LiFS: Little Human-Effort, Device-Free Localization with Fine-grained Subcarrier Information

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Motivation

Location is the key for many applications

Academia

[RADAR'00], [Cricket'04], [Horus'05],[Beepbeep'07], [SrndSense'09], [EZ'10], [BatPhone'11], [Zee'12], [Centaur'12],[ArrayTrack'13], [Guoguo'13] , [PinPoint'13], [Ubicarse'14],[Luxapose'14],[Tagoram'14],[SpotFi'15],[ToneTrack'15],[Chronos'16]...

Industry

Motivation

Location is the key for many applications

Academia

[RADAR'00], [Cricket'04],
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agoram'14],[SpotFi'15],[Tone
rack'15],[Chronos'16]...

Industry

Qualcomm izat

walkbase

iBeacon

estimote

Why device-free localization?

Motivation

Elderly Care

Unwilling to wear a wearable device

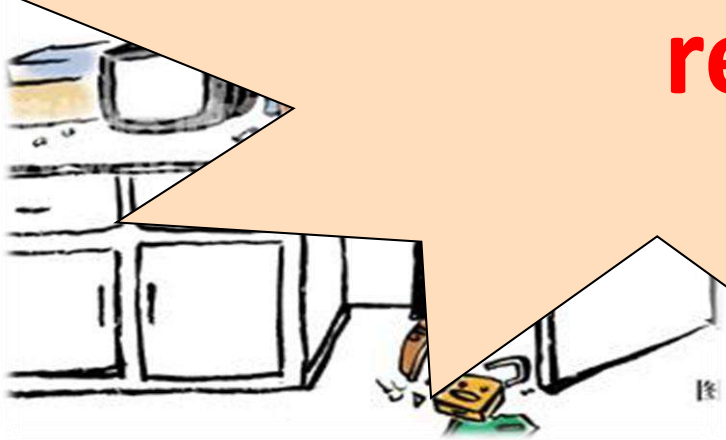
Intruder Detection

Not possible to attach a tracking device

Motivation

Unwil g to wear a
e d ice

Device-free localization is required

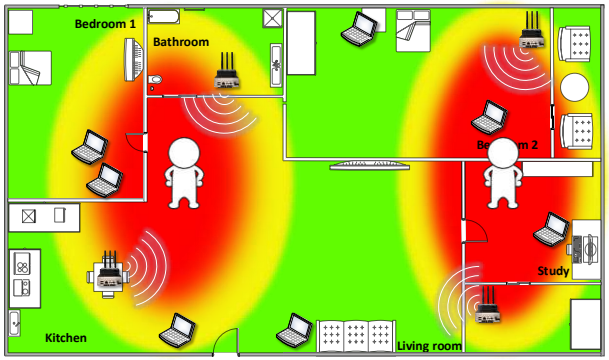


ble to
a ch a tracking device

Intruder Detection

Limitations of Existing Work

High labor-cost/hardware-cost



Build Fingerprint Database

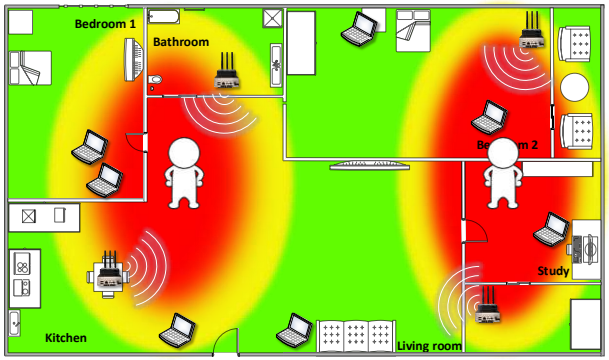
Offline training and updating cause high human-effort

Demand Software-Defined-Radio

Not cost-effective for large deployment

Limitations of Existing Work

High labor-cost/hardware-cost



Build Fingerprint Database

Demand Software-Defined-Radio

Can we do better?

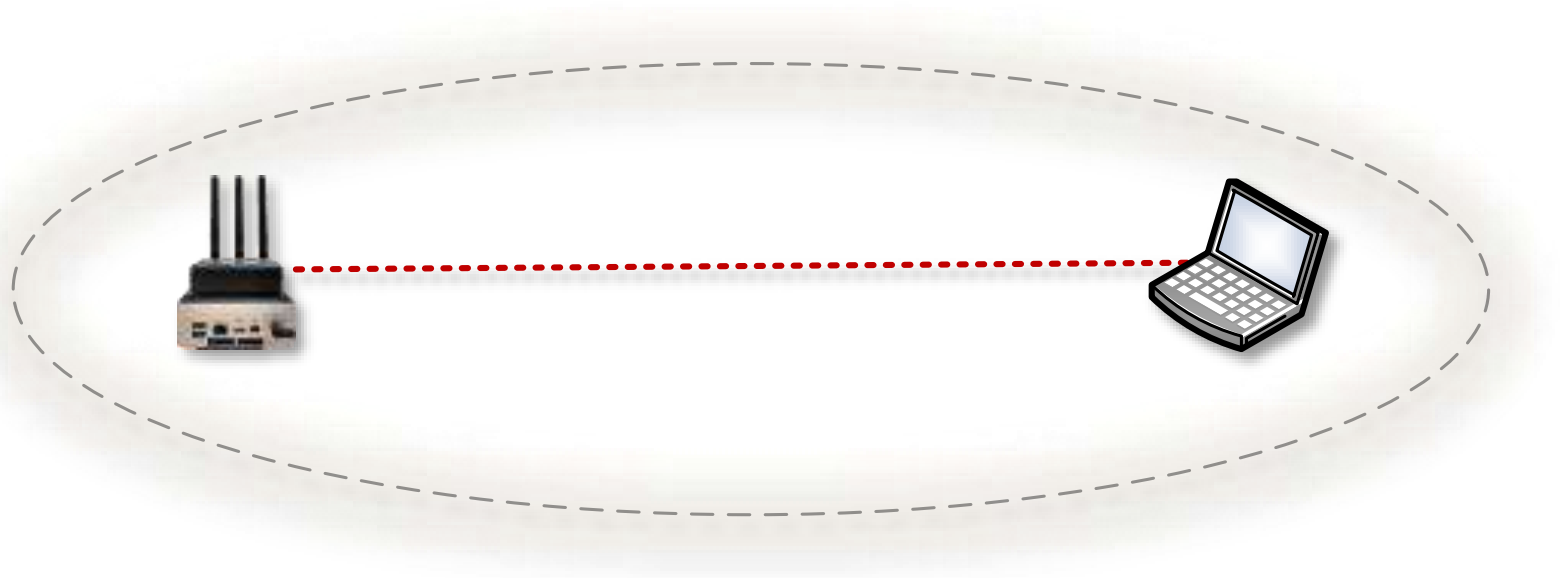
Our Approach: LiFS

A model-based device-free localization system implemented on commodity Wi-Fi device

- *Low labor cost* : no labor-intensive offline training.
- *Low hardware cost*: cheap commodity Wi-Fi device.
- *High accuracy* : around 1 m median accuracy for ***device-free*** passive localization.

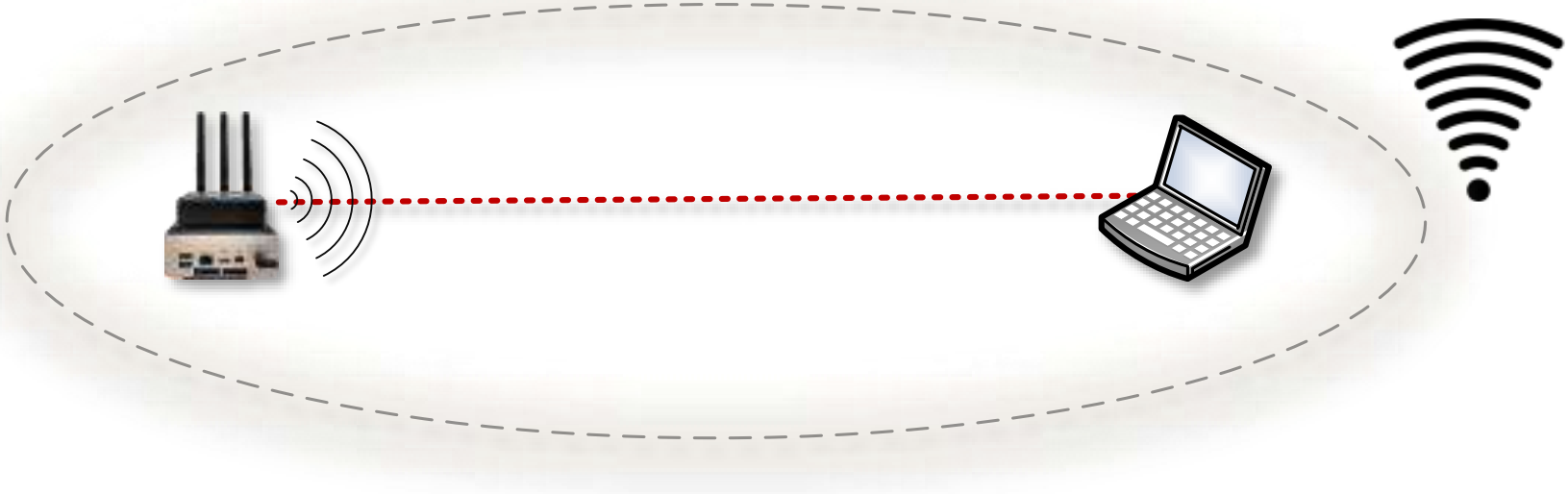
How does LiFS Work?

