Potentials of directional antennas for (Indoor Positioning) Systems in dense multipath environments

The Fifteenth International Conference on Advances in Satellite and Space Communications (SPACOMM) 2023
April 24-28, 2023 – Venice, Italy
Agenda

1) CV, Chair and Topics of University Research
2) Introduction - ICT-based Goal Formulation
3) Historical fundamental access - Antenna as a central element
4) Potentials of directional antennas – General remarks
5) Research Examples – Challenges in dense multipath environments
6) Conclusion and future outlook
1 CV Oliver Michler, University Full Professor

Scientific and Professional Positions (since 1993)

1993 - 1997  Scientific Staff and PhD-Research of TU Dresden, Faculty of Electrical and Computer Engineering
1997 – 2000  Scientific Project manager at Video-Audio-Design GmbH as a Telkom-Partner
2000 – 2005  Scientific Staff at Fraunhofer Institute for Transportation and Infrastructure Systems Dresden (FhG-IVI)
2005 – 2008  Professor at University of Applied Sciences Dresden in Signal Processing and Electronic Measurement Techniques
2010 – 2017  Head of department of TUD-Researchgroup at FhG-IVI
2008 –       Full Professor at TU Dresden in Systems Information Technology, Faculty of Transportation and Traffic Sciences
2017 -       Scientific advisory board member of MRK AG, Metirionic and ISCons GmbH as a knowledge transfer research
2019 -       Director of TU Dresden of Institute of Traffic Telematics

Research topics

Data-driven and model-based approaches, wireless mobility systems over all traffic carriers and services, autonomous driving, intelligent vehicle, next generation technologies based of communication/localization/sensing, software defined radio
1 TU Dresden (TUD) ⇒ Campus Overview

- The Technische Universität Dresden dates back to the Technische Bildungsanstalt Dresden, founded in 1828 and, thus, ranks among the oldest technical-academic educational establishments in Germany.

- The TU Dresden has about 35,000 students and almost 5,000 permanent employees (excepting the Faculty of Medicine), about 400 professors among them, and, thus, is the largest university in Saxony, today.

- TU Dresden now is a multi-discipline university, also offering humanities and social sciences as well as medicine. There are only few universities in Germany which are able to match this broad scientific spectrum.
1 University of Technology in Dresden (TUD)
The “Friedrich List” Faculty of Transport and Traffic Sciences

A unique, interdisciplinary competence center for transportation sciences

Dresden Institute of Automobile Engineering
Institute of Railway Vehicles and Railway Technology
Institute of Railway Systems and Public Transport
Technological and Market Progress in Transportation & Mobility
Changed Education in Transportation Economy and Transportation Engineering

Institute of Logistics and Aviation
Institute of Transport Planning and Road Traffic
Institute of Traffic Telematics
Institute of Transport and Economics
Faculty of Transportation and Traffic Sciences „Friedrich List“

Selected laboratories at the faculty

- Laboratories Traffic Control, Process Automation and ITS

Traffic Control Center

Car2X-Wireless Simulation

Automatic Train Driving

Driving Simulation (Tram)

Test Cars

Automatic Car Driving
1 Faculty of Transportation and Traffic Sciences „Friedrich List“
⇒ Selected laboratories at the faculty

- Aviation lab / Airbus 320 Simulator

Application / operation purpose
- Research fields: Trajectory Management and Safety Assessment
- Integration in teaching fields Cockpit Technologies and Navigation
- Training and performance / Aircraft wireless ICT Cabin
1 Traffic ICT and Research fields of Chair competence

- Overview:
1 Research focus: Traffic carrier cross-modal vehicle environment signals

Telematics and IT - Platforms (RF, LF, Software, Protocols, Interfaces, HMI)

- Modelling, Parametrisation
- Error analysis, Integrity

Radio channel simulation (PC environment)

Signal environment generation (Lab environment)

Record/Playback Field measurements (Field-, long term tests)

Automotive → Rail transport → Aviation / Aircraft cabin → Water transport
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2 Introduction - ICT-based Goal Formulation

Everything moves and all is connected
2 Important Mobility Trends for the Next Decade

