

“No one can whistle a symphony. It takes a whole orchestra to play it.”

WILL AI/ML REVOLUTIONIZE THE NEXT GENERATION OF WIRELESS COMMUNICATION?

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ROHDE & SCHWARZ

Make ideas real



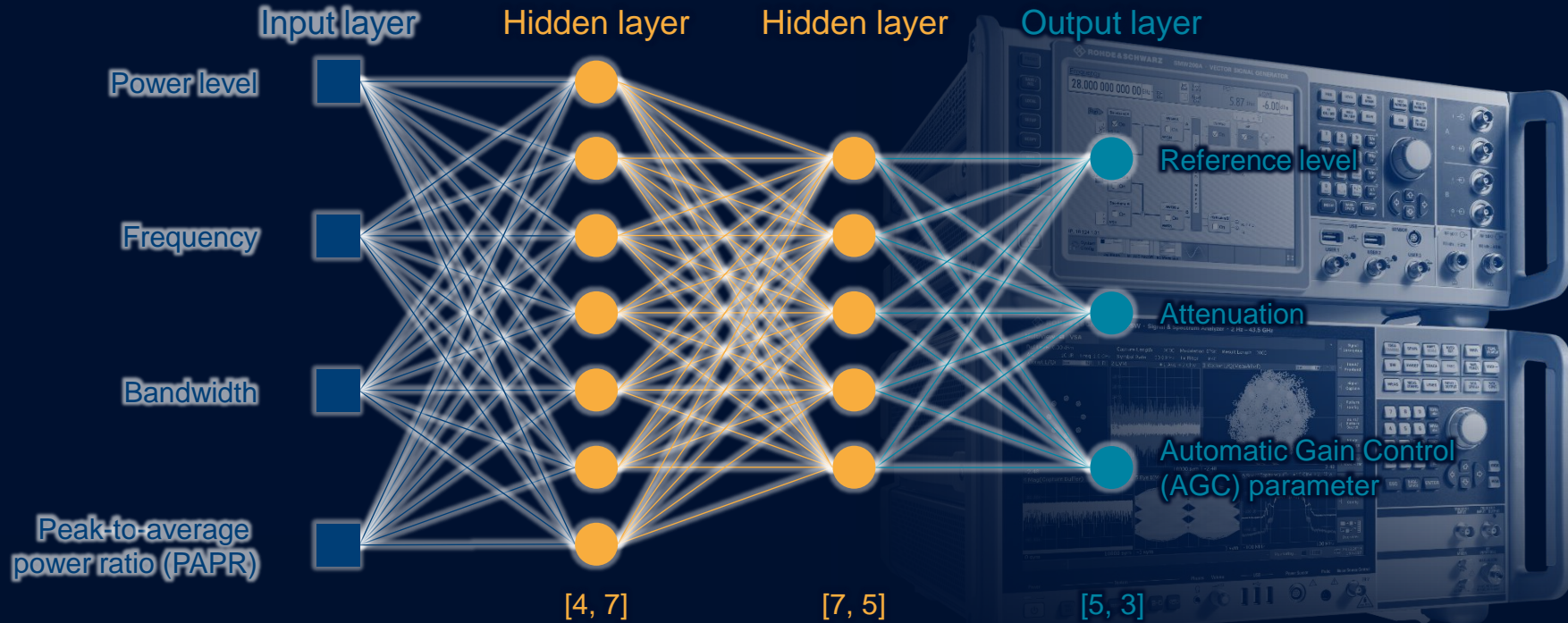
AGENDA

- ▶ Introduction and overview on 3GPP's study items for AI/ML in Rel-18
- ▶ What role will AI/ML play in a future 6G communication standard? What is a neural receiver? Is there an evolution path?
- ▶ What role do test and measurement solutions play in this context?



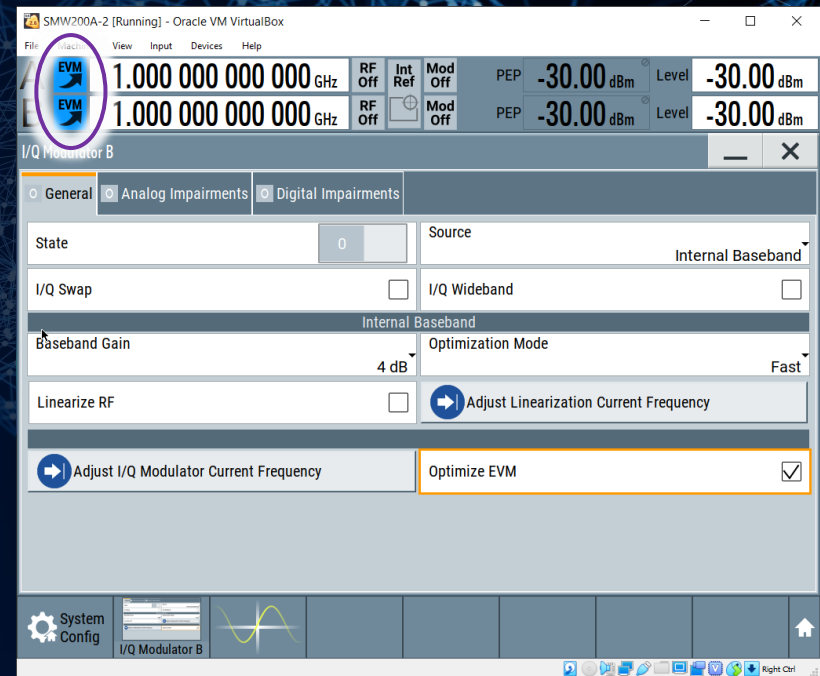
MACHINE LEARNING IS BASED ON NEURAL NETWORKS (NN)

HOW ABOUT BEST ERROR VECTOR MAGNITUDE (EVM)?



