D3PicoNet: Enabling Fast And Accurate Indoor D-Band Millimeter-Wave Picocell Deployment

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College of Engineering and Computing

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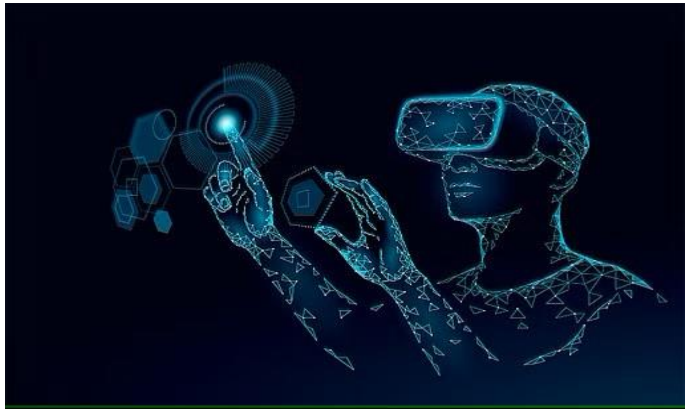
CNS-1910853
MRI-2018966

Research Motivation

Emerging Applications Stress Wireless Networks

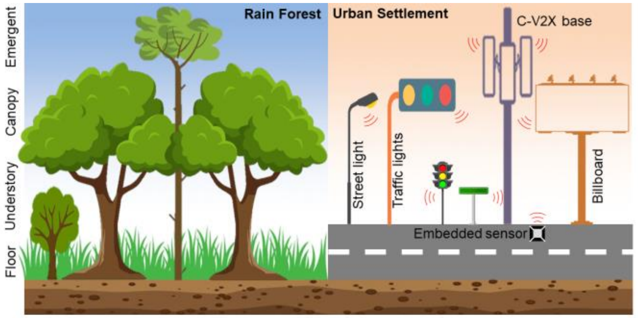


Virtual reality

V2V connectivity

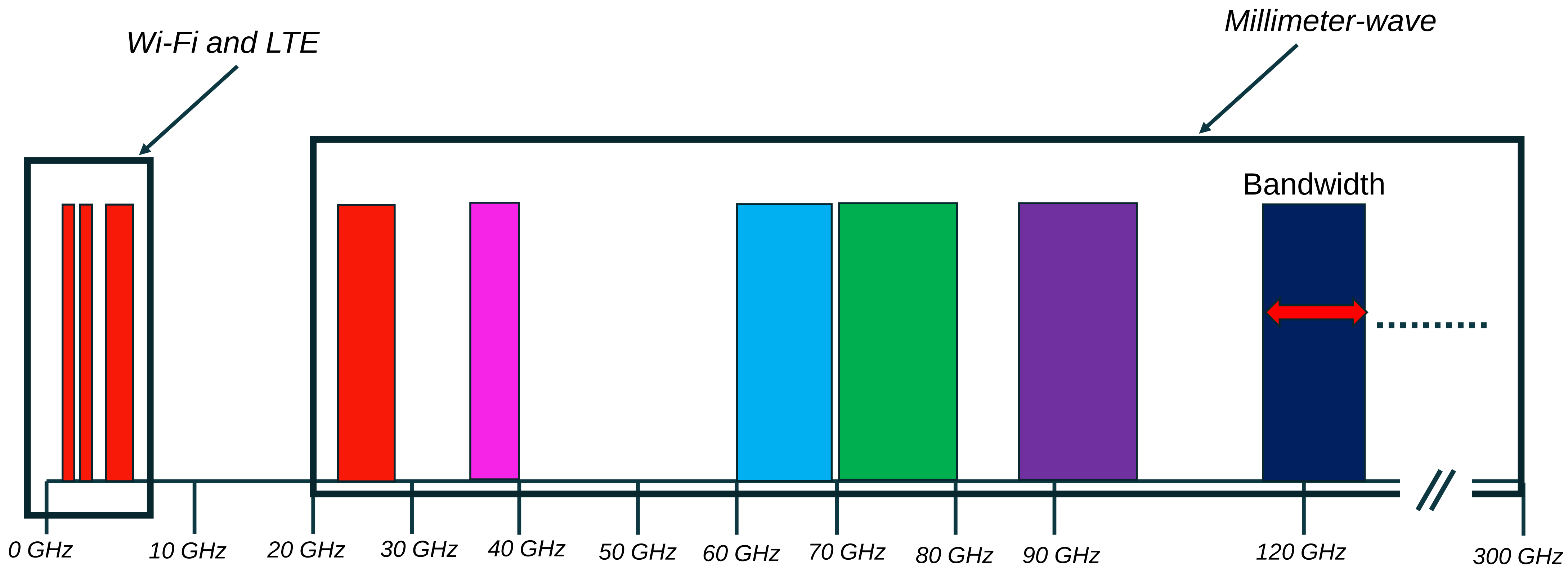
Data Rate: 10s of Gbps
Latency: 1-10 ms

Smart manufacturing



Smart city planning

Millimeter-Wave and D-Band



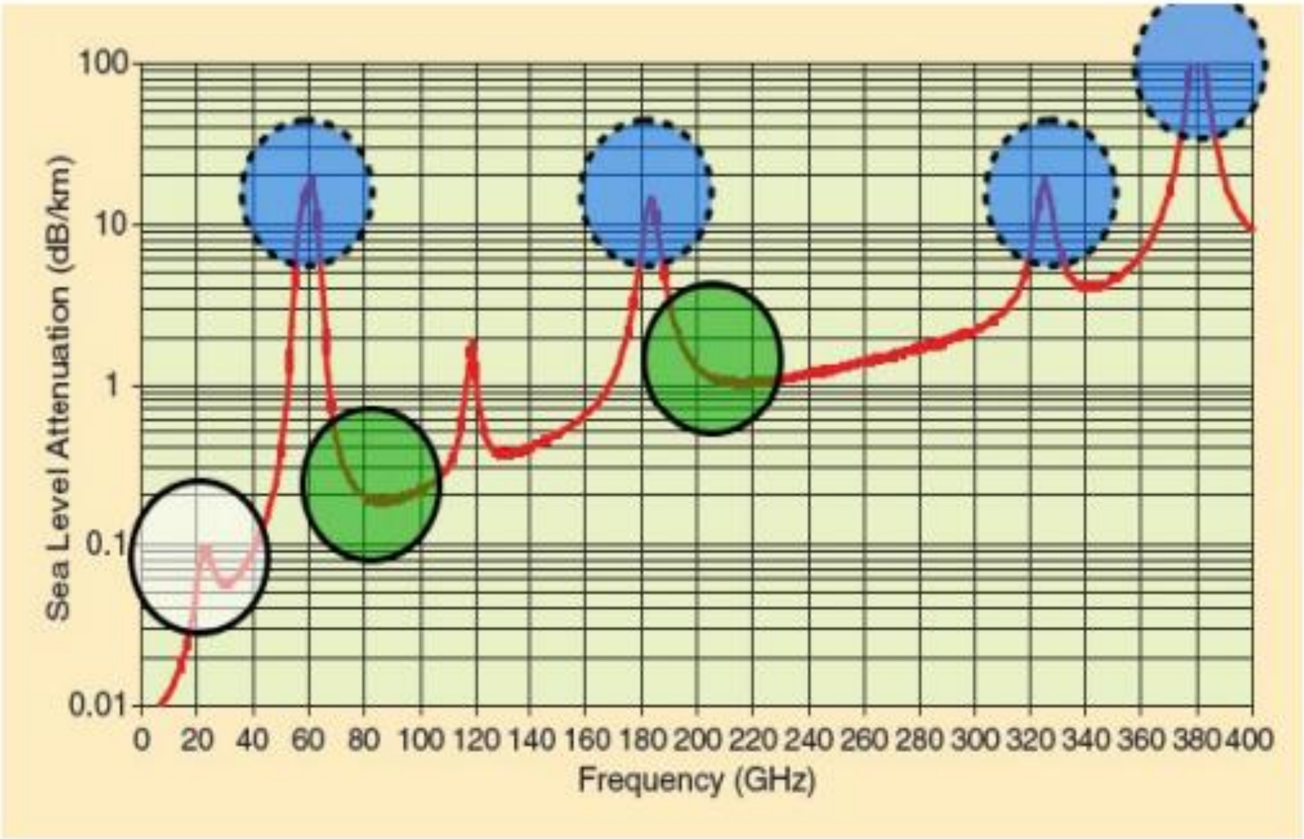
D-Band: 110 GHz to 170 GHz

Millimeter-wave (30 GHz to 300 GHz)

