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

Yimiao Sun, Yuan He*, Jiacheng Zhang, Xin Na, Yande Chen,
Weiguo Wang, Xiuzhen Guo

School of Software and BNRist, Tsinghua University

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

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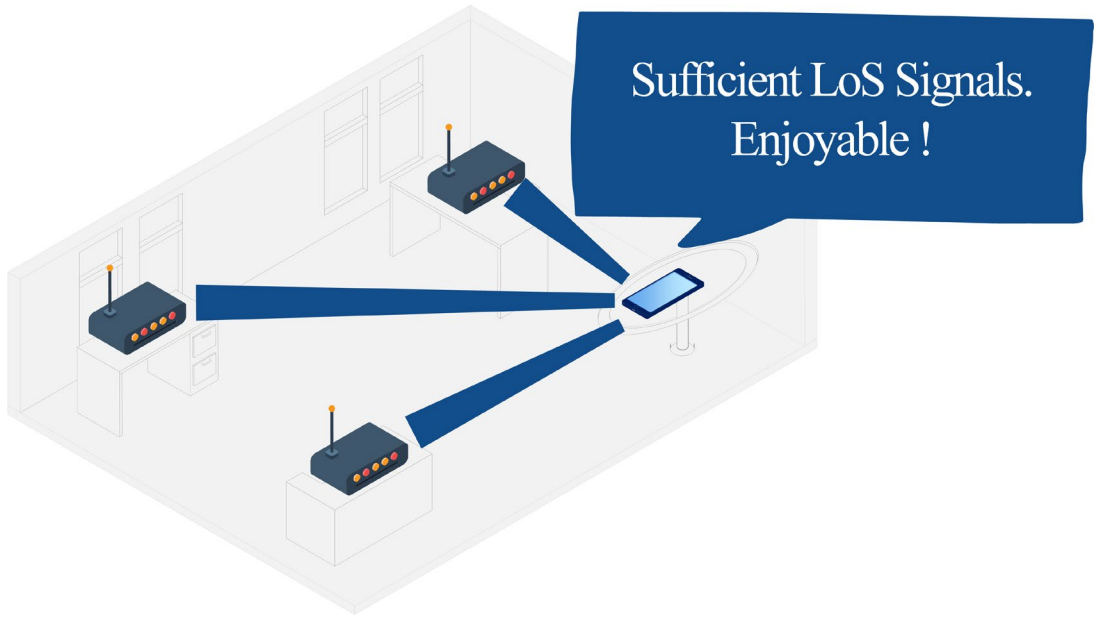
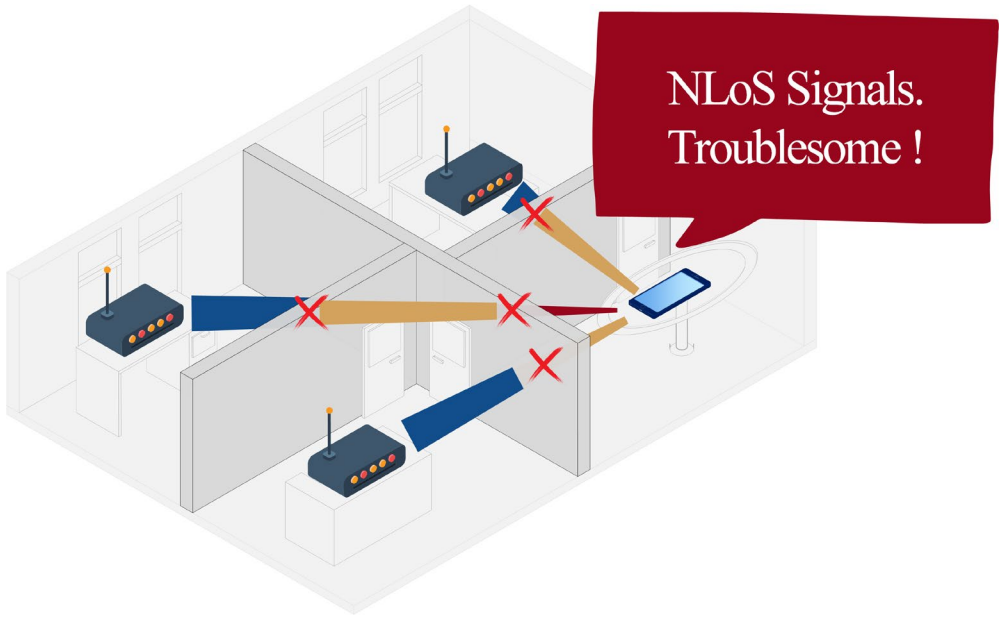
Indoor WiFi Localization: LoS *vs.* NLoS

