THE PATH TOWARDS 6G

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Agenda

- ► The ITU IMT-2030 program: setting the scene for 6G
- ► Integrated Communication and sensing: adding the 6th sense to mobile communications
- ► Reconfigurable Intelligent Surfaces: shaping the radio channel for more efficiency and capacity
- ► AI and ML in radio communications: is there any benefit?

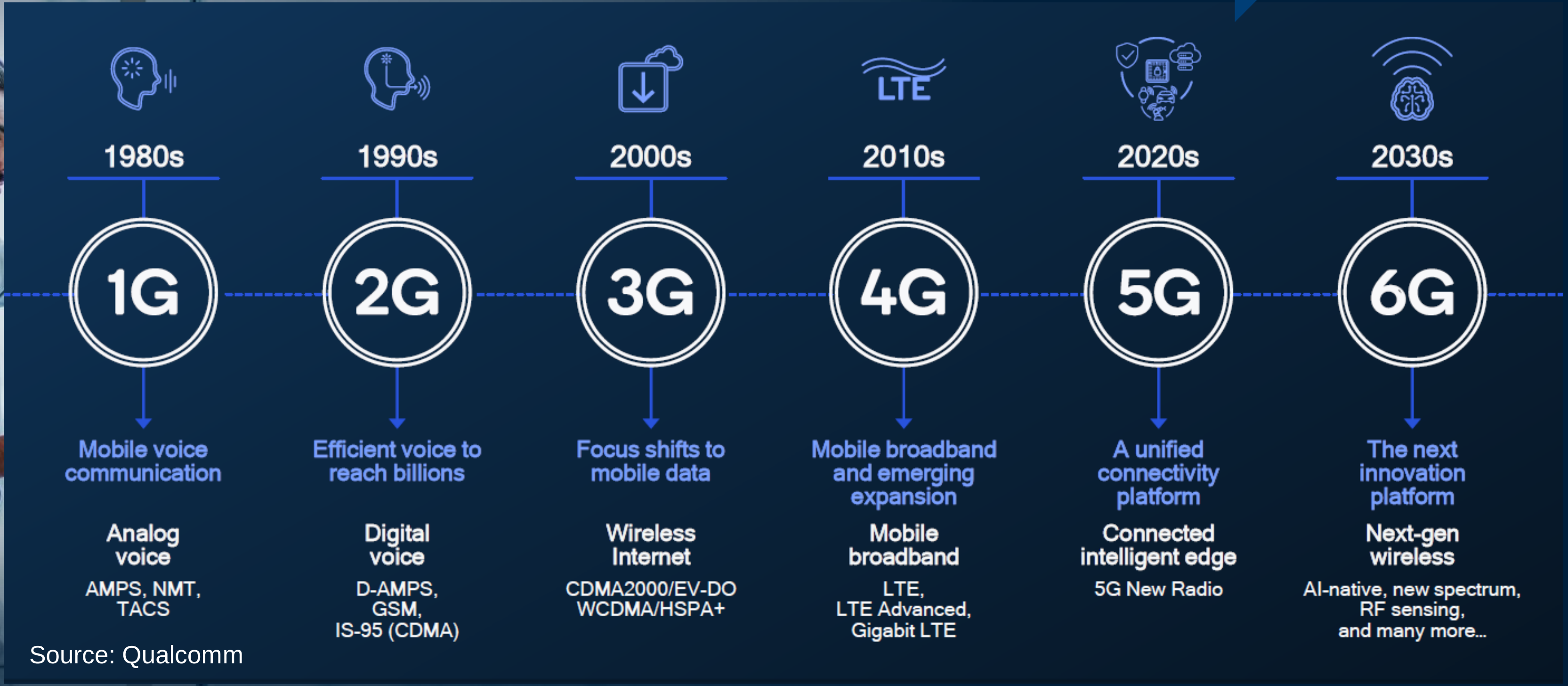
It‘s official: IMT-2030 = 6G

- The International Telecommunication Union (ITU) adopted a resolution that will guide the development of **6G standards and 6G radio interface technologies**.
- In addition to that, they also adopted the **new Recommendation ITU-R M. 2160** on the **“IMT-2030 Framework”** setting the basis for the development of IMT-2030.

Source: https://www.6gworld.com/exclusives/itu-officially-sets-agenda-for-the-6g-development/

New generations every 10 years …

3GPP: Global Standards



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

IMT-2030 framework

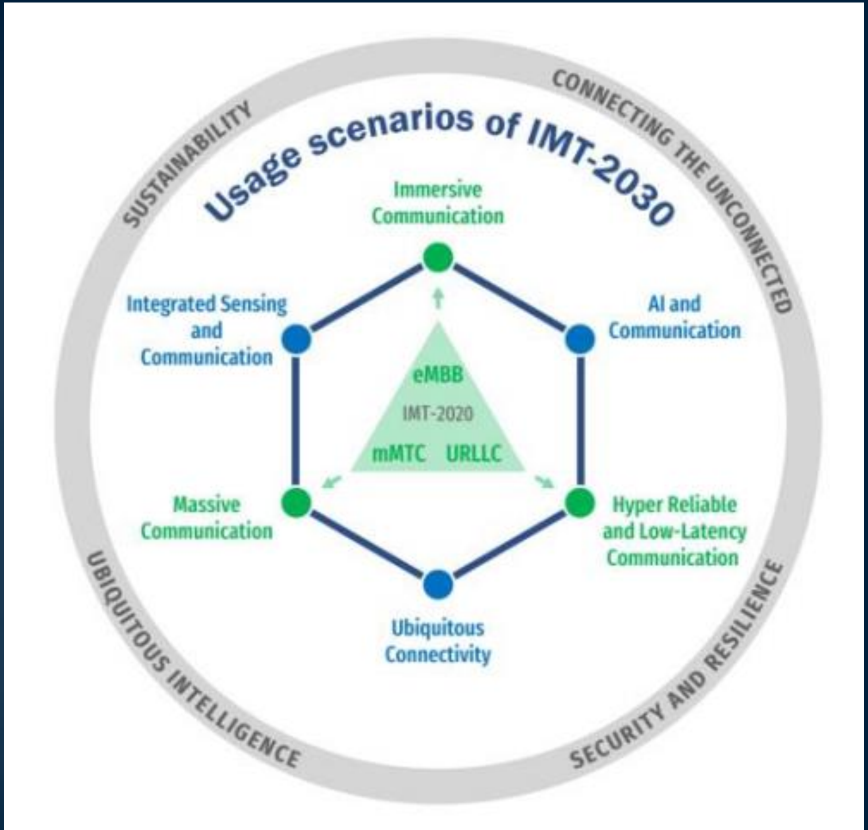

ITUPublications
Recommendations

International Telecommunication Union
Radiocommunication Sector

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

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

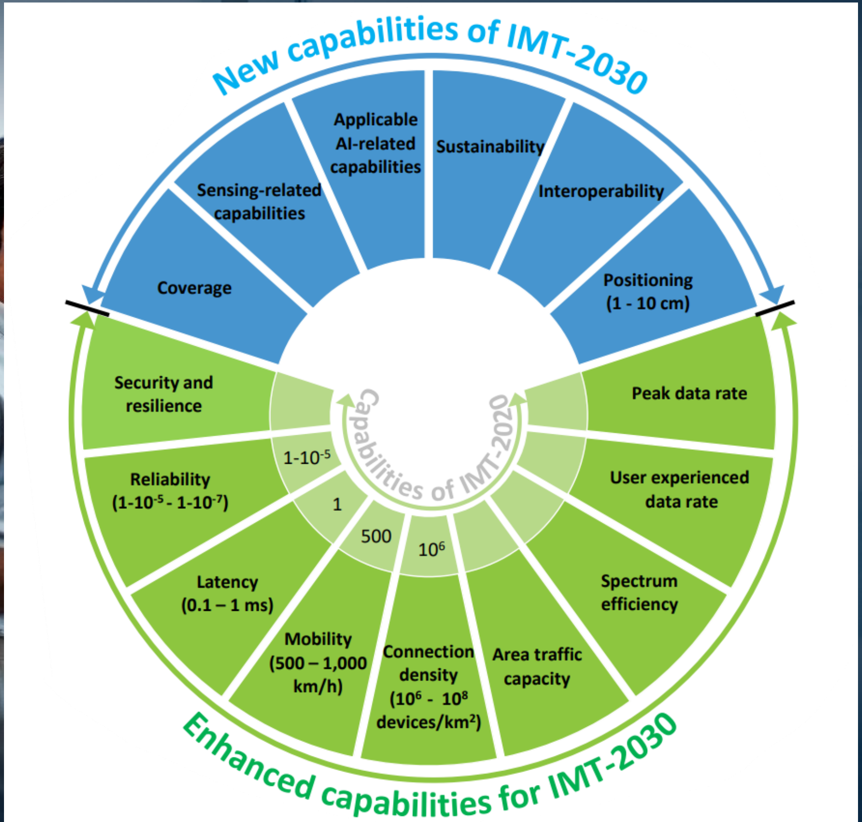
Framework and overall objectives of the future development of IMT for 2030 and beyond



In 5G we had 3 different categories, representing 3 different network slices: eMBB, mMTC and URLLC. 6G will extend those and add 3 more categories!