Wavelength: 10 mm to 1 mm

Challenges of Millimeter-Wave Networks

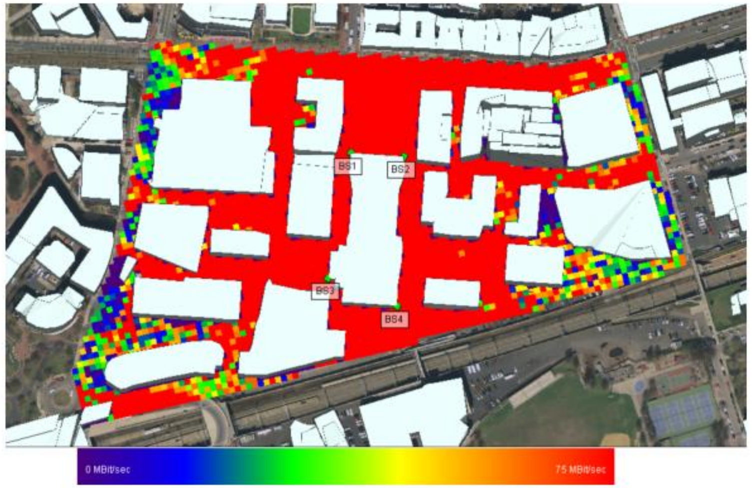
Path loss



MacCartney, et al., 2013

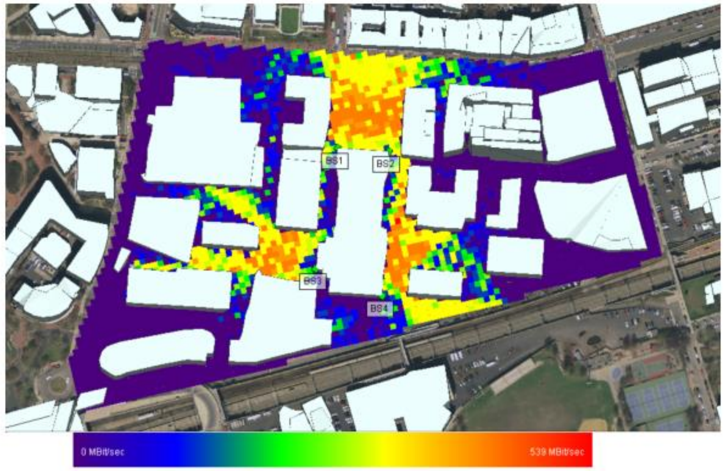
Challenges of Millimeter-Wave Networks

LTE coverage area



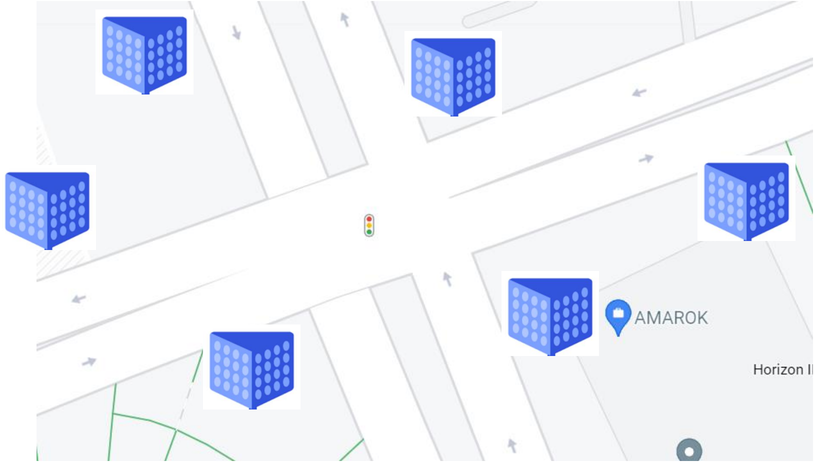
Moayyed, et al., 2021

5G-NR coverage area



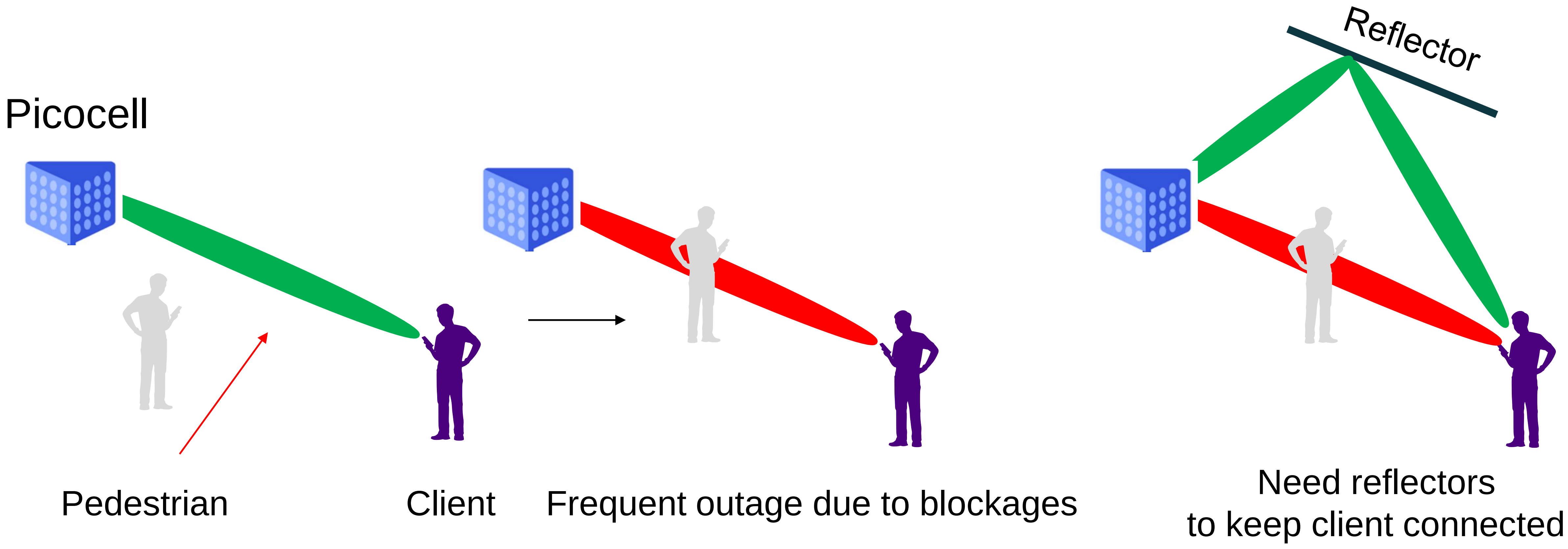
Moayyed, et al., 2021

High frequency, small coverage



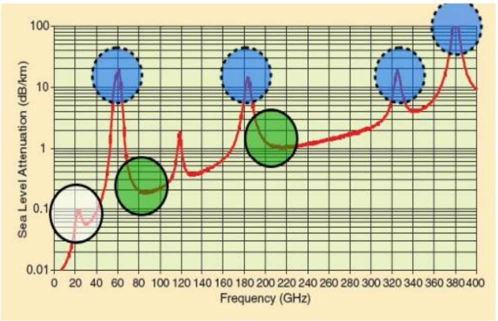
 Picocell

Challenges of Millimeter-Wave Networks



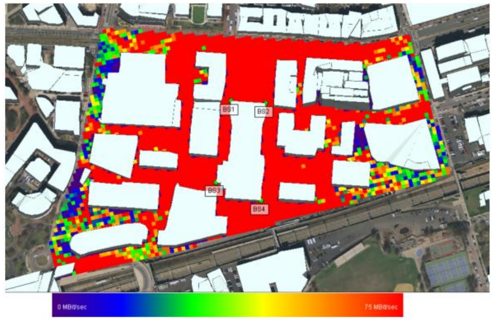
Challenges of Millimeter-Wave Networks

Air path loss



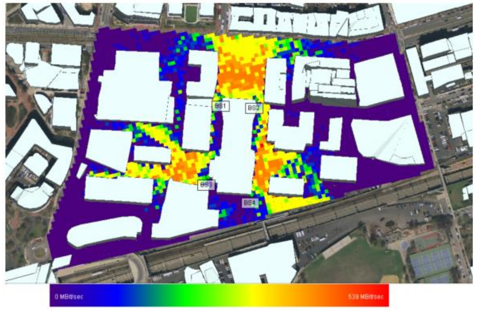
MacCartney, et al., 2013

LTE coverage area



Moayyed, et al., 2021

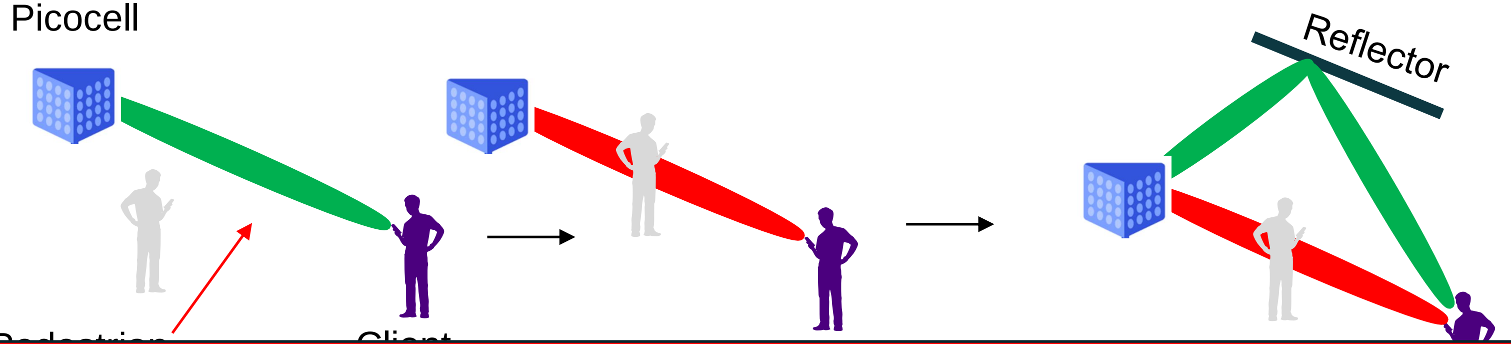
5G-NR coverage area



Moayyed, et al., 2021

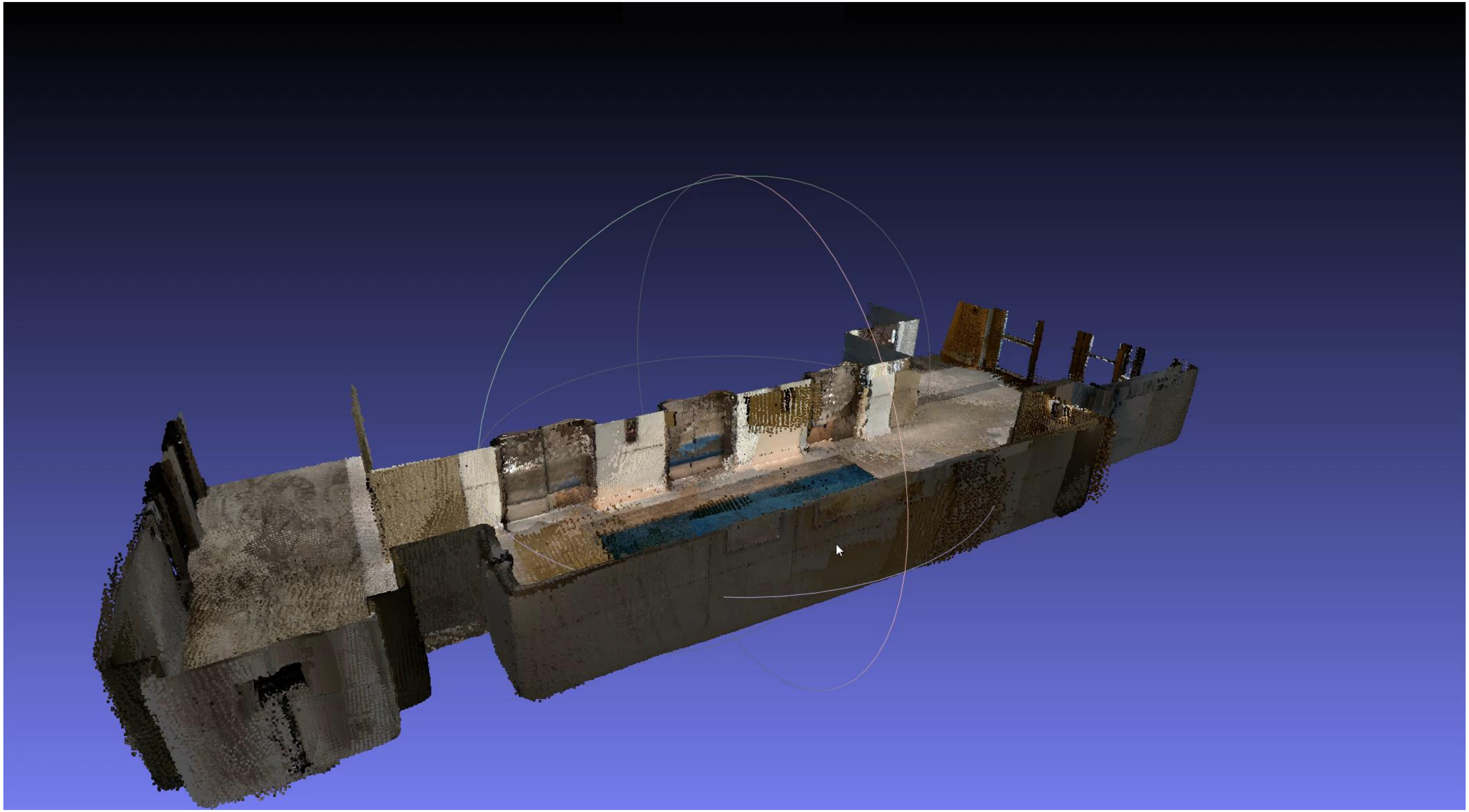
High frequency, small coverage

Picocell

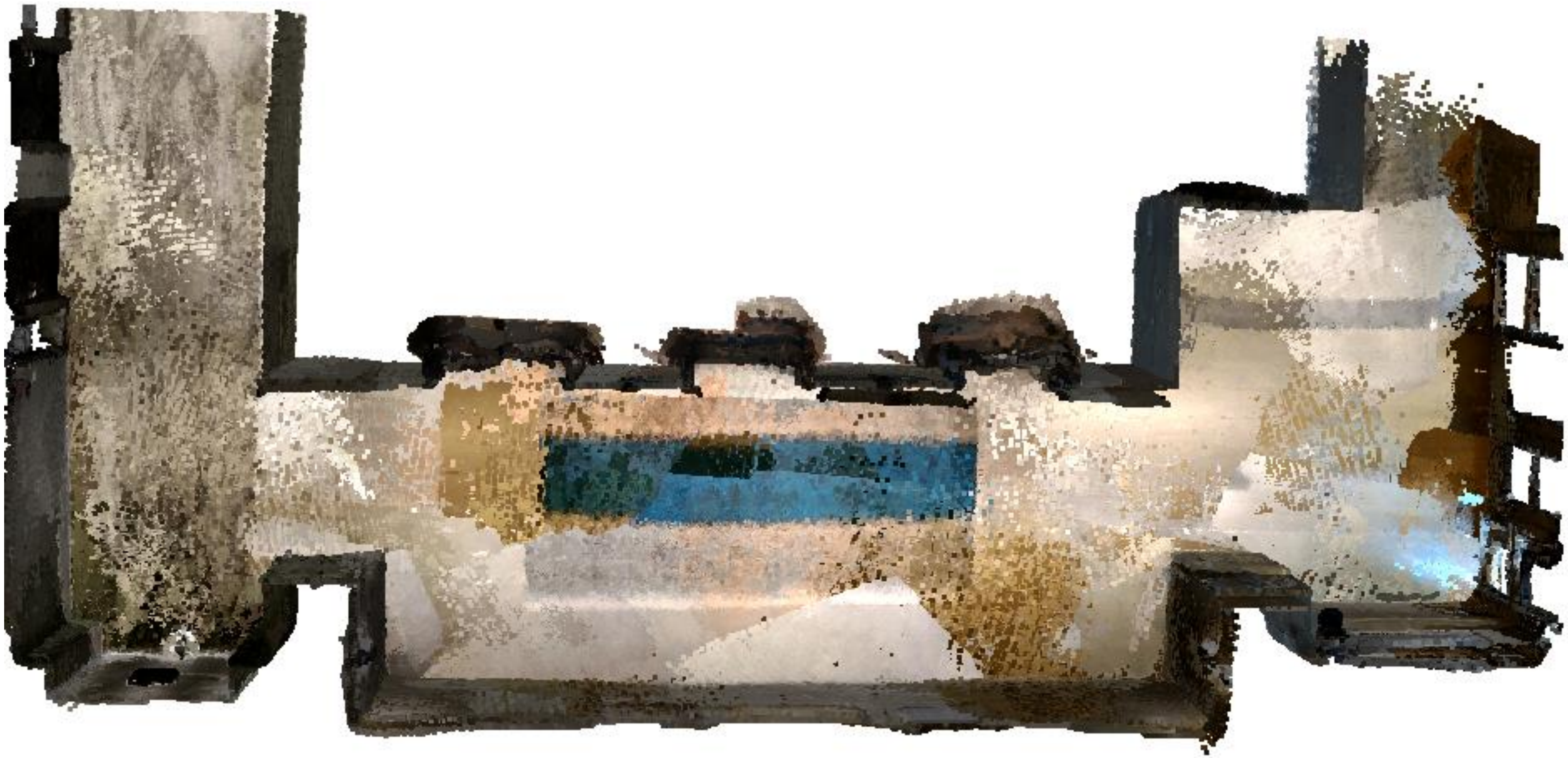


We must deploy more picocells carefully for reliable connectivity

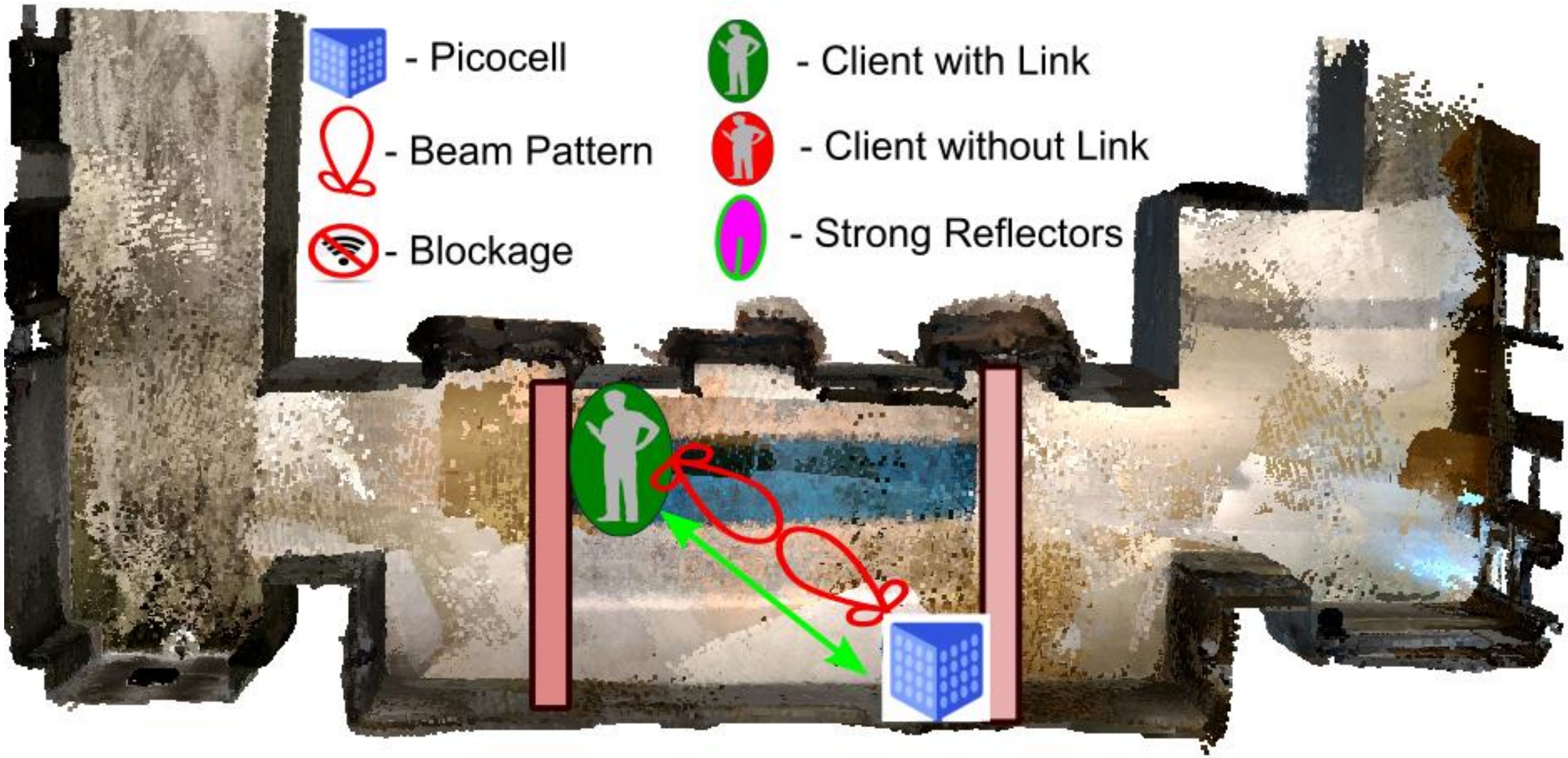
Indoor Environment



Indoor Environment

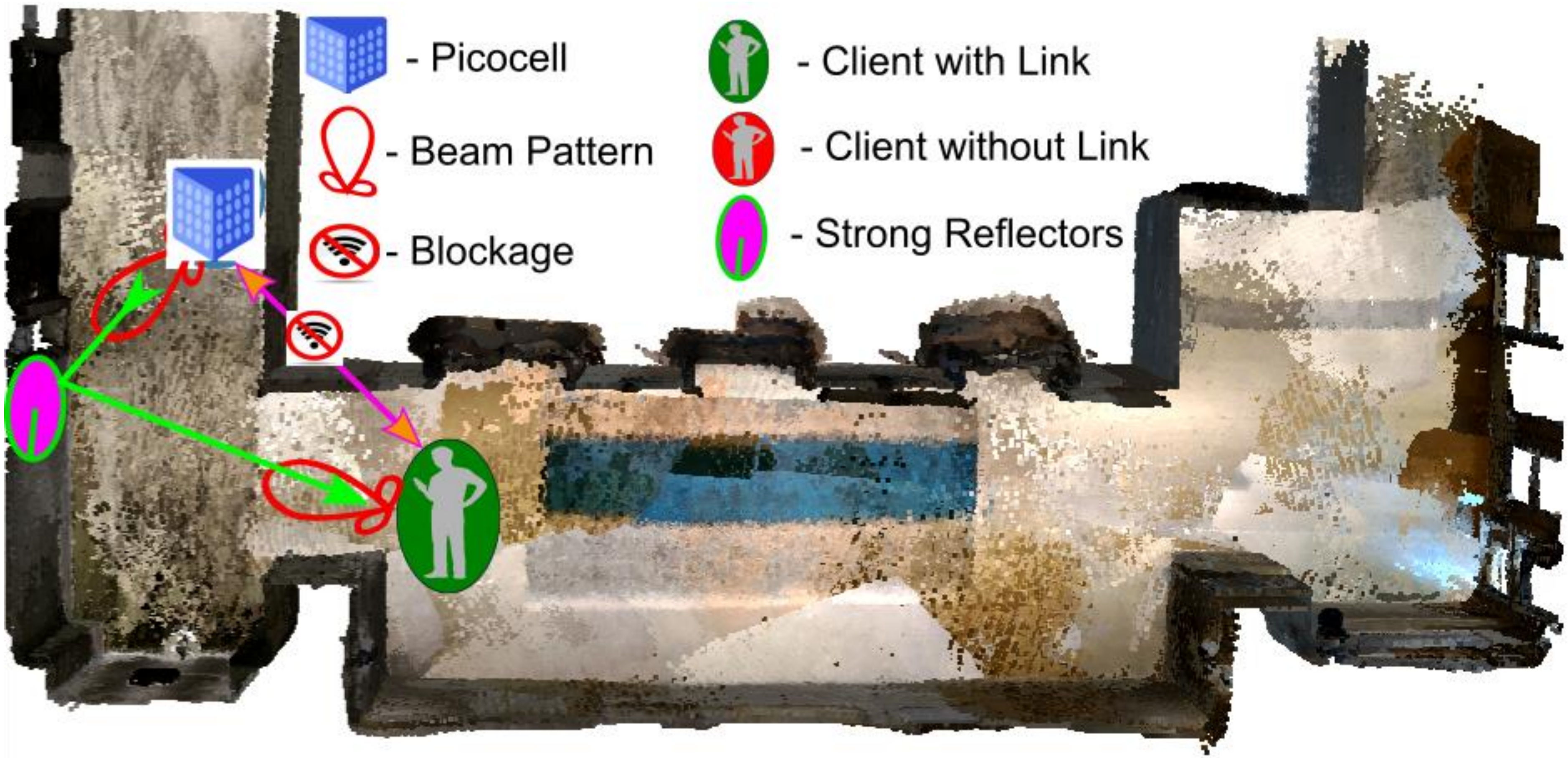


Possible Ways for Link Connectivity



Line-of-Sight (LoS) Path

Possible Ways for Link Connectivity

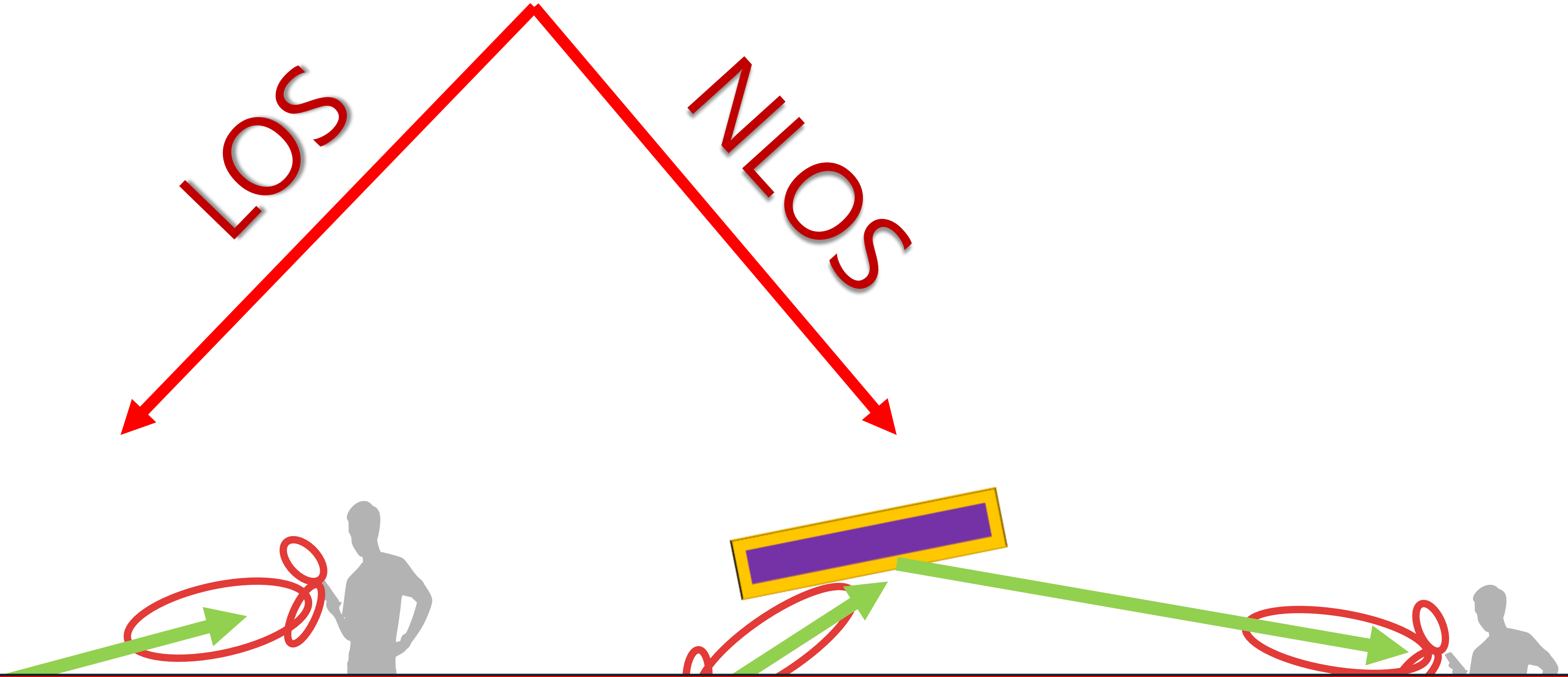


Non-Line-of-Sight (NLoS) Path

Possible Ways for Link Connectivity

It highlights the need for correct picocell deployment locations

Possible Ways for Link Connectivity



How can we deploy picocells correctly based on surrounding reflectors?