Ideal Scenario

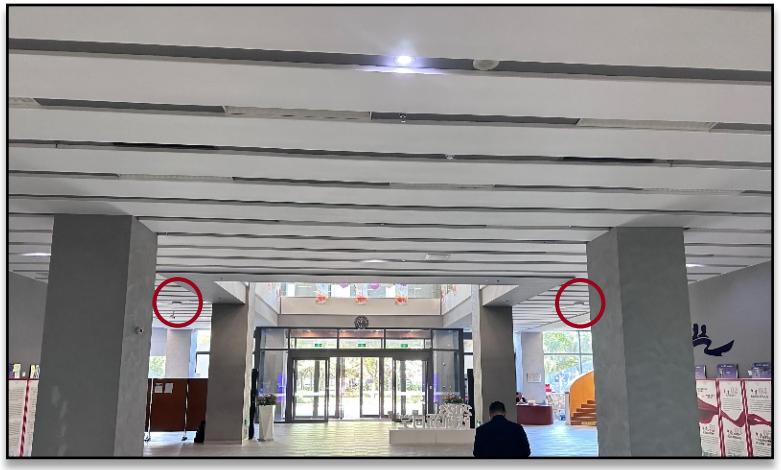


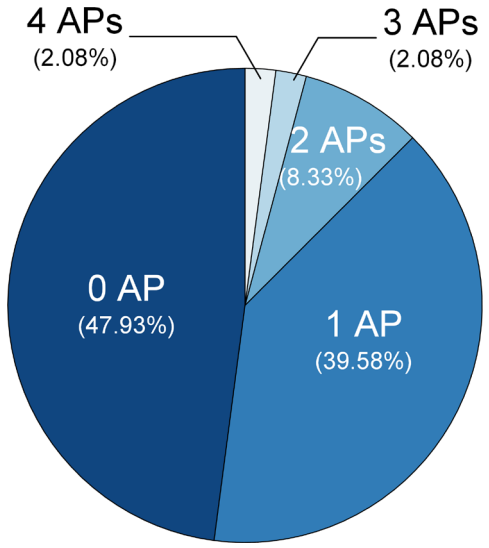
Practical Scenario



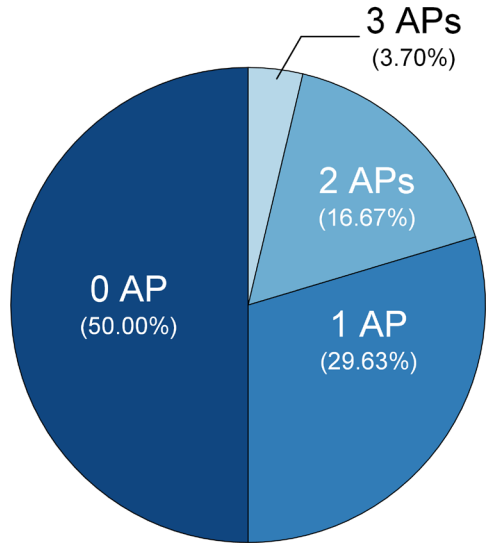
Problem: Indoor blockages are everywhere, so the WiFi APs in LoS scenarios may be rare.

Most Indoor Rooms Can't See any LoS AP





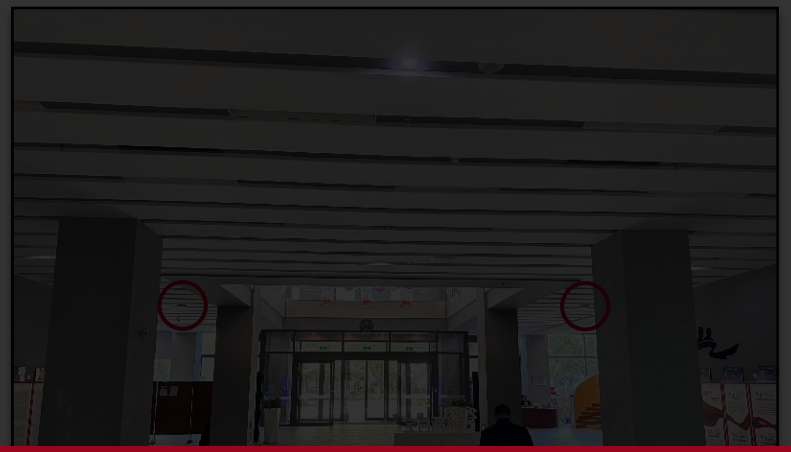
Library (48 rooms)

