The REINDEER project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101013425.

REINDEER

REsilient INteractive applications through hyper Diversity in Energy Efficient RadioWeaves technology.

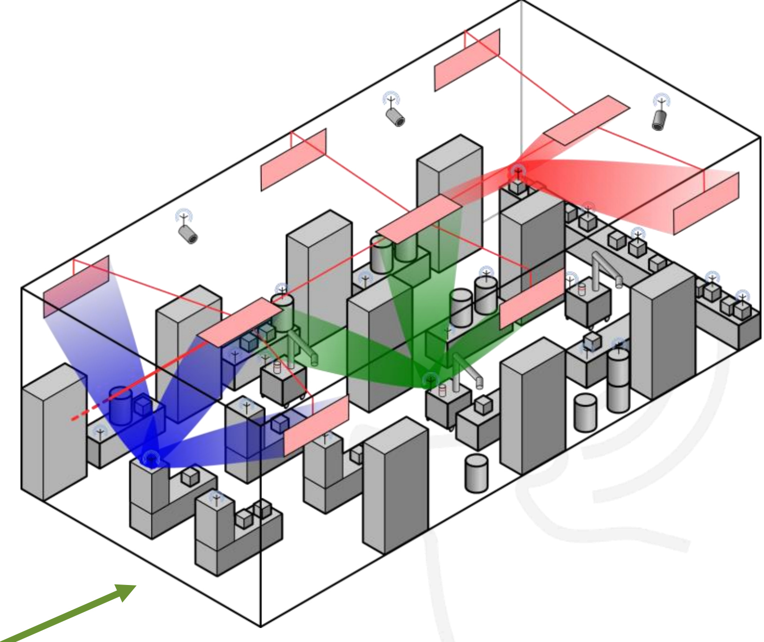
Propagation characteristics and channel models for RadioWeaves infrastructure for communication and positioning

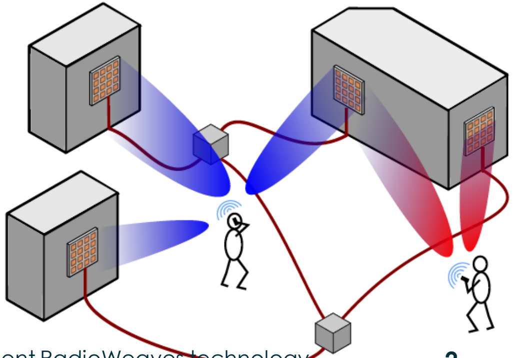
05.06.2022

Thomas Wilding, Graz University of Technology, Austria

What is REINDEER?

- „RadioWeaves“ as new wireless infrastructure
  - widely distributed contact service points (CSPs) (~basestations)
  - distribution of computational resources
- Application domains are…
  - factories, warehouses, logistics, …
  - connectivity in crowded areas
  - human-machine interaction
  - home automation, smart homes





[H2020 Reindeer, Deliverable 3.1, Jan. 2022]

Key aspects of future infrastructure (and RadioWeaves)

1. Local computational resources and interconnectivity
   - Distributed computation for increased flexibility (→ multiple CSPs)
2. (Spatial) Diversity
   - High accuracy positioning in indoor environments
   - Increased resolvability due to multitude of connections
3. Near-field conditions and device proximity
   - Reduction of overall energy needs and interference in the network
   - Charging energy-neutral devices
4. Link redundancy
   - reduced latency
   - increased reliability and proactive resource allocation

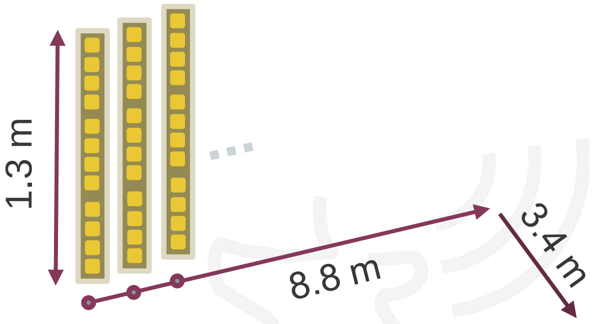
Outline

- Measurement Campaigns
- Measurement Analysis
- Propagation Modeling
- Application Examples
- Conclusion

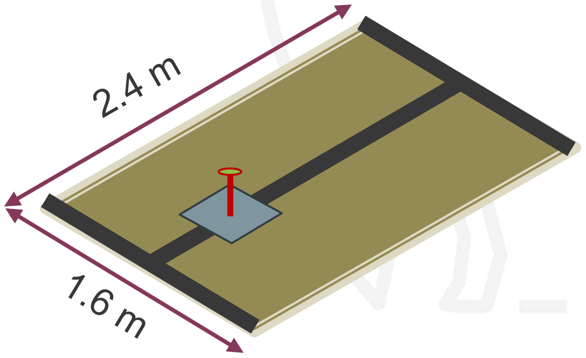
Measurement Campaigns

Measurements for Characterization, Modeling, …

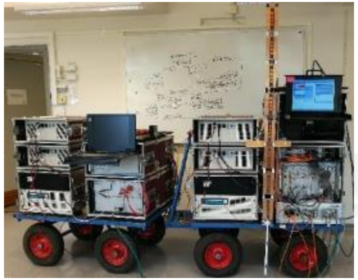
- Wideband Measurements
  - Partially synthetic array measurements
  - SDR-based system allowing small system measurements in real time
    - up to 240 MHz bandwidth
    - 300MHz, 2GHz, 5.6GHz center frequency
  - Example: 16 UEs to 15520 elements; (135+350) x 32



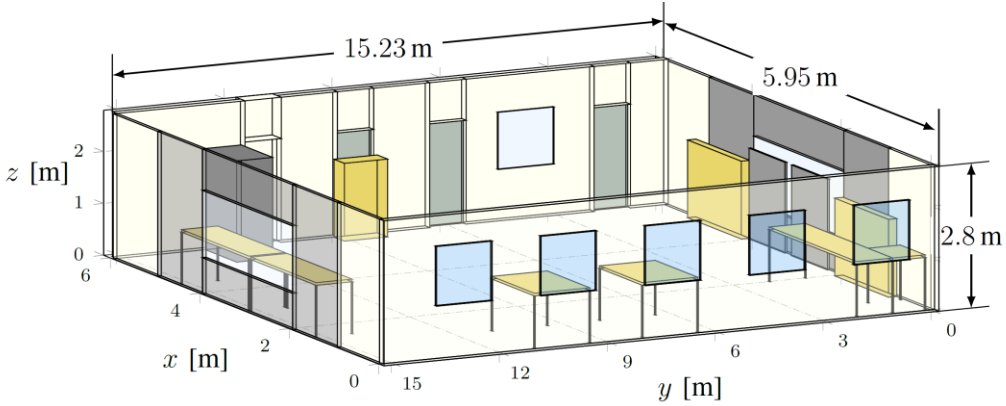
- Ultrawideband Measurements
  - Synthetic array measurements: arbitrary spacing and geometry
  - VNA measurements for ultrawideband characterization
    - 3-10 GHz target frequency range
  - *Example: array with 8400 elements; (75 x 112) = 2.4 x 1.6 m; bandwidth of 7 GHz*



