EUROPEAN MICROWAVE WEEK
JAARBEURS UTRECHT
THE NETHERLANDS
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WAVES OF INNOVATION

Distributed MIMO prototype and measurement for ISAC use cases

Device-Free Localization (DFL) in Distributed Antenna Networks (DANs)

Workshop WM03 – Monday 09/22

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EuMA EUROPEAN MICROWAVE ASSOCIATION

Acknowledgment

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  - “Nuclear Energy S&T and Human Resource Development Project (JPJA22P22683407)” made with the Japan Atomic Energy Agency (JAEA), and
  - “R&D for Expansion of Radio Wave Resources (JPJ000254)” made with the Ministry of Internal affairs and Communications (MIC), Japan.

Outline

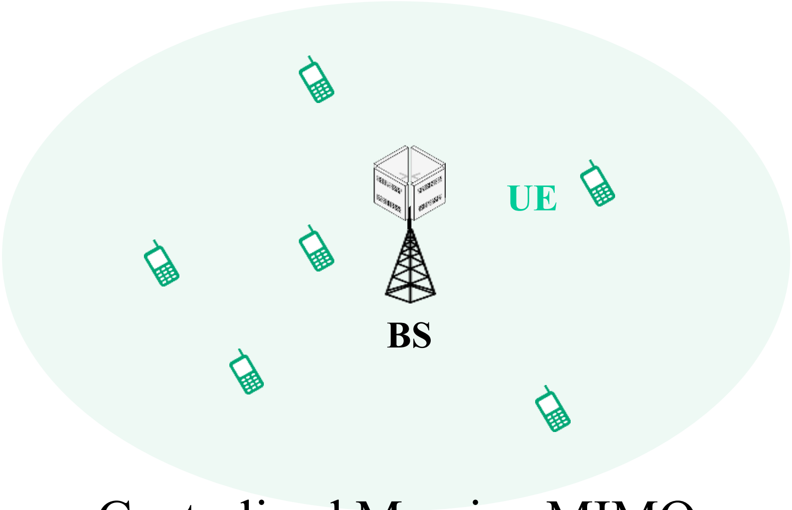
- Distributed Antenna Network (DAN) and ISAC
- Device-Free Localization (DFL)
  - Multipath-RTI using ISAC
- DAN Based DFL Implementation
  - Distributed MIMO Prototype For ISAC
  - Multilink MIMO Channel Sounder

Distributed Antenna Networks (DANs)

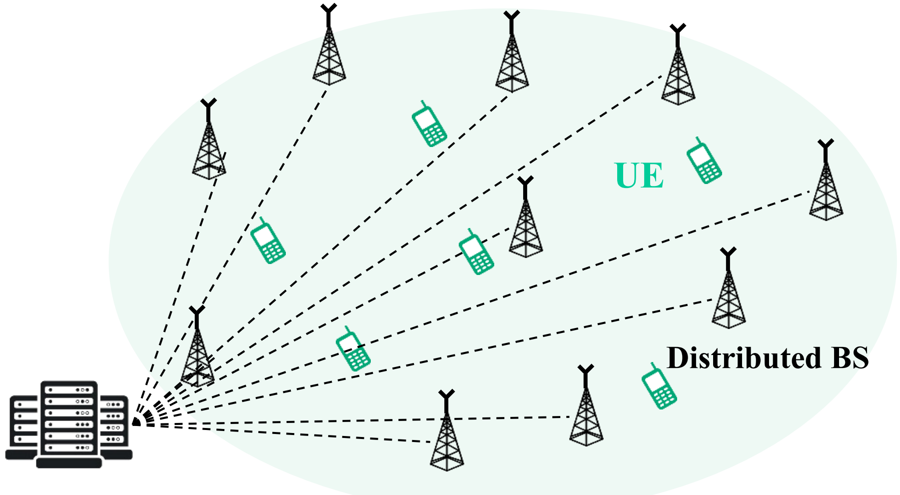
- Distributed Antenna Networks (DANs)
  - Distributed massive MIMO
  - Cell-free massive MIMO
  - ISAC localization and sensing

Benefits

- Improved coverage
- Higher spatial diversity
- Mitigate large scale fading
- Sensing capability



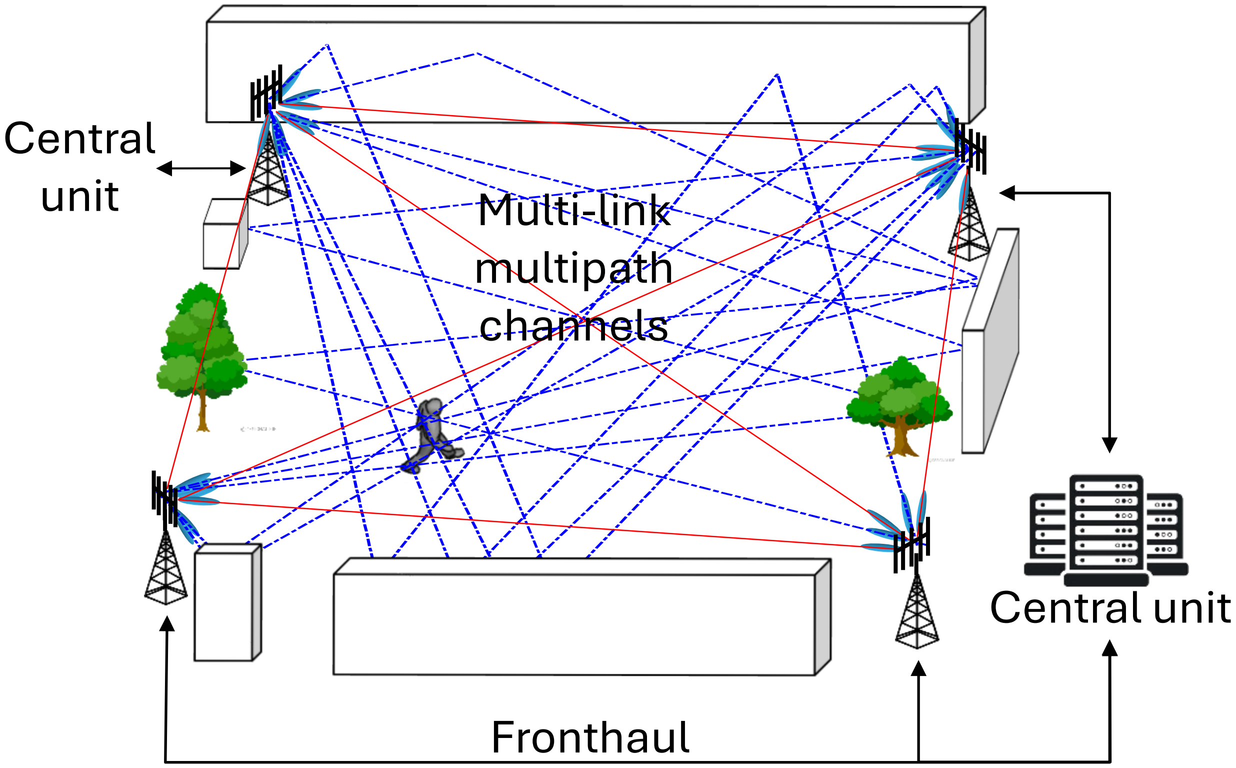
Centralized Massive MIMO



Distributed Massive MIMO

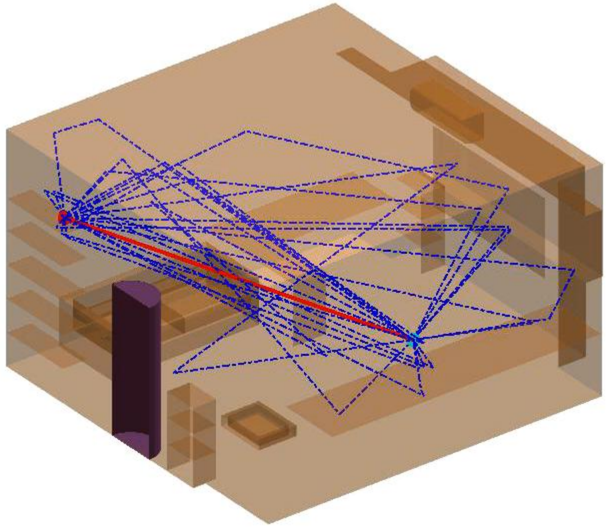
DAN based ISAC

- From a communication perspective, multipaths provide diversity and reliability
- From a sensing perspective, the same multipath information can be exploited to localize objects or people without requiring them to carry any devices
- DAN-based ISAC allows us to transform multipath into a useful signal source for DFL, tracking, and environmental awareness



Device-Free Localization (DFL)

- Smart environment technologies (smart home, smart building, etc.)
  - Rapid progress of IoT (internet-of-things) technology
  - Support safety and security
- Indoor localization and mapping will be playing an important role
  - DFL methods should be preferable
  - Various radio-based techniques have been developed, but the performance totally depends on how to control/utilize multi-path propagation.

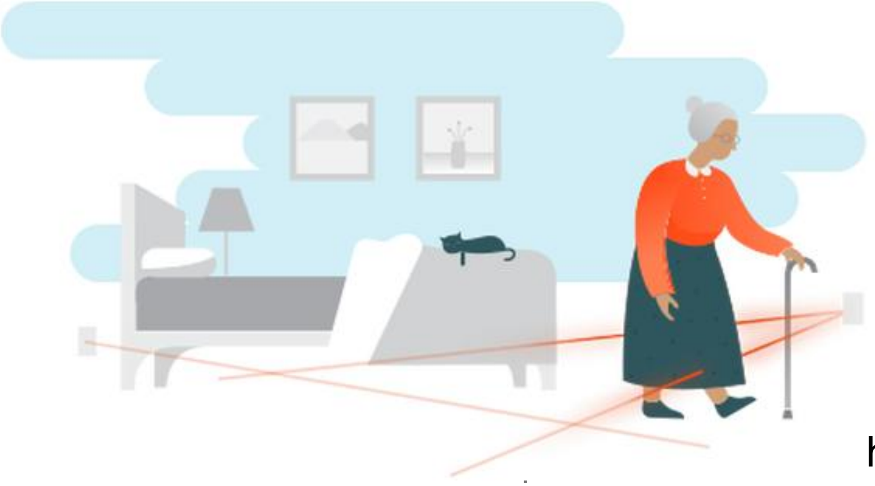


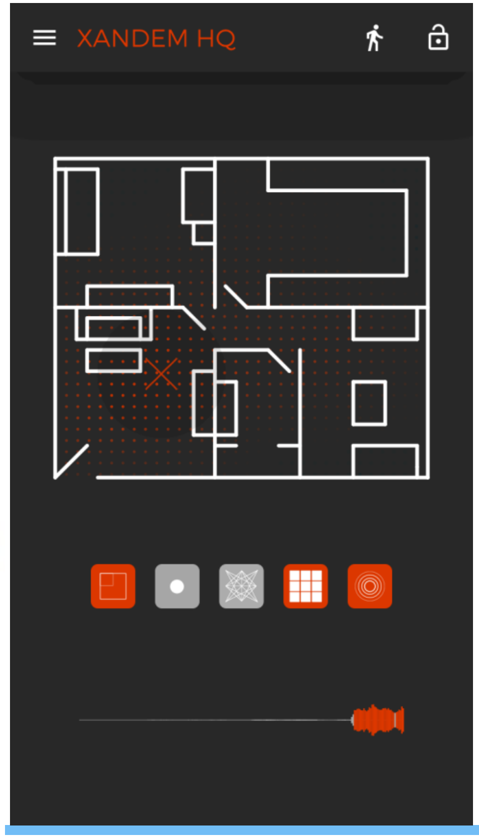
Intruder detection using radio wave [1]

[1] S. Yasukawa and M. Kim, "Intruder Detection Using Radio Wave Propagation Characteristics," IEEE/IEIE ICCE-Asia 2018, Jun. 2018.

Why DFL ?

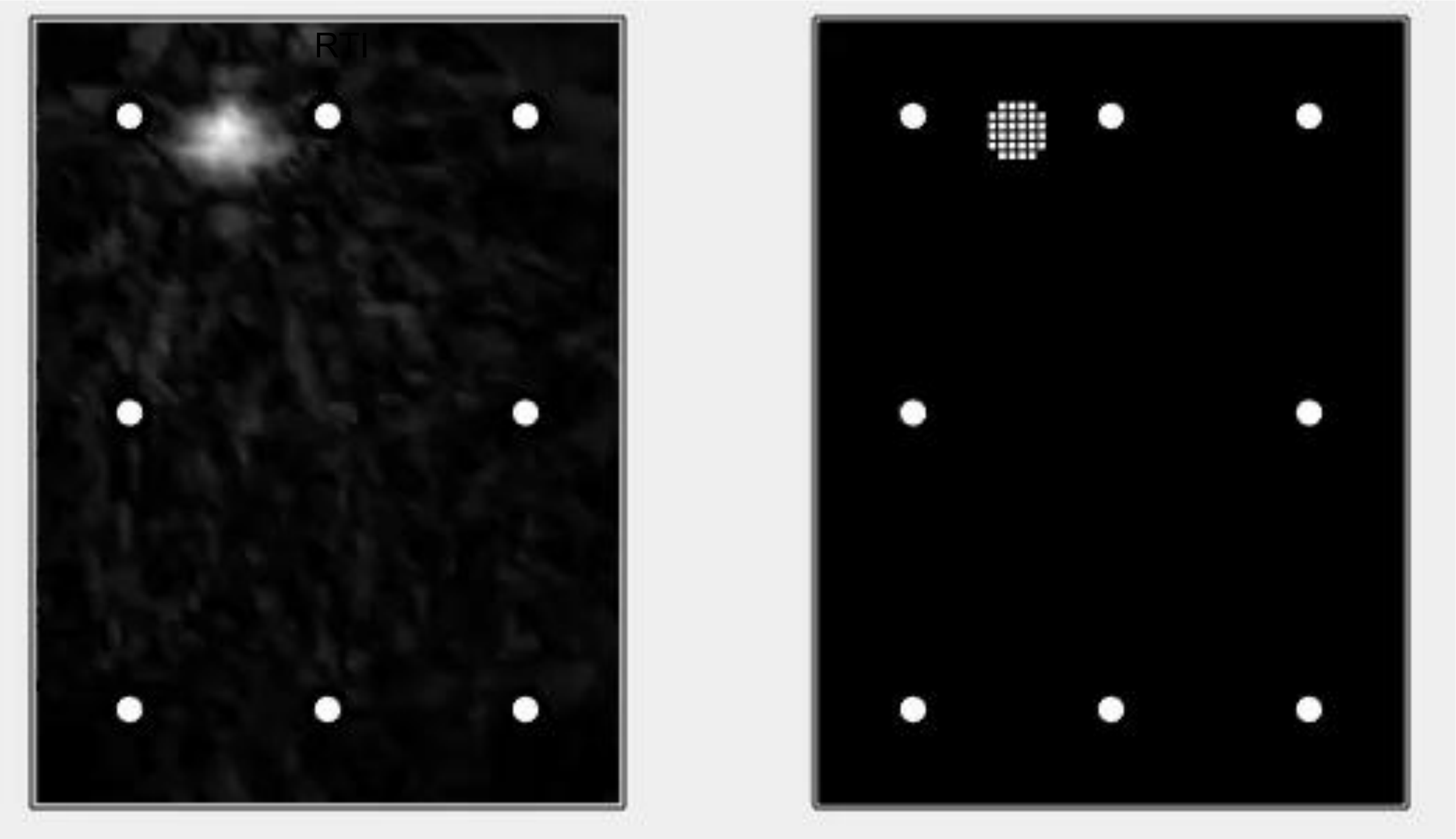
- Location monitoring of people within a building during
  - Hostage situations
  - Emergencies like building fires
  - ISAC
- Smart home monitoring
  - For elderly people or patients
  - Key function of assisted living residence





https://www.xandem.com/

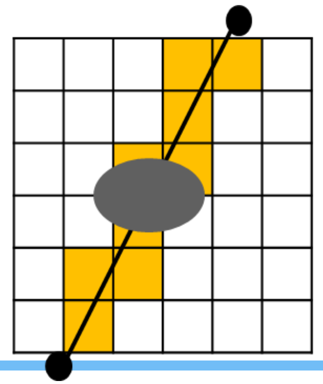
Radio Tomographic Imaging (RTI)



8 anchor nodes

What is RTI ?

- Tomographic Imaging (TI)
  - An inverse analysis technique to investigate the distribution of internal physical properties by deploying scanning lines around the target area
  - For example, computed tomography (CT) method in medical application
- Radio Tomographic Imaging (RTI)
  - When wireless nodes communicate, the radio signals pass through the physical area of the network.
  - Reconstruct the image by the attenuation in the received signal strength (RSS) among nodes due to shadowing by the target
    - The anchor nodes are placed to enclose the area
    - The area to image is divided into the voxels



RSS：Received Signal Strength

System Model

- RSS model $y_l = \sum_{m=1}^{M} w_{lm} x_m + n_l$

$$\begin{bmatrix} y_1 \\ \vdots \\ y_L \end{bmatrix} = \begin{bmatrix} w_{11} & \cdots & w_{1M} \\ \vdots & \ddots & \vdots \\ w_{L1} & \cdots & w_{LM} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_M \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_L \end{bmatrix}$$

RSS vector (Lx1) | Weighting matrix (LxM) | Voxel vector (Mx1) | Noise vector (Lx1)

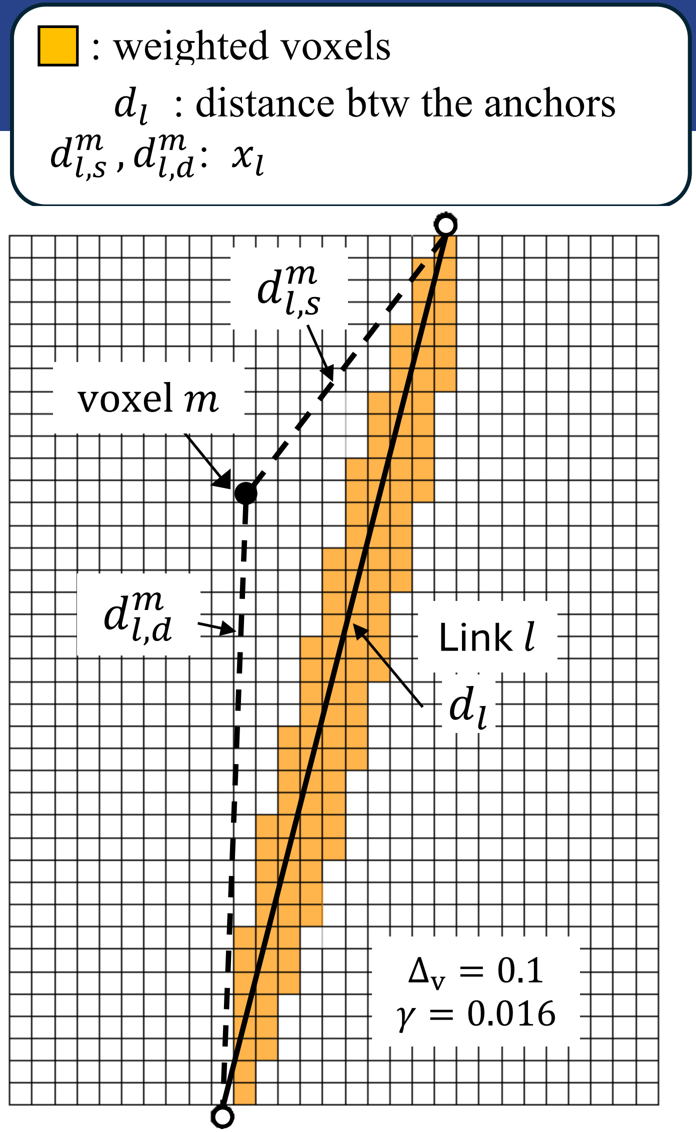
$$\boldsymbol{y} = \boldsymbol{W}\boldsymbol{x} + \boldsymbol{n}$$

- Weighting matrix, $\boldsymbol{W}$

$$w_{lm} = \begin{cases} 1/\sqrt{d_l}, & d_{l,d}^m + d_{l,s}^m < d_l + \gamma \\ 0, & \text{otherwise} \end{cases}$$

- Visualize $\widehat{\Delta \boldsymbol{x}}$

$$\boldsymbol{y}(\mathrm{t}) - \boldsymbol{y}(\mathrm{t}_0) = \Delta \boldsymbol{y} = \boldsymbol{W}\Delta \boldsymbol{x} + \Delta \boldsymbol{n}$$



fewer equations than unknowns: underdetermined
⇒ ill-posed inverse problem

System Model

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- Visualize $\widehat{\Delta \boldsymbol{x}}$

