

Rodrigo Hernangómez

The Role of Machine Learning in Vehicular Networks

Lessons learned from the AI4Mobile project

Vehicular Networks

Drivers and Use Cases

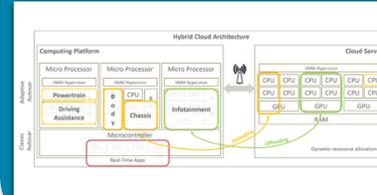
Vehicular Communication Services

Entertainment

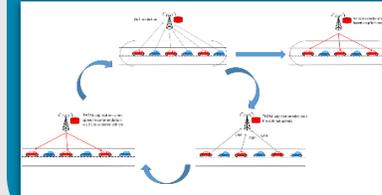
Navigation

Connected safety

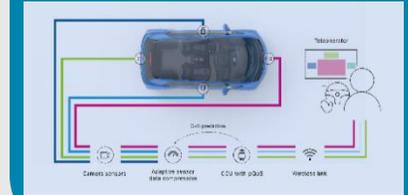
Car-as-a-Cloud



Traffic Homogenization



Teleoperated Driving



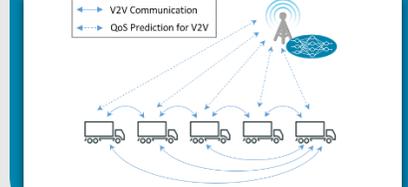
Conflict-free Map Distribution



Autonomous Route Clearance



Platooning



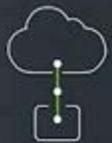
Remote Services

Trajectory Planning

D. F. Külzer *et al.*, "AI4Mobile: Use Cases and Challenges of AI-based QoS Prediction for High-Mobility Scenarios," in *IEEE VTC2021-Spring*, Apr. 2021.



Bosch
Research
bosch.com/research



Connection:
Bosch-Hildesheim



Throughput:
0.11 / 8.72
Mbps



Latency:
23 ms

70ms



0ms



ACTIVE
ECU Status: **Connected**



CampusOS



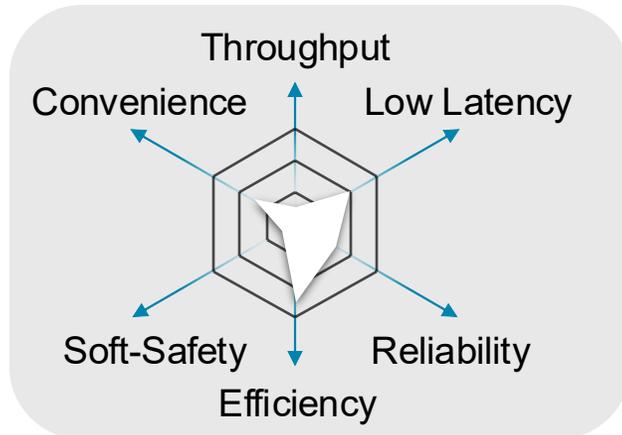
BOSCH

Vehicular Networks

Key Performance Indicators

Use-case specific

Timely guarantees for critical services



D. F. Külzer *et al.*, "AI4Mobile: Use Cases and Challenges of AI-based QoS Prediction for High-Mobility Scenarios," in *IEEE VTC2021-Spring*, Apr. 2021.