DOING “MACHINE LEARNING FOR THE SAKE OF MACHINE LEARNING” MAKES NO SENSE

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



STUDY ON ARTIFICIAL INTELLIGENCE/MACHINE LEARNING IN 3GPP RELEASES

- ▶ AI/ML in 3GPP until “now” was mainly for data analytics:
 - 3GPP Rel-15/16/17: Network Data Analytics Function (NWDAF)
 - 3GPP Rel17: RAN3-led study on further enhancing data collection
- ▶ 3GPP Release 18: 5G-Advanced
 - SA1-led study on model transfer ([TR 22.874](#)), SA2-led study on 5G system support for AI/ML-based services ([TR 23.700-80](#)), SA4-led study on AI/ML for media ([TR 26.927](#)) and an SA5-led study on AI/ML management ([TR 28.908](#)); RAN3-led continuation based on findings in Rel-17 study item
 - AI/ML for NR air interface – [3GPP TR 38.843 V1.0.0 \(2023-09\)](#)
 - Exploration of augmentation of the [5G air interface](#) by AI/ML; study is scheduled throughout the [complete release](#) until the [end of 2023](#), starting with [three pilot use cases](#) to assess performance in [comparison to traditional methods](#) and [specification impacts](#):
 1. CSI feedback enhancements
 - Compression and prediction
 2. Beam management
 3. Positioning accuracy enhancements

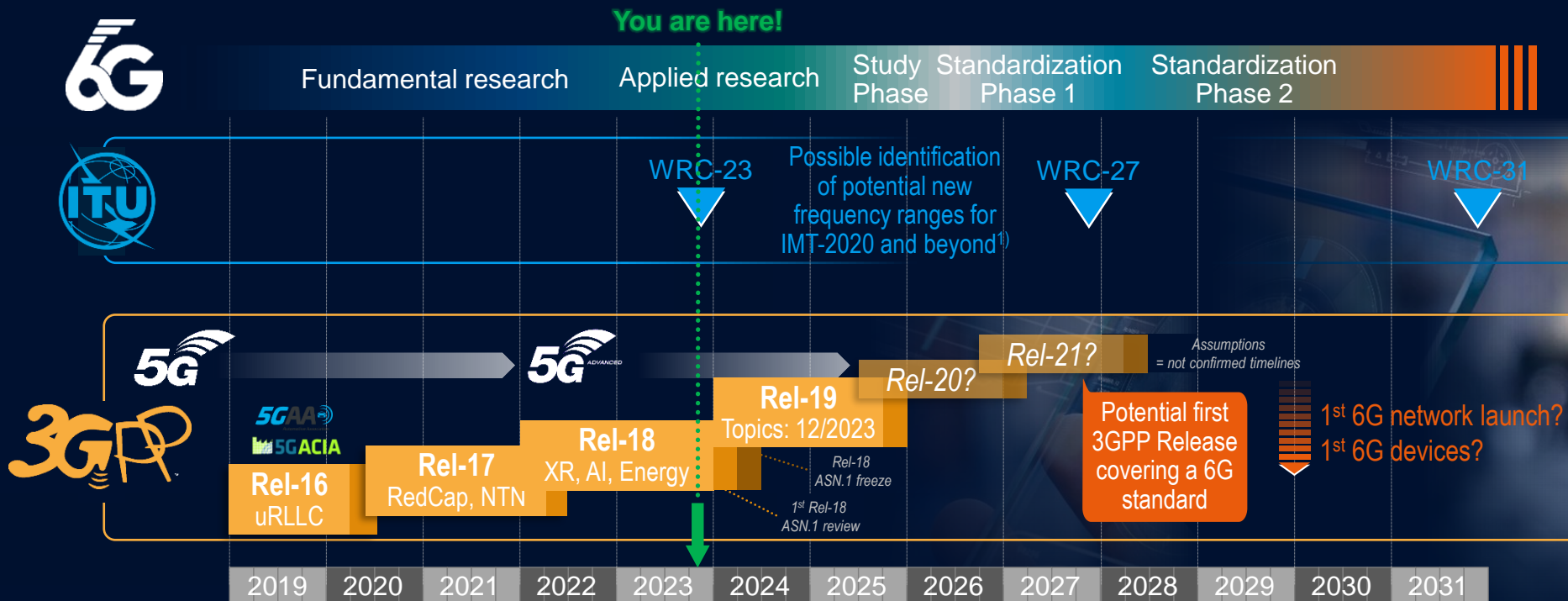
Sources: <https://arxiv.org/ftp/arxiv/papers/2305/2305.05092.pdf> and <https://www.3gpp.org/technologies/ai-ml-nr>



**WHAT ROLE WILL AI/ML PLAY IN A FUTURE
6G WIRELESS COMMUNICATION STANDARD?**

FIRST OF ALL: TIMELINES

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

FIRST OF ALL: TIMELINES IS THIS THE RIGHT TIME TO TALK ABOUT 6G? YES!

