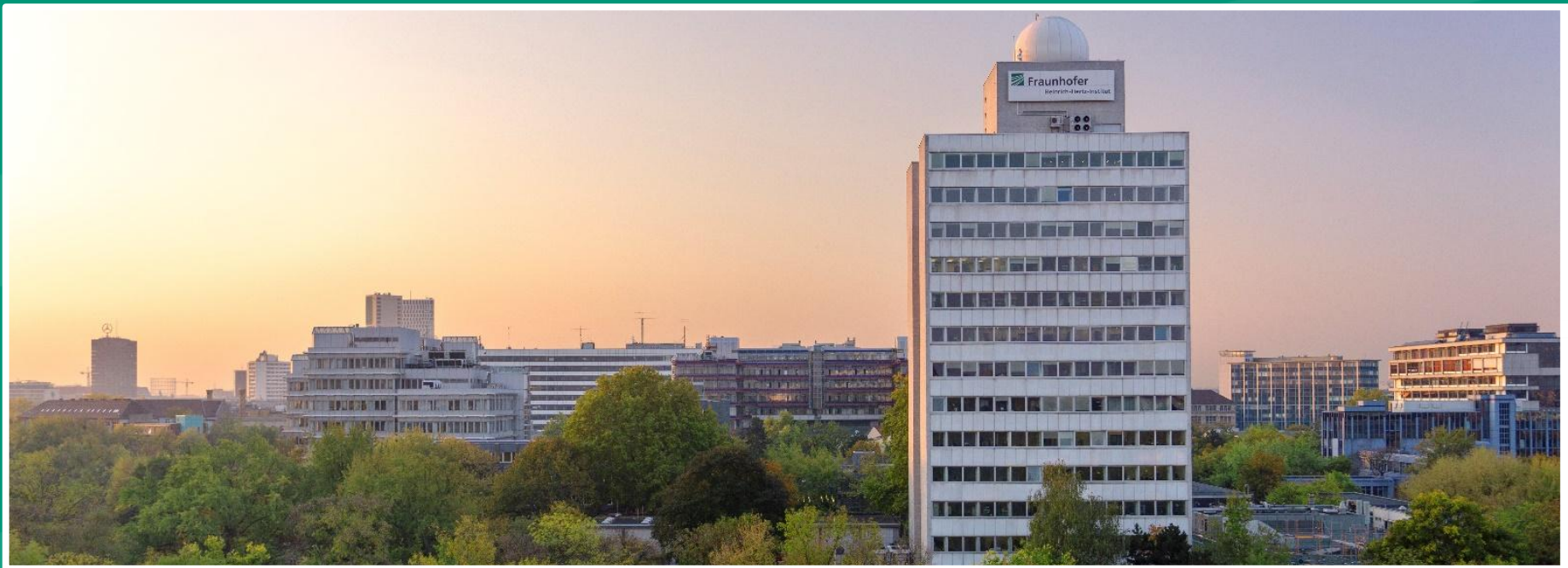

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Fraunhofer-Institut für Nachrichten-technik, Heinrich-Hertz-Institut, HHI

Network Digital Twin

Abstraction is All you Need

Ehsan Tohidi, Sustainable and Modular Networks (SMN)

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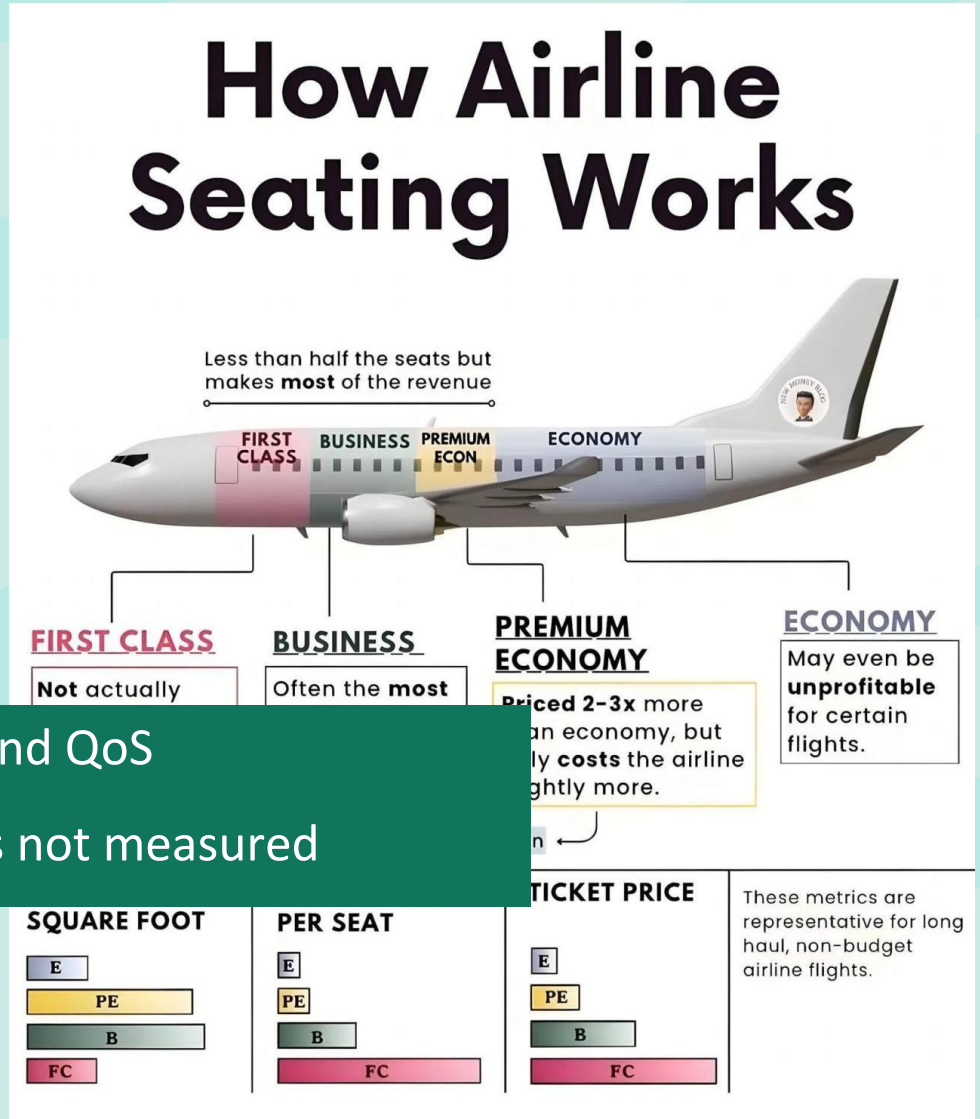
Mobile Capex is Outpacing Mobile Revenue[1]

- The need for new services and QoS
- You cannot optimize what is not measured



1: Mats Granryd, Director General of GSMA @ MWC 2025
2: Airline Seating Explained – It's More Than Just Choosing a Chair

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Why Digital Twins? Why Now?

- Evolving History
  - One of the earliest uses of digital twins was by NASA in dev
    Apollo 13 m
  - Subsequent
    medical field
    agriculture,
    (NDT), among others.
  - Siemens closed a $10B acquisition of Altair.