Working Example



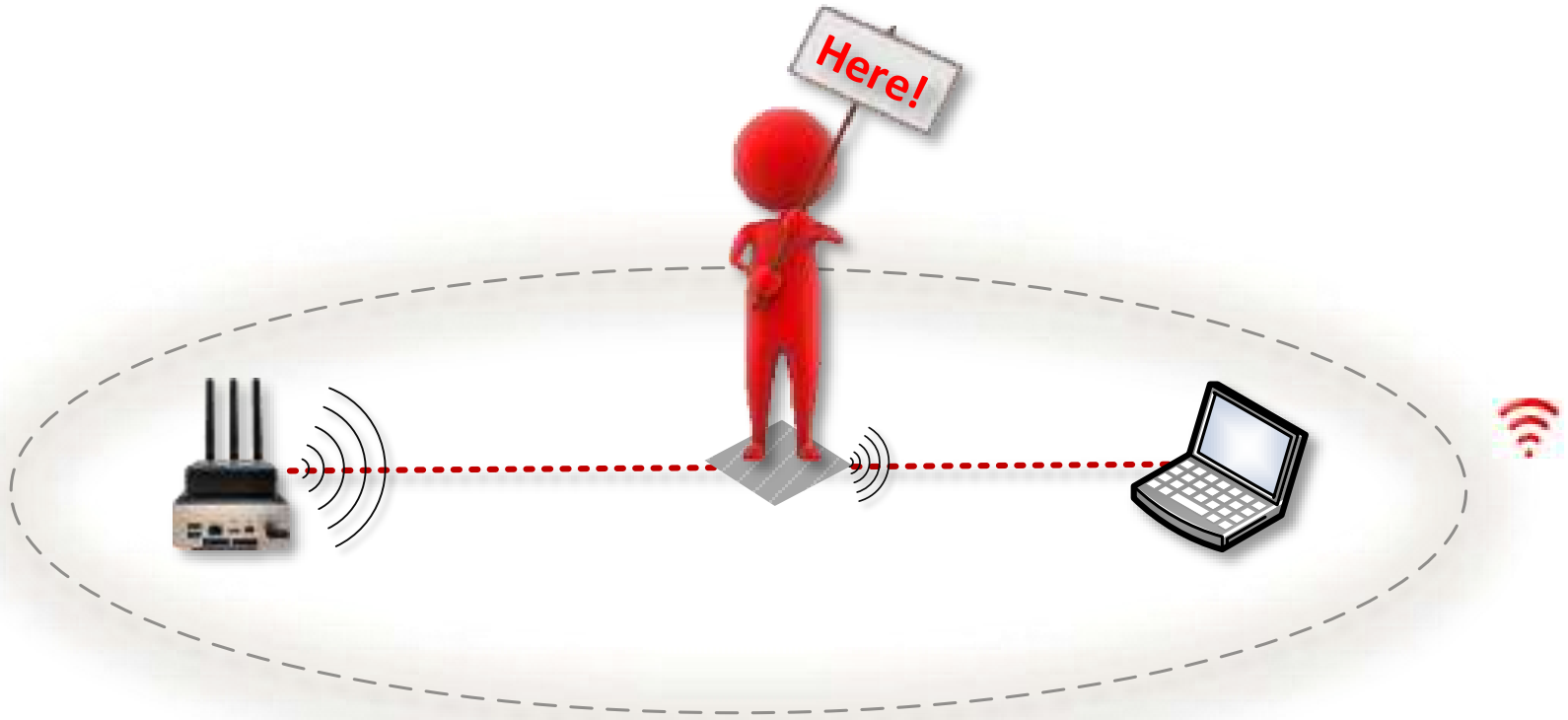
Considering a Wi-Fi link

Working Example



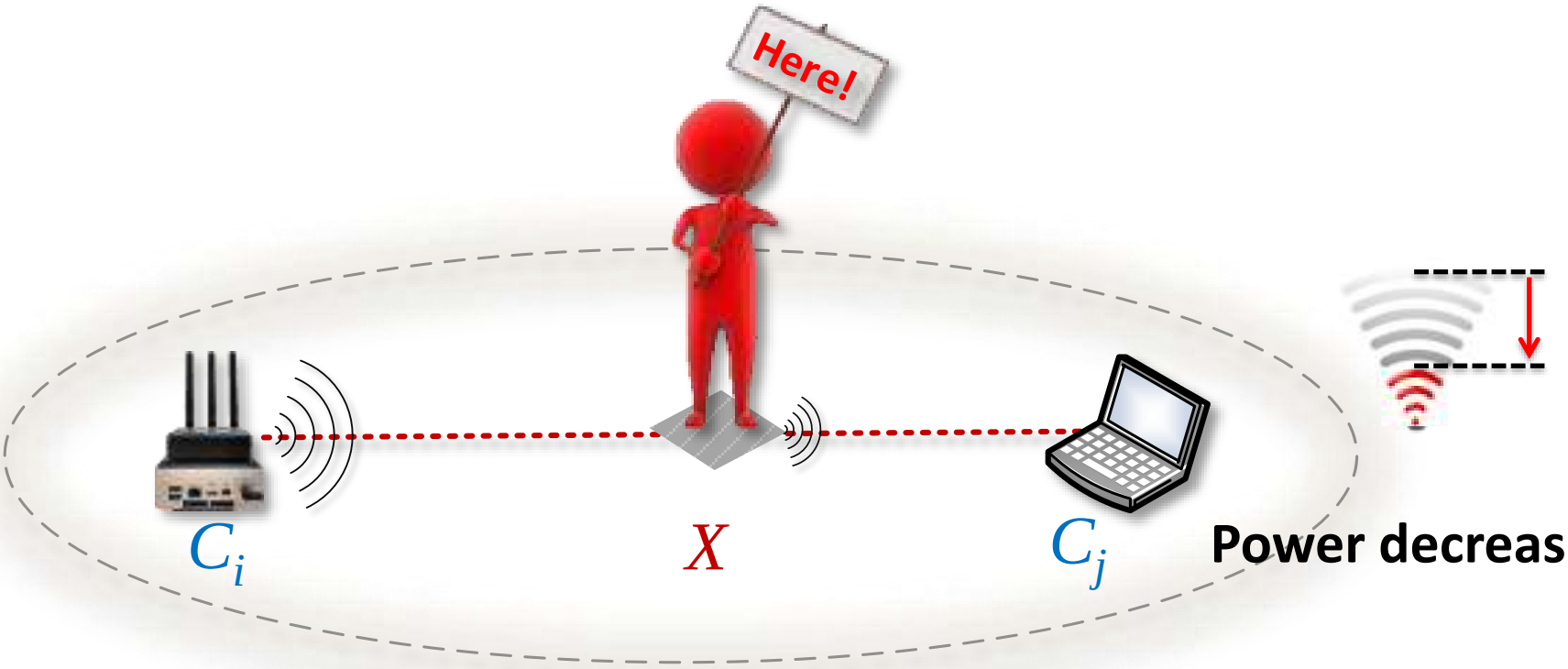
We can easily measure the signal power

Working Example



The signal power decreases if a target appears

Working Example



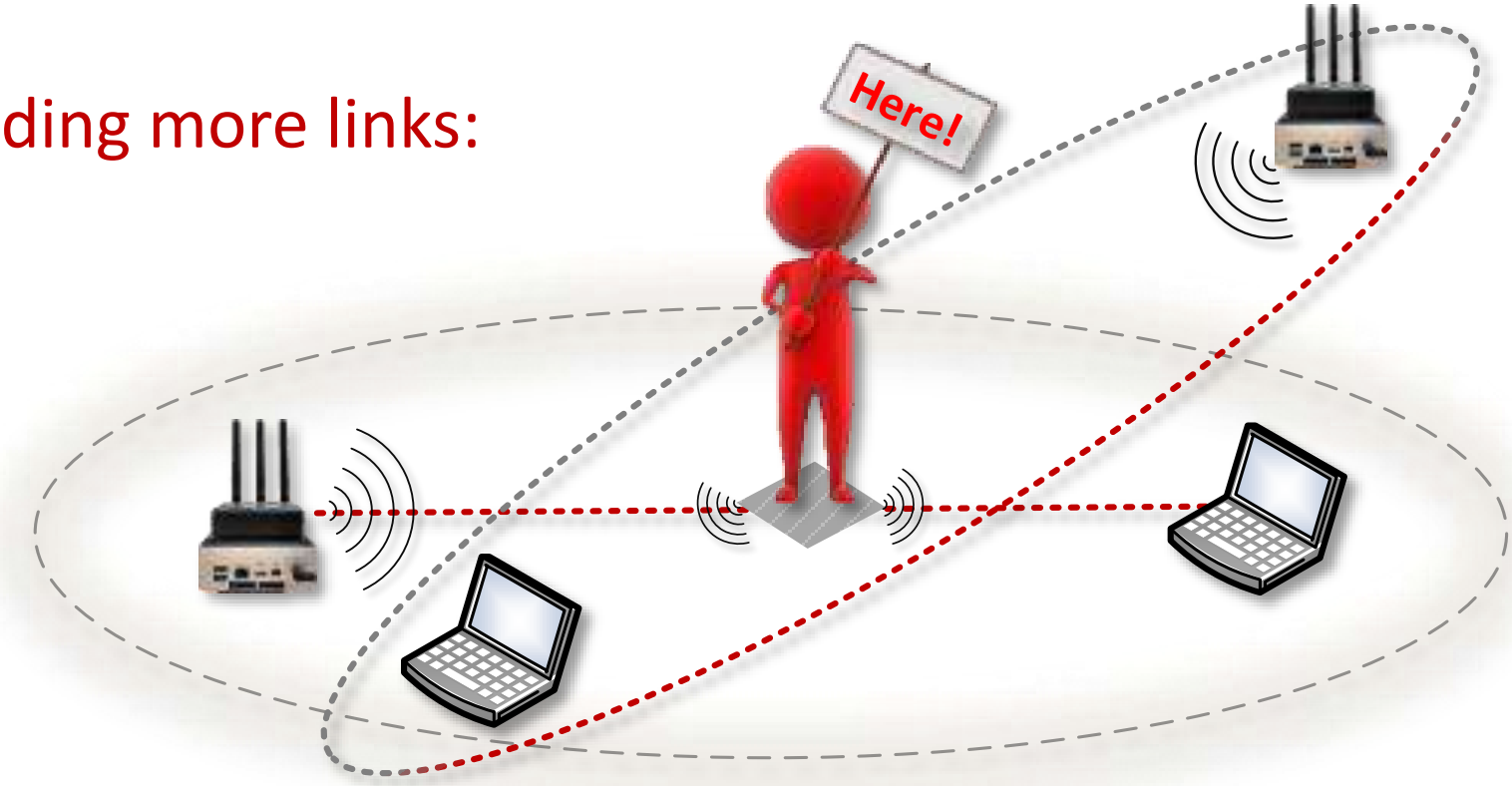
Wireless Propagation theory shows:

Power decrease *is* $R_{ij} = f(C_i, C_j, X)$

where C_i, C_j and X *are* locations of AP, client and target

Working Example

Adding more links:

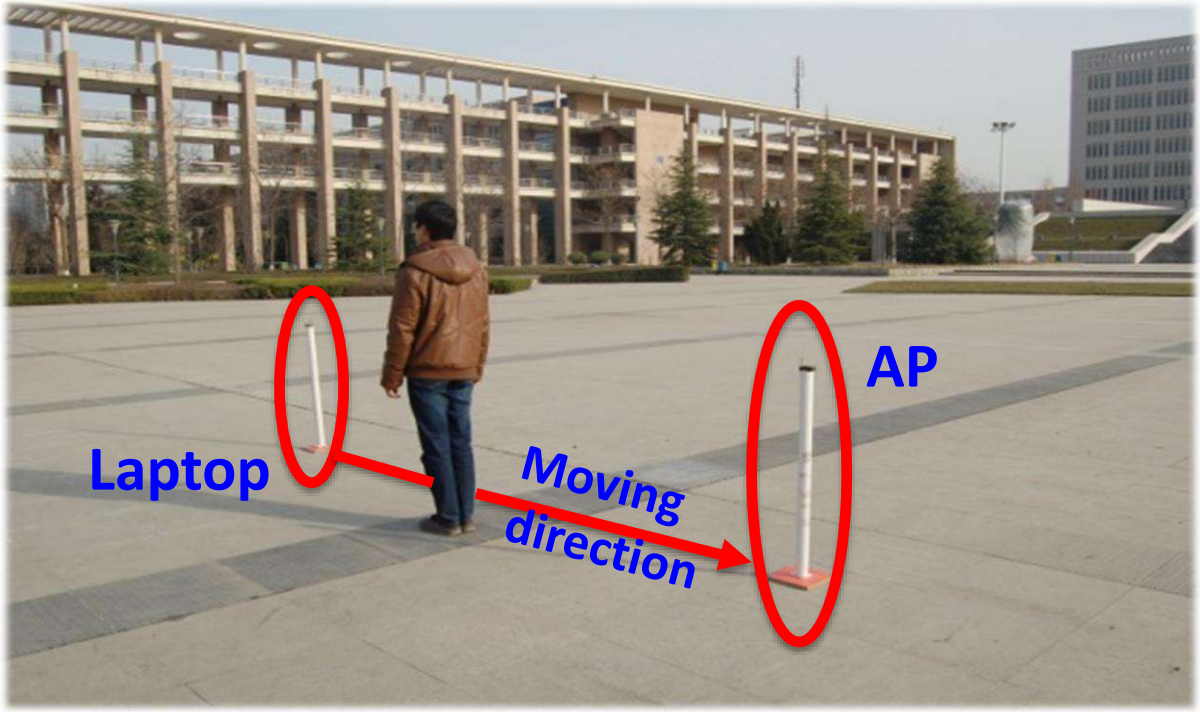


Employing models to determine the target's location, avoiding offline training

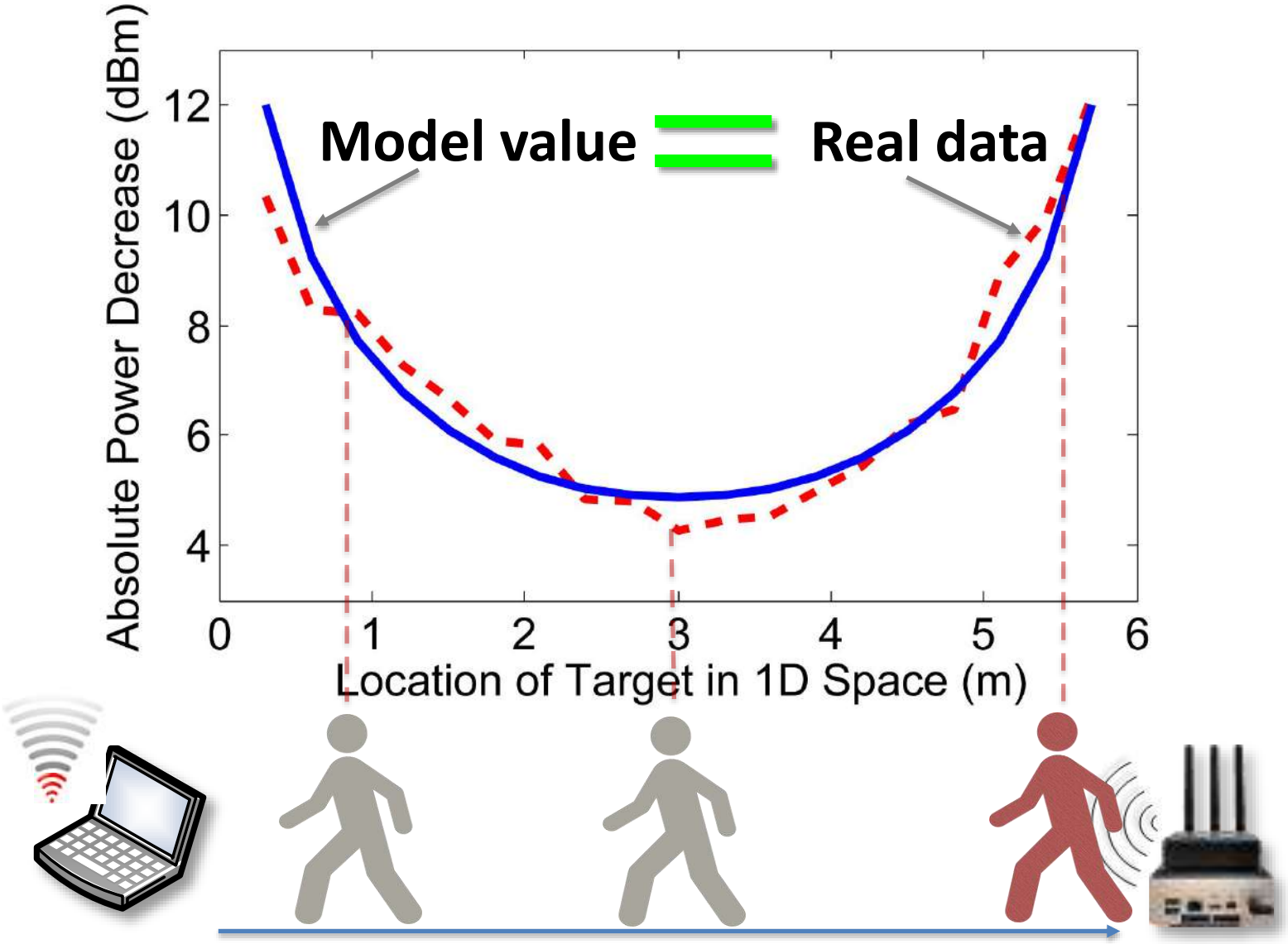
The idea is straightforward!

But, does it work in reality?

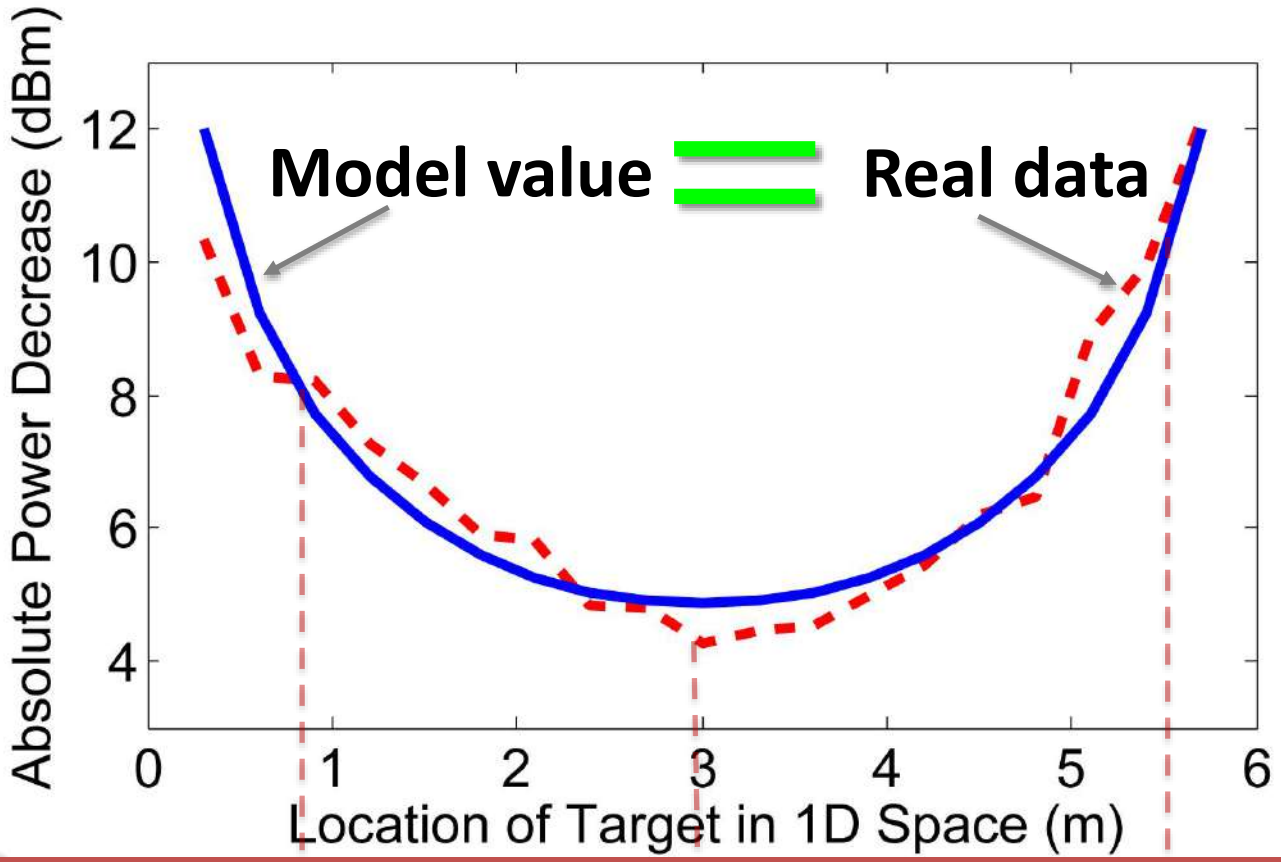
Outdoors: Few Multipath



Outdoors: Few Multipath



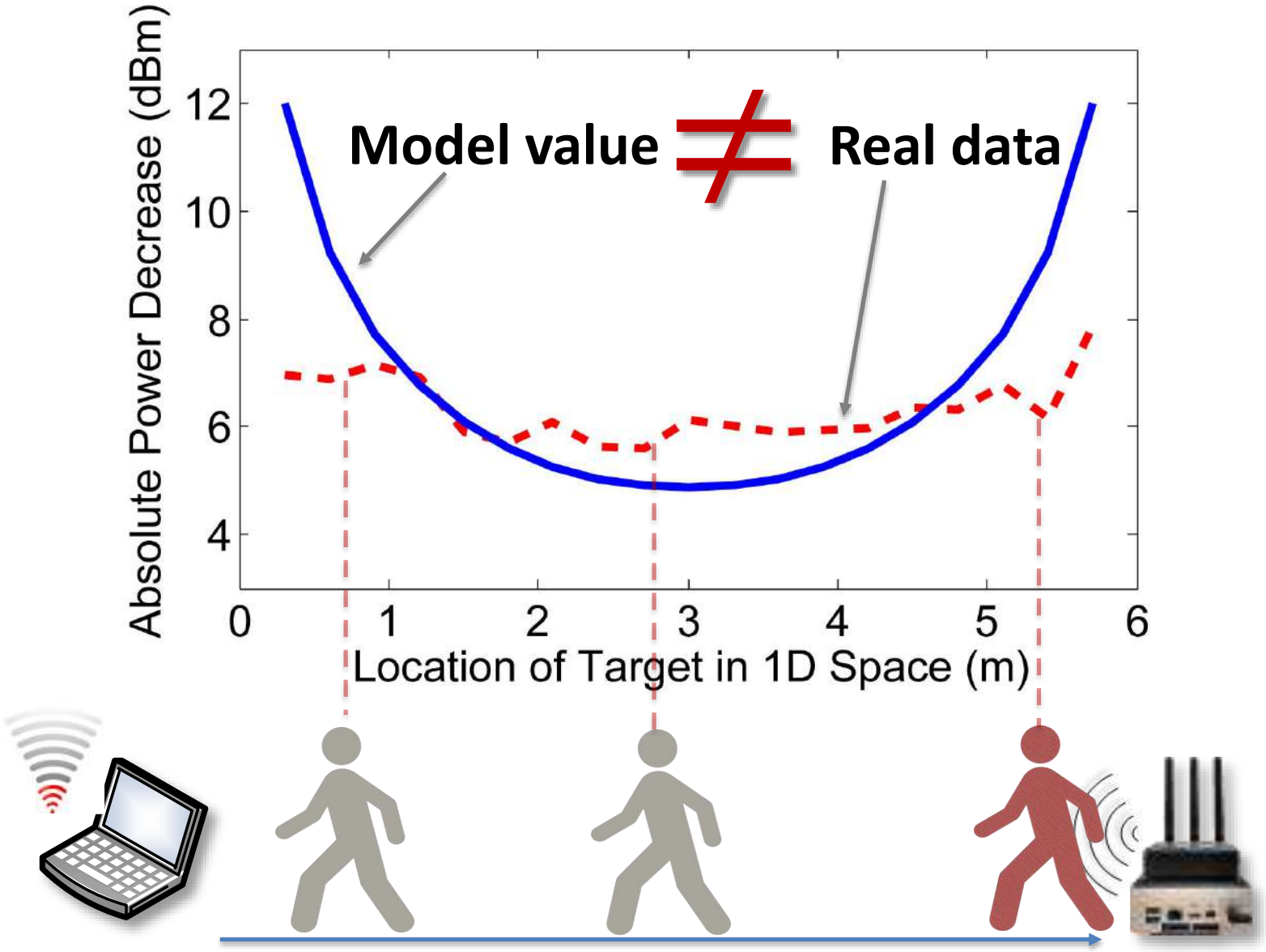
Outdoors: Few Multipath



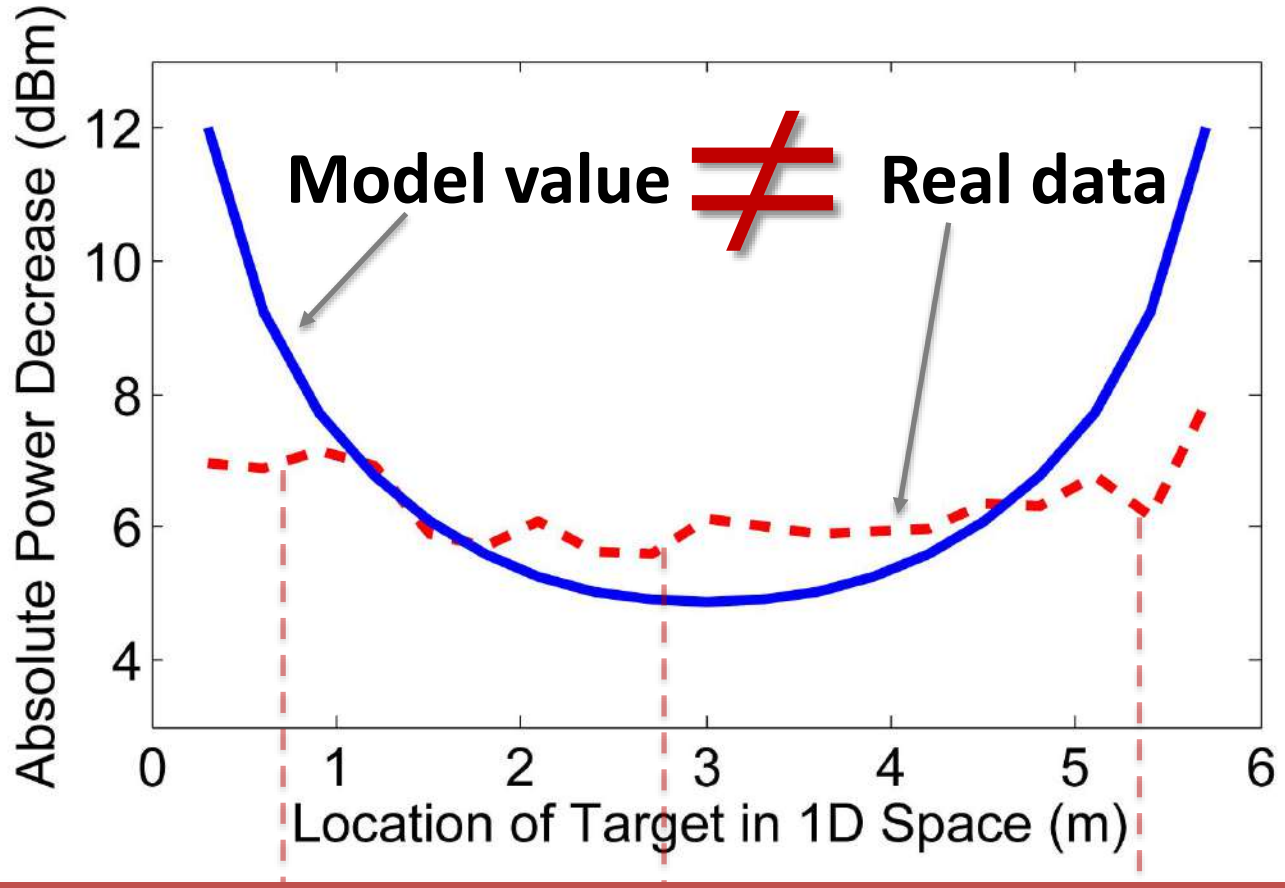
Target can be localized accurately with models due to few multipath

