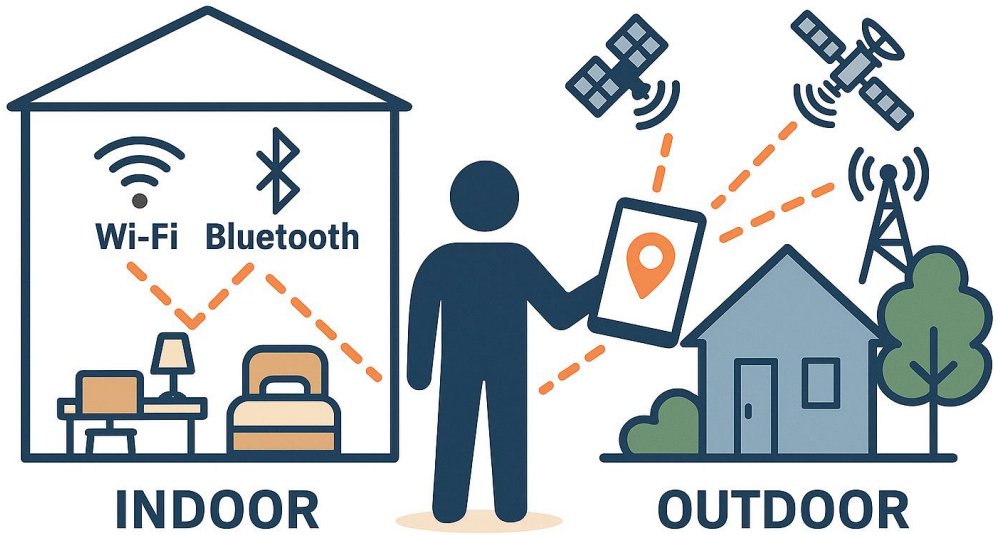
Dipl.-Ing. Albrecht Michler
TUD Dresden University of Technology, Chair of Traffic Systems Information Technology

An Empirical Assessment of Indoor-Outdoor Localization Based on Signals of Opportunity from Multiple Systems

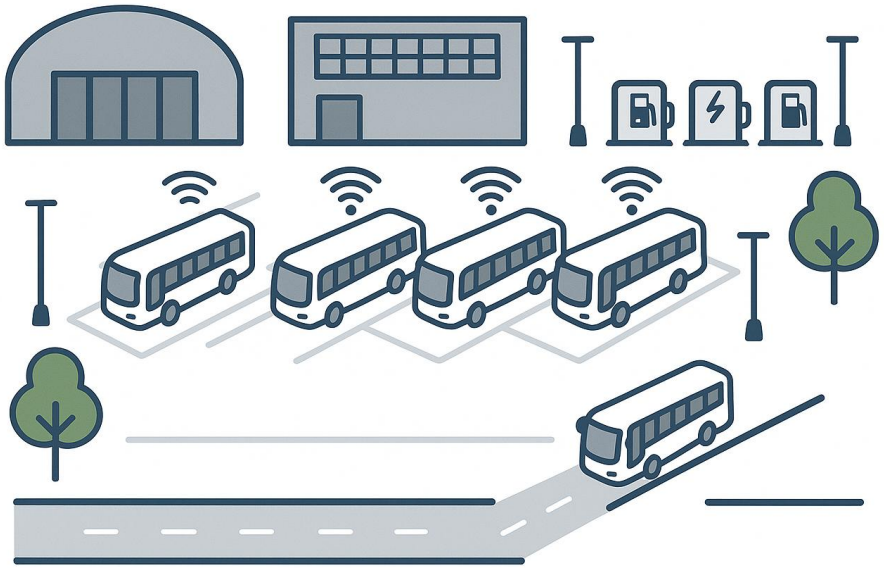
IEEE/ION PLANS 2025
Salt Lake City // 01.05.2025