TOPICS IN RADIO COMMUNICATIONS

An Introduction to Millimeter-Wave Mobile Broadband Systems

Zhaoyue Pi and Farooq Khan, Samsung Electronics

ABSTRACT

Almost all mobile communication systems today use spectrum in the range of 1-100 GHz. In this article, we review why the wireless community should be interested in the 300 GHz spectrum for mobile broadband applications. We discuss propagation and device modeling challenges associated with this band as well as the unique advantages for mobile communication. We introduce a millimeter-wave mobile broadband (MMB) system as a candidate next-generation mobile communication system. We demonstrate the feasibility for MMB to achieve gigabit-per-second data rates at a distance up to 1 km in an urban mobile environment. A few key concepts in MMB network architecture such as the MMB base station, MMB user, BS fronthaul link, and a hybrid MMB + 4G system are described. We also discuss beamforming techniques and the future extension of the MMB air interface.

INTRODUCTION

Mobile communication has been one of the most successful technology innovations in modern history. The combination of technology breakthroughs and attractive value proposition has made mobile communication an indispensable part of life for 2 billion people. Due to the increasing popularity of smart devices, mobile data services such as networks and cloud computing have experienced rapid growth. Some predictions indicate that mobile data will grow at 10% percent compound annual growth rate (CAGR) [1] with over a thousandfold increase over the next 10 years. In order to meet the exponential growth, improvements in air interface capacity and allocation of new spectrum are of paramount importance.

The current fourth-generation (4G) systems including LTE and Mobile WiMAX already use advanced technologies such as orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO), adaptive modulation, link adaptation, turbo code, and hybrid automatic repeat request (HARQ) in order to achieve spectral efficiencies close to theoretical limits in terms of bits per second per Hertz per cell [2]. With limited room for further spectral

efficiency improvement, another possibility to increase capacity per geographic area is to explore more spectral real estate in terahertz and sub-THz bands. The 300 GHz band has capacity up to only twice linearly with the number of cells and other well-known ways to increase the capacity required to accommodate orders of magnitude increase in mobile data traffic.

As the mobile data demand grows, the such GHz spectrum is becoming increasingly crowded. On the other hand, a vast amount of spectrum in the 300-300 GHz range remains underutilized. The 30-300 GHz spectrum is generally referred to as the super high frequency (SHF) band, while 30-300 GHz is referred to as the extremely high frequency (EHF) or millimeter-wave band. Some radio waves in the SHF and EHF bands show similar propagation characteristics, such as 3-300 GHz spectrum can be treated as millimeter-wave bands with wavelengths ranging from 1 to 100 mm.

Millimeter-wave communication systems that can achieve megabit-per-second data rates at a distance of up to a few kilometers already exist for point-to-point communication. However, the component electronics used in these systems, including power amplifiers, low noise amplifiers, mixers, and antennas, are too big in size and consume too much power to be applicable to mobile communication. The availability of the 30 GHz band as unlicensed spectrum has opened interest in millimeter-wave for short-range communication. Several international standards have been developed, such as IEEE 802.15.3, IEEE 802.11ad, Integrated Access (ICMA-30), IEEE 802.13, and IEEE 802.14d. Integrated circuits (ICs) based transmitters are also available for some of these technologies. Much of the engineering efforts have been focused in developing more powerful 60 GHz ICs [3]. Many of these technologies can be transformed to RFIC design for other millimeter-wave bands.

In this article, we explore the 300 GHz spectrum and describe a millimeter-wave mobile broadband (MMB) system for future mobile communication. We describe the network architecture, propagation characteristics. We then discuss the network architecture, followed by an overview of the MMB system. After that, we conclude the article with a summary and brief discussion of future work.

The support of mmWave was one of the revolutionary elements in 5G!

~4 years

Millimeter-Wave Base Station for Mobile Broadband Communication

Farshid Arjmand, Jerry Pi, Hongyu Zhou, Thomas Henige, Gary Xu, Shahid Abu-Surra, Dimitris Psychoudakis and Fatouh Khan

Samsung Research America, Richardson, TX, 75082

Abstract — In this paper a millimeter-wave base station operating at 260 GHz for mobile communication is introduced. This new station employs an element antenna phased-array to enable adaptive beamforming required for mobile communication. The phased-array is constructed of sub-arrays for spatial trade-off between performance and required energy and beamforming capability. The phased array antenna is integrated with the transceiver in the same printed circuit board (PCB) using industry standard manufacturing process to minimize the cost and routing loss. The achieved link budget fulfills the requirements of the LTE and MIMO mobile communication in the band for distances as far as 1 km. The field measurements report an additional 15 dBm power loss. This is for a 100 MHz OFDM signal with 100 MHz bandwidth.