- They simulate what could happen in the network, not just what will happen
- Network Digital Twins enable reasoning about possibilities and alternative scenarios, not certainties

- Digital Twin facilitators
  - AI
  - Computation Power
  - Data
  - Reduce design time and cost
  - Predictive maintenance
  - Data generation & collection
  - Higher efficiency
  - Counterfactual / “what-if” analysis

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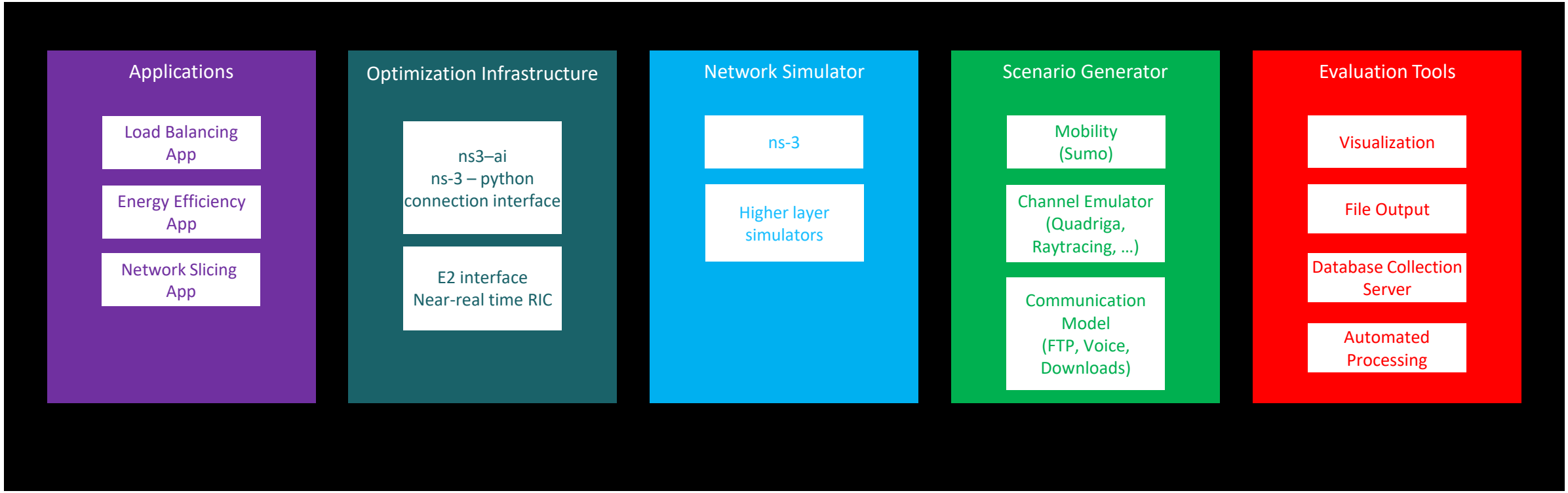
Developed Network Digital Twin Pillars



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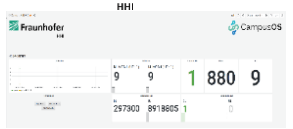
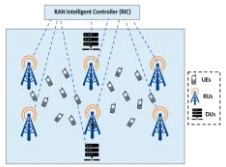
Open RAN Digital Twin

KPI-Monitoring (KPM)



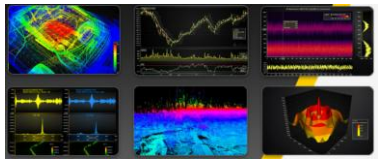
Load Balancing (KPM + RC)



Energy Saving (KPM+RC)

Optimization Algorithm (Python)

Real-time Visualization



Data Collection

- Applications
- Optimization Infrastructure
- Network Simulator
- Scenario Generator
- Evaluation Tools

Near-real time RIC

ns3–ai
ns-3 – Python Interface

E2 interface

KPIs

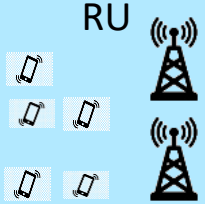
Parameters

ns-3

E2 Agent
(E2AP, E2SM)

Scenario

RU

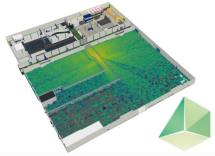


DU

CU

Communication Functionality:
EPC, 5G, ORAN, …

Channel simulator



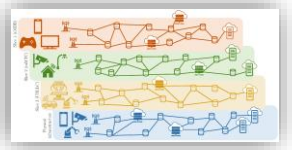
NVIDIA
sionna
Quadriga

Mobility simulator

SUMO

Scenario

Communication Model



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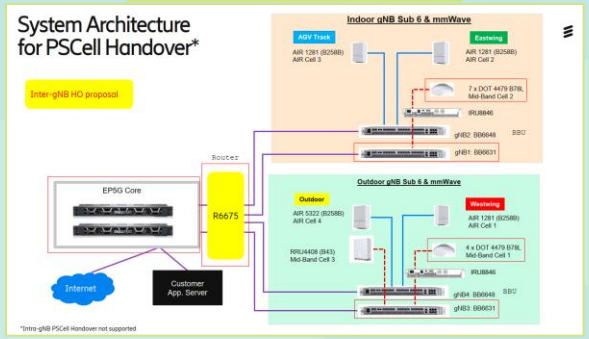
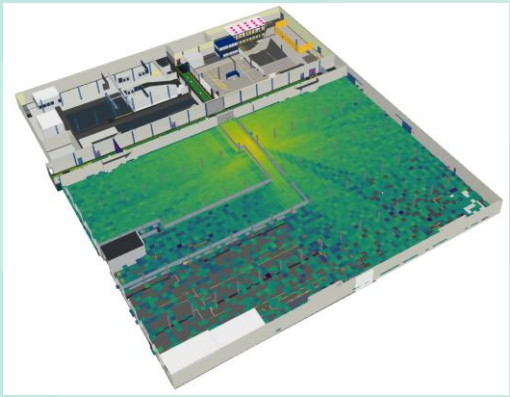
Werner-von-Siemens Centre

