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“Cognitive Autonomy” through AI: a case study in Network Automation

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The Need for Cognitive Autonomy in Communication Networks

Definitions

Autonomous - able to act on its own, without dictation or rules from anyone else

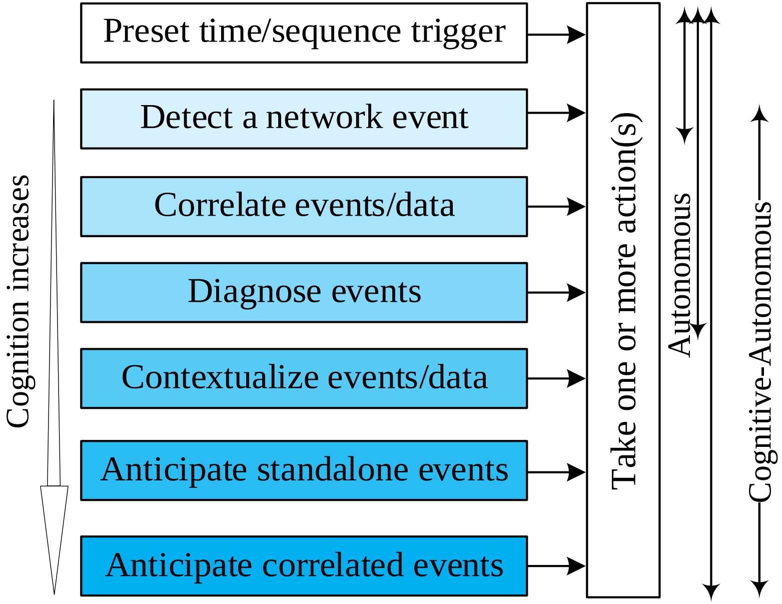
- not necessarily able to reason based on its environment or even smart enough to make the best static decisions

Cognitive - able to reason and formulate recommendations for subsequent behaviour

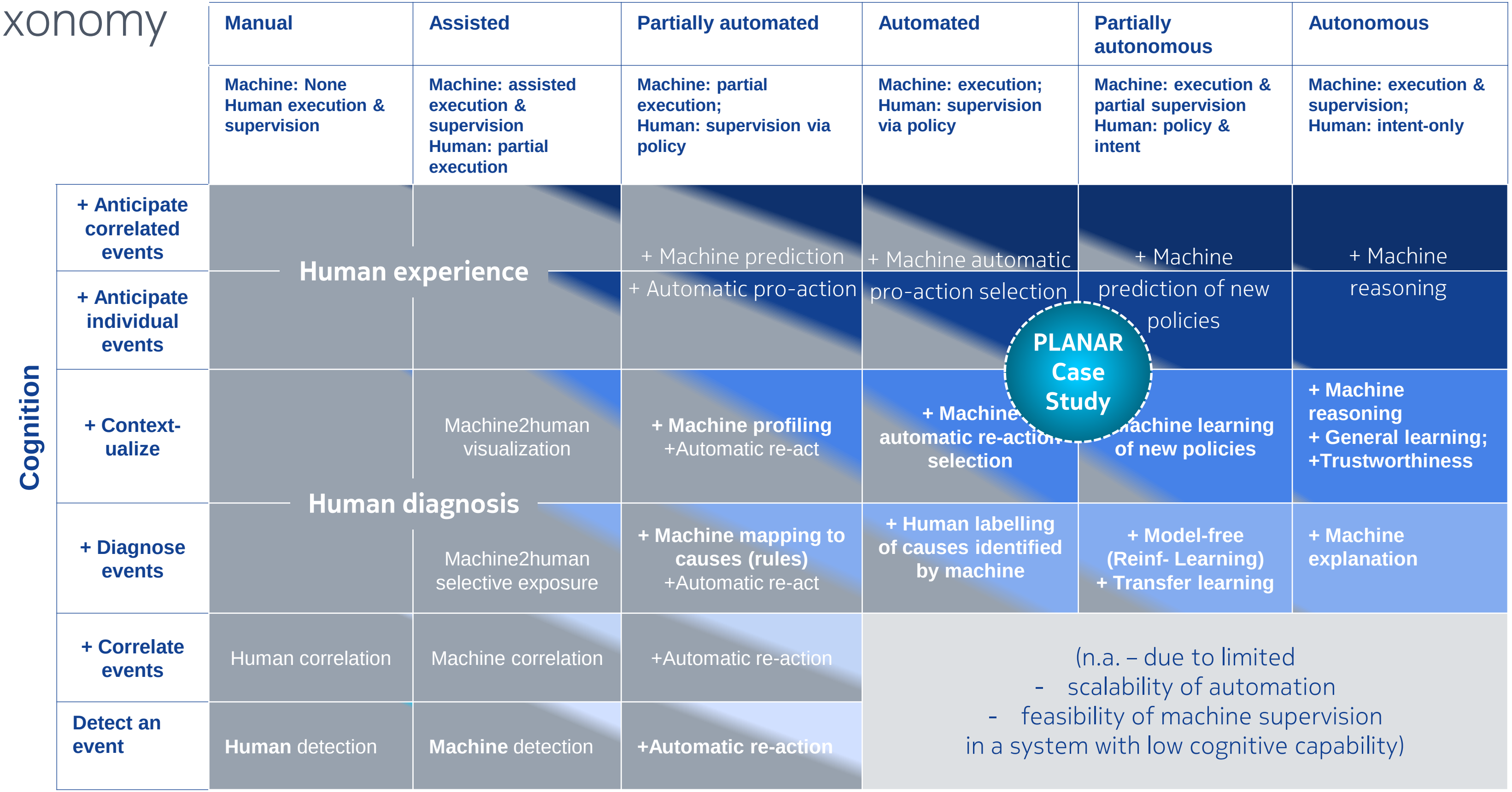
- may however require the operator’s approval

