_0 + m_{cs} + n_{cs}(\eta_{u,v}^{\mu}, l + l')) \bmod N_{SC}^{RB})$$

2. Low PAPR sequence with group  $u$  and number  $v$ , depending on frequency hopping configuration

$$r_{u,v}^{\alpha,\delta}(n) = e^{j\alpha n} \bar{r}_{u,v}(n), 0 \leq n < M_{ZC}$$

Format 0

$$x(l \cdot N_{SC}^{RB} + n) = r_{u,v}^{\alpha,\delta}(n)$$

$$n = 0, 1, \dots, N_{SC}^{RB} - 1$$

$$l = \begin{cases} 0 & \text{for single-symbol PUCCH transmission} \\ 0, 1 & \text{for double-symbol PUCCH transmission} \end{cases}$$

Format 1 BPSK or QPSK modulated content

$$y(n) = d(0) \cdot r_{u,v}^{\alpha,\delta}(n)$$

$$n = 0, 1, \dots, N_{SC}^{RB} - 1$$

spreading

$$z(m \cdot N_{SF,0}^{PUCCH,1} + m N_{SC}^{RB} + n) = w_i(m) \cdot y(n)$$

$$n = 0, 1, \dots, N_{SC}^{RB} - 1$$

$$m = 0, 1, \dots, N_{SF,m}^{PUCCH,1} - 1$$

$$m = \begin{cases} 0 & \text{no intra-slot frequency hopping} \\ 0, 1 & \text{intra-slot frequency hopping enabled} \end{cases}$$

Format 2

$$\tilde{b}(i) = (b(i) + c(i)) \bmod 2$$

Bit pattern  
Scrambling sequence

Format 3 and 4

$$\tilde{b}(i) = (b(i) + c(i)) \bmod 2$$

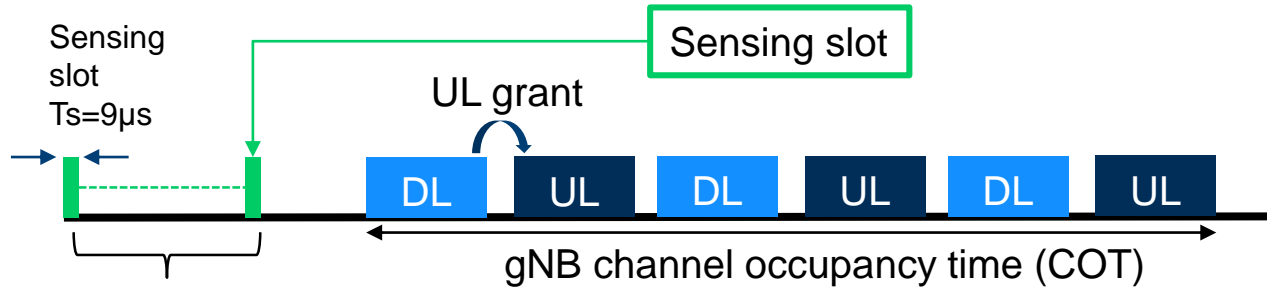
Bit pattern  
Scrambling sequence

$$y(l M_{SC}^{PUCCH,4} + k) = w_i(k) \cdot d \left( l \frac{M_{SC}^{PUCCH,4}}{N_{SF}^{PUCCH,4}} + k \bmod \frac{M_{SC}^{PUCCH,4}}{N_{SF}^{PUCCH,4}} \right)$$

$$k = 0, 1, \dots, M_{SC}^{PUCCH,4} - 1$$

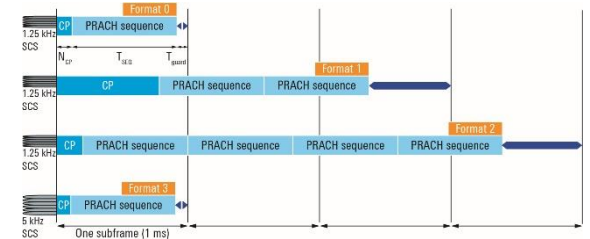
$$l = 0, 1, \dots, (N_{SF}^{PUCCH,4} M_{\text{ymb}} / M_{SC}^{PUCCH,4}) - 1$$

