

6G India 2023 International Conference

ON THE VERGE OF 6G



Mahesh Basavaraju
Market Segment Manager
Wireless Communications

ROHDE & SCHWARZ

Make ideas real

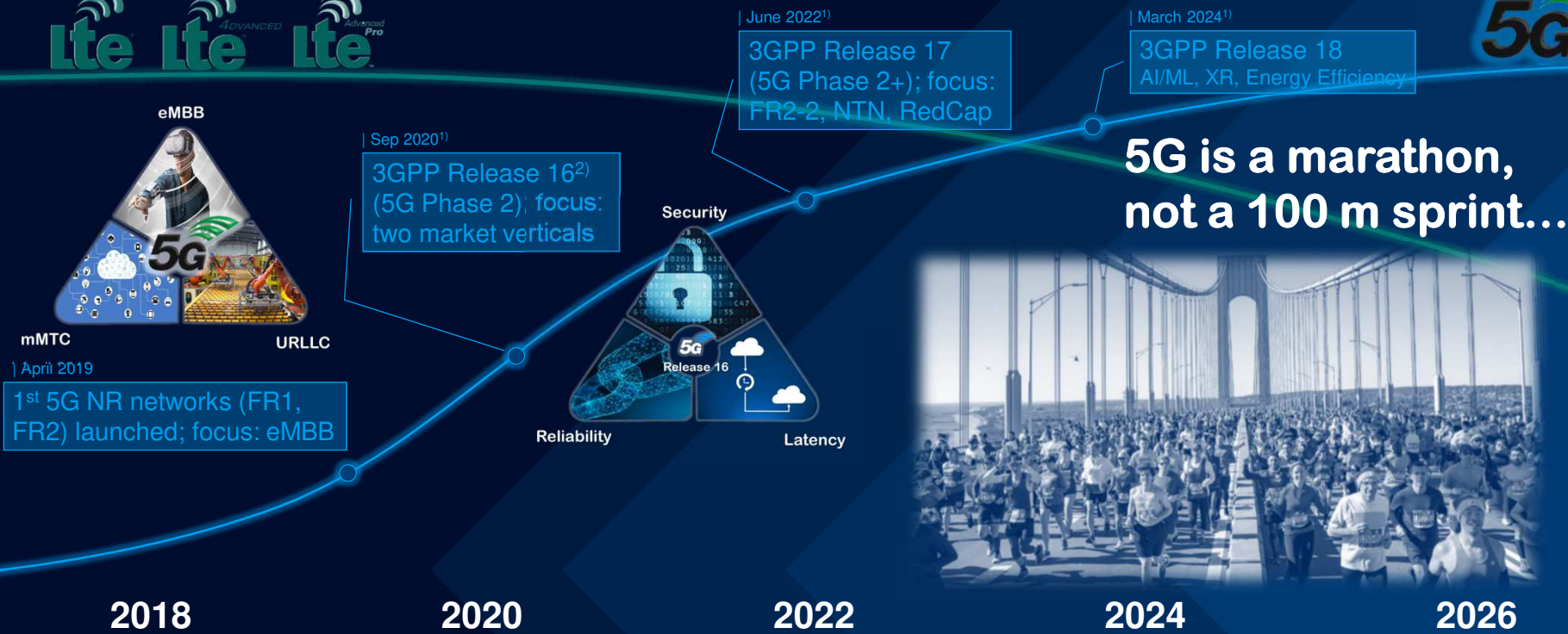


AGENDA

- ▶ 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



| June 2022¹⁾
 3GPP Release 17
 (5G Phase 2+); focus:
 FR2-2, NTN, RedCap

| March 2024¹⁾
 3GPP Release 18
 AI/ML, XR, Energy Efficiency

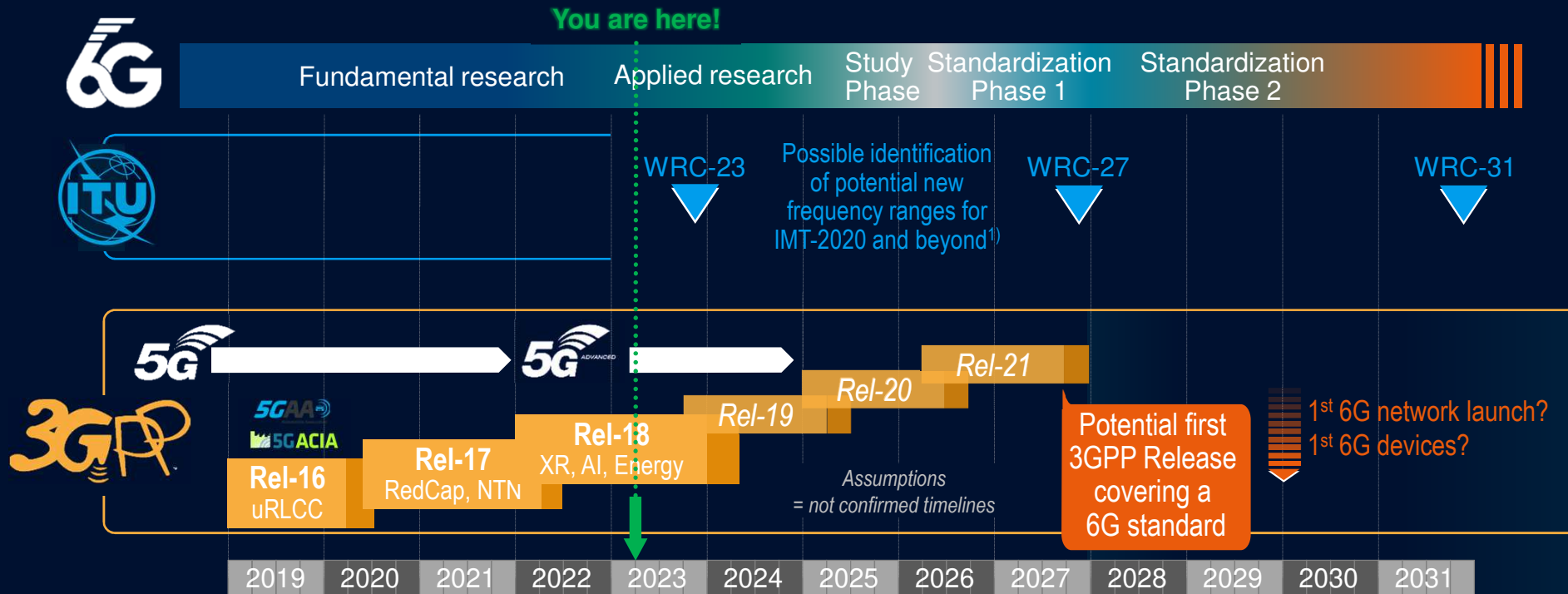
| Sep 2020¹⁾
 3GPP Release 16²⁾
 (5G Phase 2); focus:
 two market verticals

mMTC
 | April 2019
 1st 5G NR networks (FR1,
 FR2) launched; focus: eMBB



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



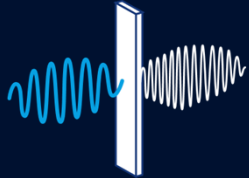
¹⁾ IMT-2020 systems are called 5G

²⁾ 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



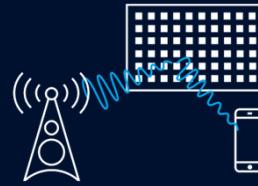
Joint communication & sensing



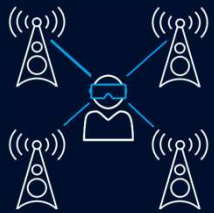
Artificial Intelligence and Machine Learning



Reconfigurable Intelligent Surfaces



Photonics, Visible Light Communication



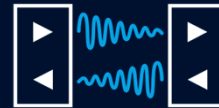
Multiple access, new waveforms, channel coding



Ultra-massive MIMO



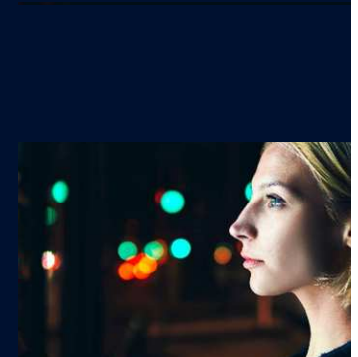
New network topologies, distributed computing



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!



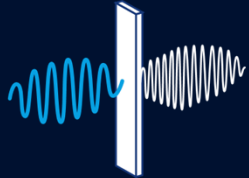
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Mobile World Congress 2023

6G RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communication, and "FR3"



Joint communication & sensing



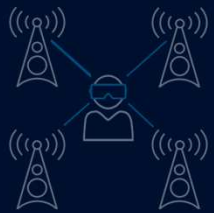
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Reconfigurable Intelligent Surfaces



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6

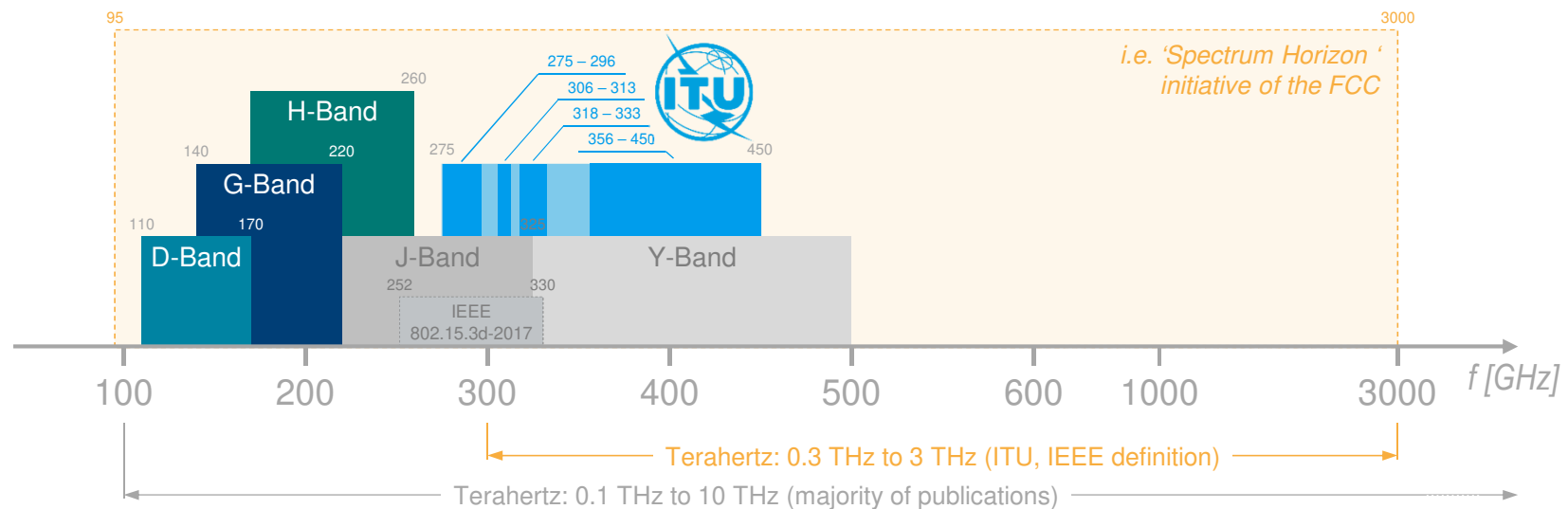
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6G India 2023

WHAT FREQUENCIES ARE WE TALKING ABOUT FOR 6G?