Effect of Multiple Picocell Locations

Effect of Multiple Picocell Locations

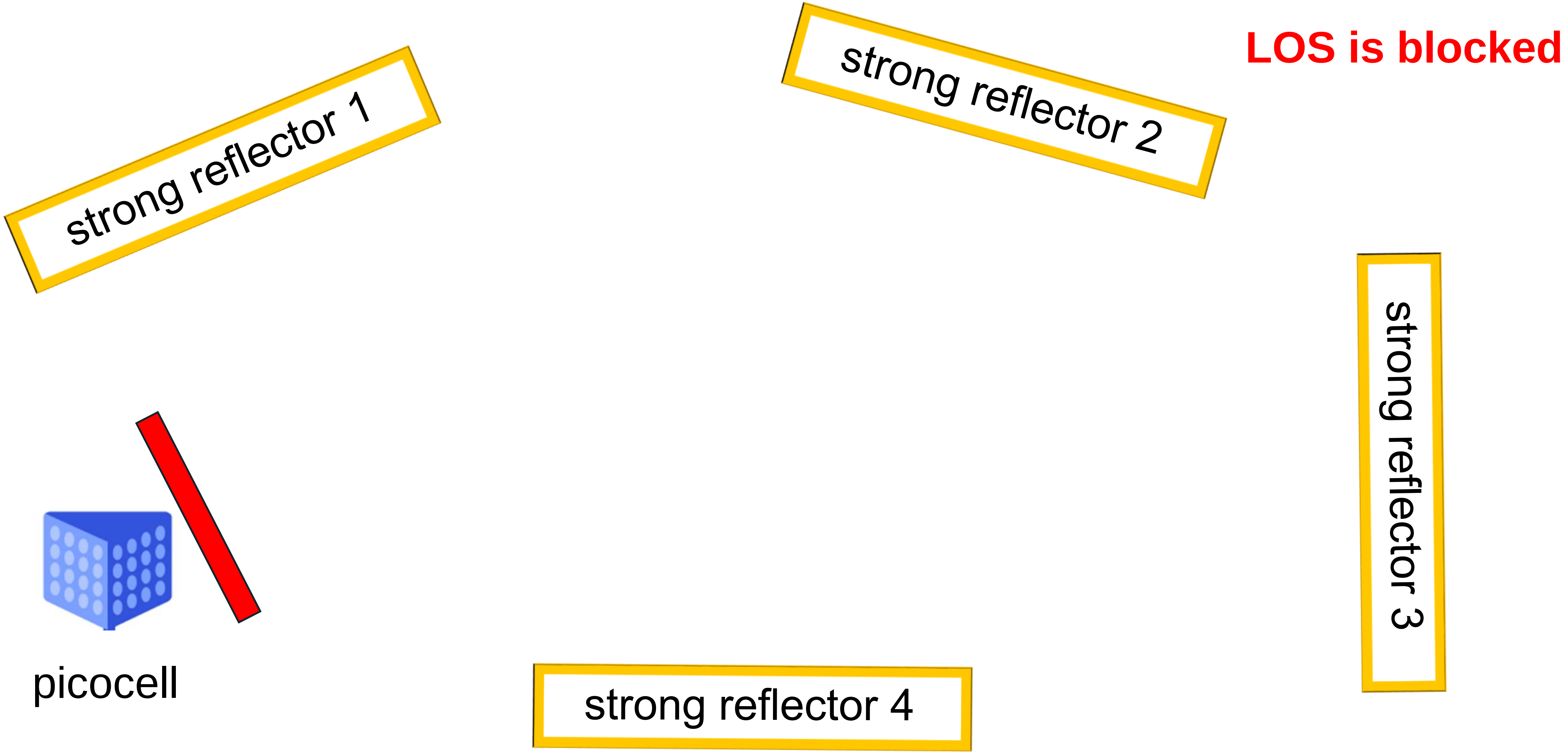
strong reflector 1

strong reflector 2

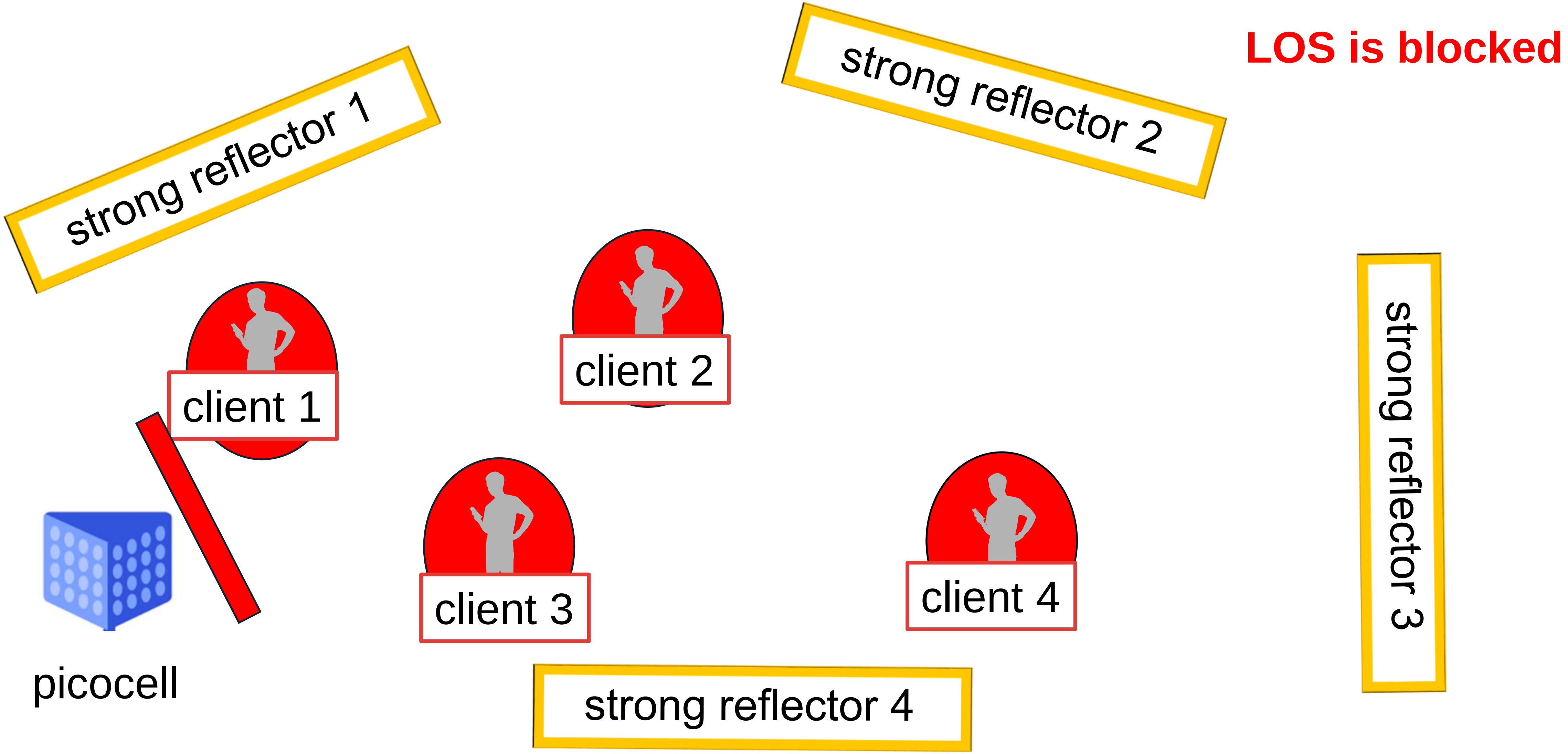
strong reflector 3

strong reflector 4

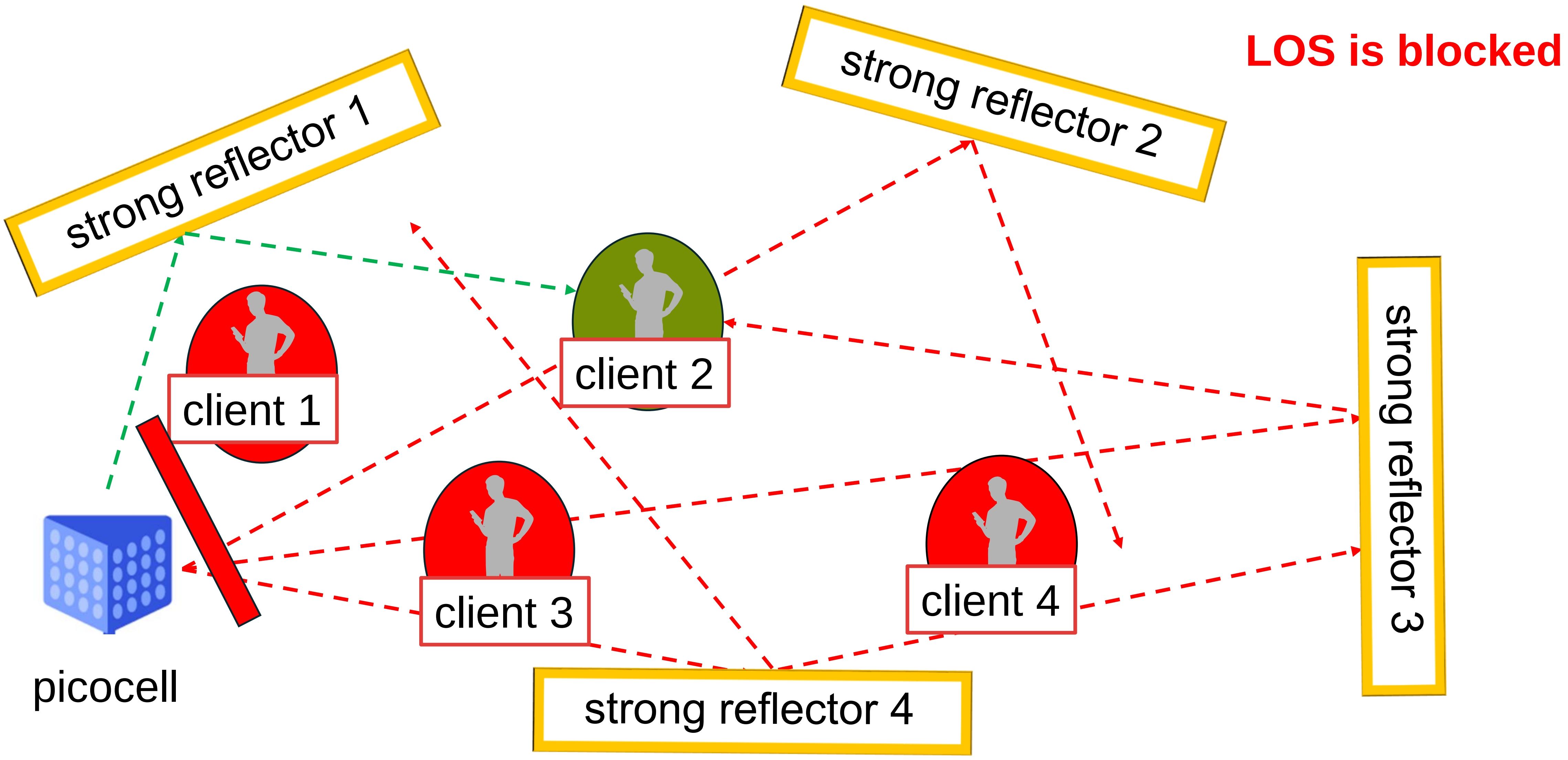
Effect of Multiple Picocell Locations



Effect of Multiple Picocell Locations



Effect of Multiple Picocell Locations



