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

| 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

| June 2022[1]

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

| March 2024[1]

3GPP Release 18
Work Package approval in Dec'21 (RAN#94-e)

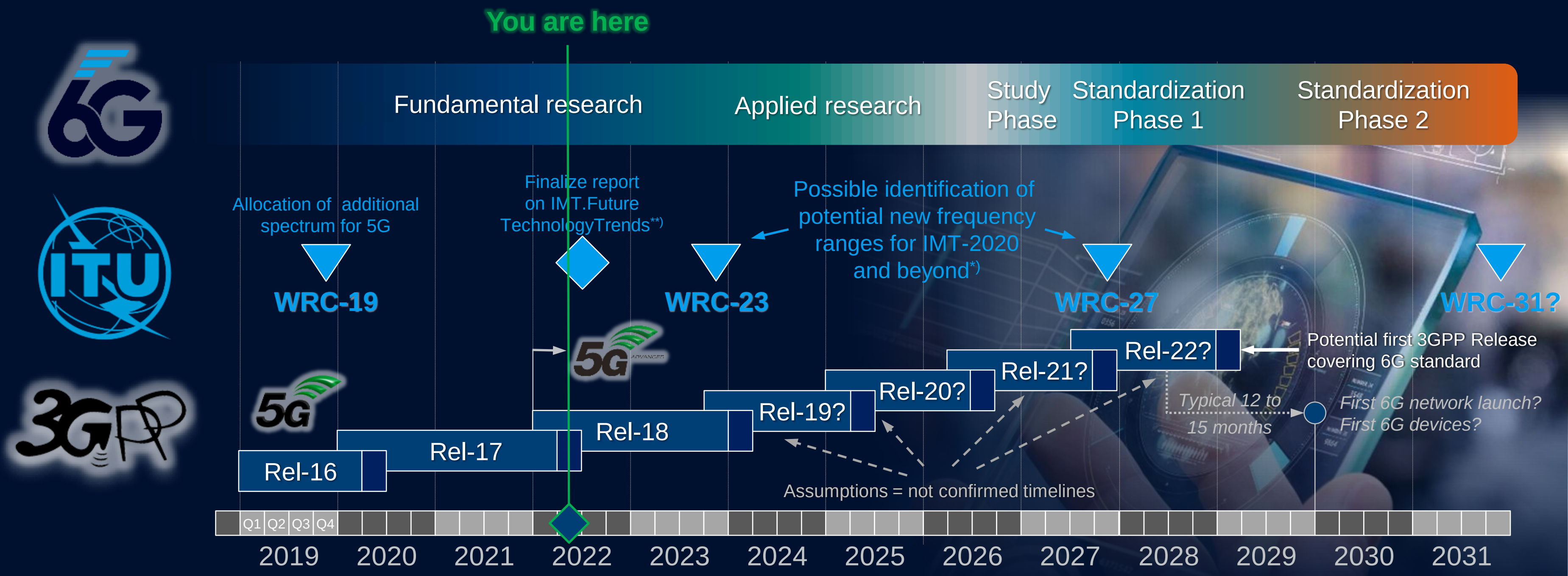
5G is a marathon, not a 100 m sprint…

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-U, MIMO enhancements, DC/CA enhancements

eMBB: enhanced Mobile Broadband
URLLC: Ultra-Reliable Low Latency Communication
mMTC: massive Machine Type Communication

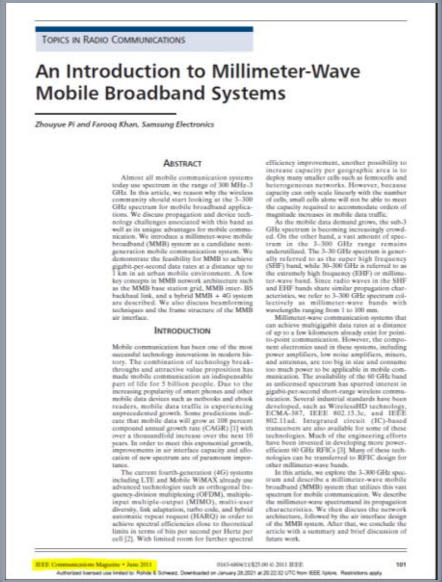
FUTURE STANDARDIZATION AND REGULATORY ROADMAP



*) *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!


TOPICS IN RADIO COMMUNICATIONS

An Introduction to Millimeter-Wave Mobile Broadband Systems

Zhouyue Pi and Farooq Khan, Samsung Electronics

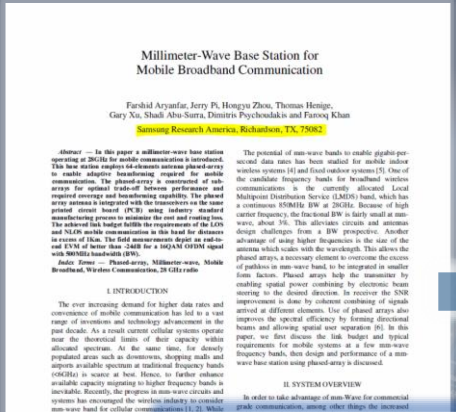
ABSTRACT

INTRODUCTION

IEEE Communications Magazine • June 2011

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

~4 years

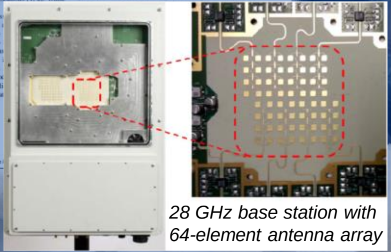

Millimeter-Wave Base Station for Mobile Broadband Communication

Farshid Aryanfar, Jerry Pi, Hongyu Zhou, Thomas Henige, Gary Xu, Shadi Abu-Surra, Dimitris Psychoudakis and Farooq Khan

Samsung Research America, Richardson, TX, 75082

I. INTRODUCTION

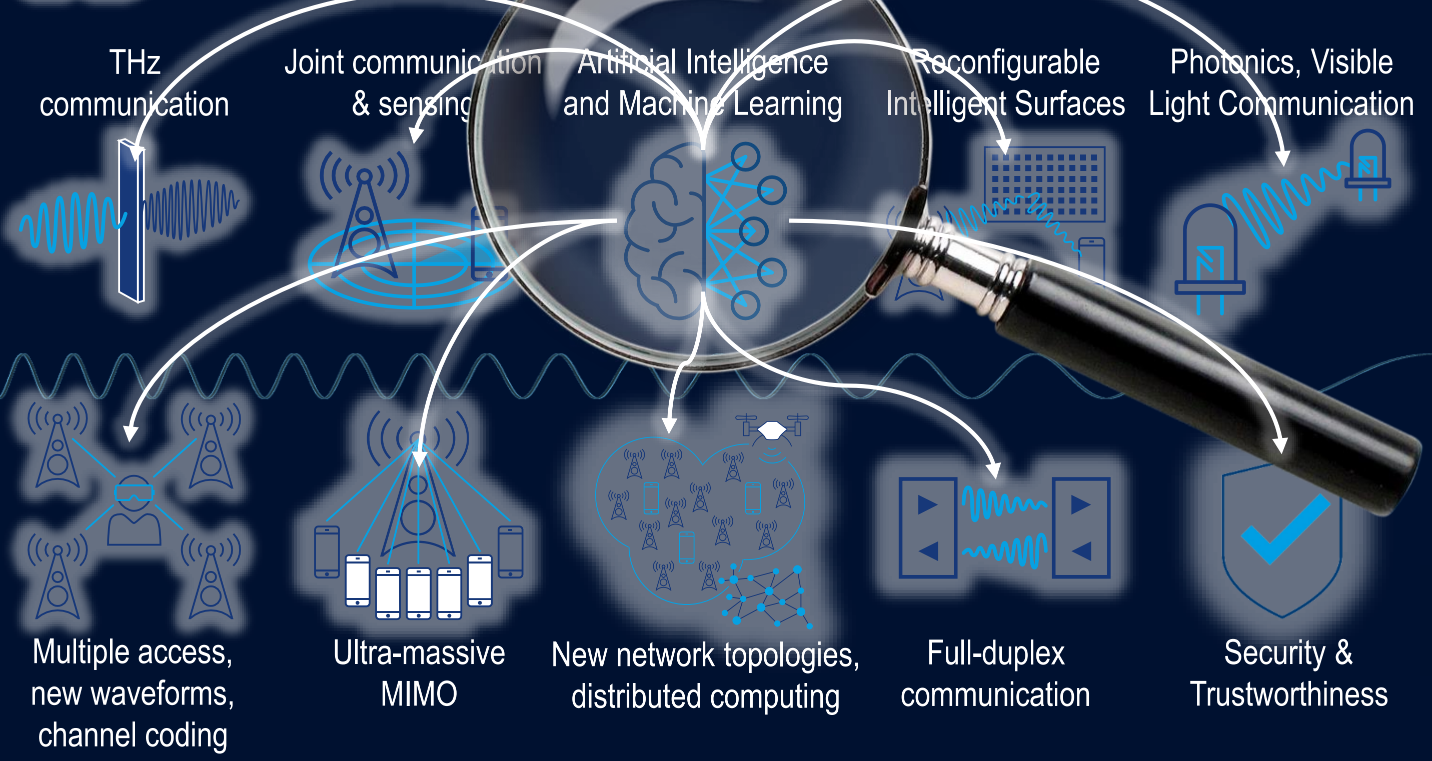
II. SYSTEM OVERVIEW


28 GHz base station with 64-element antenna array

~4+ years

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5783993 (June 2011)
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7166778&tag=1 (June 2015)

