Rohde & Schwarz

THE PATH TOWARDS UBIQUITOUS CONNECTIVITY

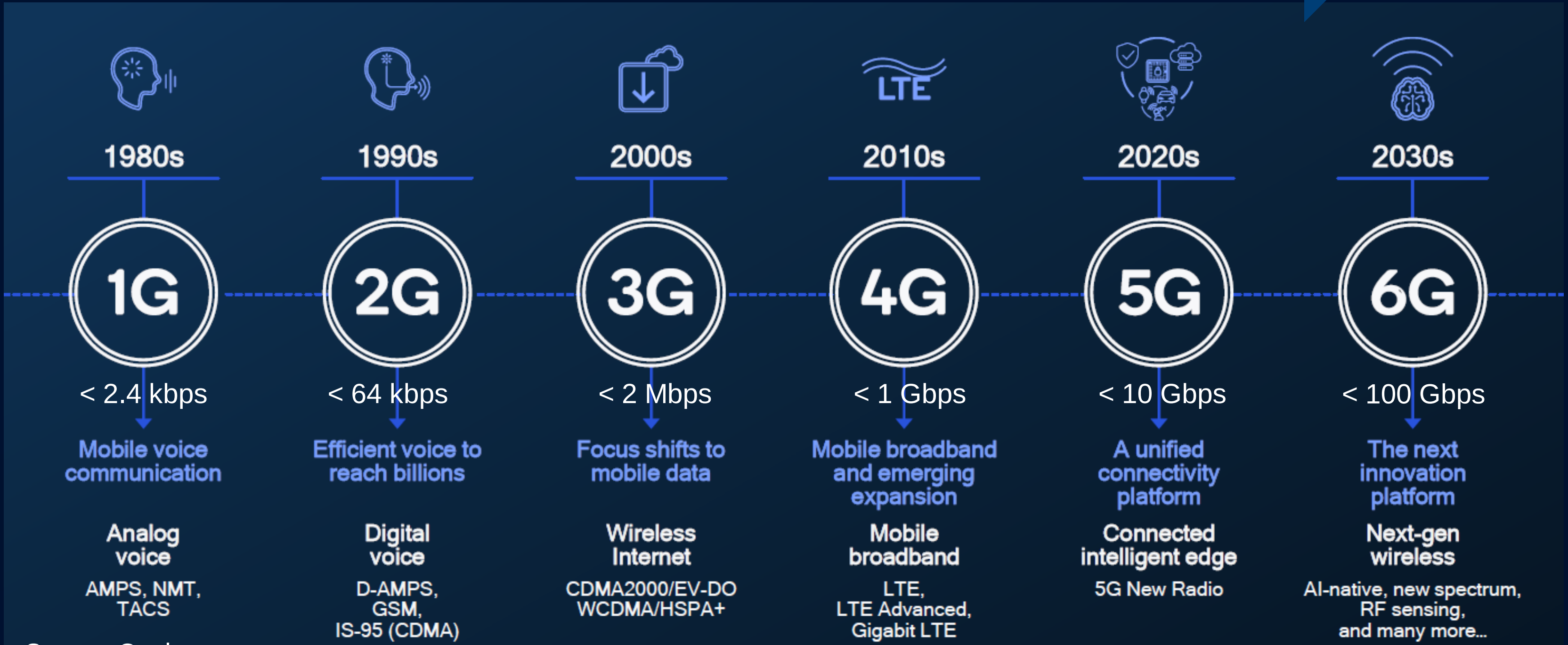
3GPP 5G-ADVANCED AND 6G CONCEPTS

Heinz Mellein
Technology Manager Wireless

EVERY DECADE A NEW GENERATION …

Road to 6G

3GPP: Global Standards



Source: Qualcomm

IMT-2000 **IMT-Advanced** **IMT-2020** **IMT-2030**

6G POPULAR RESEARCH AREAS TO DATE

Road to 6G

- 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

IMT-2030 FRAMEWORK M.2160

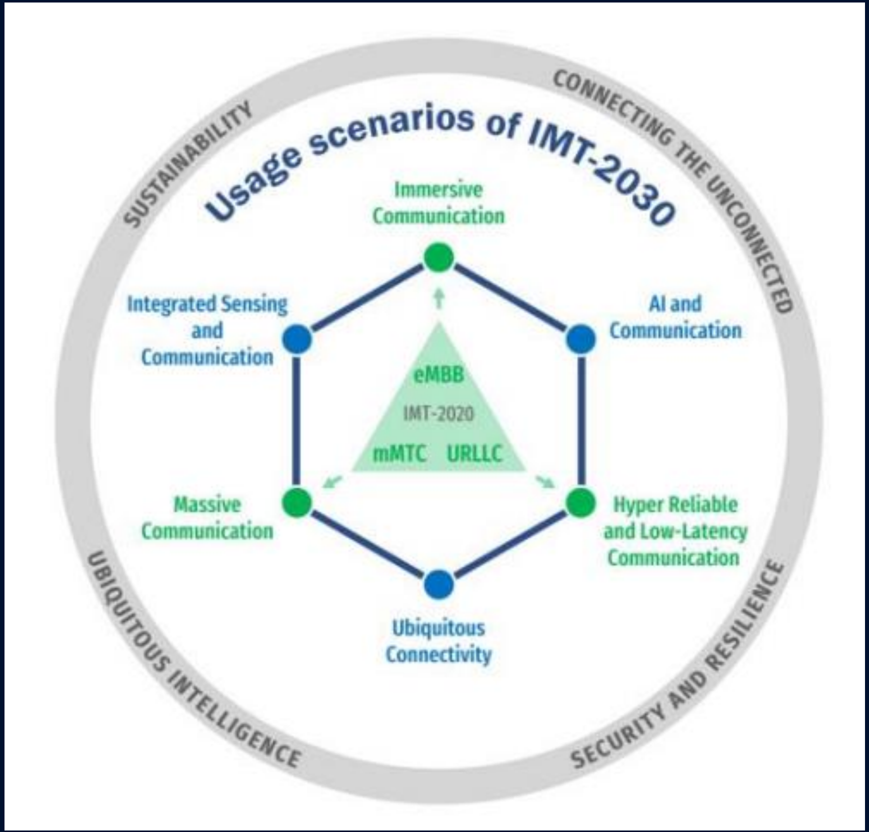
ITUPublications
Recommendations

International Telecommunication Union
Radiocommunication Sector

Recommendation ITU-R M.2160-0
(11/2023)

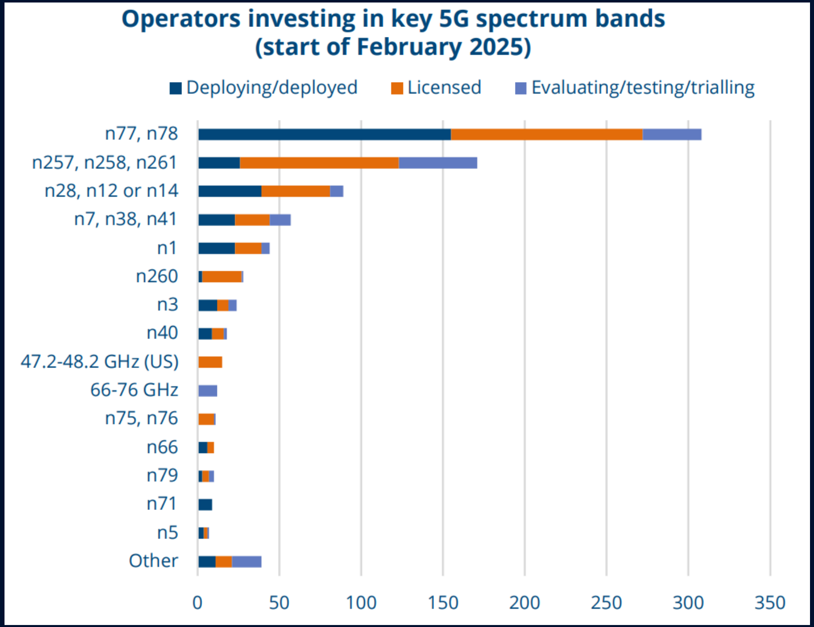
M Series: Mobile, radiodetermination, amateur and related satellite services

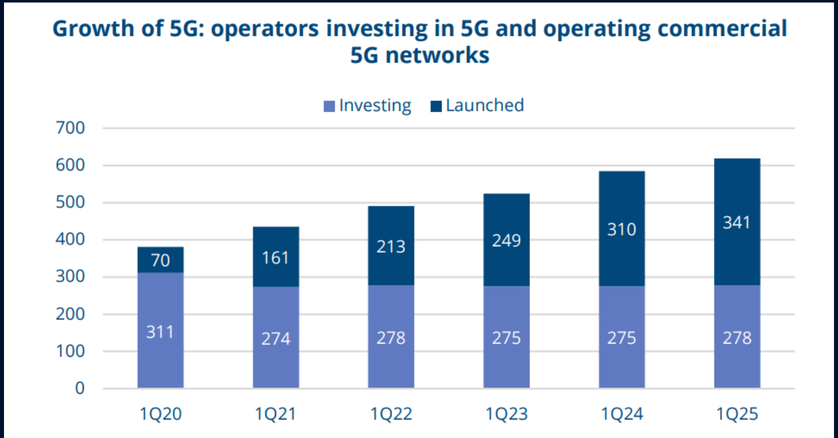
Framework and overall objectives of the future development of IMT for 2030 and beyond

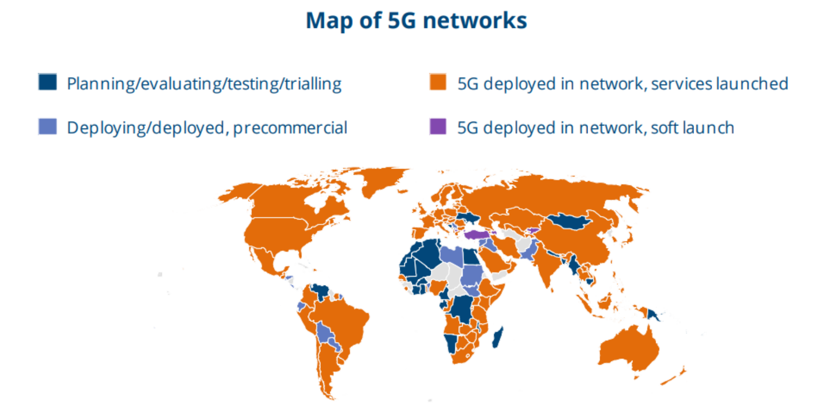


Source: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2160-0-202311-I!!PDF-E.pdf

5G MARKET SNAPSHOT 02/25

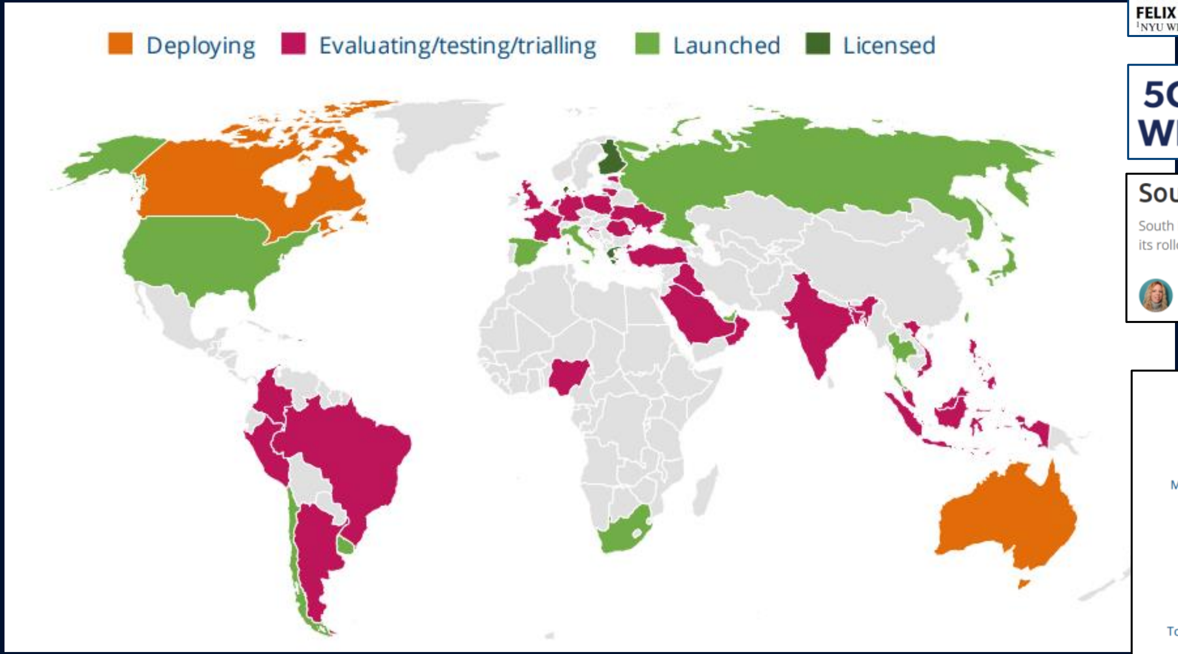






Source: www.gsacom.com/paper/5g-market-snapshot-february-2025/

LESSON LEARNED:
FR2 HYPE NEVER MET PROMISE



Countries with operators investing in bands mm-wave bands:
29 operators in 19 countries and territories

Received February 3, 2013, accepted April 8, 2013, date of publication May 10, 2013, date of current version May 29, 2013.