Indoors: Rich Multipath

Multipath is the problem

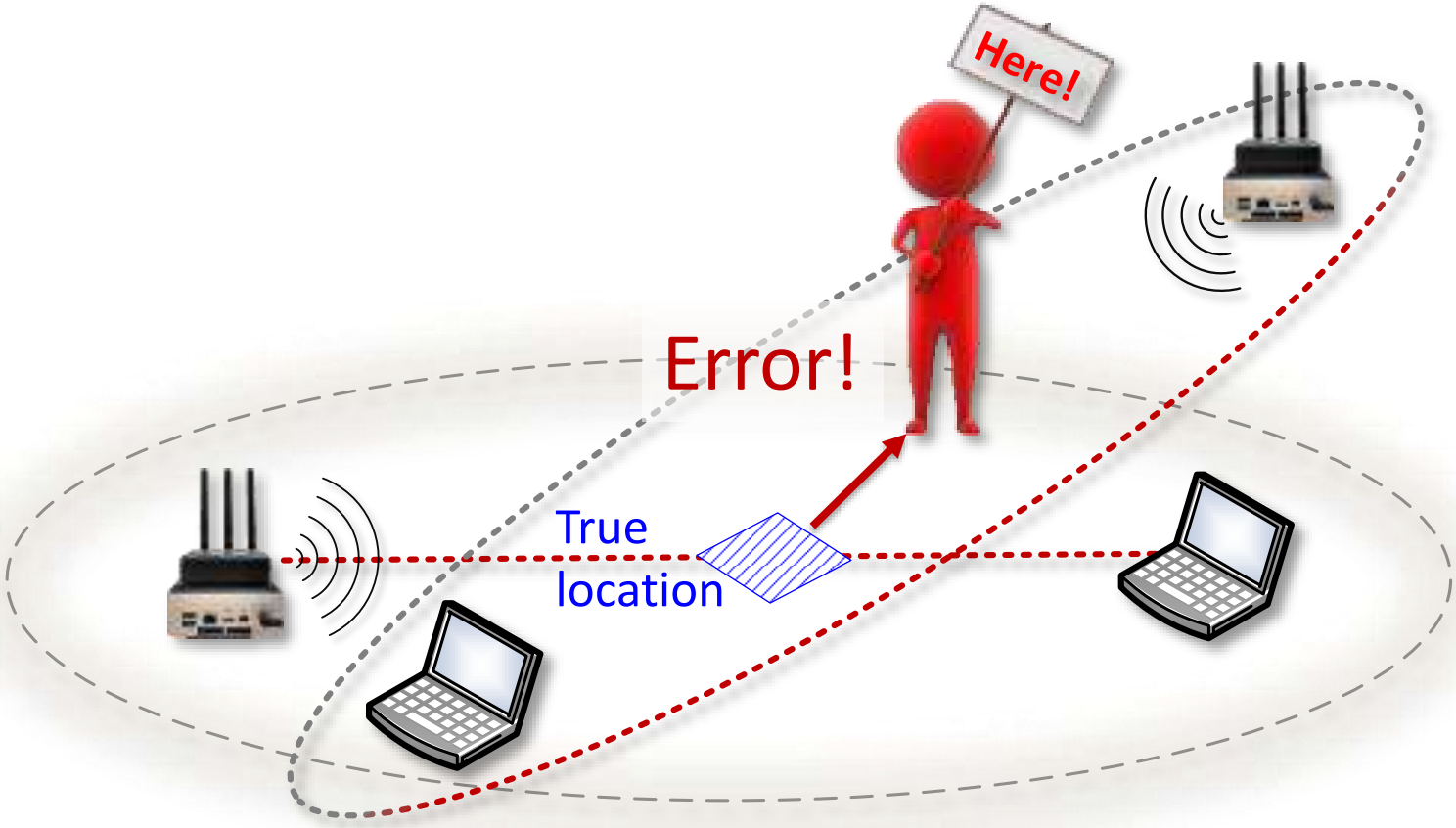


Multipath is the problem



Real data does not match model values indoors due to rich multipath!

Multipath is the problem

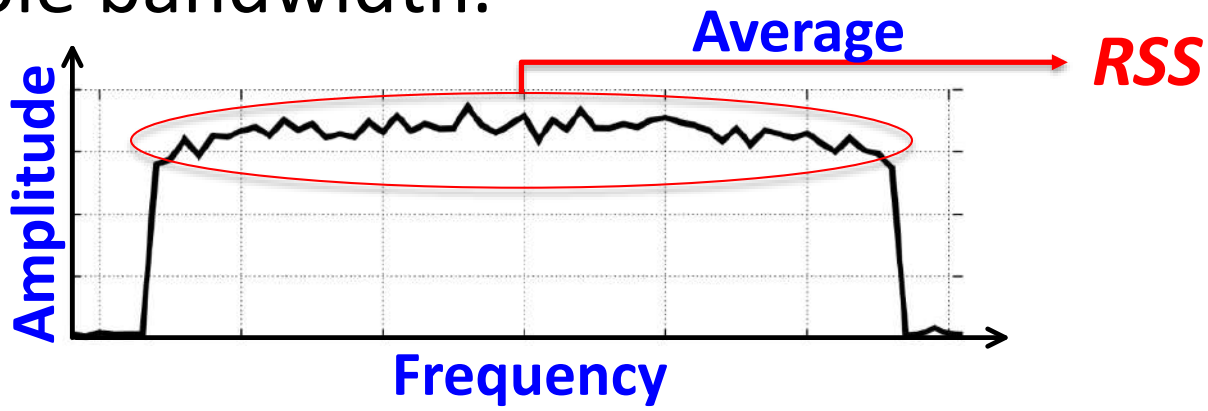


Large errors occur if employing raw data for localization indoors!

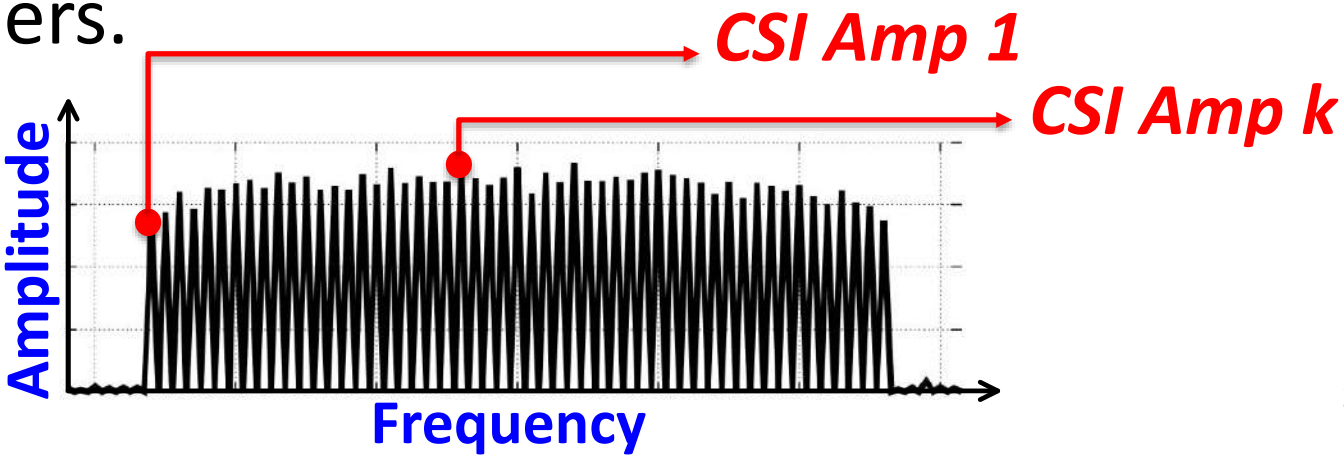
Understand Power Decrease

Measure Power with CSI

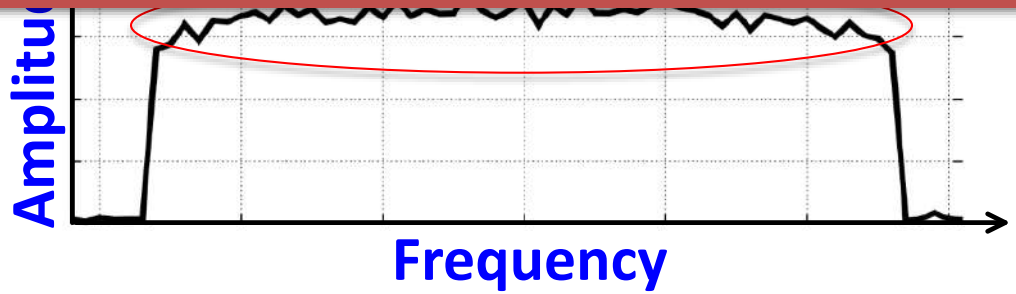
- Traditionally, power is measured as *RSS* across the whole bandwidth.



- What if, looking power at *CSI* over multiple subcarriers.



CSI provides more detailed information across multiple subcarriers



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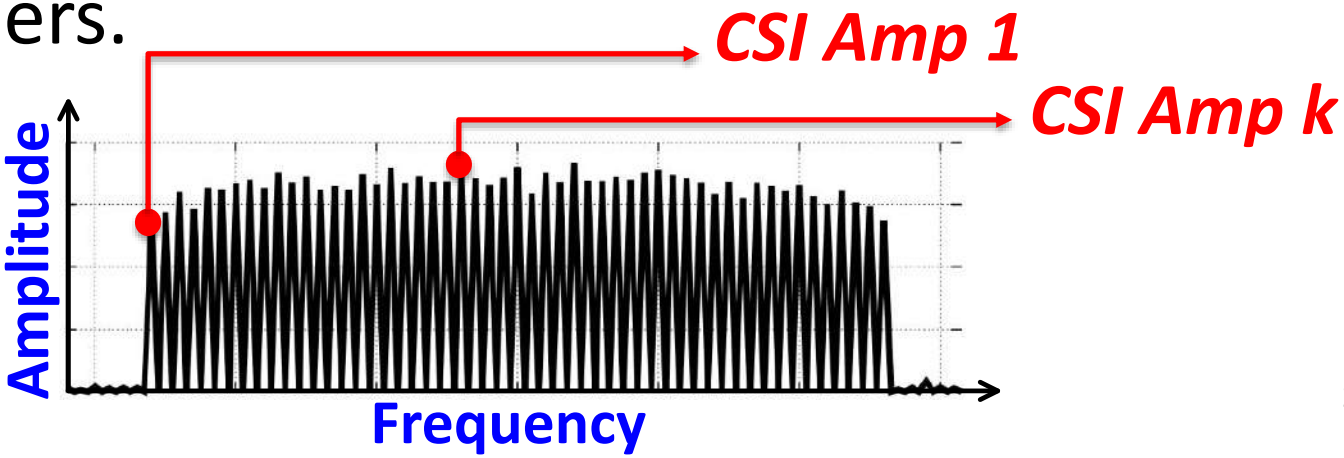
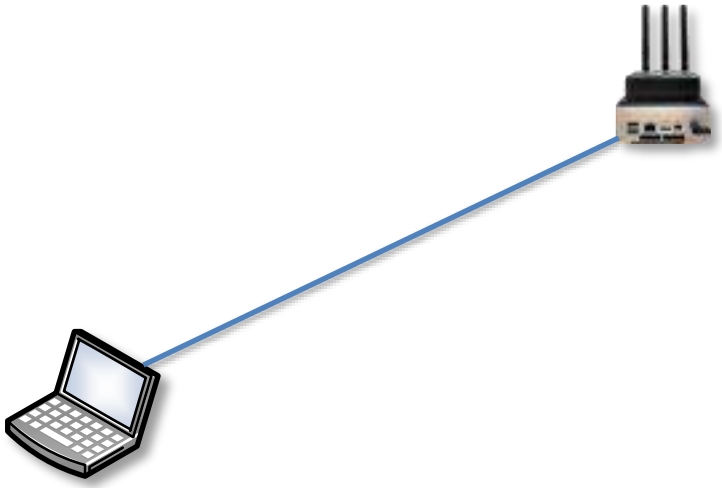
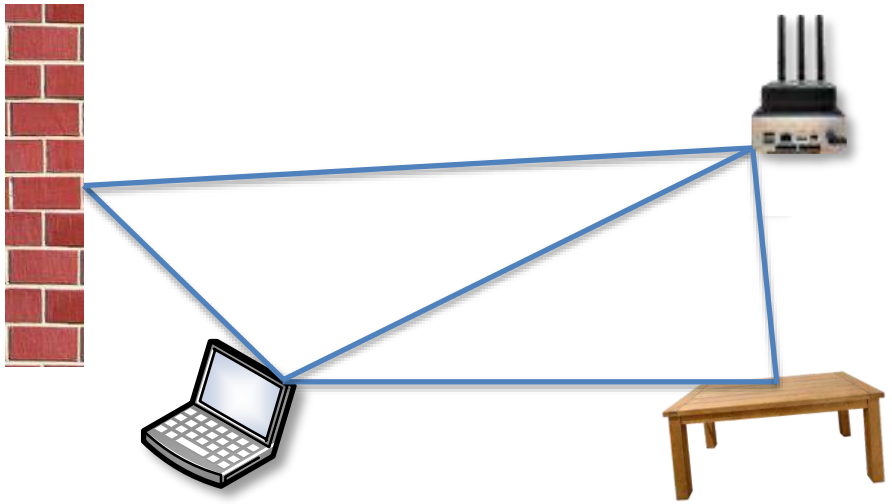


