

Welcome to our 6G Tech Talk

"The future role of AI & ML in wireless communication"

An early Test & Measurement perspective

Andreas Roessler, Technology Manager

Timo Mayer, Director R&D



AGENDA

- ▶ 5G evolution towards 6G
- ▶ The fundamentals of AI/ML & how do today's 5G networks use AI/ML?
- ▶ Status of research for an AI-native air interface support in 6G
- ▶ What role can T&M solutions play in this context?
- ▶ Future challenges & outlook



The future role of AI/ML in wireless communication

5G EVOLUTION TOWARDS 6G

5G NR TECHNOLOGY EVOLUTION – THE NEXT PHASE



eMBB



mMTC

URLLC

| April 2019

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

| Sep 2020¹⁾

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

Security



Reliability

Latency

| June 2022¹⁾

3GPP Release 17
(5G Phase 2+); focus:
FR2-2, NTN, NR Light

| March 2024¹⁾

3GPP Release 18
Work Package approval
in Dec'24 (RAN#94-e)

**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-L MIMO enhancements, DCICA enhancements

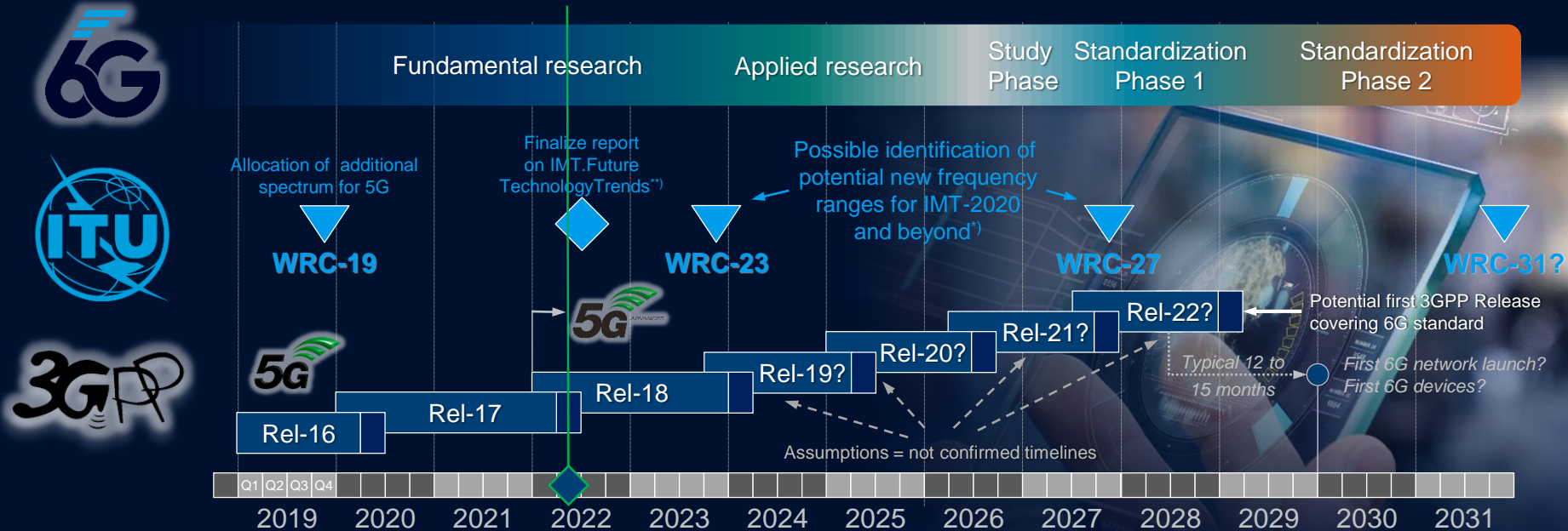
eMBB: enhanced Mobile Broadband

URLLC: Ultra-Reliable Low Latency Communication

mMTC: massive Machine Type Communication

FUTURE STANDARDIZATION AND REGULATORY ROADMAP

You are here



^{*)} 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

ARE WE GETTING AHEAD OF OURSELVES? NO!

5G

TOPICS IN RADIO COMMUNICATIONS

An Introduction to Millimeter-Wave Mobile Broadband Systems

Zhouyue Pi and Farooq Khan, Samsung Electronics

ABSTRACT

Almost all mobile communication systems today are operating in the range of 300 MHz to 6 GHz. In this article, we review why the wireless community should start thinking about the 3–300 GHz spectrum for mobile broadband applications. We discuss propagation and device technology challenges associated with this band as well as the unique advantages for mobile communication. We introduce a millimeter-wave mobile broadband (mmWB) system as a candidate next-generation mobile communication system. We demonstrate the feasibility for mmWB to achieve gigabit-per-second data rates at a distance up to 1 km in an urban mobile environment. A few key concepts in mmWB network architecture such as the MIMO base station and MIMO user devices are described. We also discuss beamforming techniques and the frame structure of the mmWB 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 3 billion people. Due to the increasing popularity of mobile devices, mobile data services such as networks and cloud computing, the demand for mobile communication is growing rapidly. Several international standards have been developed, such as 3GPP LTE, 4G LTE, and 5G. These standards have enabled high-speed mobile communication. 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 this exponential growth, improvements in air interface capacity and allocation of new spectrum are of paramount importance.

The current multi-band (4G) systems including LTE and Mobile WiMAX already use advanced technologies such as orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO), adaptive diversity, 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 resources in terahertz and millimeter-wave bands. Terahertz bands have capacity up to only wide linear with the number of cells and antennas, while millimeter-wave bands have capacity up to only wide linear with the number of antennas and antennas.

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 3–300 GHz range remains underutilized. The 3–30 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 share similar propagation characteristics, we refer to 3–300 GHz spectrum collectively as millimeter-wave bands with wavelengths ranging from 1 to 100 mm.

Millimeter-wave communication systems that can handle megabit-per-second data rates at a distance of up to a few kilometers already exist for point-to-point communication. However, the components 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 bands for mobile communication. Several international standards have been developed, such as 3GPP LTE, 4G LTE, and 5G. These standards have enabled high-speed mobile communication. 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 this exponential growth, improvements in air interface capacity and allocation of new spectrum are of paramount importance.

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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, Shadi Abu-Surra, Dimitris Psychoudakis and Fatouh Khan
Samsung Research America, Richardson, TX, 75082

Abstract — In this paper a millimeter-wave base station operating at 28 GHz for mobile communication is presented. This base station employs an element antenna phased-array for mobile broadband communication. The antenna array is composed of sub-arrays for spatial diversity of better performance and improved coverage 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 maintain the cost and routing loss. The antenna layout fulfills the requirements of the LTE and 5G mobile communication in the band for distances up to 1 km. The field measurements report an outdoor EVM of lower than -20dB for a 100MHz OFDM signal with 100MHz 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 sports available spectrum at traditional frequency bands (60GHz) is scarce as before. Hence, to further enhance available capacity requiring 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 frequencies bands are under development, the increased FCC notice of inquiry [3], building a case for the millimeter-wave band is becoming a challenging. This is mainly due to requirements for combining mm-wave performance advantages with 4G/LTE-like system advantages of recent advances in mm-wave technology. We then discuss the network architecture, followed by the air interface design of the mmWB system. After that, we conclude the article with a summary and brief discussion of future work.

The potential of mm-wave bands to enable gigabit-per-second data rates has been studied for mobile indoor systems [4] and fixed-outdoor systems [5]. One of the candidate frequency bands for broadband wireless communication is the currently allocated Local Multipoint Distribution Service (LMDS) band, which has a common 100MHz BW at 28GHz. 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 array, a necessary element to overcome the excess of paths 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 [6]. 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.