Machine Learning in Vehicular Networks

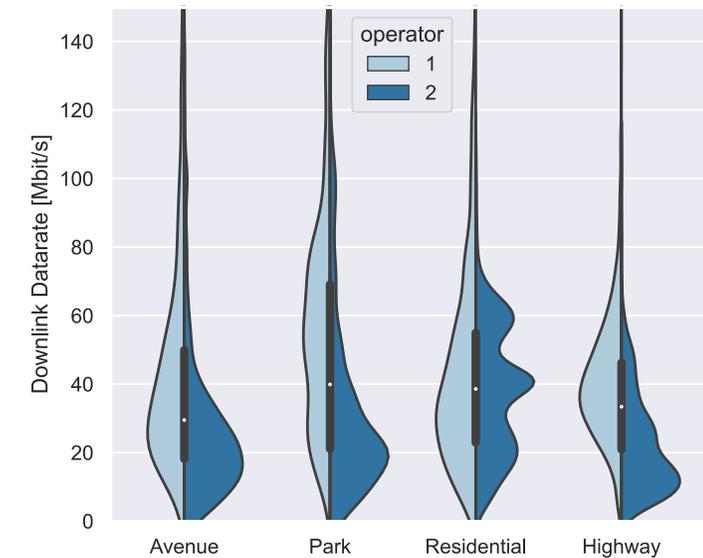
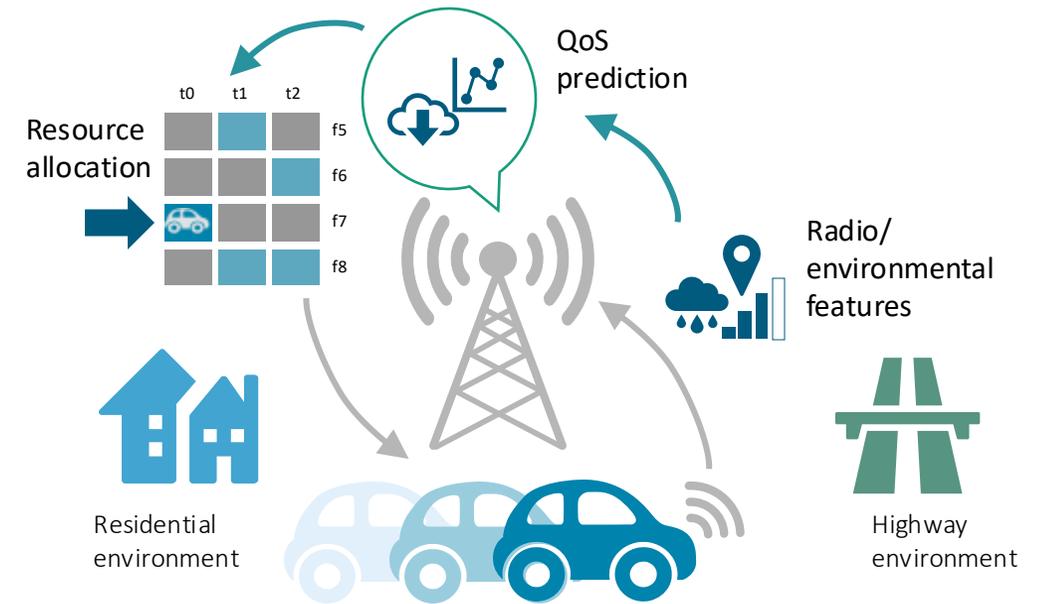
Opportunities and Challenges

Enabler for timely guarantees

- Predictive quality of service (QoS)
- Proactive radio resource management

AI/ML Challenges in Vehicular Networks

- Data acquisition and training
- Learning in highly dynamic environments (nonstationary statistics)



1. Data Acquisition

AI4Mobile Datasets

Dataset	Vehicles	Connectivity	Environment
5G-Testbed A9	 Automobile	 Cellular	 Highway/Rural
Berlin V2X	 Automobile	 Cell/Sidelink	 Highway/Urban
iV2V	 Ind. Robot	 Sidelink	 Industrial
iV2I+	 Ind. Robot	 Enterprise	 Industrial

- High variety of environments and radio access technologies
- Partially available at <https://iee-dataport.org/keywords/ai4mobile>



R. Hernangómez *et al.*, "Berlin V2X: A Machine Learning Dataset from Multiple Vehicles and Radio Access Technologies," in *IEEE VTC2023-Spring*.

R. Hernangómez *et al.*, "Toward an AI-Enabled Connected Industry: AGV Communication and Sensor Measurement Datasets," *IEEE Commun. Mag.*, Apr. 2024.