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

IMT-2030 capabilities



- **Peak data rate**
  Maximum achievable data rate under ideal conditions per device.
  50, 100, 200 Gbit/s are given as possible examples.
- **User experienced data rate**
  Achievable data rate that is available ubiquitously across the coverage area to a mobile device.
  300 Mbps and 500 Mbps are given as possible examples.
- **Spectral efficiency**
  Spectrum efficiency refers to average data throughput per unit of spectrum resource and per cell. Values up to 3 times greater than that of IMT-2020 could be a possible example.
- **Mobility**
  Maximum speed, at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/multi-RAT) can be achieved. The target of mobility could be 500 – 1 000 km/h.
- **Latency over the air interface**
  Target is 0.1 – 1 ms

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

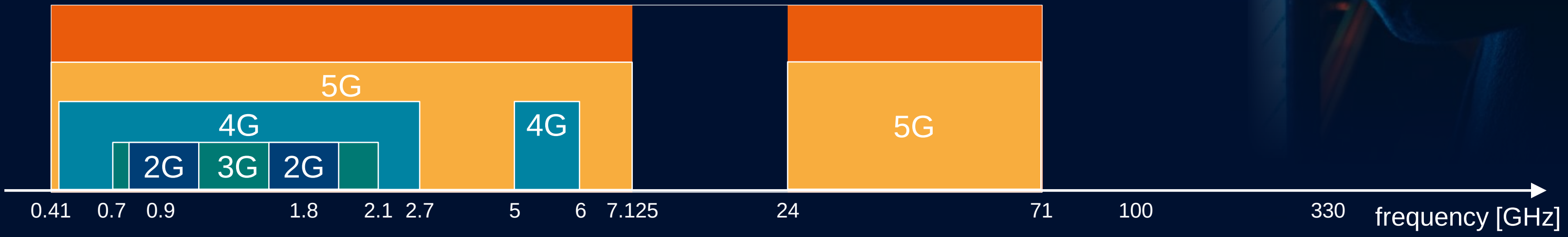
IMT-2030 Technologies to enhance air interface

- **Extreme MIMO (E-MIMO)**
  - new types of antenna arrays, much larger-scale antenna arrays, a distributed mechanism, and AI assistance.
- **Technologies with potential to tackle traditional antenna array beamforming challenges**
  - Reconfigurable intelligent surfaces (RIS)
  - Holographic radio (HR)
- **Ultra-wide bandwidth (multiple GHz)**
  - To support positioning/sensing accuracy
  - mmW and subTHz range
- **Self-interference cancellation (SIC) technology in devices and networks**
  - to enable in-band full duplex (IBFD) in future mobile communications

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

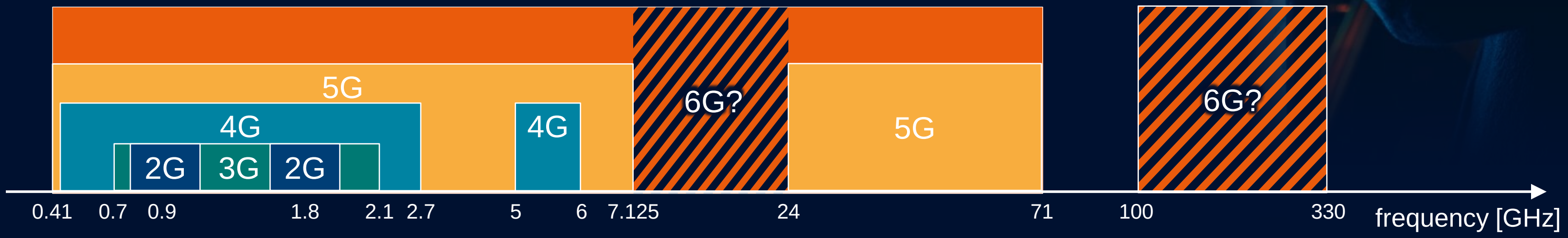
Remember: WRC-19 identified a lot of new spectrum for IMT-2020

- 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?
  - WRC-23 said no! Thus, no more spectrum was allocated for IMT-2023 this time!



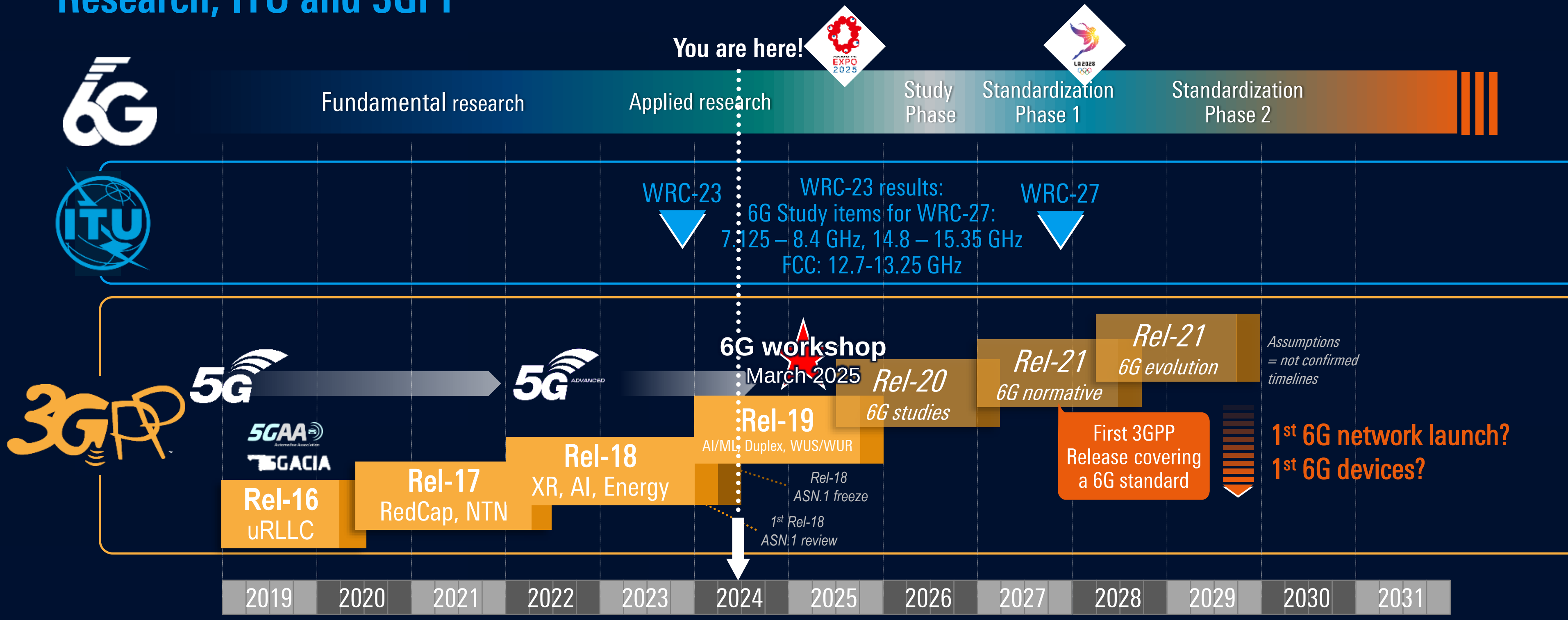
Next WRC-27 spectrum discussions

- WRC-27 New Agenda Item on IMT Frequency Studies
  - 4400 – 4800 MHz, or parts thereof, in region 1 and region 3;
  - 7125 – 8400 MHz, or part thereof, in region 2 and region 3;
  - 7125 – 7250 MHz and 7750 – 8400 MHz, or part thereof, in region 1;
  - 14.8 – 15.35 GHz – this might become the “FR3” range in 3GPP (study item ongoing)
- No Agenda Item for Frequencies > 100GHz!
- WRC-27 new satellite agenda item on
  - direct connectivity between space stations and IMT UE to complement terrestrial IMT network coverage (694 MHz - 2.7 GHz)



6G Phases and Timeline

Research, ITU and 3GPP



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 AN T&M PERSPECTIVE

6G introduces many new technology components

- 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

Joint Communication And Sensing (JCAS)

a.k.a.

Integrated Sensing And Communications (ISAC)

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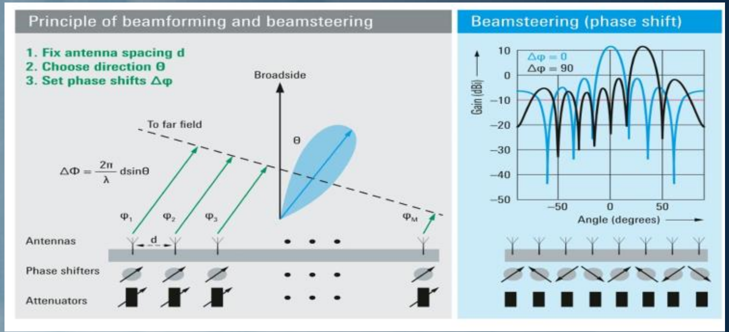
RADAR AND COMMUNICATION COMMONALITIES