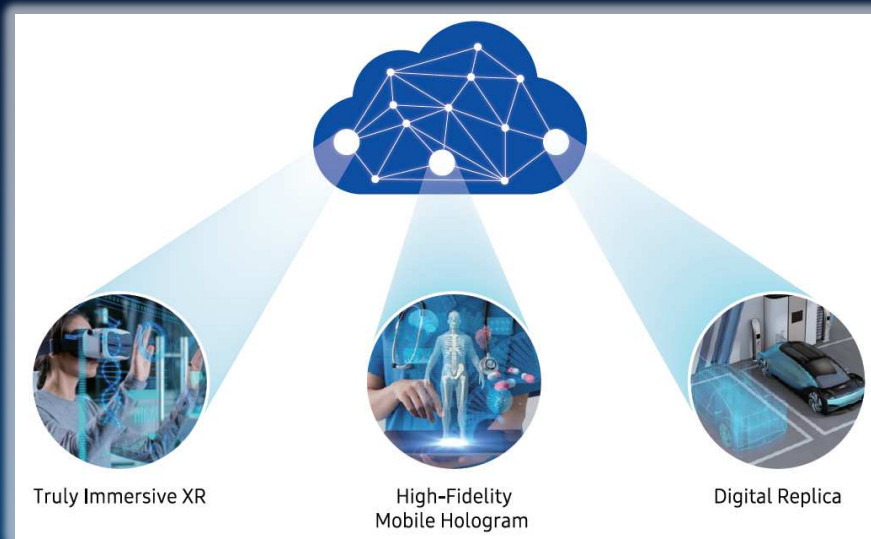
Let's be clear, a future 6G standard will also work below 100 GHz, below sub-6 and 1 GHz!

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



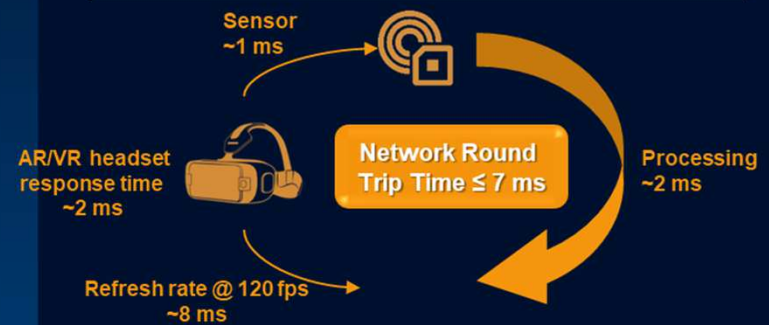
WHAT PROBLEM IS 6G TRYING TO SOLVE WITH SUPPORT OF (SUB-)THZ?

- ▶ 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

Touch

Voice

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 \rightarrow wider bandwidths required \rightarrow move to higher frequency, i.e. sub-THz (e.g. 340 GHz)

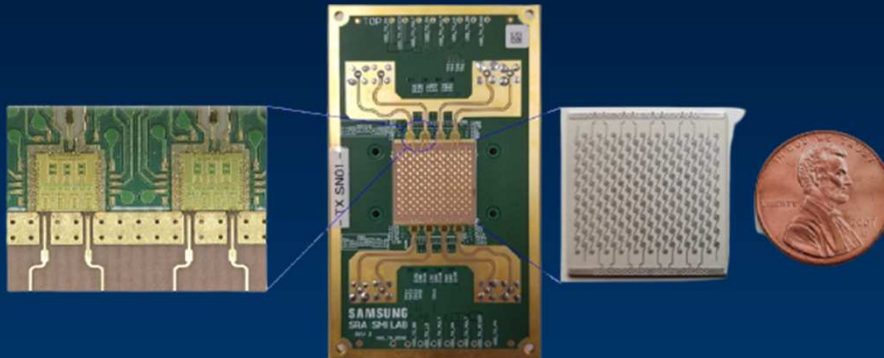


OUR CUSTOMERS ARE ACTIVELY WORKING ON THIS TECHNOLOGY

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



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 nitride (hBN). The technology is energy efficient and allows higher bandwidths



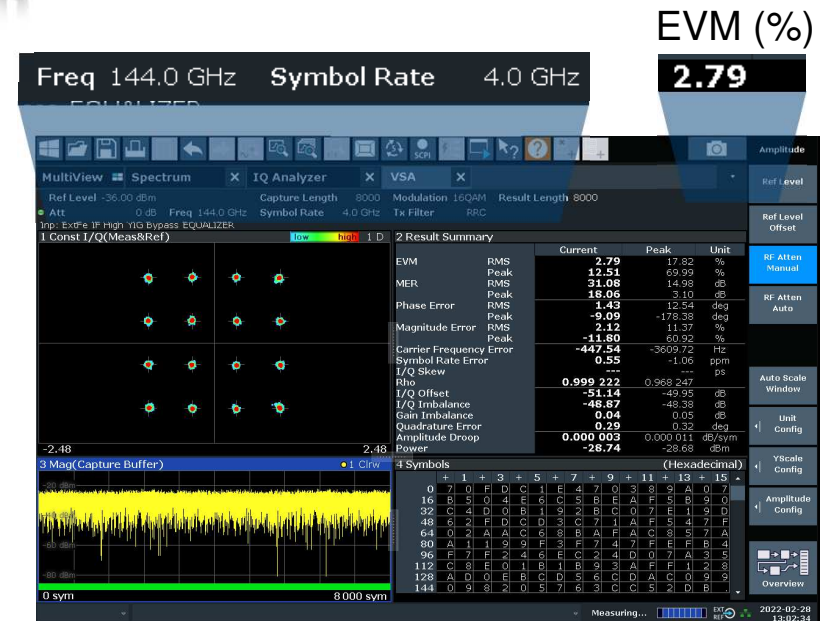
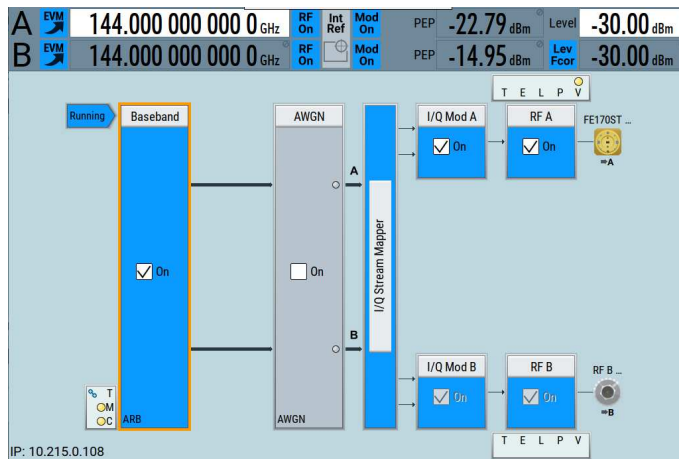
More background info: <https://spectrum.ieee.org/atomthin-switches-5g-6g-radio-signals>



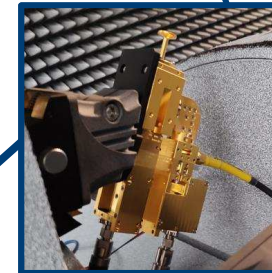
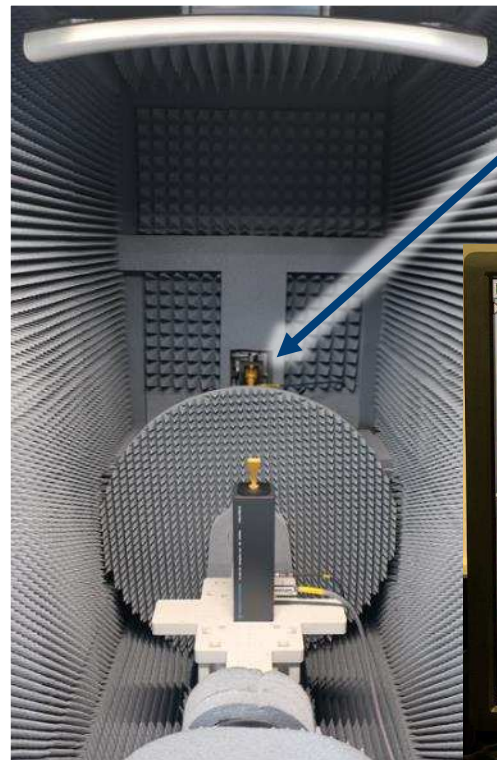
FE170ST / FE170SR FRONTENDS EXTEND THE FREQUENCY RANGE TO 110 GHz TO 170 GHz



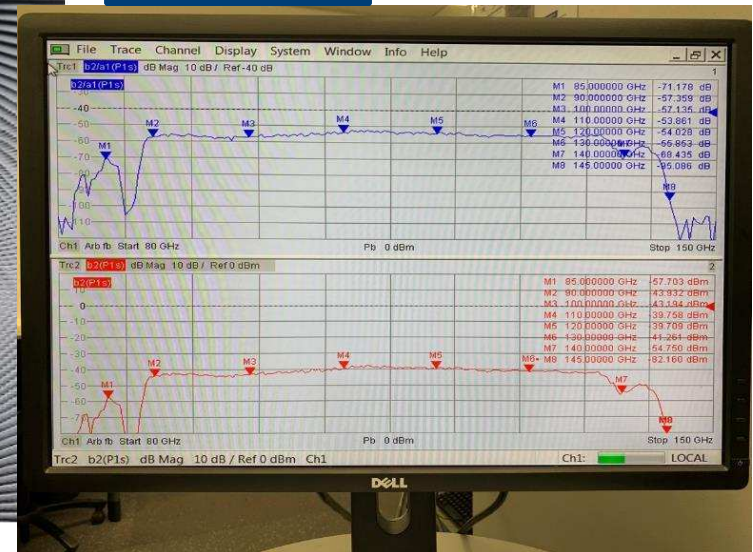
- ▶ **Compact** form factor
- ▶ Only three connections needed (IF, reference frequency, LAN)