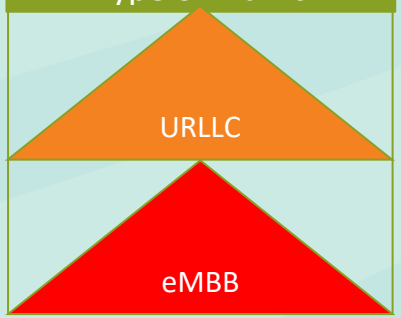
Configuration



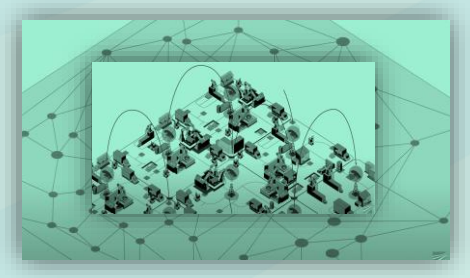
Channel Model



Type of Traffic



Scenario

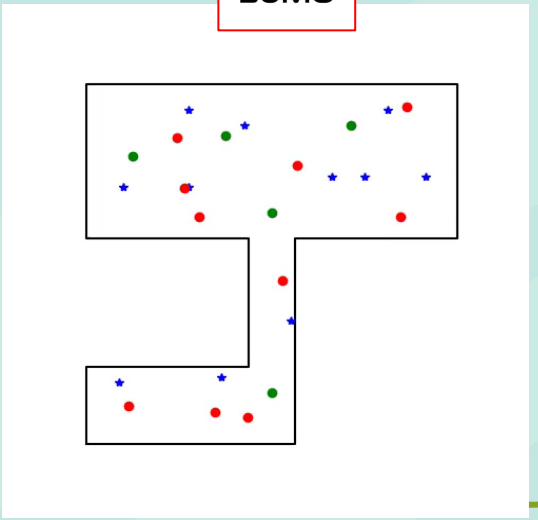


Environment Topology

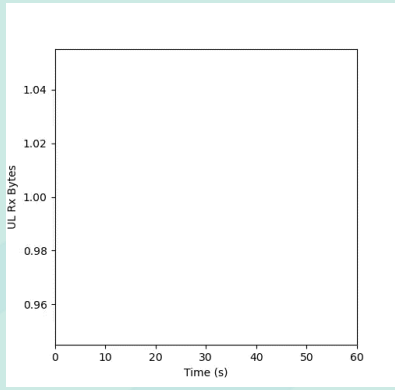
rerun.io

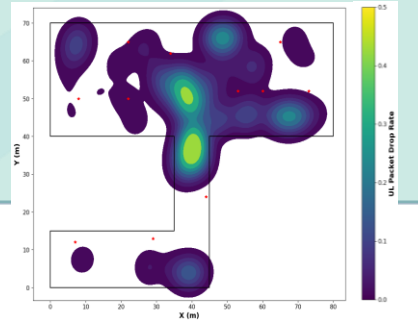
Mobility

SUMO



Performance Visualization

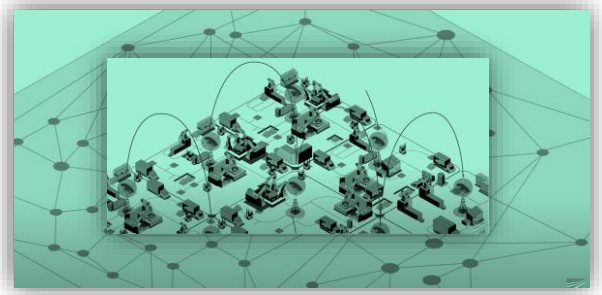




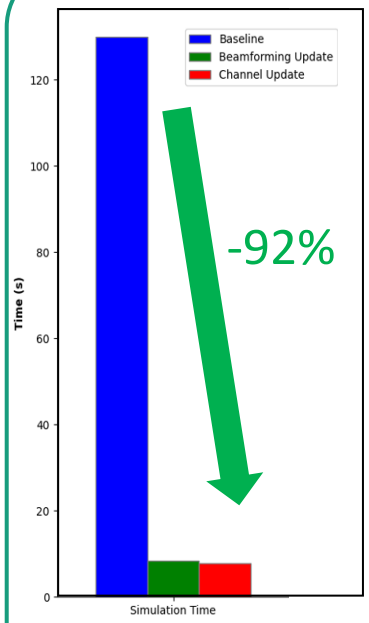
Developed NDT Usability

Modular framework

Open source contribution



Scenario generation



Scalability

Documentation

User friendliness

Abstractions

Deterministic simulations

A network simulator where we **understand the approximations in the model**, possess control over **customization and development**, have **enhanced performance**, **reduced complexity**, and can **adjust to the needs and use cases**.

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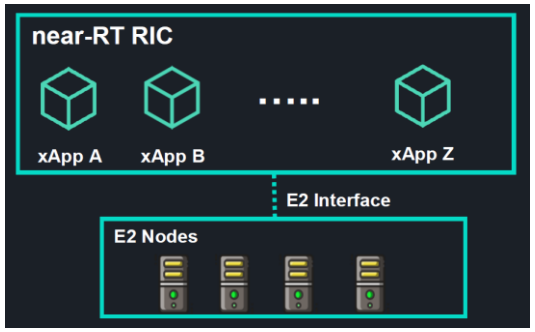
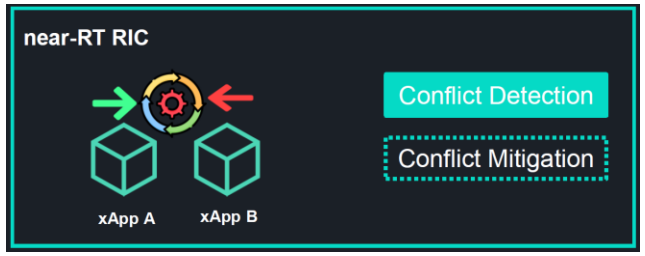
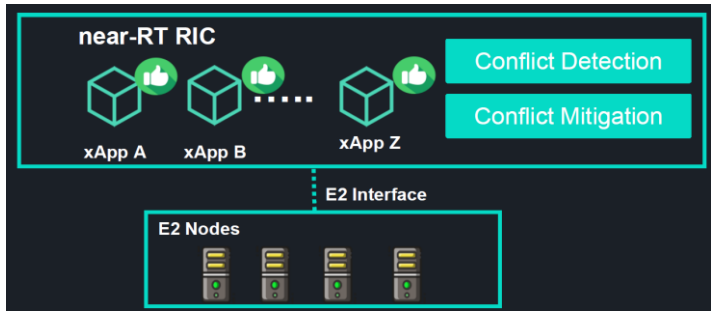
Conflict Management

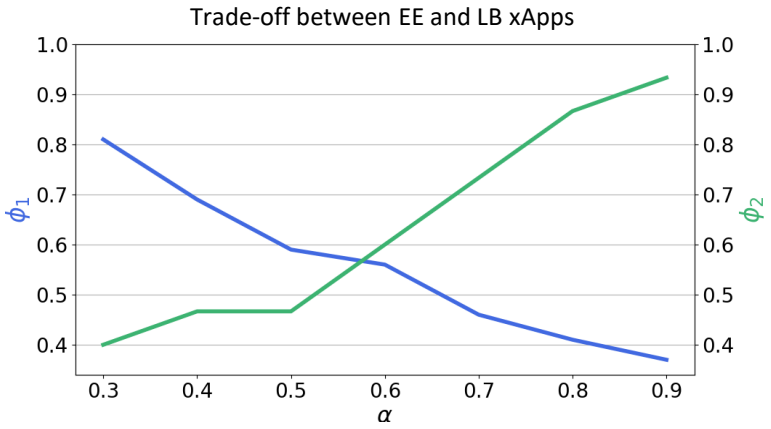
ORAN Digital Twin: Conflict Management in Multi-Vendor O-RAN Environments

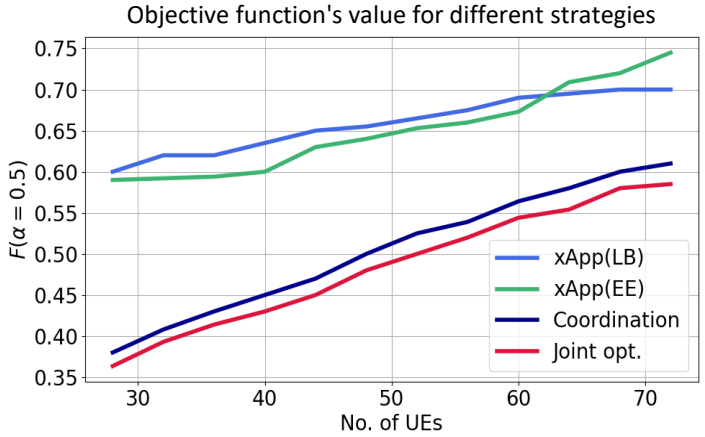
- Multi-vendor networks with xApps pursuing different optimization goals can create conflicts (e.g., load balancing vs. energy efficiency).
- Central coordination is needed to manage these conflicts effectively.

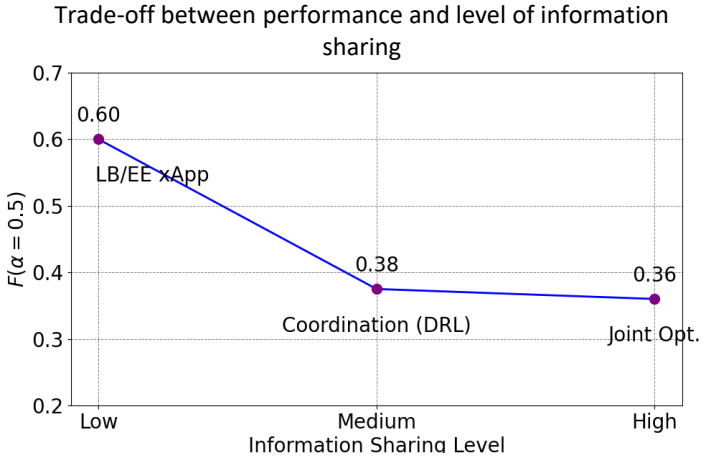












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Some New Questions for the NDT

- How does the network scale? (e.g., Berlin, Germany)
- What is the impact of a specific algorithm? (e.g., new handover strategy)
- Where are opportunities for customized services? (e.g., network slicing)
- Which areas of the network require attention or optimization?

