

Towards Cognitive Autonomous Networks (CAN): 5G and Beyond

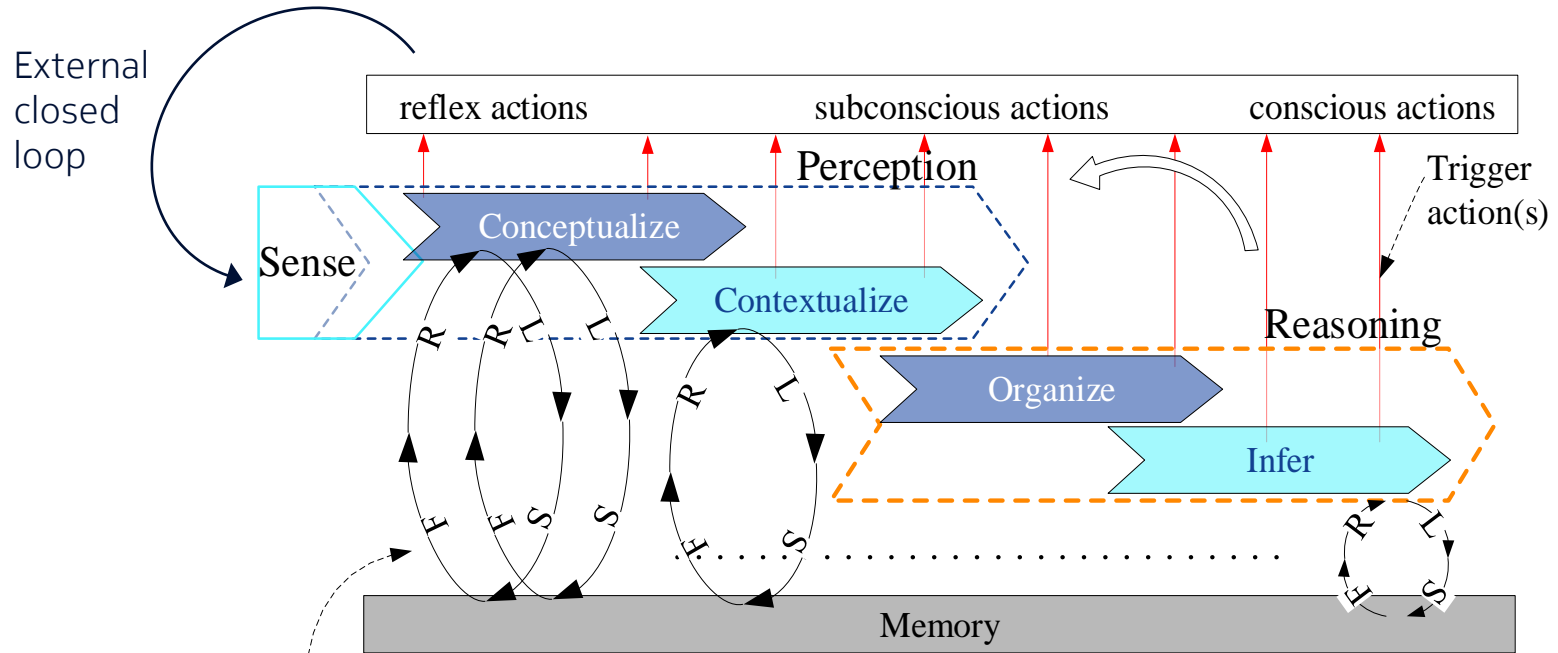
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Network Automation Research,
Nokia Standards
Munich, Germany



Modelling Cognitive Decision Making

A Perception-Reasoning pipeline



Fetch(**F**), Read labels(**R**), (re)label(**L**) (if needed depending on perception), and (re)store (**S**)

