INDUSTRIAL RADIO LAB Germany

Impuls: Lokalisierung

Wieso das "Wo" entscheidend für kritische Funkkommunikation ist


IRL Dresden
Philipp Schulz,
Zhongj Li

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Motivation
(Indoor-) Lokalisierung im industriellen Kontext

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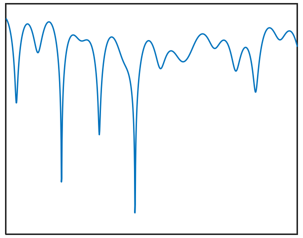
Anwendungsperspektive

- Industrie 4.0:
  - Logistik
  - Automated Guided Vehicles
  - Individuelle Fertigungsroboter
  - Geofencing
  - …

Perspektive des Funknetzes

- Kritische Anwendungen erfordern *zuverlässige* Übertragungen
  → URLLC → Kabelloser Feldbus
- URLLC-Forschung konzentriert sich auf zufällige Kanalfehler
  → z.B. Fading



- Aber was ist mit unvorhergesehenen Ereignissen?
- Lösungsansatz:
  - Resiliente Funknetze
  - Echtzeit-Spektrumsüberwachung
    - In Zeit, Frequenz und **Ort**
  - Adaptive Netzkonfiguration

Lokalisierungsmethoden

Verfügbare Informationen

- Inertialsensordaten (IMU)
- Lidar/Radar
- Ankunftszeit (ToA)
- Ankunftszeitdifferenzen (TDoA)
- Kanalimpulsantwort (CIR)
- Ankunftswinkel (AoA)
- Empfangssignalstärke (RSS)
- …

Kooperation

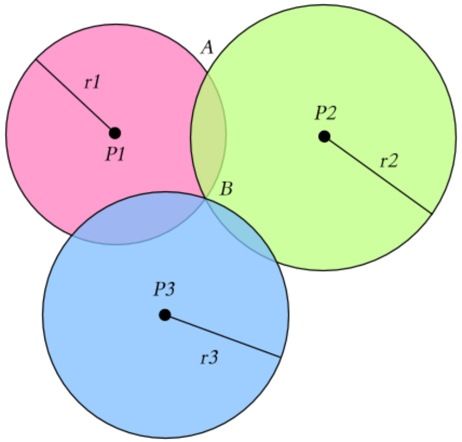
Sensorfusion

Gemeinsame Kommunikation & Sensing

Methoden

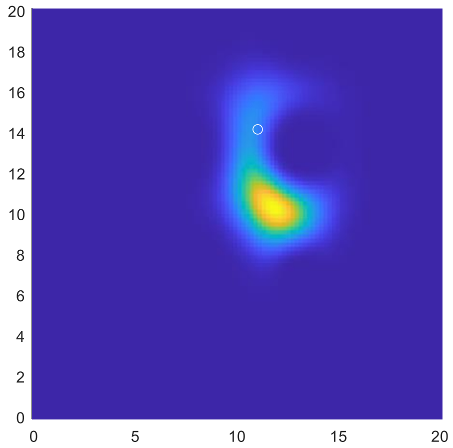
- Trilateration / Triangulation (geometrisch)
- Maximum-Likelihood (MLE)
- Extrapolation (Kriging, REM)
- Datengetriebene Modelle (Machine Learning)
- Fingerprinting (Datenbank)
- …

