Conformance Test User Meeting 2024

# 5G ADVANCED THE ONGOING EVOLUTION OF 5G
# 6G RESEARCH AREAS

**Reiner Stuhlfauth**
**Technology Management Wireless**

ROHDE&SCHWARZ

Make ideas real

# 5G NR TECHNOLOGY EVOLUTION

5G ADVANCED

| March 2024

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

| June 2022

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

lte lte 4DVANCED lte Advanced Pro

5G ACIA

**5G NR Phase 1**

eMBB

| June 2020

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

5GAA Automotive Association

Security

mMTC

URLLC

| April 2019

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

5G Release 16

Reliability

Latency

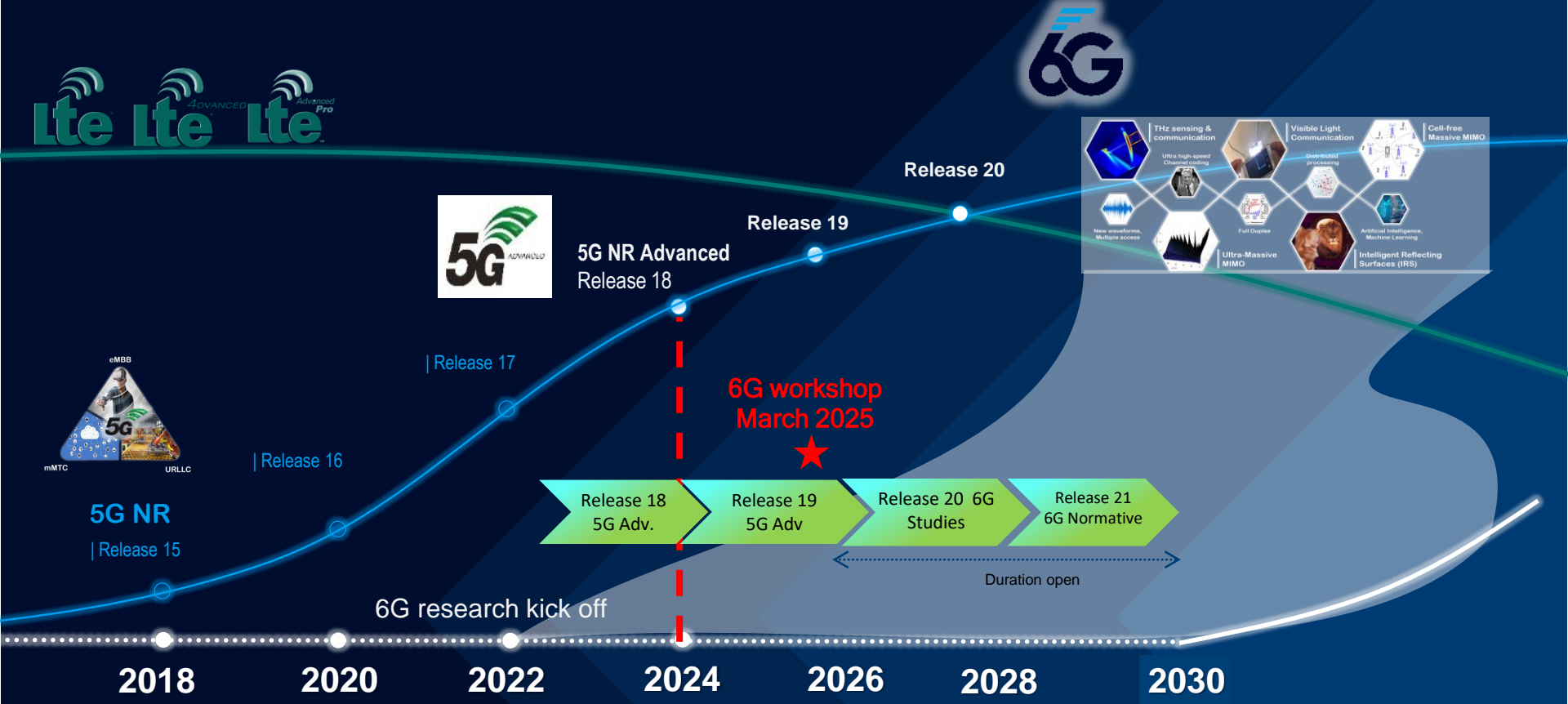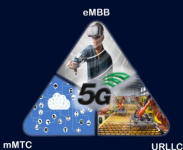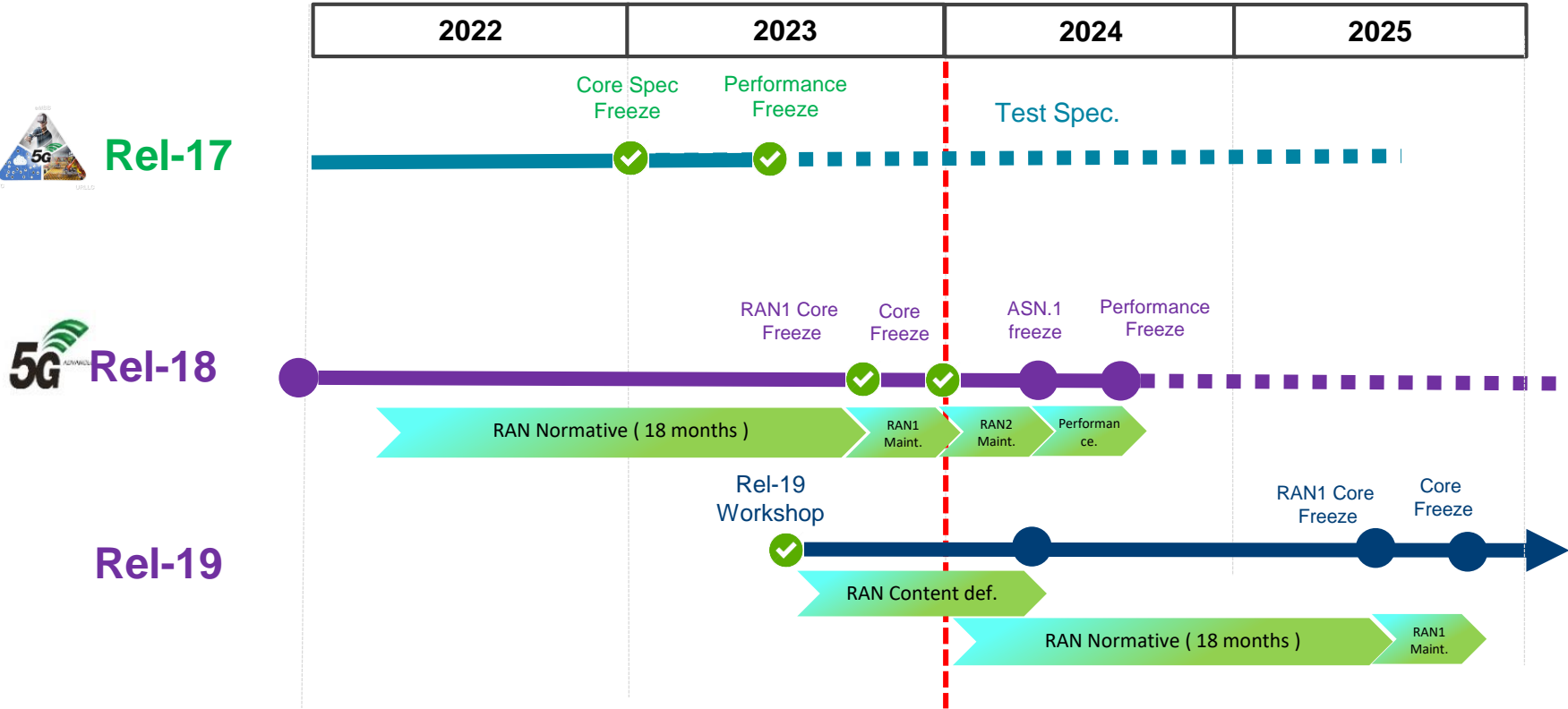5G is a marathon, not a 100 m sprint
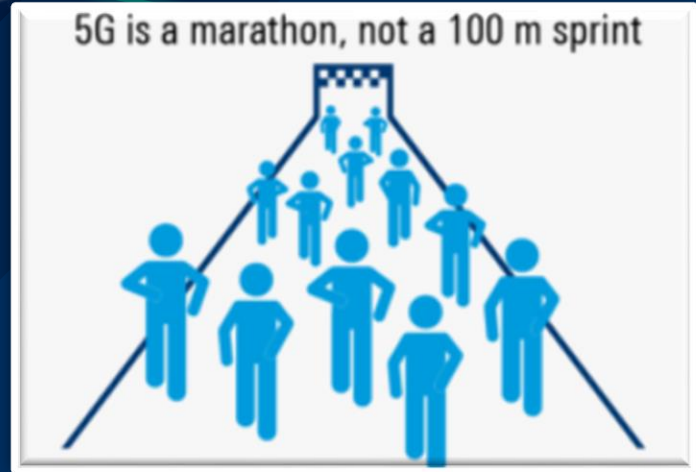
| 2018 | 2020 | 2022 | 2024 | 2026 |

