Leibniz Institute
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microelectronics

Experimental Object Localization using mmWave Beamforming Communication System

28. VDE-ITG-Fachtagung Mobilkommunikation - *VDE-ITG-Fachtagung Mobilkommunikation*

Ekaterina Sedunova, Nebojsa Maletic, Darko Cvetkovski, Eckhard Grass

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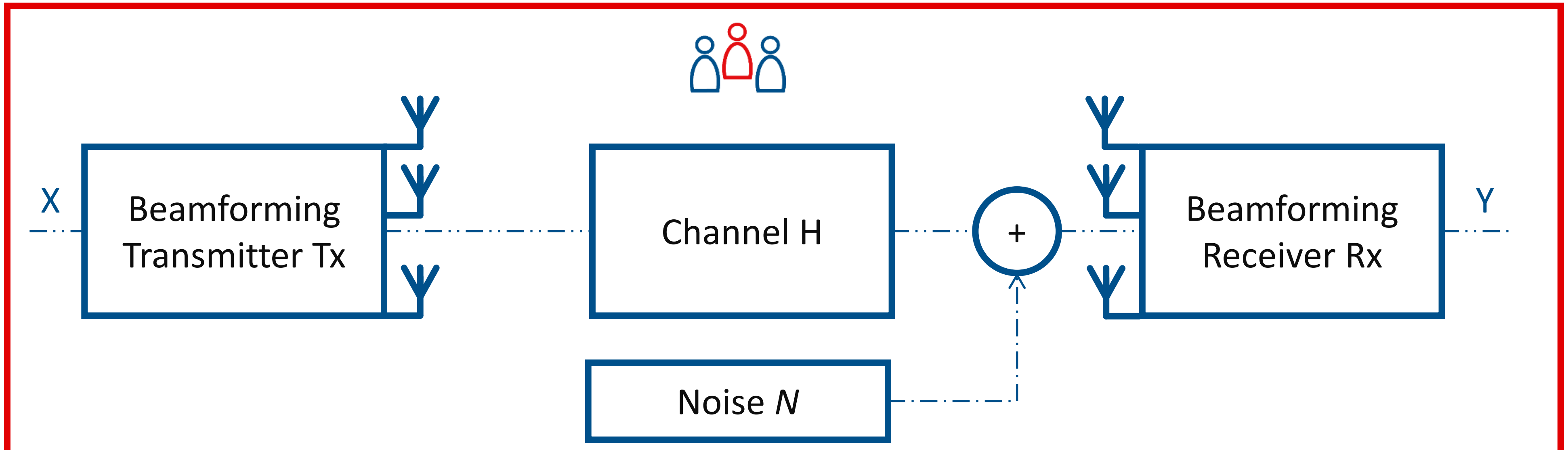
Outline

- Motivation
- System Model
- Antenna Patterns
- Algorithm
- Experimental and Simulated Setups
- Results
- Conclusion and Future work

Motivation

- **Advantage of large bandwidth for mmWave communication system**
  -> high positioning accuracy possible
- **Sparsity of reflections and high attenuation in the indoor environment**
  -> allows scanning of the environment
- **Joint Communication and Sensing as a key technology for 6G**
- **Object localization is important for the creating digital twin in the Industry 4.0 vision**
- **Antenna patterns using beamforming are angle-dependent and play a significant role for object identification**
- **In order to improve the accuracy, a method to deal with side-lobes and false identification of the objects is needed**

System Model



$$y(t,\psi_{Tx},\varphi_{Rx}) = h(t,\psi_{Tx},\varphi_{Rx}) * x(t) + n(t)$$

If signal *x(t)* - pseudo-noise (PN) sequence then cross-correlation between output and input will provide an estimation of the channel impulse response:

$$\hat{h}(t) = y(t) \otimes x(t)$$

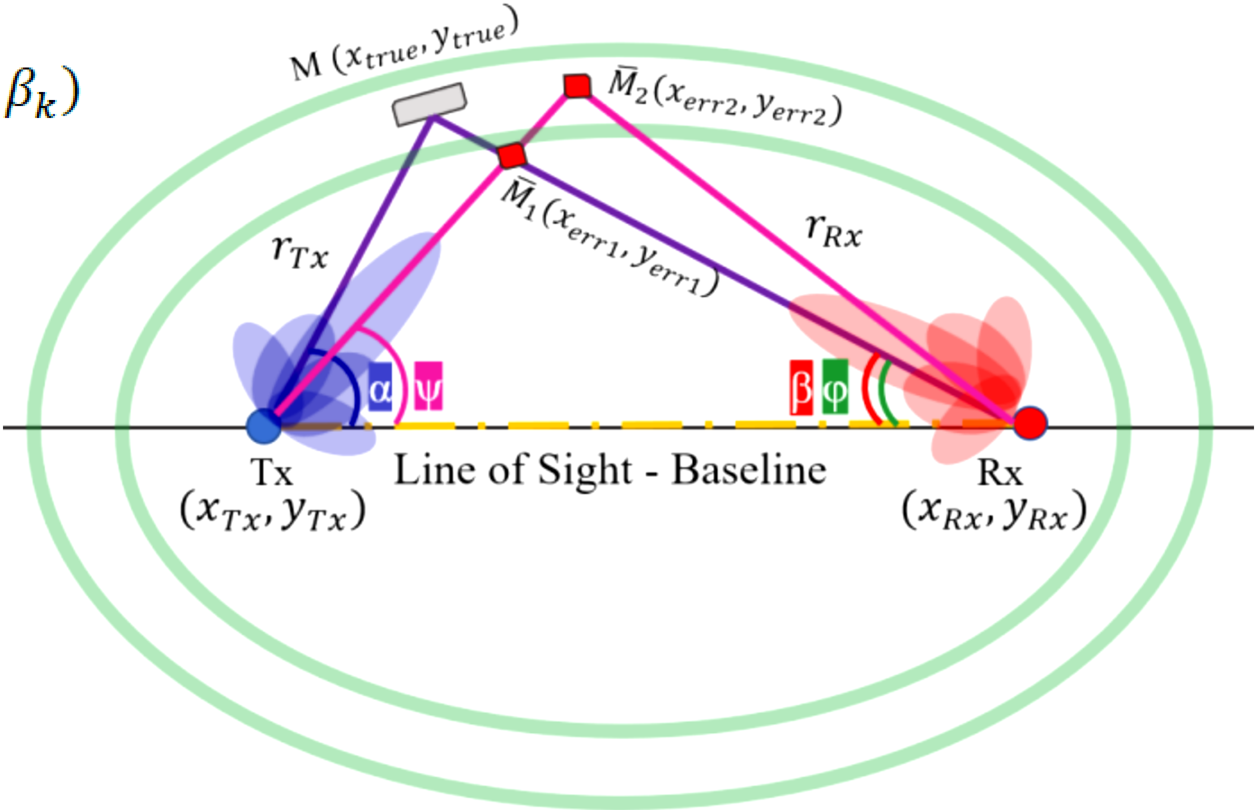
System Model

$$h(\tau, \psi_{Tx}, \varphi_{Rx}) = \sum_{k=1}^{K} r_k(\alpha_k, \beta_k, \tau) \cdot \mathrm{G}_{tot}(\psi_{Tx}, \alpha_k, \varphi_{Rx}, \beta_k)$$

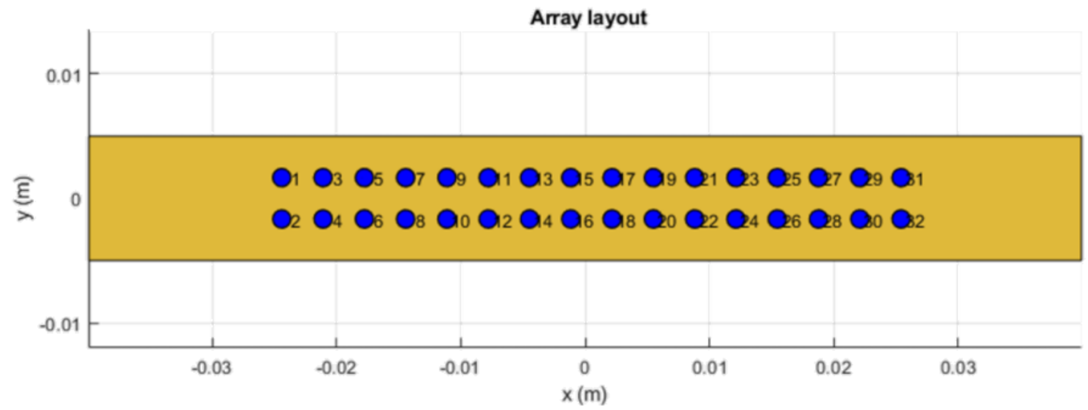
$$\mathrm{G}_{tot}(\psi_{Tx}, \alpha_k, \varphi_{Rx}, \beta_k) = G_{Tx}(\psi_{Tx}, \alpha_k) \cdot G_{Rx}(\varphi_{Rx}, \beta_k)$$