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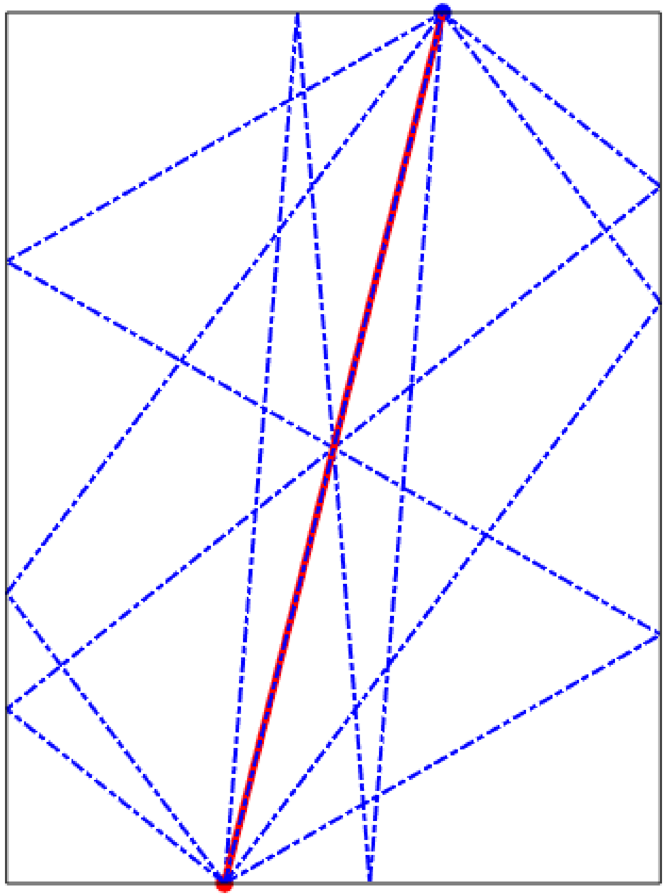
Multipaths influence on the RTI performance



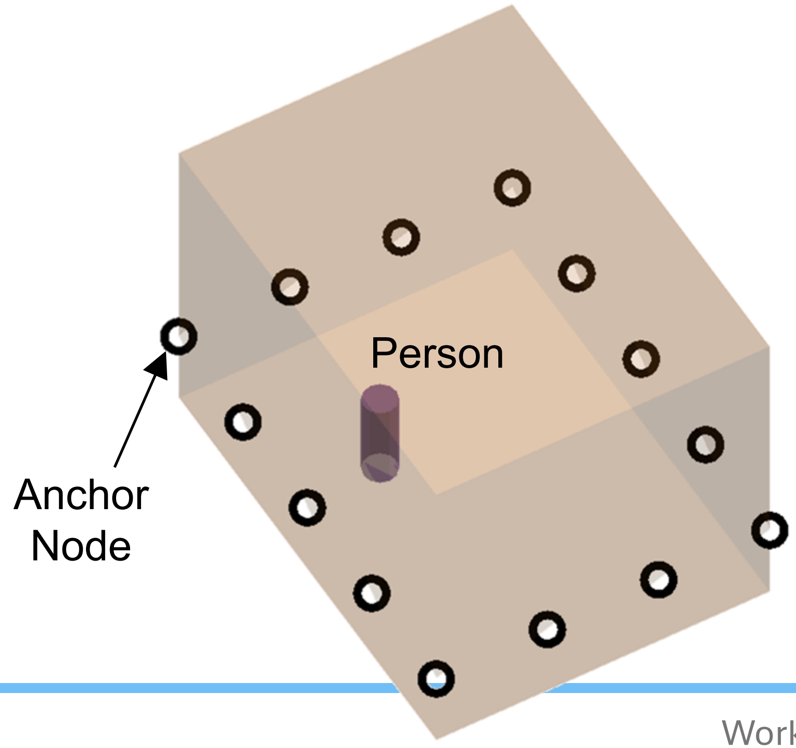
fewer equations than unknowns: underdetermined

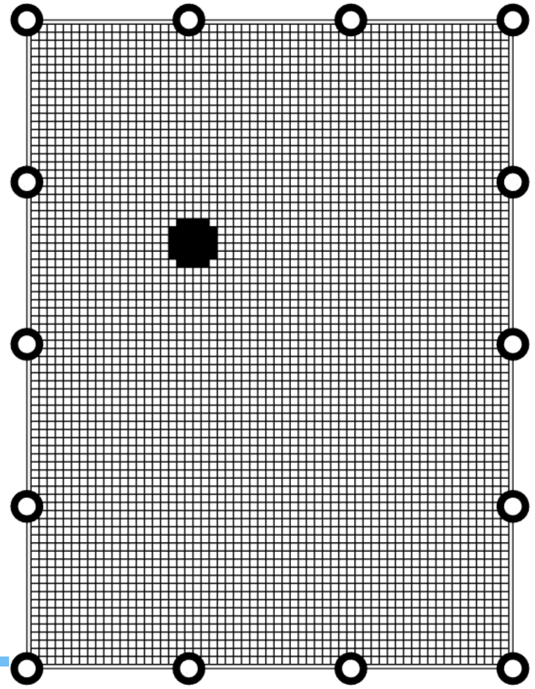
⇒ ill-posed inverse problem

Ray Tracing Simulation Model

- Simulation setup
  - Direct path
  - Reflection (up to double-bounce)

Model	$6\ [m] \times 8\ [m] \times 3\ [m]$
Person	H:1.7 m, Radius: 0.3 m
Voxel size	$\Delta_{\mathrm{v}} = 0.1\ [m]$
No. voxels	4800 (10 cm interval 60×80)
Margin	$\gamma = 0.016\ [m]$





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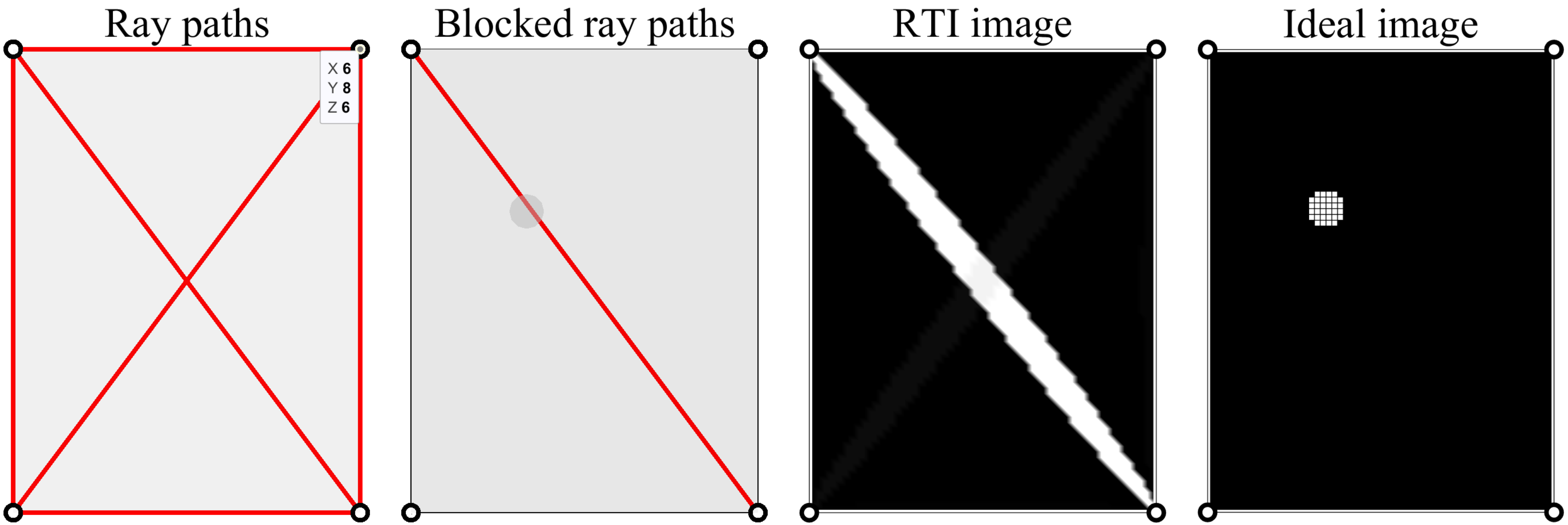
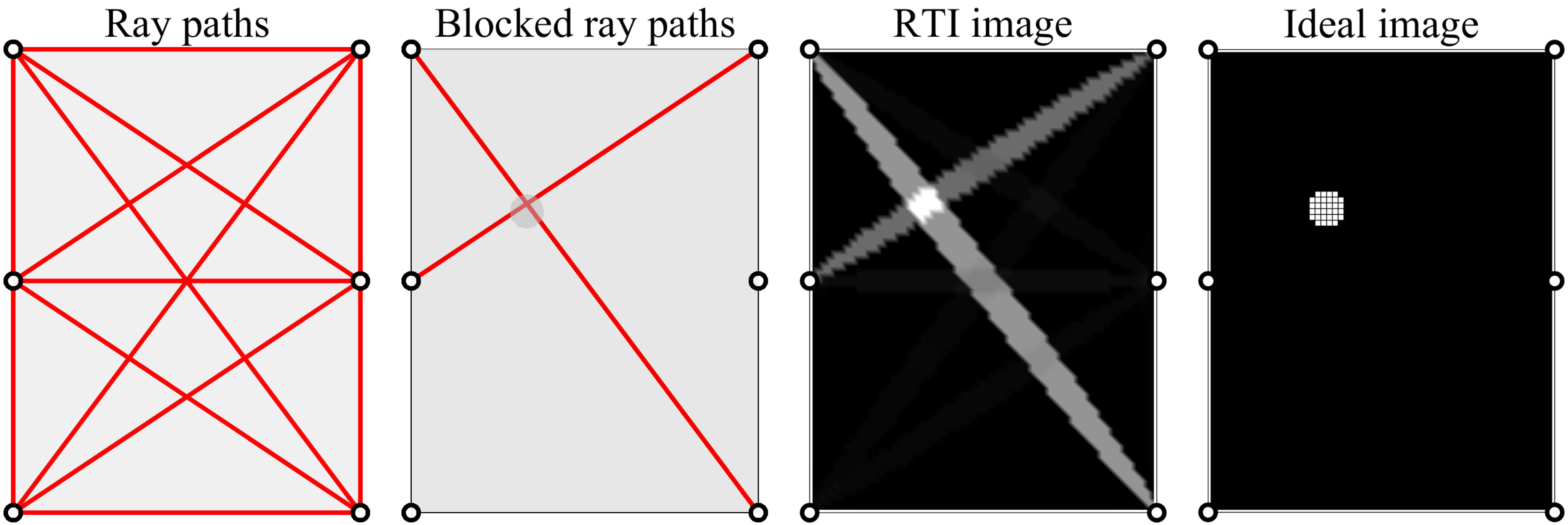
- 4 Anchors, 1 Person (direct path is only considered)



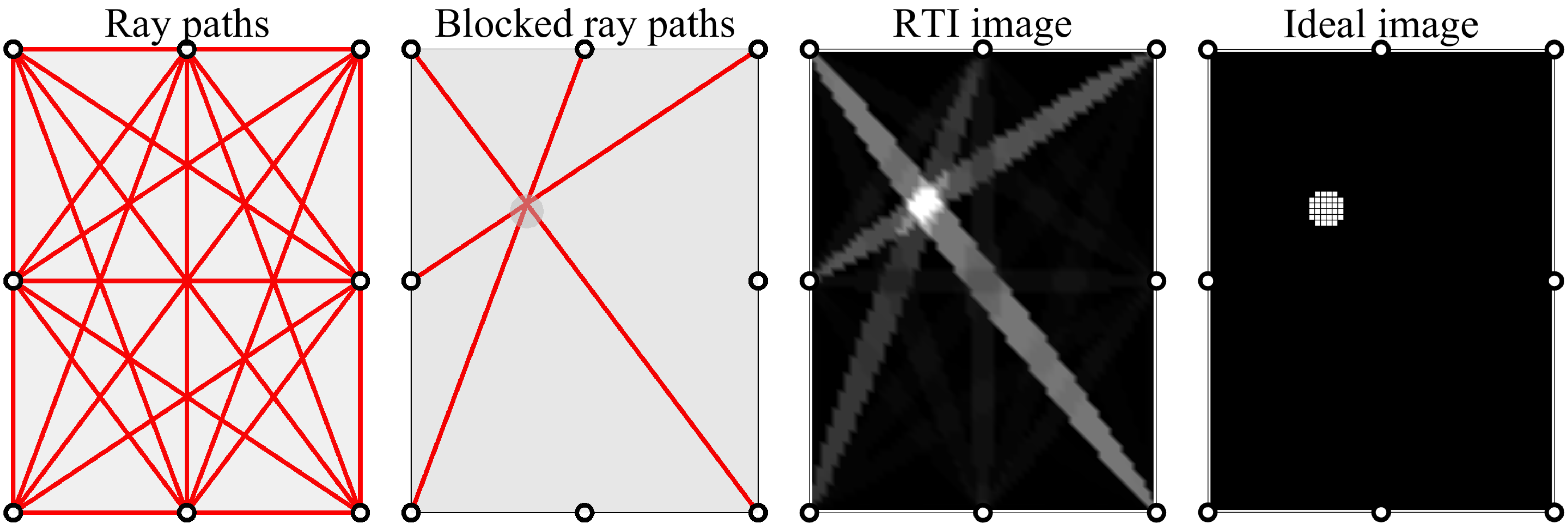
$6 = \binom{4}{2}$ paths

- 6 Anchors, 1 Person (direct path is only considered)



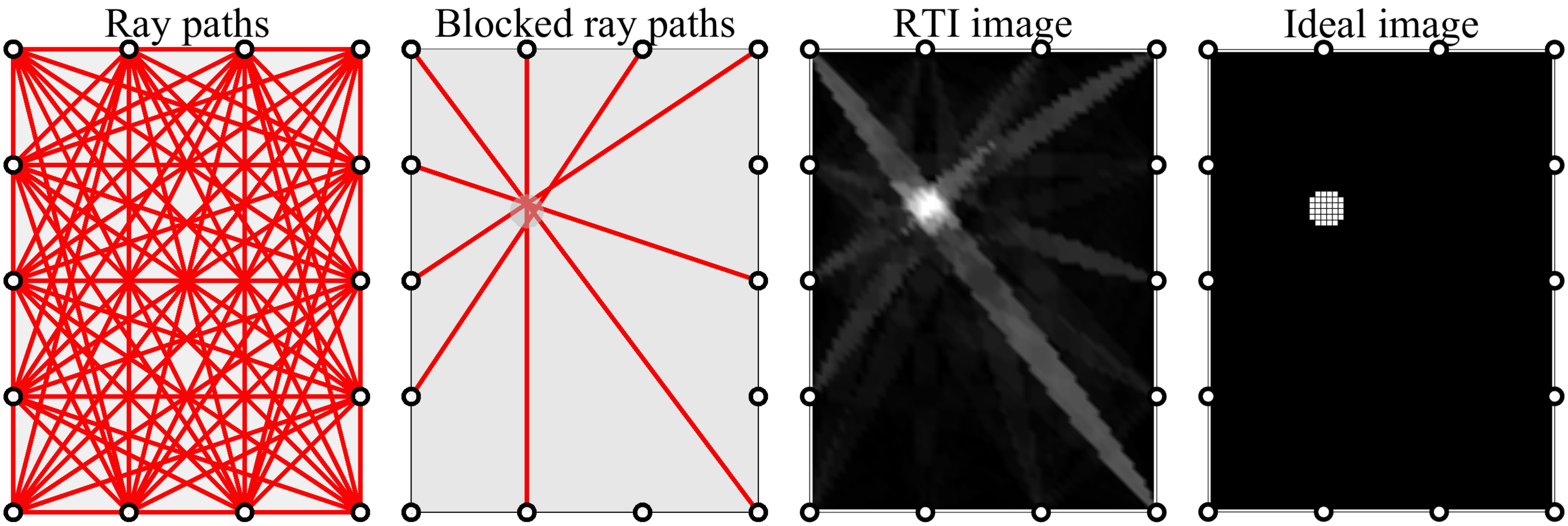
$15 = \binom{6}{2}$ paths

- 8 Anchors, 1 Person (direct path is only considered)



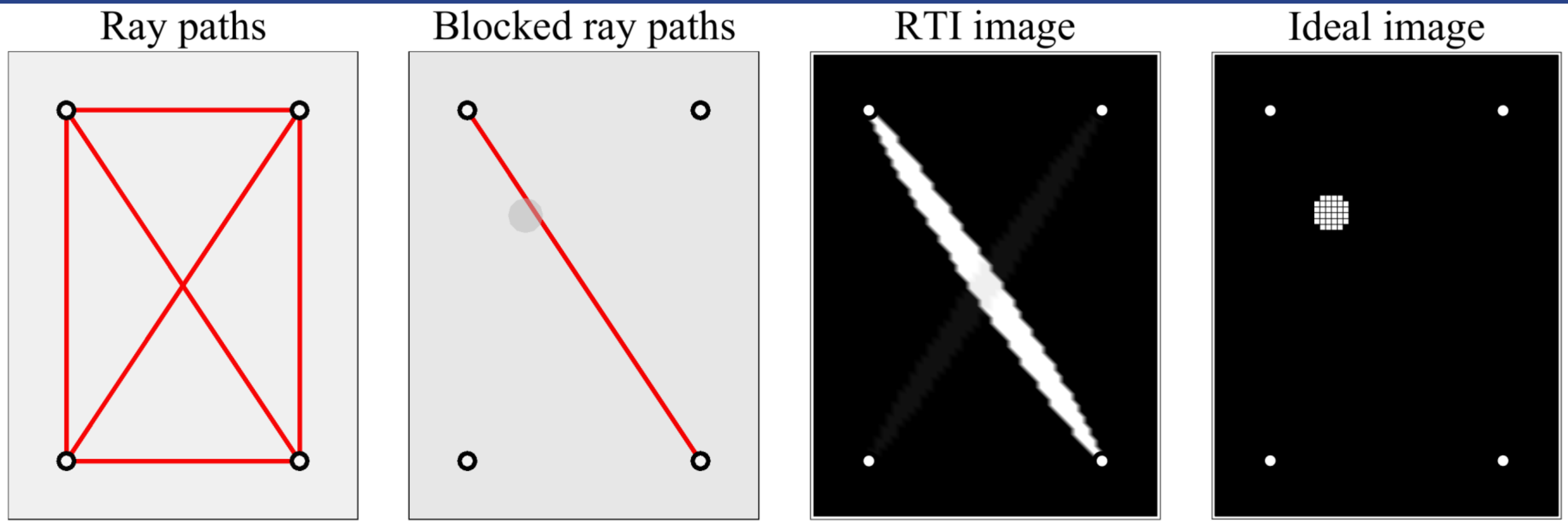
$28 = \binom{8}{2}$ paths

- 14 Anchors, 1 Person (direct path is only considered)

