Argus: Predictable Millimeter-Wave Picocells with Vision and Learning Augmentation

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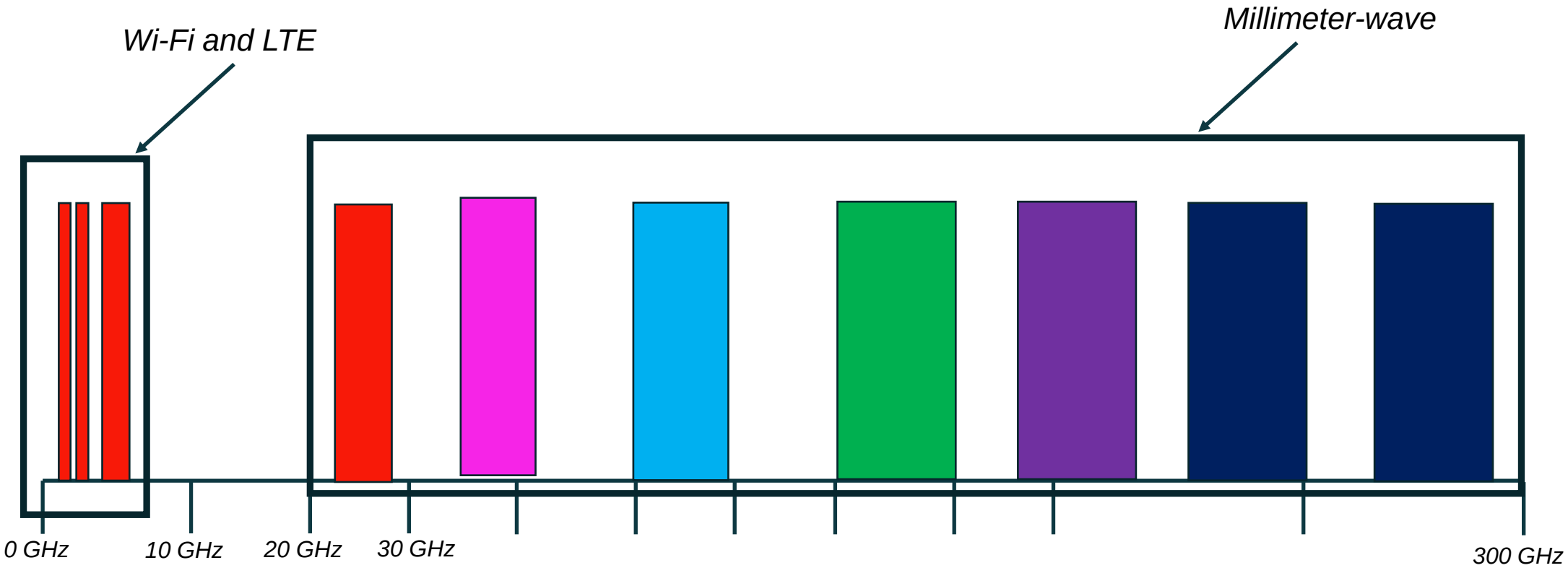
Outline

- ❑ Picocell fundamentals
- ❑ Challenges with picocells and our approach
- ❑ Deep learning design
- ❑ Semantic aware design
- ❑ Experimental results
- ❑ Conclusion

Millimeter-wave



Millimeter-wave (30 GHz to 300 GHz)

Wavelength: 10 mm to 1 mm

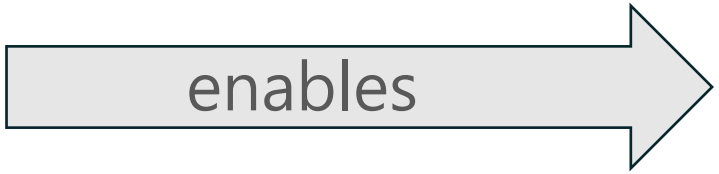
Need of Millimeter-wave

High data throughput

10s of Gbps

Low Latency

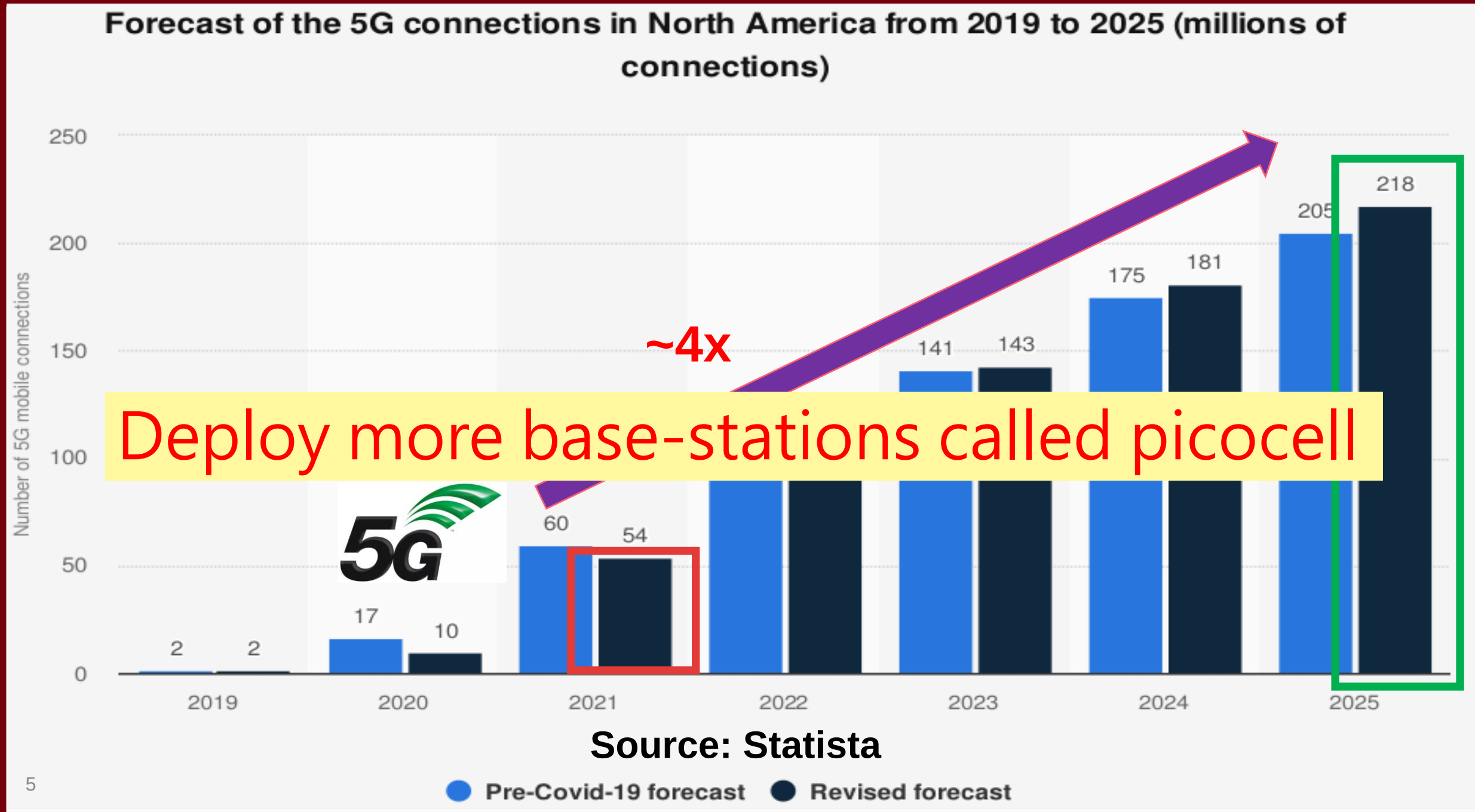
1 - 10 ms



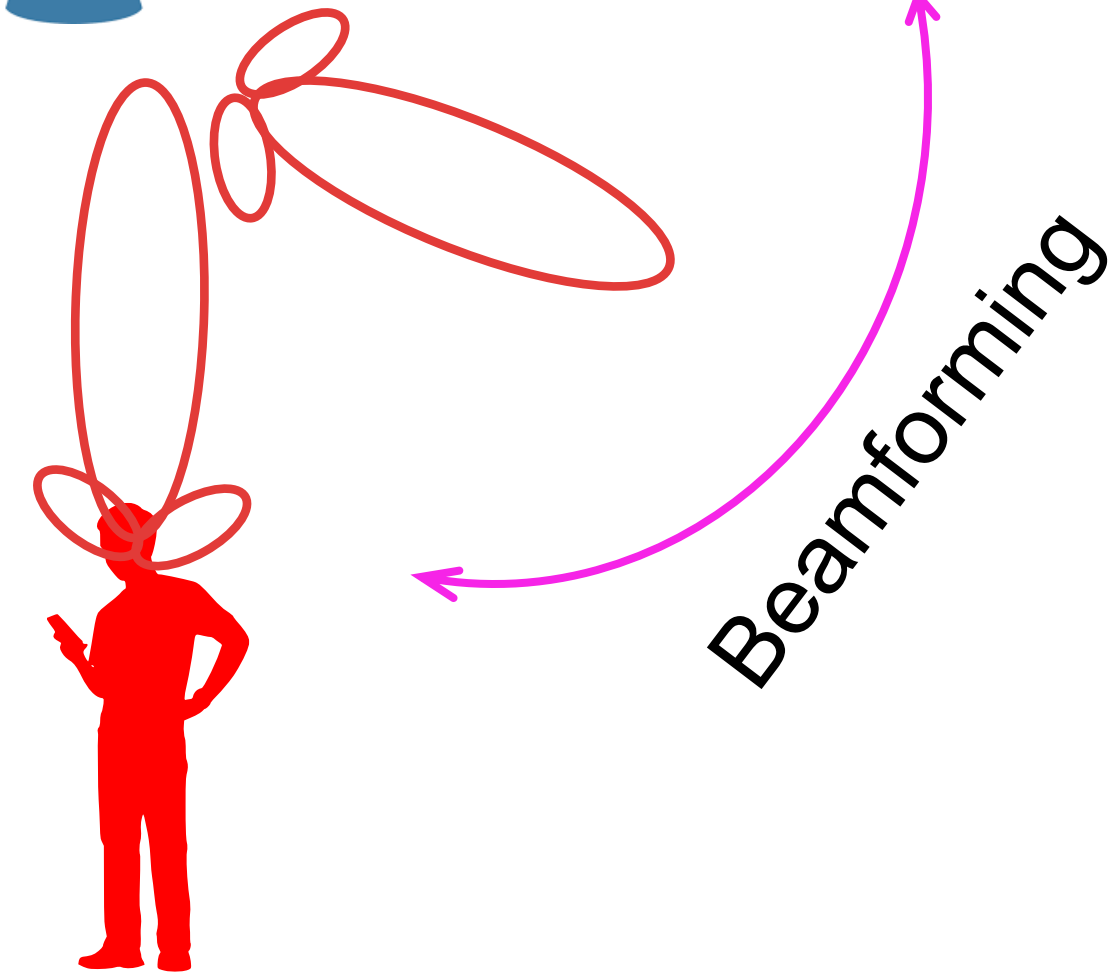
Entertainment

Education

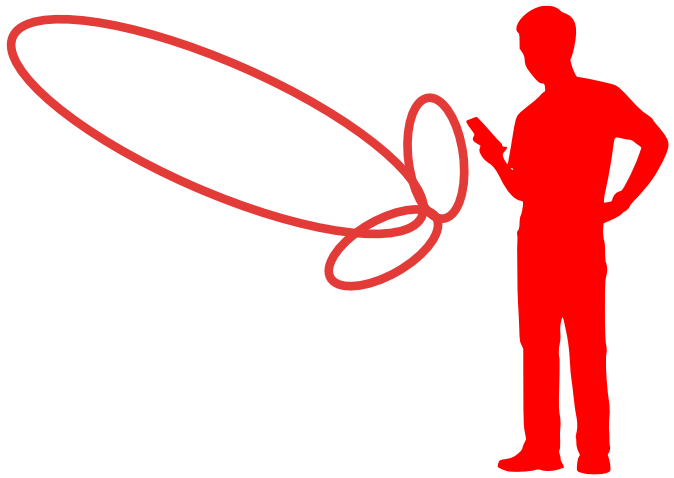
Autonomous Driving


Forecast of the 5G connections in North America from 2019 to 2025 (millions of connections)
Number of 5G mobile connections
250
200
150
100
50
0
2
2
17
10
60
54
141
143
175
181
205
218
2019
2020
2021
2022
2023
2024
2025
~4x
Deploy more base-stations called picocell
5G
Source: Statista
Pre-Covid-19 forecast
Revised forecast

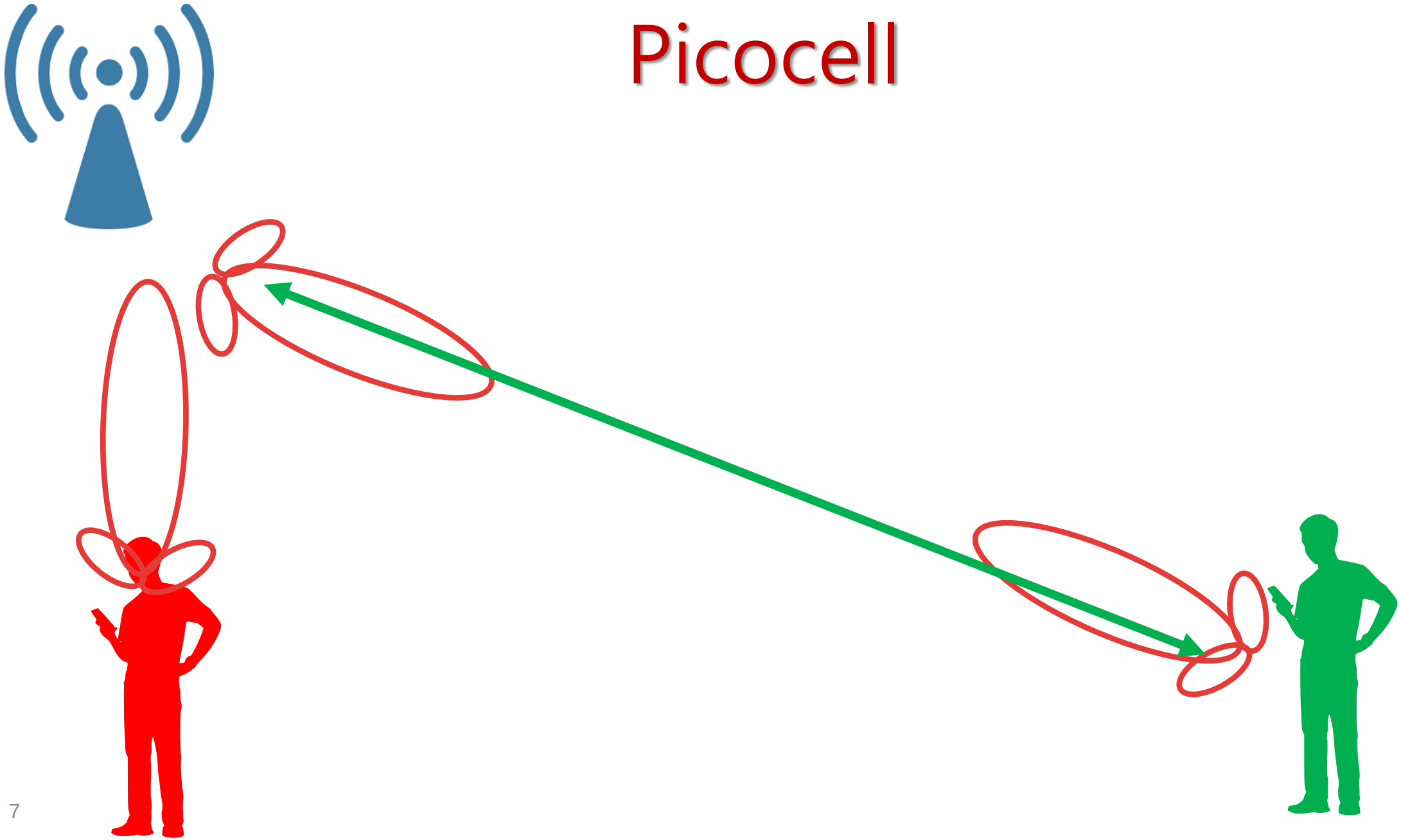
Picocell



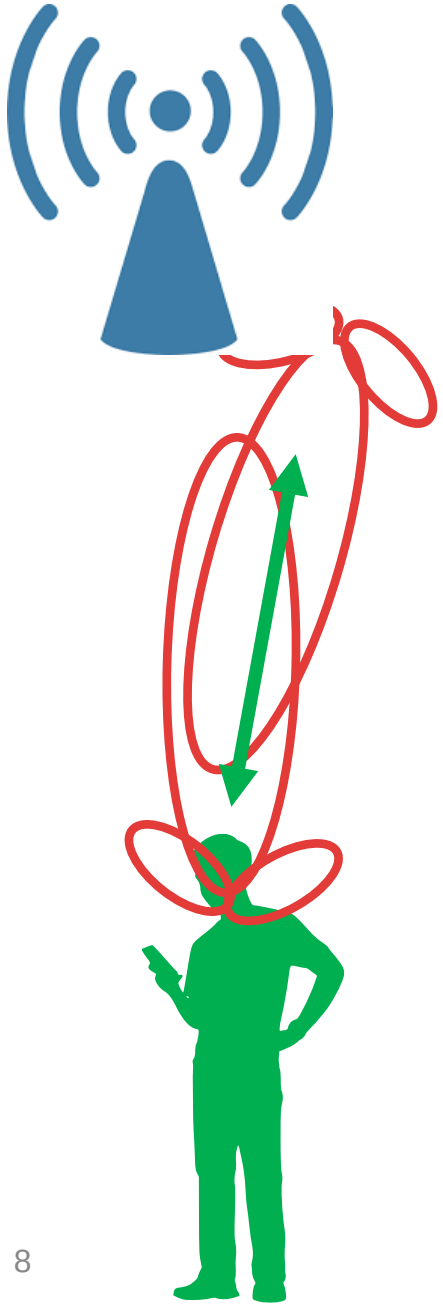
- 10-12 m range
- Small size
- Low power