Self-Organizing – Achieve steady state without external control

- automates the selection and execution of actions
- interprets events & context to determine the cause-effect relations.



Cognition vs. Autonomy Taxonomy



Autonomy

Cognition

	Manual	**Assisted**	**Partially automated**	**Automated**	**Partially autonomous**	**Autonomous**
	Machine: None Human execution & supervision	**Machine: assisted execution & supervision Human: partial execution**	**Machine: partial execution; Human: supervision via policy**	**Machine: execution; Human: supervision via policy**	**Machine: execution & partial supervision Human: policy & intent**	**Machine: execution & supervision; Human: intent-only**
+ Anticipate correlated events	**Human experience**		+ Machine prediction	+ Machine automatic pro-action selection	+ Machine prediction of new policies	+ Machine reasoning
+ Anticipate individual events			+ Automatic pro-action			
+ Context-ualize	**Human diagnosis**	Machine2human visualization	**+ Machine profiling** +Automatic re-act	**+ Machine automatic re-action selection**	**achine learning of new policies**	**+ Machine reasoning + General learning; +Trustworthiness**
+ Diagnose events		Machine2human selective exposure	**+ Machine mapping to causes (rules)** +Automatic re-act	**+ Human labelling of causes identified by machine**	**+ Model-free (Reinf- Learning) + Transfer learning**	**+ Machine explanation**
+ Correlate events	Human correlation	Machine correlation	+Automatic re-action	(n.a. – due to limited - scalability of automation - feasibility of machine supervision in a system with low cognitive capability)		
Detect an event	**Human** detection	**Machine** detection	**+Automatic re-action**			

PLANAR Case Study

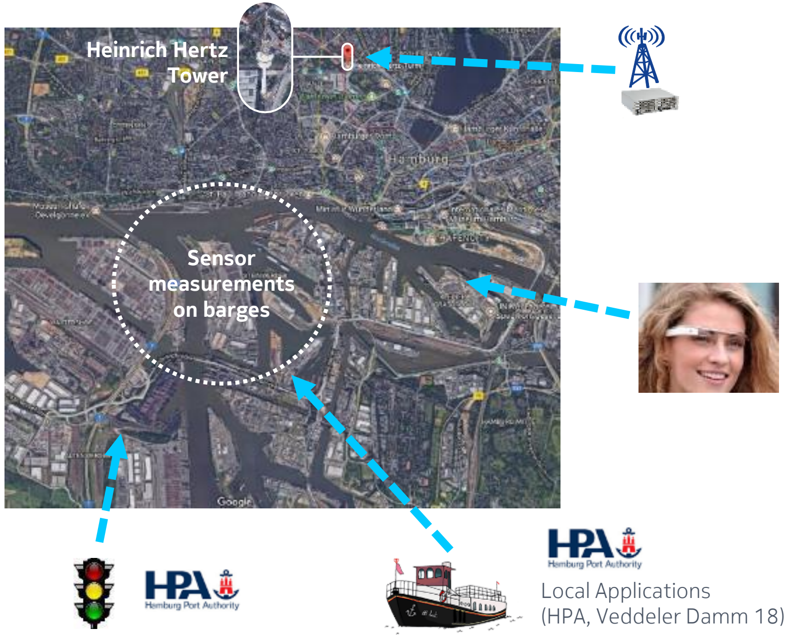
PLANAR Case Study

Predictive Location-Aware Network Automation for Radio

The 5G network slicing testbed at Hamburg Harbor

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

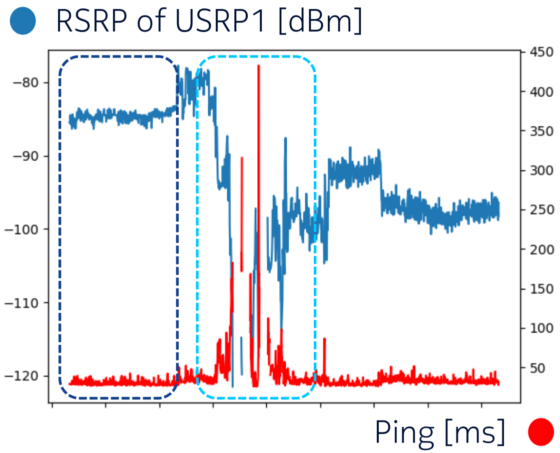
- Three slices
    - eMBB: Local applications in the harbor
    - URLLC: Traffic light control
    - **IoT: Emission sensor readings from barges**
- Data collection
    - **Slice-specific BTS KPIs**: PRB usage, throughput, latency etc.
    - **UE measurements** from up to three ships including position (by GPS), RSRP, RSRQ, ping etc.
    - Collected for 6 months every 5 seconds **~3M records**

