6G India 2023 International Conference

ON THE VERGE OF 6G

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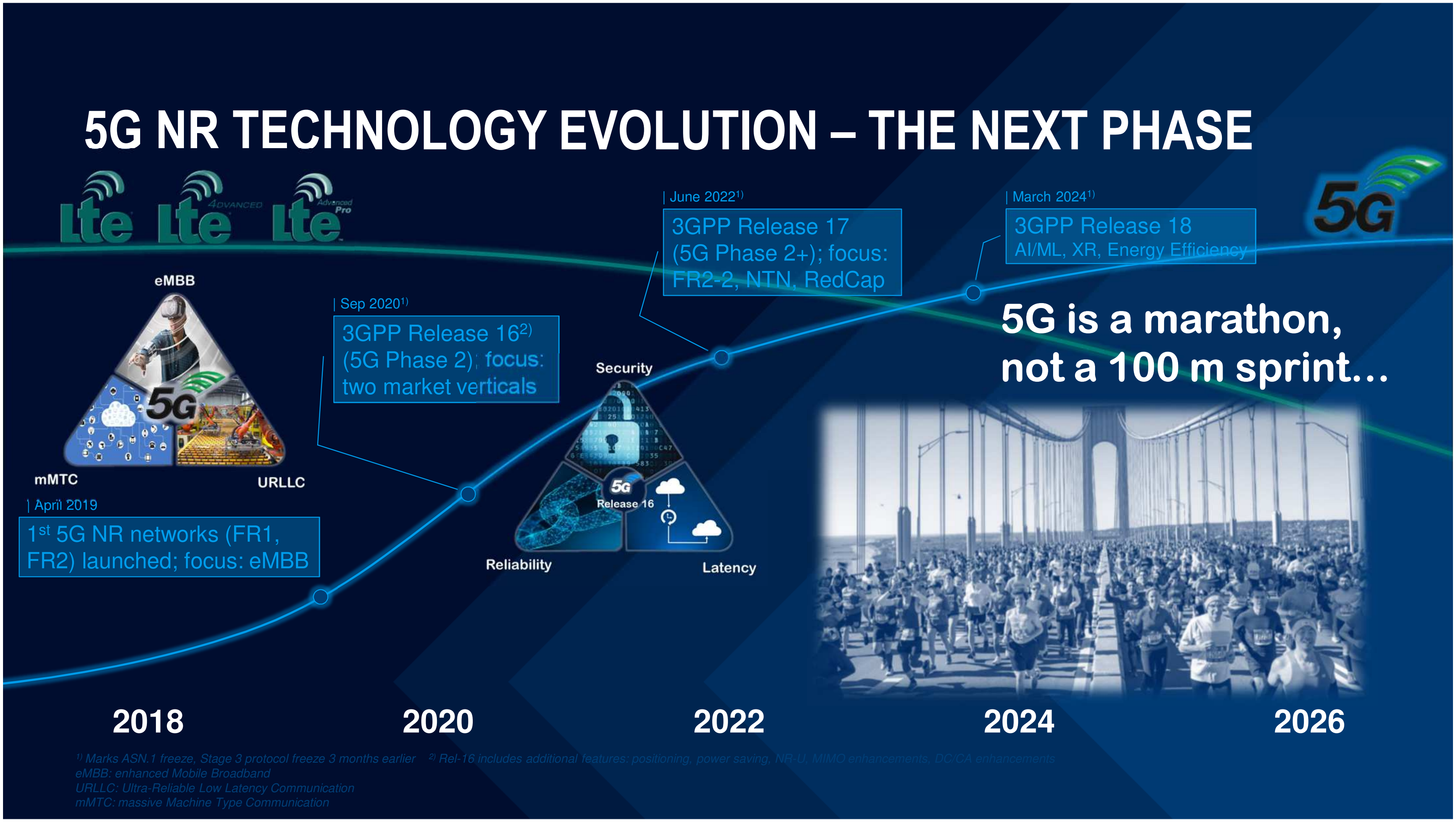
ROHDE&SCHWARZ

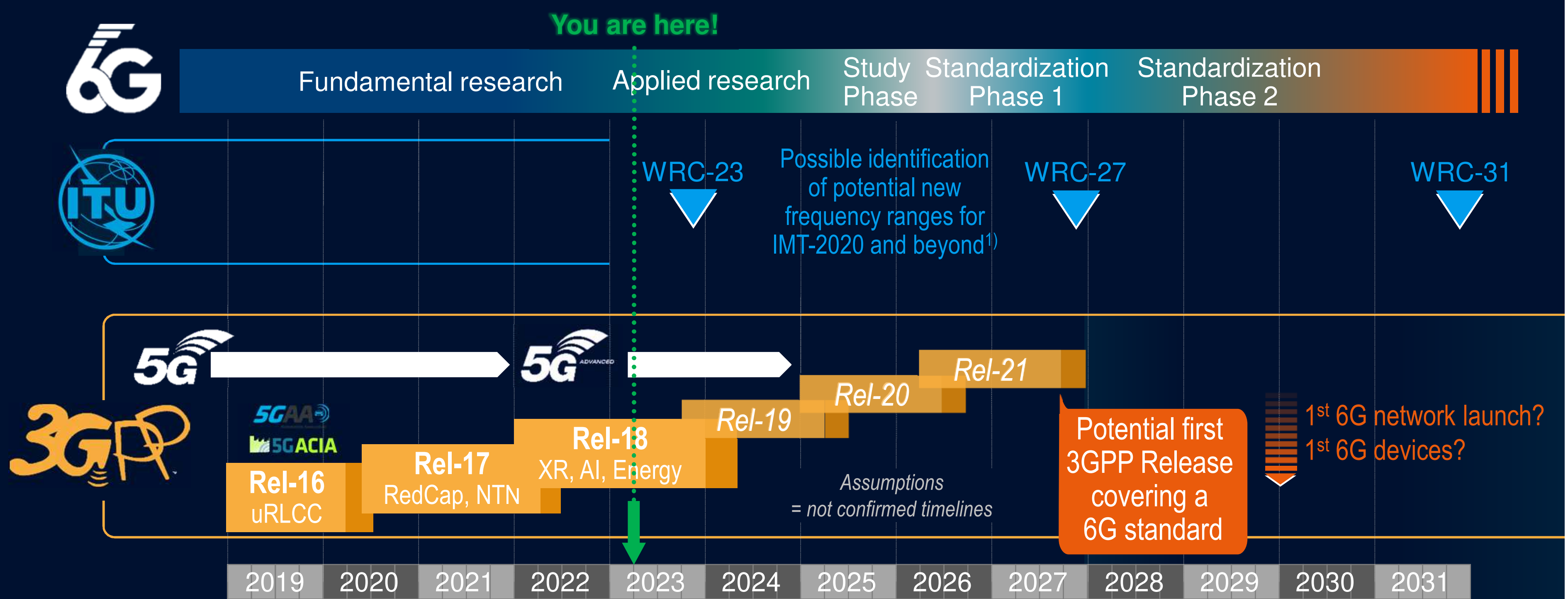
Make ideas real

AGENDA

- 6G research areas
  - THz and FR3
  - Joint Communication and sensing (JCAS)
  - Artificial Intelligence / Machine Learning (AI/ML)
  - Reconfigurable Intelligent Surfaces (RIS)
- 5G evolution and 6G timeline
- Summary


5G NR TECHNOLOGY EVOLUTION – THE NEXT PHASE
eMBB
mMTC
URLLC
| April 2019
1st 5G NR networks (FR1, FR2) launched; focus: eMBB
| Sep 2020 1)
3GPP Release 16 2) (5G Phase 2); focus: two market verticals
Security
Release 16
Reliability
Latency
| June 2022 1)
3GPP Release 17 (5G Phase 2+); focus: FR2-2, NTN, RedCap
| March 2024 1)
3GPP Release 18
AI/ML, XR, Energy Efficiency
5G is a marathon, not a 100 m sprint…
2018
2020
2022
2024
2026
1) Marks ASN.1 freeze, Stage 3 protocol freeze 3 months earlier
2) Rel-16 includes additional features: positioning, power saving, NR-U, MIMO enhancements, DC/CA enhancements
eMBB: enhanced Mobile Broadband
URLLC: Ultra-Reliable Low Latency Communication
mMTC: massive Machine Type Communication

FUTURE STANDARDIZATION AND REGULATORY ROADMAP



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*

6G RESEARCH AREAS

THz communication

Joint communication & sensing

Artificial Intelligence and Machine Learning

Reconfigurable Intelligent Surfaces

Photonics, Visible Light Communication

Multiple access, new waveforms, channel coding

Ultra-massive MIMO

New network topologies, distributed computing

Full-duplex communication

Security & Trustworthiness

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

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
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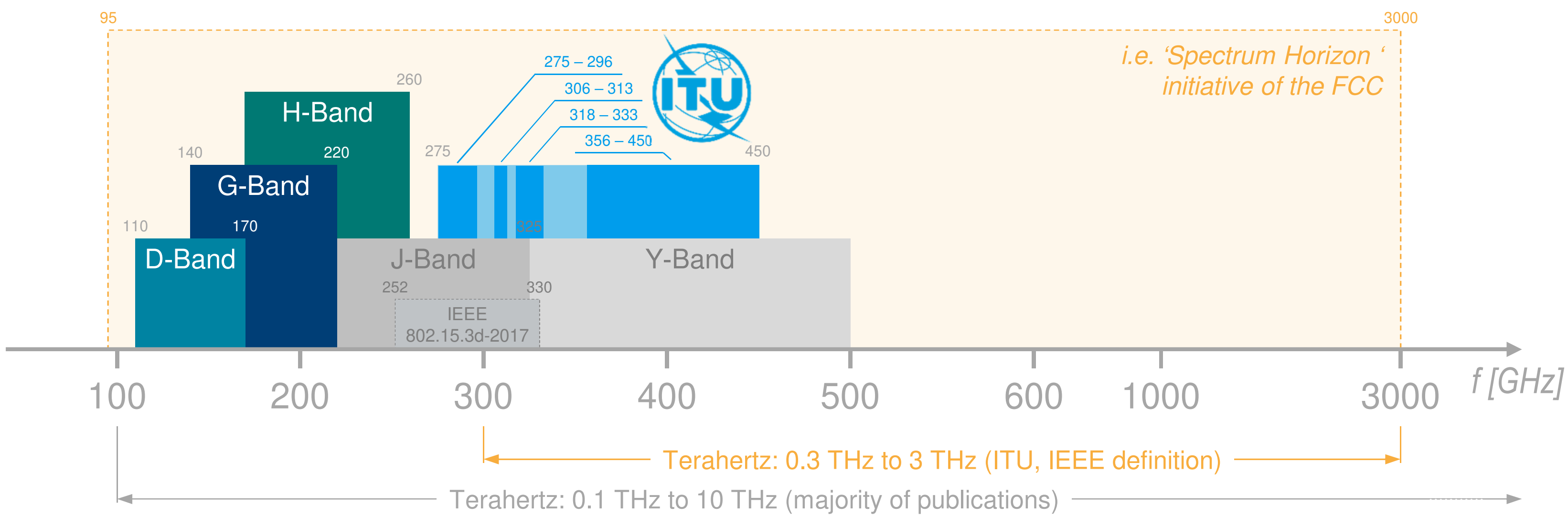
WHAT FREQUENCIES ARE WE TALKING ABOUT FOR 6G?

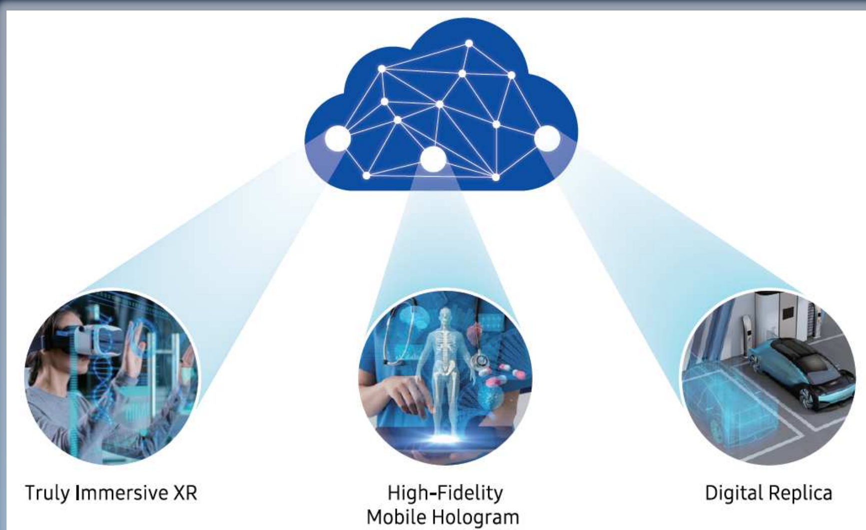
Let's be clear, a future 6G standard will also work <u>below 100 GHz, below sub-6 and 1 GHz</u>!