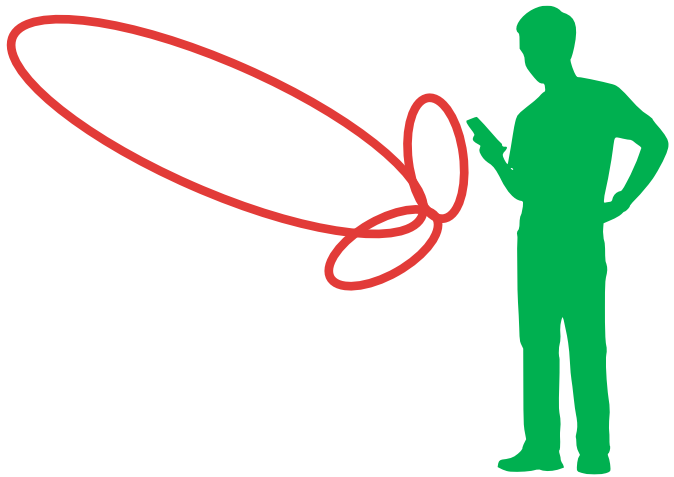


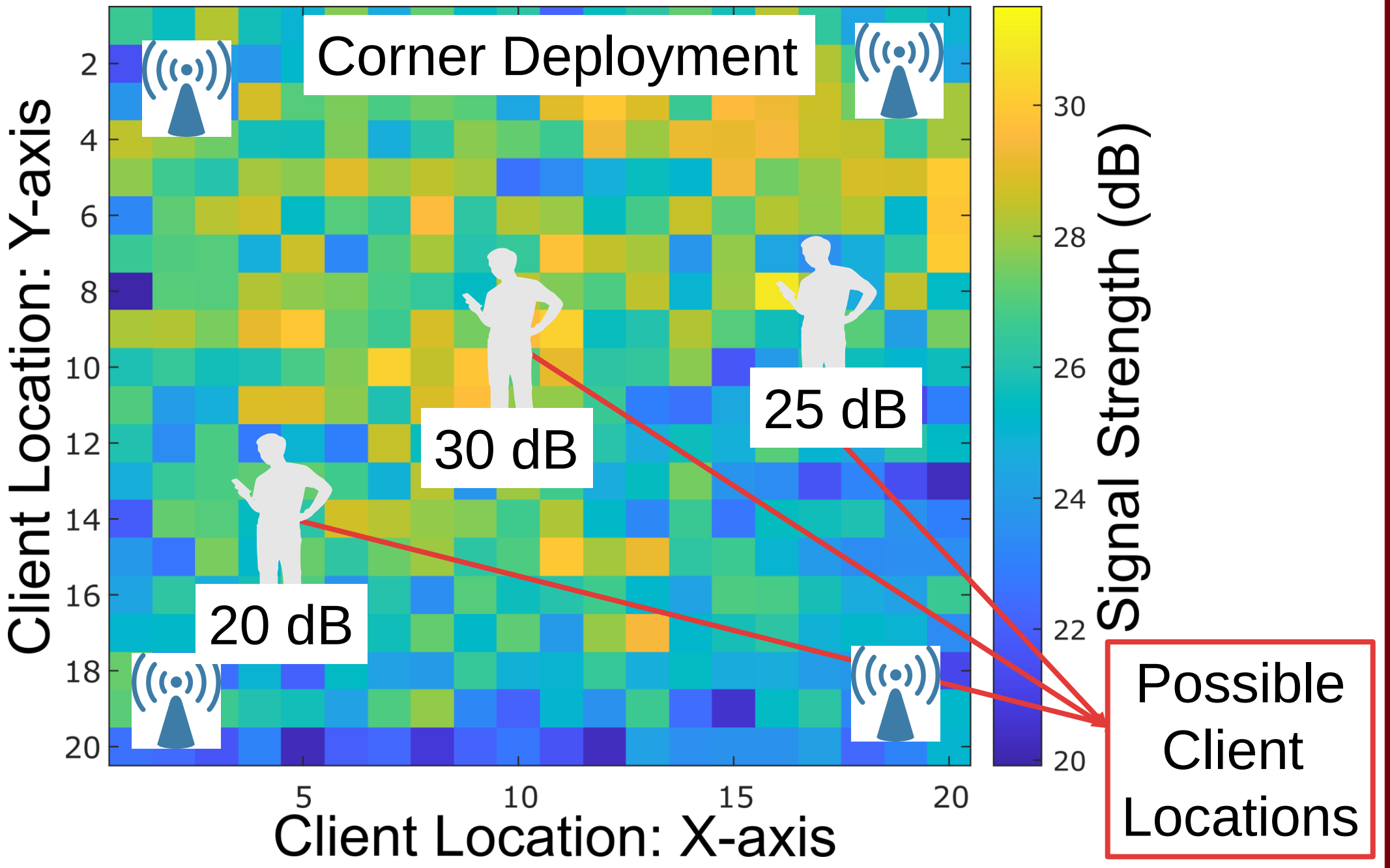
Picocell

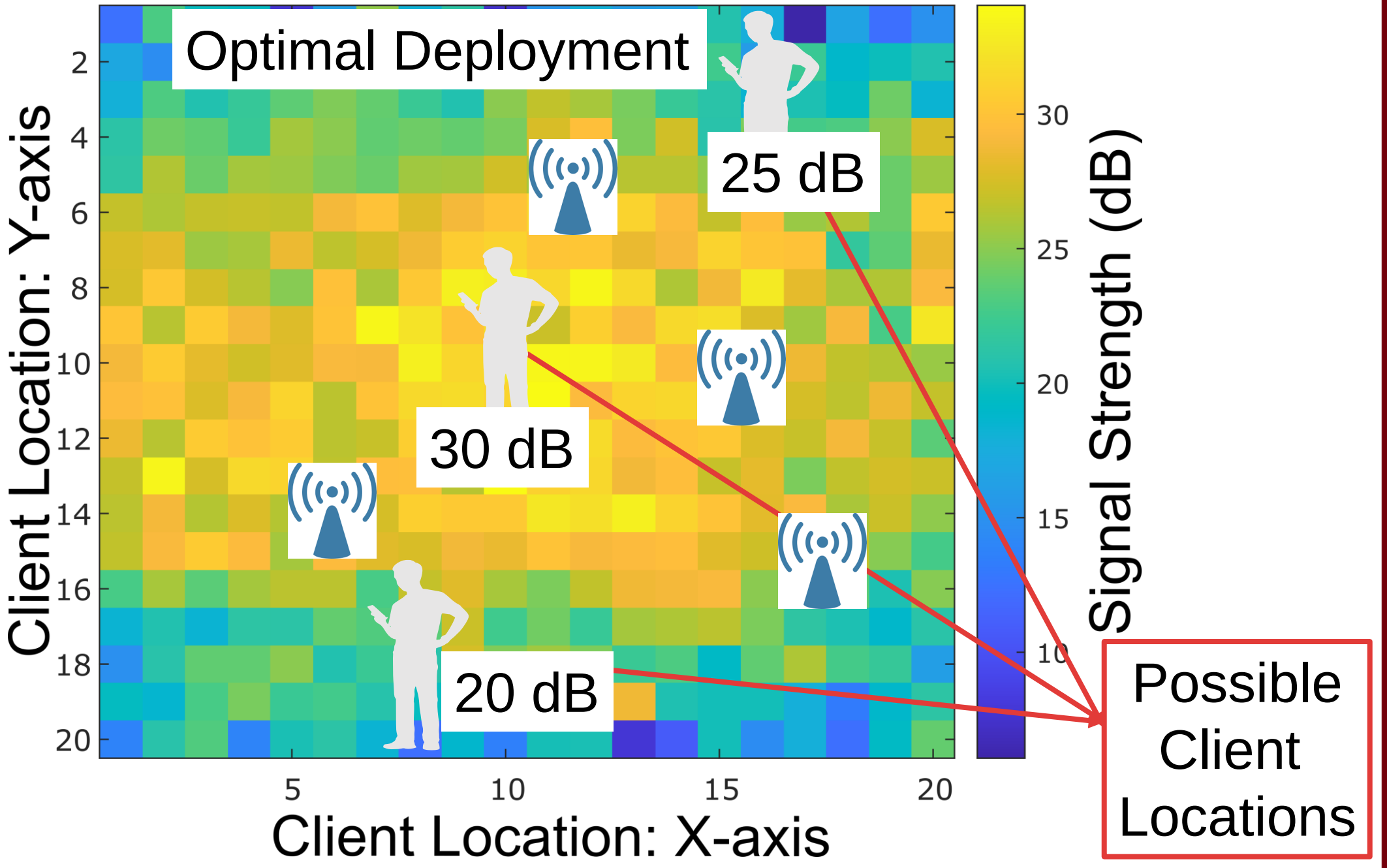


Picocell



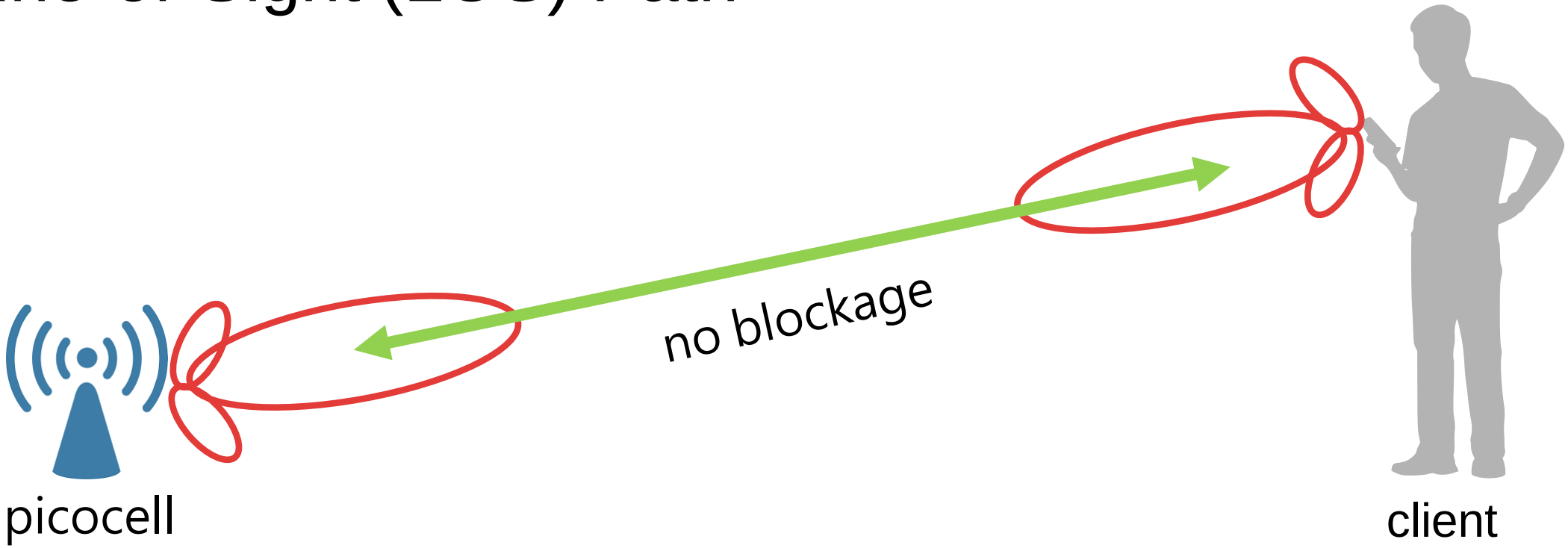



Corner Deployment
30 dB
25 dB
20 dB
Possible Client Locations
Client Location: Y-axis
Client Location: X-axis
Signal Strength (dB)
2
4
6
8
10
12
14
16
18
20
5
10
15
20
30
28
26
24
22
20


Optimal Deployment
25 dB
30 dB
20 dB
Possible Client Locations
Client Location: Y-axis
Client Location: X-axis
Signal Strength (dB)
2
4
6
8
10
12
14
16
18
20
5
10
15
20
30
25
20
15
10

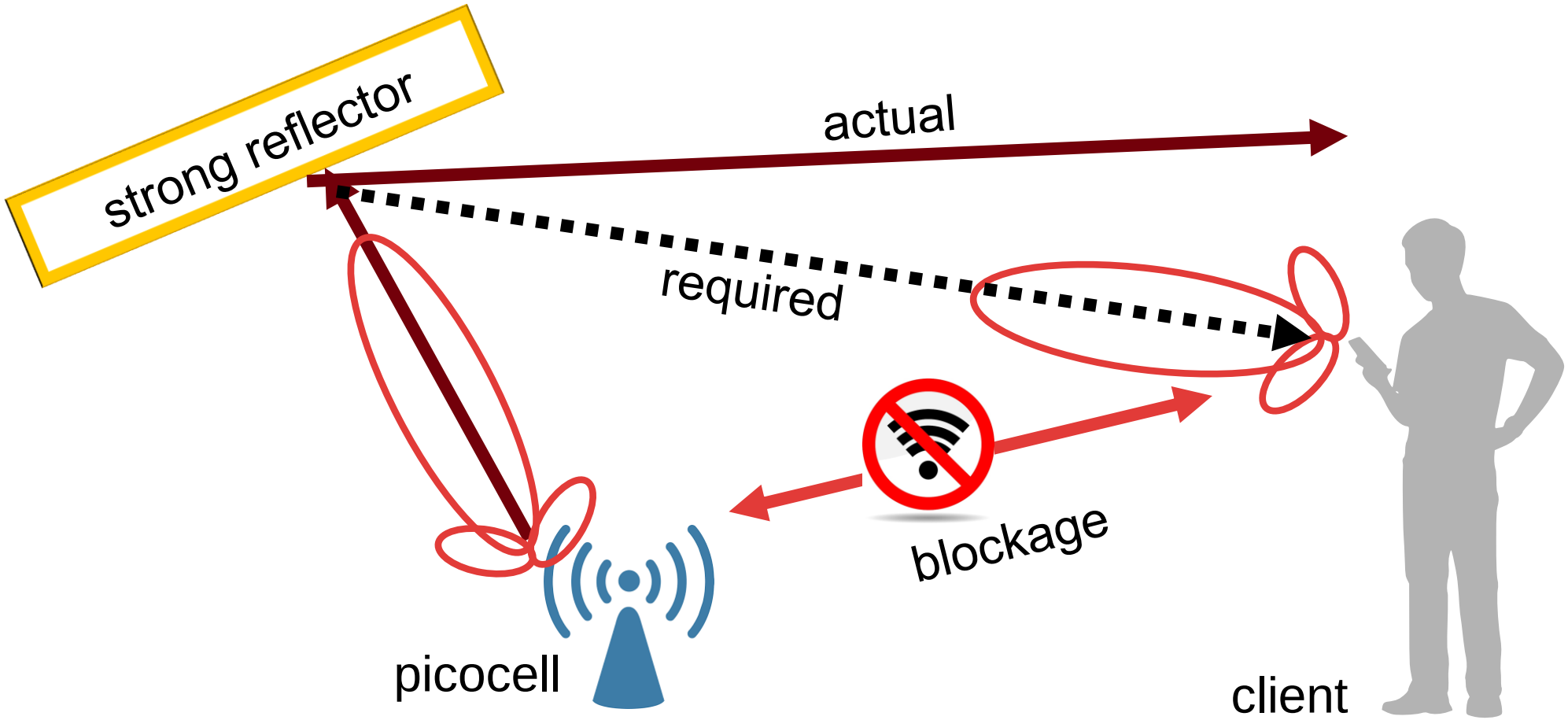
Possible Ways for Link Connectivity

Line-of-Sight (LOS) Path



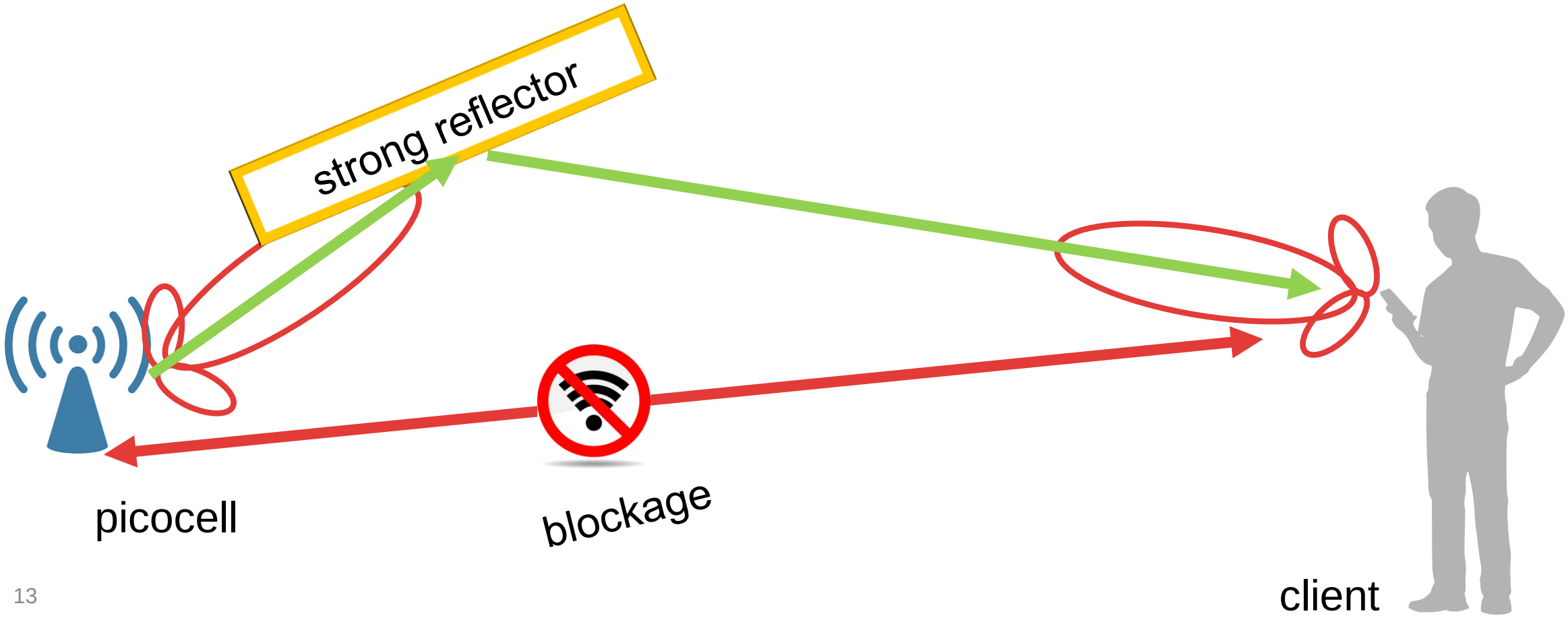
Possible Ways for Link Connectivity

Incorrect Non-Line-of-Sight (NLOS) Path

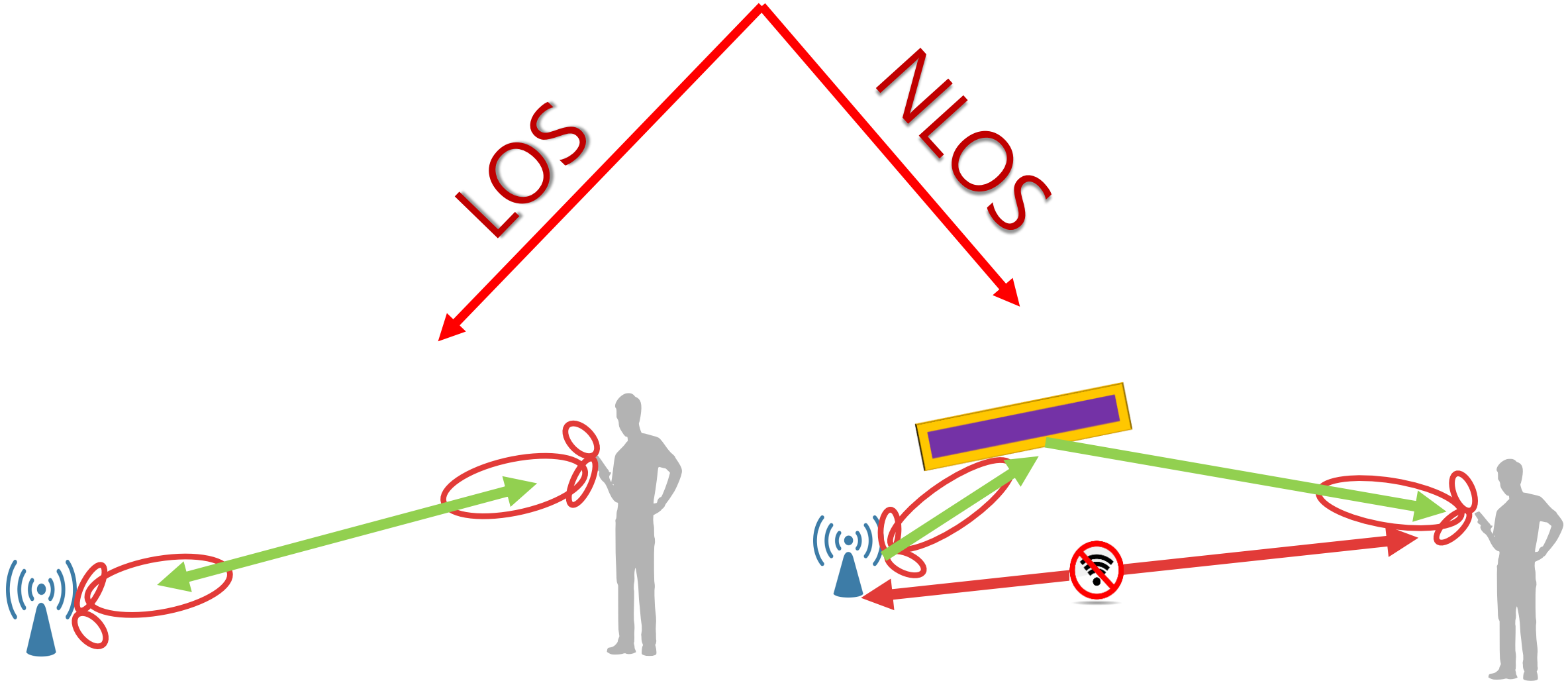


Possible Ways for Link Connectivity

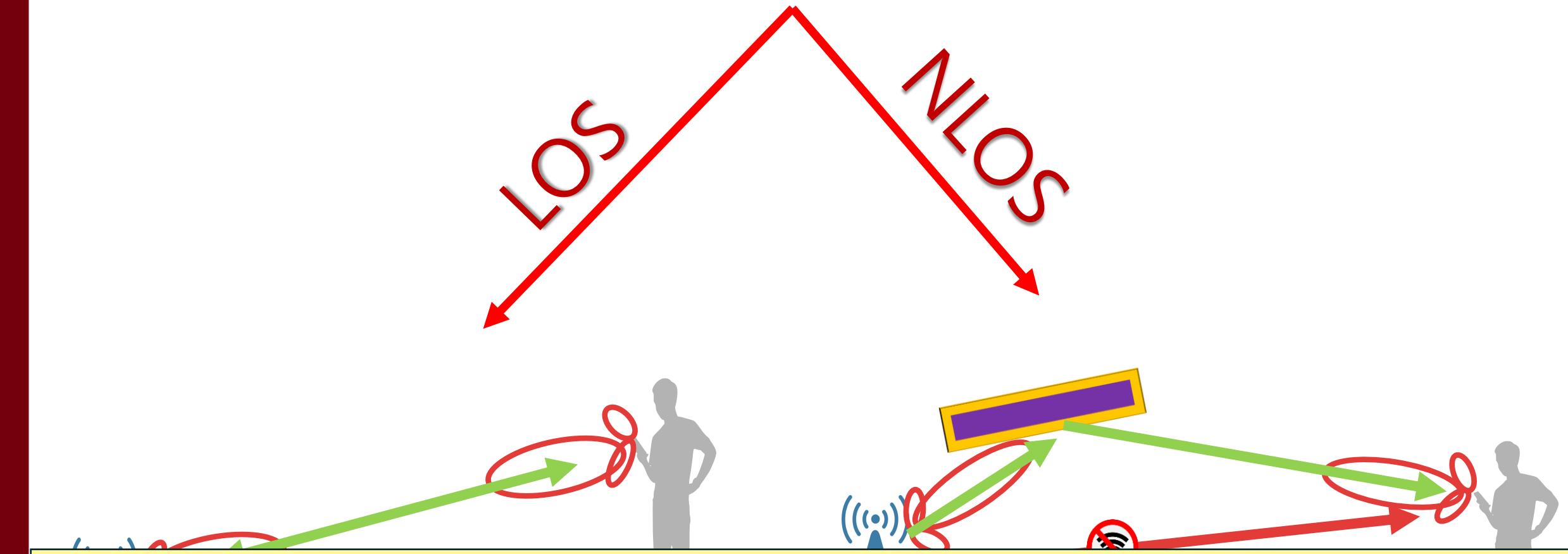
Correct Non-Line-of-Sight (NLOS) Path



Possible Ways for Link Connectivity



Possible Ways for Link Connectivity



How can we deploy picocells correctly based on surrounding reflectors?