Wideband Measurement System



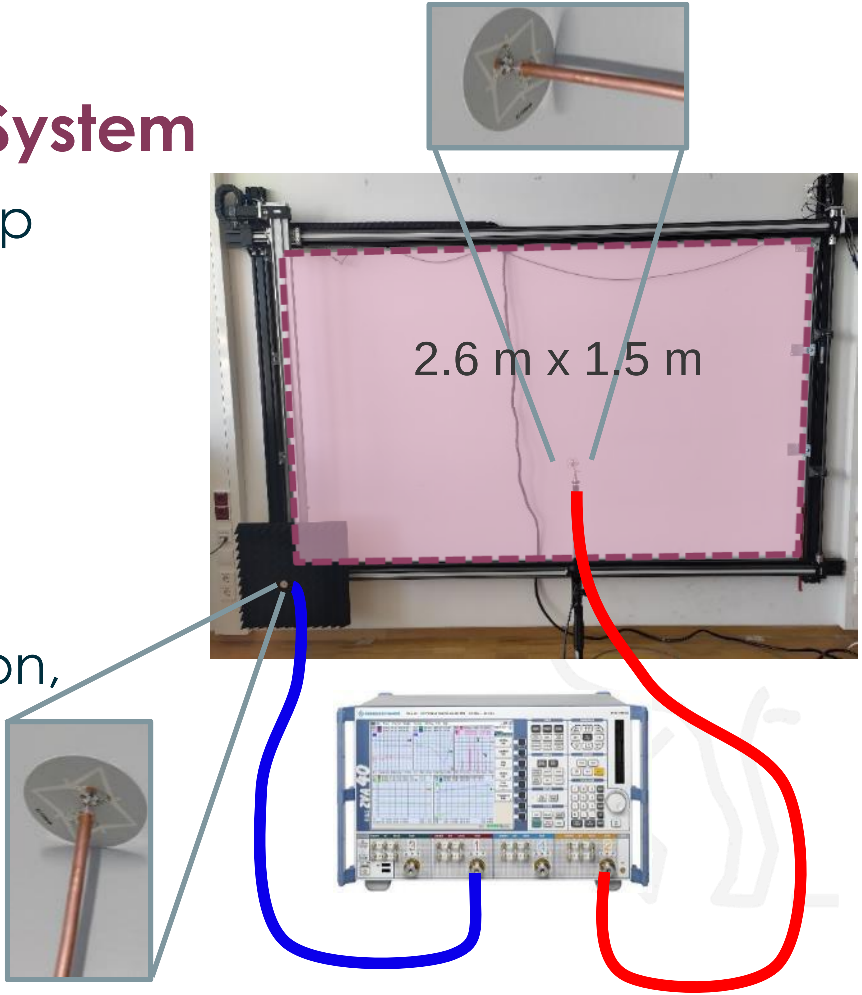
RUSK Lund sounder



monopole UE antenna

Ultrawideband Measurement System

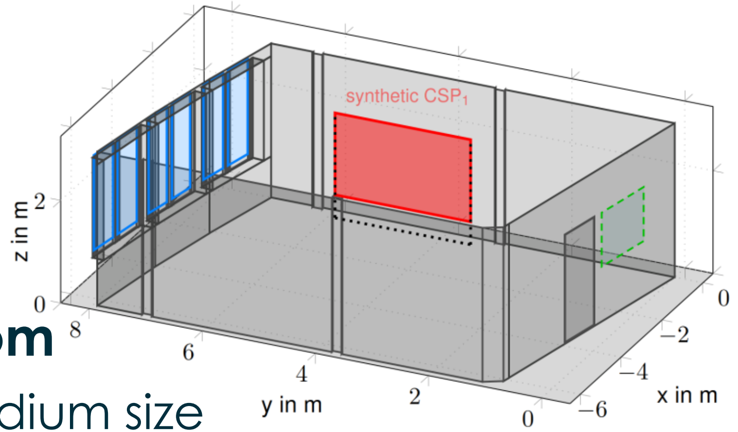
- VNA Measurements (3-10GHz) with up to 2 mechanical positioning devices and ultrawideband antennas [1]
- Measurement environments:
    - medium size - indoor office/lab
    - large size - corridor
- Application: Channel characterization, large bandwidth and measurement aperture



[1] Costa, J. R., Medeiros, C. R., & Fernandes, C. A. (2009). Performance of a crossed exponentially tapered slot antenna for UWB systems. *IEEE Transactions on Antennas and Propagation*, *57*(5), 1345-1352.

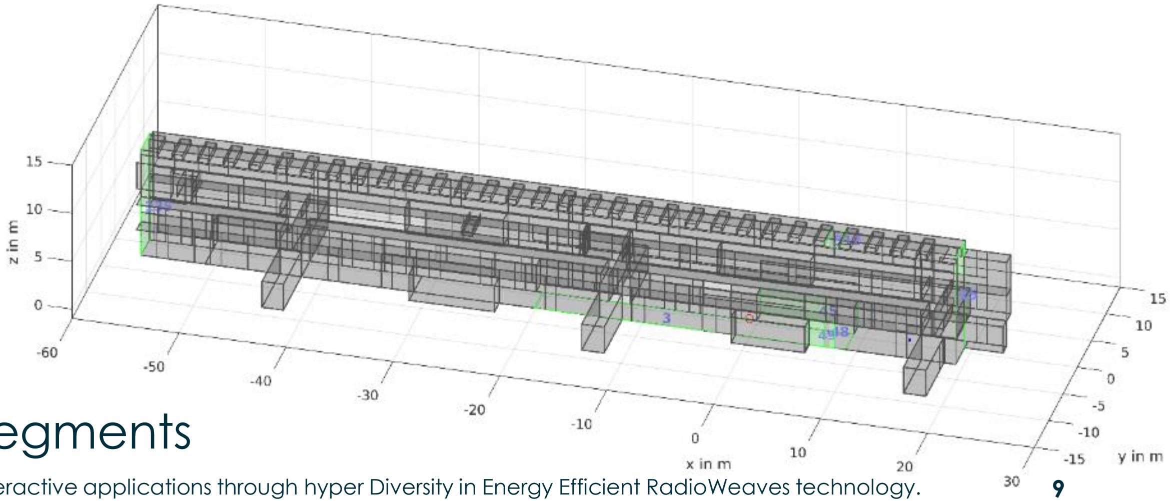
Measurement Environments

- Multipath environments
- Modeled using reflective surfaces (wall segments) and mirror sources
- 3D model based on laser scanner measurements
    - point clouds
    - wall segments



Lab room

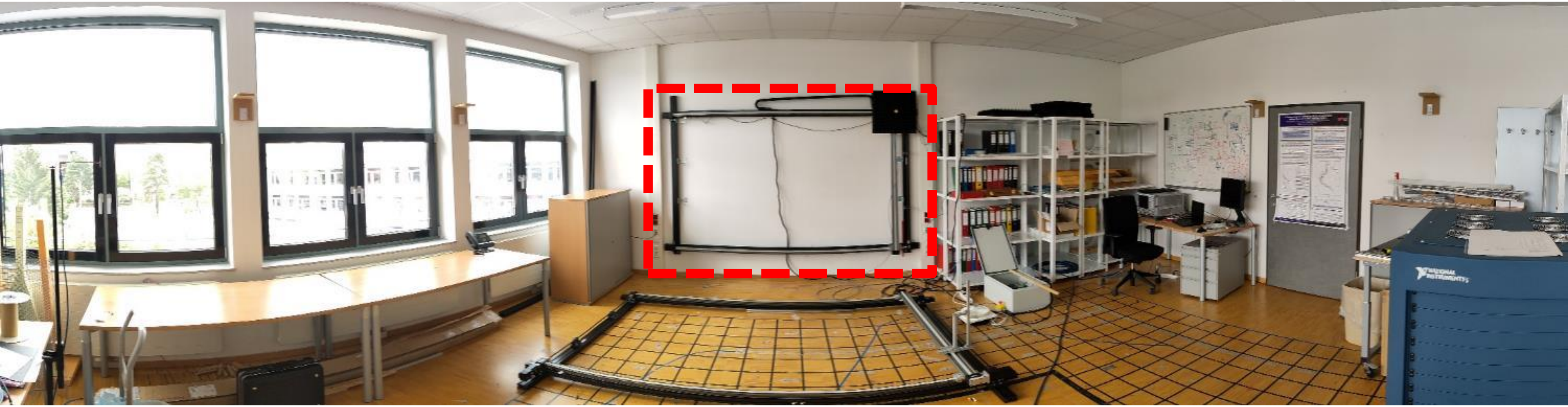
- medium size
- 117 wall segments



Corridor

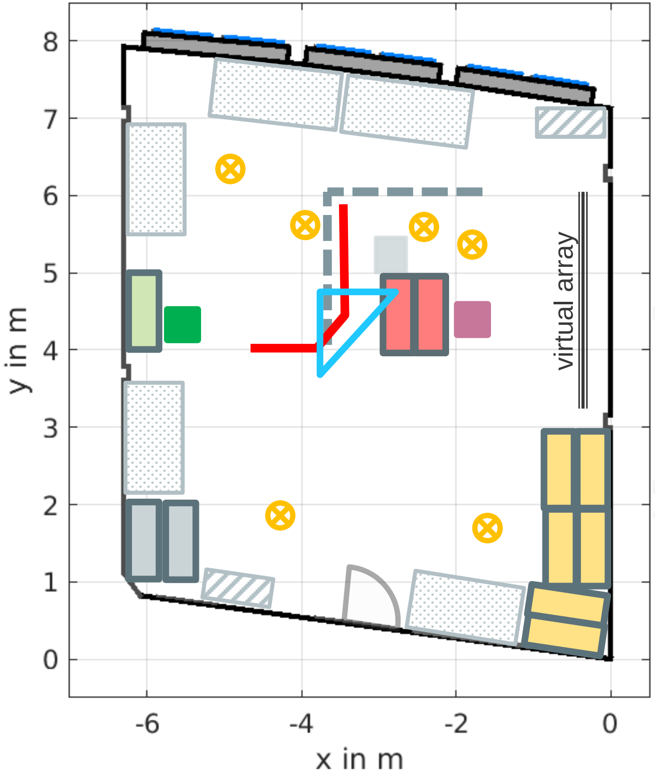
- large size
- 532 wall segments

Medium Sized Environment – "Lab room"