The Need for Cognitive Autonomy in Communication Networks

Definitions

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

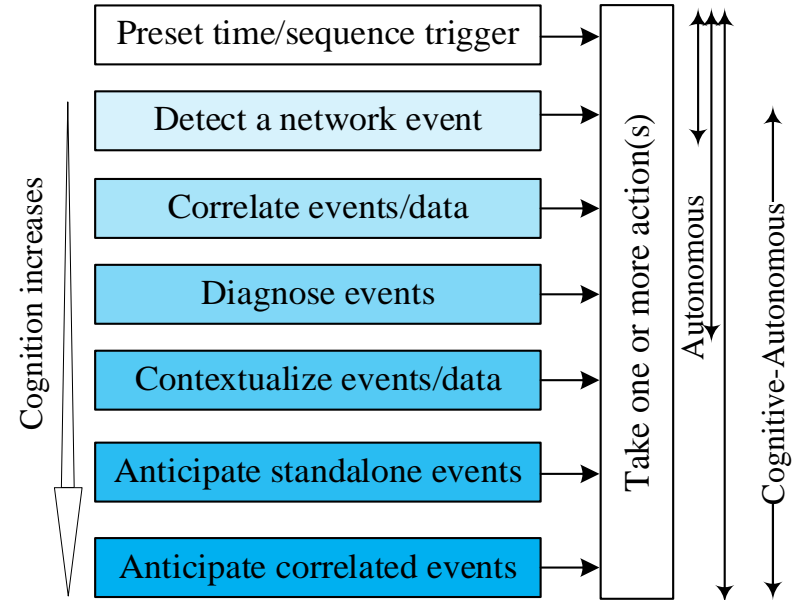
- not necessarily able to reason based on its environment or even smart enough to make the best static decisions

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 in Communication Networks

Static model vs. learning from data

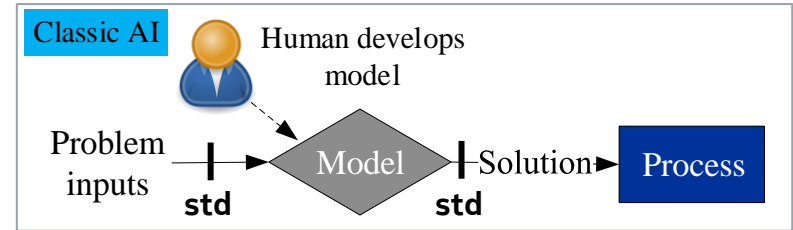
Classic AI: Model is available

- Static – fixed rule set on discrete or continuous valued logic
- Adaptive to deployment – by probabilities

Learning: Happens if performance at task T as measured by performance measure P, improves with experience E [1]

- Parameterise a model (θ) with loss function $J \rightarrow P=J(\theta)$
- Iteratively update model with experience E from data

$$\theta := \theta - \alpha \frac{\partial}{\partial \theta} J(\theta)$$



Expanded & New interfaces for standardization – data & model transfer

[1] adapted from Tom Mitchell (1997)

Cognition vs. Autonomy

Taxonomy

Autonomy

		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
Cognition	+ Anticipate correlated events	Human experience		+ Machine prediction	+ Machine automatic	+ Machine	+ Machine
	+ Anticipate individual events			+ Automatic pro-action	pro-action selection	prediction of new policies	reasoning
	+ Contextualize	Machine2human visualization		+ Machine profiling +Automatic re-act	+ Machine automatic re-action selection	machine learning of new policies	+ Machine reasoning + General learning; +Trustworthiness
	+ Diagnose events	Human diagnosis		+ 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

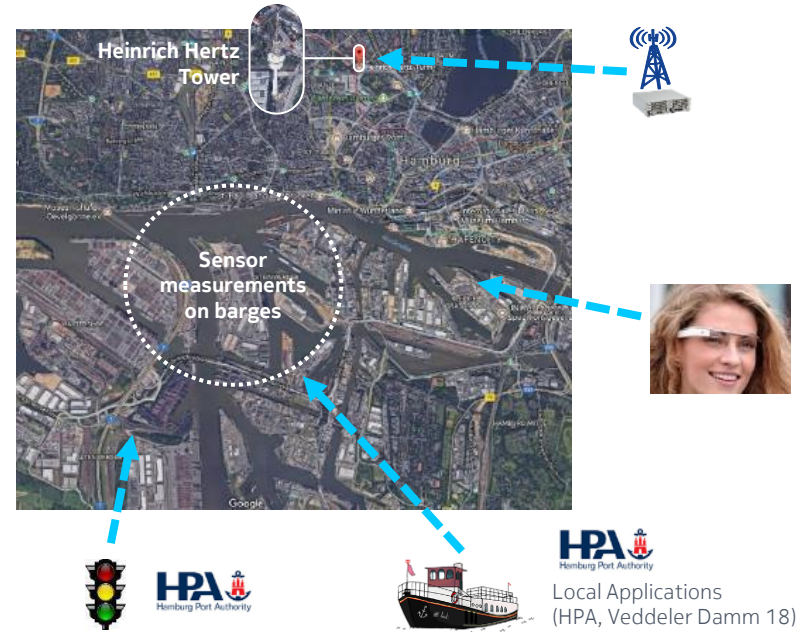


Predictive Location-Aware Network Automation for Radio

The 5G network slicing testbed at Hamburg Harbor

A live testbed created in the 5G MoNArch project demonstrating 5G slicing at the Hamburg Harbor:

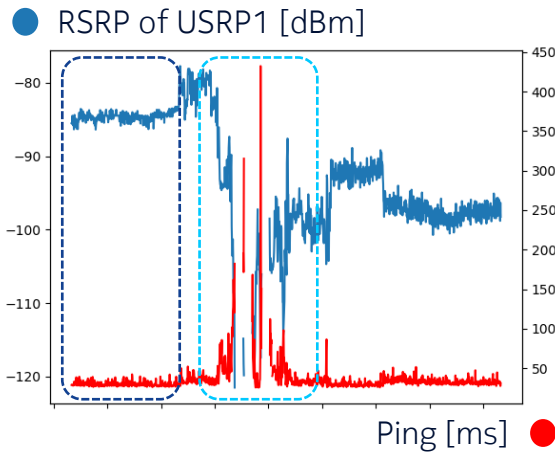
- Three slices
 - eMBB: Local applications in the harbor
 - URLLC: Traffic light control
 - **IoT: Emission sensor readings from barges**
- Data collection
 - **Slice-specific BTS KPIs:** PRB usage, throughput, latency etc.
 - **UE measurements** from up to three ships including position (by GPS), RSRP, 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

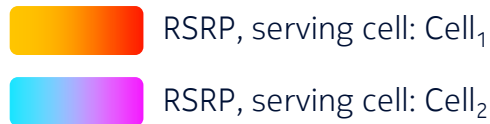
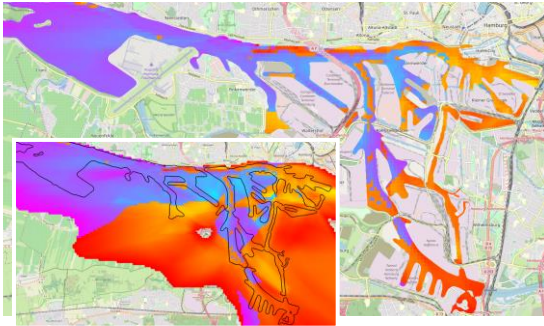


Predictive Location-Aware Network Automation for Radio

Prediction of Mobility and QoS/RSRP

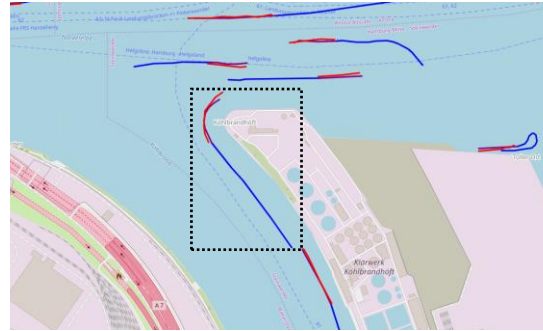
Radio Propagation Map:

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



Mobility Pattern Prediction (MPP):