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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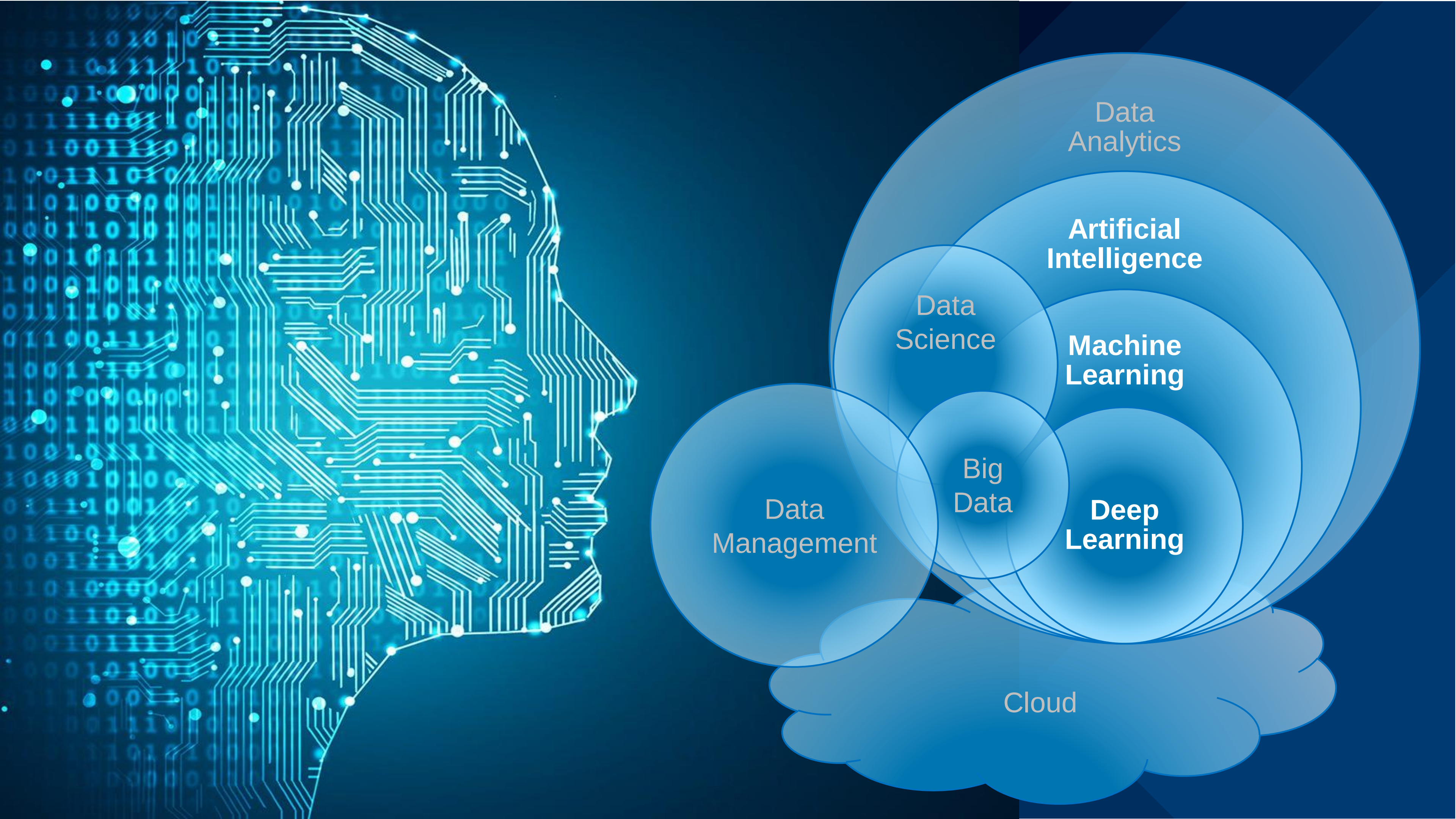
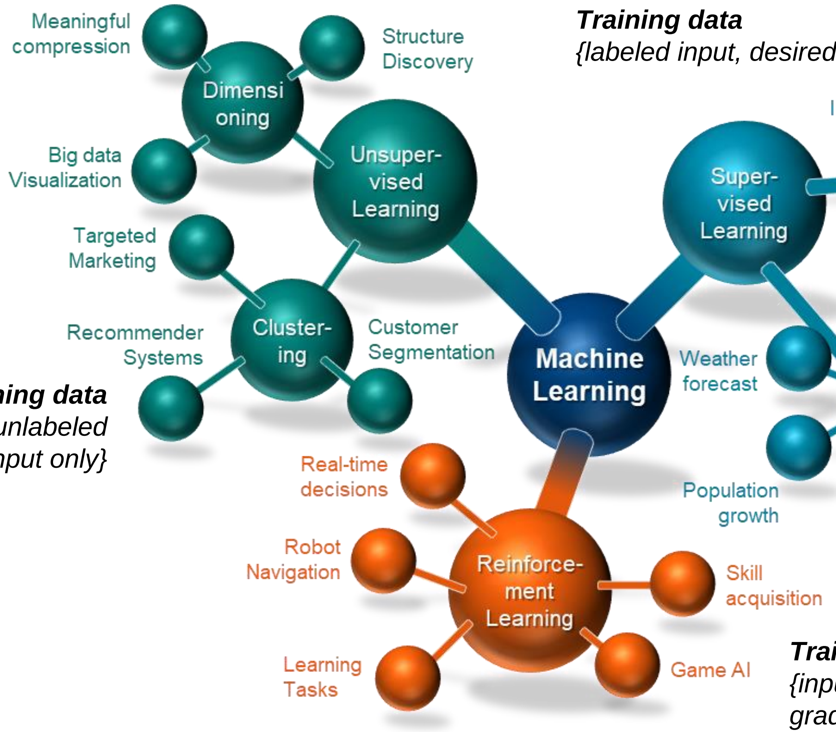
THE FUNDAMENTALS OF AI/ML


Data
Analytics
Artificial
Intelligence
Data
Science
Machine
Learning
Big
Data
Data
Management
Deep
Learning
Cloud

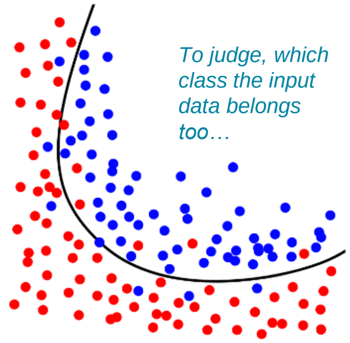
TYPES OF MACHINE LEARNING
SUPERVISED – UNSUPERVISED – REINFORCEMENT

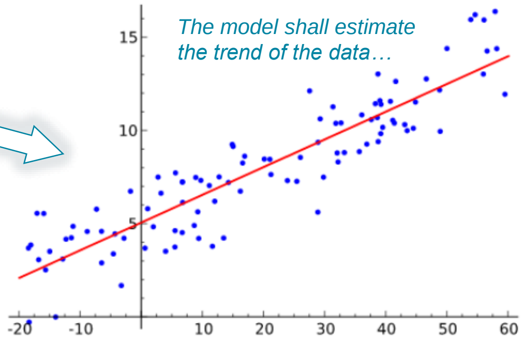
Training data
{labeled input, desired output}