One size doesn’t fit all

All Models are wrong, but some are useful

(Right Level of) Abstraction is All You Need

Capturing the characteristics

Scalability

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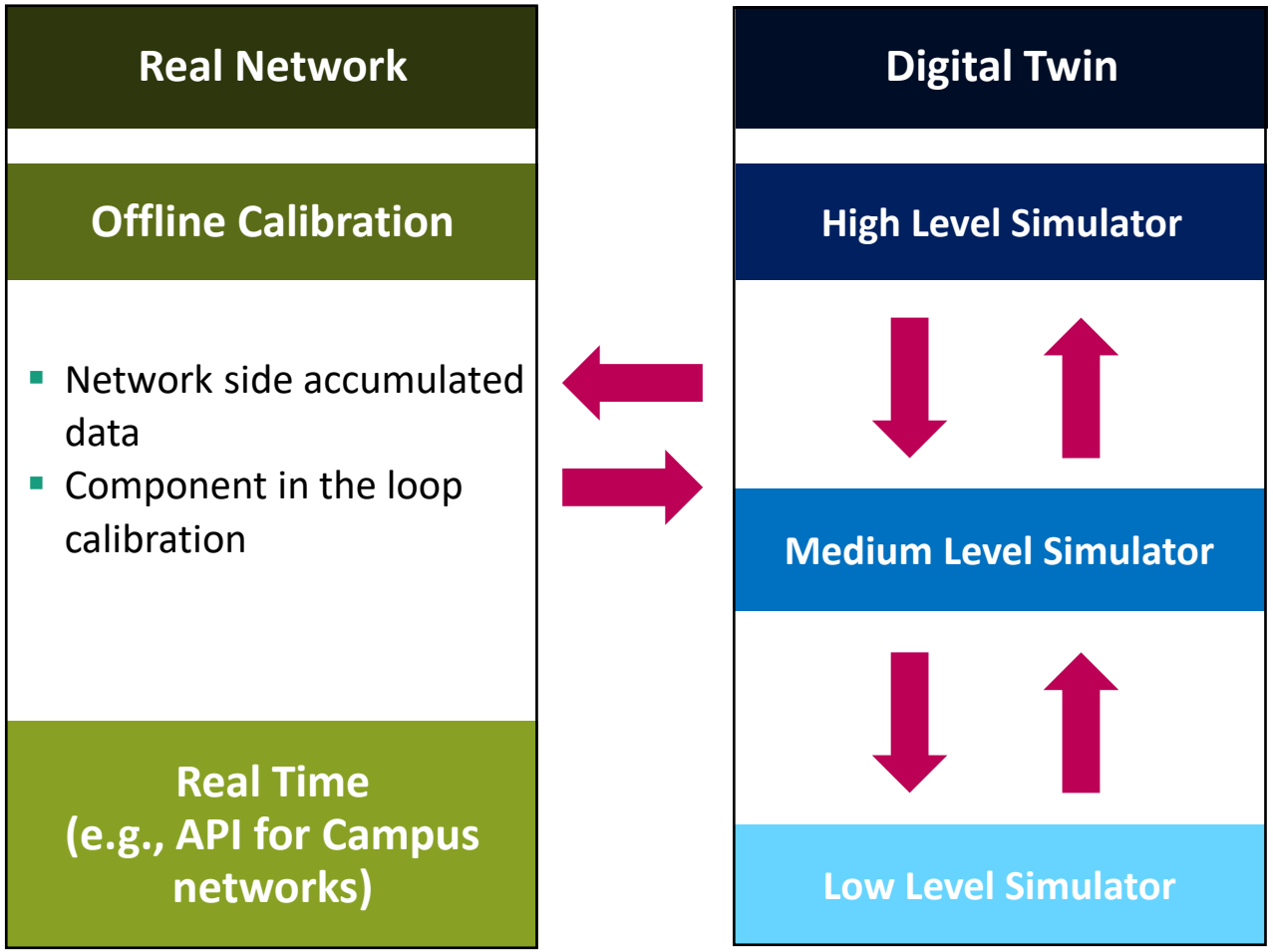
Multi-Level NDT



Abstraction

Time, Space, Users, and Functions

Overview
- **Broad Geographic Segmentation**
- **Preliminary Performance Assessment**
- **Identify Potential Bottlenecks**
- **Key questions to initiate**

Overview
- **Semi Broad Geographic Segmentation**
- **“Middle” level Assessment Accuracy**
- **Feedback for High Level**
- **Key questions to initiate**

Overview
- **Specific area of interest**
- **Detailed ns-3-based**
- **Feedback for Mid-Level**
- **Develop models about KPIs based on network parameters**

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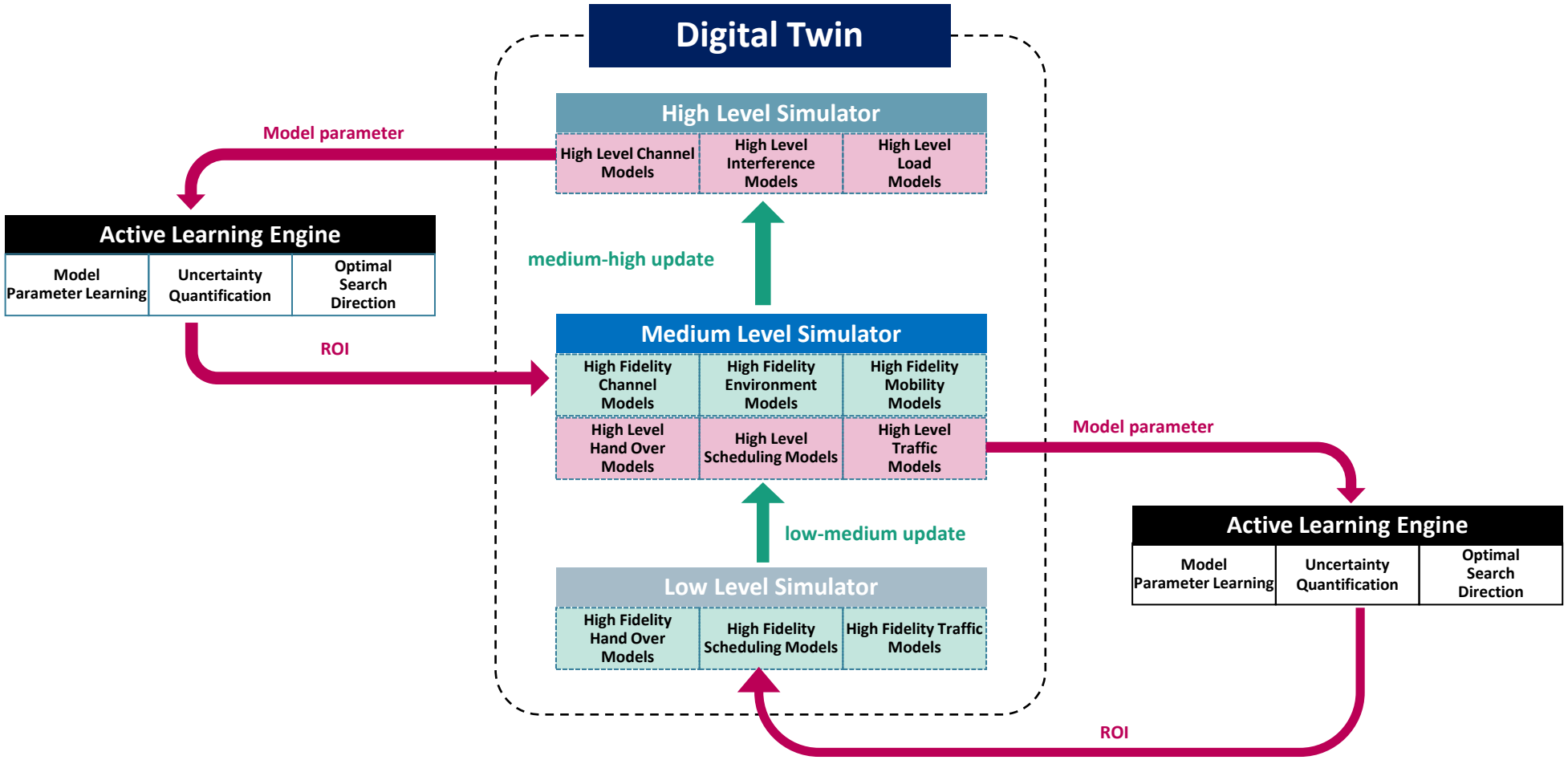
Multi Level Simulator