Motivation

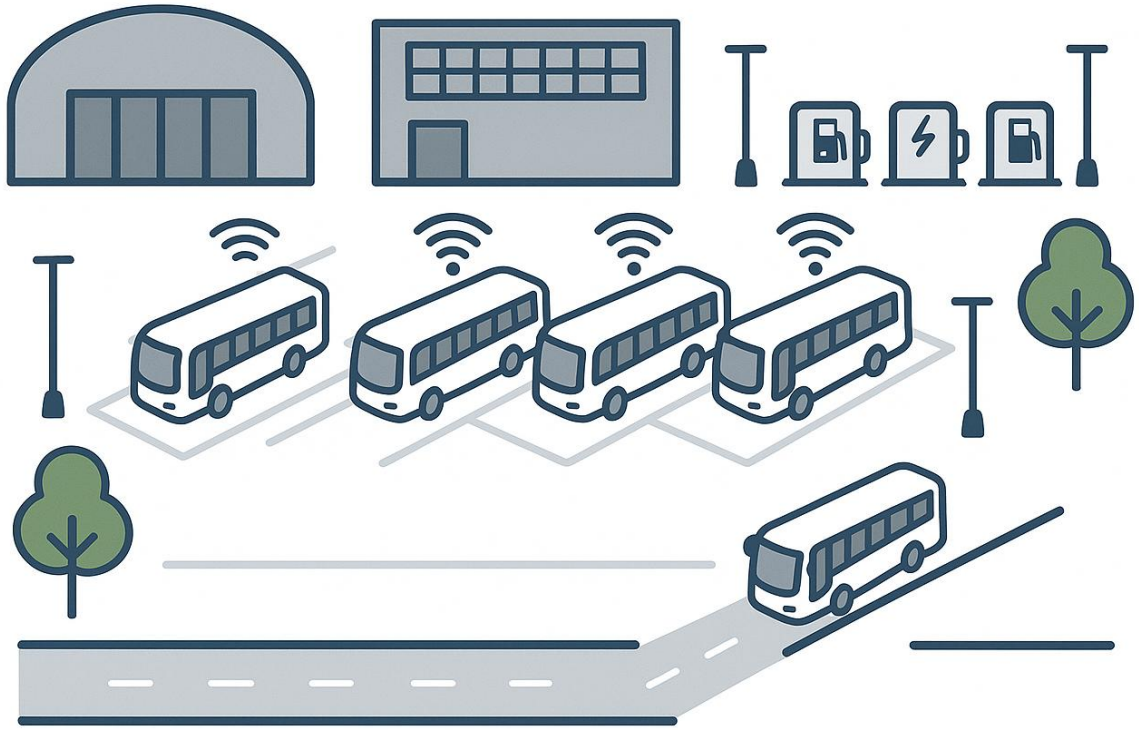
INDOOR–OUTDOOR POSITIONING



AUTOMATED BUS DEPOT



AUTOMATED BUS DEPOT



Cleaning

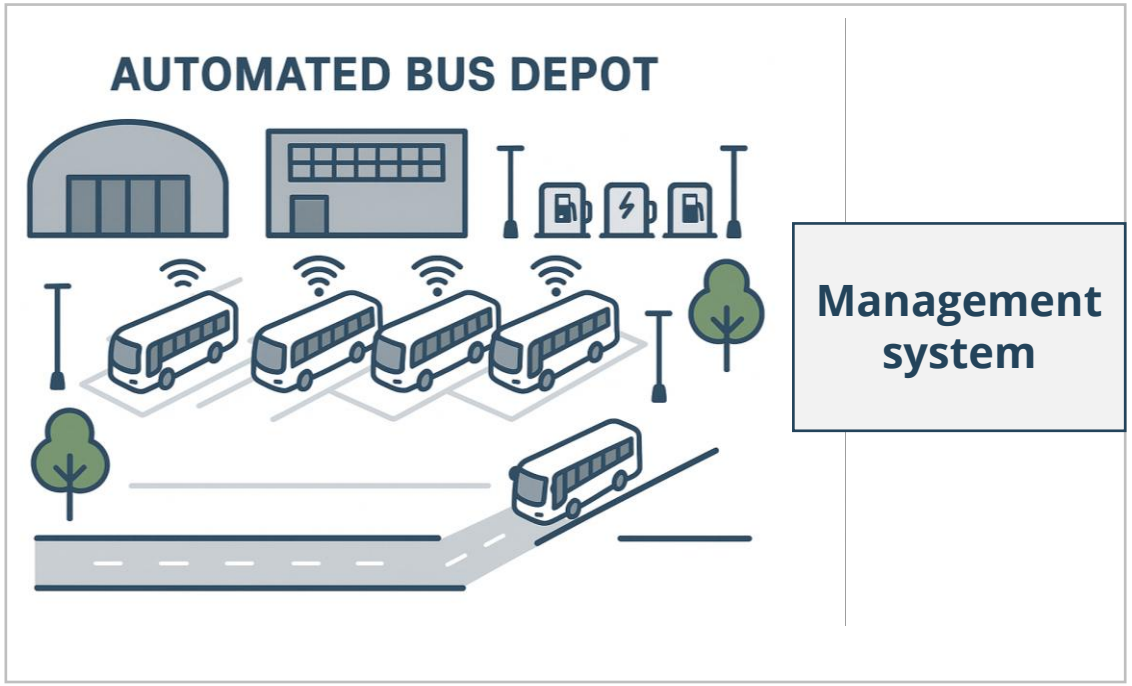
Driver pickup

Maintainance

Refueling

Charging

Parking



Management system

Tasks

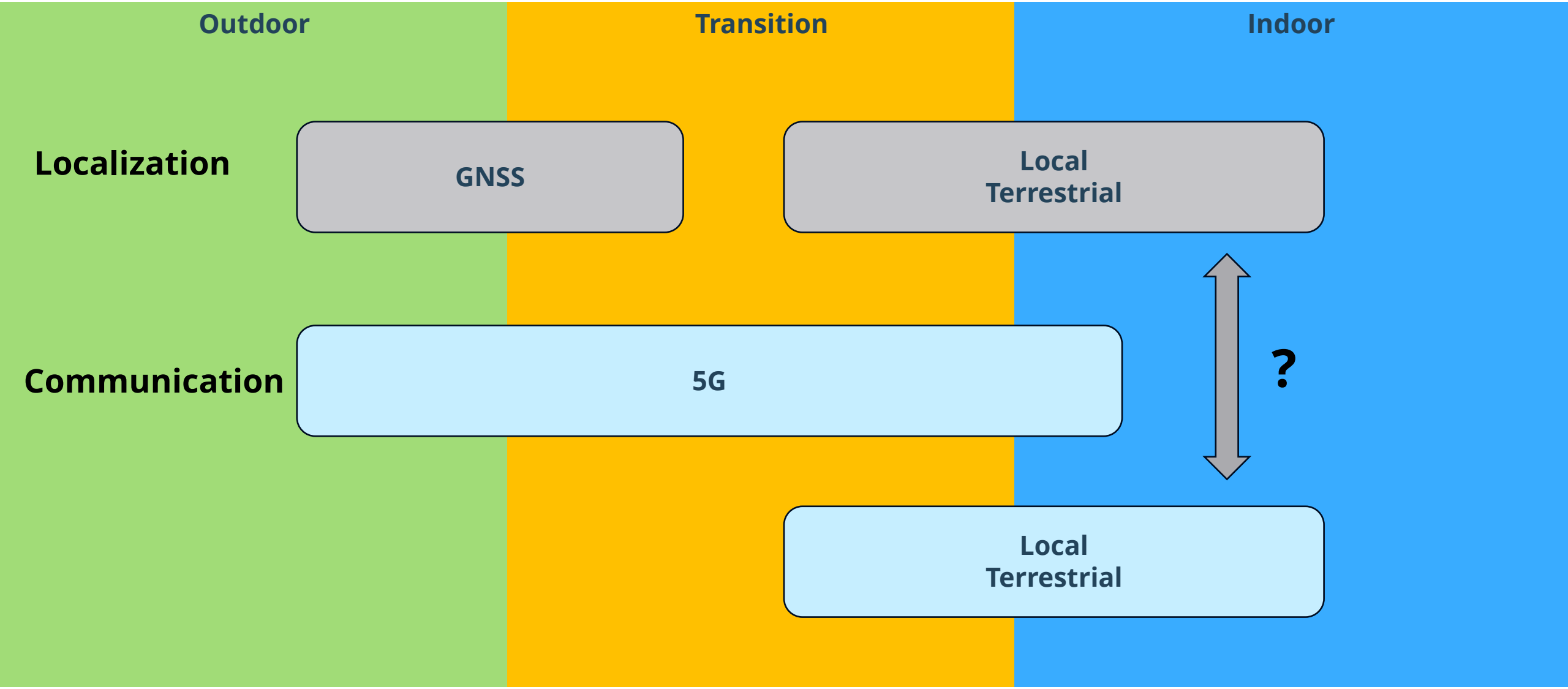
induce

Process Requirements
- Location
- State

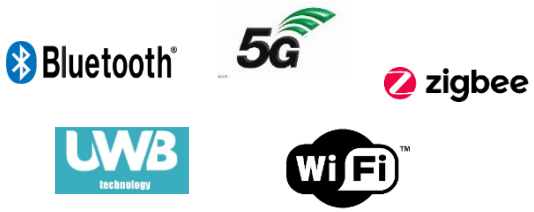
need

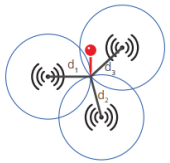
Technological Solutions

- Localization
- Communication

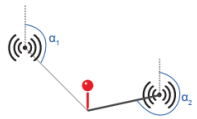

Outdoor
Transition
Indoor
Localization
GNSS
Local
Terrestrial
Communication
5G
?
Local
Terrestrial

Localization & Communication

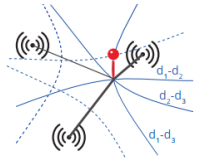




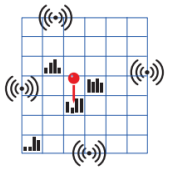
Lateration



Angulation



Hyperbolic



Fingerprinting

Sensor technology

Measurement principle

Positioning algorithm

Least squares

EKF

Particle filter

Grid positioning

Factor graph

Finger-printing (AI?)

