Cognitive Autonomy and Digital Twin – Role in 5G evolution and beyond

Satish Kanugovi (satish.k@nokia.com)

Head of Standardization APAC,

Strategy and Technology Unit, Nokia

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Defining the terms

Autonomy

Able to act on its own

Cognition

Reason and recommend future behavior

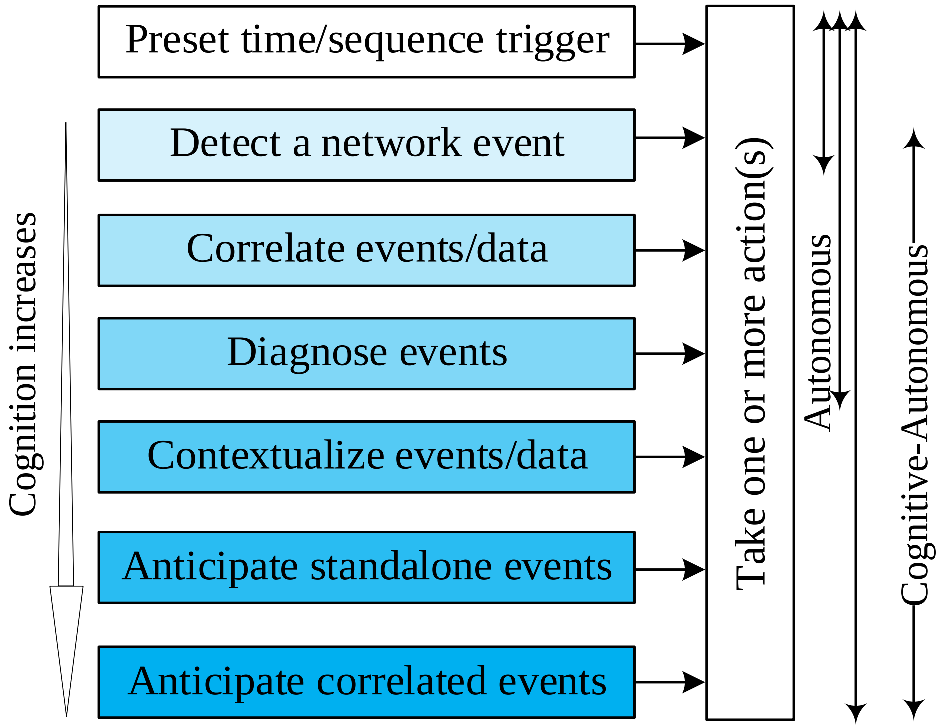
Self Organizing

Steady state without external control

Cognitive Autonomous Networking

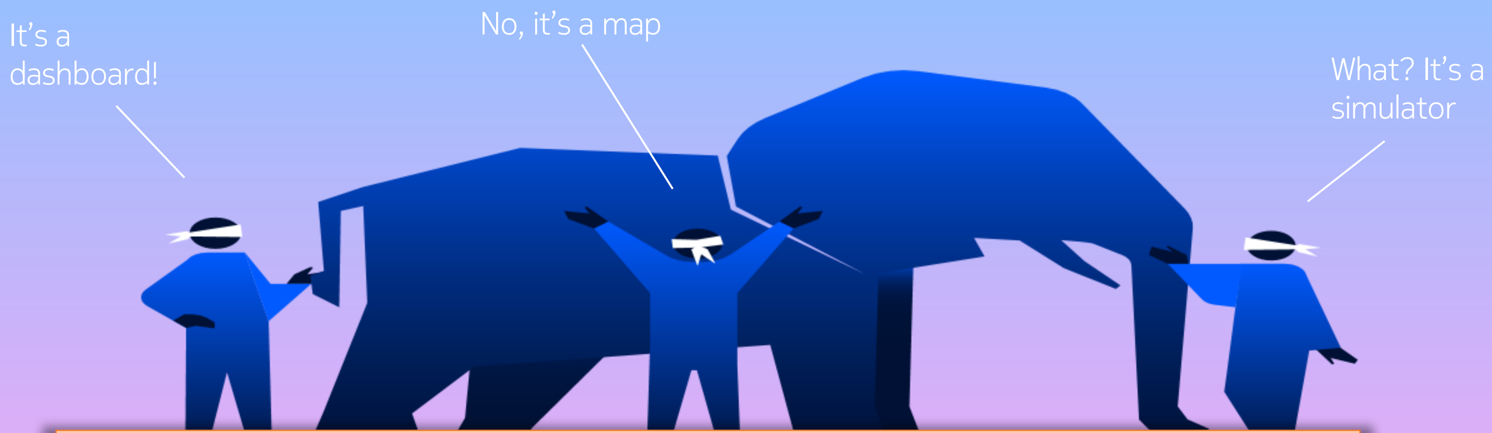
AI powered Network Automation

- Understand system concepts and contexts to enable decision making at machine level
- Actions can be taken at any step in the cognitive process
- Both are essential – Together they CAN (Cognitive Autonomous Networks)
- Key role for CAN in 5G and beyond communication networks



What is a Digital Twin?