Training data
{unlabeled input only}



Training data
{input, some output, grade of output}

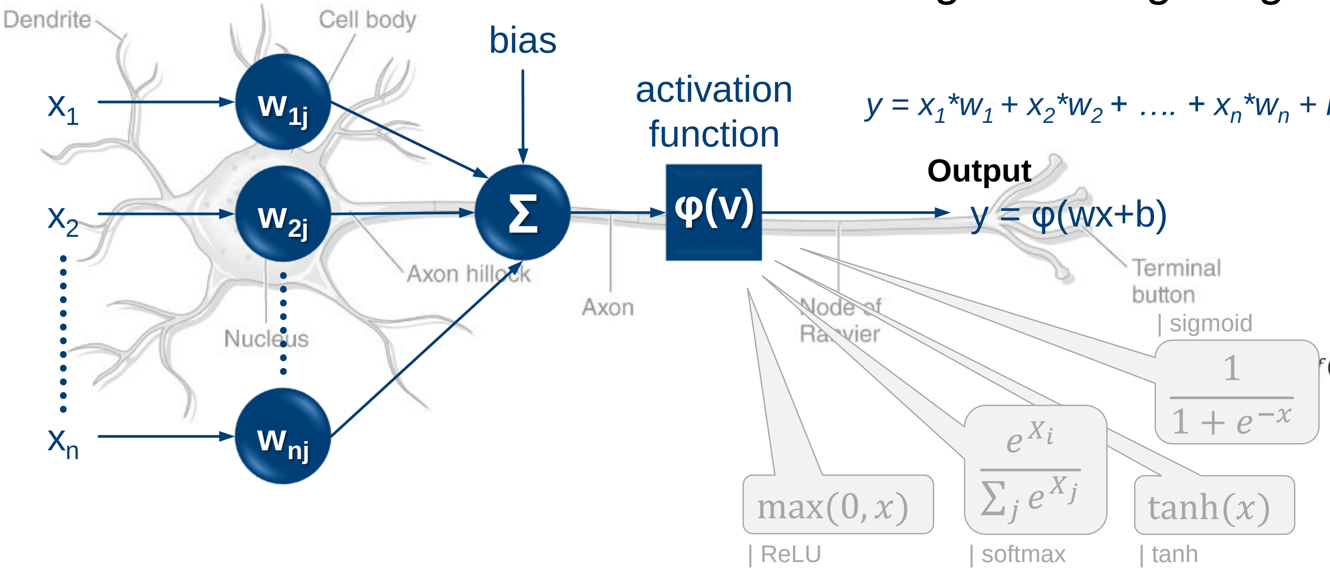


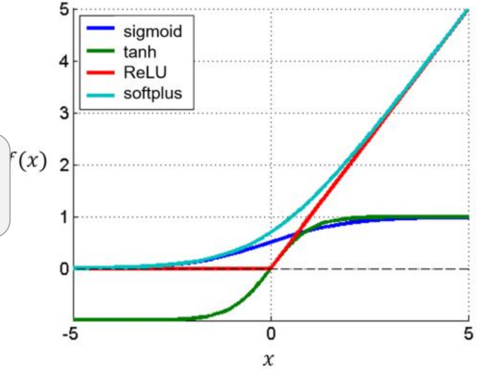


GENERAL CONCEPT OF A NEURONAL NETWORK (NN)
MODELING HOW THE HUMAN BRAIN WORKS

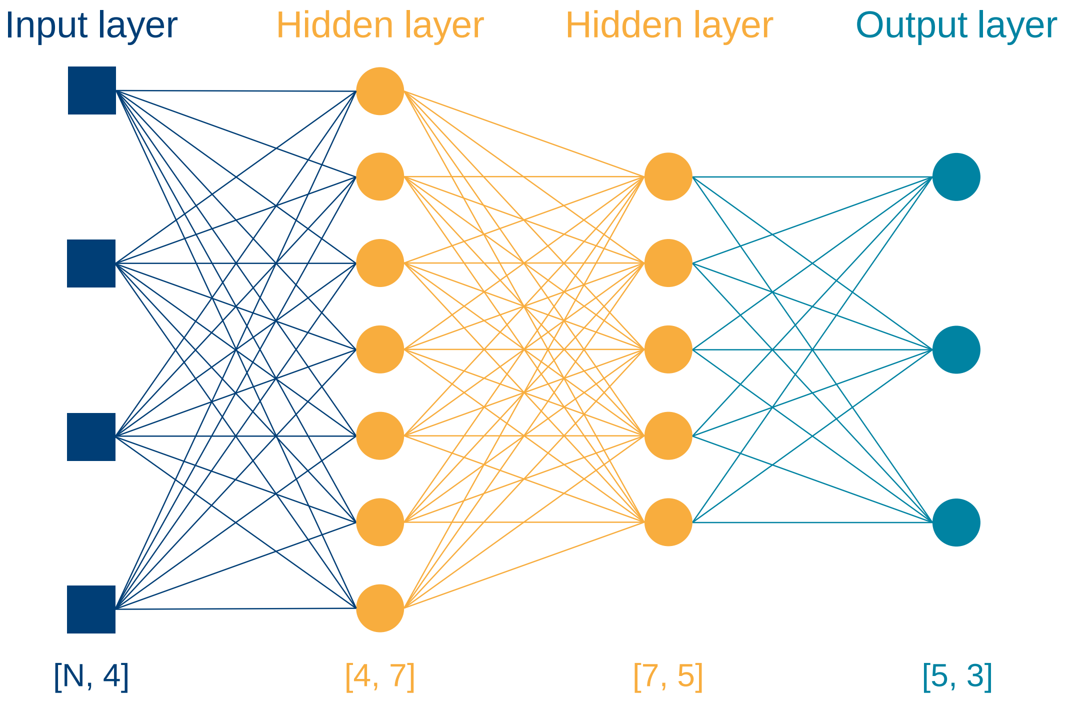
Input **Weighting**

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

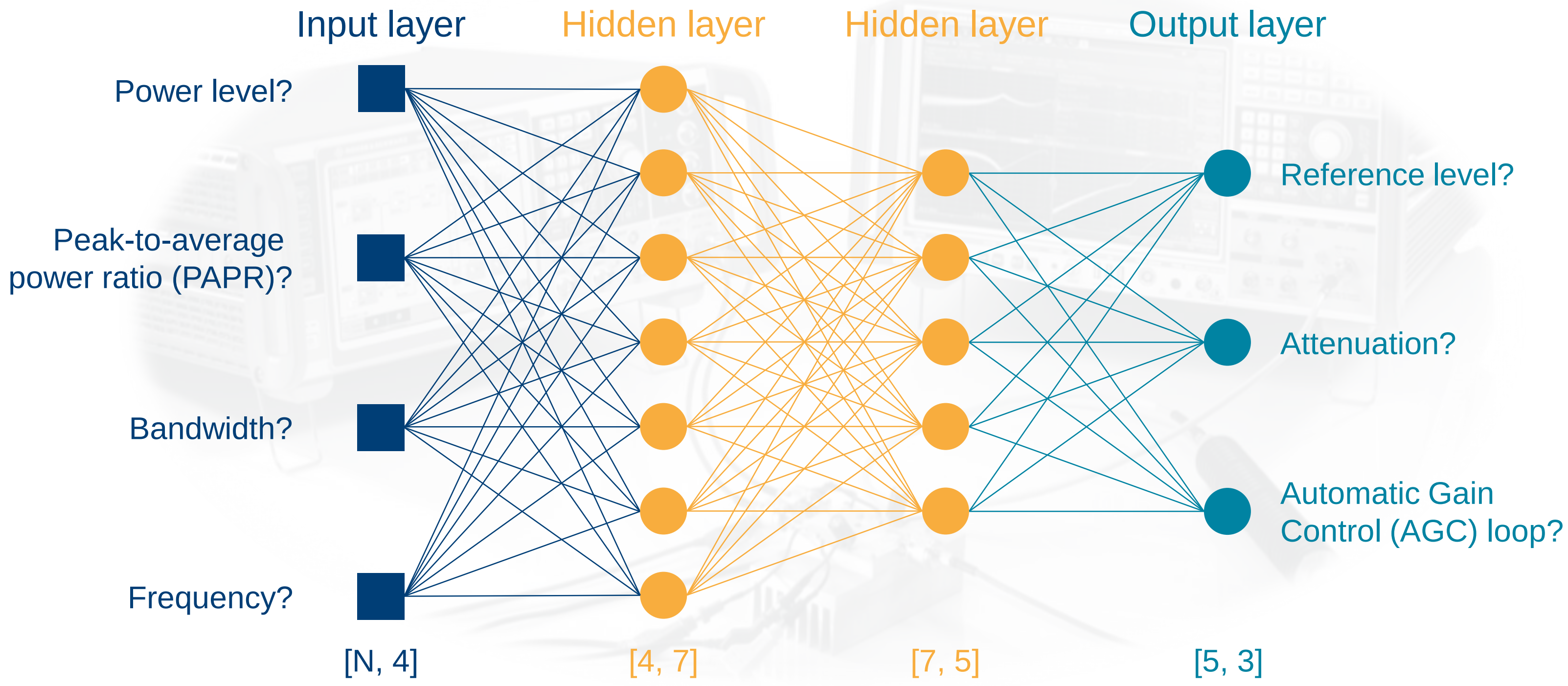




MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)

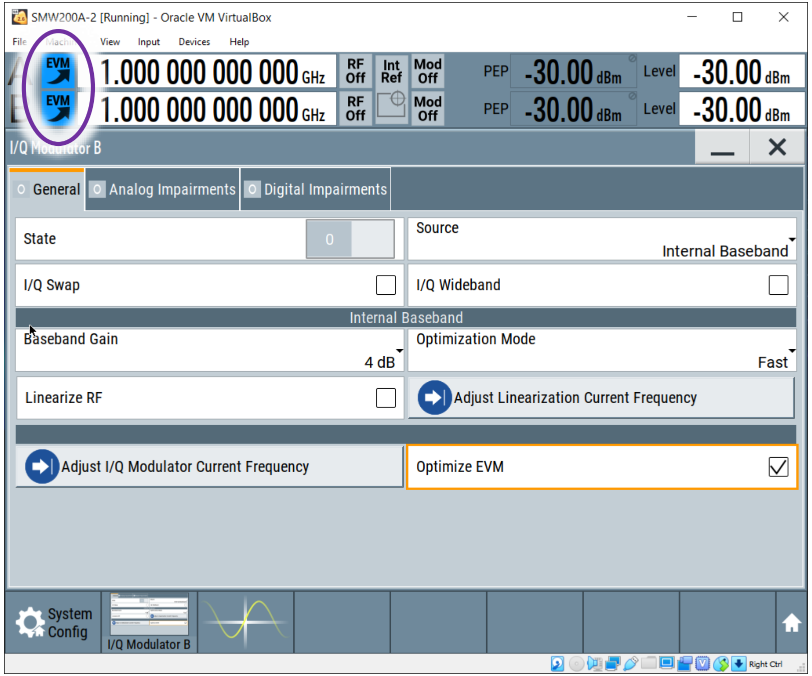


MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)
HOW ABOUT BEST ERROR VECTOR MAGNITUDE (EVM)?