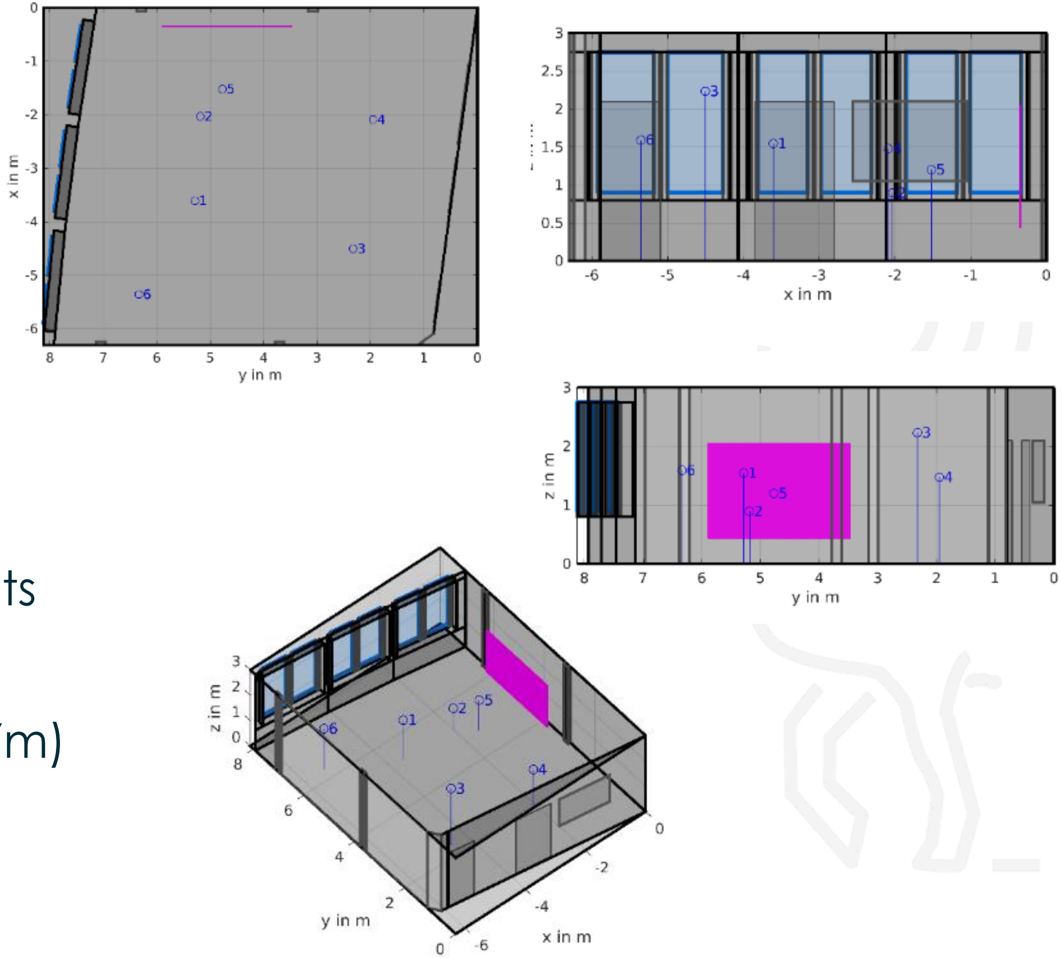
Medium Sized Environment – “Lab room”

- 6 **separate** positions
- **J-trajectory** behind shelves
  - *43 trajectory points*
  - *obstruction*
- grid in front of shelves
  - **near** / **far** (with/without bottles)
- **large grid** (ULA) with/without reflectors
- **triangular trajectory** without obstruction



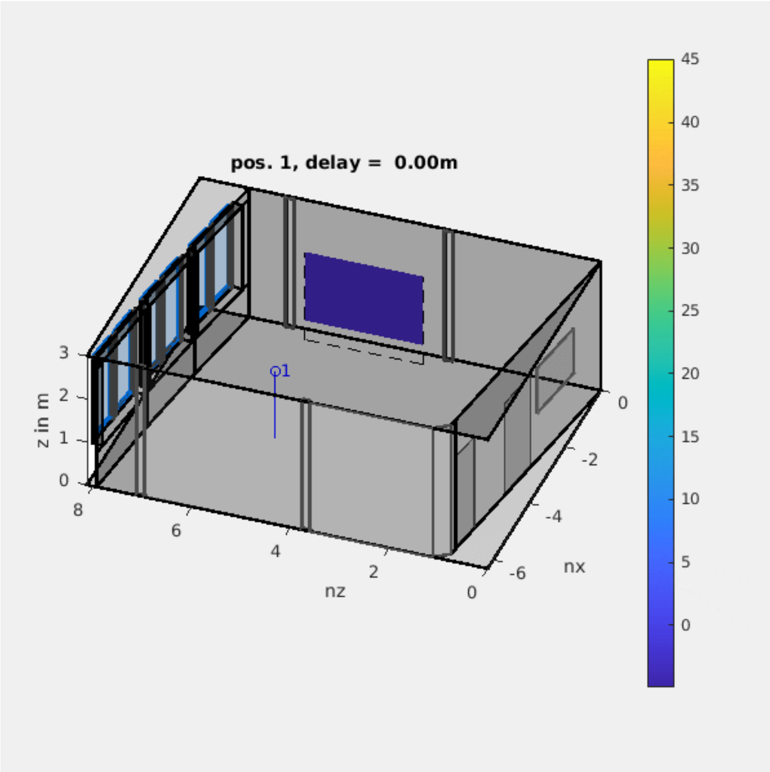
separate positions

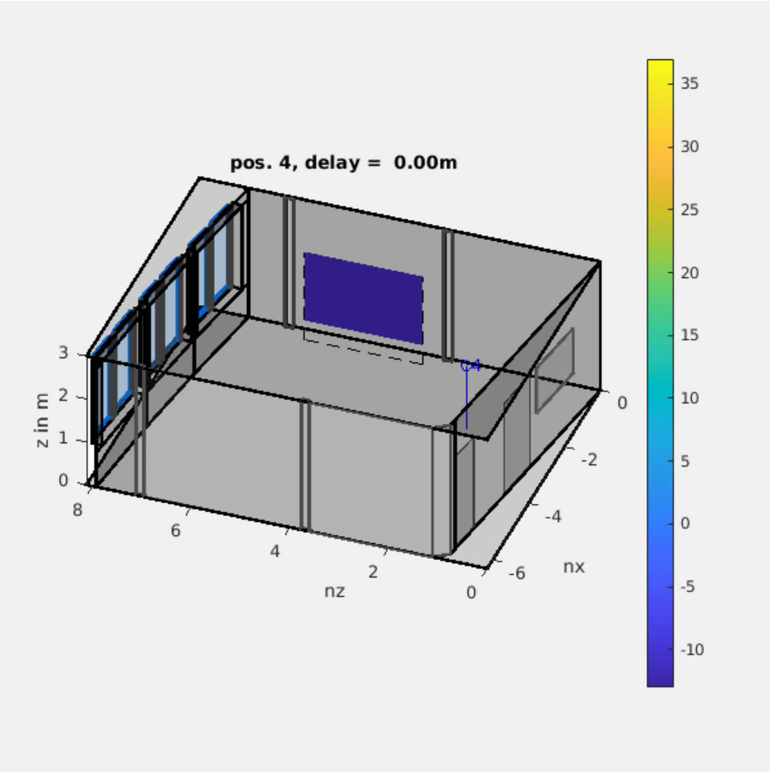
- measured 6 positions
  - varying height
- array size / dimension
  - area: 2.4 x 1.6 m
  - array: 112 x 75 = 8400 elements
- 7 GHz bandwidth (3-10GHz)
  - 4096freqs/175m, 2048freqs/87m)
  - varying signal “duration”