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



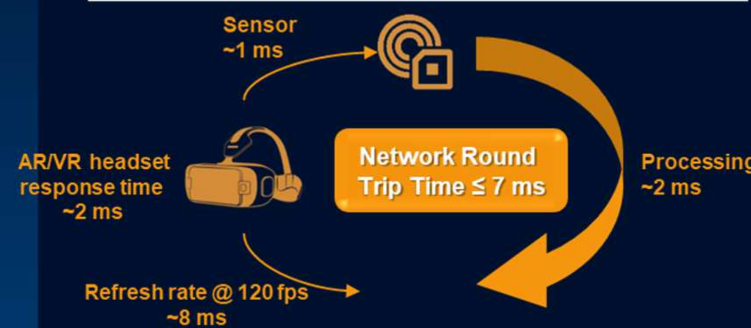
WHAT PROBLEM IS 6G TRYING TO SOLVE WITH SUPPORT OF (SUB-)THZ?

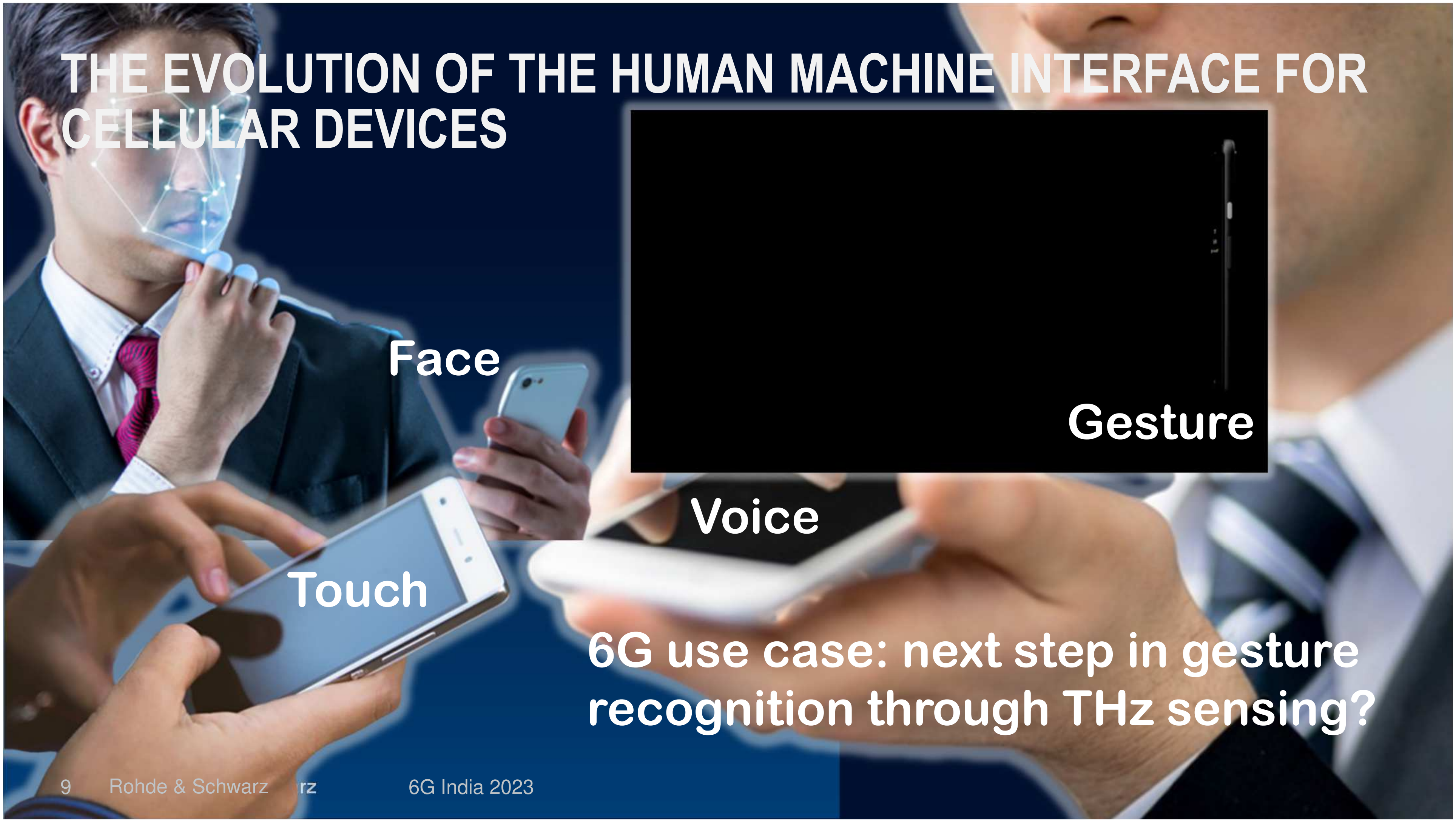
- An attempt of an explanation: eXtended Reality (XR)
  - Provide higher data rates (Tbps) and lower latency



Source: *[Samsung 6G white paper]* *(July 2020)*

Parameter	Quasi	Basic	Ultra
Frame rate	25~30 fps	50~60 fps	100~120 fps
Bit-per-pixel	8 bit	10 bit	12 bit
½ screen	~70 Mbps	~175 Mbps	~350 Mbps
3D+panorama	~840 Mbps	~2.1 Gbps	~4.2 Gbps
Motion-to-photon latency	< 20 ms		




THE EVOLUTION OF THE HUMAN MACHINE INTERFACE FOR CELLULAR DEVICES
Face
Gesture
Voice
Touch
6G use case: next step in gesture recognition through THz sensing?

SO, WHAT MIGHT BE NEXT?

- Use of phased arrays antennas (e.g. linear arrays) to “monitor” the space in front of the person, that is using the AR/VR headset, for motion of one or both hands & arms

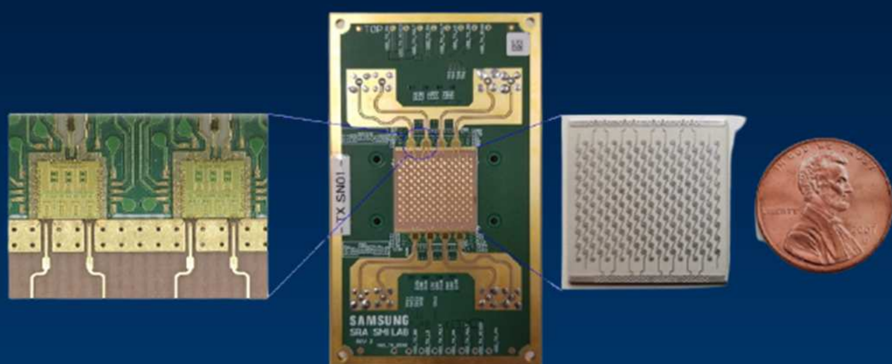
- Required range ≤ 1.5 m, but what about resolution?

- Higher resolution required to detect particular movements → wider bandwidths required → move to higher frequency, i.e. sub-THz (e.g. 340 GHz)

OUR CUSTOMERS ARE ACTIVELY WORKING ON THIS TECHNOLOGY

Samsung Electronics and University of California Santa Barbara Demonstrate 6G Terahertz Wireless Communication Prototype

Korea on June 16, 2021   Audio   Share



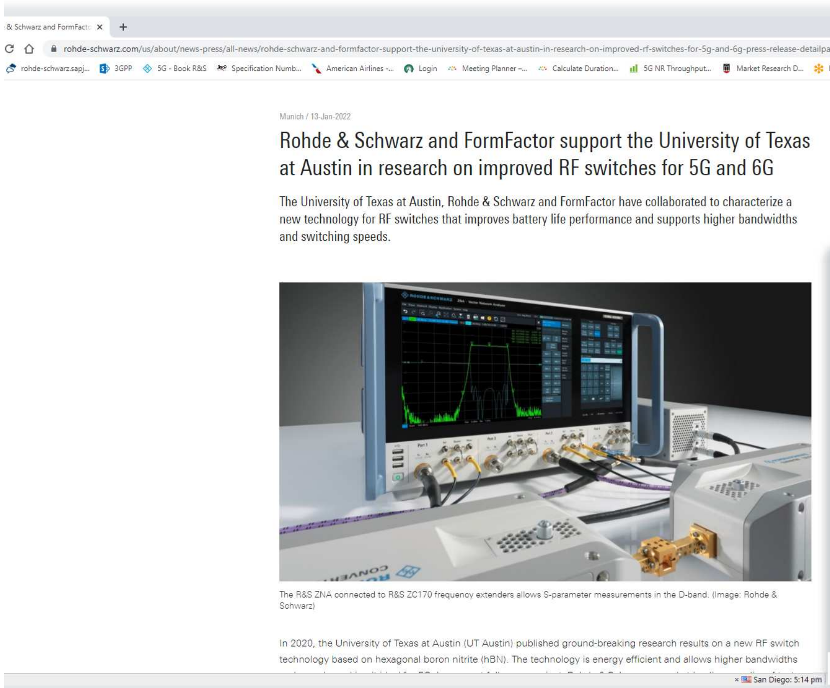
- CMOS-based D-Band (110 to 170 GHz) RFIC with 128 antenna array elements
- 2 GHz BW, MIMO 2x2, 16QAM lead to 6.2 Gbps (E2E) over 15 m distance

https://news.samsung.com/global/samsung-electronics-and-university-of-california-santa-barbara-demonstrate-6g-terahertz-wireless-communication-prototype *[June 2021]*

BUT SO DO WE…

COLLABORATION WITH UNIVERSITY OF TEXAS IN AUSTIN

Testing RF switches @ D-Band w/ R&S®ZNA43 & R&S® ZC170



Munich / 13-Jan-2022

Rohde & Schwarz and FormFactor support the University of Texas at Austin in research on improved RF switches for 5G and 6G

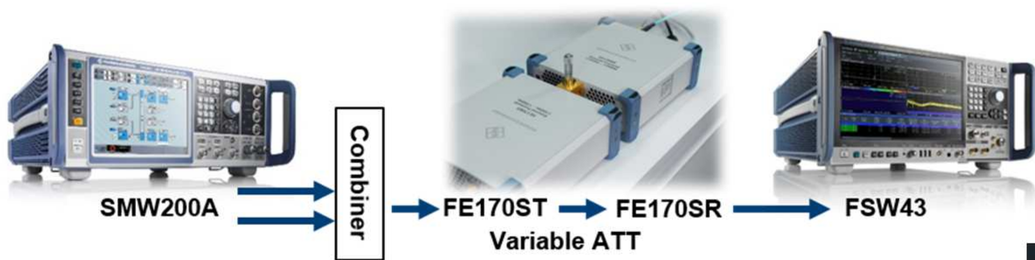
The University of Texas at Austin, Rohde & Schwarz and FormFactor have collaborated to characterize a new technology for RF switches that improves battery life performance and supports higher bandwidths and switching speeds.