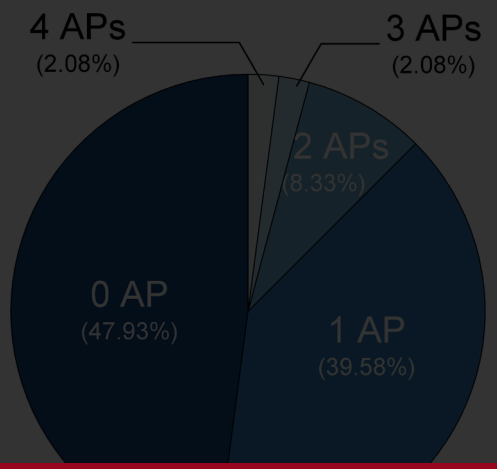


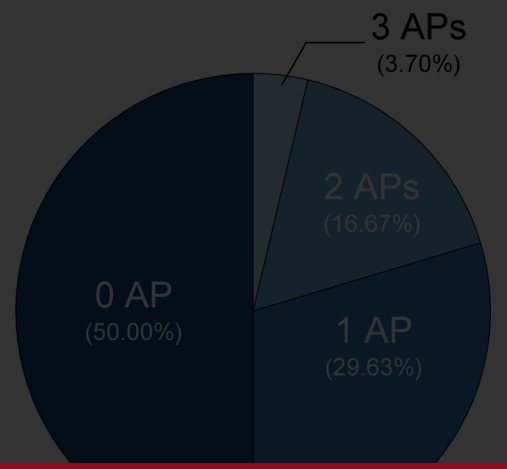
Office (54 rooms)