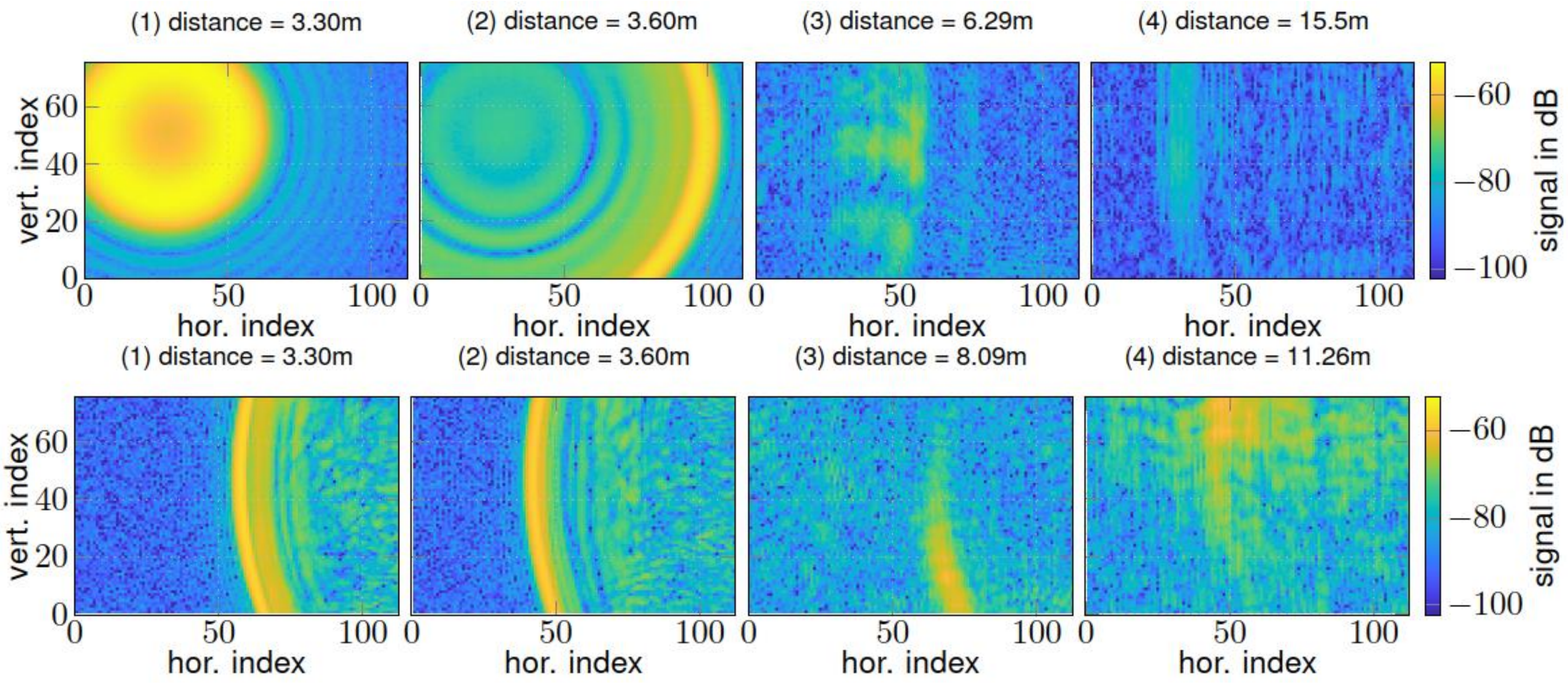
separate positions

Medium Sized Environment - Signal propagation



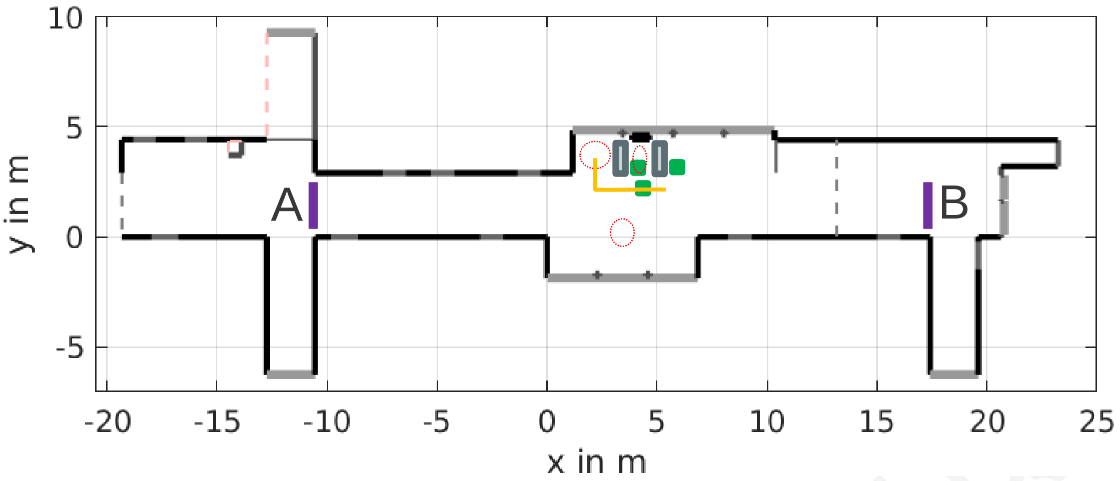


Medium Sized Environment - Signal propagation

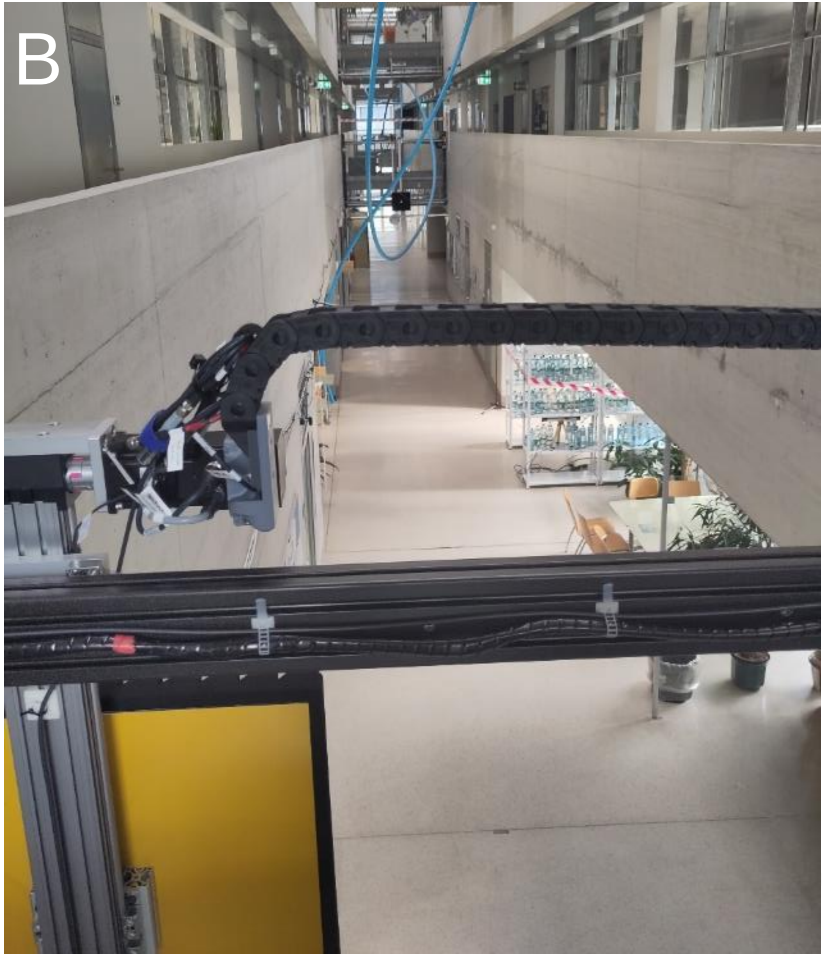


Large Sized Environment - “Corridor”

- point locations
  - distributed + small grid/linear
  - closely spaced (for sep.)
- channel conditions
  - with **obstruction**
  - without **obstruction**
- trajectory
  - UE to subarrays
  - RadioStripes, 4x4-subarrays




A


B

Exemplary Scenarios:

obstructed/NLOS

unobstructed/LOS

on shelf front (LOS/NLOS)

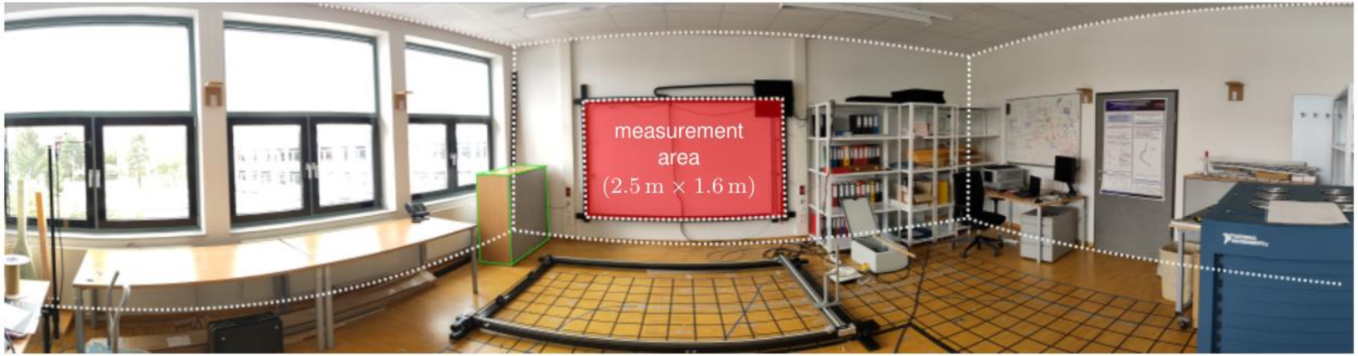
Measurement Analysis

Measurement Analysis

- “non-parametric” visibility: beamformer-based
  - computed for geometric model → “power” per array element
  - based on beamformer spectra (full array → subarrays)

- “parametric” visibility: SBL-based channel analysis
  - component visibility per subarray
  - delay spread, angular spread → depends on aperture
  - covariances of estimated components