Digital Object Identifier 10.1109/ACCESS.2013.2260813

Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!

THEODORE S. RAPPAPORT[1], SHU SUN[1], RIMMA MAYZUS[1], HANG ZHAO[1], YANIV AZAR[1], KEVIN WANG[1], GEORGE N. WONG[1], JOCELYN K. SCHULZ[1], MATHEW SAMIMI[1], AND FELIX GUTIERREZ[1]

[1]NYU WIRELESS, Polytechnic Institute of New York University, New York, NY 11201, USA

5G KICKOFF: "5G CHAMPION" AT THE WINTER OLYMPICS IN PYEONGCHANG

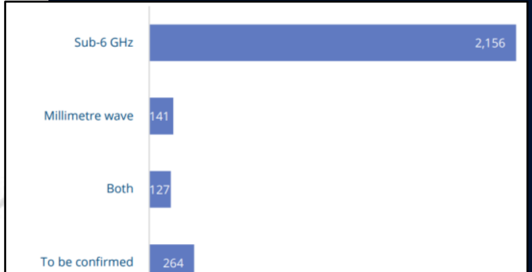
South Korea cancels SKT's 28 GHz 5G licence

South Korea has withdrawn SK Telecom's licence to operate 5G services in the 28 GHz band, the telco having failed to meet its rollout requirements.

Mary Lennighan
May 15, 2023

3 Min Read

Source: telecoms.com (2023)



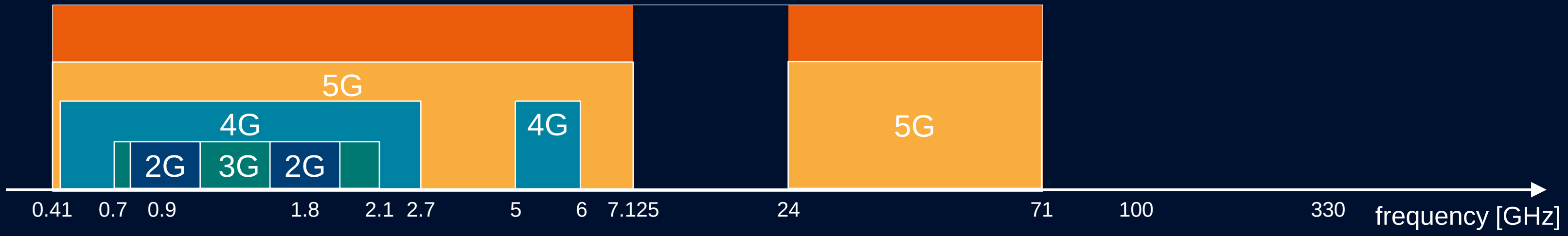
5G devices band support

Source: gsacom.com

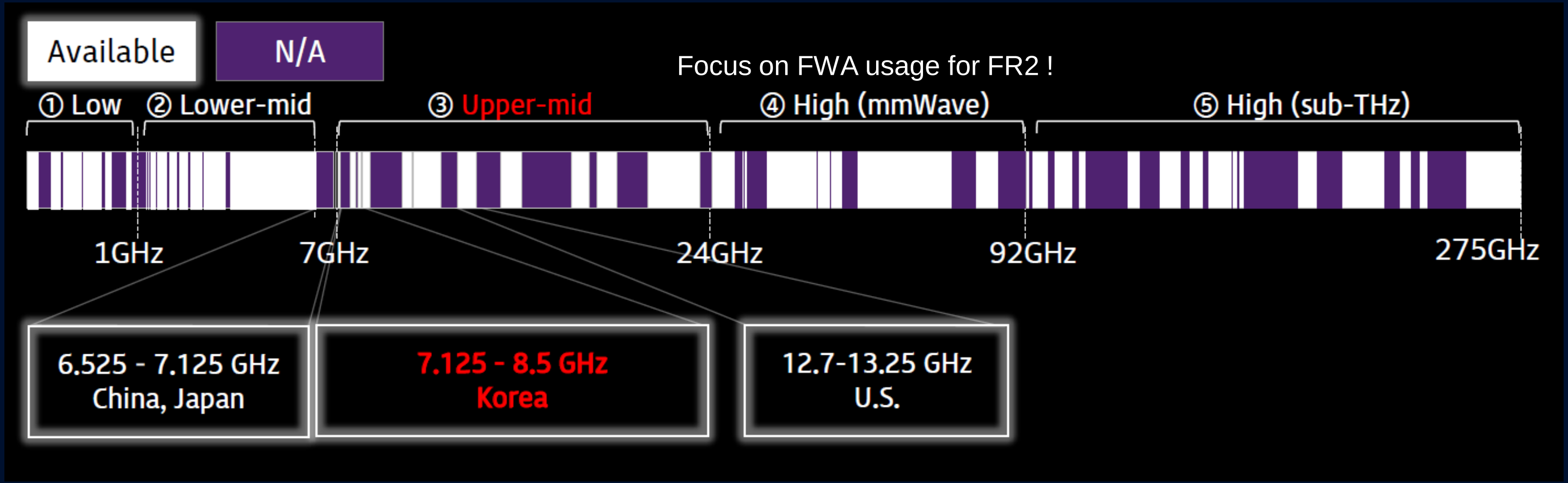
SPECTRUM FOR MOBILE COMMUNICATIONS

Road to 6G

- ▶ WRC-19 identified a bunch of spectrum for 5G
  - – 24.25-27.5 GHz
  - – 37-43.5 GHz
  - – 45.5-47 GHz & 47.2-48.2
  - – 66-71 GHz
- ▶ Is there an urgent need for more spectrum towards 6G ?
  - – WRC-23 said no! Thus, no more spectrum was allocated for 6G this time!

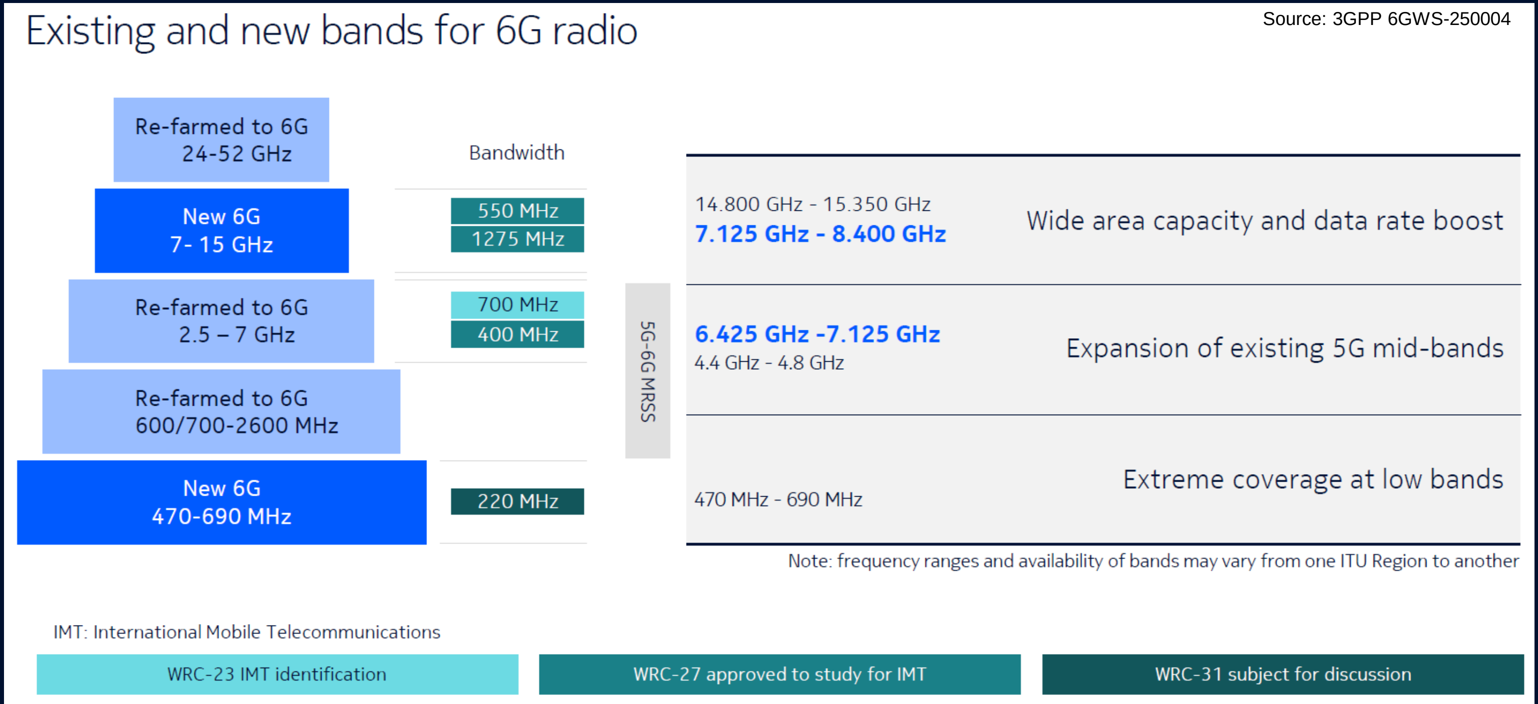


6G SPECTRUM OPPORTUNITIES IN DIFFERENT REGIONS



Source: 3GPP 6GWS-25021

3GPP 6G SPECTRUM PERSPECTIVE



COVERAGE – THE FOREMOST STEP TO UBIQUITOUS CONNECTIVITY!

Global 2G/3G/4G coverage

Common quote by operator officials:

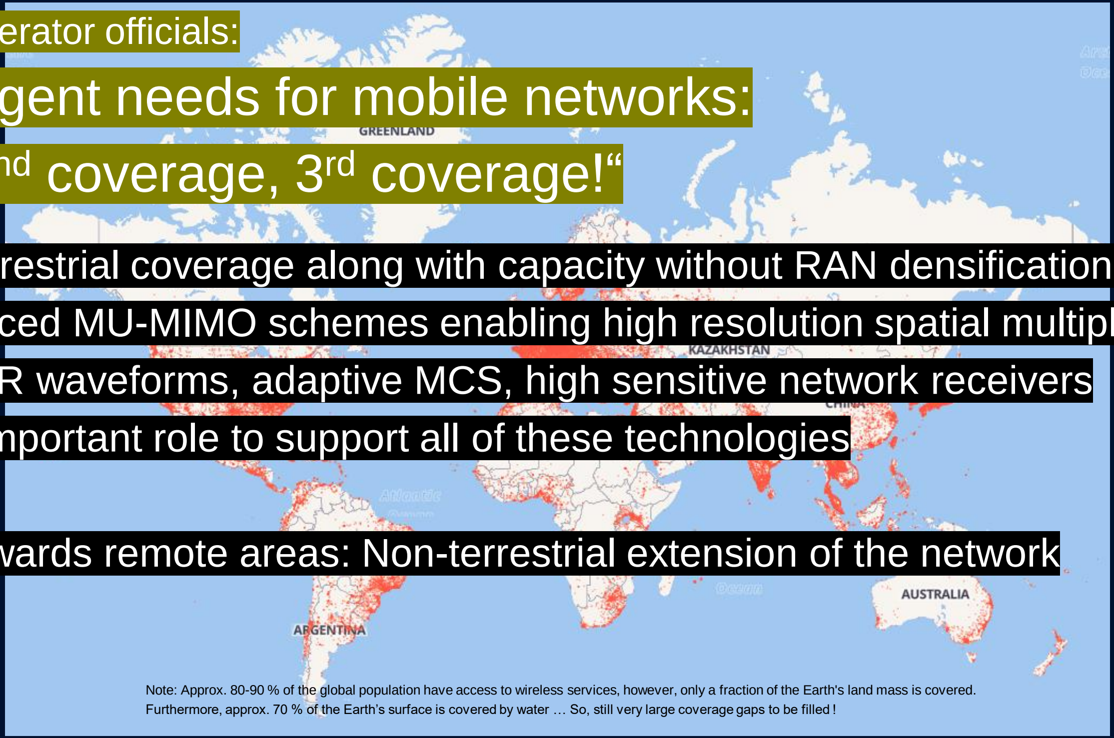
„There are 3 urgent needs for mobile networks:

1st coverage, 2nd coverage, 3rd coverage!“

Increase existing terrestrial coverage along with capacity without RAN densification:

- Downlink: Advanced MU-MIMO schemes enabling high resolution spatial multiplexing
- Uplink: Low PAPR waveforms, adaptive MCS, high sensitive network receivers
- AI/ML plays an important role to support all of these technologies

Extend coverage towards remote areas: Non-terrestrial extension of the network



Note: Approx. 80-90 % of the global population have access to wireless services, however, only a fraction of the Earth's land mass is covered. Furthermore, approx. 70 % of the Earth's surface is covered by water … So, still very large coverage gaps to be filled !