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

# 3GPP 5G ADVANCED EVOLUTION

**5G NR**

| Release 15

| Release 16

| Release 17

**5G NR Advanced**
Release 18

**Release 19**

**Release 20**

**6G workshop
March 2025**
★

6G research kick off

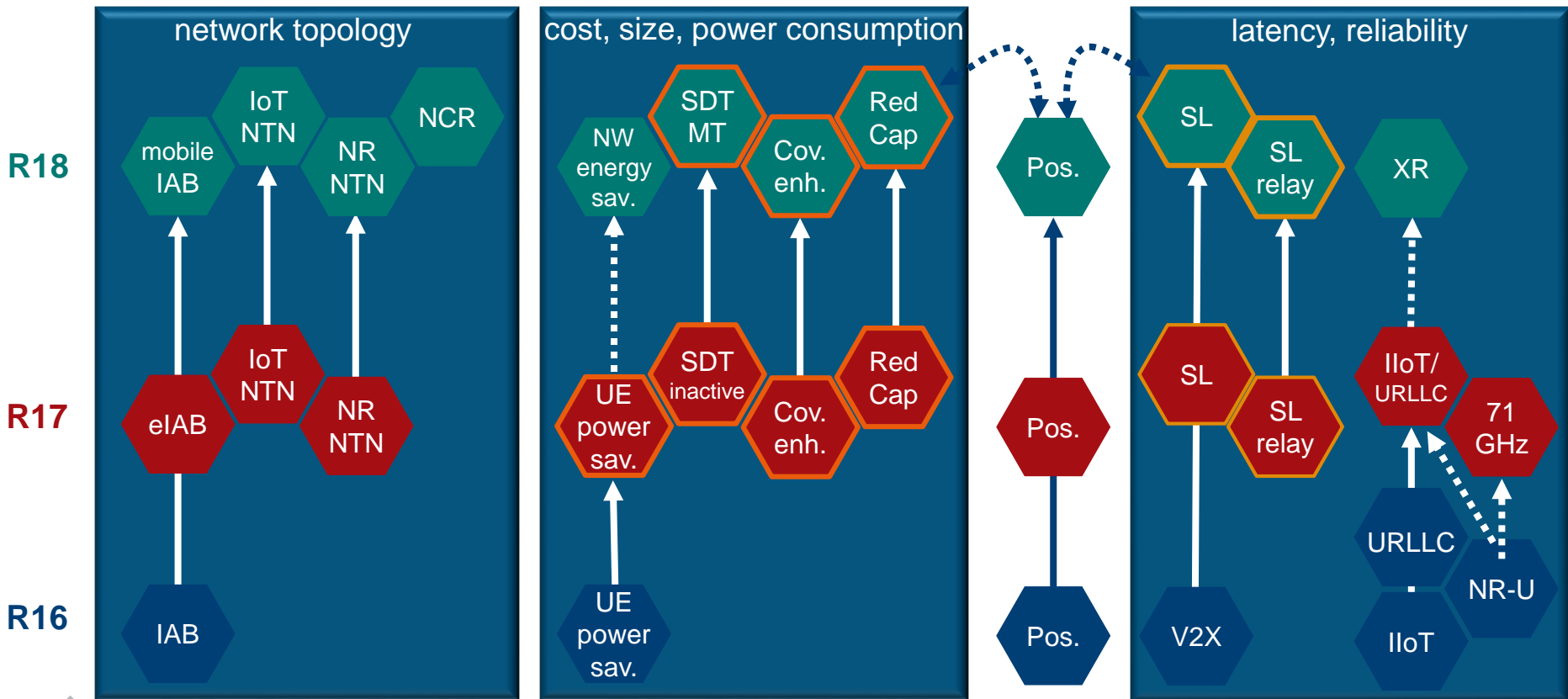| Release 18 5G Adv. | Release 19 5G Adv | Release 20  6G Studies | Release 21 6G Normative |

Duration open

2018     2020     2022     2024     2026     2028     2030

# 3GPP RELEASE SCHEDULE DEC. 2023



| 2022 | 2023 | 2024 | 2025 |
|------|------|------|------|

**Rel-17**
Core Spec Freeze
Performance Freeze
Test Spec.

**Rel-18**
RAN1 Core Freeze
Core Freeze
ASN.1 freeze
Performance Freeze
RAN Normative ( 18 months )
RAN1 Maint.
RAN2 Maint.
Performance.

**Rel-19**
Rel-19 Workshop
RAN1 Core Freeze
Core Freeze
RAN Content def.
RAN Normative ( 18 months )
RAN1 Maint.

RP-233992 Work Plan

5G Advanced Technology Aspects
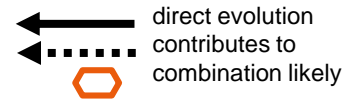
# 3GPP REL-16 TO REL-18 TOPICS AND RELATIONS

direct evolution
contributes to
combination likely



Rohde & Schwarz

5G Advanced Technology Aspects

COMPANY RESTRICTED

# 3GPP REL-16 TO REL-18 TOPICS AND RELATIONS

**Legend:**
- → direct evolution
- ⋯→ contributes to
- ⬡ combination likely

**fundamental**

**R18:** Mob. enh2, MIMO evo, Multi carrier, SON / MDT, eNPN Ph2, eNS Ph3, QoE, DSS, MBS, MU-SIM, UAV, IDC, AI/ML (SI), full duplex (SI), LPWUS (SI)

**R17:** fe MIMO, DC/CA, SON / MDT, eNPN, eNS Ph2, RAN slicing, QoE, DSS, MBS, MU-SIM

**R16:** Mob. enh., eMIMO, DC/CA, SON / MDT, NPN, eNS, 2-step RACH, SRVCC, RACS, CLI& RIM
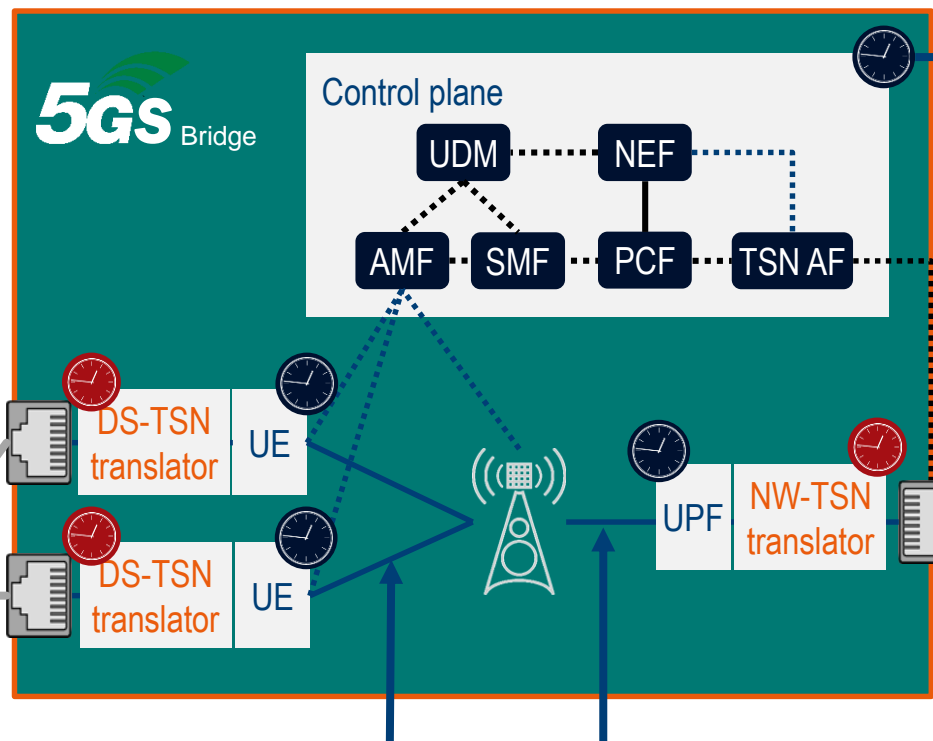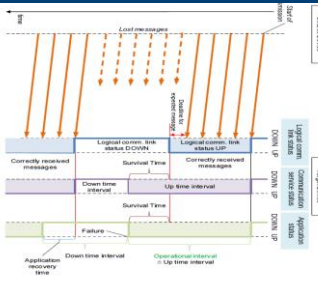
LTE
R15

5G evolution

# INDUSTRIAL IoT & NON-PUBLIC NETWORKS (NPN)

# 5G TIME SENSITIVE NETWORKS (TSN) - INTEGRATION

Deterministic network: 5G measures ingress-egress latency and sync with external networks.



**New KPI: Survival time**

**5G or PTP external as time reference**

**5GS Bridge**

**Control plane**

UDM — NEF

AMF — SMF — PCF — TSN AF

TSN based application

DS-TSN translator — UE

DS-TSN translator — UE

UPF — NW-TSN translator

TSN bridge

TSN based application

TSN bridge

🕐 5GS time synchronization

🕐 TSN time synchronization

**Enhancements on time error budget estimation to reduce uncertainty**
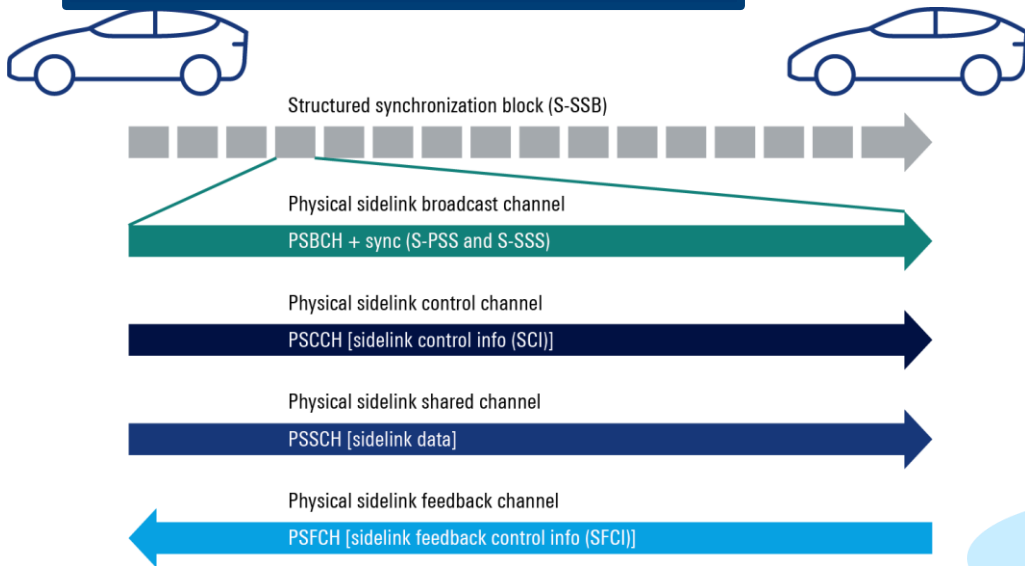
The ongoing evolution of 5G

# NR-V2X: SIDELINK ENHANCEMENTS + RELAY

# 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

Structured synchronization block (S-SSB)

Physical sidelink broadcast channel
PSBCH + sync (S-PSS and S-SSS)

Physical sidelink control channel
PSCCH [sidelink control info (SCI)]

Physical sidelink shared channel
PSSCH [sidelink data]

Physical sidelink feedback channel
PSFCH [sidelink feedback control info (SFCI)]
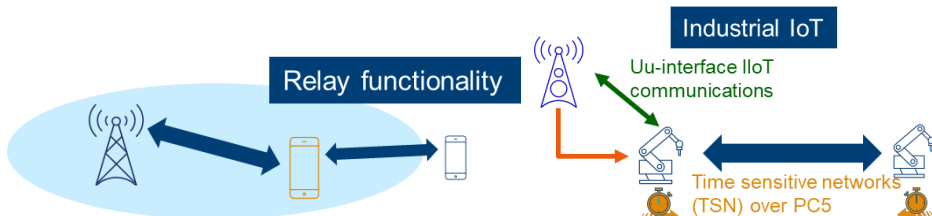
Release 16 sidelink with focus on automotive!

