TECHNISCHE UNIVERSITÄT WIEN

Bundesministerium Arbeit und Wirtschaft

Christian Doppler Forschungsgesellschaft

Digital Twin Assisting AI for Sustainable Radio Access Networks

Agnes Fastenbauer, Lukas Eller, Mariam Mussbah, Philipp Svoboda, Bashar Tahir, Sonja Tripkovic

Blickpunkt Forschung TU–Wien 2024

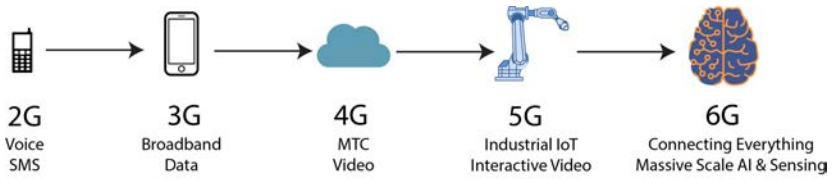
CD-Lab for Digital Twin Assisted AI for Sustainable Radio Access Networks

October 9, 2024

institute of telecommunications

ÖBB A1 NOKIA

Motivation and Challenge



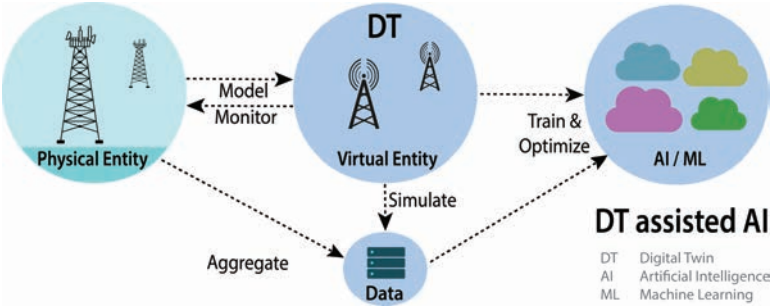
AI	Artificial Intelligence
IoT	Internet of Things
MTC	Machine Type Communication
SMS	Short Message Service

Motivation: Future wireless networks will support a wide variety of services

Challenge: Design for extreme flexibility while taming the inherent complexity

Goal: Achieving flexibility through awareness, adaptation, and optimization based on AI

DT: Virtual replica of a physical object, service, or system



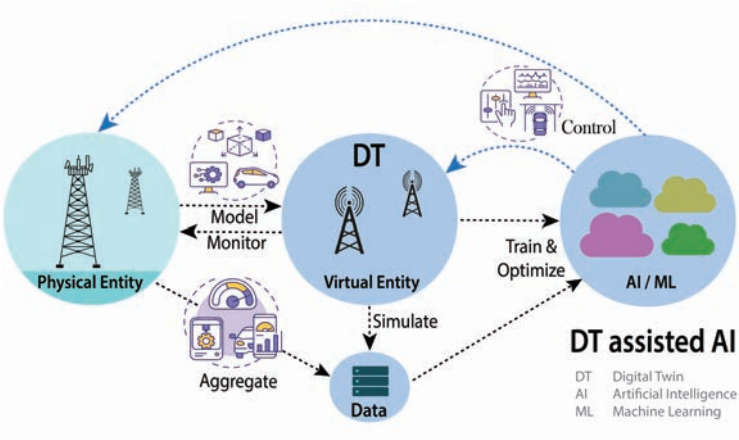
Challenges:

Large-scale, data modeling, real-time requirement, and model explainability

Requirements:

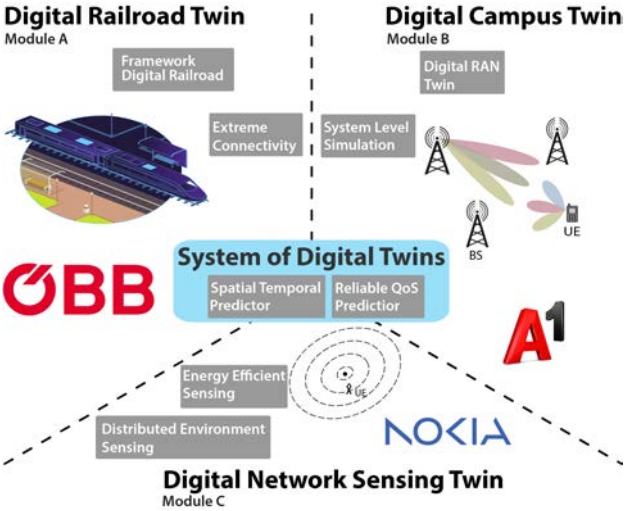
Accurate, relevant, up-to-date big-data

Digital Twin assisted AI



- Data-driven Digital Twin (DT) creation for centralized, local, and distributed AI
- Design and conduct large-scale measurement campaigns
- Distributed cooperative reinforcement learning for online resource optimization
- Preserve explainability across all DTs

Project in a Nutshell



Benefits for partners

- Local sensing AI
- Distributed control AI
- DT assisted AI in simulations
- Validation from data-set
- Cost reduction in infrastructure