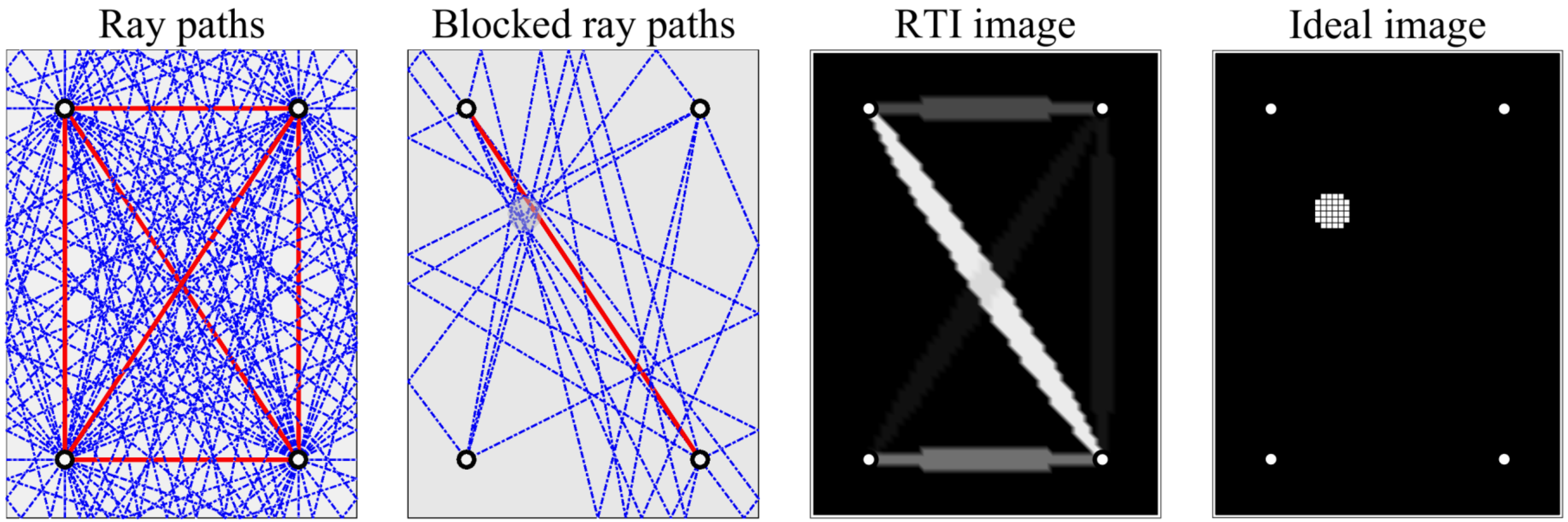


$91 = \binom{14}{2}$ paths

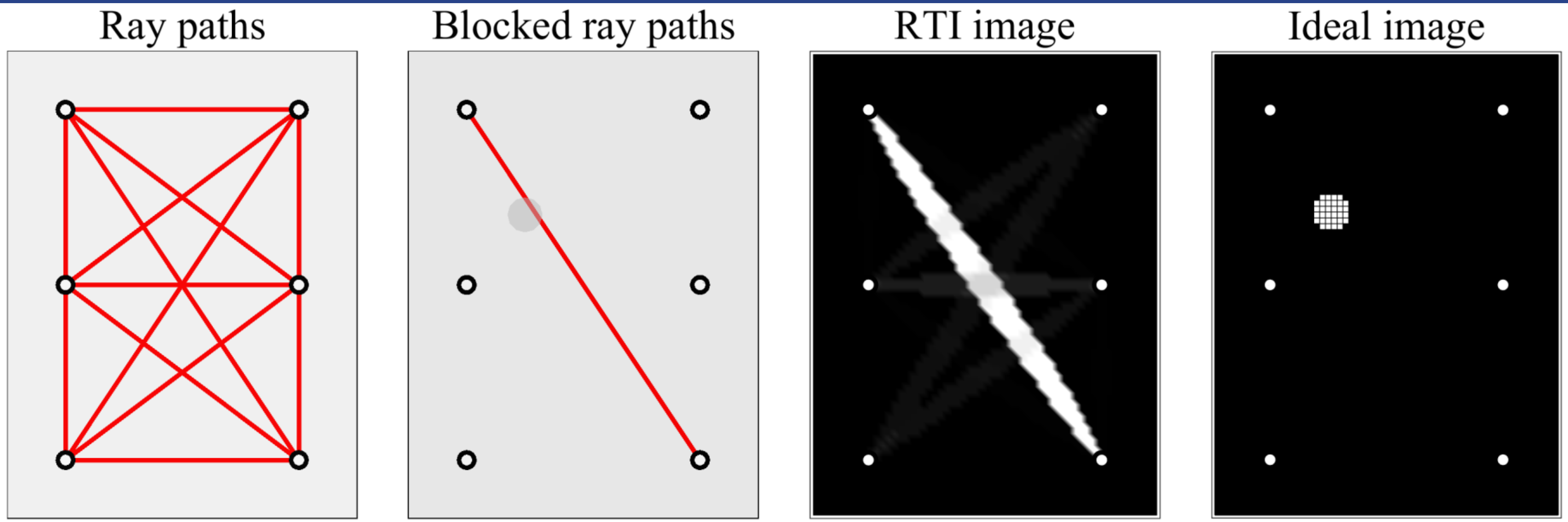
4 Anchors, 1 Persons, direct-path only



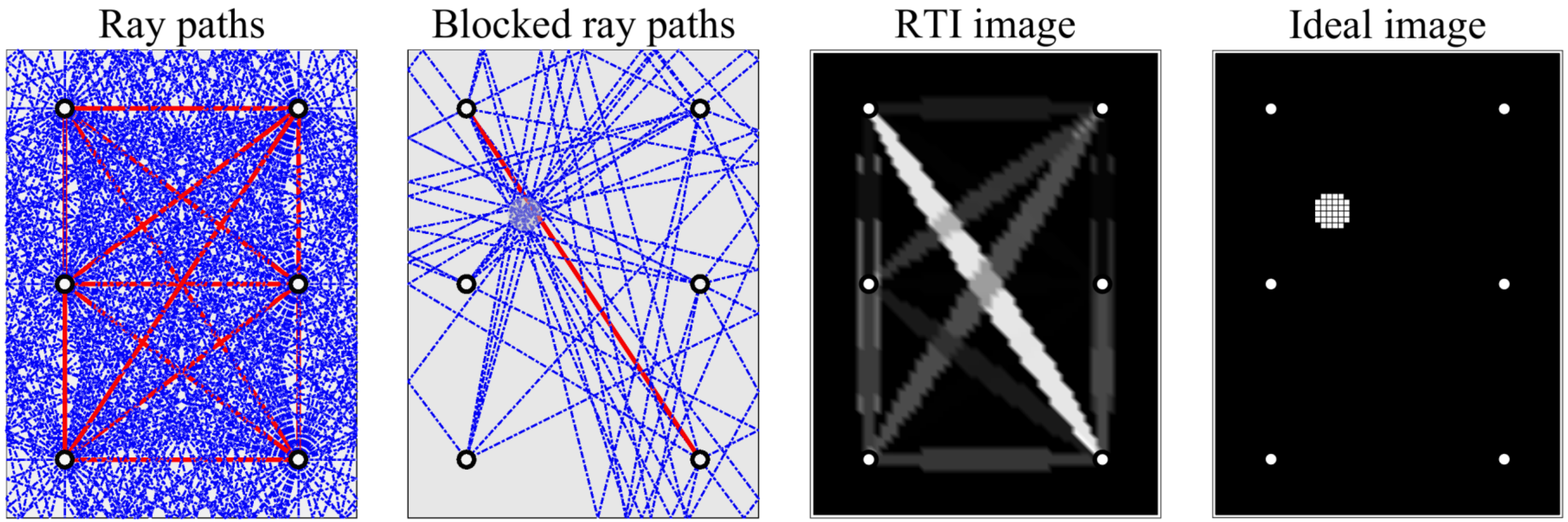
4 Anchors, 1 Persons, Multi-paths (2nd order)



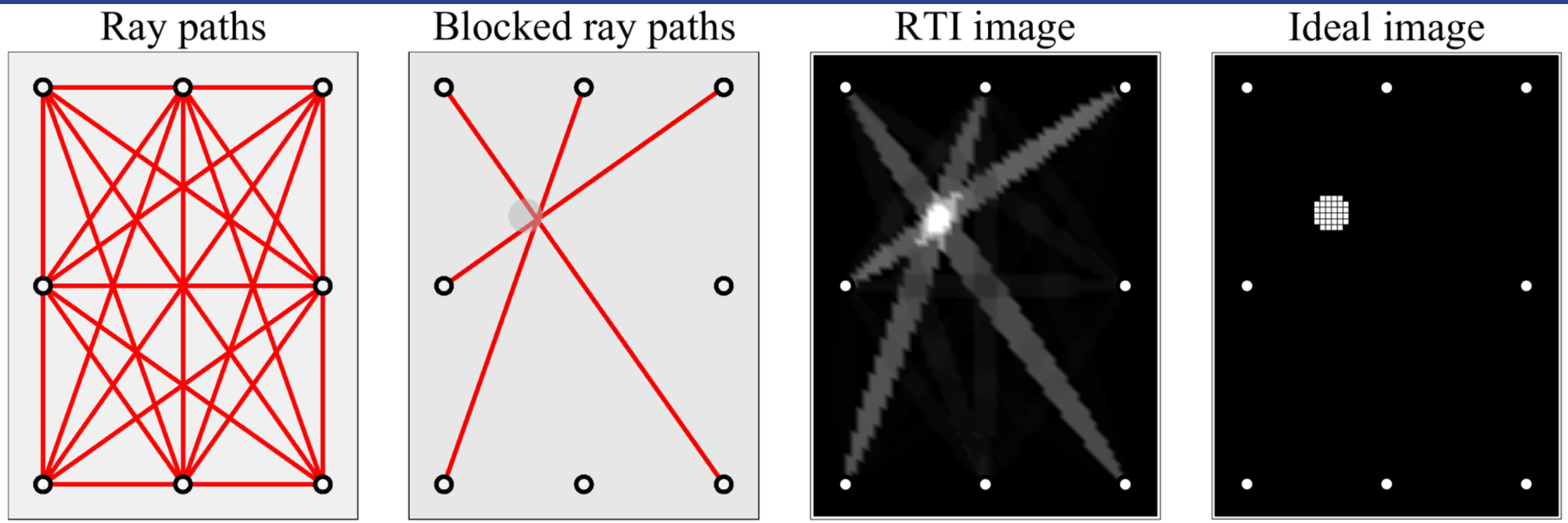
6 Anchors, 1 Persons, LoS only



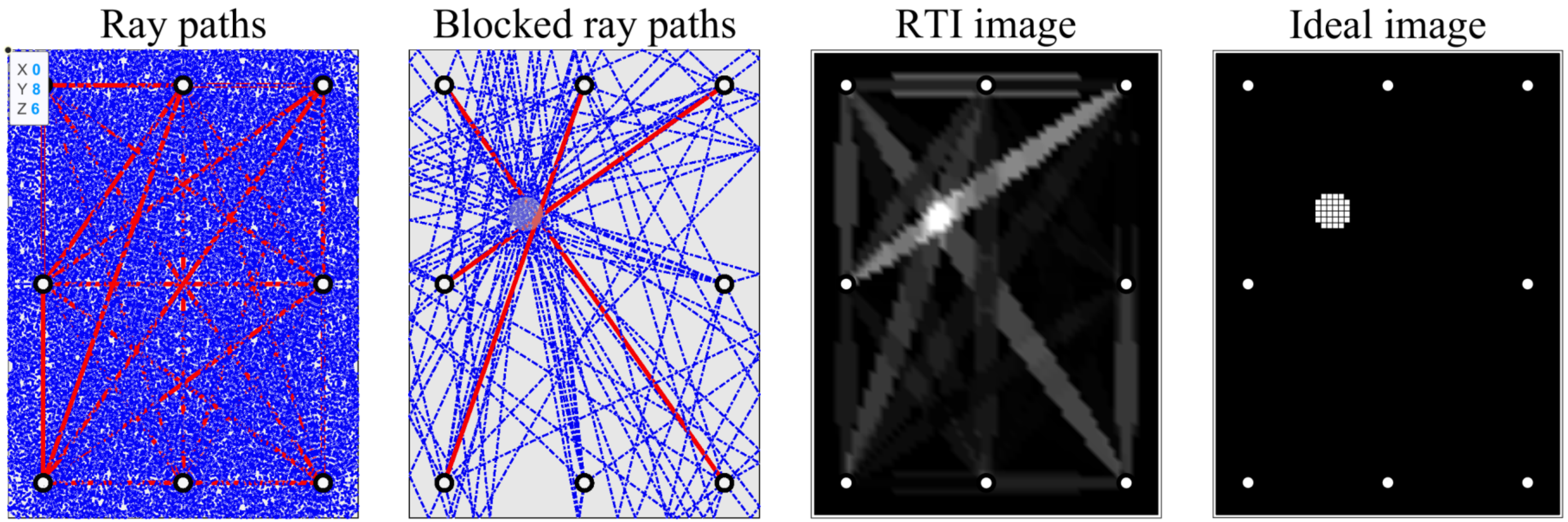
6 Anchors, 1 Persons, Multi-paths (2nd order)



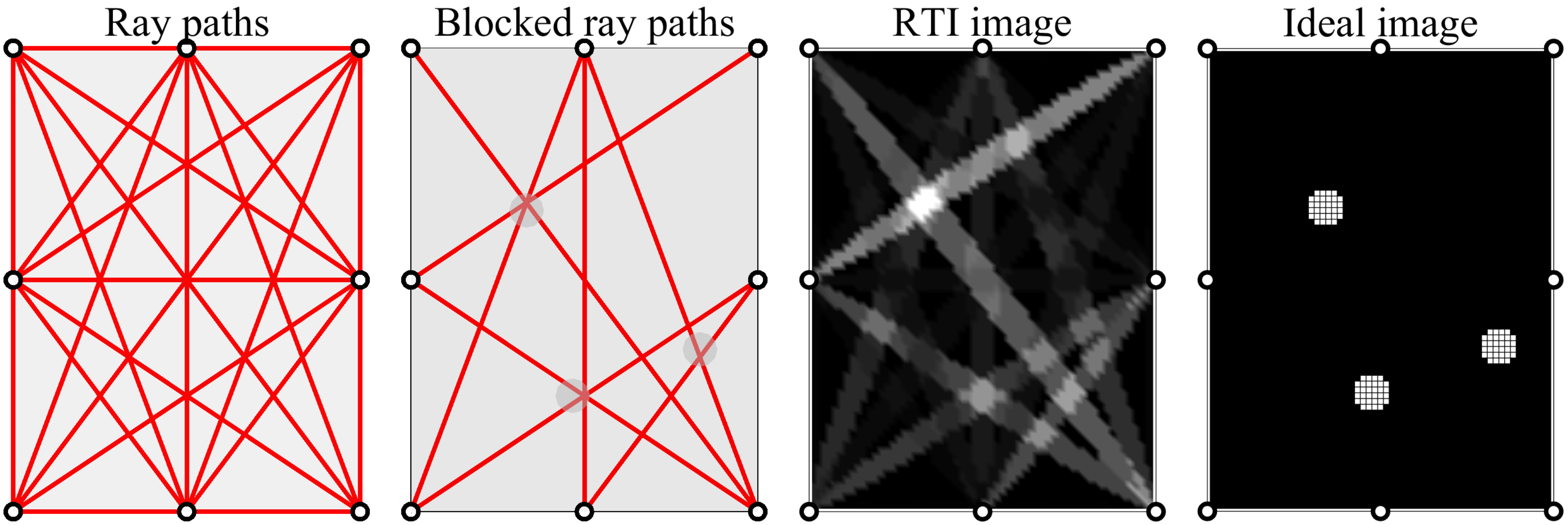
8 Anchors, 1 Persons, LoS only



8 Anchors, 1 Persons, Multi-paths (2nd order)

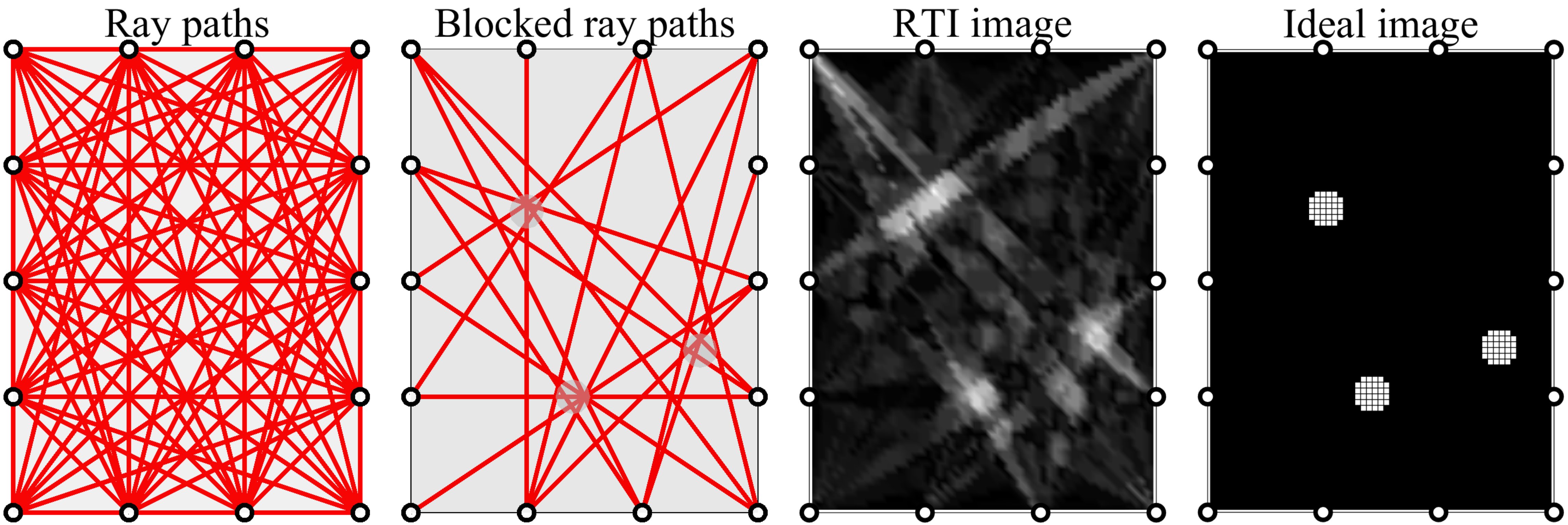


- 8 Anchors, 3 Persons



Small number of intersecting paths for each target location

- 14 Anchors, 3 Persons



Small number of intersecting paths for each target location

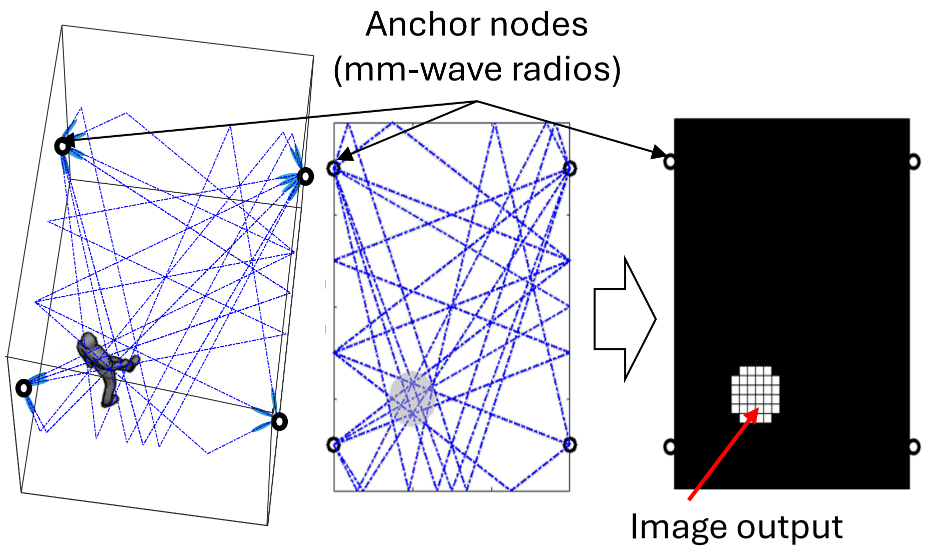
Existing Methods: RSS-RTI

- Microwave narrowband radio systems: ZigBee@2.4 GHz
- Utilizing RSS change (RSS-RTI) due to shadowing by a person in line-of-sight (LoS) path [*]
- Multipath propagation, e.g., reflection, diffraction, etc., degrades the performance
- Large number of anchor nodes are needed
  - Multipath mitigation
  - Multiple objects

[*] J. Wilson, N. Patwari, “Radio Tomographic Imaging with Wireless Networks,” IEEE Trans. Mobile Computing, Vol. 9, No. 5, pp. 621-632, May 2010.