Source: www.opencellid.org/

3GPP 6G WORKSHOP: MOTIVATION FOR 6G

Support for New Services and Use Cases

- e .g. integrated sensing and communication (ISAC), XR/immersive communication, and AI-based services

Revenue Growth and Monetization

- Creating new revenue streams by monetizing network capabilities and supporting diverse applications across industries.

AI and Automation

- Implementing AI-native networks for automation, optimization, and improved efficiency in network management and resource allocation.

Energy Efficiency and Sustainability

- Reducing energy consumption and promoting environmental sustainability through energy-saving features in network design and AI-driven power management.

Spectrum Efficiency

- Utilizing spectrum efficiently, including dynamic spectrum sharing and exploring new spectrum bands.

Ubiquitous Coverage

- Seamlessly integrating terrestrial and NTN for ubiquitous coverage and resilient services.

Total Cost of Ownership (TCO) Reduction

- Reducing capital expenditure (CAPEX) and operational expenditure (OPEX) through simplified network operations and improved energy efficiency.

Improved Service Reliability and Customer Experience

- Enhancing service reliability, resiliency, and insights for improved customer experience.

Network Simplification

- Simplifying network architecture, reducing complexity, and improving operational efficiency.

Source: 3GPP workshop presentations

Road to 6G

3GPP 6G WORKSHOP: 5G LESSONS LEARNED

Challenges in Migration

- The transition from 5G Non-Standalone (NSA) to Standalone (SA) proved complex and difficult.

Architectural Complexity

- An excessive number of architectural options, features, and configurations led to high system complexity, impacting UE capabilities and deployment efficiency.

Slow Adoption of Key Capabilities

- Certain 5G features, such as network slicing, experienced slow adoption—necessitating an analysis of underlying causes and potential simplifications in 6G.

Deployment Inefficiencies

- Issues identified during 5G rollouts, including NRF profile inefficiencies and protocol challenges (e.g., HTTP/2 over TCP), should be addressed in 6G.

Optimized Network Functions

- Ensuring efficient Network Function (NF) sizing with clear decoupling, while further exploring stateless architectures.

Functionality Optimization

- 6G should focus on a well-dimensioned set of functionalities, minimizing redundant options and excessive configurations to reduce complexity.

Source: [3GPP workshop presentations]

3GPP 6G WORKSHOP: 6G DESIGN CONSIDERATIONS

Focus and Simplicity

- Lean and streamlined standards for 6G, e.g., by dimensioning an appropriate set of functionalities, minimizing the adoption of multiple options for the same functionality, avoiding excessive configurations, etc.

Cloud-Native Architecture

- Designing networks to be cloud-native to enable flexibility, agility, and innovation.

AI-Native Design

- Integrating AI and ML frameworks natively into the network for intelligent automation, optimization, and improved efficiency.

Scalability and Modular Design

- Implementing a scalable and modular design that allows a wide range of features, device types, services, and spectrum bands to be developed and deployed as needed.

Software-Driven Deployment

- Software-driven deployment with needs-based hardware refresh to allow for continuous innovation and agility.

Interoperability

- Designing components with interoperable interfaces and a unified management framework to ensure interoperability and avoid fragmentation.

Enhanced Security

- Ensuring the 6G system is secure by design to provide enhanced security and privacy.

IoT Support

- Designing 6G to support diverse IoT device types and use cases from day one, with a focus on long-term commitments and multi-generational solutions.

Service-Aware

- Enabling a service-aware intelligent network powered by AI-native, programmable, and service-aware 6G RAN.

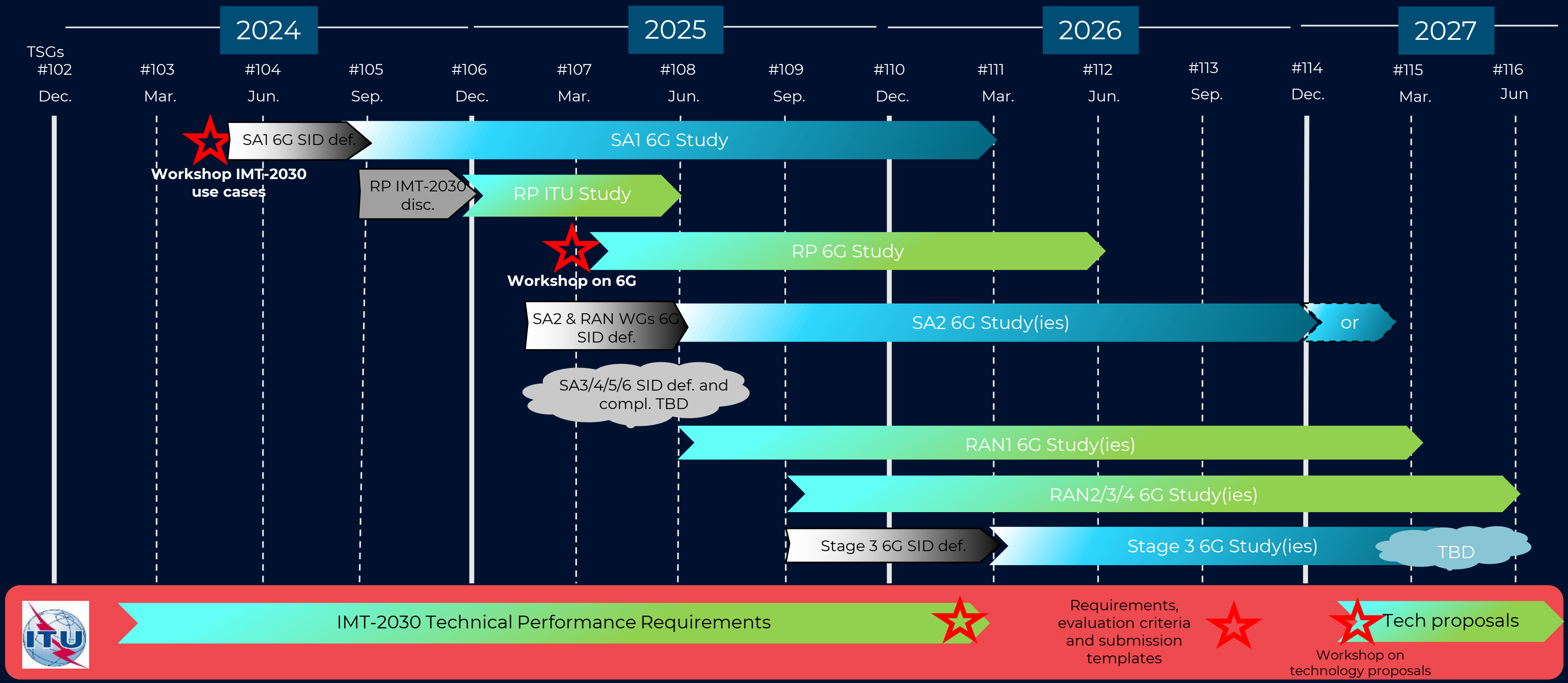
Ubiquitous Connectivity

- Providing ubiquitous coverage through seamless integration of terrestrial and non-terrestrial networks.

Source: [3GPP workshop presentations]

RELEASE 20: 6G TIMELINE

Road to 6G



3GPP 6G WORKSHOP: NEXT STEPS

2024

WG SA1

Stage-1 workshop on IMT2030 use cases

Rotterdam, Netherland, May 8 – 10, 2024

Workshop Summary: [SWS-240025]

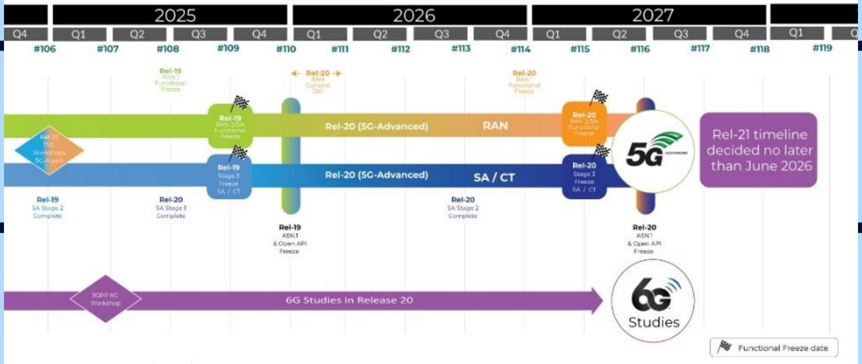
Workshop Presentations: [Link]

[SP-241391] : SA1 6G study item on use cases and service requirements (FS_6G_REQ) **approved** at TSG SA#105.

TSGs#107

First 3GPP TSG-wide 6G Workshop

Incheon, S. Korea, March 10 – 11, 2025



Studies for 6G from Release 20

Normative work for 6G from Release 21

2030

Source: [3GPP workshop presentations]

3GPP Rel-19 towards ubiquitous connectivity

Road
to 6G

BEAM MANAGEMENT HISTORY IN NR MIMO

Rel-15
- Basic beam management (BM) for each channel/signal
- PCell Beam Failure Recovery (BFR)

Rel-16
- Low latency/overhead BM:
  - default spatial relation mainly for beam correspondence case
  - Simultaneous UL/DL beam indication across multiple CC
- SCell BFR

Rel-17
- Unified TCI (uTCI) framework
- Per TRP BFR

Rel-18
- Extension of uTCI framework for multi TRP

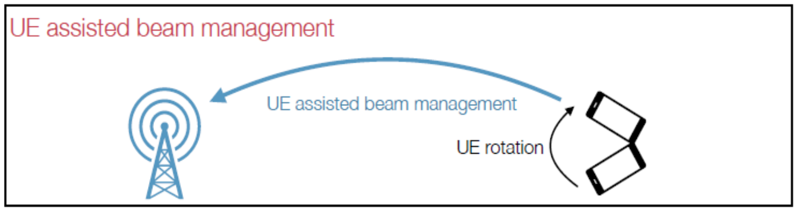
Rel-19
- UE initiated/event-driven BM
- targeting FR2 and sTRP intra- and inter-cell BM

Source: RWS-230207

Road to 6G

REL-19 BEAM MANAGEMENT ENHANCEMENT

- UE-initiated/event-driven Beam Management
- Enhancements target FR2 and sTRP with intra- and inter-cell beam management
- Legacy unified TCI framework is baseline and legacy CSI framework is leveraged
- RAN1's focus is on uplink signaling as follows:
  - content(s) (and procedure(s) as required) for UE reporting
    - Report size should be small, e.g., sending only new beam identification information
  - medium/container used, e.g., UCI based mechanism in addition to MAC-CE
    - To reduce latency may consider reserved UL resource to save time over the scheduling request (SR) procedure
- gNB will still determine beam switching because:
  - Provides NW scheduling flexibility [R1-233012]
  - Insufficient time allocated to study/specify



Source: RP-234007, RP-232975, R1-233012

Road to 6G

CSI HISTORY IN NR MIMO

Rel-15
- Type I CSI (low resolution)
  - Single panel/multiple panel codebook
- Type II CSI (high resolution)
- L1-RSRP reporting

Rel-16
- eType II: Type-II with low overhead and rank 3 & 4
- L1-SINR reporting

Rel-17
- NCJT CSI
- FeType II: type II with partial reciprocity by long term channel property in FDD band
- Group based beam reporting

Rel-18
- Type II CSI for CJT
- Type II for medium/high velocity
- Type II time domain channel property (TDCP) reporting

