Propagation Modeling for Physically Large Arrays: Measurements and Multipath Component Visibility

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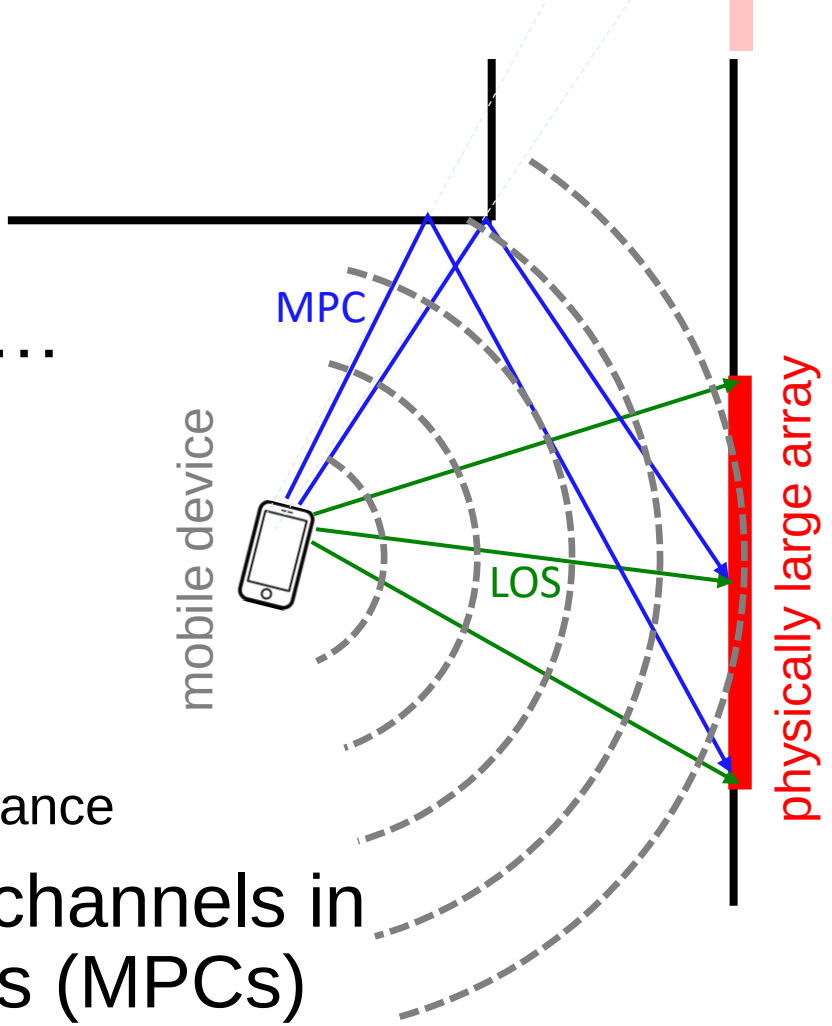
Introduction and Motivation

- Physically large arrays (PLAs) promising for …
  - positioning
  - wireless power transfer
  - communication
  - environment learning, …
- Signal transmissions in array near-field
  - large array aperture/dimension → large Fraunhofer distance
- PLAs experience nonstationary propagation channels in environments including multipath components (MPCs)
  - massive MIMO [7], XL-MIMO [8], LIS/RIS, …
  - COST2100 and MIMO extension [9] including visibility regions



Paper Contribution

- Description of measurement system for measurements of synthetic physically large arrays (PLAs)

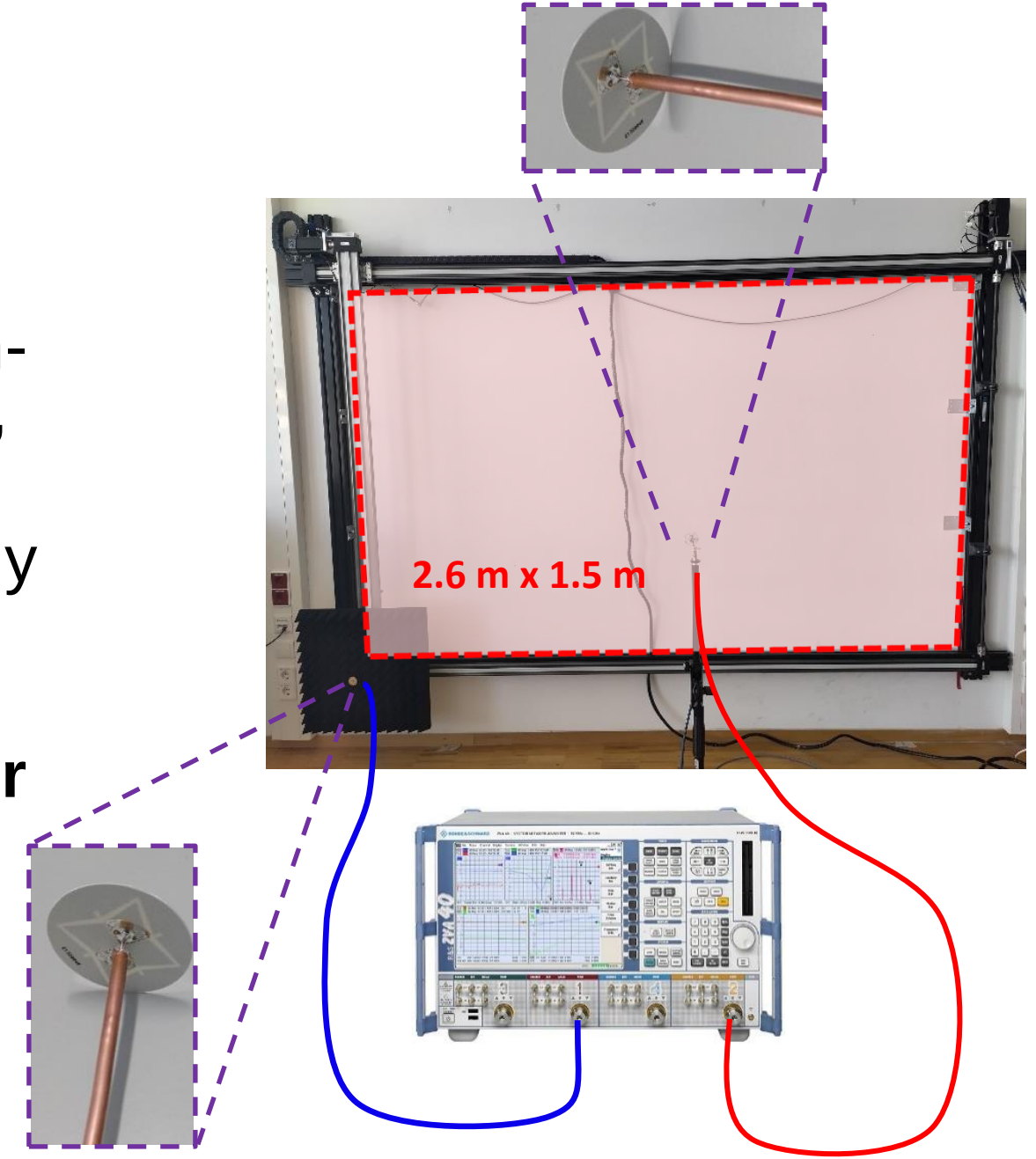
- Measurement modeling and analysis regarding …
  - multipath component (MPC) visibility
  - spherical and plane wave effects

1. Measurement System
2. Modeling
3. Multipath Component Visibility
4. Conclusion

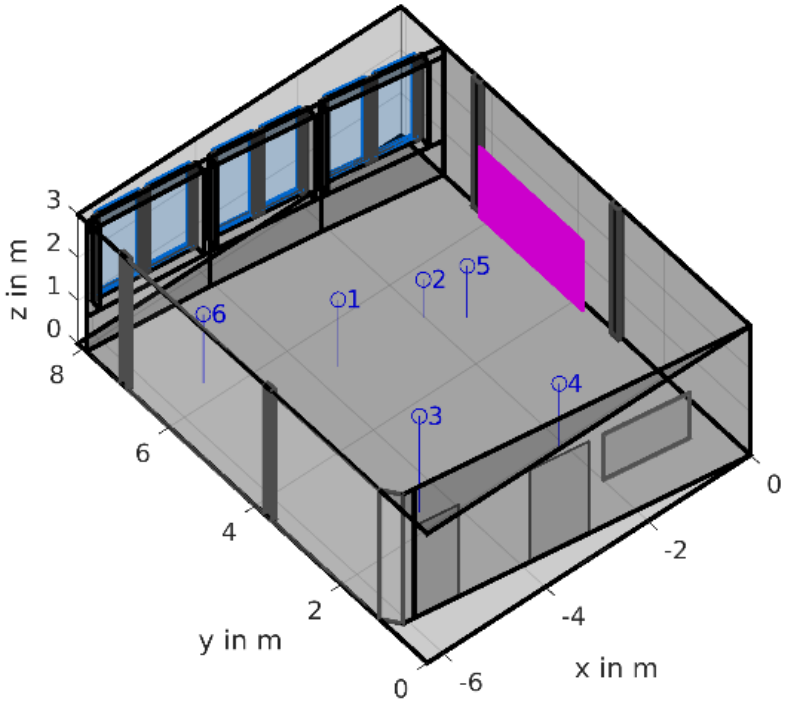
Measurement System

Measurement System

- **Application:** data collection for channel characterization and position-related applications (large bandwidth, large aperture)
- **Synthetic array system** for physically large arrays (PLAs)
  - 2.6 m x 1.5 m measurement area
- Measurements performed with **Vector network analyzer (VNA)**
  - 10 kHz – 24 GHz (ZVA24) with 4 ports
  - 3-10 GHz measurements (e.g., 4096, 2048 freqs.)
  - 2x XETS antennas (3-10GHz) [18]

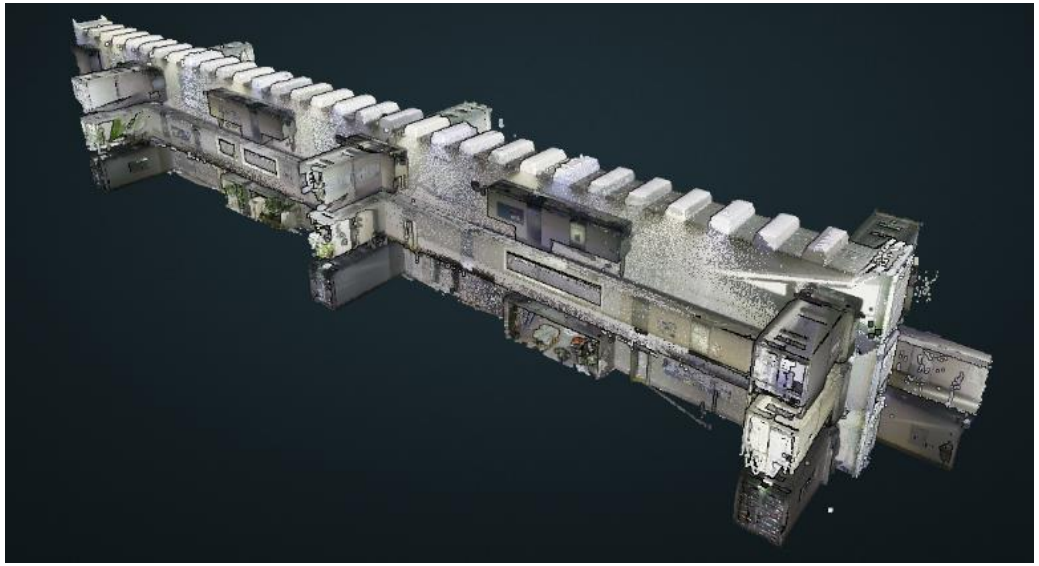


Measurement Environments



- **Medium size indoor environment (I)**
  - distributed positions
  - large array size: URA with 112 x 75 (= 2.4 x 1.6 m)
  - up to 7 GHz bandwidth