At what point does a dashboard, map, simulator, become a digital twin?



<u>The "sorites paradox"</u>

At what point do grains of sand become a heap?

"grains"

"heap"

At what point is a heap just some grains of sand?

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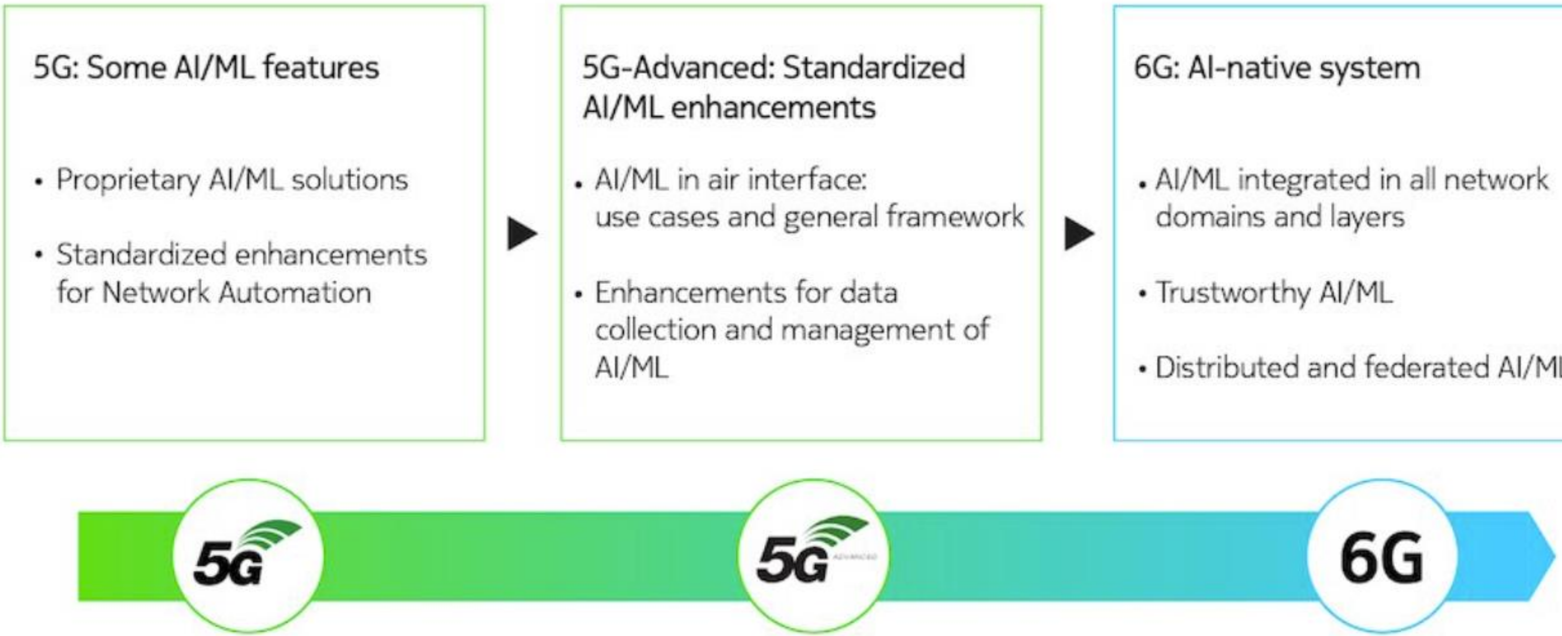
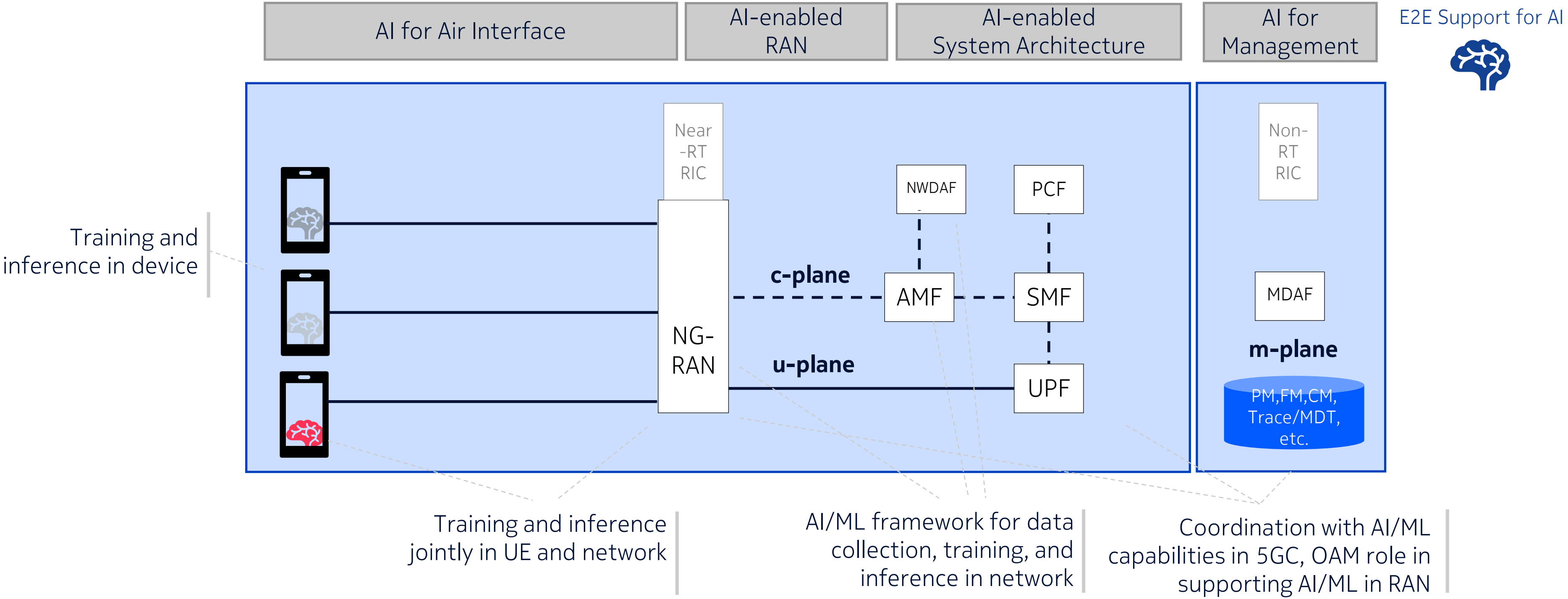
Building AI into networks