Index Terms — Phased array, Millimeter-wave, Mobile Broadband, Wireless Communication, 28 GHz radio

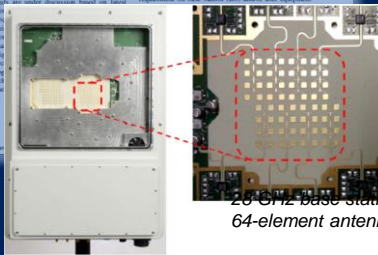
1. INTRODUCTION

The ever increasing demand for higher data rates and convenience of mobile communication has led to a vast range of inventions and technology advancement in the past decades. As a result current cellular systems operate near the theoretical limits of their capacity within allocated spectrum. At the same time, for densely populated areas such as downtown, shopping malls and airports variable spectrum at millimeter frequency bands (30 GHz) is scarce at best. Hence, to further enhance available capacity migrating to higher frequency bands is inevitable. Recently, the progress in mm-wave circuits and systems has encouraged the wireless industry to consider mm-wave band for cellular communication [1, 2]. While greater amount of spectrum at multiple mm-wave frequencies, high-order modulation based on linear

The potential of mm-wave bands to enable gigabit-per-second data rates has been studied for mobile indoor wireless systems [3] and fixed-outdoor systems [4]. One of the candidate frequency bands for broadband wireless communication is the currently allocated Local Multipoint Distribution Service (LMDS) band, which has a common 100 MHz BW of 28 GHz. Because of high carrier frequency, the fractional BW is fairly small at mm-wave, about 3%. This alleviates circuit and antenna design challenges from a BW perspective. Another advantage of using higher frequencies is the size of the antenna which scales with the wavelength. This allows the phased arrays, a necessary element to overcome the excess of pathloss in mm-wave band to be integrated in smaller form factors. Phased arrays help the transmitter by enabling spatial power combining by electronic beam steering to the desired direction. In receiver the SNR improvement is done by coherent combining of signals arrived at different elements. Use of phased arrays also improves the spectral efficiency by forming directional beams and allowing spatial reuse separation [5]. In this paper, we first discuss the link budget and typical requirements for mobile systems at a few mm-wave frequency bands, then design and performance of a mm-wave base station using phased-array is discussed.

II. SYSTEM OVERVIEW

In order to take advantage of mm-wave for commercial grade communication, among other things the increased pathloss must be addressed without imposing unrealistic requirements on base station (BS) and/or user equipment (UE) either of them. To meet this challenge, the requirements for device performance. Furthermore, the advantage of this such as ortho-OFDM, which design requirements



26 GHz base station with 64-element antenna array

~4+ years

5G



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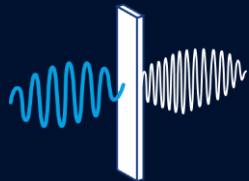
Will AI/ML revolutionize the next generation of wireless communication?

<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5783393> (June 2011)
<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7166778&tag=1> (June 2015)



RESEARCH AREAS FROM A T&M PERSPECTIVE

THz and "FR3"



Joint communication
& sensing



Artificial Intelligence
and Machine Learning



Reconfigurable
Intelligent
Surfaces



Photonics, Visible
Light Communication



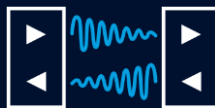
Multiple access,
new waveforms,
channel coding



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.*



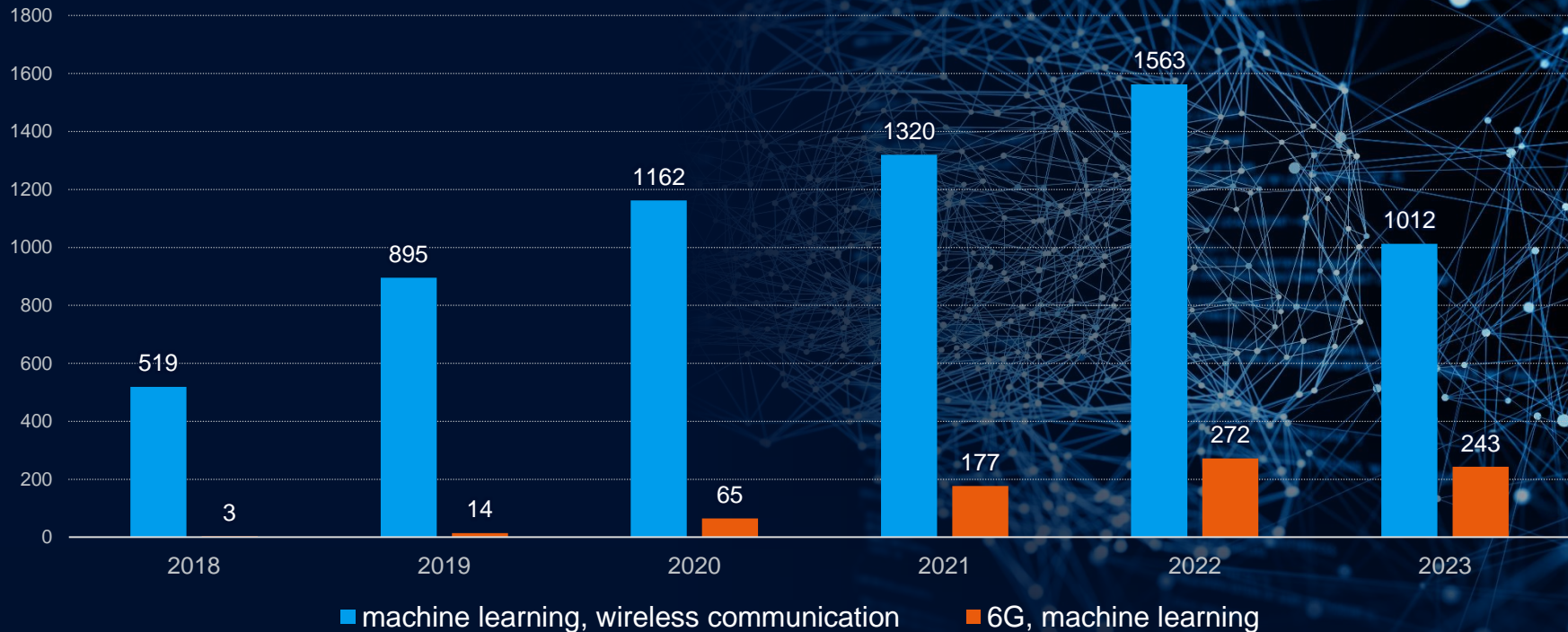
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Will AI/ML revolutionize the next generation of wireless communication?