Effect of Multiple Picocell Location

Effect of Multiple Picocell Location

Effect of Multiple Picocell Location

LOS is blocked

strong reflector 1

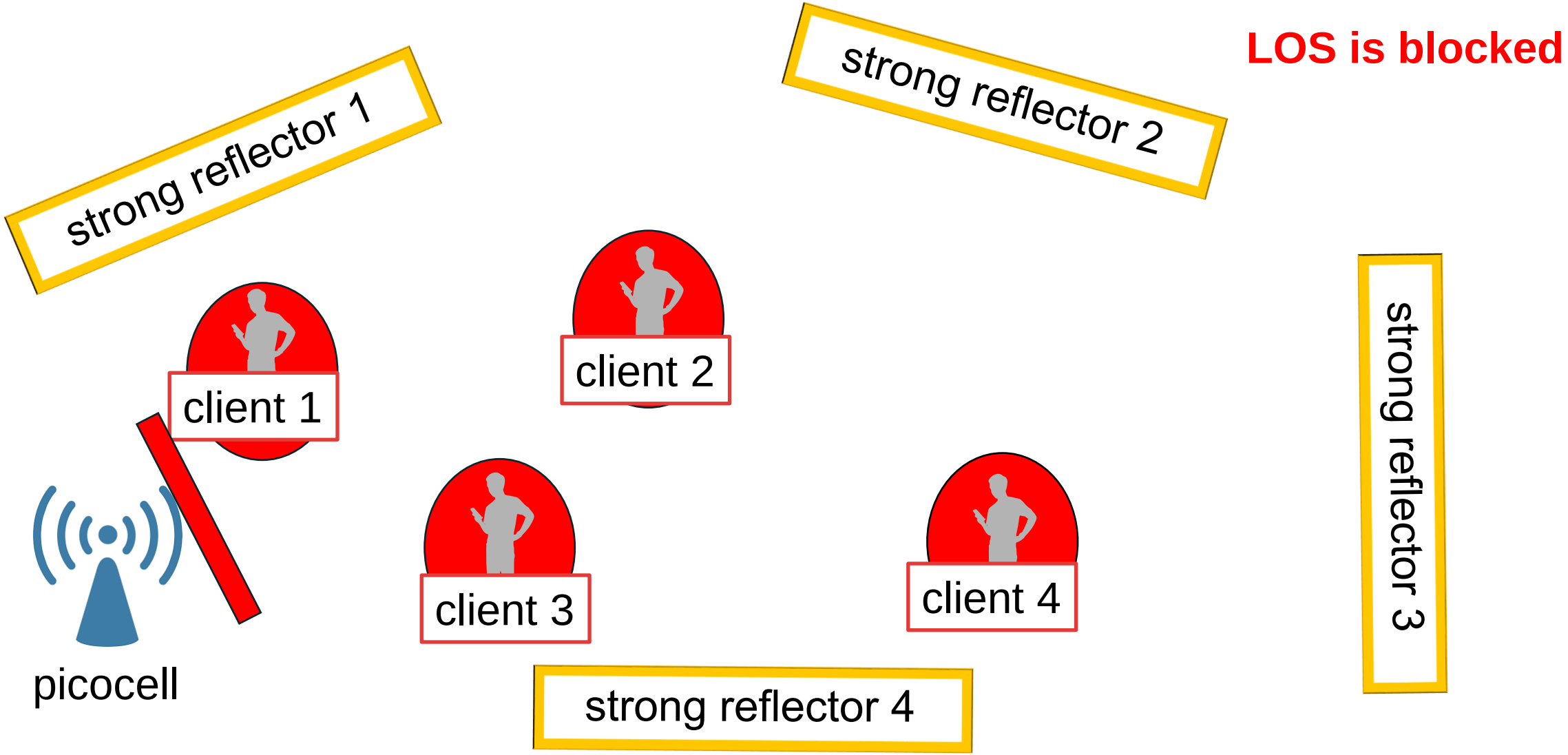
strong reflector 2

strong reflector 3

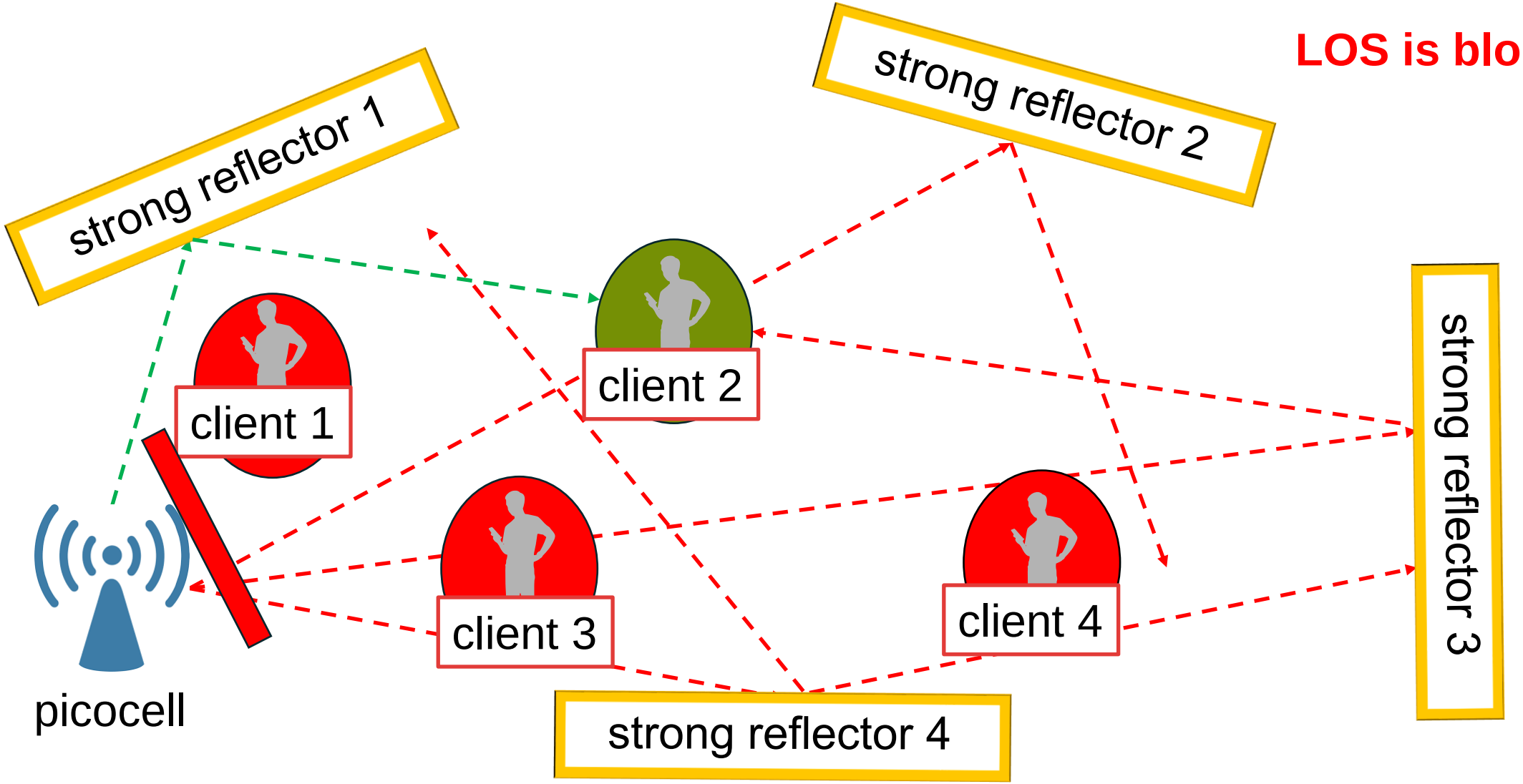
picocell

strong reflector 4

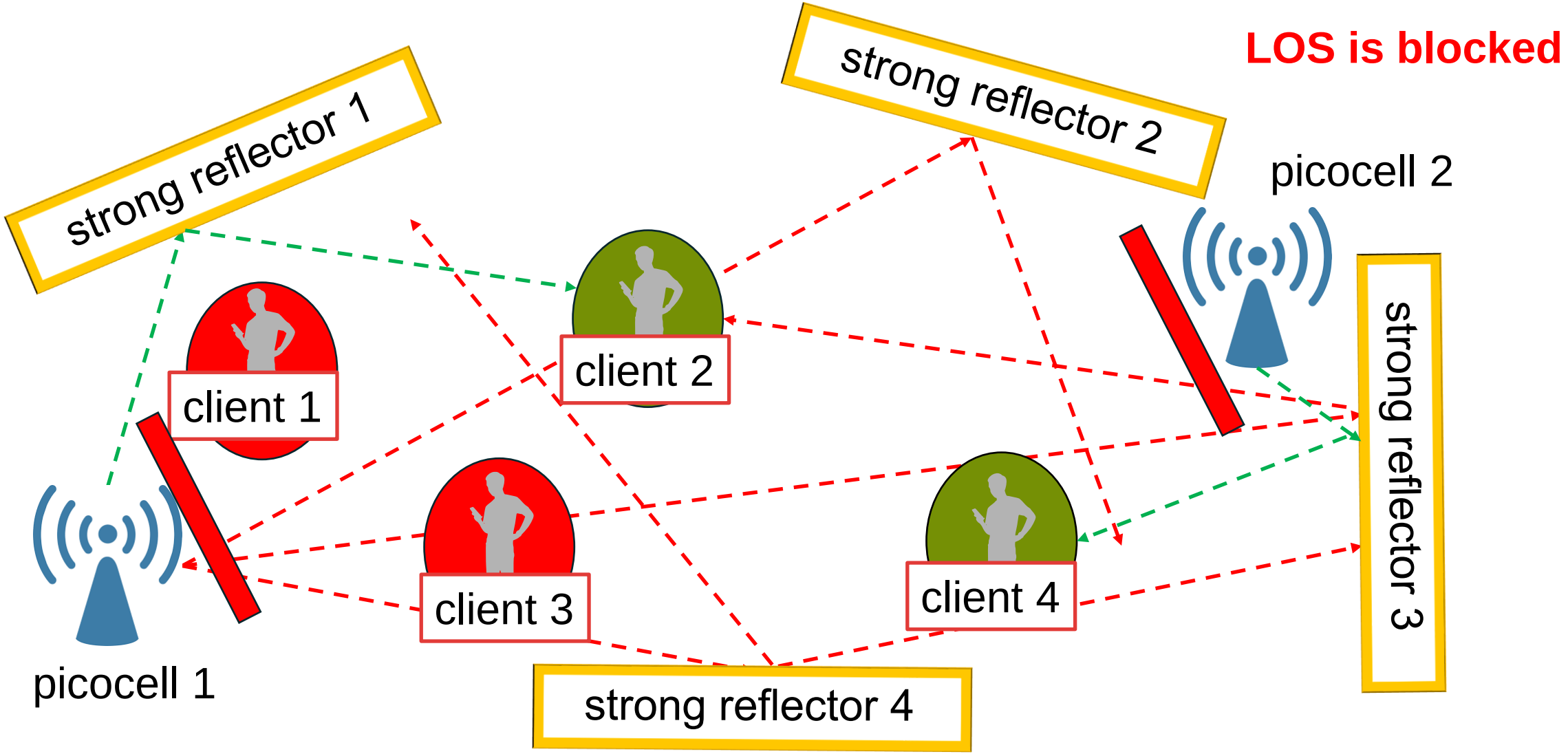
Effect of Multiple Picocell Location



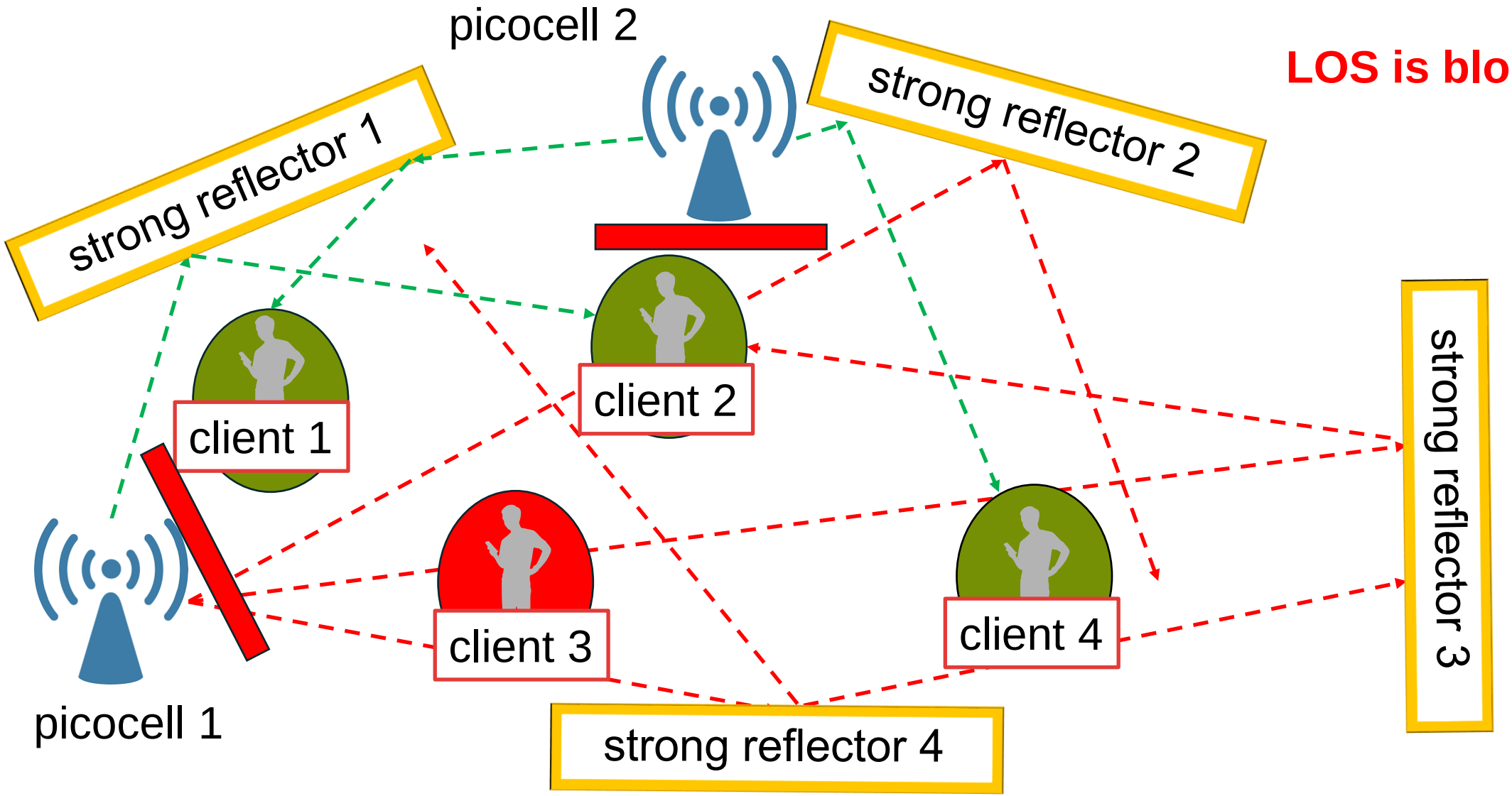
Effect of Multiple Picocell Location



Effect of Multiple Picocell Location



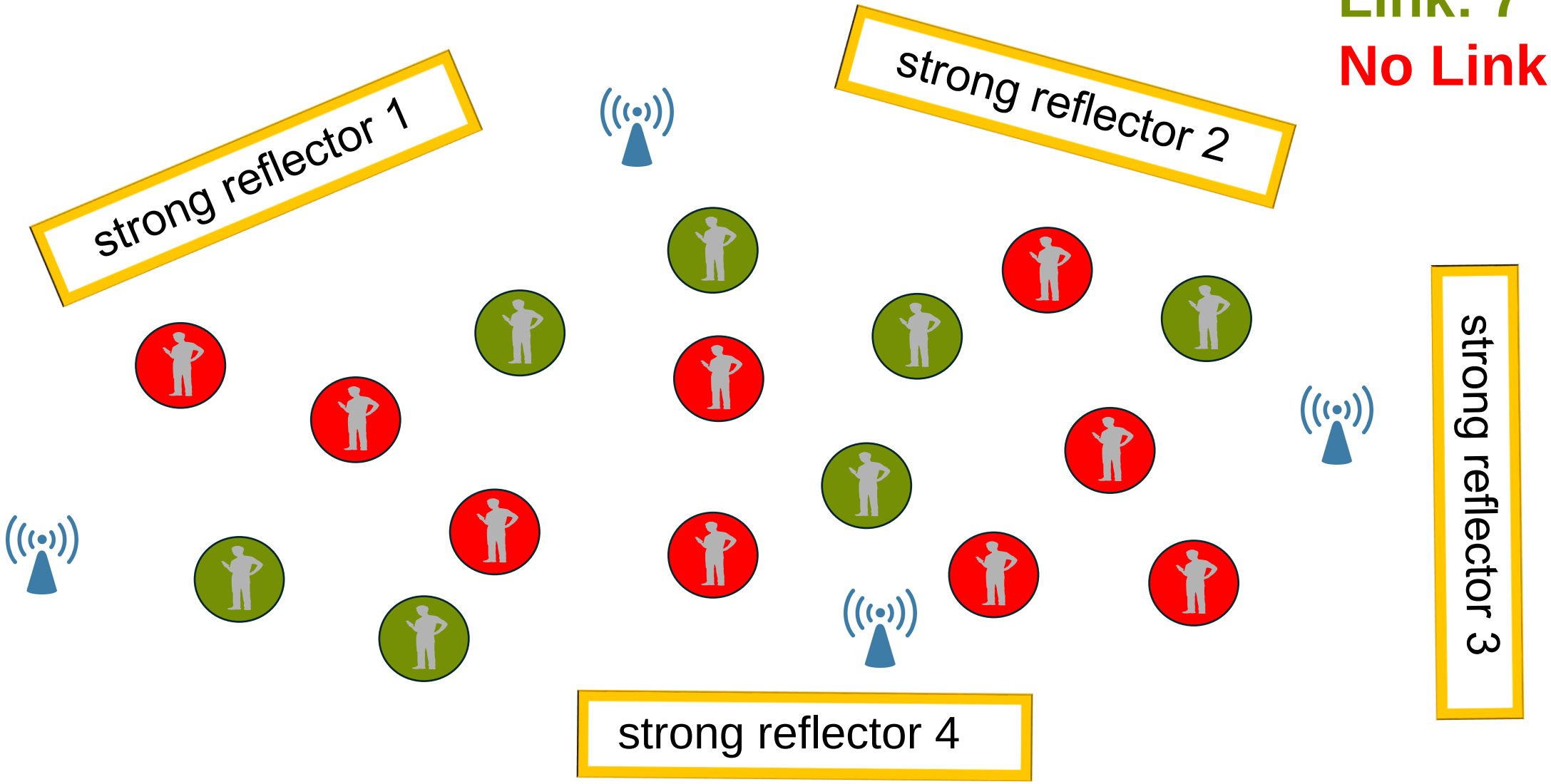
Effect of Multiple Picocell Location



Brute-Force Search?