Hardware



Processing

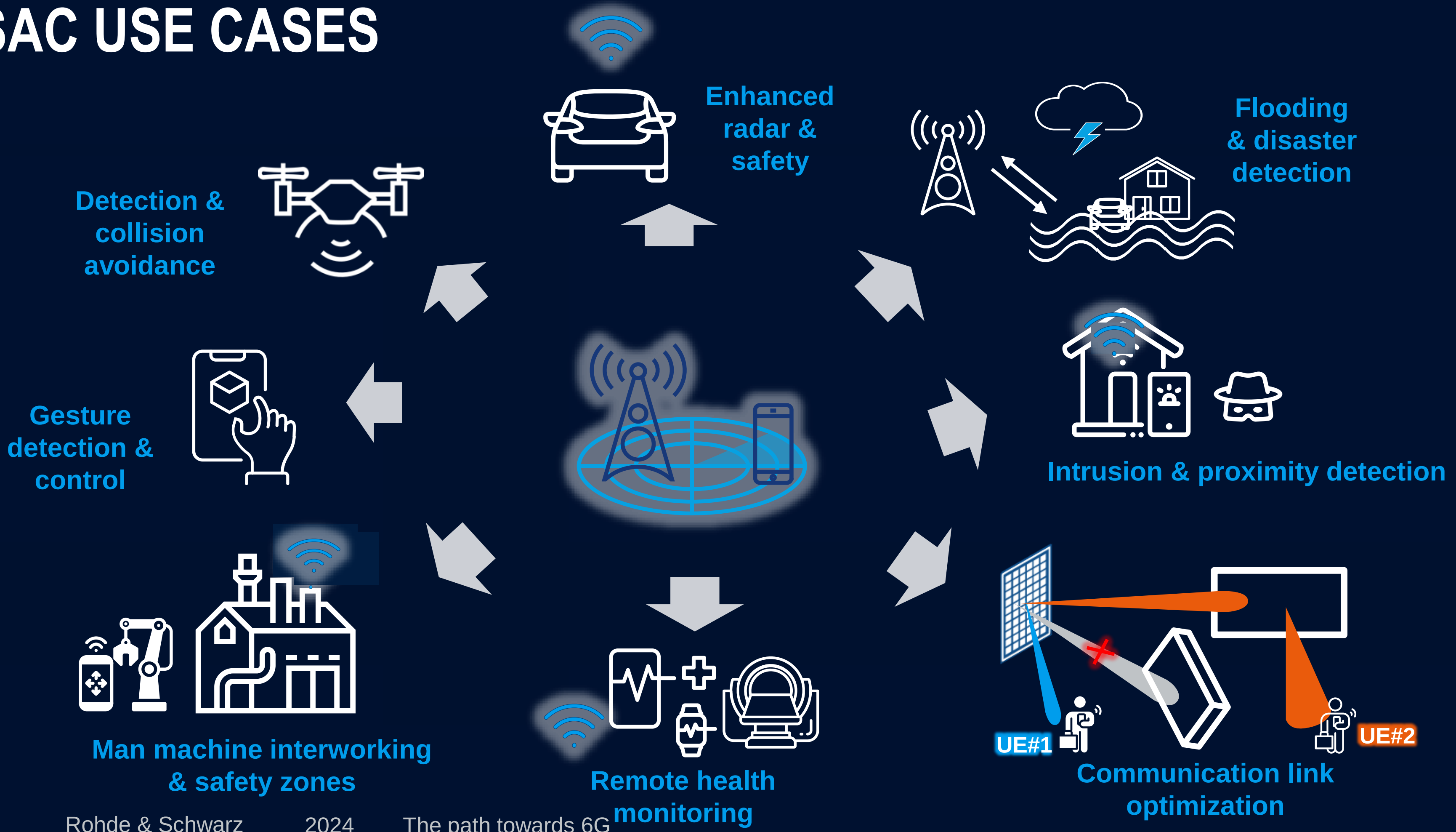
Phased array antennas and beamforming are widely used

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

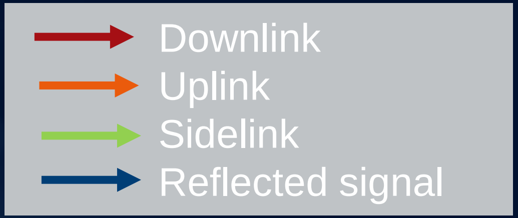
Estimation techniques (channel or target) are important

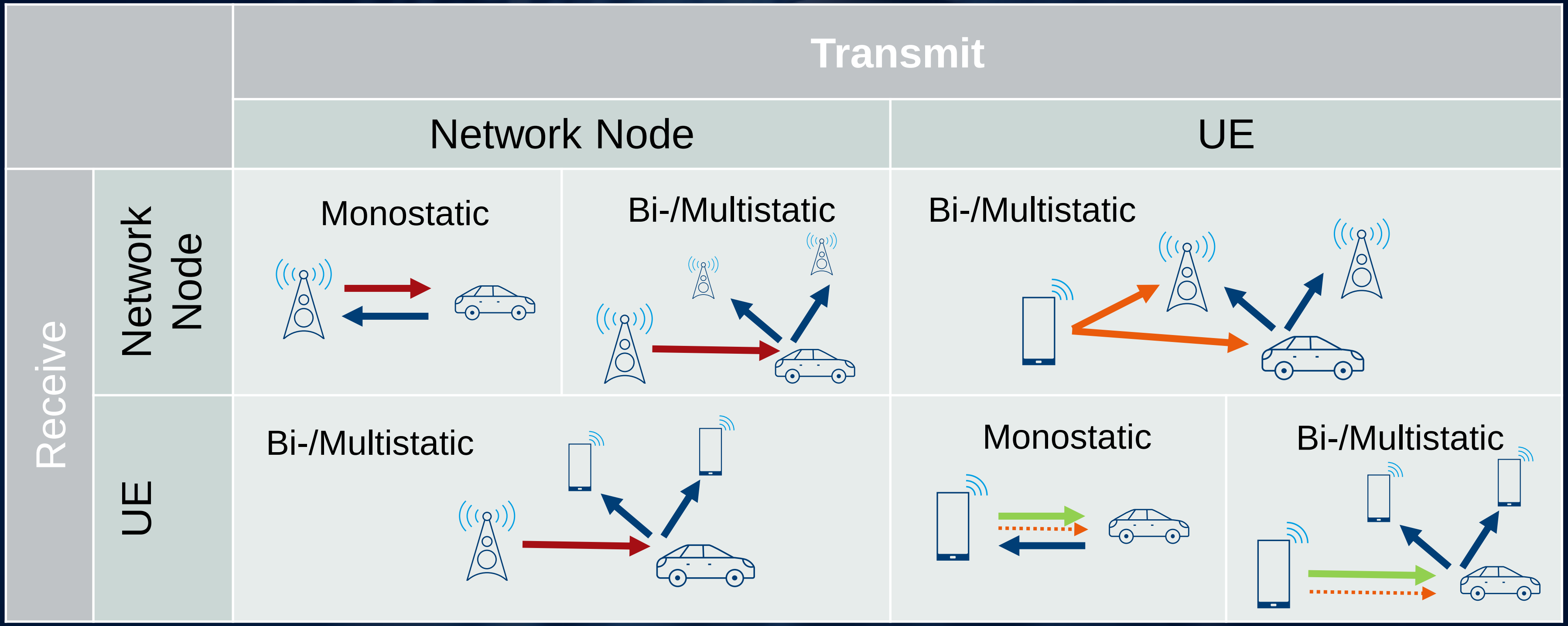
Both benefit from recent increased trends on machine learning

ISAC USE CASES



SENSING ARCHITECTURES





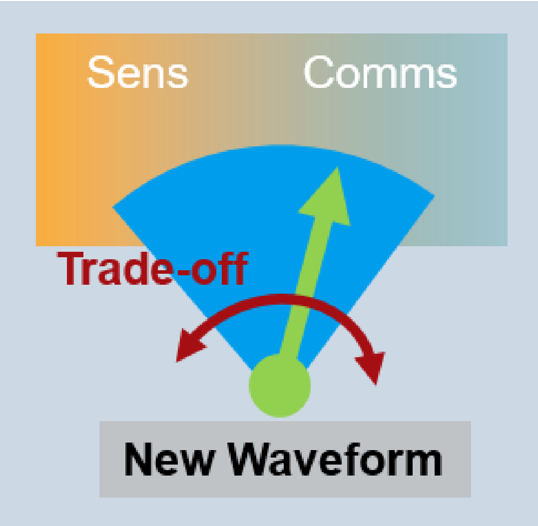
ISAC – RESEARCH CHALLENGES
WAVEFORMS – TWO ENTRY POINTS

