6G-ANNA

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On the 6G Radio Access: Perspectives from the 6G-ANNA German research project

The 6G series workshop by Hexa-X-II

Torsten Dudda, Ericsson

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6G-ANNA Project - Setup

- **Program**
  - Part of German Federal Ministry of Education and Research (BMBF) 6G initiative “6G Platform”
- **Project coordinator**
  - Nokia (Marco Hoffmann, Rastin Pries)
- **Volume**
  - 38.4 m€ total budget, 27.01 m€ funding
  - 3020 PMs
  - SME percentage: 30% of industry funding
- **Timeline**
  - Start 01.07.2022 - 3 years
- **Partners**
  - *see next slide*

WP1: Sustainable and Secure Architecture & System Design (Nokia) (173 PM)

- **Use Cases & Requirements**
- **Secure e2e Architecture & System Design**
- **Sustainable 6G**

WP2: 6G Access (Ericsson) (683 PM)

2.1 Access Overview, IW & Spectrum Usage

2.2 Flexible, Secure & Harmonized PHY

2.3 RAN protocols & Cloud-based Architecture

WP3: Network of Networks (Vodafone) (885 PM)

3.1 Subnetworks

3.2 Security & Resilience

WP4: Automation & Simplification (TUBS) (787 PM)

4.1 Management & Orchestration

4.2 Digital Twinning & Extended Reality (XR)

4.3 Distributed Applications & AI

4.4 Sustainability & Trustworthiness

WP5: Testbeds & PoCs (Smart Mobile Labs) (462 PM)

- **6G Access**
- **Mobility**
- **Security & Resilience**
- **Digital Twinning**
- **Extended Reality (XR)**
- **Production**

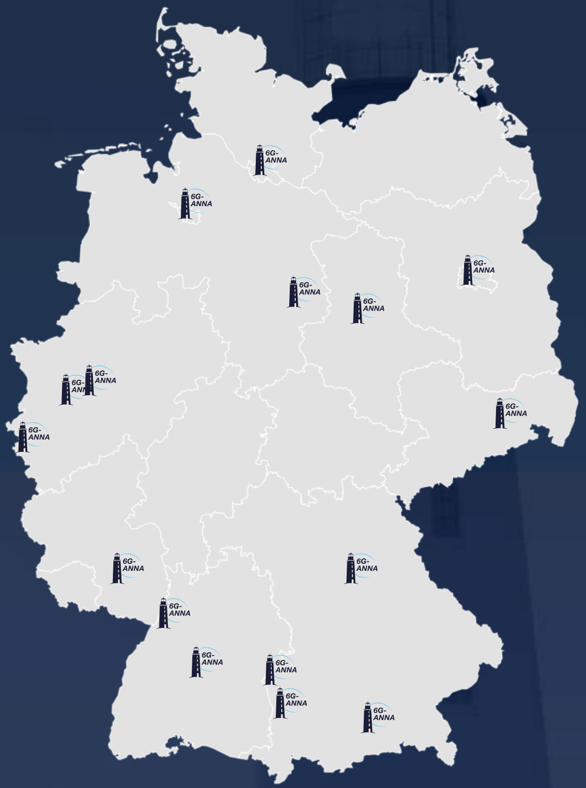
Project Partners (34)

Industry
- Nokia
- Airbus
- Bosch
- Ericsson
- Rohde & Schwarz
- Siemens
- Vodafone

SMEs
- AIN
- Blackned
- Cadami
- Meshmerize
- Mimetik
- PHYSEC
- Smart Mobile Labs
- Wandelbots

Research Institutes
- Fraunhofer AISEC
- Fraunhofer HHI
- Fraunhofer IPT

Universities
- FAU Nürnberg Erlangen
- KIT
- Ruhr-Universität Bochum
- RWTH Aachen – ICE
- RWTH Aachen – INDA
- TU Braunschweig
- TU Dortmund
- TU Dresden – MNS
- TU Dresden – ComNets
- TU Hamburg Harburg
- TU Kaiserslautern
- TU München – LKN
- TU München – LMT
- TU München – NET
- U Bremen
- U Magdeburg



Associated partners
- Airbus
- Einhell
- Mercedes-Benz
- SAP

Focus today: WP2 - 6G-Access

Task 2.1: Access Overview, Interworking & Spectrum Usage

- *Breakdown of use-case requirements for the 6G access with input from relevant projects, e.g., BMBF-6G-Hubs, Hexa-X*
- *Evaluation of 6G spectrum options and migration solutions towards 6G*

Task 2.2: Flexible, Secure & Harmonized PHY

- *Concepts for physical layer design, including programmability and inclusion of AI*
- *Development of next-generation distributed MIMO solutions*
- *Integration of concepts for physical layer security*