Short Reminder: Medium Sized Environment

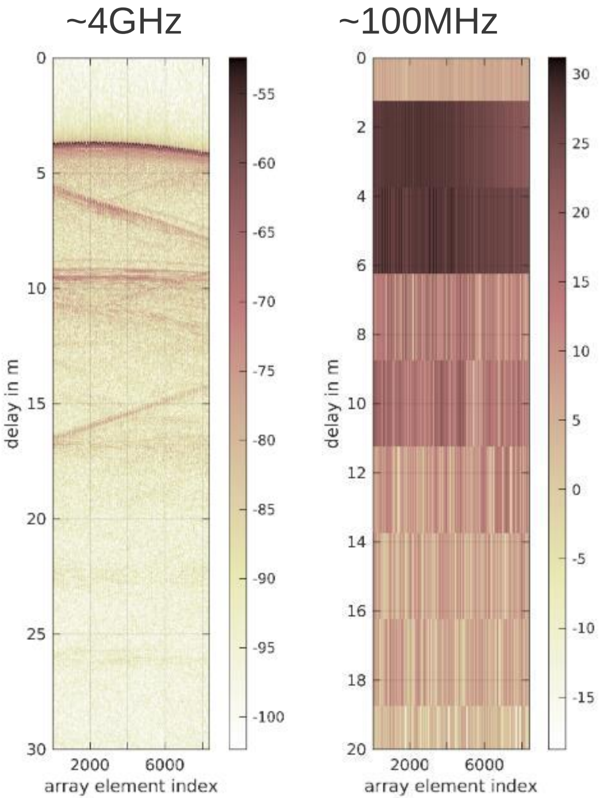


(a) view towards measurement position

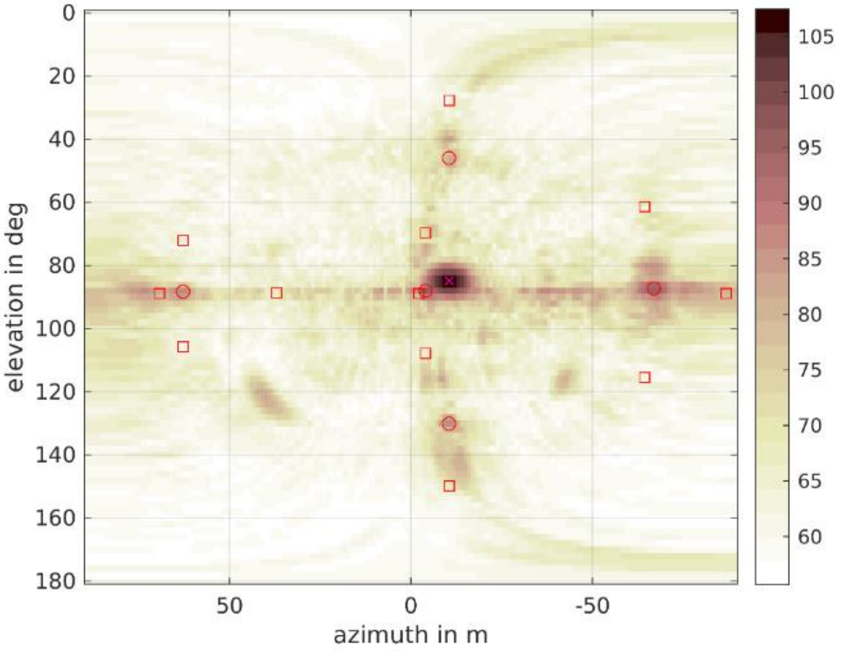
(b) view from measurement position

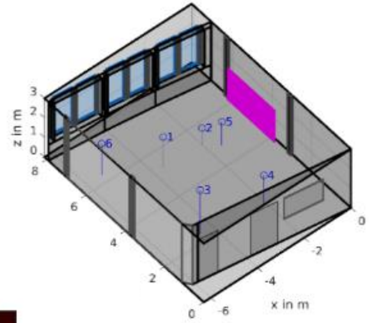
Non-parametric Analysis

x … direct path
o … first order
□ … second order



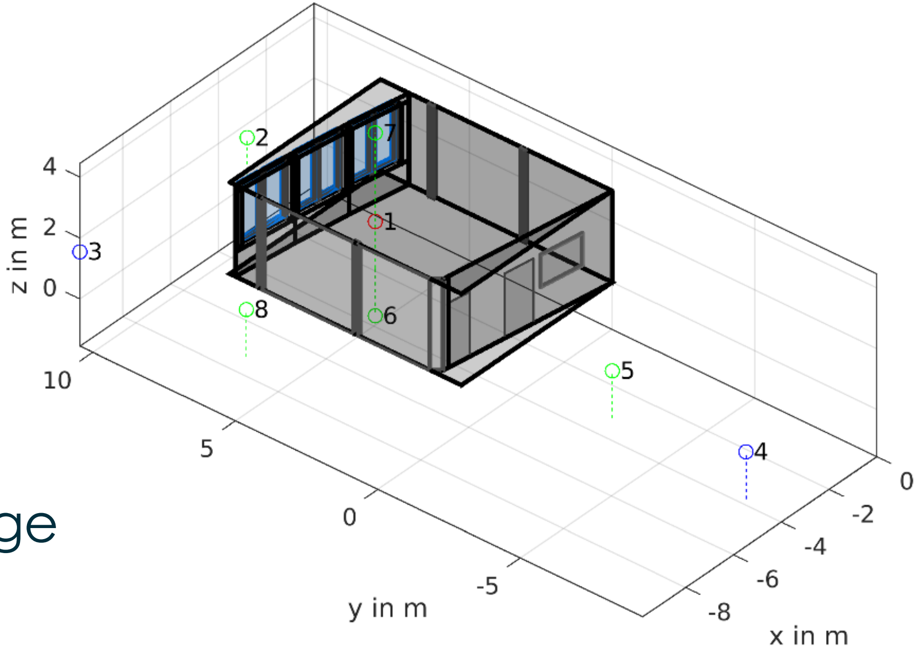
spherical wave beamforming





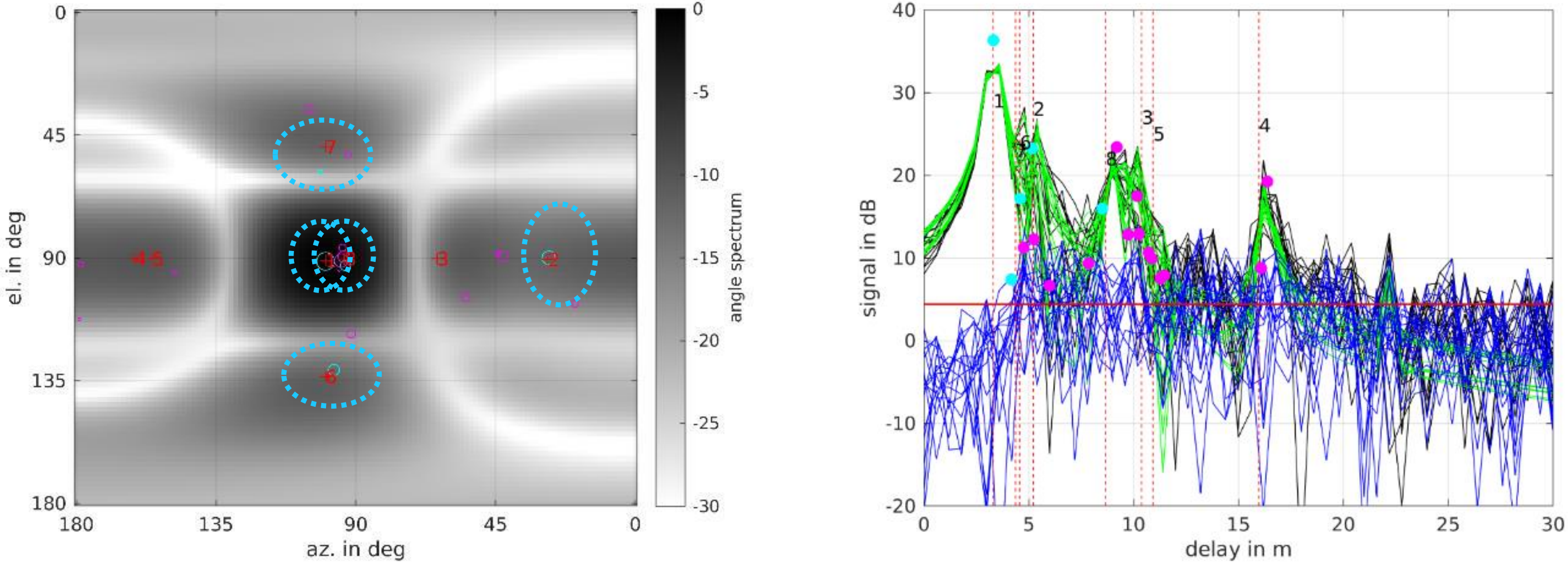
Parametric Analysis: Subarray-SBL

- sparse Bayesian learning (SBL)-based channel estimation performed for subarrays
  - 500MHz
  - 6.95GHz carrier frequency
  - 4x4, $\lambda/2$ spacing
- pre-selection of promising image sources for analysis
- **SBL results**
  - amplitude, distance, direction



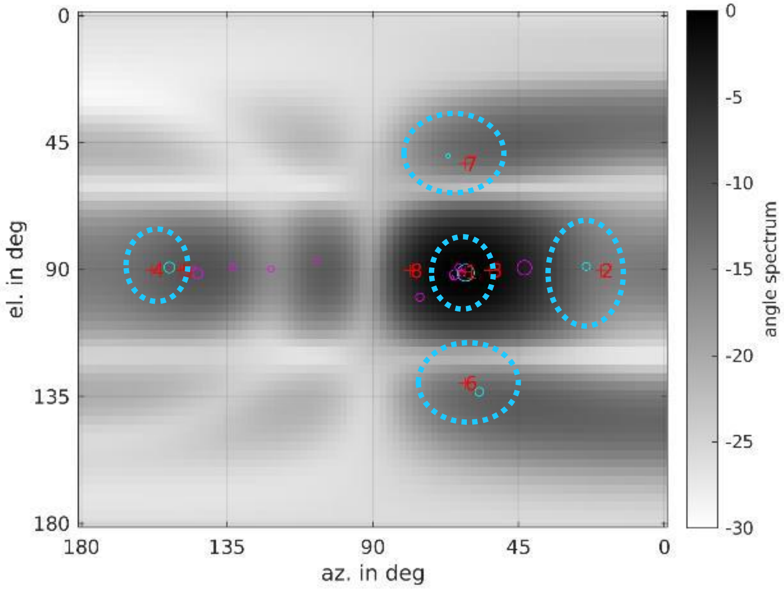
Parametric Analysis - Channel Estimation Results