Requirements

- Leverage existing system → Joint communication, localization and sensing
- Scalability, cost-efficiency

- Robust against outliers and multipath
- Allow for high accuracy

- Allow for asynchronous, aperiodic data
- Incorporate vehicle dynamics and 3D map data

Terrestrial Technology Candidates

UWB

Two-way ranging
Time difference of Arrival

Ranging
Hyperbolic

5G NR

Positioning reference signal

Ranging
Angulation
Hyperbolic

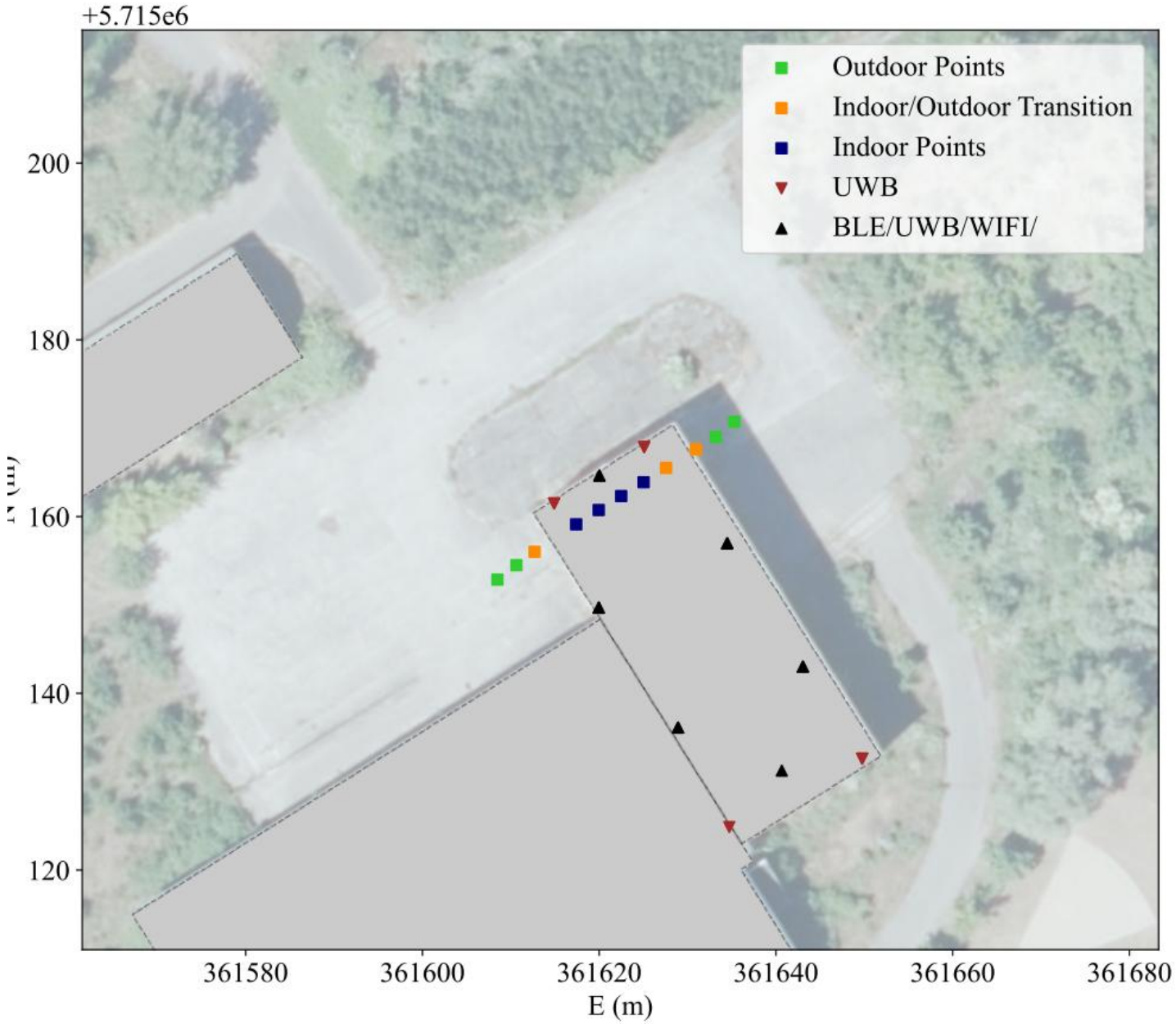
Bluetooth
"Channel sounding"

Phase-based ranging
Round-trip time
Ranging
Angulation

WiFi
"Fine time measurement"