Proposed Method: Multipath-RTI

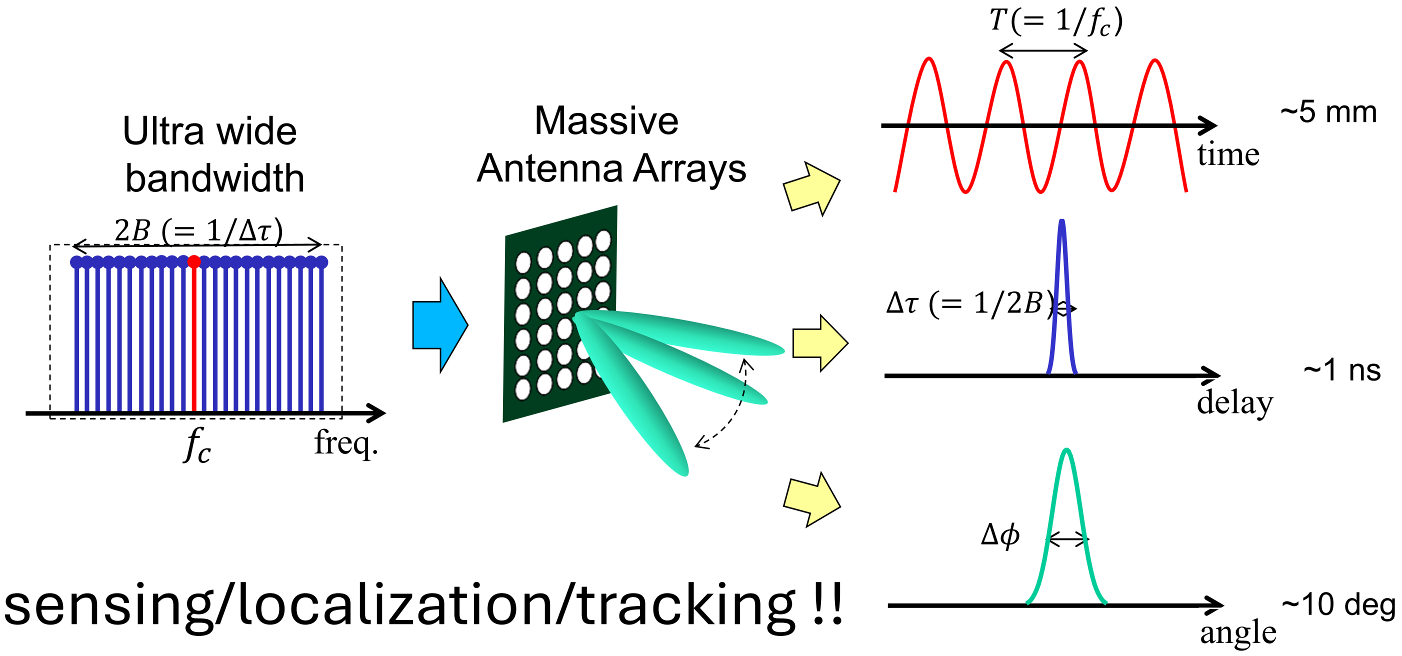
- Ultrawideband radio systems: WiGig@60 GHz
- Utilizing RSS change of the individual multipath components （Multipath-RTI） due to shadowing by a person [*]
- Reflected paths are utilized to enhance the performance
- The number of anchor nodes can be drastically reduced



[*] Togo Ikegami, Minseok Kim, Yuto Miyake, Hibiki Tsukada, "Multipath RTI: Millimeter-Wave Radio Based Device-Free Localization," IEEE Access, Vol. 12, pp. 42042-42054, 2024

Why Millimeter-Wave Radio ?

- Multi-gigabit WLANs (IEEE802.11ad/ay)
  - High frequency: 60 GHz ISM band
  - Wide bandwidth: up to 7 GHz
  - High directivity: Beamforming
- Mm-wave radios have higher resolution in distance, delay time, and directional domains

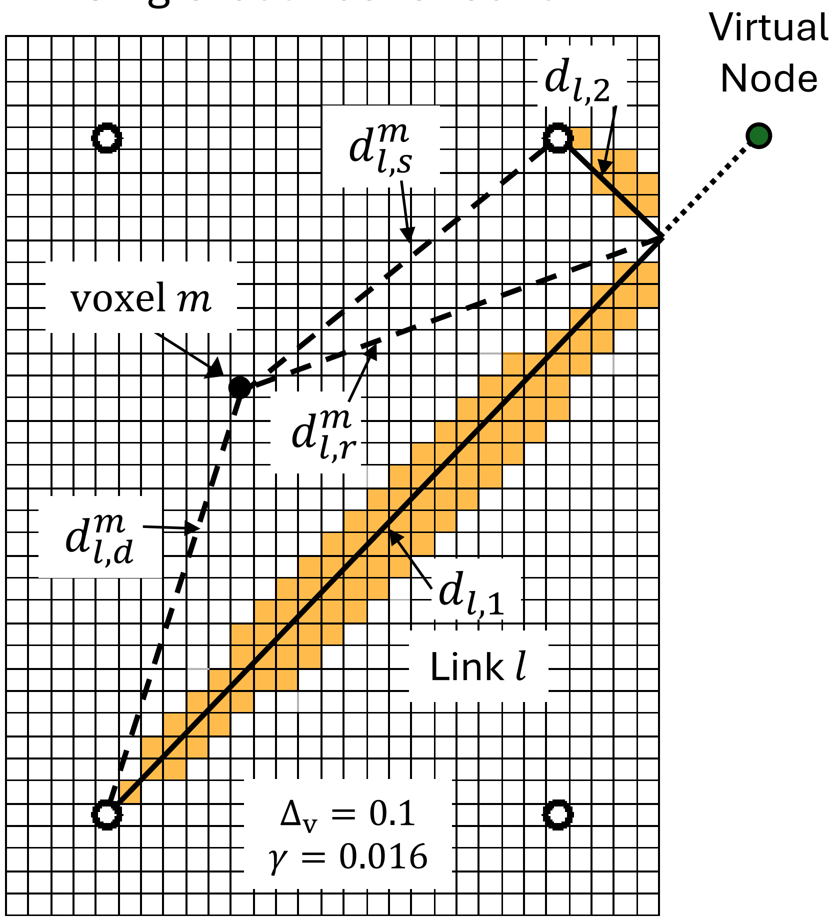


Better performance in sensing/localization/tracking !!

Multipath-RTI

- Feature
  - Reflected paths are treated as Virtual anchors (VAs)
  - VAs can reduce the no. of actual anchors
  - Manage multipaths to enhance the performance
- Virtual anchors (VAs)
  - In square room, we have up to 12 paths per link (single- and double-bounce)
  - From actual measurements, 7-14 paths were observed → enough number for RTI

Single-bounce reflection



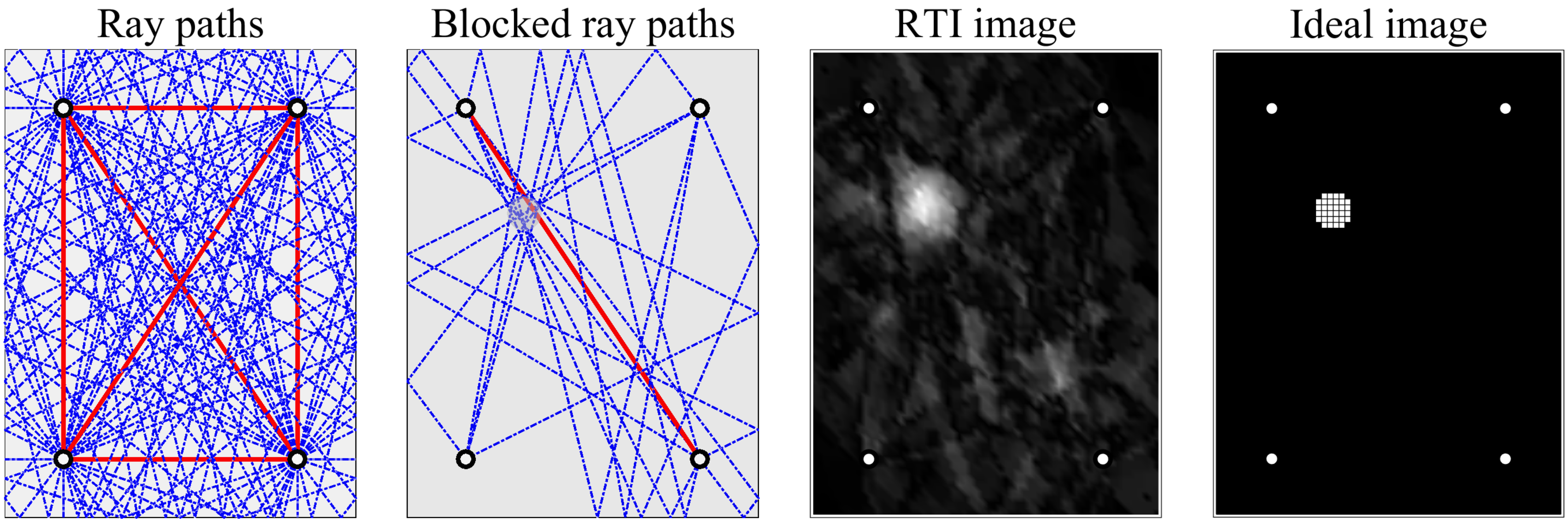
$d_l (= \sum_k d_{l,k})$: total propagation distance

$$w_{ml} = \begin{cases} 1/\sqrt{d_l}, & d^m_{l,s} + d^m_{l,r} > d_{l,2} + \gamma \\ 1/\sqrt{d_l}, & d^m_{l,s} + d^m_{l,r} > d_{l,2} + \gamma \end{cases}$$

[*] M. Kim, S. Kishimoto, S. Yamakawa, K. Guan, "Millimeter-Wave Intra-Cluster Channel Model for In-Room Access Scenarios," *IEEE Access*, Vol.8, pp. 82042-82053, May 2020

Multipath-RTI : Example (1)

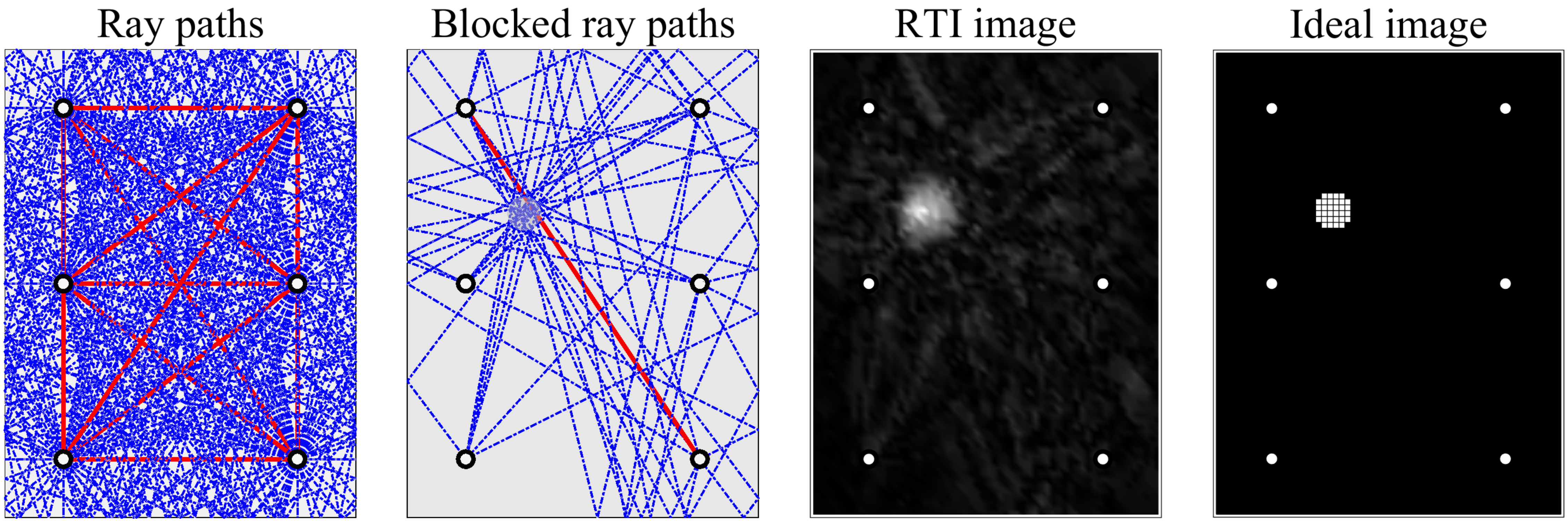
- 4 Anchors, 1 Person



78 paths from 6 links

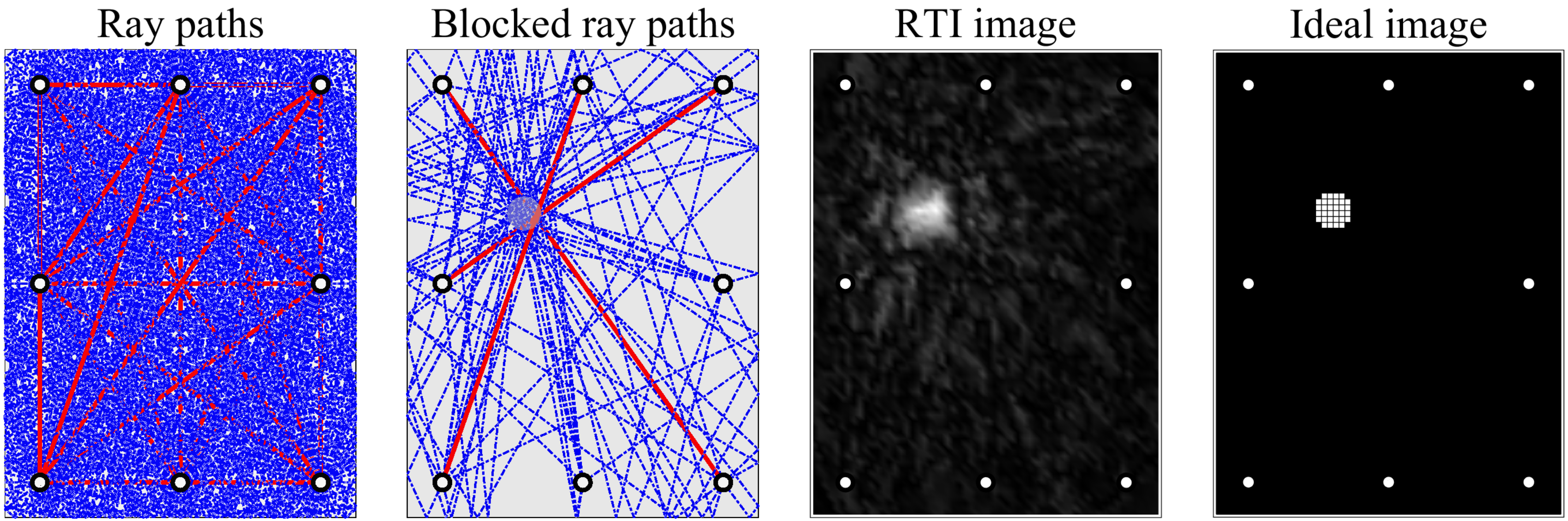
Multipath-RTI : Example (2)

- 6 Anchors, 1 Person



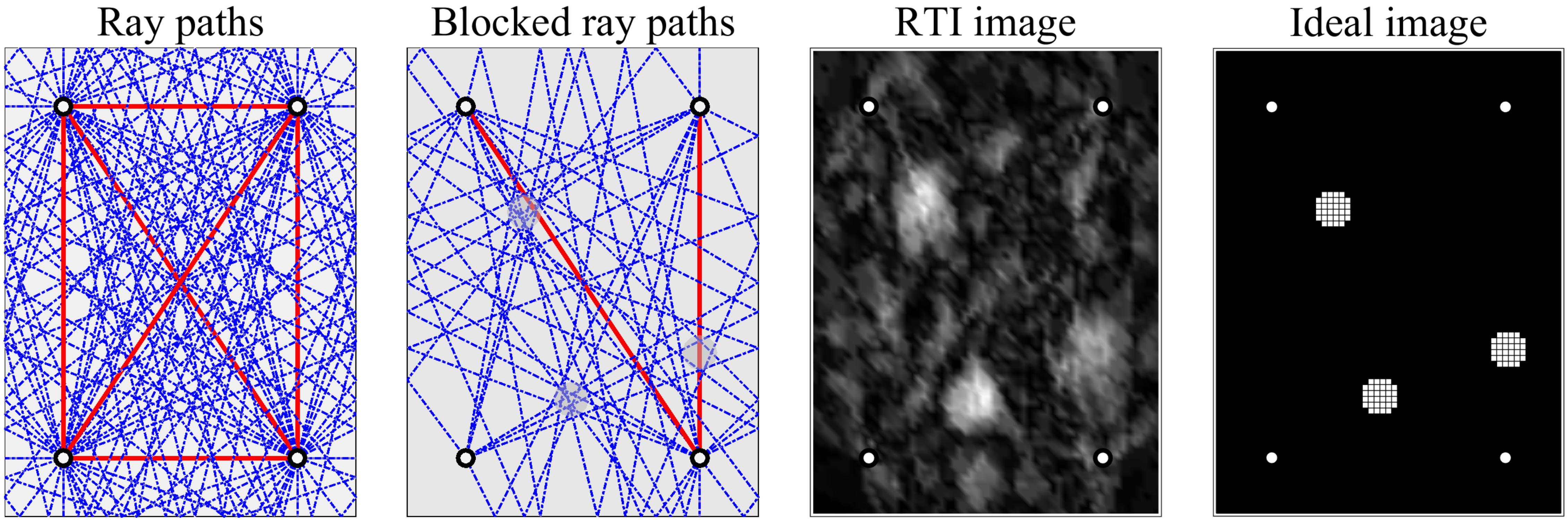
Multipath-RTI : Example (3)

- 8 Anchors, 1 Person

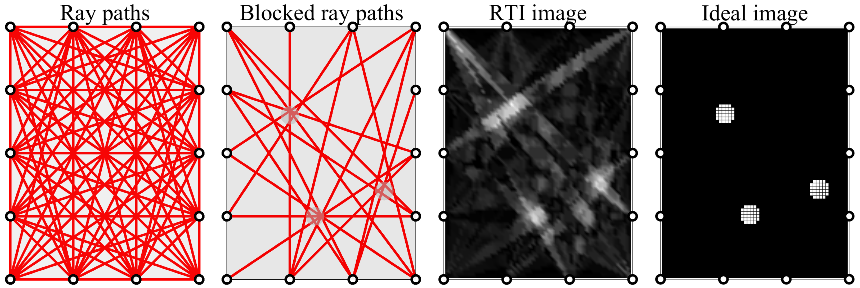


Multipath-RTI : Example (4)

- 4 Anchors, 3 Persons

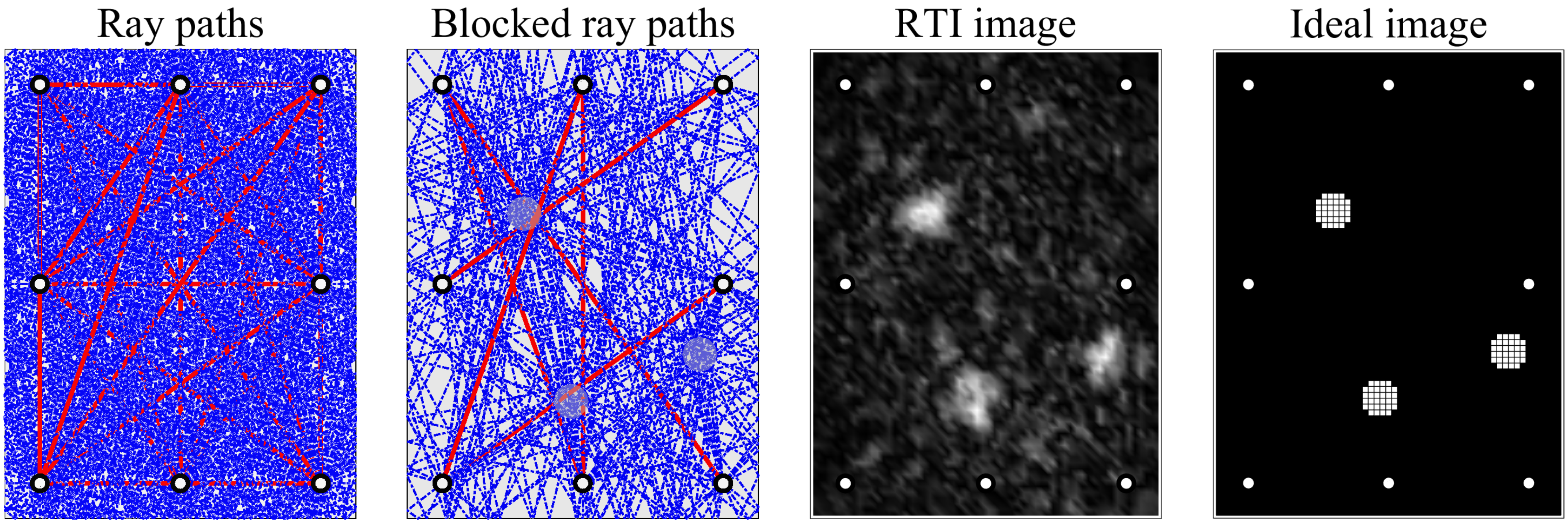


RSS RTI (14 anchors)

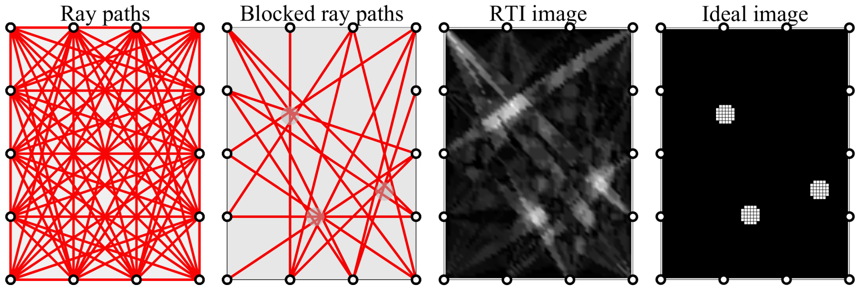


Multipath-RTI : Example (5)

- 8 Anchors, 3 Persons



RSS RTI (14 anchors)