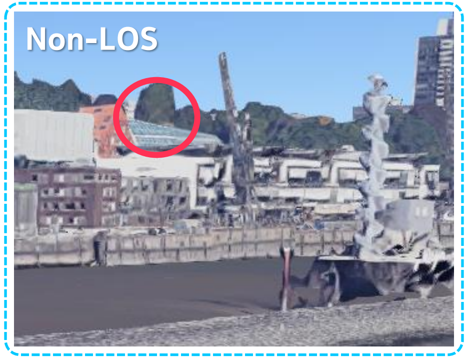


Predictive Location-Aware Network Automation for Radio

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

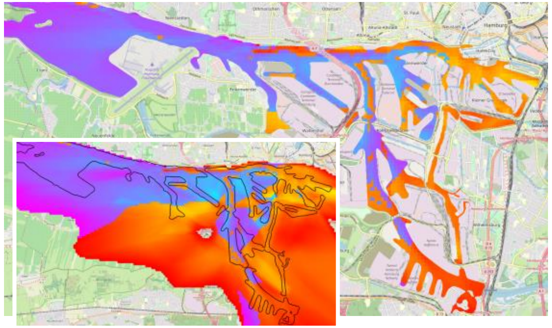




Predictive Location-Aware Network Automation for Radio
Prediction of Mobility and QoS/RSRP

Radio Propagation Map:

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

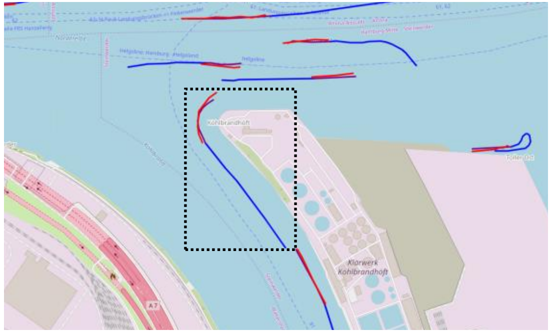


🟧 RSRP, serving cell: Cell$_1$

🟪 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

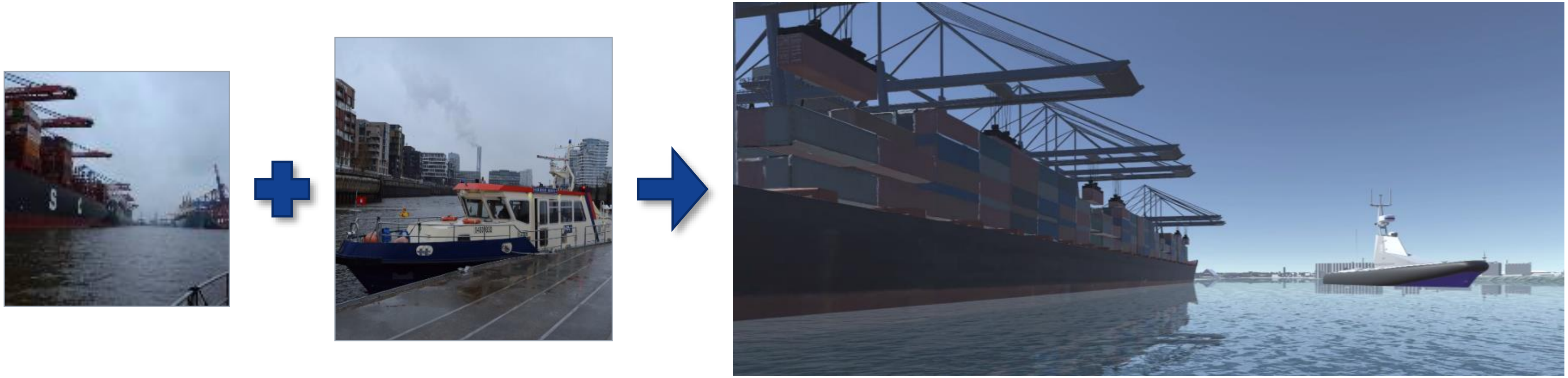
Combining the mobility prediction with the coverage model, of 62200 sequences in a validation set, we were able to predict up to **90%** of the low-RSRP events and RLFs **40 seconds** ahead