Digitization
- Real-time mobility marketplace

Decarbonization

- Integrated mobility concepts

Use of personal data

- Use of personal data

Additional transport features

- Additional transport features

Integrated and new forms of goods transport

- Integrated and new forms of goods transport

Addressing customer needs

- Addressing customer needs

Important Mobility Trends for the Next Decade

1. Autonomous driving
2. Integrated and new forms of goods transport
3. Use of personal data
4. Additional transport features
5. Addressing customer needs
6. Integrated mobility concepts
7. E-Mobility

[1] Denomination of mobility concepts
[2] Use of personal data
[3] Additional transport features
[4] Autonomous driving
[5] Addressing customer needs
[6] Integrated mobility concepts
[7] E-Mobility
2 Variety of technologies and services

- eCall, GSM, UMTS
- AIS
- PTC ETCS
- GPS, GLONASS, Galileo
- FM, DAB+, TMC, TPEG
- Vehicle-2-X
- Mobilfunk
- ITS-G5 (Erweitert)
- ITS-G5 (Basis)
- WLAN
- Broadcast
- DAB
- RDS
- 5G
- 4G
- 2G / 3G

Comm. Technologies

- IEEE 802.11ac
- IEEE 802.11ah
- mmWave
- IEEE 802.15.4
- Bluetooth
- NFC
- LPWA

Variety of technologies and services

1. CV, Chair and Topics of University Research
2 Information technology aspects and raw data (TUD-ITVS Framework)

Data input

Communication / Positioning / Tracking / Sensing

Visualization

Client/Server -> Database Software

Technology Candidates:
IEEE 802.15.x (BLE, UWB, ZigBee, ...), IEEE 802.11.x (WiFi 2.4/5GHz); MobilComm (5G, 6G), IEEE 802.15.7 (LiFi)
2 IoT–Communication, Localization / Tracking and Sensing Cross Technologies
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3 Historical fundamental access - Antenna as a central element

Signals

Begin

Informationsquelle → Quellenkodierung → Kanalkodierung → Modulation → Kanal → Demodulation → Kanaldekodierung → Quellen­dekodierung → Informations­senke

End

(Transmitting) Antenna

(Receiving) Antenna
3 Timeless decision bases for communication and localization technologies

Shannon Channel Capacity Theorem

\[ C \approx \frac{B}{3} \cdot \log_{10} \left( \frac{10^{\frac{P_s}{P_N} dB}}{SNR dB} \right) \]

- Channel capacity \( C \) max. Data rate [Mbit/s]
- Bandwidth \( B \) / [MHz]
- Signal-to-Noise Ratio \( SNR \) /[dB]

Cramer Rao Lower (Fisher) Bond

\[ \sqrt{Var(d)} \geq \frac{C}{2\sqrt{2\pi} \sqrt{SNR \cdot B}} \]

- Signal-to-Noise Ratio \( SNR \)
- Bandwidth \( B \)
3 Antenna Basics - Description

- History
  Faraday / Henry (1831) – first Experiments
  Maxwell (1864) – Theory
  Hertz (1886) – Experimental Proof
  Marconi (1901) – Technical Proof

- Phenomenological description

Leitungs- Welle  Wellentyp- wandler

Antenna

Capacitor (Shift current charge carrier)

Hertzian dipole(1)
Hertzian dipole(2)

Source: https://de.wikipedia.org

Double swirl coupling

Electrical field
Magnetical field

Electrical field
Magnetical field

Shift current charge carrier
⇒ Electromagnetic wave

Hertzian dipole (1)
Hertzian dipole (2)
Abstrahlungsverhalten des HERTZschen Dipols
3 Antenna Basics - Polarisation

Polarisation: partial orientation of the electric field strength vector
⇒ Decoupling possibilities

<table>
<thead>
<tr>
<th></th>
<th>Vertical</th>
<th>Horizontal</th>
<th>Circular Right</th>
<th>Circular Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>↑</td>
<td>→</td>
<td>3 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>Horizontal</td>
<td></td>
<td>→</td>
<td>3 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>Circular Right</td>
<td></td>
<td></td>
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<td>∞</td>
</tr>
<tr>
<td>Circular left</td>
<td></td>
<td></td>
<td>∞</td>
<td>0 dB</td>
</tr>
</tbody>
</table>