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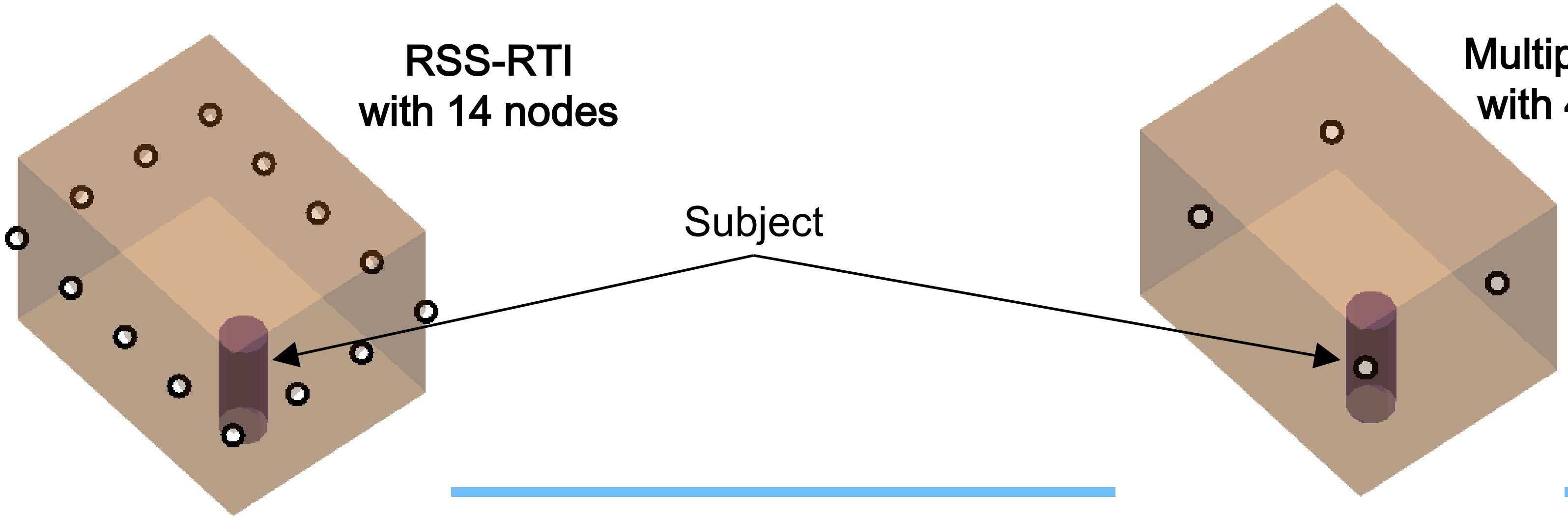
Simulation Setup

- Ray tracing simulation setup

	RSS-RTI	*Multipath-RTI*
Freq.	2.5 GHz	58.5 GHz
Anchors (K)	14	4
Model	$3\ [m] \times 4\ [m] \times 3\ [m]$	
Subject	H:1.7 m, Radius: 0.3 m	

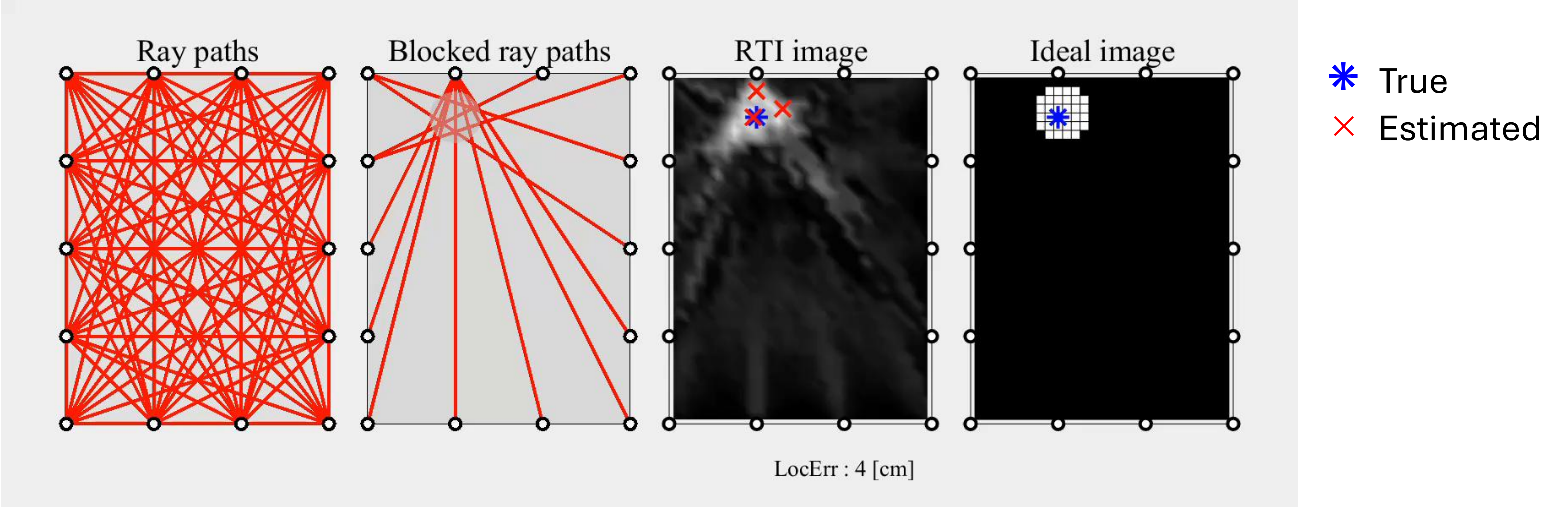
- RTI parameters

	RSS-RTI	*Multipath-RTI*
No. links	91	78 (up to double-bounce)
Voxel size	$\Delta_v = 0.1\ [m]$	
No. voxels	1200 (10 cm interval 30×40)	
Margin	$\lambda = 0.016\ [m]$	

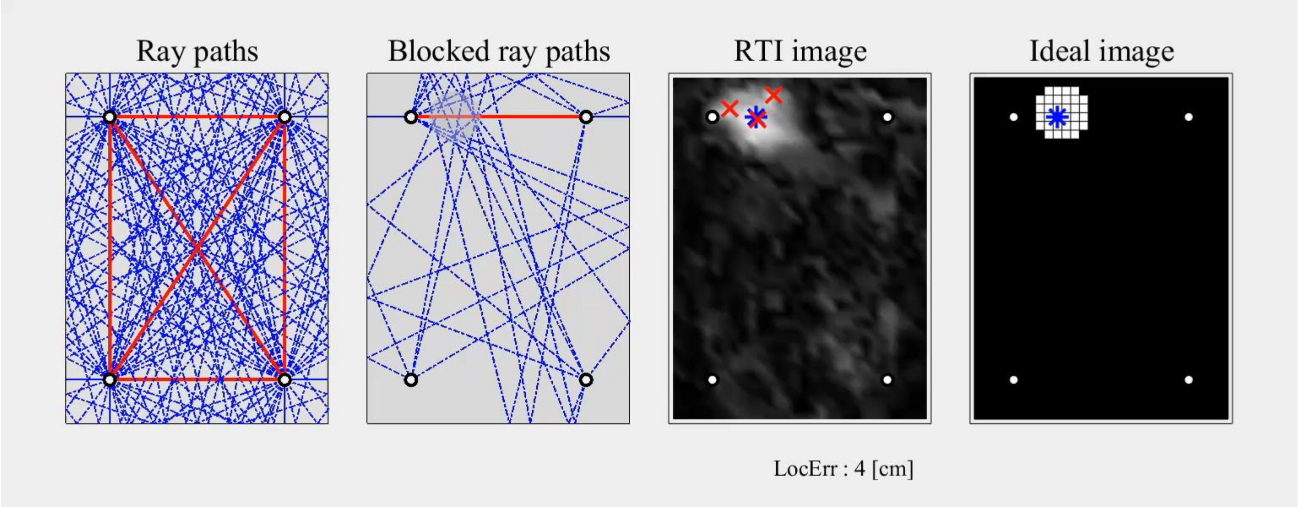


Multipath-RTI vs. RSS-RTI

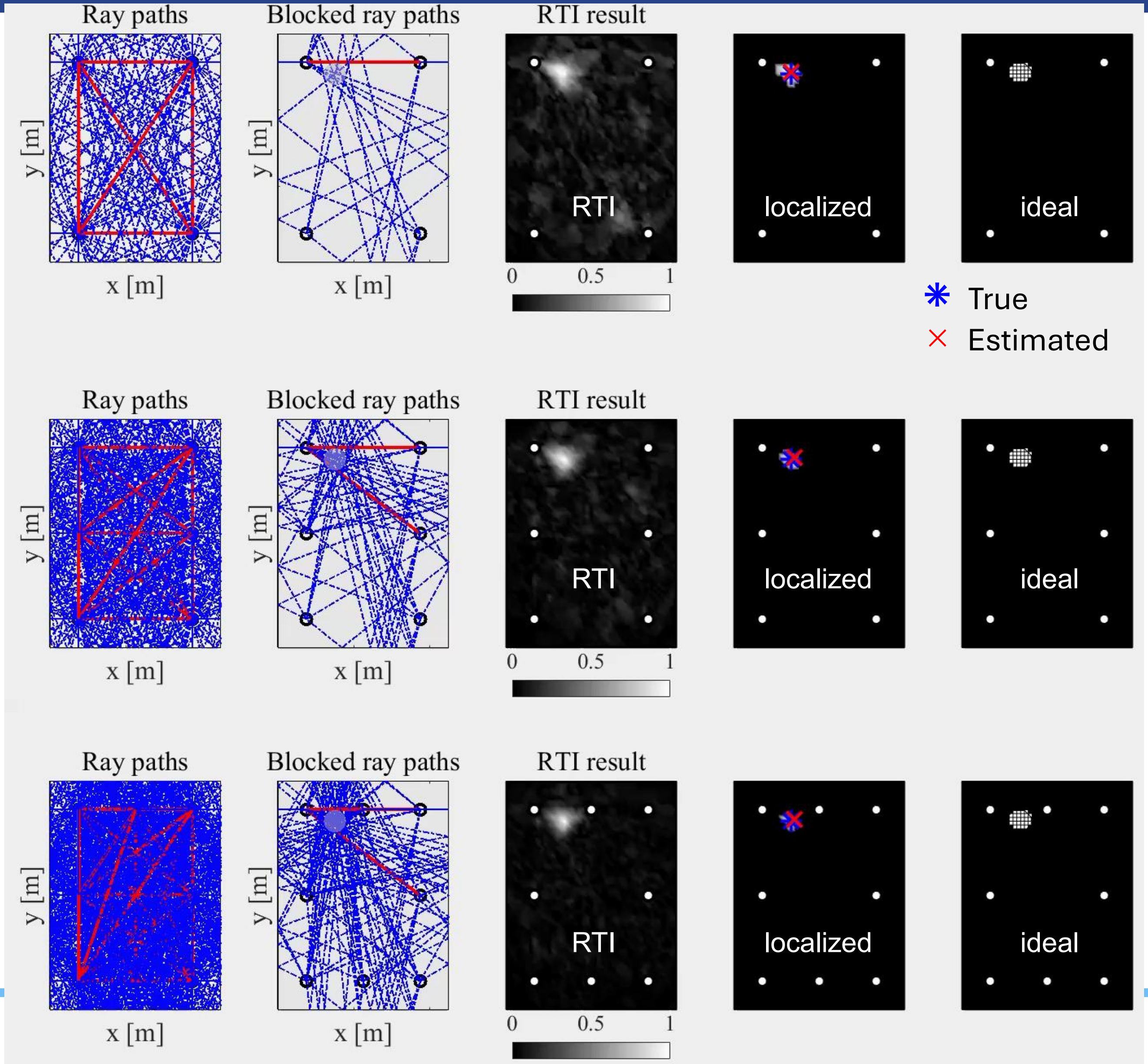
- RSS-RTI
 (14 anchors)



- Multipath-RTI
 (4 anchors, up to double-bounce reflection)



Multipath-RTI: No. Nodes



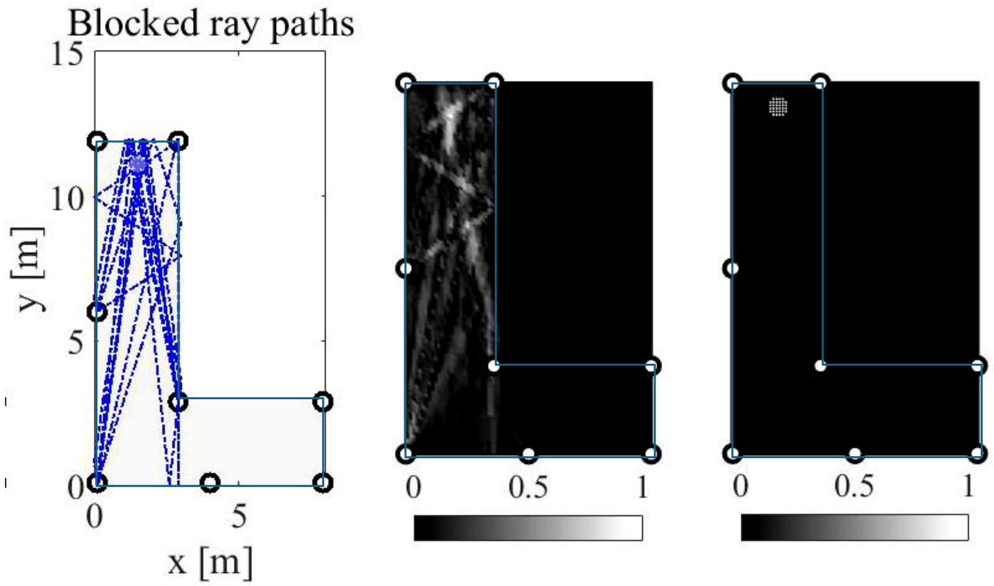
Room size: 4.5 × 6 [m]

4 Anchors
MSE: 12.87 [cm]

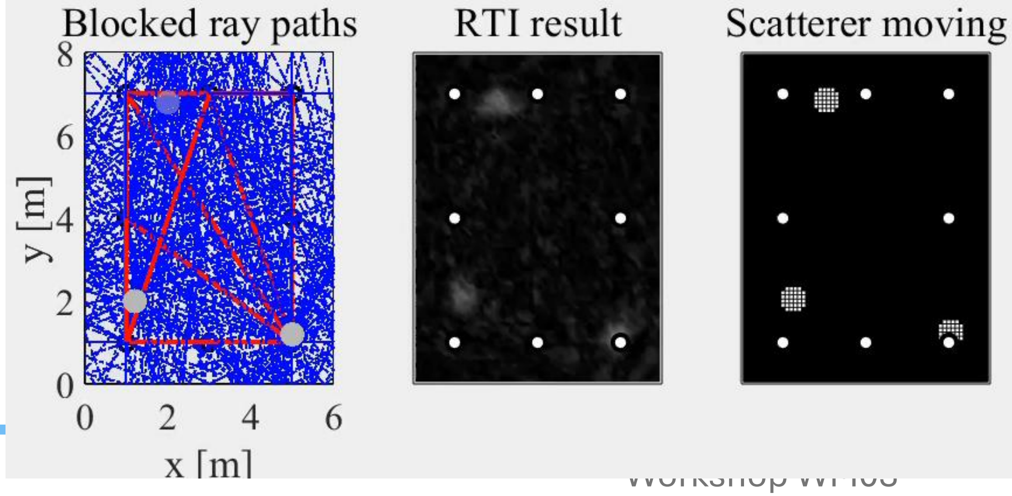
6 Anchors
MSE: 12.52 [cm]

8 Anchors
MSE: 11.99 [cm]

Multipath-RTI: Corridor & Multi-targets



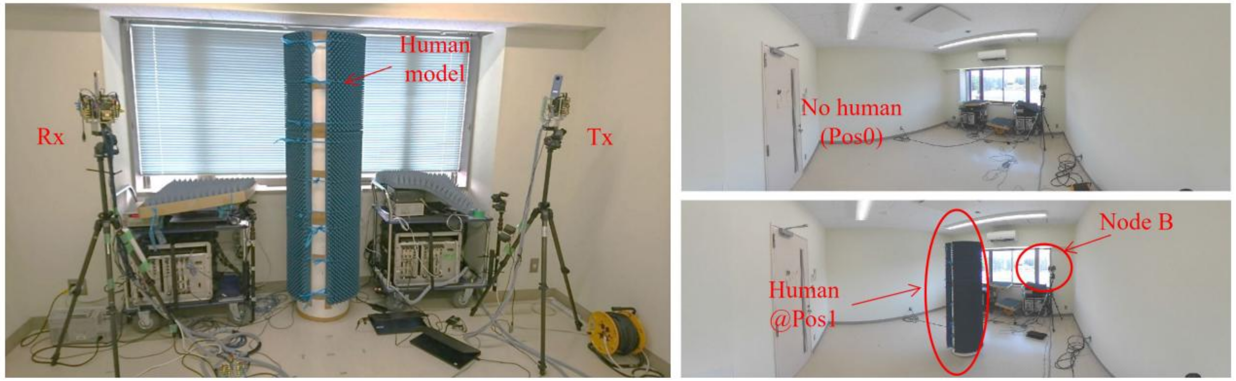
L-shaped corridor



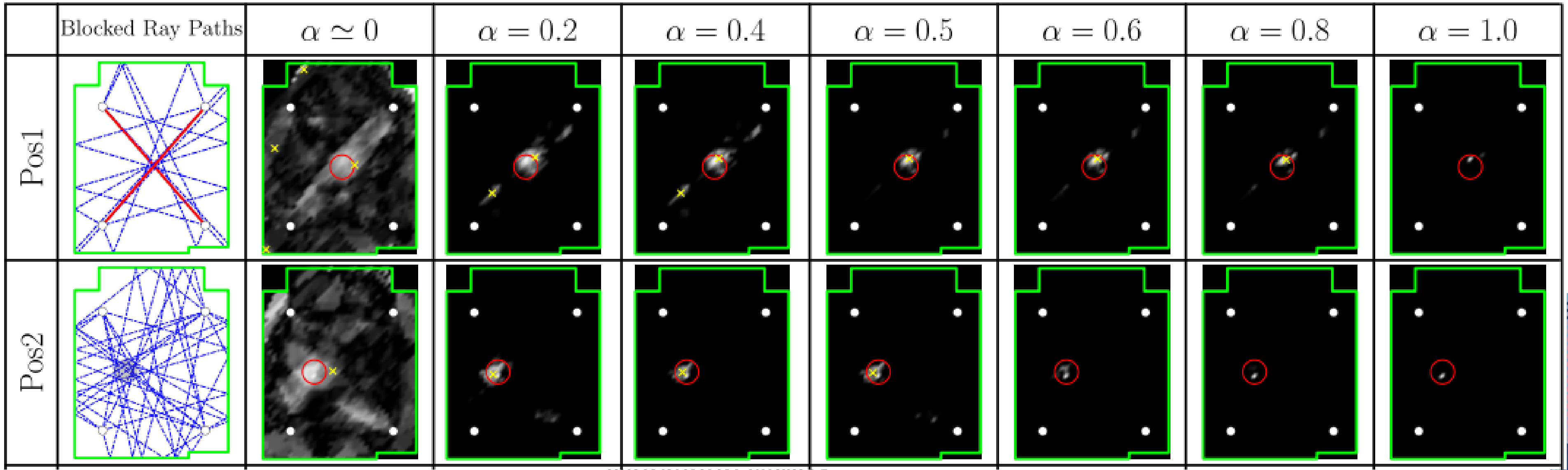
3 targets

Multipath-RTI: Experimental Validation

- P2P measurement using mmWave channel sounder



- Good results



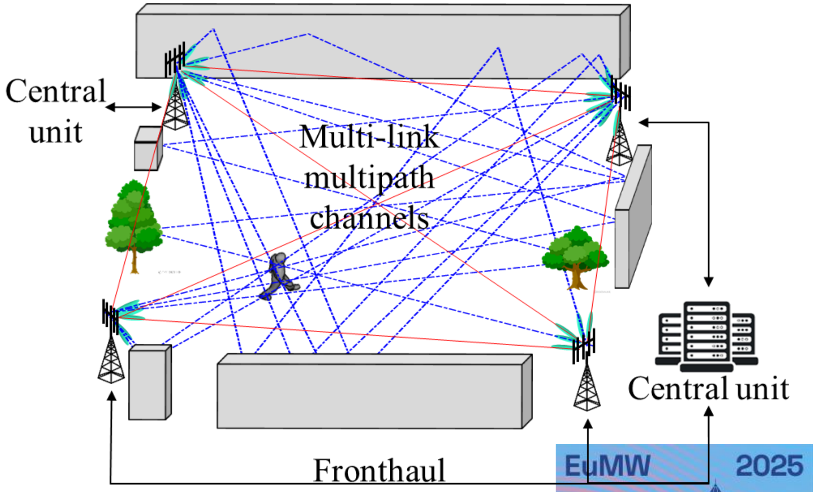
Technical Challenges

- How to Separate Multipath Components (MPCs)
  - Extraction of multipath components (MPCs) through sophisticated high-resolution signal processing
  - Clustering based on the extracted MPCs
- How to Obtain Multipath Pathway
  - Path identification via Ray launching
  - Tracking and association of multipath paths over time

Utilizing Ray Tracing (Real-time RT in 6G)

- How to Realize
  - Array antennas is required
  - Synchronization among nodes, etc.

