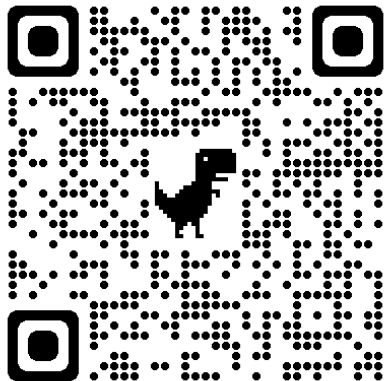


BIFROST: Reinventing WiFi Signals Based on Dispersion Effect for Accurate Indoor Localization

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<http://tns.thss.tsinghua.edu.cn/sun/>



**Tsinghua
SUN Group**

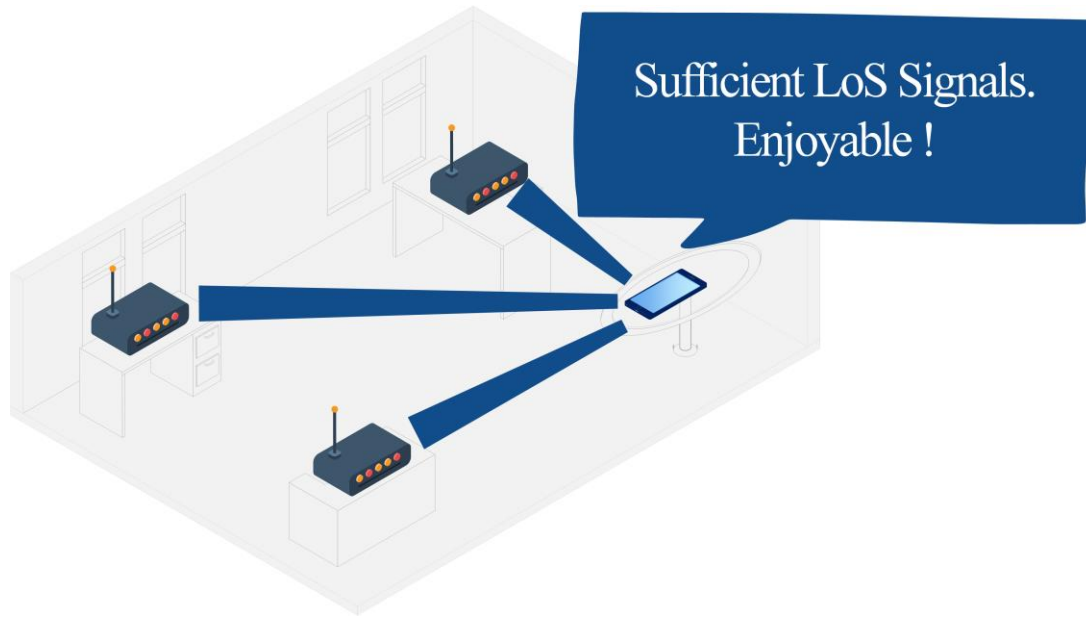


清华大学
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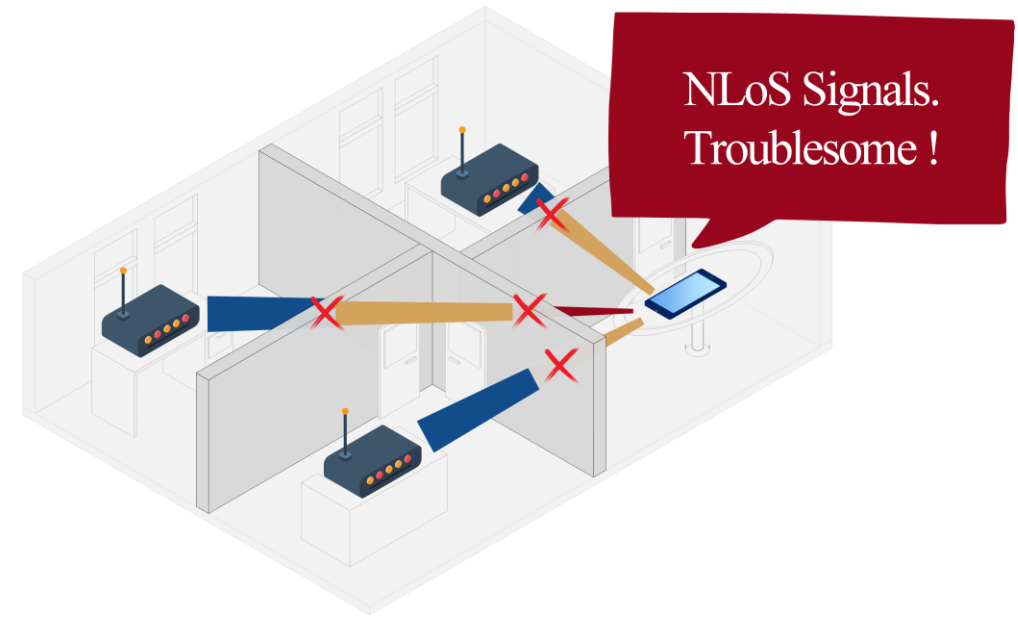
Indoor WiFi Localization: LoS vs. NLoS



Ideal Scenario

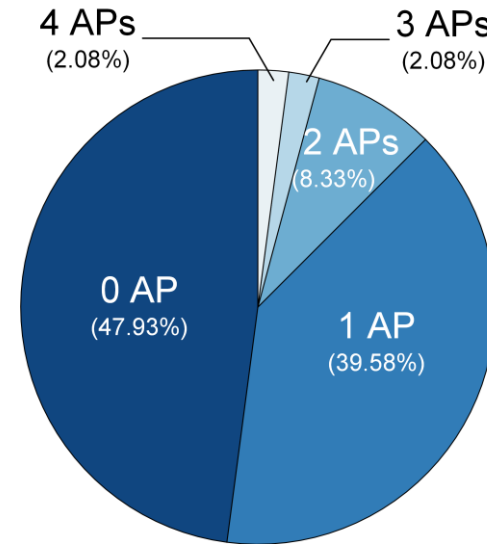
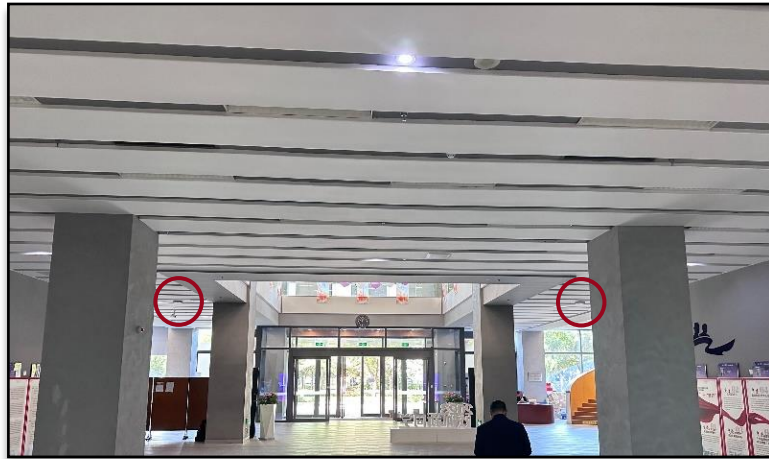


Practical Scenario

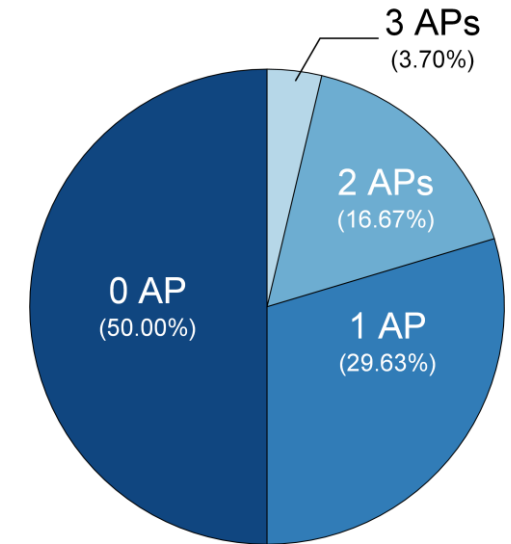


Problem: WiFi signals are everywhere, but very few of them are usable for accurate localization.