- Vertical polarisation
- Horizontal polarisation
- Circular polarisation left-/right-rotation
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4 Potentials of directional antennas – General remarks

- Antenna characteristics (general)
  - Reciprocity: Identity of the characteristic in the transmit/receive case
  - Radiation characteristic: 3D field strength characteristiaraktistik
  - Directional diagram: Cross-section through radiation pattern
  - Gain: measure for directivity
  - Half width: 3dB opening angle
  - Forward/Backward ratio
  - Side lobe damping
4 Potentials of directional antennas – Multipath aspects

- Free space propagation
- Refraction
- Scattering
- Diffraction
- Reflection
- Absorption
- Transmission
- Line-of-sight component
- Scattering
- Shadowing
- Diffraction
- Free-Space Path Loss
4 Potentials of directional antennas – Beamforming antennas

Beispiel einer Phasenbelegung der Elemente einer (5x5)-Patch-Antenne

<table>
<thead>
<tr>
<th></th>
<th>m = 0</th>
<th>m = 1</th>
<th>m = 2</th>
<th>m = 3</th>
<th>m = 4</th>
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<tbody>
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<td>n = 4</td>
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<td>333,5°</td>
<td>391,5°</td>
<td>449,3°</td>
<td>507,2°</td>
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<tr>
<td>n = 3</td>
<td>206,8°</td>
<td>264,6°</td>
<td>322,6°</td>
<td>380,3°</td>
<td>438,3°</td>
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<tr>
<td>n = 2</td>
<td>137,9°</td>
<td>195,7°</td>
<td>253,6°</td>
<td>311,4°</td>
<td>369,4°</td>
</tr>
<tr>
<td>n = 1</td>
<td>68,9°</td>
<td>126,7°</td>
<td>191,2°</td>
<td>242,5°</td>
<td>300,4°</td>
</tr>
<tr>
<td>n = 0</td>
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<td>57,9°</td>
<td>115,7°</td>
<td>173,6°</td>
<td>231,5°</td>
</tr>
</tbody>
</table>

⇒ Einsatz in Intelligenen Antennensystemen

MIMO: Multiple Input Multiple Output

Quellen:
www.harticle.sapub.org

Source: www.authorstream.com
4 Potentials of directional antennas – Beamswitching antennas
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5 Research Examples – Challenges in dense multipath environments

<table>
<thead>
<tr>
<th>Early stage evaluation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Environment</td>
<td>Anechoic Chamber</td>
</tr>
<tr>
<td>Smart Parking</td>
<td>Intelligent Freight Wagons</td>
</tr>
</tbody>
</table>

Radio Propagation Simulation

Scenario-based evaluation

Immersive Testbeds
5 Current project activities (aviation and automotive)
5 Current project activities (aviation)

Innovative air traffic (Wireless Cabin)
CabiNET, CANARIA & ADKT
5 Current project activities (automotive)

- eCall, GSM, UMTS
- LTE
- zukünftig 5G
- GPS, GLONASS, Galileo
- FM, DAB+, TMC, TPEG

Connected and automated driving
IVS-AMP, IVS-LOK, Fast Sign, V2X4All
5 Selection: Evaluation using Inhouse parking scenario
Chip Connection
5 Multipath effects in ITS- / JCS-scenarios (Parking area)
5 Measurement Area (Parking area)
5 Directional antenna result (Parking area)
5 Different directional antenna results / Ranging (Parking area)
5 Beam-forming /-switching antenna results / RSSI + Delay (Parking area)
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6 Conclusion and future outlook

- Modern and innovative antennas will continue to play a fundamental role in the next generations of radio-based communication and positioning systems (e.g. 5G, 6G ++ )

- The same principle will also apply to the optical free-space communication sector - Visible Lite Communication (VLC) or LiFi / but here with so-called Directional Lense Antennas
Thank you very much for your attention

Contact:
Prof. Dr.-Ing. Oliver Michler
Technical University Dresden
Faculty of Transportation and Traffic Sciences
Institute of Traffic Telematics
Chair of Transport Systems Information Technology
Germany 01062 Dresden, Hettnerstr. 3

Phone.: +49 351 463-3 68 41
Mobile: +49 172 2745970
e-mail: oliver.michler@tu-dresden.de
http://tu-dresden.de/vkw/vis/itvs