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

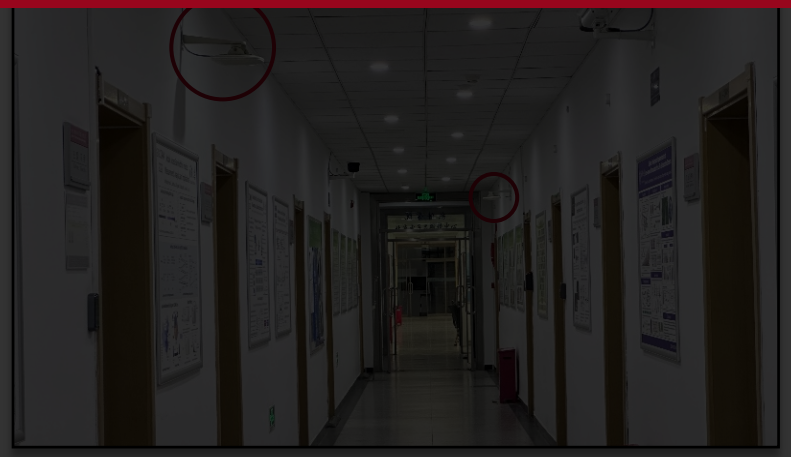
Most Indoor Rooms Can't See any LoS AP





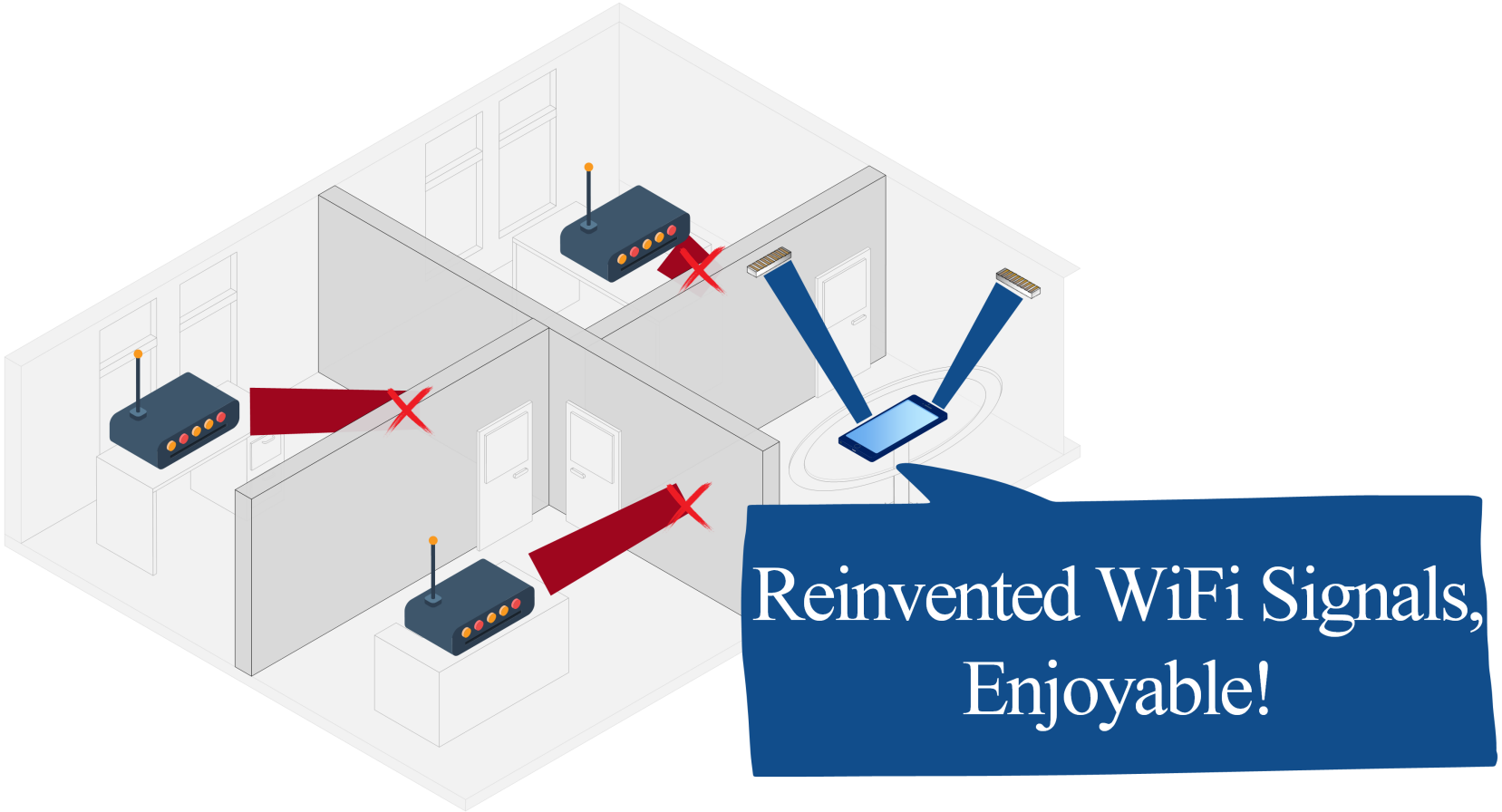


How to localize a device when LoS APs are insufficient?



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

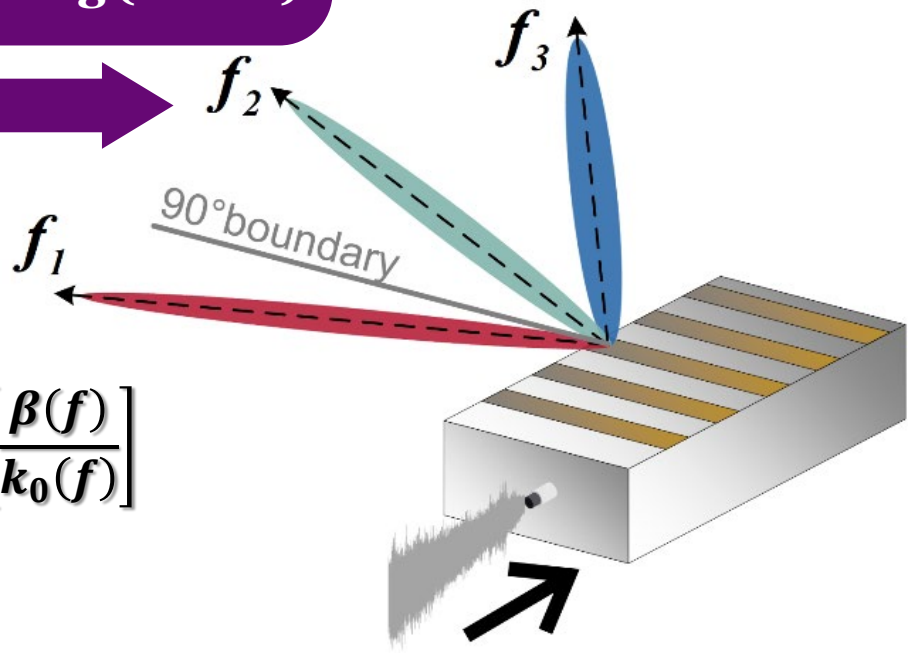
Our Solution



Solution: Reinventing the ambient WiFi signals to create the LoS paths for indoor localization.