Round-trip time (RTT)
Ranging

Measurement campaign







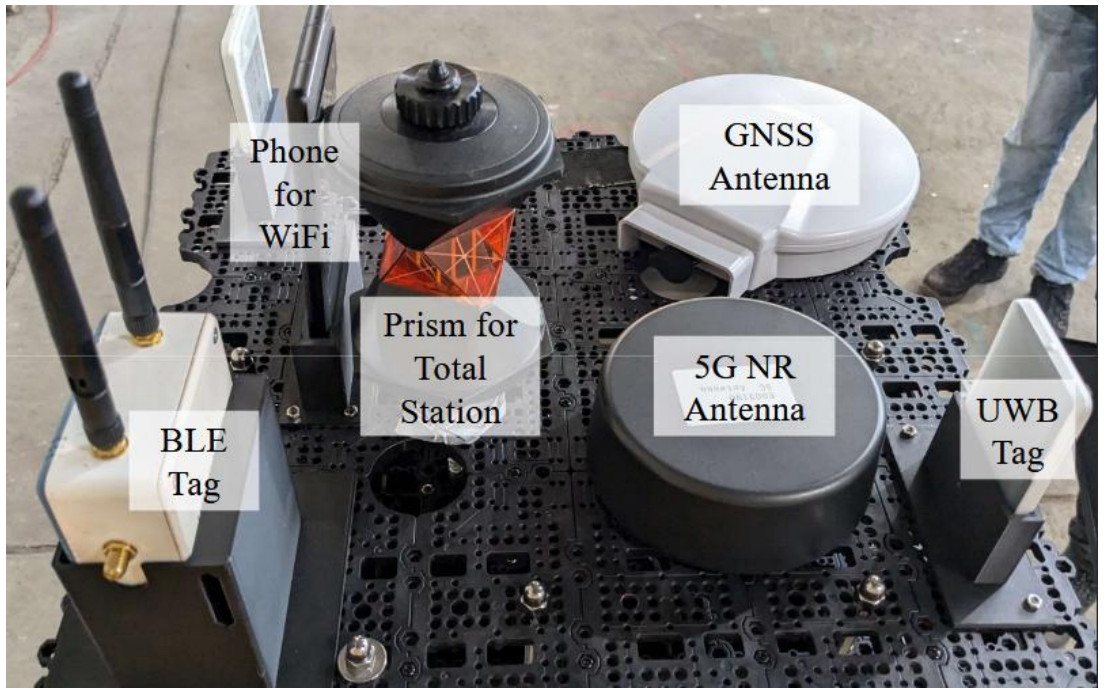
Torgau, Germany

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Measurement setup
Vehicle

GNSS
Novatel PwrPak 7
GNSS-IMU fusion

WiFi
Pixel 6a smartphone +
WifiRttScan App



5G NR
Proprietary solution :(

BLE
Metirionic DMK 215
Bluetooth 6.0 channel
sounding PBR

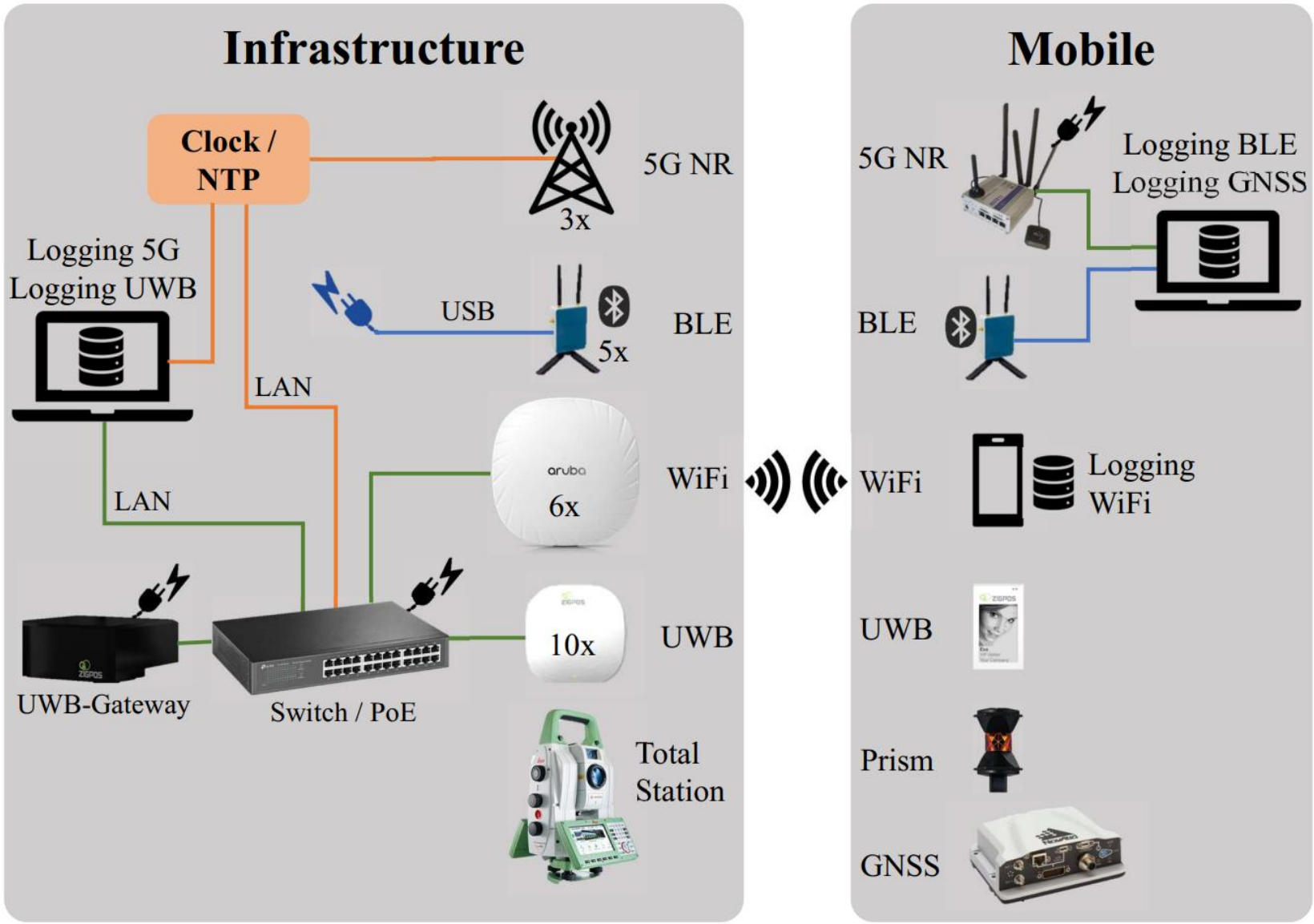
UWB
Zigpos RTLS
UWB two-way ranging

Ground truth