6G RESEARCH AREAS FROM A T&M PERSPECTIVE



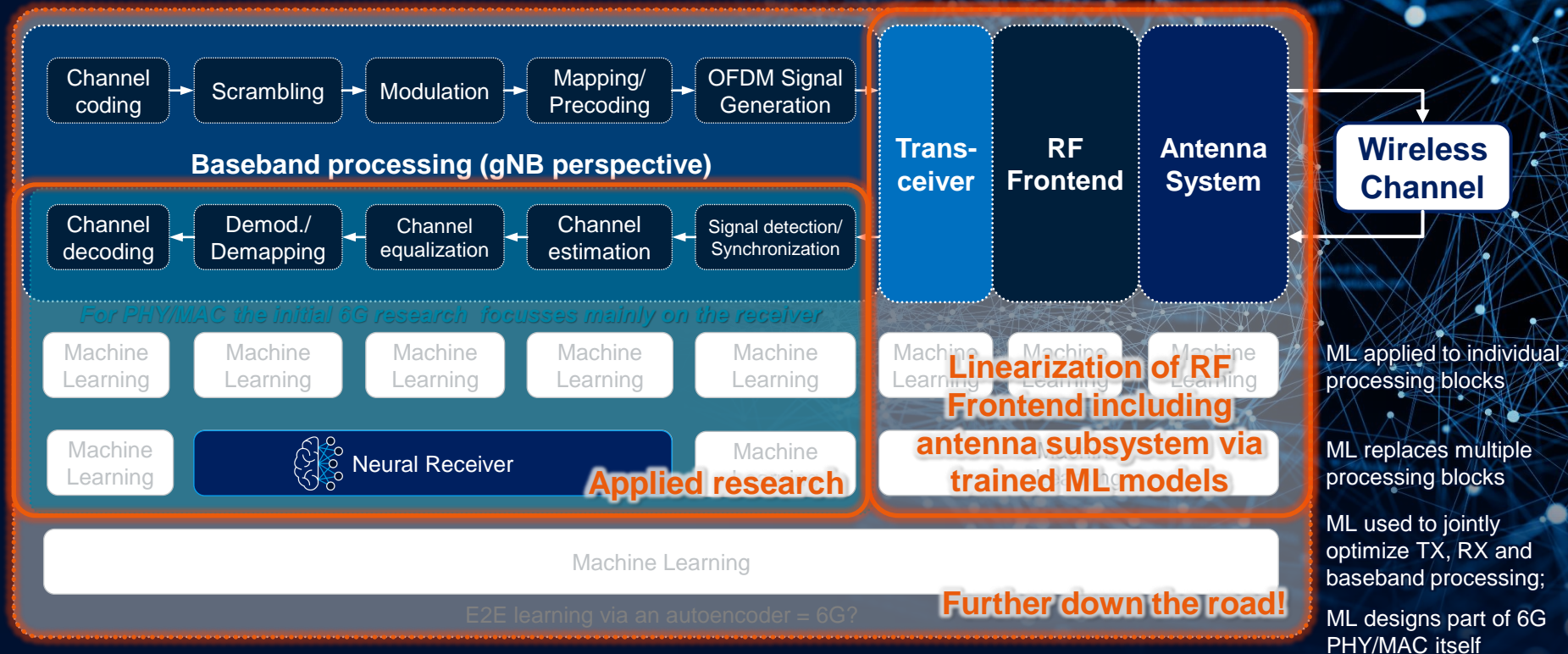
NUMBER OF PUBLICATIONS IEEE *Xplore*®



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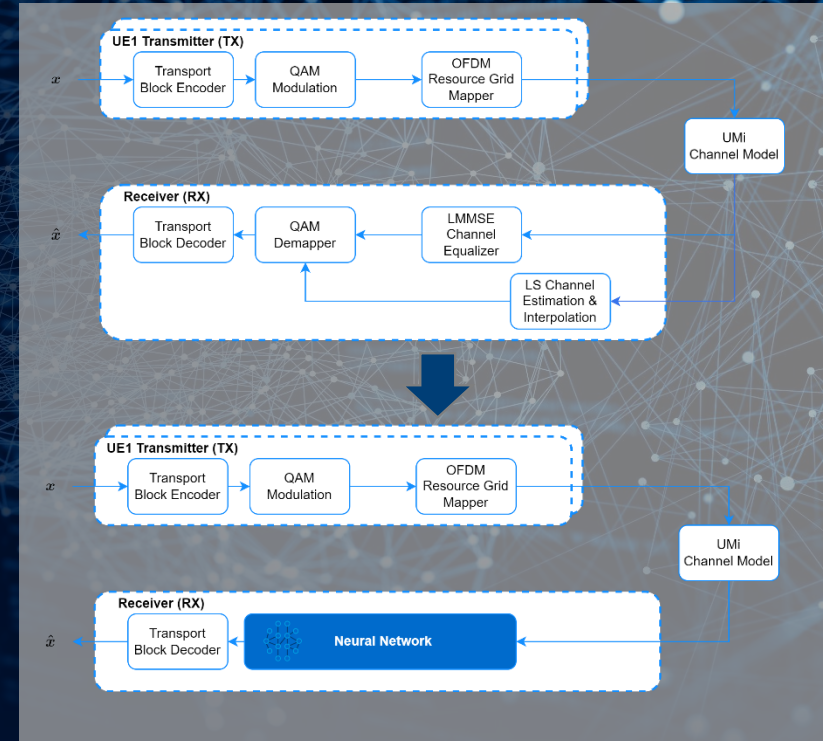


TOWARDS AN AI-NATIVE AIR INTERFACE FOR 6G



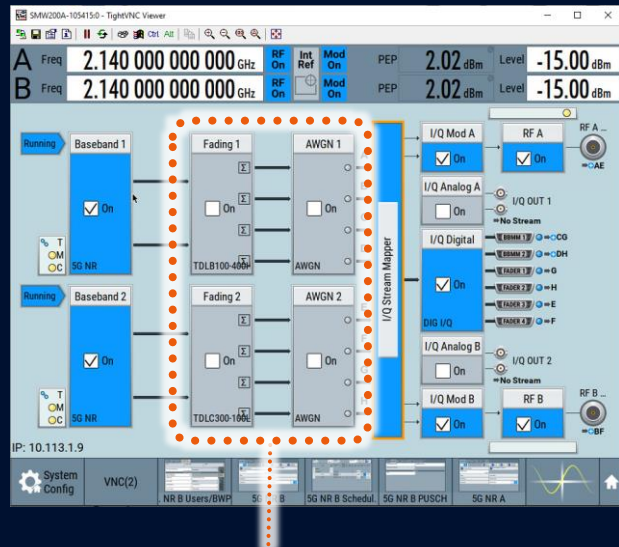
NEURAL RECEIVER TESTBED

- ▶ Neural receiver: replacing conventional Digital Signal Processing (DSP) by AI/ML models
- ▶ Partnered up with **NVIDIA** to build industry-first neural receiver testbed
- ▶ 5G NR signal generation, receiving, pre-processing by **Rohde&Schwarz test & measurement solutions**
- ▶ Design of a neural receiver based on NVIDIA's **SIONNA™** open software framework: MIMO detection, channel estimation, equalization, demapping