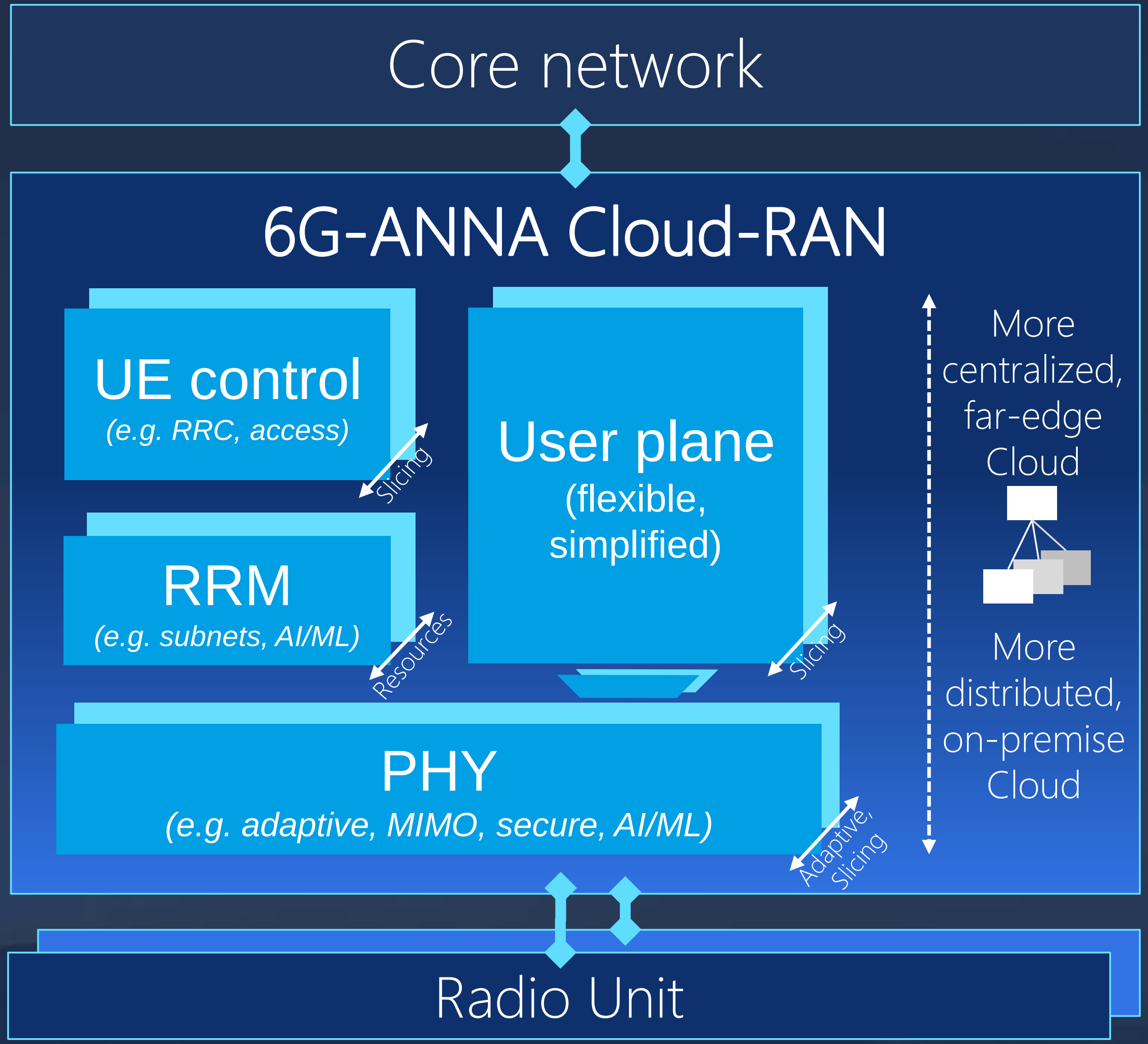
Task 2.3: RAN Protocols & Cloud-Based Architecture

- *Concepts for RAN protocol design, user-/control plane and mobility*
- *Development and evaluation of concepts for AI into radio resource management aspects*
- *Development of solutions for RAN virtualization and Cloud RAN.*

6G Access

- *Energy-efficient*
- *Flexible*
- *Reliable*
- *Secure*

6G-ANNA Cloud-RAN vision



*RRM: radio resource management
*RRC: radio resource control
*PHY: physical layer

[1] M. Hoffmann et al., "A Secure and Resilient 6G Architecture Vision of the German Flagship Project 6G-ANNA," in IEEE Access, vol. 11, pp. 102643-102660, 2023, doi: 10.1109/ACCESS.2023.3313505.