- **CD-Lab for Digital Twin assisted AI for sustainable Radio Access Networks:**
  - A1 Telekom Austria: Network automatization and radio planning
  - OEBB Personenverkehr : Optimizing connectivity along railways
  - Nokia Solutions and Network: Network sensing and MIMO modeling

[a] Eller, Lukas, et al. "Localizing basestations from end-user timing advance measurements." IEEE Access, 2022

[b] Eller, Lukas, et al. "A Deep Learning Network Planner: Propagation Modeling Using Real-World Measurements and a 3D City Model." IEEE Access, 2022

[c] Eller, Lukas, et al. "A Differentiable Throughput Model for Load-Aware Cellular Network Optimization through Gradient Descent." IEEE Access, 2023 (Submitted)

Recent Work & Christian Doppler Laboratory

- **CD-Lab for Digital Twin assisted AI for sustainable Radio Access Networks:**
  - A1 Telekom Austria: Network automatization and radio planning
  - OEBB Personenverkehr : Optimizing connectivity along railways
  - Nokia Solutions and Network: Network sensing and MIMO modeling

- **Goal:** Data-driven modeling of cellular networks that enables efficient and scalable optimization → radio planning, coverage & capacity, energy-efficiency...

[a] Eller, Lukas, et al. "Localizing basestations from end-user timing advance measurements." IEEE Access, 2022

[b] Eller, Lukas, et al. "A Deep Learning Network Planner: Propagation Modeling Using Real-World Measurements and a 3D City Model." IEEE Access, 2022

[c] Eller, Lukas, et al. "A Differentiable Throughput Model for Load-Aware Cellular Network Optimization through Gradient Descent." IEEE Access, 2023 (Submitted)

Recent Work & Christian Doppler Laboratory

- **CD-Lab for Digital Twin assisted AI for sustainable Radio Access Networks:**
  - A1 Telekom Austria: Network automatization and radio planning
  - OEBB Personenverkehr : Optimizing connectivity along railways
  - Nokia Solutions and Network: Network sensing and MIMO modeling

- **Goal:** Data-driven modeling of cellular networks that enables efficient and scalable optimization → radio planning, coverage & capacity, energy-efficiency...

- **Own Previous Work:**
  - Localization of base stations from crowdsourced measurements[a]
  - Learning a data-driven propagation model from drive-tests[b]
  - Troughput model for cellular network optimization via gradient descent[c]

[a] Eller, Lukas, et al. "Localizing basestations from end-user timing advance measurements." IEEE Access, 2022

[b] Eller, Lukas, et al. "A Deep Learning Network Planner: Propagation Modeling Using Real-World Measurements and a 3D City Model." IEEE Access, 2022

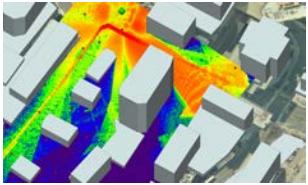
[c] Eller, Lukas, et al. "A Differentiable Throughput Model for Load-Aware Cellular Network Optimization through Gradient Descent." IEEE Access, 2023 (Submitted)

Deep Learning based Network Planning

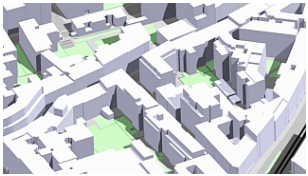
- **Radio planning** for optimal layout and antenna configurations
- Propagation modeling, cell-load, throughput ... → **Abstractions**
- Vast amount of "free" **monitoring data** available → **Data-Driven**

- **Publication**[a]: Drive-test RSRP measurements and 3D city model
- Substantially improved RSRP prediction → physically sound

- Sketch a path for a comprehensive **radio planning** scheme:
  1. Extent the empirical validation to **RS-SIR prediction**
  2. Data-driven **objective function** and methods for **optimization**



Ray-Tracing



City Model

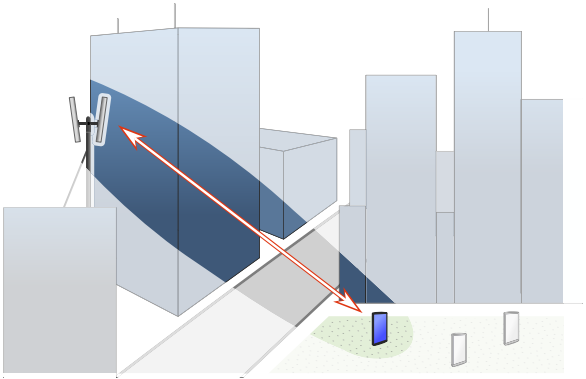
[a] Eller et al., "A Deep Learning Network Planner: Propagation Modeling Using Real-World Measurements and a 3D City Model," in IEEE Access, 2022

Sensing Digital Twins in Mobile Networks

- Current wireless systems focus on data transmission
- Channel in-between is estimated end-to-end

- Knowledge about the environment enables
  - **Environment-aware transmission**
  - Localization
  - Tracking
  - ...
  - **Digital twin (RF) construction**

- Future wireless systems integrate sensing / radar function
  - Integrated sensing and communications (ISAC)
  - Joint communications and sensing (JCAS)
  - ...