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



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**

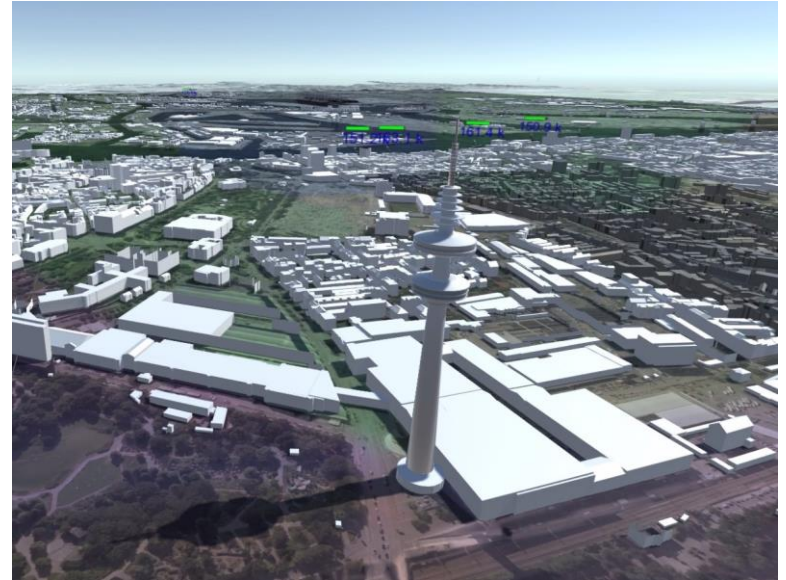


Predictive Location-Aware Network Automation for Radio

Closed-Loop Automation Evaluation with Simulation

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

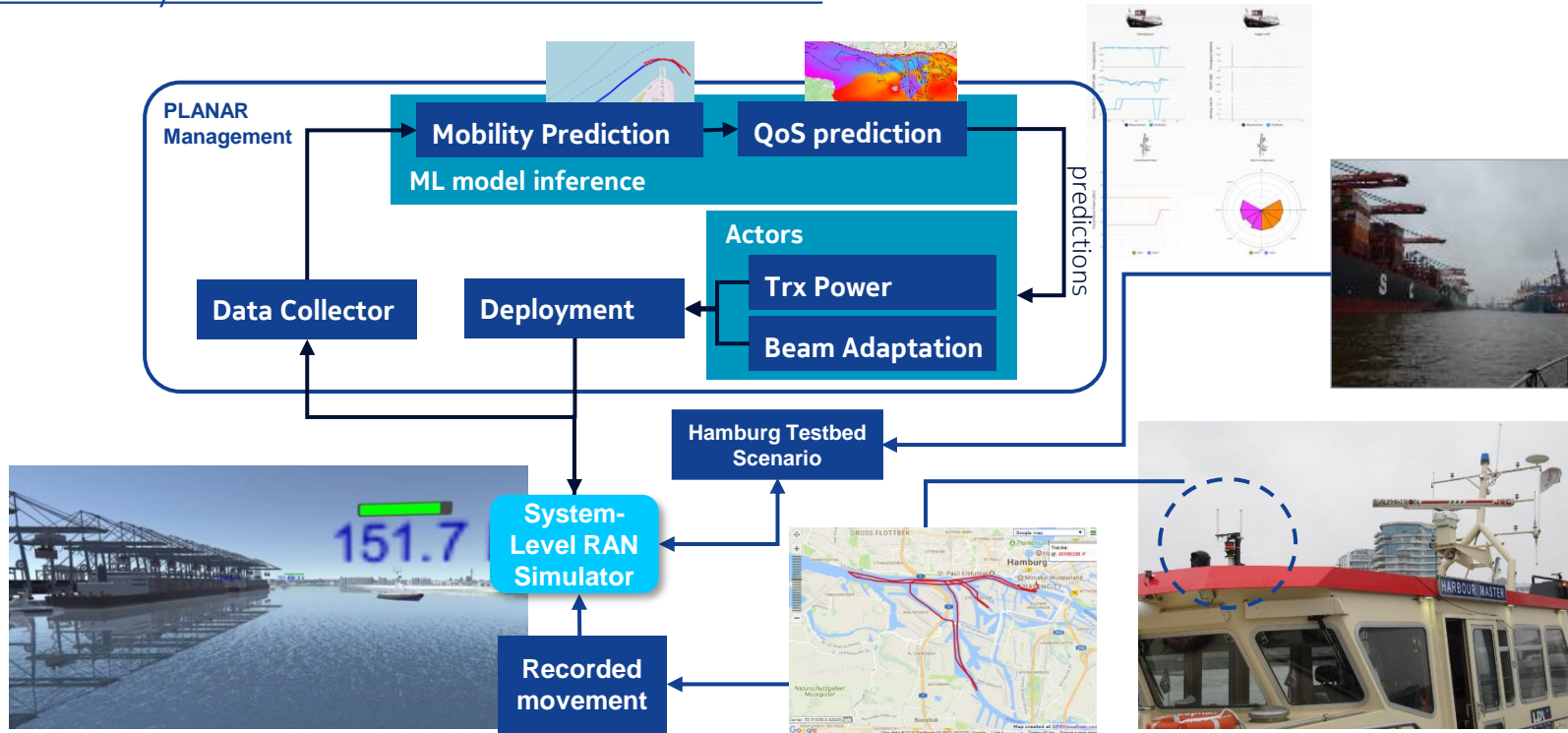
- Four beams per each of the two cells, with two antenna elements for two simultaneous beams