The R&S ZNA connected to R&S ZC170 frequency extenders allows S-parameter measurements in the D-band. (Image: Rohde & Schwarz)

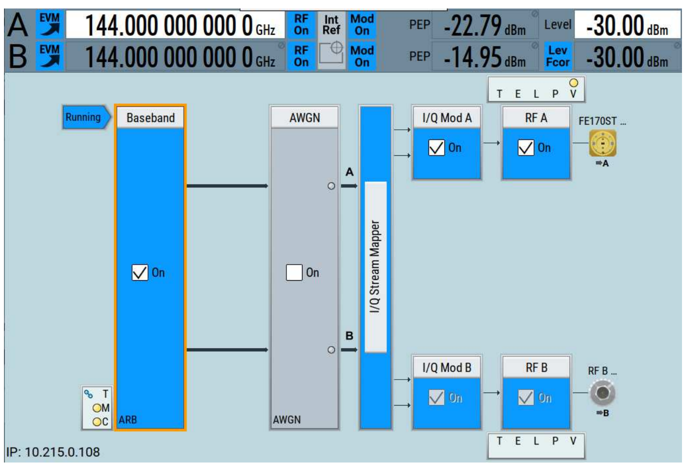
In 2020, the University of Texas at Austin (UT Austin) published ground-breaking research results on a new RF switch technology based on hexagonal boron nitrite (hBN). The technology is energy efficient and allows higher bandwidths

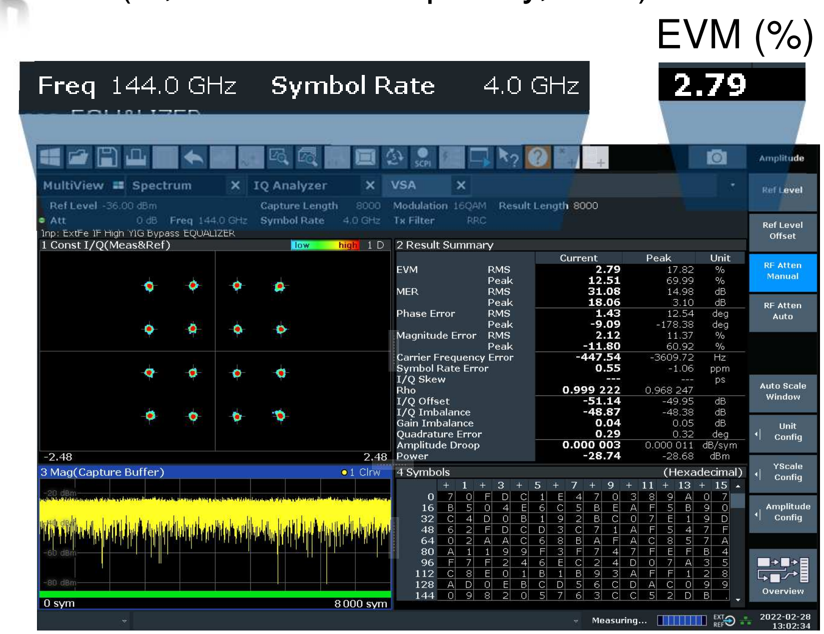
More background info: https://spectrum.ieee.org/atomthin-switches-5g-6g-radio-signals

FE170ST / FE170SR FRONTENDS EXTEND THE FREQUENCY RANGE TO 110 GHz TO 170 GHz

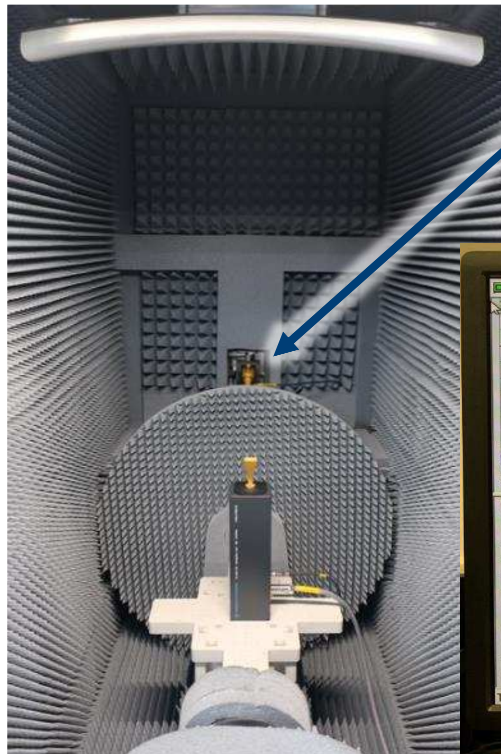


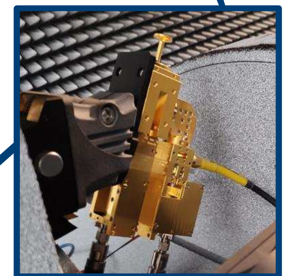
- **Compact** form factor
- Only three connections needed (IF, reference frequency, LAN)





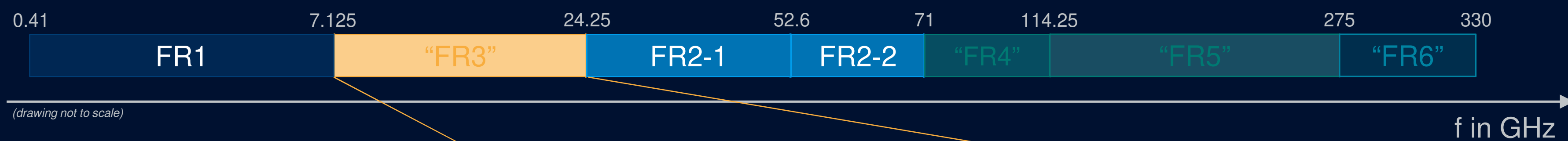
SIMULTANEOUSLY WE TAKE THE NEXT STEP TOWARDS FULL OVER-THE-AIR TEST SOLUTIONS FOR D-BAND (110-170 GHz)





Initial realization:
90 to 140 GHz
– full D-band support under development

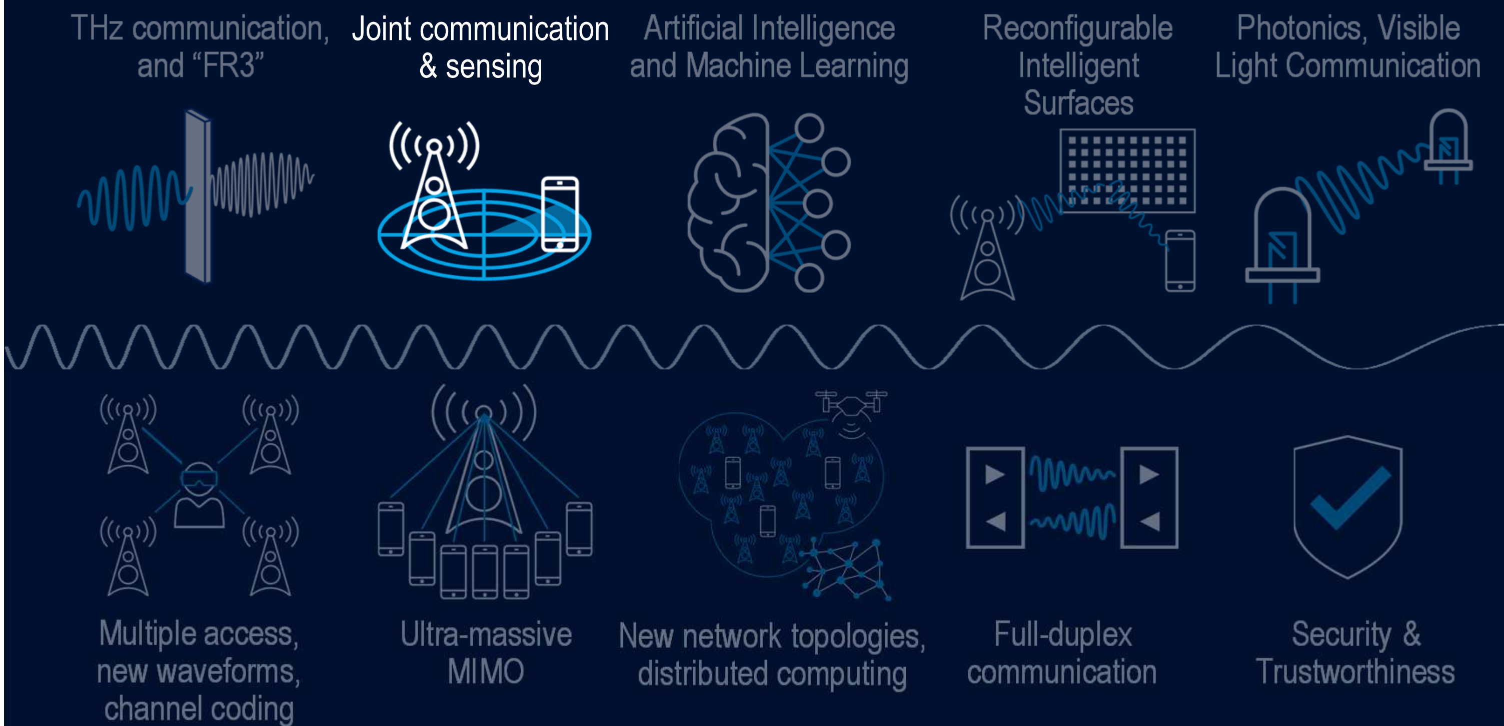
6G WILL TAKE ADVANTAGE OF FR1 AND FR2
THz AND “FR3” WILL BE ANOTHER FREQUENCY LAYER



- 6.1.6 Potential Spectrum bands for study
  - 6.1.6.1 UHF Band
    - 6.1.6.1.1 1300-1350 MHz
    - 6.1.6.1.2 1780-1850 MHz
  - 6.1.6.2 Lower-cmW spectrum
    - 6.1.6.2.1 3100-3450 MHz
    - 6.1.6.2.2 3980-4180 MHz (TBD)
    - 6.1.6.2.3 4400-4940 MHz
    - 6.1.6.2.4 7125-8500 MHz
  - 6.1.6.3 Upper-cmW spectrum
    - 6.1.6.3.1 10-10.5 GHz
    - 6.1.6.3.2 10.7-12.2
    - 6.1.6.3.3 12.2 – 12.7 GHz
    - 6.1.6.3.4 12.7-13.75 GHz
    - 6.1.6.3.5 13.75-15 GHz
    - 6.1.6.3.6 25.25-27.5 (TBD)
  - 6.1.6.4 EHF Band
    - 6.1.6.4.1 37.0-37.6 GHz
    - 6.1.6.4.2 42-43.5 (TBD)
    - 6.1.6.4.3 92-114.25 GHz (W-band) and 122.25-174.8 GHz (D-band):