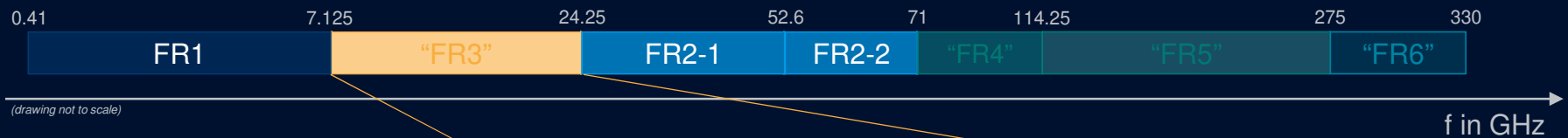
SIMULTANEOUSLY WE TAKE THE NEXT STEP TOWARDS FULL OVER-THE-AIR TEST SOLUTIONS FOR D-BAND (110-170 GHz)



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

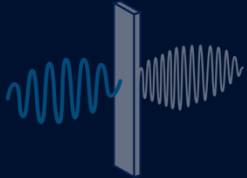


- 6.1.6 Potential Spectrum bands for study
 - 6.1.6.1 UHF Band
 - 6.1.6.1.1 1300-1350 MHz
 - 6.1.6.1.2 1780-1850 MHz
 - 6.1.6.2 Lower-cmW spectrum
 - 6.1.6.2.1 3100-3450 MHz
 - 6.1.6.2.2 3980-4180 MHz (TBD)
 - 6.1.6.2.3 4400-4940 MHz
 - 6.1.6.2.4 7125-8500 MHz
 - 6.1.6.3 Upper-cmW spectrum
 - 6.1.6.3.1 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 23.25-27.5 (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

THz communication,
and "FR3"



Joint communication
& sensing



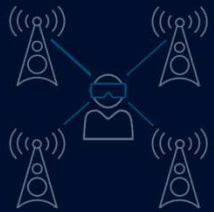
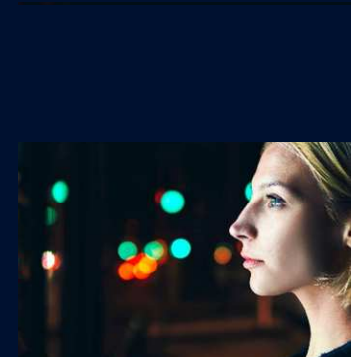
Artificial Intelligence
and Machine Learning



Reconfigurable
Intelligent
Surfaces



Photonics, Visible
Light Communication



Multiple access,
new waveforms,
channel coding



Ultra-massive
MIMO



New network topologies,
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Full-duplex
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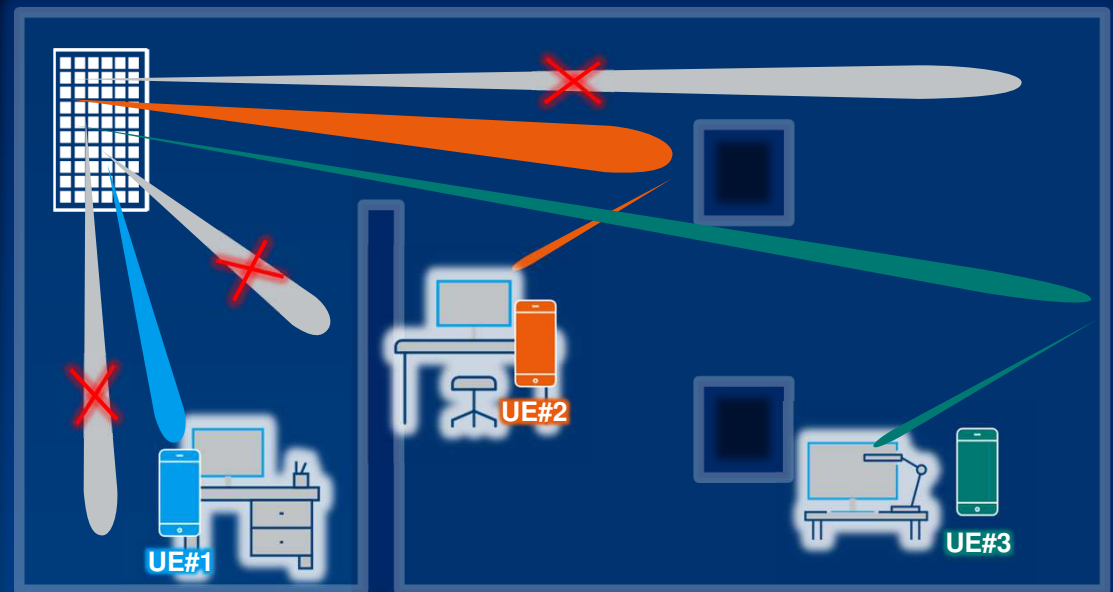


JOINT COMMUNICATION AND SENSING (JCAS) USE CASE EXAMPLES



JOINT COMMUNICATION AND SENSING (JCAS) MOTIVATION AND RESEARCH CHALLENGES

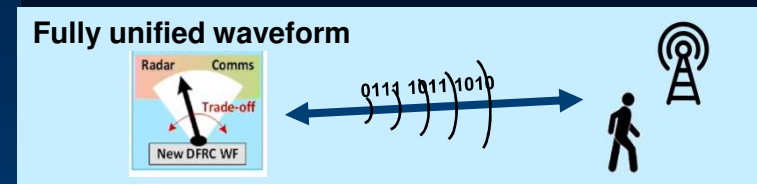
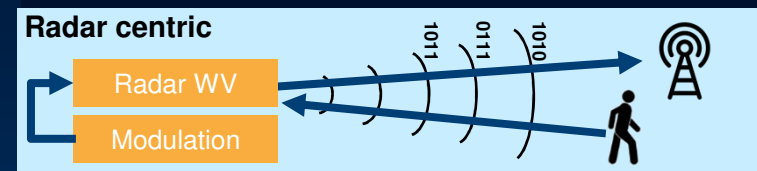
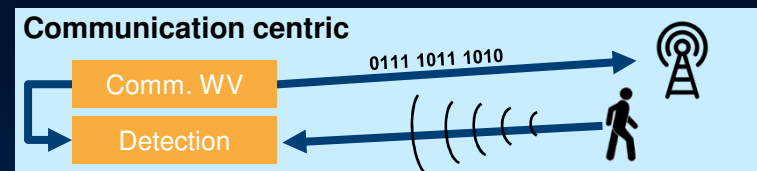
- ▶ Design a communication signal that can be used for objection detection, tracking, recognition, localization, and imaging
- ▶ Sensing-assisted communication by utilizing sensed information to aid beam management/alignment, CSI acquisition, medium-aware links, interference mitigation, etc.
- ▶ Research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



JOINT COMMUNICATION AND SENSING (JCAS) MOTIVATION AND RESEARCH CHALLENGES

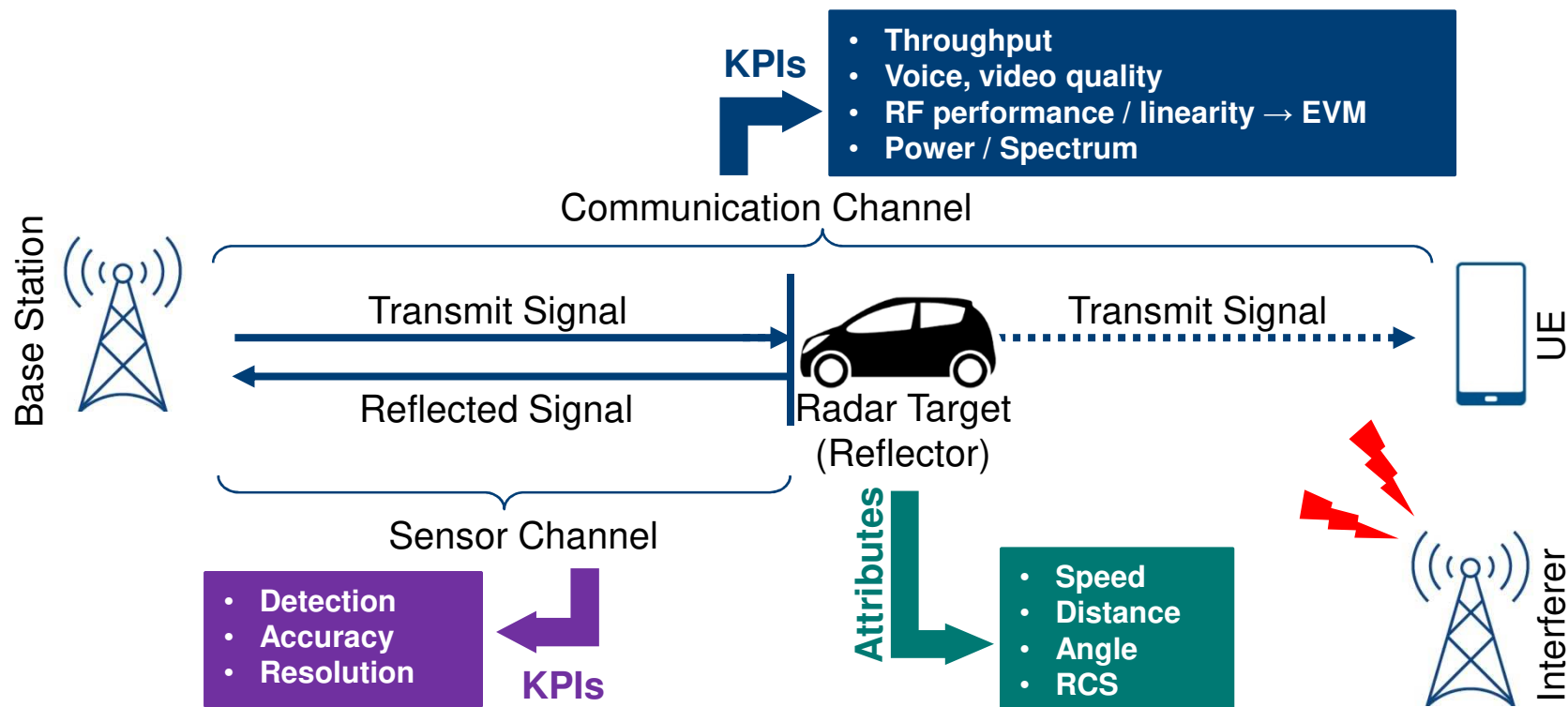
► Integrated JCAS system using single transmitted waveform and full-duplex operation:

- 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



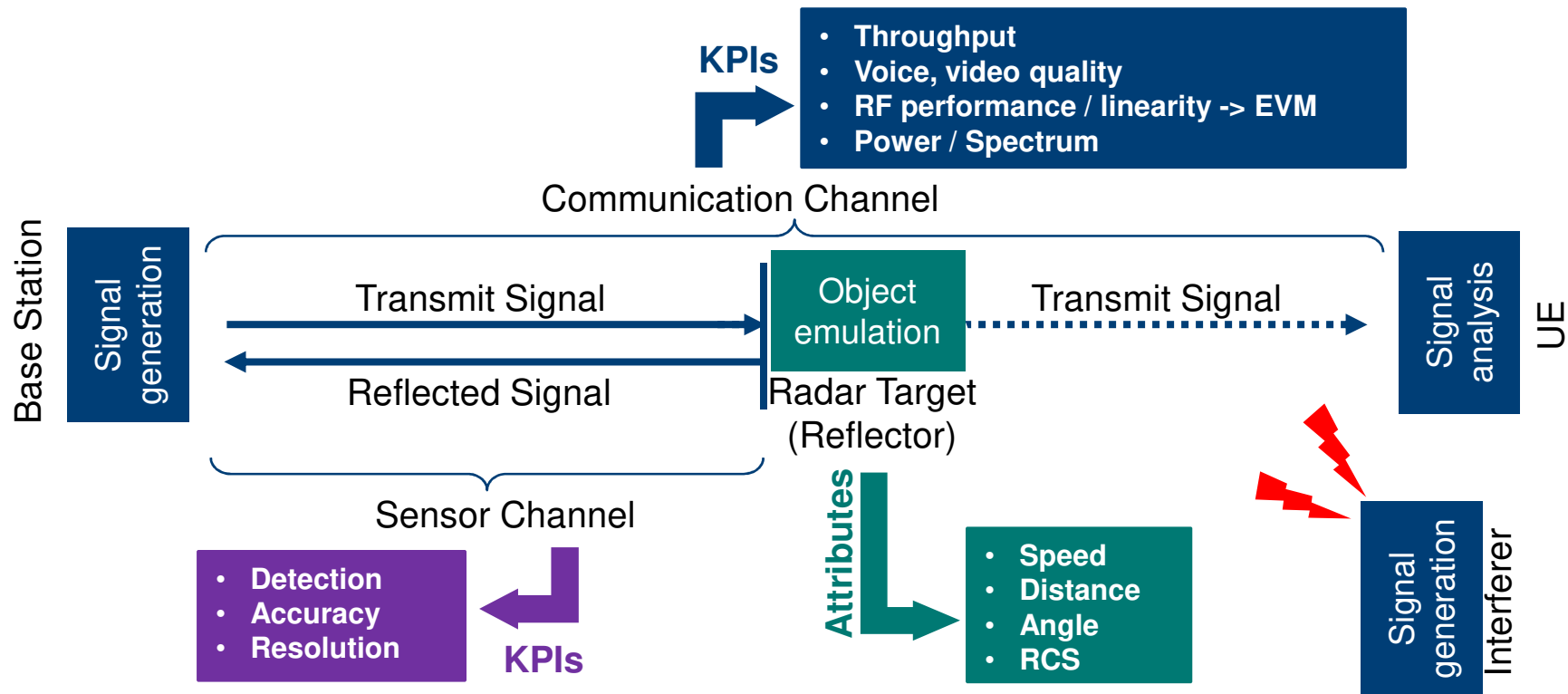
JOINT COMMUNICATION AND SENSING

DIFFERENCES IN PERFORMANCE INDICATION



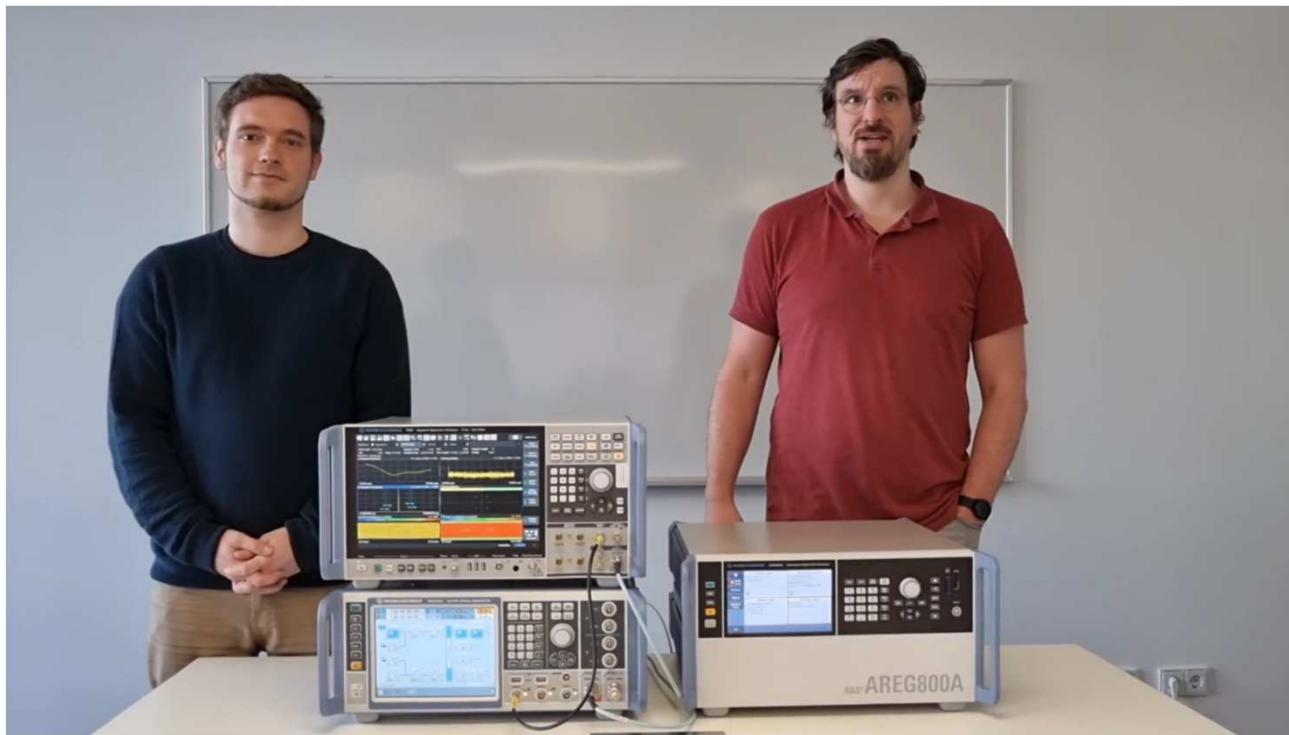
JOINT COMMUNICATION AND SENSING

DIFFERENCES IN PERFORMANCE INDICATION



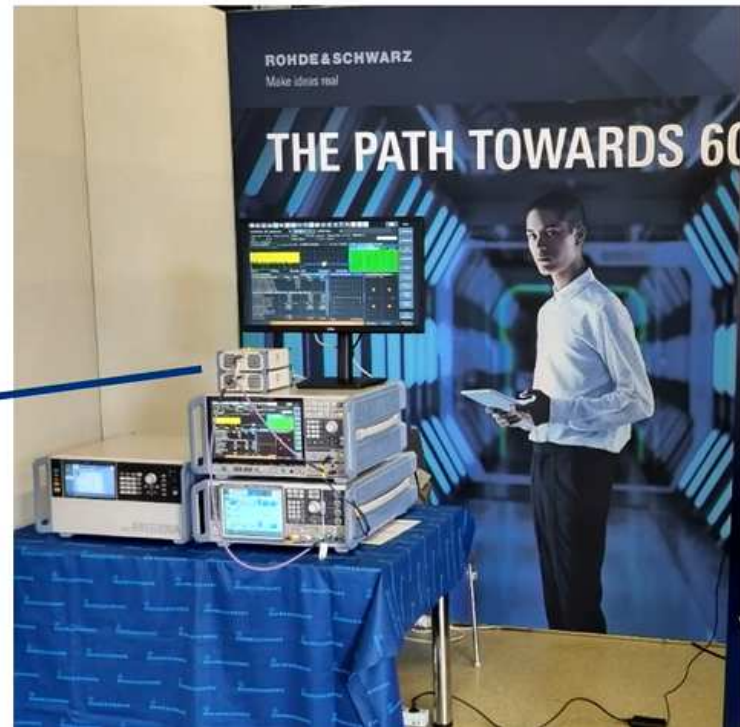
JOINT COMMUNICATION AND SENSING

HOW TO TEST JCAS KPI – SOME INITIAL T&M CAPABILITIES



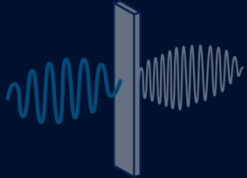
TESTABILITY OF JOINT COMMUNICATION AND SENSING (JCAS) DEMONSTRATION OF OUR CURRENT CAPABILITIES

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



6G RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communication,
and "FR3"