Release 17 sidelink with focus on battery consumption!

Release 17 sidelink with focus on uRLLC!

Release 17 sidelink with focus on public safety!

Industrial IoT

Relay functionality

Uu-interface IIoT communications

Time sensitive networks (TSN) over PC5

The ongoing evolution of 5G

# REDUCED CAPABILITY (RedCap) + POWER SAVING ASPECTS

# 5G NR REDUCED CAPABILITIES - ADVANTAGES

**User:**
New IoT-based services (throughput, latency, QoS support)

Interactivity score (KPI)

3GPP deployments using network slicing
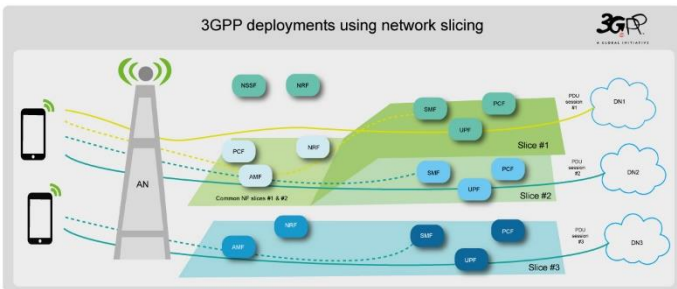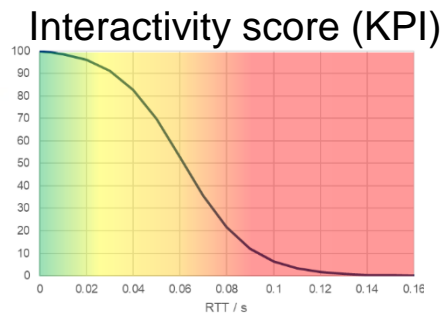
**Operator:**
RedCap is the first pure 5G IoT technology. Connect to 5GC and use additional methods, e.g. network slicing

**Device:**
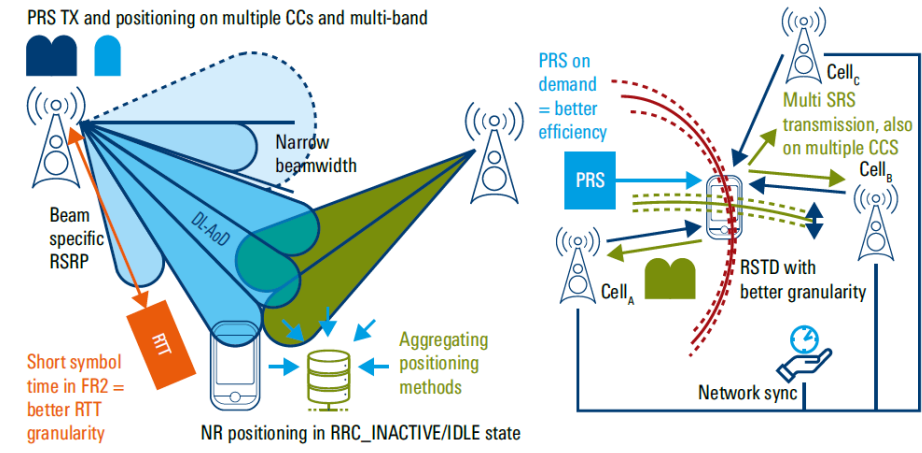Portfolio extension - ranging from mMTC (NB-IoT) via RedCap to high-end IoT devices (IIoT)
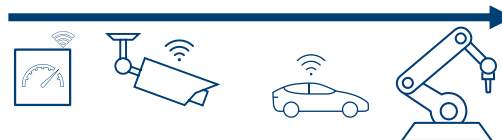
The ongoing evolution of 5G

# POSITIONING ENHANCEMENTS

# POSITIONING METHODOLOGIES - EVOLUTION

**RAT based positioning methodologies**



PRS TX and positioning on multiple CCs and multi-band

Narrow beamwidth

Beam specific RSRP

DL-AoD

RTT

Short symbol time in FR2 = better RTT granularity

NR positioning in RRC_INACTIVE/IDLE state

Aggregating positioning methods

PRS on demand = better efficiency

PRS

Multi SRS transmission, also on multiple CCS

Cell_C

Cell_B

Cell_A

RSTD with better granularity

Network sync

**Enhance accuracy due to hybrid (e.g. GNSS, UWB, Bluetooth)**
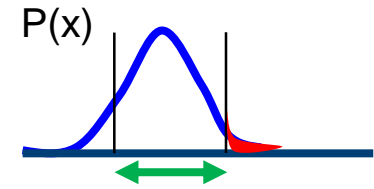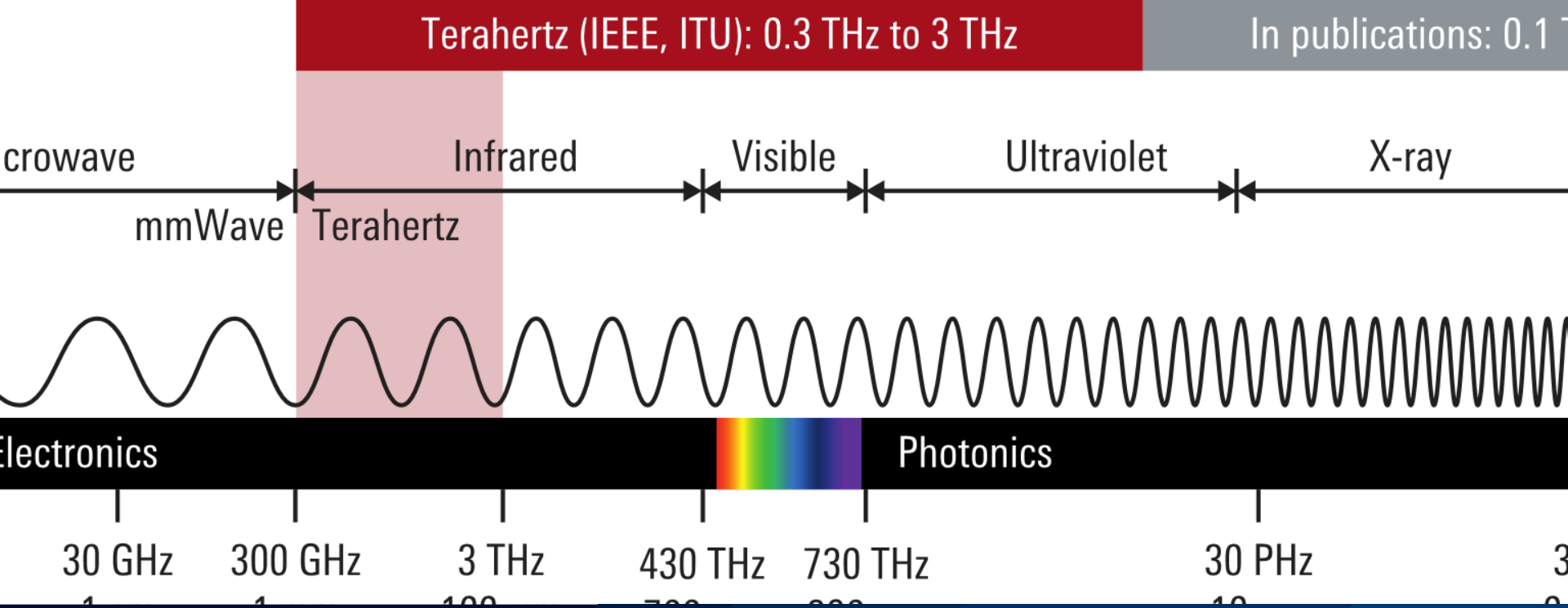
GNSS

UWB ALLIANCE

**Differential positioning, e.g. sidelink RTT and AoD methodologies**



**Positioning integrity & verification (e.g. AI, statistics, two-factor authentication)**

$P(x)$

Confidence interval, mean score, error distribution (sigma)

Rel. 17 => GNSS integrity → Rel. 18 => any RAT integrity → UE or LMF based integrity / Indoor

Terahertz (IEEE, ITU): 0.3 THz to 3 THz

In publications: 0.1 T

crowave          Infrared          Visible          Ultraviolet          X-ray

mmWave   Terahertz

Electronics                                        Photonics

30 GHz      300 GHz      3 THz      430 THz      730 THz              30 PHz
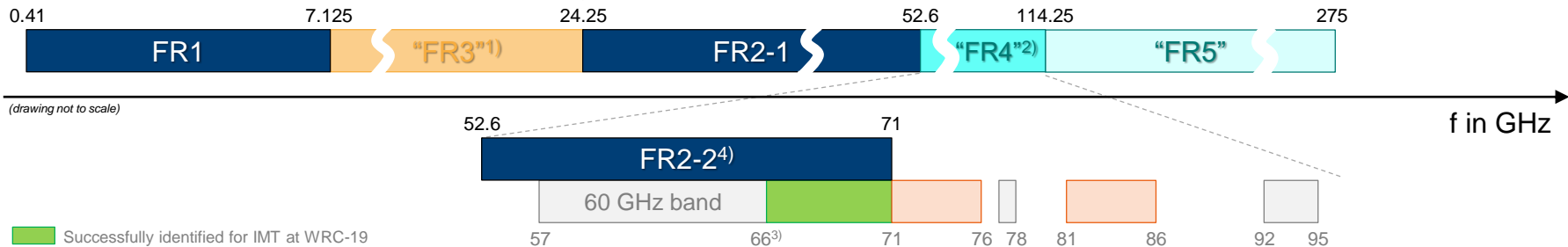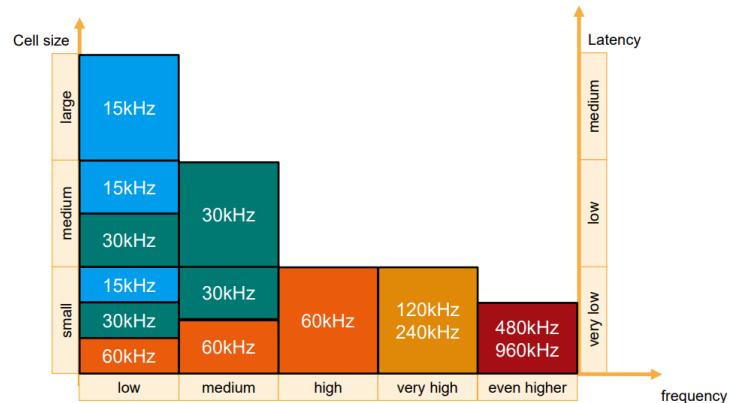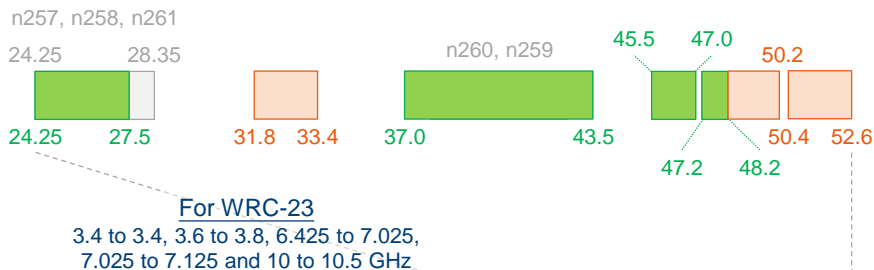
The ongoing evolution of 5G