Most Indoor Rooms Can't See any LoS AP



Library (48 rooms)

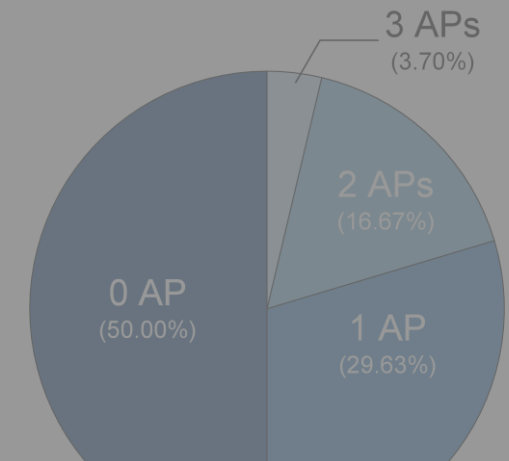
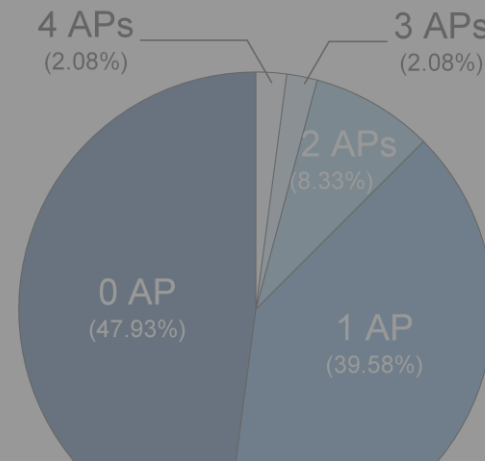


Office (54 rooms)



Less than 5% rooms can see sufficient LoS APs in our real-world investigations.

Most Indoor Rooms Can't See any LoS AP



How to localize a device when LoS AP is insufficient ?

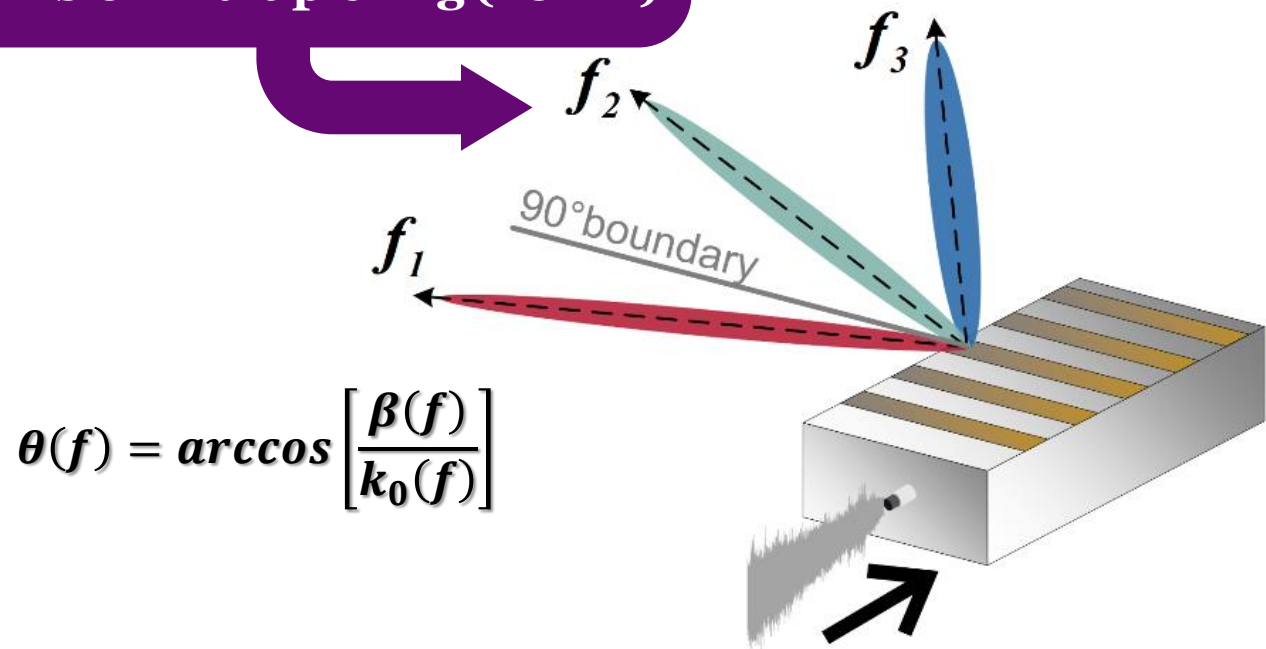


The chance to receive sufficient LoS signals is less than 5% in our real-world investigations

Our Insight



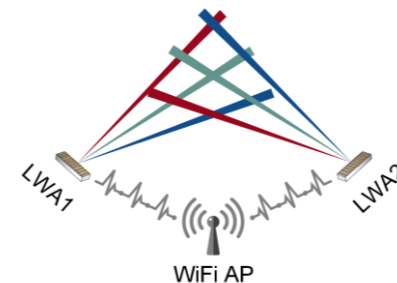
Frequency and Spatial Division Multiplexing (FSDM)



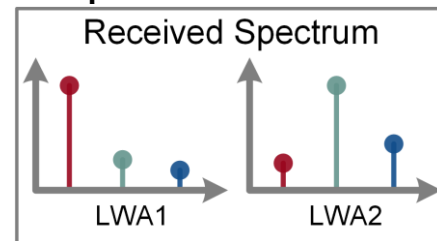
Leaky Wave Antenna: Signals with different frequencies will be radiated to different directions.

Basic Idea

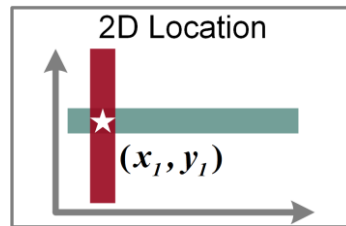
1. Exploit two LWAs to radiate FSDM signals



2. Capture frequencies of the two FSDM signals



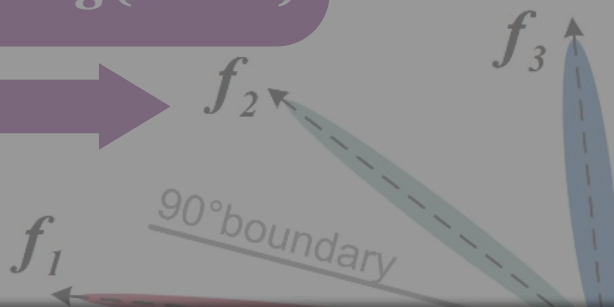
3. Estimate AoAs and location by finding the frequencies with the highest energy.