Source:
Spectrum Working Group

6G RESEARCH AREAS FROM A T&M PERSPECTIVE



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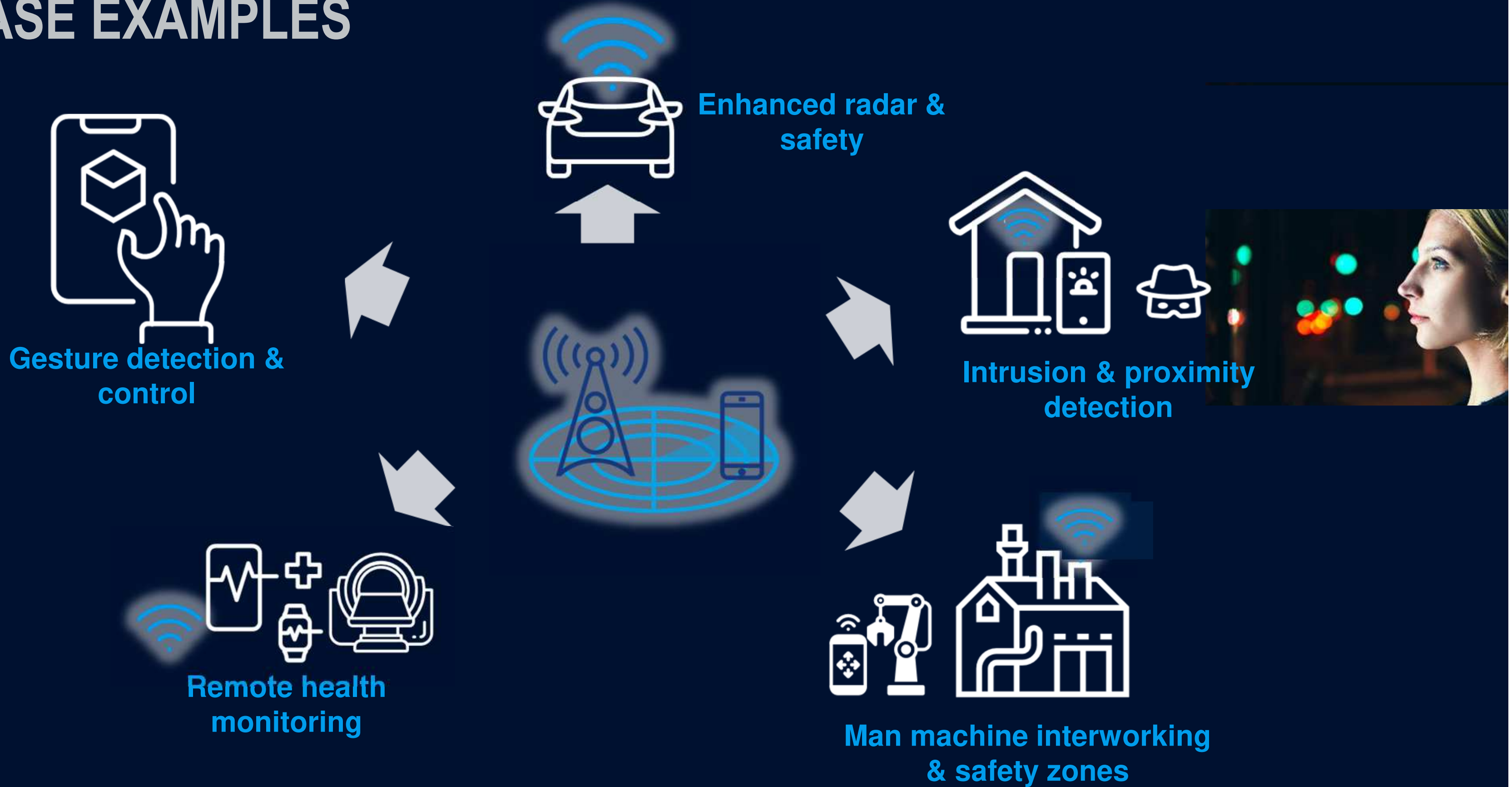
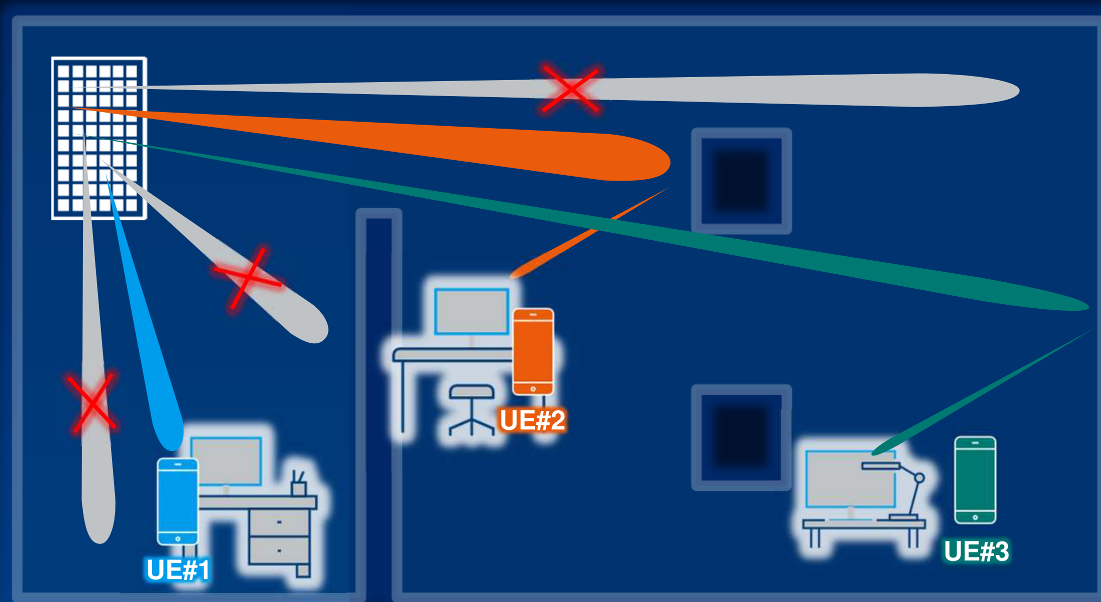
JOINT COMMUNICATION AND SENSING (JCAS)
USE CASE EXAMPLES



JOINT COMMUNICATION AND SENSING (JCAS)
MOTIVATION AND RESEARCH CHALLENGES

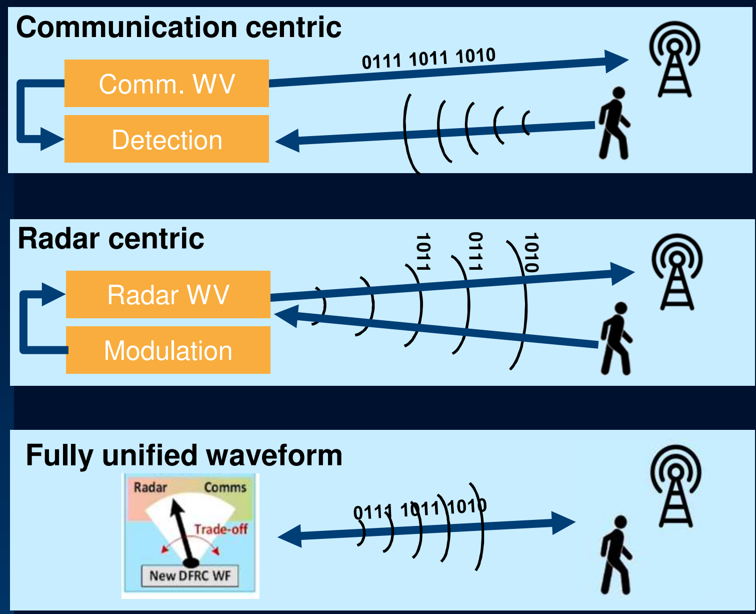
- Design a communication signal that can be used for objection detection, tracking, recognition, localization, and imaging
- Sensing-assisted communication by utilizing sensed information to aid beam management/alignment, CSI acquisition, medium-aware links, interference mitigation, etc.
- Research challenges
  - What frequency/bandwidth?
  - Waveform design (e.g. PAPR)?
  - Full duplex transceivers?
  - Interference? Distributed sensing?



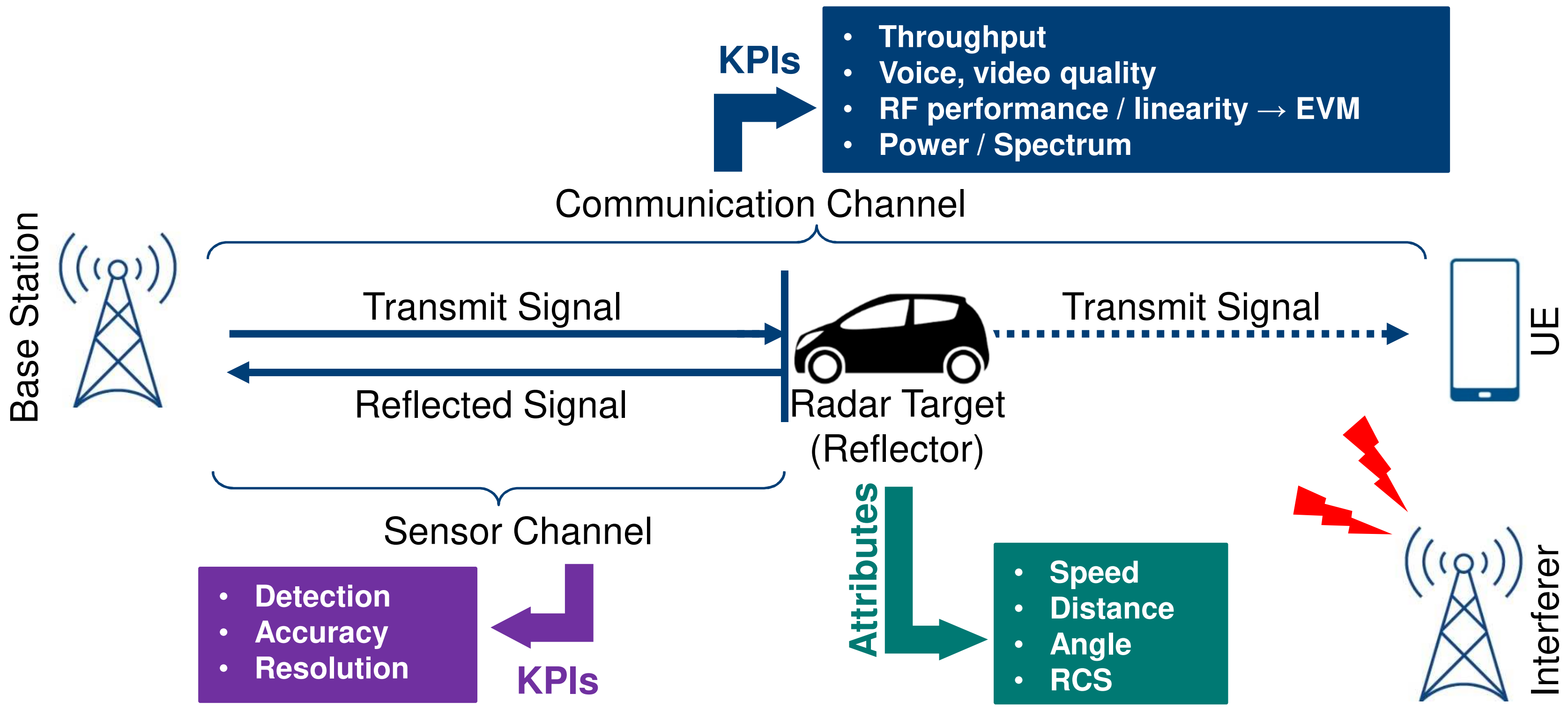
JOINT COMMUNICATION AND SENSING (JCAS)
MOTIVATION AND RESEARCH CHALLENGES

► Integrated JCAS system using single transmitted waveform and full-duplex operation:

- Communication-centric design, with guaranteed communication performance (e.g. OFDM-based)
- Radar-centric design, optimized for sensing performance (e.g. using chirp signals as information carriers → PC-FMCW)
- Jointly optimized design, with freely scalable sensing and communication performance trade-off