6G PHY fundamentals - Evolutionary and revolutionary aspects

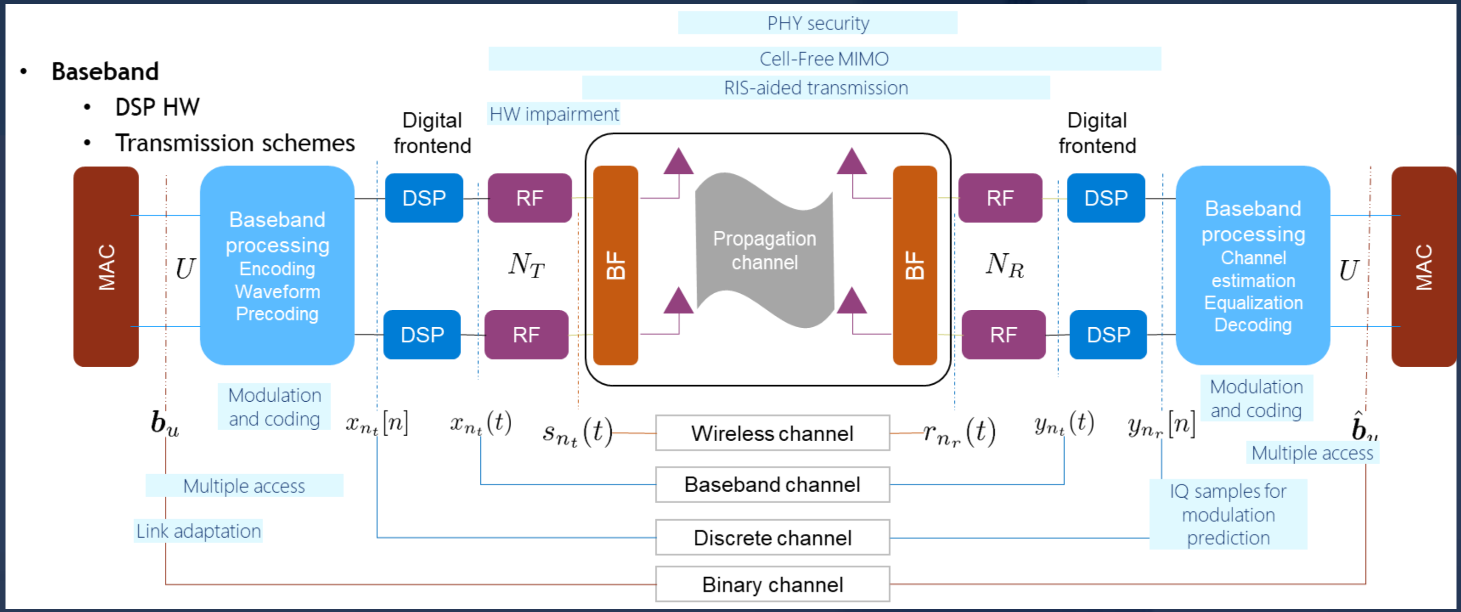
Fundamentals

- 6G will support 5G use-cases like eMBB and many new ones.
- 6G will utilize spectrum available between 450 MHz and sub-THz, including 5G spectrum.
- Evolutionary aspects of 6G comprise mature 5G features, like OFDM as the baseline waveform.

- Revolutionary of 6G are expected new breakthroughs and special designs, e.g. for
  - Scalable support for e.g. Mobile XR devices
  - AI/ML techniques for the physical layer
  - Advances in MIMO e.g. distributed
  - Specialized waveforms and protocols, for sub-THz, joint communications and sensing, zero energy devices, or wake-up radios.

Adaptiveness

- Is required for considering both spectral and energy efficiency, optimally for a given situation.
- Different radio options may be chosen, as considered in the gearbox PHY approach [2].



[2] G. P. Fettweis and H. Boche, "6G: The Personal Tactile Internet—And Open Questions for Information Theory," in IEEE BITS the Information Theory Magazine, vol. 1, no. 1, pp. 71-82, 1 Sept. 2021, doi: 10.1109/MBITS.2021.3118662.

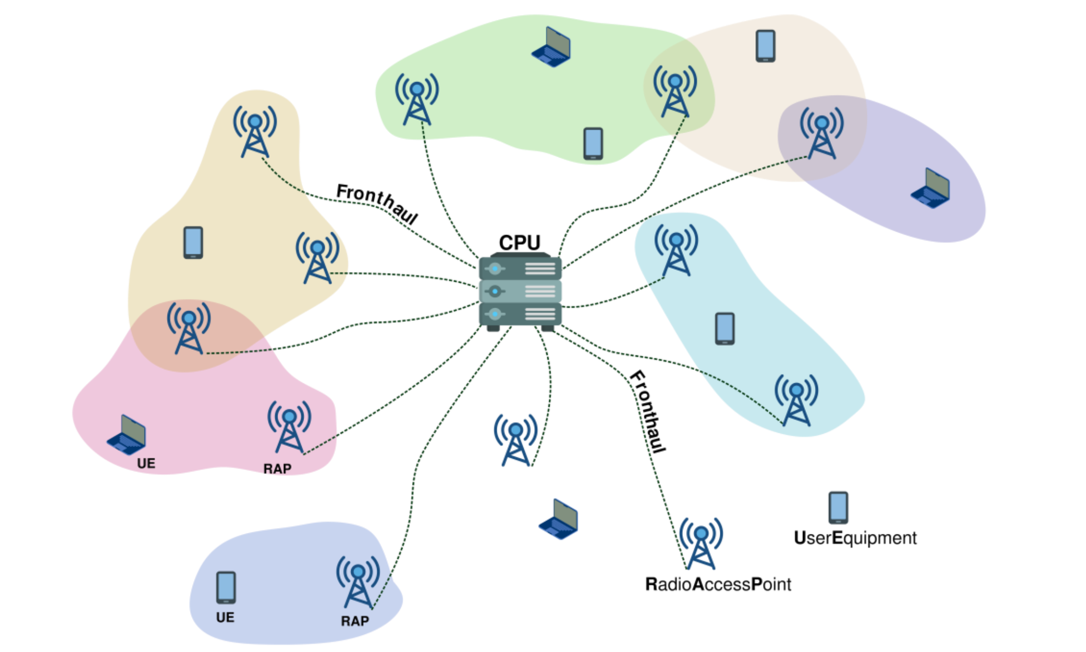
6G PHY - Distributed MIMO & very large arrays