Link: 7

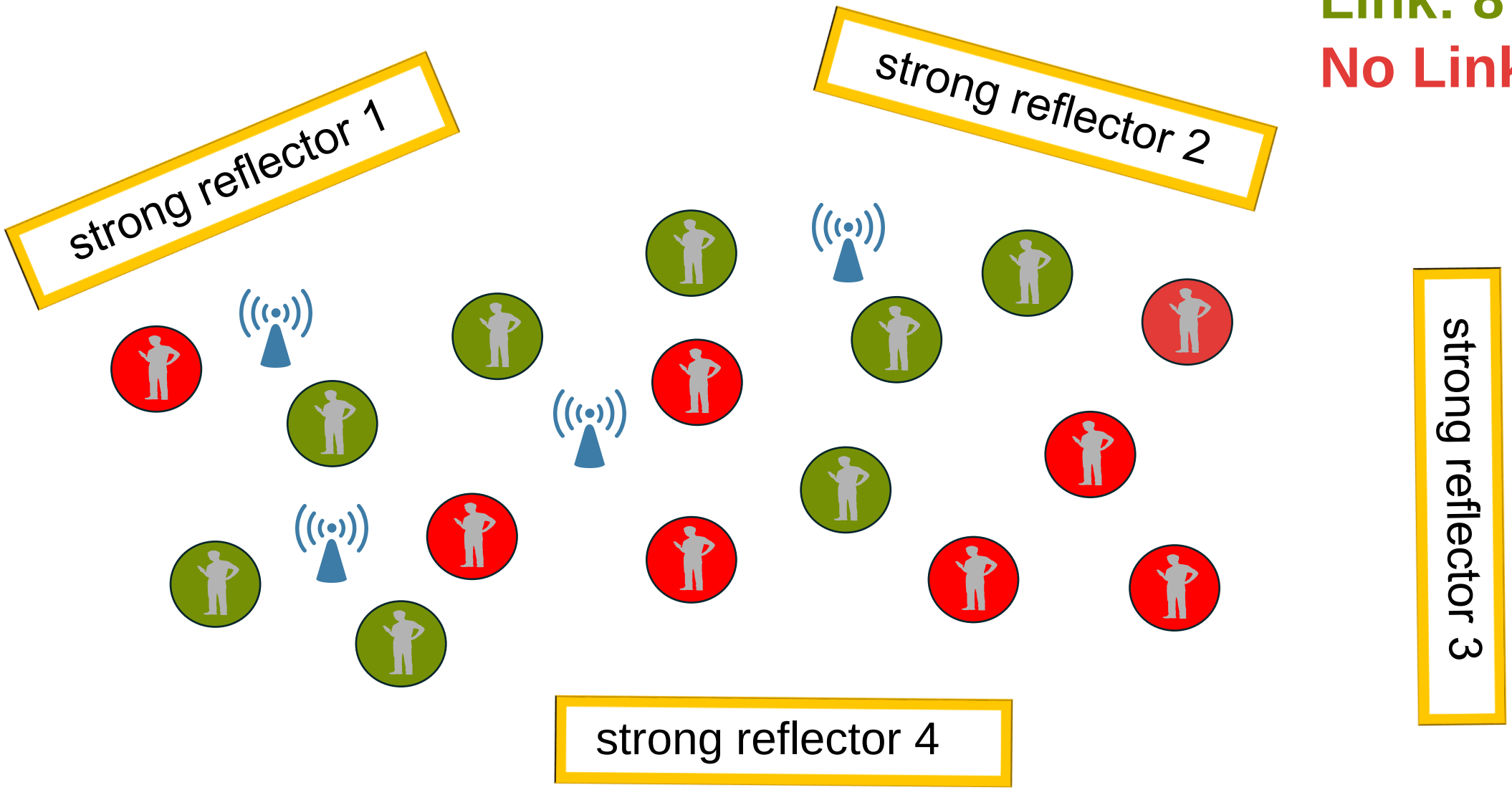
No Link: 8



Brute-Force Search?

Link: 8

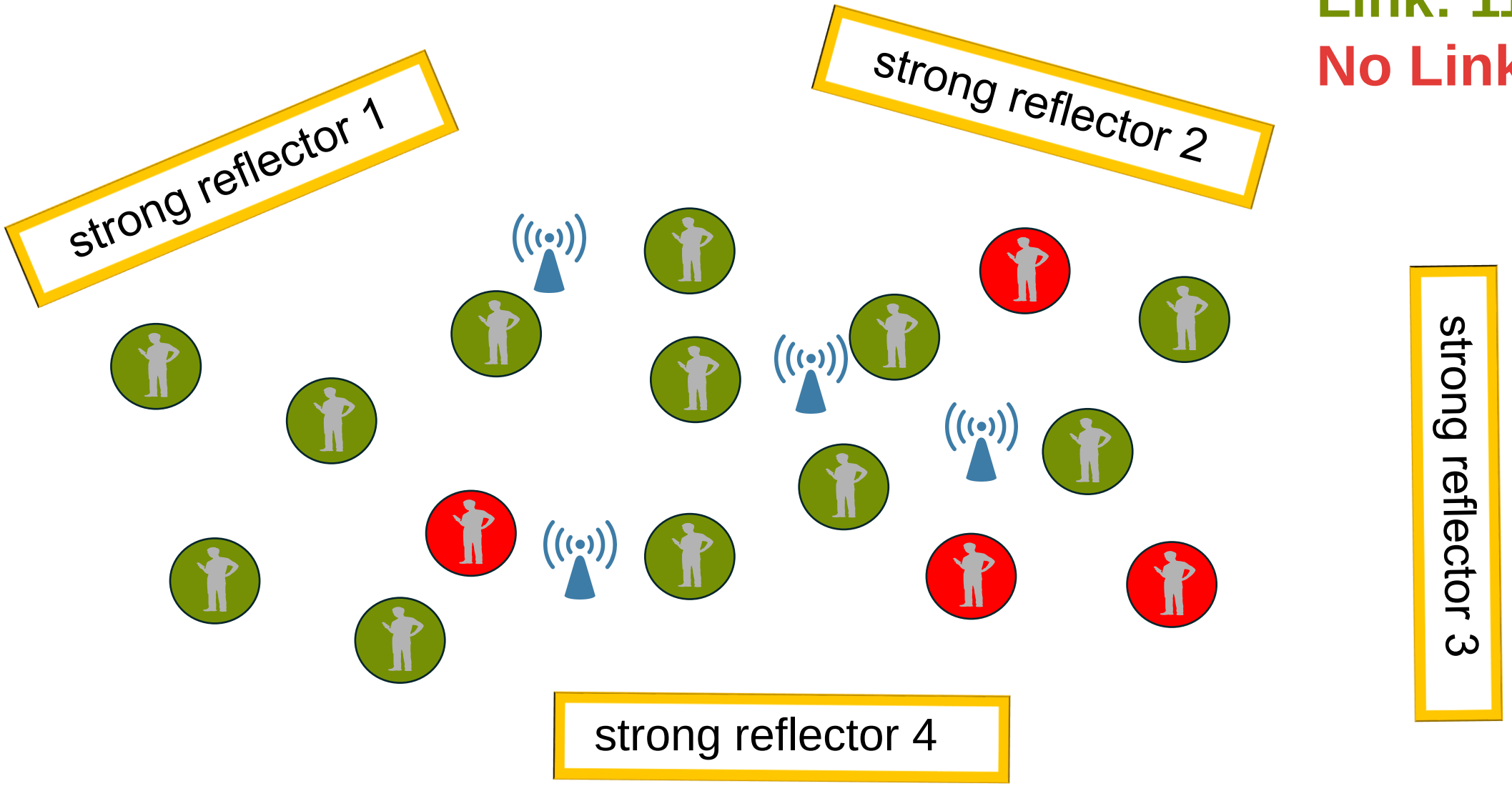
No Link: 7



Brute-Force Search?

Link: 11

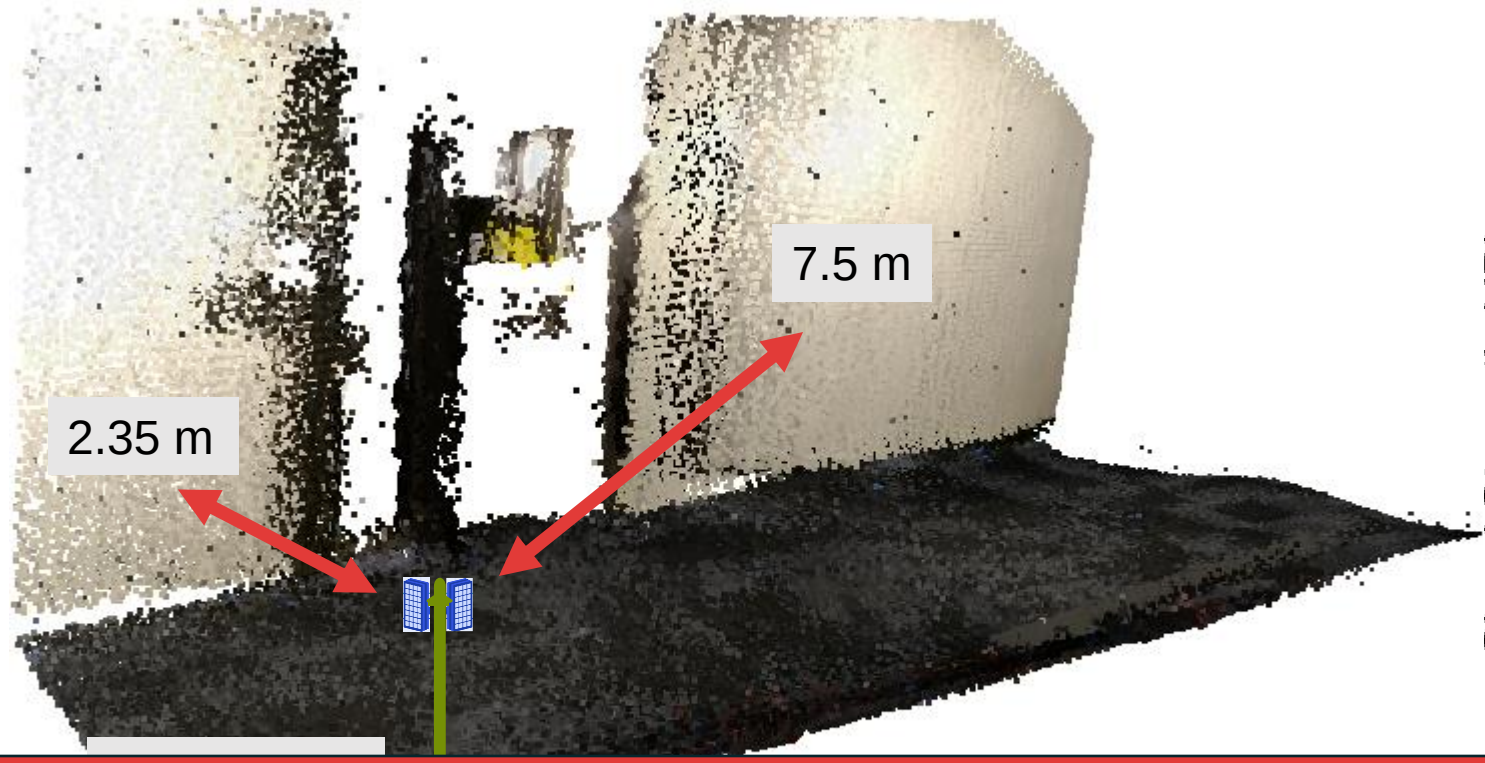
No Link: 4

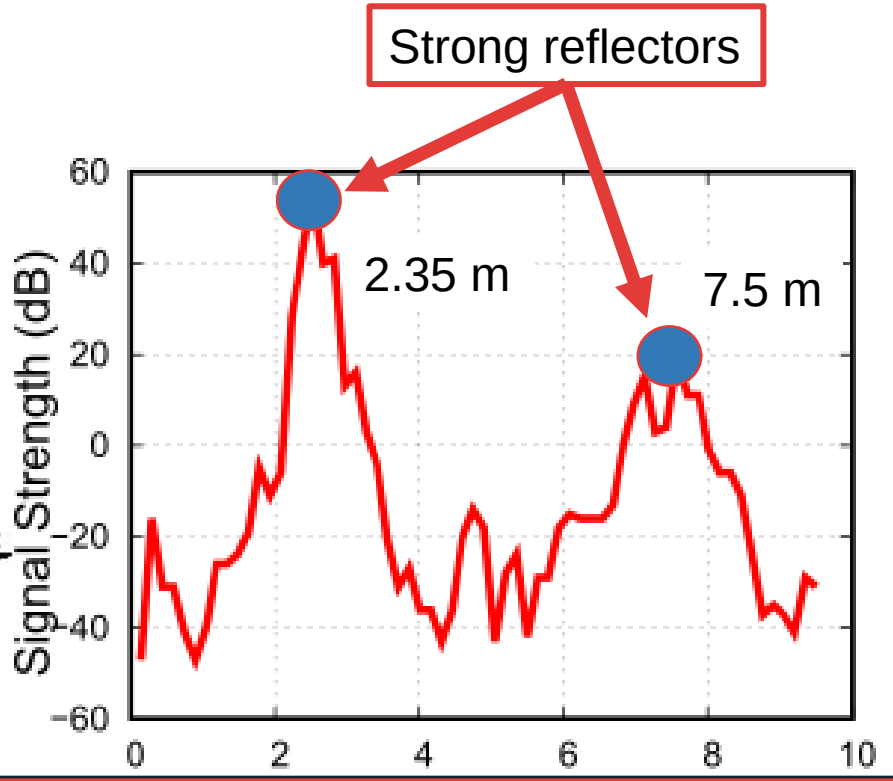


Understanding the Environment

How visual camera sees

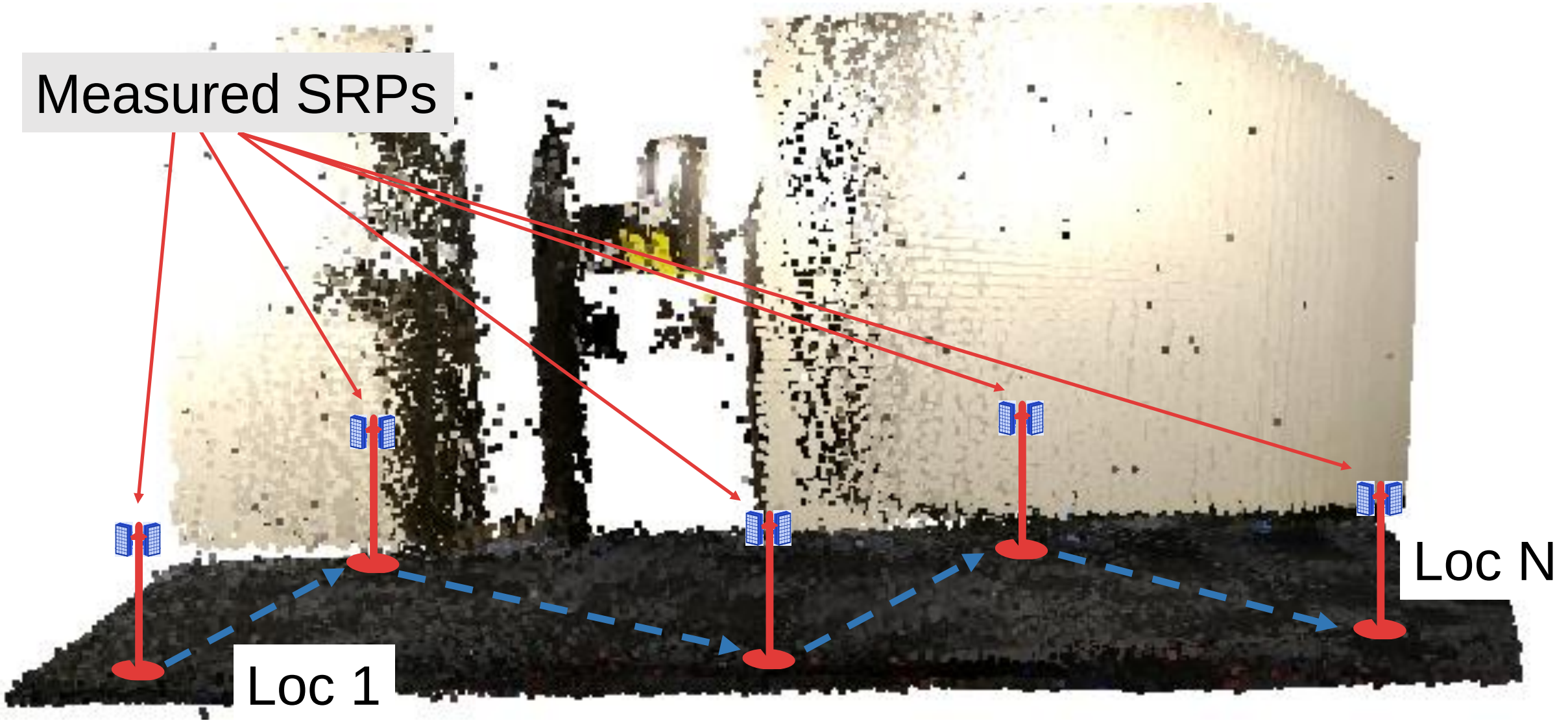
How mmWave device sees



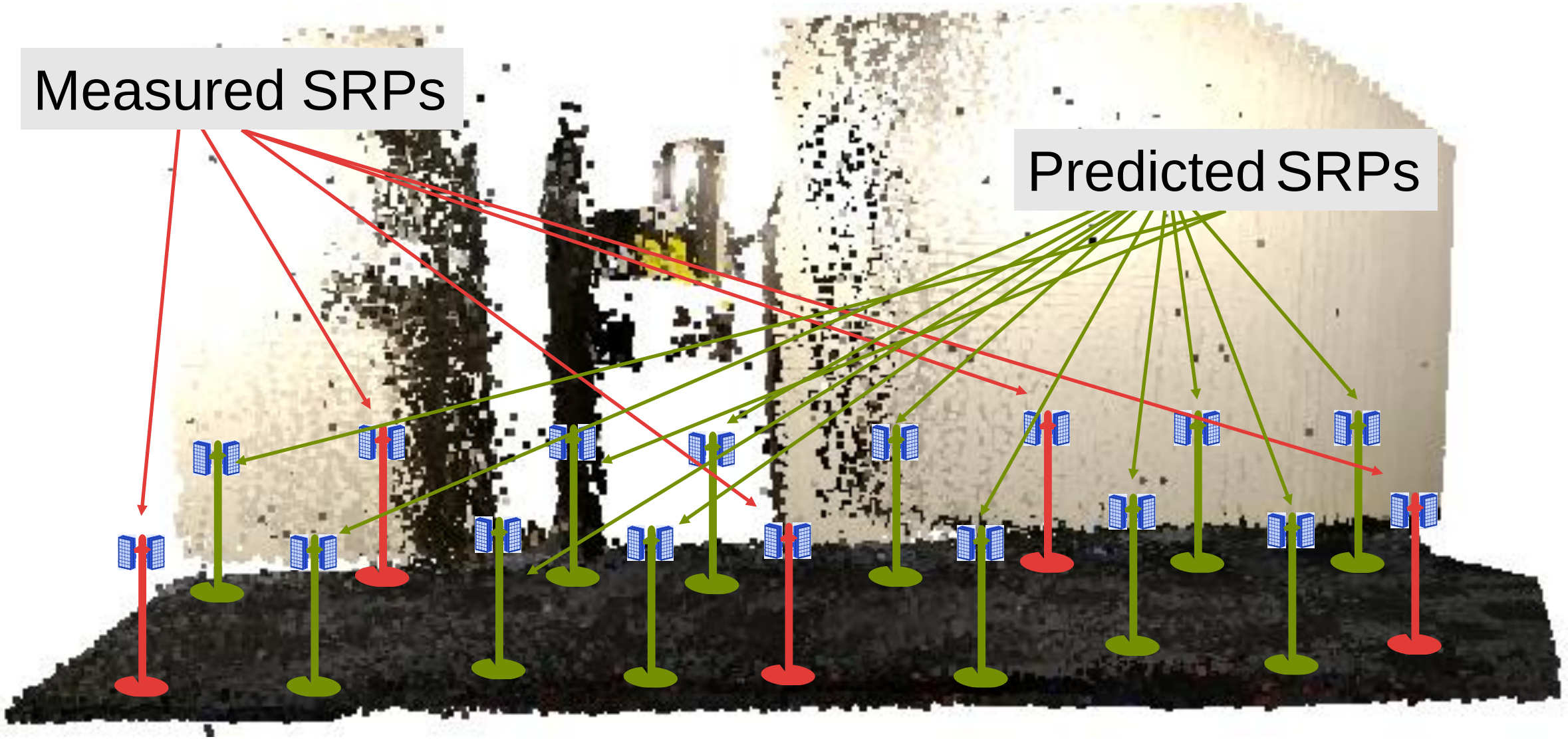


Can we use visual camera input to predict Signal Reflection Profile (SRP)?