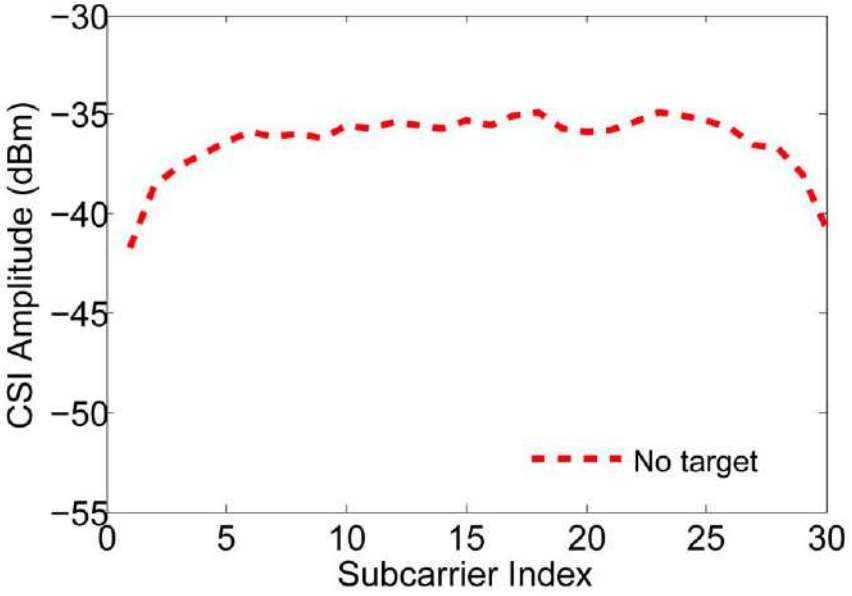
Understand Power Decrease

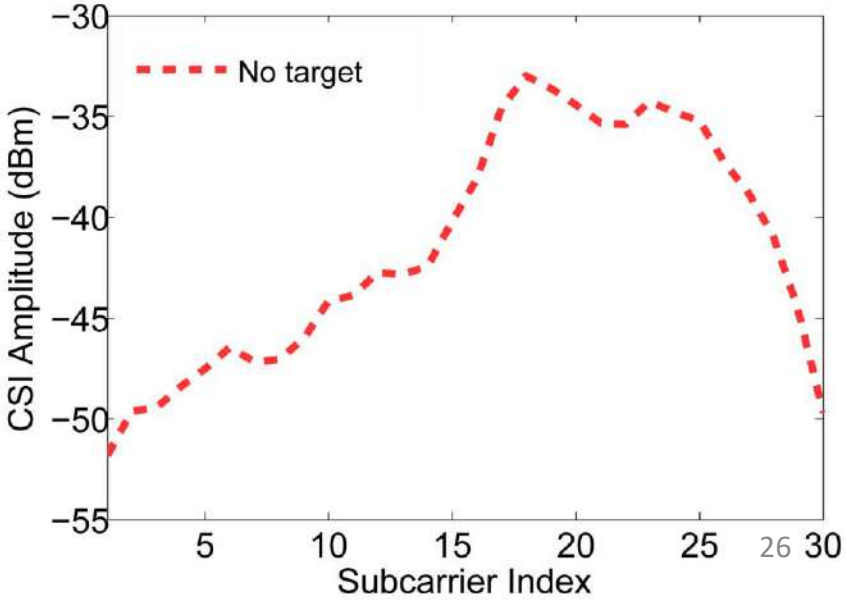


Outdoor with few multipath



Indoor with rich multipath

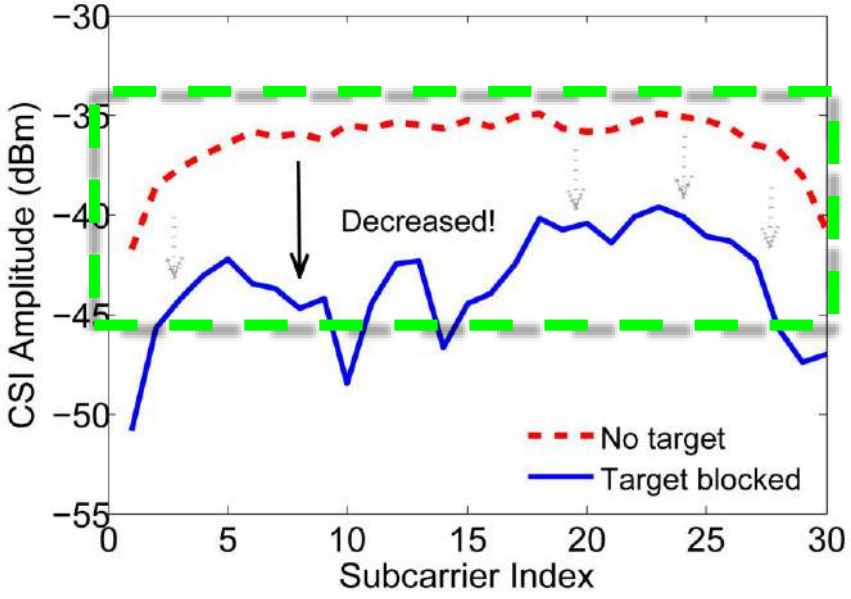




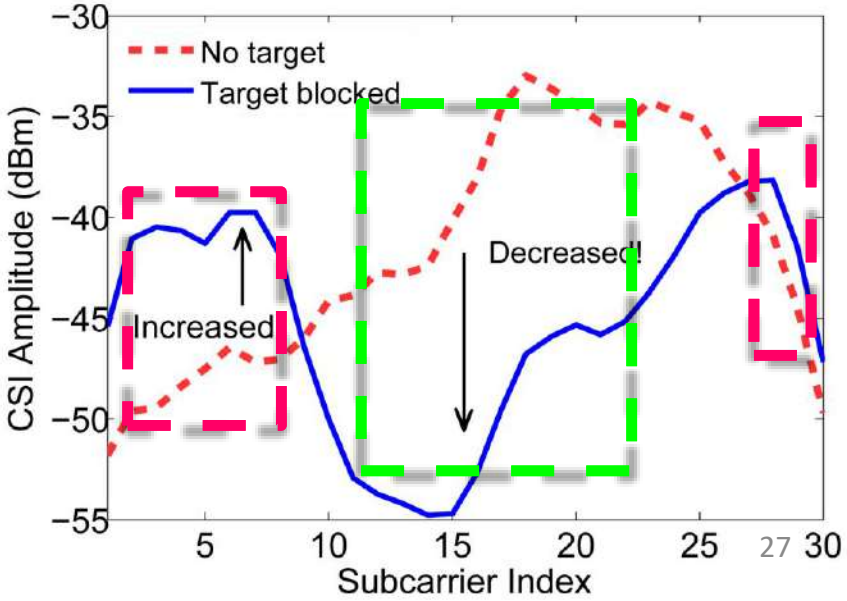
Understand Power Decrease

Not all subcarriers are affected equally by multipath!