- **Large size indoor environment (II)**
  - wide distribution of PLAs and users
  - long, high corridor
  - 3D-environment model obtained from laser scanner point cloud data



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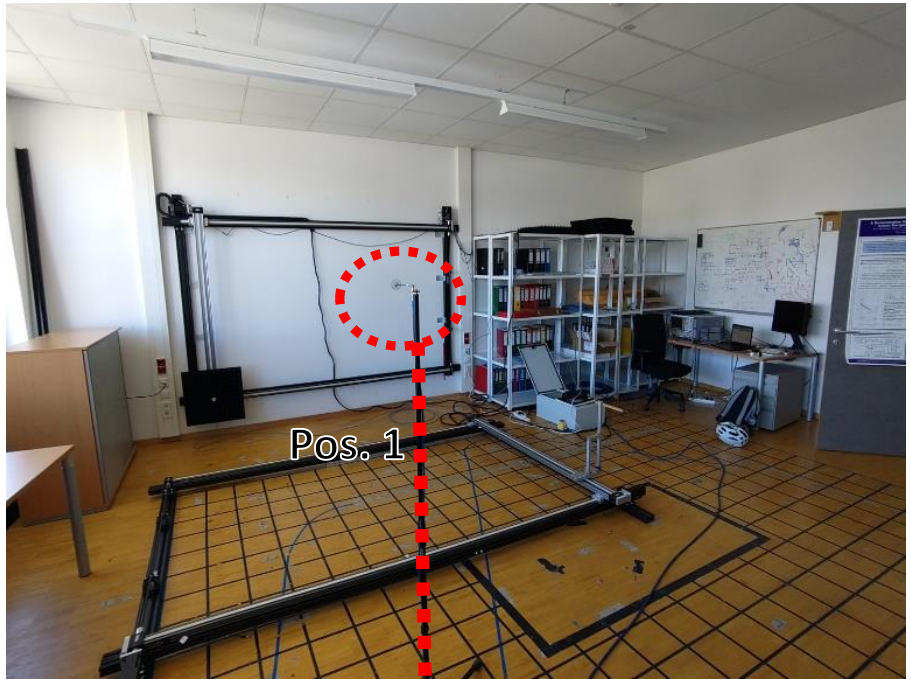


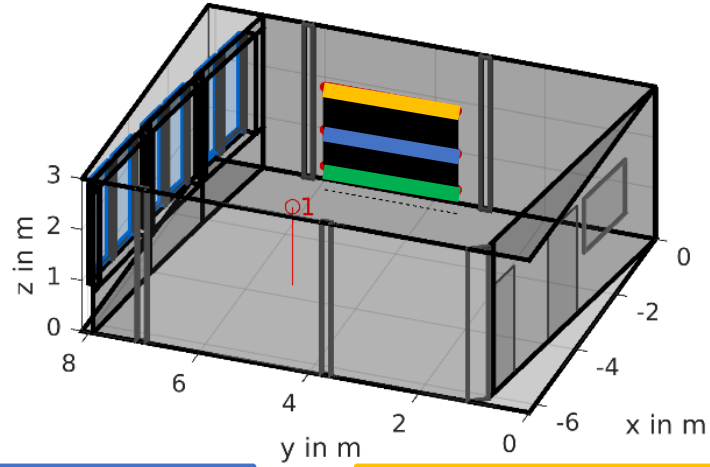
Modeling

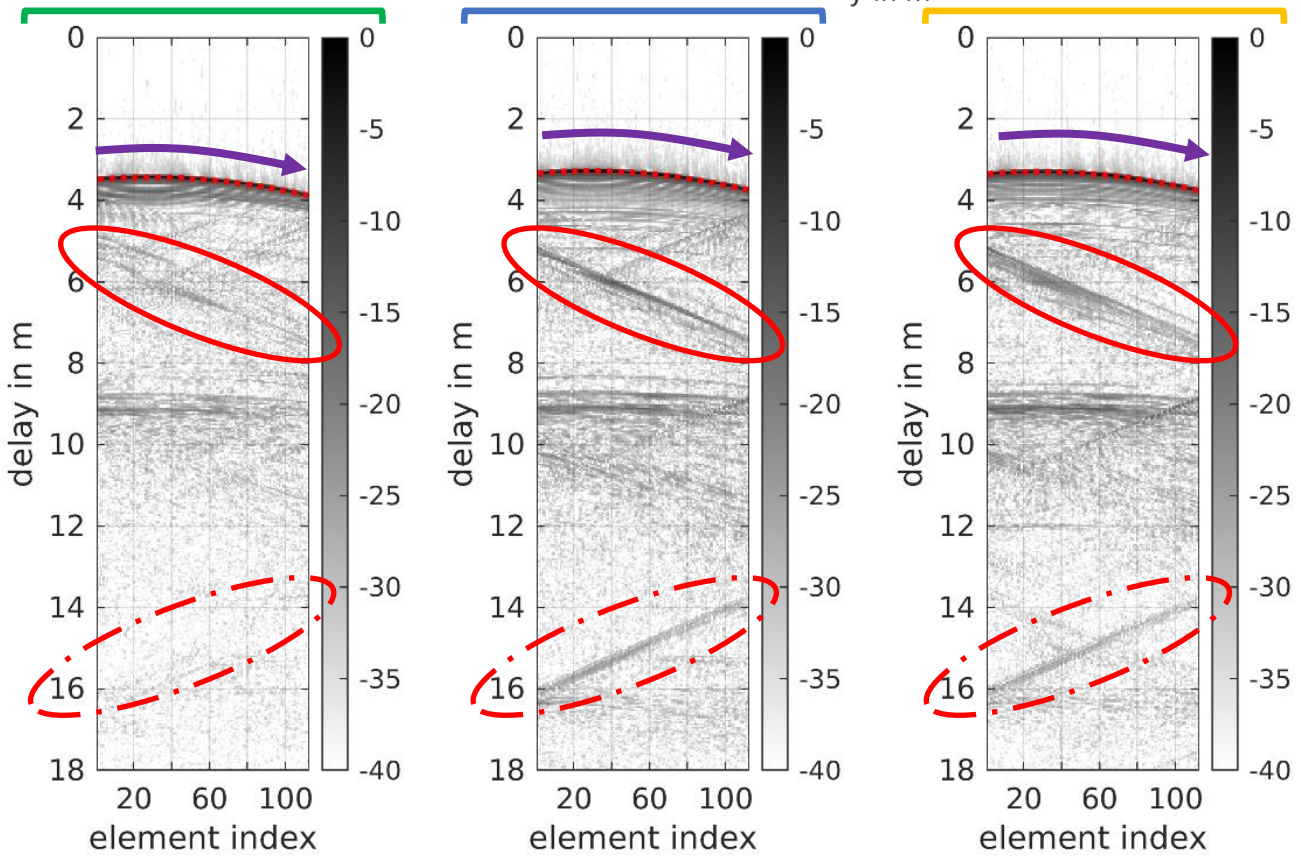
Propagation Effects

- **Propagation modeling:**
  - large array size results in non-stationary environment
  - component **visibility** varies along array

    $K \rightarrow K(\text{element}, \text{position})$
  - component **amplitude** varies along array

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





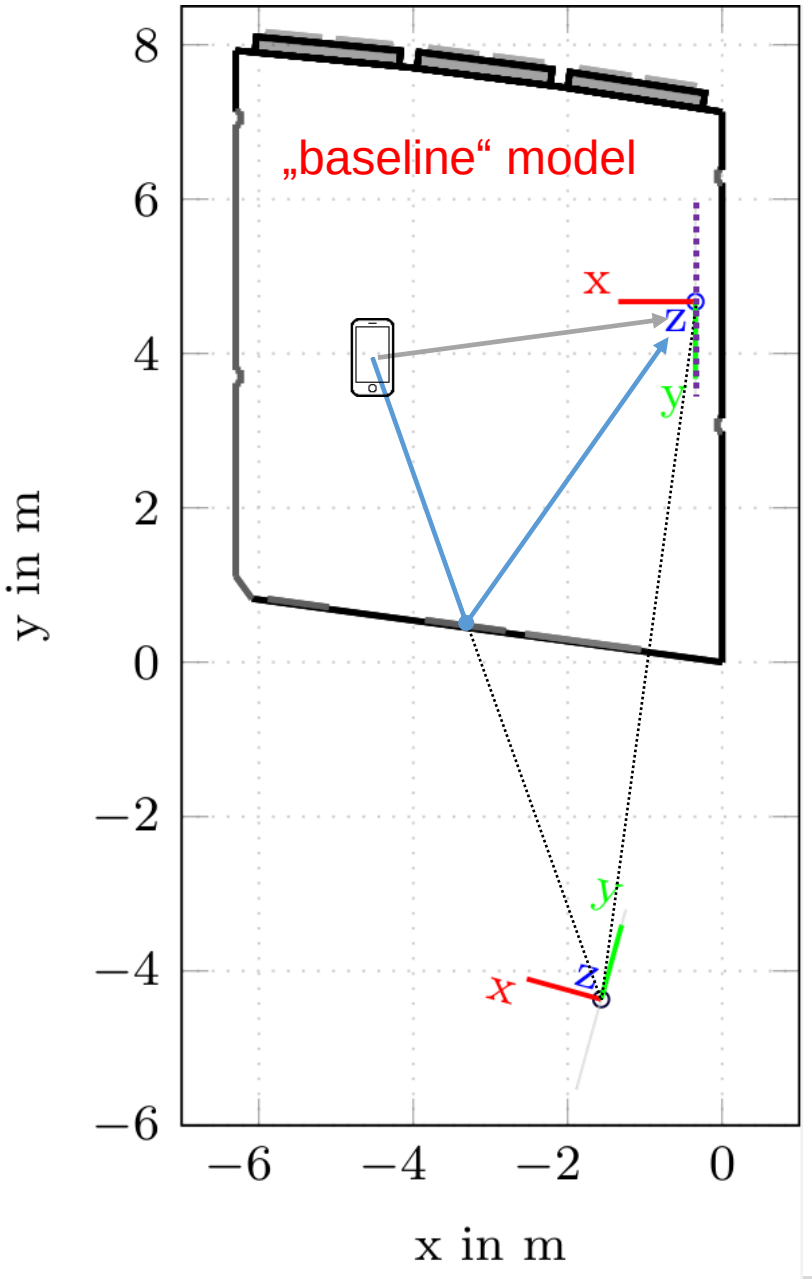
Signal Model

- **“Baseline”** image/mirror source model for (deterministic) multipath propagation:

$$\boldsymbol{r}_m = \sum_k \alpha_k b(\boldsymbol{\theta}_k)\boldsymbol{s}(\boldsymbol{\theta}_k) + \text{noise}$$