JOINT COMMUNICATION AND SENSING
DIFFERENCES IN PERFORMANCE INDICATION



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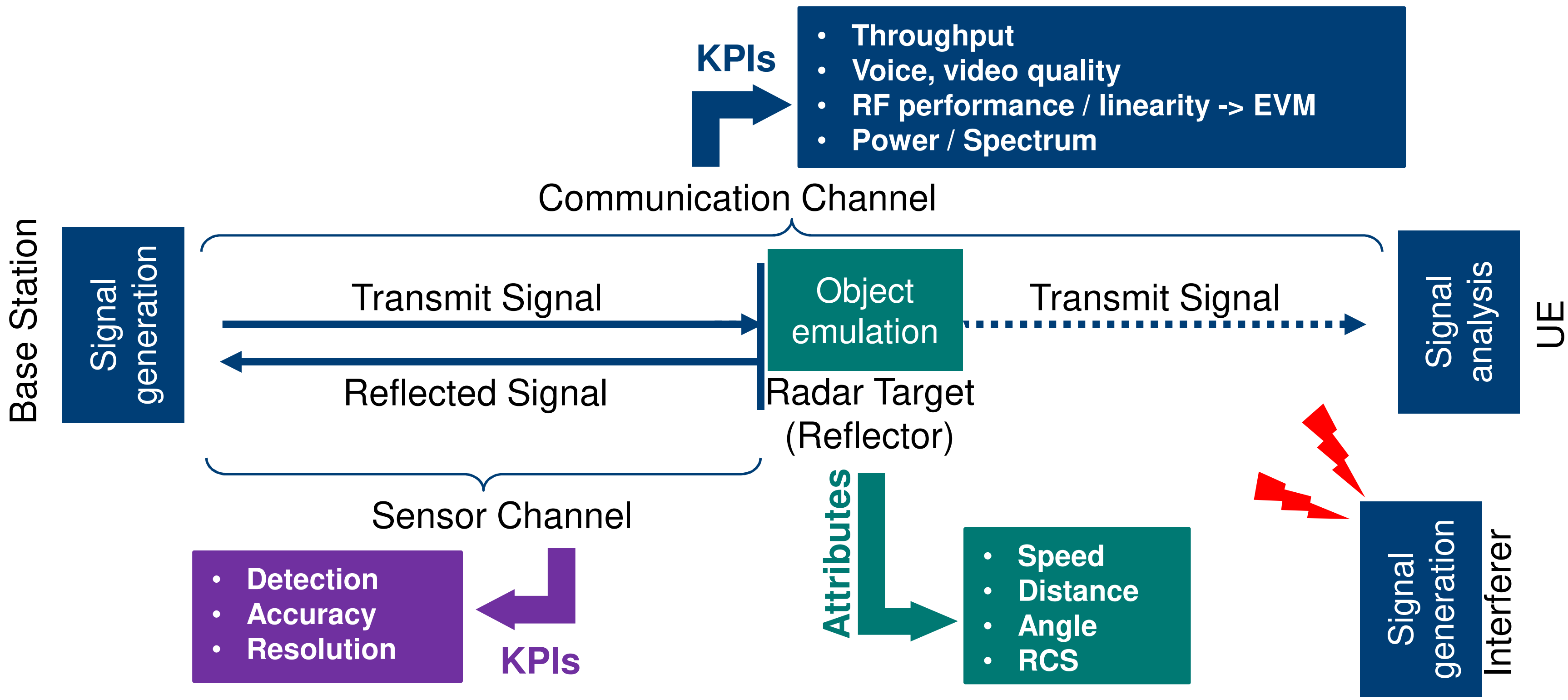
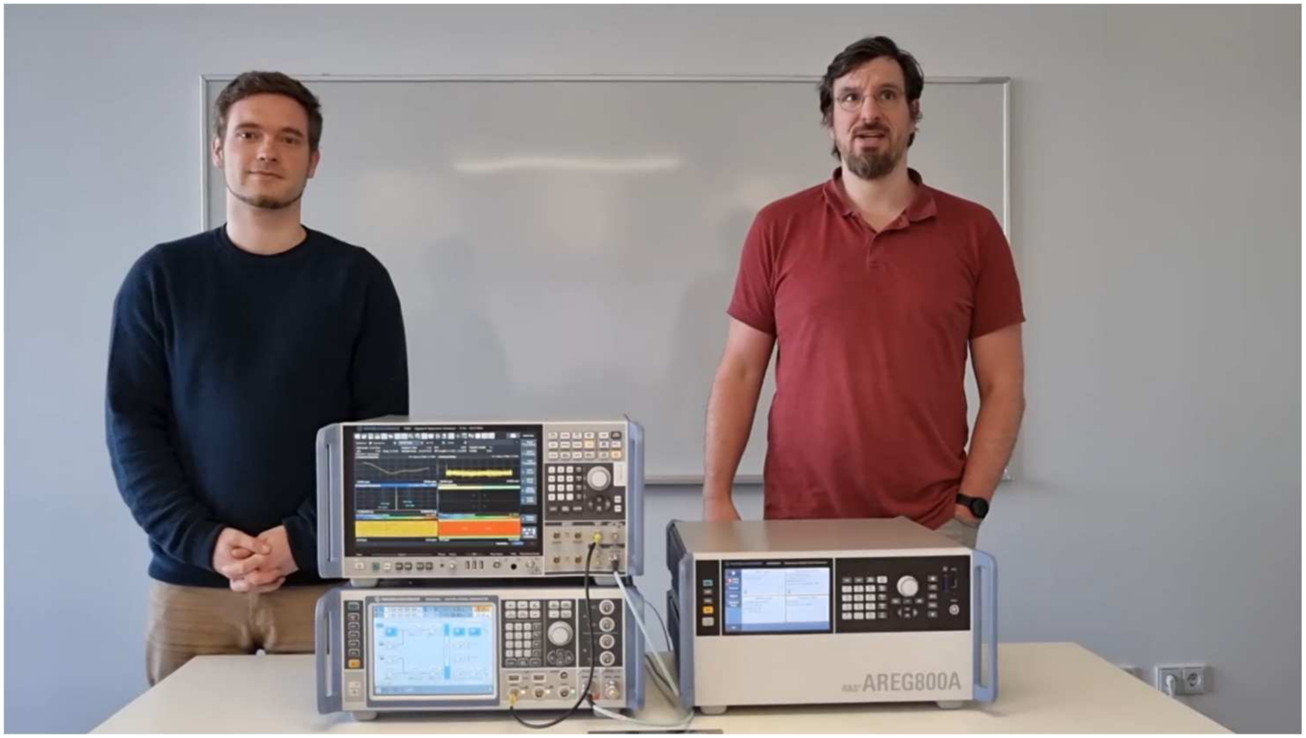


JOINT COMMUNICATION AND SENSING
HOW TO TEST JCAS KPI – SOME INITIAL T&M CAPABILITIES



TESTABILITY OF JOINT COMMUNICATION AND SENSING (JCAS)
DEMONSTRATION OF OUR CURRENT CAPABILITIES

- Demonstrated at the 7th IEEE 5G+ Summit Dresden in May 2022
- Frontends support frequency bands from 24 GHz to 44 GHz

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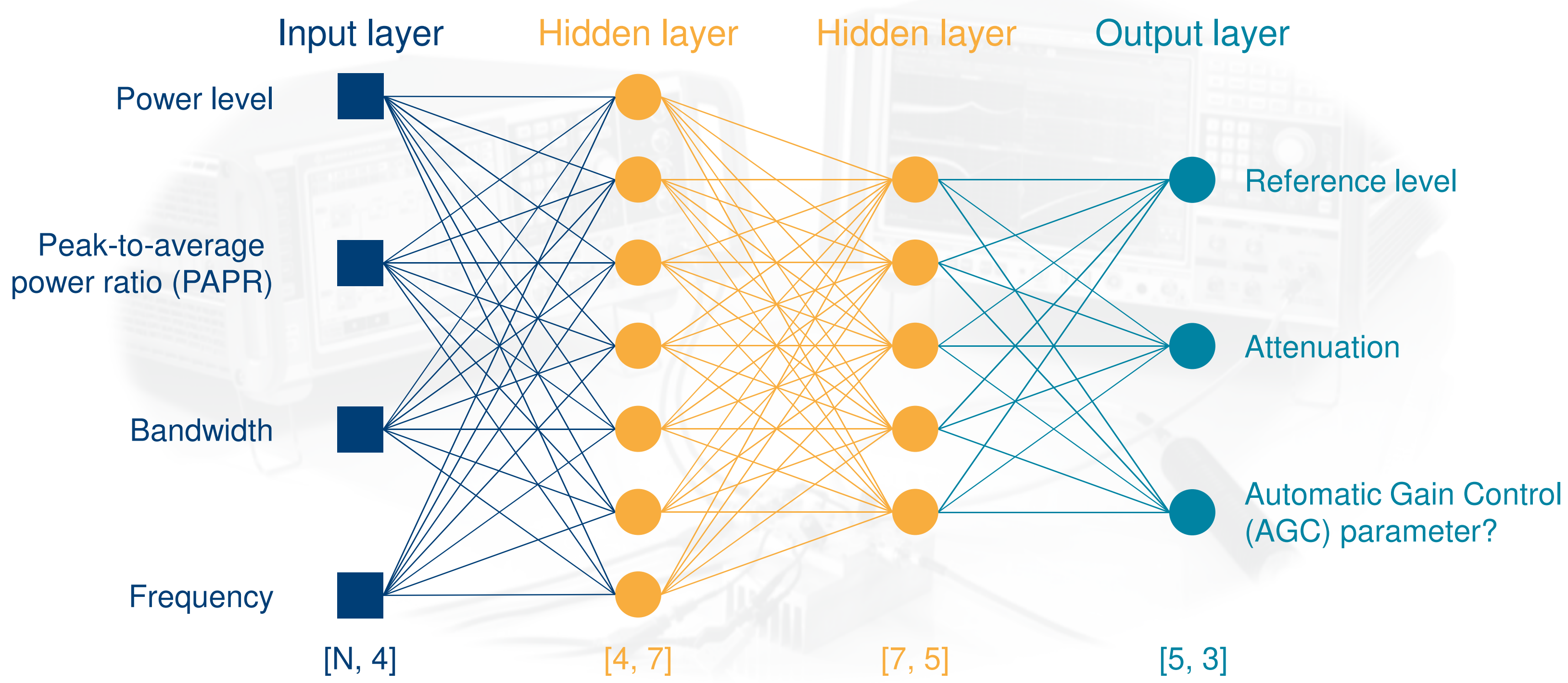
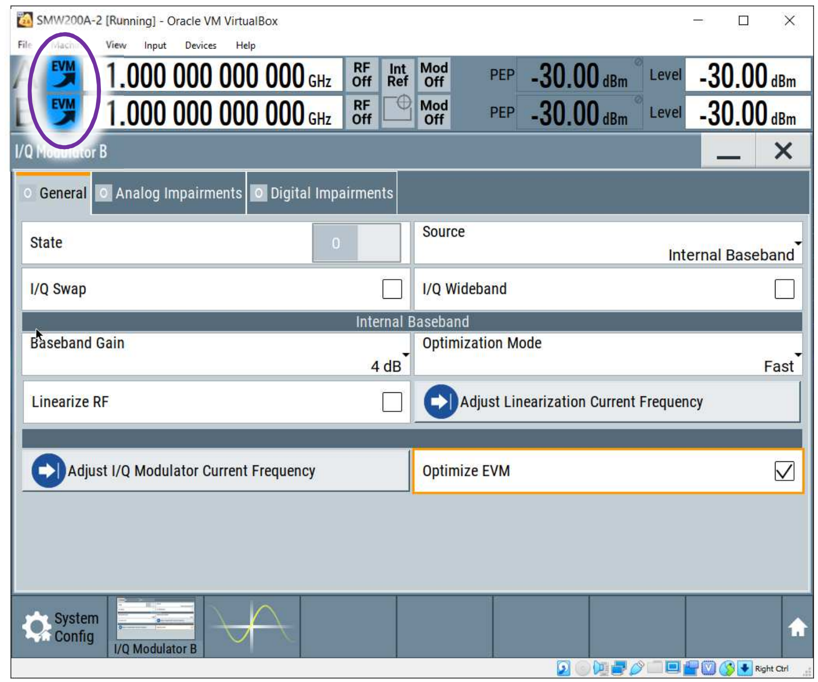
MACHINE LEARNING IS BASED ON NEURAL NETWORKS (NN)

HOW ABOUT BEST ERROR VECTOR MAGNITUDE (EVM)?



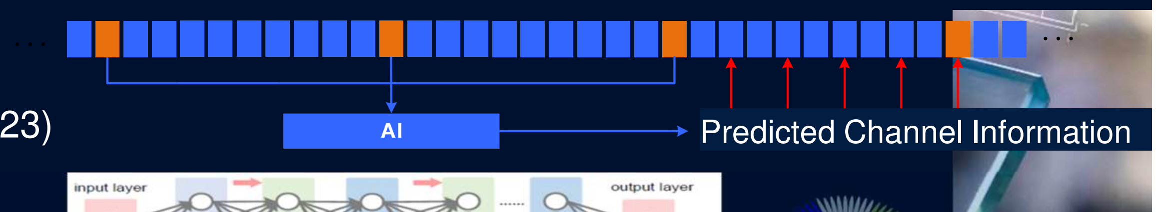
DOING “MACHINE LEARNING FOR THE SAKE OF MACHINE LEARNING” MAKES NO SENSE – USE CASE IS IMPORTANT!

Optimizing instrument parameters related to EVM by push of simple button (not ML-based!)