Predictive Location-Aware Network Automation for Radio

Closed-Loop Automation Evaluation with Simulation

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

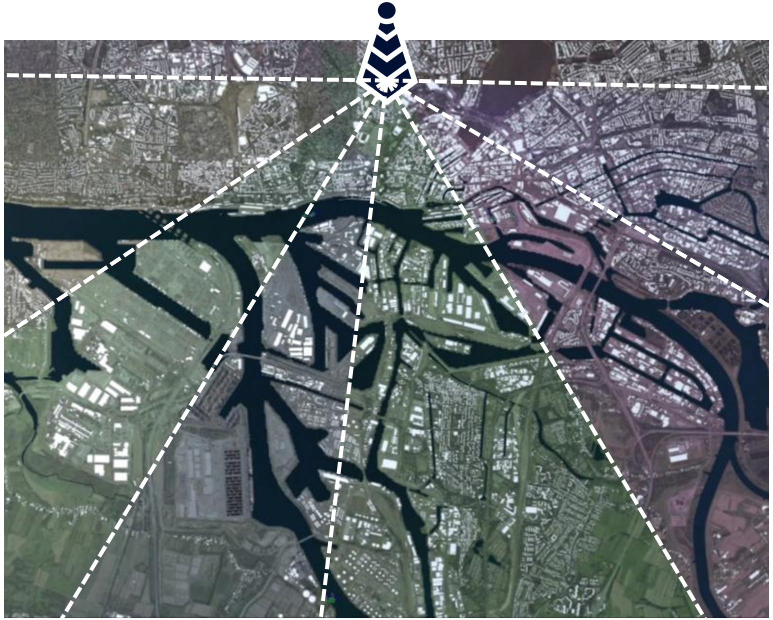


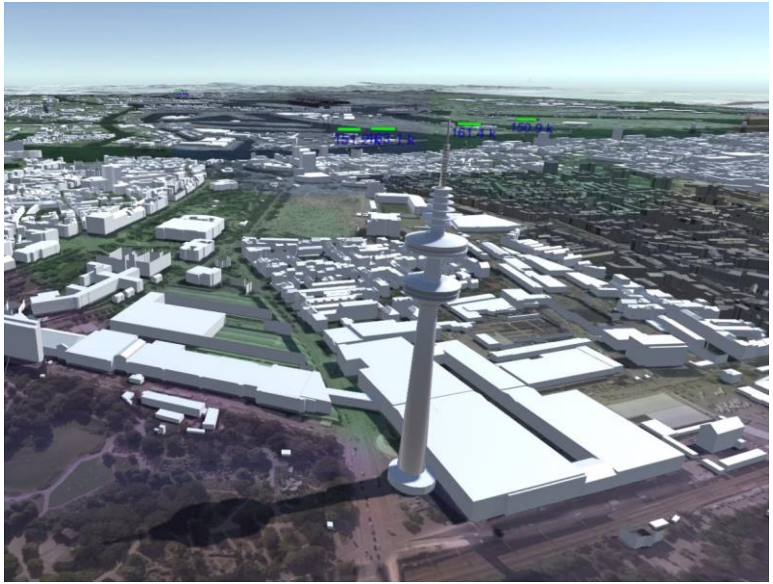
Predictive Location-Aware Network Automation for Radio