Total station Leica TS15
+ tracking prism

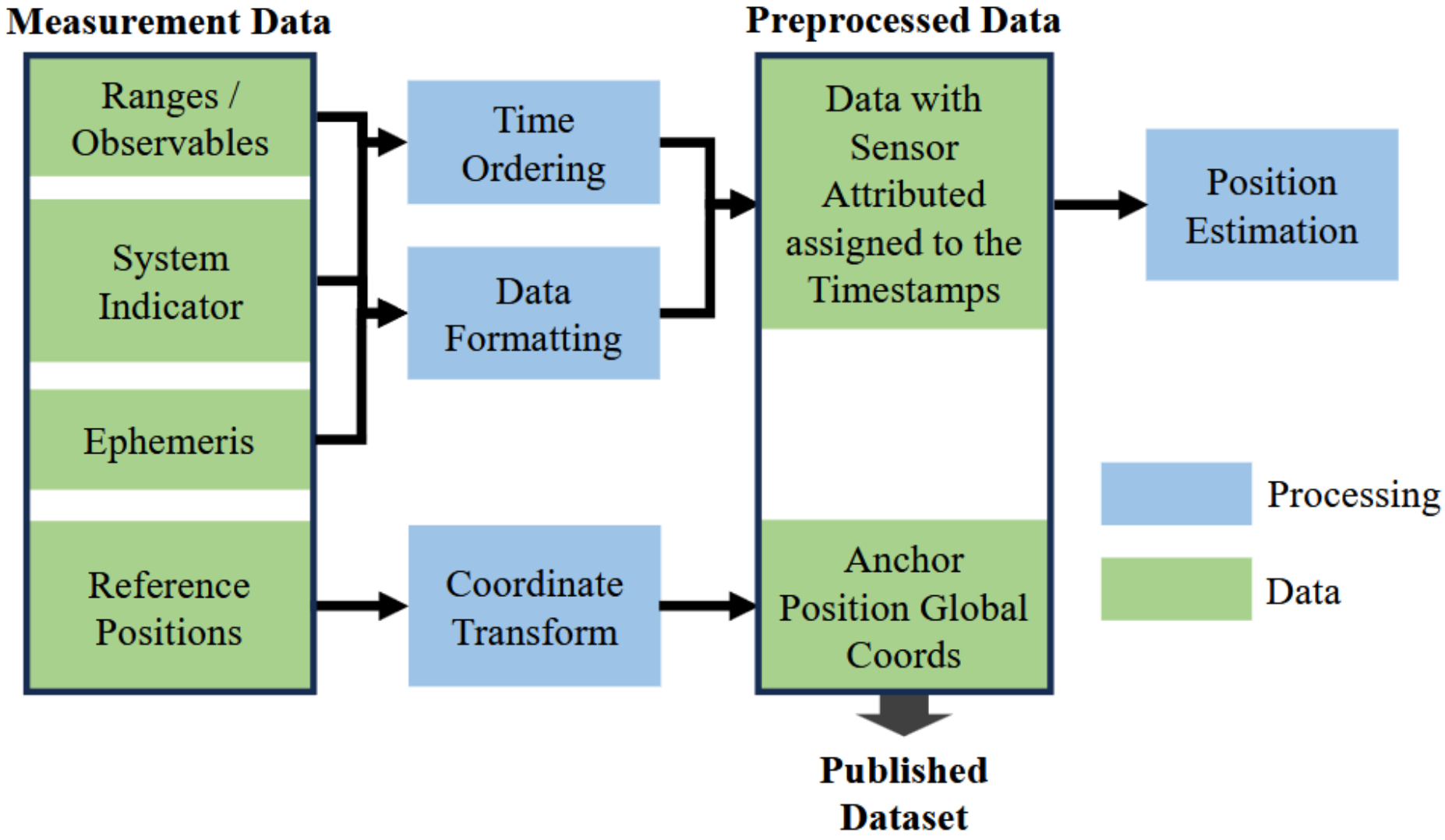
Measurement setup
Infrastructure



Measurement setup
Logging



Data processing



Data processing

WiFi
Ranges

GNSS
Position
PR, PRR, phase, C/N_0

BLE
Ranges

5G NR
Position
SNR

UWB
Zigpos RTLS
UWB two-way ranging

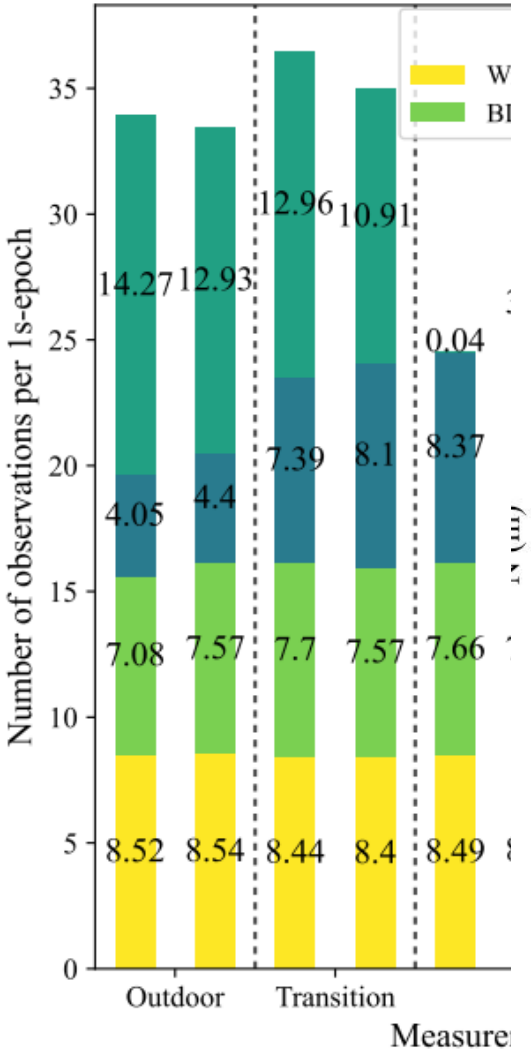
Ground truth
Position

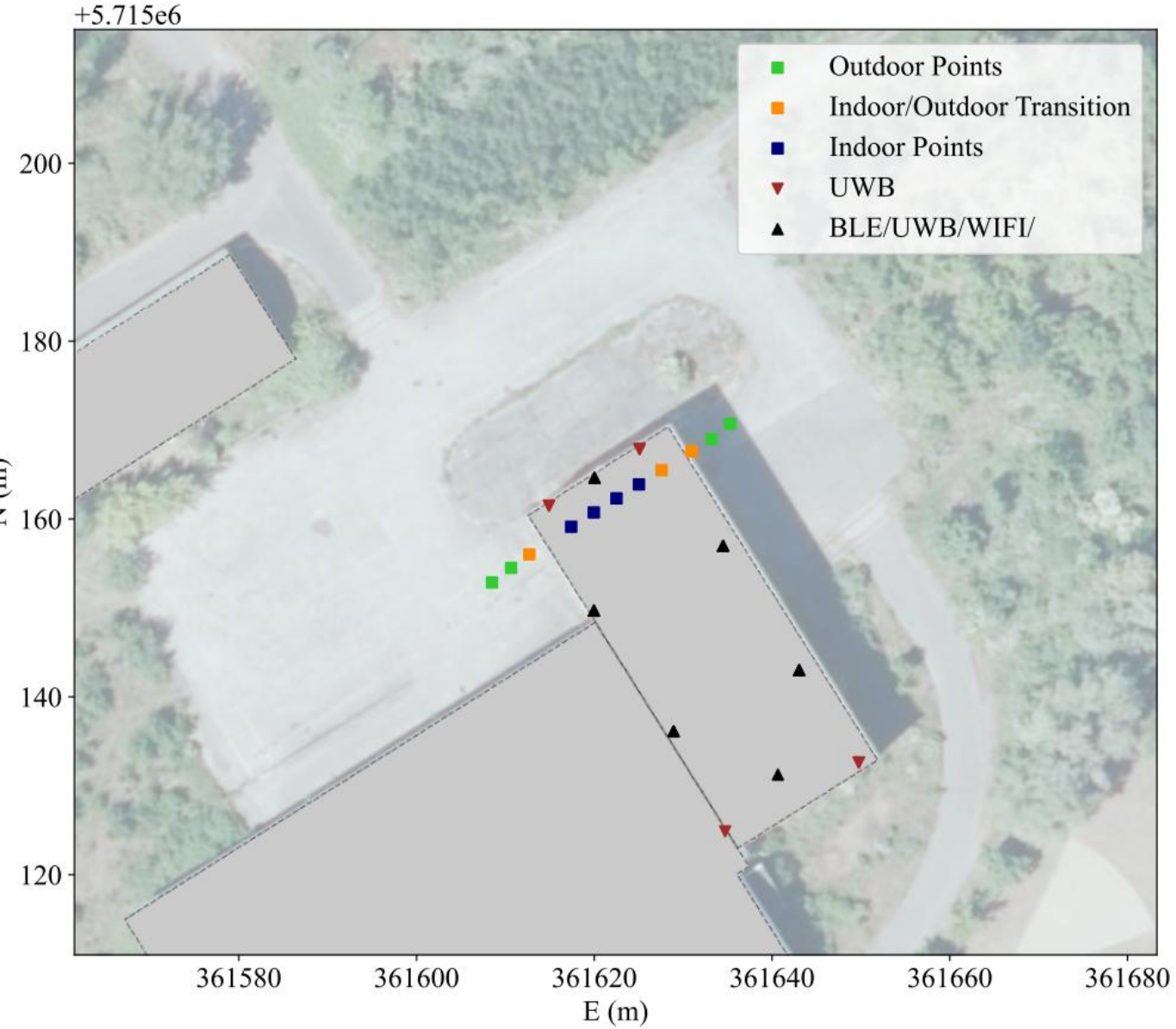
https://gitlab.com/tud-itvs/opportunistic-localization-dataset