Radar centric

PMCW, FMCW, …

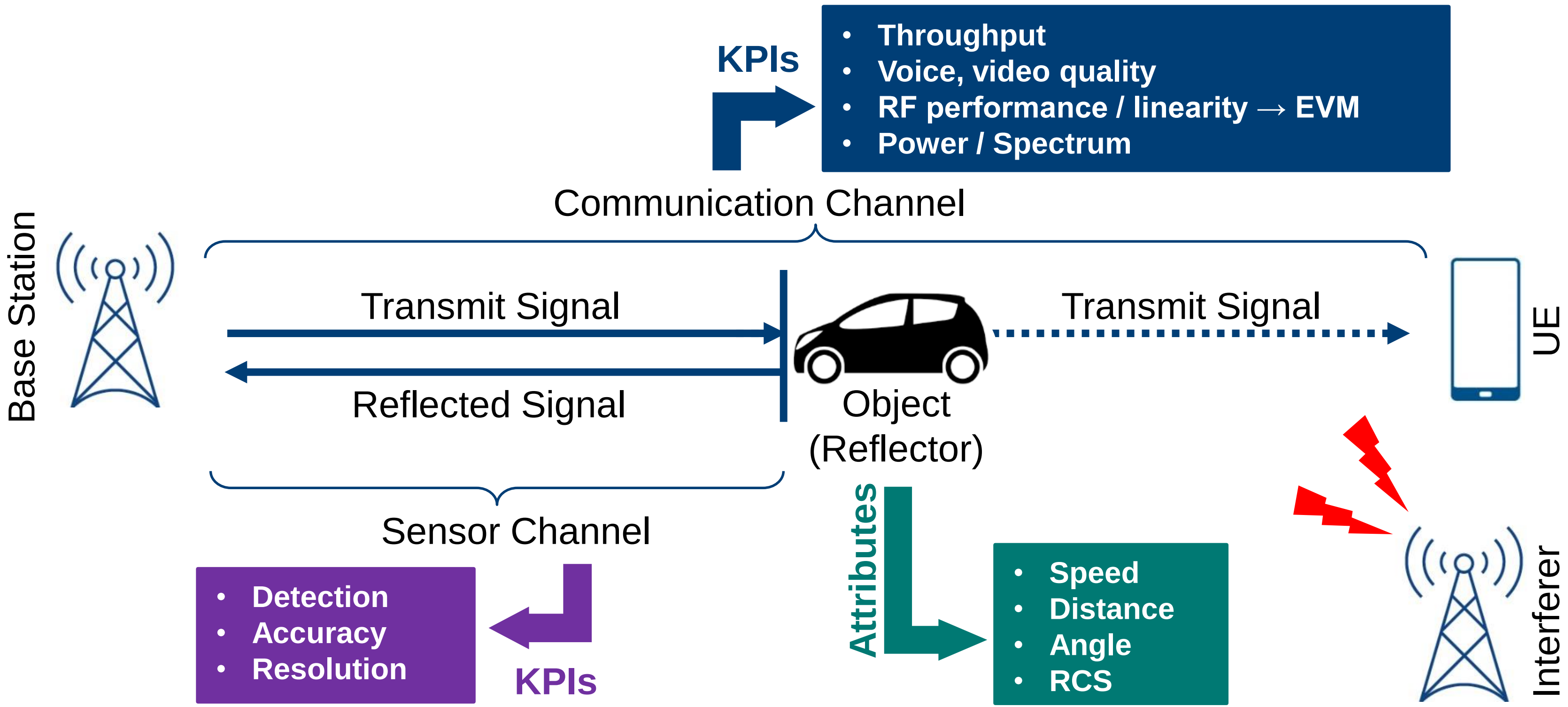
Communication centric

OFDM

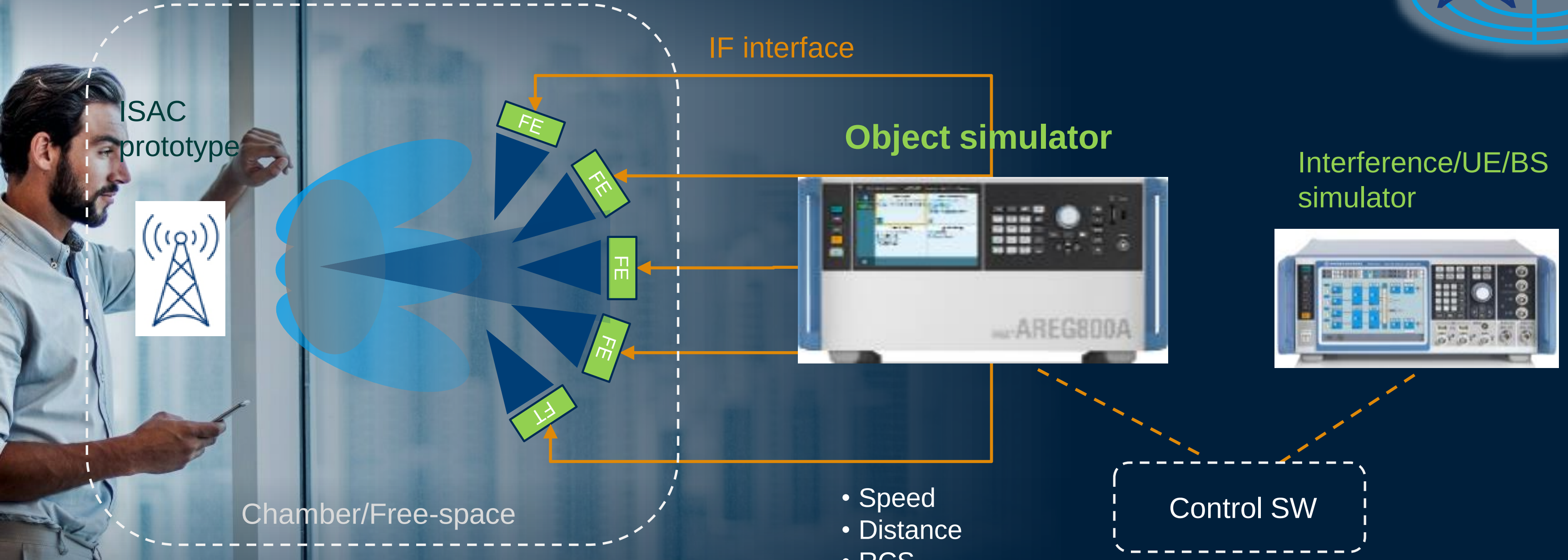


- Research challenges:
  - *Adaptable waveform for optimal tuning towards sensing or communication performance*
  - In addition: frequency/bandwidth? Full duplex transceivers? Interference? Distributed sensing?

ISAC: TESTING CONSIDERATIONS



R&S ISAC SENSING TEST APPROACH



- Speed
- Distance
- RCS

KomSens 6G

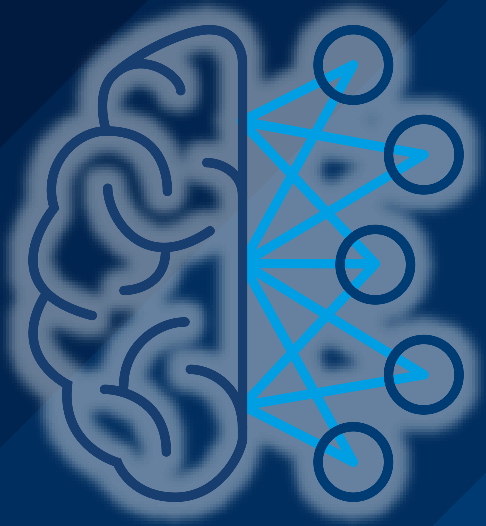
Perceptive communication networks with integrated sensor technology for 6th generation mobile communications

Federal Ministry of Education and Research

Live Demo at 6G conference in Berlin, 2024:

Live Demo at Open6G hub:

AI/ML FOR WIRELESS

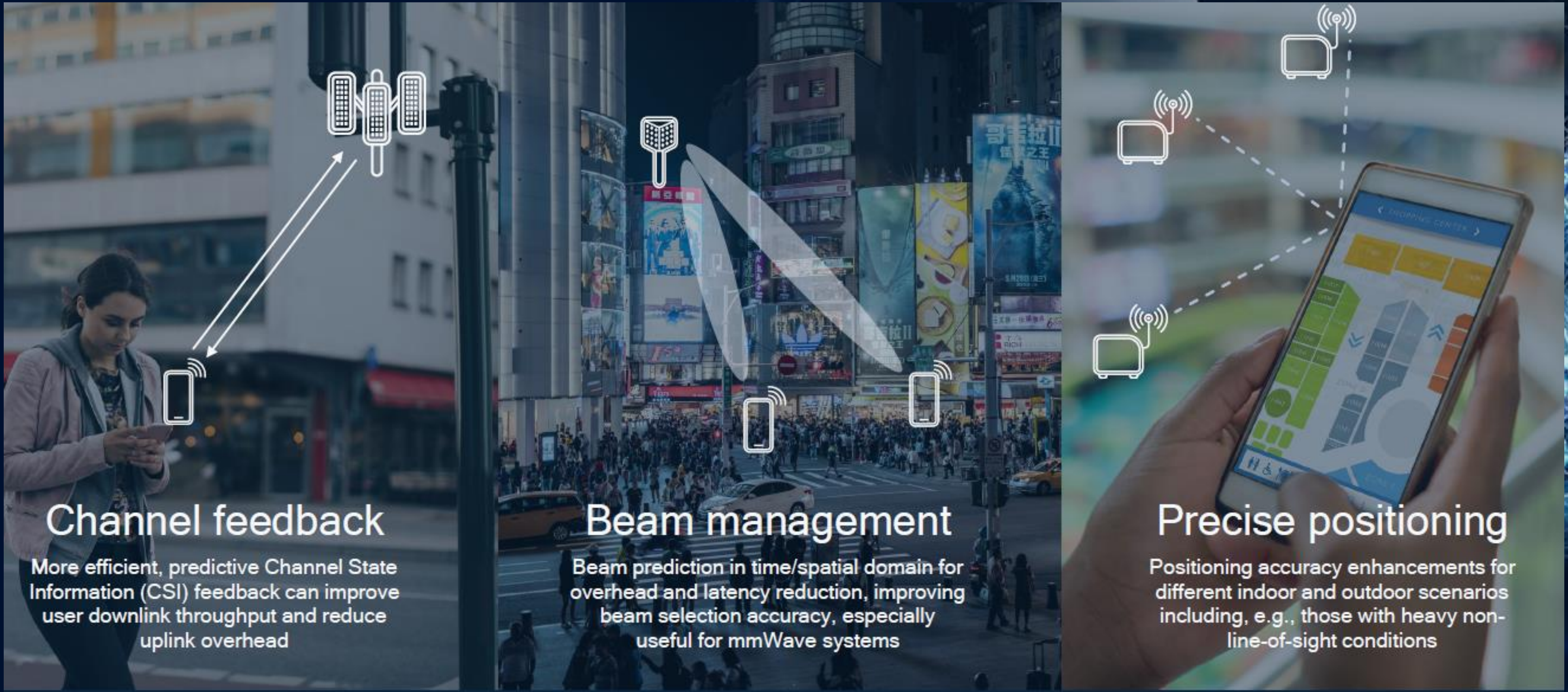


*AI/ML – Artificial Intelligence / Machine Learning

ROHDE & SCHWARZ

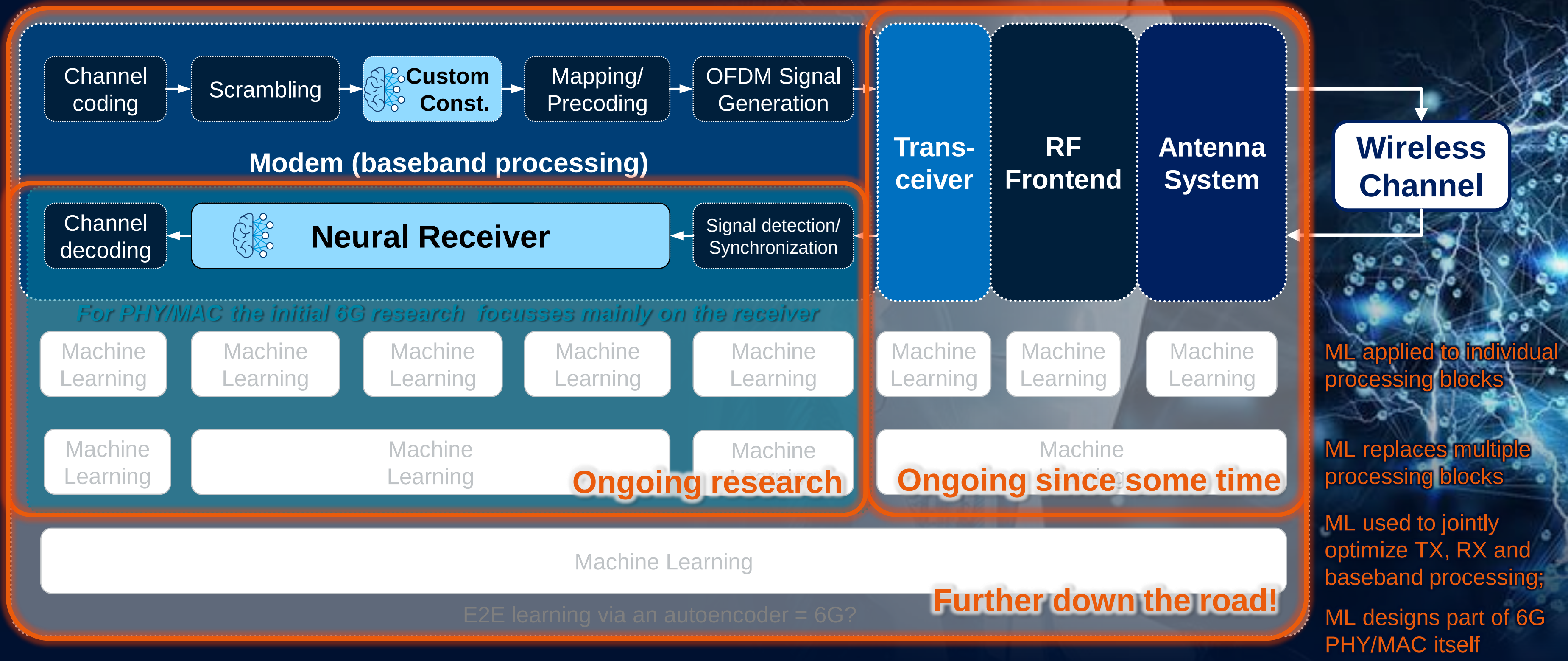
Make ideas real

AI FOR WIRELESS: 3GPP R18/R19 FOCUS



Source: Qualcomm

SO, WHAT POTENTIALLY COMES NEXT?
AI-NATIVE AIR INTERFACE FOR 6G?



NEURAL RECEIVER TESTBED

MWC 2023

Industry-first Neural RX Testbed

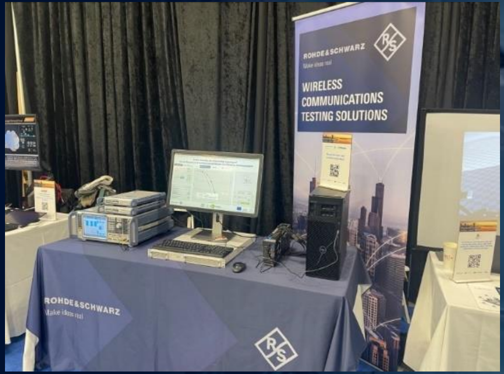
Munich / 21-Feb-2023

Towards 6G: Rohde & Schwarz showcases AI/ML-based neural receiver with NVIDIA at MWC Barcelona

With research on the technology components for the future 6G wireless communication standard in full swing, the possibilities of an AI-native air interface for 6G also are being explored. Rohde & Schwarz, working with NVIDIA, is taking a step forward from simulations to implementing artificial intelligence and machine learning (AI/ML) in future 6G technology. At MWC Barcelona, the companies will present the industry's first hardware-in-the-loop demonstration of a neural receiver, showing the achievable performance gains when using trained ML models compared to traditional signal processing.

Brooklyn 6G Summit 2023

End-to-End Learning Testbed



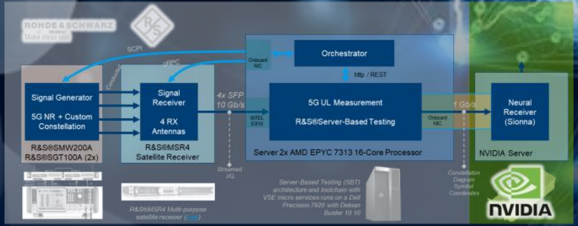
Columbia, MD / 30.10.2023

Enabling an AI-native air interface for 6G: Rohde & Schwarz showcases AI/ML-based neural receiver with optimized modulation at Brooklyn 6G Summit, in collaboration with NVIDIA

With research on the technological components of the future 6G wireless communication standard in full swing, the possibilities of an AI-native air interface for 6G are also being explored. In collaboration with NVIDIA, Rohde & Schwarz takes another step forward and presents an enhancement to its recent hardware-in-the-loop demonstration of a neural receiver, showing the achievable performance gains when using trained ML models compared to traditional signal processing — while for the first time also optimizing the transmitter side.

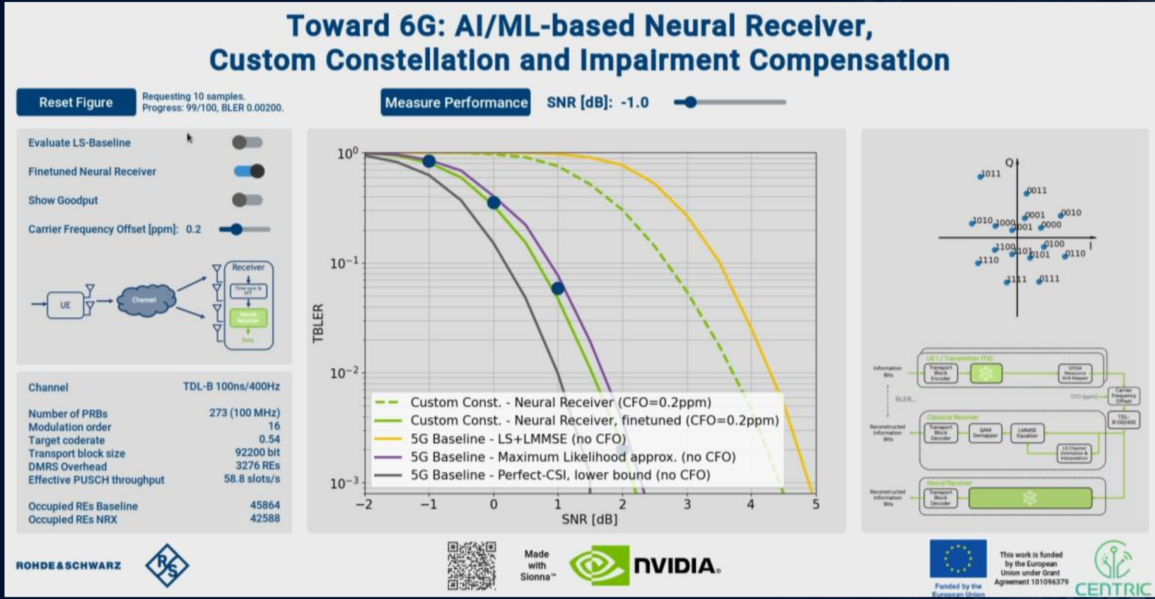
MWC 2024

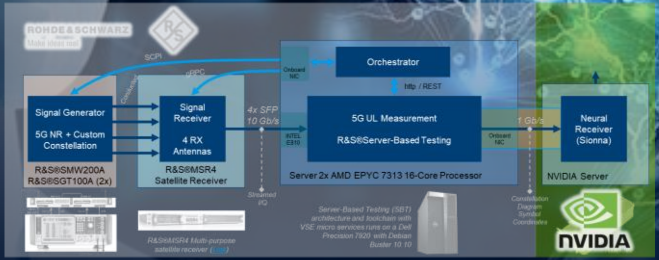
Neural RX + Impairment Compensation



END-TO-END LEARNING TESTBED

Demoed @ MWC24

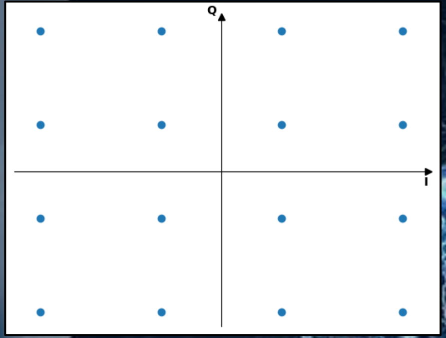




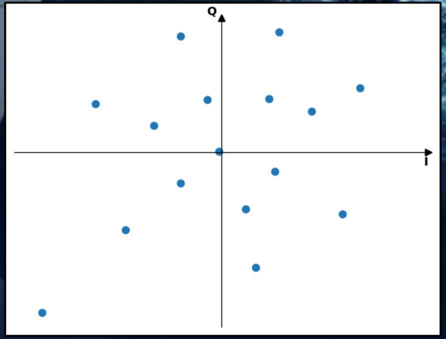
END-TO-END CONSTELLATION LEARNING

- Joint **End-to-End Learning** (TX, wireless channel, RX) of custom constellation points and neural receiver
- AI/ML models learn constellation with superimposed pilots; joint optimization of neural receiver performance
- **Pilotless Communication:** No need for 5G NR Demodulation Reference Signals (DMRS)
- Free resources can be used for data transmission → higher bandwidth efficiency/throughput
- **Additionally in this demo:** Neural RX trained with carrier frequency offsets in range 0 – 0.5 ppm