Interactions Across Abstraction Levels



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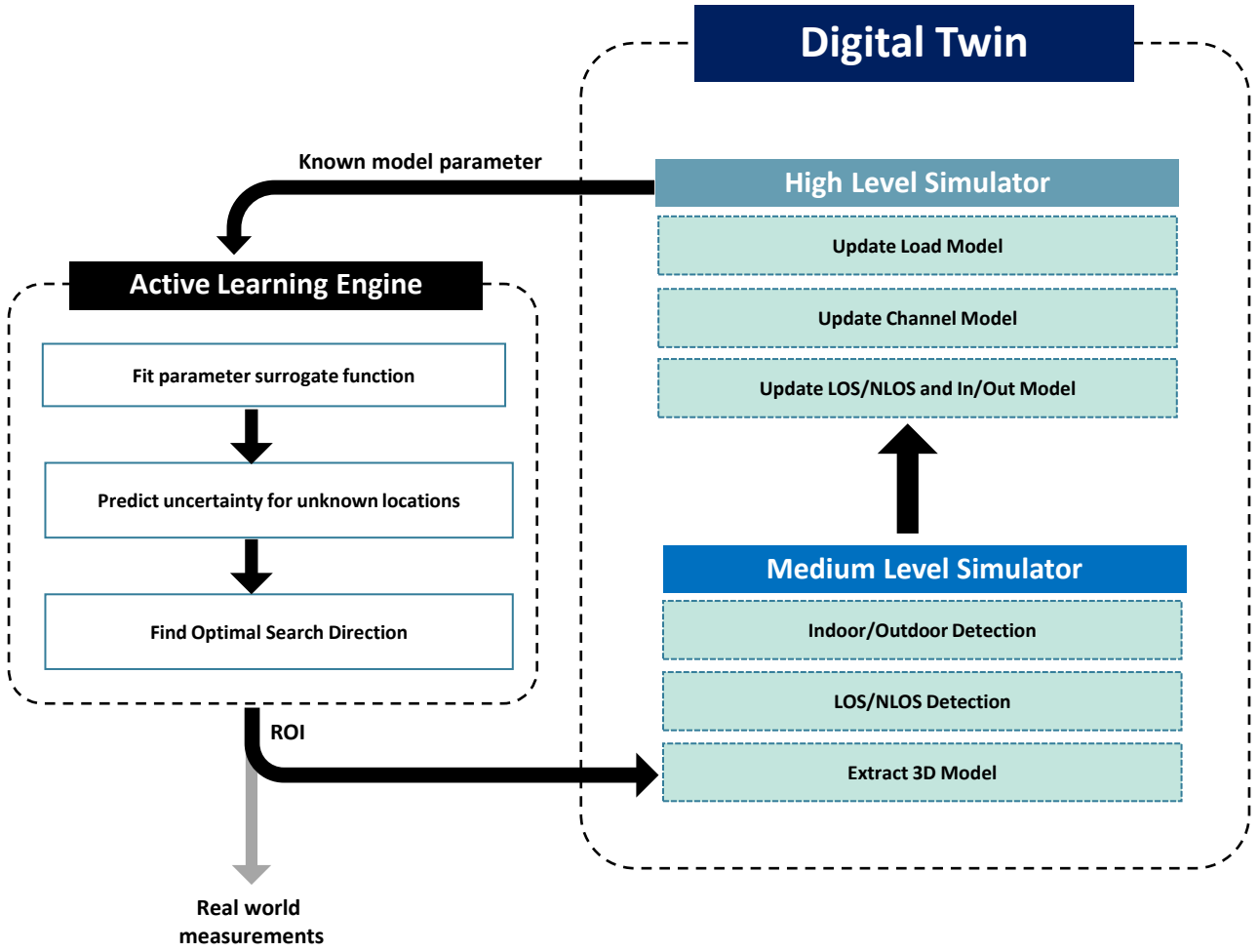
Network Load Monitoring

High-Level NDT

Network Load Monitoring

- **High-level simulator** uses statistical channel models for general performance estimation
- **Medium-level simulator** incorporates environment-specific details, including:
  - Line-of-Sight (LOS) vs. Non-Line-of-Sight (NLOS)
  - Indoor vs. Outdoor
  - Spatial distribution of users
- **Active learning engine** enhances sampling efficiency and reduces simulation overhead
- Further coupling with **real world** measurements possible



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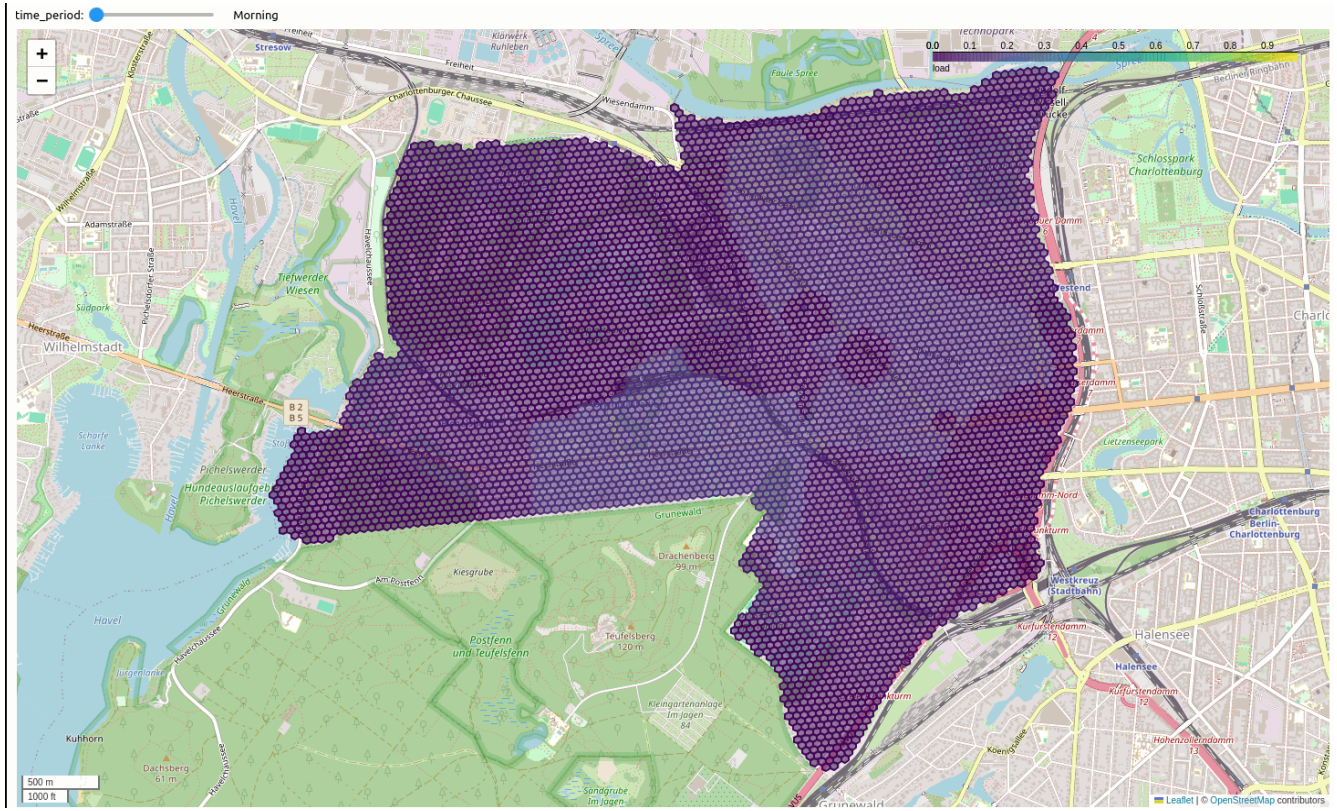
High-Level NDT