BIFROST

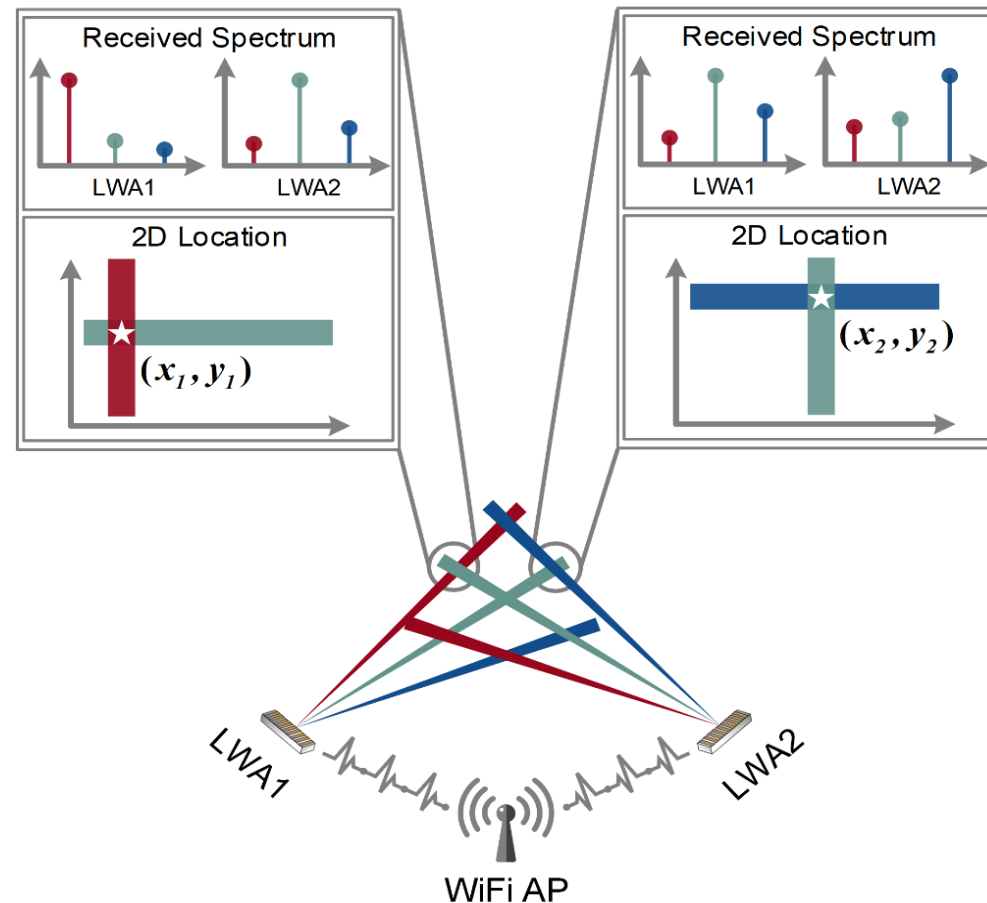


Frequency and Spatial
Division Multiplexing (FSDM)



Where there is WiFi signal,
one can be localized.

High-level Principle

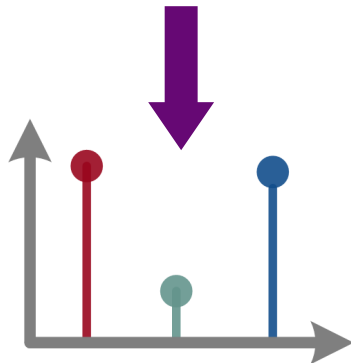
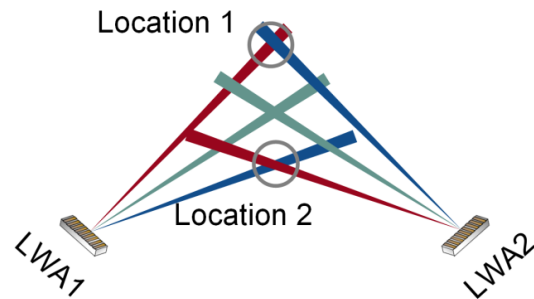


Challenges



Challenge 1

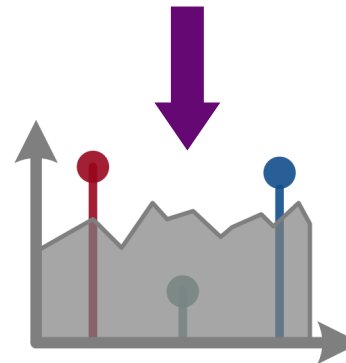
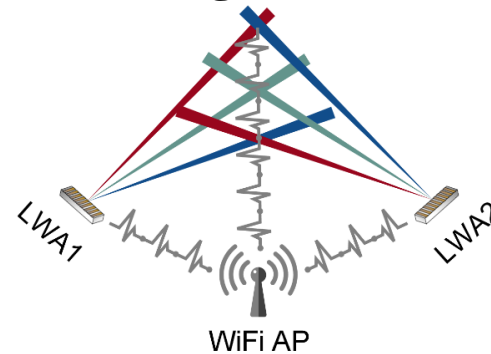
- How to distinguish the two different LWAs?



Different locations obtain the same frequencies, causing location ambiguity.

Challenge 2

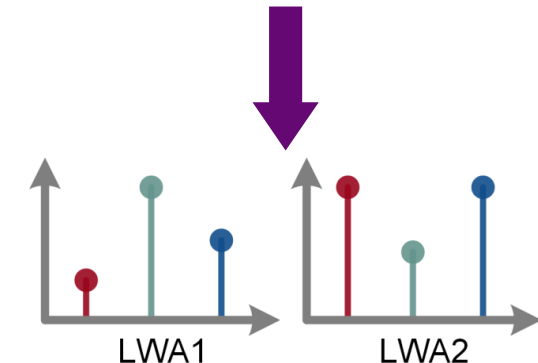
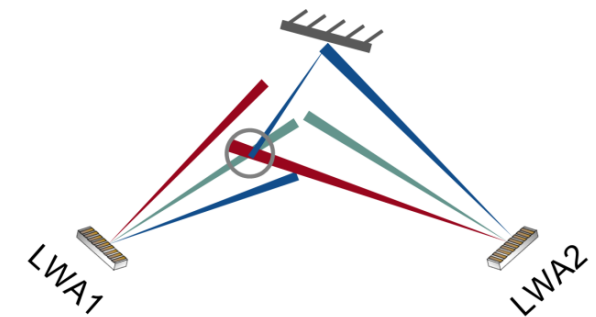
- How to extract FSDM signal from WiFi signal?



FSDM and WiFi signals operate within the same band, leading to interference.

Challenge 3

- How to mitigate the indoor multipath effect?

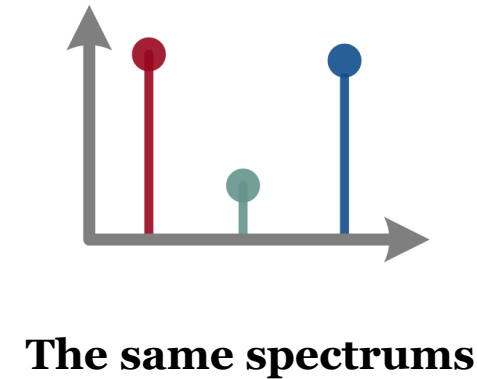
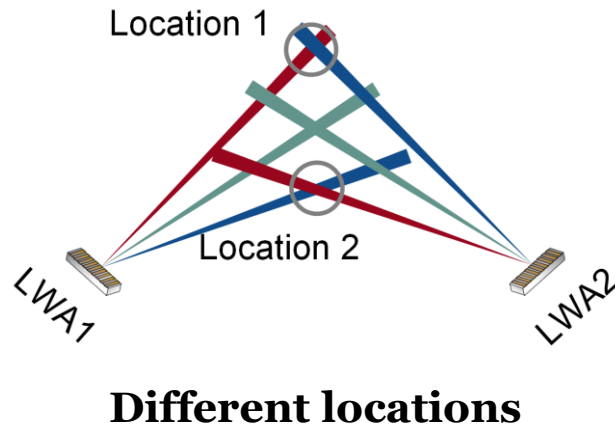


Indoor multipath effect affects the quality of receiving the FSDM signals.

How to distinguish the two different LWAs?