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

$$\boldsymbol{r}_m = \sum_k \frac{\alpha_{k,m}}{d_{k,m}} v_{k,m}^{\text{vis}} b(\boldsymbol{\theta}_{k,m})\boldsymbol{s}(\boldsymbol{\theta}_{k,m}) + \text{noise}$$



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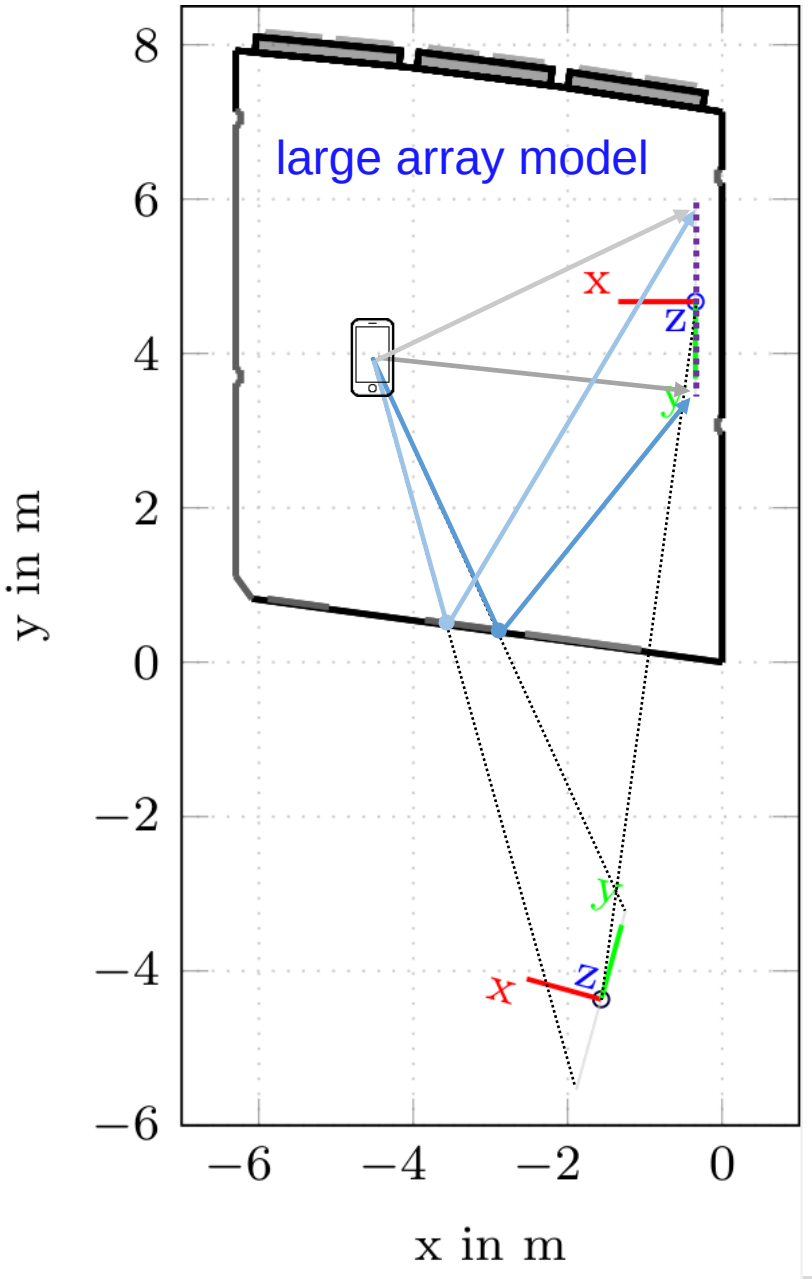
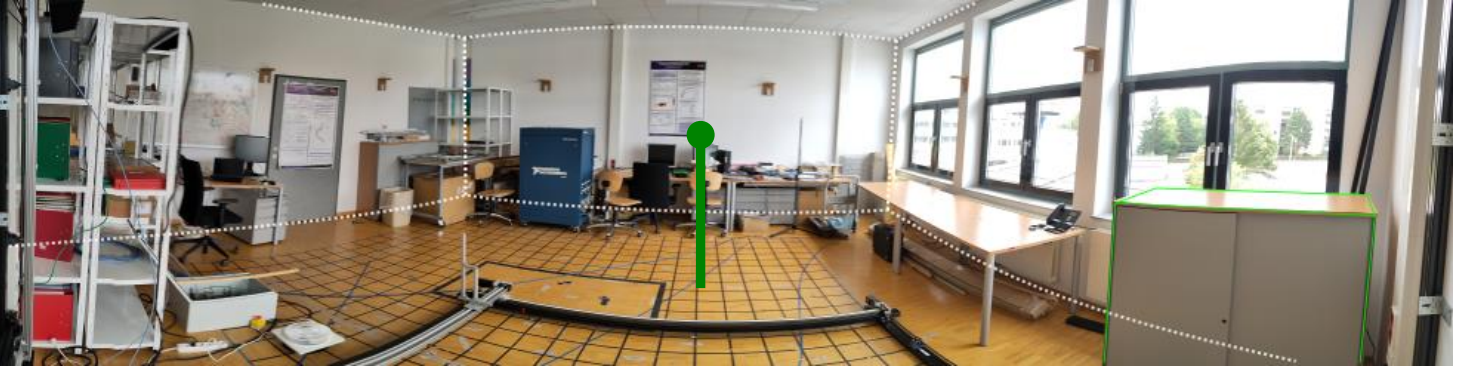
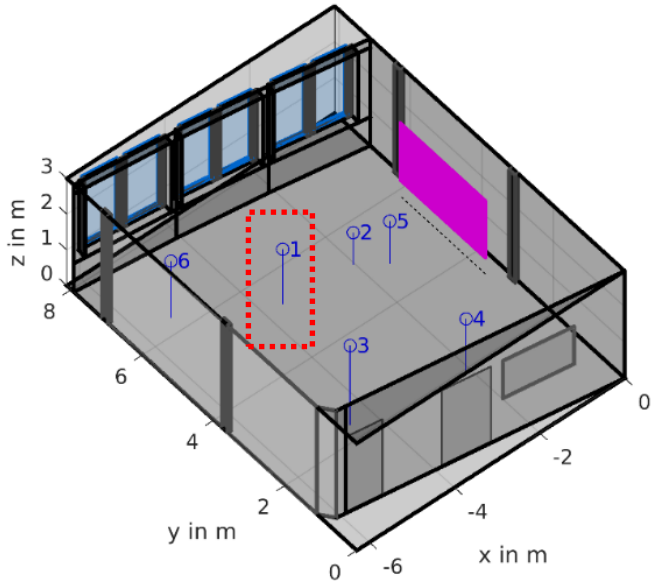


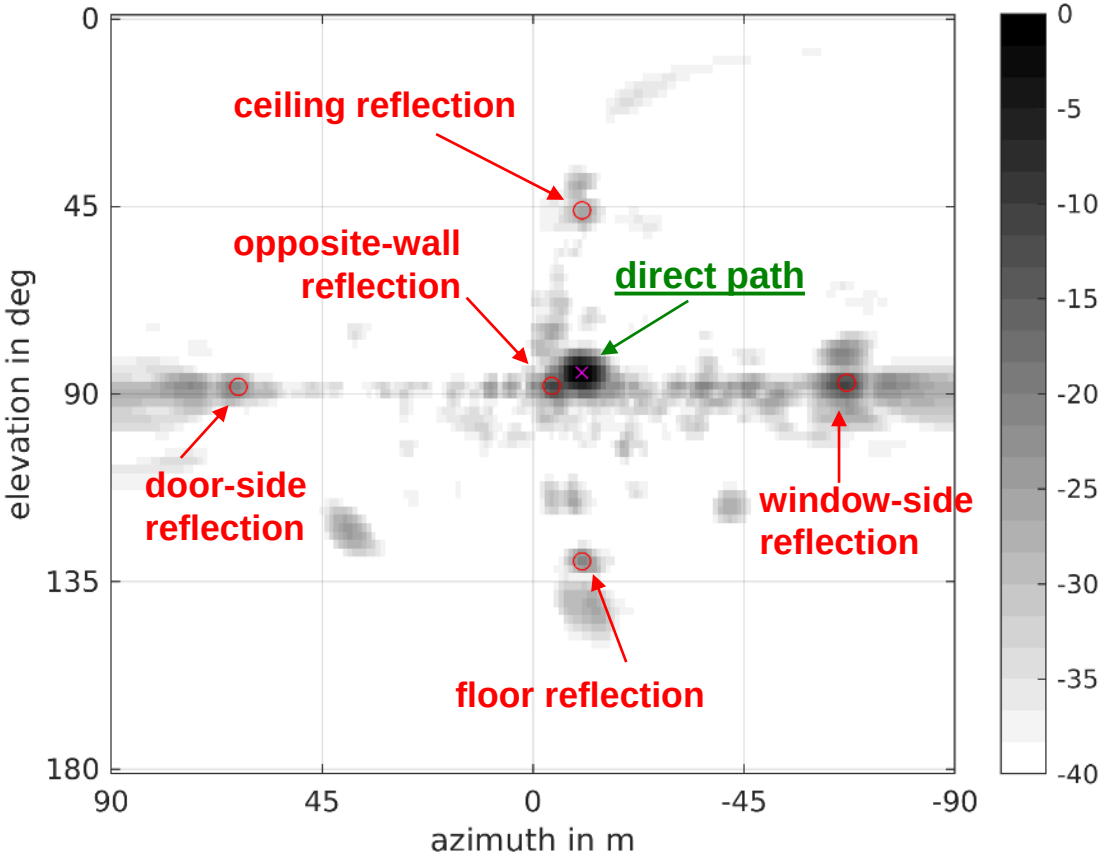
Multipath Component Visibility

Measurement Analysis

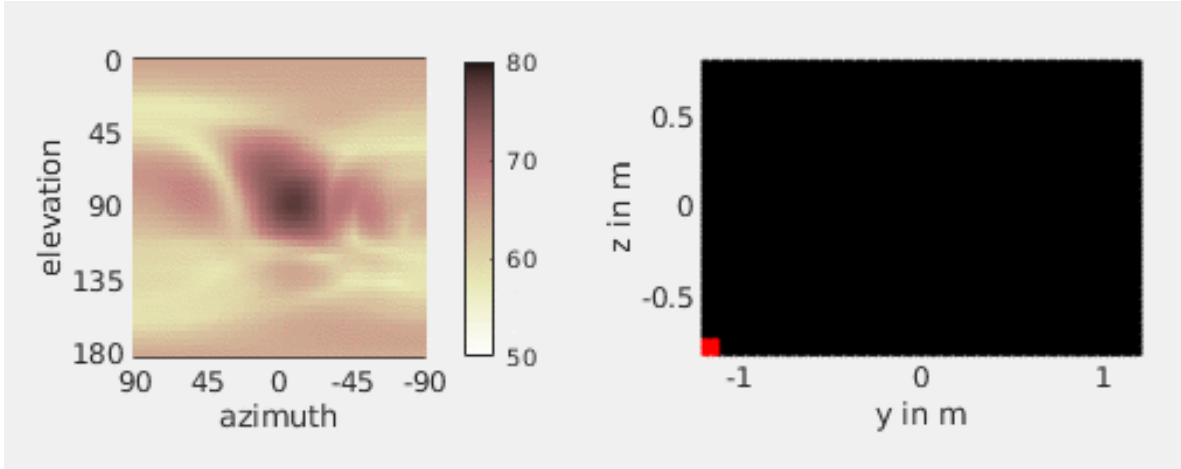




full array processed (112x75, sph. wave beamf.)



subarrays (4x4, plane wave beamf.)