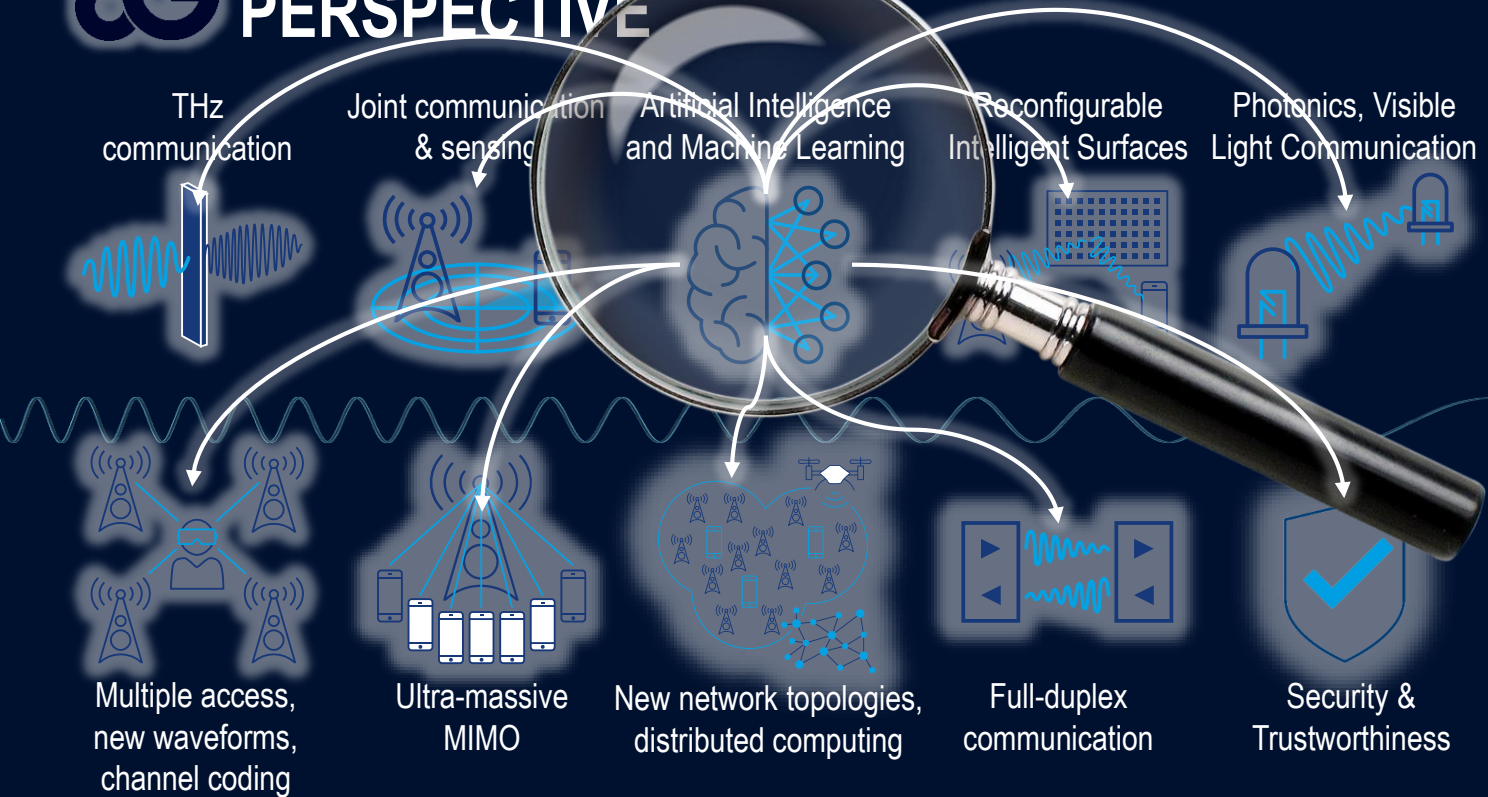
II. SYSTEM OVERVIEW

In order to take advantage of mm-wave for commercial 4G/LTE communication, among other things the increased greater amount of spectrum at frequencies bands are under development, the increased FCC notice of inquiry [3], building a case for the millimeter-wave band is becoming a challenging. This is mainly due to requirements for combining mm-wave performance advantages with 4G/LTE-like system advantages of recent advances in mm-wave technology. We then discuss the network architecture, followed by the air interface design of the mmWB system. After that, we conclude the article with a summary and brief discussion of future work.

28 GHz base station with 64-element antenna array



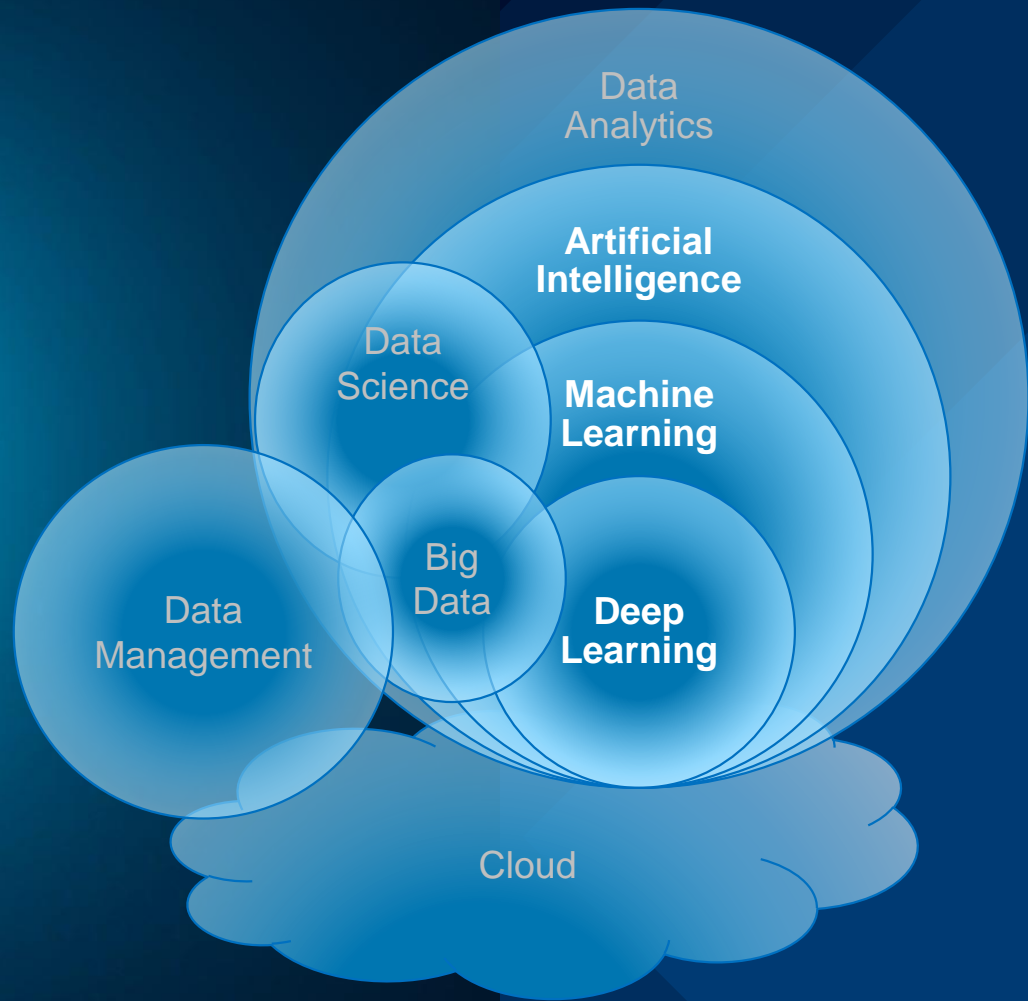
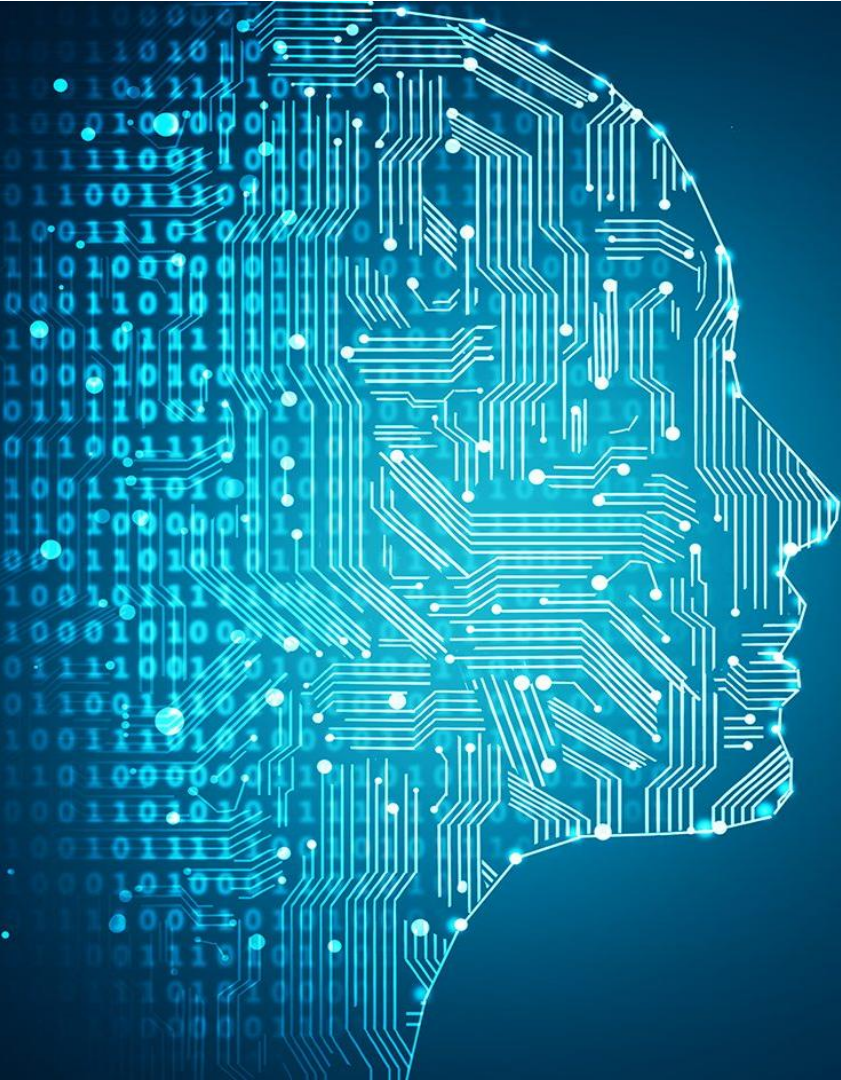
RESEARCH AREAS FROM A TEST & MEASUREMENT PERSPECTIVE