Modellwissen



Trilateration

https://de.wikipedia.org/wiki/Lateration#/media/Datei:Trilateration.png



MLE

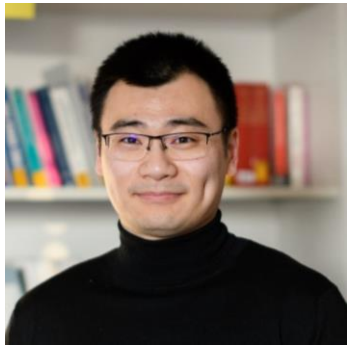
Lokalisierung „bekannter“ Sender

Bekannte Sender

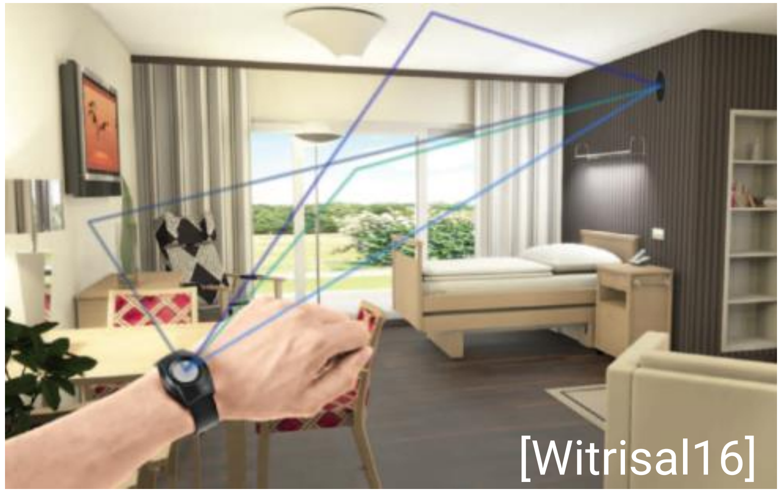
- Kooperativ:
  - Beliebige Referenzsignale
- Nicht-kooperativ:
  - Interferer, die sich standardkonform (WLAN, Bluetooth, …)
    → bekannte Referenzsignale

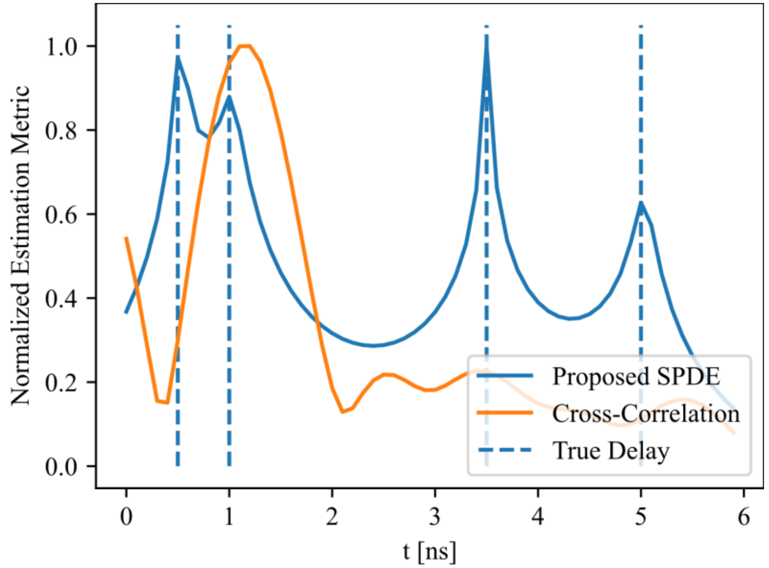
ToA, TDoA, **Kanalschätzung**,… als verfügbare Information

Beispielresultate [Li22]



- Mehrwegeausbreitung
- Konventionelle Methoden stark durch Bandbreite begrenzt
- Superresolution der Pfadverzögerungen