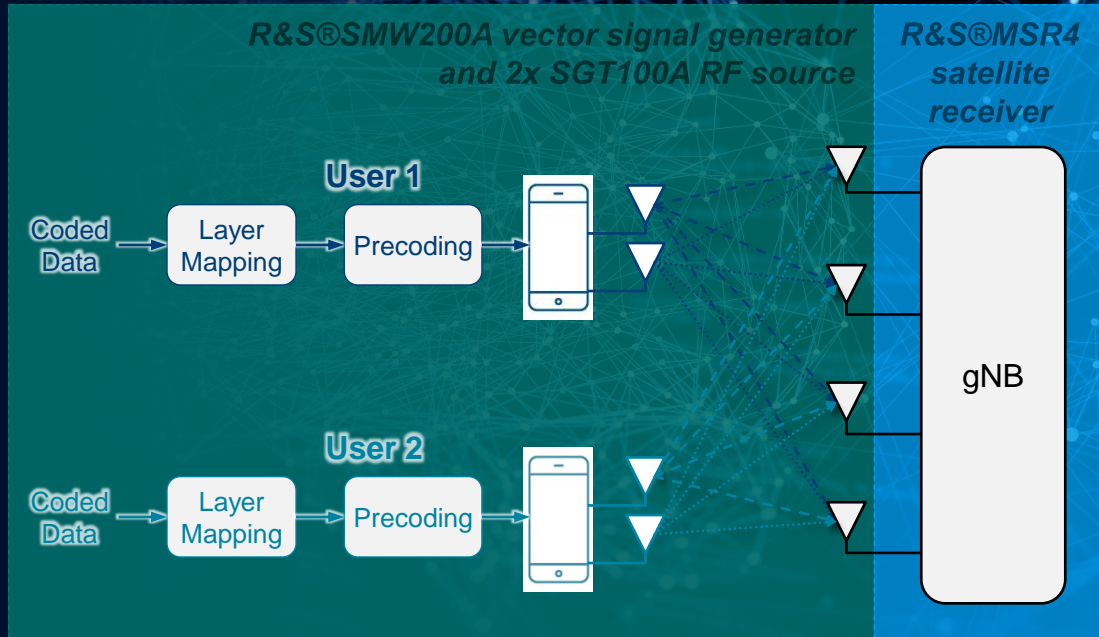


TEST SCENARIO: 5G NR PUSCH MU-MIMO

NUMBER OF USERS, MIMO MODE AND NUMBER OF LAYERS

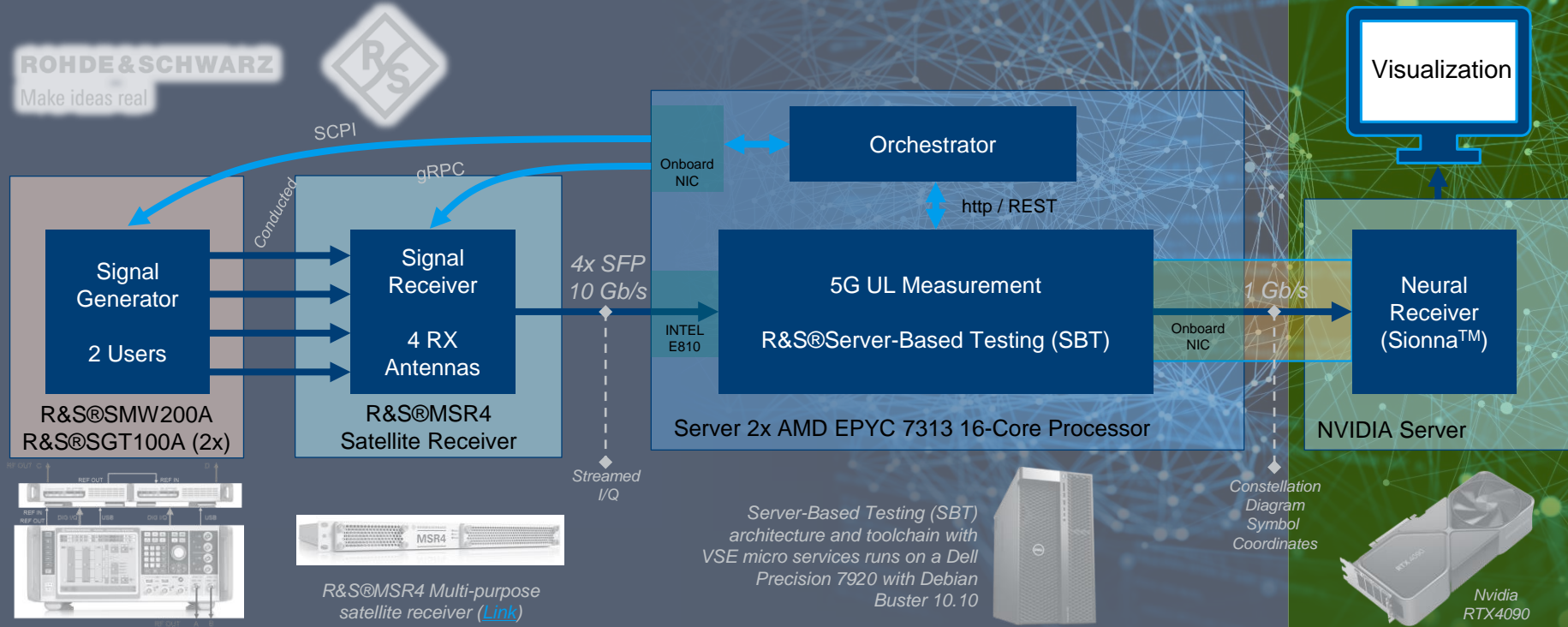


Both users independently faded,
independent noise settings



Both users transmit simultaneously on 80 MHz signal bandwidth (PRB 217), 16QAM modulation
DMRS symbols 2 and 11, User#1 on even-numbered subcarriers, user#2 on odd-numbered subcarriers

NEURAL RECEIVER TESTBED DEMONSTRATED @ MWC BARCELONA 2023