AI4Mobile Datasets

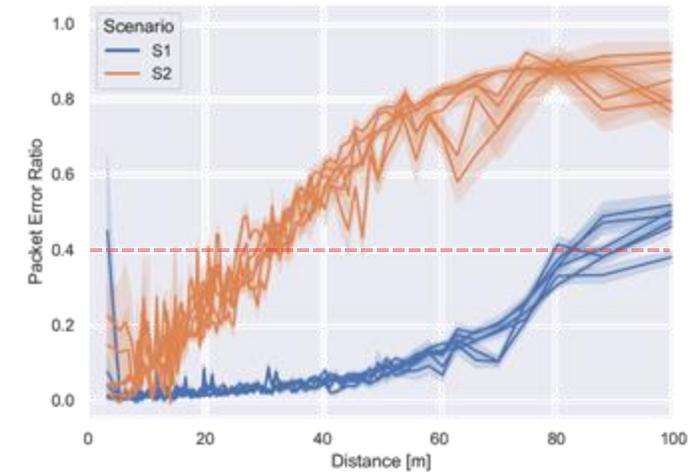
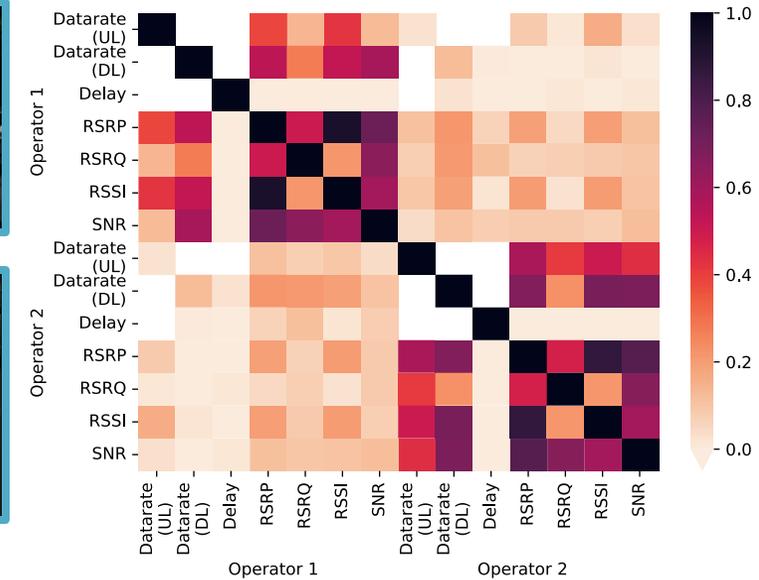
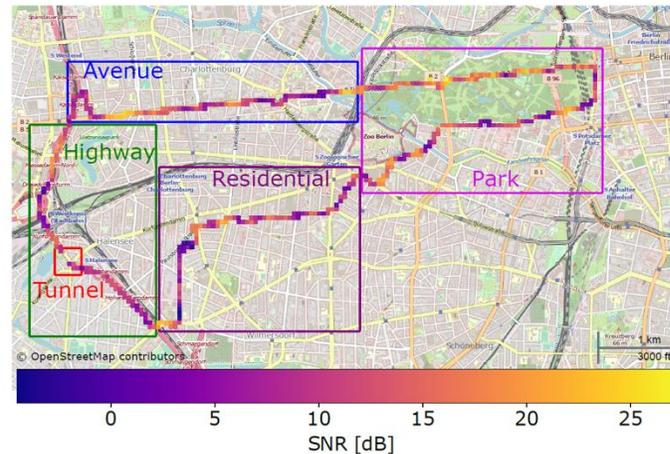
Berlin V2X

Key figures

- Over 800km drive test data, up to 4 cars
- 4 urban environments
- Full LTE stack from 2 operators
 - Datarate, latency and jitter
- Vehicle-to-vehicle sidelink
 - PHY layer & Packet loss
- GPS localization, weather, traffic

ITU AI/ML in 5G Challenge 2023

- Datarate prediction up to 95% accurate across operators/environments
 - Thorough feature engineering needed



R. Hernangómez *et al.*, "Berlin V2X: A Machine Learning Dataset from Multiple Vehicles and Radio Access Technologies," in *IEEE VTC2023-Spring*. github.com/fraunhoferhhi/BerlinV2X