Cell free Massive MIMO

- User centricity, for meeting high-capacity demands.
- Analyzing tradeoffs between centralized and distributed architectures regarding scalability
- Developing algorithms for beamforming, power control (transmit + hardware), and requirements and limitations of the fronthaul and computational complexity [3]

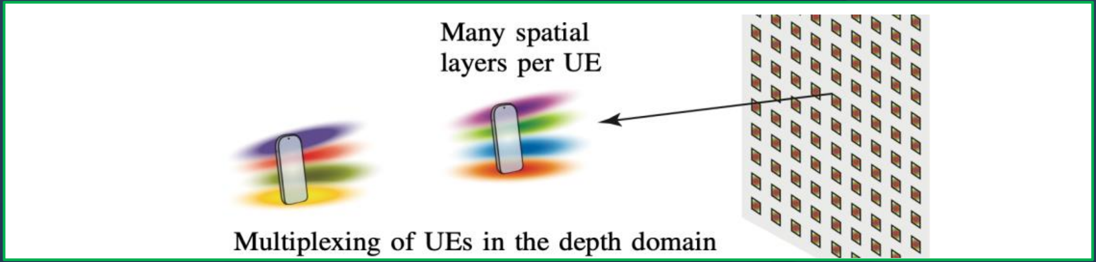
Very large aperture arrays

- As enhancement of MIMO technologies: Very large aperture massive arrays in low and high bands [4]
- Potential advantages include MU-MIMO along the depth dimension and SU-MIMO for LoS channels
- Our objective: understand the propagation characteristics specific to near-field
- Developing transmitter algorithms for near-field UEs and quantify the potential spatial multiplexing gains using realistic hardware models



User-Centric Cell-Free Massive MIMO

[3] L. Miretti, R. L. Cavalcante, S. Stańczak, "Fixed-point methods for long-term power control and beamforming design in large-scale MIMO", submitted to IEEE JSAC.

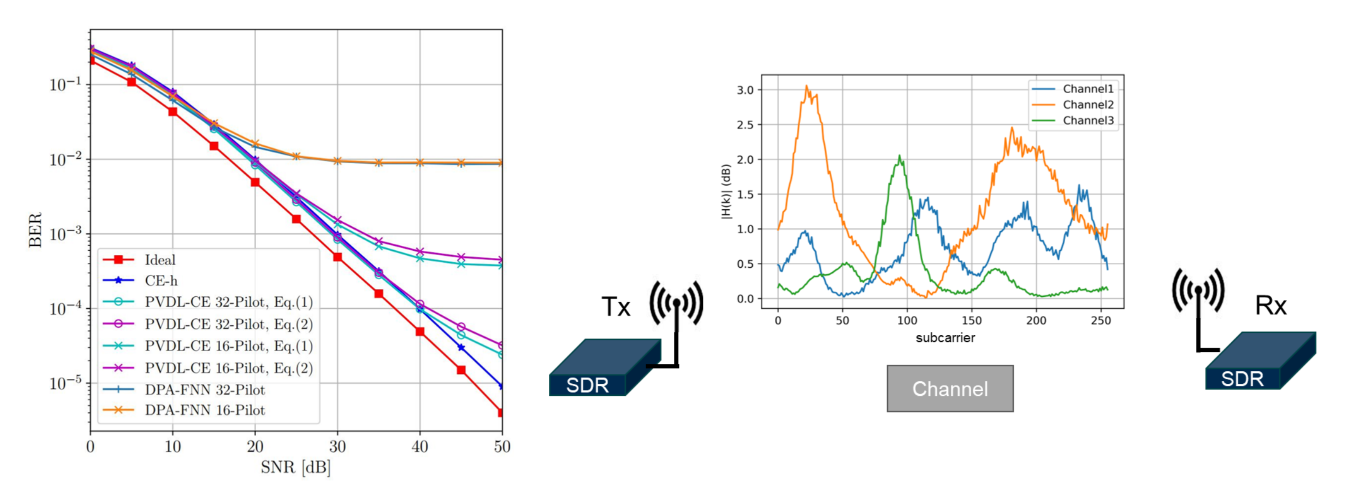


[4] Björnson, E., Chae, C. B., Heath Jr, R. W., Marzetta, T. L., Mezghani, A., Sanguinetti, L., ... & Demir, Ö. T. (2024). Towards 6G MIMO: Massive Spatial Multiplexing, Dense Arrays, and Interplay Between Electromagnetics and Processing. arXiv preprint arXiv:2401.02844.