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

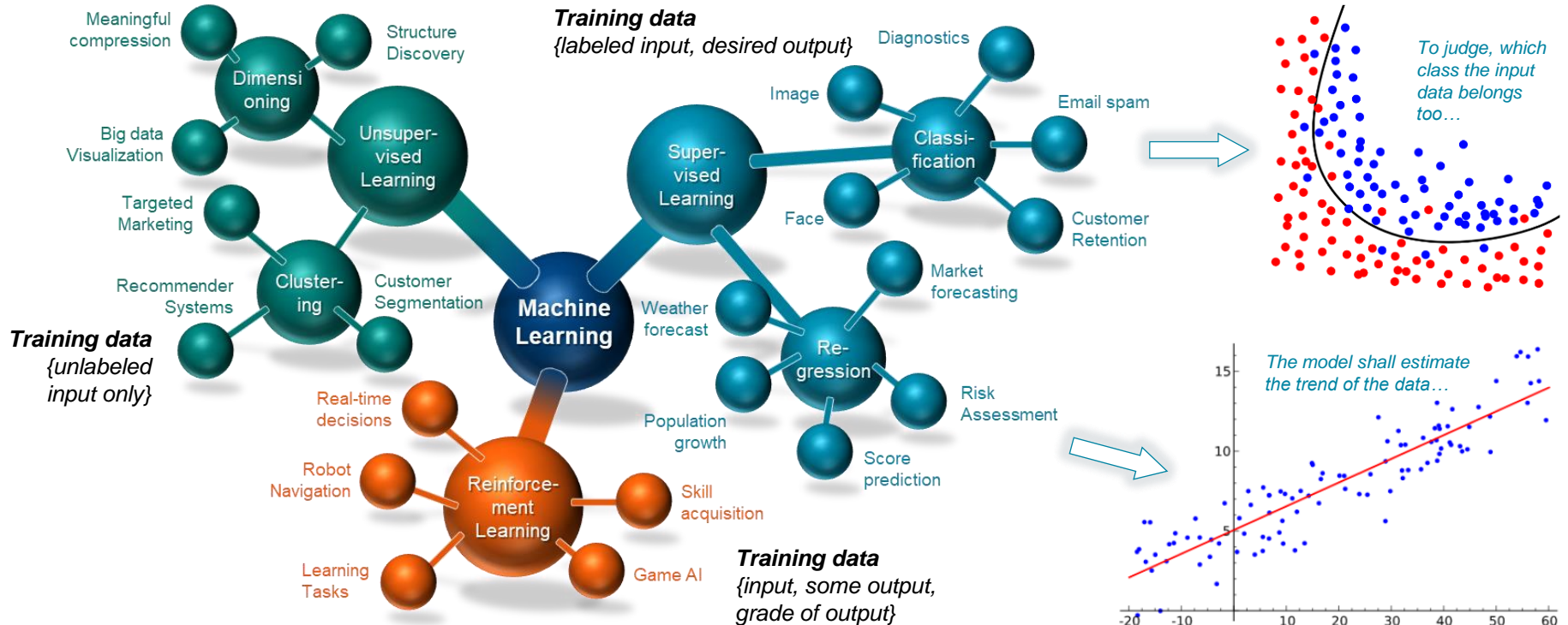
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THE FUNDAMENTALS OF AI/ML



TYPES OF MACHINE LEARNING

SUPERVISED – UNSUPERVISED – REINFORCEMENT

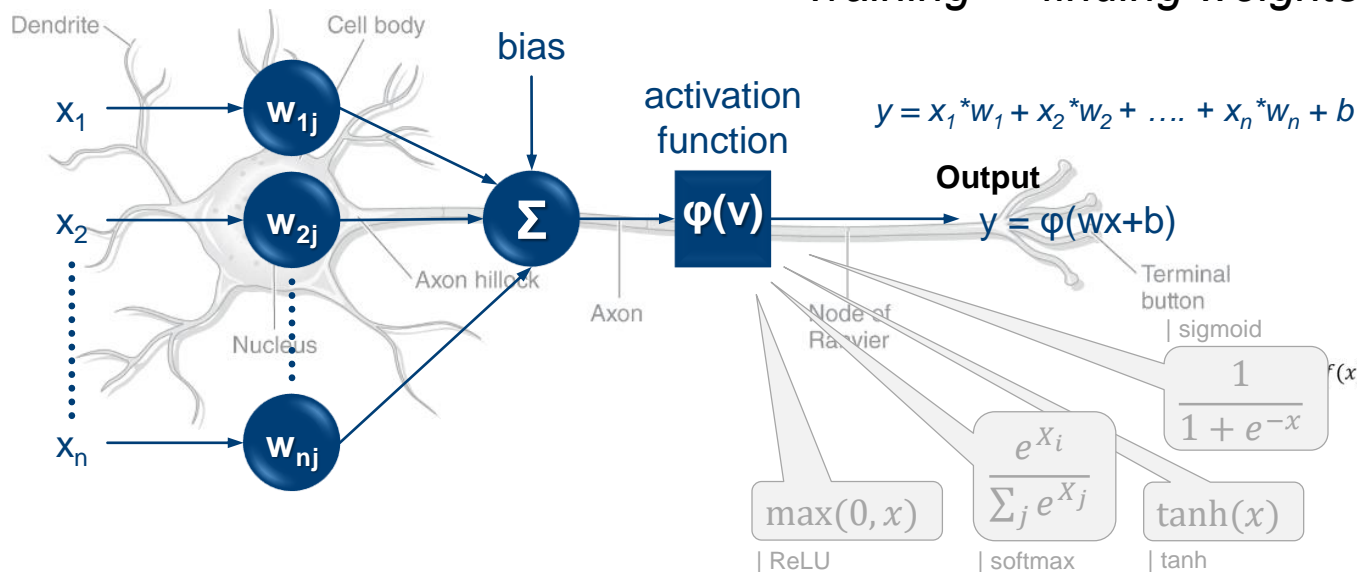


GENERAL CONCEPT OF A NEURONAL NETWORK (NN)

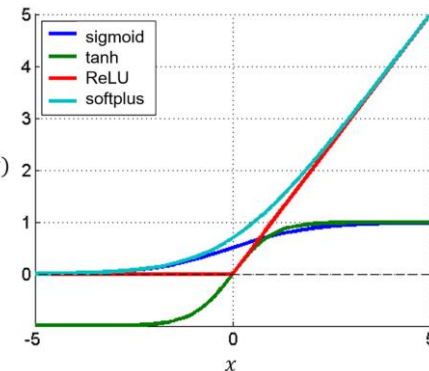
MODELING HOW THE HUMAN BRAIN WORKS

Input

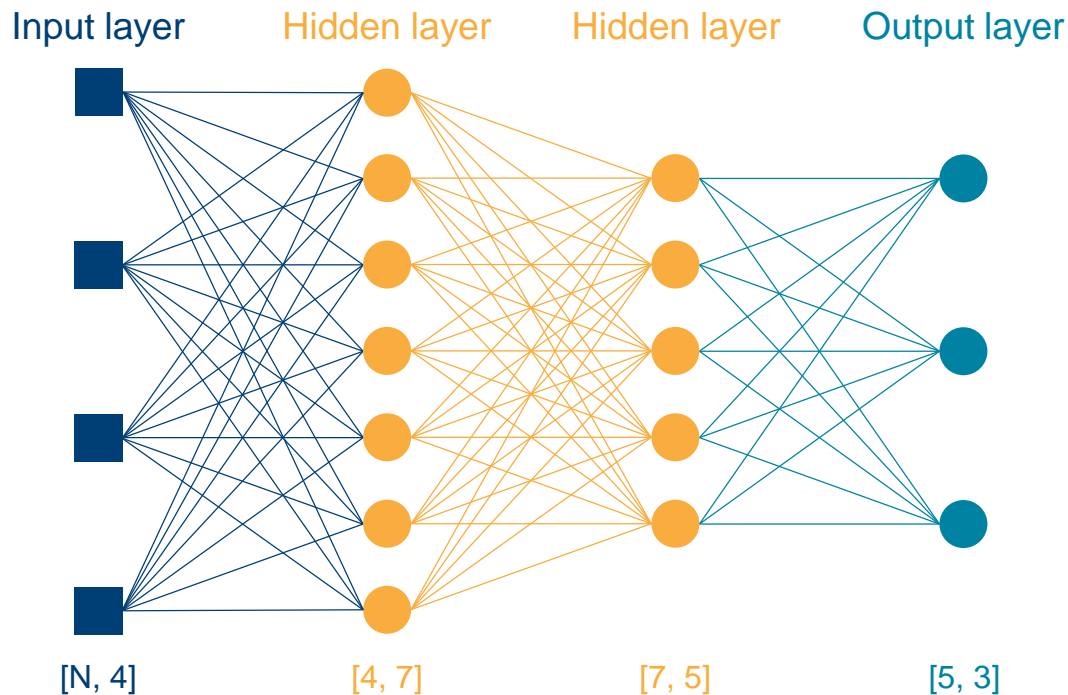
Weighting



“Training” = finding weights (w_{ij}) and bias (b)