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

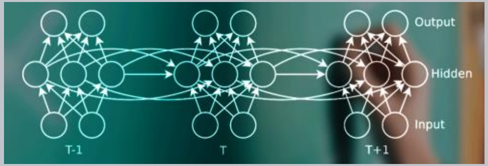
Optimizing instrument parameters related to EVM by push of simple button (not ML-based!)



MACHINE LEARNING BASED ON NEURAL NETWORKS (NN)
WHAT NN ARCHITECTURES ARE RELEVANT IN WIRELESS?

a1) Recurrent Neural Network (RNN)

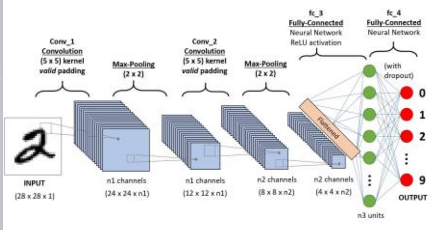
- Recurrent Neural Network (RNN) are a type of Neural Network where the output from previous step are fed as input to the current step
- Useful, in time series prediction (“memory”)



Source: geeksforgeeks.org, analyticsindiamag.com

a2) Convolutional Neural Network (CNN)

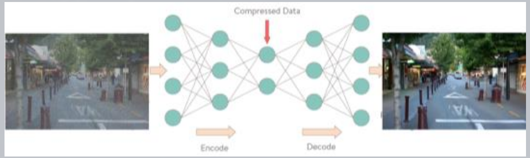
- A convolutional neural network is a feed-forward neural network, often with up to 30 (hidden) layers, designed for processing structured arrays of data such as images



Source: deepai.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, towardsdatascience.com

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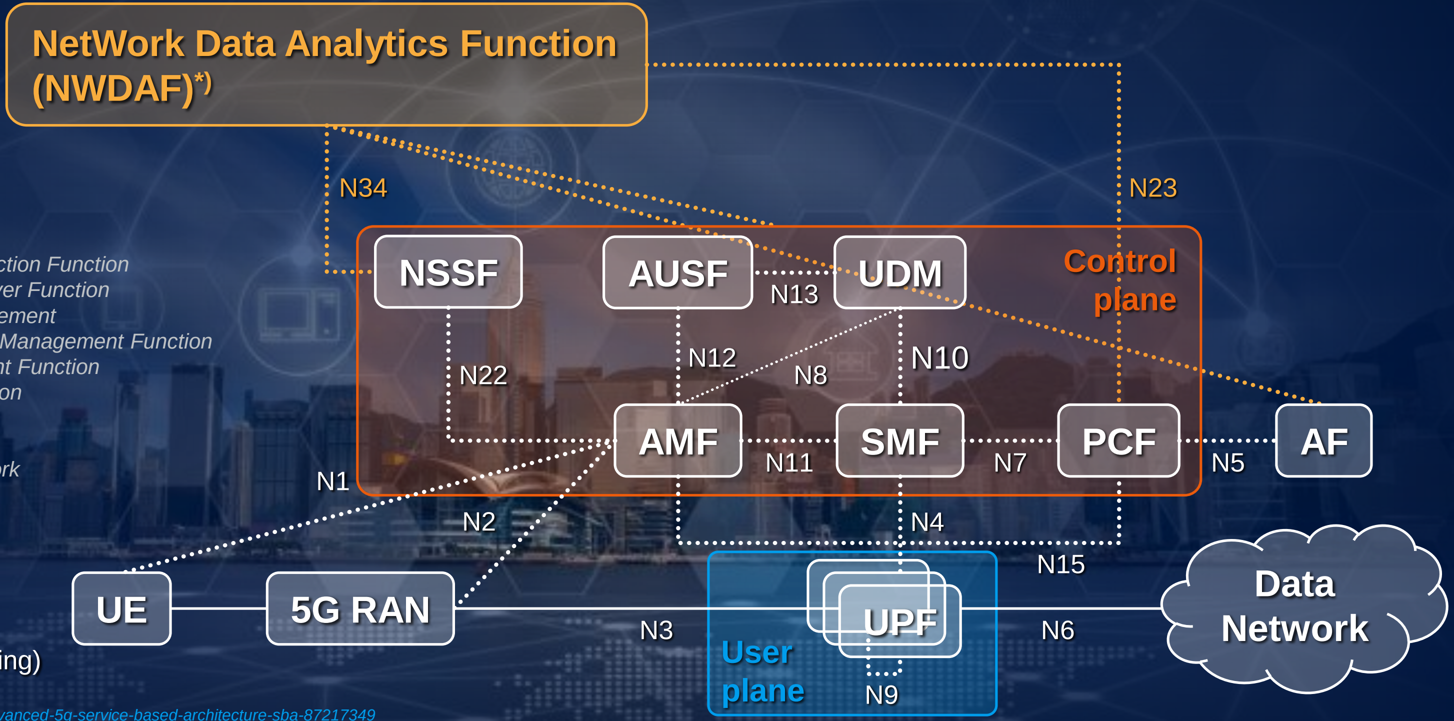
HOW DO TODAY’S 5G NETWORKS USE AI/ML?

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

NSSF – Network Slice Selection Function
AUSF – Authentication Server Function
UDM – Unified Data Management
AMF – Access and Mobility Management Function
SMF – Session Management Function
PCF – Policy Control Function
AF – Application Function
UE – User Equipment
RAN – Radio Access Network
UPF – User Plane Function

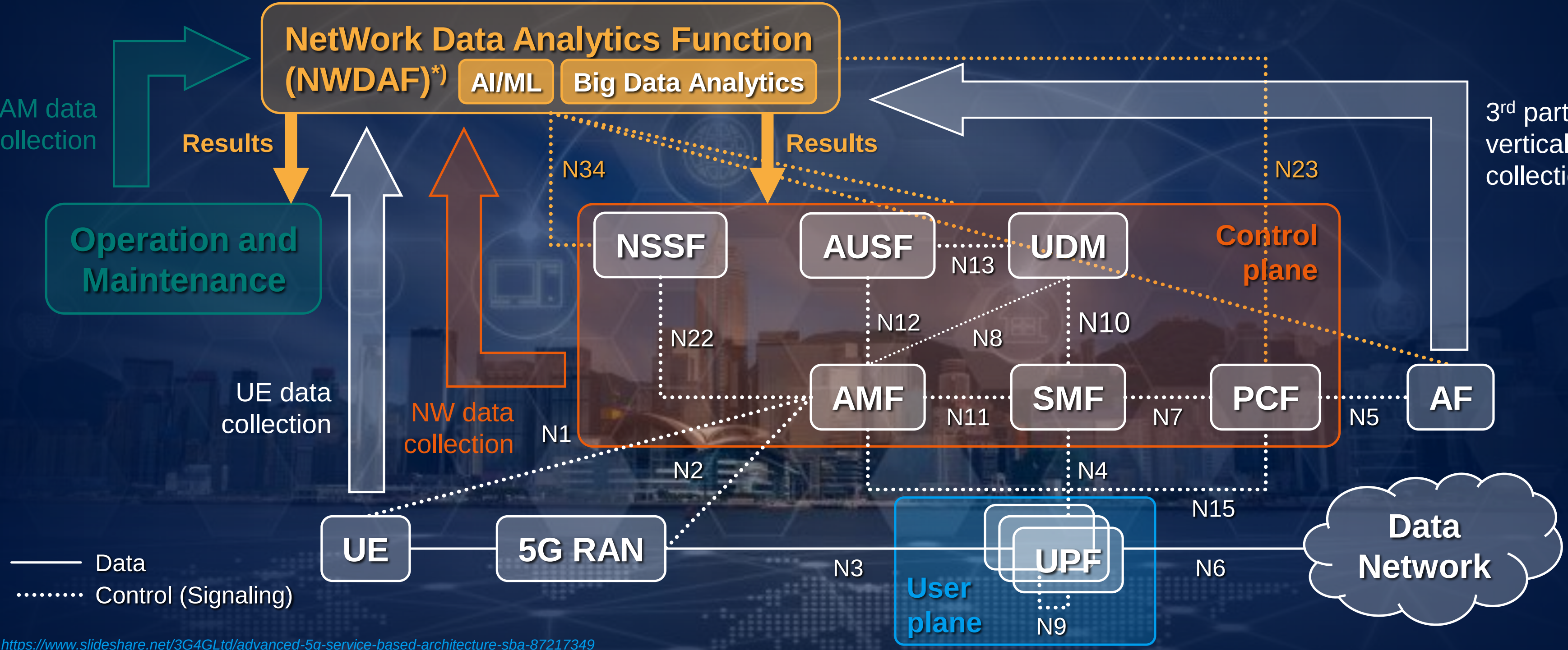


——— Data
········· Control (Signaling)

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

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/nwdaf-automating-the-5g-network-with-machine-learning-and-data-analytics/