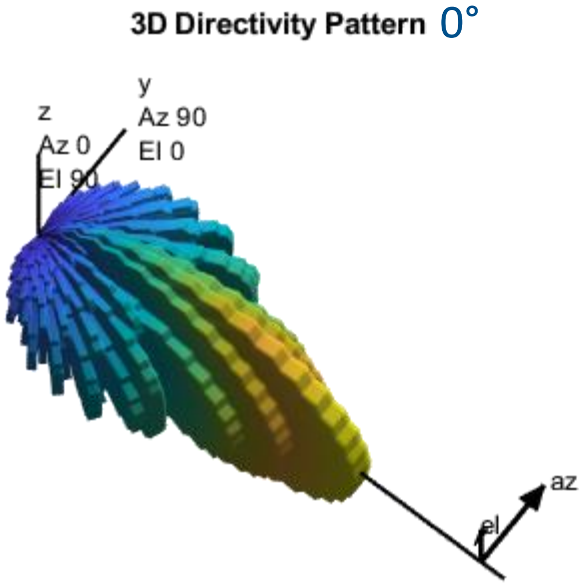
The system of equations can be written as:

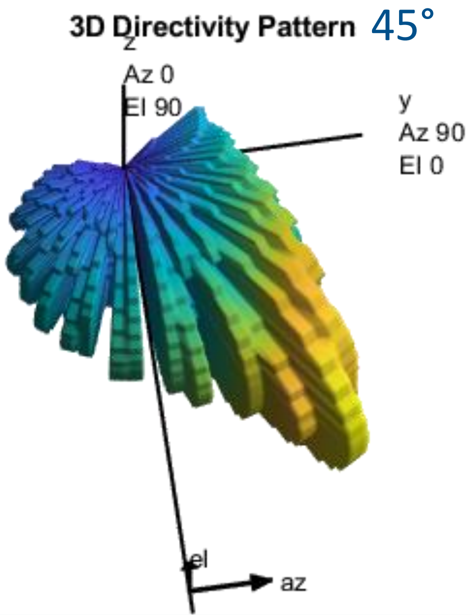
$$\begin{cases} \mathrm{G}_{tot}(\psi_{Tx}, \alpha_1, \varphi_{Rx}, \beta_1) * R_{11}(\alpha_1, \beta_1) = h(\psi_{Tx}, \varphi_{Rx}) \\ \dots \\ \mathrm{G}_{tot}(\psi_{Tx}, \alpha_k, \varphi_{Rx}, \beta_i) * R_{ki}(\alpha_k, \beta_i) = h(\psi_{Tx}, \varphi_{Rx}) \end{cases}$$