Our Approach



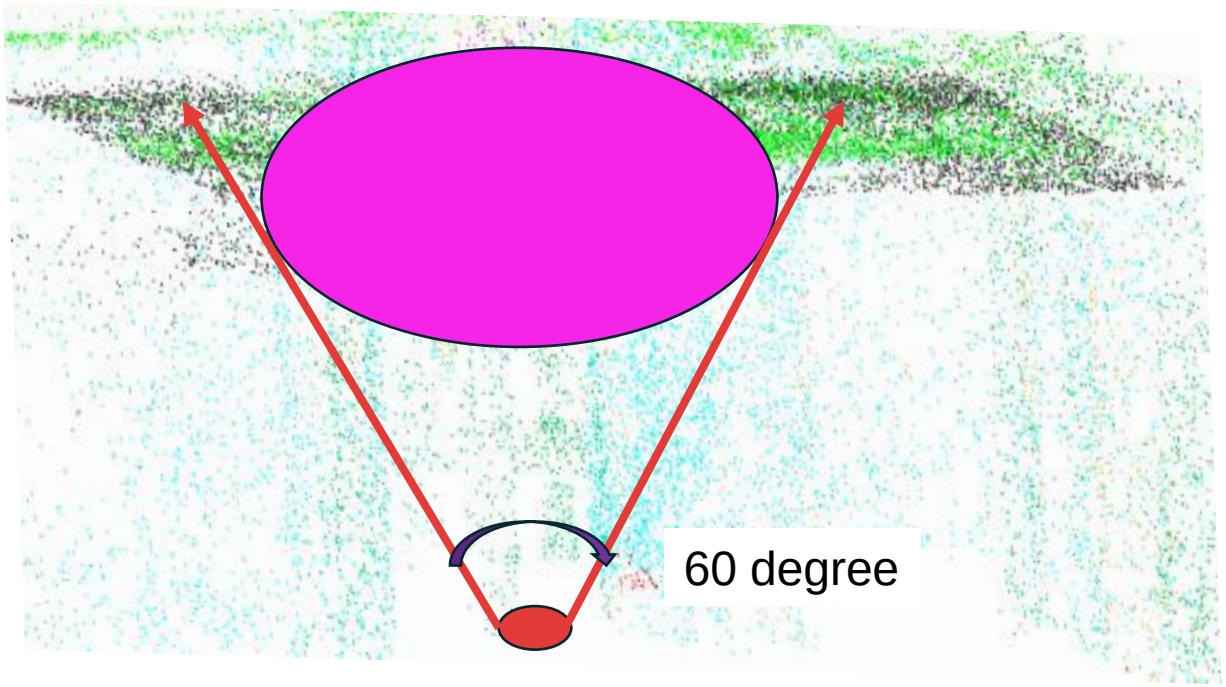
Our Approach

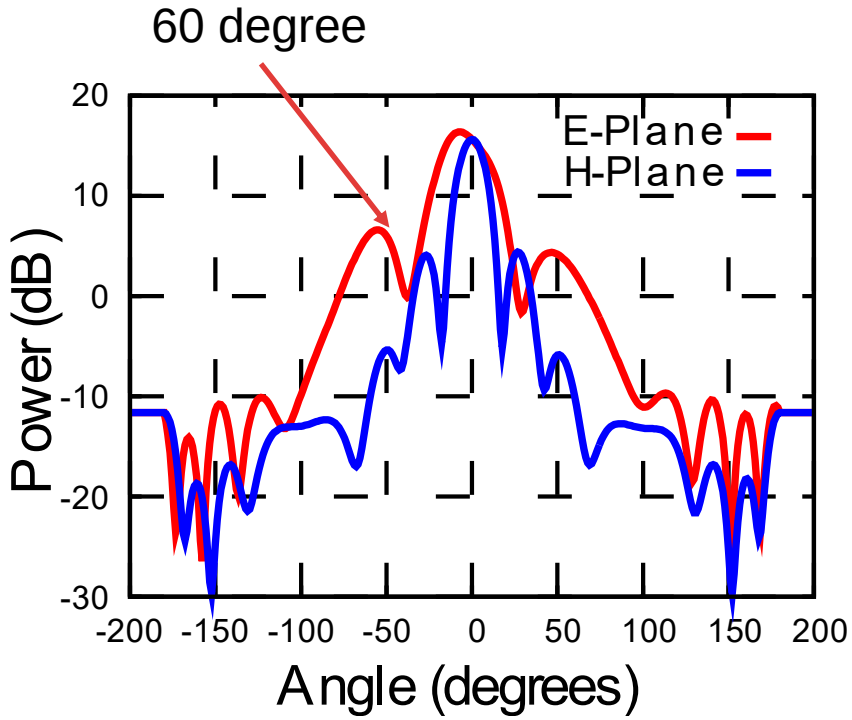


Challenges in Predicting SRP from Visual Data

1. Signal Reflection Profile (SRP) Prediction

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

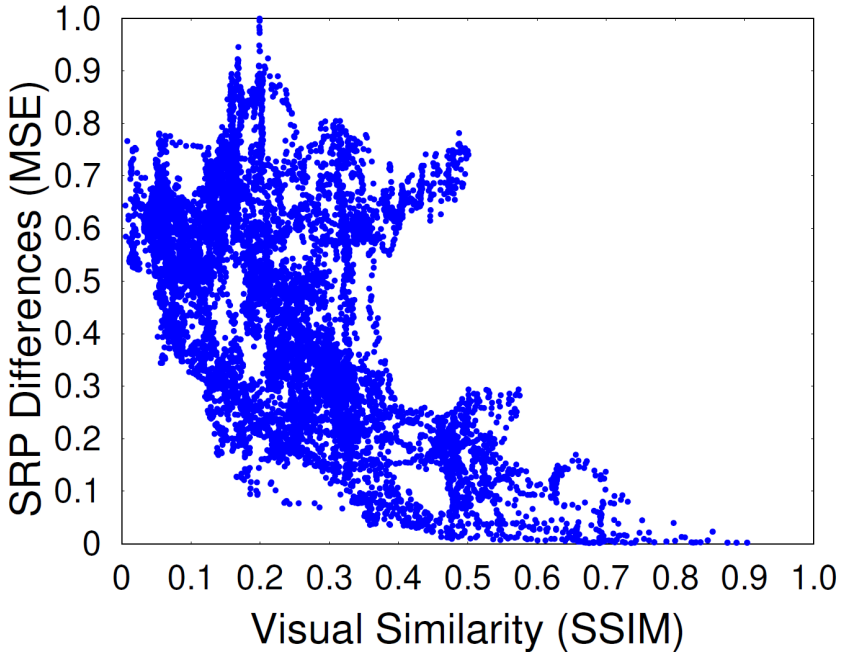




Challenges in Predicting SRP from Visual Data

1. Signal Reflection Profile Prediction

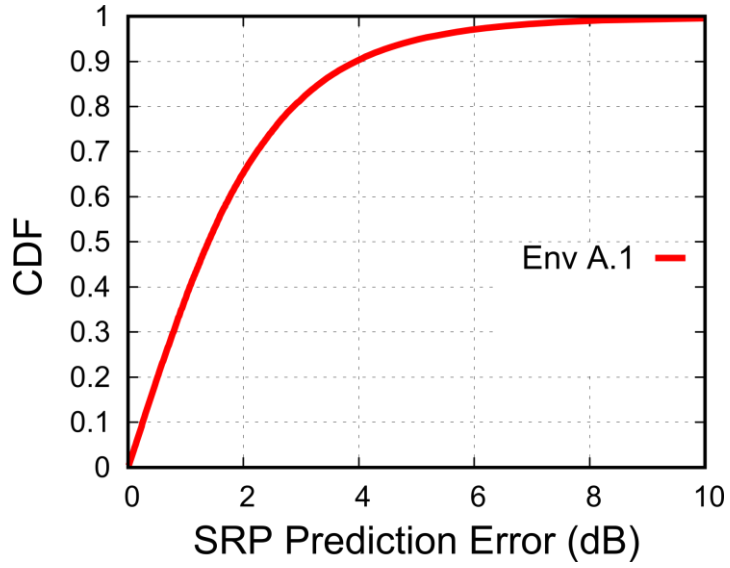
- ❑ Different Field-of-View of visual AR device and mmWave device
- ❑ Non-linearity between visual depth image and signal reflection profile