*) 3GPP TS 29.520

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

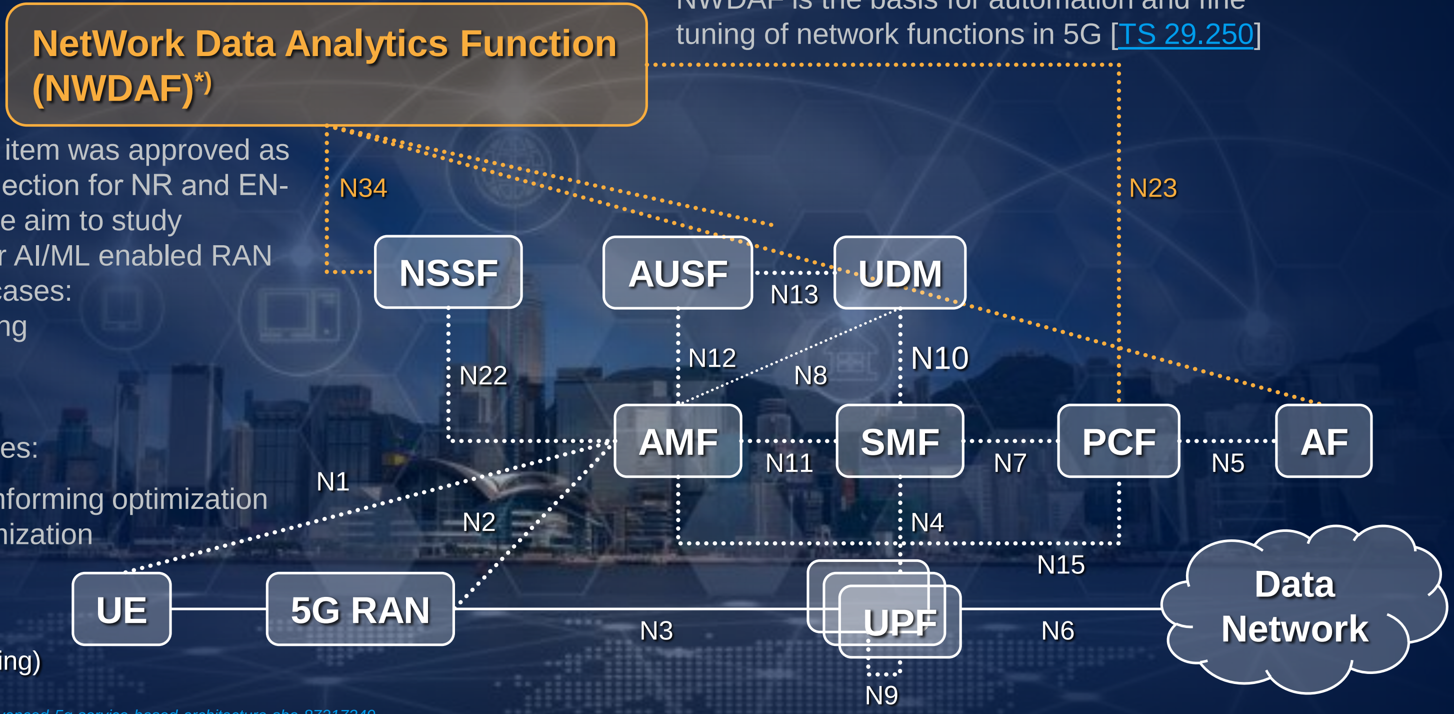
NWDAF is the basis for automation and fine tuning of network functions in 5G [TS 29.250]

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:

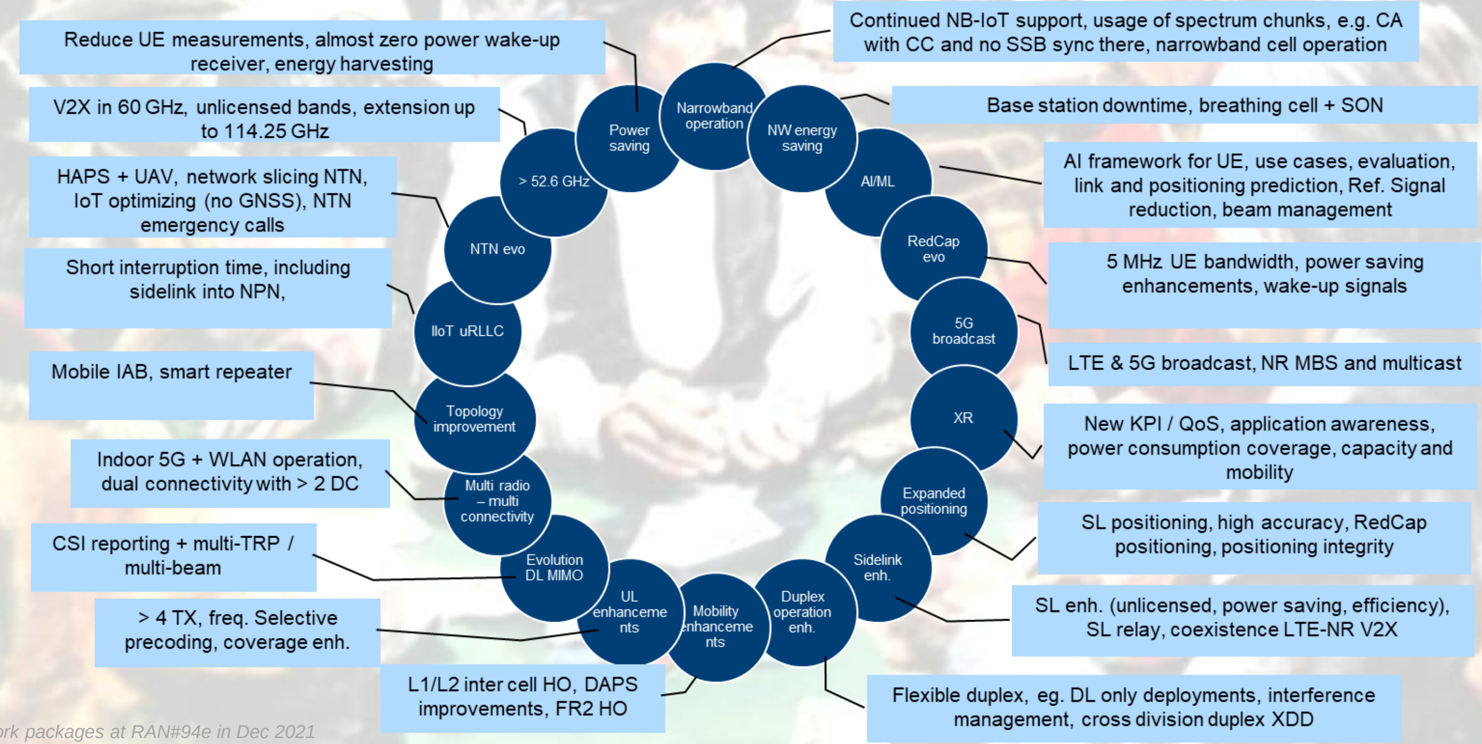
- Massive MIMO beamforming optimization
- Link adaptation optimization
- Traffic steering



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

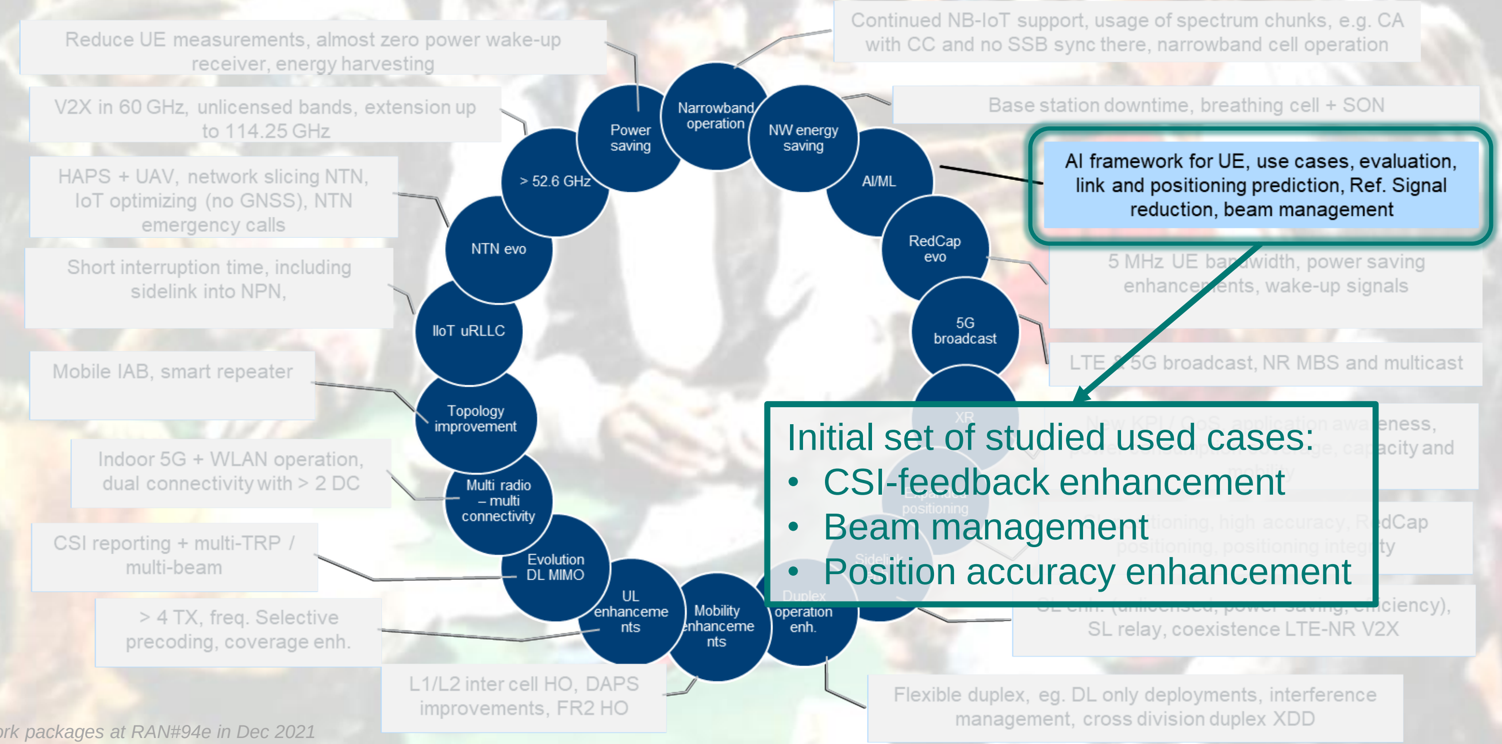
3GPP RELEASE 18
PROPOSED STUDY AND WORK ITEM'S*)