Towards an AI native network

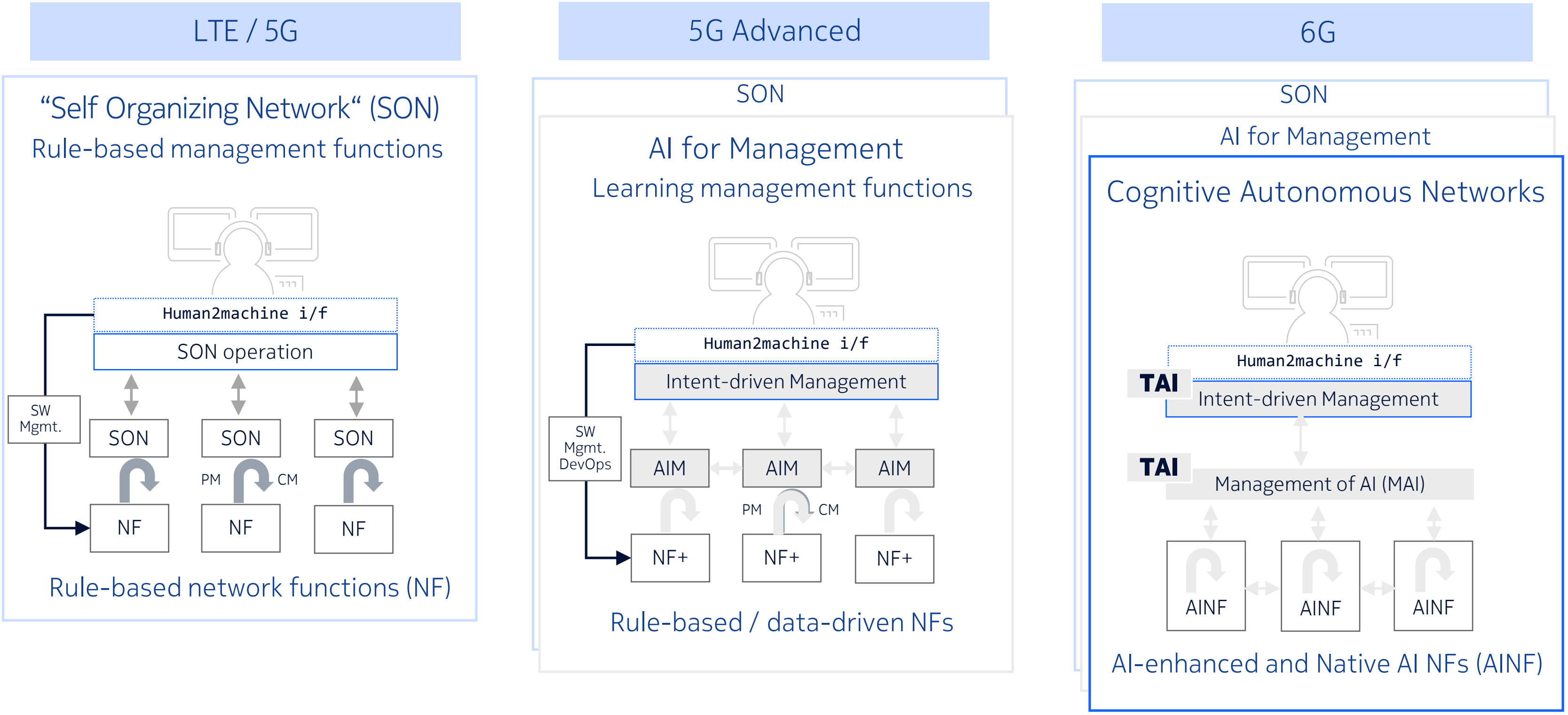


5G-Advanced: stepping stone - Framework for AI/ML in network

AI/ML techniques will be enabled in all parts of the system



.. Evolving to CAN in 6G



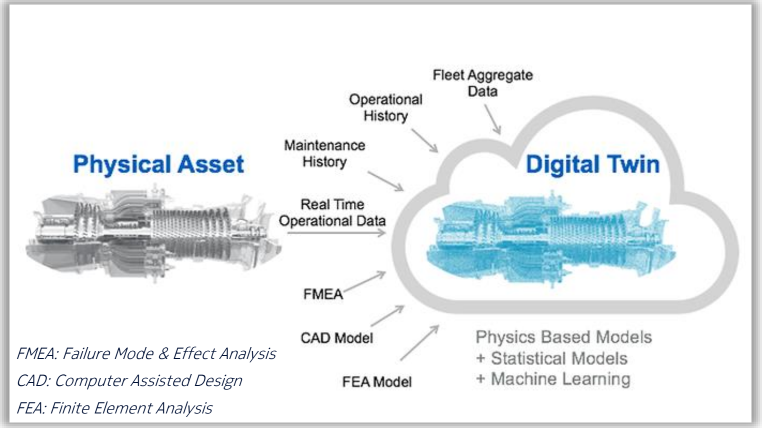
AIM: AI-enabled Network Management

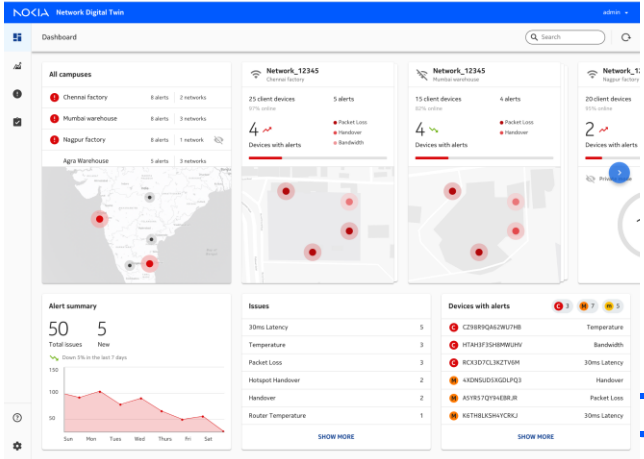
TAI: Trustworthy AI

Leveraging the Digital Twin

https://commons.wikimedia.org/wiki/File:Oil_rig_Jan_23.jpg

Image credit: Entso-E
https://www.entsoe.eu/Technopedia/techsheets/digital-twin





Visualize, Model, Track, Predict

- CAN with DT do better?
  - Predict and evaluate impact of changes in the physical environment
  - Predict and evaluate impact of current and recommended network configurations

Use case:

Predictive Location-Aware Network Automation for Radio (PLANAR)