Outdoor with few multipath



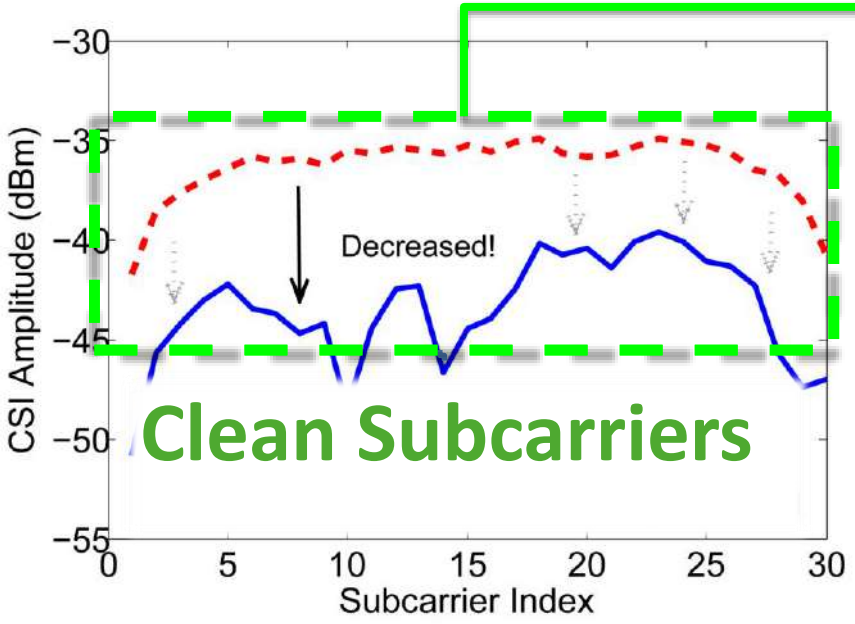
Indoor with rich multipath



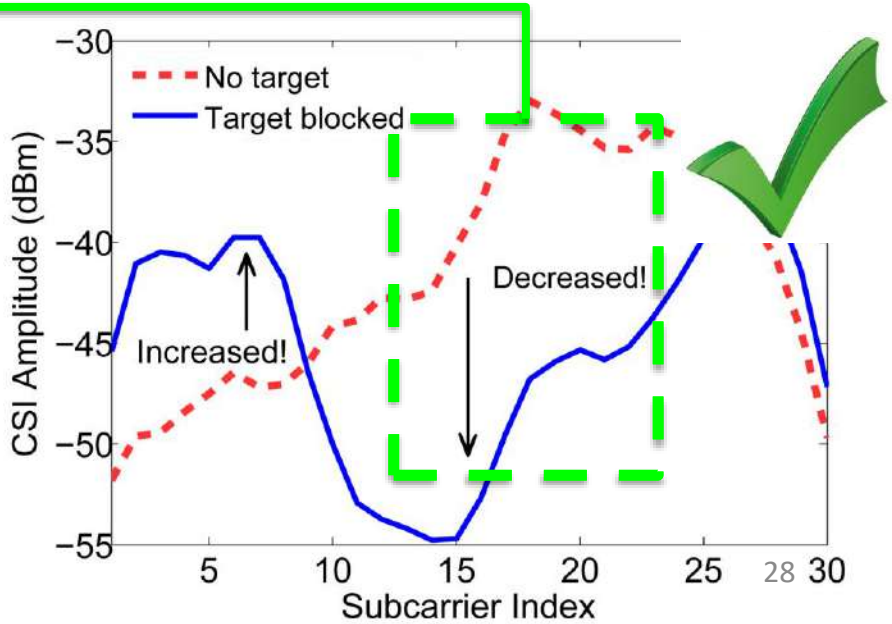
Key Idea

Identify "clean" subcarriers not affected by multipath for localization

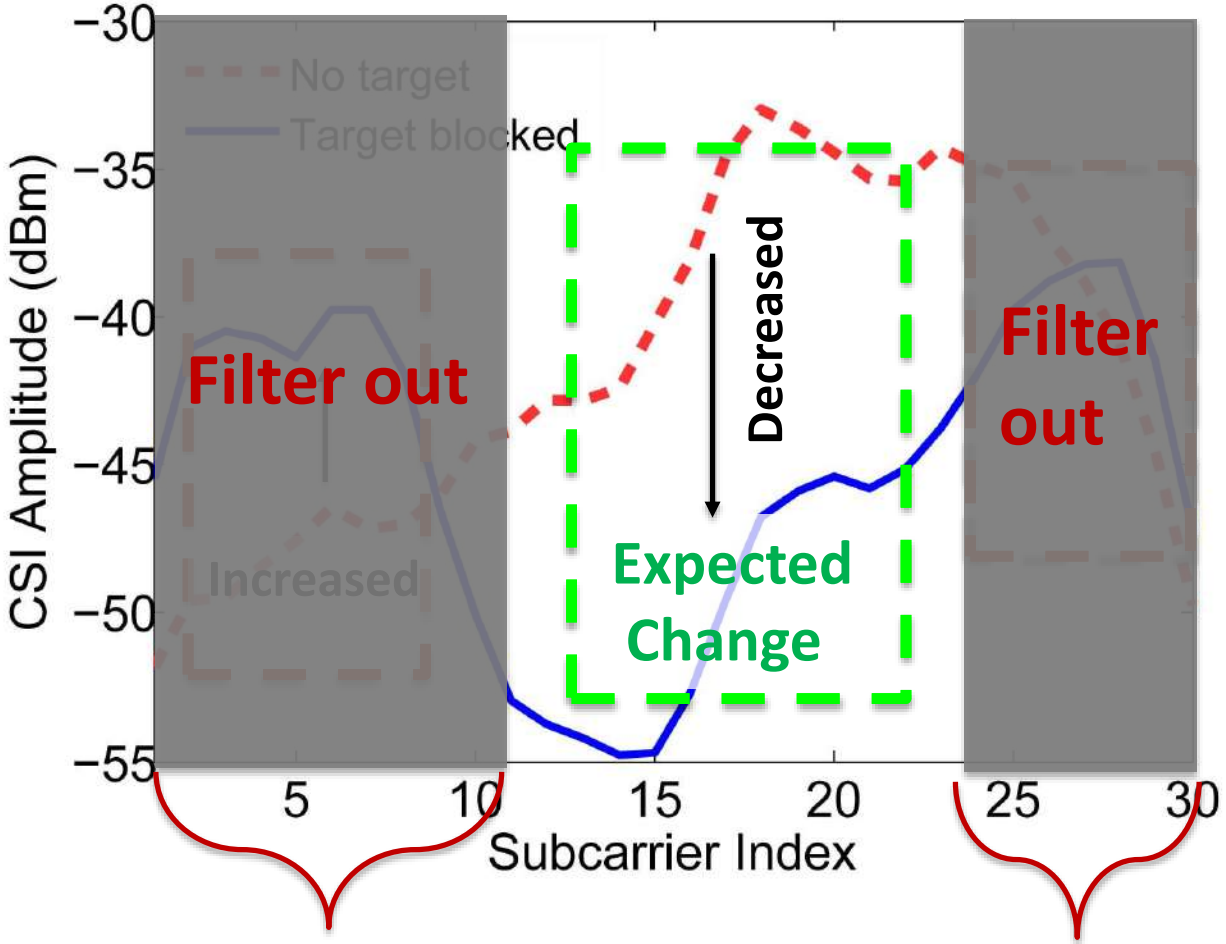
Outdoor with few multipath



Indoor with rich multipath

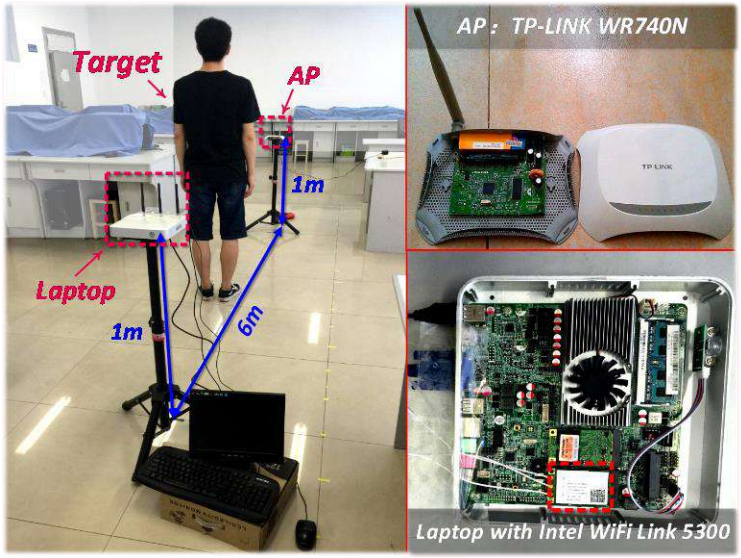


Find "Clean" Subcarriers: Pre-Processing Method for CSI

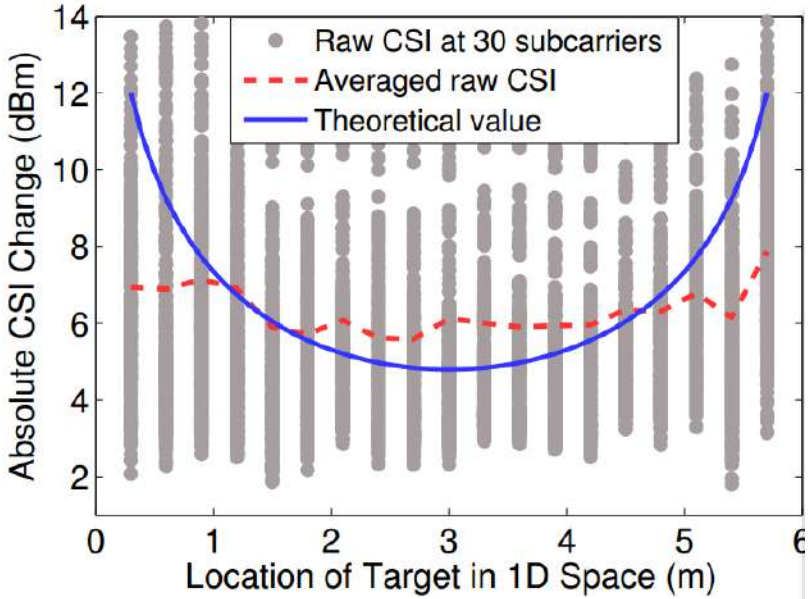


Subcarriers greatly affected by multipath

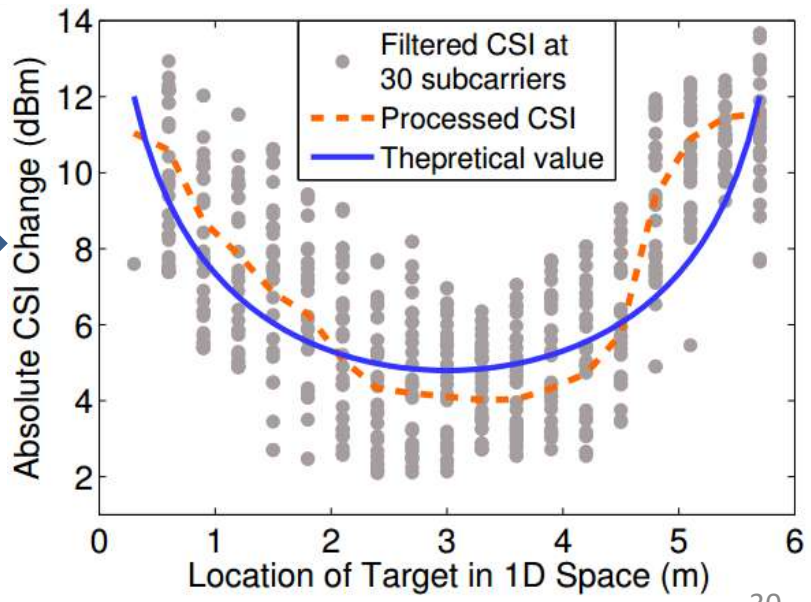
CSI Pre-Processing Method Verification



- **Environment:** Indoor
- **TX：** AP (TP-Link)
- **RX:** Laptop with Intel 5300
- **TX-RX distance:** 6 meters