6G PHY - Integration of AI in PHY for communication

Neural networks in the PHY receiver [5]

- AI integration into physical layer, i.e., DNN for channel estimation, where performance gains are analyzed.
- Analyzing the tradeoffs: performance, system complexity, generalization possibility, e.g. to MIMO scenario [6]

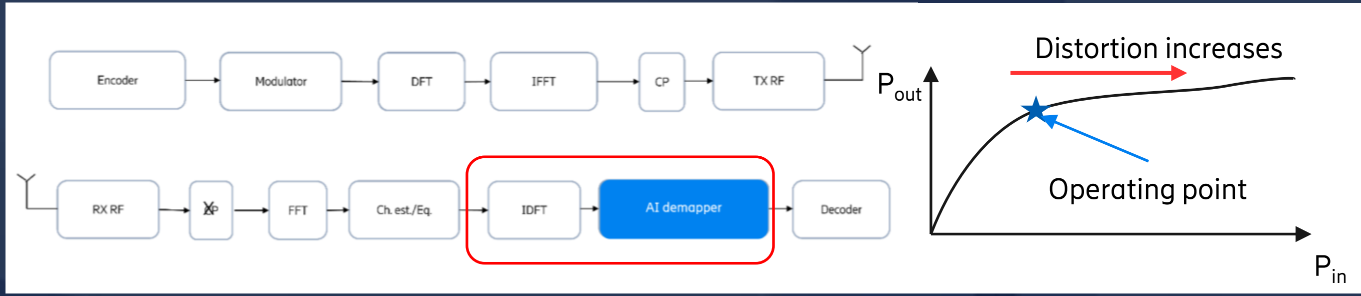


[5] S. Cammerer et al., "A Neural Receiver for 5G NR Multi-user MIMO", presented at IEEE Globecom 2023, https://arxiv.org/abs/2312.02601

[6] S. Joodaki, K. Turbic, A. Sezgin and H. Gacanin, "Deep Learning-based Channel Estimation in High-Speed Wireless Systems With Imperfect Frame Synchronization," 2023 IEEE 34th Annual International Symposium on Personal, PIMRC, Toronto, ON, Canada, 2023.

AI in power amplifier (PA) digital post-distortion

- Desired to operate PA for max output power & energy efficiency → non-linearities → signal distortions
- Instead to mitigate in transmitter, e.g. UE in uplink, move complexity to the network → allow distortion at the transmitter and compensate at the receiver
- AI/ML to enhance receiver to learn and compensate non-linear distortions [7]
- Our objective: quantify performance gains & required complexity



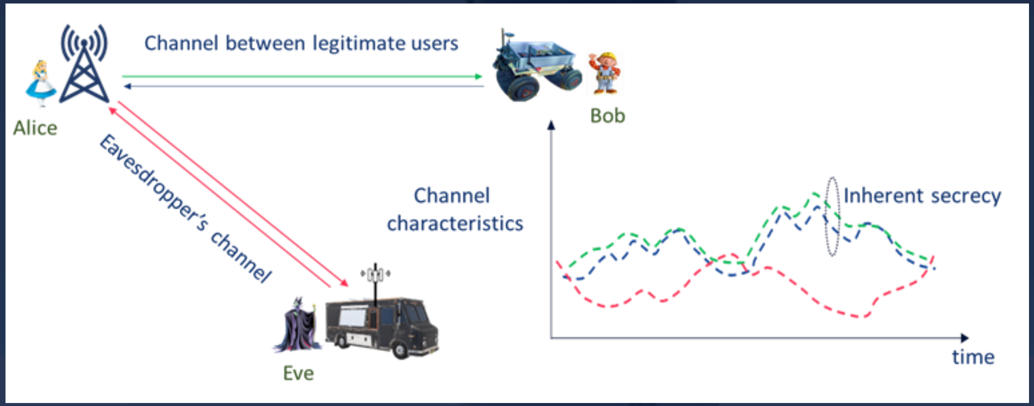
[7] H. Farhadi, J. Haraldson and M. Sundberg, "A Deep Learning Receiver for Non-Linear Transmitter," in IEEE Access, vol. 11, pp. 2796-2803, 2023, doi: 10.1109/ACCESS.2023.3234501.

6G PHY – Complementary security from physical layer

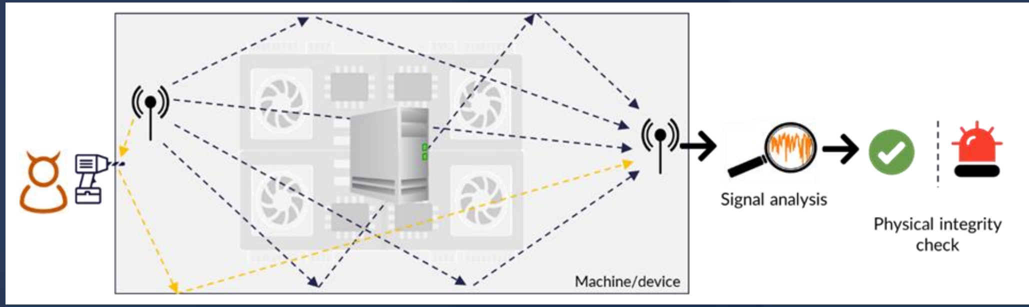
PHY layer security aspects

- Traditionally security technologies primarily at higher layers, cryptography-based methods
  - Challenges by spoofing, jamming, eavesdropping
- PHY security to complement traditional security protocols

- The objectives of the project are to analyze performance for:
  - Security by utilizing wireless channel properties, e.g. by improving the secrecy performance of the channel by use of reconfigurable intelligent surfaces (RIS) [8]
  - Ensuring hardware integrity, “anti-tamper radio” [9]
  - Authentication methods e.g. for campus networks [10]
  - For URLLC low-latency requirements (finite blocklengths) [11]



[8] C. Li, A. Sezgin, IRS-Assistance with Outdated CSI: Element subset selection for secrecy performance enhancement. arXiv preprint arXiv:2211.08777 (accepted for ICC 2023).