Closed-Loop Automation Evaluation with Simulation

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

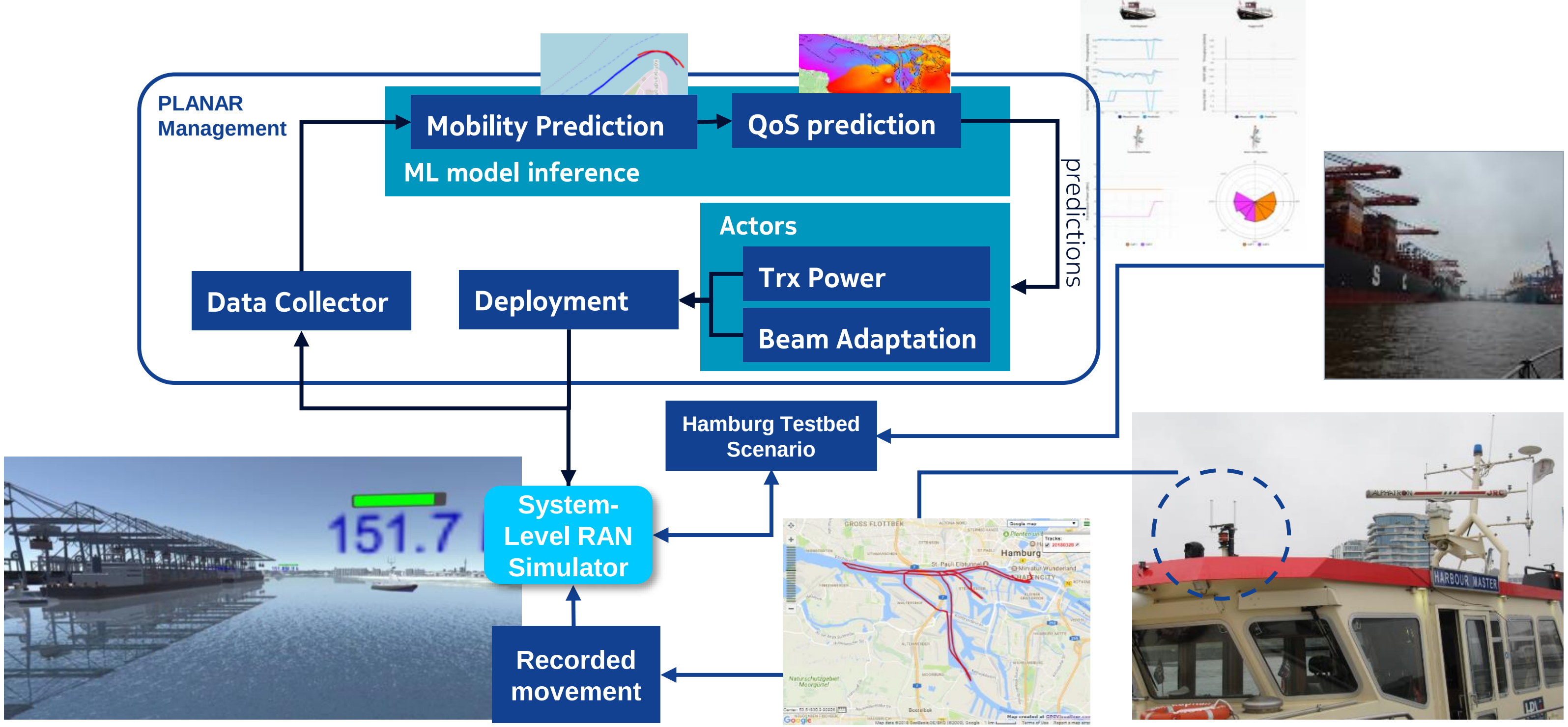




Predictive Location-Aware Network Automation for Radio

Demo @ IEEE NOMS

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



PLANAR Management

Mobility Prediction

QoS prediction

ML model inference

predictions

Actors

Trx Power

Beam Adaptation

Data Collector

Deployment

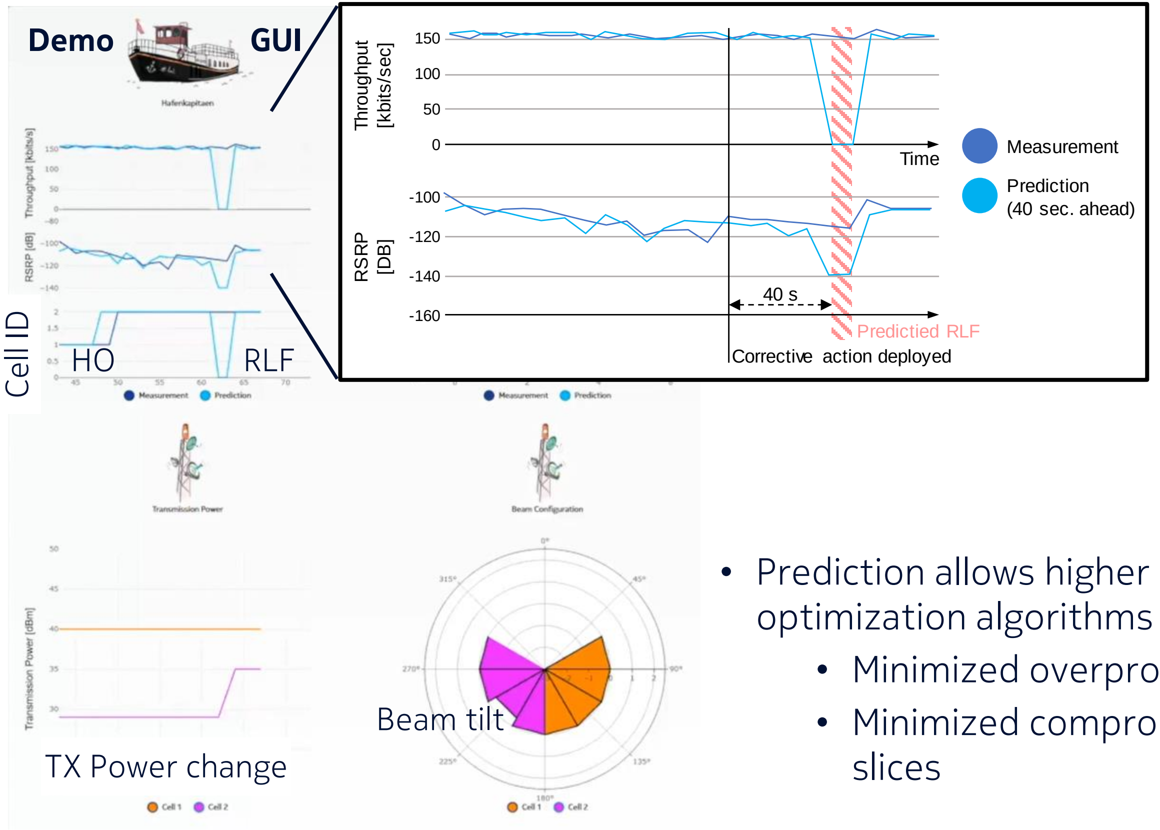
Hamburg Testbed Scenario

System-Level RAN Simulator

Recorded movement

Predictive Location-Aware Network Automation for Radio (PLANAR)