# EXTENSION OF FREQUENCY RANGE 2: FR2-2

# SPECTRUM FOR 5G NR AND 5G ADVANCED

| 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 | | | | |

n257, n258, n261

24.25   28.35

n260, n259

45.5   47.0

50.2

24.25   27.5

31.8   33.4

37.0   43.5

47.2   48.2

50.4   52.6

For WRC-23
3.4 to 3.4, 3.6 to 3.8, 6.425 to 7.025,
7.025 to 7.125 and 10 to 10.5 GHz

0.41    7.125    24.25    52.6    114.25    275

| FR1 | "FR3"[1)] | FR2-1 | "FR4"[2)] | "FR5" |

*(drawing not to scale)*

f in GHz

52.6    71

| FR2-2[4)] |

60 GHz band

57    66[3)]    71    76   78    81    86    92   95

Cell size

| 15kHz | | | | |
| 15kHz | 30kHz | | | |
| 30kHz | | | | |
| 15kHz | 30kHz | | | |
| 30kHz | | 60kHz | 120kHz 240kHz | 480kHz 960kHz |
| 60kHz | 60kHz | | | |

low   medium   high   very high   even higher

frequency

Latency

medium

low

very low

■ Successfully identified for IMT at WRC-19

□ Failed to be identified for IMT at WRC-19

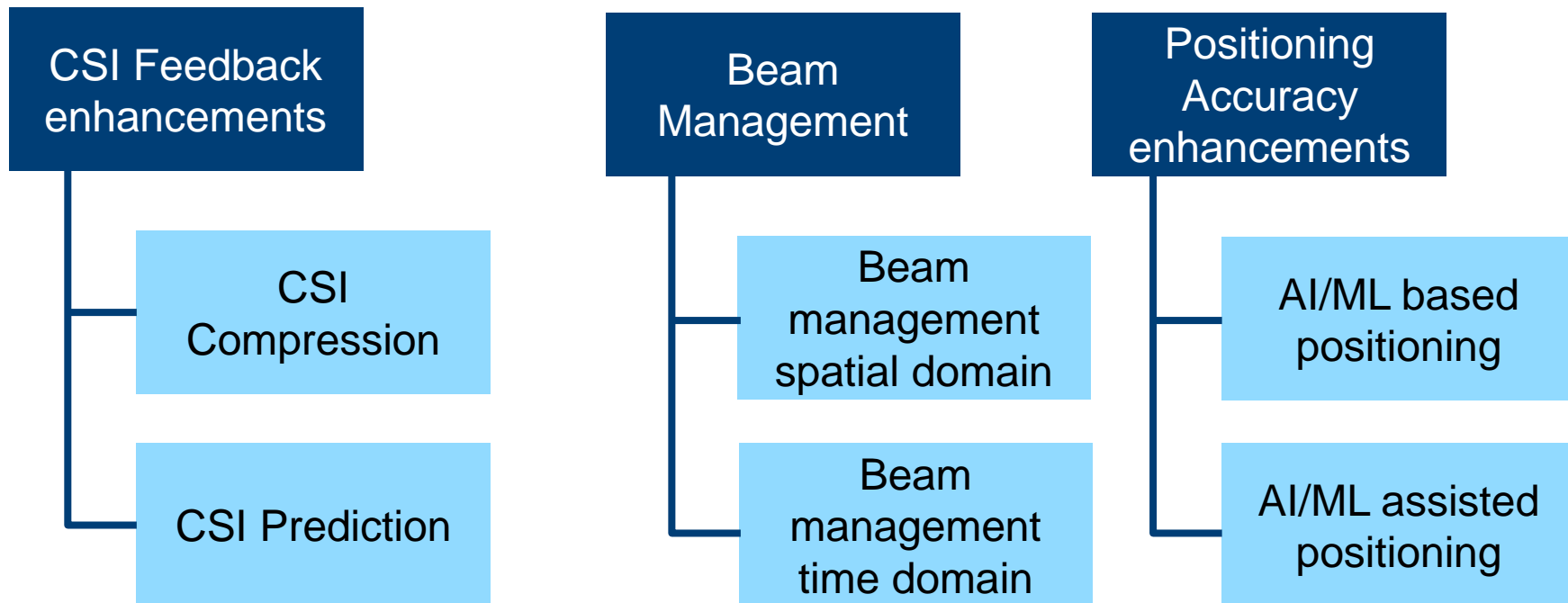## New channel bandwidth of 2GHz possible

The ongoing evolution of 5G

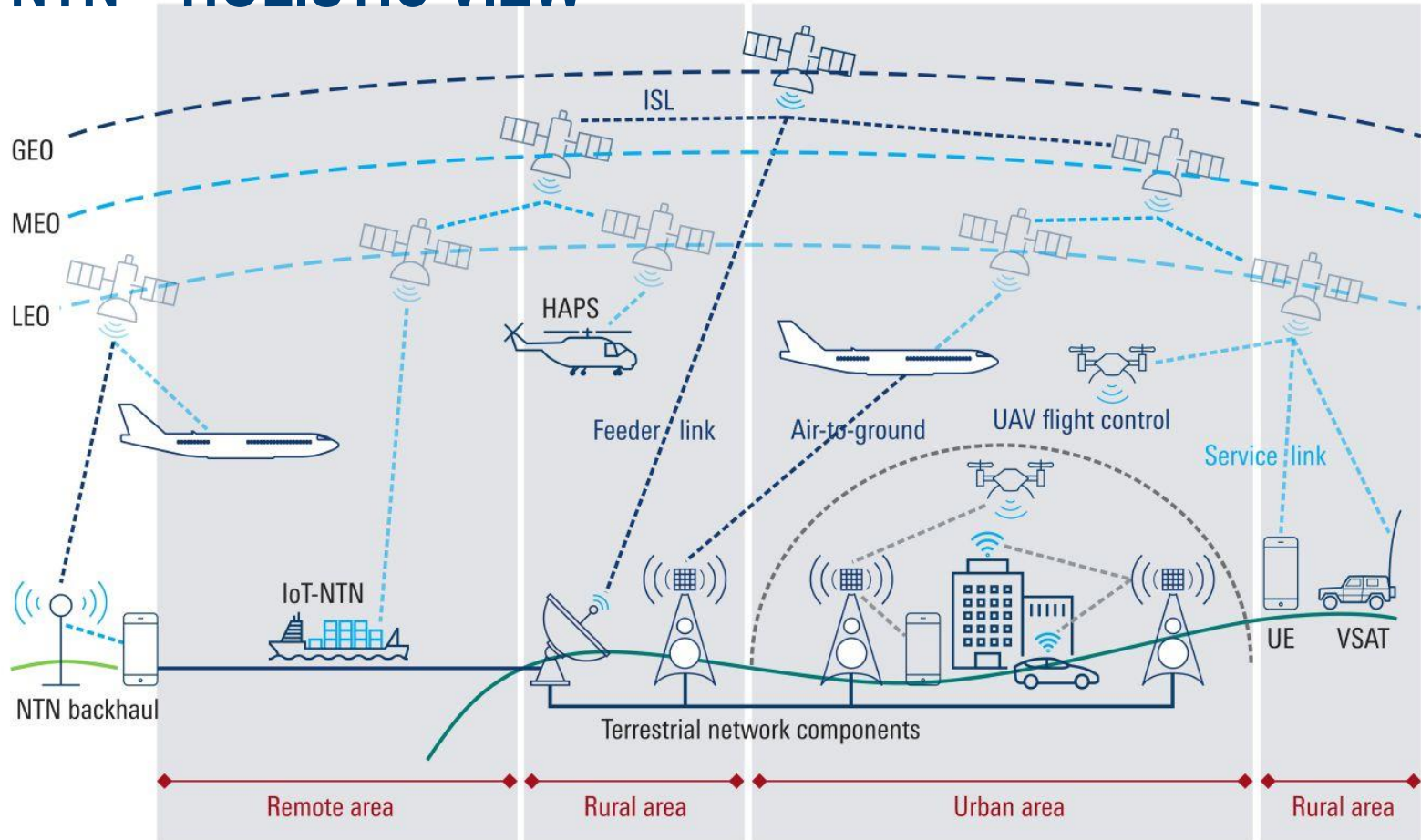# ARTIFICIAL INTELLIGENCE (AI) IN 5G

# 5G – FIRST AI – USE CASES

| CSI Feedback enhancements | Beam Management | Positioning Accuracy enhancements |
|---|---|---|
| CSI Compression | Beam management spatial domain | AI/ML based positioning |
| CSI Prediction | Beam management time domain | AI/ML assisted positioning |

5G Advanced Technology Aspects

Non-terrestrial networks (NTN)