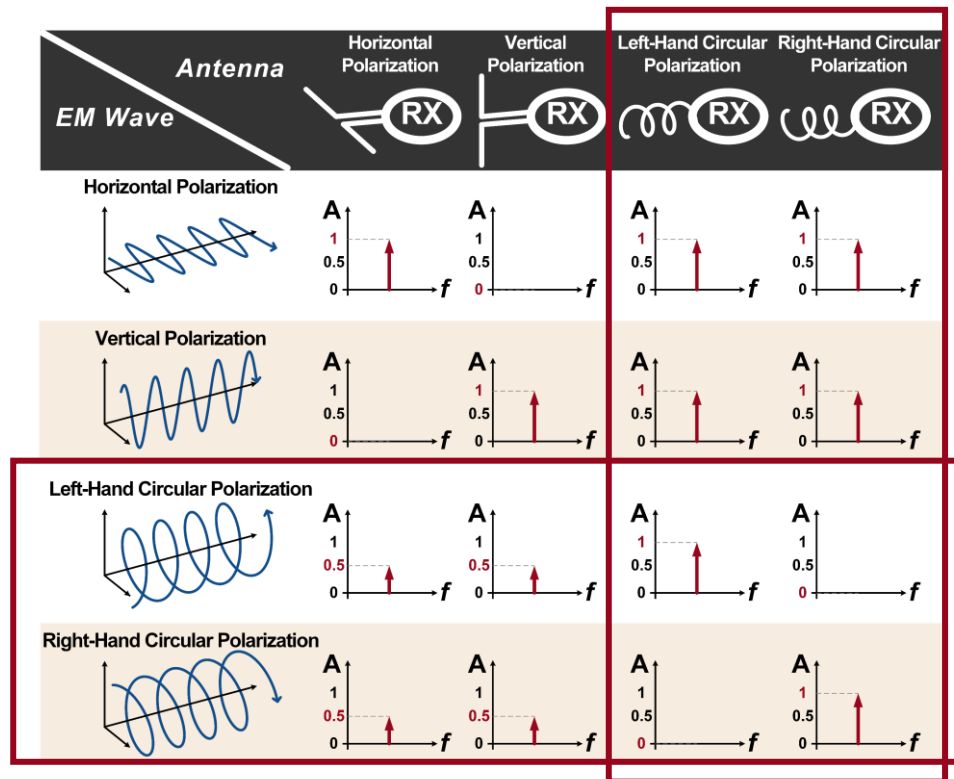


Ambiguity between Different LWAs



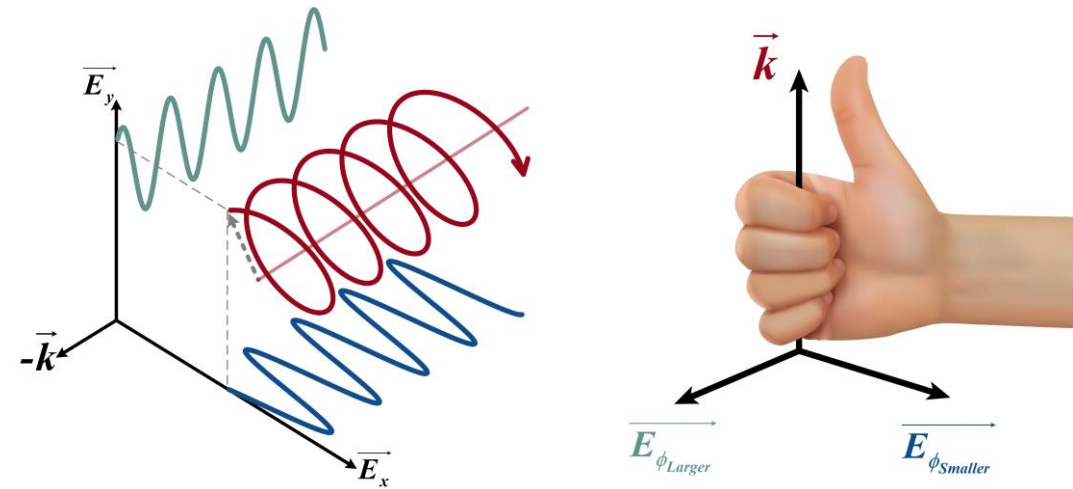
Problem: Another signal property, besides frequency, must be explored to distinguish the two LWAs

Signal Polarization



Polarization Mismatch

LHCP is orthogonal to RHCP



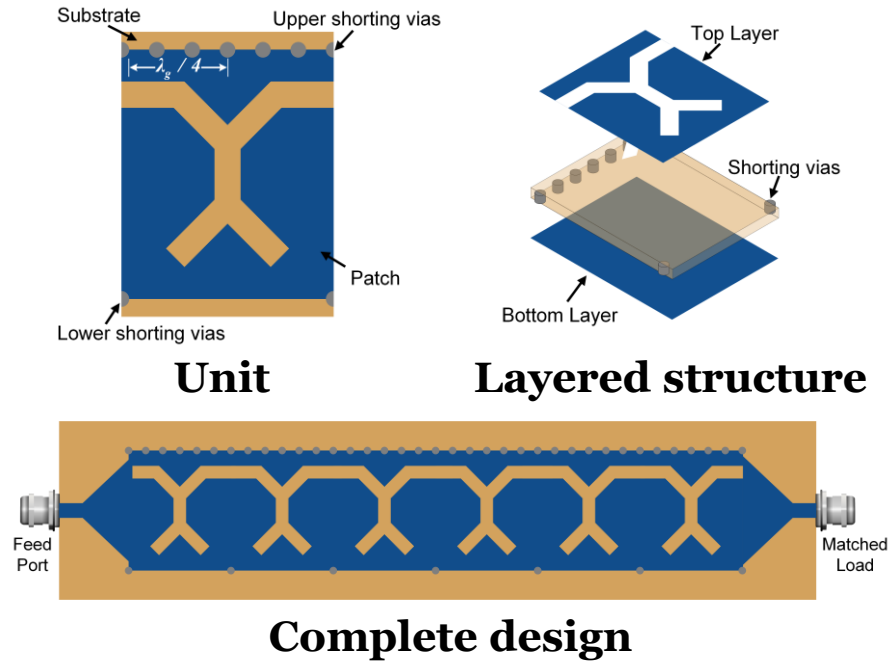
CP signal synthesis

Solution: Exploiting orthogonal circular polarization (LHCP & RHCP) to cancel the ambiguity between the two different LWAs

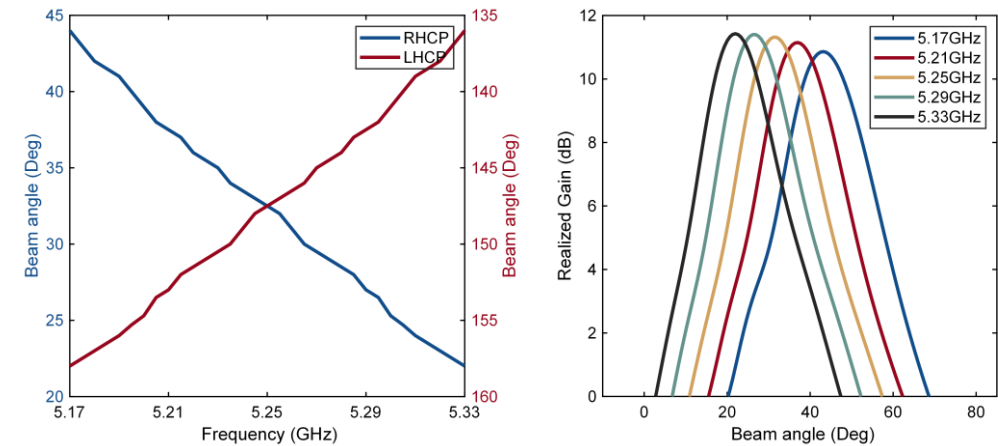
CPLWA Design



General View of CPLWA



Quick Validation



Main beam direction

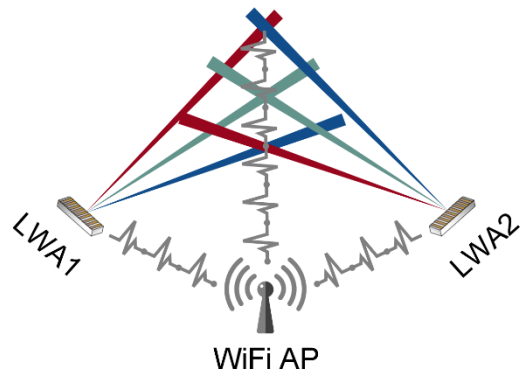
Realized gain

CPLWA: Orthogonal circular polarized signals can be generated by switching the signal feed port. The emitted signal is both CP and FSDM