## FR2-2 unlicensed: only dynamic shared mode + LBT



Listen before talk (LBT)

## FR2-2 PRACH: longer sequences for better efficiency

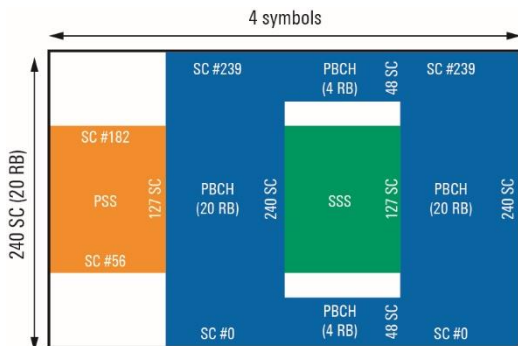


# EXTENDING NR OPERATION TO 71GHz – some details

## FR2-2 study phase: discussions

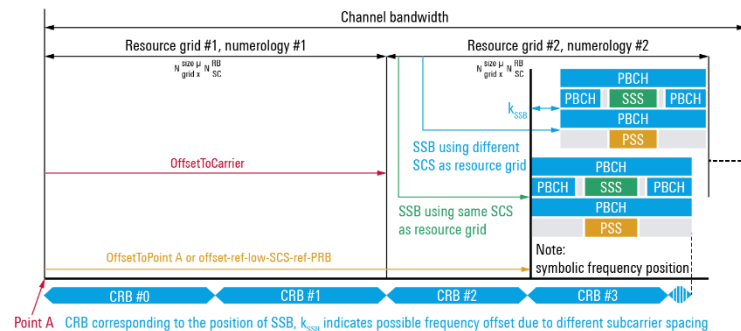
Subcarrier spacing [kHz]	Minimum bandwidths [MHz]	Maximum bandwidths [MHz]
120	50, 400 (Note)	400
480	200	1600
960	400, 2160 (Note)	1600, 2000, 2160, 3200 (Note)

## FR2-2: SSB with wider subcarrier spacing



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

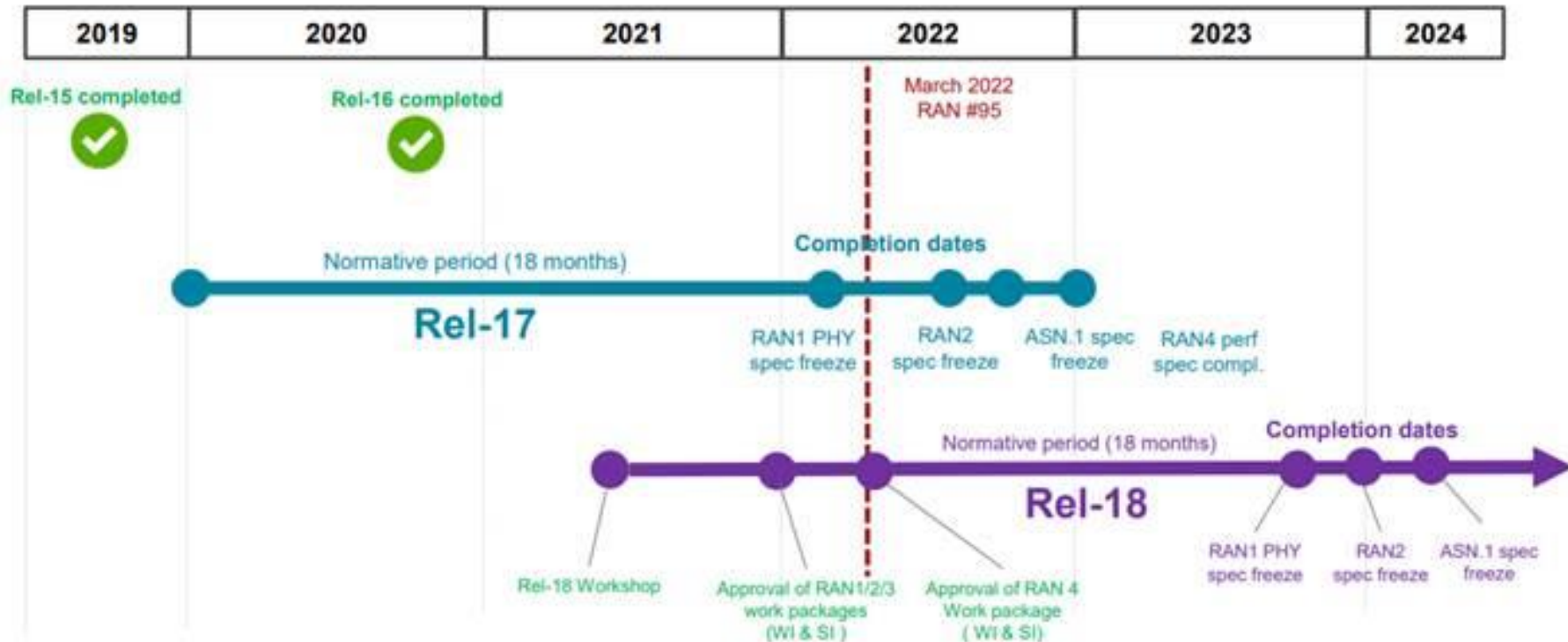
## SSB mixed numerology possible and offset signaling via $k_{SSB}$