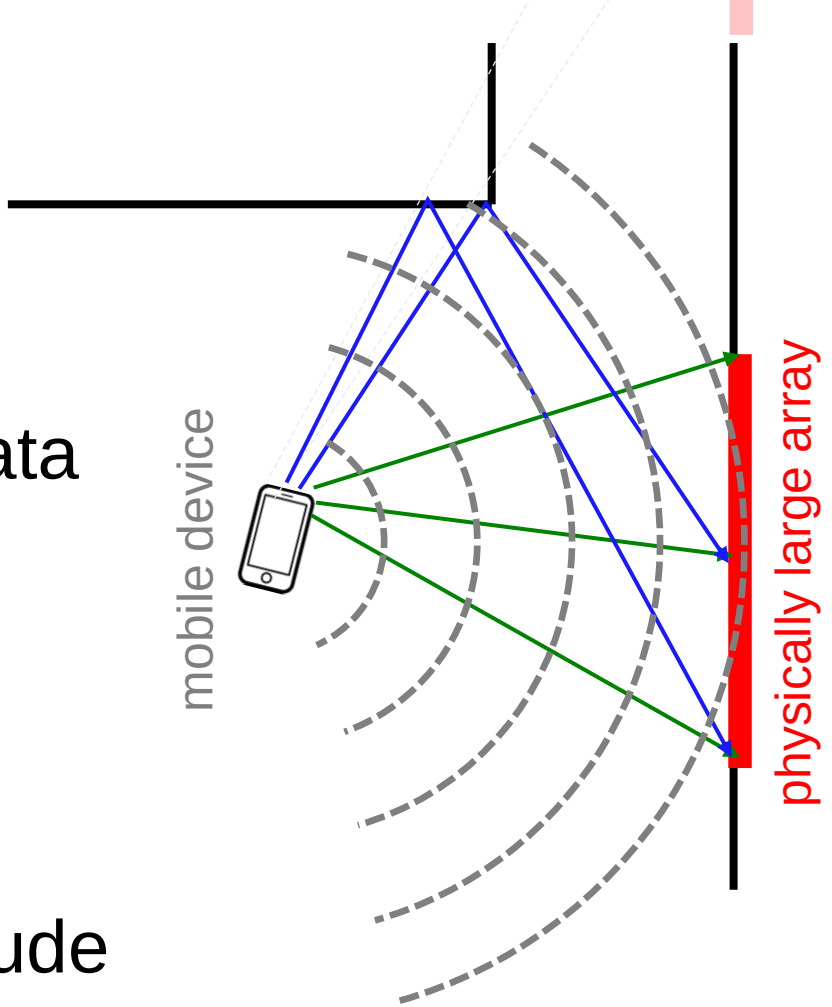


Multipath Channel Estimation

- sparse Bayesian learning (SBL) multipath channel estimator [21] applied to subarray-data
  → not feasible on full array data
- **plane wave** assumption per subarray

$$\boldsymbol{r} = \sum_{k=1}^{K} \alpha_k \boldsymbol{s}(\boldsymbol{\theta}_k) + \boldsymbol{w} = \boldsymbol{S}(\boldsymbol{\theta})\boldsymbol{\alpha} + \boldsymbol{w}$$

- yields $\widehat{K}$ delay, azimuth, elevation and amplitude estimates $\{\hat{\alpha}_k, \hat{\tau}_k, \hat{\vartheta}_k, \hat{\varphi}_k\}$ for SMC candidates
- estimator artifacts can „distort“ propagation effects



spherical processing

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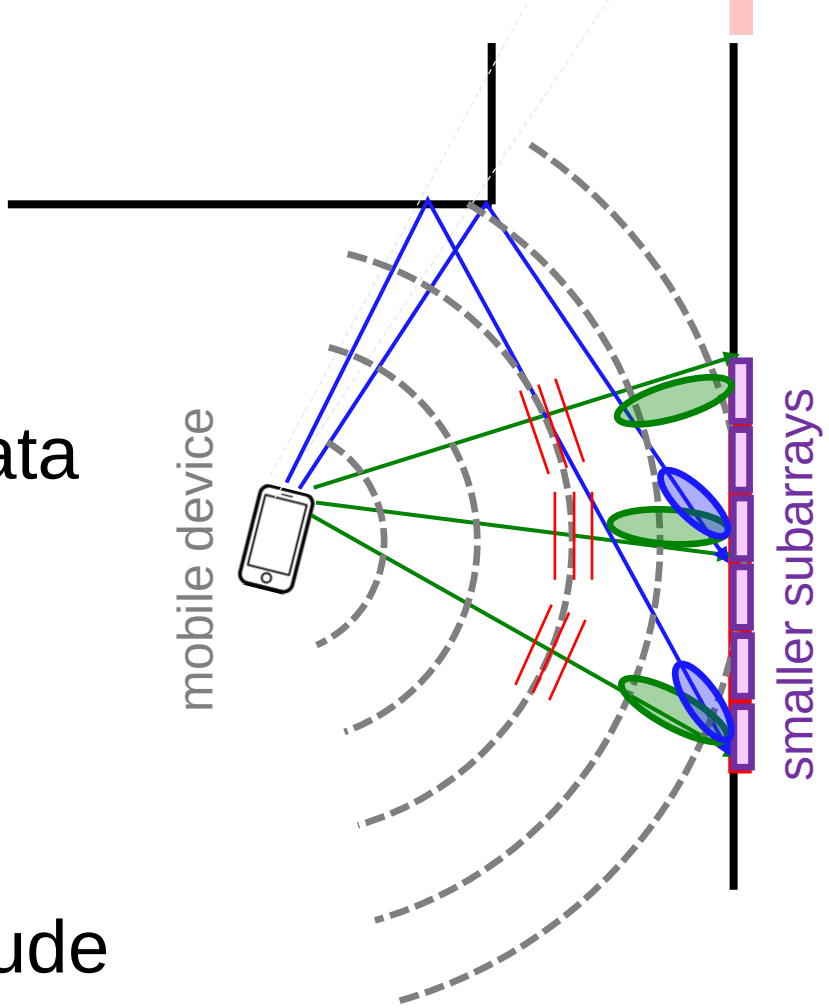