[9] Staat, P., Tobisch, J., Zenger, C., & Paar, C., Anti-Tamper Radio: System-Level Tamper Detection for Computing Systems. In 2022 IEEE Symposium on Security and Privacy (SP), May 2022
[10] Bin Han, Yao Zhu, Anke Schmeink, and Hans D. Schotten, “Non-Orthogonal Multiplexing in the FBL Regime Enhances Physical Layer Security with Deception,” SPAWC 2023.
[11] Y. Zhu, X. Yuan, Y. Hu, R. F. Schaefer and A. Schmeink, "Trade Reliability for Security: Leakage-Failure Probability Minimization for Machine-Type Communications in URLLC," in IEEE Journal on Selected Areas in Communications, vol. 41, no. 7, pp. 2123-2137, July 2023

6G protocols - Simplification of the user plane stack

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Simplification

- The overall objective is to simplify the protocol stack compared to 5G NR [12]
- Lower operating costs while maintaining flexibility for the diverse QoS of 6G use cases
- Enable pre-processing of incoming packets & effective "online" processing when scheduled.

Key functions of radio protocols

- Security over the air → optimize for pre-processing
- Adaptation packets to frames → speed up segmentation/concatenation
- Retransmissions → revisit current split among 3 layers: HARQ, RLC, PDCP
- Active queue management → speed up indication of congestion (ECN/L4S)
- Re-ordering → optimize for shorter round-trip times
- QoS handling → for 6G use-cases with varying requirements, e.g. XR traffic flows

Pre-processing of incoming packets

PDCP
- Security
- Header compression
- Handover anchoring

Fast "online" processing when scheduled

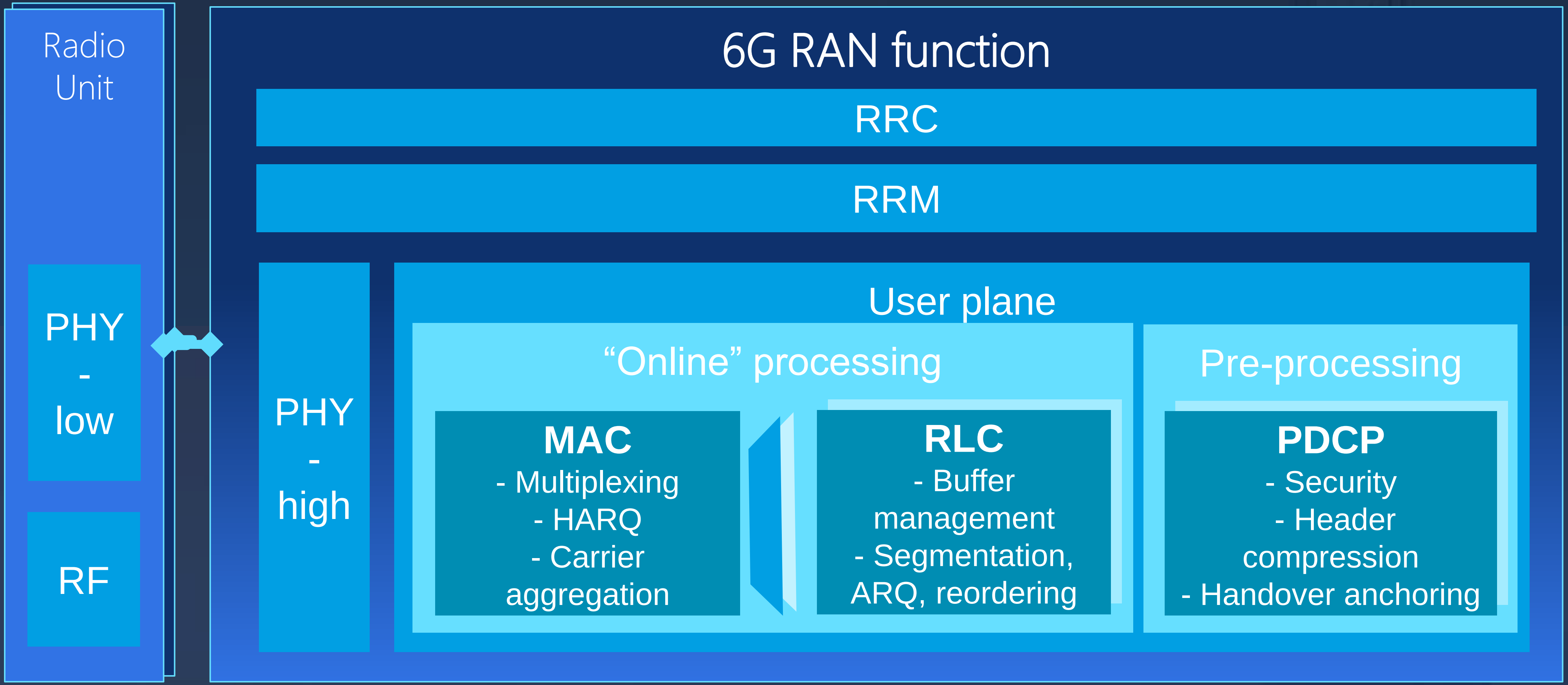
RLC
- Buffer management
- Segmentation, ARQ, reordering