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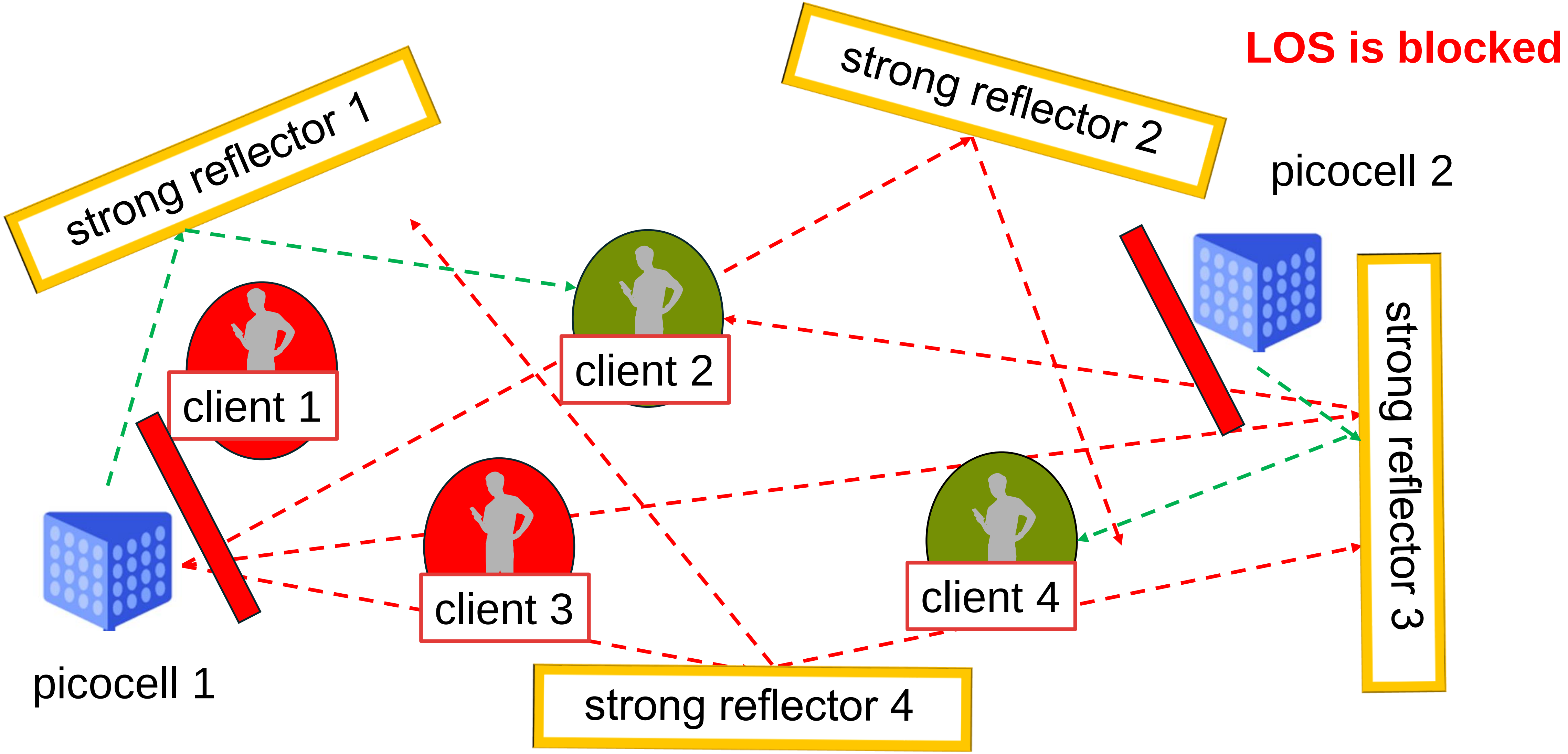

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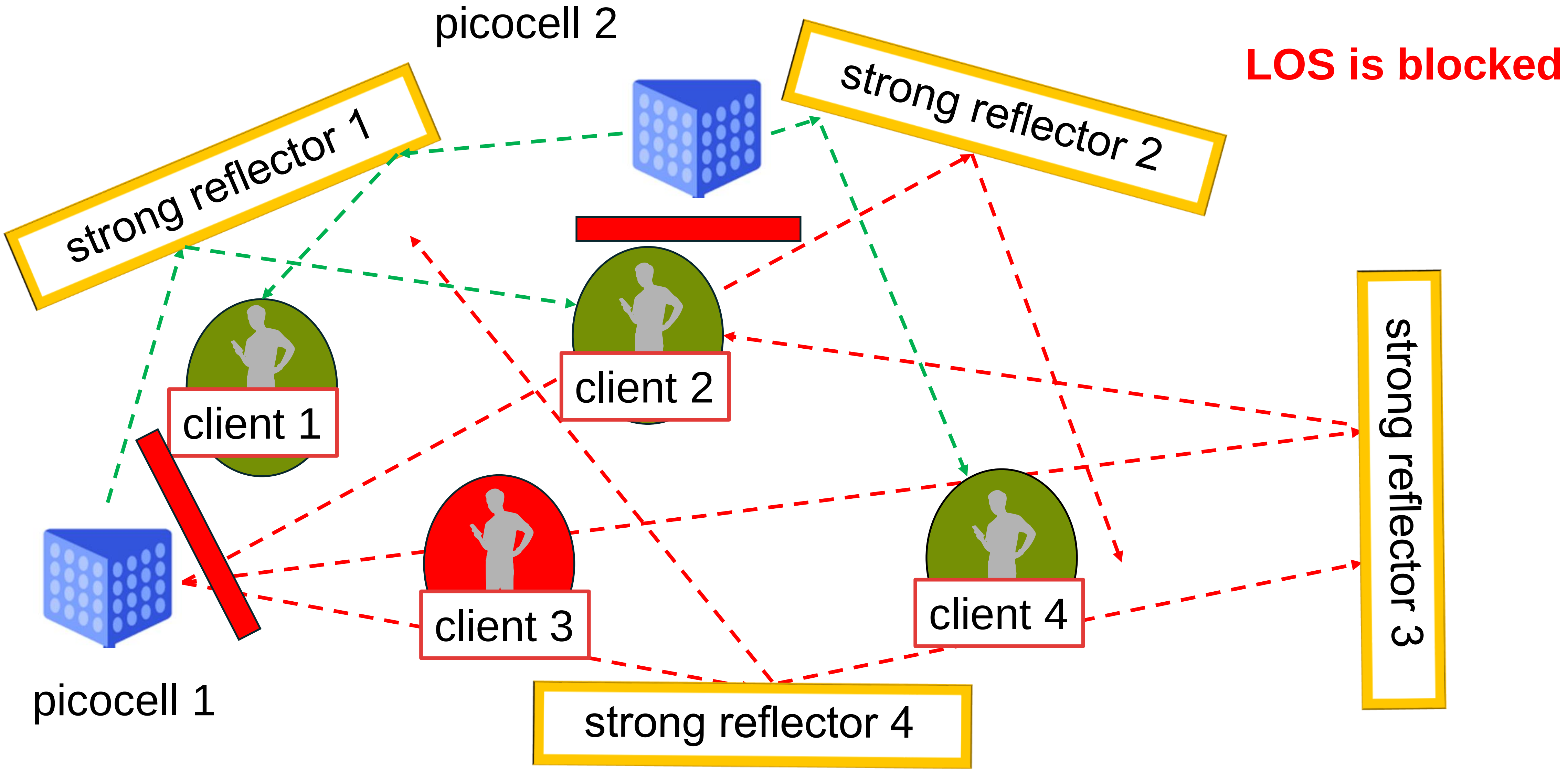
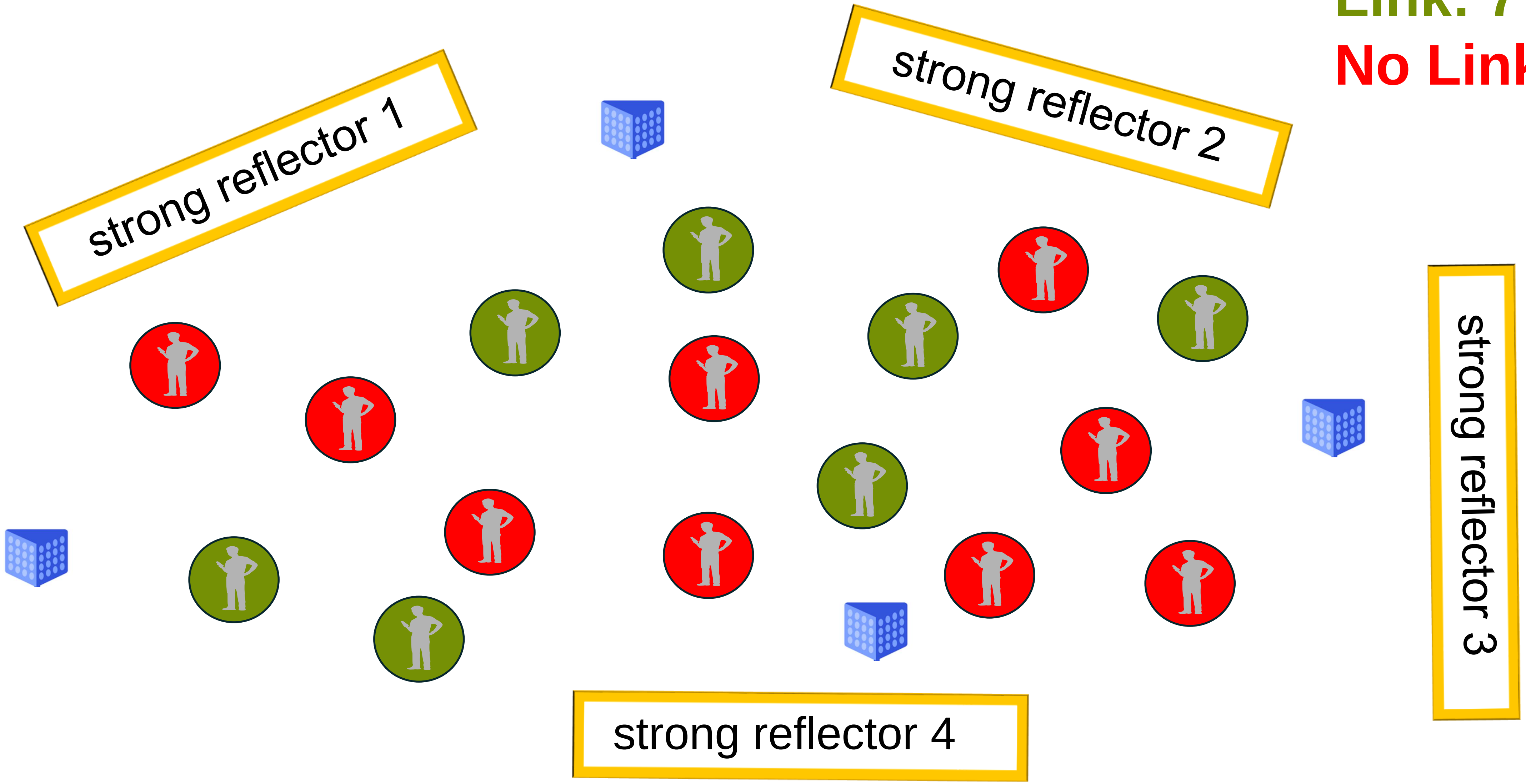
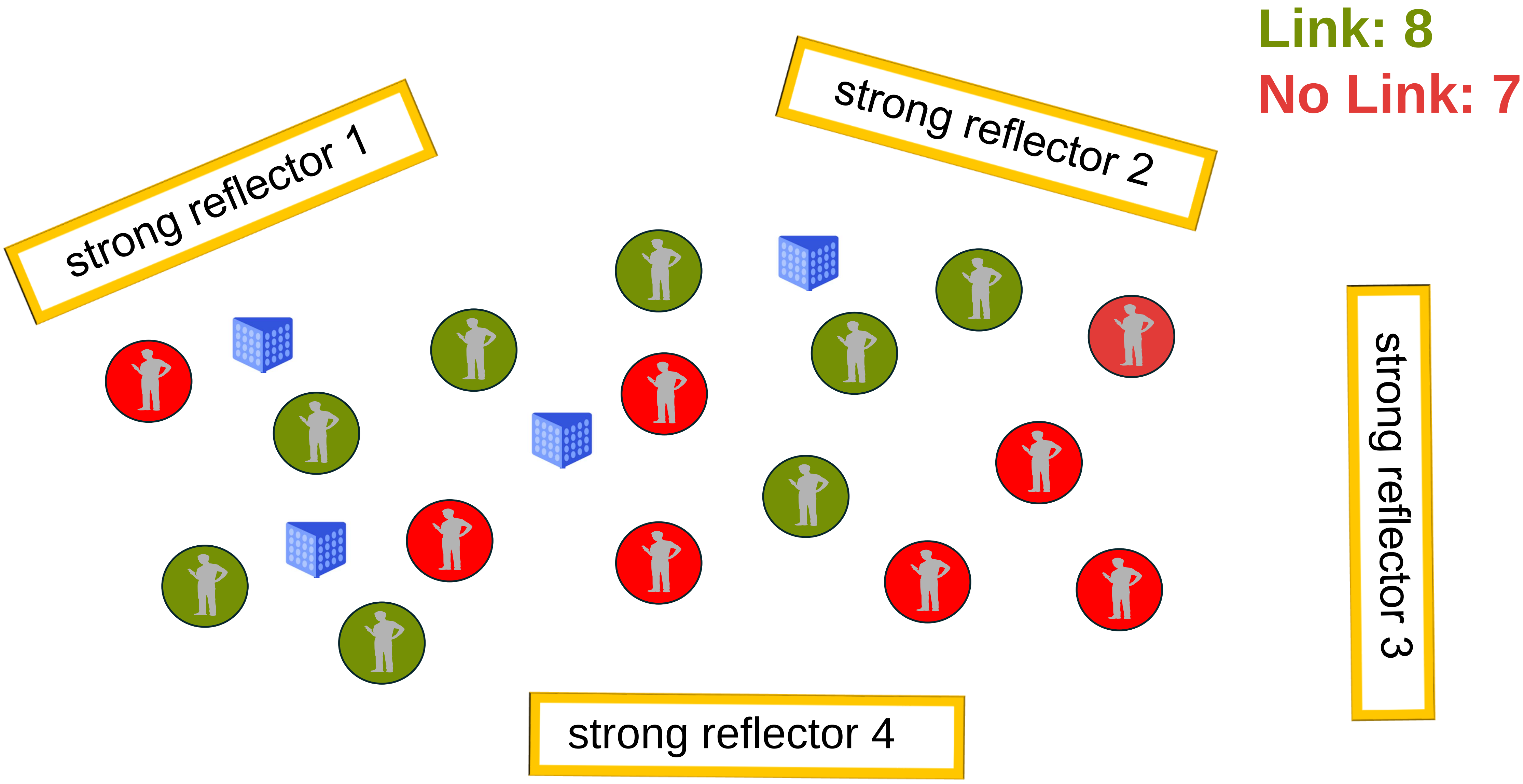


Brute-Force Search?

Link: 7
No Link: 8

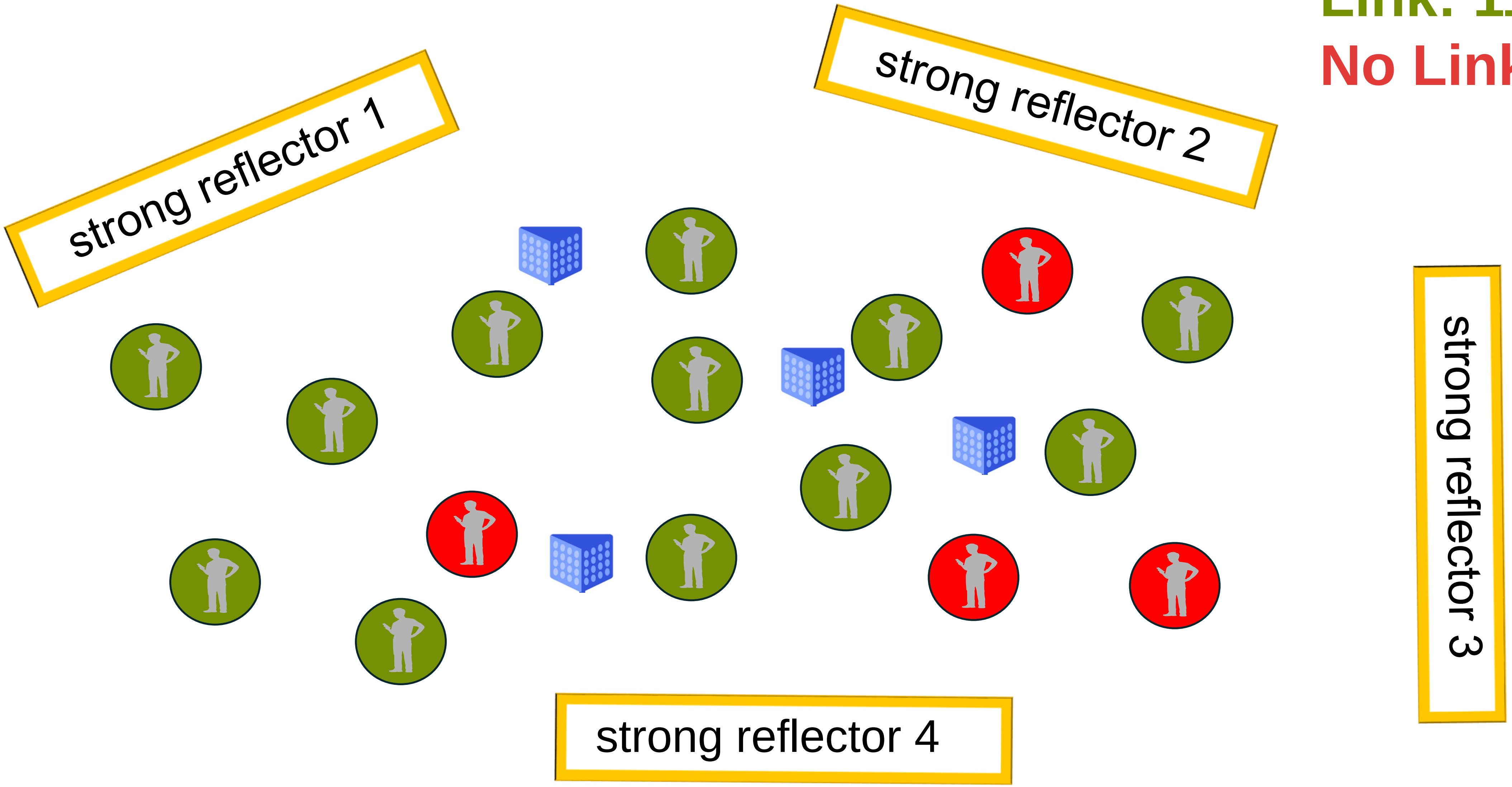


Brute-Force Search?