# 5G NTN TECHNOLOGY ASPECTS

# 5G NTN – HOLISTIC VIEW

# 5G NTN SPECTRUM & UE ASPECTS

## FR1: NTN bands (R17)

| Band | Region | Related bands | Band type | UL low MHz | UL high MHz | DL low MHz | DL high MHz |
|------|--------|---------------|-----------|------------|-------------|------------|-------------|
| n253 | EU | L-ext | FDD | 1668.0 | 1675.0 | 1518.0 | 1525.0 |
| n254 | EU | L+53 | FDD | 1610.0 | 1626.5 | 2483.5 | 2500.0 |
| n255 | EU | n65 | FDD | 1626.5 | 1660.5 | 1525.0 | 1559.0 |
| n256 | NA | n24 | FDD | 1980.0 | 2010.0 | 2170.0 | 2200.0 |

## FR2-1N: new NTN bands (R18). FR2-1N range 17.3 – 52.6GHz

| Band | Region | Band type | UL low MHz | UL high MHz | DL low MHz | DL high MHz |
|------|--------|-----------|------------|-------------|------------|-------------|
| n510 | US | FDD | 27500 | 28350 | 17300 | 20200 |
| n511 | US | FDD | 28350 | 30000 | 17300 | 20200 |
| n512 | EU | FDD | 27500 | 30000 | 17300 | 20200 |

## „FR3" bands Ku: requested in R19

| Band | Region | Band type | UL (Earth to space) GHz | DL (Space to Earth) MHz |
|------|--------|-----------|-------------------------|-------------------------|
| Ku | Region 1 | FDD | 12.75 – 13.25 & 13.75 – 14.5 | 10.7 – 12.75 |
| Ku | Region 2 | FDD | 12.75 – 13.25 & 13.75 – 14.5 | 10.7 – 12.7 |

## UE aspects for NTN

| Link level assumptions | FR1 NTN-UE or IoT-UE | FR2-1N VSAT UE |
|------------------------|----------------------|----------------|
| TX power | 23dBm ± 2dB (200mW) (note: more likely 23 dBm + 2dB) | 33 dBm (2W) |
| Antenna type | Omnidirectional | 60cm aperture diameter |
| Antenna gain | TX/RX 0dBi | TX: 43.2 dBi / RX: 39.7 dBi |
| Noise figure | 9 dB | 1.2 dB |
| Polarization | Linear (dual polarized possible) | Circular polarized phased array antenna |

# NTN: RTT ASPECTS AND DOPPLER SHIFT



$RTT_{exit}$ = two way latency at connection termination

$RTT_{nadir}$ = two way latency at shortest distance, corresponds to $RTT_{min}$

$RTT_{init}$ = two way latency at connection setup
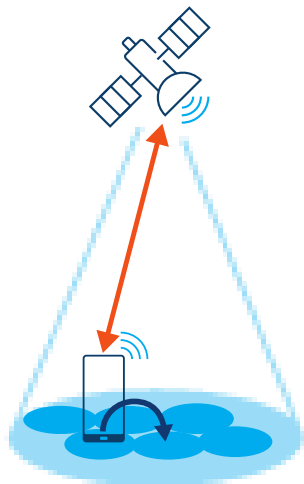
Elevation angle
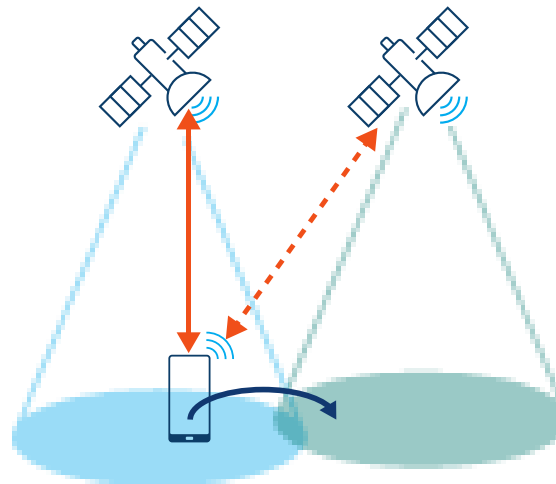
GNSS

GNSS

Rohde & Schwarz
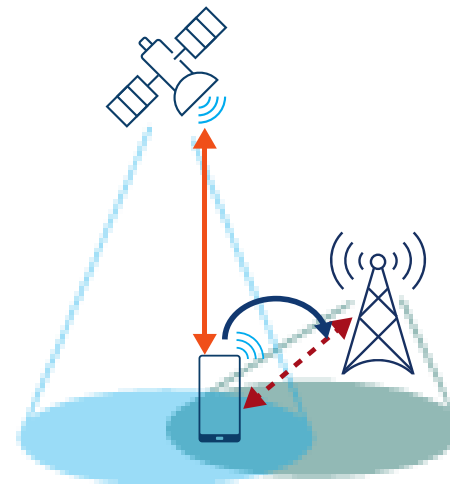
5G NTN takes flight
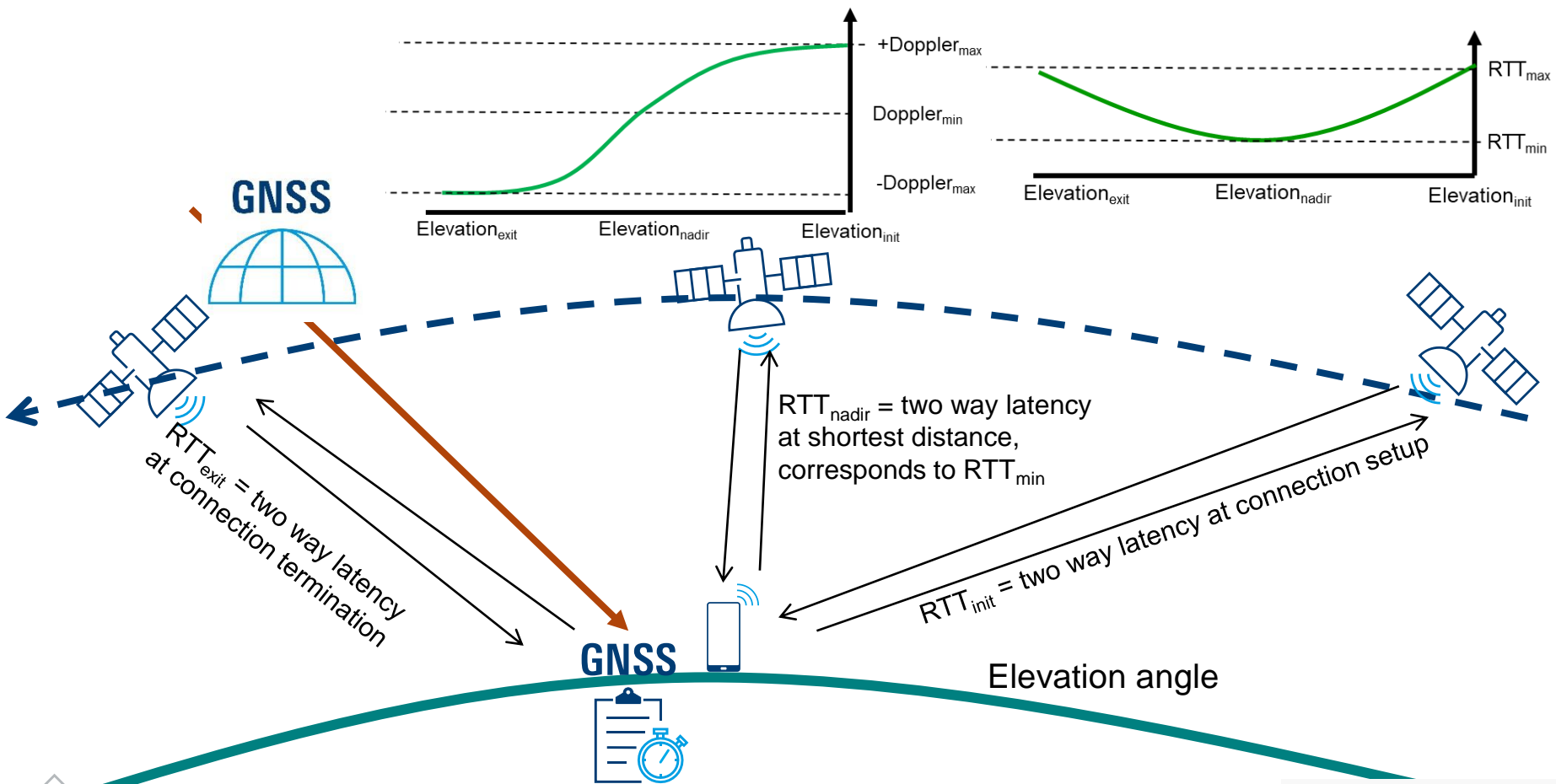
# 5G NTN MOBILITY SCENARIOS - EXAMPLES



**Cell selection/ cell reselection**

**Intra-satellite/ inter-beam handover**

**Inter-satellite handover/ inter-satellite dual connectivity (DC)**

**NTN – terrestrial handover/DC**

→ NR-NTN connection

⇢ Target or simultaneous dual connectivity NR-NTN connection

⇠⇢ Target or simultaneous dual connectivity terrestrial connection
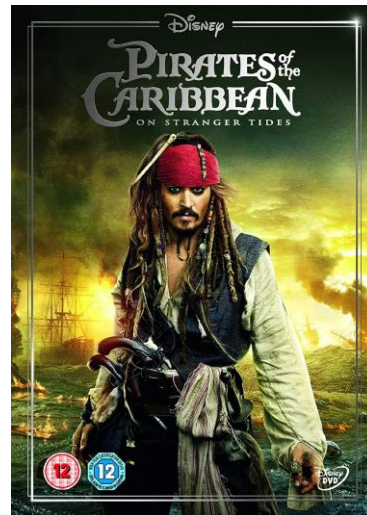
5G evolution, Releases 16, 17 and 18

# 5G PERSONAL AND RESIDENTIAL NETWORKS

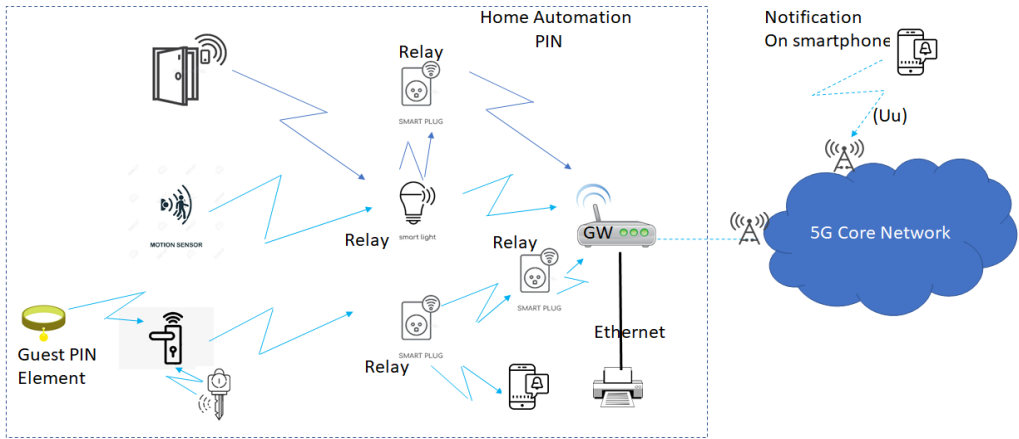# PERSONAL IOT AND RESIDENTIAL NETWORKS (PIRATES)