Rel-19 (targeting FR1)
- Type I codebook enhancements to support 128 CSI ports
- Type II enhancements to support 128 CSI ports (only changes needed to support 128)
- Extension of CRI-based CSI reporting for hybrid beamforming supporting 128 CSI-RS ports

Source: RWS-230207

Road to 6G

REL-19 CSI ENHANCEMENTS: 128 PORT CSI-RS

- Motivation: Industry interest is increasing for larger antenna arrays with more elements
  - Addresses coverage issues
  - Better DL spectrum efficiency
- Current CSI-RS supports up to 32 ports and enh are needed to
  - Support fully digital gNB implementation options
  - Extend hybrid beamforming for larger arrays and increased MU-MIMO scheduling flexibility
- Rel-19 objectives
  - Type I codebook refinement to support 128 ports (type 1 CBs have not changed since R15)
  - Type II CB refinement to support 128 ports but only changes required for increased ports
  - Extension of CRI(s) based CSI reporting for hybrid BF

Source: RWS-230207

Road to 6G

mTRP HISTORY IN NR MIMO

Rel-16
- mTRP SDM based PDSCH (for eMBB)
- mTRP PDSCH repetition (for URLLC)

Rel-17
- mTRP PDCCH/PUCCH/PUSCH repetition
- Inter-cell, HST scenario support

Rel-18
- 2 TAs for mDCI mTRP
- CJT based PDSCH

Rel-19
- CJT enhancements for UE to report Inter TRP time misalignment and frequency/phase offset
- Asymmetric DL sTRP / UL mTRP deployment scenario enhancements (for FR1 and FR2)

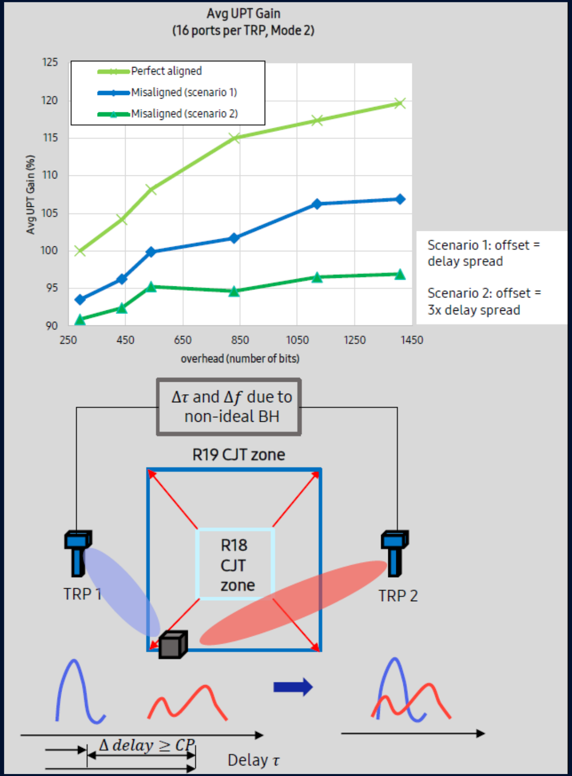
Source: RWS-230207

mTRP = multi transmission and reception point
sTRP = single transmission and reception point
CJT = Coherent joint transmission

Road to 6G

REL-19 mTRP ENHANCEMENTS (1)

- UE reporting enhancements for CJT
- Motivation:
  - CJT provides spectral efficiency and enhances coverage gain
  - R18 Type II CSI for CJT assumes ideal synchronization and backhaul
    - This assumption is not realistic for many deployments (especially inter-site)
    - Inter-TRP phase/delay and frequency offsets cause throughput degradation
- Rel-19 enh:
  - UE provides inter TRP time misalignment and freq/phase offset measurements and reporting
  - Assumes legacy CSI-RS design with stand alone aperiodic reporting on PUSCH

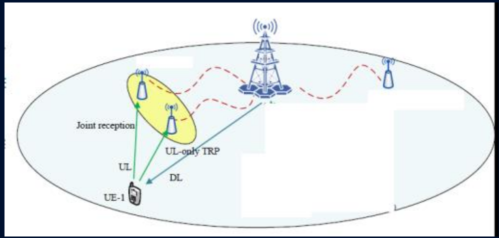


Source: RWS-230207

Road to 6G

REL-19 mTRP ENHANCEMENTS (2)

- Asymmetric DL sTRP/UL mTRP deployment scenarios
- Motivation: Heterogeneous network deployments to improve UL throughput
  - UE receives DL signals from macro gNB
    - The pathloss RS is sent from the macro gNB
  - UE transmits UL to macro gNB or micronodes
    - The PC is determined from the macro gNB pathloss RS



- Power control enhancements planned for Rel-19:
  - Configure UE with PL offset to accurately determine PL to micro node
  - Need to support 2 closed loop PC adjustments for SRS separate from PUSCH
    - CLPC for DL CSI acq to macro gNB for DL TX
    - SRS to the micro nodes for UL mTRP reception

Source: RWS-230207

3GPP NR UPLINK MIMO HISTORY

Rel-15
- Codebook based (CB) PUSCH
- Non-Codebook based PUSCH
- SRS (≤ 4 ports, ≤ 4T4R for antenna switching)

Rel-16
- Low PAPR RS
- UL full power TX

Rel-17: SRS
- Flexible AP triggering
- ≤ 4T8R for antenna switching
- Capacity / coverage enhancements

Rel-18
- Simultaneous transmission by 2 panels
- DMRS, SRS, TPMI for UL 8 TX

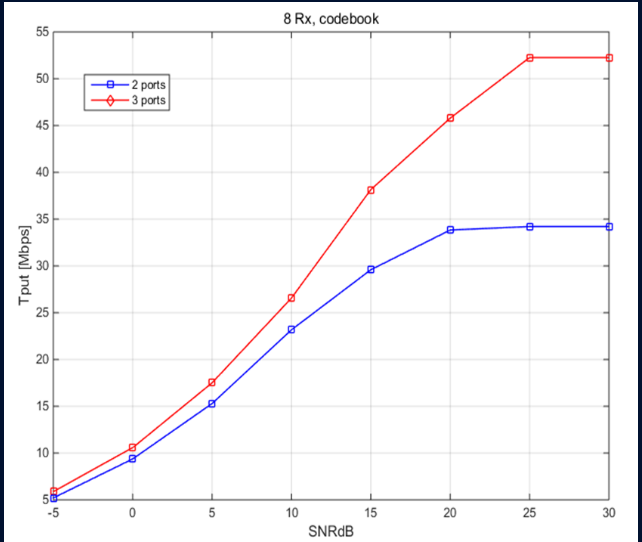
Rel-19
- 3 antenna port CB based TX

Source: RWS-230207

REL-19 UL MIMO ENHANCEMENTS: SUPPORT 3 TX UL MIMO

Road to 6G

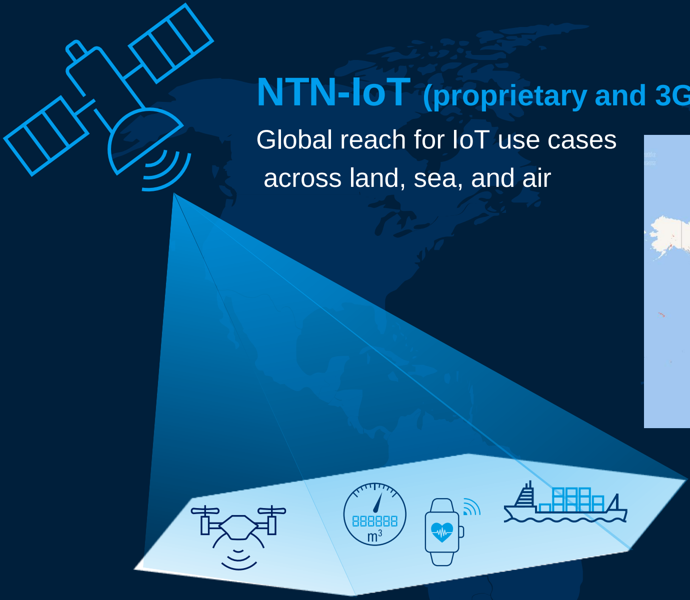
- Motivation: Increase UL throughput
  - Advanced UE hardware is able to support 3 TX chains in one band
  - 4 TX chains are not likely due to the limited form factor of UE
  - Today, 3GPP NR does support 2 and 4 ports but not 3 ports in the uplink



Simulations suggest 50% Tput gain

Source: RWS-2300315

NTN for global IoT service coverage and to complement terrestrical network coverage

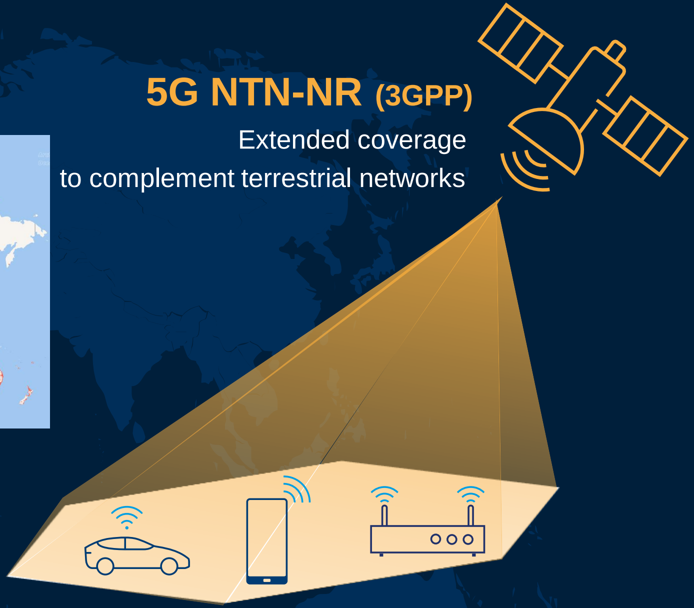


NTN-IoT (proprietary and 3GPP)

Global reach for IoT use cases across land, sea, and air

5G NTN-NR (3GPP)

Extended coverage to complement terrestrial networks



Today | 2026/2027 | 5G Advanced/6G

*Source: GSMA Intelligence

3GPP NTN EVOLUTION R17 TOWARDS R19

Road to 6G

3GPP NTN evolution

R17	R18	R19
Transparent Architecture	Enhanced mobility	Regenerative Architecture
FR1 and FR2	Enhanced coverage	DL enhancement with power sharing
FDD and TDD	Network based UE location	UL capacitity with high power UE
VSAT and Handheld	VSAT above 10 GHz	RedCAP UE
GNSS		

3GPP NTN IoT evolution

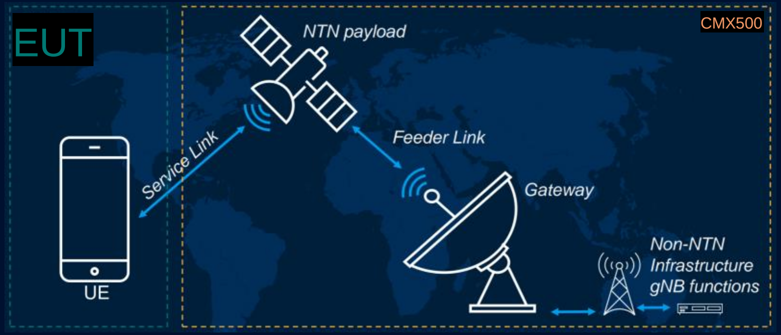
R17	R18	R19
Transparent Architecture	Power consumption	Store & Forward Regenerative Payload
FR1 / sub 6 GHz	Enhanced mobility	Enhanced UL
FDD and EPC	Discontinuous coverage	Improved location reporting
Short data transmission		5GC network
GNSS support		

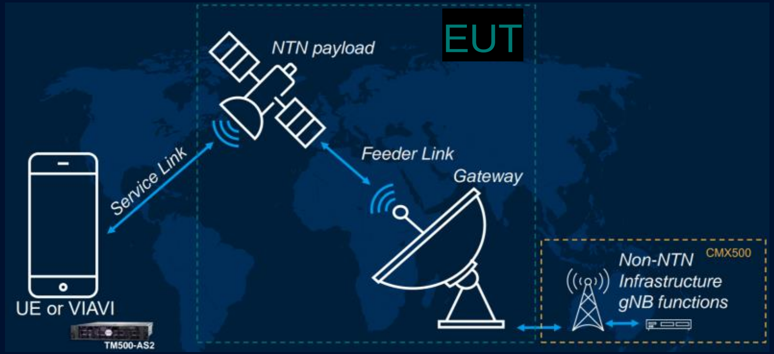
NTN COMMUNICATION SPECTRUM

- FR1 (L, S and C band)
  - (1.5 – 1.6 GHz)
    - GPS, GAL, Iridium, Globalstar, …
  - (2.5 GHz)
    - Skylo, Dish/Echostar, Globalstar, …
  - (4 – 4.2 GHz and 5 – 7 GHz)
    - Currently not envisioned for NR-NTN
- FR3 (X/Ku band)
  - (10 – 15 GHz)
    - TV satellites, Starlink, OneWeb, IRIS²
- FR2 (K, Ka band)
  - (18 – 30 GHz)
    - Amazon, Kuiper, KA-SAT, IRIS², …