Predictive Location-Aware Network Automation for Radio

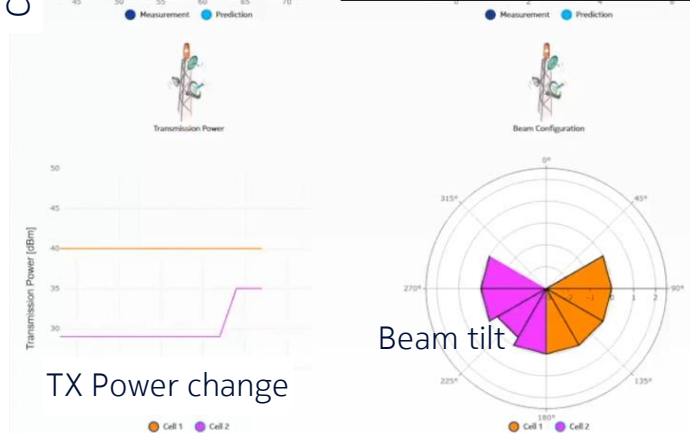
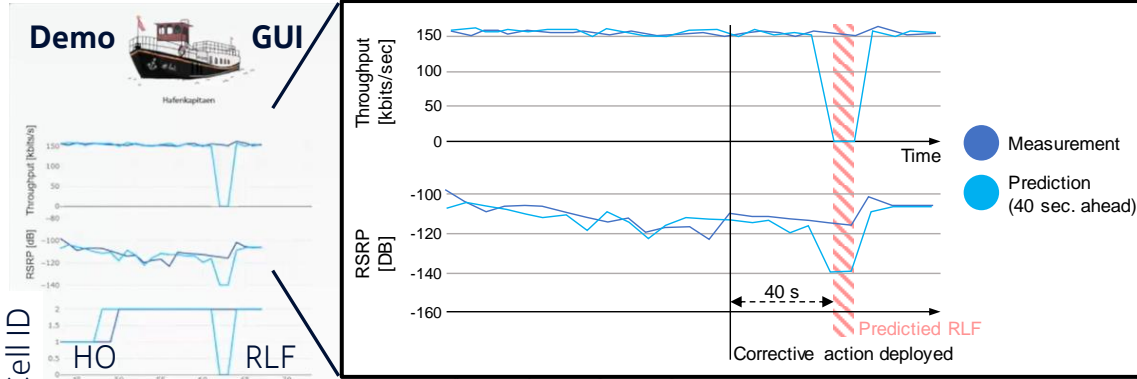
Demo @ IEEE NOMS 2020

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



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



CK Project (kick-project.de)