MAC
- Multiplexing
- HARQ
- Carrier aggregation

[12] M. Abad, M. Kuehlewind, T. Dudda, Retransmissions and Reordering in 6G User Plane Protocols" presented at European Wireless, Oct, 2023

HARQ: hybrid ARQ
MAC: Medium access control
RLC: Radio link control
PDCP: packet data convergence protocol

6G ANNA – RAN functional architecture & protocol features



ARQ: automated repeat request
HARQ: hybrid ARQ
MAC: Medium access control
RLC: Radio link control
PDCP: packet data convergence protocol
RF: radio frequency

6G RRM – Interference management for sub-networks

Sub-networks

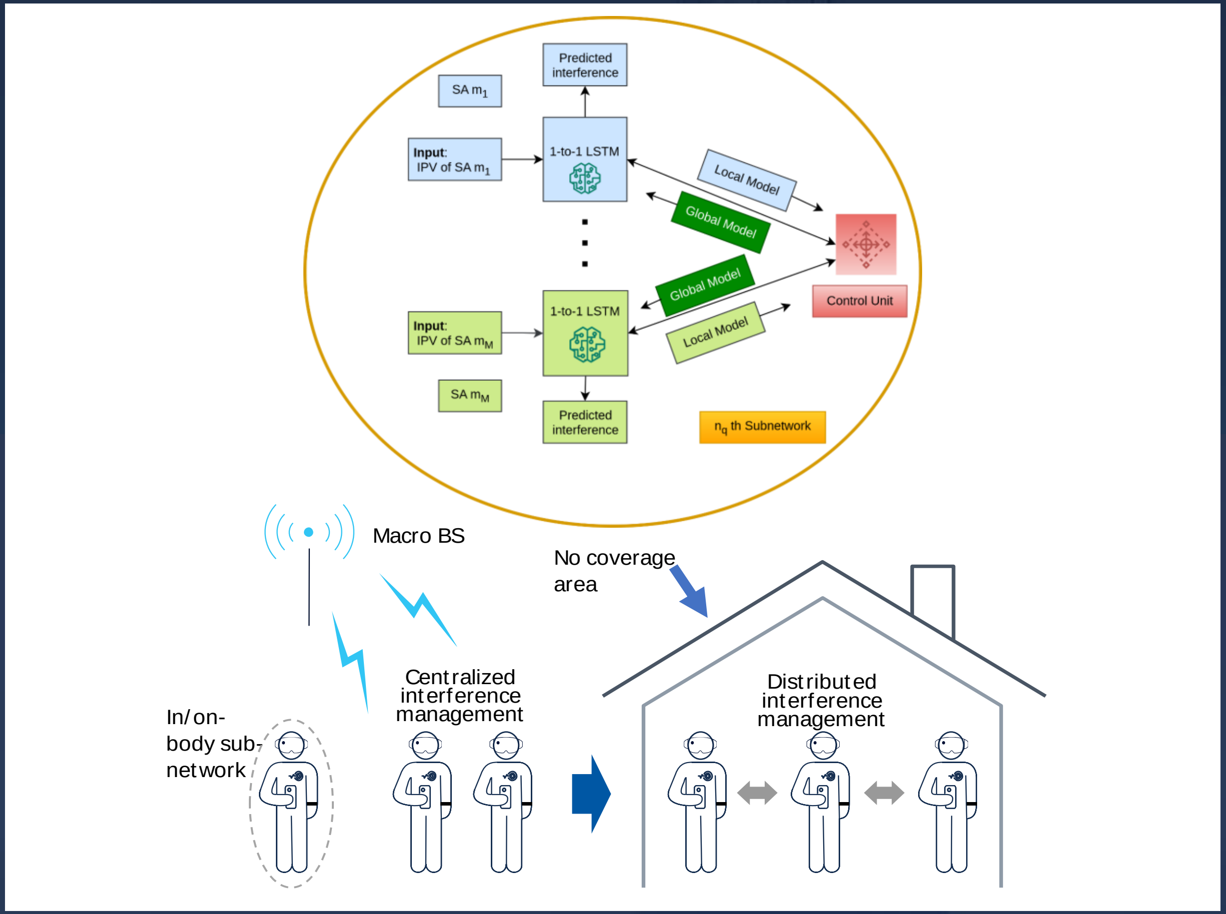
- Sub-networks: short range mobile cells supporting extreme heterogeneous requirements, e.g. low latency for in-factory and in-vehicle use cases [13]

Interference management

- Challenged by mobility of sub-networks, wireless channel uncertainties, ultra-dense deployments, low-latency demand
- Solutions foreseen in the frequency domain, algorithms to divide into and select appropriate sub-band
  - Distributed, hybrid, centralized approaches

Interference estimation

- Data-driven methods, e.g., machine learning
- Long short-term memory (LSTM) & federated learning [14]



[13] G. Berardinelli et al., "Extreme communication in 6G: Vision and challenges for 'in-X' subnetworks," IEEE Open Journal of the Communications Society, vol. 2, pp. 2516–2535, 2021.