Integration of DAN based ISAC [*]



Prototype Development of Sub-6 GHz Hardware

[*] Minseok Kim, Gesi Teng, Nishi Keita, Togo Ikegami, Masamune Sato, "Device-Free Localization Using Multi-Link MIMO Channels in Distributed Antenna Networks," ***IEEE J. Sel. Top. Electromagn. Antennas Propag. (JSTEAP)*** (early access)

Multipath-RTI based DFL

- Measure the RSS change of each path

$$\Delta \boldsymbol{y} = \boldsymbol{y}(t) - \underline{\boldsymbol{y}(t_0)} = \boldsymbol{W}\Delta \boldsymbol{x}$$

Baseline measurement

- $\boldsymbol{W} \in \mathbb{R}^{N \times M}$ has no inverse matrix, so $\Delta \boldsymbol{x}$ is not uniquely determined
- Derivation of the estimated solution $\Delta \hat{\boldsymbol{x}}$ → regularization

- Image reconstruction via Elastic Net

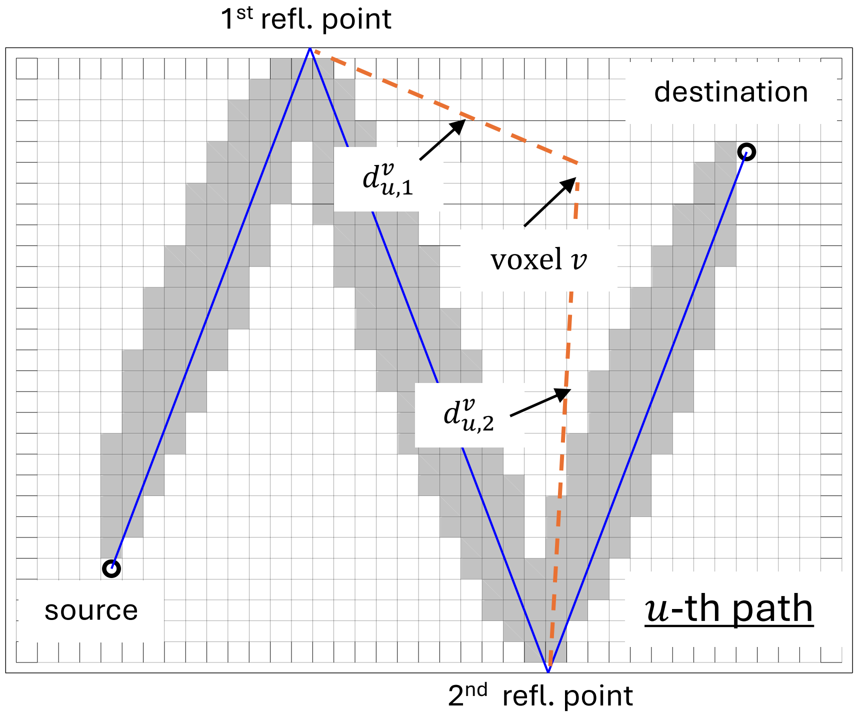
$$\boldsymbol{\Delta \hat{x}} = \arg\min_{\boldsymbol{\Delta x}} \left\{ \frac{1}{2} \|\boldsymbol{y}_{\Delta} - \boldsymbol{W}_{\boldsymbol{\Delta x}}\|_2^2 + \lambda P_\alpha(\boldsymbol{\Delta x}) \right\}$$

$$P_\alpha(\boldsymbol{\Delta x}) = \frac{1-\alpha}{2} \|\boldsymbol{\Delta x}\|_2^2 + \alpha \|\boldsymbol{\Delta x}\|_1$$

  - λ : regularization parameter → Control the intensity of regularization
  - α : relative contribution of L_2 regularization and L_1 regularization
    - Specified in the range of 0 to 1
    - The closer to 1, the sparser the vector

Multipath-RTI based DFL (2)

- Weight Matrix

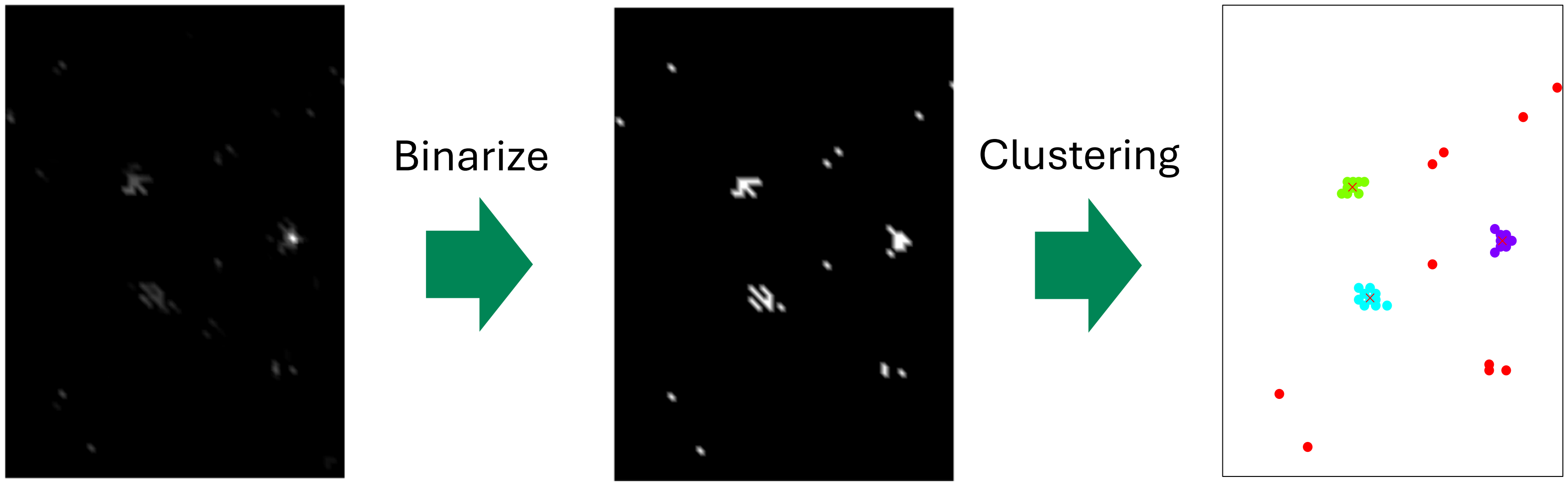


$$[\boldsymbol{W}]_{u,v} = \begin{cases} 1/\sqrt{d_u}, & d_{u,\mathrm{src}}^v + d_{u,1}^v < d_{u,1} + \gamma \\ 1/\sqrt{d_u}, & d_{u,1}^v + d_{u,2}^v < d_{u,2} + \gamma \\ & \vdots \\ 1/\sqrt{d_u}, & d_{u,K_u}^v + d_{u,\mathrm{des}}^v < d_{u,K_u+1} + \gamma \\ 0, & \text{elsewhere} \end{cases}$$

- As the reflection order increases, the pathways become less correlated with the actual target position, leading to a higher likelihood of generating artifacts.
- Utilizing up to second-order reflections is a reasonable choice

Image Reconstruction and Clustering

- Step 1: Sparse voxel estimation via Elastic Net
- Step 2: Otsu's binarization to detect active voxels
- Step 3: DBSCAN clustering to identify target regions
  - $\varepsilon = 0.5, \mathrm{minPts} = 3$ (typical values)
- Step 4: Centroid of cluster gives final target estimate
  - Parameter tuning via Bayesian Optimization for α and γ



MIMO Channel Model

- MIMO impulse response model (l-th link)

$$\boldsymbol{h}_l = \boldsymbol{A}(\boldsymbol{\Omega}_l)\boldsymbol{\Gamma}_l \in \mathbb{C}^{M_{\mathrm{T},l}M_{\mathrm{R},l}D\times 1}$$

N_l : Number of propagation paths
$M_{\mathrm{T},l}$, $M_{\mathrm{R},l}$: Number of MIMO antennas
D : Number of delay time bins

- Response matrix

$$\boldsymbol{A}(\boldsymbol{\Omega}_l) = \left[\boldsymbol{a}\left(\boldsymbol{\Omega}_{l,1}\right), \cdots, \boldsymbol{a}\left(\boldsymbol{\Omega}_{l,N_l}\right)\right] \in \mathbb{C}^{M_{\mathrm{T},l}M_{\mathrm{R},l}D\times N_l}$$

$$\boldsymbol{a}\left(\boldsymbol{\Omega}_{l,n_l}\right) = \boldsymbol{a}_{\mathrm{T}}\left(\phi_{\mathrm{T},l,n_l}\right)\otimes\boldsymbol{a}_{\mathrm{R}}\left(\phi_{\mathrm{R},l,n_l}\right)\otimes\boldsymbol{a}_{\tau}\left(\tau_{l,n_l}\right) \in \mathbb{C}^{M_{\mathrm{T},l}M_{\mathrm{R},l}D\times 1}$$

- Response vectors

$$\boldsymbol{a}_{\tau}(\tau) = [a_{\tau}(\check{\tau}_0 - \tau), \cdots, a_{\tau}(\check{\tau}_{D-1} - \tau)]^T$$

$$\boldsymbol{a}_{\mathrm{T}}(\phi_{\mathrm{T}}) = \left[1, e^{-\mathrm{j}\pi \sin\phi_{\mathrm{T}}} \ldots, e^{-\mathrm{j}\pi\left(M_{\mathrm{T},l}-1\right)\sin\phi_{\mathrm{T}}}\right]^T$$

$$\boldsymbol{a}_{\mathrm{R}}(\phi_{\mathrm{R}}) = \left[1, e^{-\mathrm{j}\pi \sin\phi_{\mathrm{R}}} \ldots, e^{-\mathrm{j}\pi\left(M_{\mathrm{R},l}-1\right)\sin\phi_{\mathrm{R}}}\right]^T$$

$$\boldsymbol{\Gamma}_l = \left[\gamma_{l,1}, \cdots, \gamma_{l,N_l}\right] \in \mathbb{C}^{N_l\times 1}$$

$$\boldsymbol{\Omega}_{l,n_l} = \left[\tau_{l,n_l}, \phi_{\mathrm{T},l,n_l}, \phi_{\mathrm{R},l,n_l}\right]$$

$$a_{\tau}(\tau) = \frac{1}{D}e^{-\mathrm{j}\pi\Delta_f\tau}\cdot\frac{\sin(\pi D\Delta_f\tau)}{\sin(\pi\Delta_f\tau)}$$

Path RSS Extraction via Beamforming

- Use of double-directional spatiotemporal beamforming
- RSS change per path:

$$[\Delta \boldsymbol{y}_l]_{n_l} = 10\log_{10}\left(\frac{\mathbb{E}\left[\left|\boldsymbol{a}^H(\boldsymbol{\Omega}_{l,n_l})\boldsymbol{h}_l(t)\right|^2\right]}{\mathbb{E}\left[\left|\boldsymbol{a}^H(\boldsymbol{\Omega}_{l,n_l})\boldsymbol{h}_{\mathrm{base},l}(t)\right|^2\right]}\right)$$

$$\Delta \boldsymbol{y}_l = \boldsymbol{y}_l(t) - \boldsymbol{y}_{\mathrm{base},l}(t)\ \text{[dB]}$$

$$\Delta \boldsymbol{y} = [\Delta \boldsymbol{y}_1^T, \dots, \Delta \boldsymbol{y}_L^T]^T \in \mathbb{C}^{N\times 1}$$

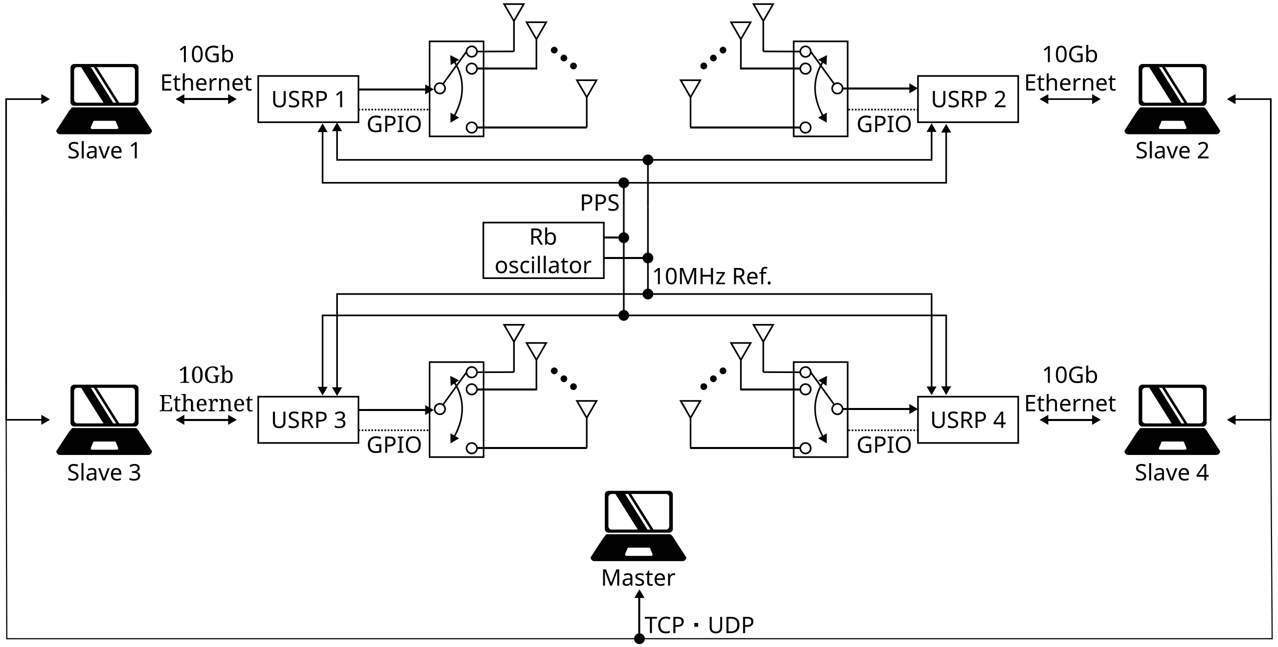
  - $\boldsymbol{a}(\boldsymbol{\Omega})$: Combined response vector from antenna and signal model
  - $\boldsymbol{\Omega} = [$AoA (ϕ_{Rx}), AoD (ϕ_{Tx}), delay time (τ) $]$ extracted via ***Ray tracing***

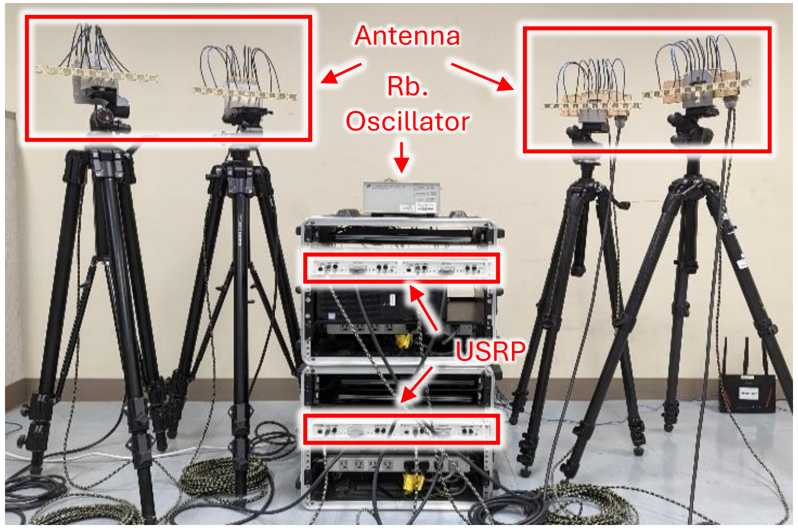
$$\boldsymbol{\Omega}_{l,n_l} = \left[\tau_{l,n_l}, \phi_{\mathrm{T},l,n_l}, \phi_{\mathrm{R},l,n_l}\right]$$

- Enables separation of multipath components for precise localization

Sub-6 GHz (4.85 GHz) Hardware

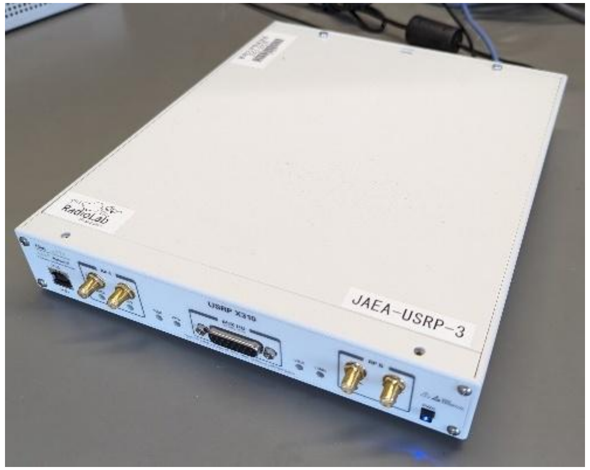
- 4 nodes → 6 link simultaneous measurement





USRP Based Implementation

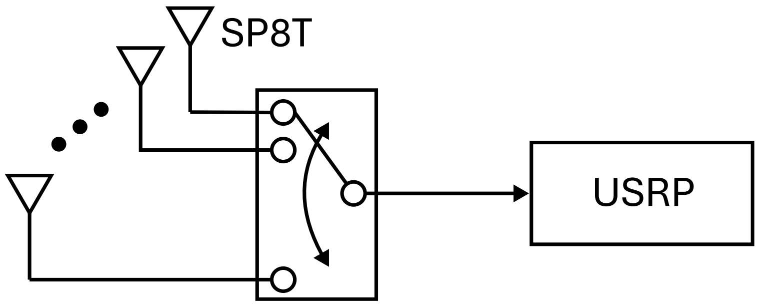
- USRP X310 (Ettus) used
- Channels:
  - 2 channels: one Tx/Rx, one Rx-only
- Host Interface:
  - USB, PCIe, 1G/10G Ethernet
  - Up to 200 MSps per channel
- Daughterboard:
  - UBX-160
  - Frequency range: 10 MHz to 6 GHz
  - Bandwidth: 160 MHz
  - Max transmit power: approx. +20 dBm
- Development Environment:
  - UHD C++ API (v4.4.0)



USRP inside

Antenna Switching

- Multiple Tx/Rx antennas are switched via SP8T RF switch
- RF switch: SR-J030-8S (Universal Microwave Components)
- Controlled through 15-pin GPIO on the USRP X310
- Switching control via UHD API functions



GPIO I/F

RF Switch

Table 1 Specifications of the RF switch.