Load Simulation Throughout the Day

UE distribution	RMa	UMa	UMi
Morning	2%	30%	68%
Noon	1%	9%	90%
Afternoon	2%	13%	85%
Night	0%	10%	90%

	Morning	Noon	Afternoon	Night
#UEs	25000	38000	30000	18000
Demand	10 Kbps	15 Kbps	30 Kbps	60 Mbps



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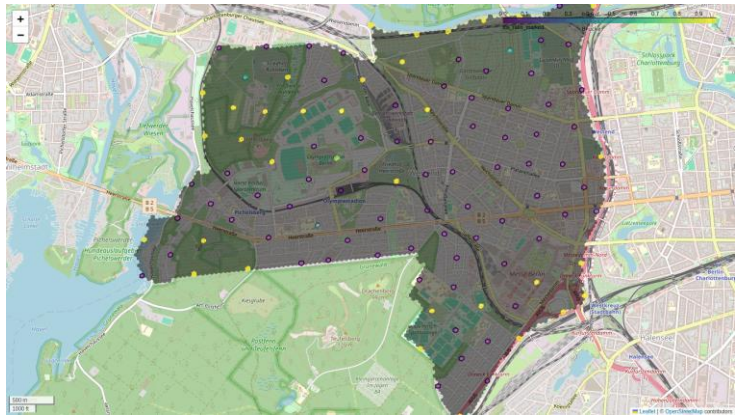
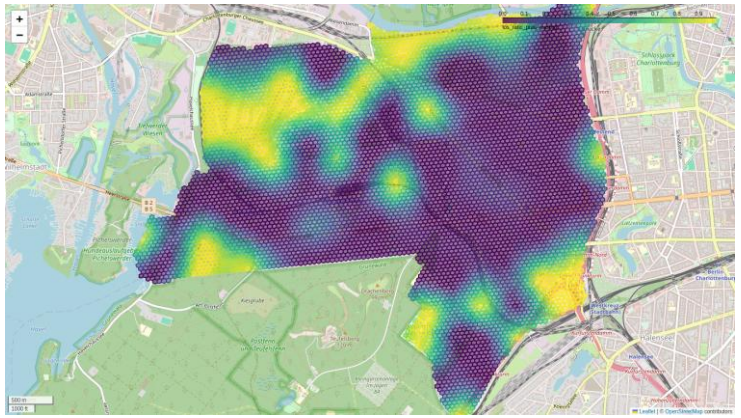
High-Level NDT

Medium-Level Feedback and Extrapolation: LOS ratio

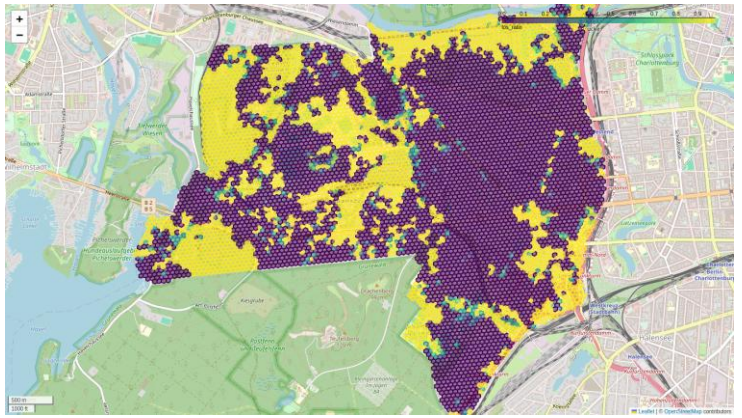
LOS ratio



LOS ratio kriging



Ground truth LOS ratio



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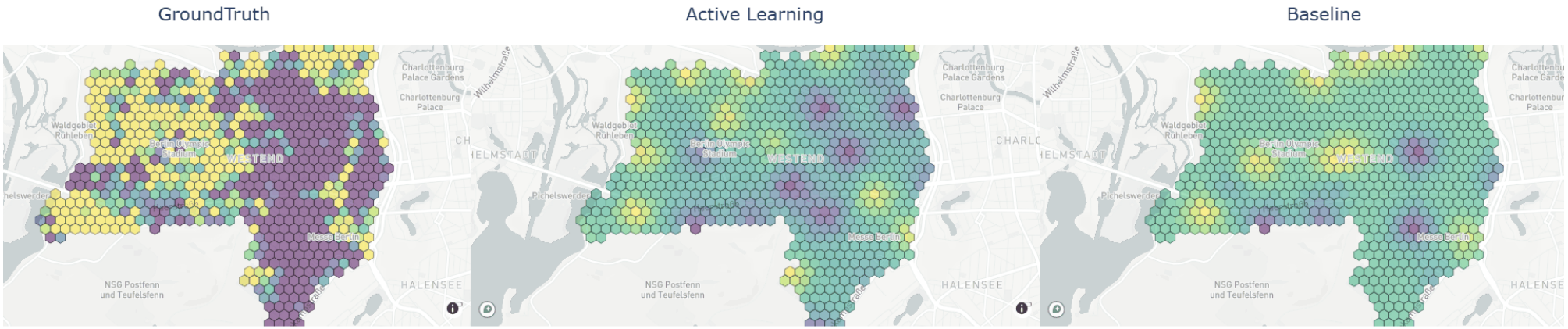
High-Medium Level NDT

Active Learning of LOS-Ratios



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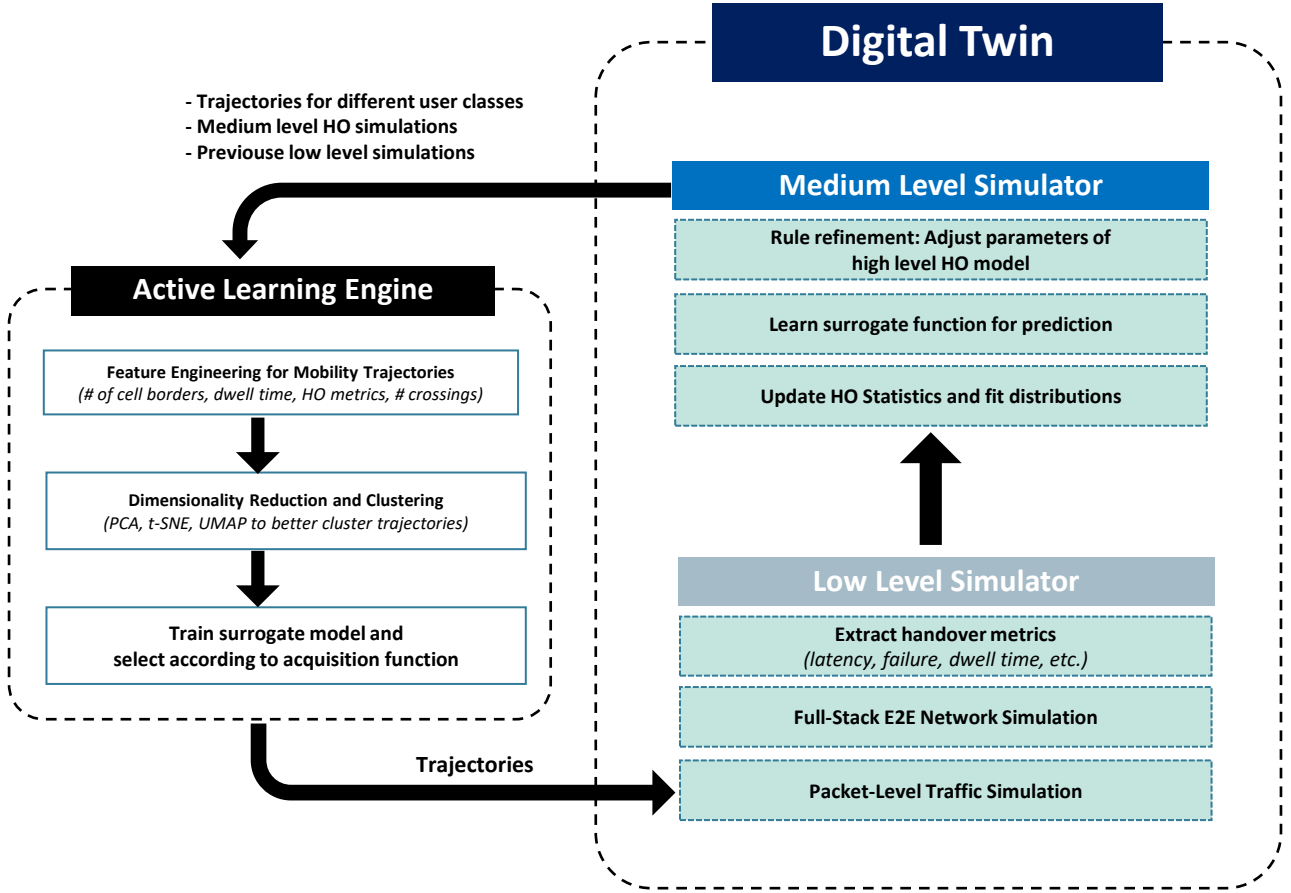
Handover Analysis