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

3GPP RELEASE 18

PROPOSED STUDY AND WORK ITEM'S*)



Initial set of studied used cases:

- CSI-feedback enhancement
- Beam management
- Position accuracy enhancement

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

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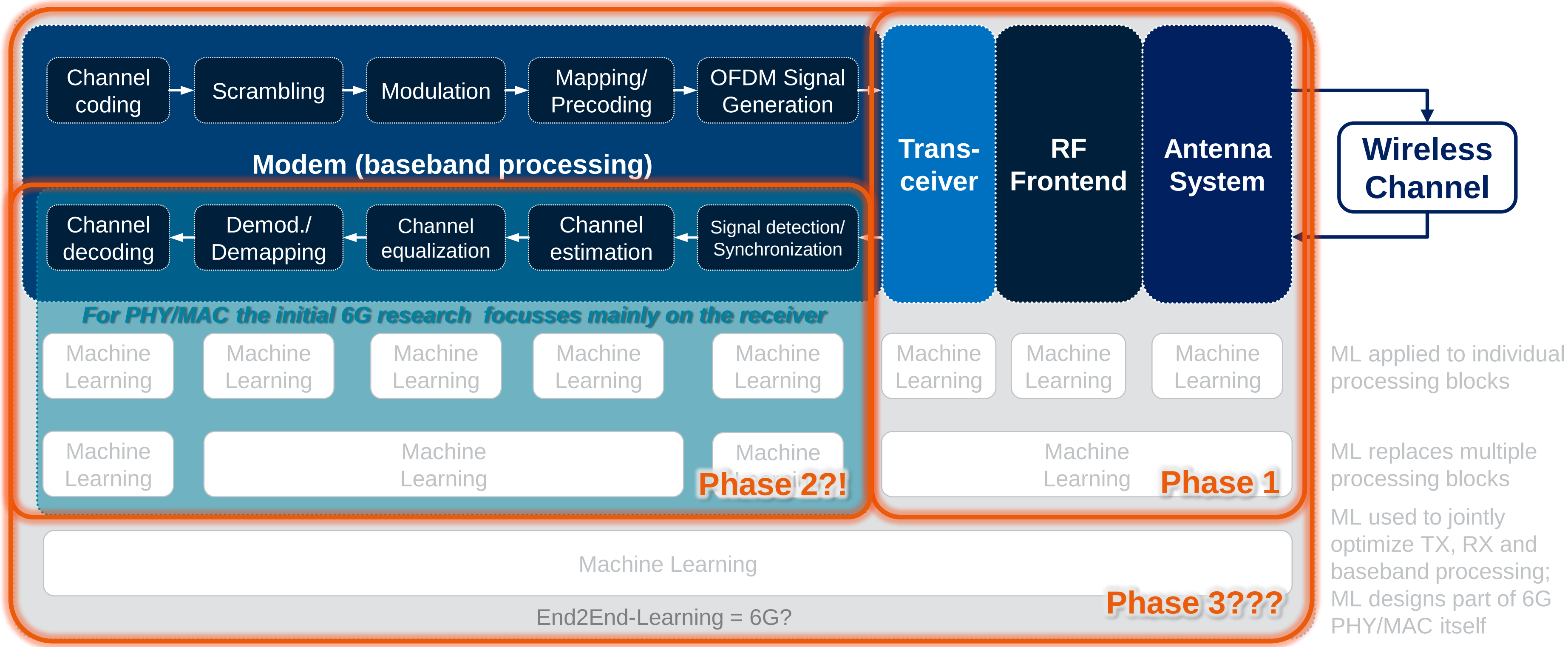
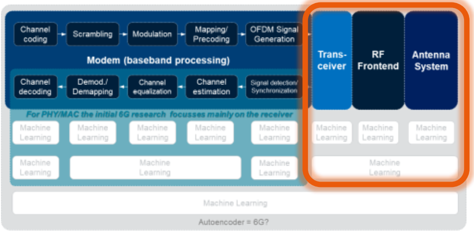
STATUS OF RESEARCH FOR AN AI-NATIVE AIR INTERFACE SUPPORT IN 6G

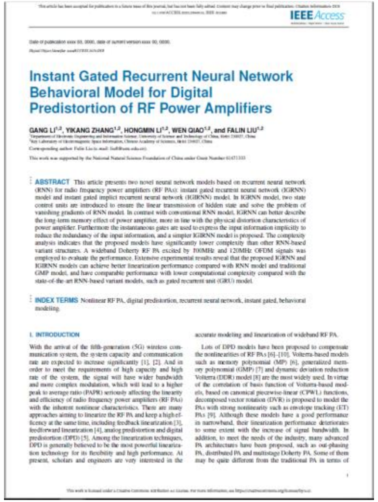
HOW TO APPLY MACHINE LEARNING FOR 6G PHY?



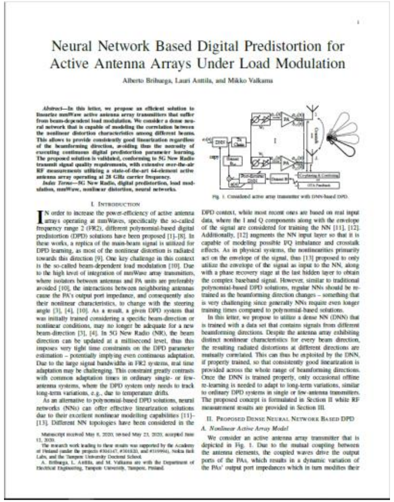
PHASE 1 FOCUSES ON RF FRONTEND AND IS NOT NECESSARILY 6G RELATED!



► 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.

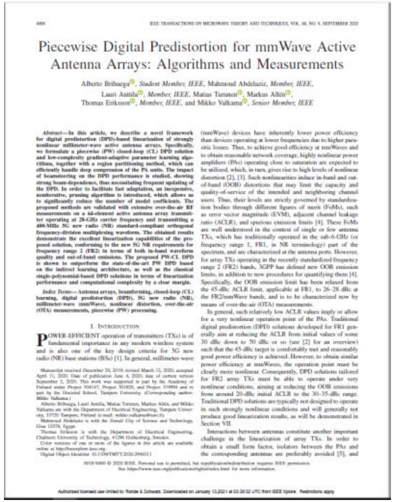

Instant Gated Recurrent Neural Network Behavioral Model for Digital Predistortion of RF Power Amplifiers

(April 2020)

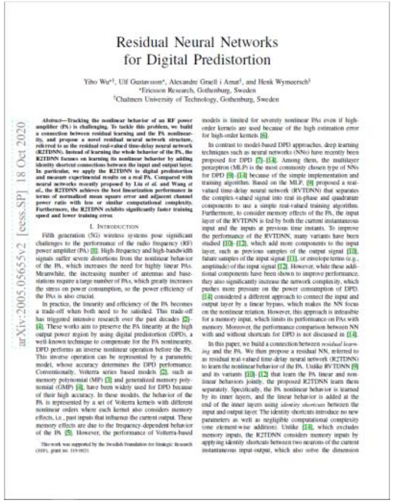

Neural Network Based Digital Predistortion for Active Antenna Arrays Under Load Modulation

Alberto Brihuega, Lauri Anttila, and Mikko Valkama

(June 2020)