Joint communication
& sensing



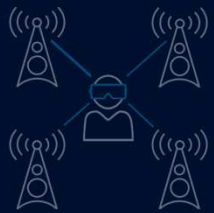
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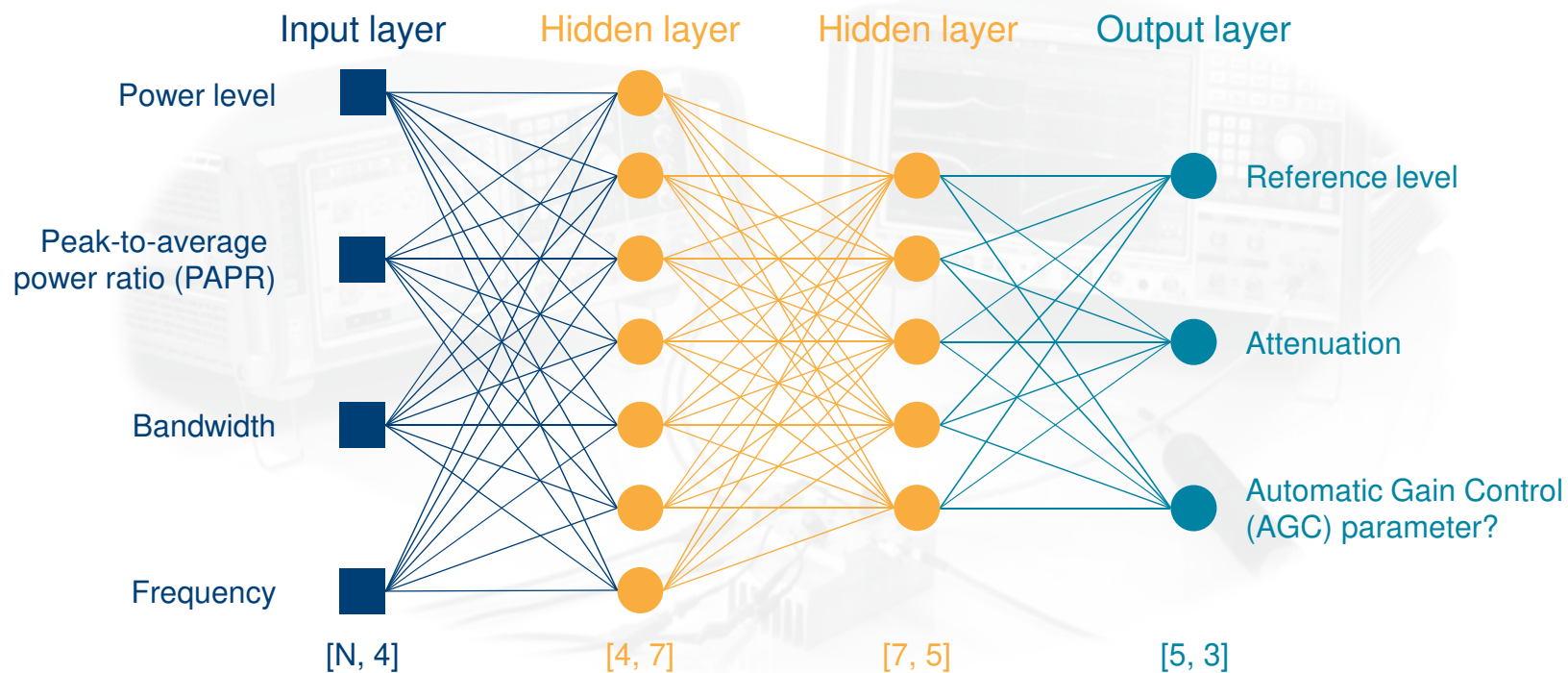
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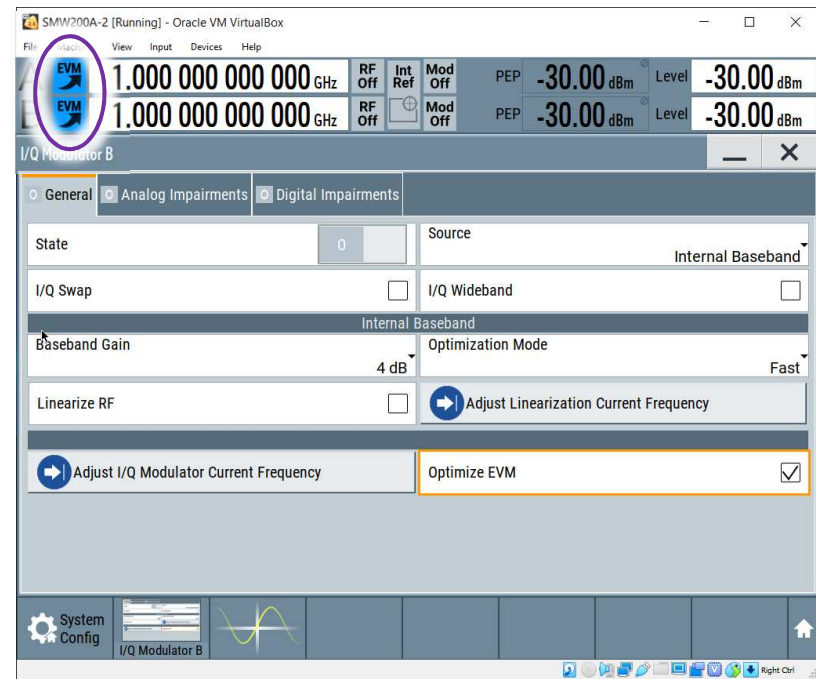
MACHINE LEARNING IS BASED ON NEURAL NETWORKS (NN)

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!)



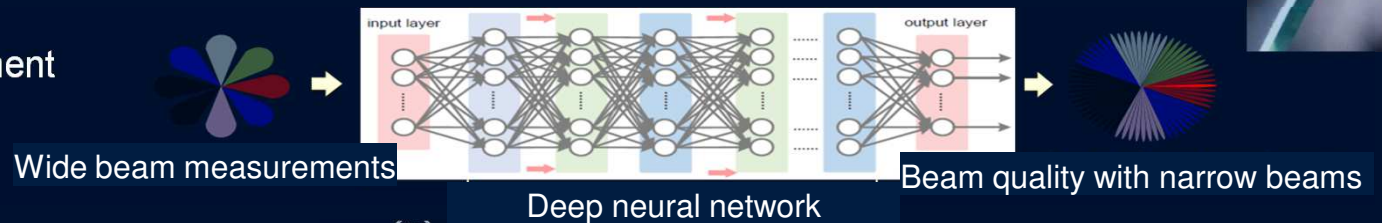
FIRST STEPS IN 5G-ADVANCED (3GPP RELEASE 18) STUDY ON ARTIFICIAL INTELLIGENCE/MACHINE LEARNING

- ▶ 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)



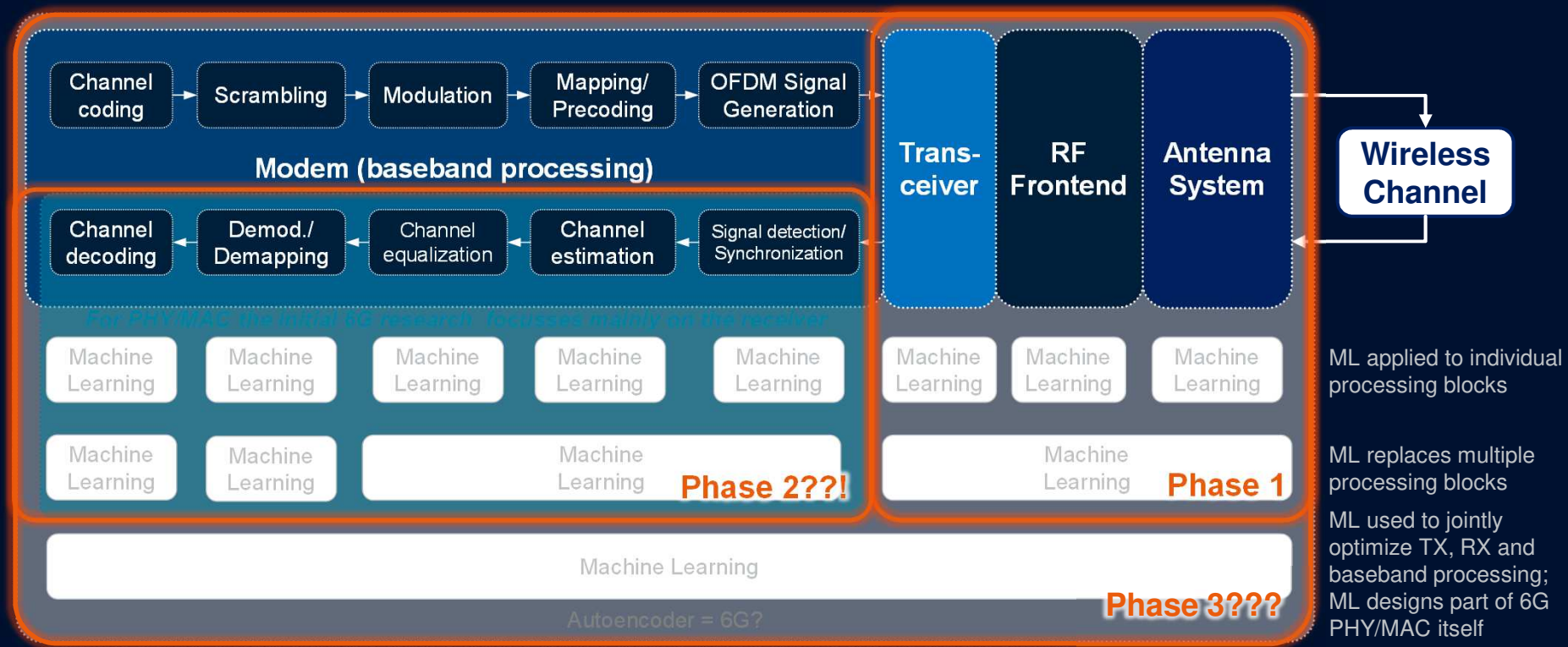
2. Beam management



3. Positioning accuracy enhancements



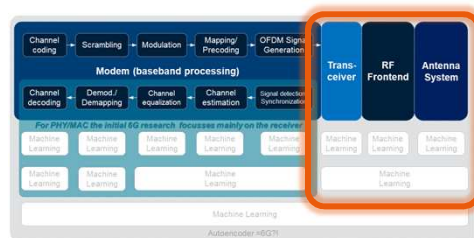
WHAT POTENTIALLY COMES NEXT? AI-NATIVE AIR INTERFACE FOR 6G



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.



10.1109/ACCESS.2020.3018808

Date of publication: 05. 08. 2020, date of current version: 05. 09. 2020

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

GAO L¹, YANG ZHANG¹, HONGMIN LI¹, WEN QIAO¹, and FALIN LI²

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² Beijing Key Laboratory of Microwave Nonlinear Circuit, Beijing University of Posts and Telecommunications, Beijing 100024, China

Corresponding author: Li F. (e-mail: lialin@bupt.edu.cn)

This work was supported by the National Natural Science Foundation of China under Grant 61871227.