Item	Specification
Frequency range	0.5–12.4 GHz
Insertion loss	3.0 dB Max
Isolation	0.5–6 GHz: 60 dB Min 6–12.4 GHz: 50 dB Min
VSWR (on state)	1.8:1 Max
Rise/Fall time*a	40 ns Max
On/Off time*b	90 ns Max

*a 10–90%RF, 90–10%RF
*b 50%TTL–90%RF, 50%TTL–10%RF

Specifications

- Parameters

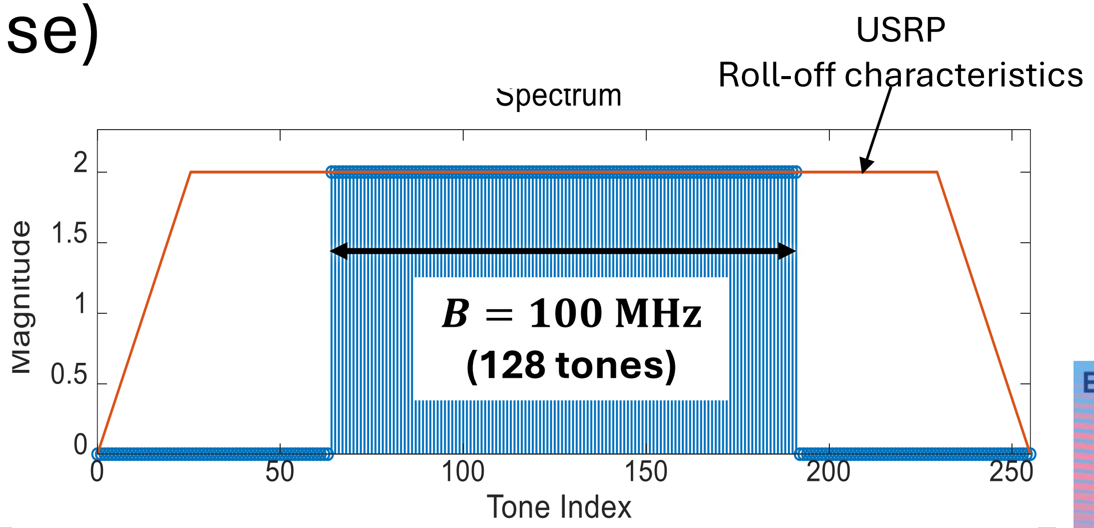
Item	Value
Carrier frequency	4.85001 GHz
Sampling rates	200 MSa/s
Signal bandwidth	100 MHz
Sounding signal	Multitone (Newman Phase)
No. subcarriers (tones)	128

Item	Value
Tone spacing	781.25 kHz
Symbol duration	1.28 μs
Delay resolution	10 ns
No. FFT Points	256
Transmission power	15 dBm (typ.)
Snapshot duration	164 μs （8 × 8 MIMO）

- Multitone signal (Newman phase)

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=-N/2}^{N/2-1} \exp\left(\mathrm{j}2\pi\Delta_f t + \mathrm{j}\phi_k\right)$$

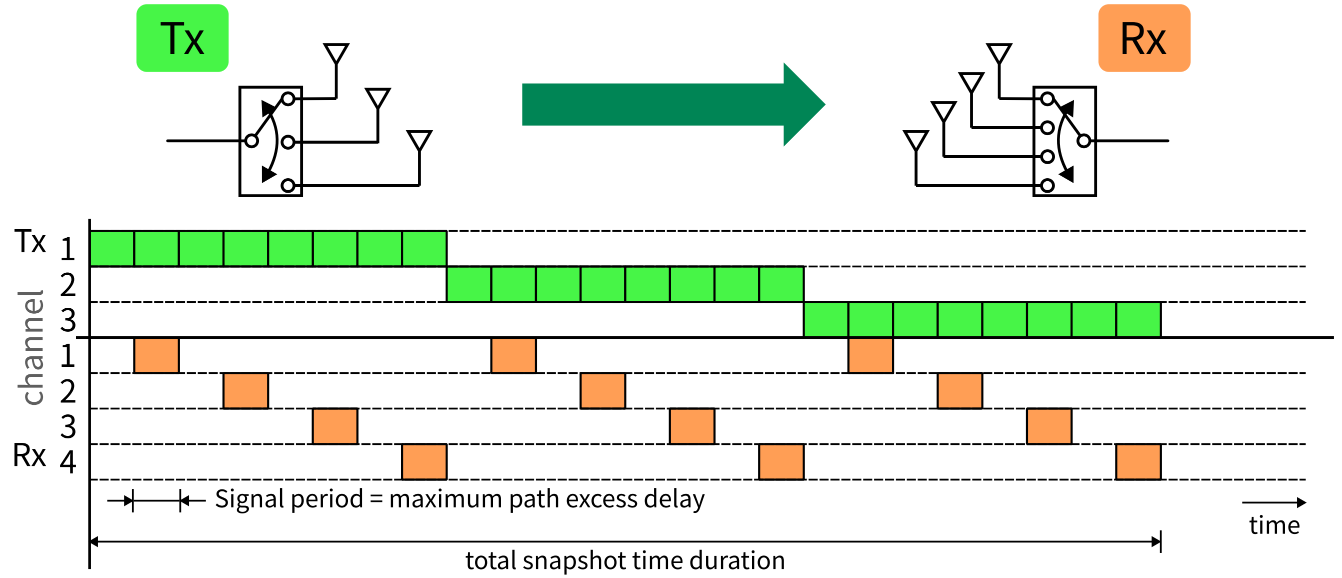
N: No. tones.
$\Delta_F = B/N$: Tone spacing
$\phi_k = \frac{k^2\pi}{N}$: Newman phase



Sequence for MIMO Channel Sounding

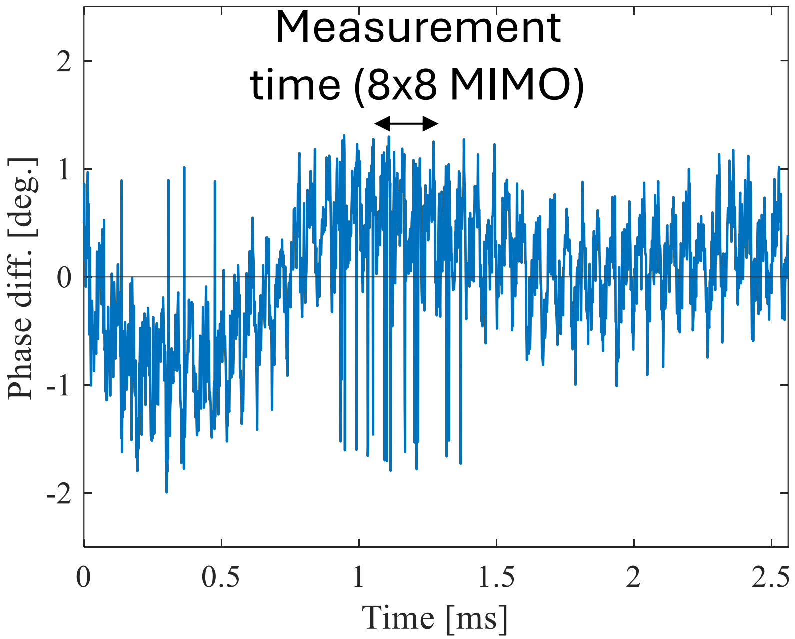
- Each signal is transmitted twice, and the second transmission is used for reception
- Symbol duration: 1.28 μs (256 samples @ 200 Msps)
- Time required for a single 8 × 8 MIMO snapshot 164 μs

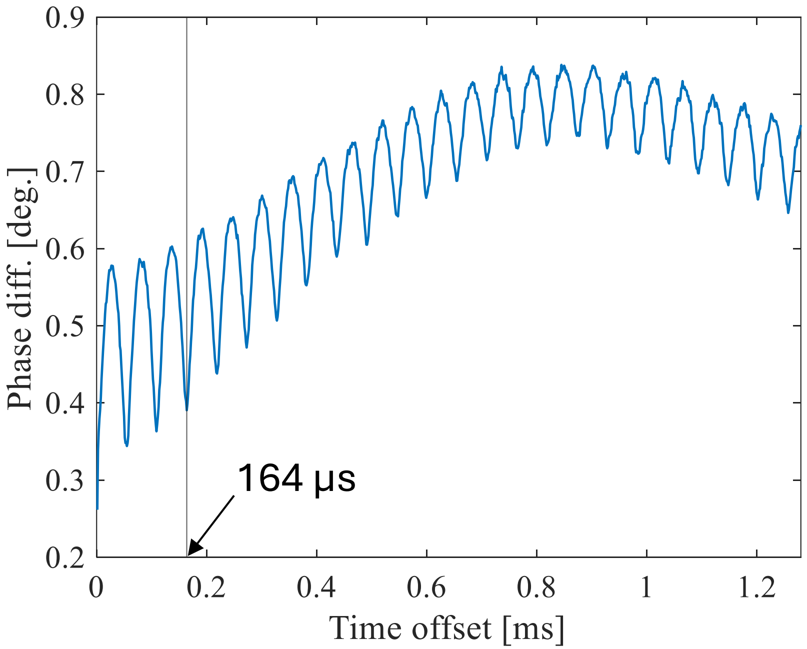
1.28 μs
× 2 (symbols)
× 8 (Tx antennas)
× 8 (Rx antennas)



Phase Synchronization

- The reference clock and 1PPS signal are supplied to both Tx and Rx USRPs from a common rubidium (Rb) frequency standard

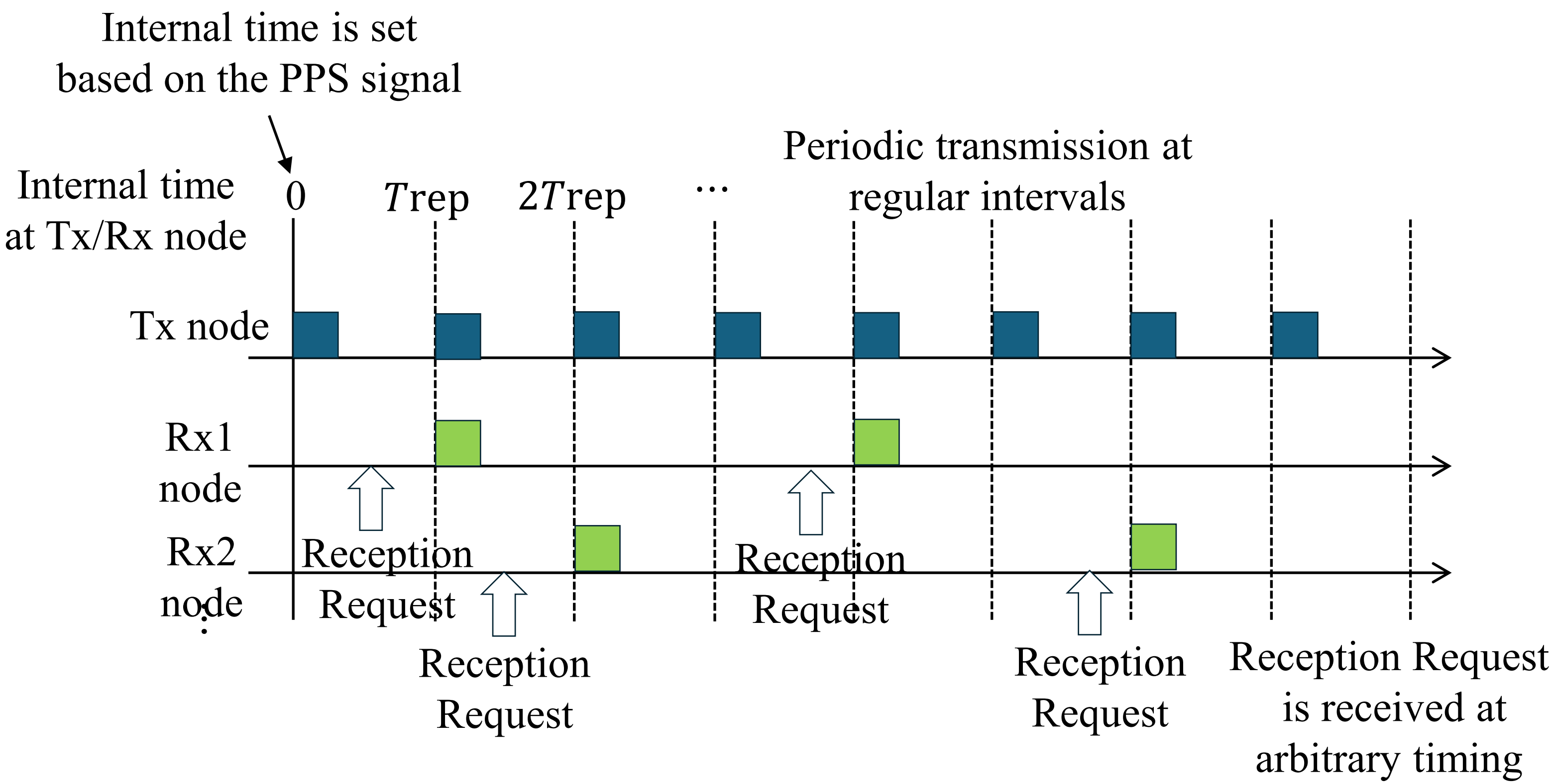




Observed phase variation is approximately 3 degrees. The impact on MIMO channel measurement is considered negligible.

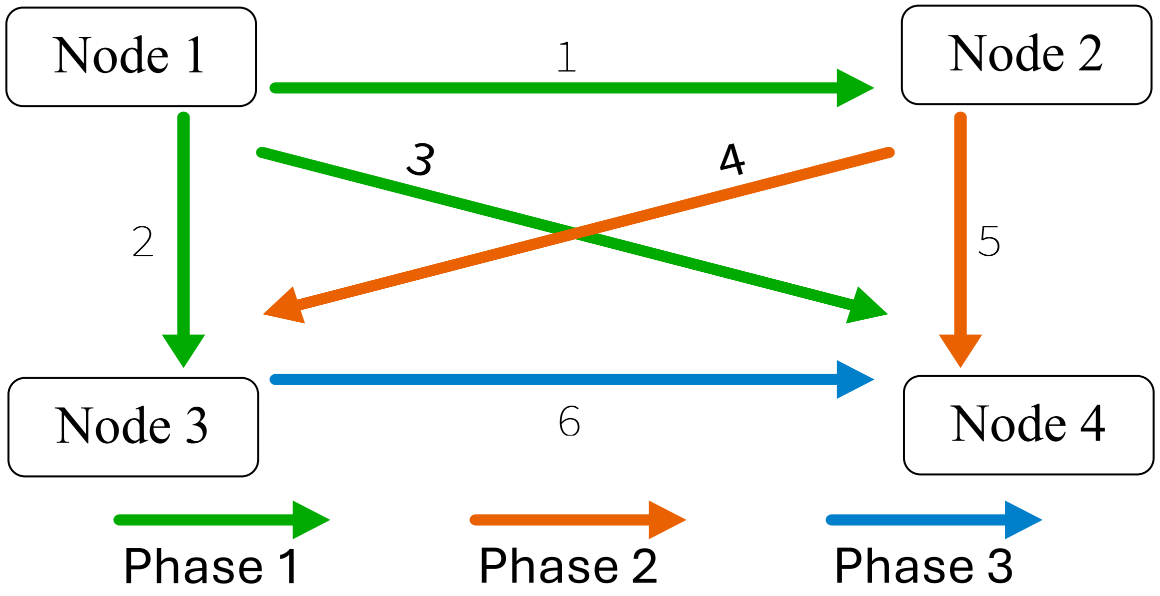
Timing Synchronization

- Common reference signal (Rb) is shared between distributed units
  - 10 MHz reference → Synchronizes the internal clocks of each USRP
  - 1PPS (Pulse Per Second) → Aligns transmit and receive timing



Extension to Multilink MIMO

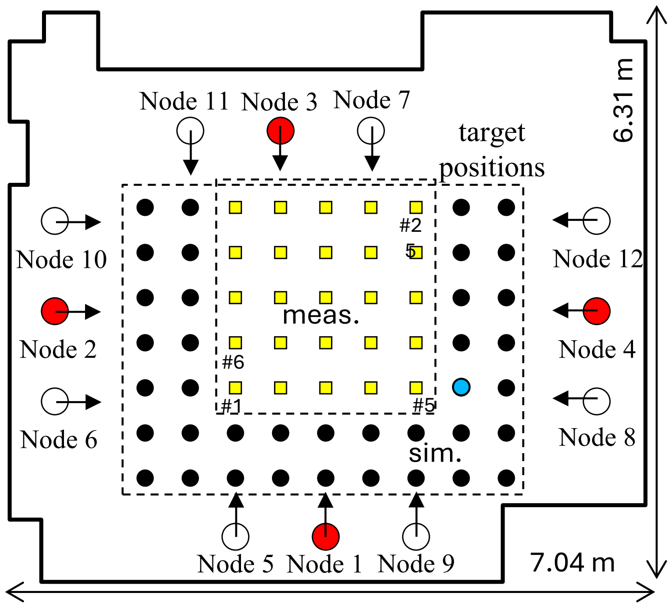
- Measurement sequence for 6 links is divided into 3 phases under the assumption of channel reciprocity

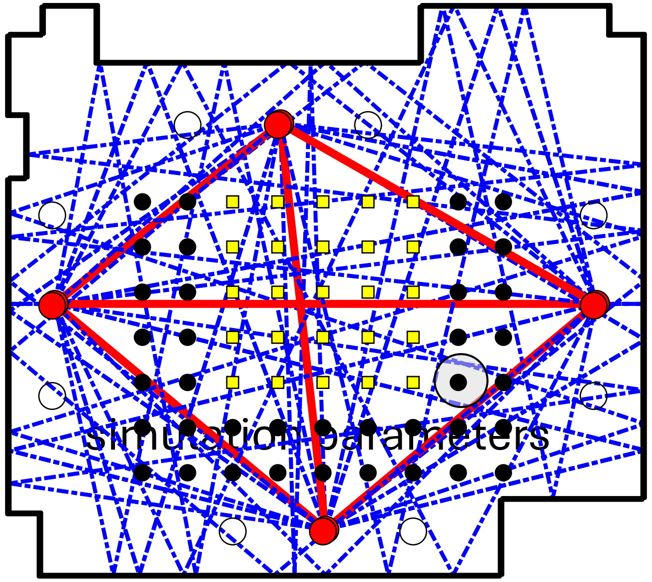


- Total measurement duration for all links: approx. 4 seconds

Experimental Evaluation

- Node and target placement / simulation parameters
  - Anchor nodes are linear array antenna
  - Target is a radio wave absorber with a radius of 0.3m

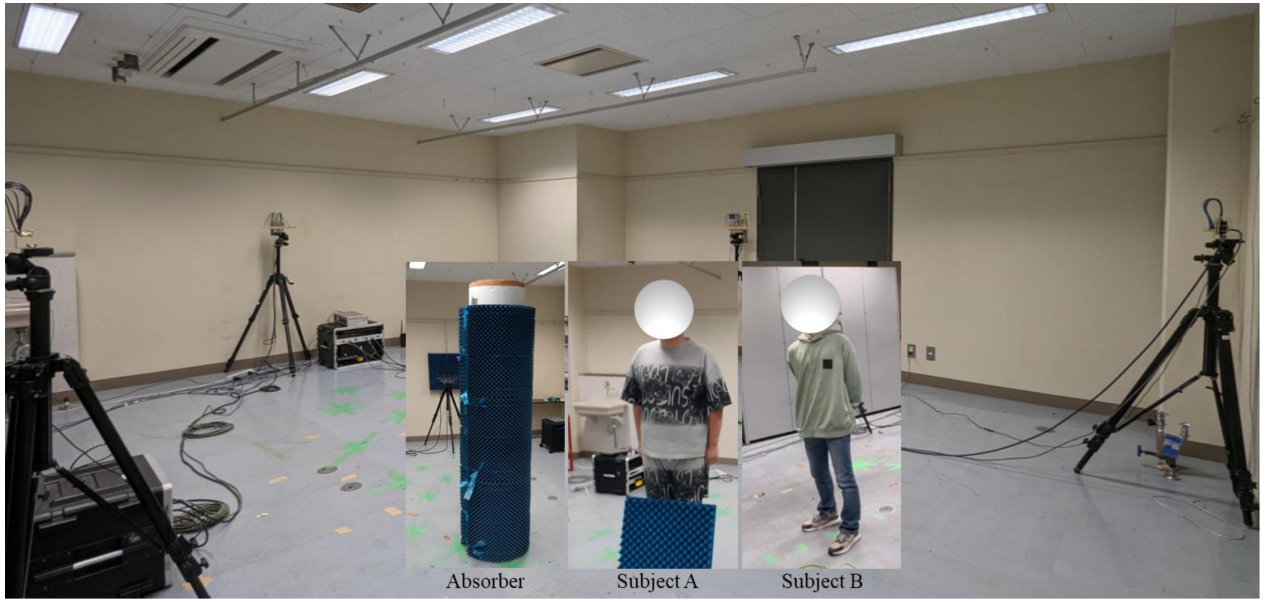


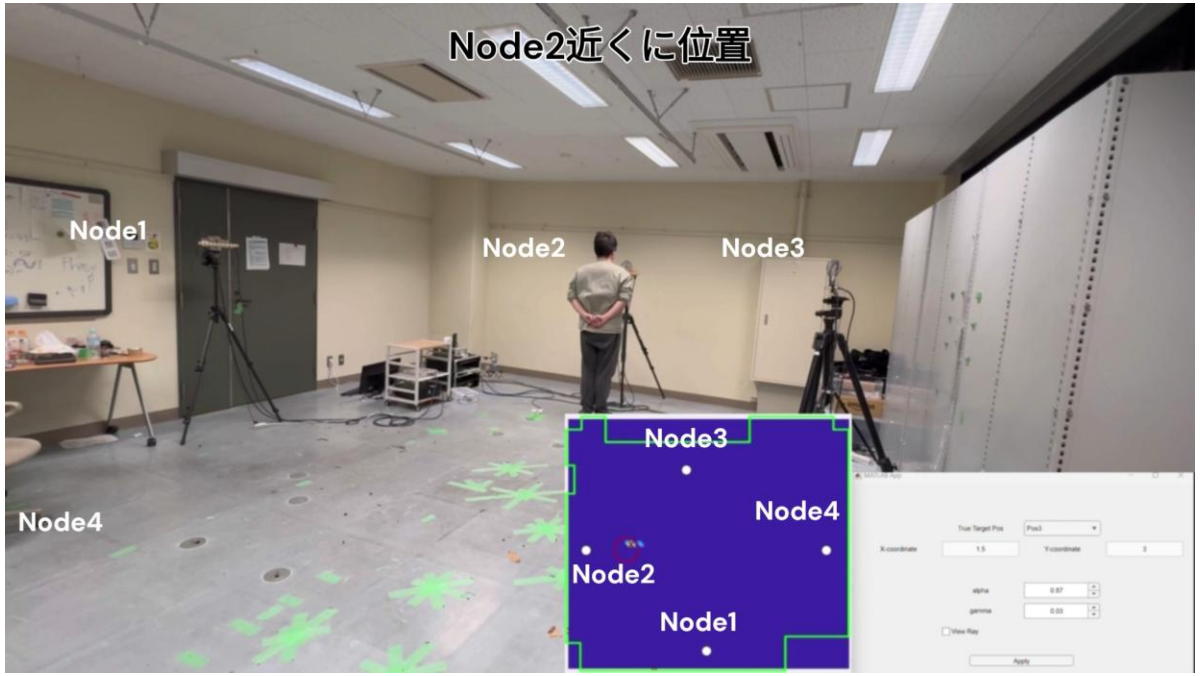


Number of antenna elements K	8
Antenna elements spacing d	half-wavelength
RTI voxel size	0.1 m
Signal Bandwidth	100 MHz
Number of delay time beam N	128
RTI oval parameter γ	0.05 m
Regularization parameter λ	Determined by 5-division cross-validation
Regularization parameter α	0.75
DBSCAN ϵ	0.3 m
DBSCAN minPts	3