Preventive Closed-Loop Optimization



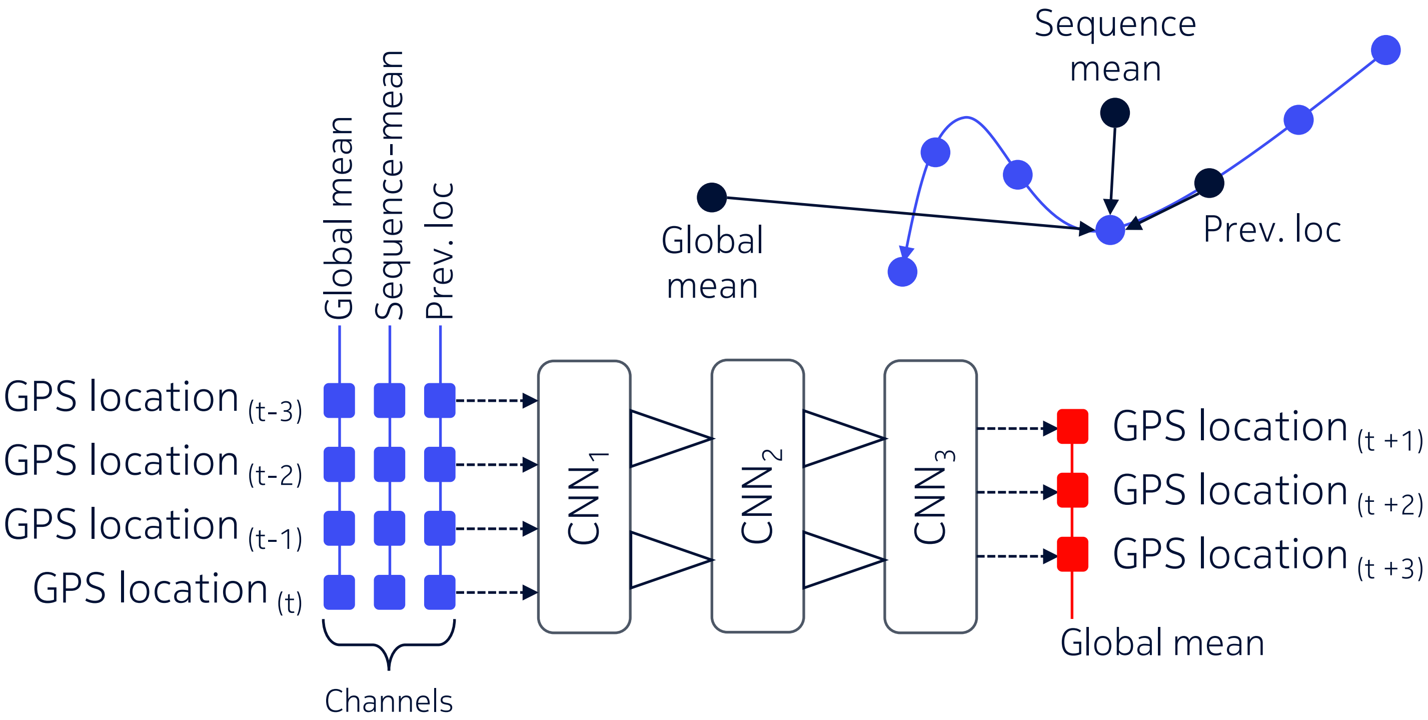
QoS and RLFs can be predicted and prevented by:

- 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

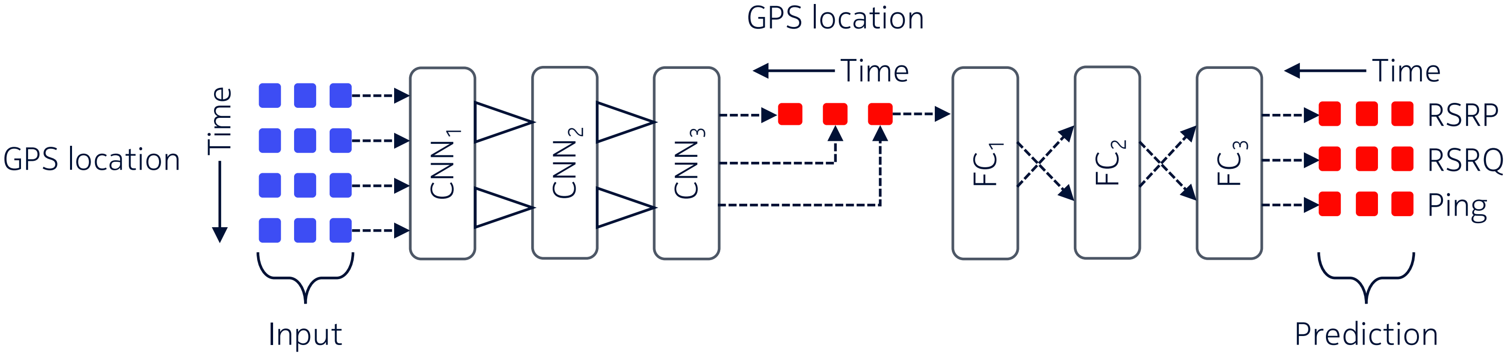
Predictive Location-Aware Network Automation for Radio (PLANAR)