Study on Personal IoT
Networks (PIN)
TR 22.859

Study on Enhancements for
Residential 5G
TR 22.858

Merged as one work item
PIRates
(SP-211505)

# PERSONAL IoT NETWORK (PIN) AND RESIDENTIAL NETWORKS



Personal IoT networks:
- Direct access to 5G core for IoT devices via „mediator" UE
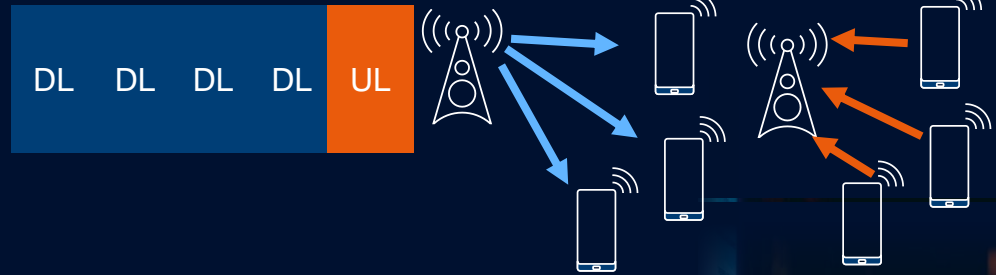- Step towards shared computing concept

Residential networks:
- Enhanced concept of small cells/personal cells and usage of unlicensed spectrum

Note: The UE has 3GPP credentials, i.e. the PRAS is not a WiFi AP



Source: TR 22.859

# R18 Full Duplex

| DL | DL | DL | DL | UL |
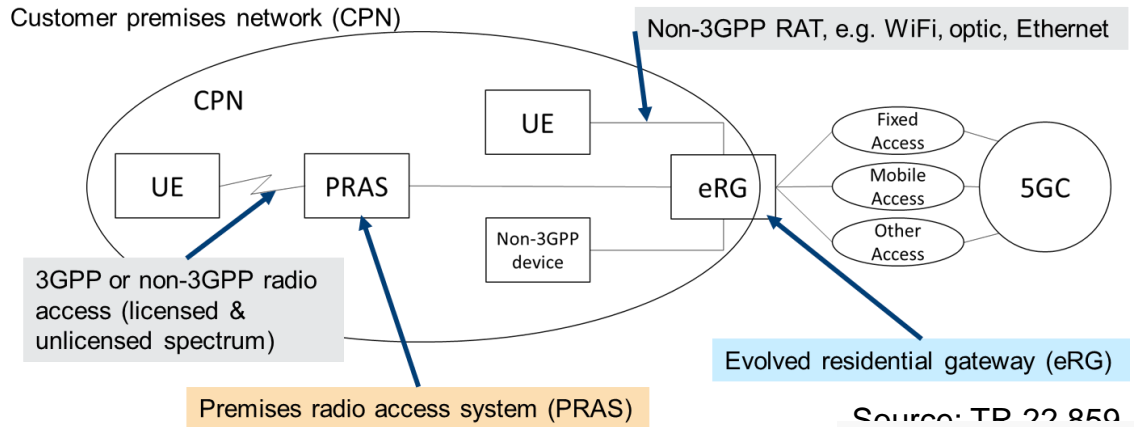
**Justification :**

- TDD is widely used in commercial NR deployments
- TDD limited time duration in UL
- This implies reduced UL band/coverage and increased latency
- CLI handling and RIM for NR were introduced in Rel-16

**Objectives** :

| DL | DL | DL | DL | UL |
| UL | UL | UL | UL | |

- 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)

# R18 "5G ADVANCED"  - EVOLUTION AND REVOLUTION



**Mobile Broadband**

**Extended Verticals**

**Dynamic Infrastructure**

**Sensing & Ranging**

**Wireless Intelligence**

Evolution →  ← Revolution

# RELEASE 19

# REL-19 : ITEMS ( CORE )

| Project (RAN1 Led) | WI/SI/Effort | Ref. |
|---|---|---|
| AI/ML - Air Interface | WI (4) | RP-234039 |
| NR-MIMO Evolution | WI(2.5) | RP-234007 |
| Evolution of duplex operation | WI(2.5) | RP-234035 |
| Network energy savings | WI(2) | RP-234065 |
| Low power WUS/WUR | WI(1.5) | RP-234056 |
| ISAC | SI 2Q'24 (1) | RP-234069 |
| Exploring study in new spectrum (7-24GHz) | SI 2Q'24 (1) | RP-234018 |
| Ambient IoT | SI (3.5) | RP-234058 |

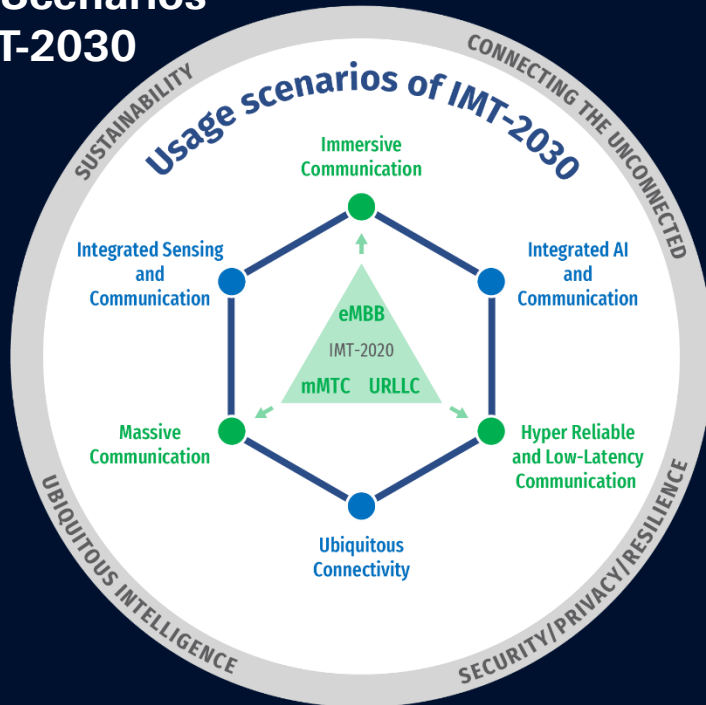| Project (RAN2 Led) | WI/SI/Effort | Ref. |
|---|---|---|
| Mobility Enhancements | WI(2) | RP-234036 |
| Enhancements for XR | WI(2) | RP-234057 |
| NTN (Non-Terrestrial Networks) evolution - NR | WI(2) | RP-234075 |
| NTN (Non-Terrestrial Networks) evolution - IoT | WI(1) | RP-234070 |
| AI/ML for Air Interface (Mobility) | SI(2) | RP-234055 |

| Project (RAN3 Led) | WI/SI/Effort | Ref. |
|---|---|---|
| SON/MDT Enhancements | ~1.5 TUs | RP-234038 |
| AI/ML for NG-RAN | SI+WI(2) | RP-234054 |
| Additional topological improvements | SI+WI(2) | RP-234041 |

- RAN4 Items will be defined in March 2024
- Additional LTE WI tbd in March 2024

Legend : WI Only ; SI only; SI + WI
Effort 1= 1 TU pro meeting

Rohde & Schwarz

# IMT-2030 capabilities and usage scenarios

**Usage Scenarios of IMT-2030**



**Capabilities of IMT-2030**

6G major research areas - Mar 24
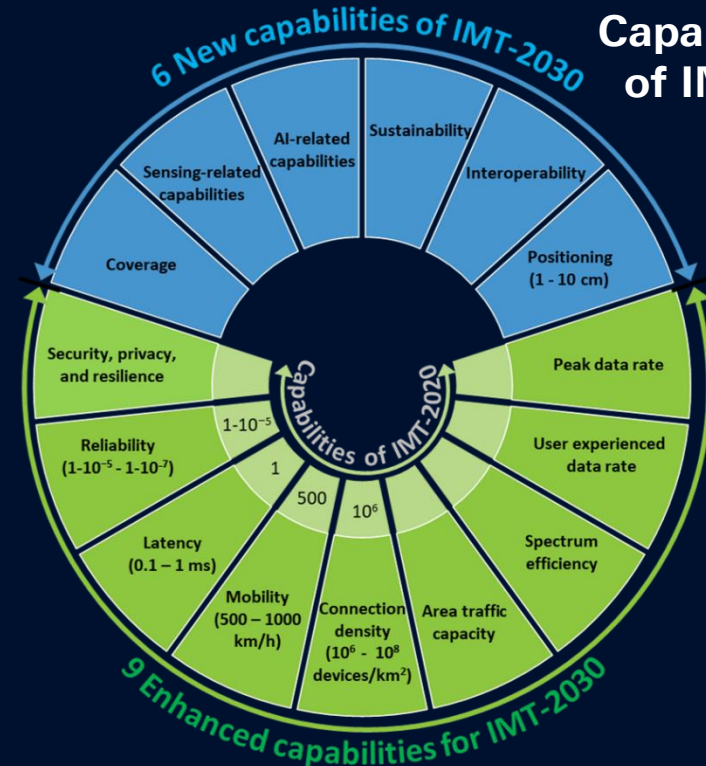
# Shaping the future of mobile communication by standardization



**6G**
- Fundamental research
- You are here!
- Applied research
- Study Phase
- Standardization Phase 1
- Standardization Phase 2

**ITU**
- WRC-23
- WRC-23 results:
  6G Study items for WRC-27:
  7.125 – 8.4 GHz, 14.8 – 15.35 GHz
  FCC: 12.2-12.7 GHz
- WRC-27
- WRC-31

**3GPP**
- 5G
- 5G ADVANCED
- 5GAA Automotive Association
- 5GACIA
- 6G workshop March 2025
- Rel-16 uRLLC
- Rel-17 RedCap, NTN
- Rel-18 XR, AI, Energy
- Rel-19 AI/ML, Duplex, WUS/WUR
- Rel-20 6G studies
- Rel-21 6G normative
- Rel-21 6G evolution
- Assumptions = not confirmed timelines
- Rel-18 ASN.1 freeze
- 1st Rel-18 ASN.1 review
- First 3GPP Release covering a 6G standard
- 1st 6G network launch?
- 1st 6G devices?