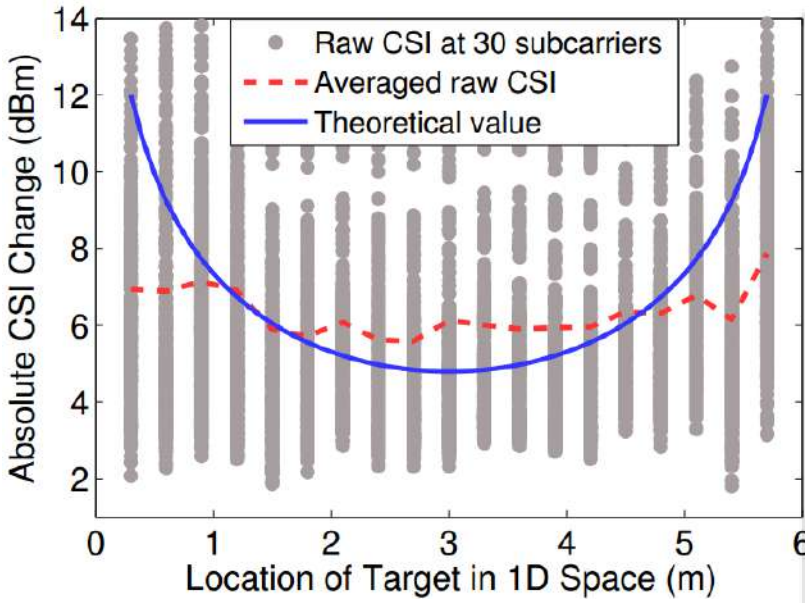
Raw CSI change data



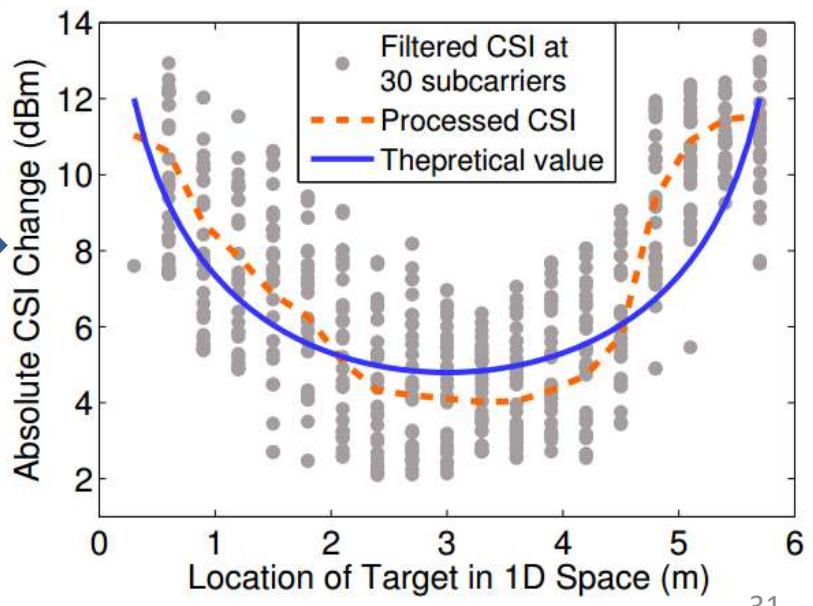
Pre-processed CSI change data

CSI Pre-Processing Method Verification

Pre-processed CSI measurements match the theoretical values

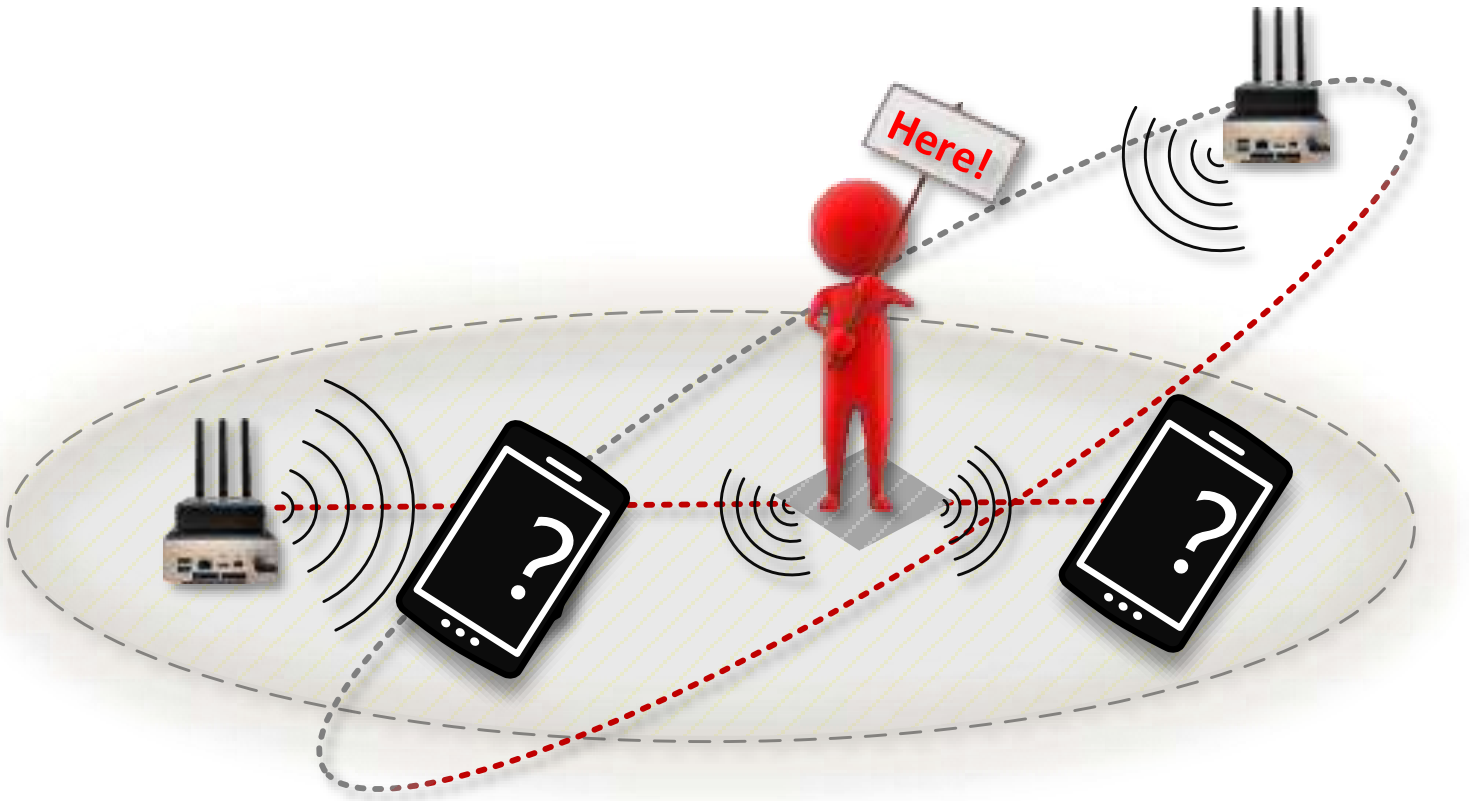


Raw CSI change data



Pre-processed CSI change data

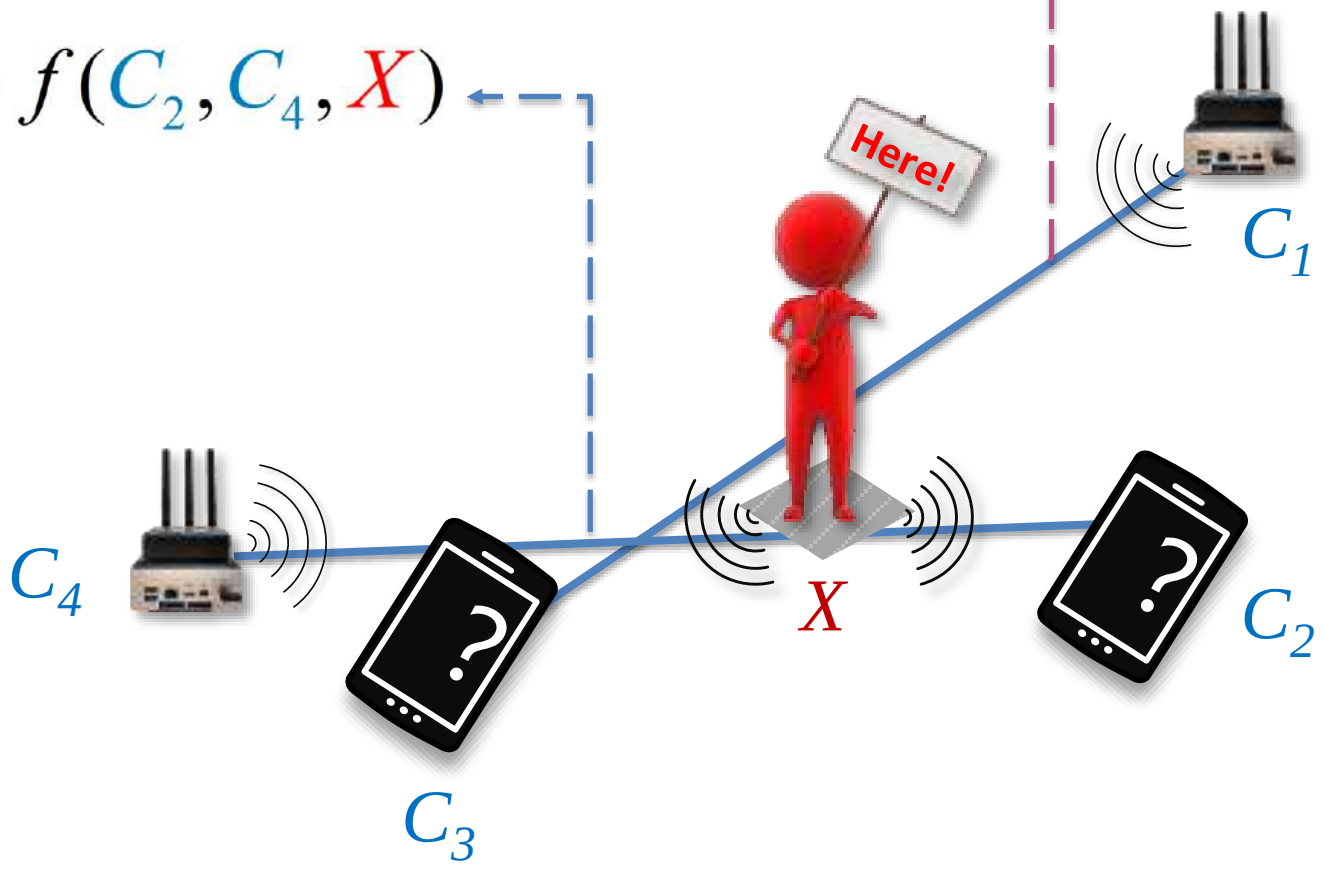
Challenge: locations of some transceivers (e.g. mobiles) are unknown!



Unknown Transceiver Locations

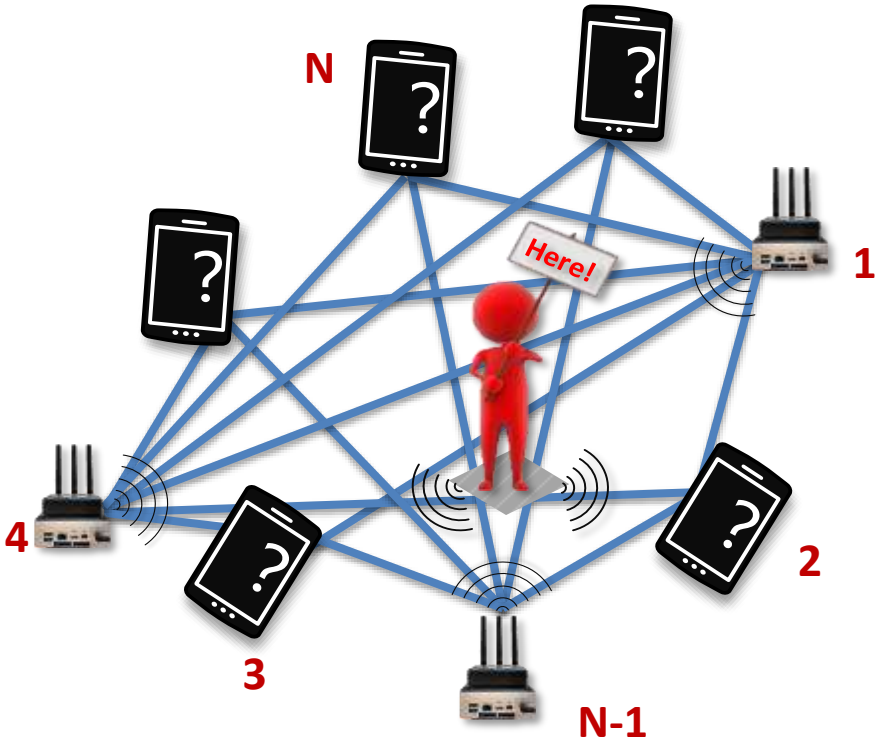
$$R_{1,3} = f(C_1, C_3, X)$$

$$R_{2,4} = f(C_2, C_4, X)$$



Unknown Transceiver Locations

Consider more transceivers…



$$\begin{cases} R_{1,3} = f(C_1, C_3, X) \\ R_{2,4} = f(C_2, C_4, X) \\ \vdots \\ R_{N,N-1} = f(C_N, C_{N-1}, X) \end{cases}$$

Key Observation

$$R_{1,3} = f(C_1, C_3, X)$$
$$R_{2,4} = f(C_2, C_4, X)$$
$$\vdots$$
$$R_{N,N-1} = f(C_N, C_{N-1}, X)$$

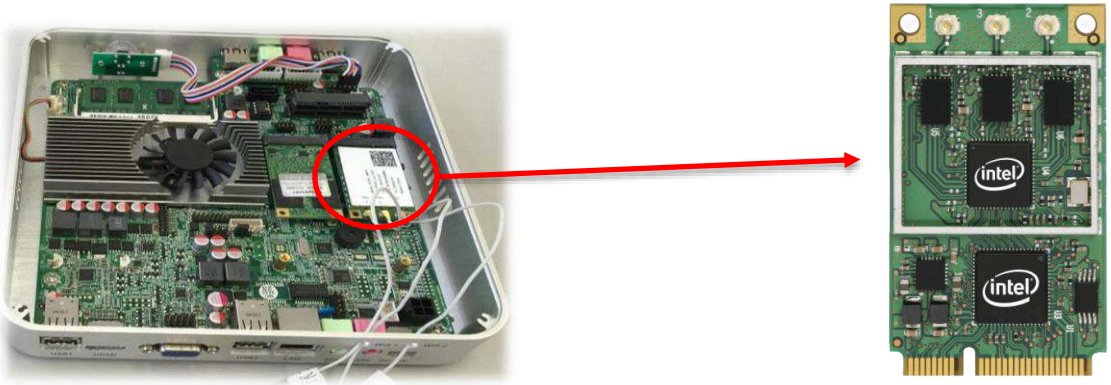
N(N-1)/2* equations >> *2(N+1) unknowns

Given enough number of transceivers, all unknown locations can be estimated!

Implementation & Evaluation

Implementation

- Implemented: 11 laptops, which are equipped with Intel 5300 Wi-Fi card.



Laptop **Intel 5300 Wi-Fi card**

- 4 laptops act as APs and the rest are clients.
- APs and one client have known locations.
- Objective: device-free passively localize a target.