Artificial Intelligence for Campus Communication

NOKIA Stuttgart
Munich

DFK Deutsches
Forschungszentrum
für Künstliche
Intelligenz GmbH

GHMT

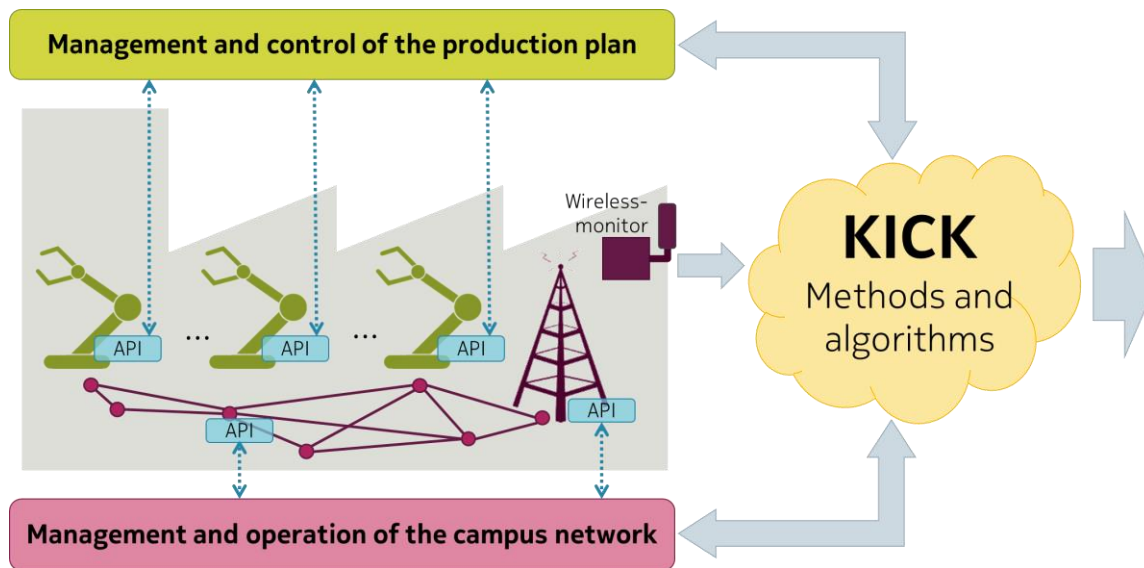
BOSCH
SIEMENS

TRUMPF

Fraunhofer
HHI

atesio

infosim



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

SPONSORED BY THE

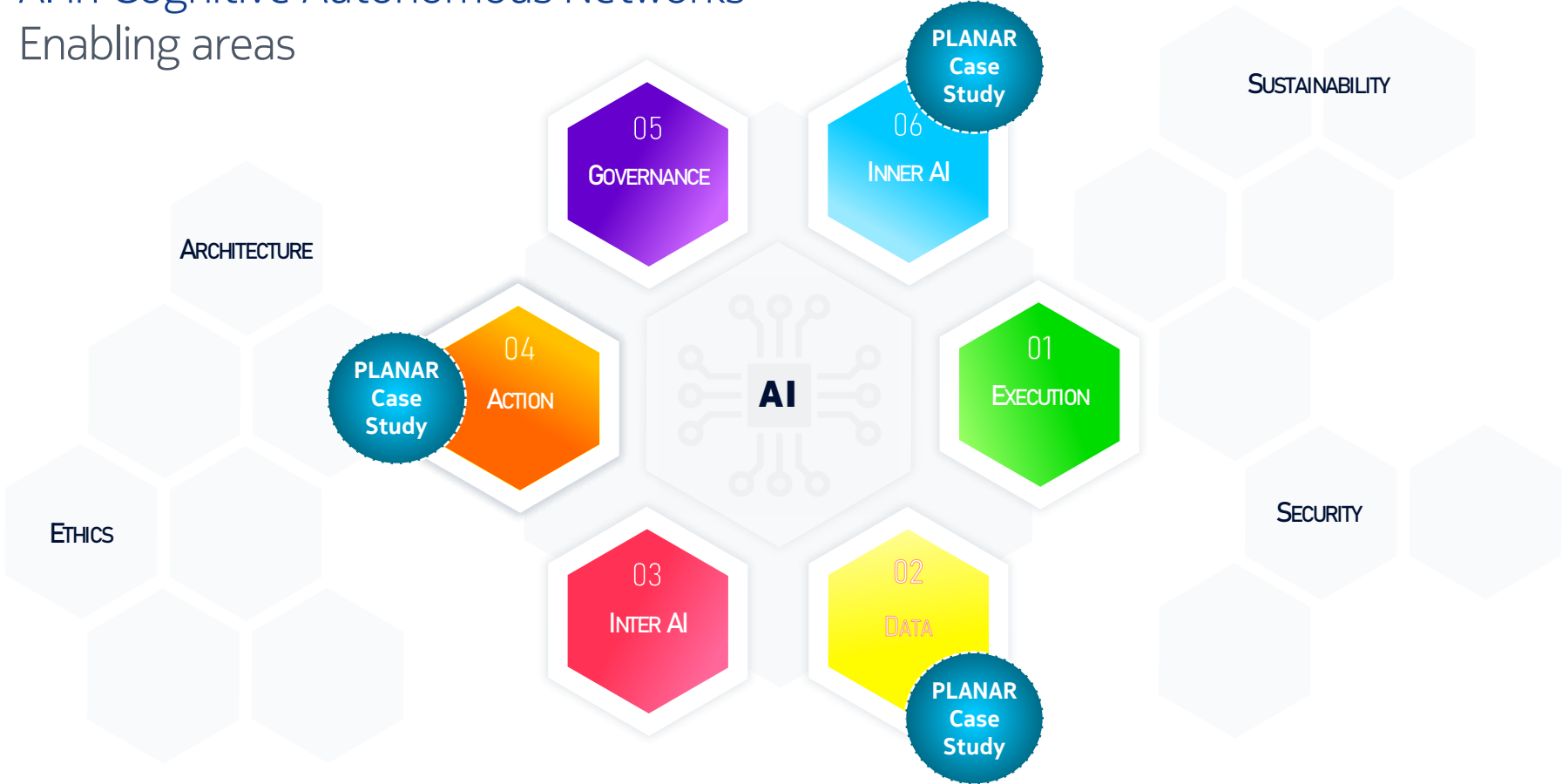


Federal Ministry
of Education
and Research

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

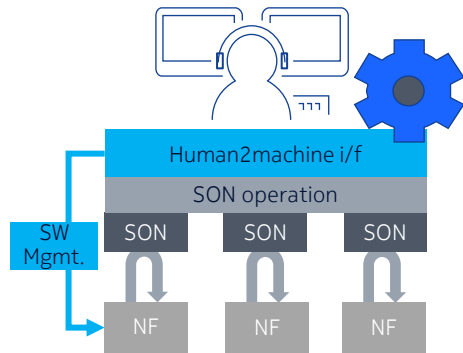


Towards Cognitive Autonomous Networks

5G and Beyond (RAN)