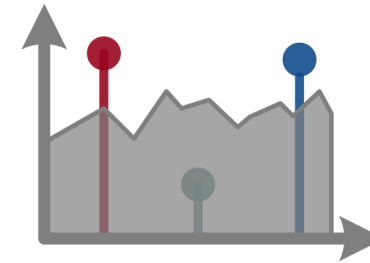
How to extract FSDM signal from WiFi signal?



Signal Extraction from the Interfered Frequency Band



WiFi and FSDM signals
in the same space



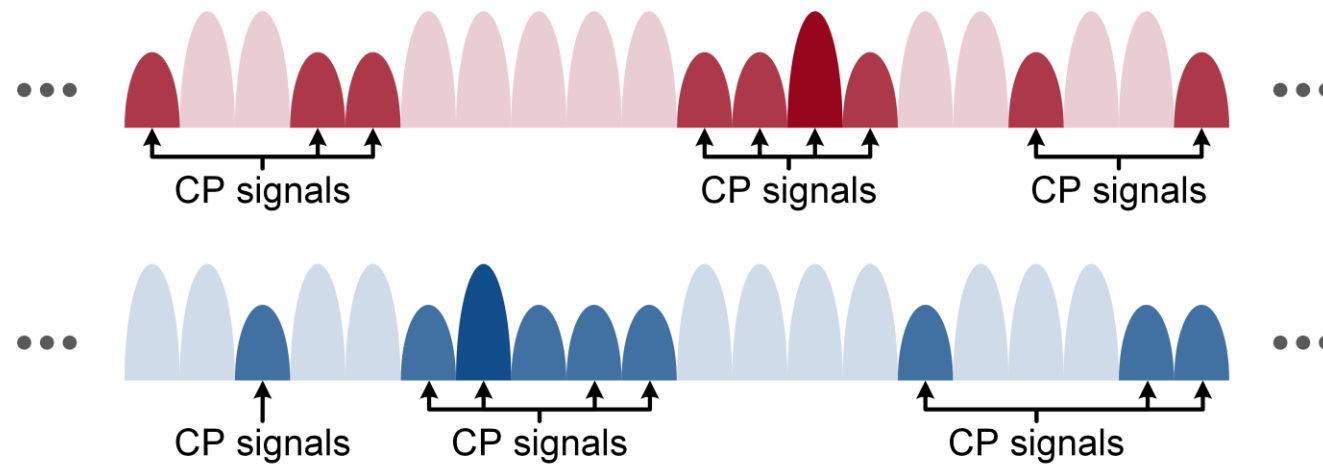
Overlapped noisy
spectrum

Problem: FSDM signals and WiFi signals operate within the same frequency band, so they may interfere with each other.

Duty-cycled Operating Manner



Identify CP Signals by Duty-cycled Operating Manner

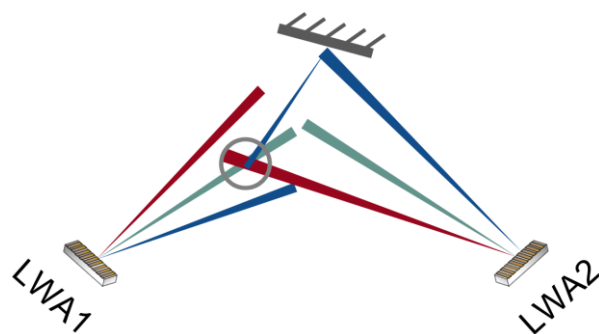


Solution: LWAs are periodically turned on and off to identify frequencies corresponding to the CP signal by analyzing the variation of received spectrum.

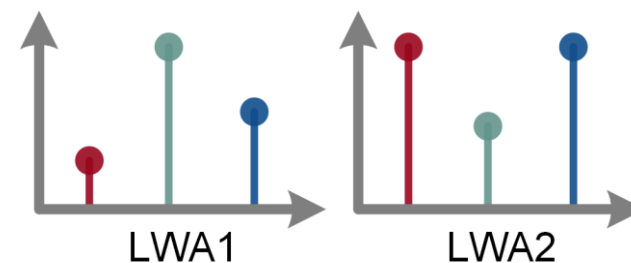
How to mitigate the indoor multipath effect ?



Indoor Multipath Effect



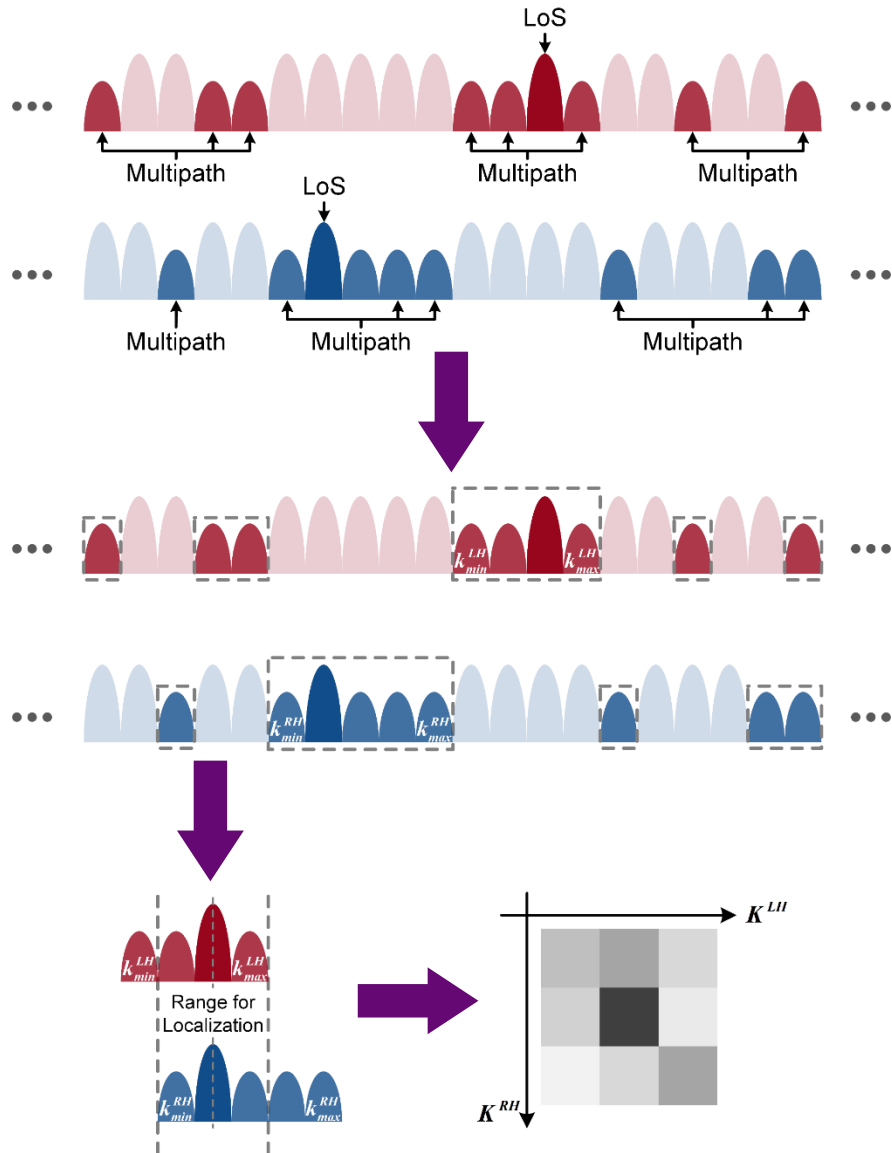
Undesired reflection



Distorted received spectrum

Problem: The multipath effect in the indoor environment may seriously affect the quality of the received FSDM signals and the localization accuracy.