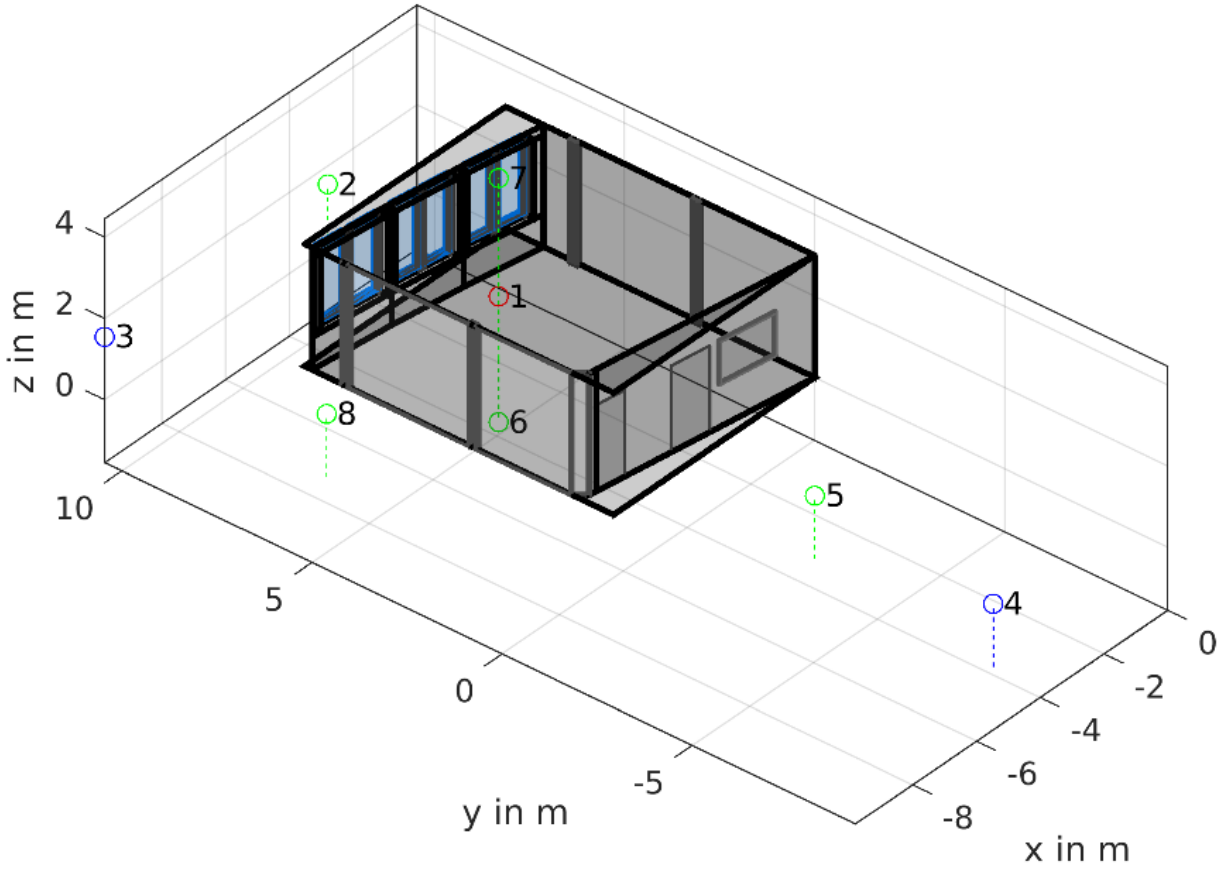
subarray-PW processing

\+

data fusion

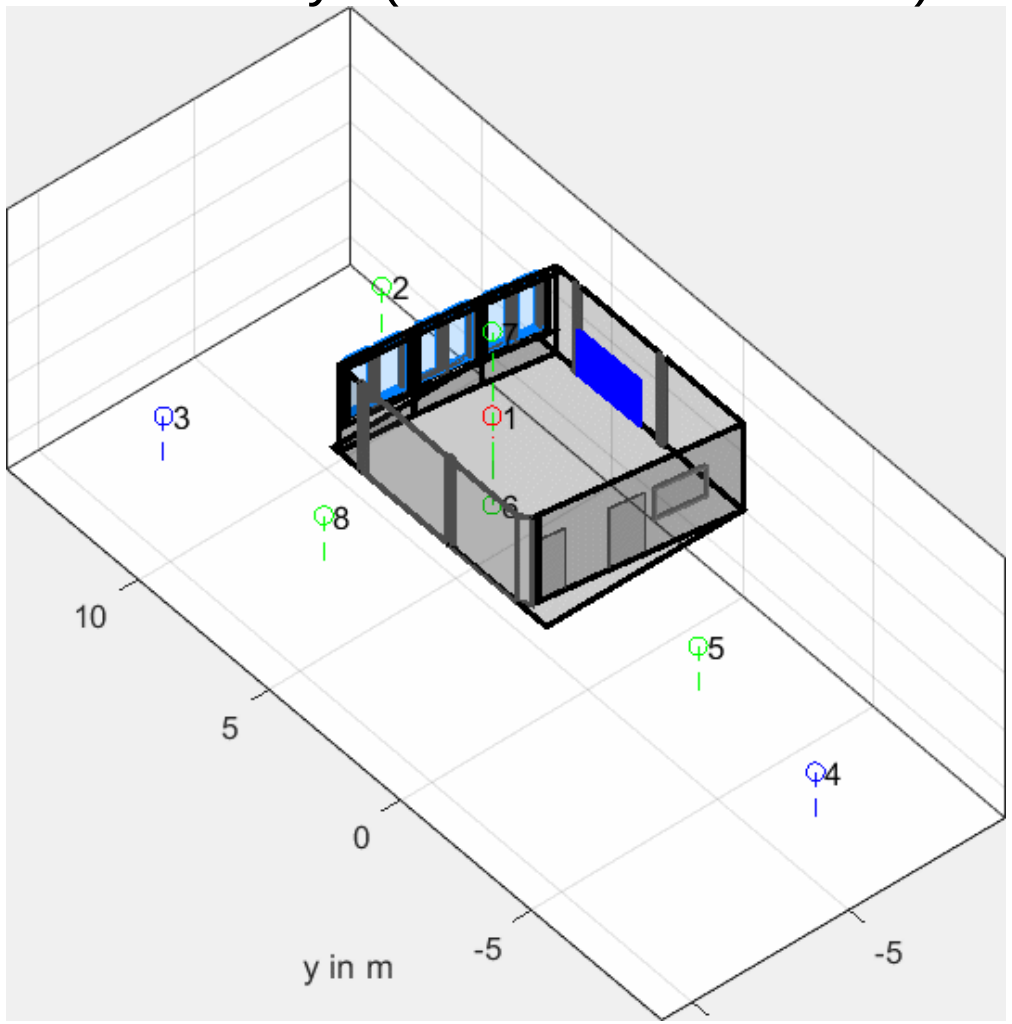
Multipath Channel Estimation

- SBL-based channel estimation performed per subarray
  - URA dimension: 4x4 or 8x8
  - bandwidth: 500 MHz
  - carrier: 6.95 GHz and corresponding $\lambda/2$ spacing
- pre-selection of image/mirror sources for analysis via *data association*
- **results:** amplitude, distance, azimuth, elevation

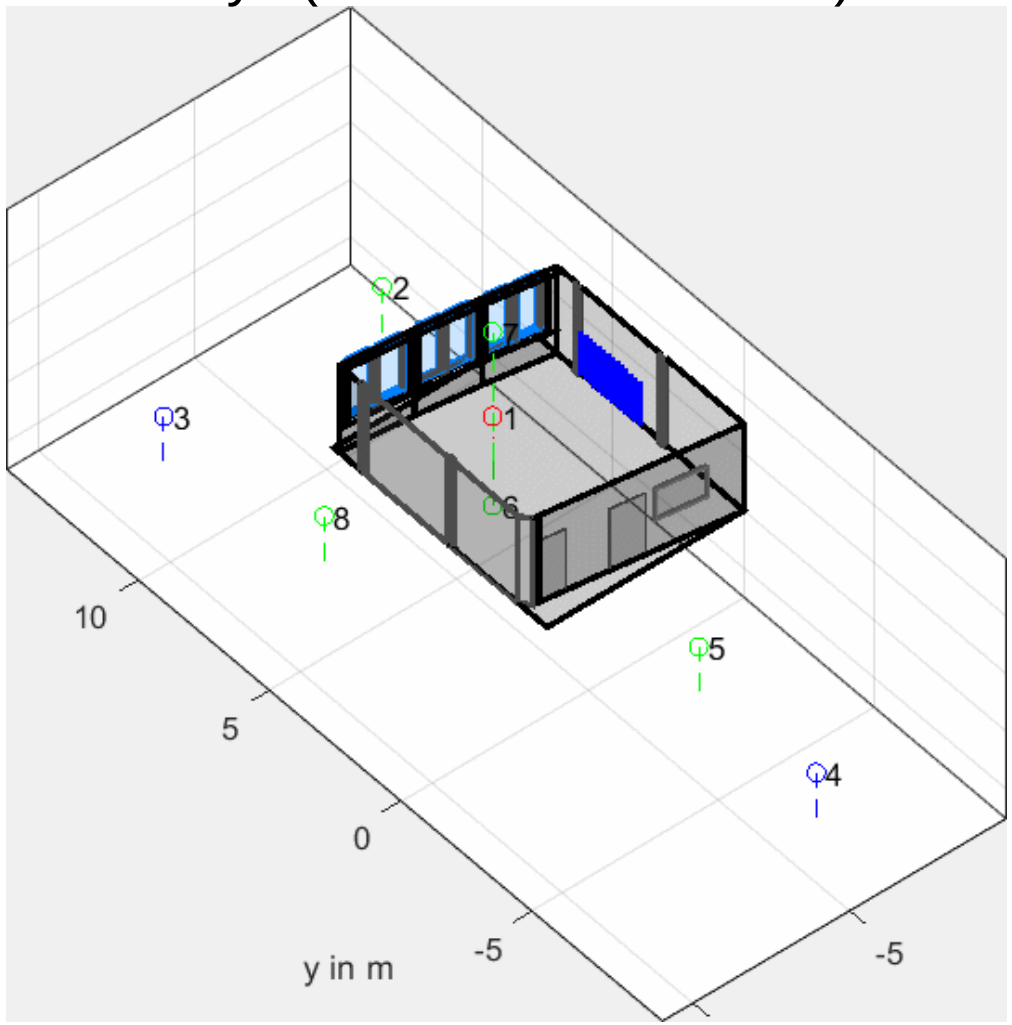


Multipath Channel Estimation

4x4 arrays (500MHz at 6.95GHz)



8x8 arrays (500MHz at 6.95GHz)



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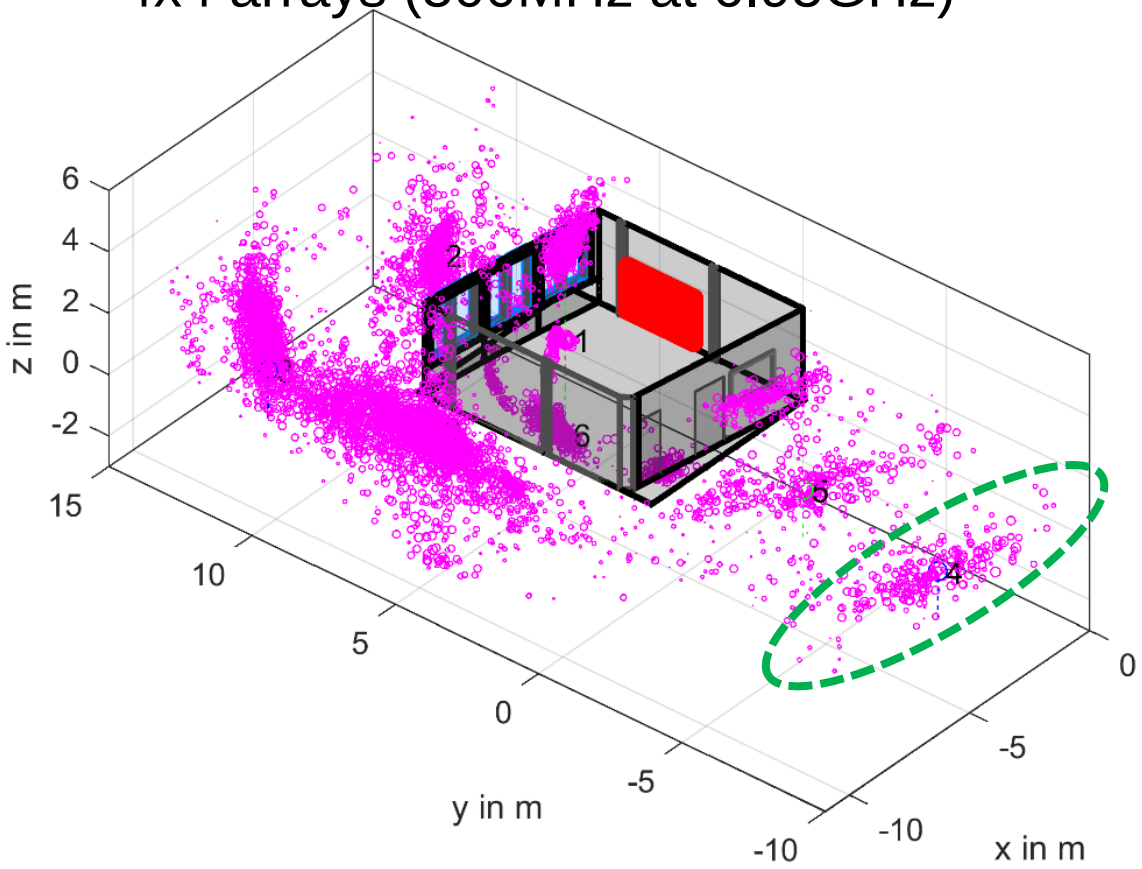

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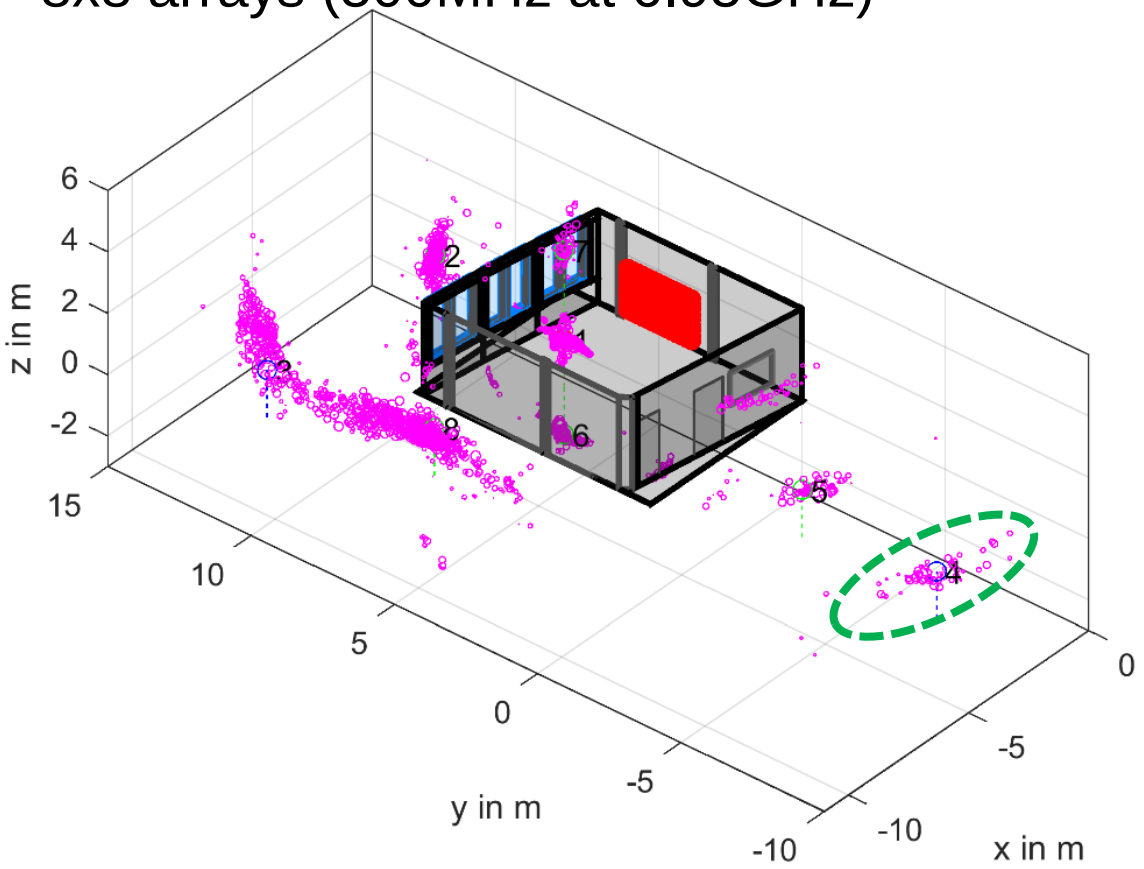