2. Learning in High-Dynamic Environments

Insights from A9-Testbed

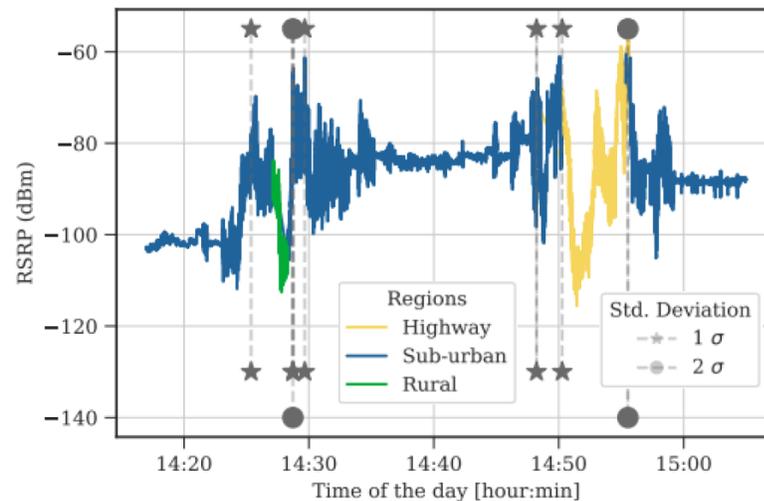
Statistical drifts in ultramobile connectivity

Violation of ML assumptions

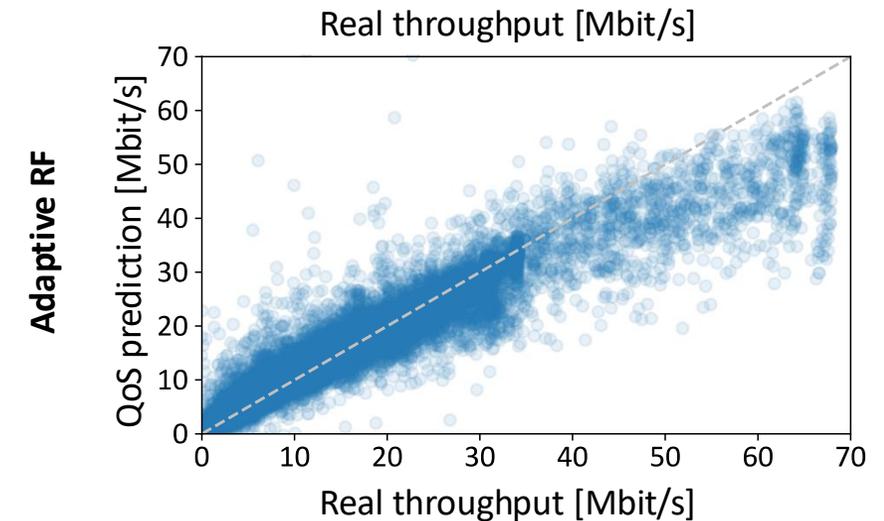
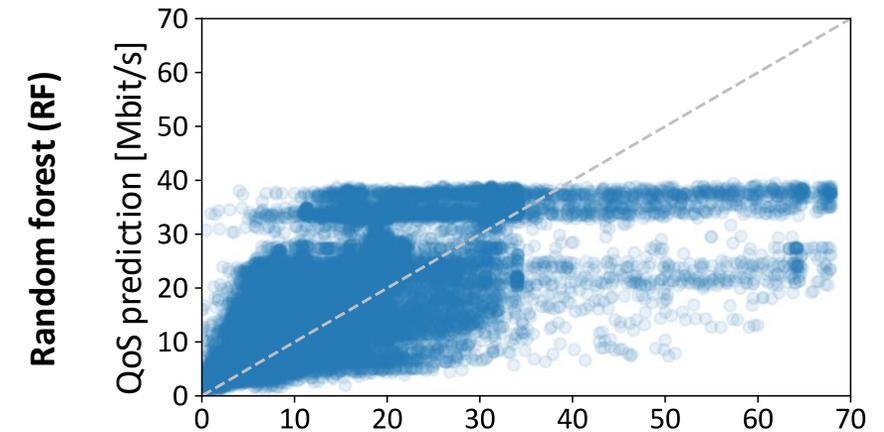
Nonstationary time series

Online algorithms

- Conventional AI cannot deliver
- Adaptive ML
 - Able to detect and react to drifts



Suburban training , highway evaluation



A. Palaios et al., "Machine Learning for QoS Prediction in Vehicular Communication: Challenges and Solution Approaches," *IEEE Access*, 2023.