Measurement Campaign

- 4 nodes; 6 links

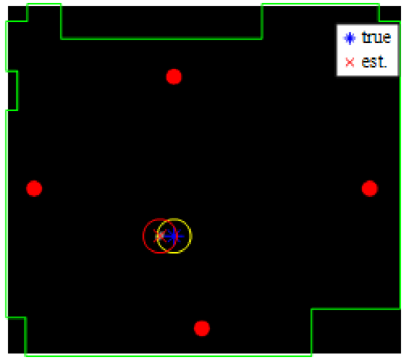
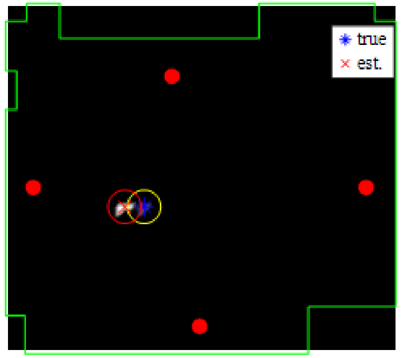
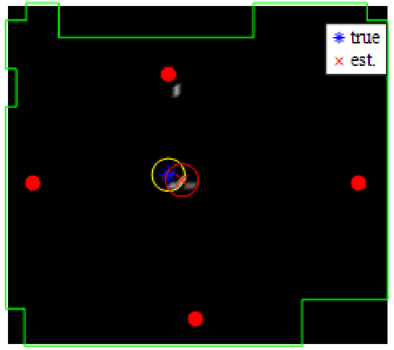
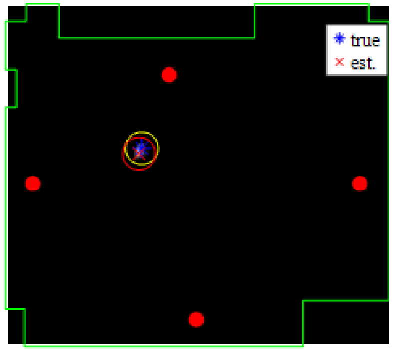
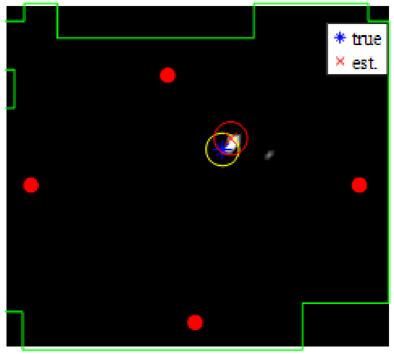
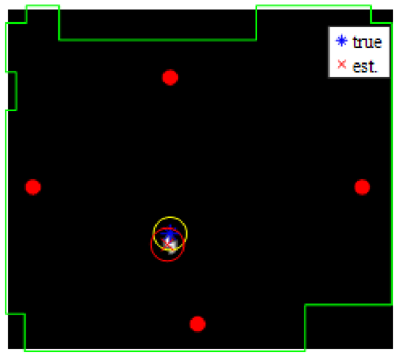
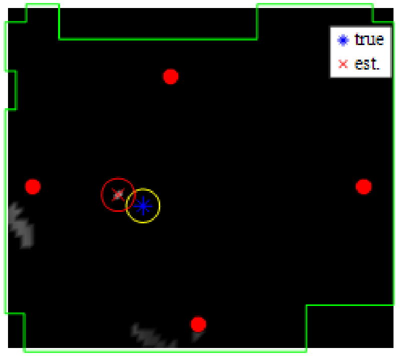
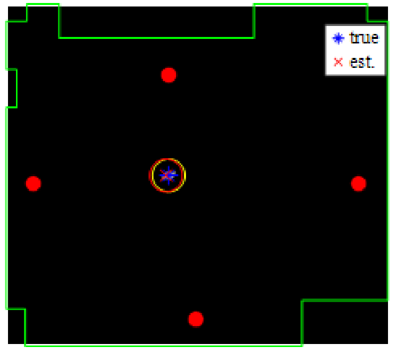
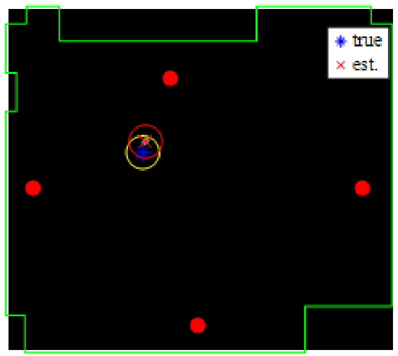
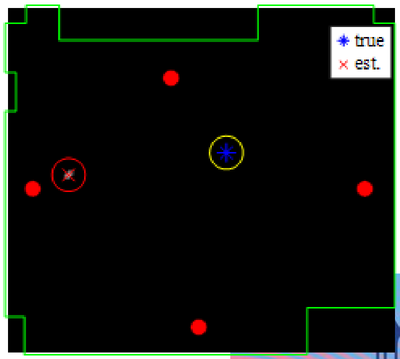




Localization Results

- Comparison

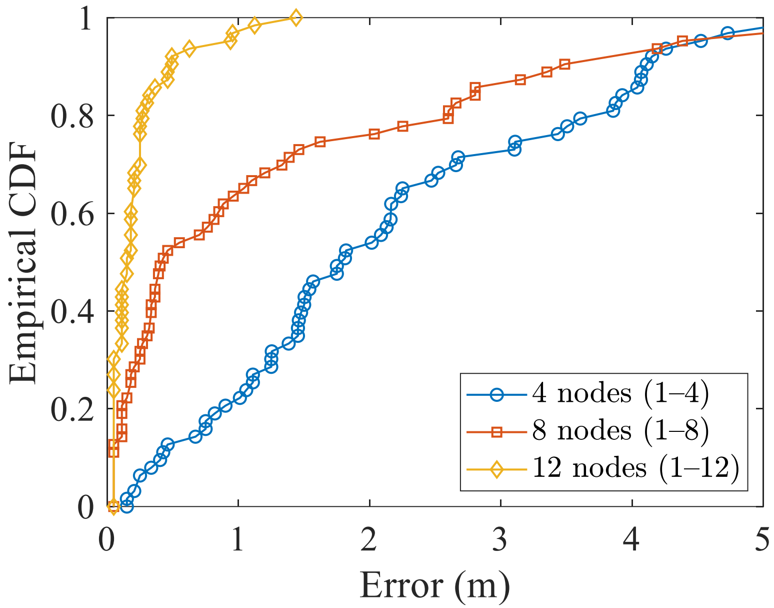
✱ true
× est.

	Pos. #2	Pos. #6	Pos. #12	Pos. #16	Pos. #19
Simulation					
Measurement					

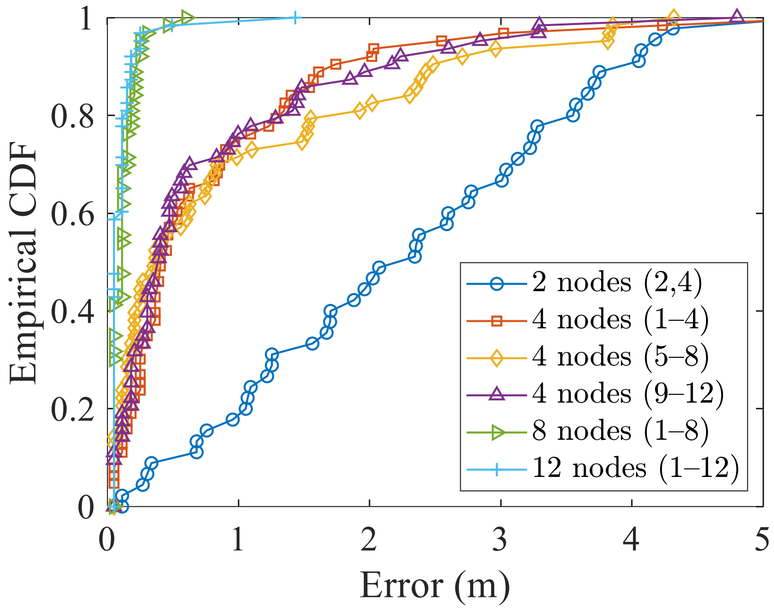
Estimation Accuracy

- Simulation

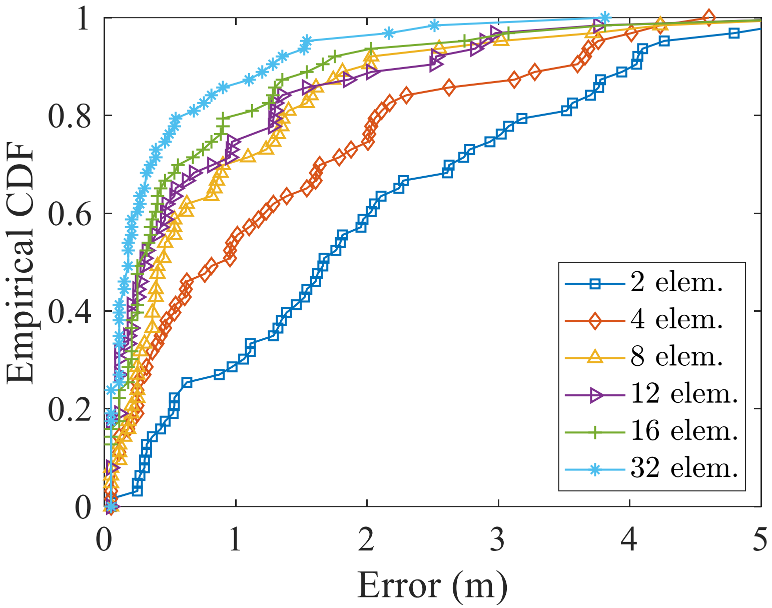
(a) Number of nodes (single antenna per node)



(b) Number of nodes (eight elements per node)



(c) Size of antenna array (four nodes)



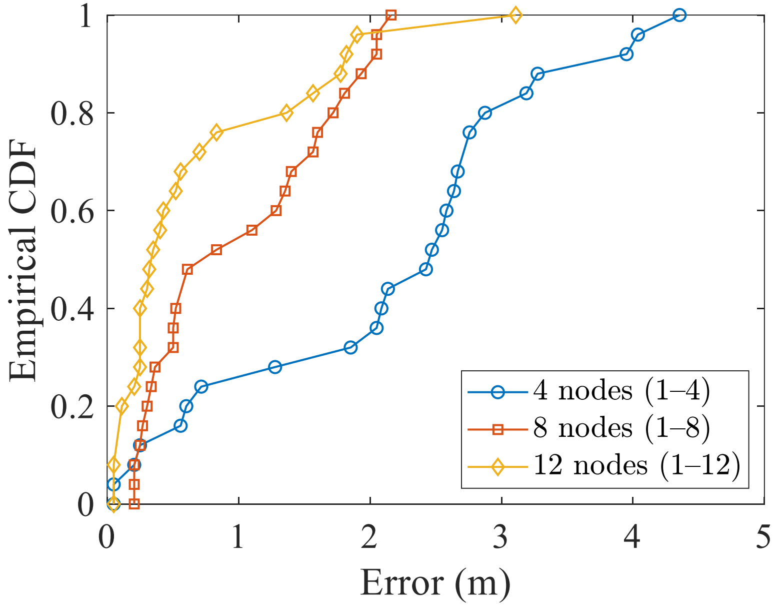
RSS-RTI

Multipath- RTI

Estimation Accuracy (2)

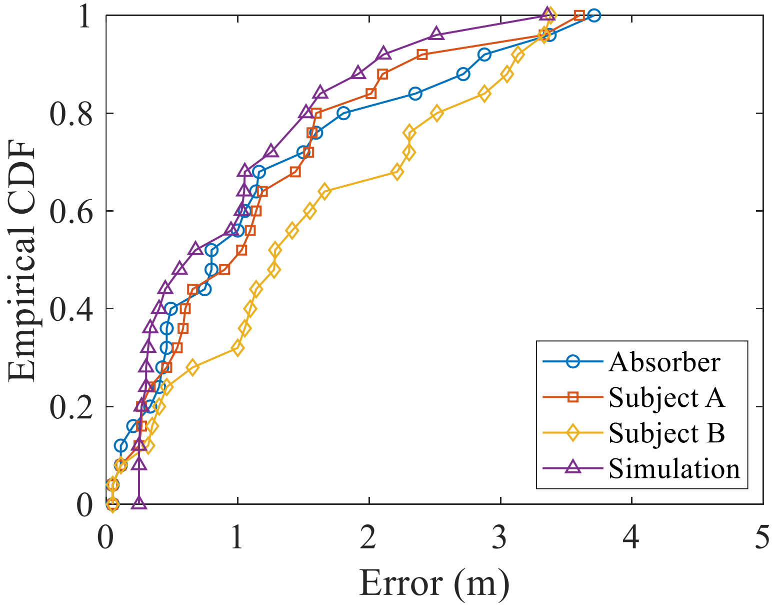
- Measurement

(a) Number of nodes (signle antenna per node); the subject is absorber.



RSS-RTI

(b) Different targets (four nodes with eight antennas per node).



Multipath- RTI

Summary

- Proposed Method: DFL via Multipath-RTI
  - Implemented on a sub-6 GHz SDR platform
  - Verified through switched-antenna MIMO channel sounding system
- Evaluation Results
  - Achieved sub-meter localization accuracy
  - Performance improves with increasing number of nodes / MPCs
  - Body-dependent shadowing affects the results
- Future Outlook
  - Requires high-precision synchronization and propagation path estimation
  - Well aligned with 6G-native DAN / cell-free ISAC systems

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WAVES OF INNOVATION

Thank you!

Workshop WM03 – Monday 09/22
Minseok Kim
Niigata University, Japan
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RadioLab Niigata Univ.

NIIGATA UNIVERSITY

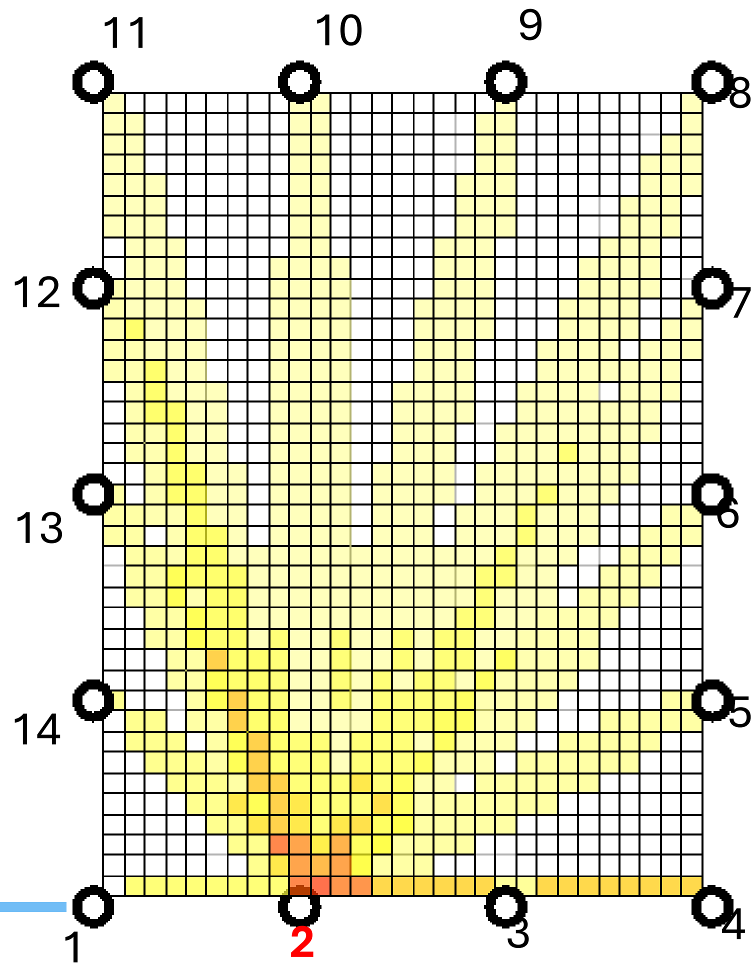
EuMA
EUROPEAN MICROWAVE ASSOCIATION

Weighted Voxels

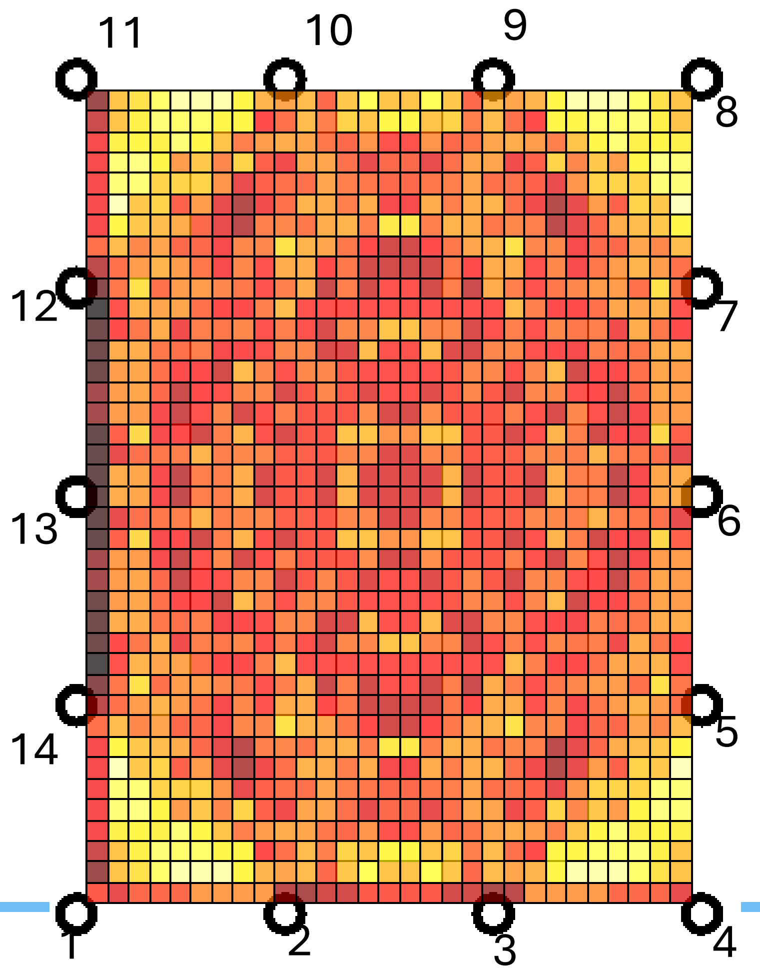
$$w_{lm} = \begin{cases} 1/\sqrt{d_l}, & d_{l,d}^m + d_{l,s}^m < d_l + \gamma \\ 0, & \text{otherwise} \end{cases}$$

- RSS-RTI with 14 anchors

All paths that anchor #2 is involved



All paths generated by all anchors



Weighted Voxels

- Multi-path RTI 4 Anchors
  - A path with double-bounce reflection (anchor #1- anchor #3)
  - All paths btw anchor #1 and anchor #3
  - All paths