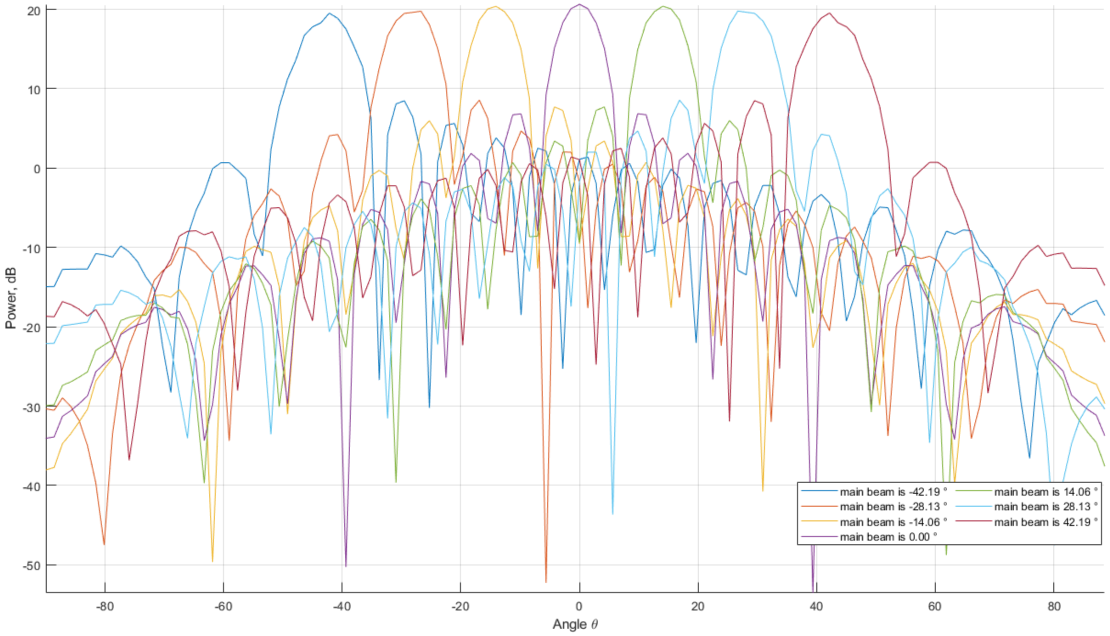


Antenna Patterns







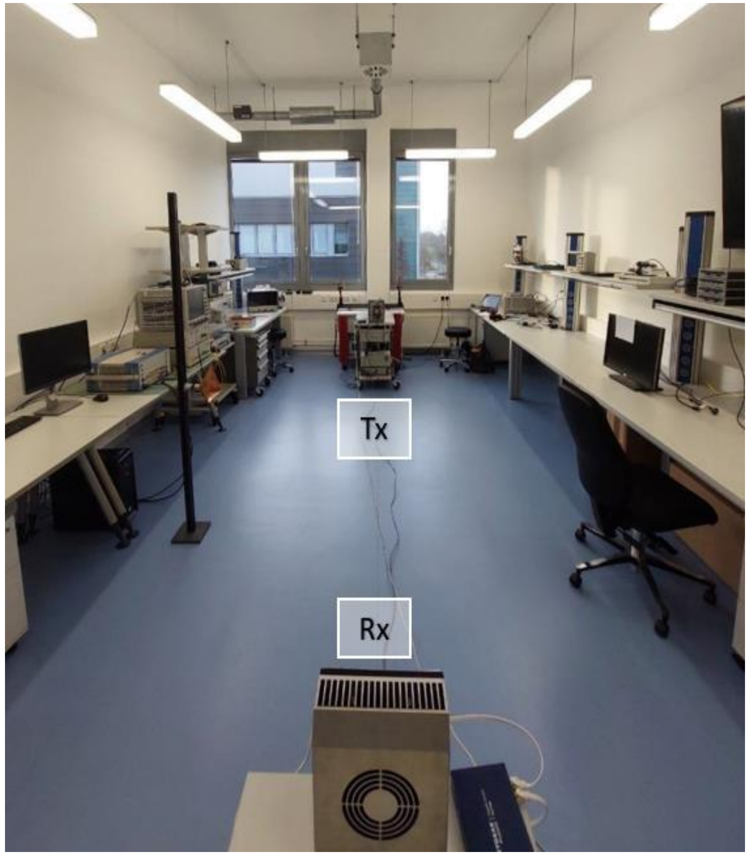


Azimuth gain for 7 out of 63 selected antenna patterns

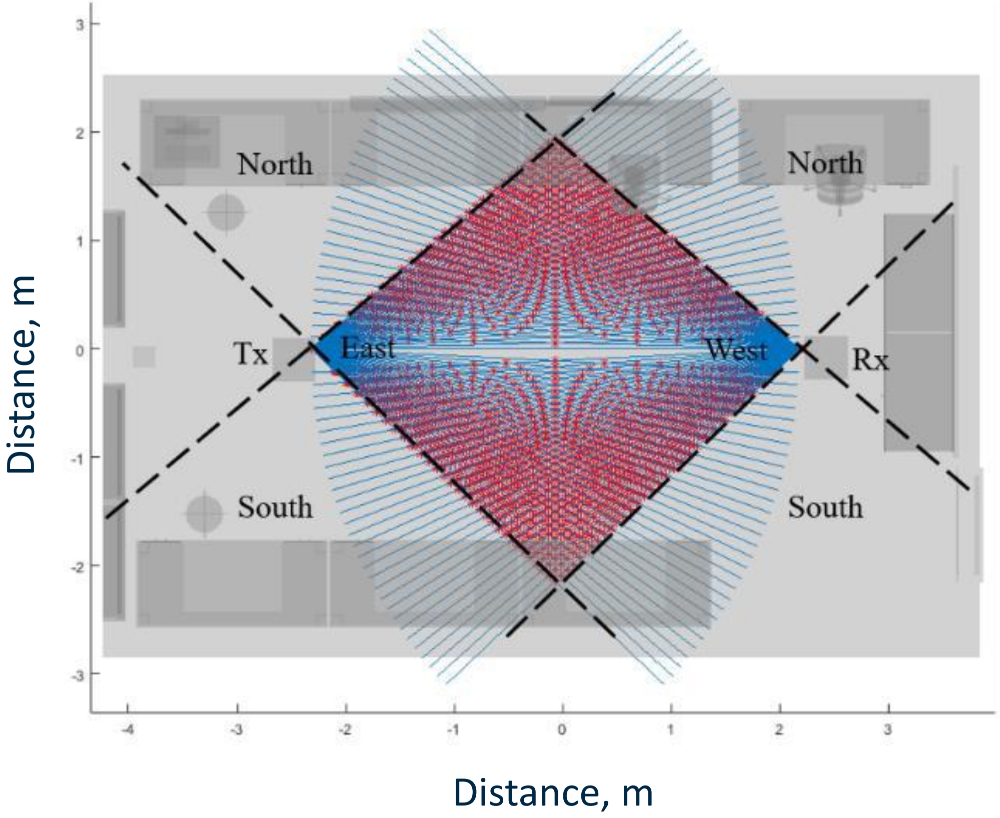
Algorithm for object localization

```
Input: received signal for each Tx-Rx pair of angles $y(t, \psi, \varphi)$
Output: plot reflectivity r  corresponding to possible reflections from the objects
Initialization: Angular Range for Tx-Rx
    Find intersections for Tx-Rx pairs of angles
    Get Normalized Power Delay Profiles P$(t, \psi, \varphi)$
    Simulate antenna patterns for the angular range $G_{\mathrm{T}x}(\psi, \theta)$ and $G_{\mathrm{R}x}(\varphi, \theta)$
        for each $t$
            Define $\theta_{AoD}$ and $\theta_{AoA}$ for an ellipse related to the time $t$
        for each Tx_Index
        for each Rx_Index
            A = $G_{rx}(\psi_{\mathrm{T}x\_index}, \theta_{AoD}) G_{rx}(\varphi_{\mathrm{R}x\_index}\varphi, \theta_{AoA})$
            b = $\mathrm{P}(\mathrm{t}, \psi_{\mathrm{Tx\_index}}, \varphi_{\mathrm{Rx\_index}})$
            Solve for r : $Ar = b$
            Exclude  r < 0 and r = NaN
            Plot the results r for the intersection points
        end
        end
        end
```