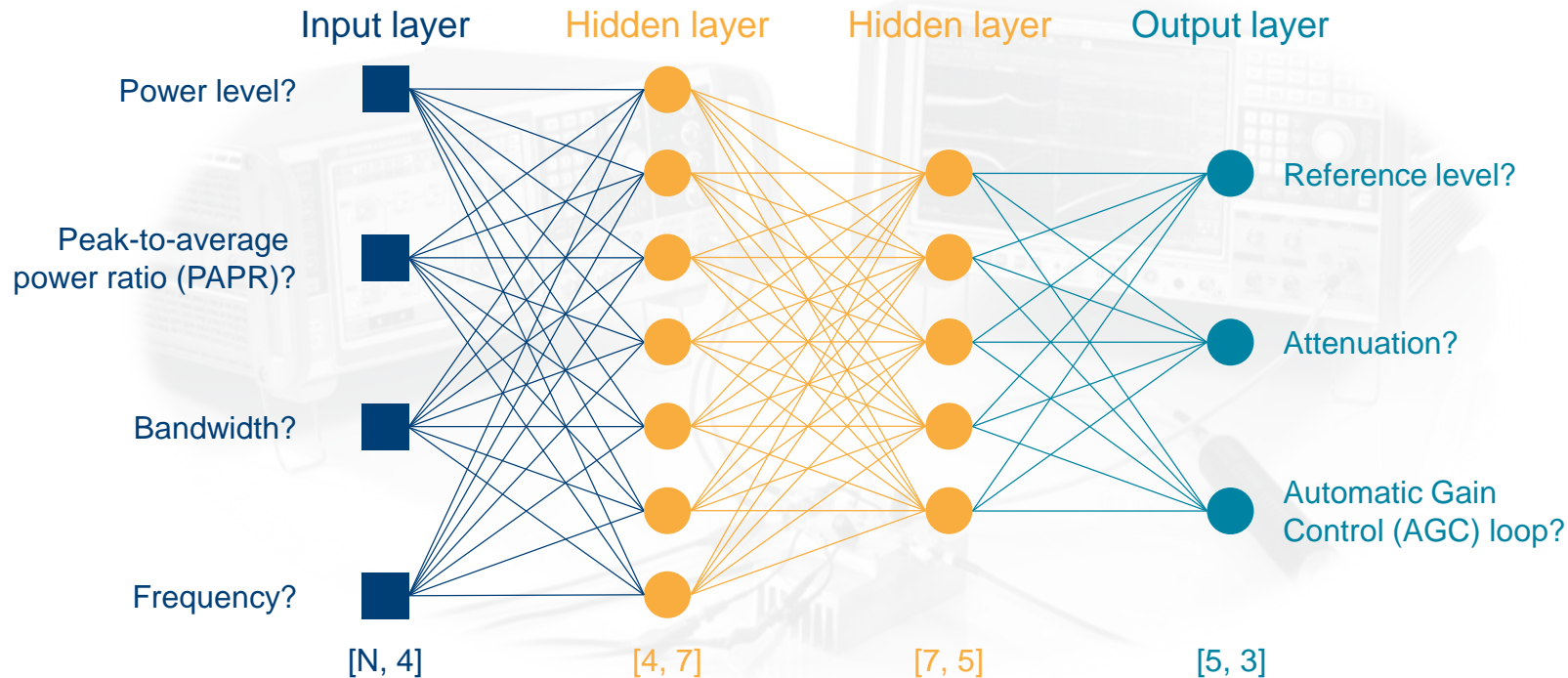


MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)



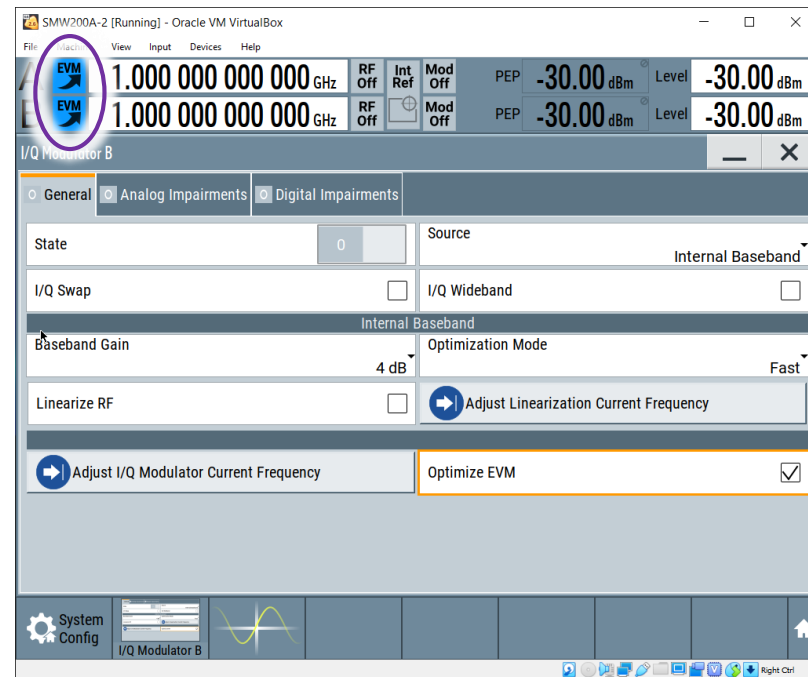
MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)

HOW ABOUT BEST ERROR VECTOR MAGNITUDE (EVM)?



BUT 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!)

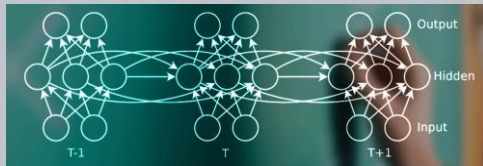


MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)

WHAT NN ARCHITECTURES ARE RELEVANT IN WIRELESS?

a1) Recurrent Neural Network (RNN)

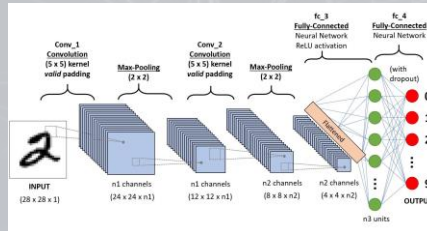
- ▶ Recurrent Neural Network (RNN) are a type of Neural Network where the output from previous step are fed as input to the current step
- ▶ Useful, in time series prediction (“memory”)



Source: [geeksforgeeks.org](https://www.geeksforgeeks.org/) analyticsindiamag.com

a2) Convolutional Neural Network (CNN)

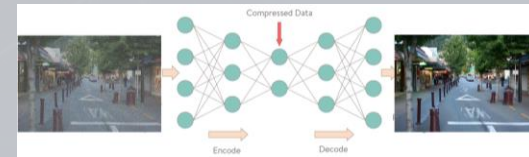
- ▶ A convolutional neural network is a feed-forward neural network, often with up to 30 (hidden) layers, designed for processing structured arrays of data such as images



Source: deeptai.org analyticsvidhya.com

b) Concept of an Autoencoder

- ▶ Special type of artificial neural network to learn efficient data coding in an unsupervised manner
- ▶ Autoencoder learns a representation for data set, by training the network to ignore insignificant data