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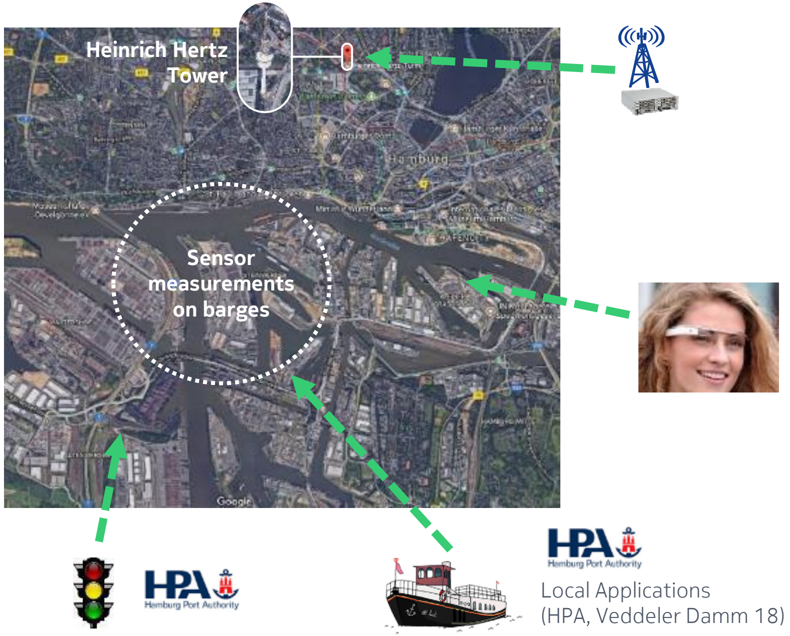
The 5G network slicing testbed at Hamburg Harbor

A live testbed demonstrating 5G slicing at the Hamburg Harbor:

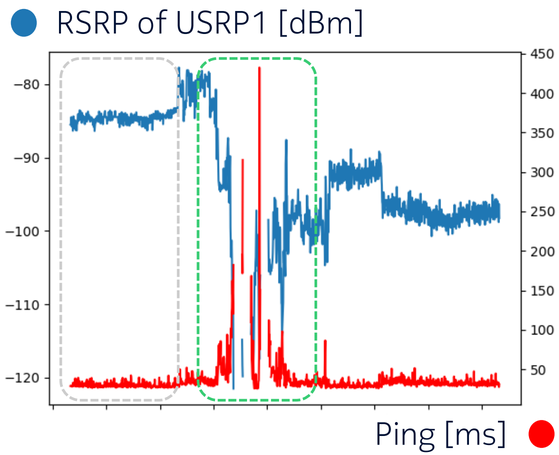
- Three slices
    - eMBB: Local applications in the harbor
    - URLLC: Traffic light control
    - **IoT: Emission sensor readings from barges**

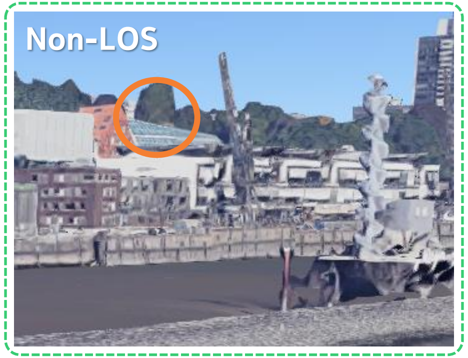
- Data collection
    - **Slice-specific BTS KPIs**: PRB usage, throughput, latency etc.
    - **UE measurements** from up to three ships including position (by GPS), RSRP, RSRQ, ping etc.
    - Collected for 6 months every 5 seconds
      ~3M records



Problem statement

- IoT requires high reliability
- In certain areas of the testbed, coverage and mobility issues are observed in the IoT slice
  - Shadowing effects and/or
  - Long distances from the base station
- Reliable service must be guaranteed, but without overprovisioning of resources or compromising the performance of the other slices