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Will AI/ML revolutionize the next generation of wireless communication?

HARDWARE-IN-THE-LOOP VALIDATION OF A NEURAL RECEIVER IMPLEMENTATION



MWC 2023 Demo: Neural Receiver for MU-MIMO

AI/ML-based Neural Receiver for 5G NR PUSCH Multi-User MIMO

Set Config

No TB Error detected
Early stopping

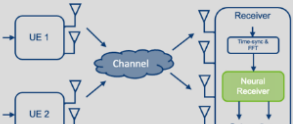
Measure Performance

SNR [dB]: -1.0

Emulate Training

0 %

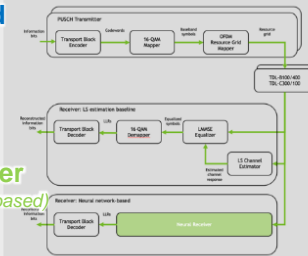
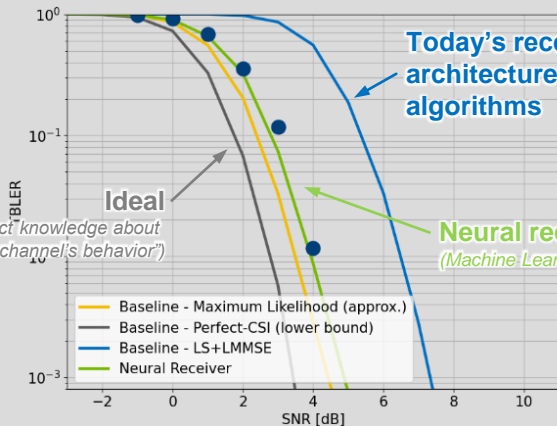
Synthetic Data
Evaluate TB-LR
Evaluate LS-Baseline