Medium–Low Level NDT

Handover Analysis

- **Medium-level simulator:**
  - High fidelity mobility and channel models
  - High level system level models, i.e., HO, scheduling
- **Low-level simulator:**
  - Packet level traffic simulation
  - Full stack E2E network simulation
- **Active learning engine**
  - Diversity sampling via clustering and parameter uncertainty prediction



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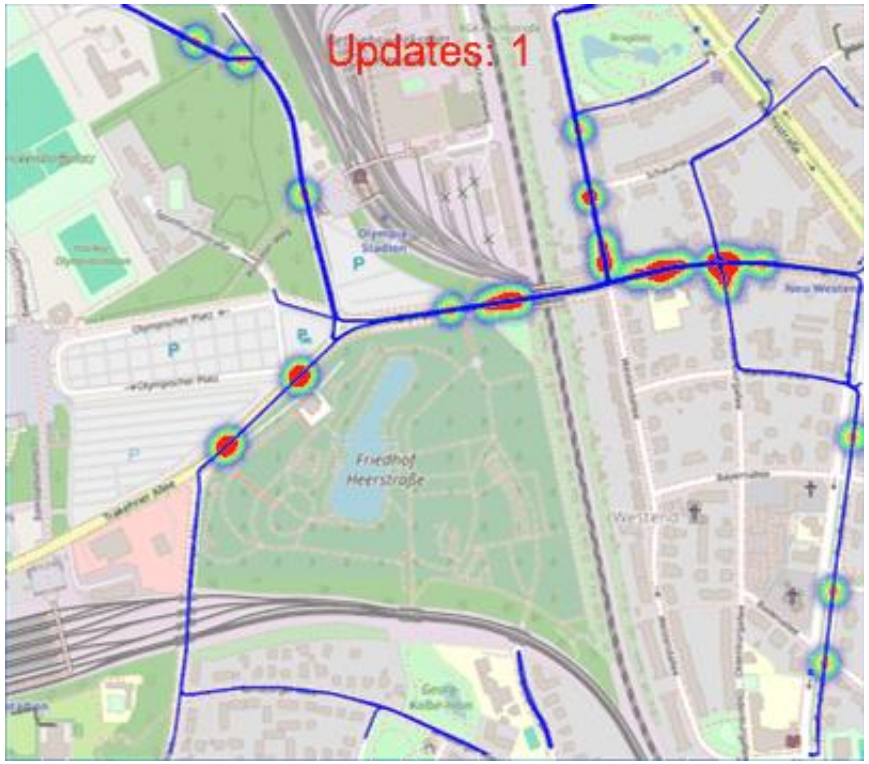
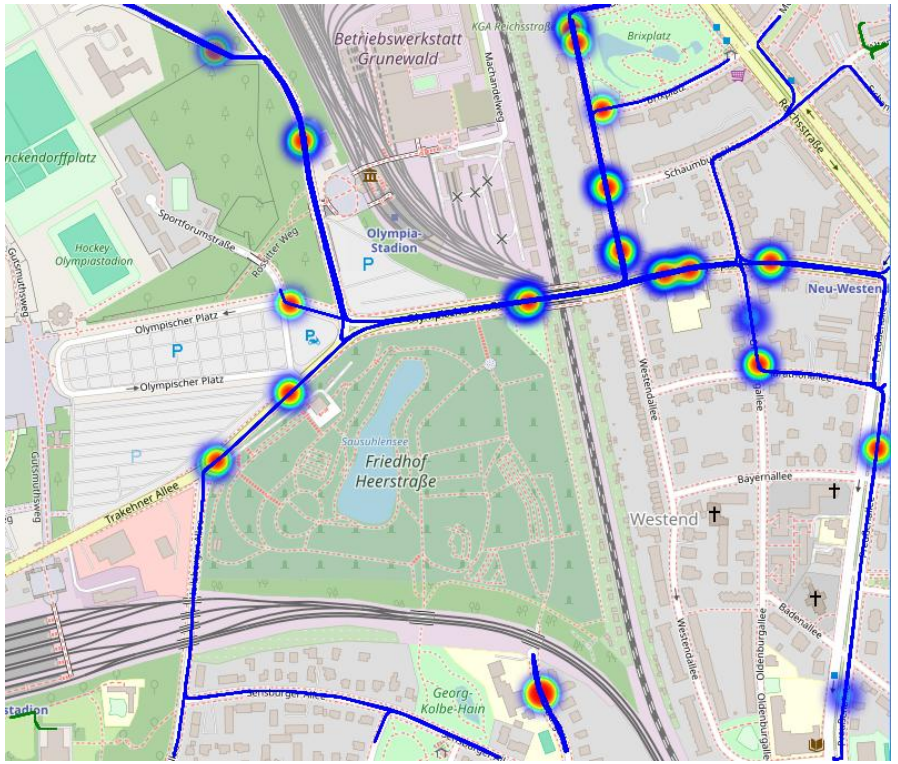
Medium–Low Level NDT