[14] P. Gautam et al., "Cooperative Interference Estimation using LSTM-based Federated Learning for In-X Subnetworks," in Proc. IEEE GLOBECOM 2023, Kuala Lumpur, Malaysia,2023, pp. 1–7.

6G RRM – further aspects

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Non-orthogonal multiple access (NOMA)

- Tackled tradeoff between massive connectivity & edge compute demands with low latency while ensuring energy efficiency [15]

Contention-based uplink access

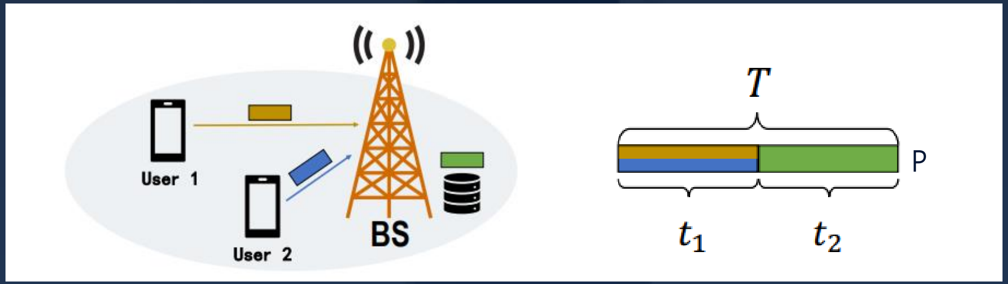
- 5G considers dynamic grants based on request, as well as pre-configured grants
- Contention-based access, in conjunction with switch-over to dynamic scheduling enable fast initial access & efficient scheduling of subsequent data

Enrichment information

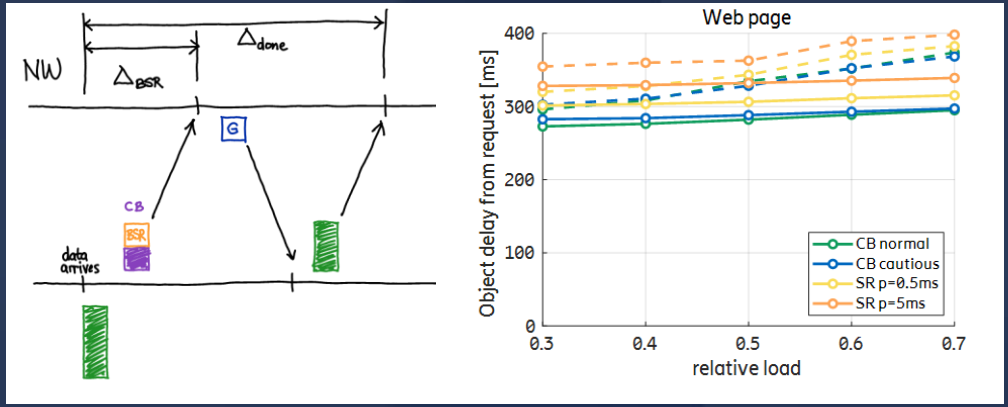
- 6G RRM may consider enrichment info to optimize, e.g. comprehensive system knowledge, like spatial characteristics (e.g. continuously monitored)

Integration of AI

- ML-based RRM (centralized, distributed, federated). Example: resource and power allocation in a V2X scenario, to lessen required signaling [16]



[15] H. Xu, Y. Zhu, K. Xiang, Y. Hu and A. Schmeink, "Energy Consumption Minimization for NOMA-Assisted Mobile Edge Computing," 2022 International Symposium on Wireless Communication Systems (ISWCS), Hangzhou, China, 2022, pp. 1-6



[16] M. Parvini, A. Gonzalez, A. Villamil, P. Schulz and G. Fettweis, "Joint Resource Allocation and String-Stable CACC Design with Multi-Agent Reinforcement Learning," in Proceedings of 2023 International Conference on Communications (ICC 2023), Rome, Italy, May 2023.

Conclusion

6G-ANNA: The German 6G lighthouse project

- 6G Radio Access (WP2)
  - Flexible & secure PHY
  - Simplified RAN protocols & Cloud-RAN architecture
  - Highly-performant RRM

- Contact: Torsten Dudda

- Further info?
  - Project publication

    M. Hoffmann et al., "A Secure and Resilient 6G Architecture Vision of the German Flagship Project 6G-ANNA," in IEEE Access, vol. 11, 2023

  - https://6g-anna.de/

Thank You!