2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

1) IMT-2020 systems are called 5G, The ITU has already started a new technology trend report to prepare the work on "IMT-2020 and beyond" that is likely to become 6G

# RESEARCH AREAS FROM A T&M PERSPECTIVE
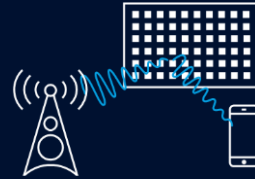
**Spectrum for 6G: "FR3" and THz**
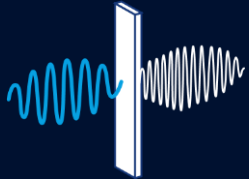
**Integrated sensing & communication**
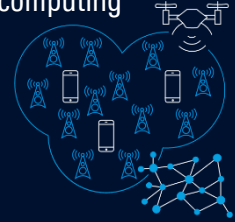
**Artificial Intelligence and Machine Learning**

**Reconfigurable Intelligent Surfaces**

**Photonics, Visible Light Communication**
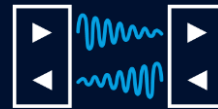
**New network topologies, distributed computing**

**Multiple access, new waveforms, channel coding**

**Ultra-massive MIMO**

**The Metaverse and eXtended Reality (XR)**
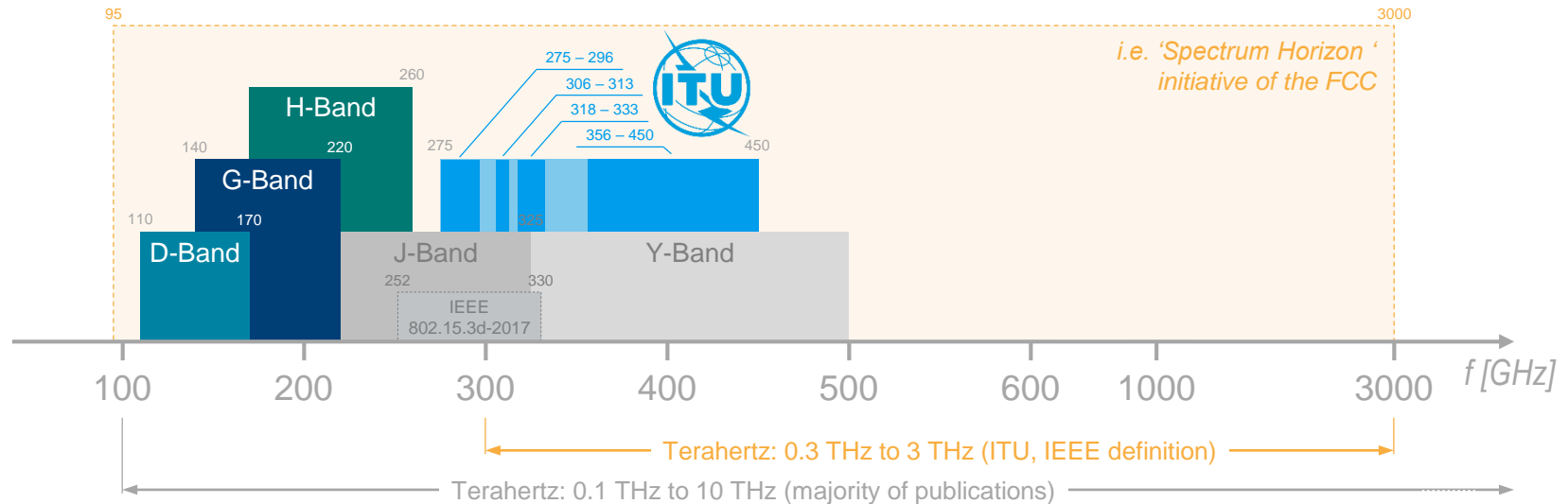
**Full-duplex communication**

**Security & Trustworthiness**

*A high-level overview of all these research areas is provided in one of our #THINKSIX videos*

# WHAT FREQUENCIES ARE WE TALKING ABOUT FOR 6G?

**Let's be clear, a future 6G standard will also work <u>below 100 GHz, below sub-6 and 1 GHz</u>!**

► (sub-)THz will "just" be another frequency layer!

# 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.

# FR3 Overview

| FR1 | 7.125GHz ➡ | FR3 | ⬅ 24GHz | FR2 |
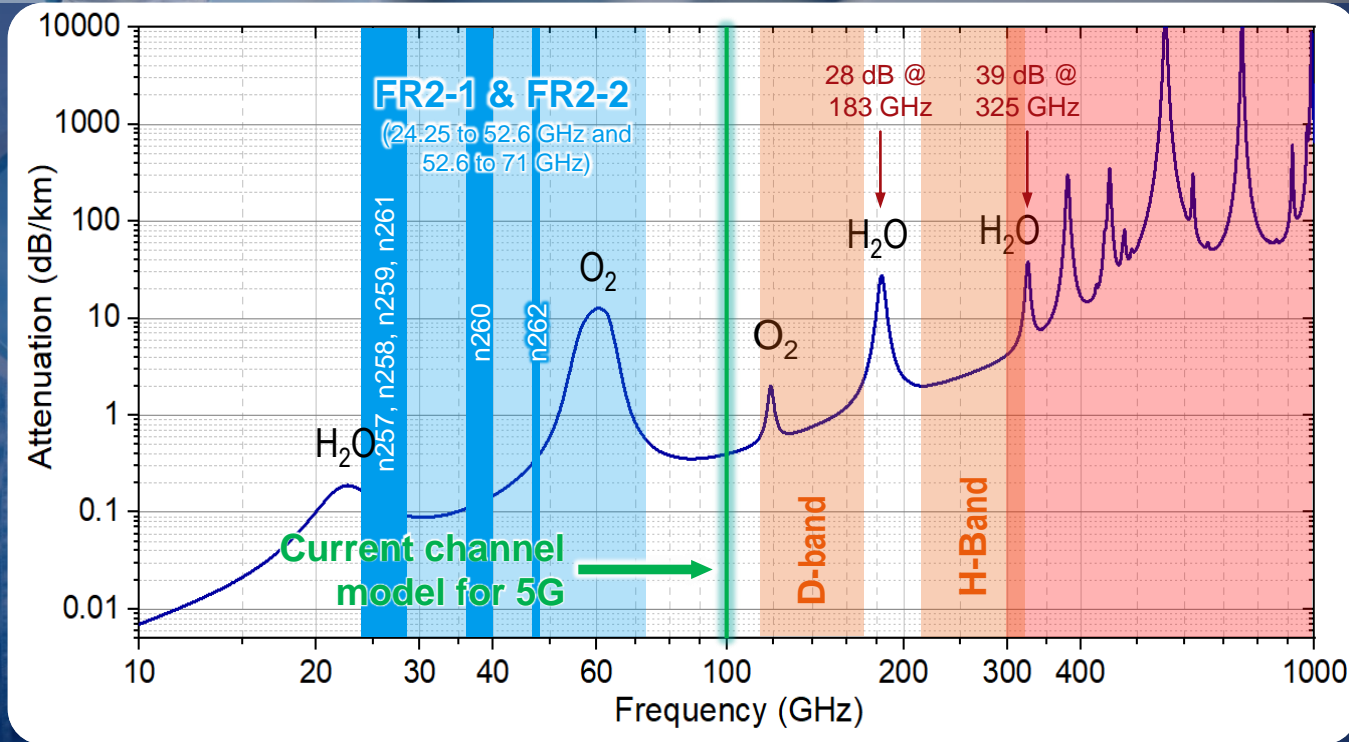
In June 2023 FCC approved AT&T's request to demonstrate the functionality and capabilities of 5GA and 6G in three bands: 5.925GHz-8.4GHz; 10.7GHz-15.35GHz; 92GHz-100GHz - the license is valid through June 1st, 2024.

The FCC adopted rules to preserve spectrum between 12.2-12.7 GHz for current and future satellite services. The FCC also proposed 12.7-13.25 GHz band to support flexible terrestrial wireless use, including 5G/6G wireless services. Focus on study for 7.125 to 8.5 GHz expected by 2023

Base station community seems to focus on 7-15 GHz, targeting sub 8.5GHz BSs in 2027 for 5G advanced and sub 15GHz BSs in 2028 for 6G.

Some component/chip manufacturers seem to focus on 6-15 GHz

Discussions in mobile chipset community to potentially extend frequency range up to 16 GHz, as 12-15GHz is occupied in some regions
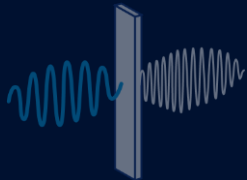
Korea/Japan up to 15.3 GHz for the RU market – mainly driven from Japanese/Korean NetOps