ABSTRACT This article presents two novel neural network models based on recurrent neural network (RNN) for radio frequency power amplifiers (RF PA). Instant gated recurrent neural network (IGRNN) model and instant gated recurrent neural network (IGRNN) model. In IGRNN model, two state control units are introduced by using the linear characteristic of input and output. The proposed models are compared with conventional RNN models. The proposed models can better describe the long-term memory effect of power amplifier, and can better describe the non-linear characteristic of power amplifier. Furthermore, the instantaneous gain and delay are taken into account to improve the prediction accuracy. The experimental results show that the proposed models have significantly lower complexity than other RNN-based neural networks. A validated RF PA is verified by HSPICE and ZEMAX. OPTIM course was employed to obtain the performance. Extensive experimental results reveal that the proposed IGRNN and RNN models can achieve better transmission performance compared with RNN model and traditional GMP model, and can provide performance with lower computational complexity with the cost of the RNN-based neural models, such as gated recurrent neural network.

INDEX TERMS Nonlinear RF PA, digital predistortion, recurrent neural network, instant gated behavioral modeling.

I. INTRODUCTION

With the arrival of the fifth-generation (5G) wireless communication system, the system capacity and communication rate are expected to increase significantly [1], [2], and its role to meet the requirements of high capacity and high speed of the system, the signal will have wider bandwidth and more complex modulation, which will lead to a higher peak-to-average power ratio (PAPR) and higher PAPR, and therefore, it will require power amplifiers (PA) with wider nonlinear characteristics. There are many approaches aiming to increase the PA and their nonlinear characteristics at the same time, including feedback linearization [3], digital predistortion (DPD) [4], analog pre-distortion and linearization (APDL) [5]. Among the linearization techniques, DPD is most popular because of its flexibility and high performance. At present, various and extensive work is continued in the

instant modeling and linearization of wideband RF PA. Lots of DPD models have been proposed to compensate the nonlinearity of RF PA [6]–[10]. Volterra-based models are expected to increase significantly [11], [12], and its role to meet the requirements of high capacity and high speed of the system, the signal will have wider bandwidth and more complex modulation, which will lead to a higher peak-to-average power ratio (PAPR) and higher PAPR, and therefore, it will require power amplifiers (PA) with wider nonlinear characteristics. There are many approaches aiming to increase the PA and their nonlinear characteristics at the same time, including feedback linearization [3], digital predistortion (DPD) [4], analog pre-distortion and linearization (APDL) [5]. Among the linearization techniques, DPD is most popular because of its flexibility and high performance. At present, various and extensive work is continued in the

(April 2020)

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

Alberto Bolognani¹, Luca Antonia, and Mikko Valkama

¹ Institute of Information Technology, University of Jyväskylä, Finland

² School of Electrical Engineering, Aalto University, Finland

ABSTRACT—In this letter, we propose an efficient solution to nonlinear digital predistortion (DPD) for active antenna arrays (AAA) under load modulation. We consider a different type of neural network-based DPD solution, which is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation.

I. INTRODUCTION

In order to increase the power efficiency of active antenna arrays (AAA) operating at millimeter-wave (mmWave) frequencies, digital predistortion (DPD) solutions have been proposed [1]–[3]. In this work, a novel DPD solution is proposed for AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation.

INDEX TERMS Neural network, digital predistortion, active antenna arrays, load modulation.

(June 2020)

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

Alberto Bolognani¹, Student Member, IEEE, Mahmood Adhikari, Member, IEEE, Luca Antonia², Member, IEEE, Maria Turunen³, Markus Aliakbar⁴, Thomas Eriksson⁵, Member, IEEE, and Mikko Valkama¹, Senior Member, IEEE

¹ Institute of Information Technology, University of Jyväskylä, Finland

² School of Electrical Engineering, Aalto University, Finland

³ School of Information Science, University of Jyväskylä, Finland

⁴ School of Information Science, University of Jyväskylä, Finland

⁵ School of Information Science, University of Jyväskylä, Finland

ABSTRACT—In this article, we describe a novel framework for digital predistortion (DPD) for mmWave active antenna arrays (AAA) under load modulation. We consider a different type of neural network-based DPD solution, which is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation.

I. INTRODUCTION

Piecewise digital predistortion (DPD) solutions have been proposed [1]–[3]. In this work, a novel DPD solution is proposed for AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation.

(Sep 2020)

Residual Neural Networks for Digital Predistortion

Yi Wu¹, UI-Gunnarsson, Alexandru Gadiu¹, and Henrik Wymeersch¹

¹ Ericsson Research, Gothenburg, Sweden

ABSTRACT—Tracking the nonlinear behavior of an RF power amplifier (PA) is challenging. To tackle this problem, we build a connection between neural networks and the PA nonlinear behavior. We consider a residual neural network (ResNet) for digital predistortion (DPD) for active antenna arrays (AAA) under load modulation. We consider a different type of neural network-based DPD solution, which is able to model the nonlinear characteristics of the AAA under load modulation. The proposed solution is able to model the nonlinear characteristics of the AAA under load modulation.

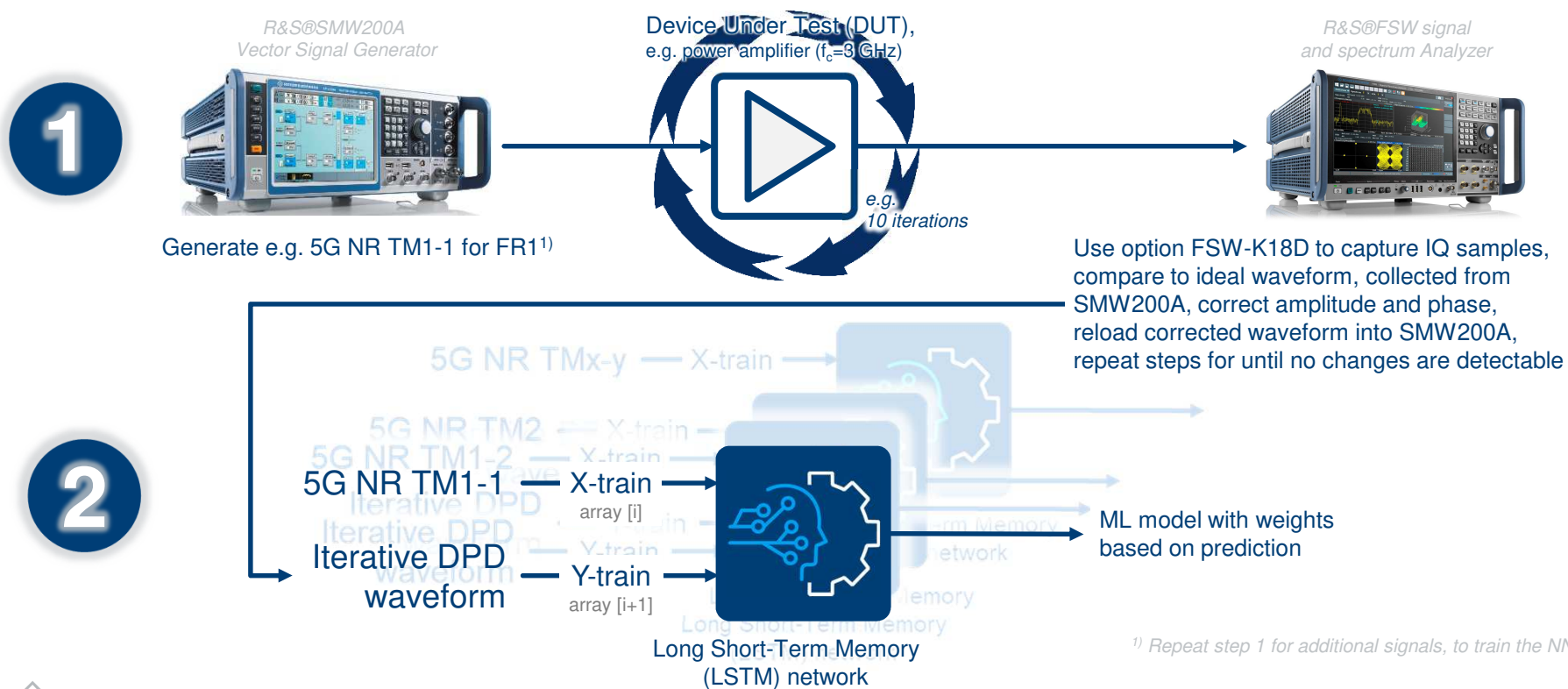
I. INTRODUCTION

Residual neural networks (ResNet) have been proposed to compensate the nonlinearity of RF PA [6]–[10]. Volterra-based models are expected to increase significantly [11], [12], and its role to meet the requirements of high capacity and high speed of the system, the signal will have wider bandwidth and more complex modulation, which will lead to a higher peak-to-average power ratio (PAPR) and higher PAPR, and therefore, it will require power amplifiers (PA) with wider nonlinear characteristics. There are many approaches aiming to increase the PA and their nonlinear characteristics at the same time, including feedback linearization [3], digital predistortion (DPD) [4], analog pre-distortion and linearization (APDL) [5]. Among the linearization techniques, DPD is most popular because of its flexibility and high performance. At present, various and extensive work is continued in the

(Oct 2020)