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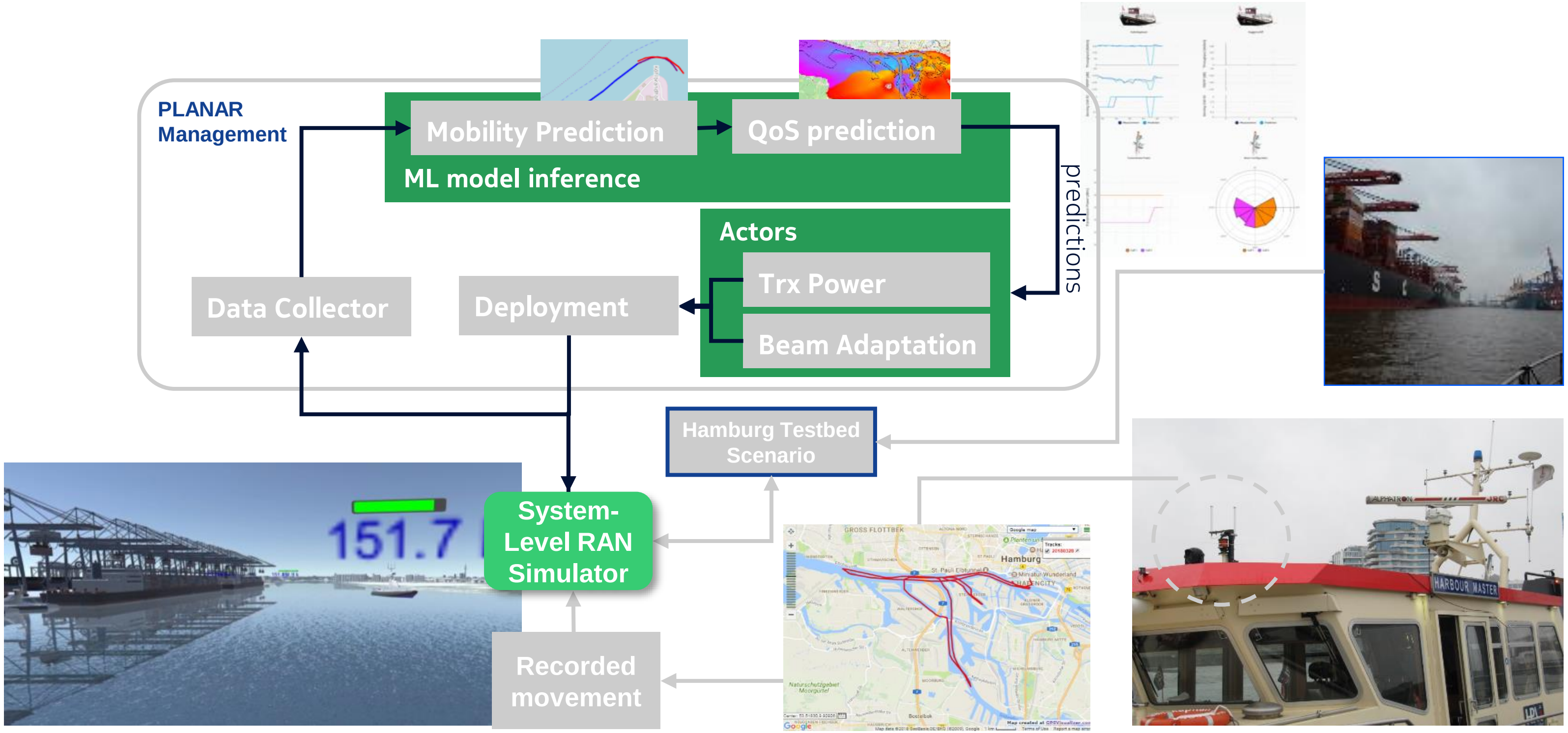
System setup

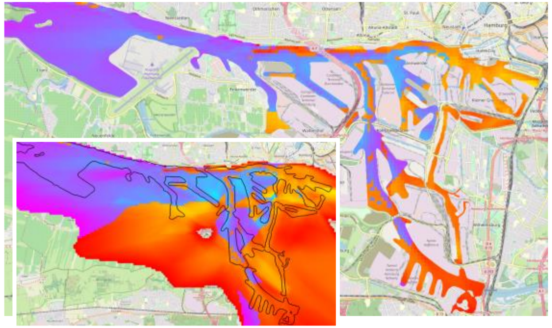
https://www.youtube.com/watch?v=nMdBbLv2G98



Prediction of Mobility and QoS/RSRP

Radio Propagation Map:

- Created based on UE measurements (reported GPS position, RSRP)
- Using a FNN

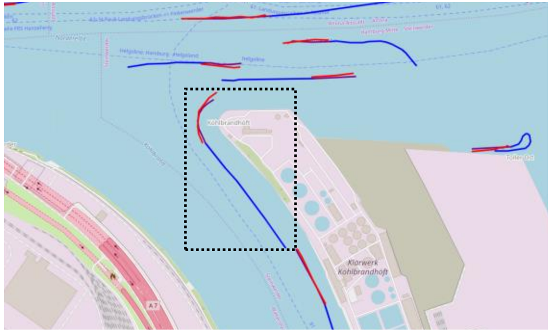


RSRP, serving cell: $Cell_1$

RSRP, serving cell: $Cell_2$

Mobility Pattern Prediction (MPP):

- Positions reported by the barges
- Prediction of barge movement using a convolutional neural network



Input sequence

Ground truth

Prediction

Combining the mobility prediction with the coverage model, of 62200 sequences in a validation set, we were able to predict up to **90%** of the low-RSRP events and RLFs **40 seconds** ahead