Mobility prediction



Predictive Location-Aware Network Automation for Radio (PLANAR)

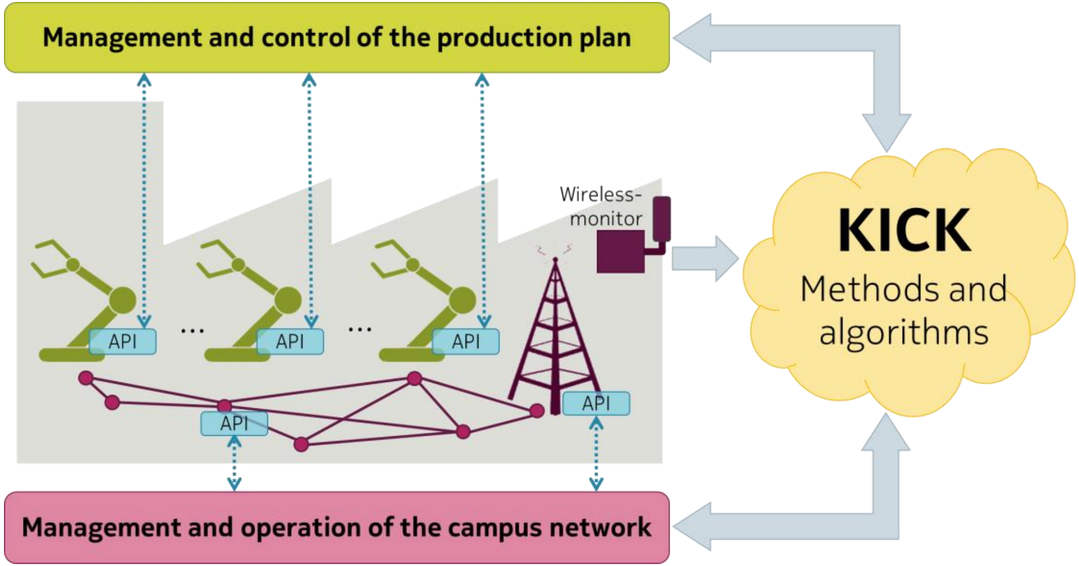
Evaluation with location and radio environment combined



- 62200 sequences in the validation set
- Predicting RLFs **40 seconds** ahead
- True positives: **97.6%**
- False positives: **16.7%** of predicted events
- We optimized for high true positive rate, since the corrective actions were non-intrusive
- In many of the examples classified as false positive, the actions were still justified

KICK Project (kick-project.de)

Artificial Intelligence for Campus Communication



1. **Optimization** across communication and production
2. **Simplification** of the campus network operation
3. **Economical viability** of private networks in factories
4. **Validation** of AI/ML methods in the joint production and communication worlds

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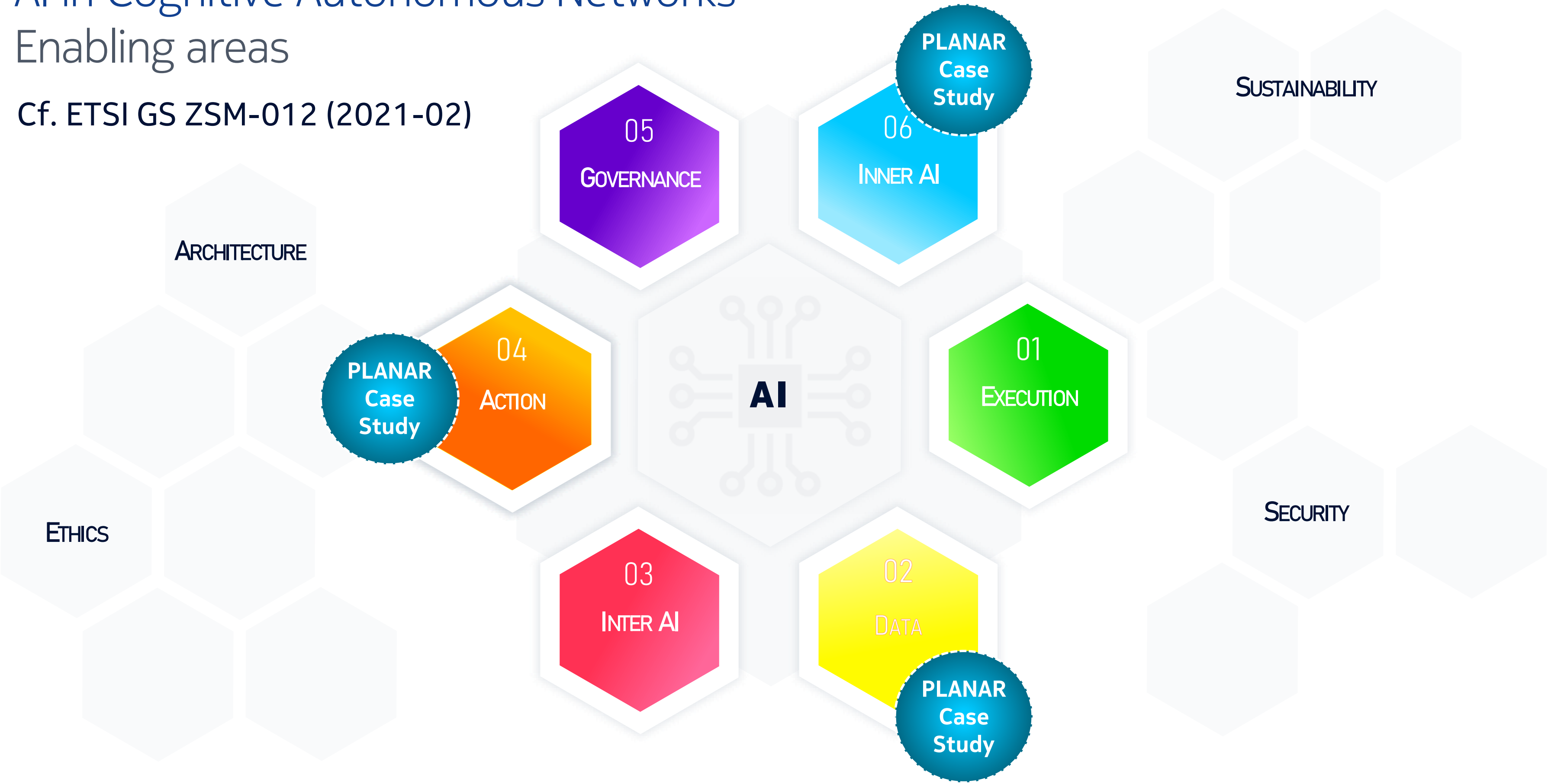
Application of AI methods in a highly dynamic wireless network and flexibly reconfigurable factory environment for monitoring and controlling communication and production