Compared Approaches

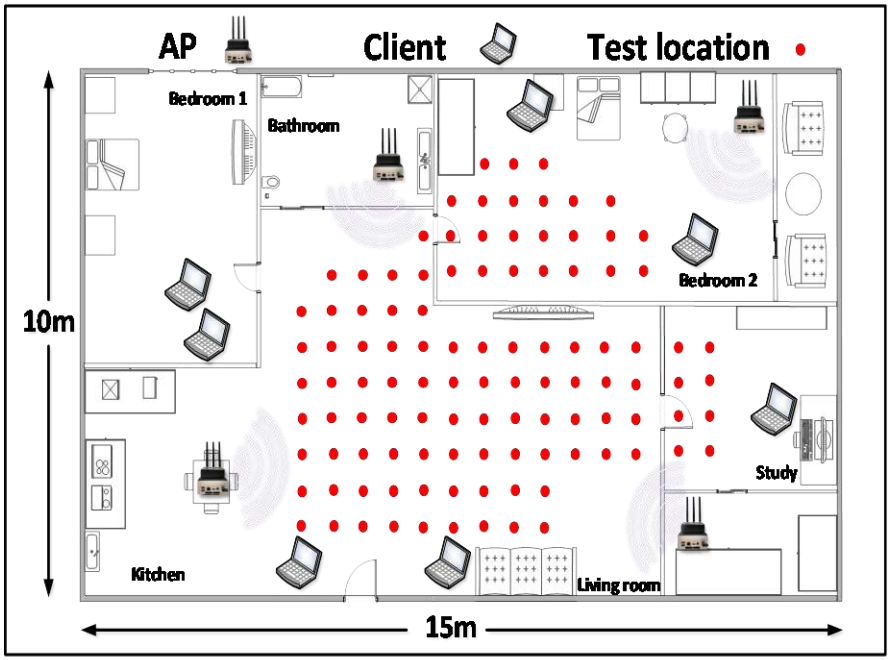
	Signal Feature	*Methodology*	*Requirement*
Pilot [1]	CSI	Kernel-based MAP	Fingerprinting
RASS [2]	RSS	SVM	Fingerprinting
RTI [3]	RSS	Maximum attenuation	Knowledge of deployment

[1] J. Xiao, K. Wu, Y. Yi, L. Wang, and L. M. Ni. Pilot: Passive device-free indoor localization using channel state information. In Proc. IEEE International Conference on Distributed Computing Systems (**ICDCS**), pages 236–245, 2013.
[2] D. Zhang, Y. Liu, X. Guo, and L. M. Ni. RASS: A real-time, accurate, and scalable system for tracking transceiver-free objects. IEEE Trans. on Parallel and Distributed Systems (**TPDS**), 24(5):996–1008, 2013.
[3] J. Wilson and N. Patwari. See-through walls: Motion tracking using variance-based radio tomography networks. IEEE Trans. on Mobile Computing (**TMC**), 10(5):612–621, 2011.

Evaluation in Medium Multipath

- Home environment: ***medium*** multipath

Home environment



Testbed floorplan

Evaluation in LoS & NLoS

- Empty classroom and Library environments, corresponding to ***low*** and ***high*** multipath

Strong LoS

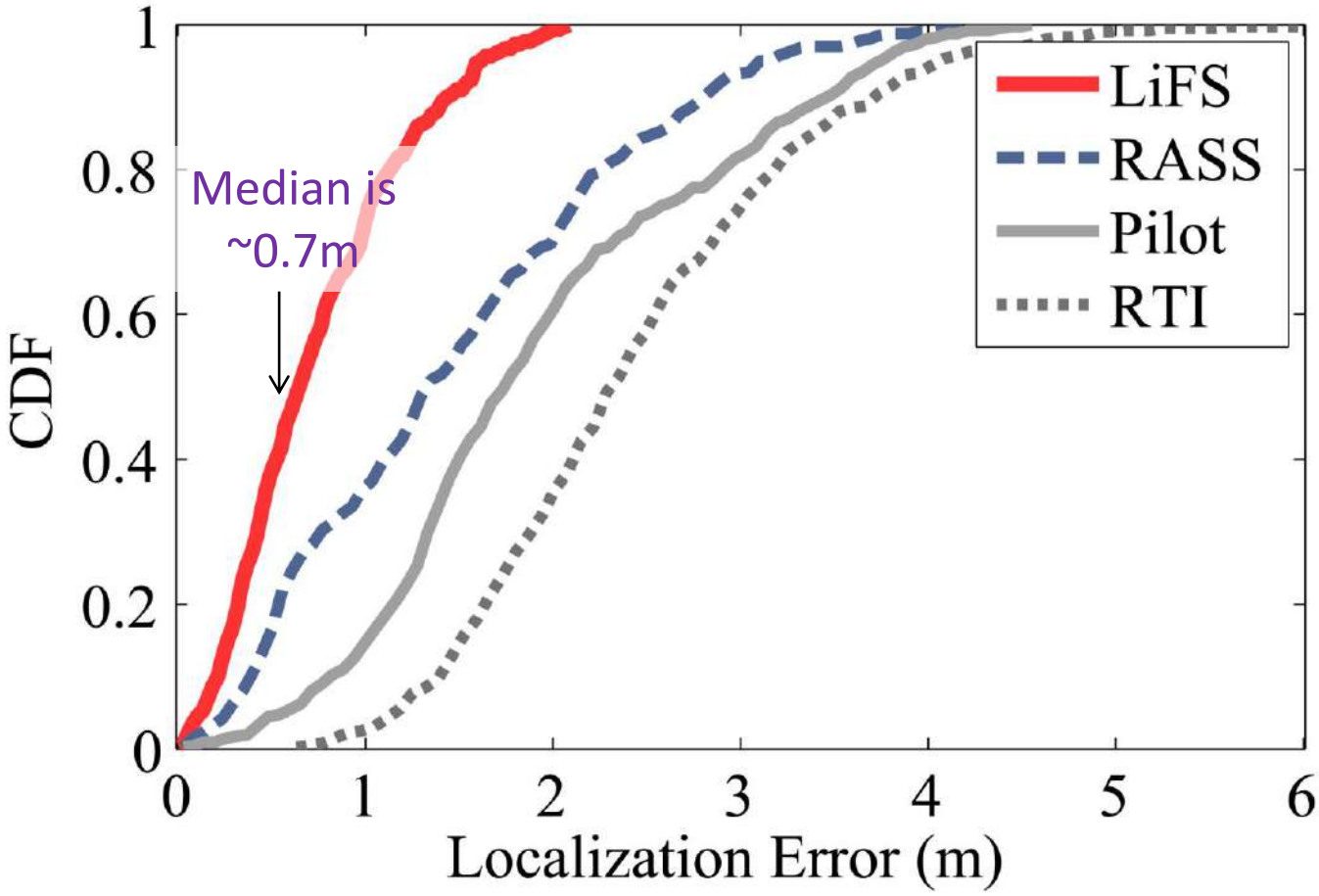
(9 m x 12 m)

Strong NLoS

(7 m x 12 m)

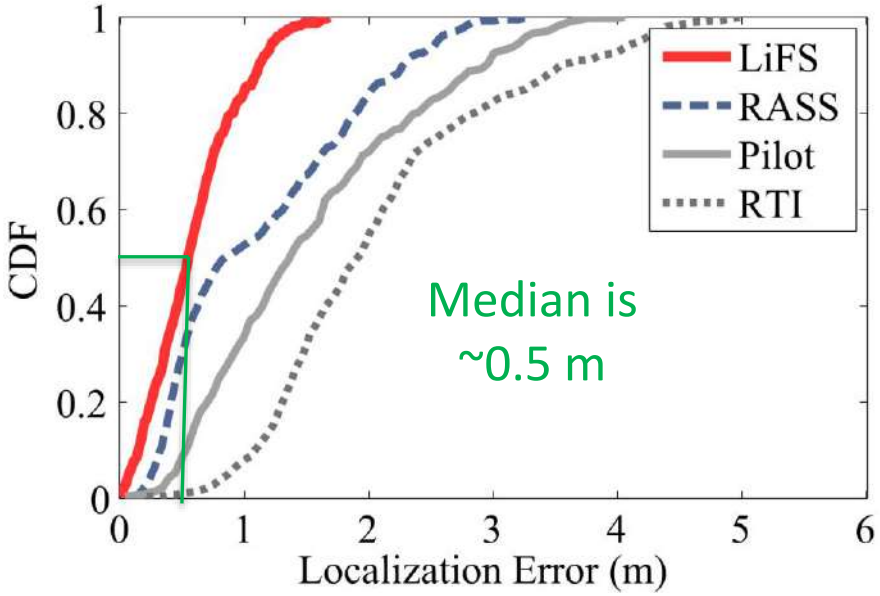
Evaluation in Medium Multipath

- Home environment: ***medium*** multipath

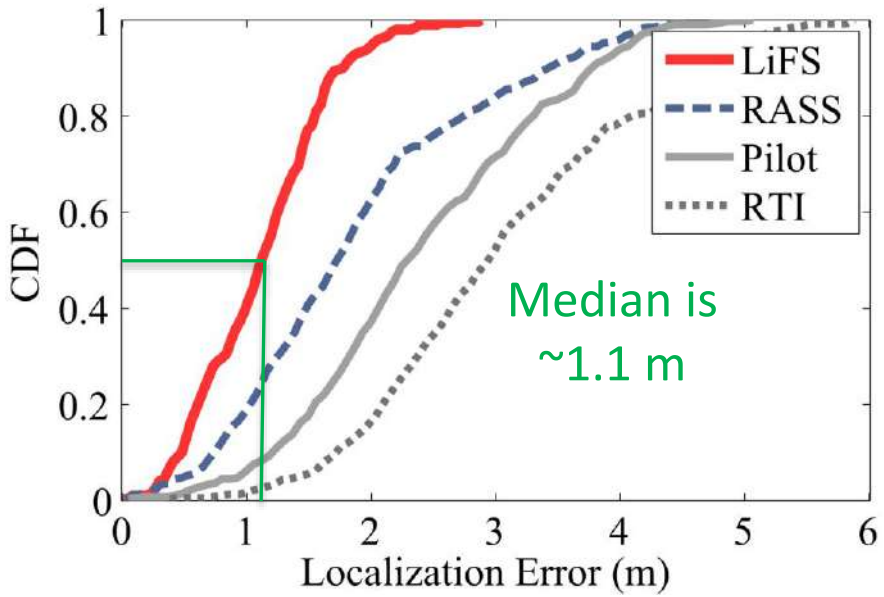


Evaluation in LoS & NLoS

- Empty classroom and Library environments, corresponding to ***low*** and ***high*** multipath



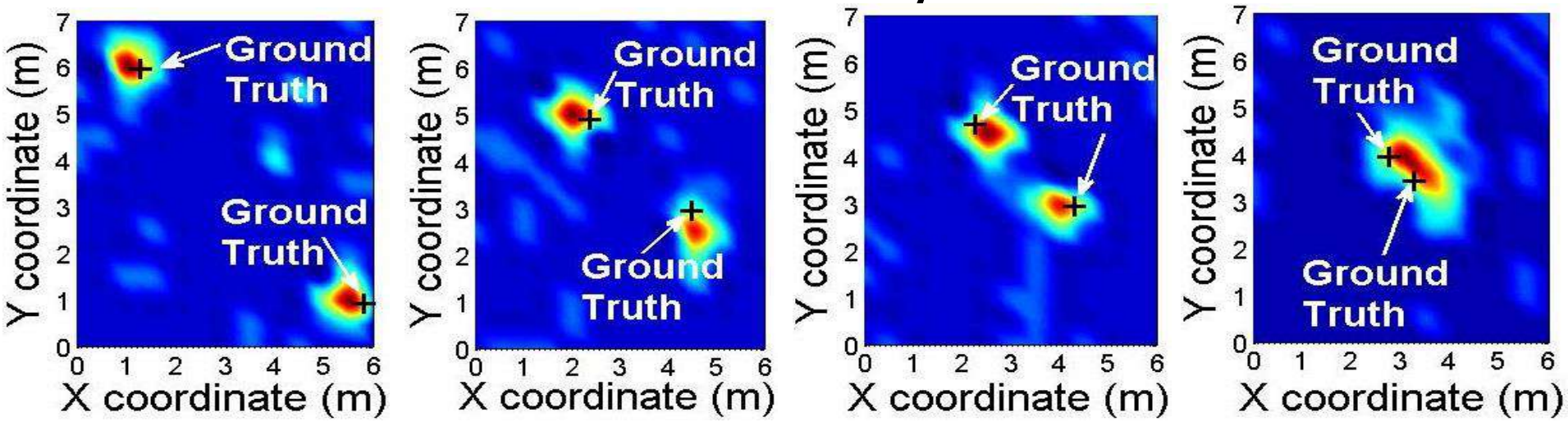
Classroom (Strong LoS)



Library (Strong NLoS)

Two-Target Localization

- **Intuition**: a target is not able to affect all the wireless links simultaneously.



Four snapshot localization results when two targets are 5.4 m, 3 m, 1.8 m and 0.6 m apart.

LiFS can localize each individual target accurately when they are not too close!

Conclusions

- **Device-free localization** is important for many applications.
- Even in a rich multipath environment, it's possible to identify **"clean" subcarriers** for model-based localization.
- Extensive experiments demonstrate the effectiveness of LiFS.