From QAM16…



… to an AI/ML-learned constellation



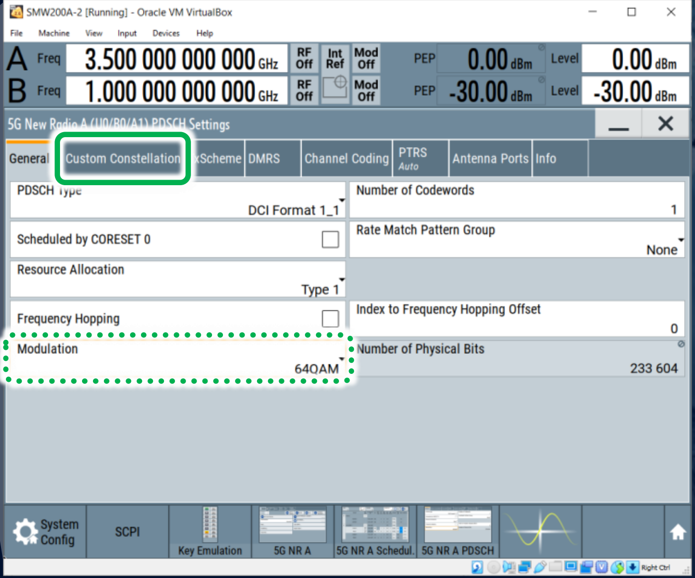
FIRST STEP TOWARDS END-TO-END LEARNING

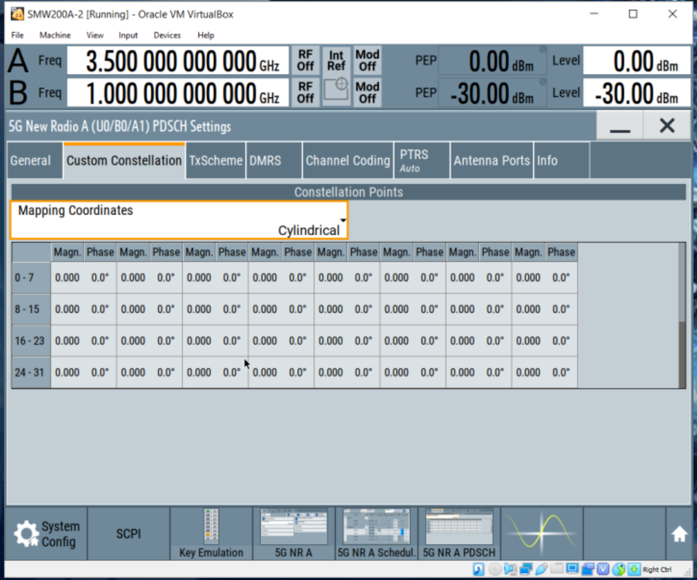
- Rohde&Schwarz implemented a ‘custom constellation’ feature into its 5G NR software options for signal generator and spectrum analyzer; next step: end-to-end learned neural receiver with custom constellation

R&S®SMW200A
Vector Signal Generator

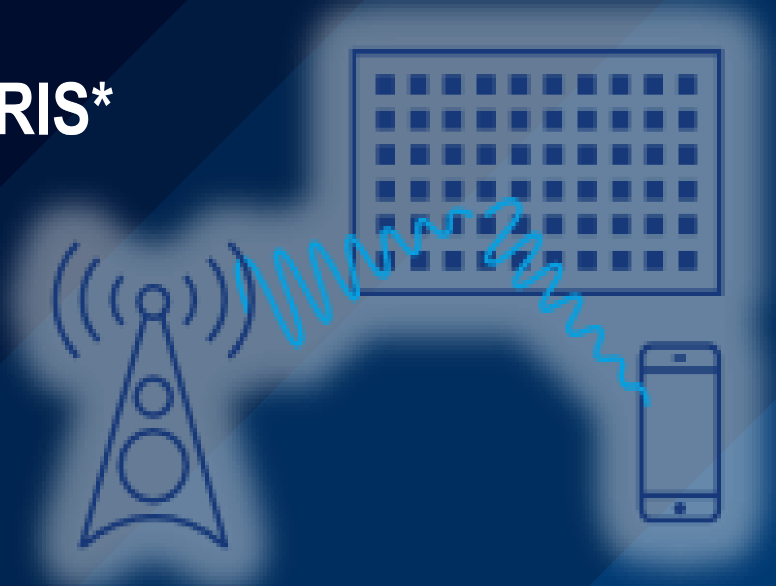
R&S®FSW
Signal and spectrum analyzer

+ Vector Signal Explorer (VSE) software





T&M ASPECTS REGARDING RIS*



*RIS - Reconfigurable Intelligent Surfaces

ROHDE&SCHWARZ

Make ideas real

ADJUST THE CHANNEL – ALONG WITH THE SIGNAL

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

- The classical approach to maximize reception quality:
  - Adapt s(t) transmission scheme to target channel h(t), e.g., CP-OFDM for the multipath channel, carrier frequency, and bandwidth, pre-coding/equalization, modulation and coding schemes, etc.
- RIS offers an adaptation of channel h(t) to maximize reception quality.

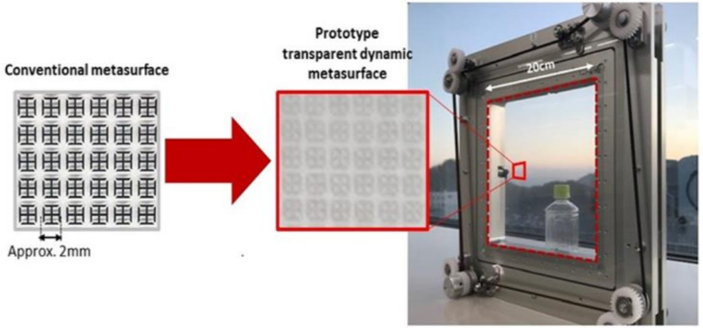
Press Release

https://www.nttdocomo.co.jp/english/info/media_center/pr/2020/0117_00.html

January 17, 2020

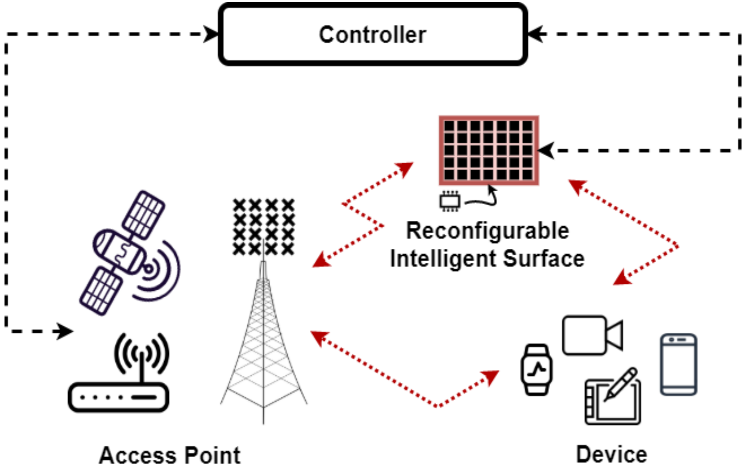
DOCOMO Conducts World's First Successful Trial of Transparent Dynamic Metasurface

— Dynamic wave manipulation and high transparency expected to optimize 5G network construction —

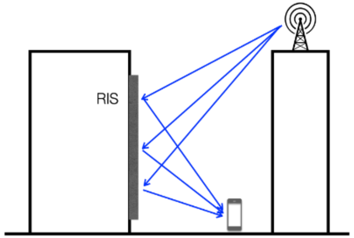


Prototype of transparent dynamic metasurface

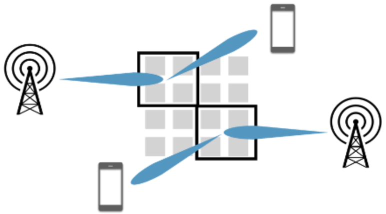
ETSI DEFINITION OF RIS

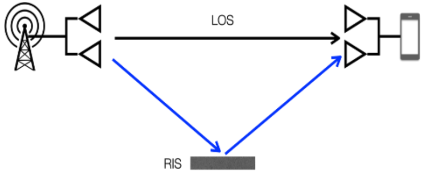


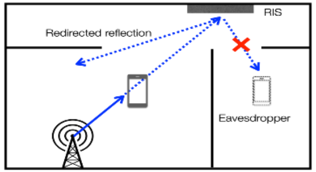
ETSI identified use cases:



- Coverage enhancement
- Spectral efficiency improvement
- Beam management
- Secure communication
- Localization accuracy
- Sensing capabilities
- Energy efficiency

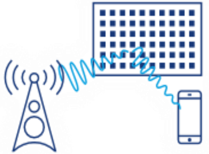


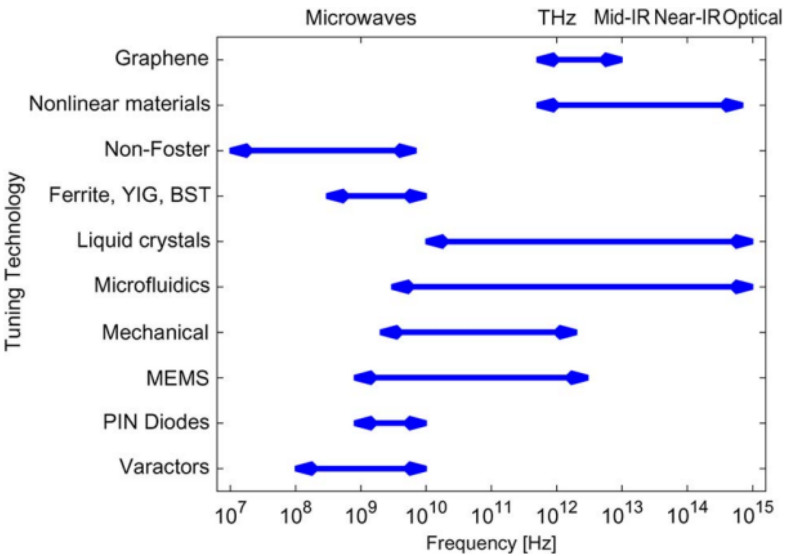




Source: ETSI ISG RIS GR001

THE KEY TO RIS: META-MATERIAL





Tuning Technologies for reconfigurable meta-materials vs. operation frequency

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

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

Di Renzo *et al.*: Communication Models for RISs

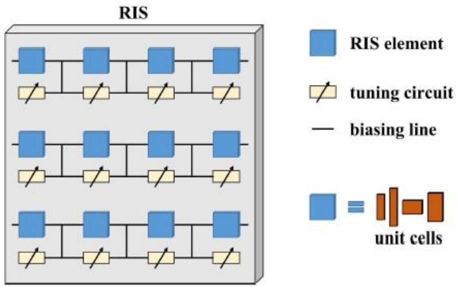


Fig. 2. *Conceptual architecture of an RIS.*

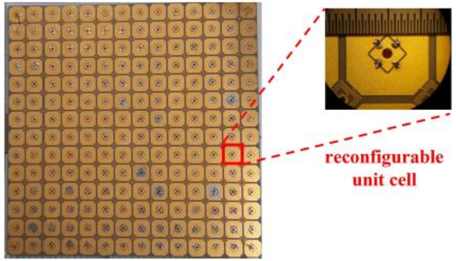
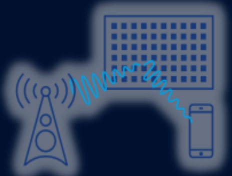