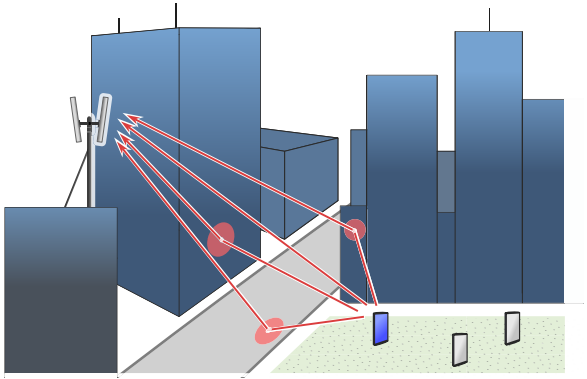


Sensing Digital Twins in Mobile Networks

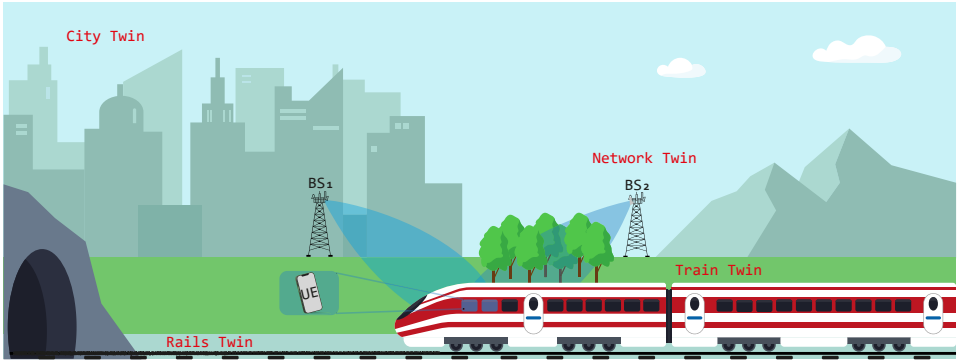
- Current wireless systems focus on data transmission
- Channel in-between is estimated end-to-end

- Knowledge about the environment enables
  - **Environment-aware transmission**
  - Localization
  - Tracking
  - ...
  - **Digital twin (RF) construction**

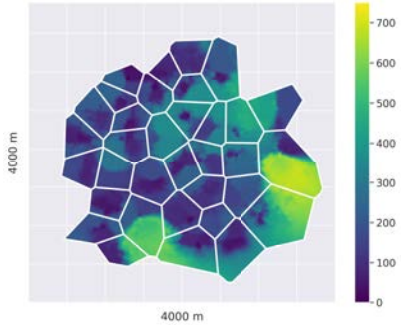
- Future wireless systems integrate sensing / radar function
  - Integrated sensing and communications (ISAC)
  - Joint communications and sensing (JCAS)
  - ...



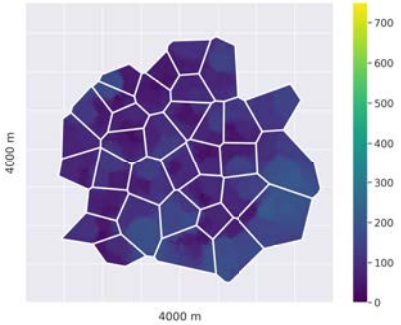
Digital Twins in Railroad Scenarios



Outage reduction near real–time power and tilt optimization



Outage Ratio: $\mathcal{L}_{\text{outage}} = 0.46$



Outage Ratio: $\mathcal{L}_{\text{outage}} = 0.15$

Summary & Conclusions

1. **Digital Twin Integration**:
   - Merge simulations with real-time data.
   - Create dynamic models for wireless networks.
2. **Network Management and Planning**:
   - Predict and optimize network behavior.
   - Proactively address network issues.
3. **Research at the Institute of Telecommunications**:
   - Vienna 5G Link Simulator
   - Vienna 5G System Simulator
   - RIS Measurements
   - mm – Indoor channel measurement
   - ML network prediction (MDT, drive test, . . .)
   - Digital Twin Railroad networks
   - Digital Twin for integrated communication and sensing

TECHNISCHE UNIVERSITÄT WIEN

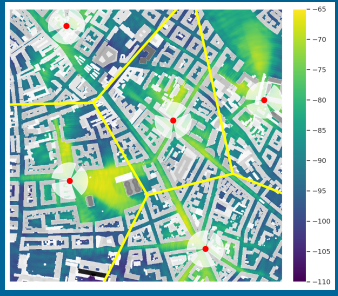
Bundesministerium Arbeit und Wirtschaft

Christian Doppler Forschungsgesellschaft

Thank you for your attention! Questions?

Agnes Fastenbauer, Lukas Eller, Mariam Mussbah, Philipp Svoboda, Bashar Tahir, Sonja Tripkovic
Blickpunkt Forschung TU–Wien 2024
first.last@tuwien.ac.at

Native AI Network Planning



institute of telecommunications

ÖBB A1 NOKIA