R. Hernangómez, A. Palaios, G. Guruvayoorappan, M. Kasparick, N. U. Ain, and S. Stańczak, "Online QoS estimation for vehicular radio environments," *EUSIPCO* 2022.

Industrial AI4Mobile

ML beyond wireless data

iV2I+ Dataset

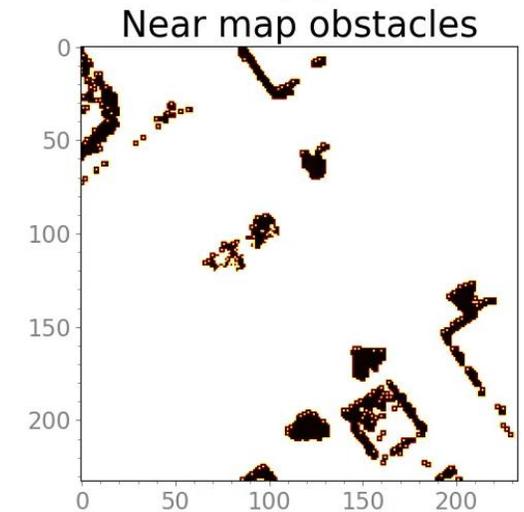
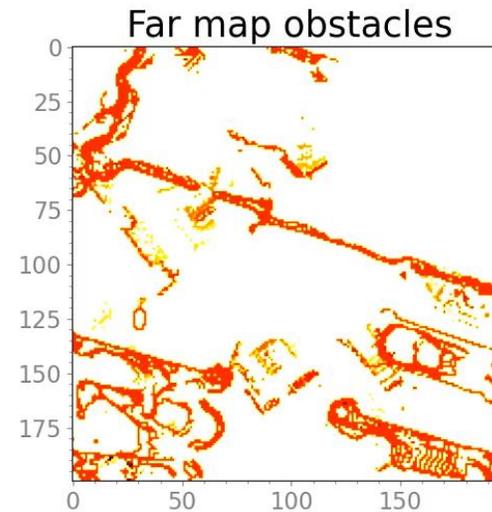
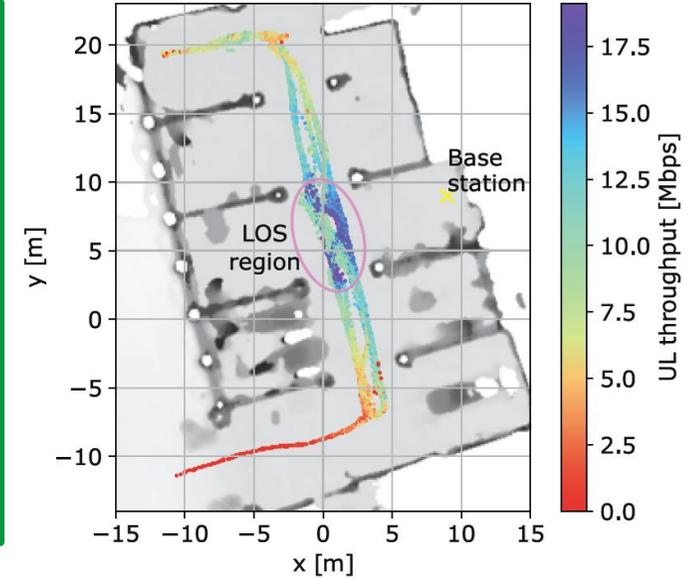
Industrial autonomous sweeping robot

- Connected to campus network
- LTE & QoS data
- + Robot sensory data
 - Odometry, LIDAR, etc.