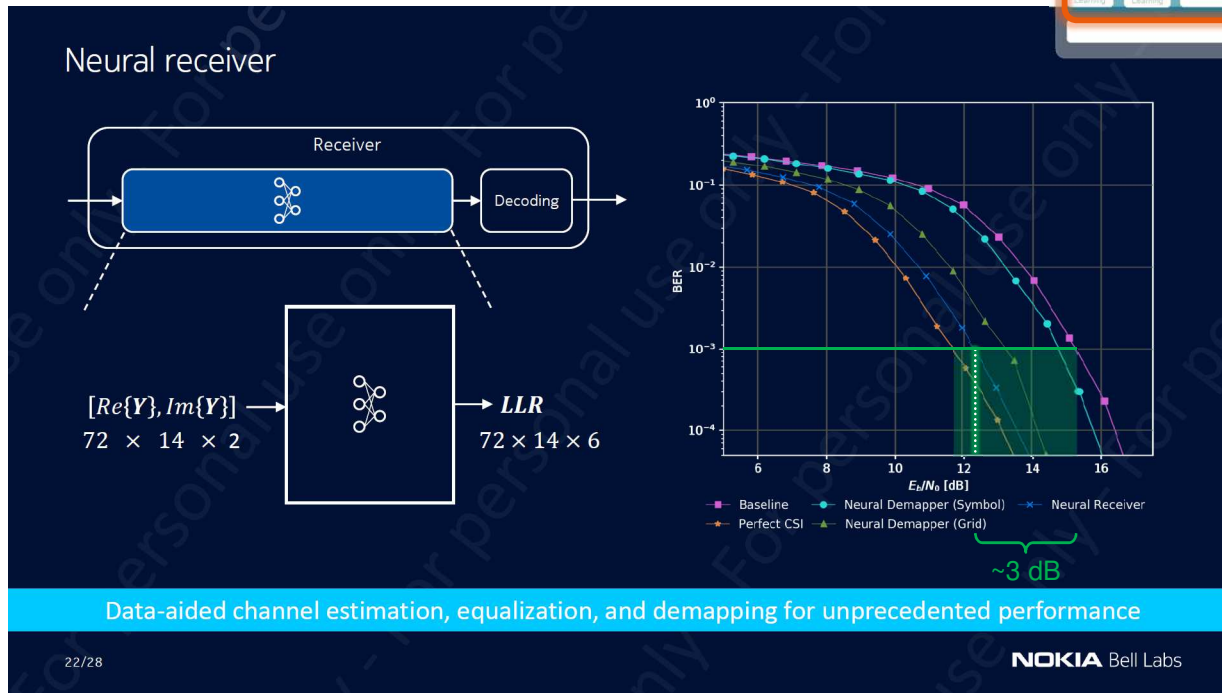
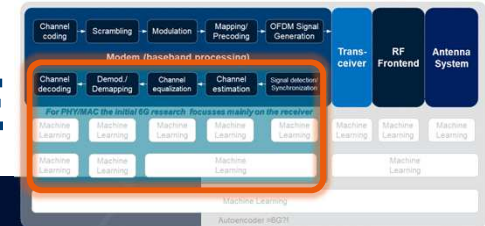
MACHINE LEARNING FOR DIGITAL PRE-DISTORTION (DPD)

GENERAL DATA COLLECTION AND TRAINING PROCEDURE



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

PHASE 2: APPROACHING PERFORMANCE CLOSE TO PERFECT CHANNEL KNOWLEDGE

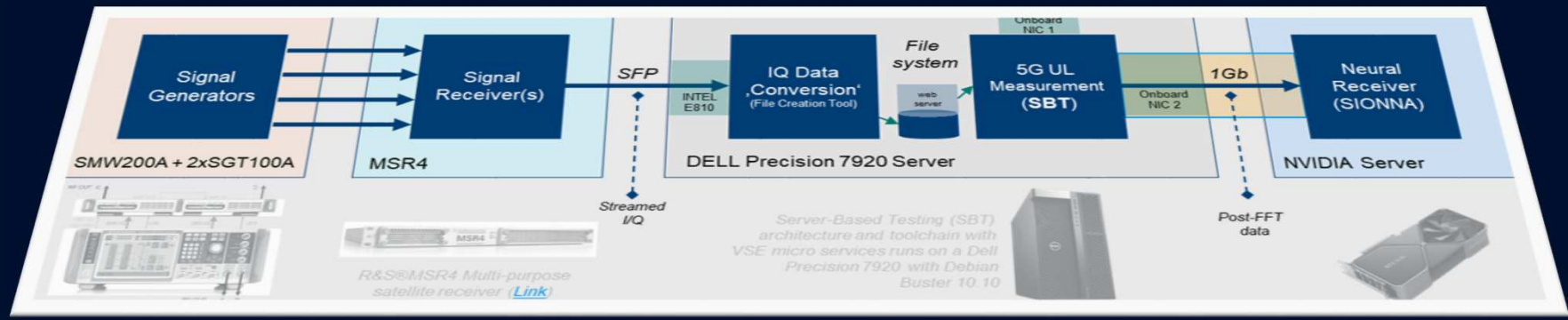
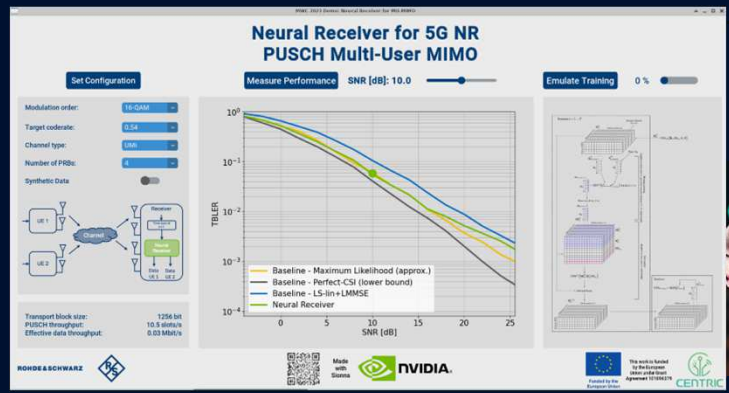
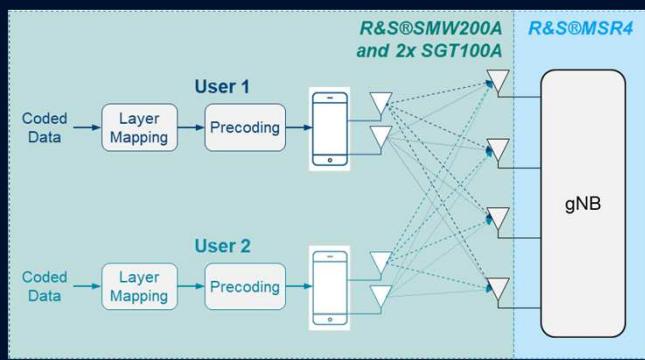


Source: <https://aiforgood.itu.int/events/the-road-towards-an-ai-native-air-interface-for-6g/> [Nov 2020]



TOWARDS 6G

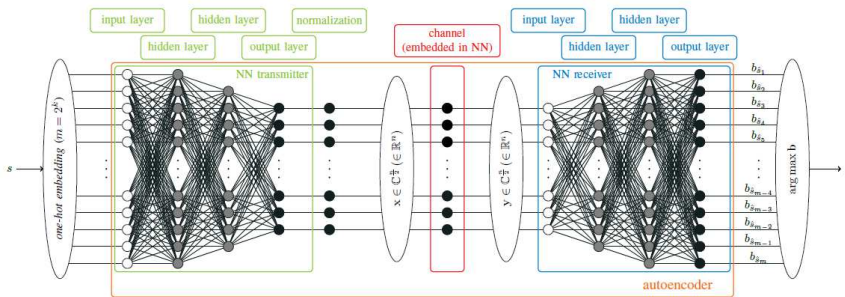
PHASE 2: NEURAL RECEIVER FOR 5G NR PUSCH MU-MIMO SCENARIO



PHASE 3: TRANSITION TO AN AUTOENCODER, OR?

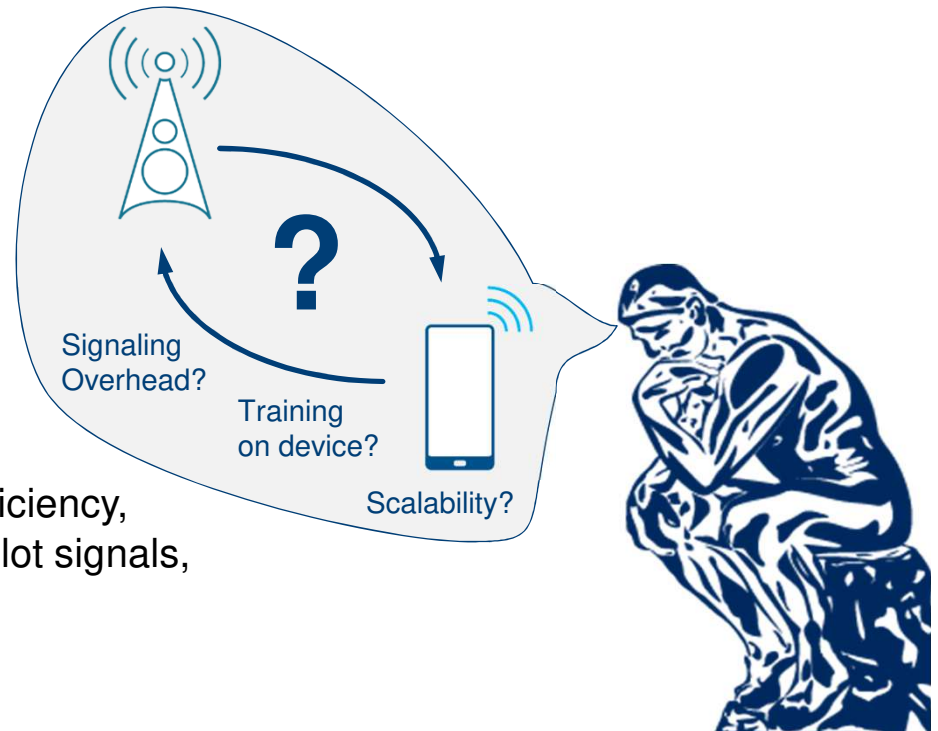
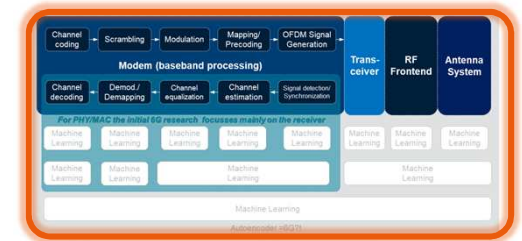
The autoencoder challenge

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



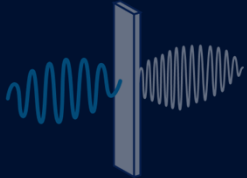
Source: [OFDM-Autoencoder for End-to-End learning of communication systems](#)

- 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

THz communication,
and "FR3"



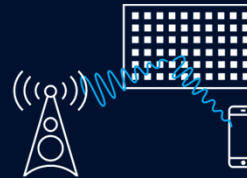
Joint communication
& sensing



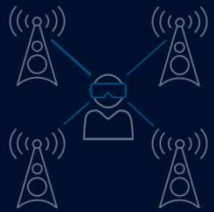
Artificial Intelligence
and Machine Learning



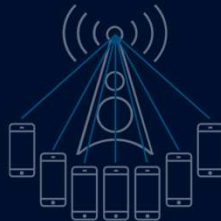
Reconfigurable
Intelligent
Surfaces



Photonics, Visible
Light Communication



Multiple access,
new waveforms,
channel coding



Ultra-massive
MIMO



New network topologies,
distributed computing



Full-duplex
communication



Security &
Trustworthiness

*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.