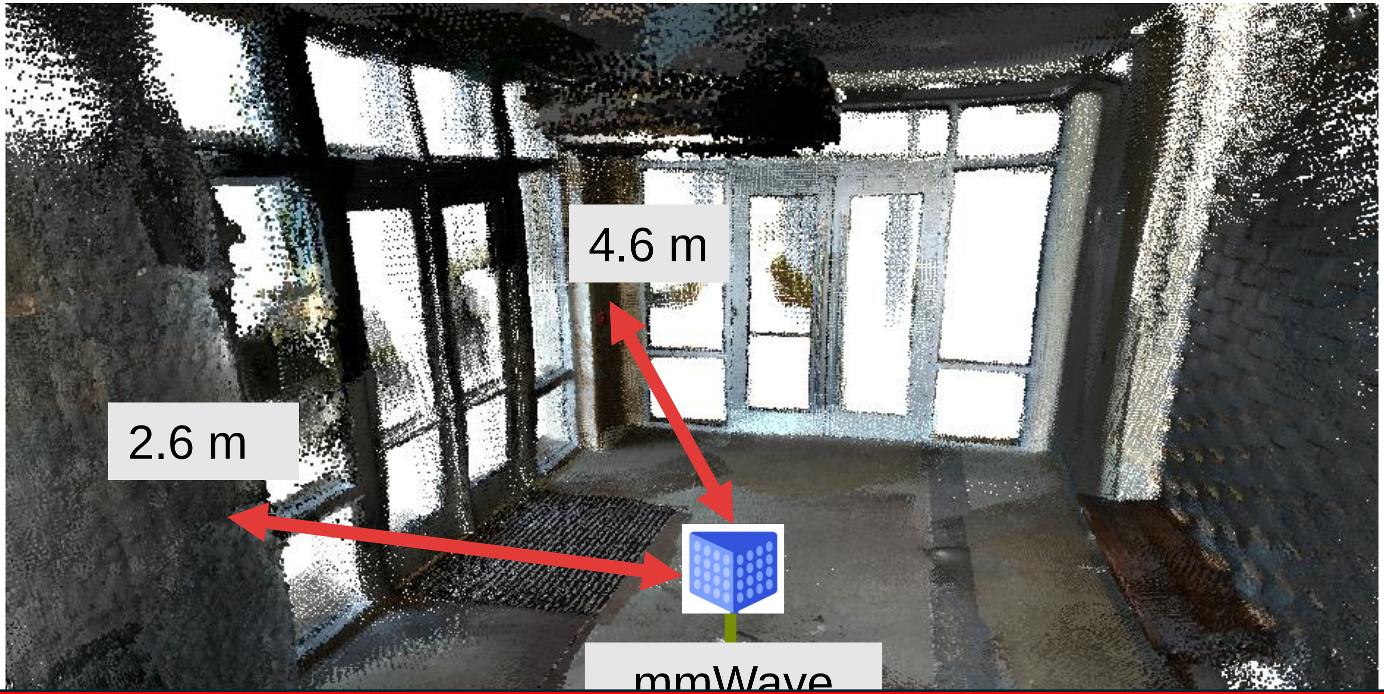
Brute-Force Search?

Link: 11
No Link: 4

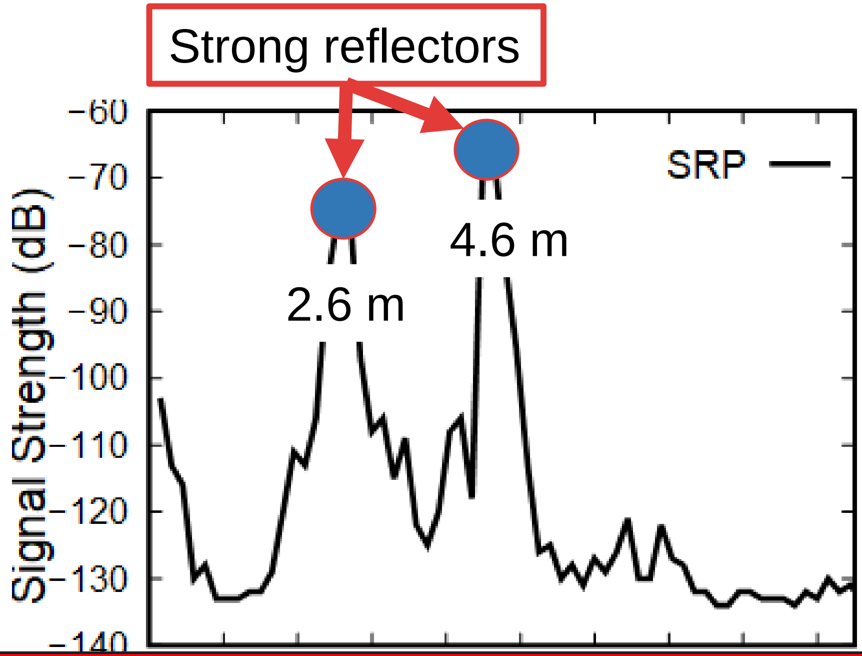


Understanding the Environment

How visual camera sees

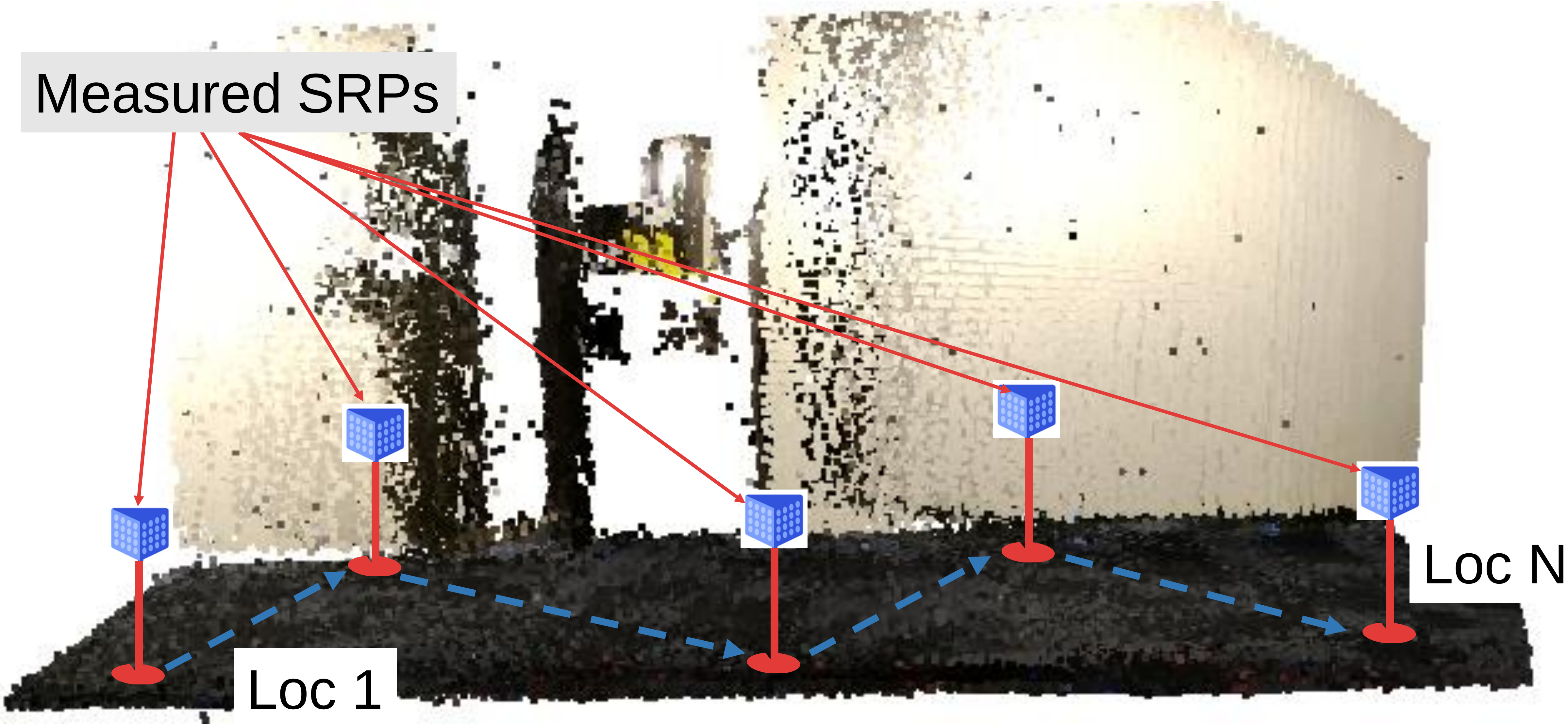


How mmWave device sees

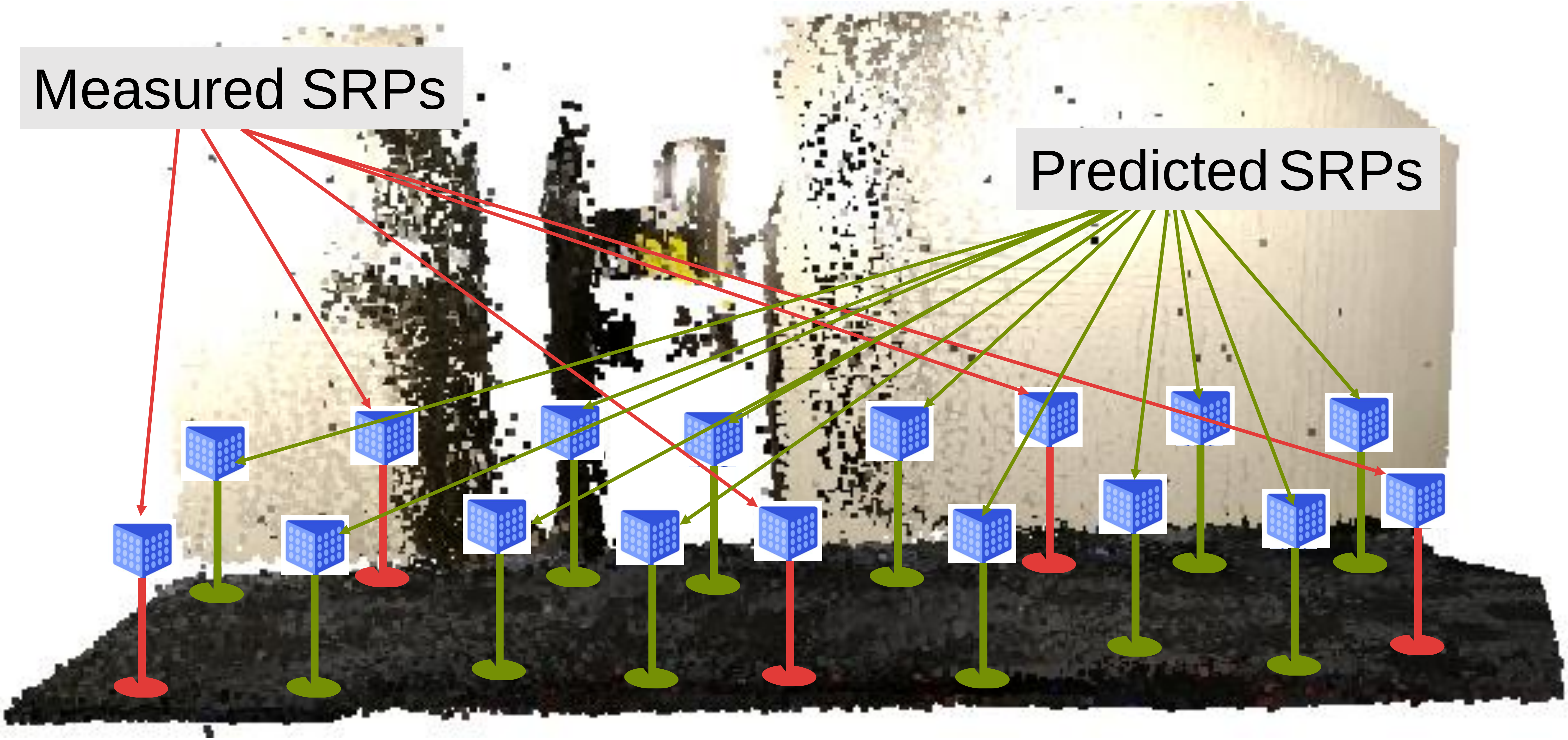


Can we use visual camera input to predict Signal Reflection Profile (SRP)?

Our Proposed Approach



Our Proposed Approach



Challenges in Predicting SRP from Visual Data

- ❑ Different Field-of-View of visual AR device and mmWave device
- ❑ Non-linearity between visual depth image and signal reflection profile
- ❑ Inaccuracy in transfer-learning to new environment

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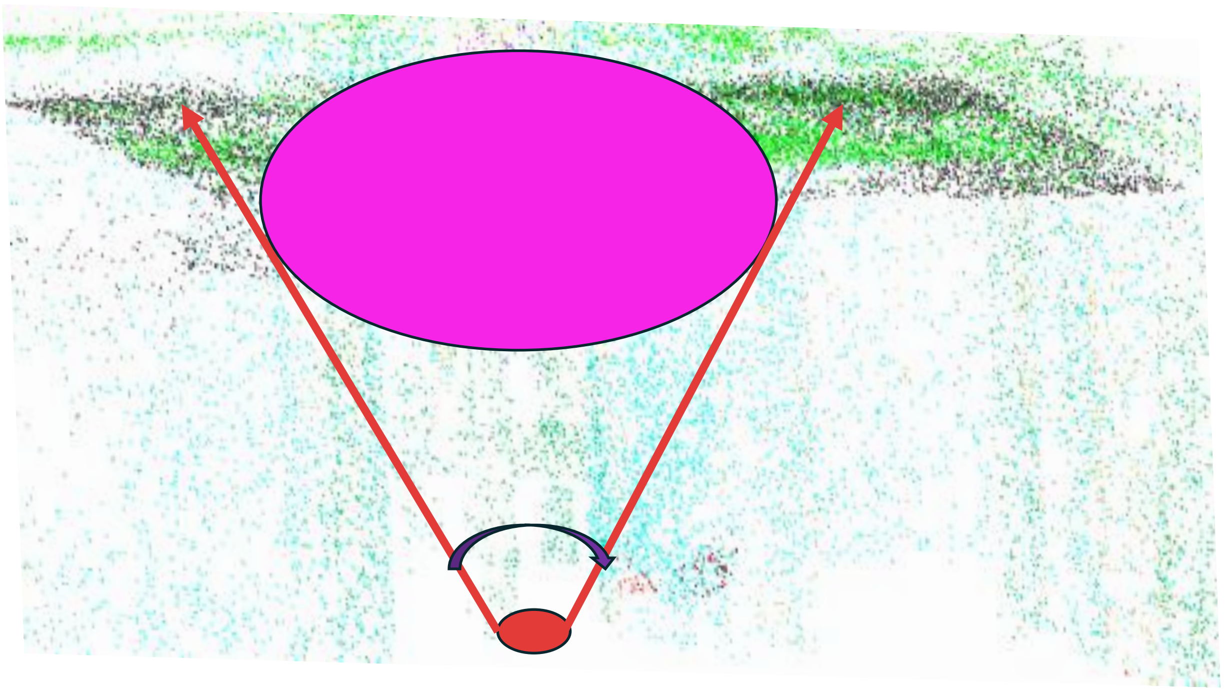