Data descriptor article will be published soon

Availability evaluation

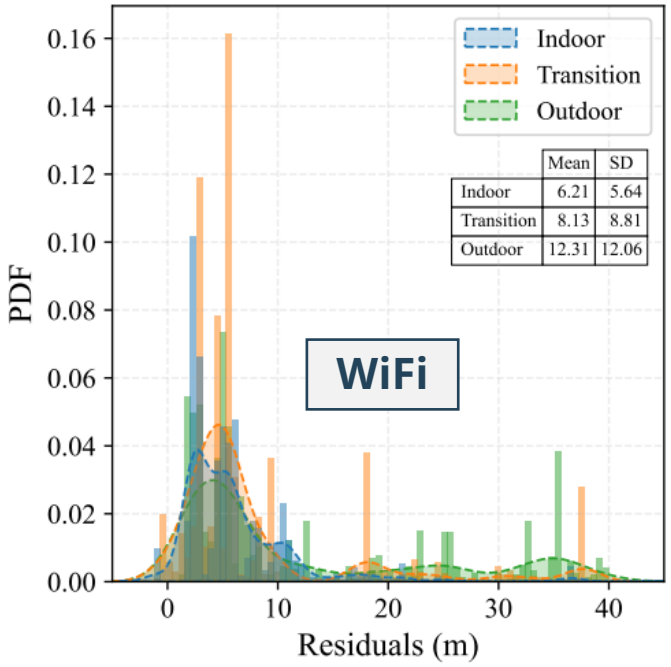
Availability analysis



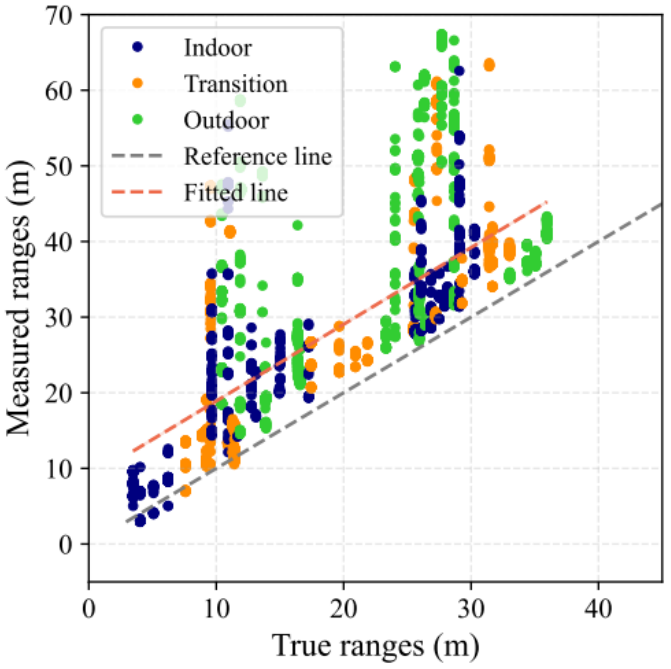


Number of obse **r measurement**

Ranging Residual distribution



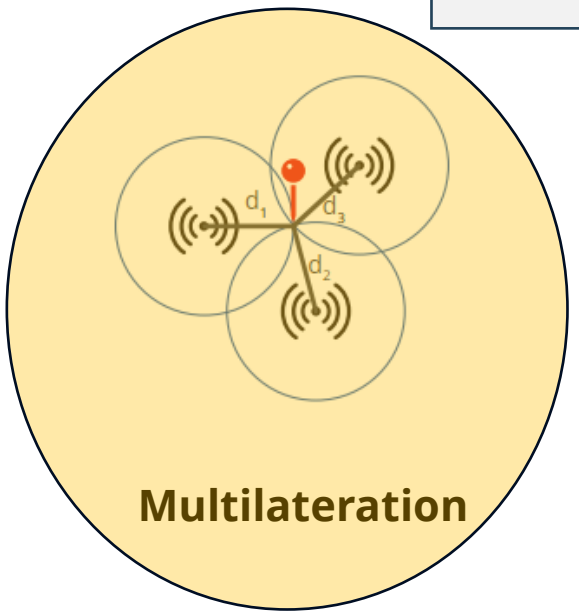
Measured range/ True range



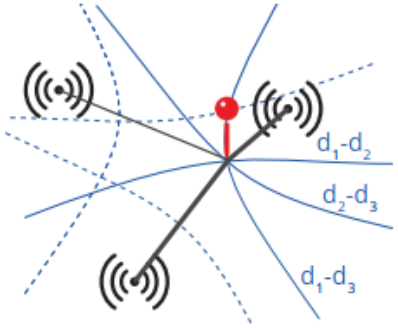
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Localization evaluation