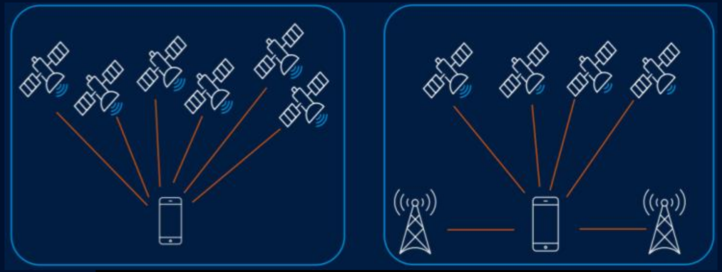
Band	GHz
L	1 – 2
S	2 – 4
C	4 – 8
X	8 – 12
Ku	12 – 18
K	18 – 27
Ka	27 – 40
V	40 – 75
W	75 – 110

BASIC NTN TEST APPROACHES





EUT = Equipment under test



Active RF links seen by the UE

NTN DEMOS AT MWC2025

NR-NTN DEVICE TESTING

NTN CONFORMANCE AND CARRIER ACCEPTANCE TESTING

CUSTOMIZED 5G SIGNALS FOR FR3 AND NTN TESTING

MEDIATEK NR-NTN in LEO

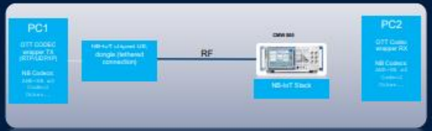
Using our FSW/SMW for NR-NTN LEO channel emulation over Ka and Ku band demonstrating NR-NTN connection for OneWeb sats.

VIAVI E2E NR-NTN TESTBED

NR-NTN E2E testbed with CMX500 and TM500, demoing LEO Sat channel with dynamic Doppler and delay, with CHO mobility

MURATA VOICE OVER NB-NTN

Using CMW500 and our own developed application for low bitrate codecs, this demo shows interactively E2E one way voice over NB-NTN GEO connection, on murata module



KOREA TELEKOM AND KTSAT

Using R&S and Viavi E2E NR-NTN testbed, after a successful PoC of live testing over Ktsat GEO, KT will demonstrate their future capabilities

3GPP Rel-19/20 studies towards 6G

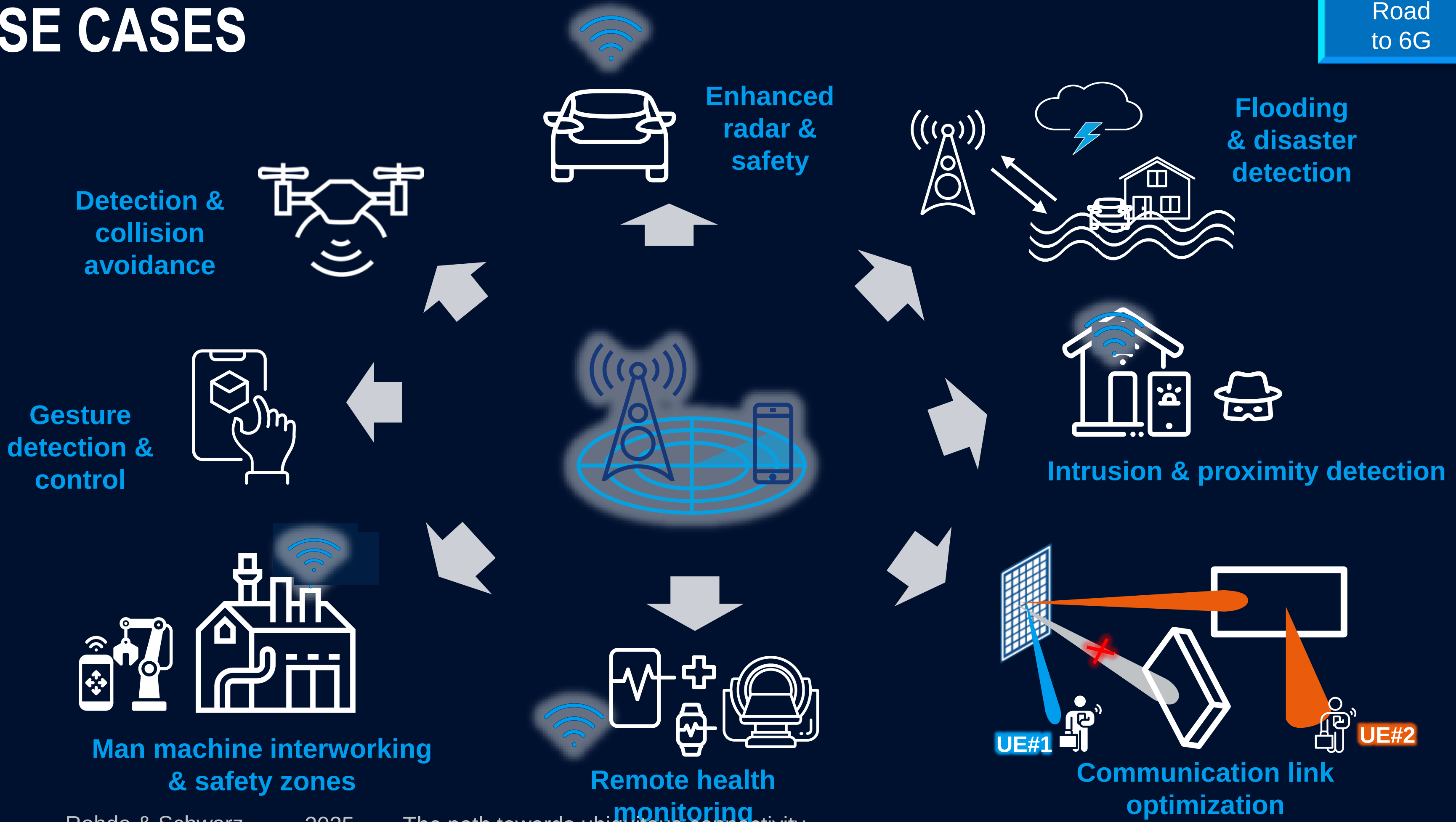
INTEGRATED SENSING AND COMMUNICATIONS (ISAC)

ROHDE&SCHWARZ

Make ideas real

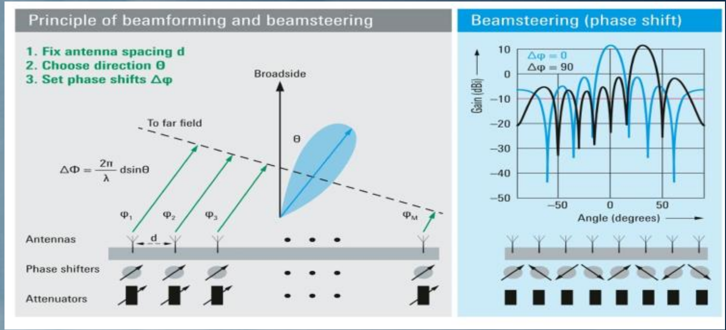
USE CASES

Road to 6G



RADAR AND COMMUNICATION COMMONALITIES

Hardware



Processing

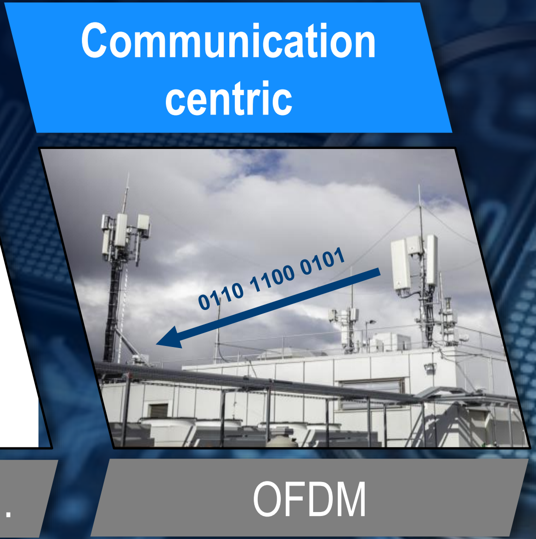
Phased array antennas and beamforming are widely used

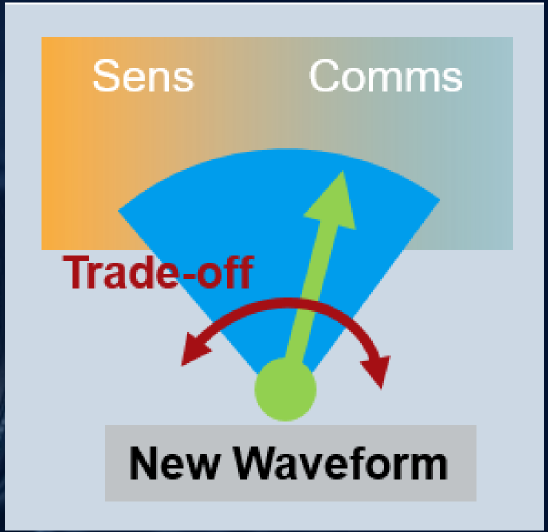
Both benefit from high bandwidth in higher frequency ranges (FR2 and 70 GHz)

Estimation techniques (channel or target) are important

Both benefit from recent increased trends on machine learning

ISAC – RESEARCH CHALLENGES
WAVEFORMS – TWO ENTRY POINTS





- Research challenges:
  - *Adaptable waveform for optimal tuning towards sensing or communication performance*
  - In addition: frequency/bandwidth? Full duplex transceivers? Interference? Distributed sensing?

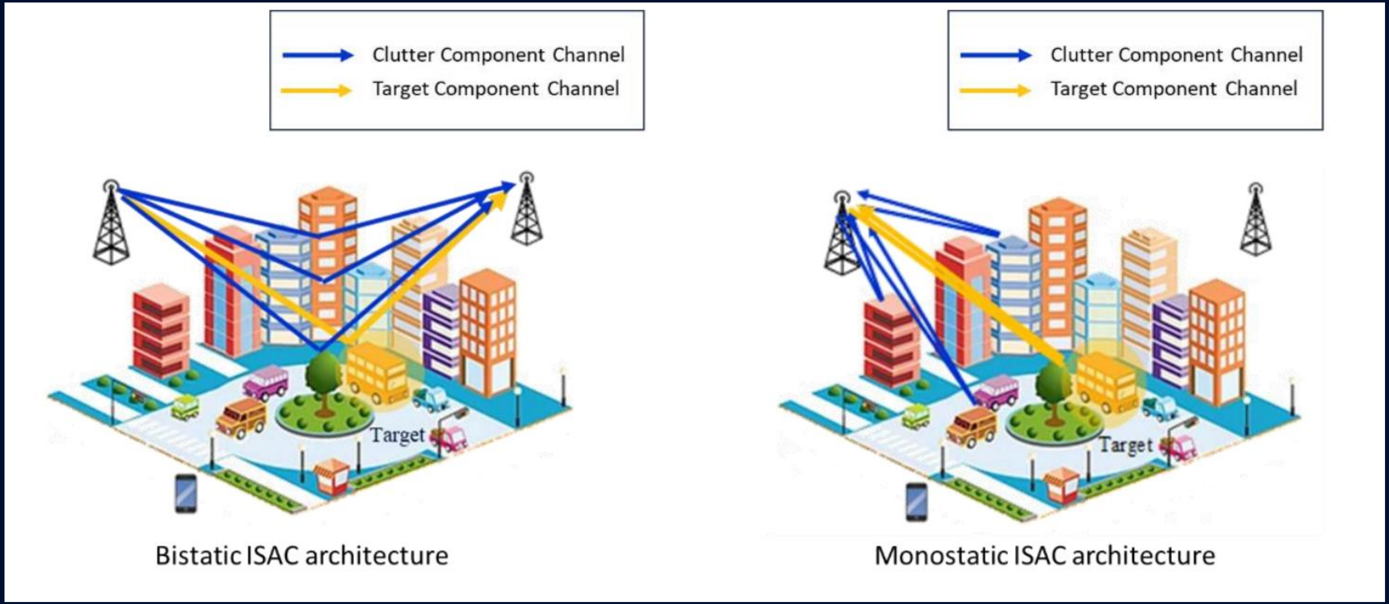
SENSING MODES

		Transmit			
		Network Node		UE	
Receive	Network Node	Monostatic	Bi-/Multistatic	Bi-/Multistatic	
	UE	Bi-/Multistatic		Monostatic	Bi-/Multistatic