Clustering and Filtering Multipath Signals



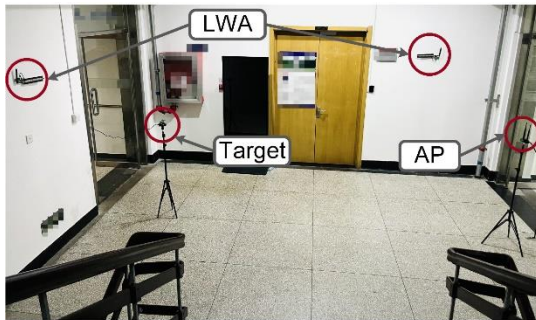
Workflow of Selecting Correct Frequencies

1. Cluster the selected subcarriers corresponding to CP signals
2. Find the cluster with the highest integrated energy
3. Align subcarriers bearing the highest energy in reserved clusters of RHCP and LHCP signals
4. Keep the common part of clusters
5. Multiply the two reserved sequences to form a matrix and output the weighted average value of the matrix.

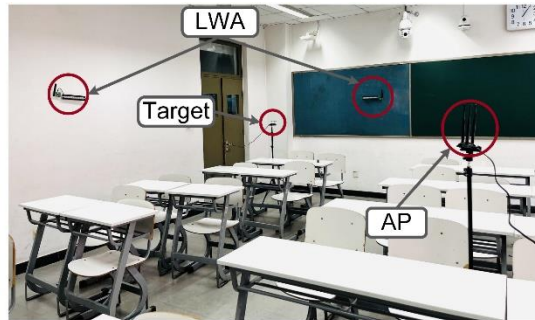
Implementation



Hall and Classroom Scenarios

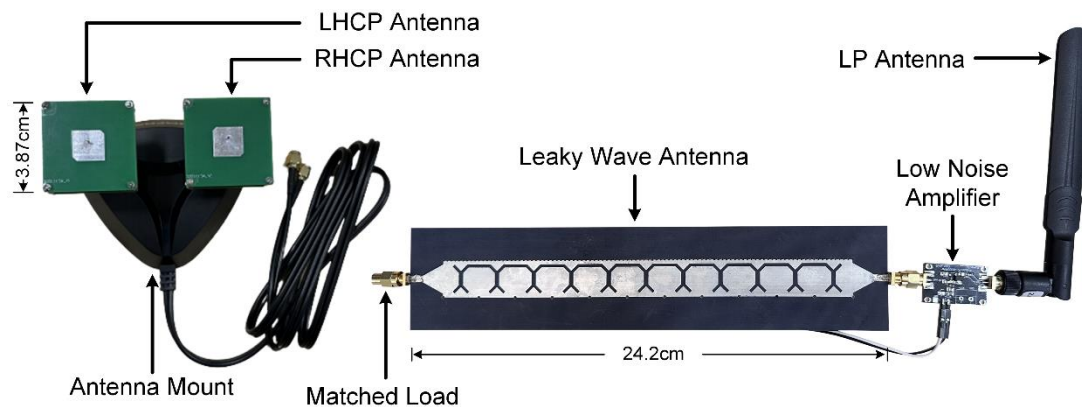


(Hall: 6.2 m × 4.5 m)



(Classroom: 10.6 m × 7.1 m)

Localized Target and Proposed LWA

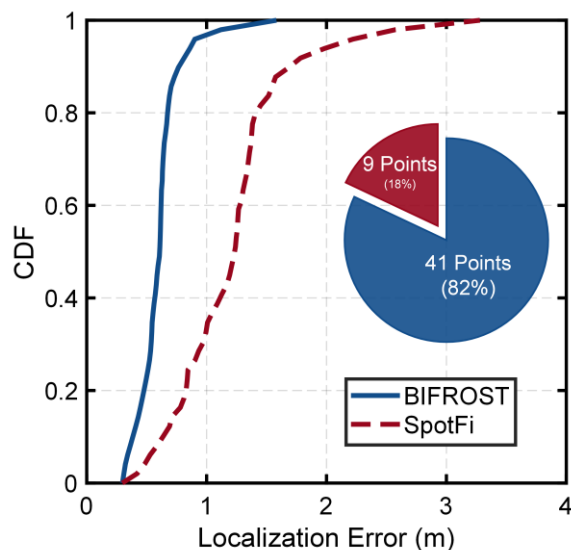


(Frequency Band: 5.17 GHz ~ 5.33 GHz)