Handover Analysis

Medium-level NDT

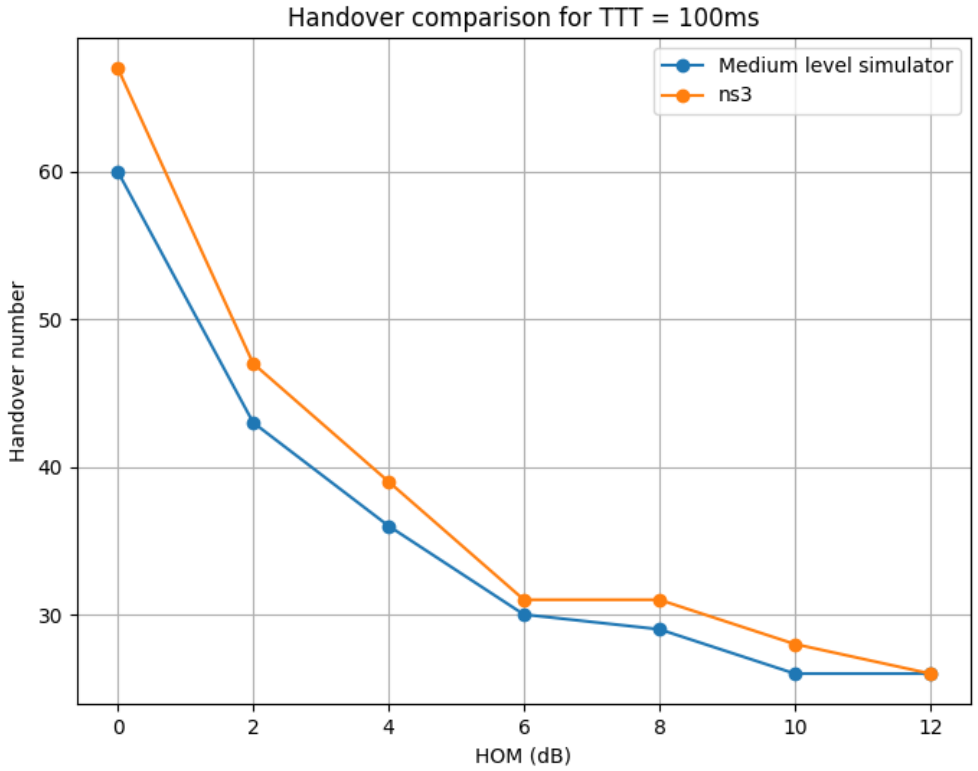


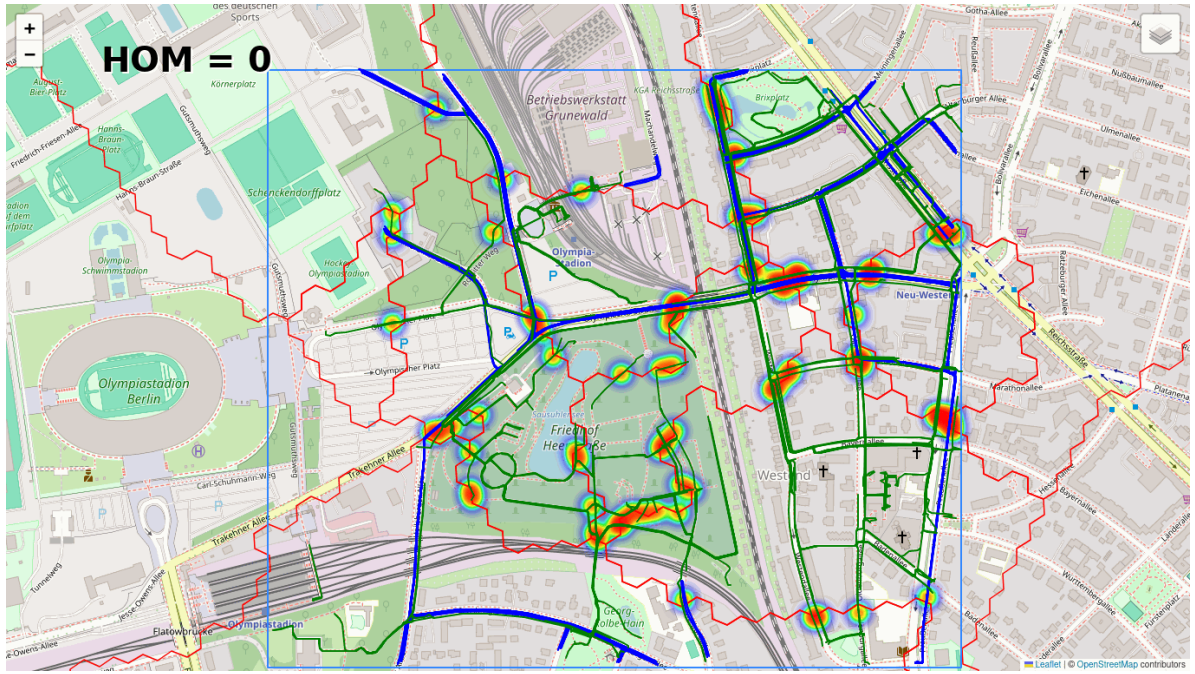
Low-level NDT



Medium–Low Level NDT

Handover Analysis





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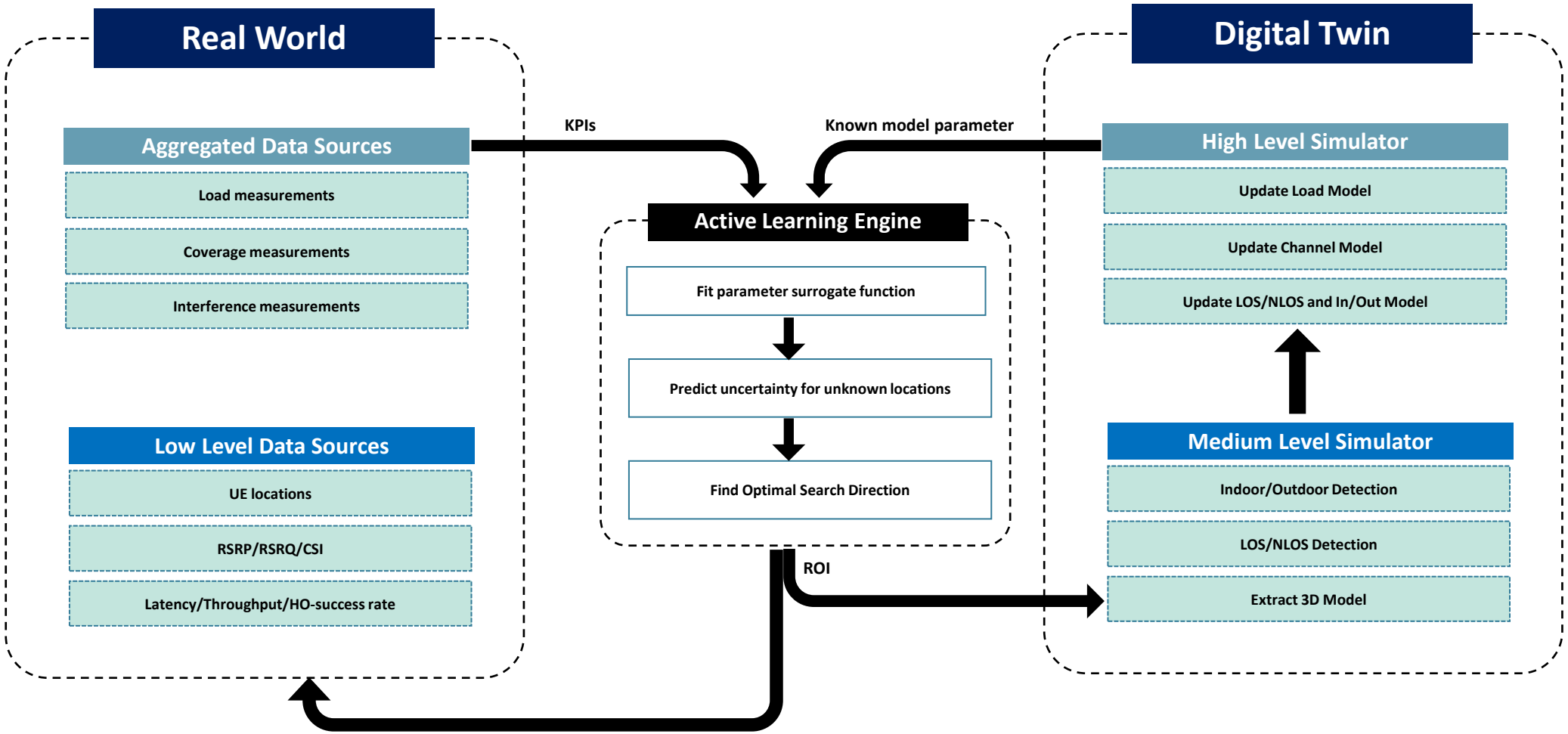
NDT Calibration



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If you want to go fast, go alone. If you want to go far, go together!

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Slawomir Stanczak

Patrick Agostini

Sven Haesloop

Vahid Rajabi

Hammad Zafar

Arndt Busse

T-Labs

Heiko Lehmann

Martin Stahn

Matthias Weh

Ns3 Playground Project

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Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, HHI

Thank you!

Questions?

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