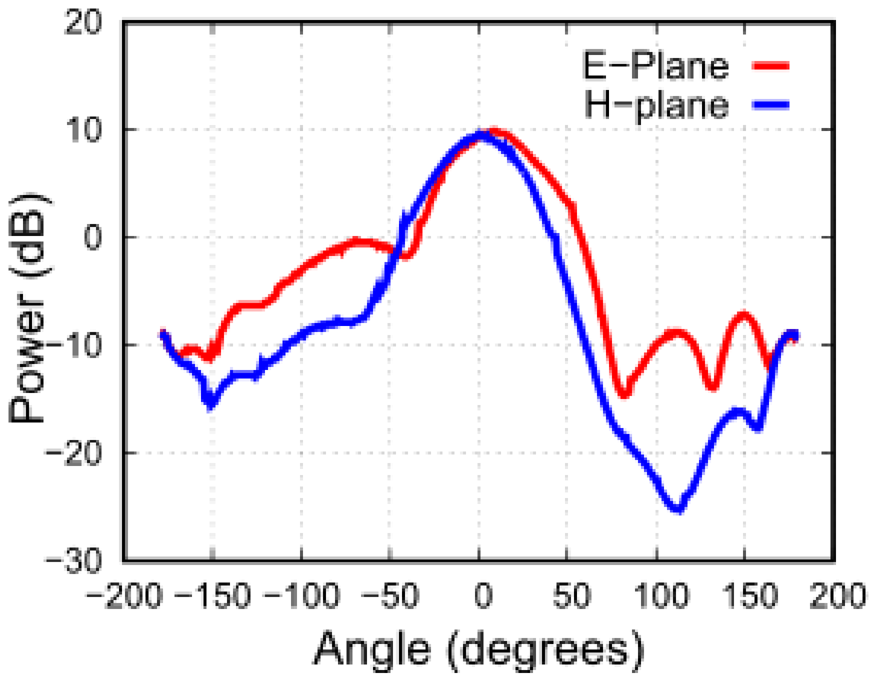

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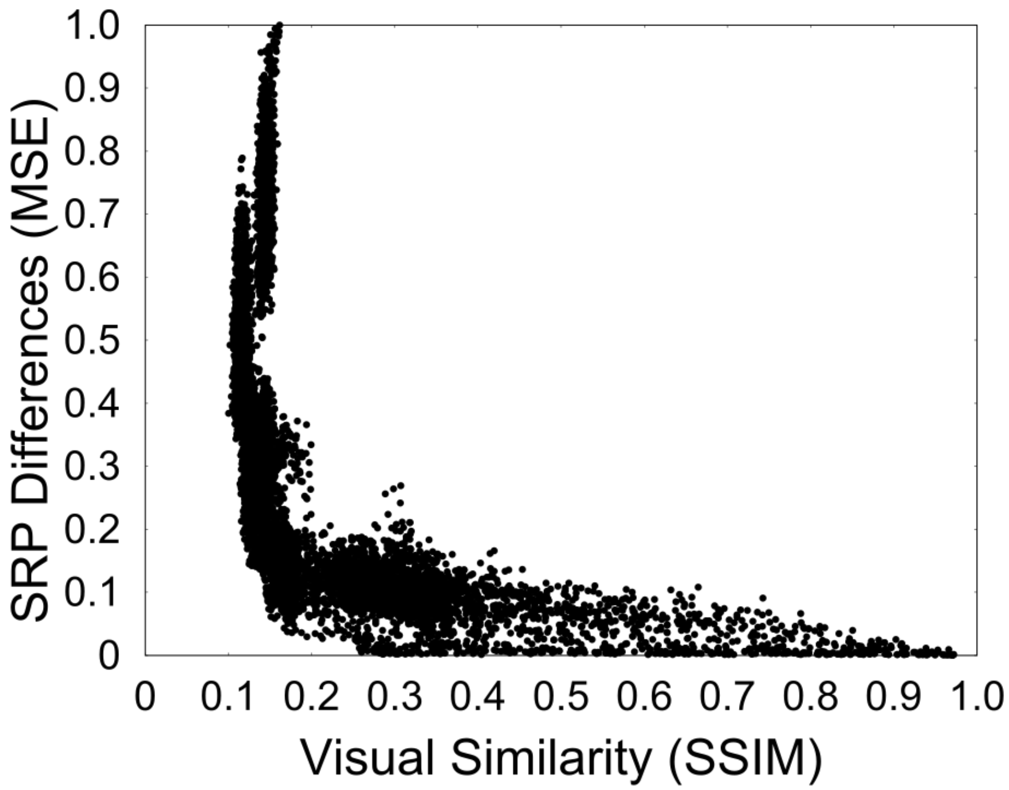

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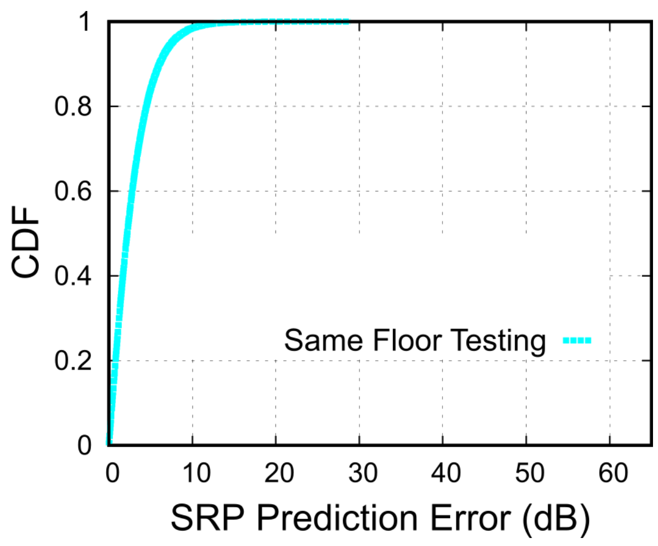
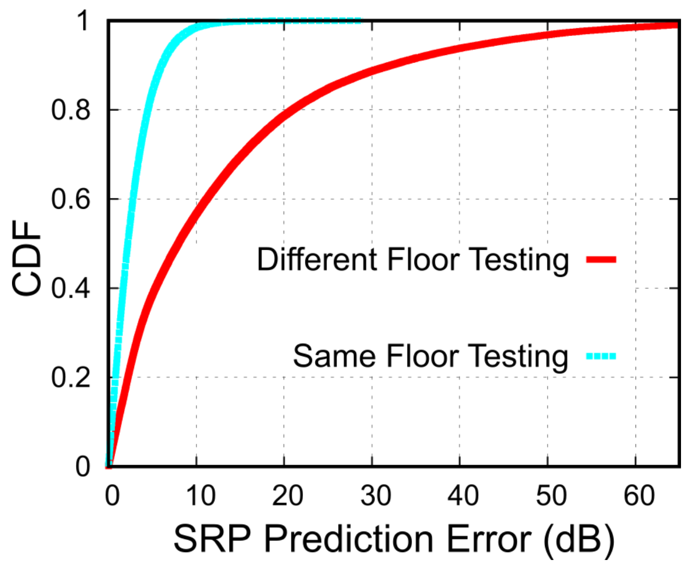
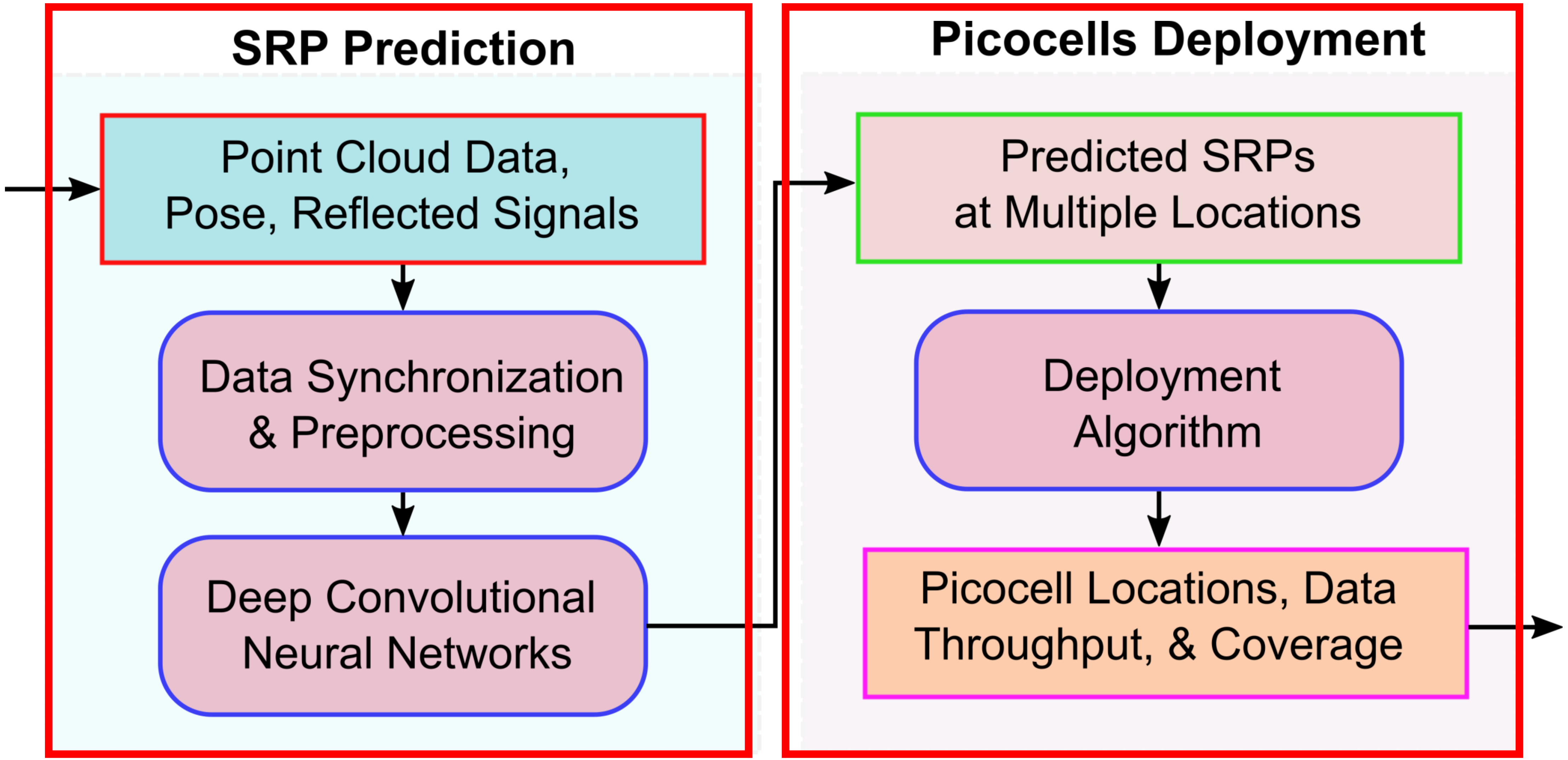




System Overview



Different Field-of-View (FoV)

- ❑ Different Field-of-View of visual AR device and mmWave device
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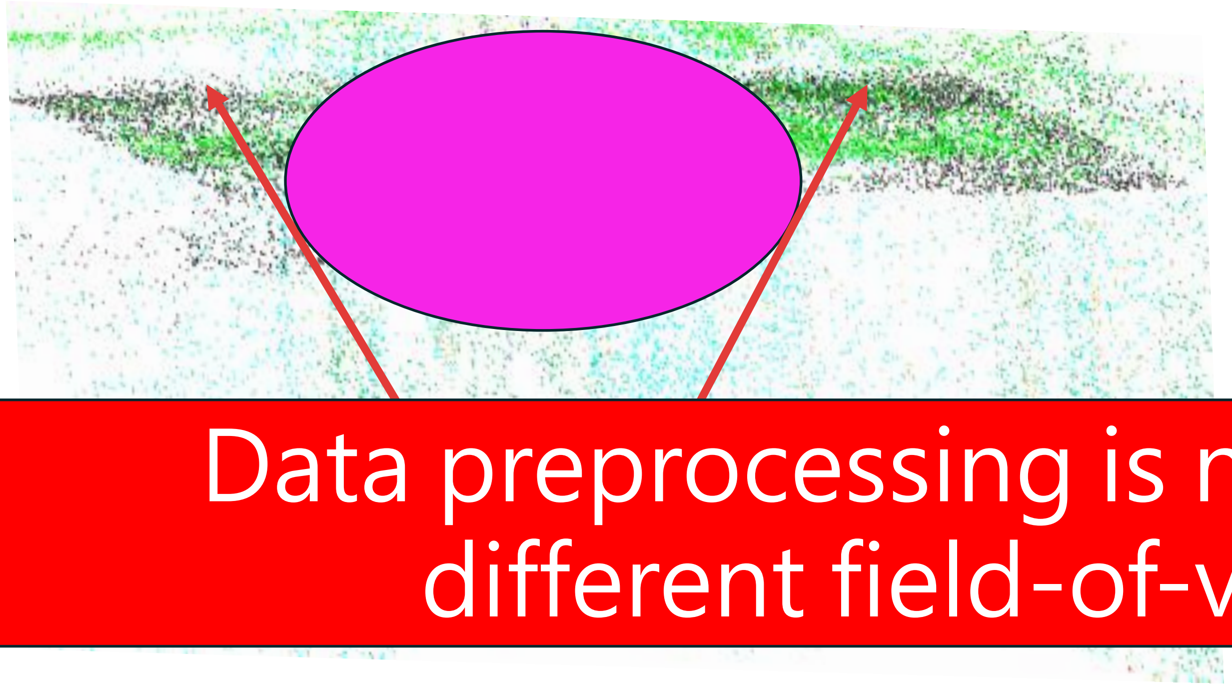
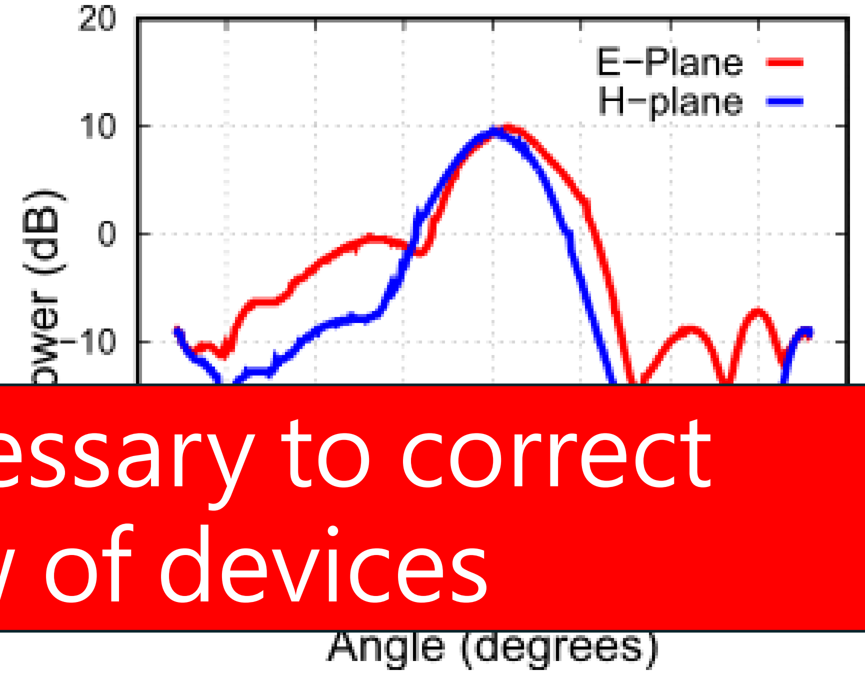
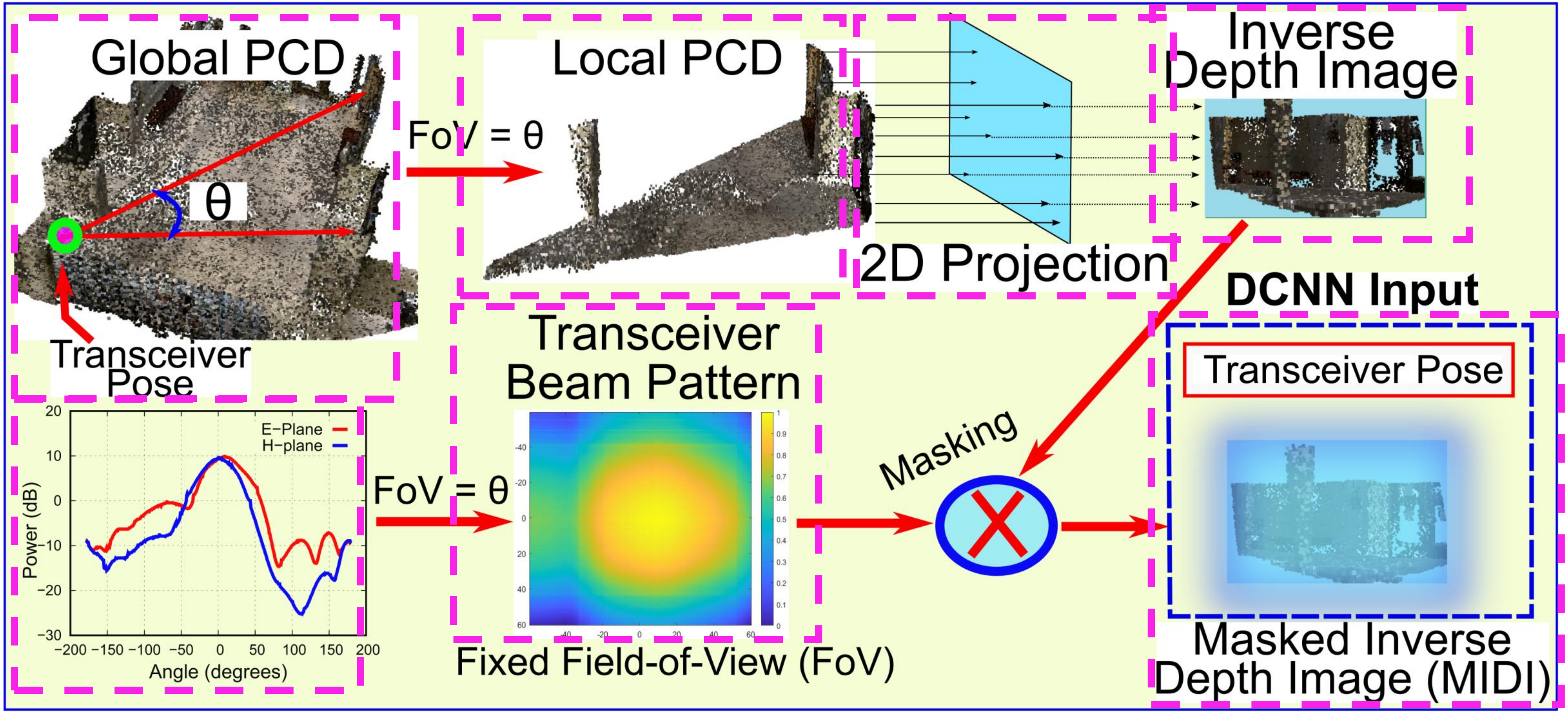