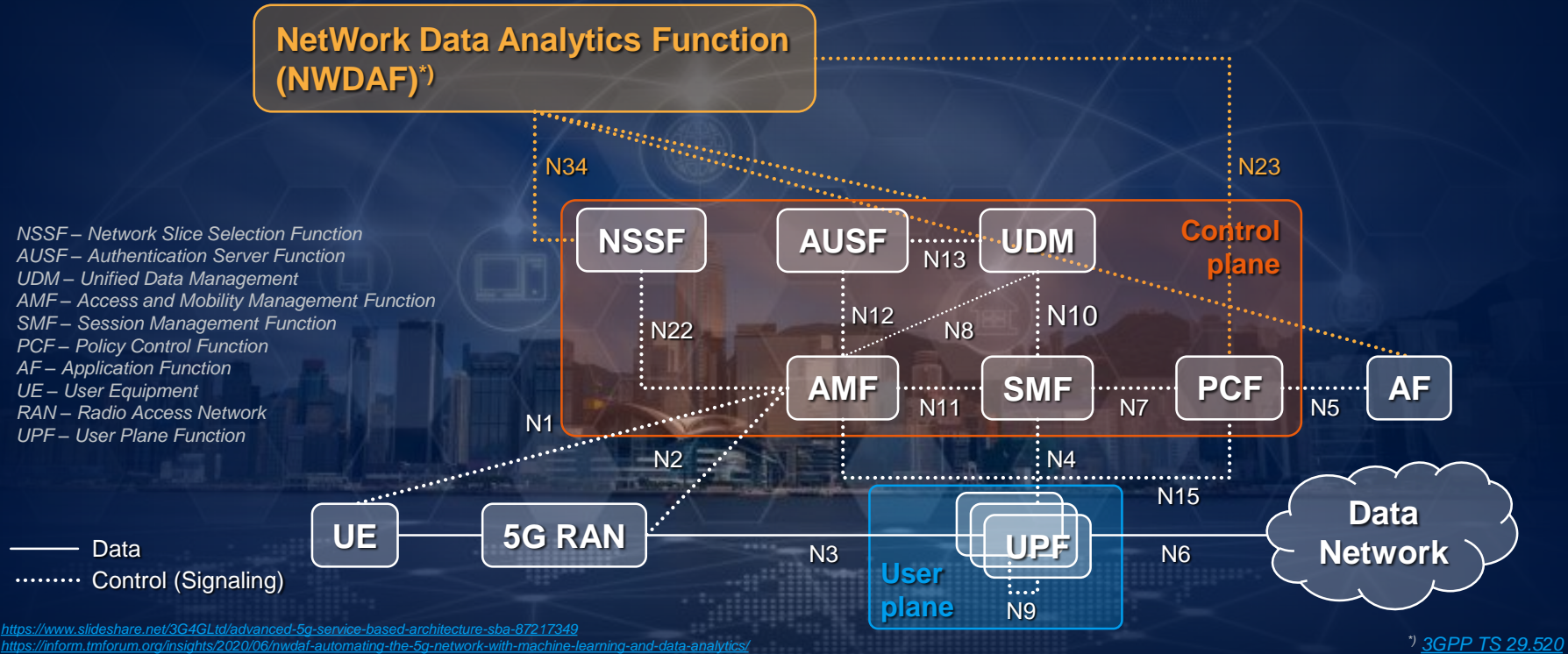


Source: [wikipedia.org](https://en.wikipedia.org/) towardsdatascience.com

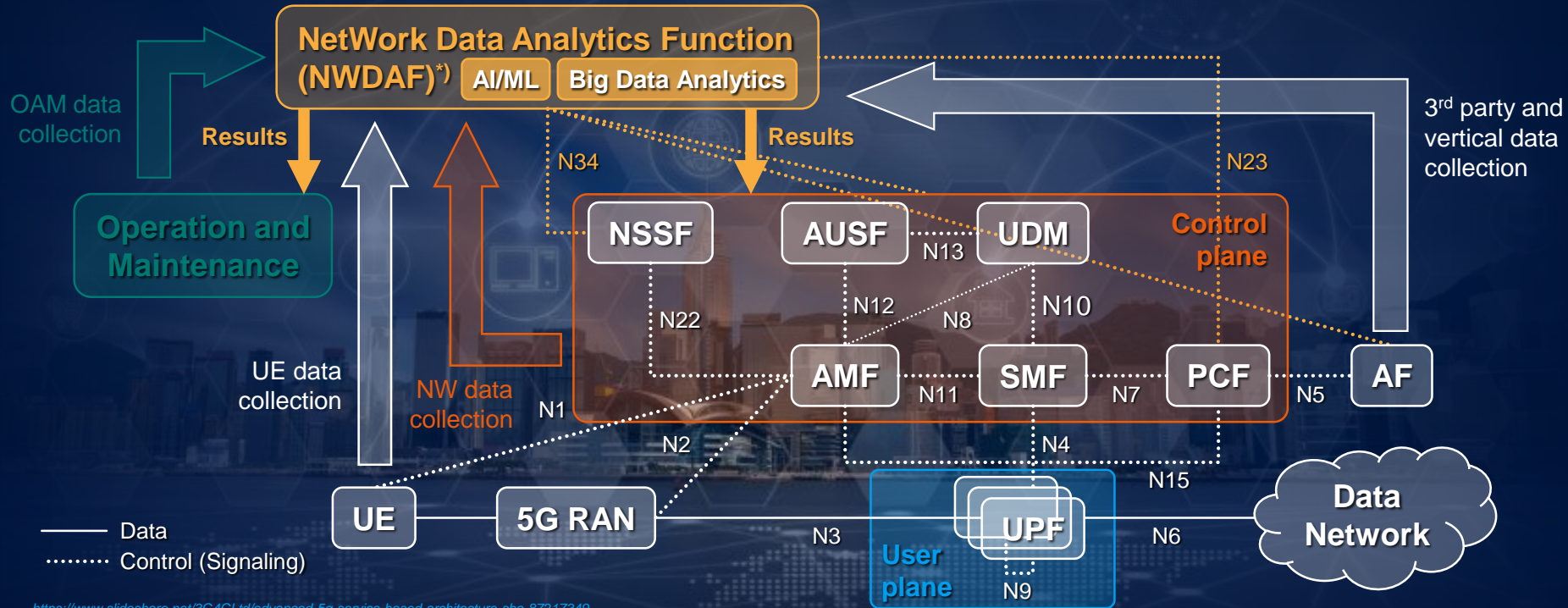
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HOW DO TODAY'S 5G NETWORKS USE AI/ML?

WHERE IS AI/ML AND BIG DATA ANALYTICS USED TODAY?



WHERE IS AI/ML AND BIG DATA ANALYTICS USED TODAY?



<https://www.slideshare.net/3G4GLtd/advanced-5g-service-based-architecture-sba-87217349>

<https://inform.tmforum.org/insights/2020/06/nwda-automating-the-5g-network-with-machine-learning-and-data-analytics/>

¹ 3GPP TS 29.520

WHERE IS AI/ML AND BIG DATA ANALYTICS USED TODAY?

NetWork Data Analytics Function (NWDAF)*

NWDAF is the basis for automation and fine tuning of network functions in 5G [TS 29.250]

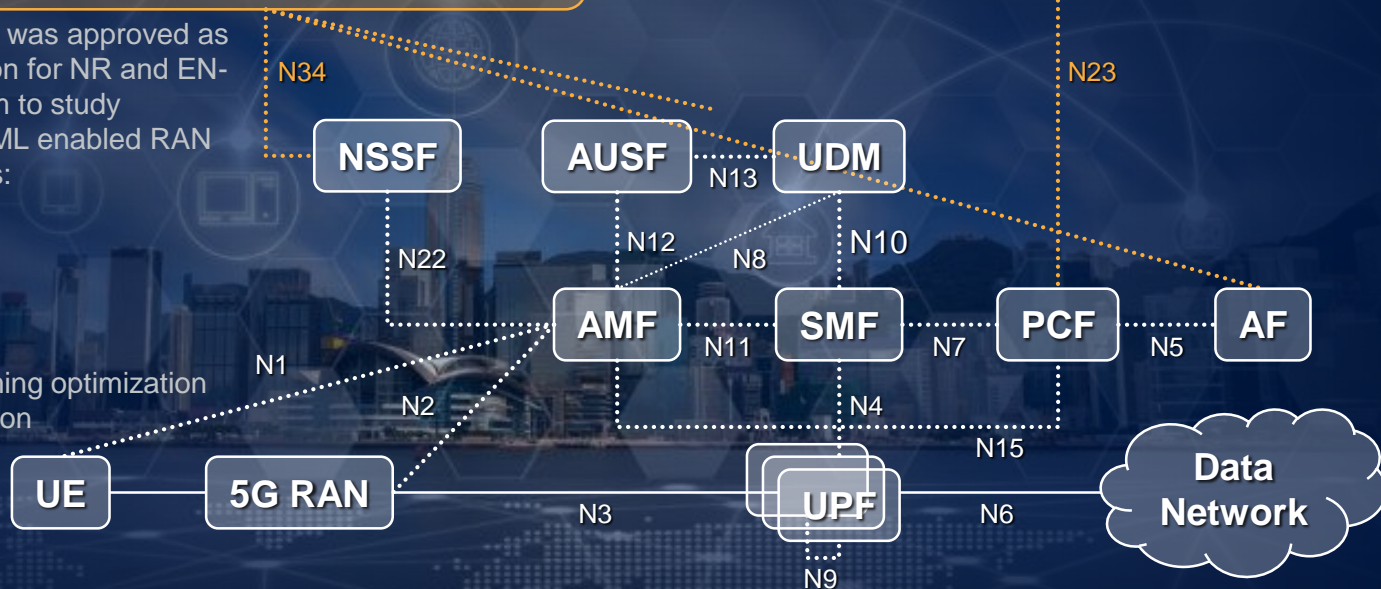
For Rel-17 a new study item was approved as "Study Item for data collection for NR and EN-DC" [TR 37.817] with the aim to study functional framework for AI/ML enabled RAN intelligence; initial use cases:

- Network energy saving
- Load balancing
- Mobility optimization

Potential future use cases:

- Massive MIMO beamforming optimization
- Link adaptation optimization
- Traffic steering

—— Data
..... Control (Signaling)



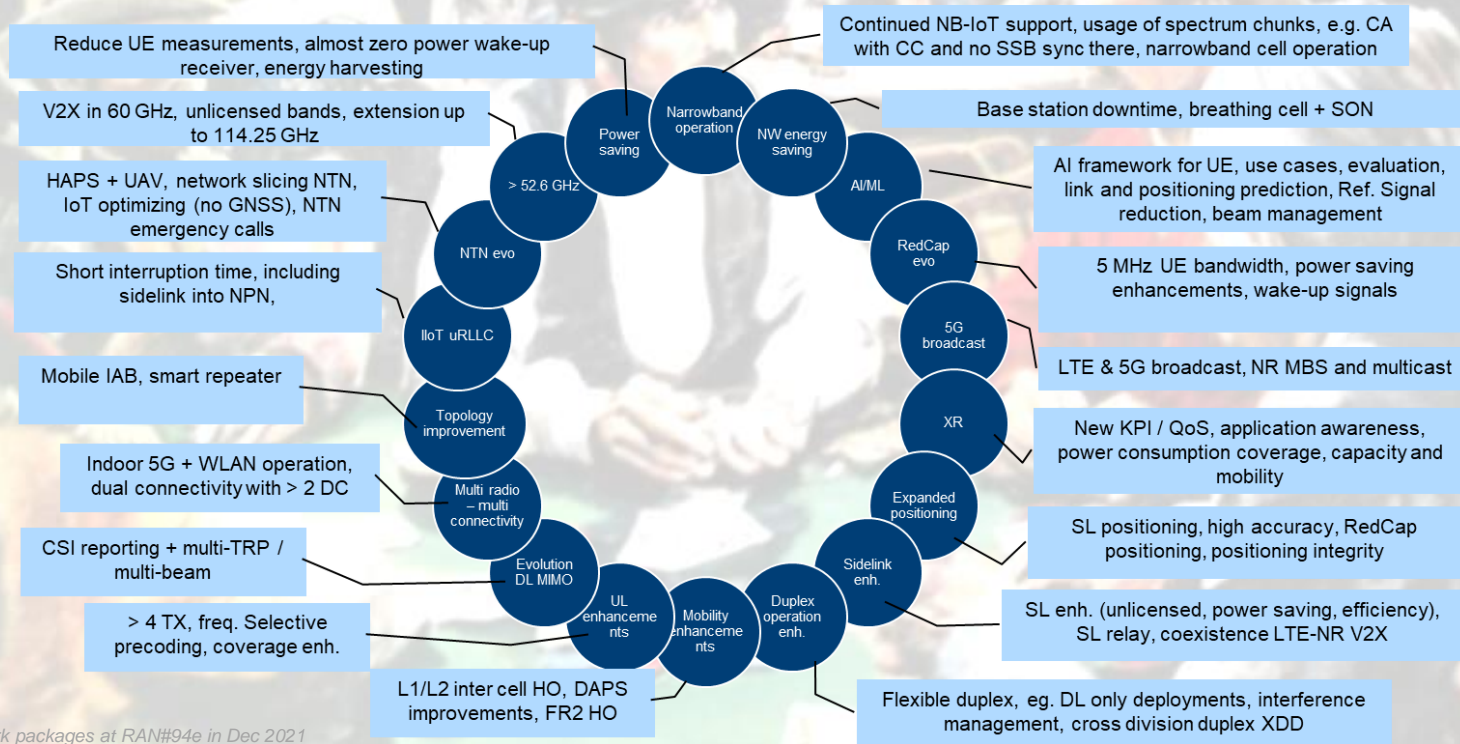
<https://www.slideshare.net/3G4GLtd/advanced-5g-service-based-architecture-sba-87217349>