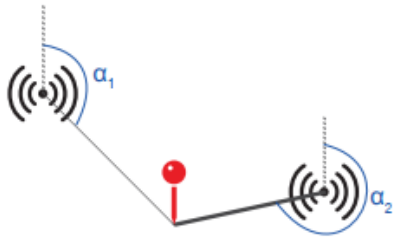
Positioning principles



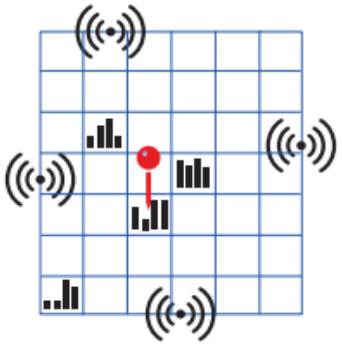
Multilateration



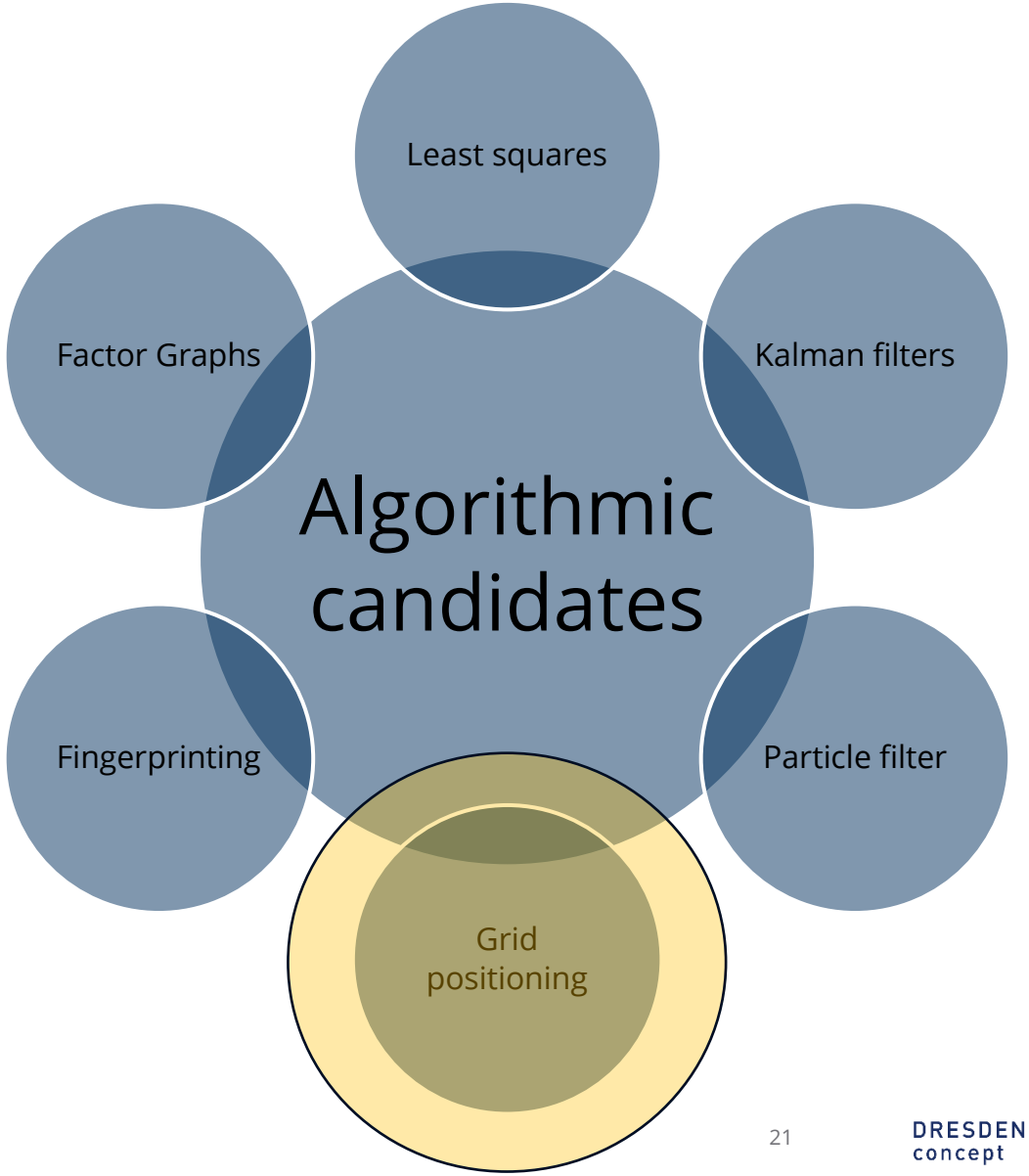
Hyperbolic



Multiangulation

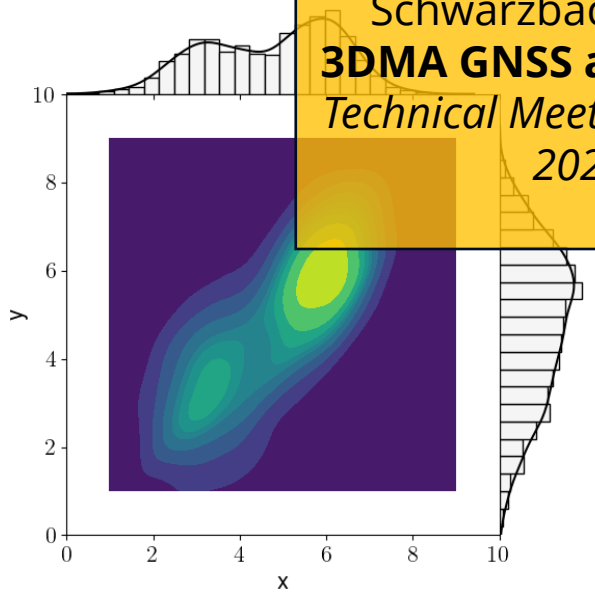


Fingerprinting

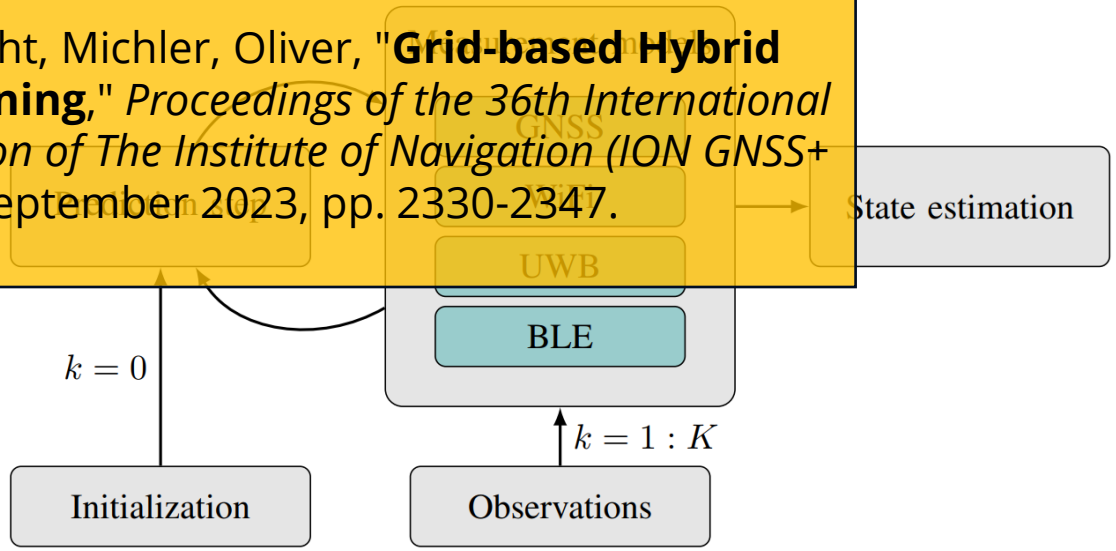


Grid positioning

Probability grid



Recursive Bayes Filter

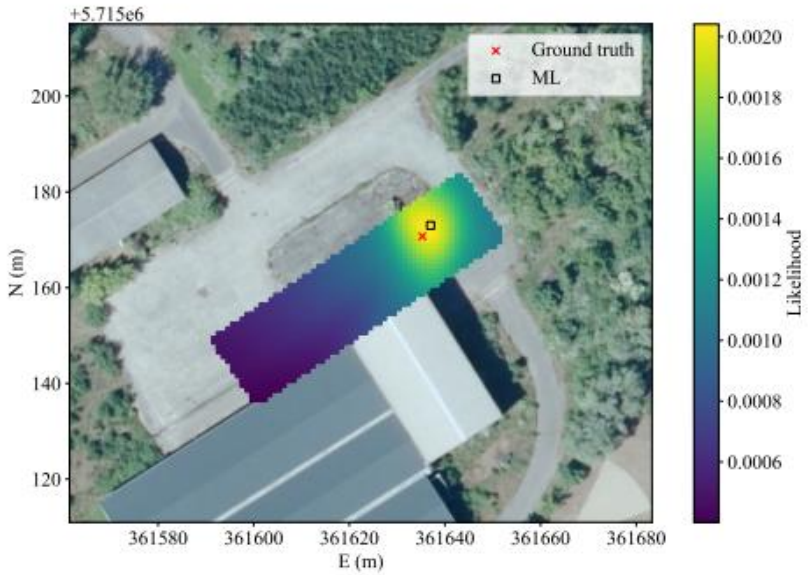


Schwarzbach, Paul, Michler, Albrecht, Michler, Oliver, "**Grid-based Hybrid 3DMA GNSS and Terrestrial Positioning**," *Proceedings of the 36th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2023)*, Denver, Colorado, September 2023, pp. 2330-2347.

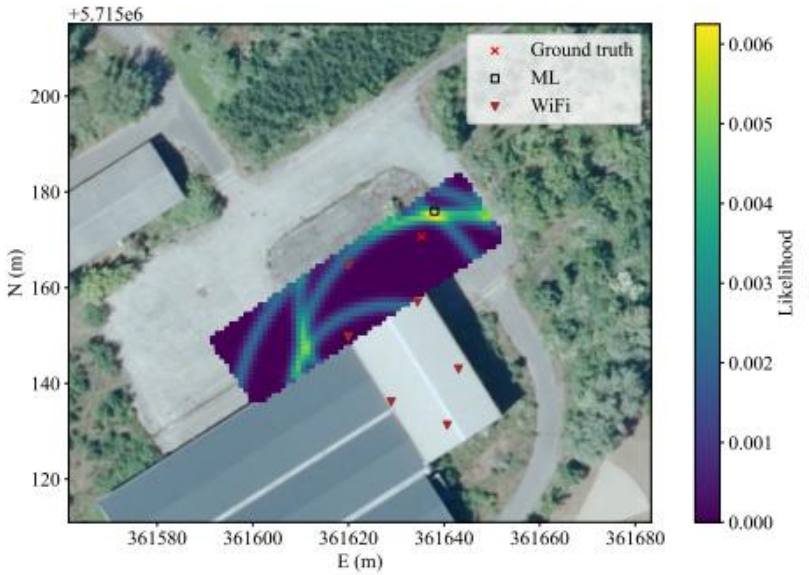
- Create grid on possible realization space
- Assign probabilities based on measurement and model assumptions
- Calculate position based on probability space