Road
to 6G

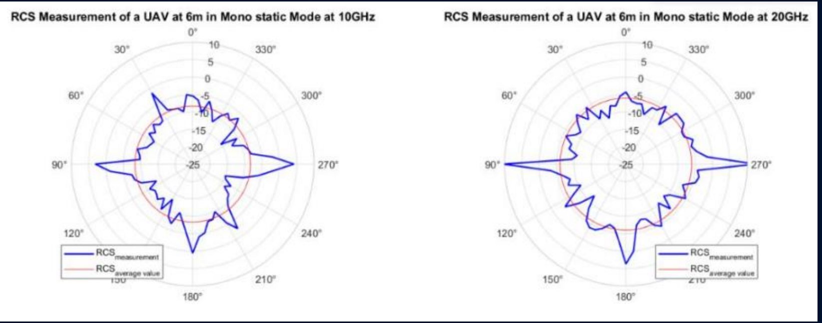
ISAC CHANNEL MODELING FRAMEWORK

$$H_{ISAC} = H_{target} + H_{background}$$

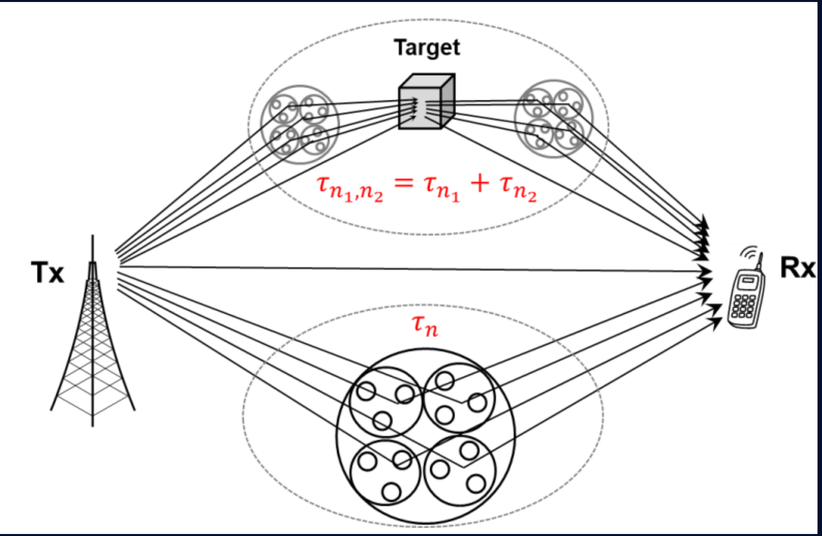


STUDY ITEM INVESTIGATIONS

- Target Radar Cross Section (RCS)



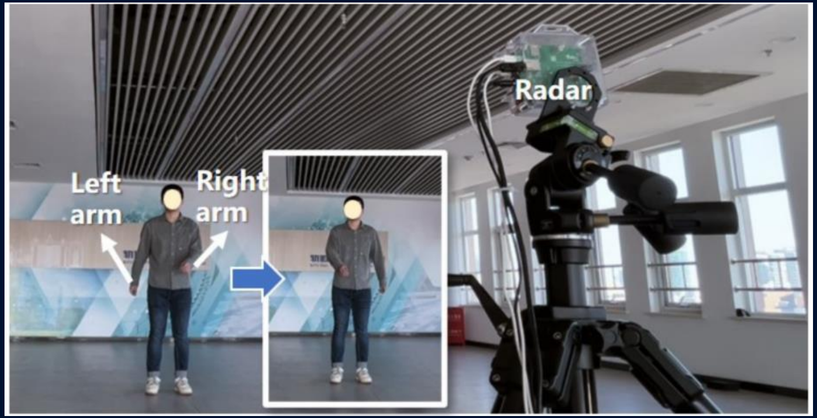
- Target/Background Channel

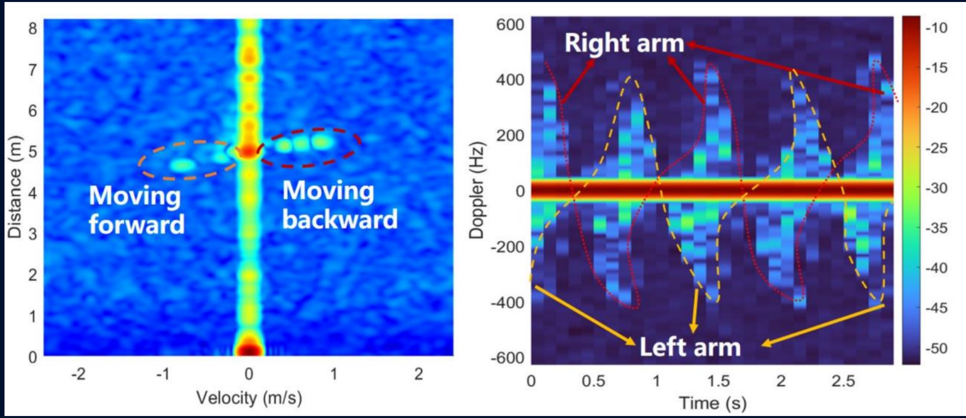


MICRO DOPPLER MODELLING

Applications based on micro doppler analysis:

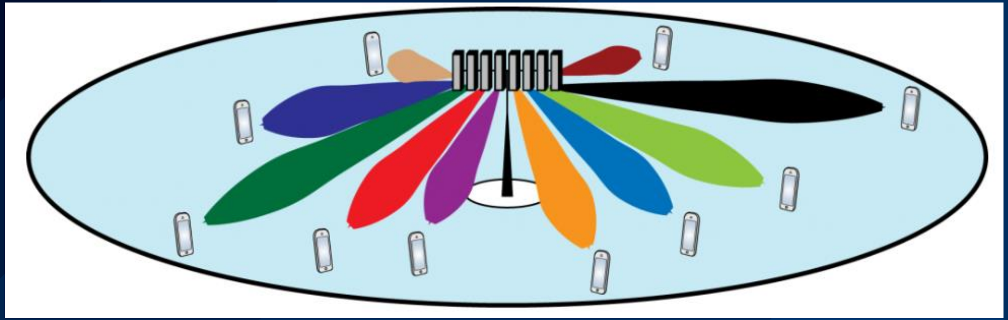
- **Radar Systems**
  To detect and classify moving objects, such as vehicles or people
- **Surveillance and Security**
  To identify specific activities or behaviors,
  such as walking, running, or waving,
  based on the unique micro-Doppler patterns
  they generate
- **Medical Imaging**
  e.g. analyze blood flow or other physiological movements.





Source: 3GPP

MASSIV TO GIGANTIC MIMO

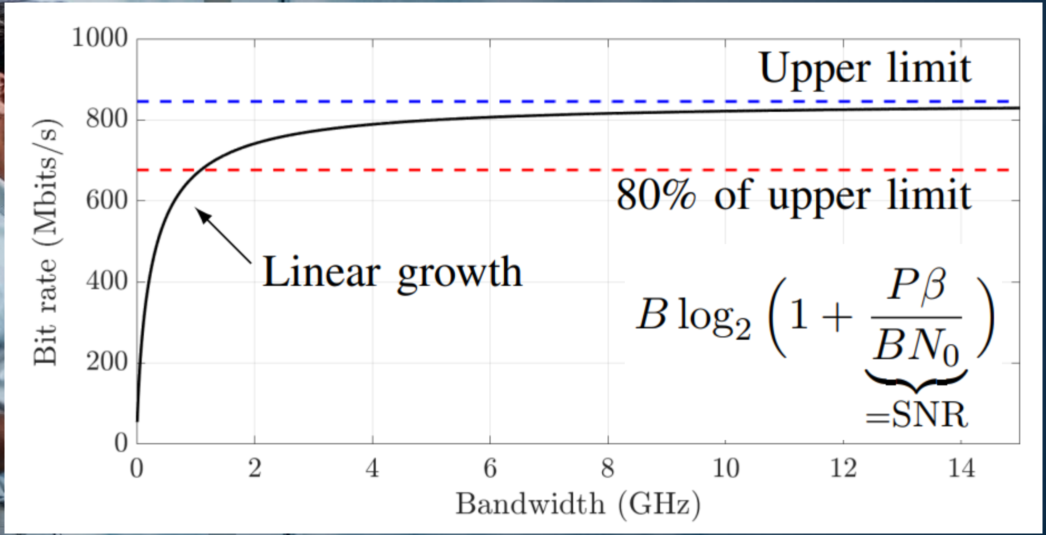


ROHDE&SCHWARZ

Make ideas real

CHANNEL CAPACITY: MORE BANDWIDTH IS NO MORE ANSWER

Road to 6G



channel gain β

So far, bandwidth B is the preferred way to enhance capacity, however, beyond 1 GHz of bandwidth, capacity enters saturation level!

This is because power P is distributed across the bandwidth, which reduces SNR!

Furthermore, channel gain drops with increasing operating frequencies!

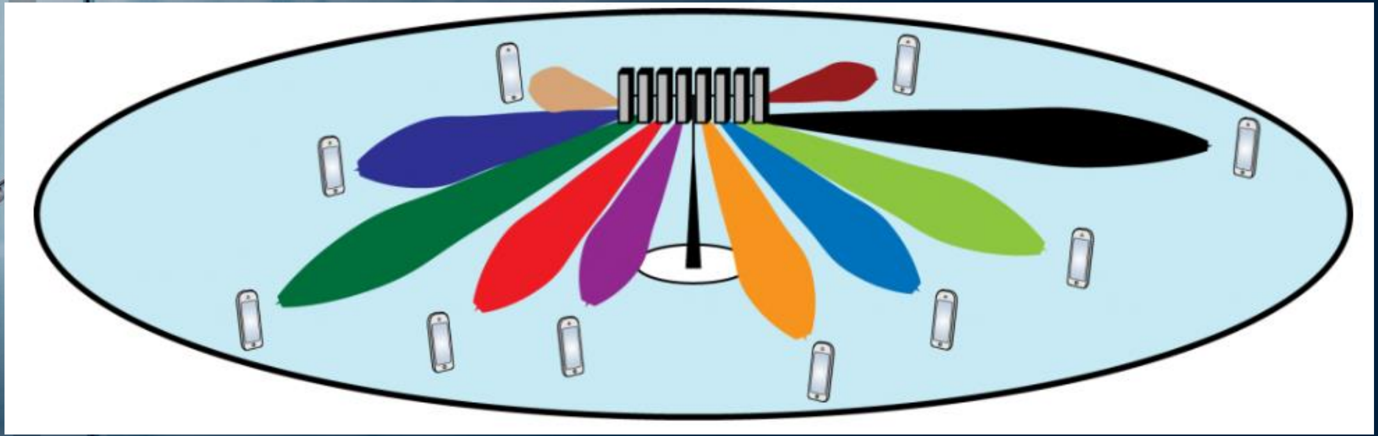
To combat SNR “loss” with increasing bandwidth and channel gain loss with increasing operating frequencies, beamforming is the only way out!

Source: BJÖRNSON et al.: Massive Spatial Multiplexing: Vision, Foundations, and Challenges, 2023

MASSIVE MU-MIMO: Coverage AND Capacity increase

Road to 6G

In a nutshell, massive MIMO (mMIMO) uses a base station with many antennas (e.g., ≥ 64) to deliver large array gains and perform spatial multiplexing of many users on the same time-frequency resource.