LTE / early 5G Self Organizing Network

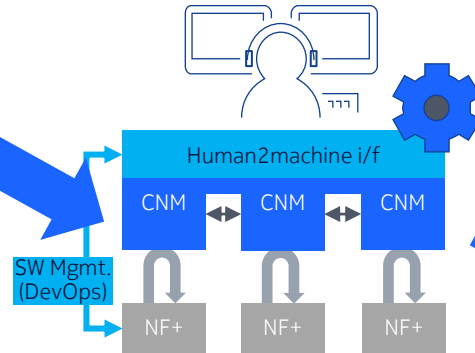
Rule-based management functions,
Software Management



Rule-based network functions

5G Evolution Cognitive Network Management

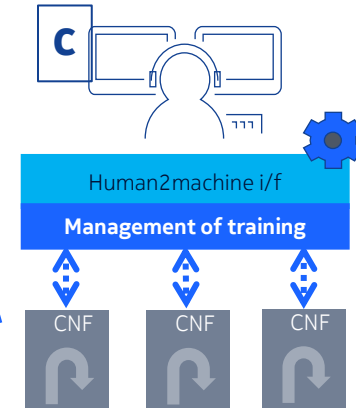
Learning management functions,
Software Management (DevOps)



Rule-based / data-driven
network functions

Towards 6G Cognitive Network

Management of training +
Comprehension (C)