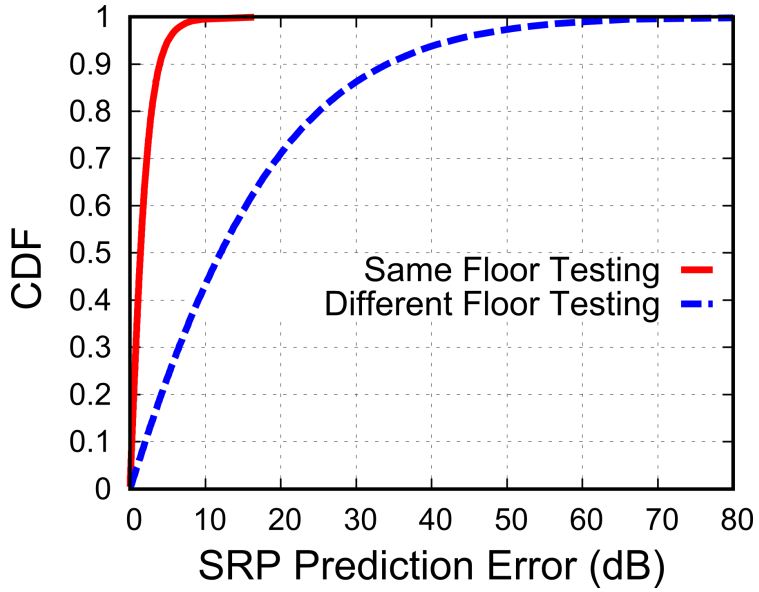


Challenges in Predicting SRP from Visual Data

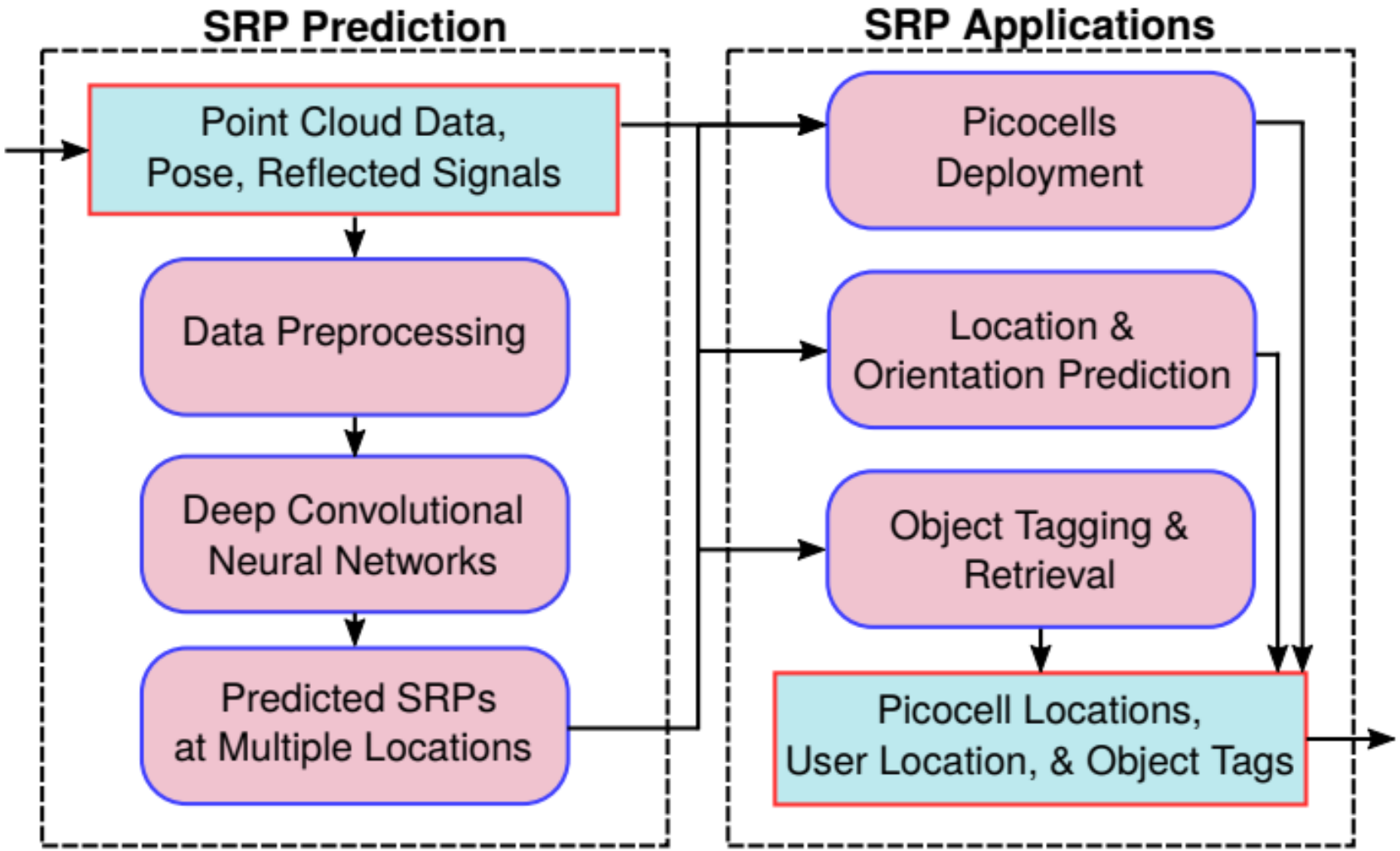
1. Signal Reflection Profile Prediction

- ❑ 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



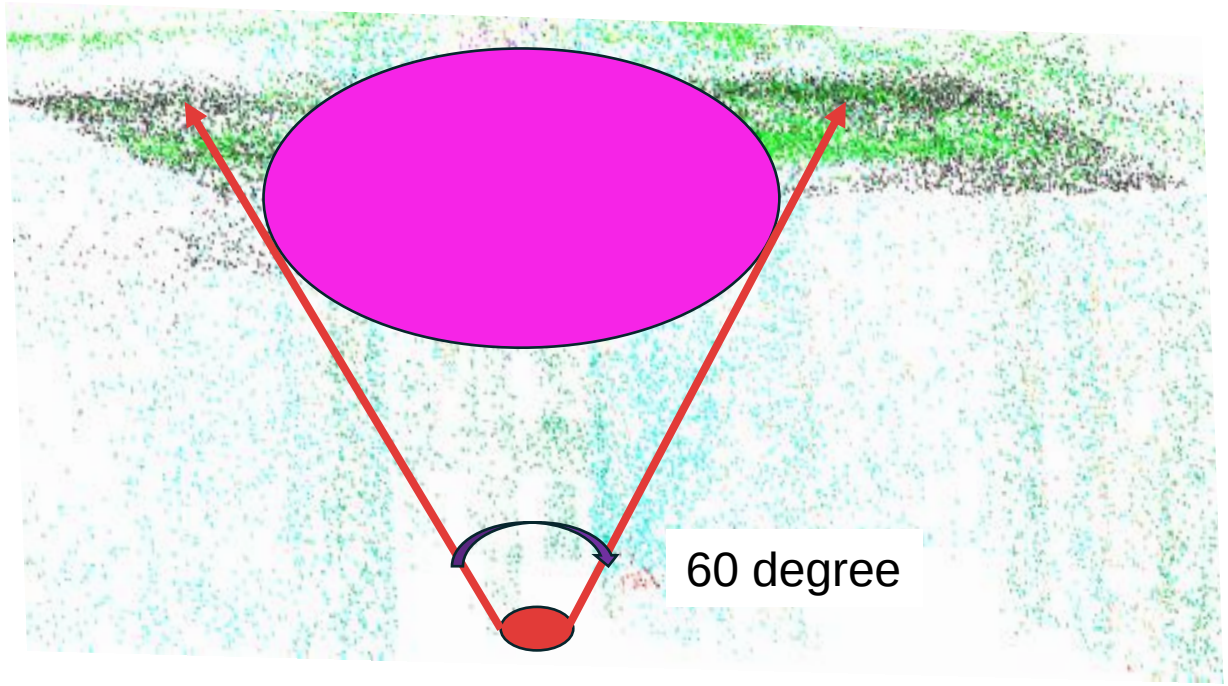


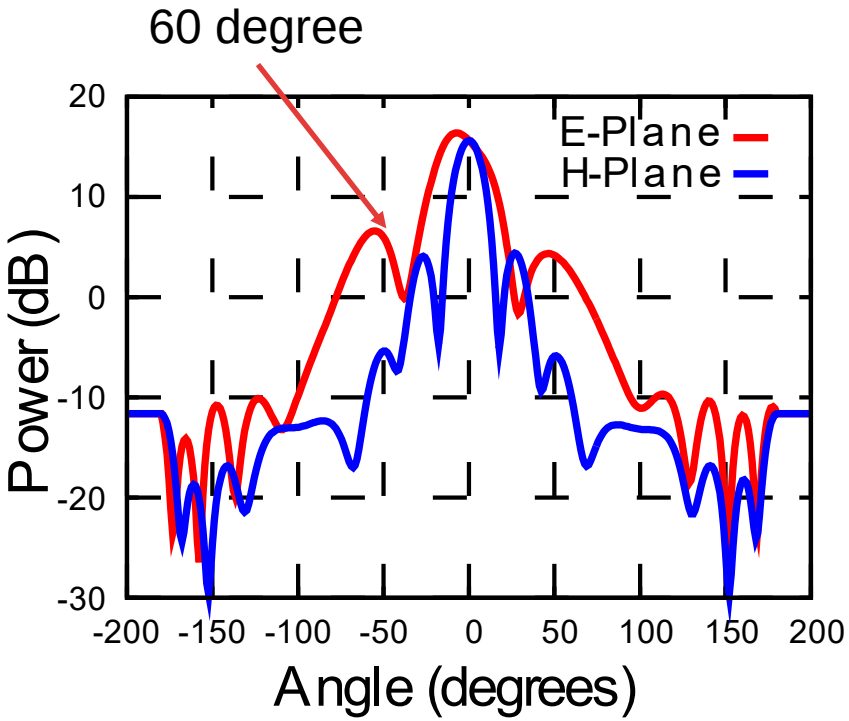
System Overview



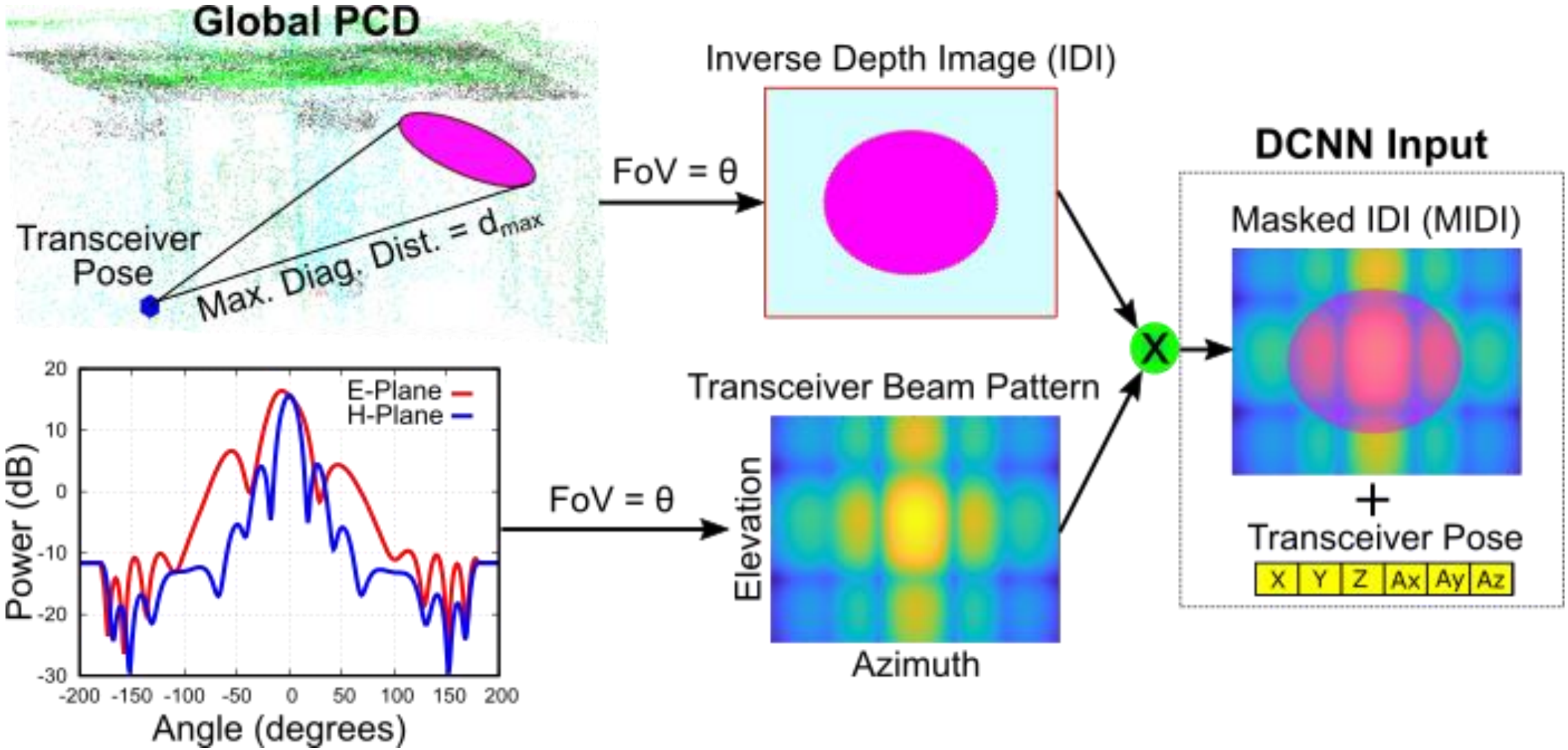
Different Field-of-View (FoV)

- mmWave device has limited FoV and does not see as much as visual AR device sees

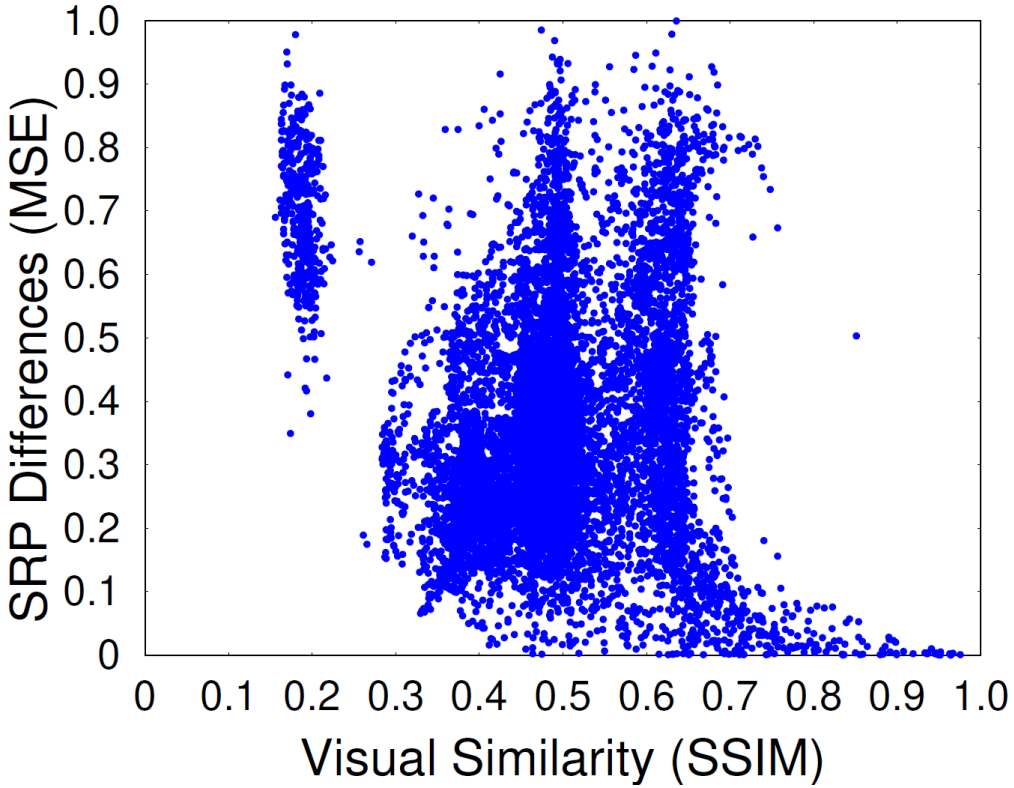


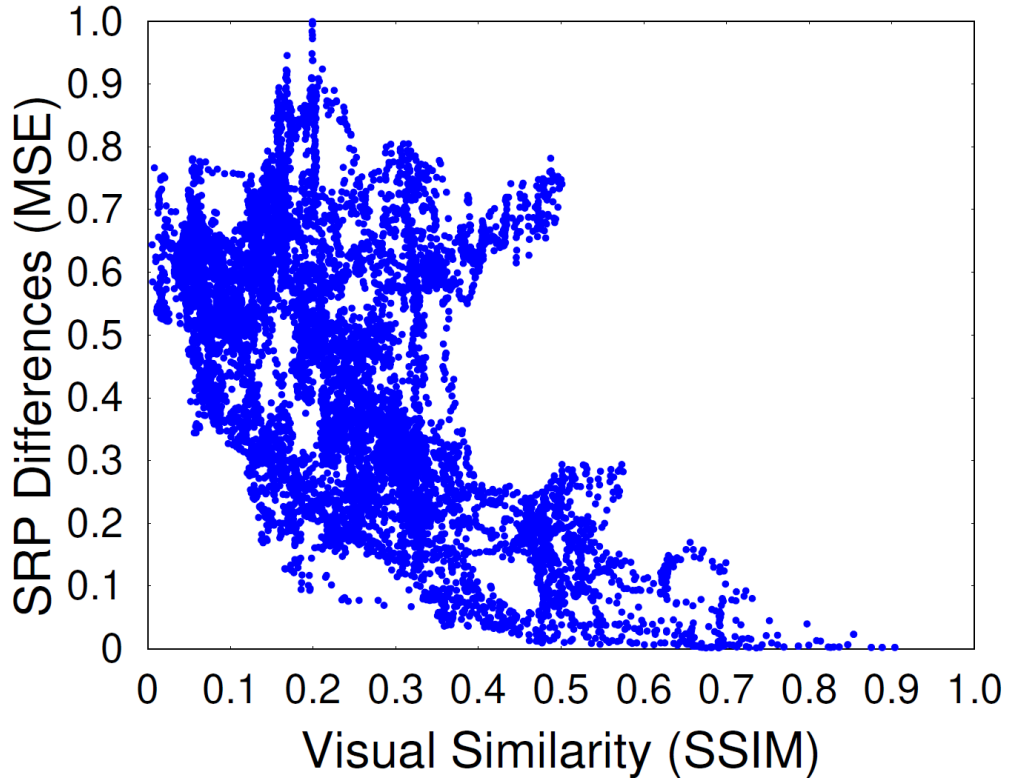


Different Field-of-View (FoV)



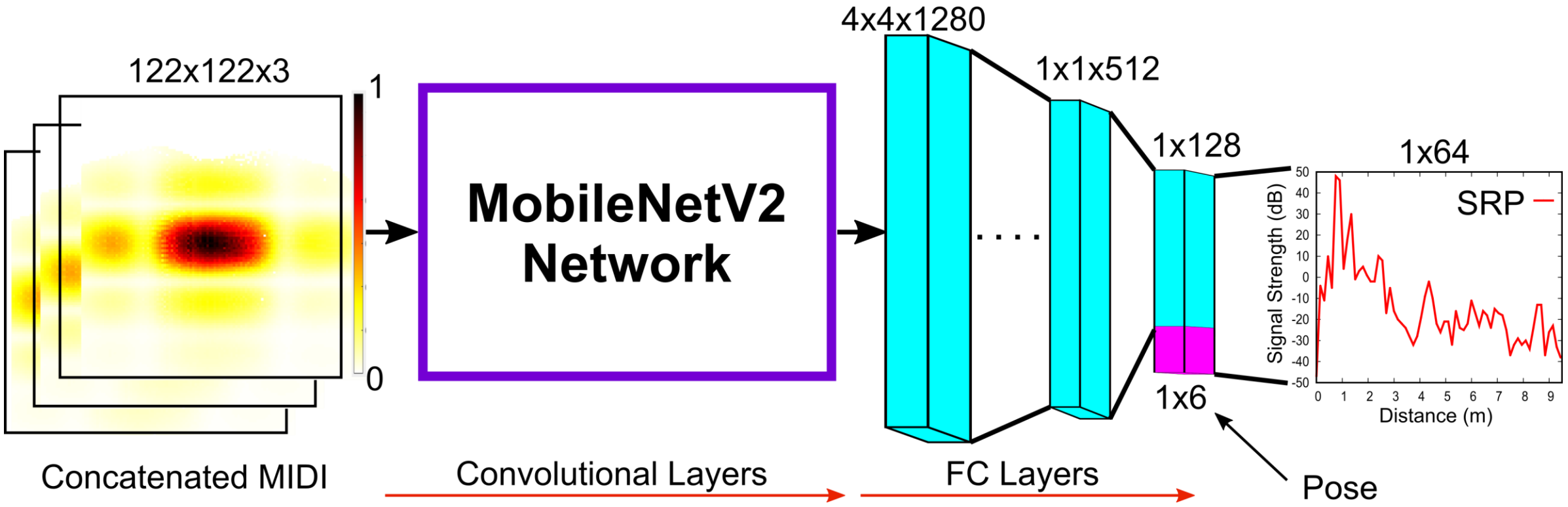
Non-Linear Relationship





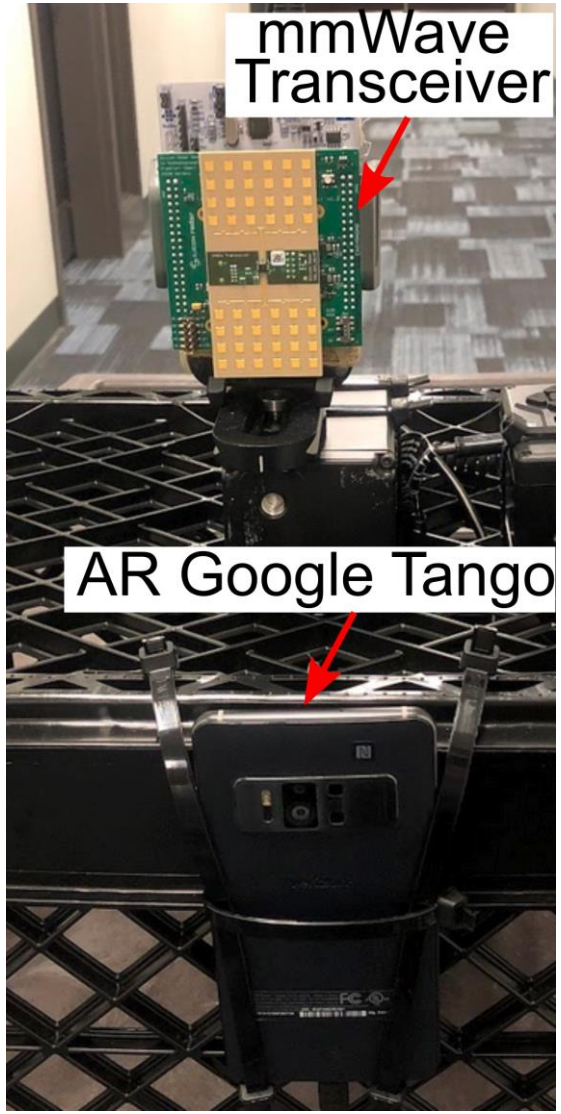
Visual data and SRP shows the non-linear relationship

Deep Learning Base Model



https://openaccess.thecvf.com/content_cvpr_2018/papers/Sandler_MobileNetV2_Inverted_Residuals_CVPR_2018_paper.pdf

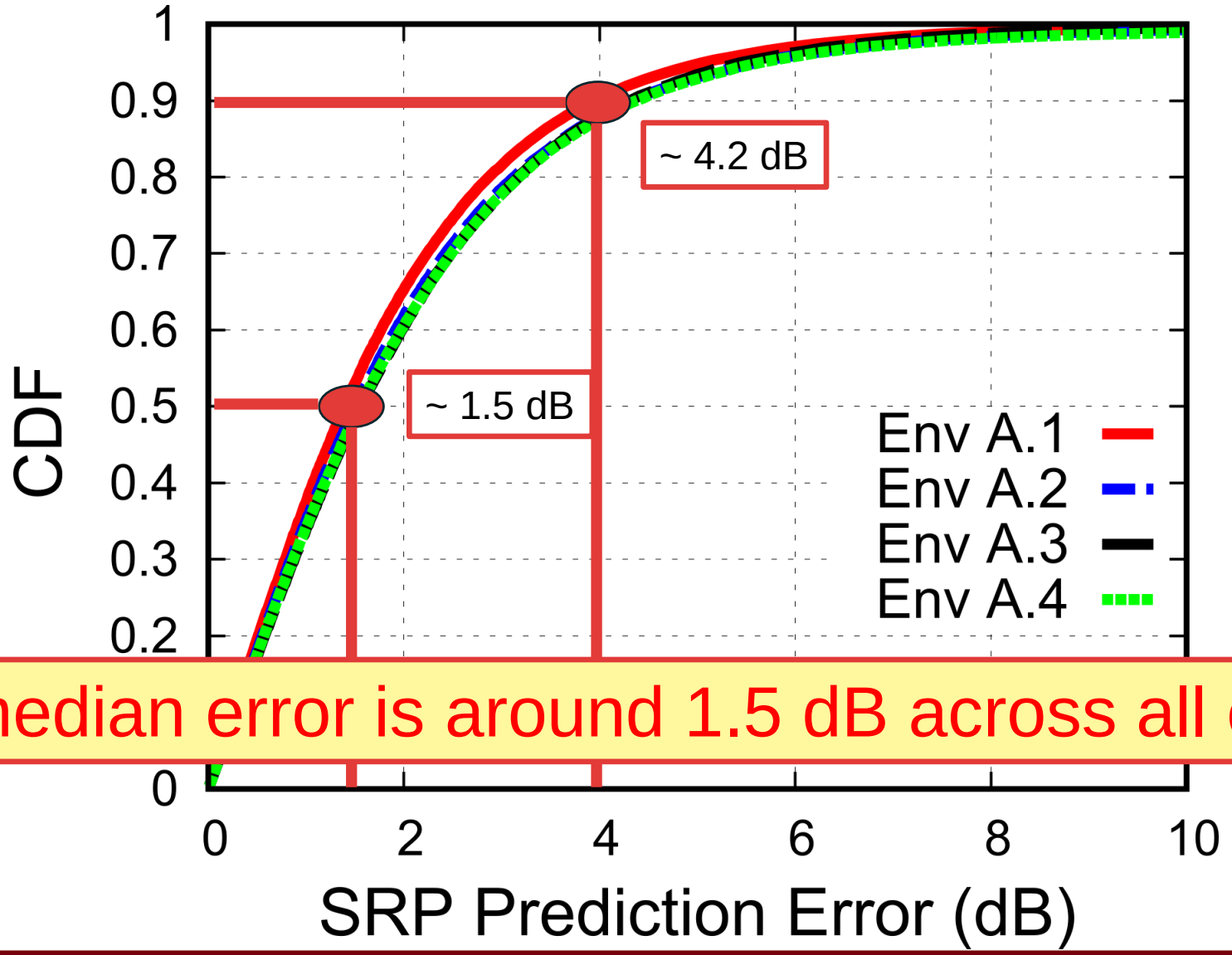
Data Collection Platform



- ❑ Center Freq. 24 GHz
- ❑ Bandwidth: 1 GHz
- ❑ AR Google Tango

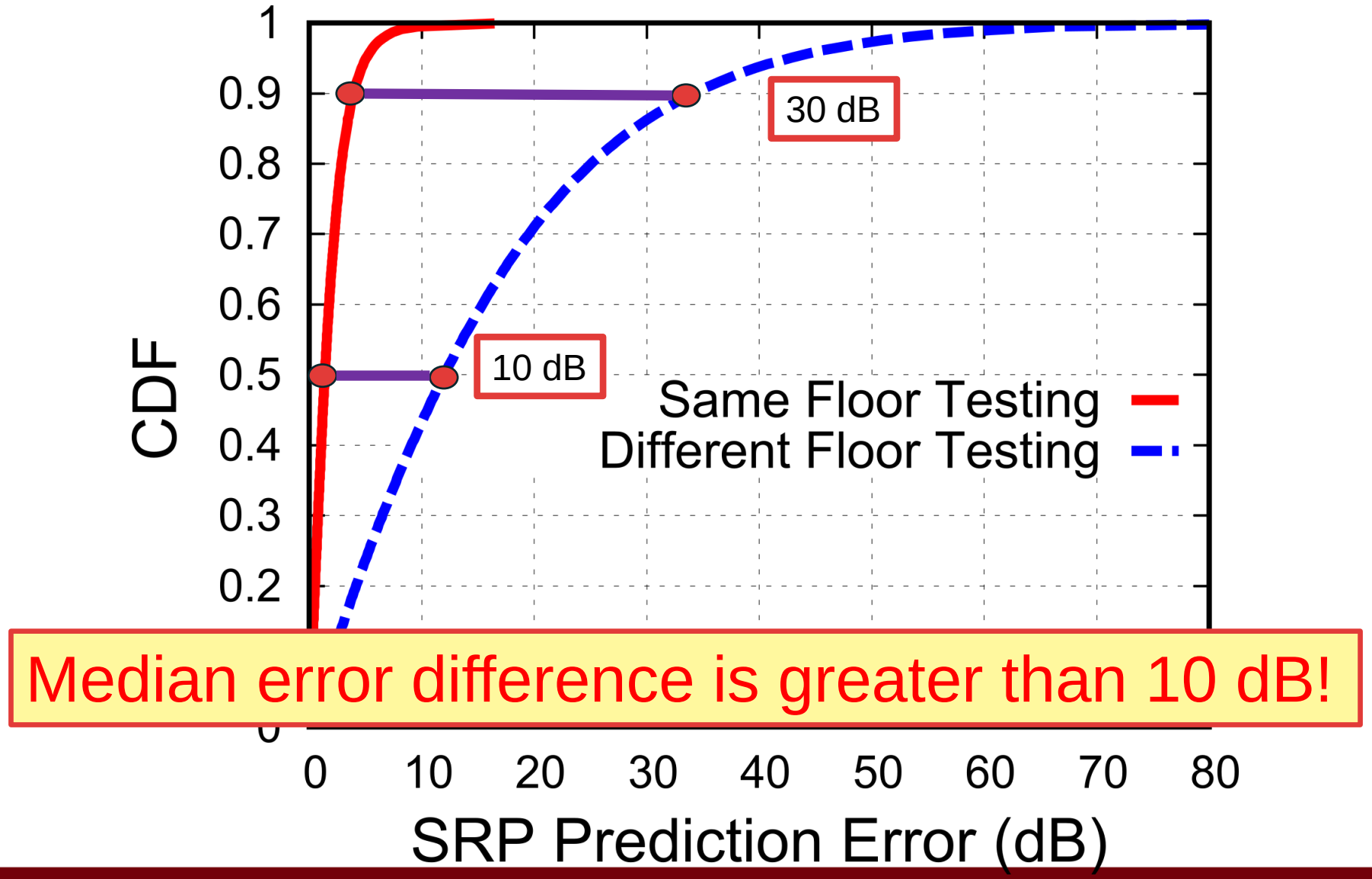
- ❑ 1.1 million data samples
- ❑ 16 diverse environments
- ❑ 280 K for training
- ❑ 812 K for testing