Channel UE 1
Channel UE 2

TDL-B 100ns/400Hz/low
TDL-C 300ns/100Hz/low

Number of PRBs: 217
Modulation order: 16-QAM
Target code rate: 0.54
Transport block size: 67584 bit
PUSCH throughput: 49.9 slots/s



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Made with Sionna™



This work is funded by the European Union under Grant Agreement 101096379



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6G NEURAL RECEIVER TESTBED APPLICATION VIDEO



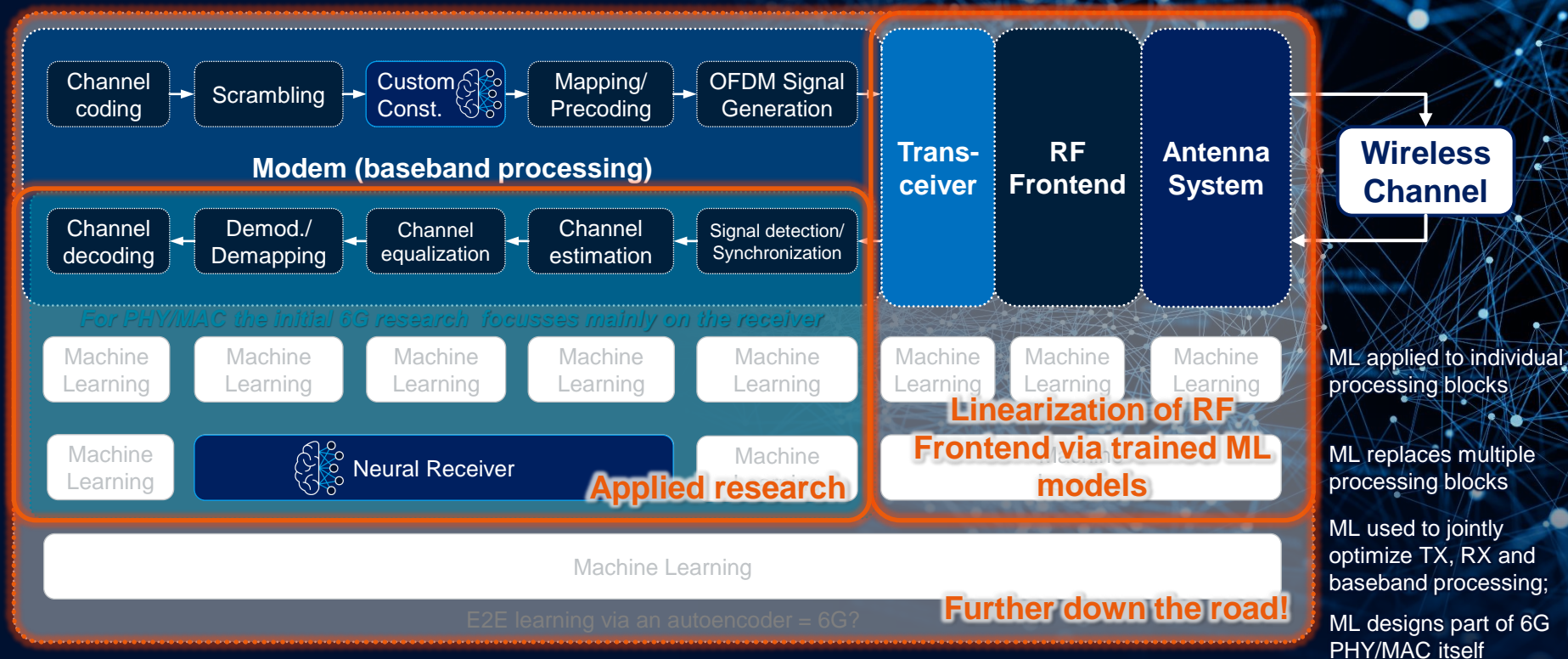
► YouTube link: <https://youtu.be/BQyxBYzda5k>



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Will AI/ML revolutionize the next generation of wireless communication?

ENHANCING THE NEURAL RECEIVER? TOWARDS AN AI-NATIVE AIR INTERFACE FOR 6G



6G NEURAL RECEIVER TESTBED DEMO



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ADOPTION OF AI/ML WILL REQUIRES ADAPTATION OF NEW TESTING METHODOLOGIES AND TEST PROCEDURES

- ▶ 3GPP Rel-18 and 19 lay the foundation for an AI/ML framework in 3GPP that 6G may build on.
- ▶ We demonstrated first promising results of replacing traditional signal processing blocks and classic signal processing algorithms with trained machine learning models
- ▶ Still a long way to go; several research challenges are currently under investigation by multiple research projects worldwide, e.g.:
 - Processing power, power consumption, etc.: implementation in GPU vs. FPGA or ASIC?
 - Training with synthetic data only? How to move to entirely real-world data-driven models?
 - Wireless radio channel characteristic representation in the form of fading profiles vs. real-time channel
 - Local adaptation of default models: “online training” in the field = site-specific neural receiver model
- ▶ The R&S testbed for neural receiver can help to validate performance of initial concepts before putting them into silicon.

**THANK YOU!
QUESTIONS?**

**“No one can whistle a
symphony. It takes a
whole orchestra to
play it.”**

Halfrod E. Luccock (1885-1960)