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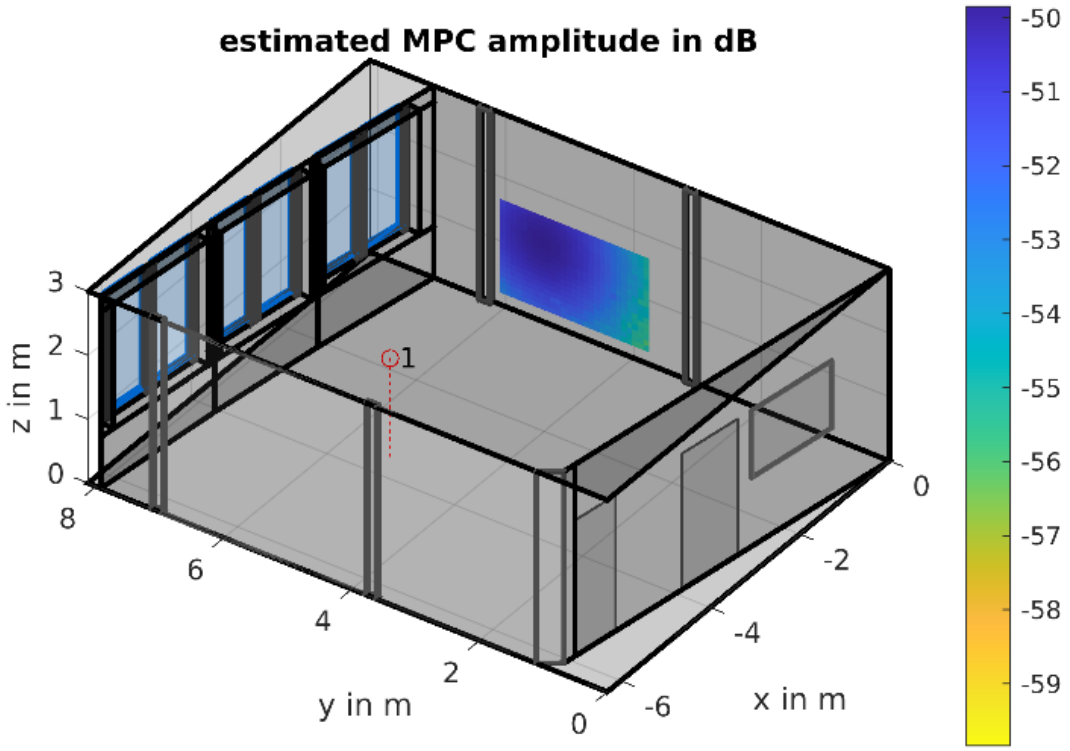

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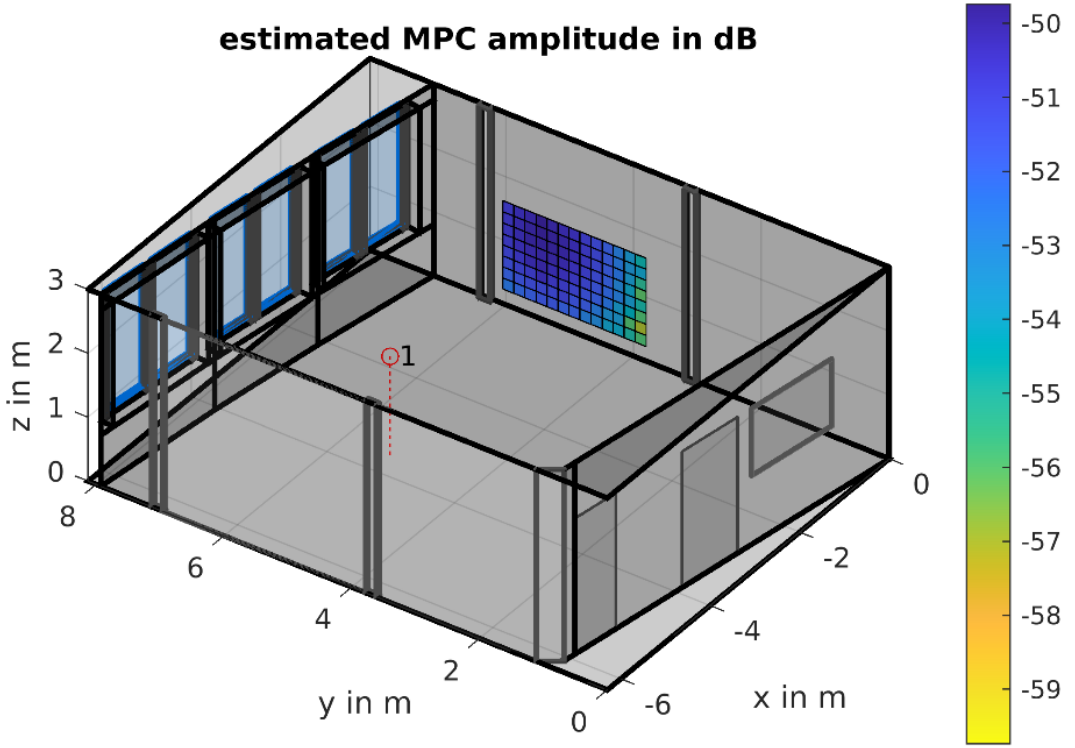

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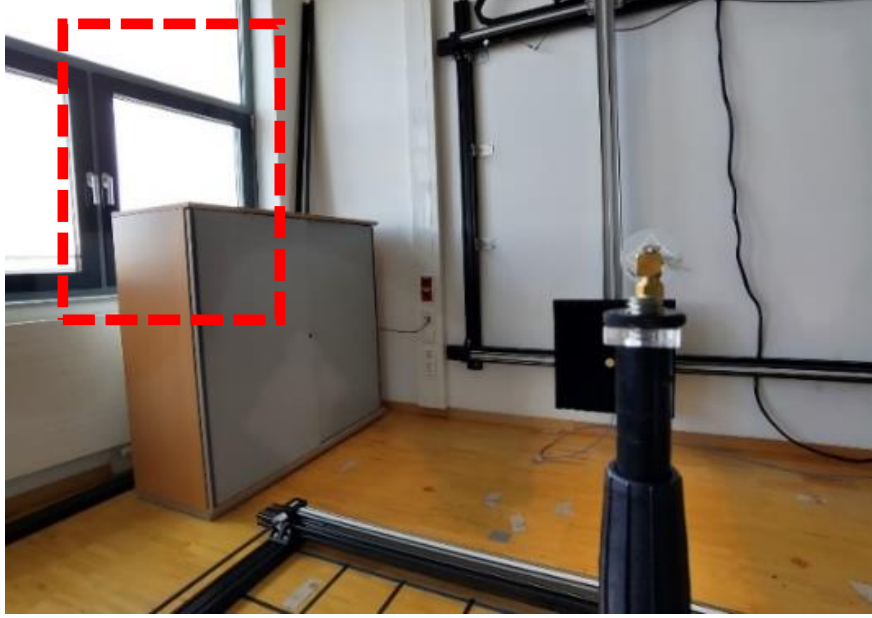