# RAN#95 : 3GPP RELEASE SCHEDULE

## MARCH 2022



*"If you want to go fast, go alone.  
If you want to go far, go together!"*

*African proverb*

[www.rohde-schwarz.com/5G](http://www.rohde-schwarz.com/5G)



Rohde & Schwarz

5G Today and Into the Future

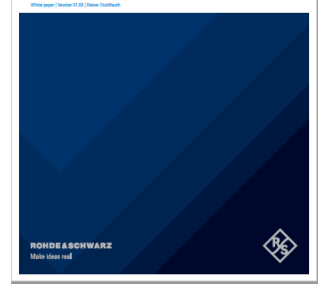
# ADDITIONAL RESOURCES AND WHITEPAPER RELATED TO THE CONTENT OF TODAY'S PRESENTATIONS:

5G technology book online version (>1000 pages on 5G technology):  
[www.rohde-schwarz.com/5G](http://www.rohde-schwarz.com/5G)



[5G Voice over New Radio \(VoNR\) | Rohde & Schwarz \(rohde-schwarz.com\)](http://www.rohde-schwarz.com/5G)

5G VOICE OVER NEW RADIO (VoNR)



[5G Non-terrestrial Networks | Technology Update | Rohde & Schwarz \(rohde-schwarz.com\)](http://www.rohde-schwarz.com/5G)

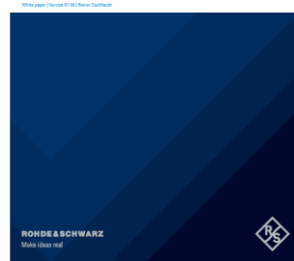
TAKING NEXT STEPS ON NON-TERRESTRIAL NETWORKS AND SATELLITE 5G/loT

Non-terrestrial networks technology from a 3GPP perspective



5G NR-V2X FOR ENHANCED AUTOMOTIVE COMMUNICATIONS

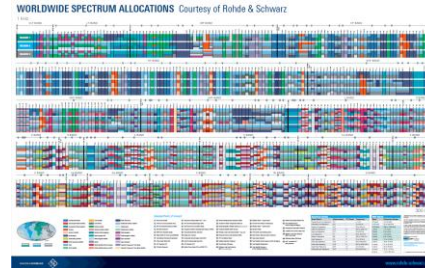
Technology deep dive into architecture, protocols and physical layer aspects



[5G in Automotive | Rohde & Schwarz \(rohde-schwarz.com\)](http://www.rohde-schwarz.com/5G)

[White paper: Positioning in 5G NR | Rohde & Schwarz \(rohde-schwarz.com\)](http://www.rohde-schwarz.com/5G)

POSITIONING IN 5G NR: A LOOK AT THE TECHNOLOGY AND RELATED TEST ASPECTS



## Additional Resources

- [Worldwide Spectrum Allocation Poster \(2020\)](http://www.rohde-schwarz.com/5G)
- [Free "Demystifying 5G NR" poster | Rohde & Schwarz \(rohde-schwarz.com\)](http://www.rohde-schwarz.com/5G)



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