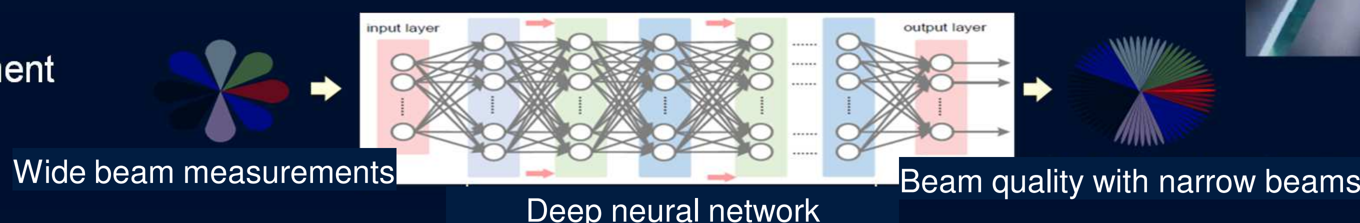


FIRST STEPS IN 5G-ADVANCED (3GPP RELEASE 18)
STUDY ON ARTIFICIAL INTELLIGENCE/MACHINE LEARNING

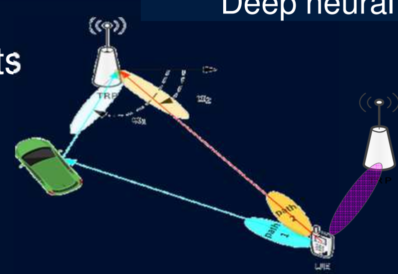
- Augmentation of air interface by AI/ML is explored
- Study is scheduled throughout the complete release until end of 2023
- Starting with only three use cases to assess performance in comparison to traditional methods & specification impacts:
  1. CSI feedback enhancements (CMX demo planned for end of 2023)



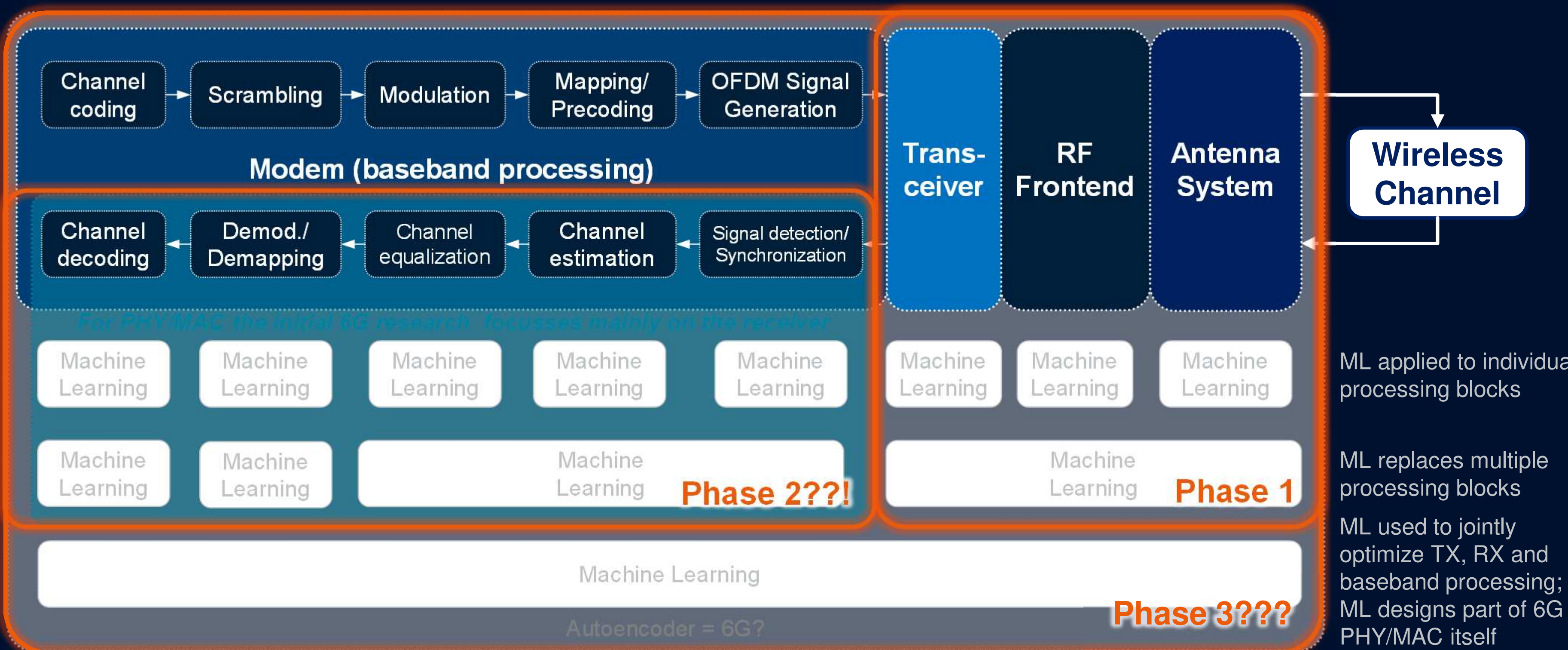
  2. Beam management



  3. Positioning accuracy enhancements

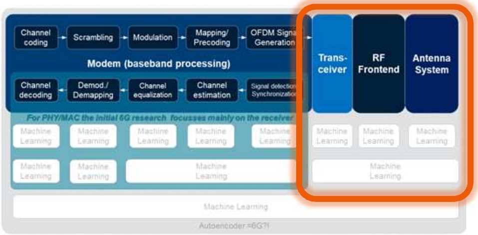


WHAT POTENTIALLY COMES NEXT?
AI-NATIVE AIR INTERFACE FOR 6G

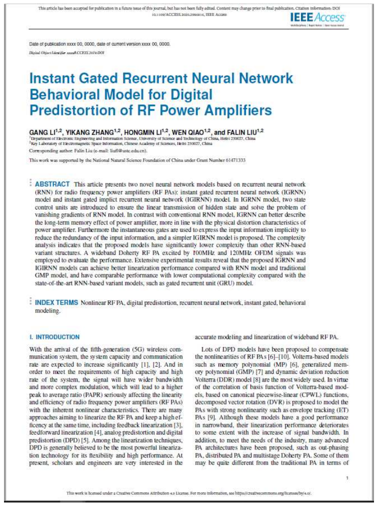


The potential roadmap for AI/ML in 6G

PHASE 1 IS RF FOCUSED AND NOT NECESSARILY 6G RELATED!

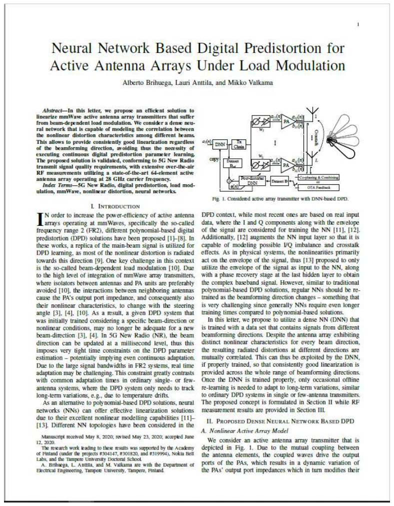


► Optimization of RF Frontend, modelling the non-linearities, analog and digital impairments seems to be an 'easy' entry point for applied machine learning in wireless communication.



Instant Gated Recurrent Neural Network Behavioral Model for Digital Predistortion of RF Power Amplifiers

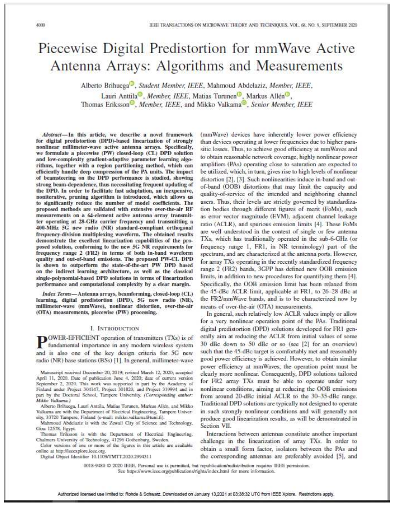
(April 2020)



Neural Network Based Digital Predistortion for Active Antenna Arrays Under Load Modulation

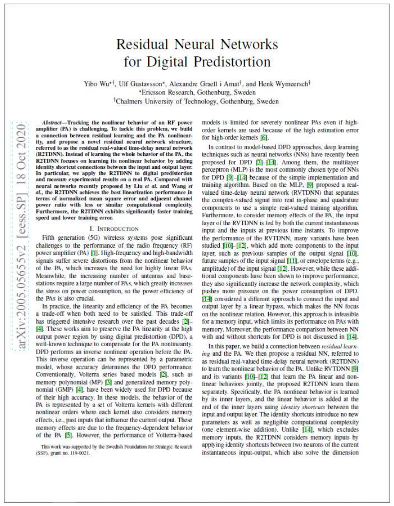
Alberto Brihuega, Lauri Anttila, and Mikko Valkama

(June 2020)



Piecewise Digital Predistortion for mmWave Active Antenna Arrays: Algorithms and Measurements

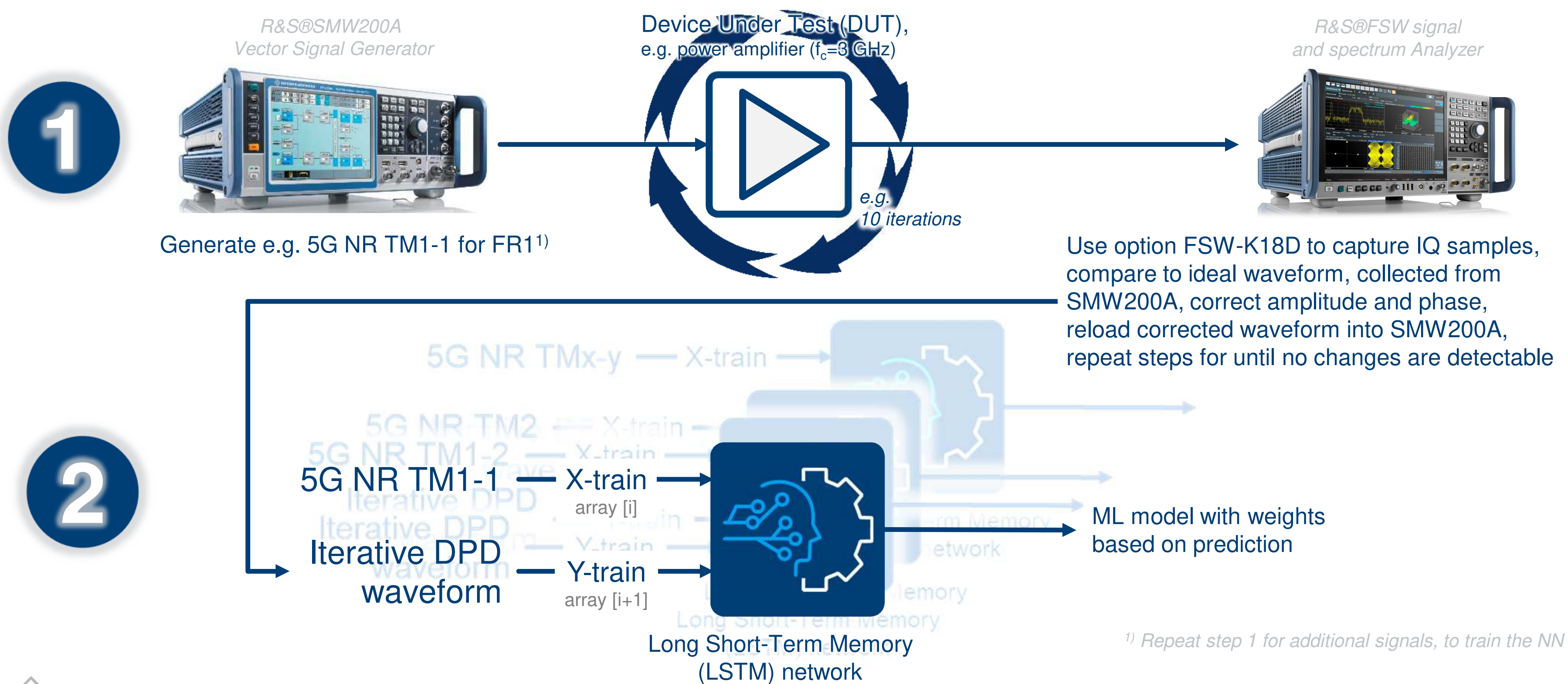
(Sep 2020)



Residual Neural Networks for Digital Predistortion

(Oct 2020)

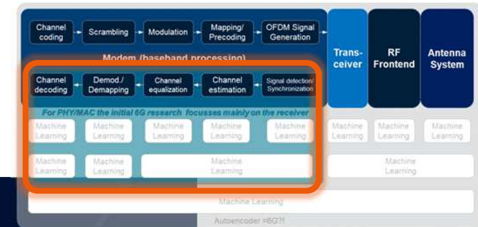
MACHINE LEARNING FOR DIGITIAL PRE-DISTORTION (DPD)
GENERAL DATA COLLECTION AND TRAINING PROCEDURE