Sensing data

- Additional insights
 - e.g., line-of-sight (LOS) detection
- Digital twins
- Sensing via wireless?
 - Integrated sensing and communication (ISAC)

R. Hernangómez *et al.*, "Toward an AI-Enabled Connected Industry: AGV Communication and Sensor Measurement Datasets," *IEEE Commun. Mag.*, 2024. github.com/fraunhoferhhi/ai4mobile-industrial



Machine Learning in Vehicular Networks

In a nutshell

ML enables connected mobility

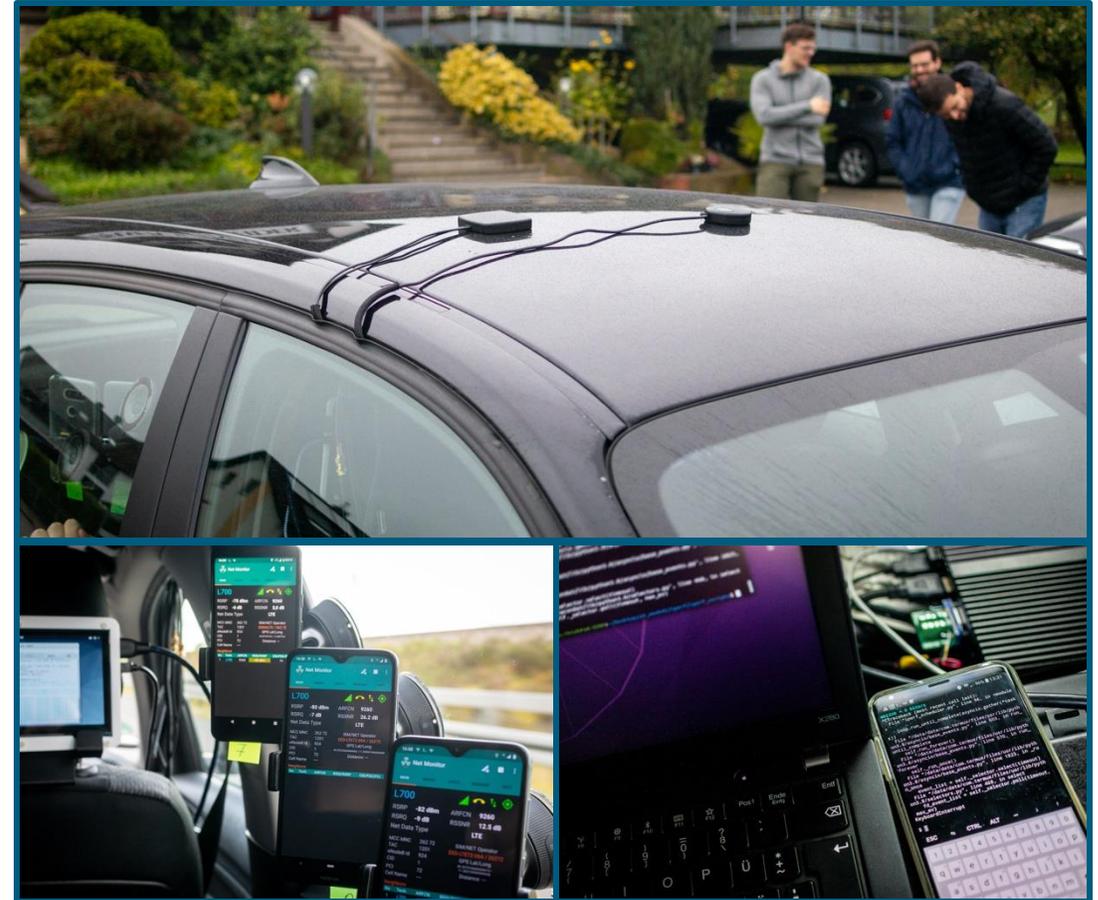
For recreational and **critical** use cases

- ML provides guarantees via
 - QoS prediction
 - Proactive resource allocation

High-speed mobility challenges

Very dynamic environments

- Basic ML is not enough
- Way forward:
 - Adaptive learning
 - Rich datasets, open to all



Thank you for your attention

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