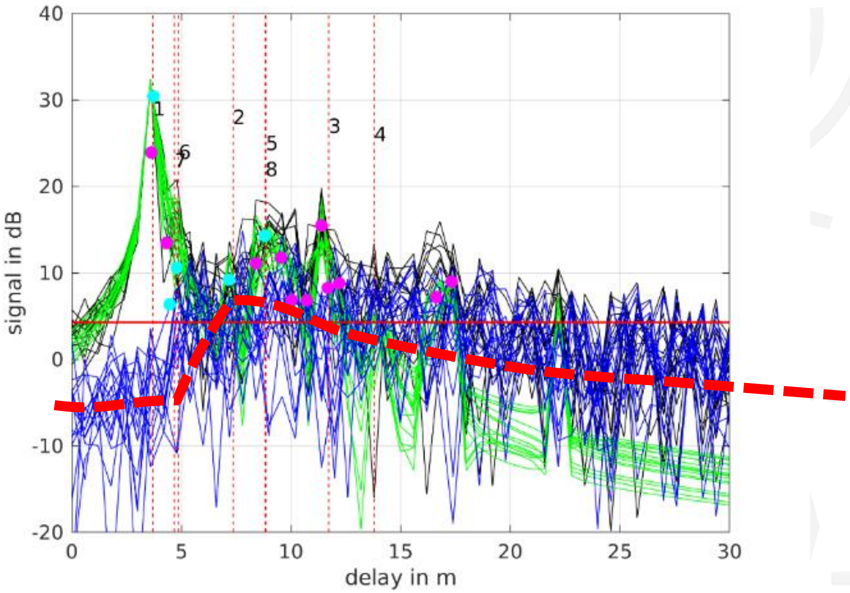
(4x4) subarray close to window



Parametric Analysis - Channel Estimation Results

(4x4) subarray close to door



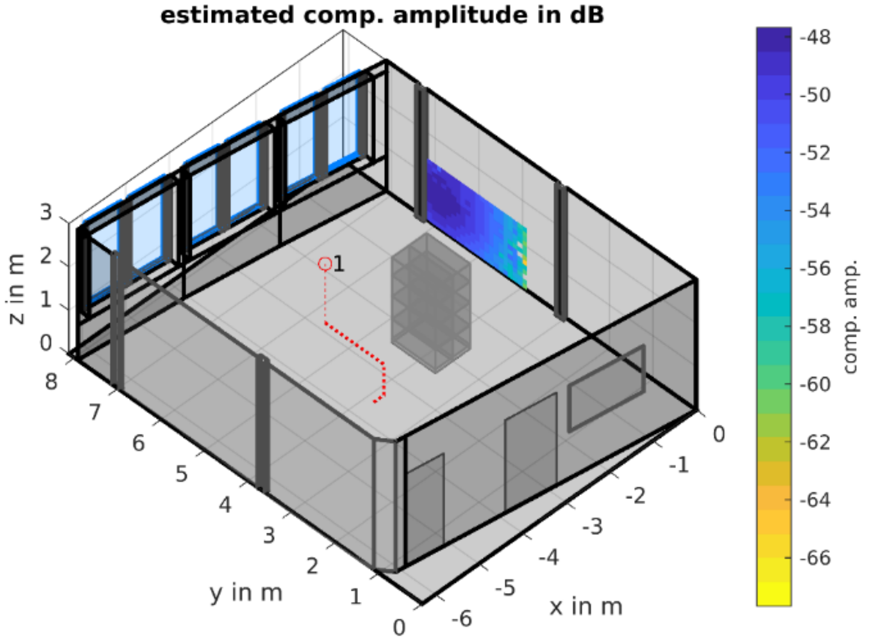


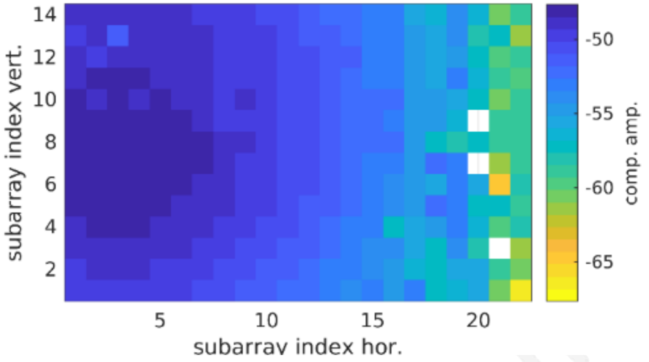
Parametric Analysis - Obstruction

- strong obstruction by large object (2x shelves)
- filled with wideband absorbers (2x) and binders
- wire mesh between shelves for improved obstruction
- analysis of LOS/NLOS condition

Parametric Analysis - Obstruction

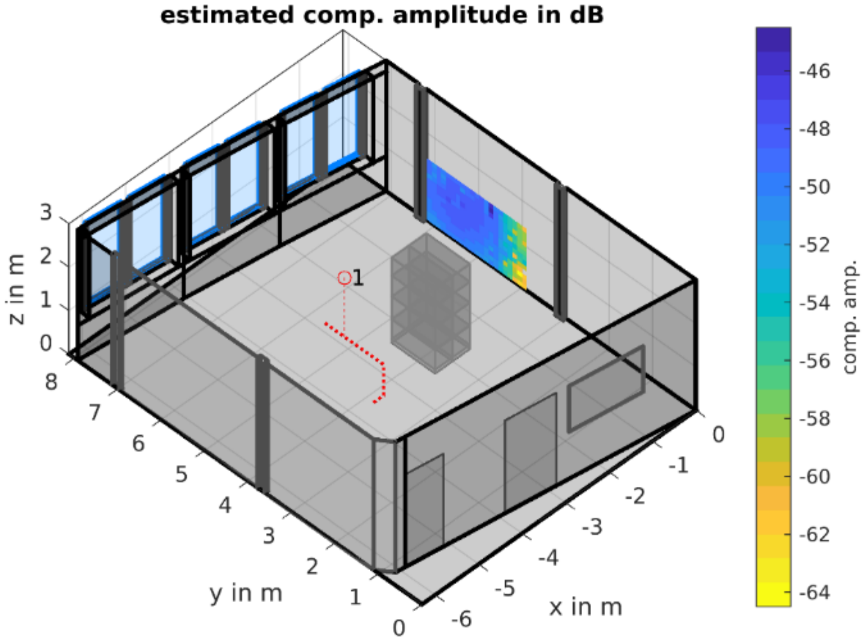
- visibility along partially obstructed trajectory (pos. 1)

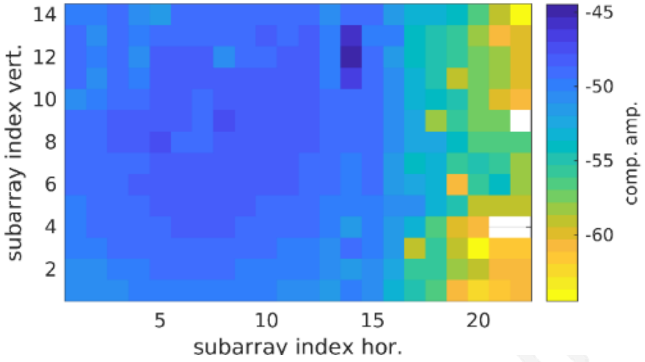




Parametric Analysis - Obstruction

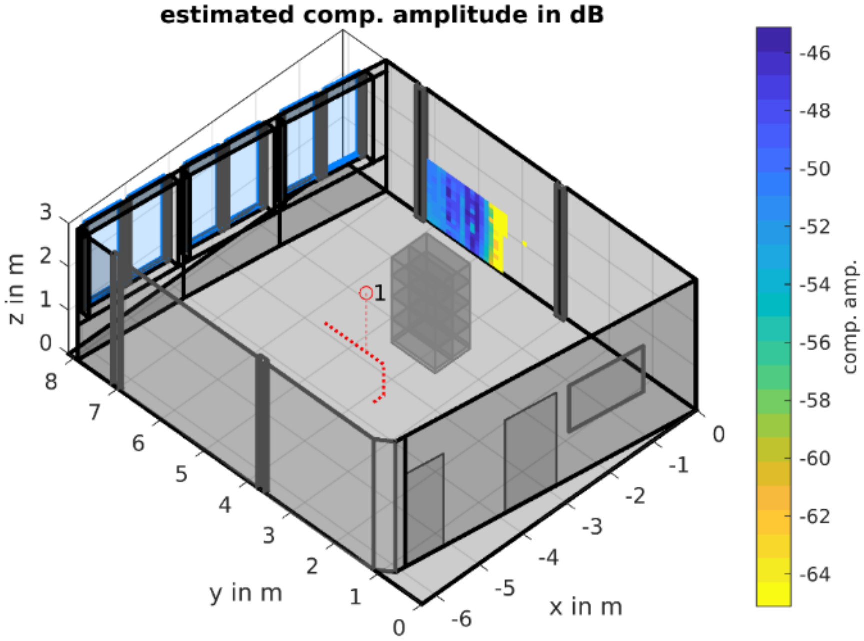
- visibility along partially obstructed trajectory (pos. 10)

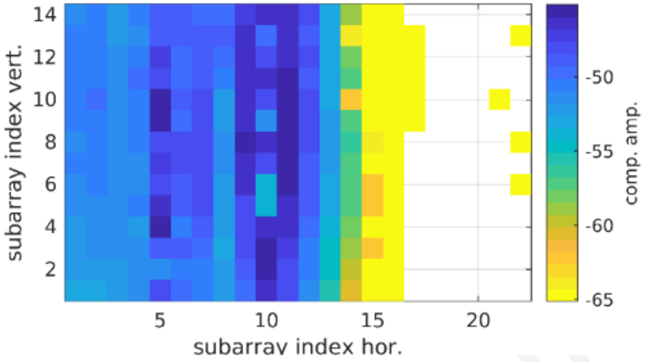




Parametric Analysis - Obstruction

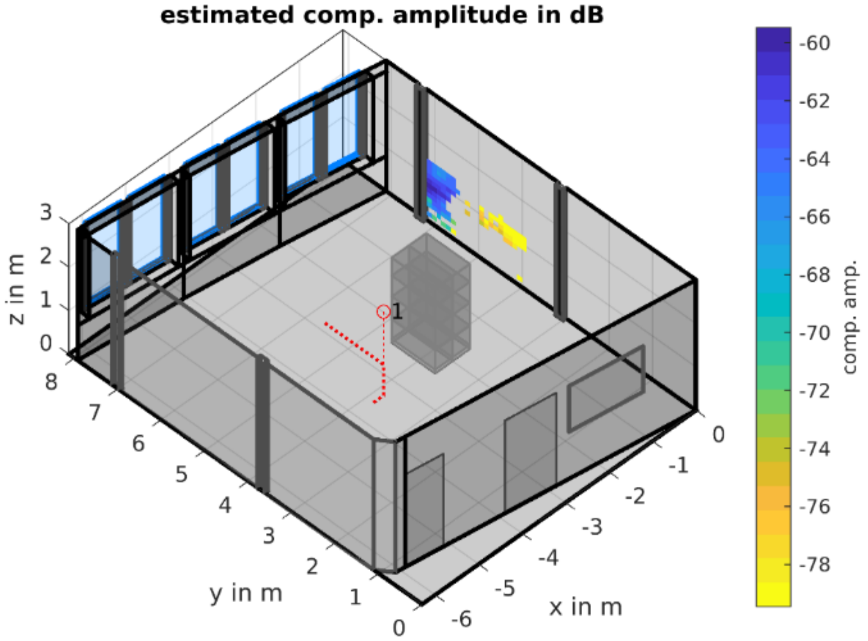
- visibility along partially obstructed trajectory (pos. 20)