<https://inform.tmforum.org/insights/2020/06/nwdaf-automating-the-5g-network-with-machine-learning-and-data-analytics/>

* 3GPP TS 29.520

3GPP RELEASE 18

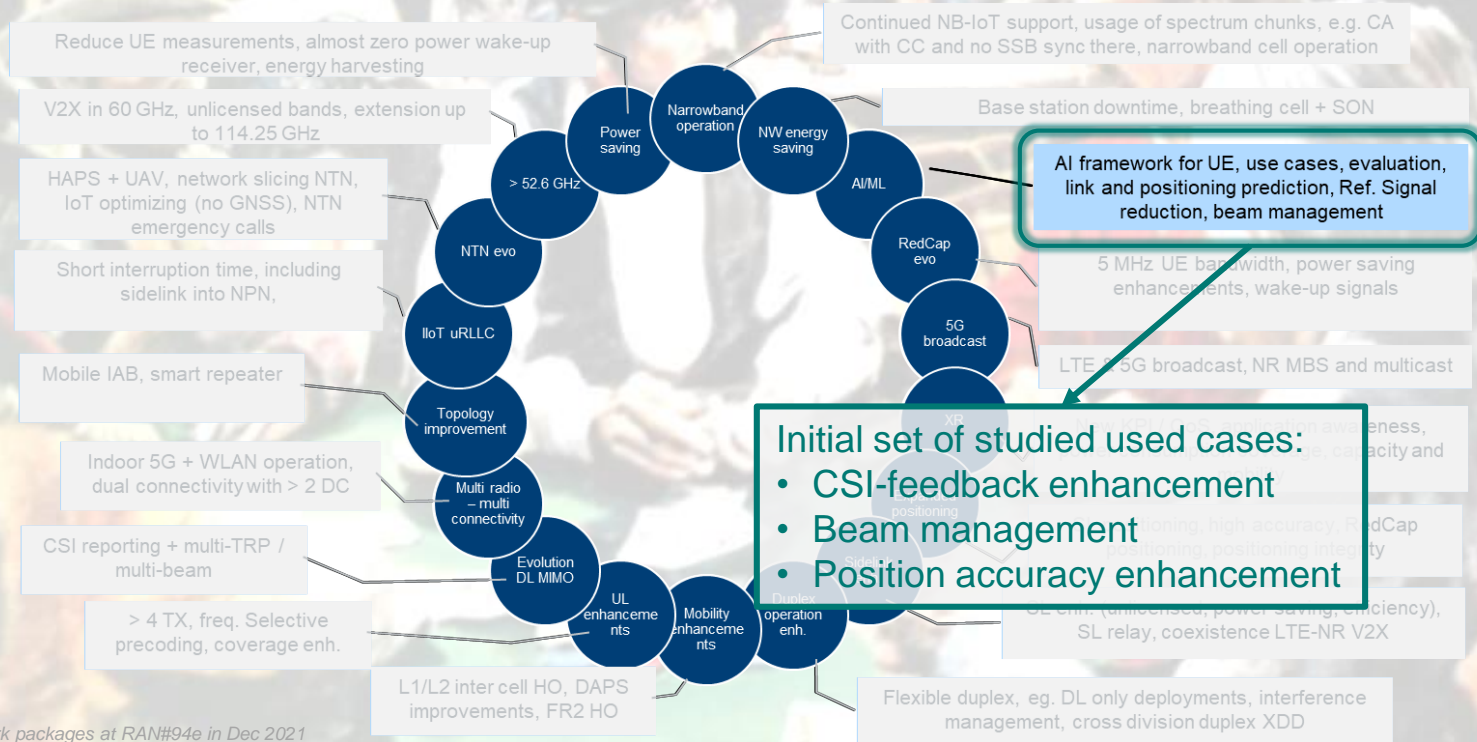
PROPOSED STUDY AND WORK ITEM'S*)



*) Approval of work packages at RAN#94e in Dec 2021

3GPP RELEASE 18

PROPOSED STUDY AND WORK ITEM'S*)

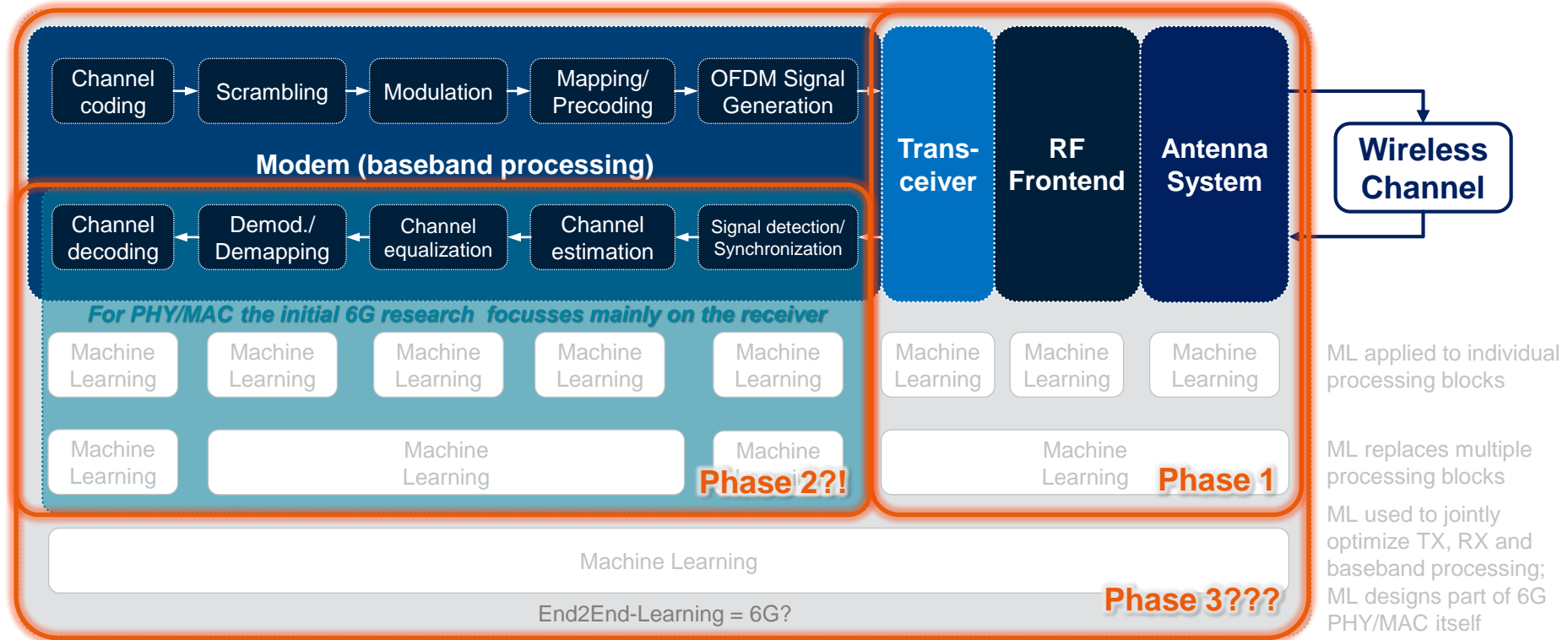


*) Approval of work packages at RAN#94e in Dec 2021

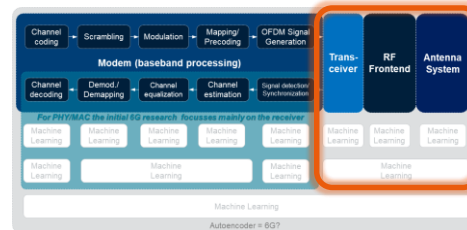
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STATUS OF RESEARCH FOR AN AI-NATIVE AIR INTERFACE SUPPORT IN 6G

HOW TO APPLY MACHINE LEARNING FOR 6G PHY?

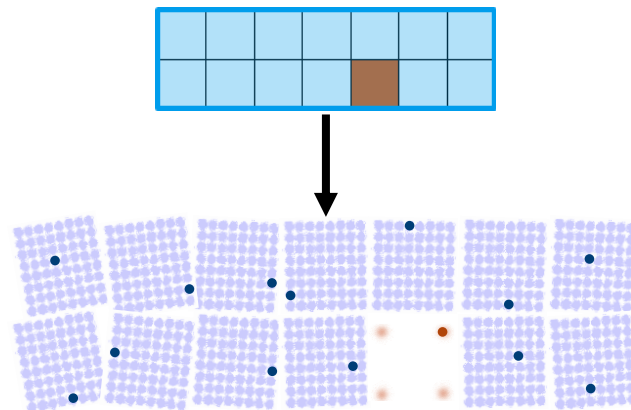
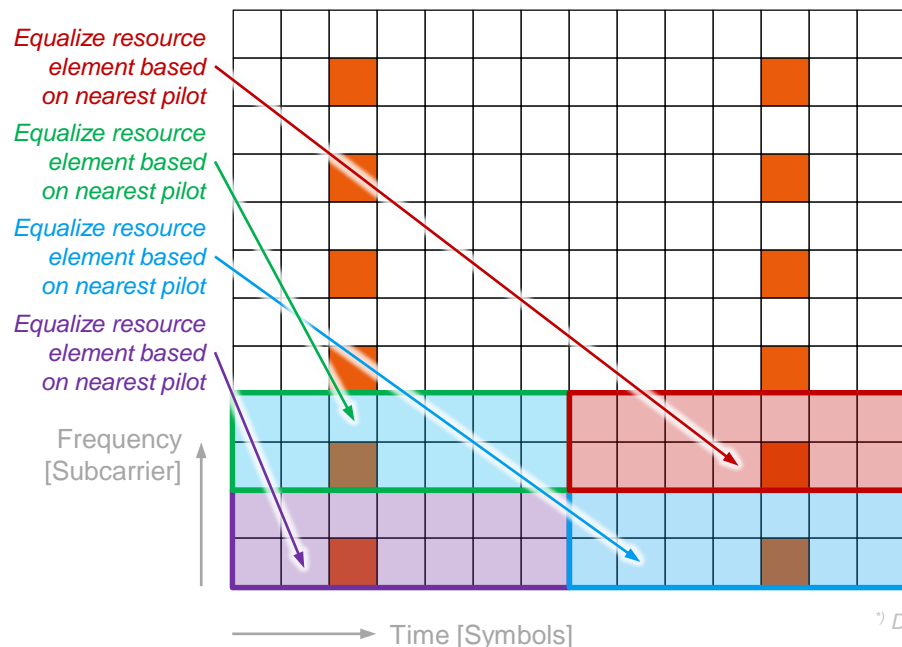


- Optimization of RF Frontend, modelling the non-linearities, analog and digital impairments seems to be an ‘easy’ entry point for applied machine learning in wireless communication.