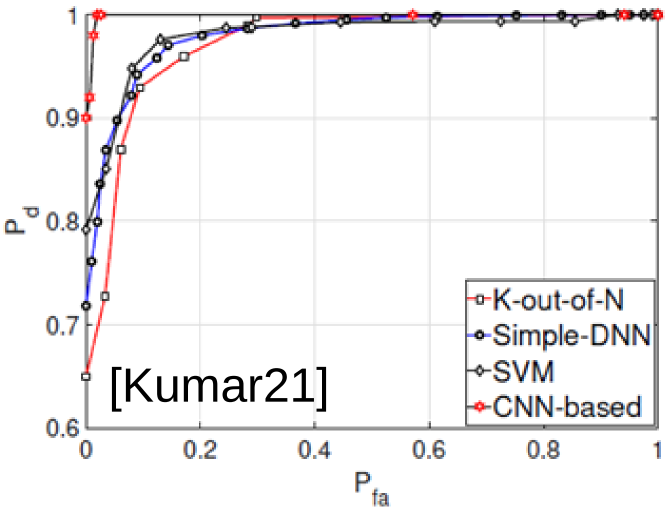


Lokalisierung unbekannter Störer

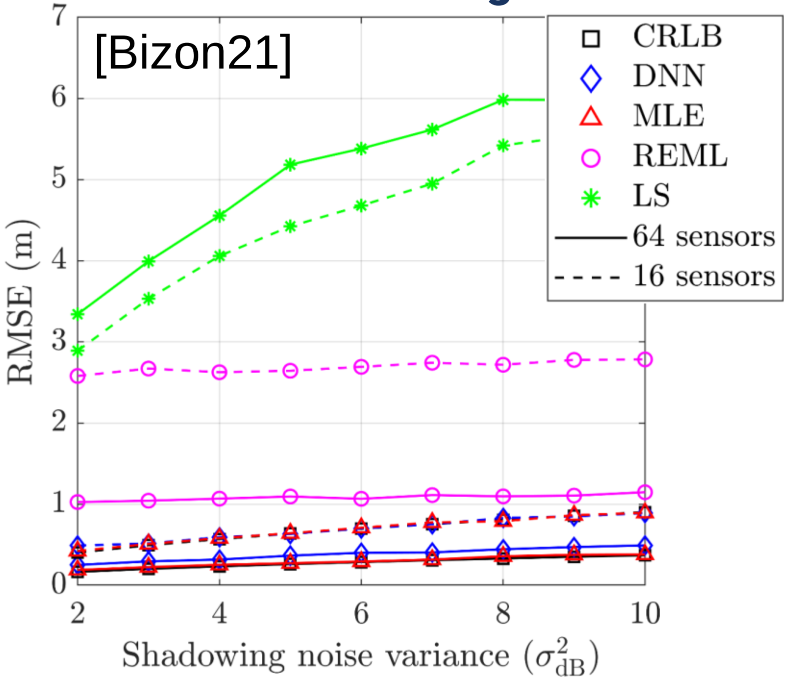
- Jammer kooperieren nicht
  - keine bekannten Referenzsignale
  - Empfangsstärke (RSS) verfügbar
- Intelligente Jammer

- **Machine Learning**
  - Adaptiv
    - Dynamische & komplexe Umgebungen
    - Dynamisches Jamming Verhalten
  - Geeignet:
    - Detektion
    - Lokalisierung
    - Klassifizierung