AI in Cognitive Autonomous Networks

Enabling areas

Cf. ETSI GS ZSM-012 (2021-02)



Architecture

Ethics

05 Governance

06 Inner AI

PLANAR Case Study

04 Action

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AI

01 Execution

03 Inter AI

02 Data

PLANAR Case Study

Sustainability

Security

“Cognitive Autonomy” through AI: a case study in Network Automation

Conclusions

- Cognition & Autonomy are crucial, separable properties
  - Understand system concepts and contexts to enable decision making at machine level
  - Actions can be taken at any step in the cognitive process

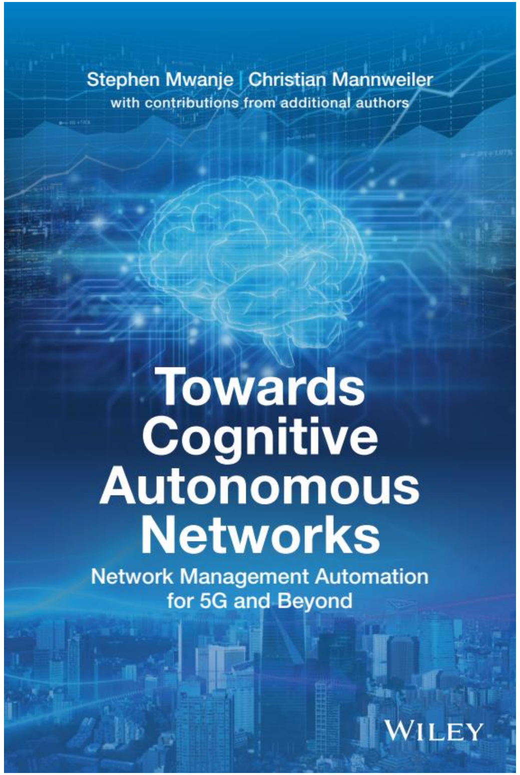
- PLANAR case study
  - Replica of physical testbed (digital twin) enabling to evaluate features (beamforming) not (yet) present in the testbed
  - Separated (but chained) modeling of the network (QoS) and application (barges) mobility

- AI requires expanded (training data) and new (model management) standardized interfaces
  - AI Enablers: Data → Execution → Action; inter-AI & Governance
    - “Inner AI”: telco- / NM-specific choice and adaptation of AI Algorithms
  - ETSI ISG ZSM WI12 defines the AI enablers within the ZSM architectural framework

→ Performance improvement of existing network (management) functions & enabling of new functions

→ Simplification from operator perspective (shift from “execution” to “supervision”)

Towards Cognitive Autonomous Networks
Network Management Automation for 5G and beyond



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with contributions from additional authors

Towards Cognitive Autonomous Networks

Network Management Automation for 5G and Beyond

WILEY

Book structure and outline

Background	Core argumentation	Solutions/Application	Open challenges
2. Network Evolution	1. Introduction	7. Cognitive Auto-Configuration	11. System Challenges of CANs
3. SON in pre-5G Networks	4. Modeling Cognition	8. Cognitive Autonomy in Optimization	12. Towards realizing CANs
	5. Classical AI for reasoning	9. Cognitive Self-Healing	
	6. ML for cognitive decision making	10. Cognitive Self-Operation	

https://www.wiley.com/en-us/Towards+Cognitive+Autonomous+Networks+%3A+Network+Management+Automation+for+5G+and+Beyond-p-9781119586388