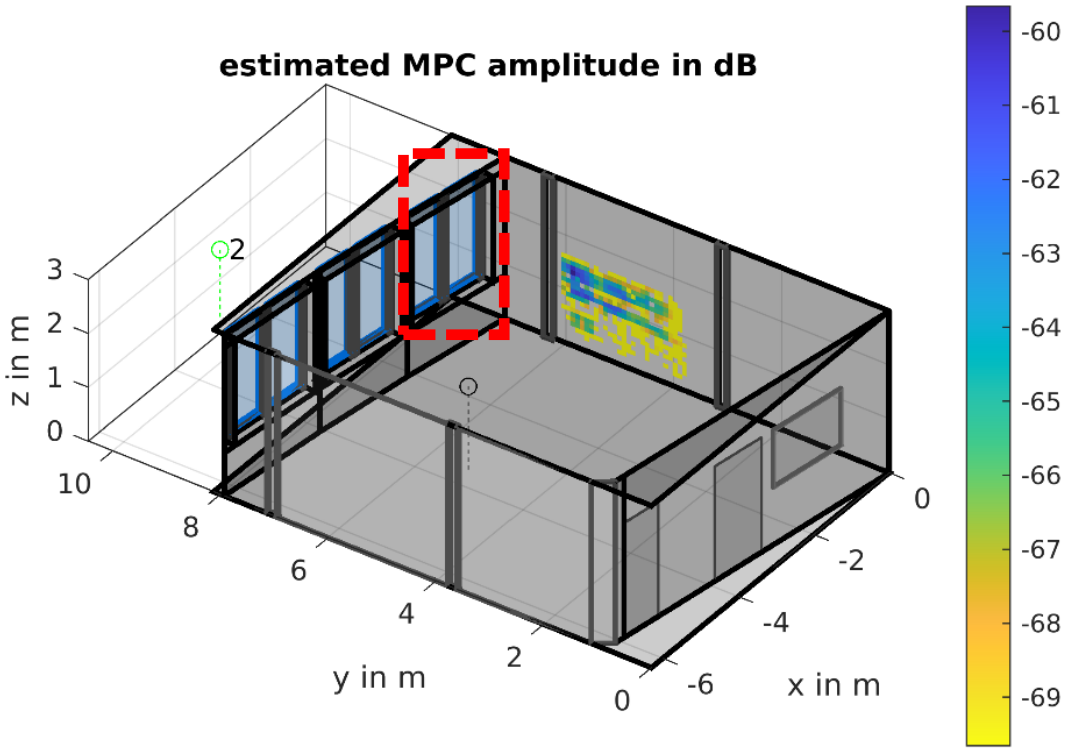

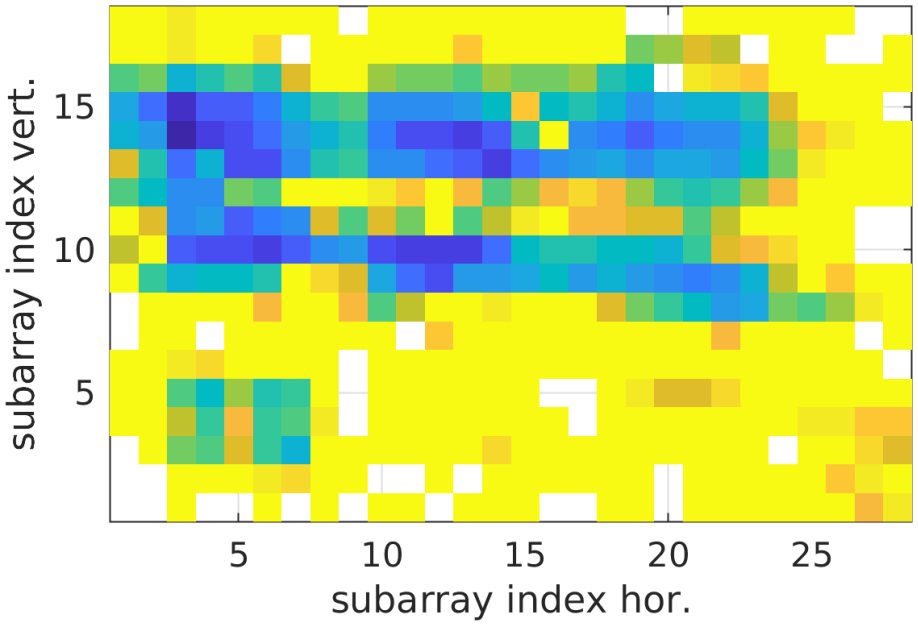

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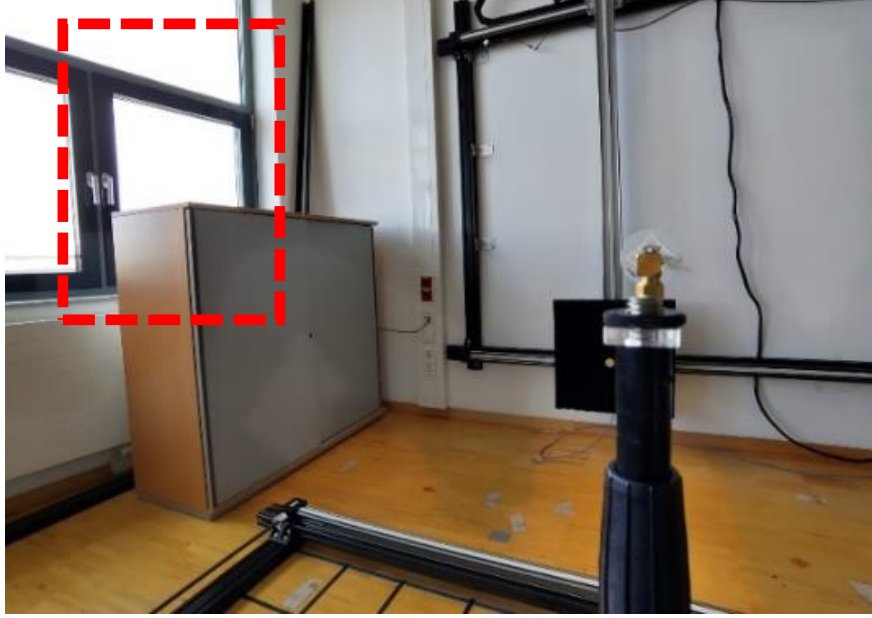

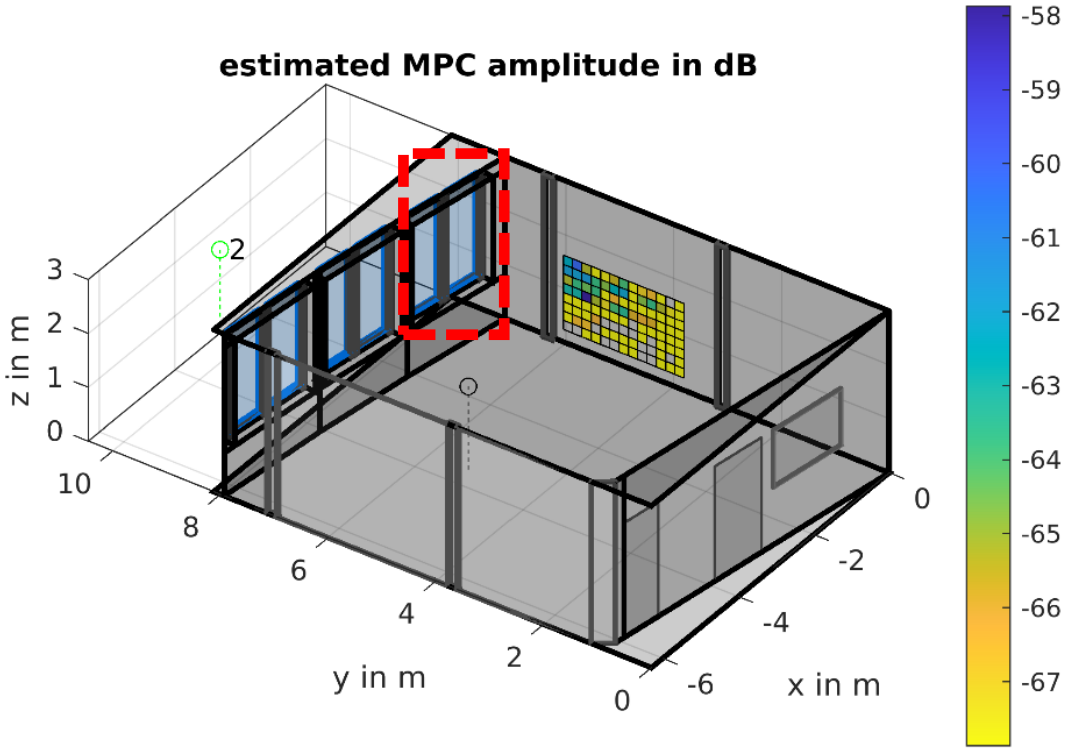

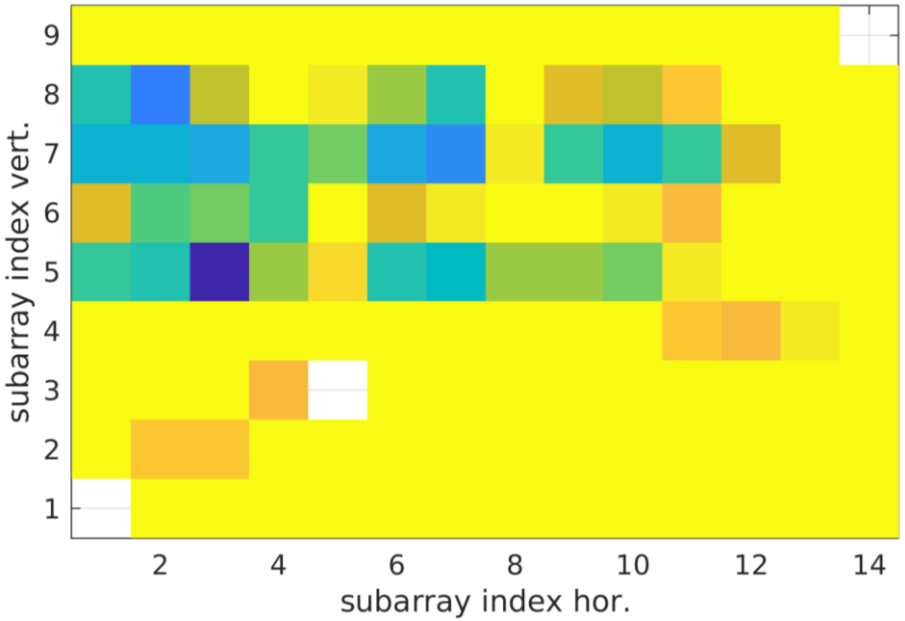

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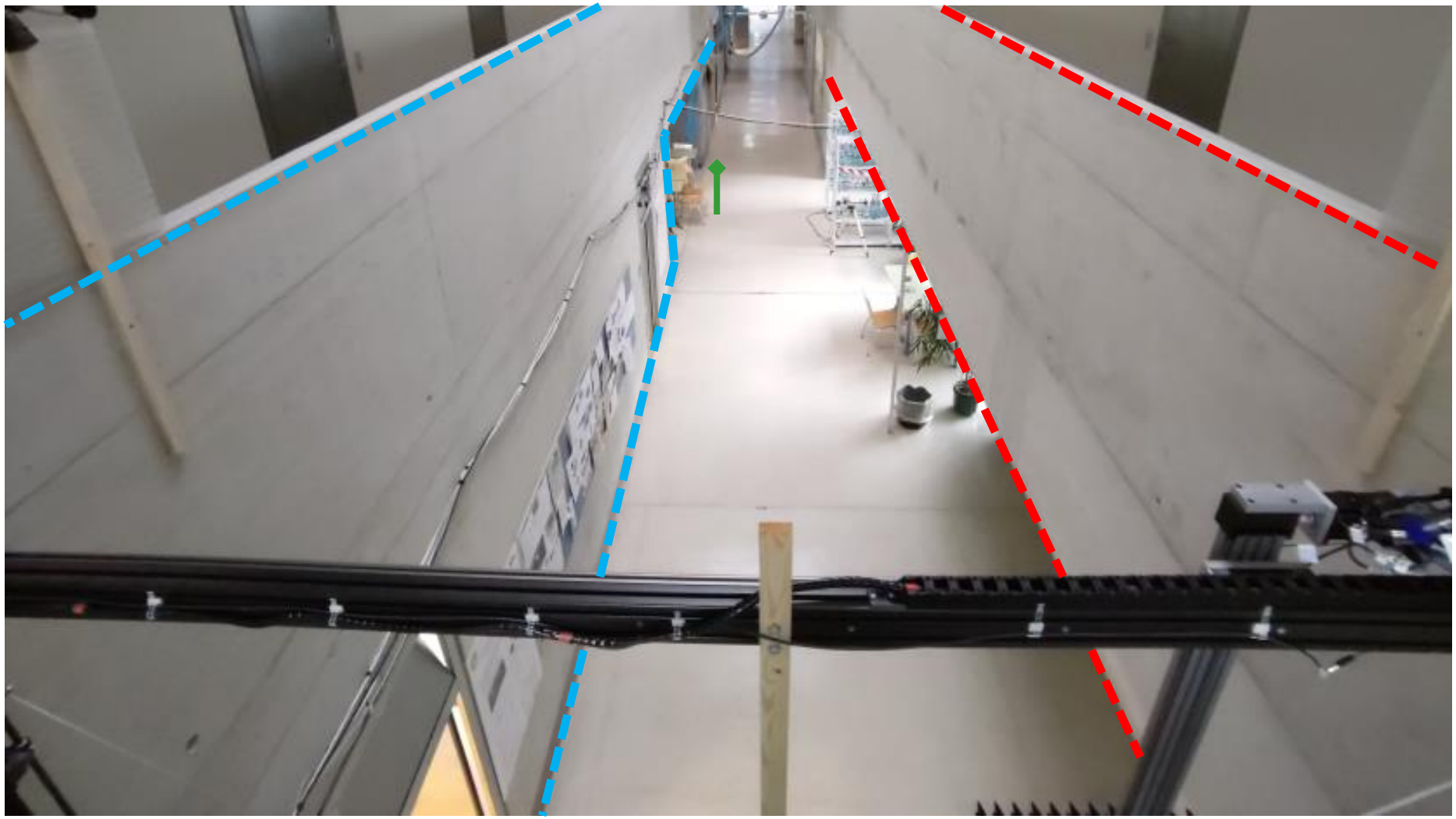
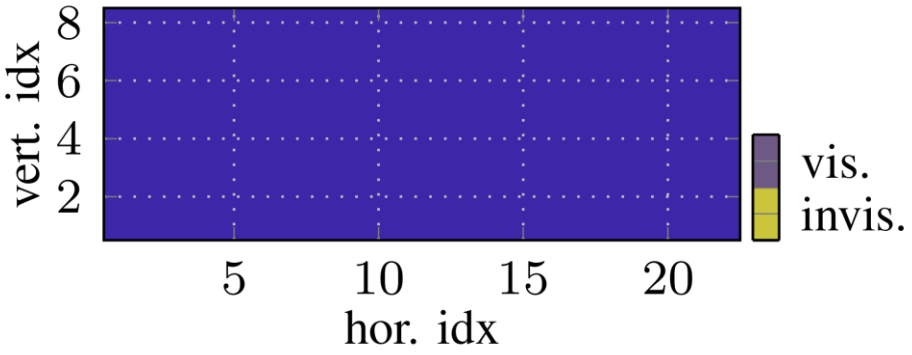
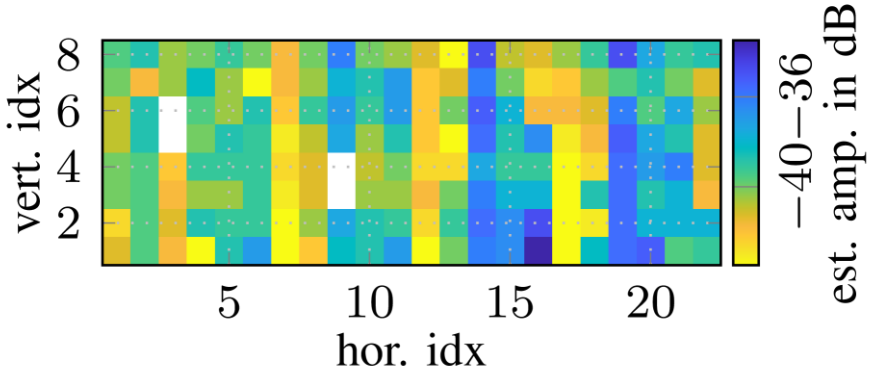