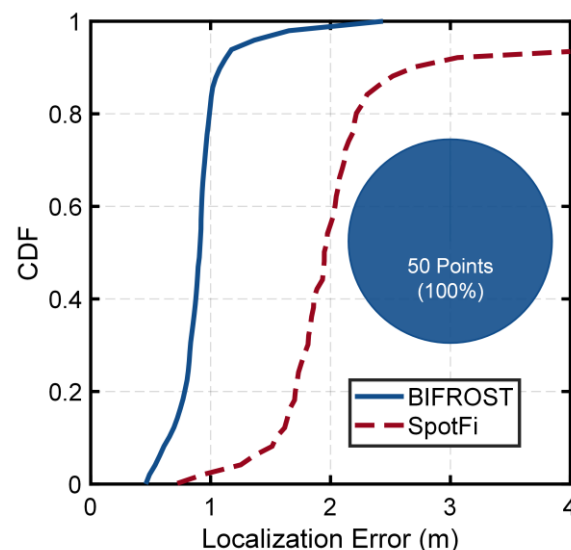
The Realistic AP Deployment



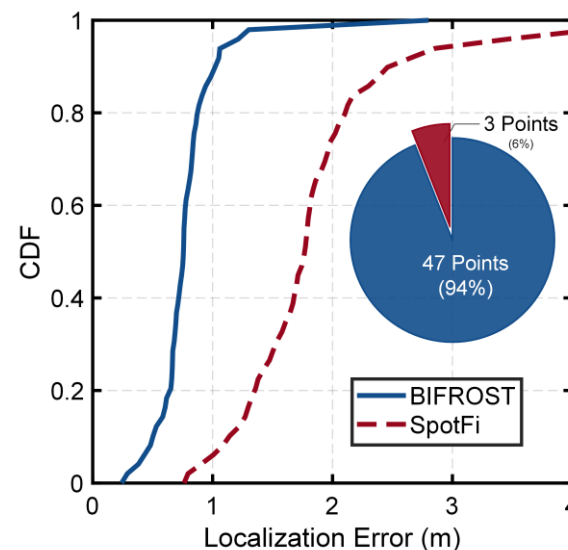
Overall Performance



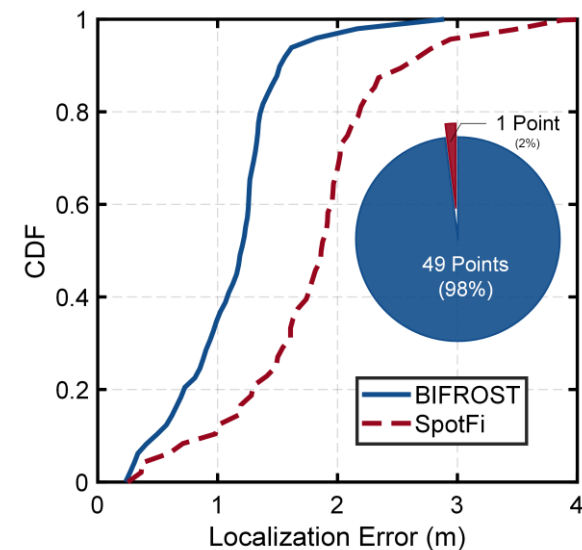
Hall



Corridor



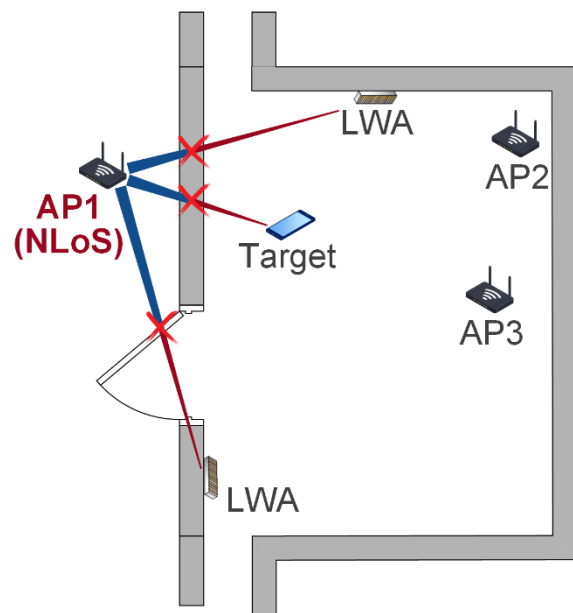
Meeting Room



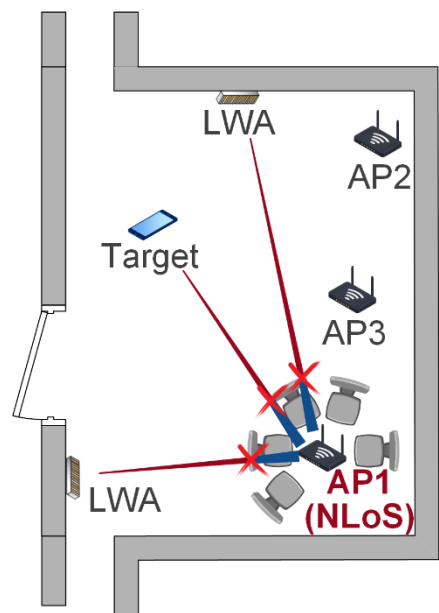
Classroom

Feature: The median error of BIFROST is 0.81m, **52.35% less** than that of SpotFi in the arguably realistic indoor settings.

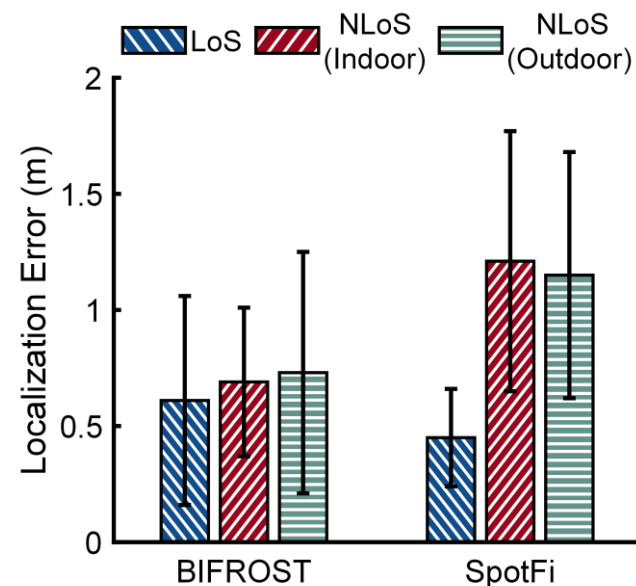
Performance in NLoS



The NLoS AP outdoors



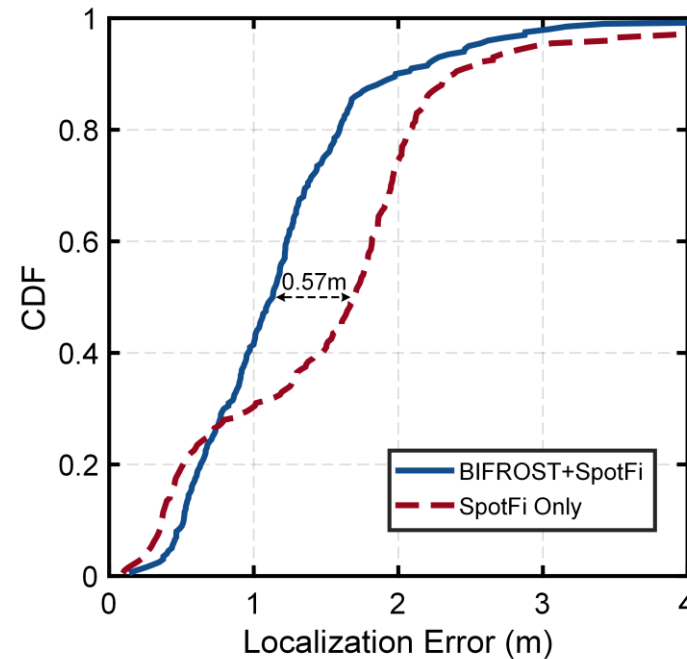
The NLoS AP indoors



Performance comparison

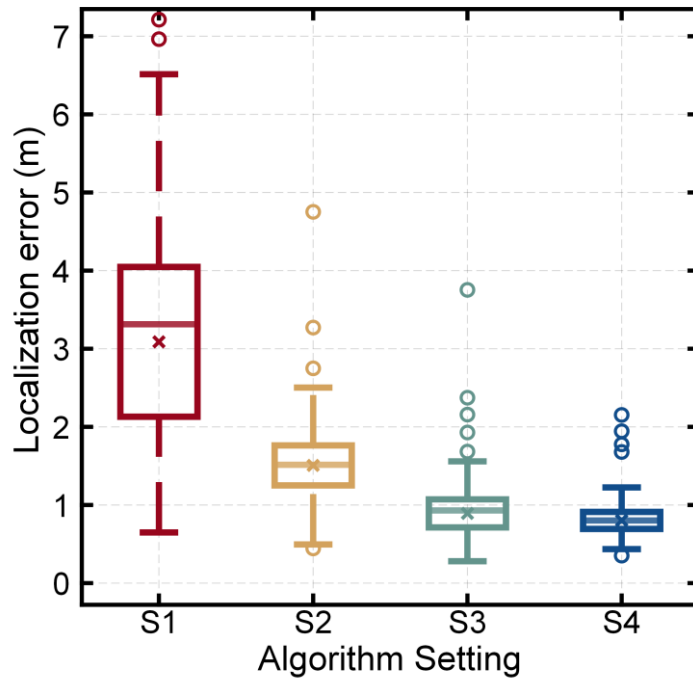
Feature 1: BIFROST provides stable performance when the AP is in LoS and NLoS.
Feature 2: In NLoS scenarios, BIFROST achieves more accurate results than SpotFi.

Performance Enhancement



Feature: BIFROST can enhance localization accuracy of existing localization techniques and achieve **33.54%** error reduction (From **1.70m** to **1.13m**).

Ablation Study



Settings of ablation study

S1: Localizing with raw data.