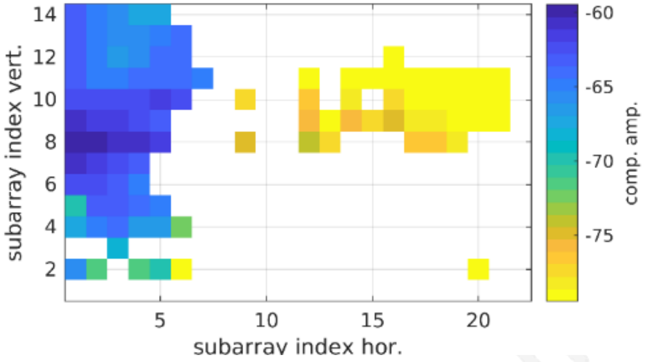




Parametric Analysis - Obstruction

- visibility along partially obstructed trajectory (pos. 30)





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Propagation Modeling

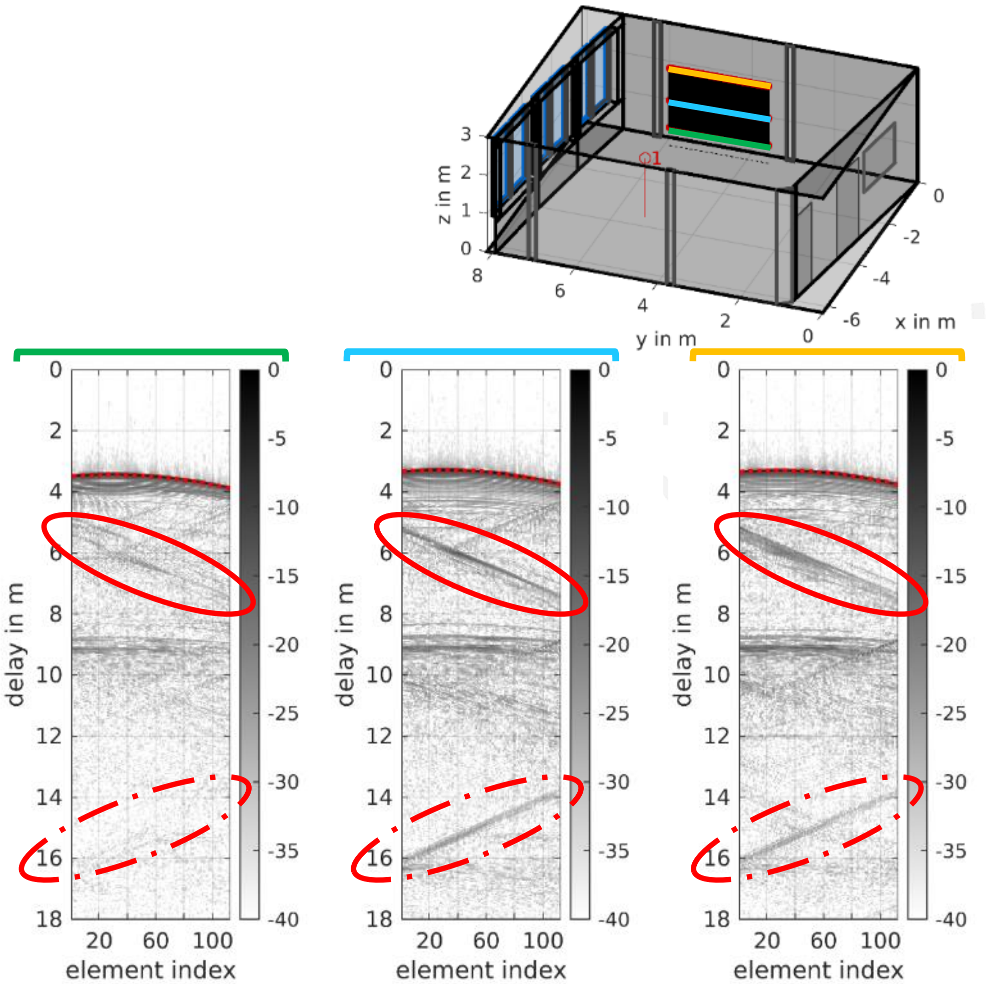
Propagation Modeling

- large array size results in non-stationary environment
- component **visibility** varies along the array

$$K \rightarrow K(\text{array element, position})$$

- component **amplitude** varies along the array

$$\text{amp.} \propto \frac{b(\text{array element,} \quad \text{position})}{\text{distance}}$$



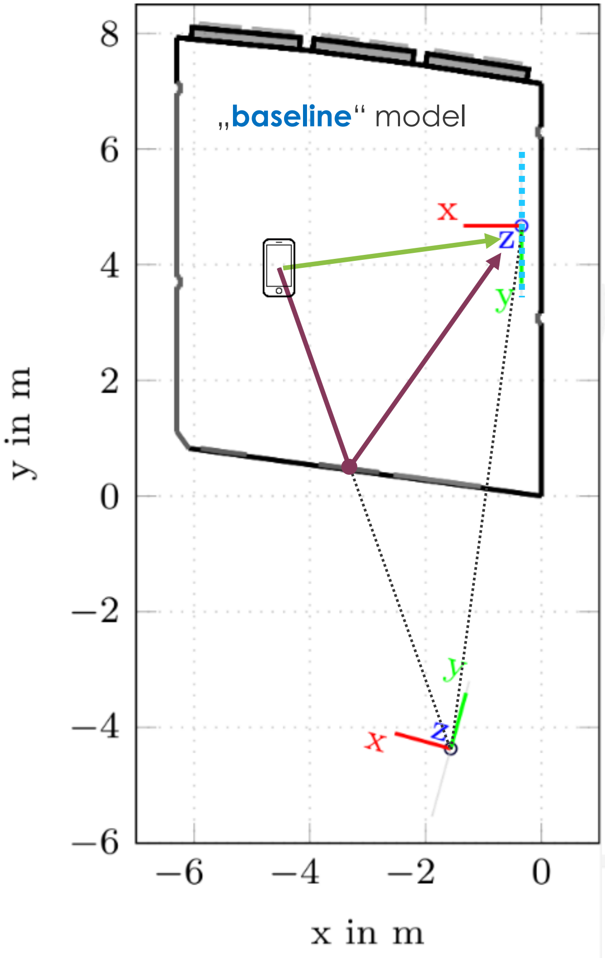
Multipath Signal Model

- "**Baseline**" mirror source model for (deterministic) multipath propagation:

$$\boldsymbol{r}_{\mathrm{det},m} = \sum_k \alpha_k b(\boldsymbol{\theta}_k)\boldsymbol{s}(\boldsymbol{\theta}_k)$$

- Modifications for **large antenna arrays**
  - varying propagation conditions to array elements: $\alpha_k \to \alpha_{k,m}$
  - visibility regions $v_{k,m}^{\mathrm{vis}}$ and "different" antenna patterns due to large array aperture
  - parameters-per-element: $\boldsymbol{\theta}_k \to \boldsymbol{\theta}_{k,m}$

$$\boldsymbol{r}_{\mathrm{det},m} = \sum_k \frac{\alpha_{k,m}}{d_{k,m}} v_{k,m}^{\mathrm{vis}} b(\boldsymbol{\theta}_{k,m})\boldsymbol{s}(\boldsymbol{\theta}_{k,m})$$