Integrating with Digital Twin

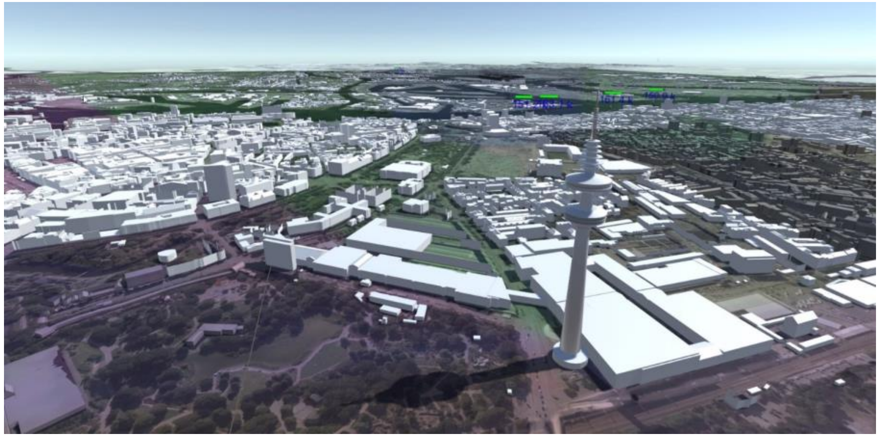
A **digital twin** of the testbed setup is **mirrored** in a simulator

- Full 3D model of the city of Hamburg and especially the harbor area
- Network topology and configuration as in the real testbed
- Traces of the movement of the real barges are collected from the testbed and imported into the simulation scenario

Closed-Loop Automation Evaluation with Simulation

The coverage issues of the real testbed can be **reproduced**:

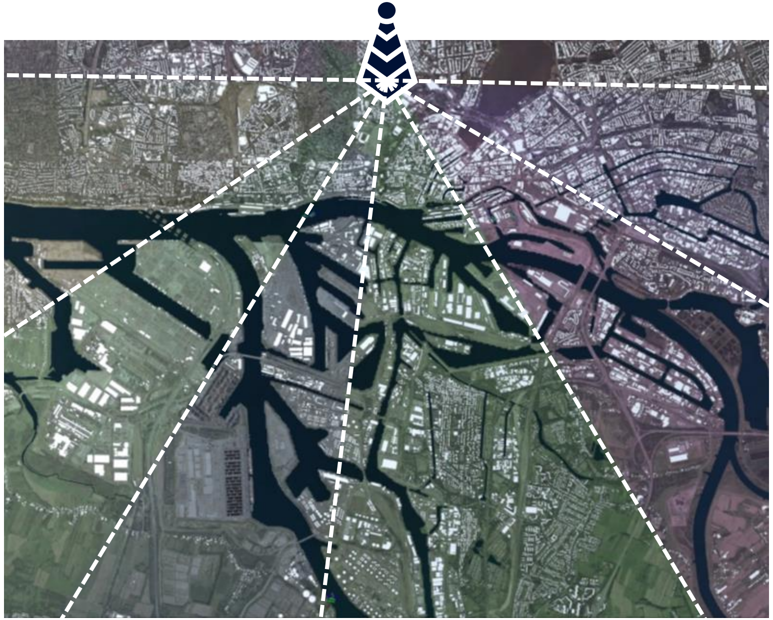
- The simulator is connected to a cognitive network management experimental system, which does the ML inference and implements the closed-loop automation functions
- The mobility predictions from the MPP model are created for each ship, simulation's radio propagation model is used for modeling the RSRP
- Prediction 40 simulated seconds ahead