Experimental Setup



Laboratory room with front-end devices

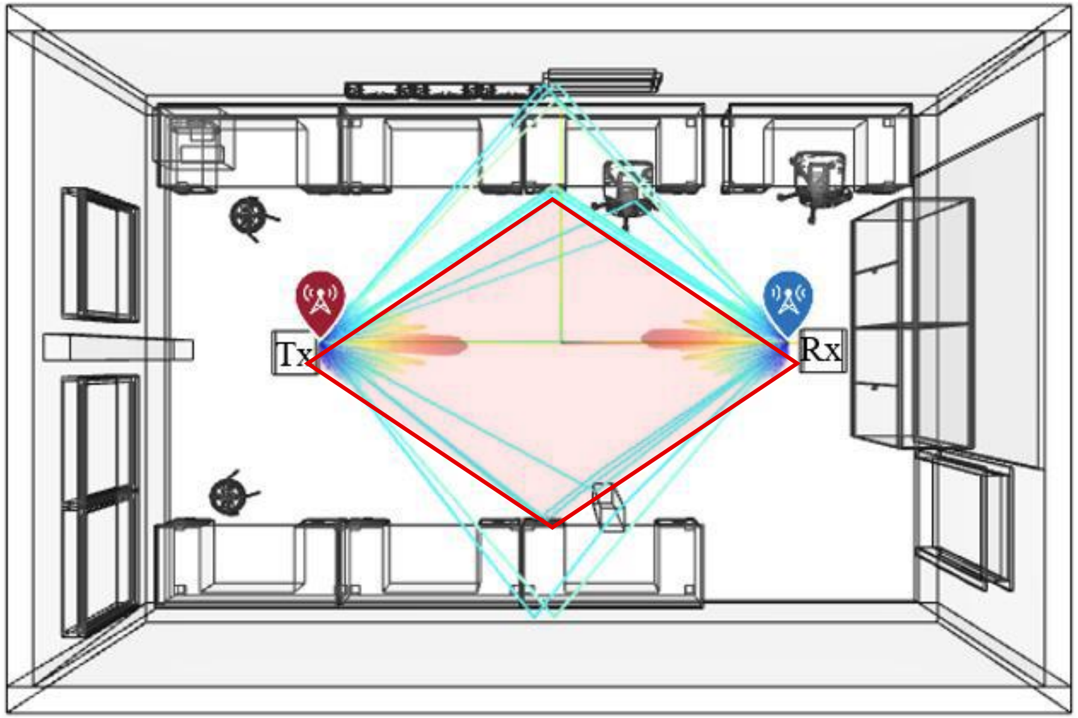


Top view, the room with all possible reflection point for East-West (EW) scenario

Simulated Setup

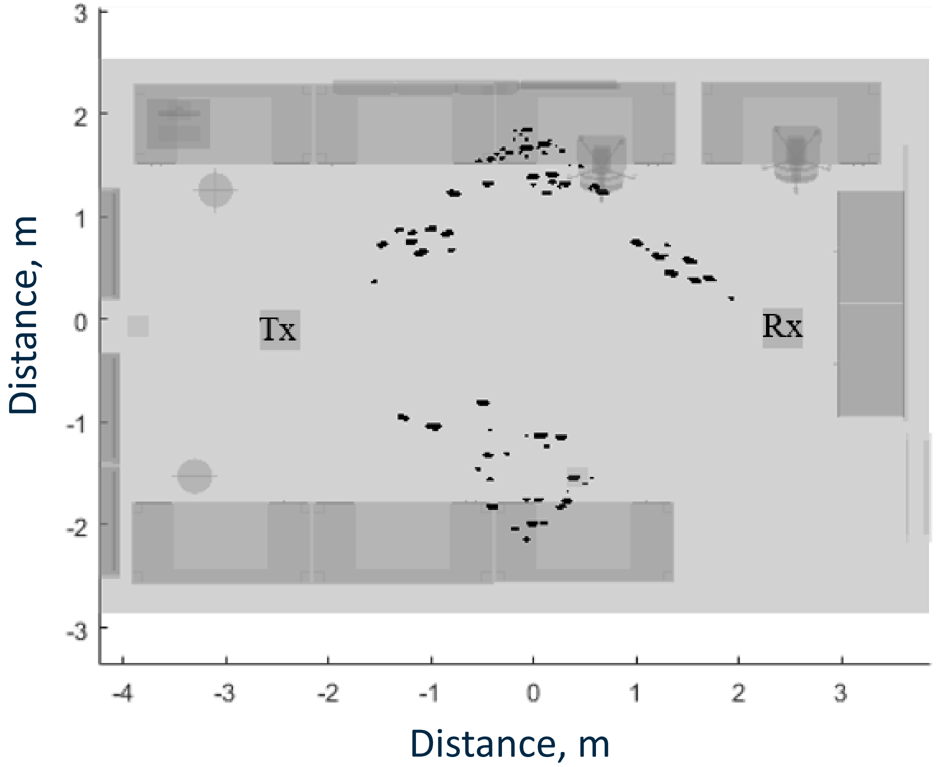
Simulated setup has the same parameters as experimental:

- **Room size - 7.7 m × 4.9 m× 3.6 m**
- **Distance between Tx and Rx - 4.5 m**
- **The height from the floor – 0.7 m**
- **The angular range from -45 to 45 with approximately 1.4° step size**
- **The sampling frequency – 2.16 GHz**
- **A distance resolution ≈ 0.138 m**
- **The same intersection points as for EW experimental scenario (red area)**

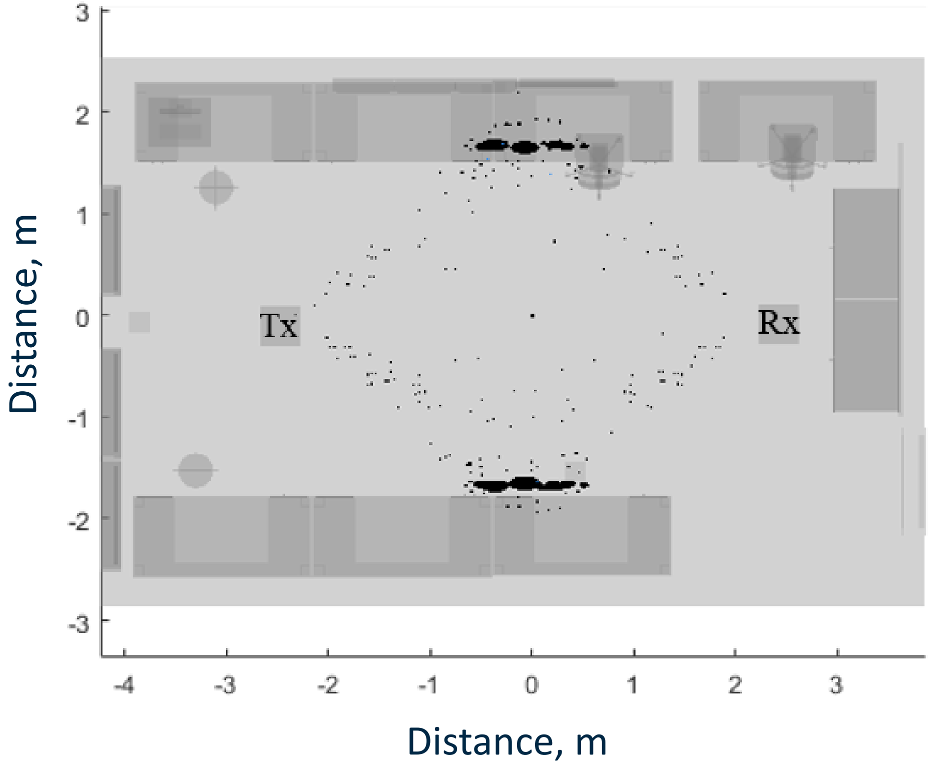


Results

Measured



Simulated



Conclusions and Future work

Conclusions

- Developed a method for object localization with direction-dependent antenna pattern that is reducing the side-lobe effect
- Unfortunately, for the measured dataset the results were not as good as expected
  -> due to possible mismatch of the simulated and real antenna patterns.
  -> due to reflections from ground and ceiling
  -> hardware limitations (bandwidth, sampling rate, impairments, …)
- The method shows better results for the simulated dataset, mainly, since for simulation used the 'correct' antenna patterns.

Future work

- Measure the antenna patterns of the complete codebook and a new measurement campaign
- Improve the method by including reflections from ground and ceiling
- Adopt machine learning methods to solve the cases when the method was not able to find good solutions for system of equations

Thank you for your attention!

IHP – Innovations for High Performance Microelectronics
Im Technologiepark 25
15236 Frankfurt (Oder)
Tel.: +49 (0) 335 5625 319
E-Mail: sedunova@ihp-microelectronics.com