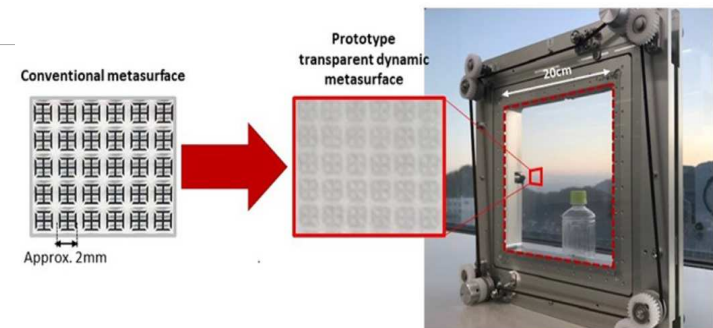
Press Release

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

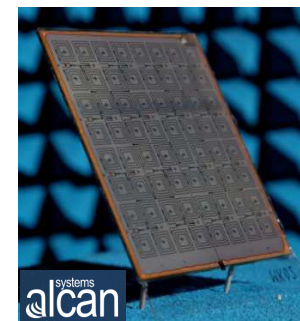
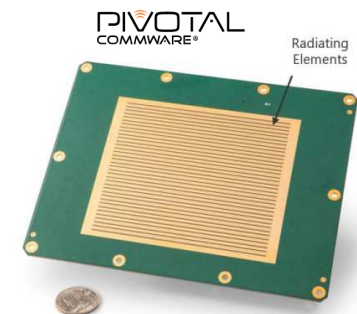
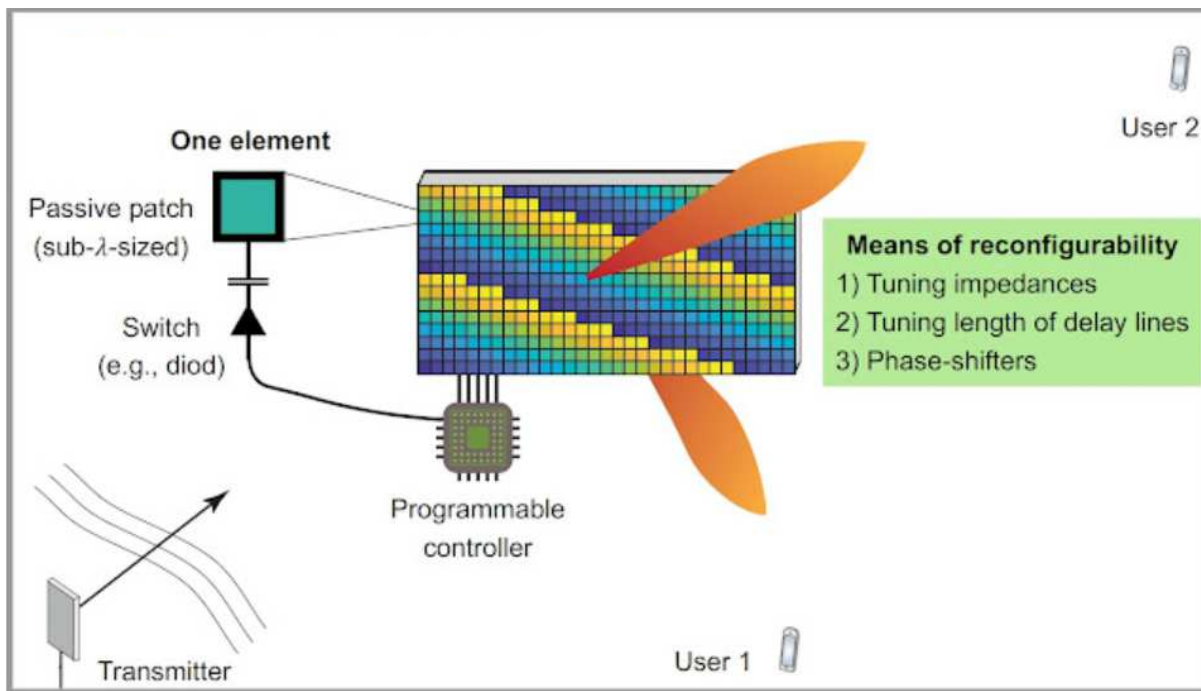
— Dynamic wave manipulation and high transparency expected to optimize 5G network construction —



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=9cBn5pil9Ms>

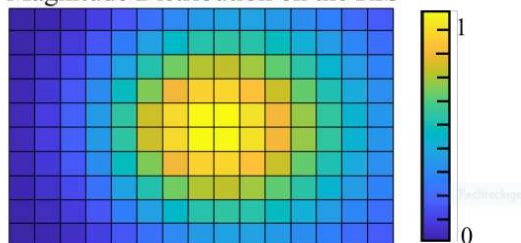


INTELLIGENT REFLECTING SURFACES

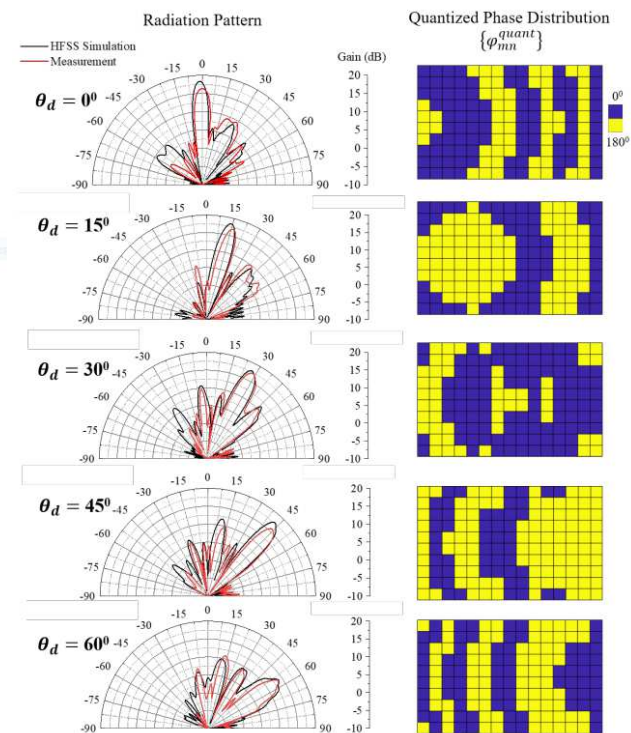
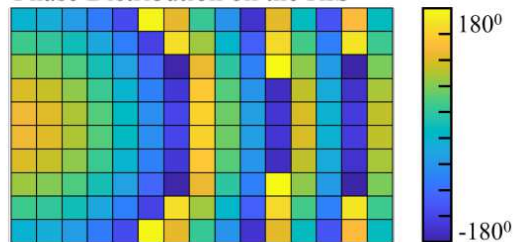
DESIGN AND EVALUATION



Magnitude Distribution on the RIS



Phase Distribution on the RIS



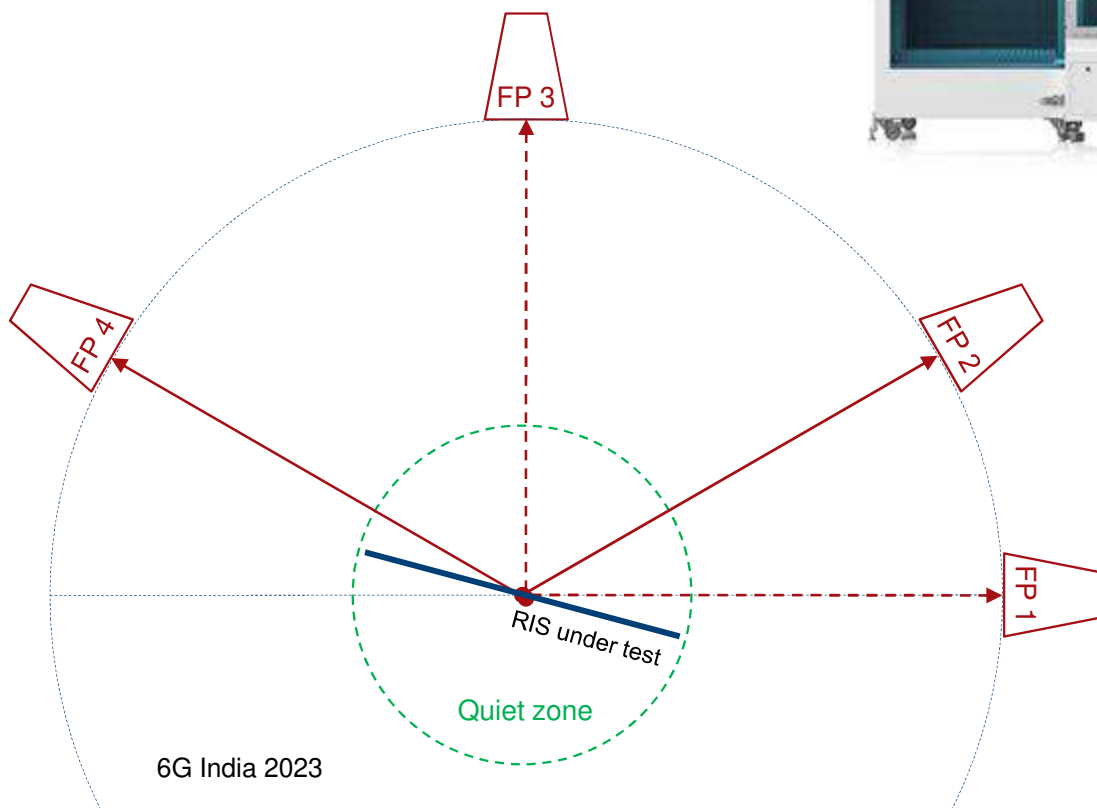
Source: Design and Evaluation of Reconfigurable Intelligent Surfaces in Real-World Environment by Georgios C. Trichopoulos, Panagiotis Theofanopoulos, Bharath Kashyap, Aditya Shekhawat, Anuj Modi, Tawfik Osman, Sanjay Kumar, Anand Sengar, Arkajyoti Chang, and Ahmed Alkhateeb



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



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