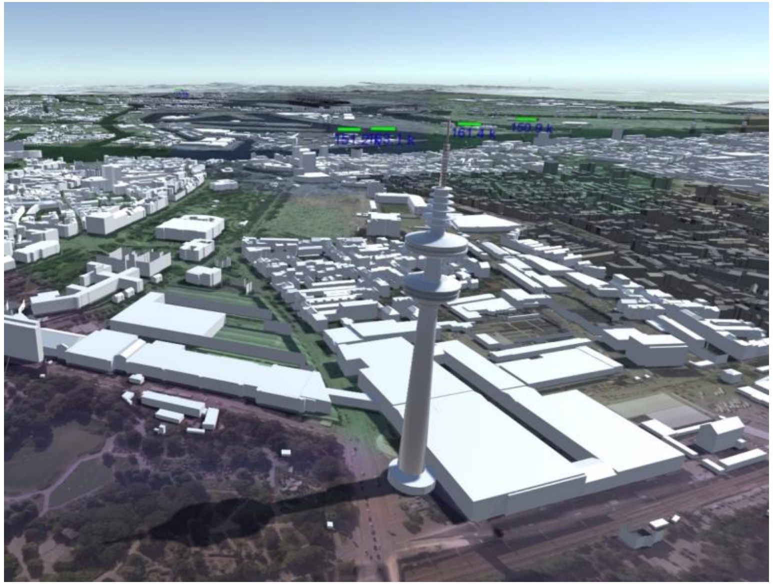


Evaluating predicted actions in Digital twin environment

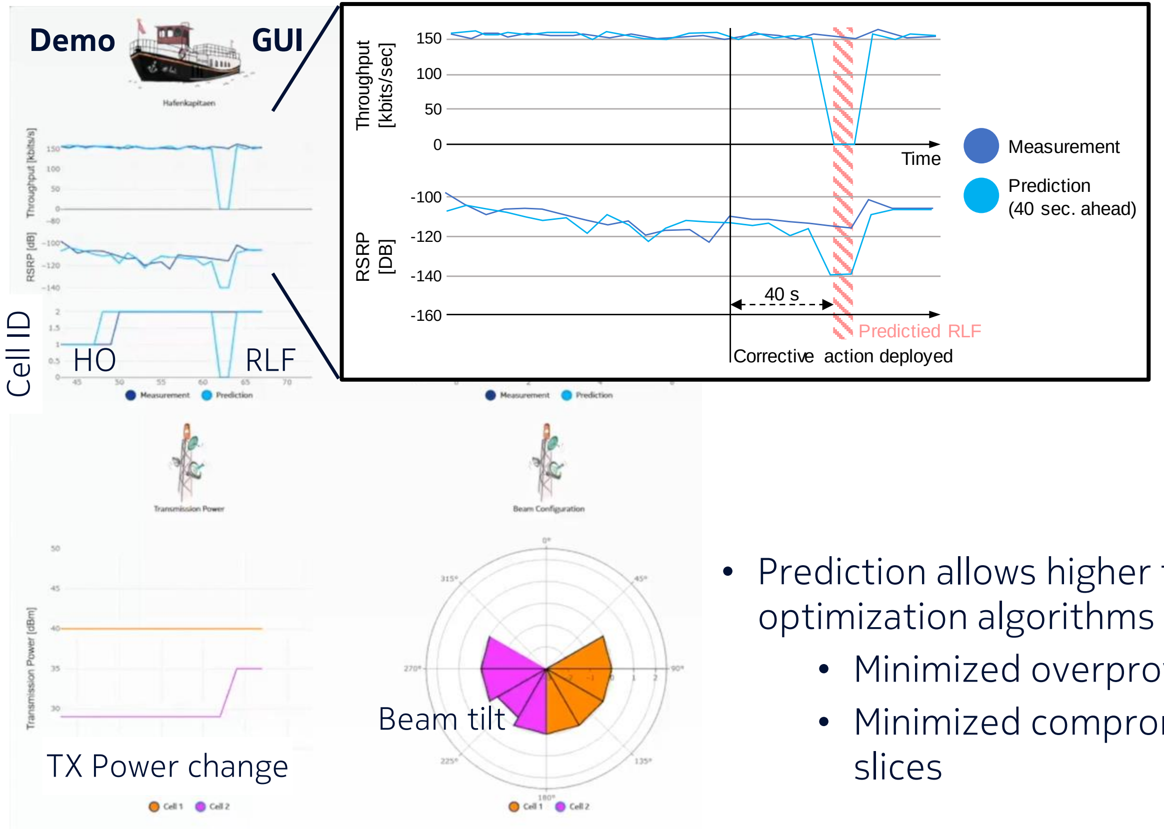
The **digital twin is extended** to simulate NR with **beam forming**

- Four beams per each of the two cells, with two antenna elements for two simultaneous beams





Preventive Closed-Loop Optimization



QoS and RLFs can be predicted and prevented by:

- Optimizing the transmission power
- Beam forming
    - Activate or de-active beams
    - Tilting of individual beams

- Prediction allows higher thresholds to be used in the optimization algorithms
    - Minimized overprovisioning of resources
    - Minimized compromises between different network slices

Key takeaways

- Cognition and Autonomy are key enablers for future networks
  - Performance improvement of existing network (management) functions & enabling of new functions
  - Simplification from operator perspective (shift from “execution” to “supervision”)
- Value addition from integration with Digital Twin, as illustrated by the PLANAR use case
  - Replica of physical testbed (digital twin) enabling to evaluate features (beamforming), that may not be yet present in the testbed
  - Separated (but chained) modeling of the network (QoS) and application (barges) mobility
- LTE/early 5G: SON =>5.5G: Cognitive NM (CNM) => 6G: Cognitive Autonomous Network (CAN)
  - Cognition & Autonomy penetrate the u- and c-plane
    - AI is the technology area to enable this
  - AI requires expanded (training data) and new (model management) standardized interfaces
  - m-plane takes a new role (managing the AI on the u- and c-plane)

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