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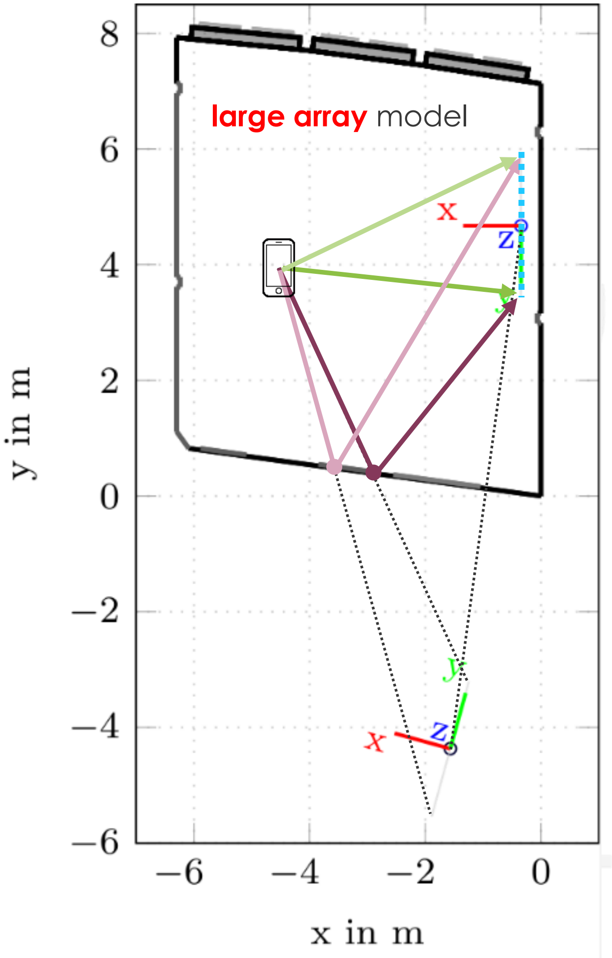
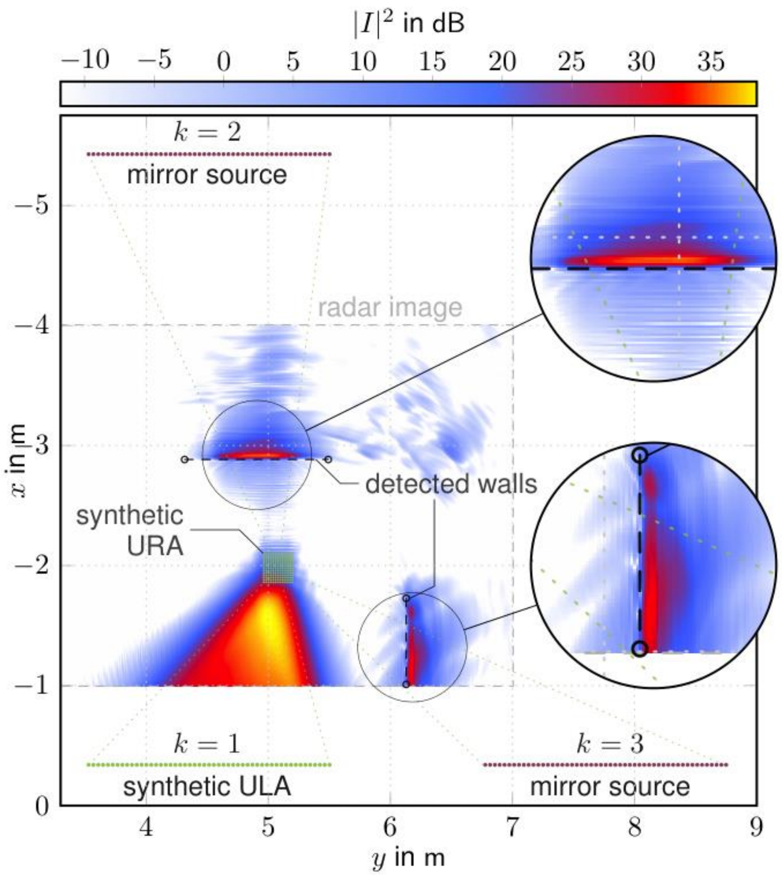


Application Examples

(i) MIMO Radar sensing

- sensing of reflective surfaces:
  - *Radar imaging* using location-based MIMO beamforming
  - *edge detection* based on Hough transfrom

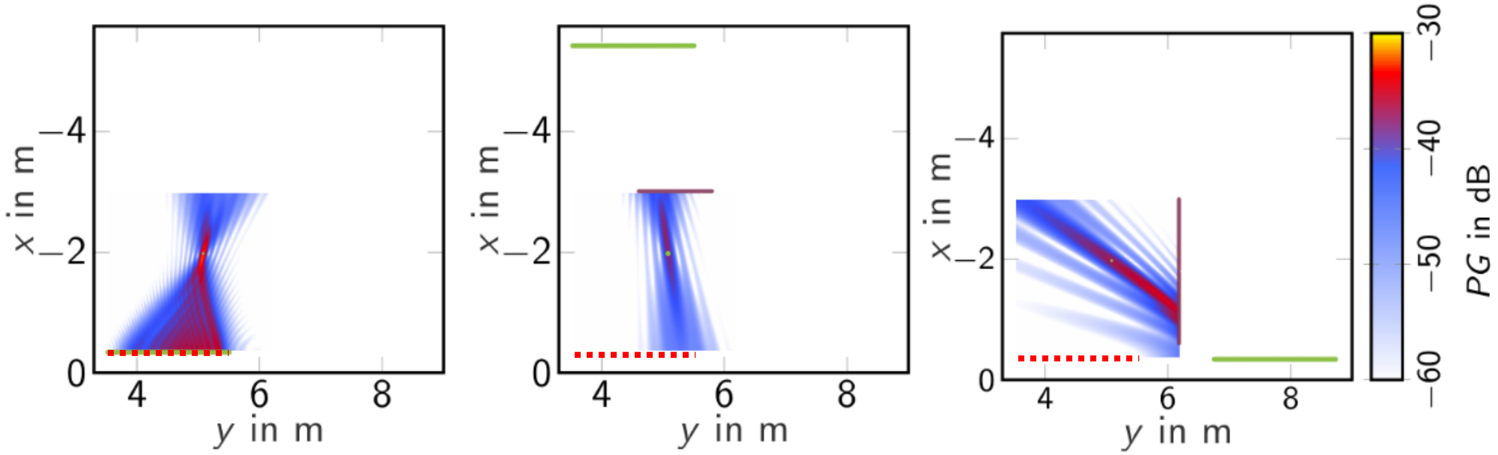


[2] Deutschmann, B. J., Graber, M., Wilding, T., & Witrisal, K. (2023). Bistatic MIMO Radar Sensing of Specularly Reflecting Surfaces for Wireless Power Transfer. *arXiv preprint arXiv:2305.05002*.

(ii) Geometry-based beamforming

- exploiting specular multipath components (SMCs) for…
    - wireless power transfer
    - positioning

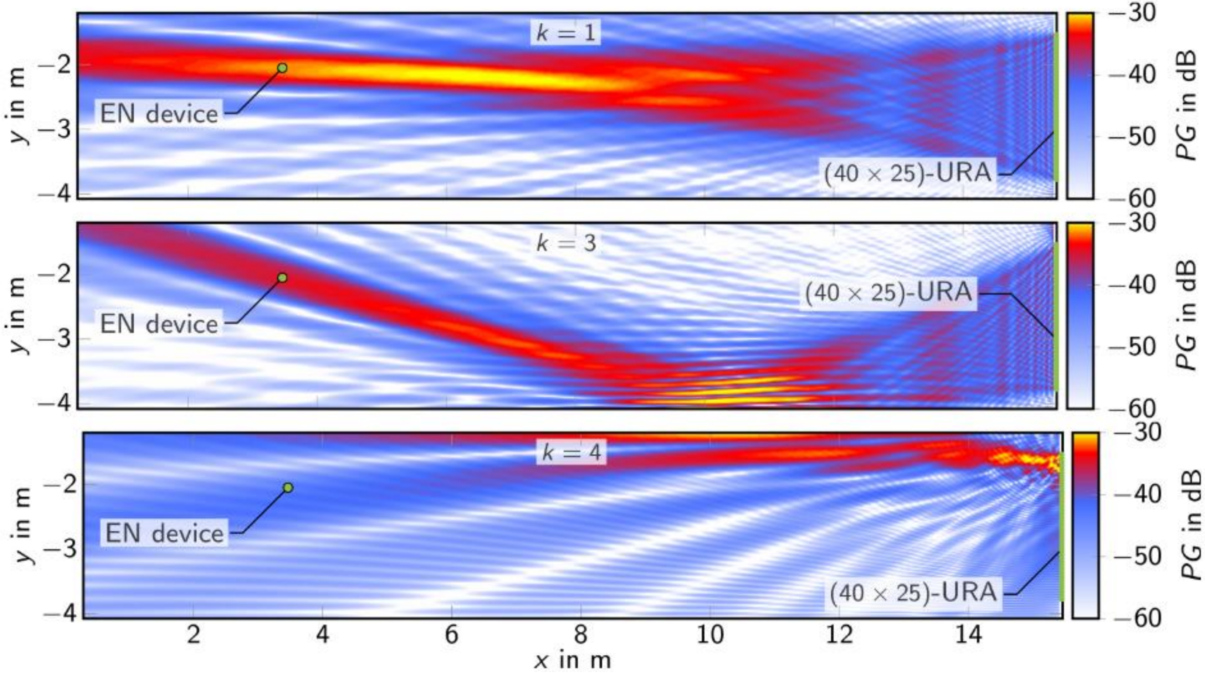
[2] Deutschmann, B. J., Graber, M., Wilding, T., & Witrisal, K. (2023). Bistatic MIMO Radar Sensing of Specularly Reflecting Surfaces for Wireless Power Transfer. *arXiv preprint arXiv:2305.05002*.



(iii) Wireless Power Transfer (WPT)

- position-based beamforming for wireless power transfer (WPT)
- enables communication with fully energy neutral devices (ENDs)

k	P_g in dB
1	-33.4
3	-36.6
4	-49.9



[3] Deutschmann, B. J., Wilding, T., Graber, M., & Witrisal, K. (2023). XL-MIMO Channel Modeling and Prediction for Wireless Power Transfer. *arXiv preprint arXiv:2302.11969*.

Conclusion

Conclusion

- Large number of antennas
  - beneficial for positioning, communication, wireless power transfer
  - high focussing capabilities
- Large aperture
  - antennas "see" different propagation channels
  - nonstationary or spatially consistent models need to be considered for optimum algorithms (model mismatch)
- Expected performance gains
  - increased reliability, energy efficiency, and sensing cababilities

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