Data preprocessing is necessary to correct different field-of-view of devices

Data Preprocessing



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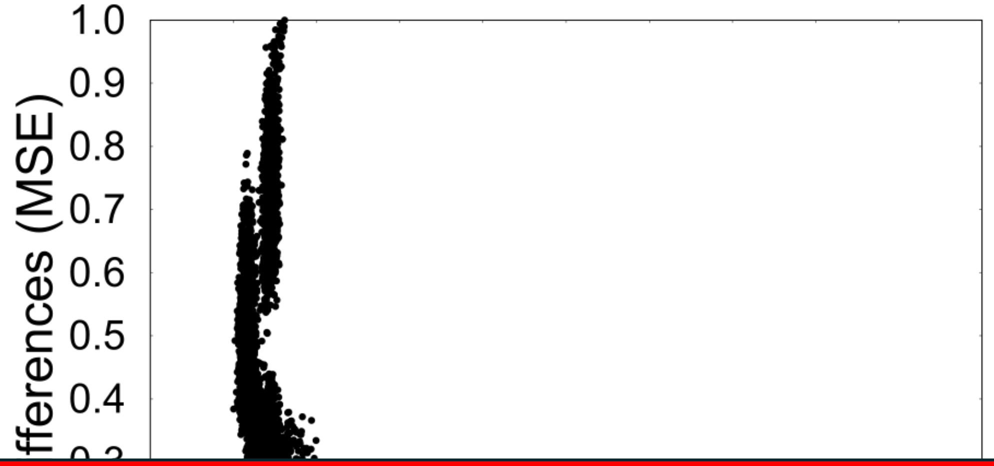
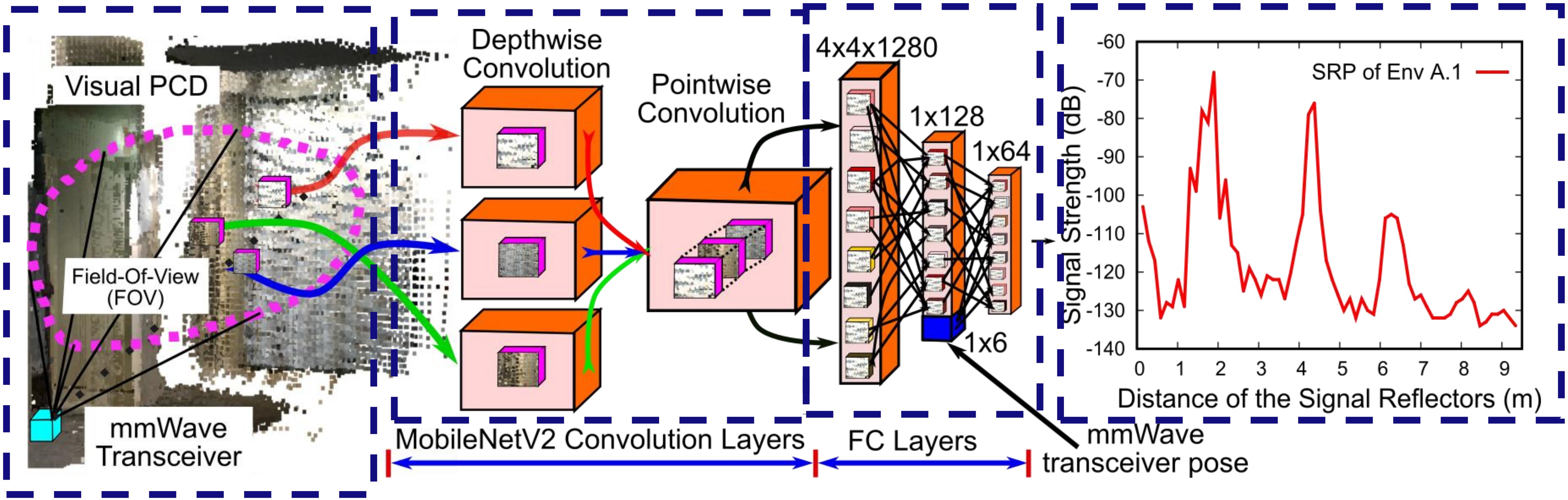


Complex non-linear models are necessary to predict SRPs from visual depth images

Visual Similarity (SSIM)

Base Model


Visual PCD
Field-Of-View
(FOV)
mmWave
Transceiver
Depthwise
Convolution
Pointwise
Convolution
4x4x1280
1x128
1x64
1x6
MobileNetV2 Convolution Layers
FC Layers
mmWave
transceiver pose
SRP of Env A.1
Signal Strength (dB)
-60
-70
-80
-90
-100
-110
-120
-130
-140
0
1
2
3
4
5
6
7
8
9
Distance of the Signal Reflectors (m)

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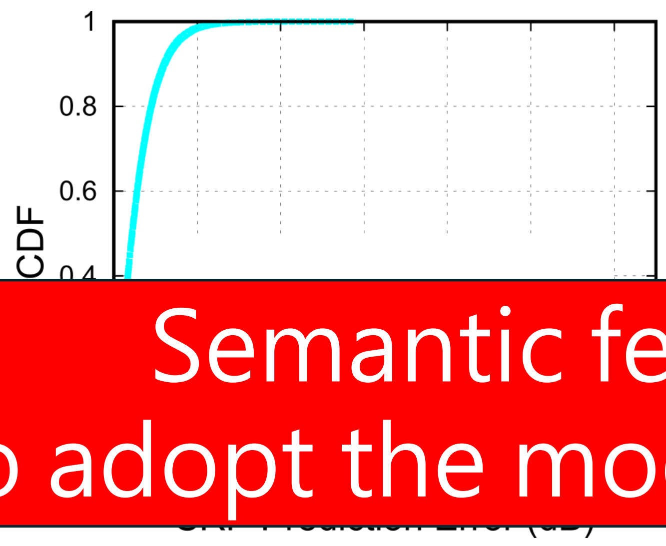
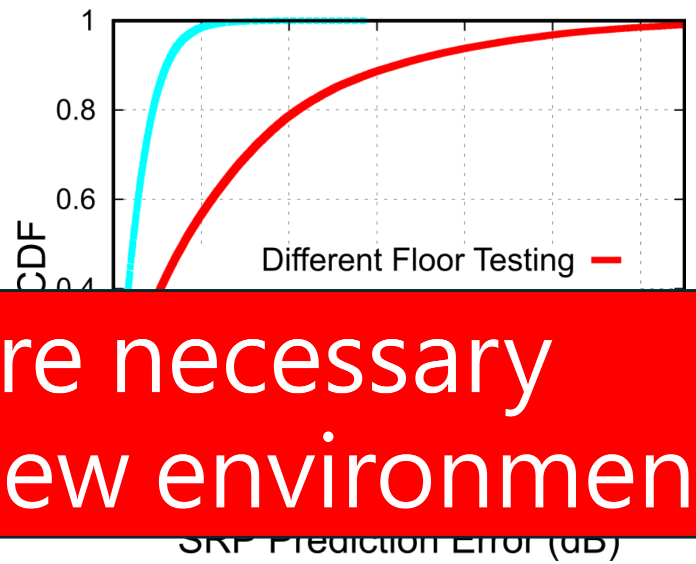
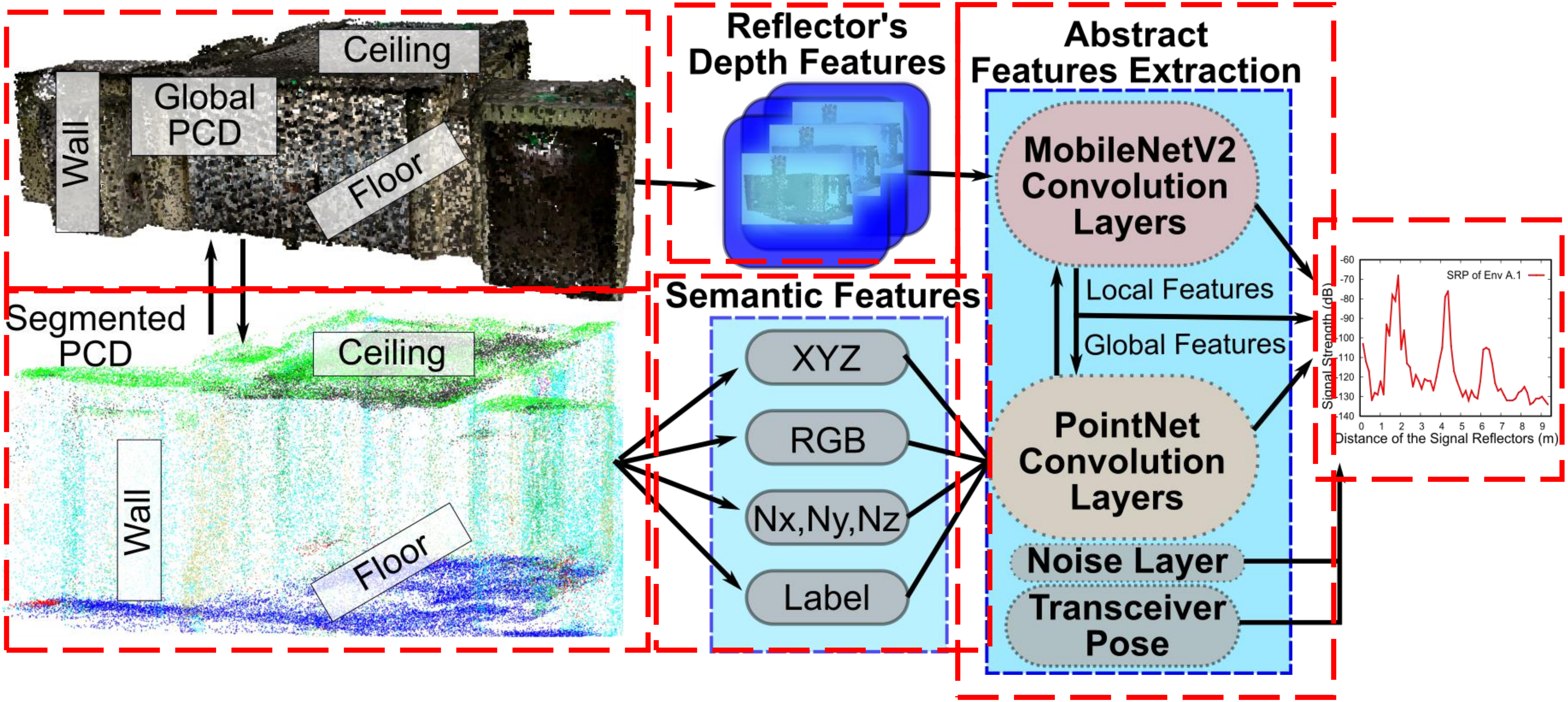