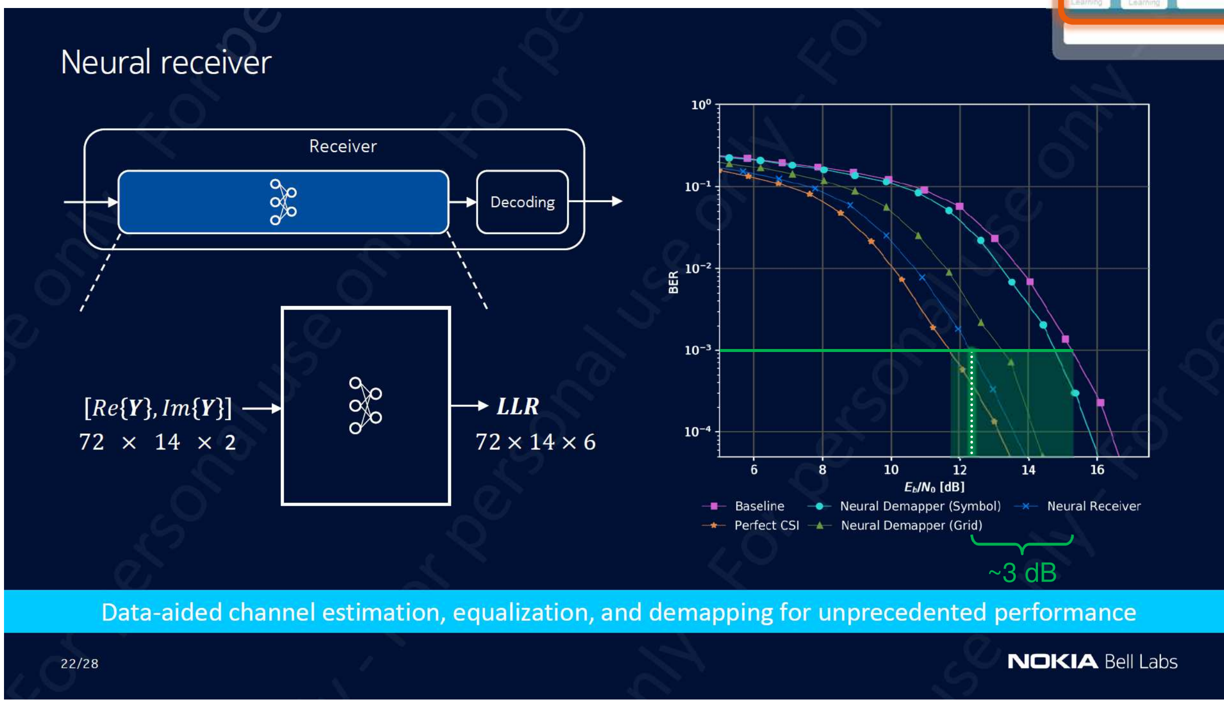


1) Repeat step 1 for additional signals, to train the NN

Status of AI/ML in wireless communication: Academia & Research

PHASE 2: APPROACHING PERFORMANCE CLOSE TO PERFECT CHANNEL KNOWLEDGE

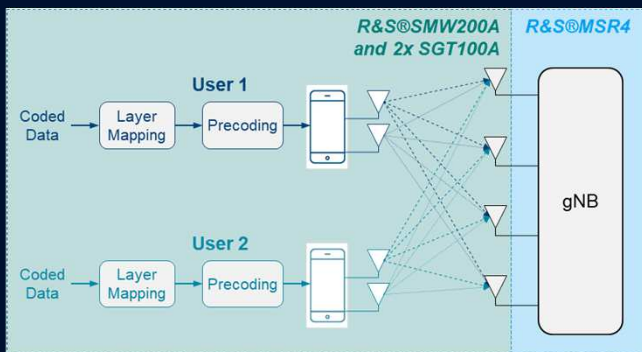


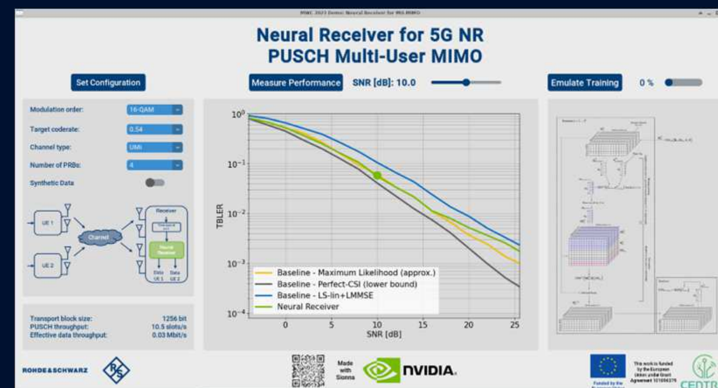


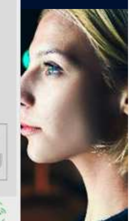
Source: https://aiforgood.itu.int/events/the-road-towards-an-ai-native-air-interface-for-6g/ [Nov 2020]

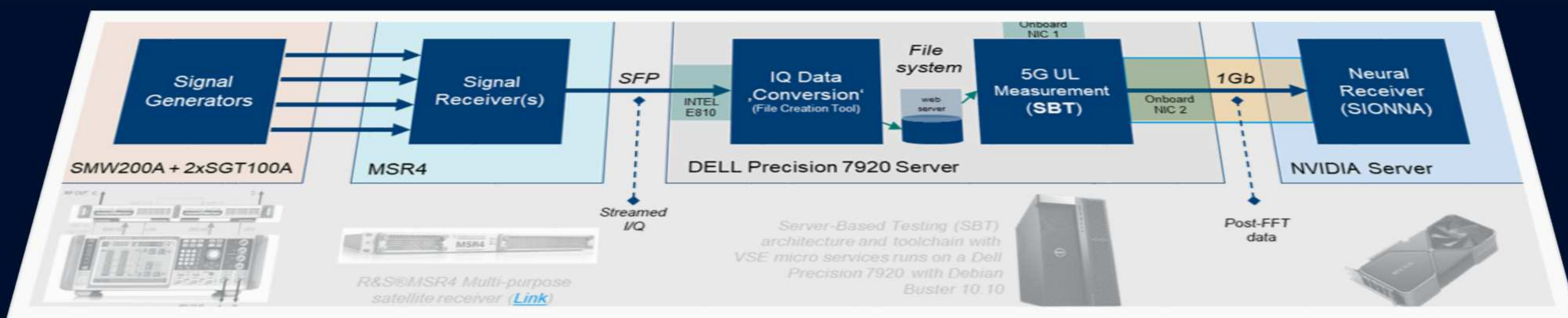
TOWARDS 6G
PHASE 2: NEURAL RECEIVER FOR 5G NR PUSCH MU-MIMO SCENARIO

Demonstration at MWC GSMA

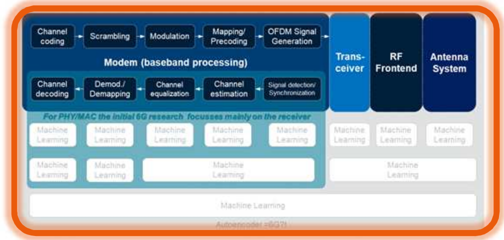






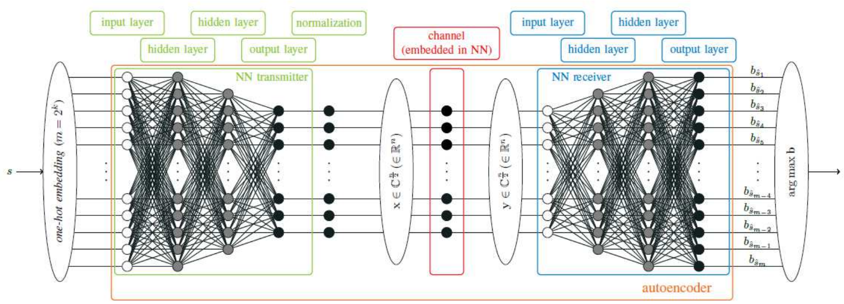


PHASE 3: TRANSITION TO AN AUTOENCODER, OR?

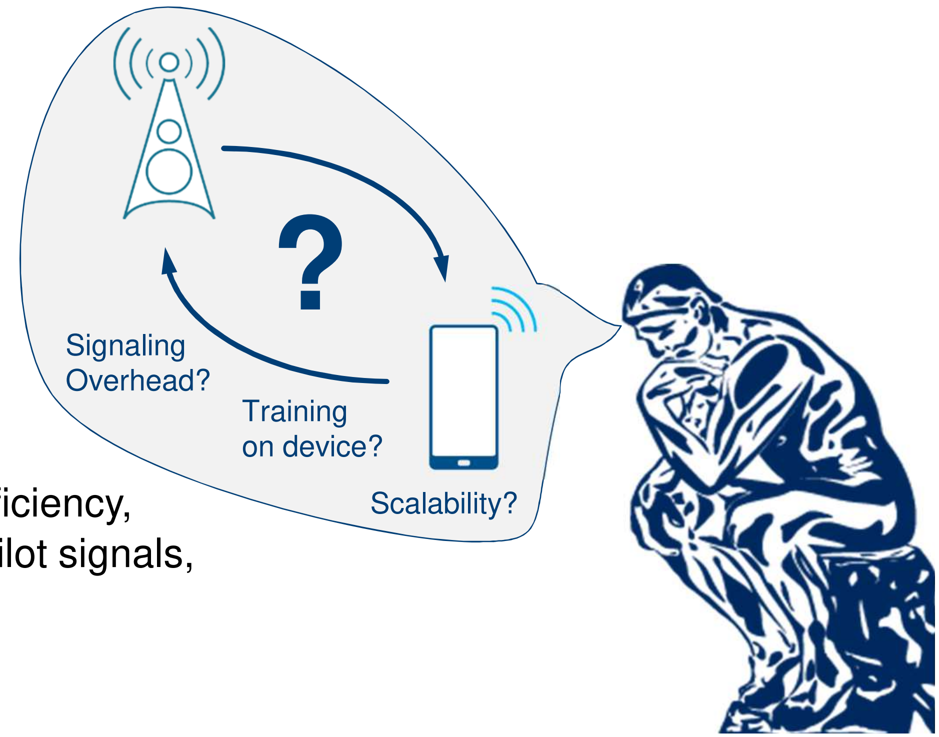


The autoencoder challenge

► Learning the behavior of an End-to-End (E2E) communication link via an autoencoder

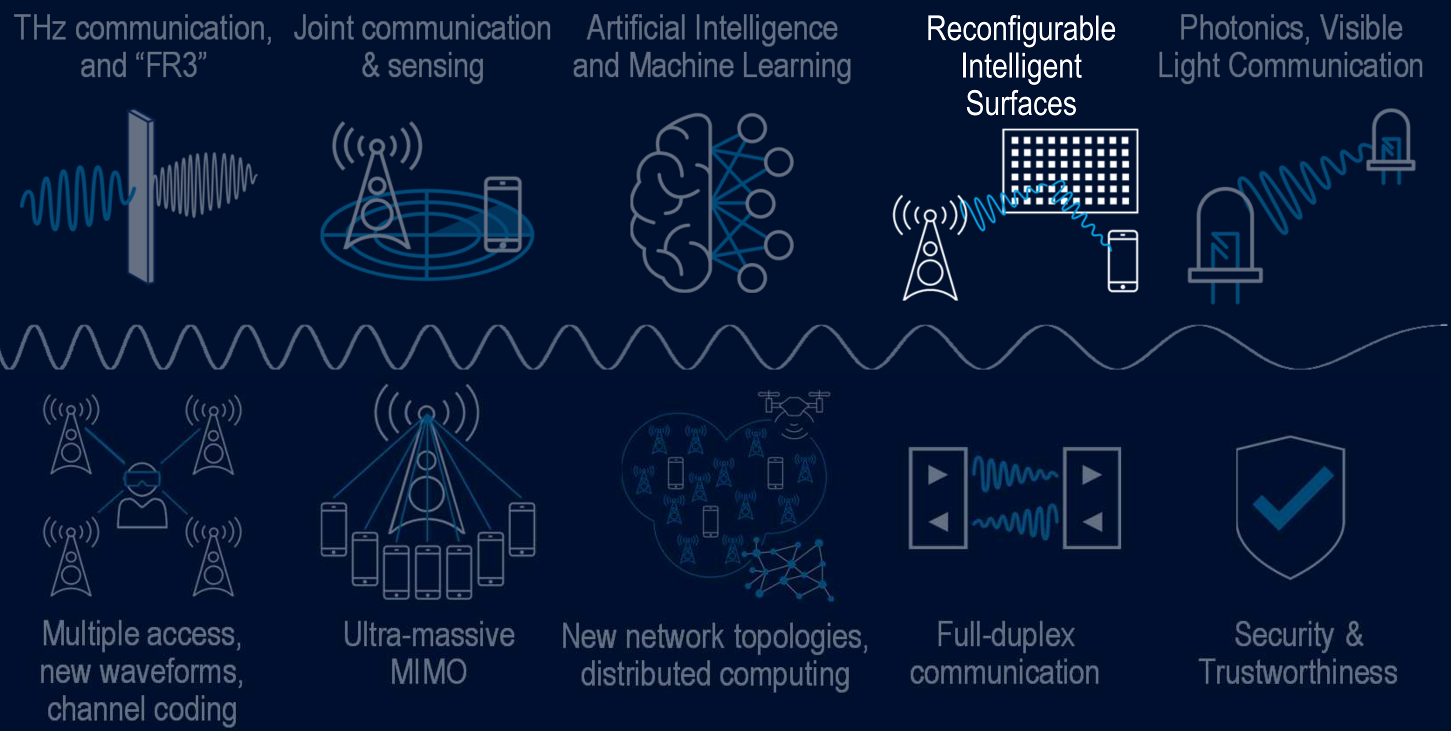


Source: OFDM-Autoencoder for End-to-End learning of communication systems



► Yes, provides additional performance gains & efficiency, e.g. can eliminate the need for transmission of pilot signals, but how practical is this solution in ‘real life’?