Fig. 3. *Example of manufactured RIS made of 196 identical elements (unit cells) and four voltage-controlled varactors for each cell [30].*

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

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

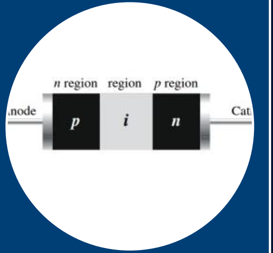


RIS PROTOTYPES

Published prototypes:

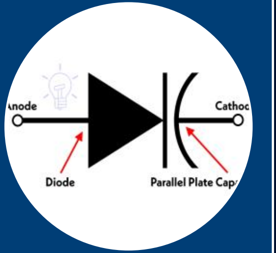
Center frequency [GHz]	Phase shift method	Number of unit cells
2.3	PIN-diodes	16x16 = 256
2.4	RF switches	2x2
4	Varactor-diodes	16x8 = 128
4.25	Varactor-diodes	8x32 = 256
5	Varactor-diodes	6x6 = 36
5.3	PIN-diodes	8x8 = 64
5.7	Varactor-diodes	8x6=48
5.8	PIN-diodes	10x16 = 160
5.8	Varactor-diodes	20x55 = 1100
9.8	PIN-diodes	8x8 = 64
10	PIN-diodes	8x8 = 64
10.4	PIN-diodes	244
11.2	PIN-diodes	1600
11.2	MEMS	2x1 = 2
12	PIN-diodes & Varactor-diodes	22x22 = 484
17.5	LC metamaterial	2x2 = 4
17.5	LC metamaterial	2x2 = 4
27.5	PIN-diodes	400
28	LC metamaterial	24x24 = 576
28	PIN-diodes	16x16 = 256
28.5	PIN-diodes	16x16 = 256
30	LC metamaterial	4x1=4
60	Relay switches	14x16 = 224

Majority of prototypes based on 3 kinds of metamaterial



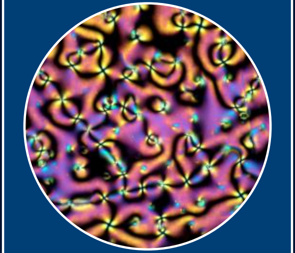
PIN diodes

- Discrete tunability
- Few GHz to mmWave
- Current flow is adjusted by changing PIN diode(s) states → Load impedance changes → Reflection coefficient is adapted



Varactor diodes

- Continuous tunability
- Few GHz
- Tuning of biasing voltage → Load impedance becomes controllable → Reflection coefficient is adapted

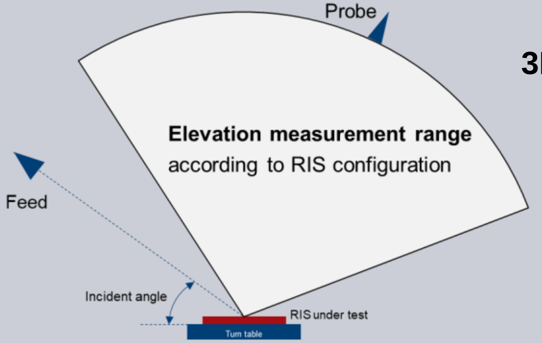


Liquid Crystal

- Technology known from LC-Displays
- Continuous tunability
- > 10 GHz
- Good scalability → low fabrication costs for large surfaces
- Permittivity and resonant frequency is influenced by external voltage → Reflection phase depends on resonant frequency → Direction can be conf.