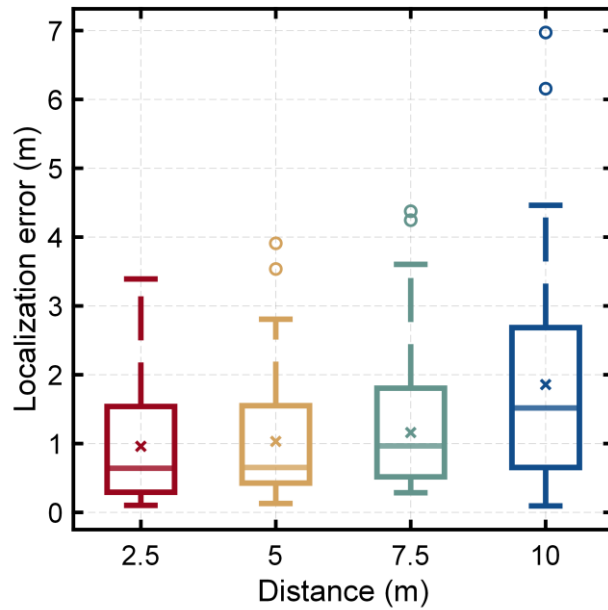
S2: only ①identifying the frequencies of CP signals.

S3: ① identifying the frequencies of CP signals and ② filtering out the multipath signal.

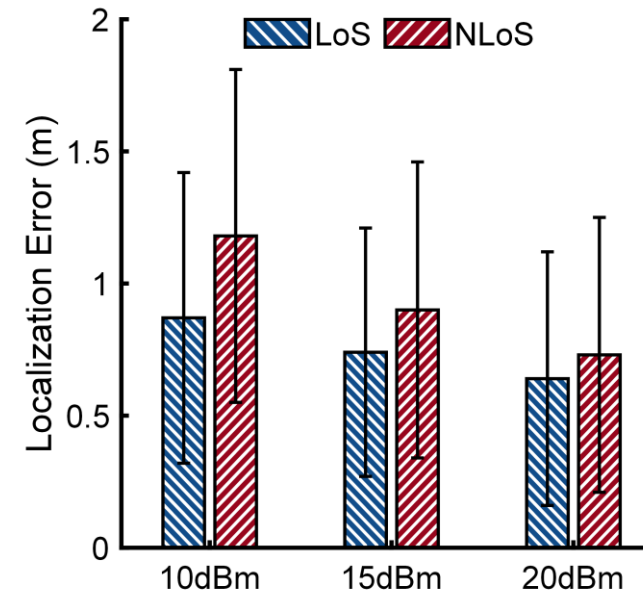
S4: ① identifying the frequencies of CP signals,
② filtering out the multipath signal and
③ purifying the LoS signal for localization.

Feature: Each sub-module in our algorithm owes necessity and contribution to the better localization performance.

Impacting Factors



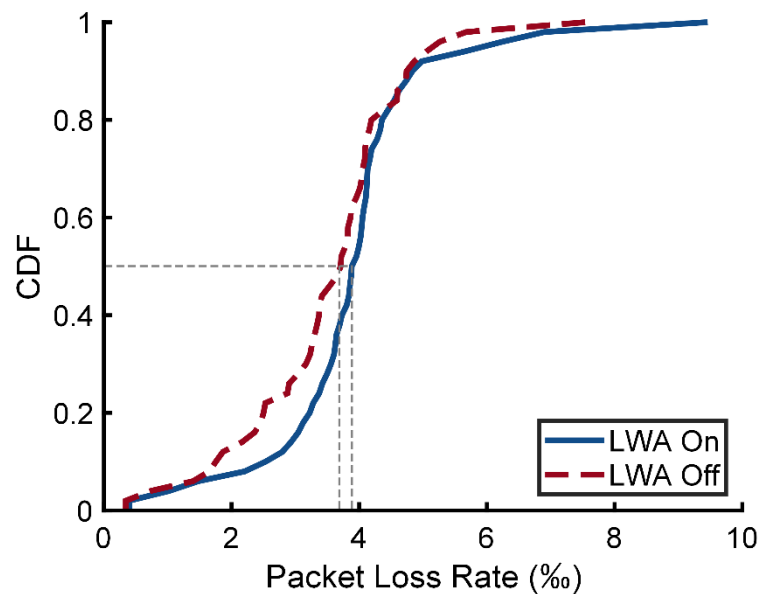
Distance between AP and LWAs



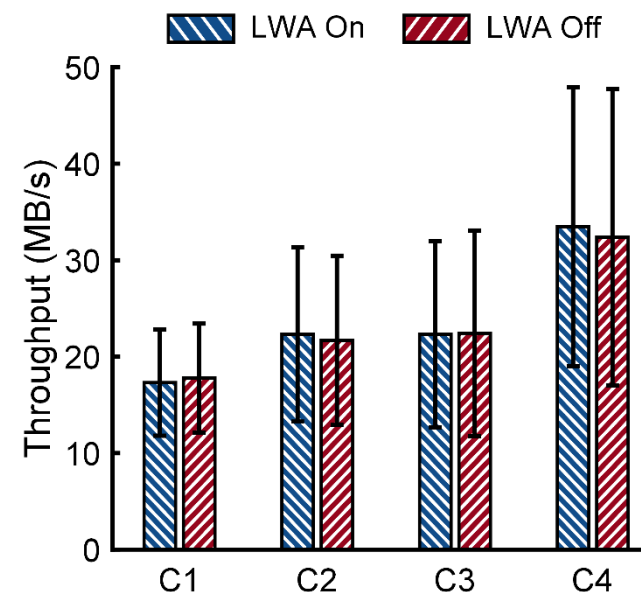
Transmission power

Feature: These factors influence BIFROST's performance differently, yet the absolute accuracy never degrades drastically.

Impact on Communication



Impact on the AP and the target



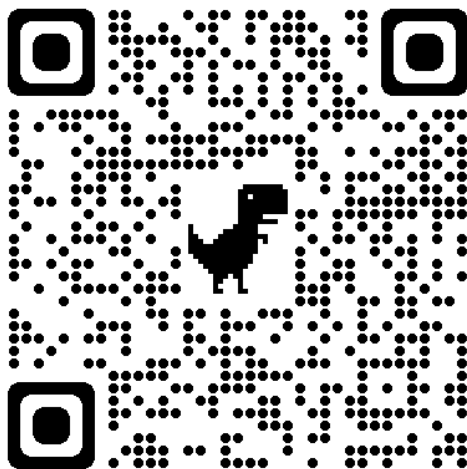
Impact on other WiFi connections

Feature: The deployment of BIFROST has a negligible impact on the communication quality of either the link between the AP and the target or other WiFi connections.

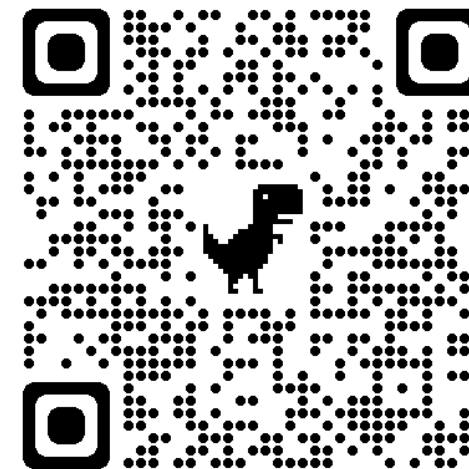
- **BIFROST** tackles a significant problem, namely the limited availability of LoS signals, to enhance the availability of WiFi localization.
- The key innovation is the exploration of the **signal polarization** and **dispersion effect**, which embodies the concept of **RF computing**.
- **BIFROST** can either improve the performance of other methods, or operate independently to outperform the STOA, without affecting the ongoing data communication of WiFi networks.

Thank You!

Please find more details in:



<http://tns.thss.tsinghua.edu.cn/sun/>



<https://yimiao-sun.github.io/>