[illegible][illegible][illegible][illegible]

PHASE 2: WHY IS THERE ROOM FOR MACHINE LEARNING TO BE APPLIED IN WIRELESS?

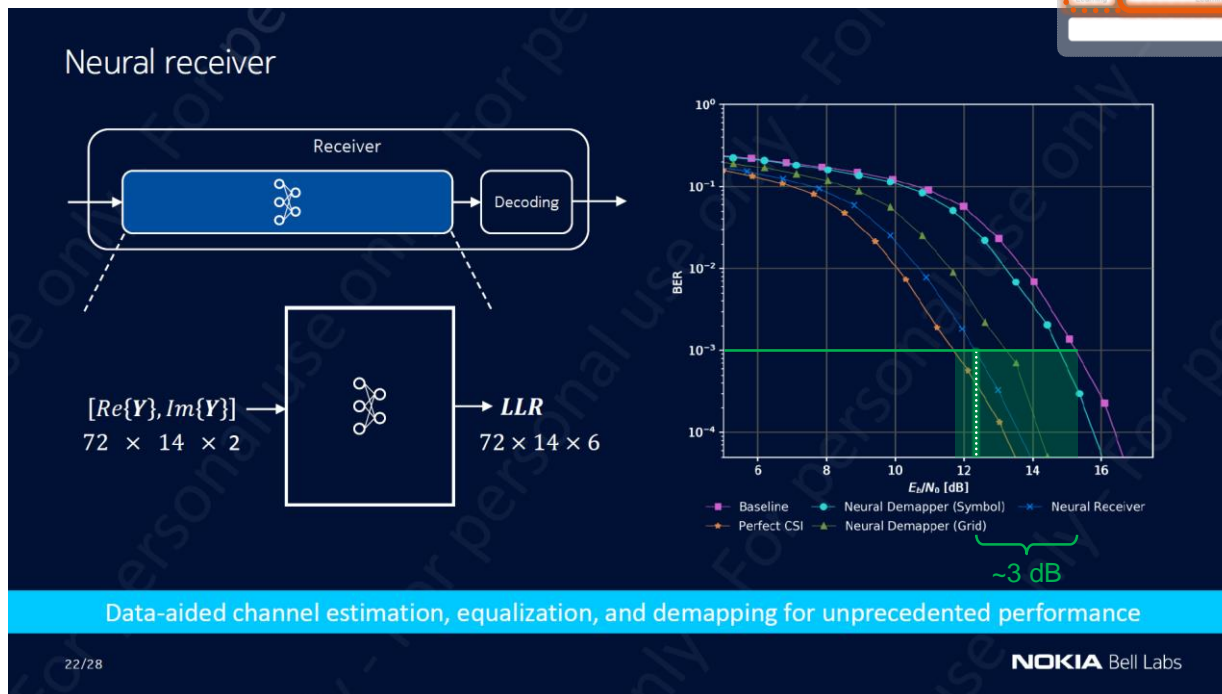
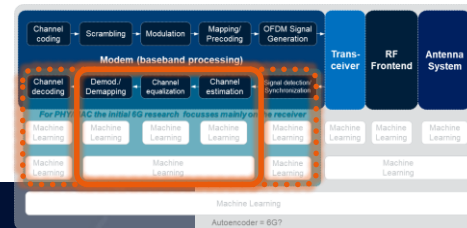
- 5G: there is a zoo of reference signals^{*)} to allow the receiver to estimate the channel properties and ultimately equalize resource elements for the propagation effects



The imperfect channel estimation and channel aging leads to SNR degradation and mismatched computation and thus equalization errors → Machine Learning will help to overcome this mismatch!

^{*)} DMRS for each physical channel in DL and UL direction, PTRS; DL: CSI-RS, TRS, PRS; UL: SRS

PHASE 2: APPROACHING PERFORMANCE CLOSE TO PERFECT CHANNEL KNOWLEDGE

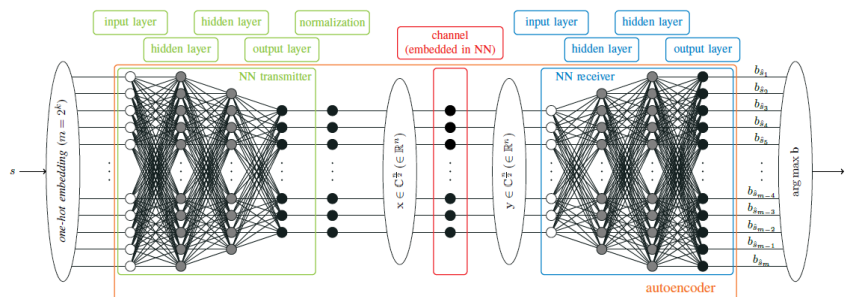


Source: <https://aiforgood.itu.int/events/the-road-towards-an-ai-native-air-interface-for-6g/> [Nov 2020]

PHASE 3: TRANSITION TO END-TO-END-LEARNING?

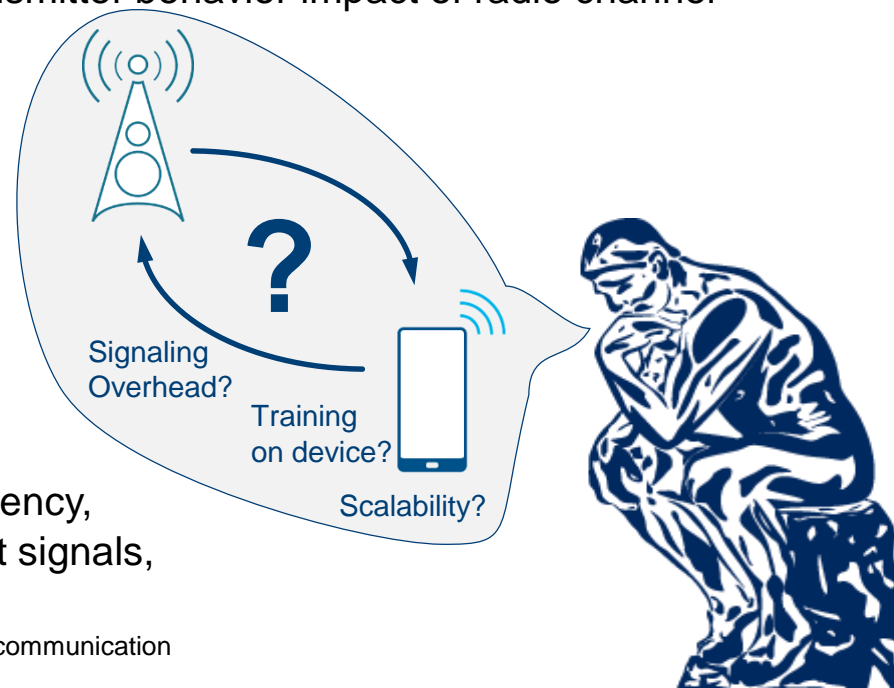
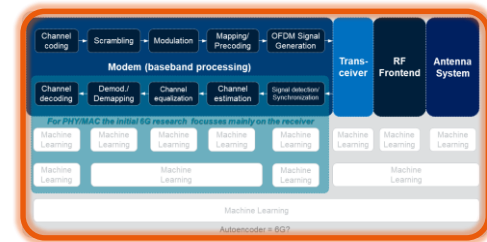
The 3rd step: The E2E-learning challenge?

- Learning the behavior of an End-to-End (E2E) communication link (e.g., via an autoencoder), including application, signal processing errors, transmitter behavior impact of radio channel conditions



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

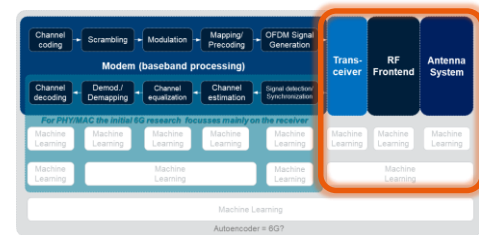
- Yes, provides additional performance gains & efficiency, e.g. can eliminate the need for transmission of pilot signals, but how practical is this solution in 'real life'?