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

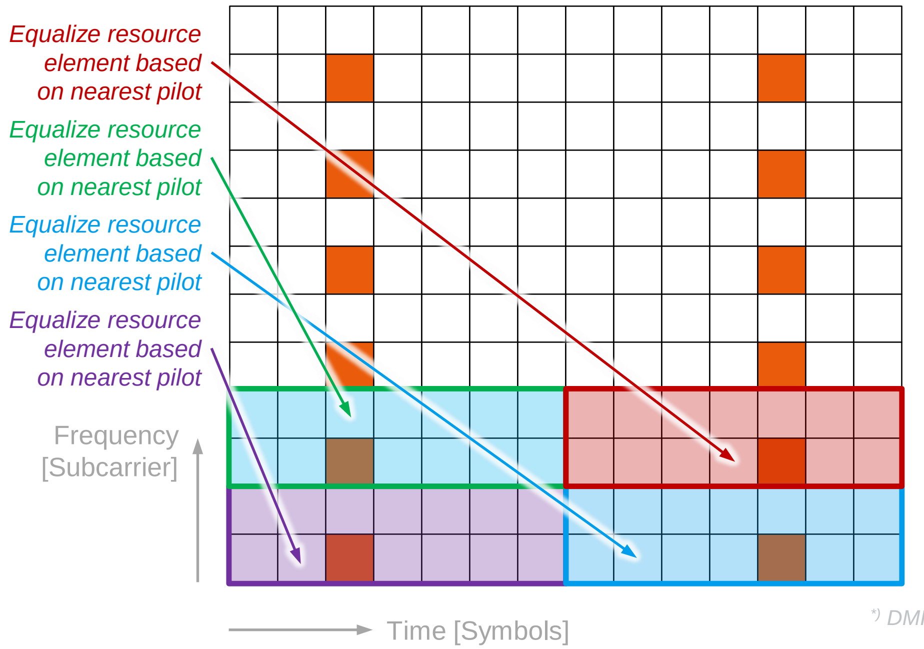
(Sep 2020)

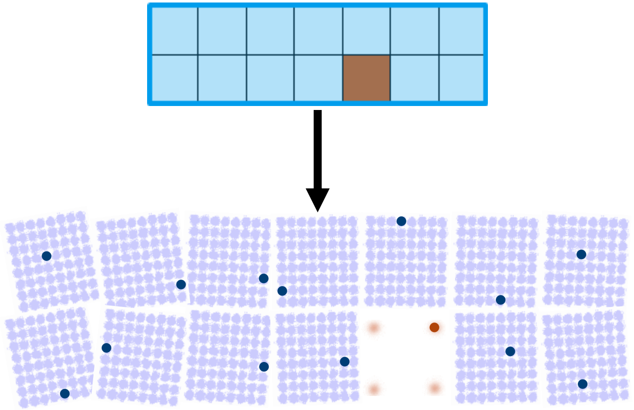

Residual Neural Networks for Digital Predistortion

(Oct 2020)

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

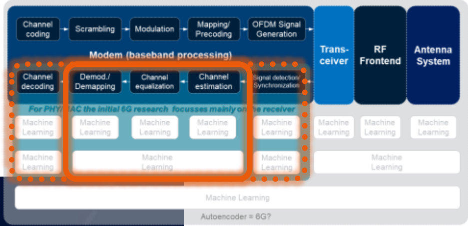


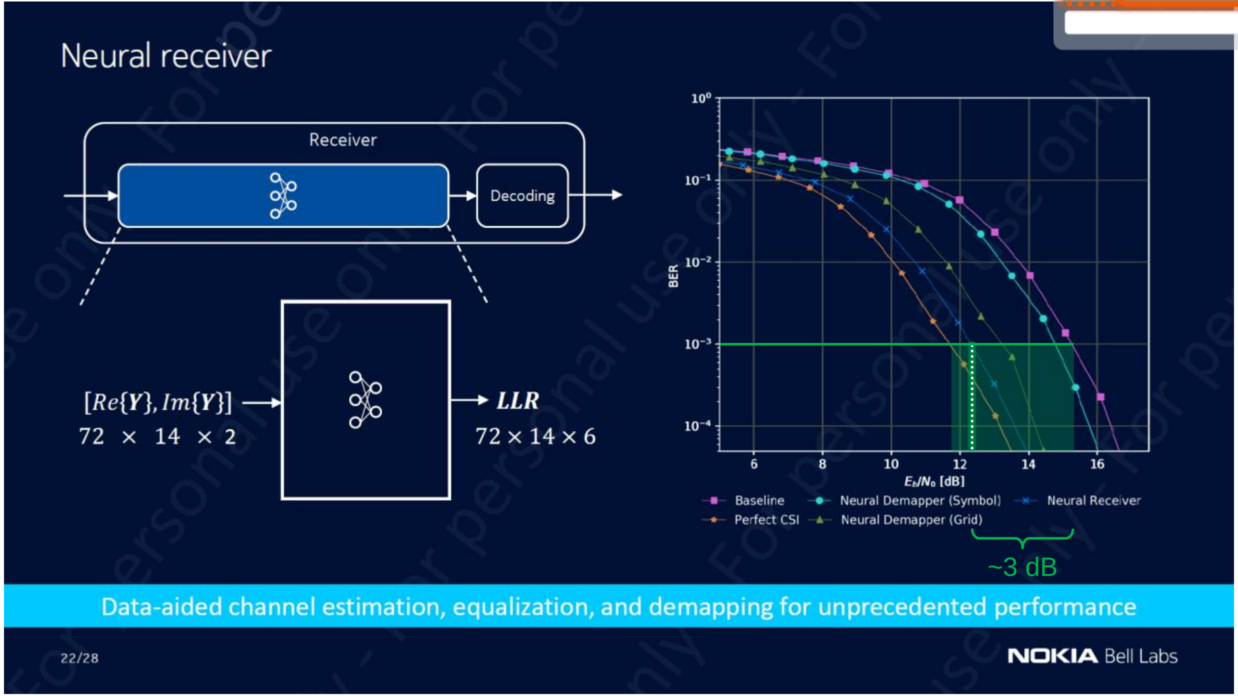


The imperfect channel estimation and channel aging leads to SNR degradation and mismatched computation and thus equalization errors → Machine Learning will help to overcome this mismatch!

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

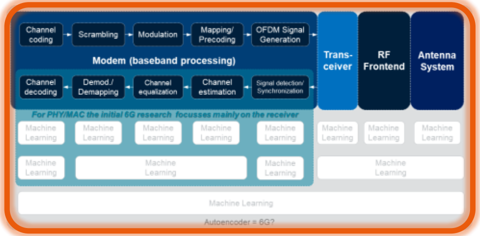
PHASE 2: APPROACHING PERFORMANCE CLOSE TO PERFECT CHANNEL KNOWLEDGE





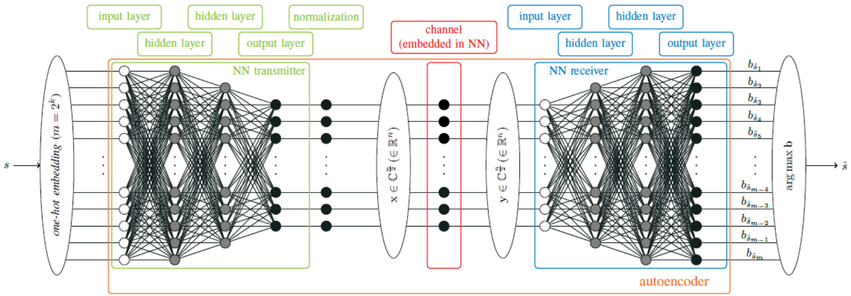
Source: https://aiforgood.itu.int/events/the-road-towards-an-ai-native-air-interface-for-6g/ [Nov 2020]

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

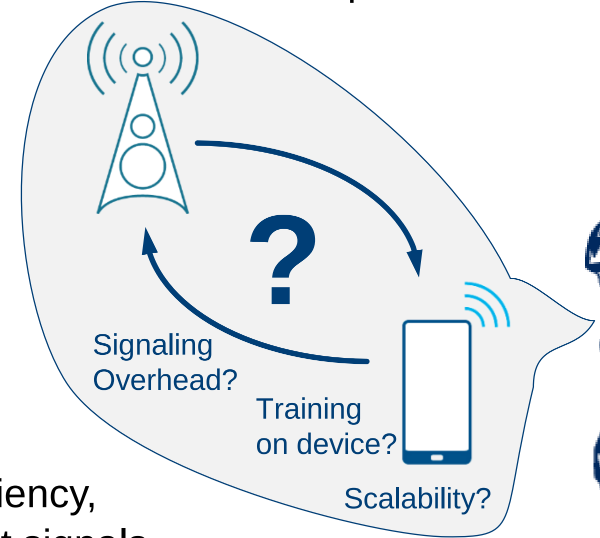


The 3rd step: The E2E-learning challenge?

► 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’?

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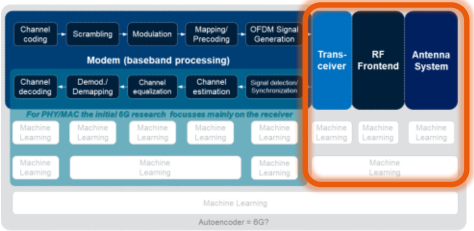
WHAT ROLE CAN TEST & MEASUREMENT SOLUTIONS PLAY IN THIS CONTEXT?