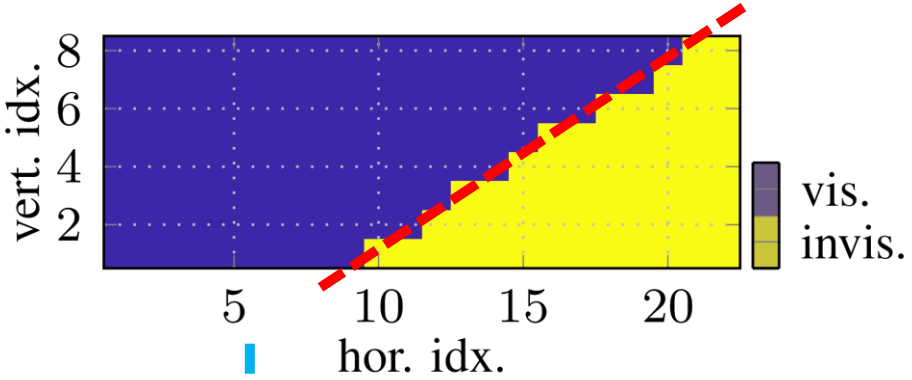
Multipath Channel Estimation

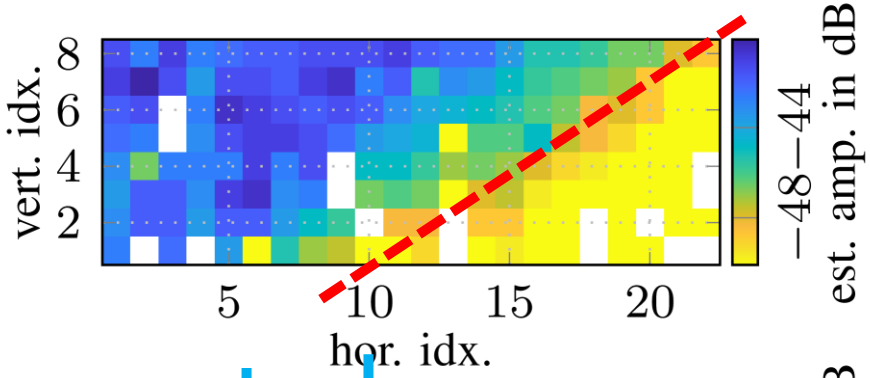
4x4 arrays (500MHz, 6.95GHz)



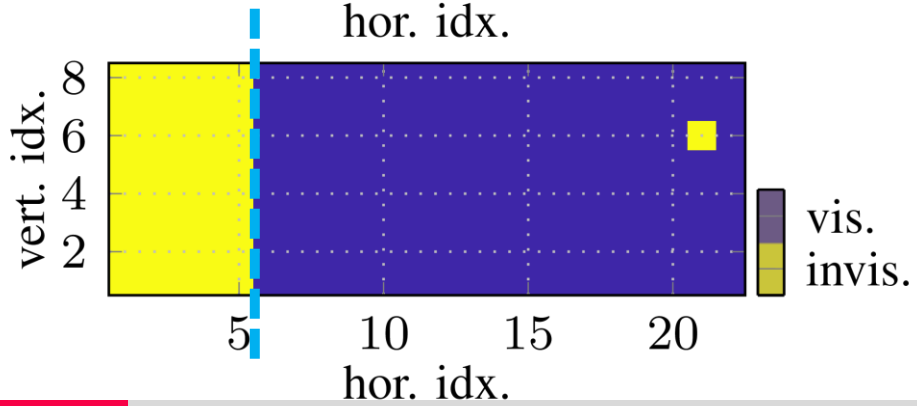


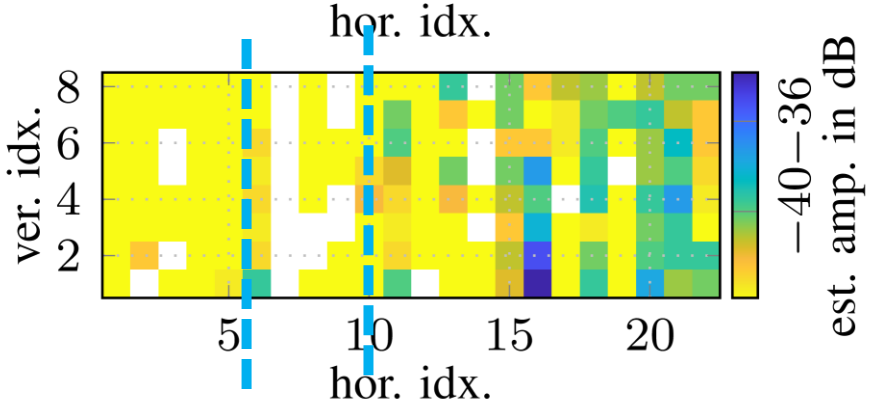
LOS path, fading due to side wall reflections resulting in path overlap





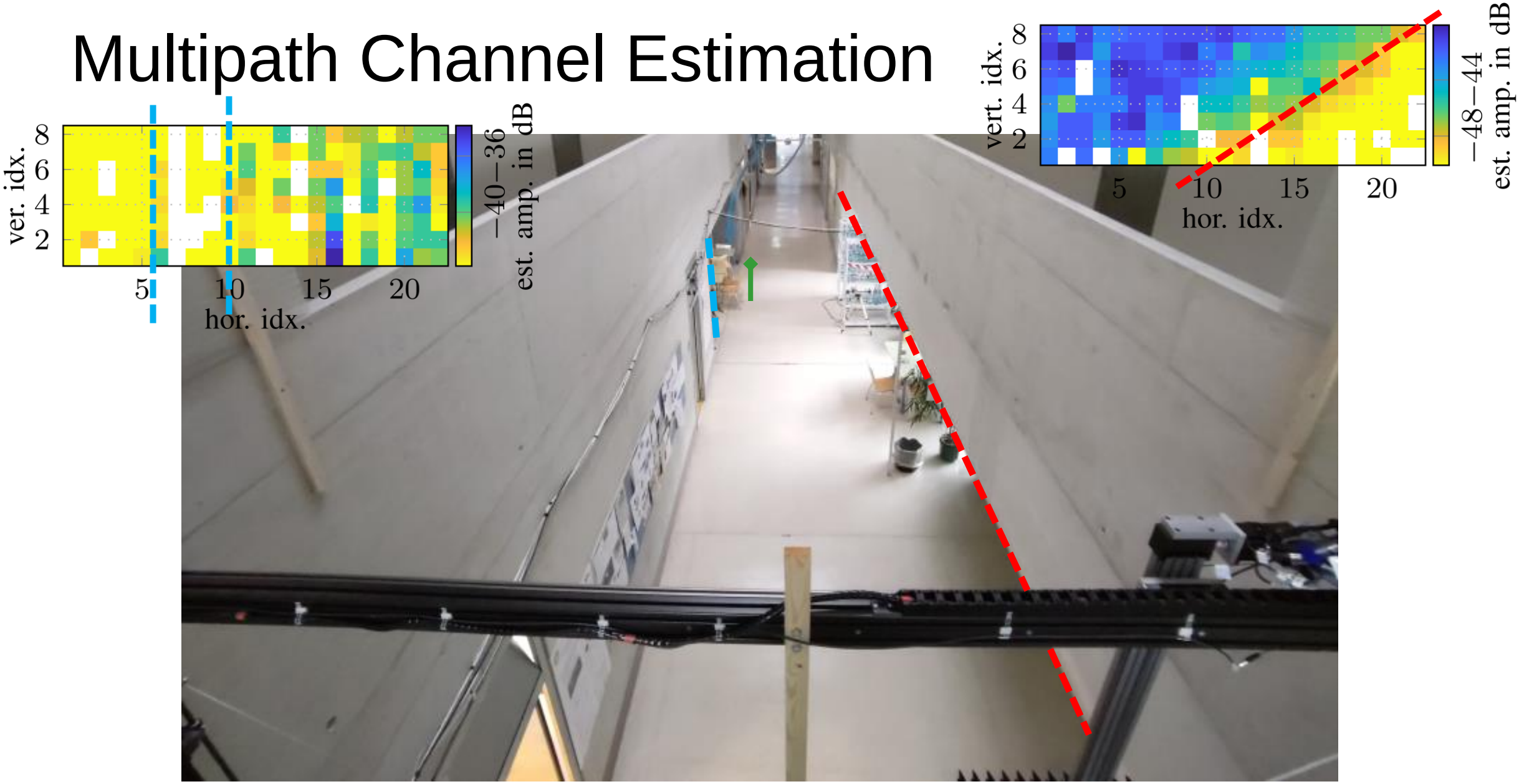
right wall path, edge due to limited size





left wall path, edge due to limited size, smeared due to fading from component overlap?

Multipath Channel Estimation



Conclusion

Conclusion

- Multipath component visibility can change over large arrays
- Estimated amplitudes include visibility
- Using subarrays allows to use high resolution algorithms
- Subarray size as trade-off between accuracy and component stationarity

Future Work

- Data fusion algorithms for subarray estimates
  → Positioning, Environment Mapping/Sensing/Learning
- Measurements to be made publicly available

References

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