Base Model Results



Average median error is around 1.5 dB across all environments

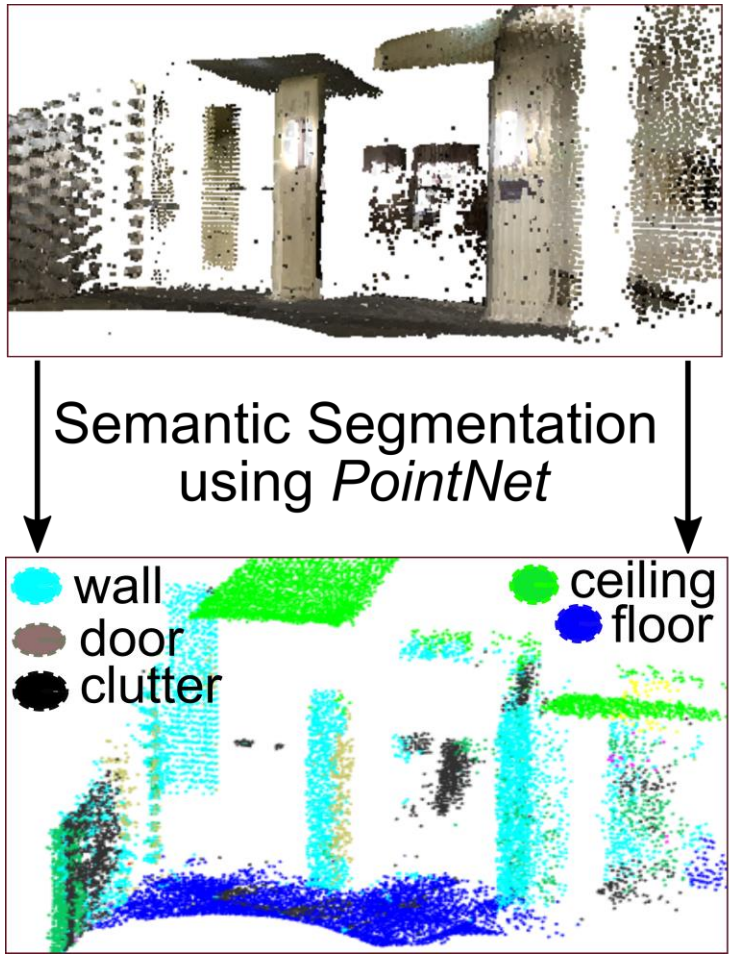
Inaccurate Transfer-Learning



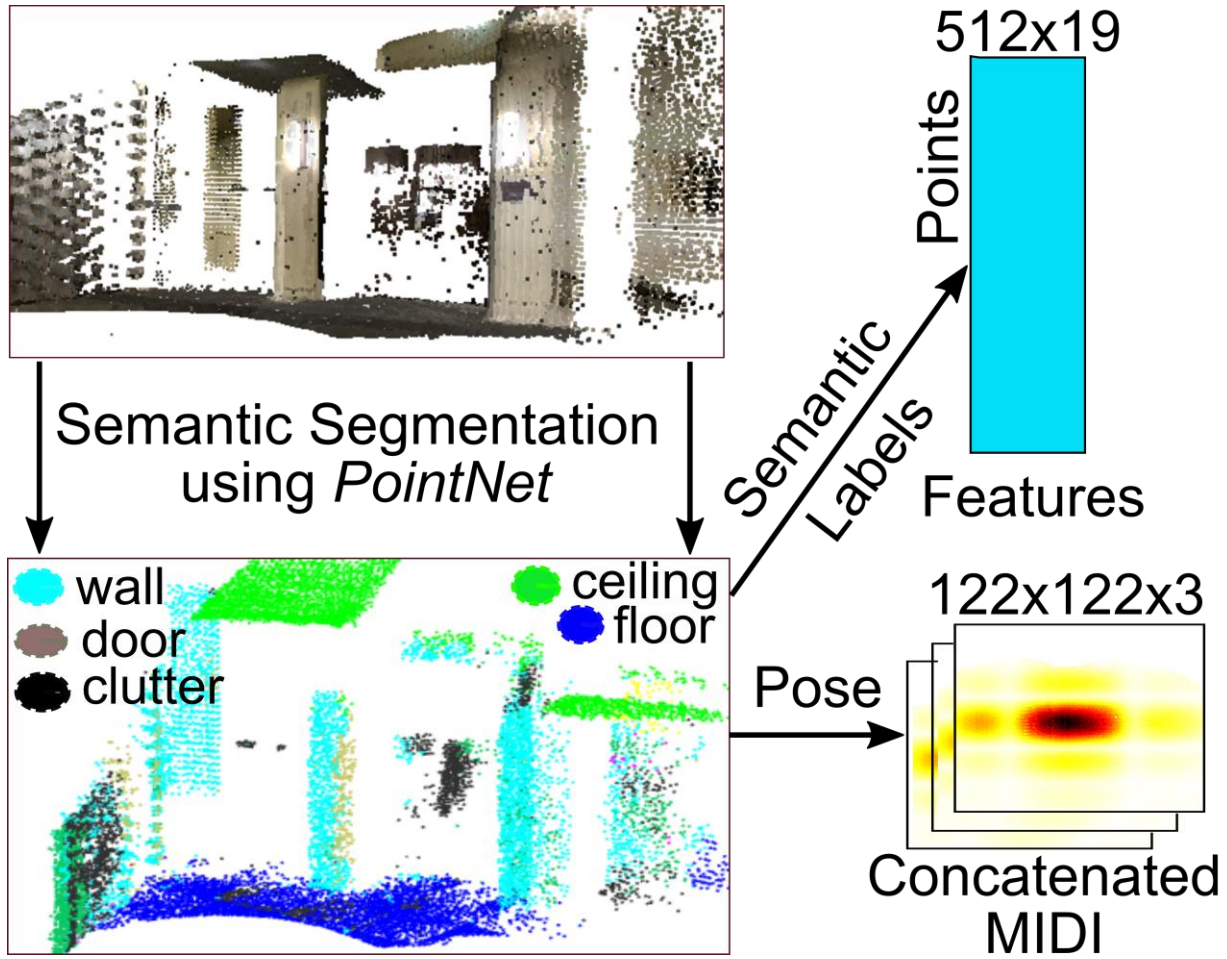
Median error difference is greater than 10 dB!