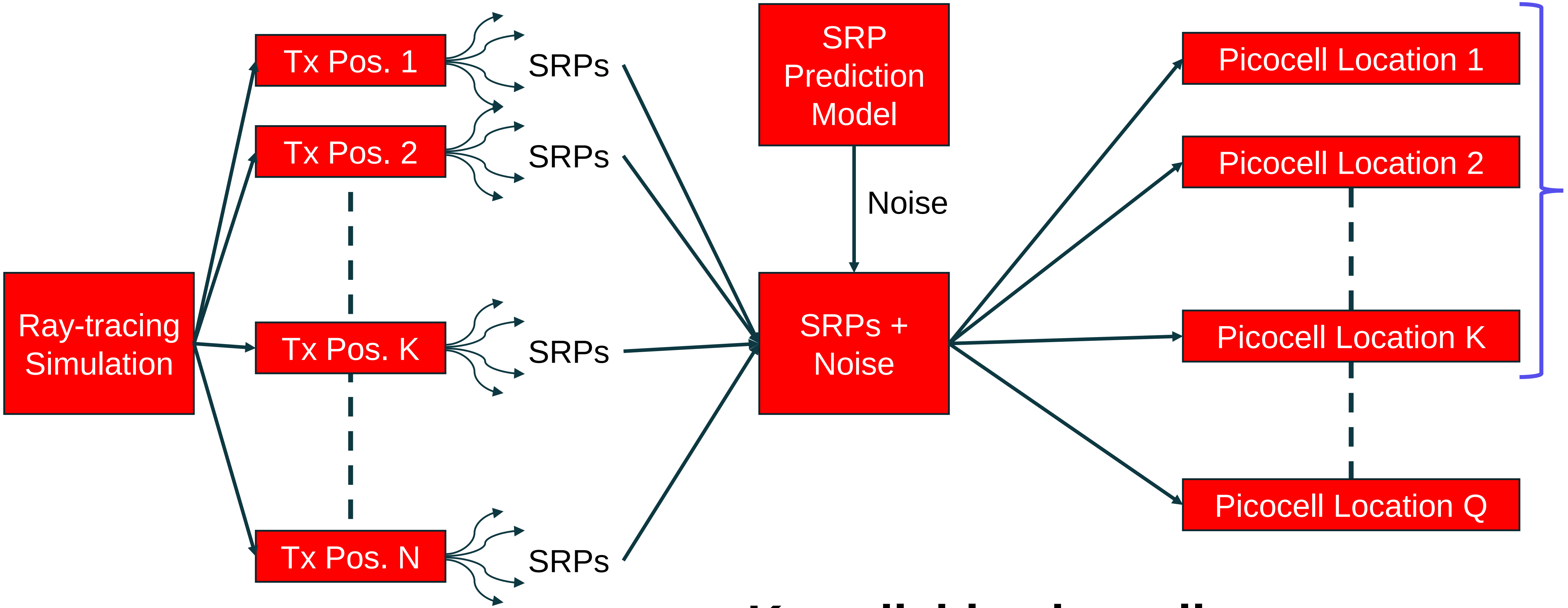


Semantic features are necessary
to adopt the model for new environments

Semantic Aware Design

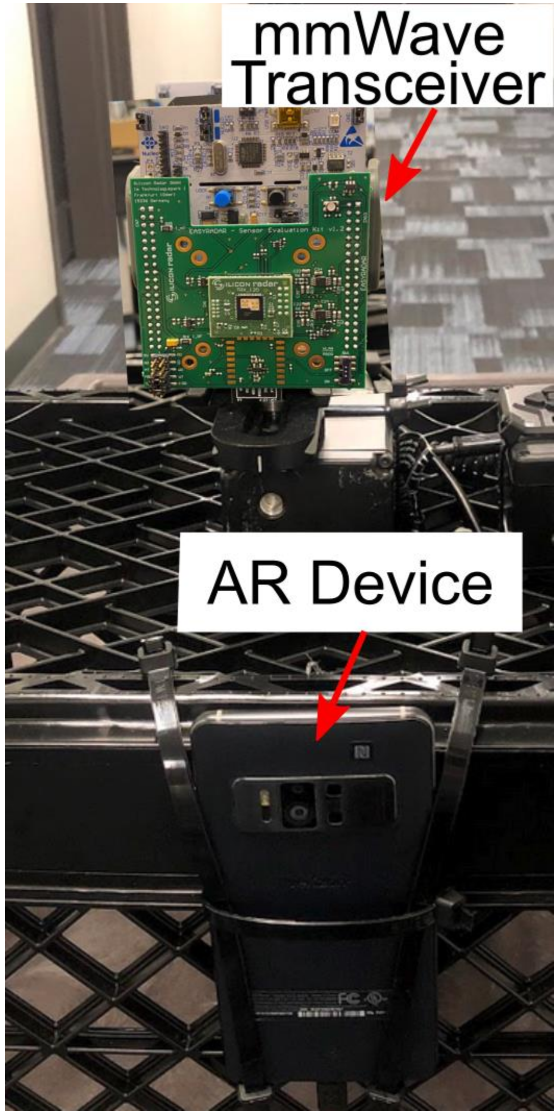


Picocells Deployment Algorithm



K available picocells

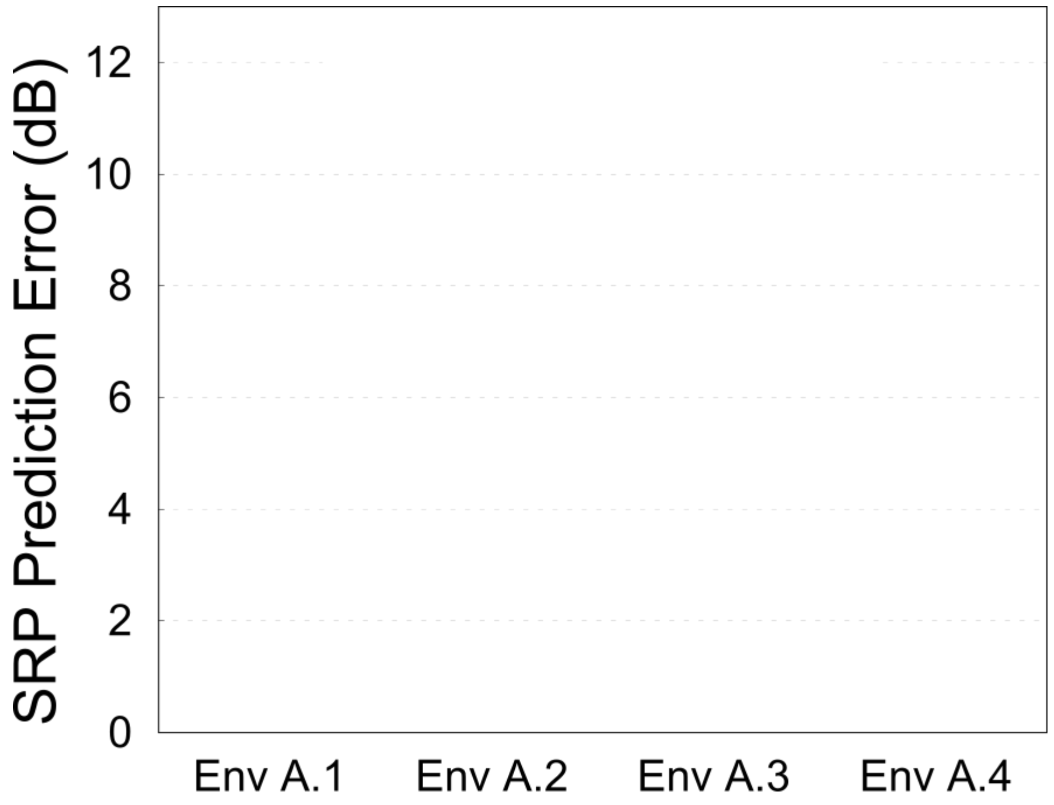
Data Collection Platform



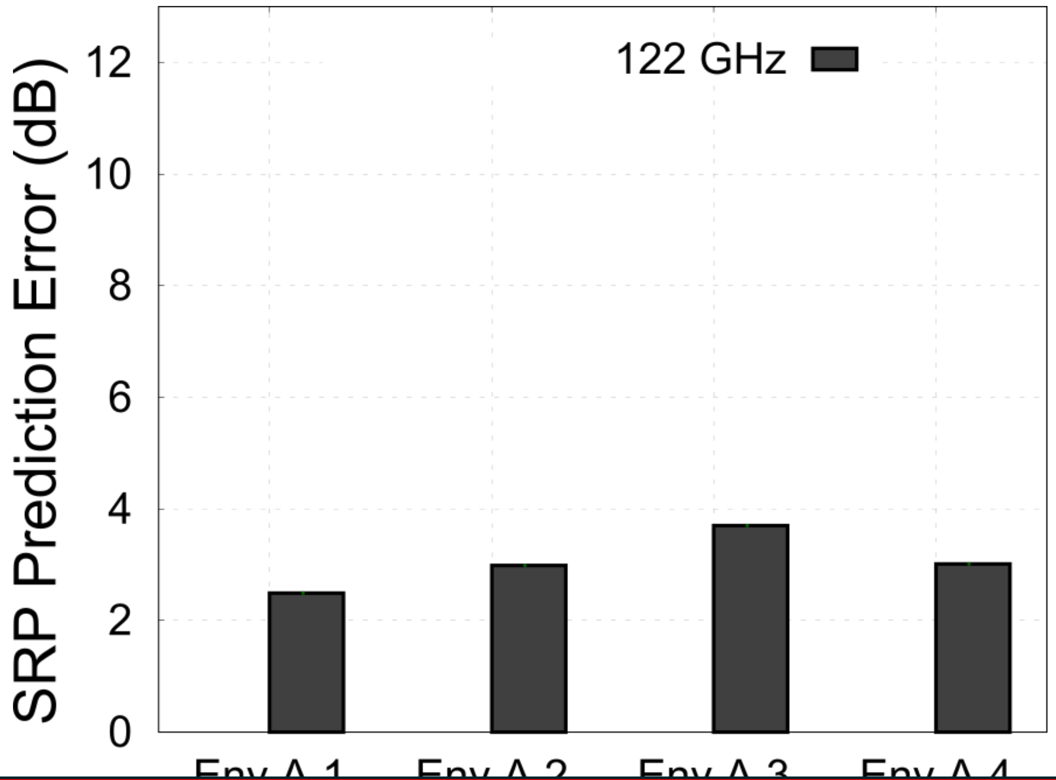
- ❑ Center frequency: 122 GHz
- ❑ Bandwidth: 1 GHz
- ❑ AR Google Tango

- ❑ 4.2M data samples
- ❑ 16 diverse environments
- ❑ 420K for training
- ❑ 3.8M for testing

Base Model Performance

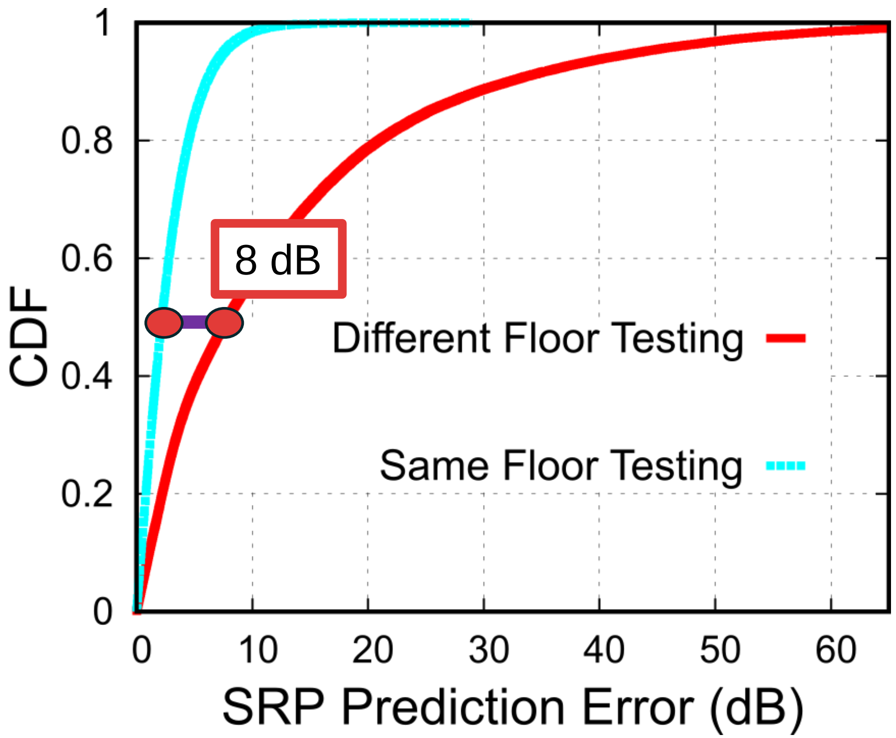


Base Model Performance



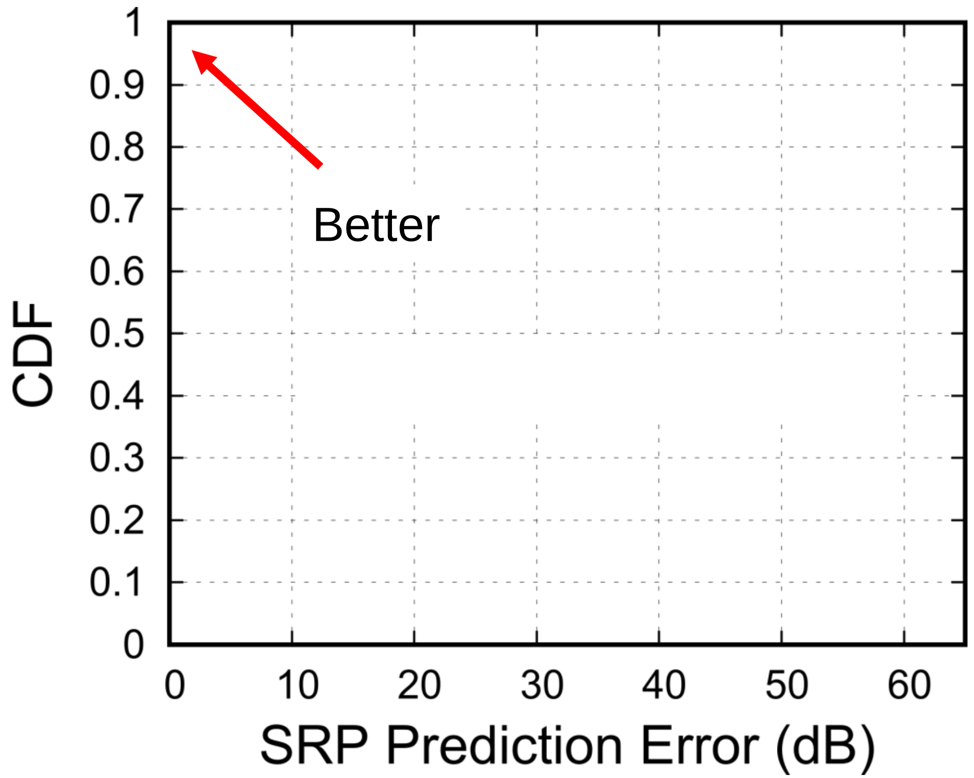
Average median SRP prediction error is 3.0 dB across 4 diverse environments

Inaccurate Transfer-Learning

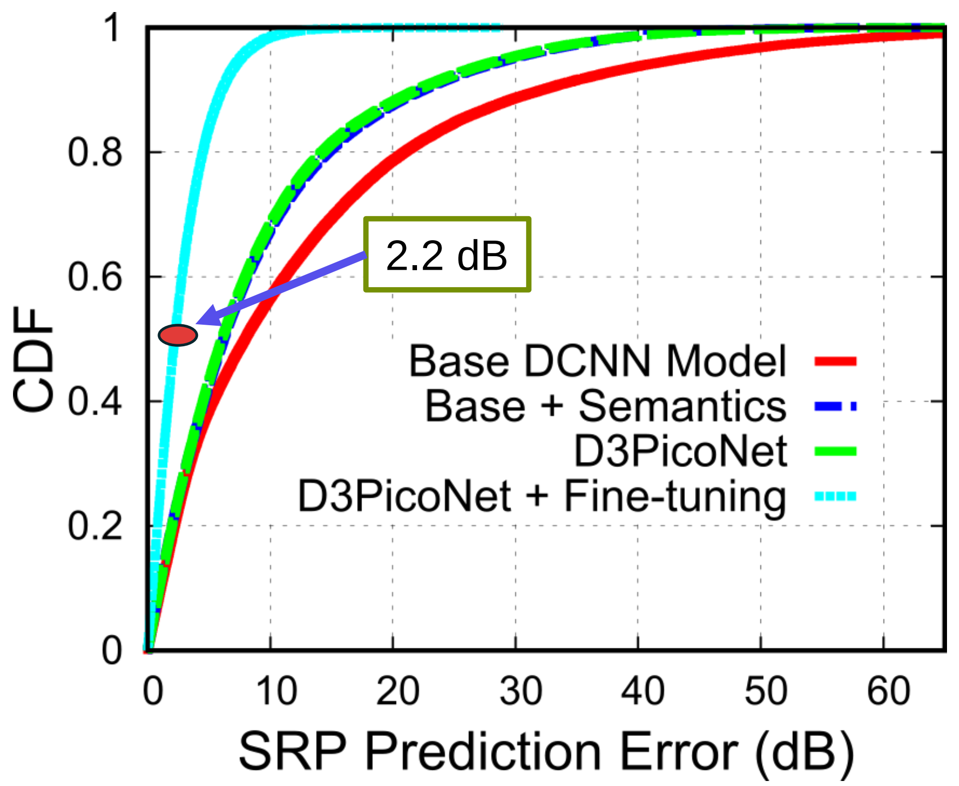


Median SRP prediction error reaches 8 dB when tested with different floor of similar surroundings

Improvement in SRP Prediction

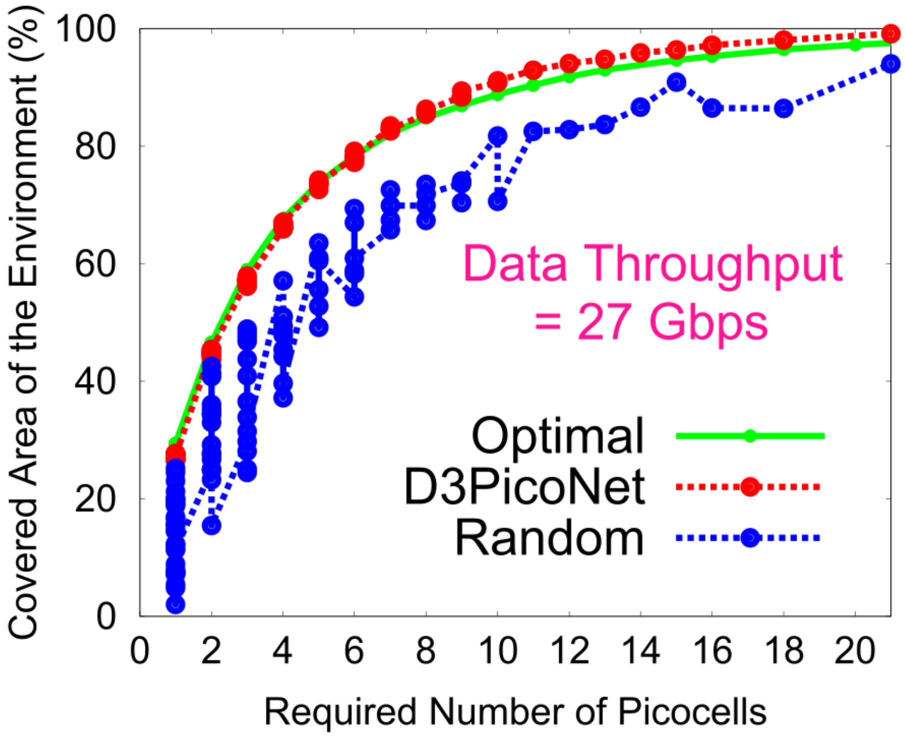


Improvement in SRP Prediction



Semantic aware model reduces SRP error from 8 dB to 2.2 dB with limited fine-tuning

Number of Picocells and Coverage Area



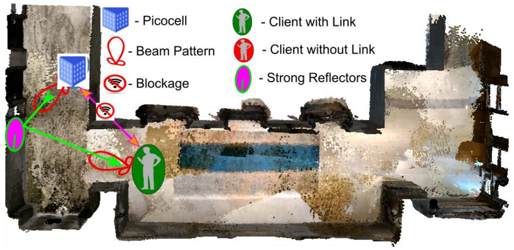
D3PicoNet consistently deploys picocells to cover more areas than Random placements

Conclusion

- D3PicoNet accurately **predicts SRP** across diverse **environments**
- **Semantic-aware** model facilitates **transfer-learning**
- Accurate **SRP prediction** enables **optimal picocell deployment**

Thank you!

Check out our group website for more results



Contact:

hregmi@email.sc.edu

SyReX
Systems Research on X