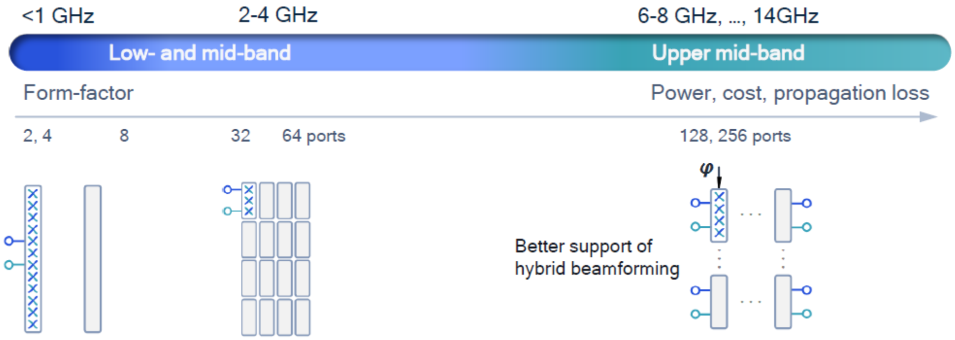


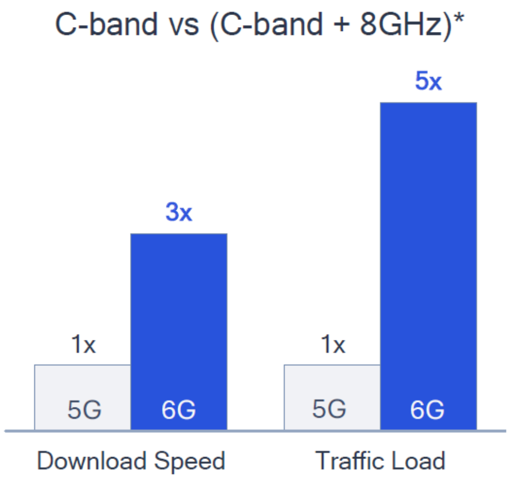
Source: BJÖRNSON et al.: POWER SCALING LAWS AND NEAR-FIELD BEHAVIORS OF MASSIVE MIMO AND INTELLIGENT REFLECTING SURFACES, IEEE ComSoc Vol. 1 - 2020

6G DL CAPACITY BOOST WITH GIGA-MIMO

Qualcomm's prototype Giga-MIMO system supports mobile communications in the 13 GHz band with 4,096 antenna elements and 256 digital chains in a form factor comparable to 5G base stations

Increasing degrees-of-freedom for higher-rank SU and higher-order MU





Detailed results

* Assumptions: C-band 100 MHz, 8 GHz 400MHz; Traffic load for sustained edge download speed of 100Mbps

Network side (digital-dominant)

- HBF MU-MIMO
- SRS enhancement
- CSI enhancement
- DMRS enhancement

**Rel-19 introduces 128-port CSI already*

Device side

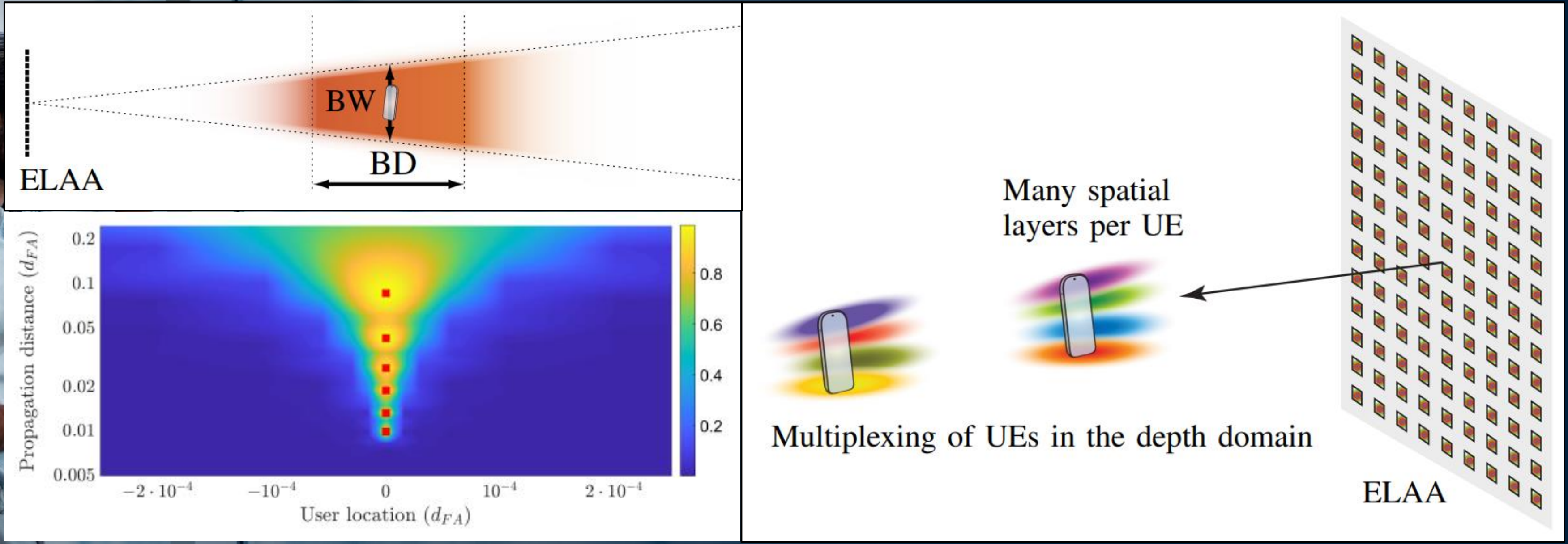
- Up to 4Tx/8Rx for phones, more for CPE/FWA
- Sharing discrete antennas across bands
- Network-assisted antenna selection

HBF = Hybrid BeamForming

5X capacity by adding G-MIMO upper midband to 3.5 GHz without densification

Source: 3GPP 6GWS-250068

Near-Field Beamforming: True 3D spatial multiplexing

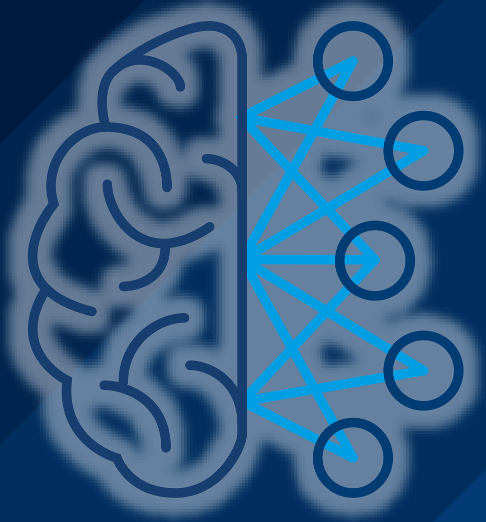


ELAA (Electrically large Antenna Arrays) can act like a lens that **focuses the signal on a specific location** (BW x BD) in the near field, instead of a specific direction in the far-field. This offers multiplexing in the depth domain, too!

Source: BJÖRNSON et al.: Massive Spatial Multiplexing: Vision, Foundations, and Challenges, 2023

AI/ML TO SUPPORT RADIO COVERAGE AND PERFORMANCE

*AI/ML – Artificial Intelligence / Machine Learning



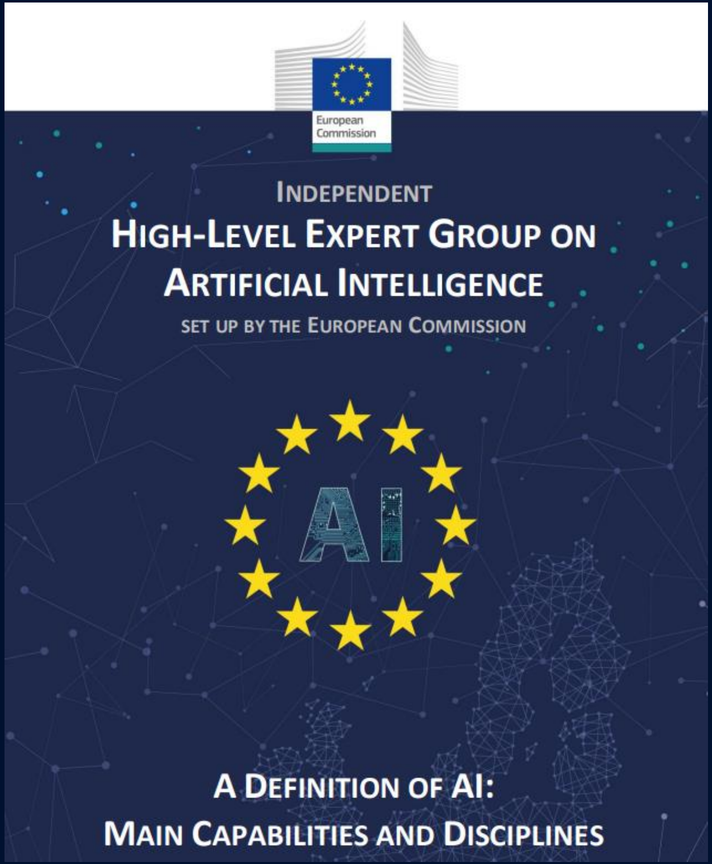
ROHDE&SCHWARZ

Make ideas real

WHAT IS AI ?

- AI referes to systems designed by humans that, given a complex goal, act in the physical or digital world by perceiving the environment, interpreting the collected structured or unstructured data, reasoning on the knowledge derived from this data and deciding the best action(s) to take (according to pre-defined parameters) to achieve the given goal. AI systems can also be designed to learn to adapt their behaviour by analysing how the environment is affected by their previous actions.

- AI in wireless: Perceiving the radio environment:
  – $r(t) = h(t) \cdot s(t) + n(t)$



AI IN WIRELESS COMMUNICATIONS

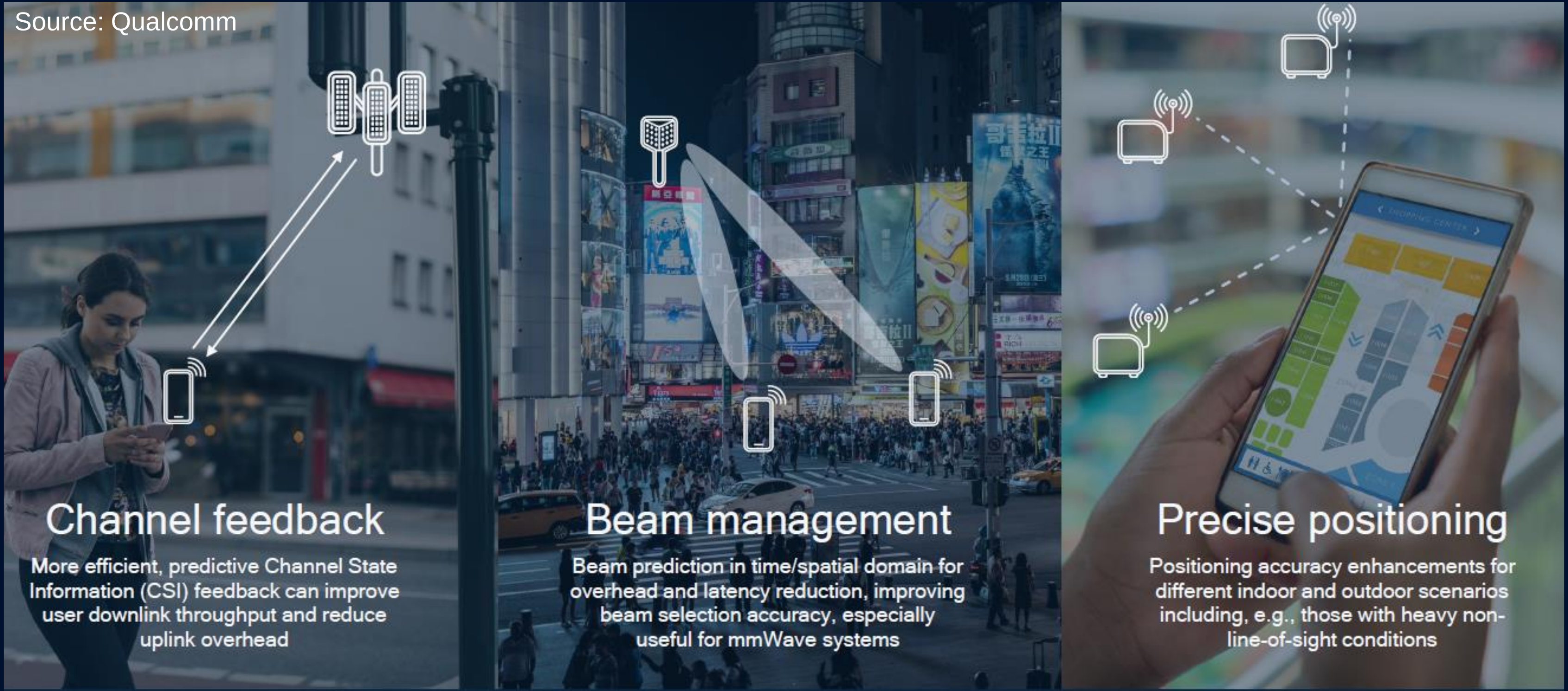
Today, we already experience AI capabilites, defined by the following five key features:

1. Logical reasoning, e.g., AlphaGo
2. Perception, e.g., face recognition
3. Knowledge representation, e.g., IBM’s Watson for Oncology
4. Language processing, e.g., Apple’s Siri, Amazon’s Alexa
5. Planning and navigation, e.g. self-driving cars

With Machine Learning (ML) capabilities systems can learn from huge data sets, e.g. radio network data to improve radio link operation in terms of spectral and energy efficiency.