6G RESEARCH AREAS FROM A T&M PERSPECTIVE



A high-level overview of all these research areas is provided in one of our [#THINKSIX](#) videos.

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.
- IRS offers an adaptation of channel h(t) to maximize reception quality.

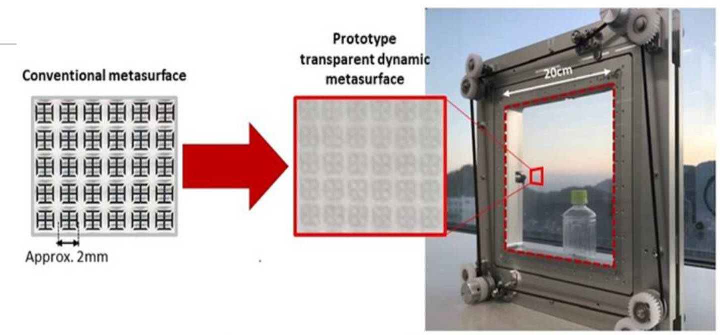
Press Release

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

January 17, 2020

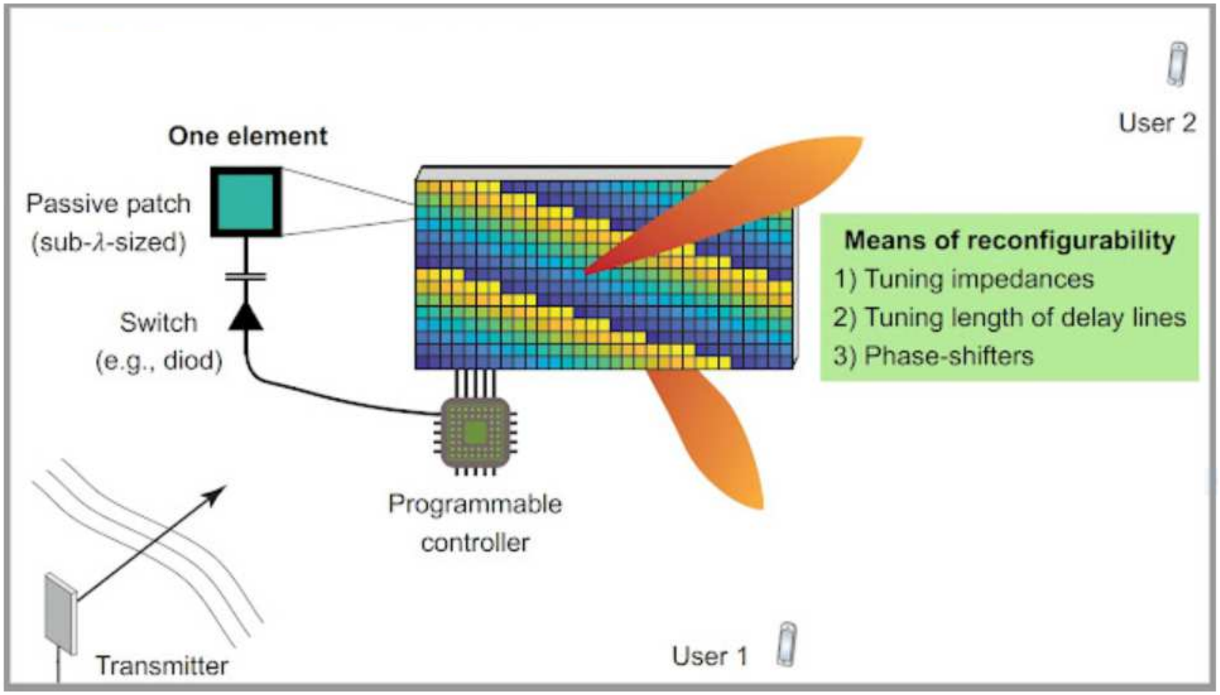
DOCOMO Conducts World's First Successful Trial of Transparent Dynamic Metasurface

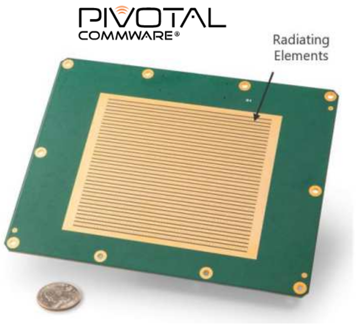
— Dynamic wave manipulation and high transparency expected to optimize 5G network construction —



Prototype of transparent dynamic metasurface

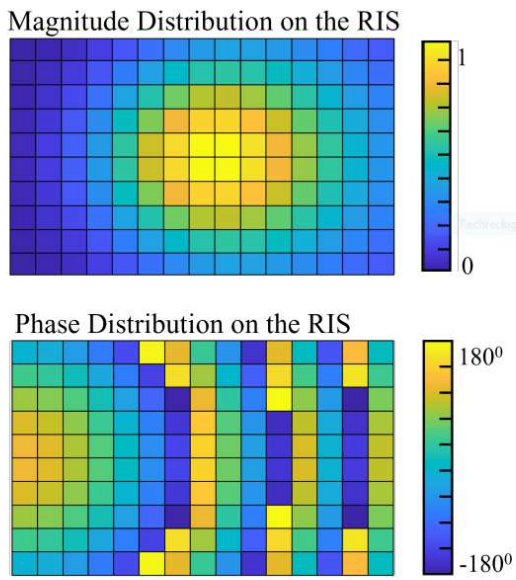
INTELLIGENT REFLECTING SURFACES
OPERATION IN A NUTSHELL

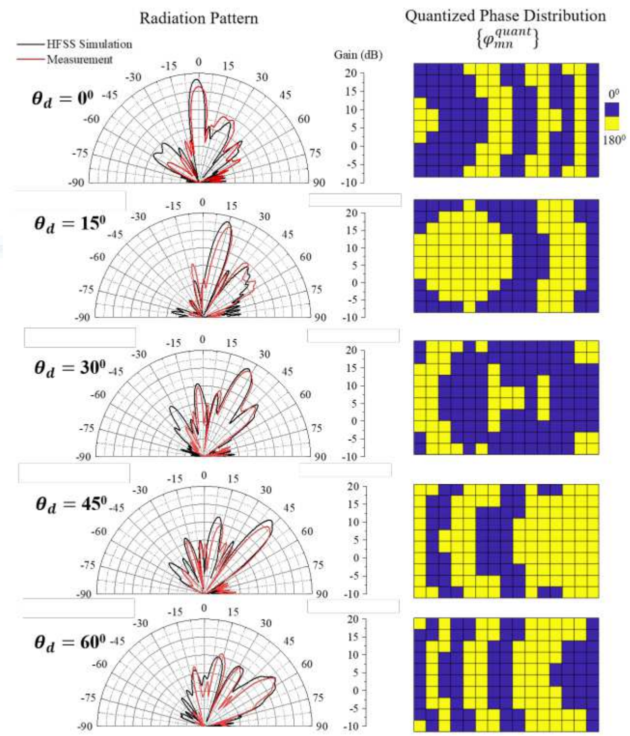




Sources: https://www.free6gtraining.com/2020/12/communications-using-intelligent.html and https://www.youtube.com/watch?v=9cBn5piI9Ms

INTELLIGENT REFLECTING SURFACES
DESIGN AND EVALUATION



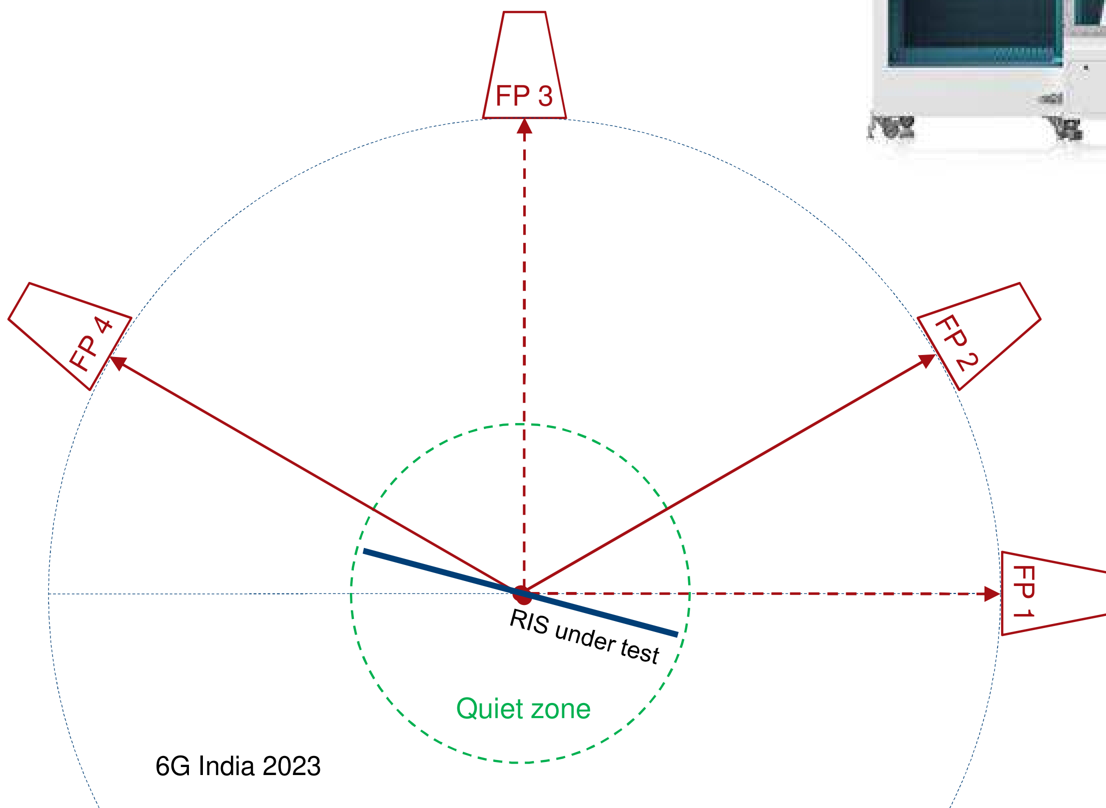


Source: Design and Evaluation of Reconfigurable Intelligent Surfaces in Real-World Environment by Georgios C. Trichopoulos, Panagiotis Theofanopoulos, Bharath Kashyap, Aditya Shekhawat, Anuj Modi, Tawfik Osman, Sanjay Kumar, Anand Sengar, Arkajyoti Chang, and Ahmed Alkhateeb

MULTI-ANGLE IRS ASSESSMENT SETUP

FP* = Feed or Probe

FP	Angle
FP1	0°
FP2	30°
FP3	90 °
FP4	150°



*Any FP can be used either as feed for impinging wave or probe for reflecting wave.

Turning of RIS allows any impinging wave angle

ROHDE & SCHWARZ CURRENT 6G ENGAGEMENTS WITH ACADEMIA & INDUSTRY

Academia & research institutes

- RWTH AACHEN UNIVERSITY
- Fraunhofer HHI
- DFKI Deutsches Forschungszentrum für Künstliche Intelligenz GmbH
- Technische Universität München (TUM)
- 5G+ Lab GERMANY
- TECHNISCHE UNIVERSITÄT DRESDEN
- Fraunhofer IAF
- 6G-ANNA
- 6G@UT
- 6G FLAGSHIP
- CHALMERS UNIVERSITY OF TECHNOLOGY
- ihp

Industry alliances, initiatives & cooperation's

- ITU
- NGMN
- ZD.B THINKNET 6G
- NEXT G ALLIANCE

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