Detektion



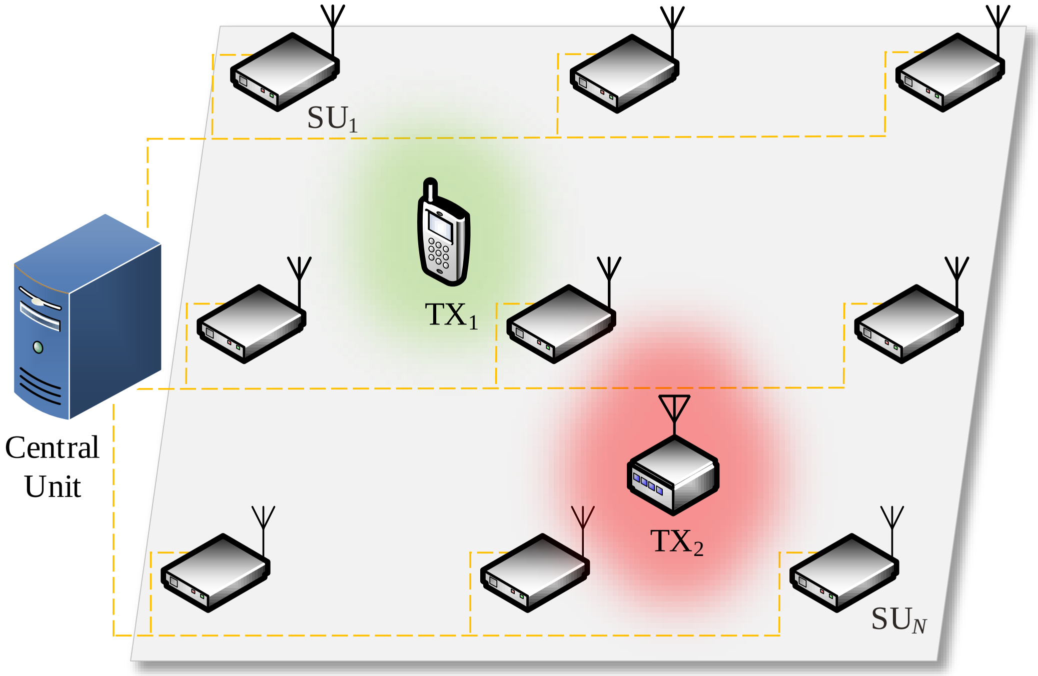
Lokalisierung



Ausblick und Vision

Adaptives Sensing Network

- Gemeinsame Nutzung von Ressourcen
  - Kommunikation
  - Sensing (Lokalisierung)
  - Ggf. weitere Sensordaten
- Beamforming (mmWave)
- Gewährleistung Resilienz
  - Kontinuierliche Spektrumsüberwachung
    - In Zeit, Frequenz und **Ort**
  - Adaptive Netzkonfiguration
    - Frequenzen, Technologien, …
    - Safe Modes
    - Ggf. manuelle Eingriffe



Übersicht [Obeidat21]

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Table 1 Localization technologies performance overview

Technology	Technique	Method	Accuracy (m)	Cost	Coverage	Pros	Cons
Satellite	Trilateration	TOA TDOA	3–5		Floor level	Low power consumption	
Inertial	Dead Reckoning	–	2	Low	Floor level	Cheap	Accumulative errors
Magnetic Based	Trilateration Fingerprinting	–	2	Low	Floor level	Cheap	Requires mapping
Ultrasonic Based	Trilateration	TOA TDOA	0.01–1	Medium–High	Room level	Good accuracy No effect of multipath	Interference Cost for hardware
Acoustic	Trilateration	TOA	meters	Low	Room level	Cheap	Poor accuracy
Infrared	Proximity Trilateration	TOA	1–2	Medium	Room level (few meters)	Cheap No effect of multipath Low power consumption	Sunlight interference Short-range Cost for hardware
Visible light	Angulation	AOA	0.1	Medium	Floor level	No interfering	Expensive construction
Wi-Fi	Proximity Trilateration Angulation Fingerprinting RSS-Propagation model	AP ID RSS TOA TDOA AOA	10 (proximity) 1–5	Low	Floor level (around 35)	Good accuracy Low cost Wi-Fi signals can penetrate walls/ No need for additional infrastructure	RF interference with devices operating at 2.4 GHz Fingerprinting requires a huge effort
ZigBee	Proximity Trilateration Fingerprinting RSS-Propagation model	AP ID RSS	3–5	Medium	Floor level	Low cost Low power consumption	Requires special equipment
Bluetooth	Proximity Trilateration Fingerprinting	AP ID RSS TOA	2–5	Low-Medium	around 10	Good accuracy No need for additional infrastructure Low power consumption	RF interference Limited coverage and mobility
UWB	Trilateration Angulation	TOA TDOA RSS AOA	0.01–1	High	Few meters	Accurate	Expensive Coverage is limited Performance degrades in NLOS
RFID	Proximity Trilateration Fingerprinting RSS-Propagation model	AP ID RSS	1–5	Low	Room level	Cheap Real-time localization	Low accuracy Response time is high
FM	Fingerprinting	RSS	2–4	Low	100 km	Low sensitivity to objects	Vast change of signal over a small distance
Cellular network	Fingerprinting Proximity Trilateration	RSS TOA	2.5–25	Low	80 km	Networks available all over areas	Low accuracy

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