Satellite operators are pushing for 3GPP adoption of Ku band

# 6G RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communication, and "FR3"

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
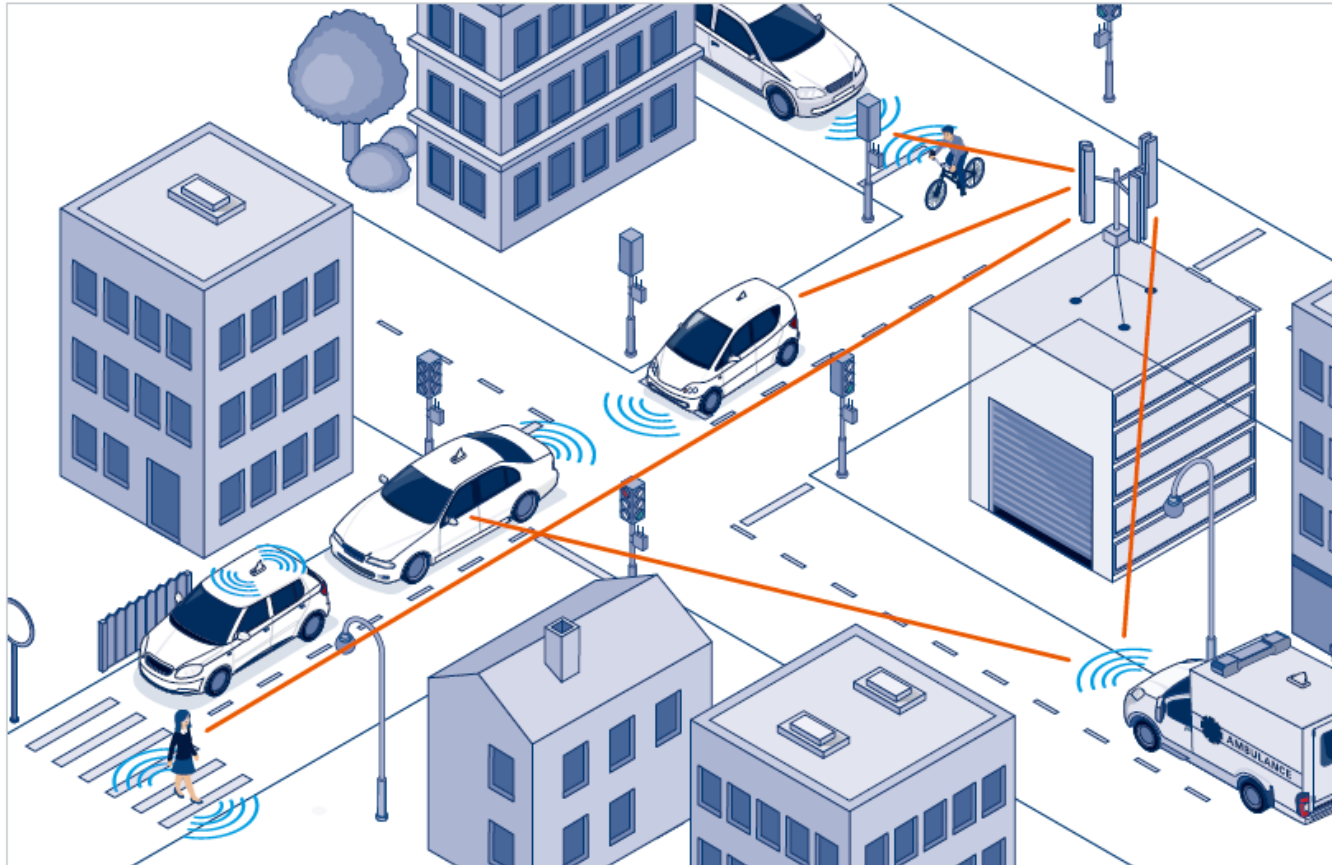
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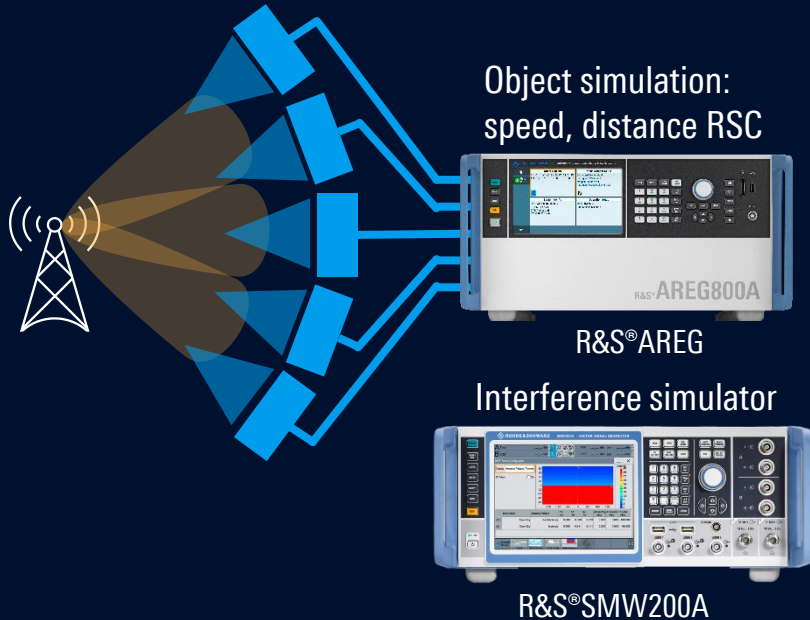
# JOINT COMMUNICATION AND SENSING (JCAS)

6G major research areas - Mar 24

# JOINT COMMUNICATION AND SENSING (JCAS)
## USE CASE EXAMPLES



Enhanced radar & safety

Gesture detection & control

Intrusion & proximity detection

Remote health monitoring

Man machine interworking & safety zones

6G major research areas - Mar 24

# Towards 6G
## Integrated sensing and communication



Object simulation:
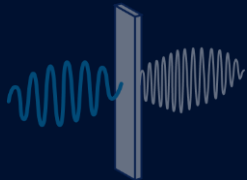speed, distance RSC

R&S®AREG

Interference simulator

R&S®SMW200A

Verifying JCAS technology

◆ R&S®AREG800A Automotive Radar Echo Generator for object simulation and the R&S®FE44S external frontends.

◆ R&S®SMW200 to generate interference signals
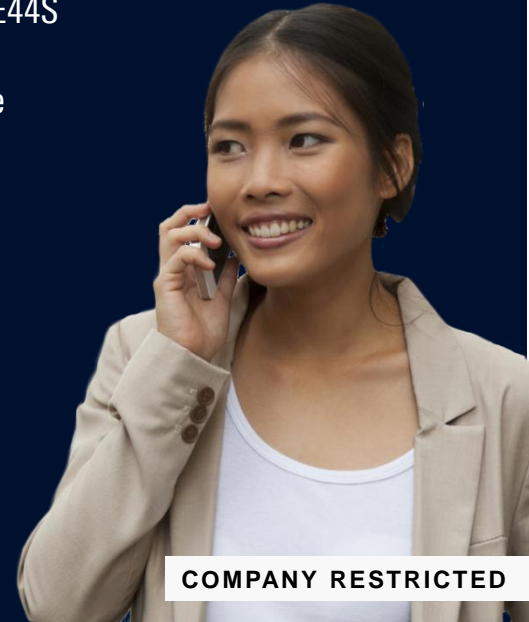
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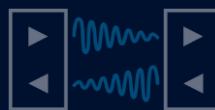
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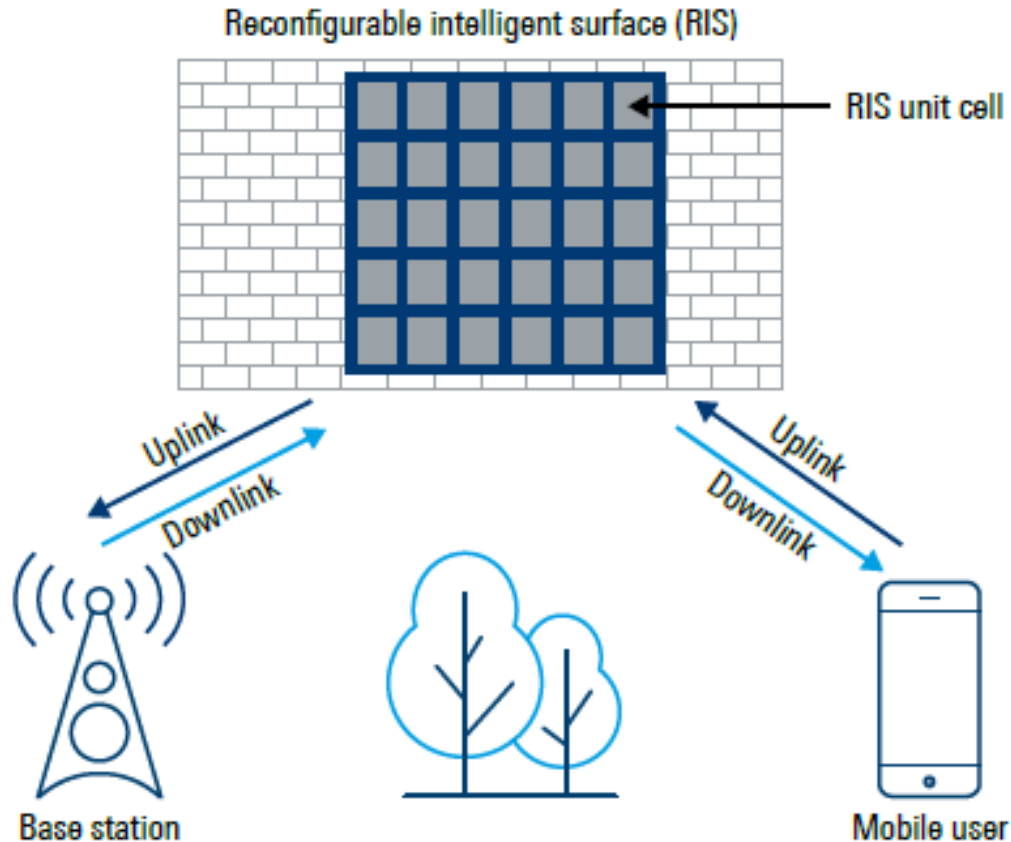
Full-duplex communication

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# RECONFIGURABLE INTELLIGENT SURFACES (RIS)

6G major research areas - Mar 24

# Thought & solution leadership on the way to the next generation of mobile communication (6G)

**FR3**

**Sub-THz**

**AI/ML**

**ISAC**

**RIS**

**XR/AR/VR**

- ◆ Target simulation for Integrated Sensing and Communication (ISAC)
- ◆ Testing Reconfigurable Intelligent Surfaces (RIS)
- ◆ AI/ML training and performance test
- ◆ Sub-THz mesesurements

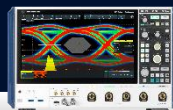| R&S®FSW/SMW | R&S®FE170ST/SR | R&S®NRP170 | R&S®AREG800A | R&S®RTP | R&S®CMX500 | R&S®ATS1800C |

# SUMMARY

► Deployment of 5G networks is in full swing! Clear evolution path provided by the industry's standardization organization

► Academia and key industry players are exploring the boundaries and started looking into next generation of wireless communication aka 6G

► New, challenging technology components may complement the existing concept of cellular networks or even provide revolutionary aspects

► Rohde&Schwarz is actively engaged in this phase of fundamental research, providing our expertise in test and measurement to make ideas real

Thank you very much

ROHDE & SCHWARZ

Make ideas real