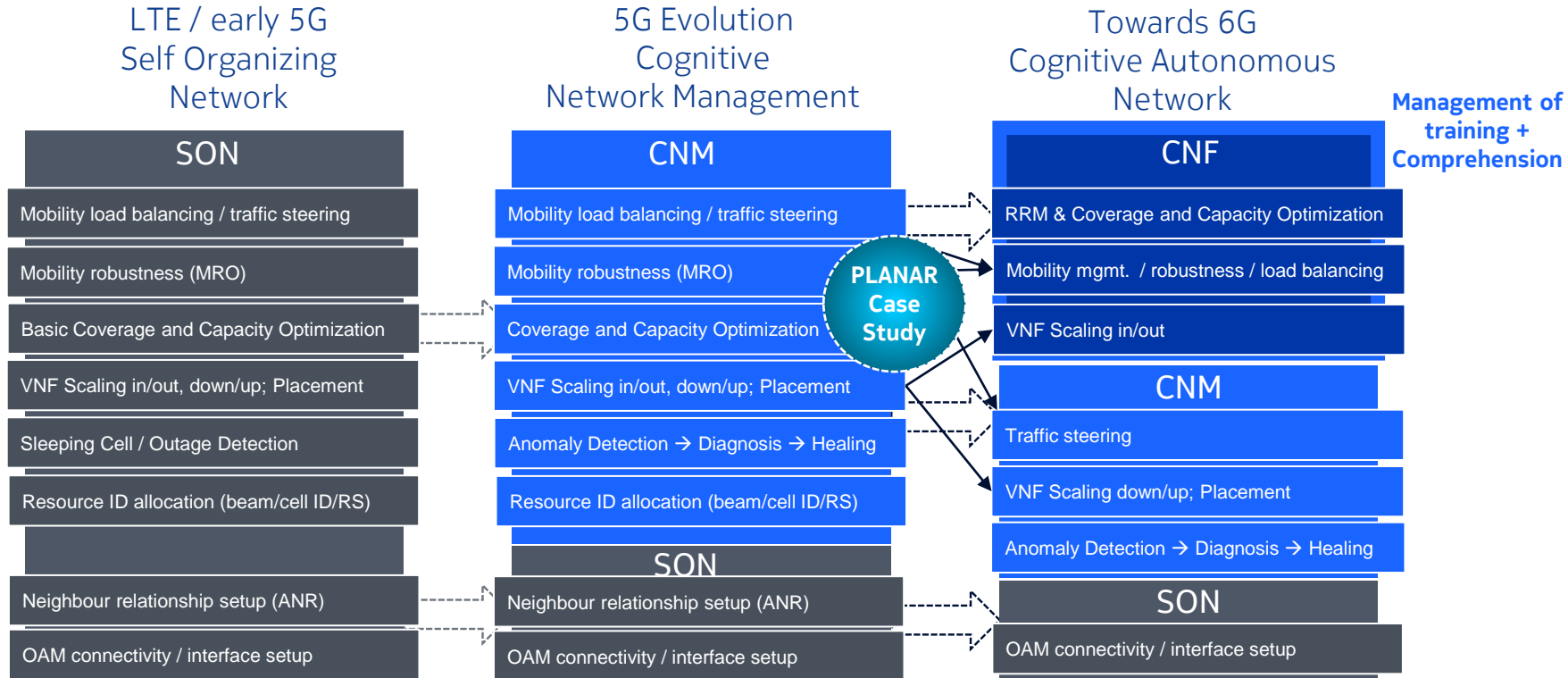


Learning network functions
(embedded management)

(CNF): (Cognitive) Network Functions

Towards Cognitive Autonomous Networks

5G and Beyond (RAN)



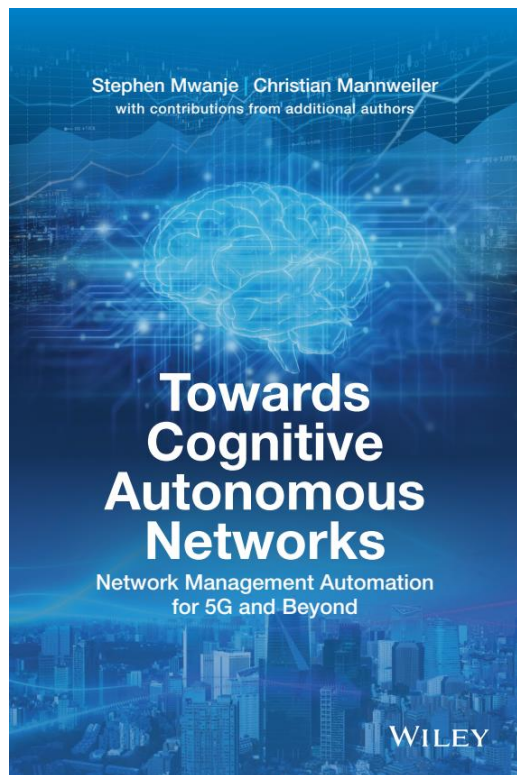
Towards Cognitive Autonomous Networks

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
 - AI Enablers: Data → Execution → Action; inter-AI & Governance
 - “Inner AI”: telco- / NM-specific choice and adaptation of AI Algorithms
 - AI requires expanded (training data) and new (model management) standardized interfaces
 - 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
 - m-plane takes a new role (managing the AI on the u- and c-plane)
 - Process (integration / replacement of legacy functions)
 - Some SON and CNM functions remain
- 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



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	

- Published October 2020

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

Towards Cognitive Autonomous Networks

Recent journal / conference publications & tutorials

- S. Mwanje, M. Kajo, J. Ali-Tolppa, Environment Modeling and Abstraction of Network States using Deep Clustering, IEEE Network special issue "AI for mobile networks" 2020
- M. Kajo, B. Schultz, Deep clustering of mobile network data with sparse autoencoders, IEEE NOMS 2020
- M.L. Mari-Altozano, S. Mwanje, S. Luna-Ramirez, M. Toril, H. Sanneck, C. Gijon, A Service-centric Q-learning Algorithm for Mobility Robustness Optimization in LTE, IEEE TNSM, 2021.
- A. Masri, T. Veijalainen, H. Martikainen, J. Ali-Tolppa, S. Mwanje, M. Kajo, Machine Learning Based Predictive Handover, IEEE IM 2021
- A. Banerjee, S. Mwanje, G. Carle, Optimal configuration determination in cognitive autonomus networks, IEEE IM 2021
- A. Banerjee, S. Mwanje, G. Carle, RAN Cognitive Controller, 2nd KuVS Fachgespräch on Machine Learning and Networking, 2020
- A. Banerjee, S. Mwanje, G. Carle, Game theoretic Conflict Resolution Mechanism for Cognitive Autonomous Networks, IEEE SPECTS 2020
- P. Kalmbach, P. Diederich, W. Kellerer, R. Pries, A. Blenk, sfc2cpu: Operating a Service Function Chain Platform with Multi-Agent Reinforcement Learning, IEEE IM 2021
- S. Mwanje, Towards Cognitive Autonomous Networks, Tutorial, IEEE NoF 2020
- S. Mwanje, Towards Cognitive Autonomous Networks, Tutorial, IEEE CNSM 2020

NOKIA