Semantic Aware Design

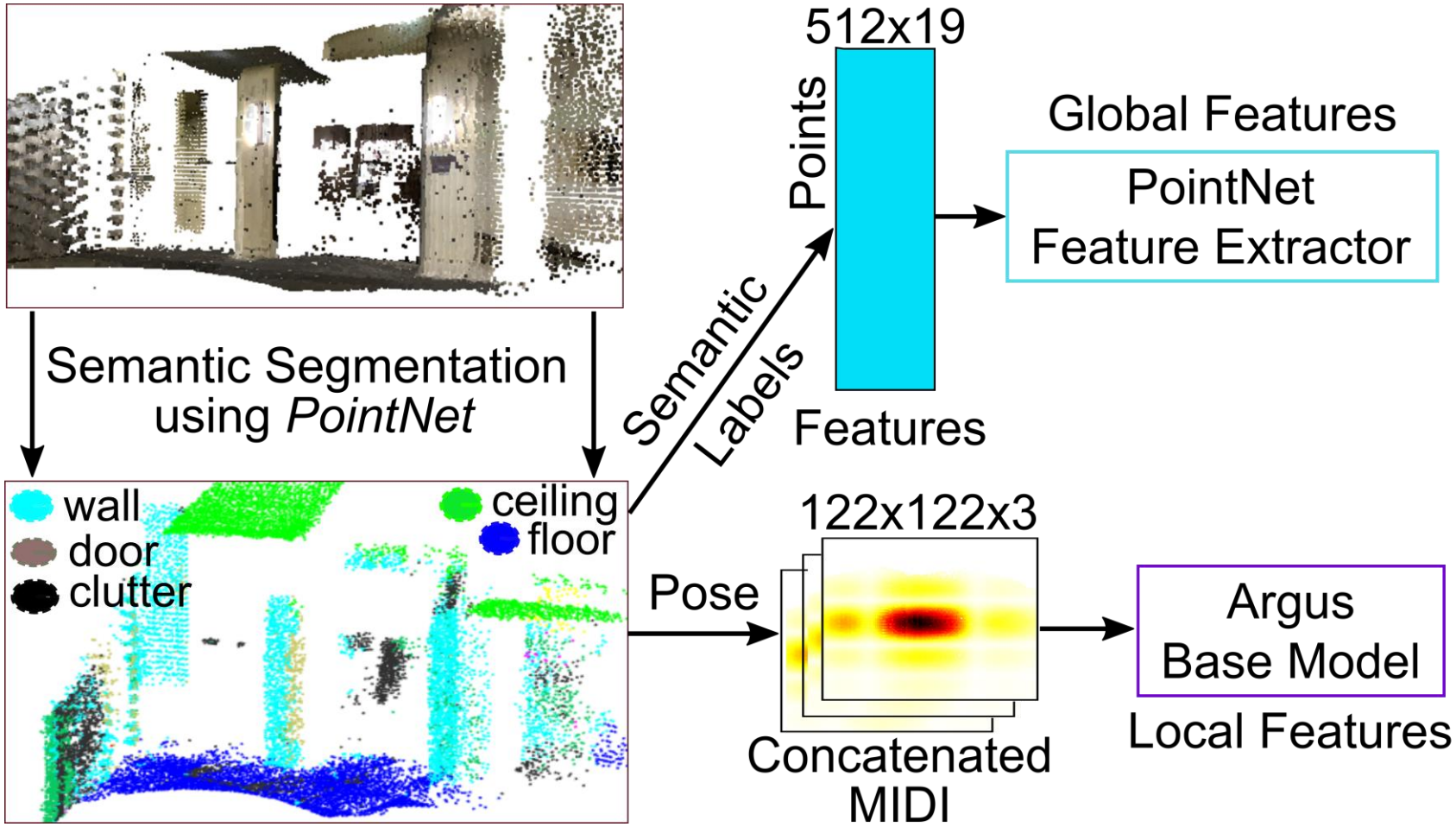
Semantic Aware Design



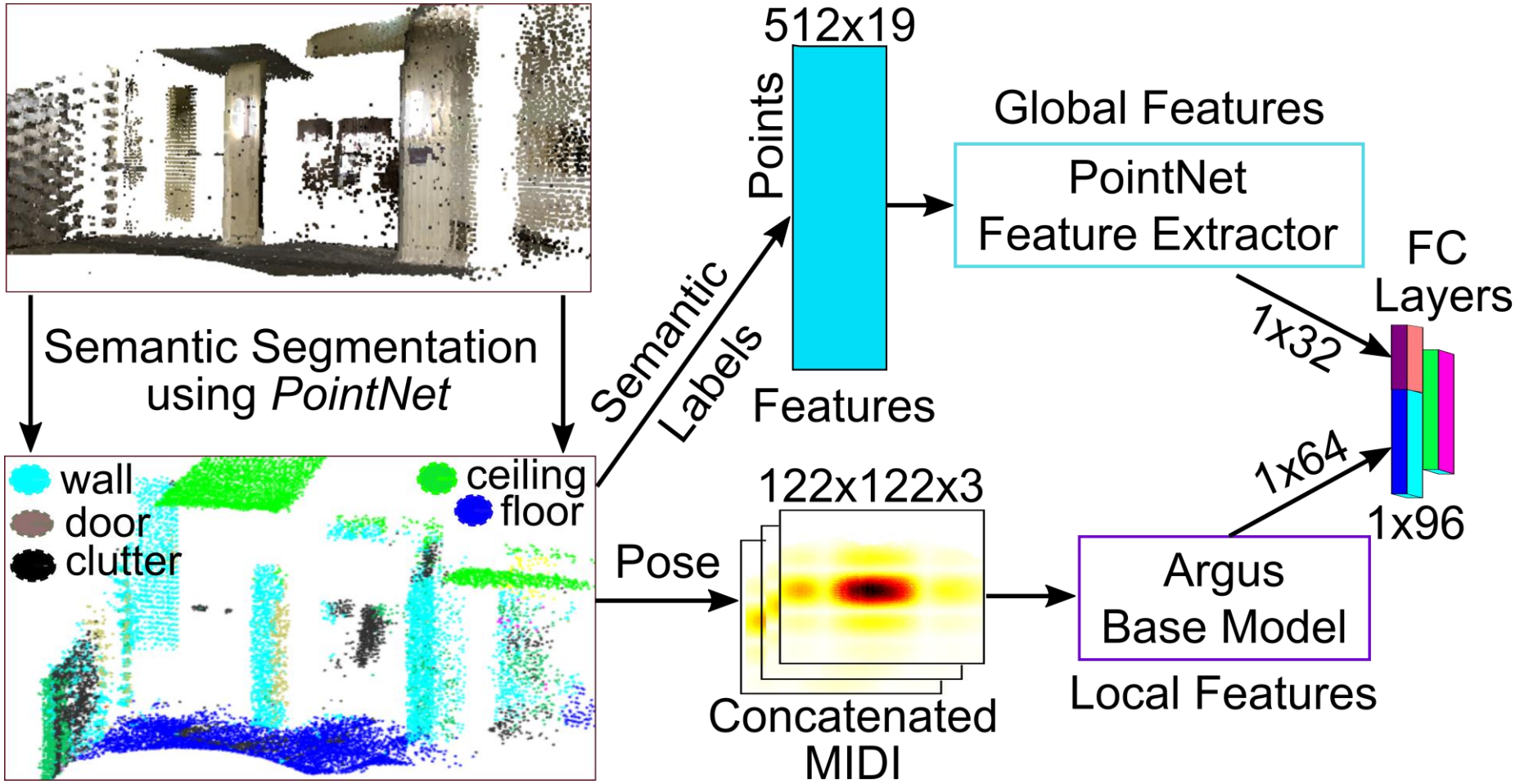
Semantic Aware Design



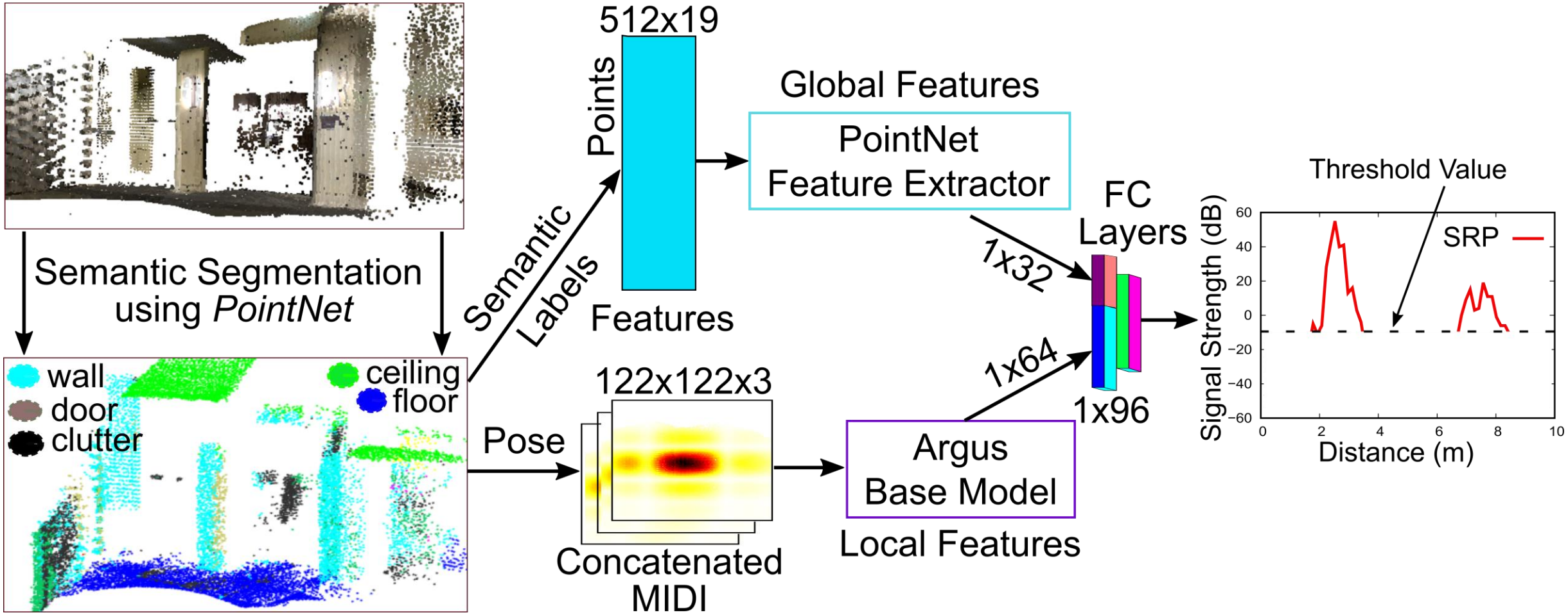
Semantic Aware Design



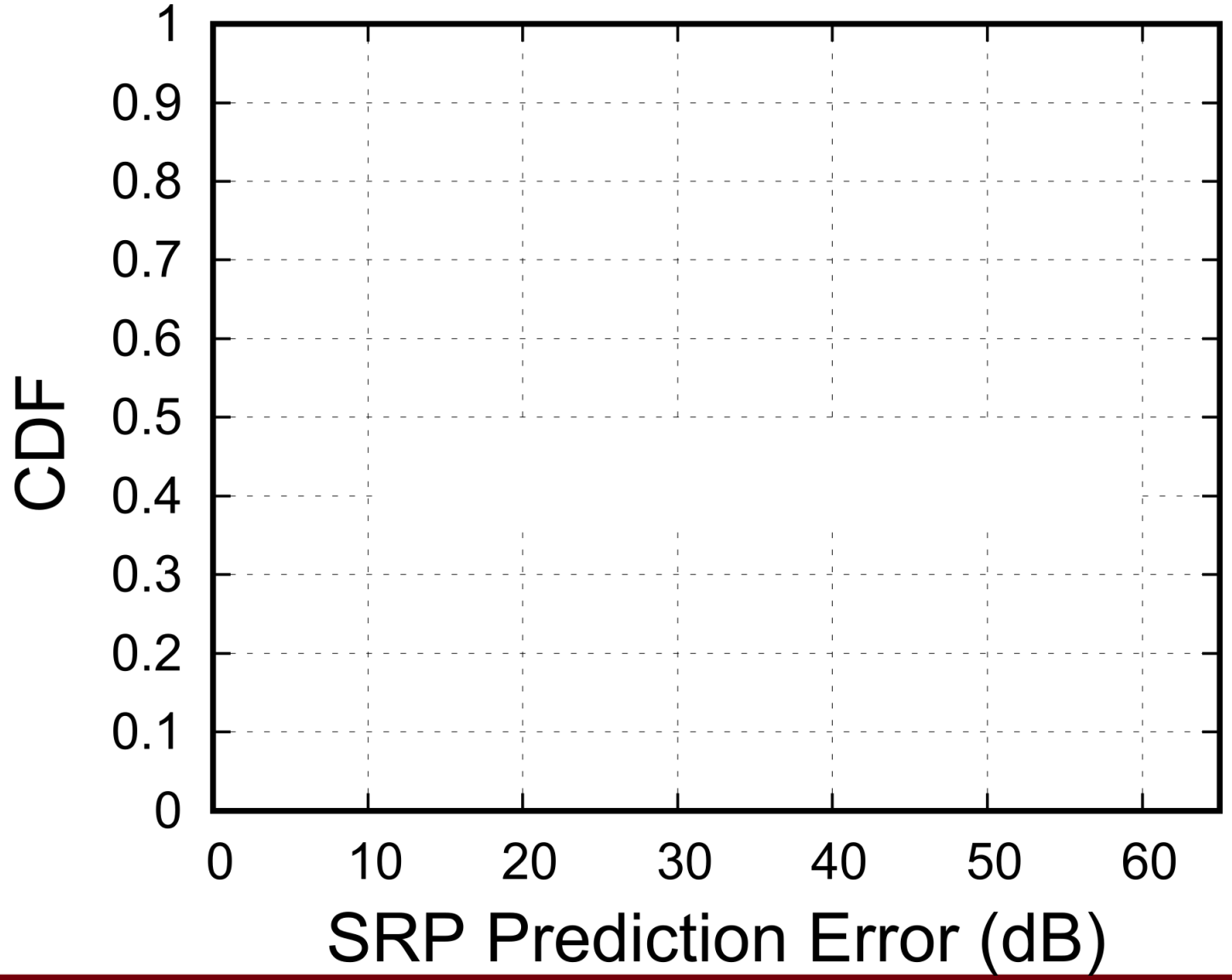
Semantic Aware Design



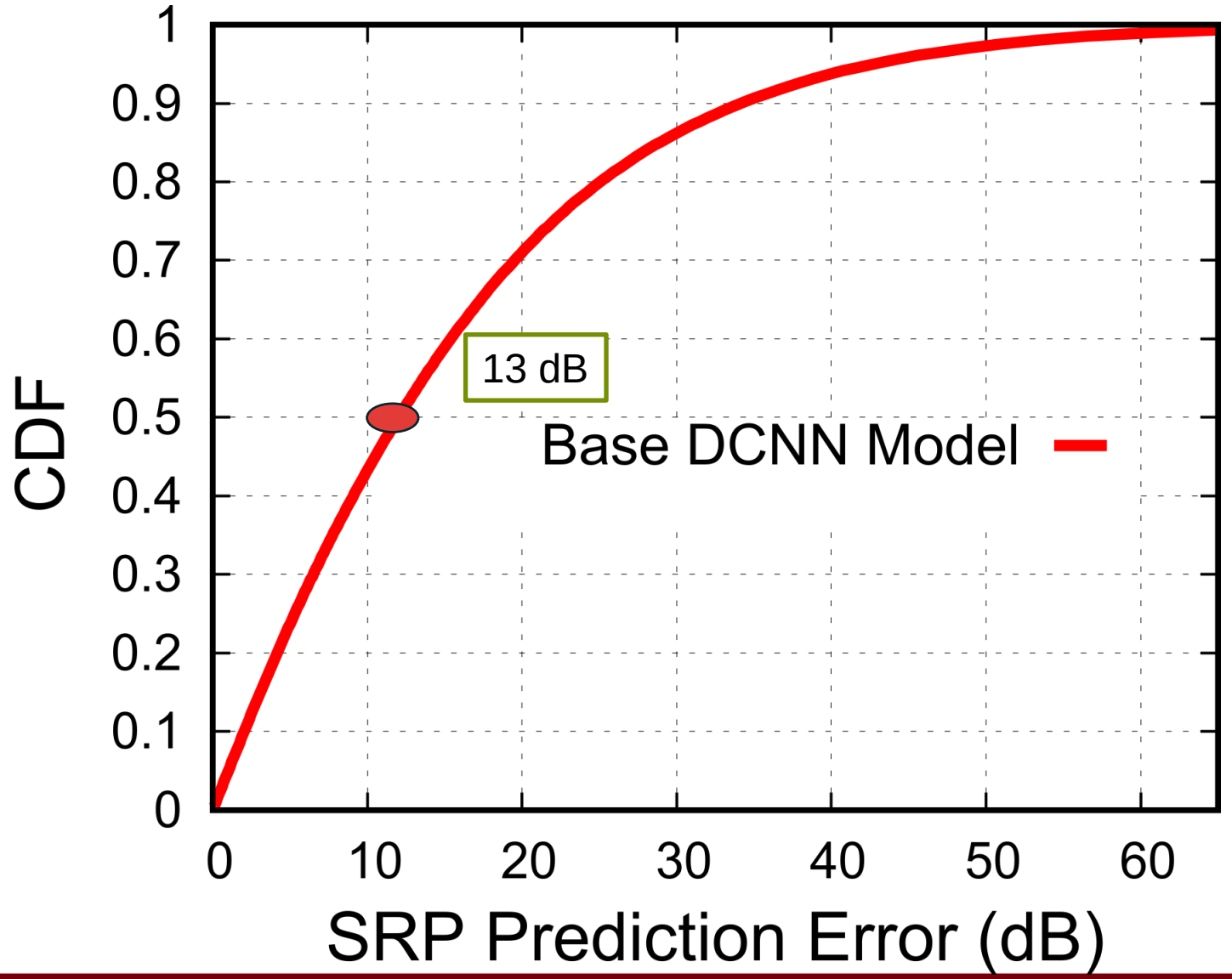
Semantic Aware Design



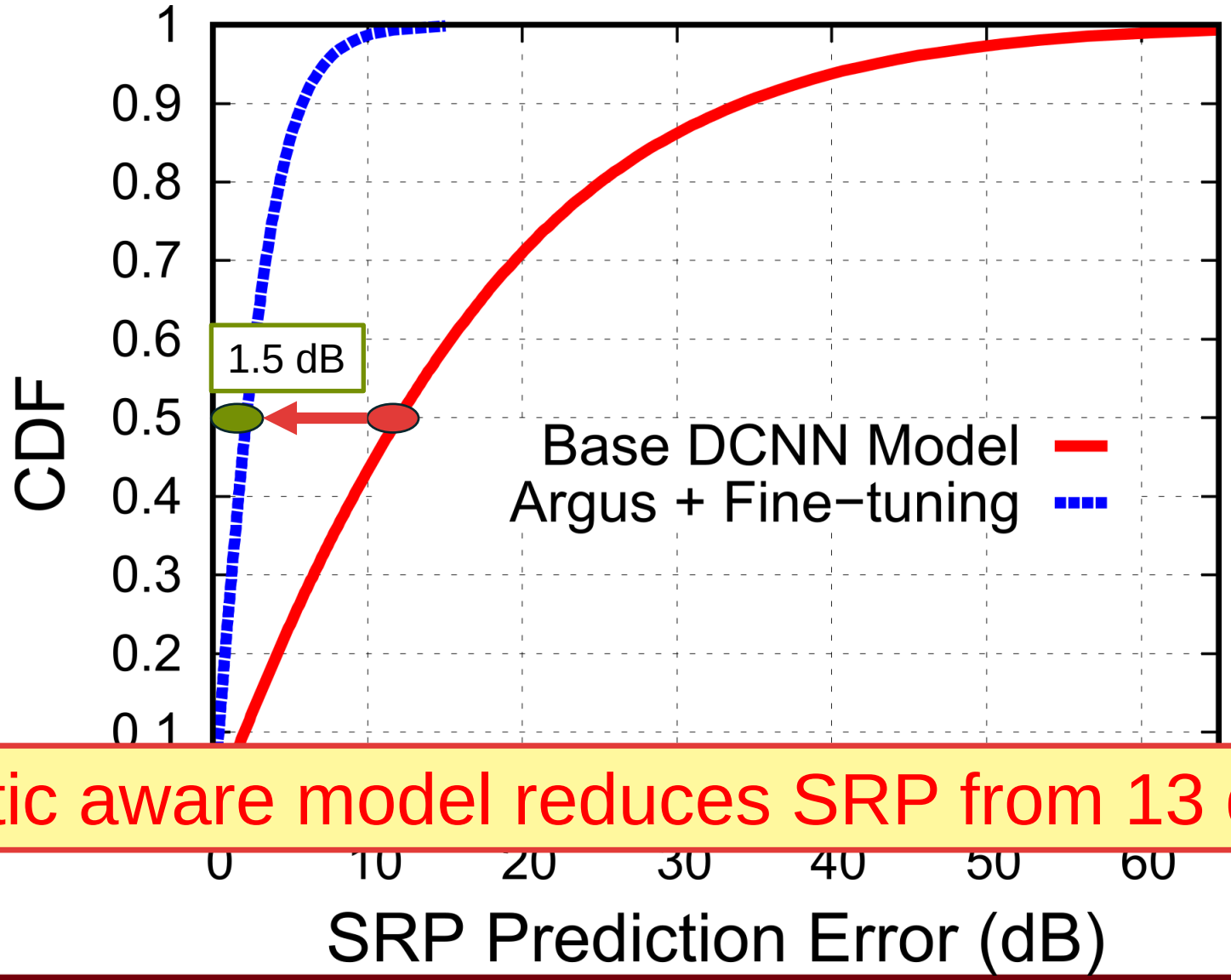
SRP Improvement



SRP Improvement



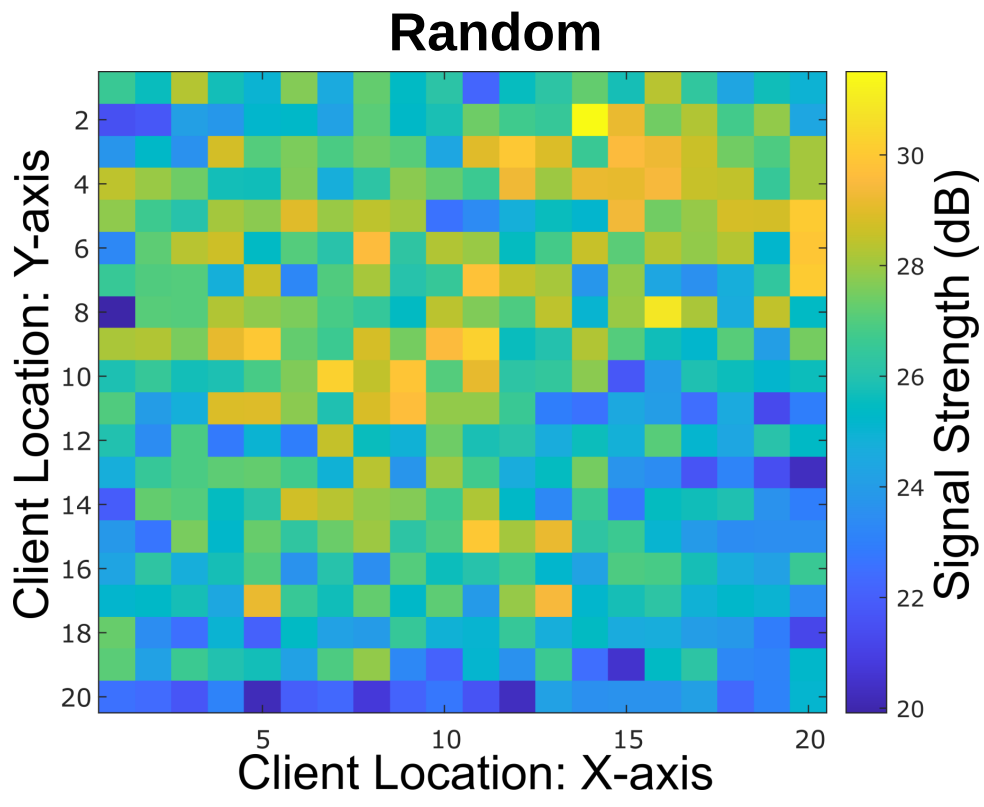
SRP Improvement



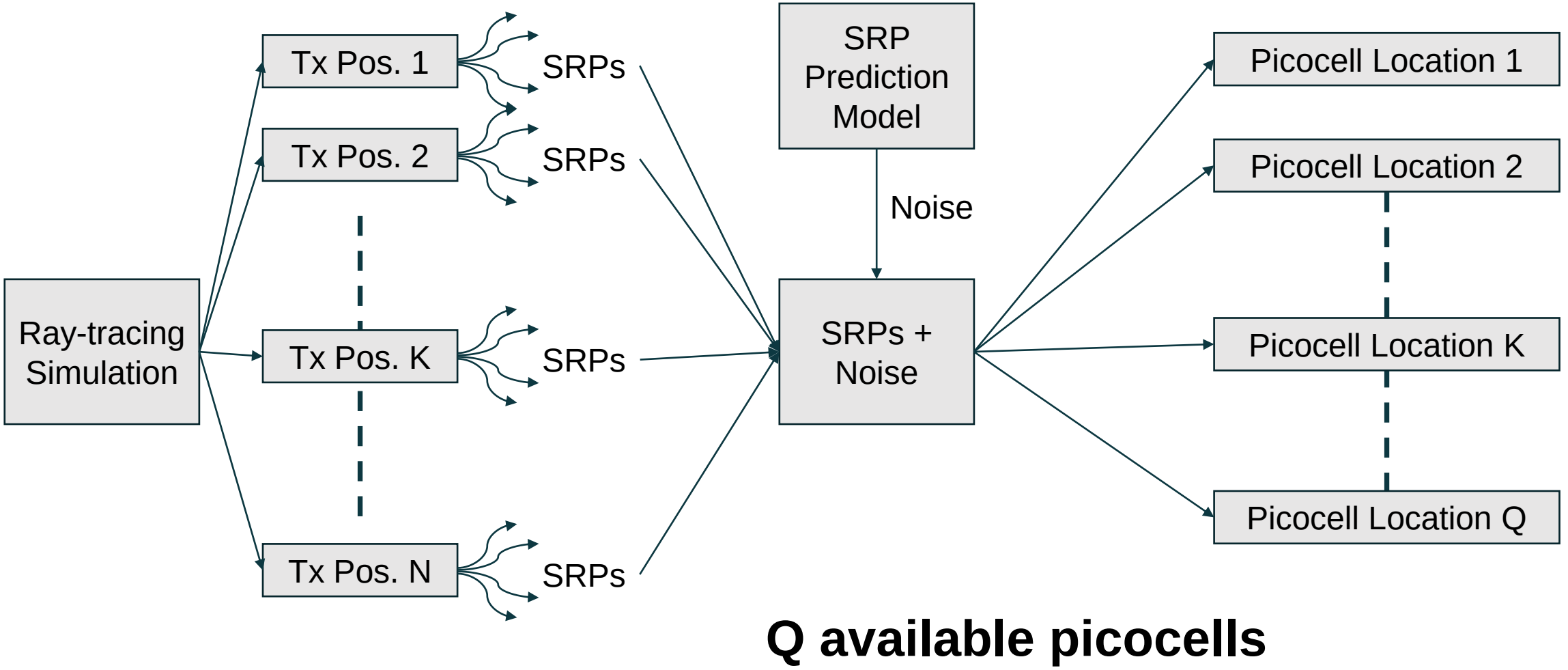
Semantic aware model reduces SRP from 13 dB to 1.5 dB

Picocell Deployment

- Random and common-sense deployment doesn't cover properly



Deployment Algorithm

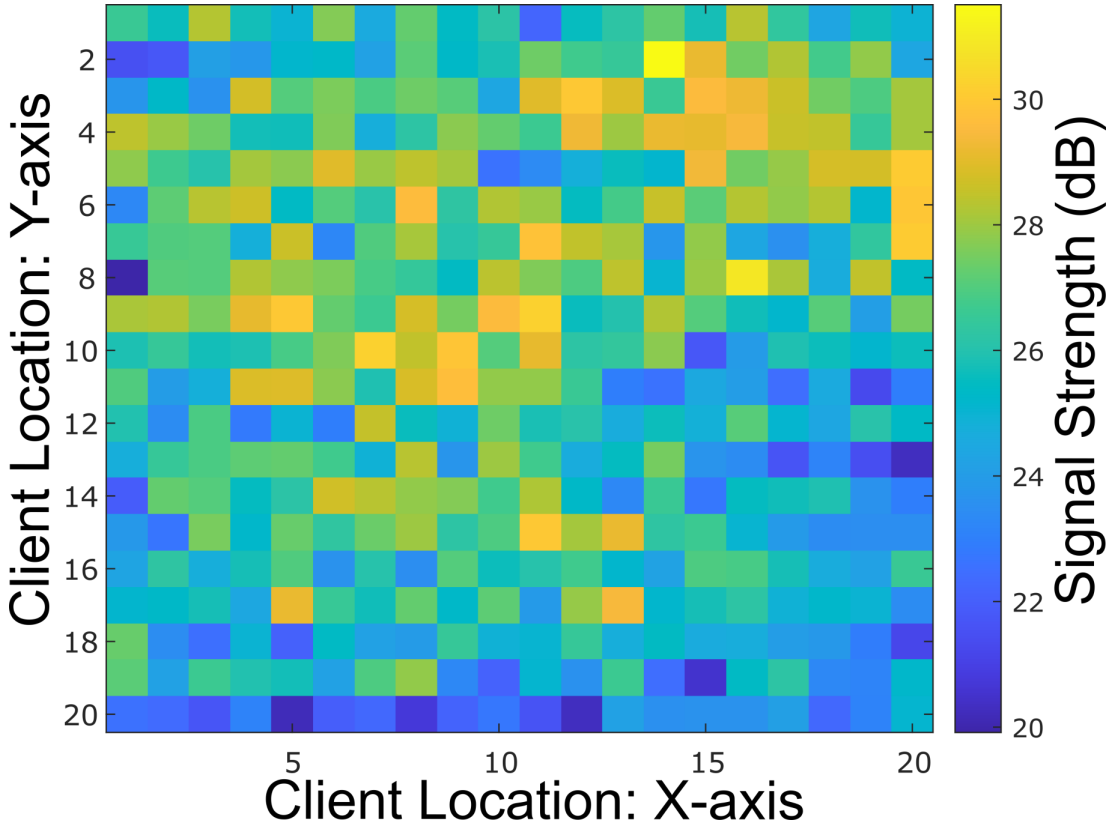


Q available picocells

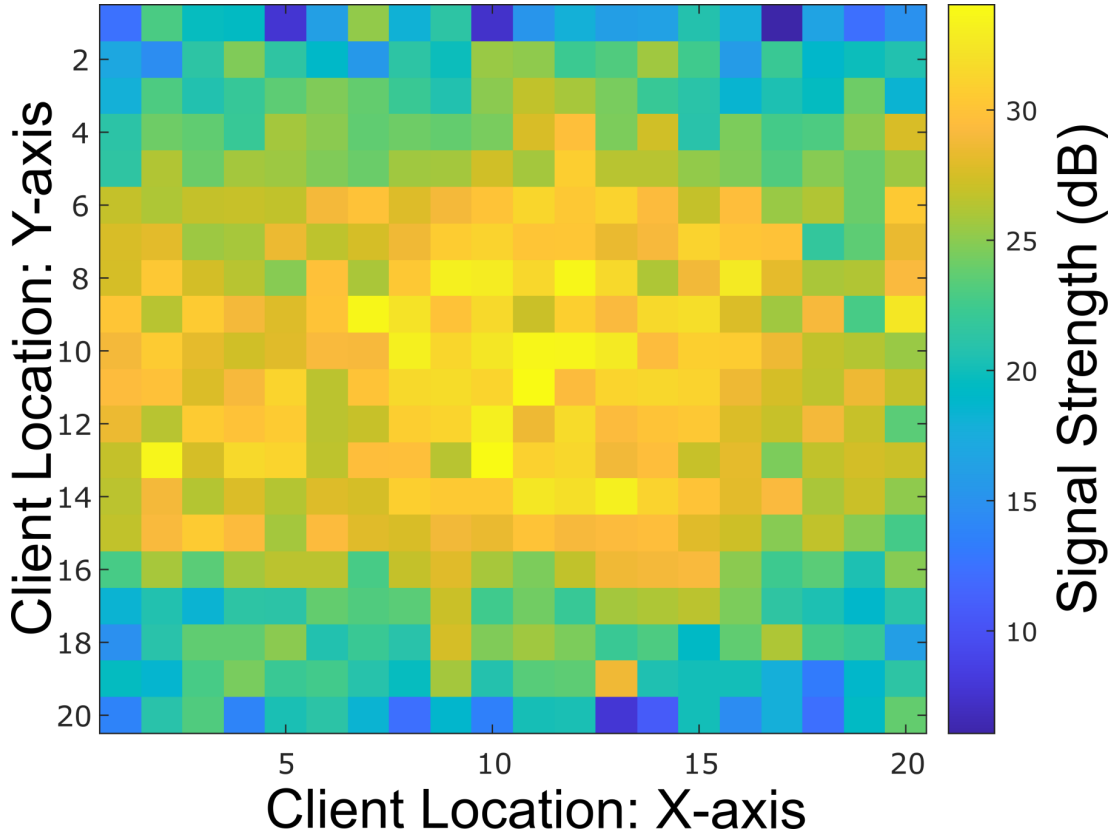
Coverage Map

Coverage Map

Common-Sense



Argus (ours)



Received signal strength is higher for most client locations in Argus

Conclusion

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

Thank you!

For more results, please check:
https://cse.sc.edu/~hregmi/Argus.pdf

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