The future role of AI/ML in wireless communication

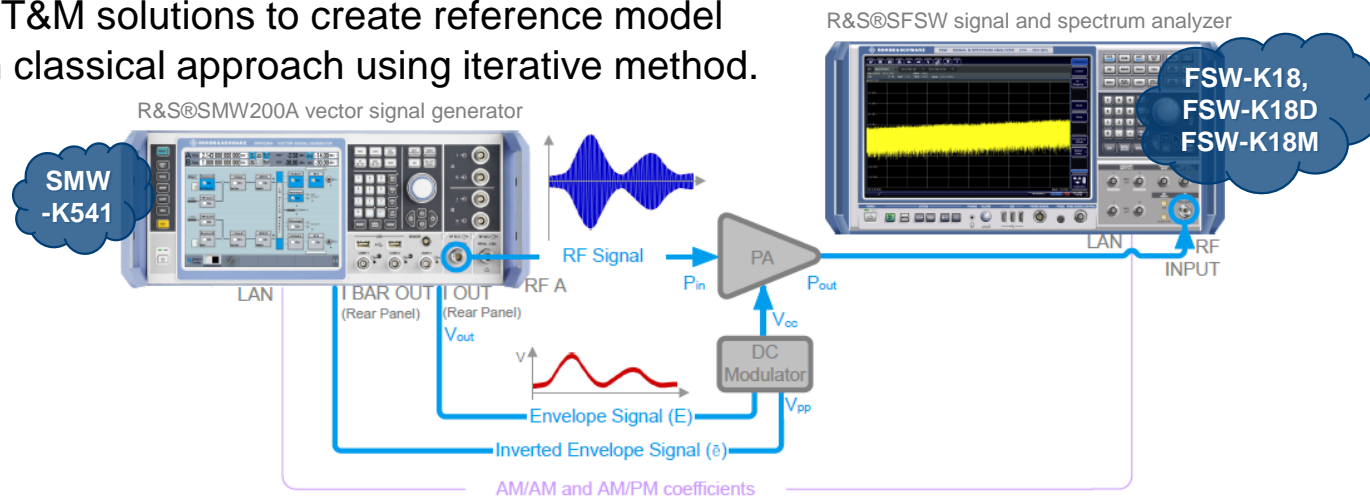
WHAT ROLE CAN TEST & MEASUREMENT SOLUTIONS PLAY IN THIS CONTEXT?

ACCOMPANY RESEARCH CHARACTERIZING RF FRONTENDS USING ML MODELS



- Measure CCDF, EVM, ACLR, CUBIC METRIC and just compare?
- Develop additionally a deterministic DPD algorithm and compare against ML-based model?

- ▶ NO! Use T&M solutions to create reference model based on classical approach using iterative method.



More information: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/application_notes/1ef99/1EF99_Iterative_Direct_DPD_1e.pdf

EXAMPLE: DATA GENERATION AND TRAINING PROCEDURE

1



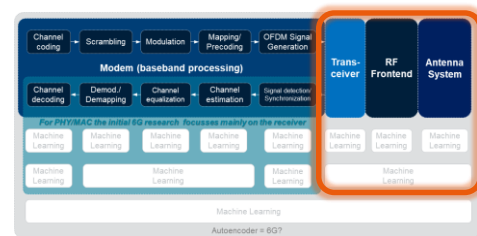
Generate e.g. 5G NR TM1-1 for FR1¹⁾

Device Under Test (DUT),
e.g. power amplifier ($f_c = 3 \text{ GHz}$)



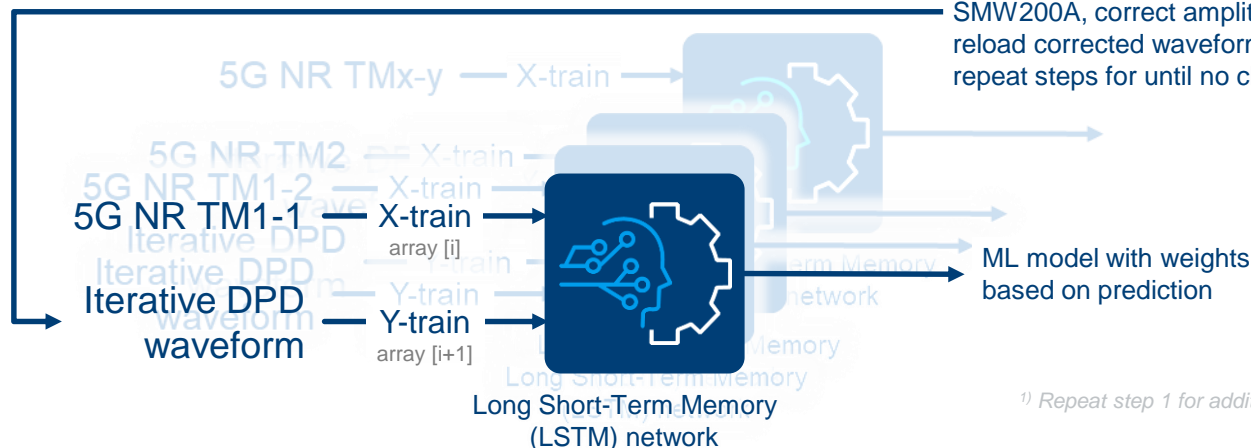
e.g.
10 iterations

R&S FSW signal
and spectrum Analyzer



Use option FSW-K18D to capture IQ samples, compare to ideal waveform, collected from SMW200A, correct amplitude and phase, reload corrected waveform into SMW200A, repeat steps for until no changes are detectable

2

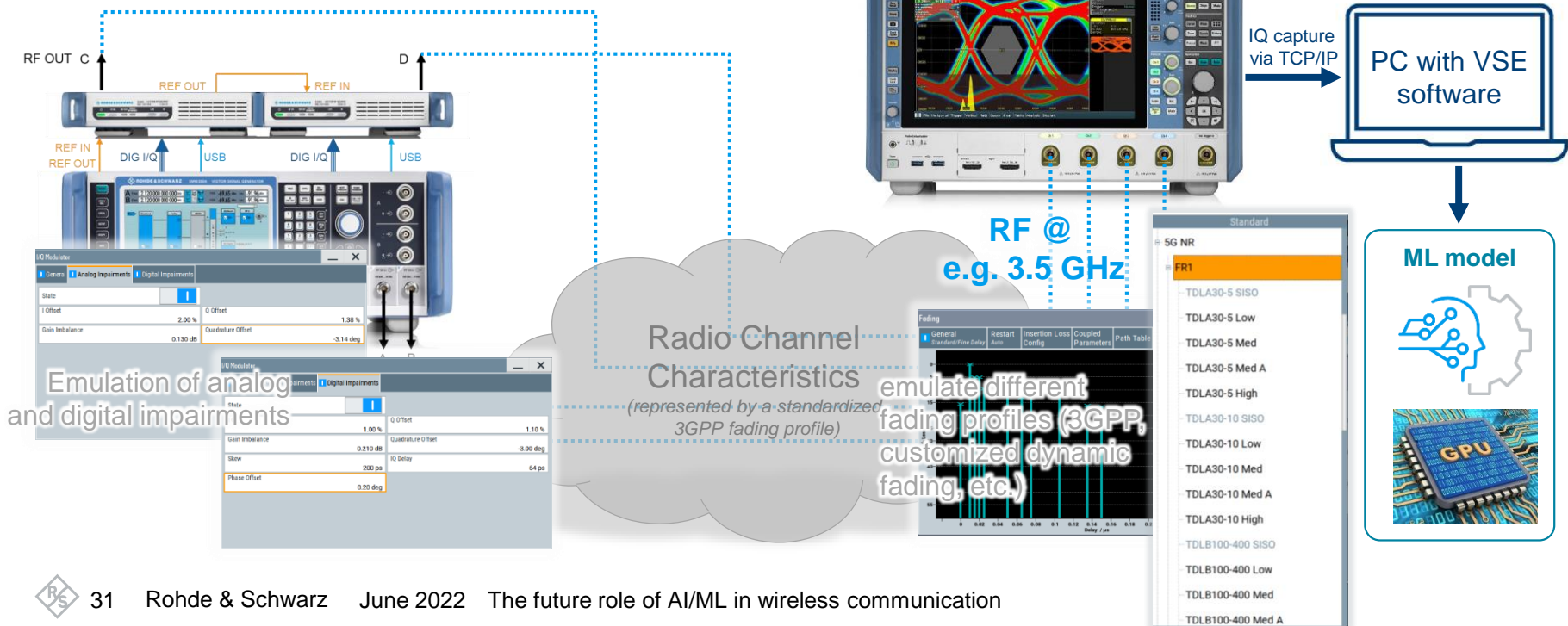


¹⁾ Repeat step 1 for additional signals, to train the NN

What role can test & measurement solutions play in this context?

NO MACHINE LEARNING WITHOUT TRAINING DATA

- Generating data sets based on different 5G NR signal configurations, fading and impairments; e.g.: 5G NR FR1 MIMO 4x4



The future role of AI/ML in wireless communication

FUTURE CHALLENGES & OUTLOOK

- +++++

-
- The diagram illustrates the Federated Learning (FL) architecture. At the top, a 'Global model' is shown as a neural network. Below it, a 'Global Aggregation' process is depicted with a solid arrow pointing right and a dashed arrow pointing left, leading to the formula: $w(t) = \frac{\sum_{k=1}^K |D_k| * w_k(t)}{\sum_{k=1}^K |D_k|}$. The central part of the diagram shows a cloud icon with a server and a triangle representing the global model. Below the cloud, several 'Local model' icons are shown, each associated with a specific 'Edge device' (UE #1, UE #2, UE #k, UE #K). Each local model is represented by a neural network icon and a database icon. Arrows indicate the flow of information: solid arrows labeled $w(t)$ point from the global model to the local models, and dashed arrows labeled $w_k(t)$ point from the local models back to the global model.

Source: *Federated learning and wireless communication* [May 2020]

You'd like to be part of the Rohde & Schwarz family?

TECH & CONNECT

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