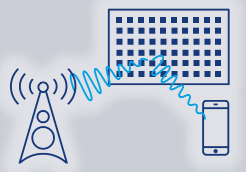
BASIC RIS T&M NEEDS

RIS as intelligent antenna



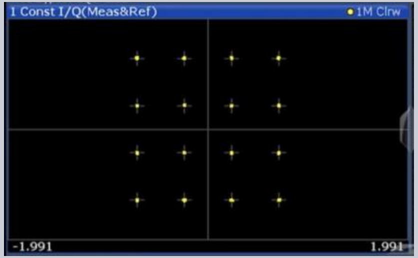
3D radiation pattern

Regarding RIS as intelligent reflector



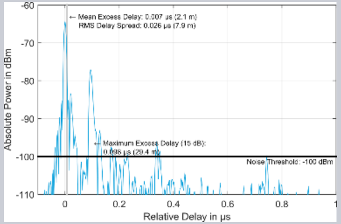
Speed of reconfiguration

RIS as network node



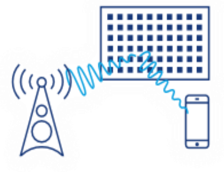
Reflected signal quality

RIS as radio channel component

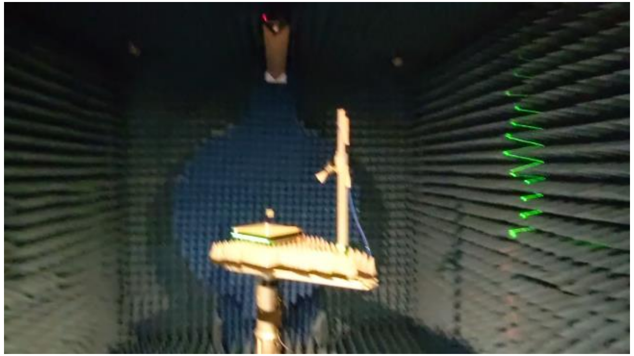


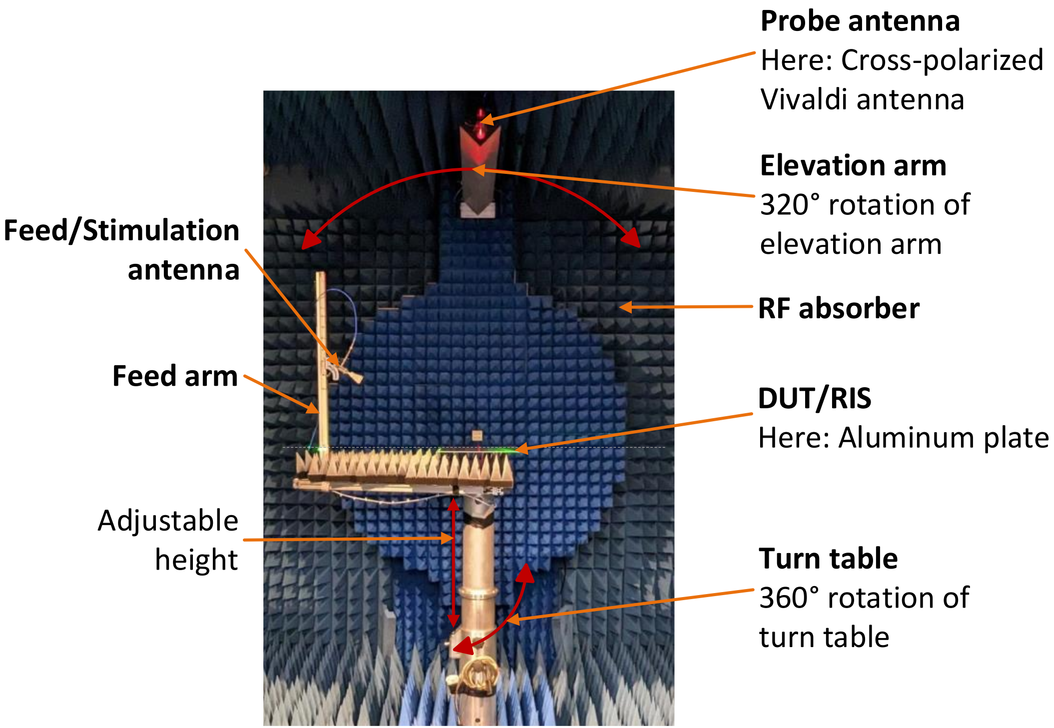
Channel sounding: CIR

RADIATED RIS CHARACTERIZATION



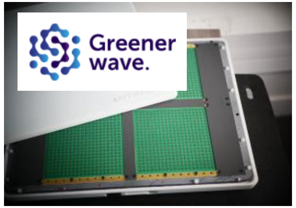
Video of test setup



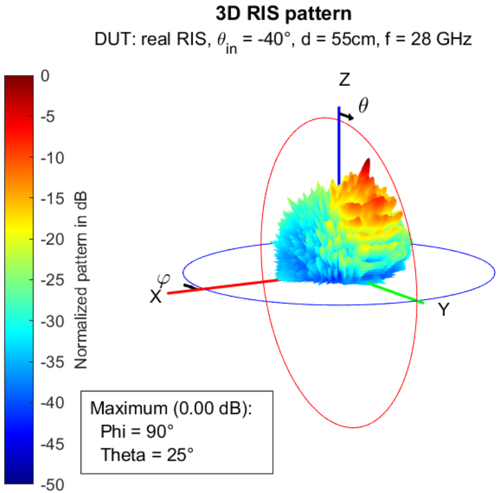


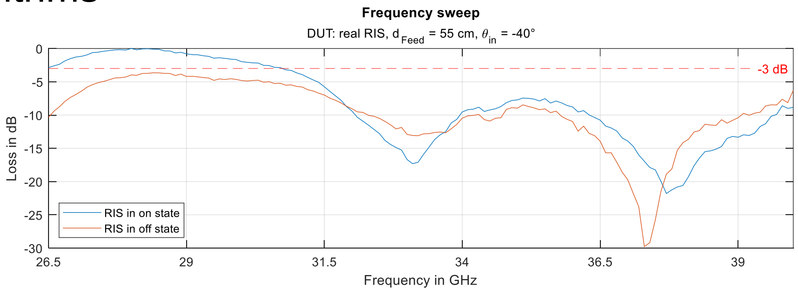
RESULTS OF REAL RIS

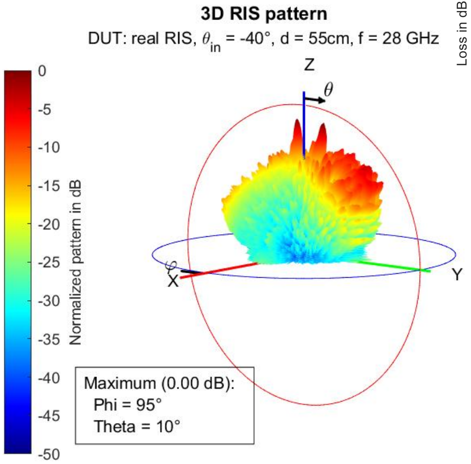
- Measurement scenarios: Frequency sweep
- 3D patterns for different incident angles
- RIS multibeam scenarios
- RIS configuration algorithms

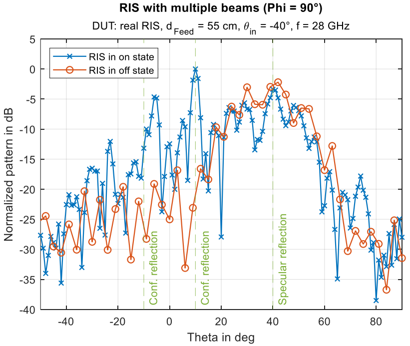


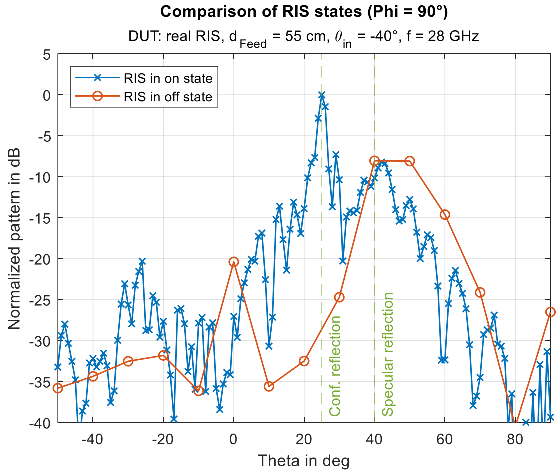
28 GHz Access Point Extender





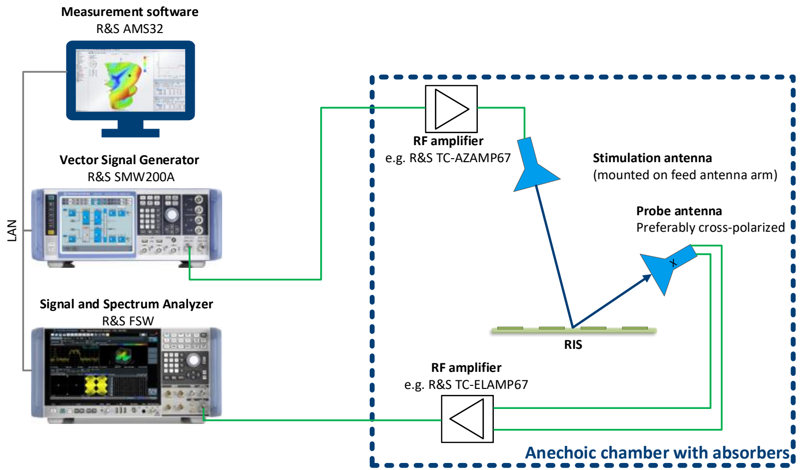






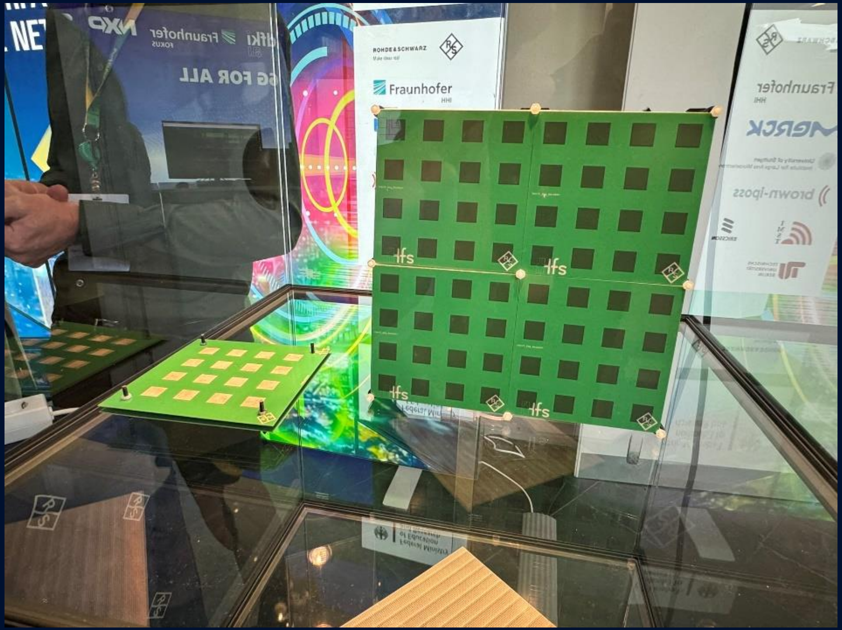
RIS PERFORMANCE TEST

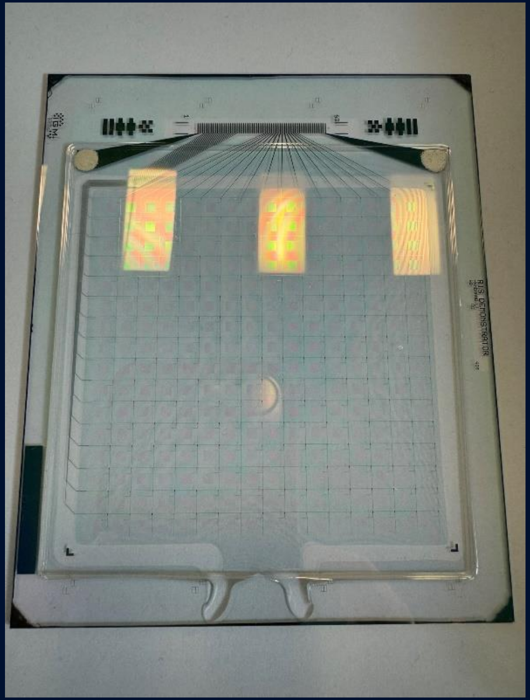
„Regarding RIS as a network node“



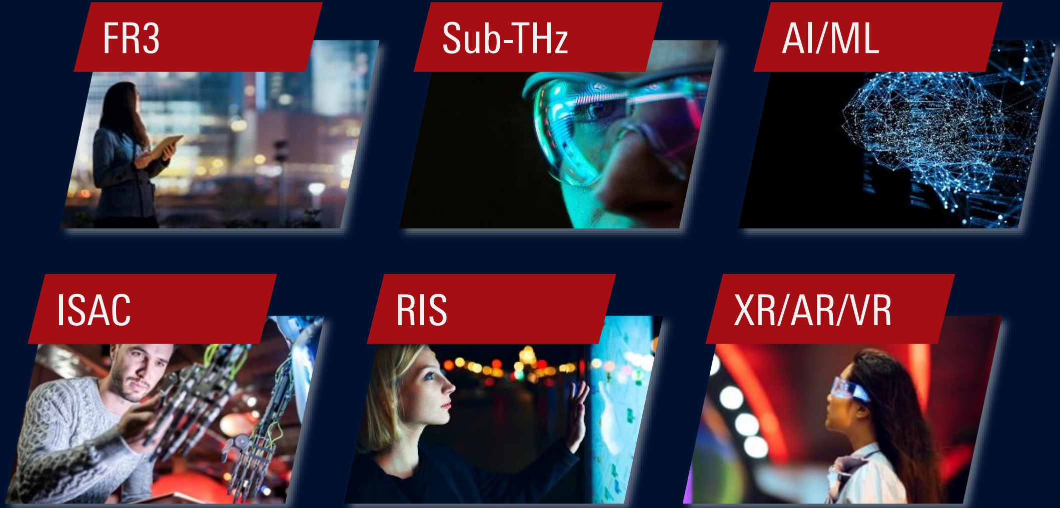
6G-LICRIS demo at 6G conference in Berlin, 2024

Liquid crystal reconfigurable intelligent surfaces for 6G mobile networks





TAKE AWAYS – R&S IS “6G READY!”



- Testing FR3
- Target simulation for Integrated Sensing and Communication (ISAC)
- Testing Reconfigurable Intelligent Surfaces (RIS)
- AI/ML training and performance test
- XR/AR/VR testing
- (Sub-)THz measurements

#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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ons and more.

Joint communication and s

Discover the insights of Rohde
and other industry leaders as t
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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