Road to 6G

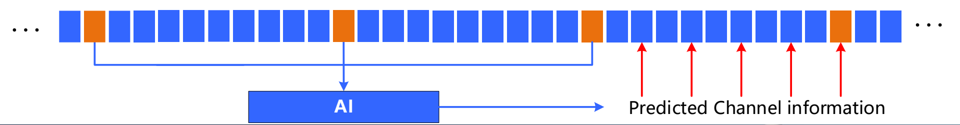
REL-19 AI FOR WIRELESS FOCUS



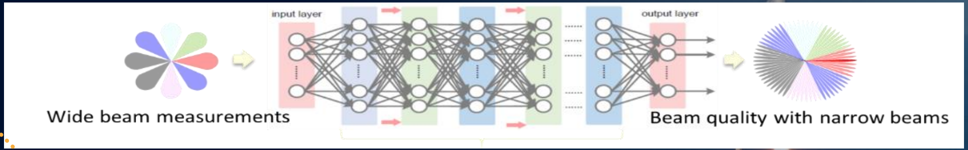
THREE PILOT USE CASES IN 3GPP RELEASE 18 AND 19

- CSI feedback enhancements
  - Compression and prediction

Remains a study item in Rel-19

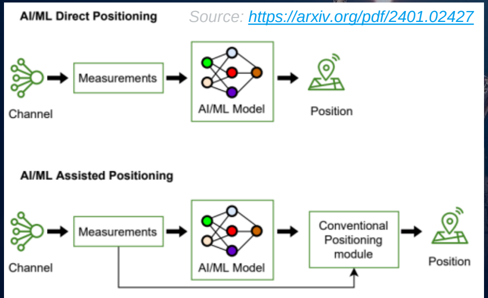


- Beam management
  - Beam prediction in time, and/or spatial domain for overhead and latency reduction, beam selection accuracy improvement



- Positioning accuracy enhancements
  - Heavy Non-Line of Sight (NLOS) conditions

Transferred to a work item in Rel-19

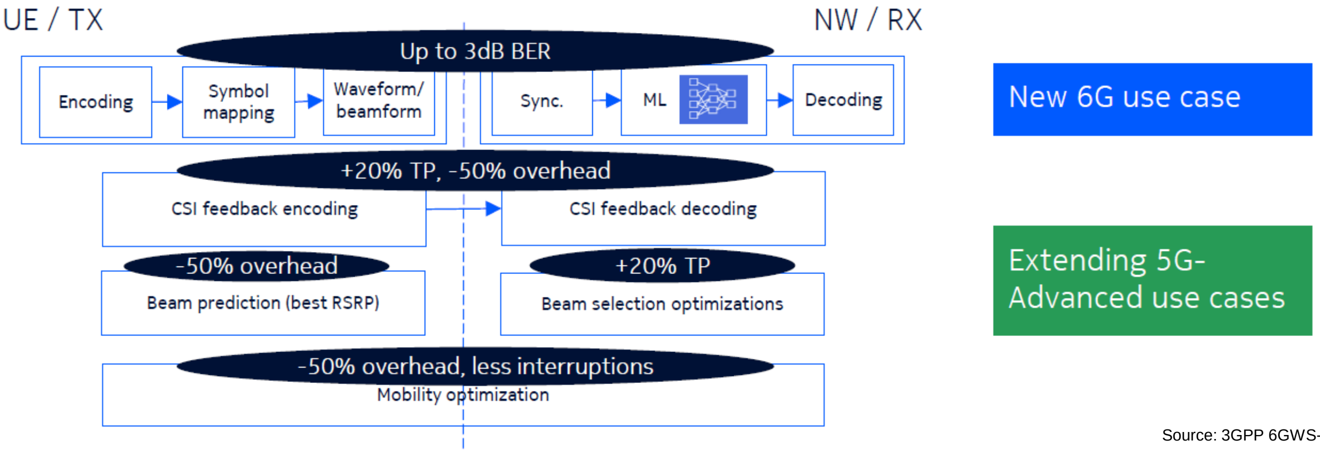


- New RAN2-led study item in Rel-19: AI/ML for mobility in NR

AI/ML ENABLED RADIO INTERFACE PERFORMANCE BOOST POTENTIALS

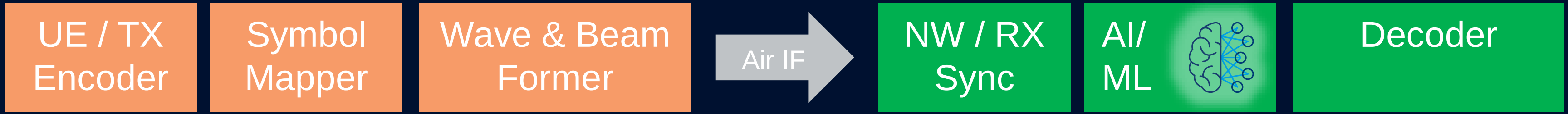
Road to 6G

- Future-proof AI/ML framework enabling continually improving 6G radio
- New and extended use cases for 6G radio
- Integrate AI/ML-based solutions into the fundamental design of the 6G Air-Interface to ensure that the 6G day one specifications enable AI/ML-based implementations alongside to conventional approaches



Source: 3GPP 6GWS-250004

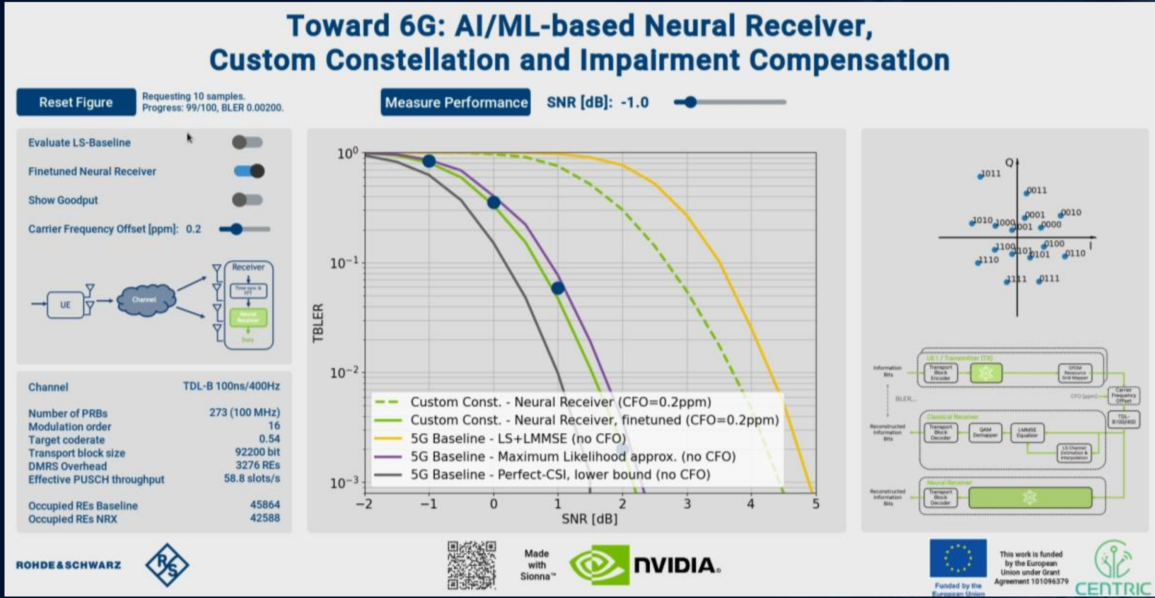
ENHANCE UL COVERAGE: AI ENABLED HIGH SENSITIVITY NETWORK RECEIVERS

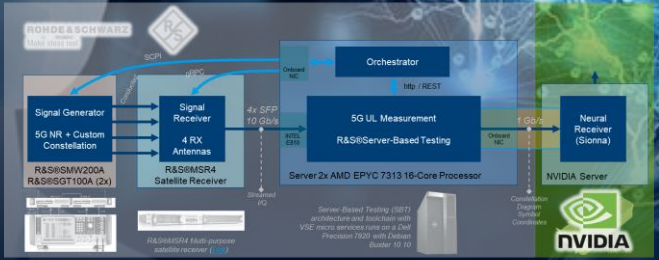


- AI / ML receiver benefits
  - Deals with HW impairments/non-linearites
  - Reduces pilot signal overhead
  - Allows radio channel adaptation (e.g. customized constellation shape)
- Simulations and prototype deployments show 1 – 3 dB sensitivity improvements

- 3GPP design impact
  - Machine Learning support
    - e.g. with tailored pilot sequences
  - To unleash full AI/ML potential:
    - Specifiy e.g. pilotless transmission
    - Support higher QAM orders (e.g. up to 4K QAM)
    - Relax EVM requirements and inband emissions
  - AI/ML RX implementation remains proprietary

DEMO AT MWC2025





AI-NATIVE RADIO PROTOCOLS ?

Protocol adapts to the user experience instead of the user experience being defined by the protocol behavior

Paradigm shift

- Current configuration options in the user plane do not support a range of performance that allows the device to match App requirements
- Standard is defined to produce predictable performance and simple compliance test of protocol functions instead of allowing flexibility to adapt to various scenarios

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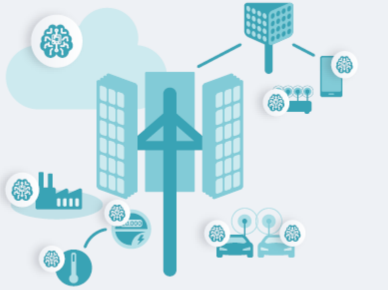

Leveraging AI capabilities

- Continual improvement through self-learning
- Data-driven development of AI models responsive to user experiences and services
- Dynamic parameter adaptation based on fast machine learning algorithms hosted at the device and assisted by the cloud

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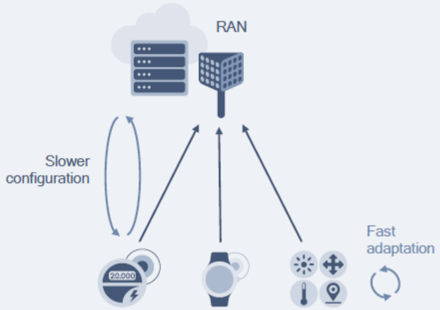

User experience optimization

- Slower network configuration to define a range of behavior within which the device can autonomously adapt based on current state
- Device's contextual awareness determines how to support user experience based on real-time application requirements and local conditions

Source: 3GPP 6GWS-250068

CONCLUSION: „KEEP IT SIMPLE AND USE AI“

- Standalone RAN only for the sake of simplifiation and efficiency
  - Limited backward compatibility to 4G, none to 3G and 2G
- Coverage and capacity enhancements towards ubiquitous connectivity
  - with given spectrum and focus on FR1 and FR3
  - FR2 usage focus on FWA
  - Avoid need for RAN densification (MU-MIMO, UL coverage enhancements)
  - Spectral efficiency improvement by AI/ML, advanced MCS (e.g. non-uniform constellations)
  - NTN Device-to-Device communication from day 1
- Sustainability
  - Re-use existing network HW
  - Save energy in network and user equipment

#ThinkSix – Video Series

The #ThinkSix video series explores important topics relevant to the question of what is beyond 5G. We will follow the surrounding discussions and work with partners and customers to support this initial phase of research on the road to 6G

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6G Overview and vision

Rohde & Schwarz is not just an observer; we're actively shaping the future of 6G as part of various research projects. Join us on this journey toward a wireless world. Together, we'll make it extraordinary.

#ThinkSix - Validating a Machine-Learning Based Neural Receiver with 5G NR Multiple MIMO Signals

Using Machine Learning (ML) powered by Artificial Intelligence for signal processing tasks in wireless communication really is beginning to move from theory to practice. Watch this video for a demonstration of the first hardware setup capable of validating the performance of a self-training neural receiver.

#ThinkSix - Phase noise characterization in the D-band

This video introduces the topic of phase noise, demonstrates a test setup for investigating phase noise for the latest communication systems, and with D band (110-170 GHz) frequencies a hot tip for 6G research.

Thank you very much