ACCOMPANY RESEARCH CHARACTERIZING RF FRONTENDS USING ML MODELS

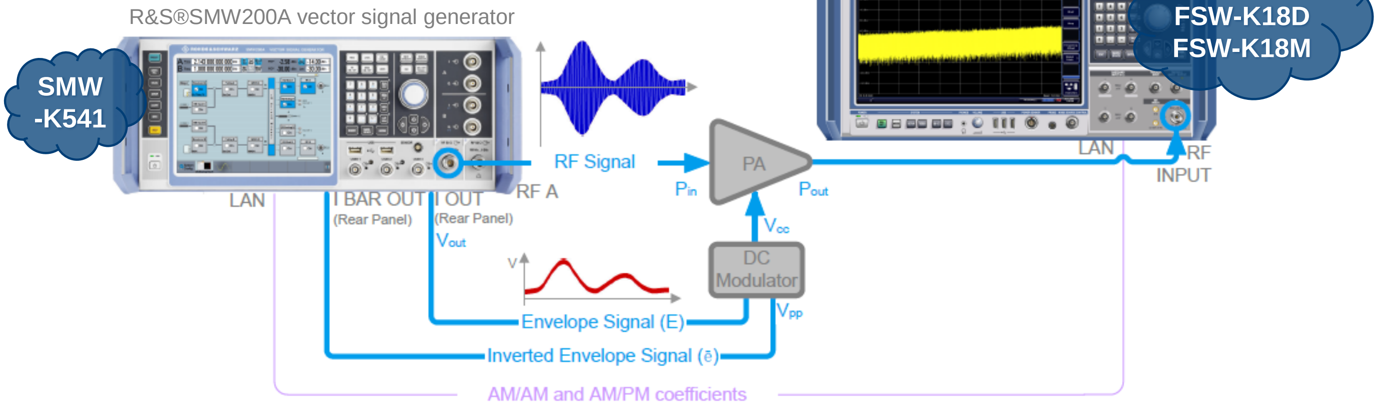


What to compare my ML-based DPD model too?

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

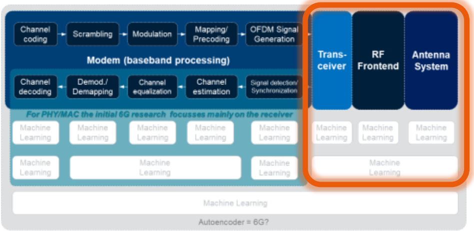
► NO! Use T&M solutions to create reference model based on classical approach using iterative method.

R&S®SFSW signal and spectrum analyzer



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 AND TRAINING PROCEDURE



1

R&S®SMW200A
Vector Signal Generator

Generate e.g. 5G NR TM1-1 for FR1[1)]

Device Under Test (DUT),
e.g. power amplifier (f_c=3 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

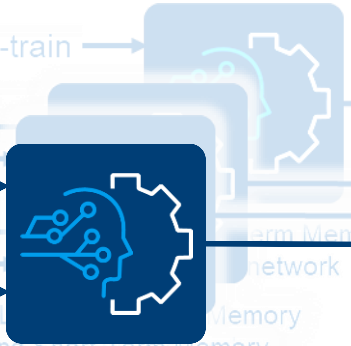
5G NR TMx-y — X-train

5G NR TM2 — X-train

5G NR TM1-2 — X-train

5G NR TM1-1 — X-train
array [i]

Iterative DPD waveform — Y-train
array [i+1]

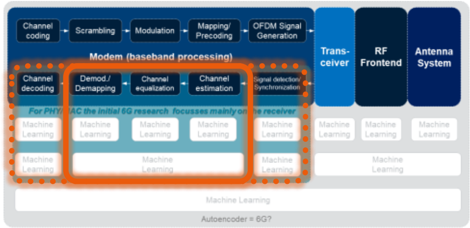


Long Short-Term Memory (LSTM) network

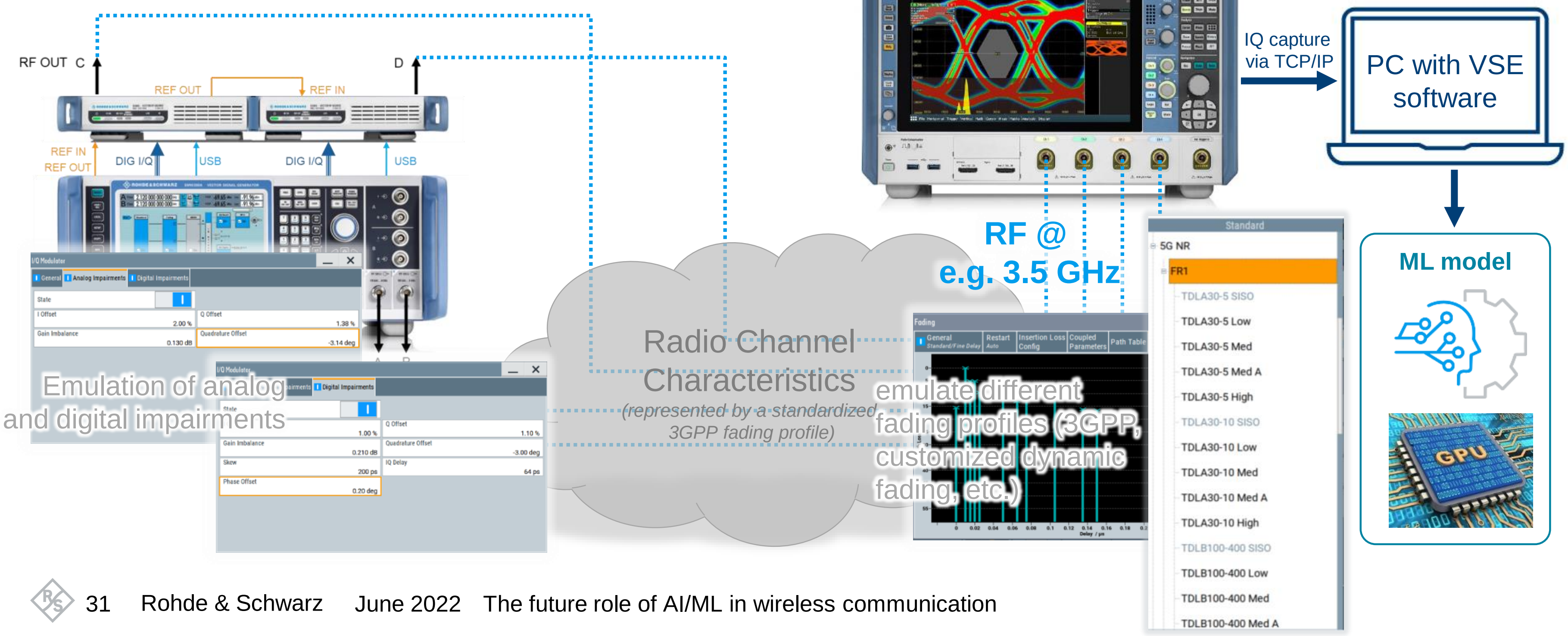
ML model with weights based on prediction

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

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

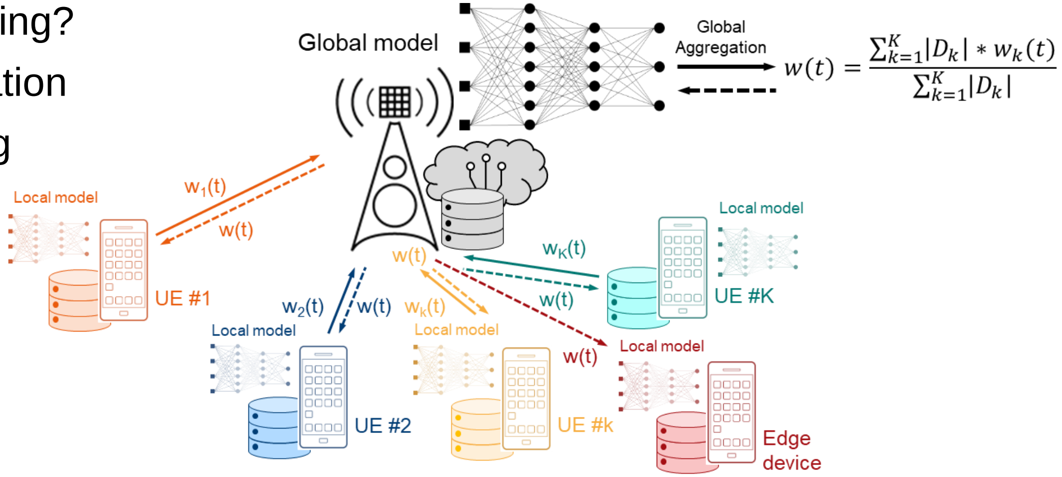
FUTURE CHALLENGES & OUTLOOK

FUTURE RESEARCH TOPICS ON MACHINE LEARNING FOR WIRELESS*)

- New waveform for new spectrum
- Learning for systems with (extreme) hardware constraints
- Joined communication + X → X = sensing?
- Signals conveying a few bits of information
- Application-specific end-to-end learning
- Semantic communications
- Decentralized & federated learning
- Transfer & meta learning

++++++++++++++++++++++++++++++++

- Can we learn the MAC protocol?
  - Channel Access Policy, Signaling ('Vocabulary', Policy)



*) According to Nokia Bell Labs

Source: Federated learning and wireless communication [May 2020]

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

TECH & CONNECT

Sonja Kupfer

Sonja.kupfer@rohde-schwarz.com

LinkedIn | Xing

Thomas Ammermann

Thomas.ammermann@rohde-schwarz.com

LinkedIn | Xing

Johanna Vordermayer

Johanna.vordermayer@rohde-schwarz.com

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have a look at our open positions

Thank you for joining

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to be informed about upcoming talks