- Prediction – apply model assumptions
- Measurement – apply data

Grid positioning
Measurement model



GNSS

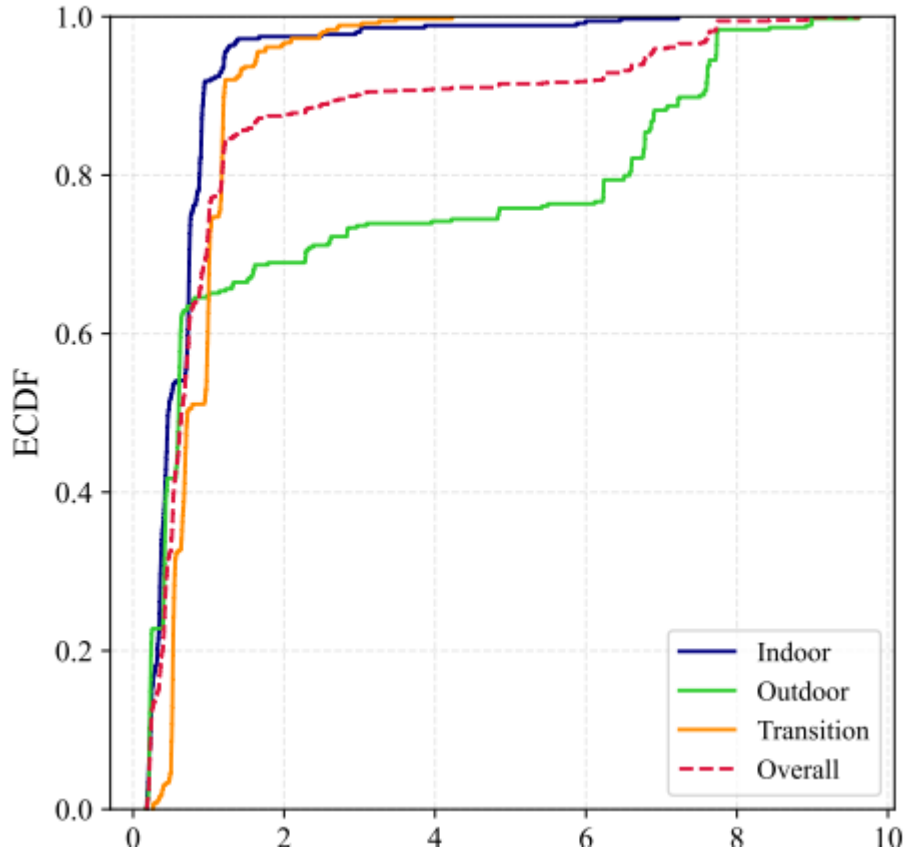


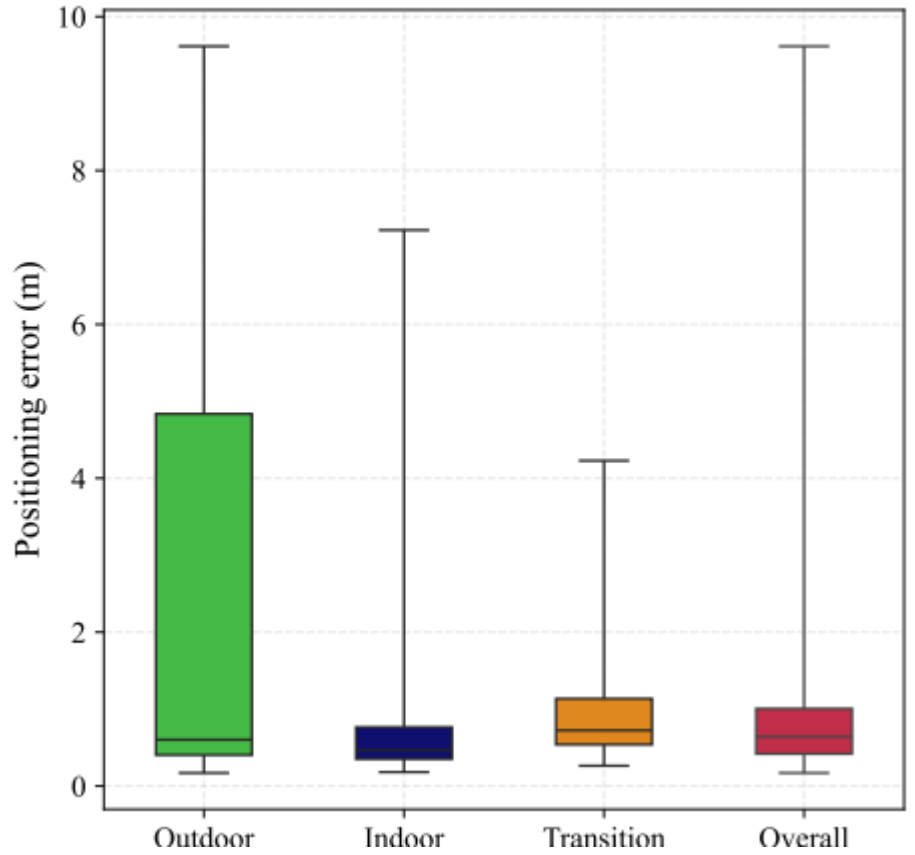
WiFi



UWB

Grid positioning
Position accuracy





2D RMS error [m]

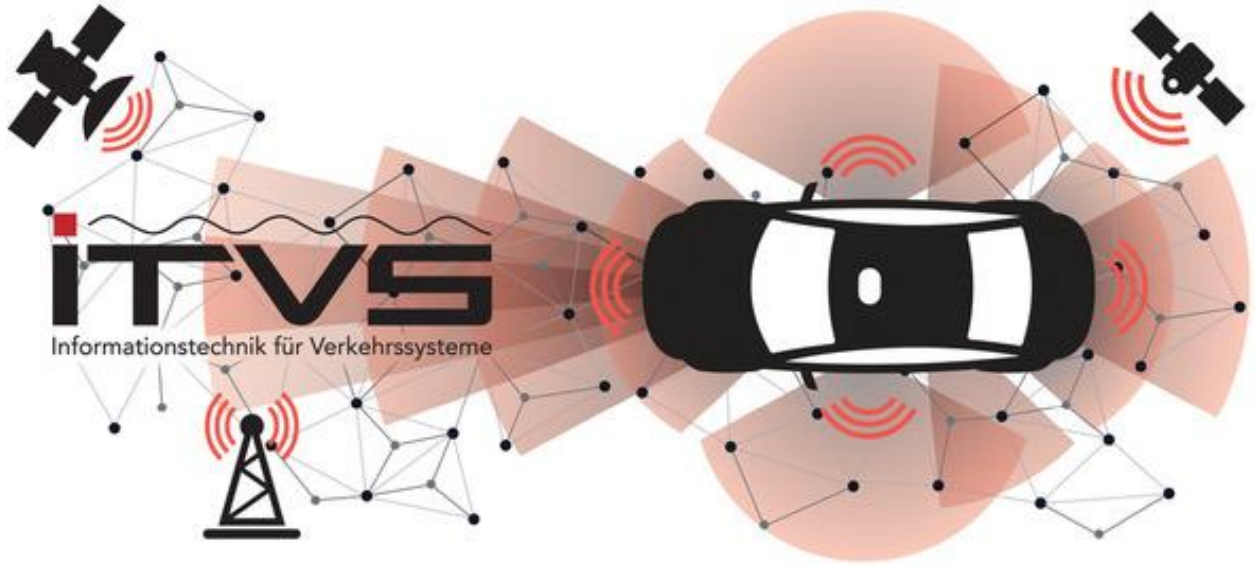
Future work

Dataset publication

Factor graph implementation

Evaluation of dynamic trajectories

Deep learning 5G positioning



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Oliver Michler (oliver.michler@tu-dresden.de)

ACKNOWLEDGMENT

This work has been funded by the German Federal Ministry for Digital and Transport (BMDV) following a resolution of the German Federal Parliament within the projects IDEA (FKZ: 19OI22020C).

Bundesministerium für Verkehr und digitale Infrastruktur

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