Key Technique

Frequency and Spatial Division Multiplexing (FSDM)

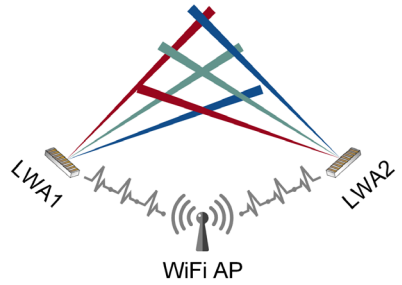


$$\theta(f) = arccos\left[\frac{\beta(f)}{k_0(f)}\right]$$

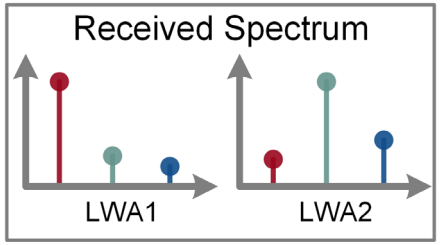
Leaky Wave Antenna (LWA): Signals with different frequencies will be radiated to different directions.

Basic Idea

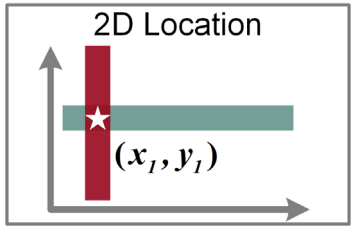
1. Employ two LWAs to radiate FSDM signals



2. Capture frequencies of the two FSDM signals



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

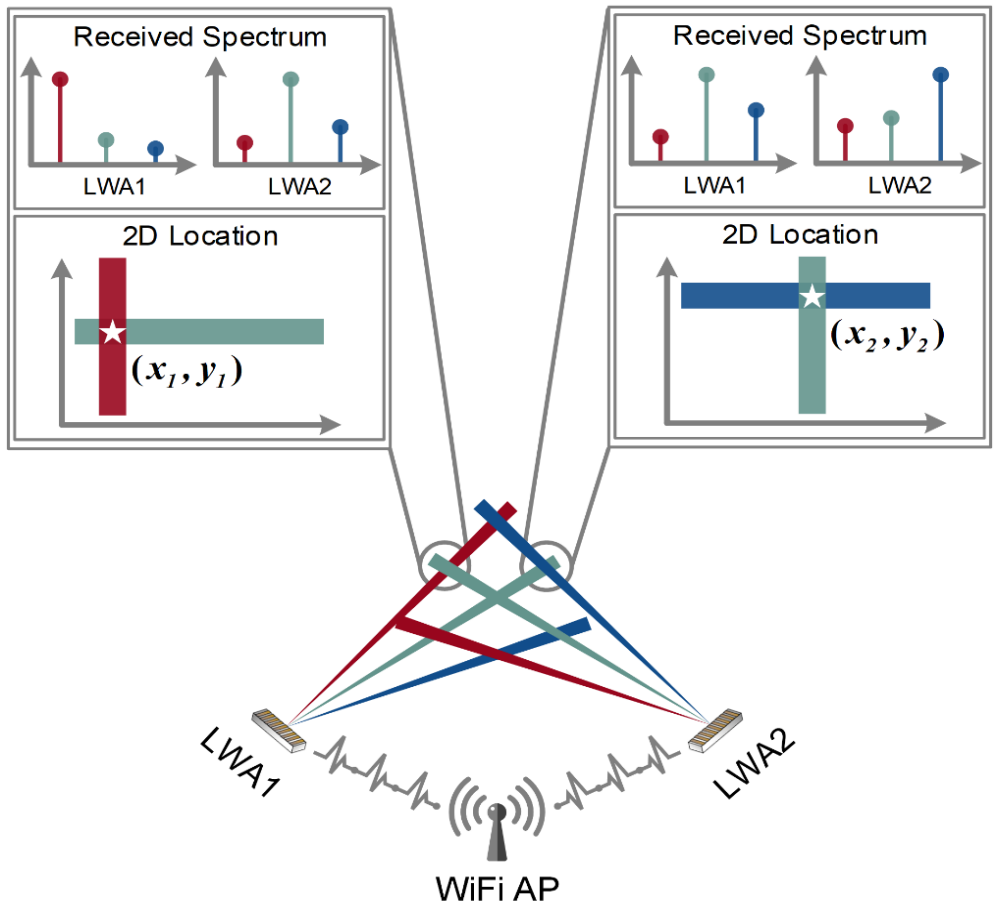


BIFROST

Frequency and Spatial Division Multiplexing (FSDM)

Where there is WiFi signal, one can be localized.

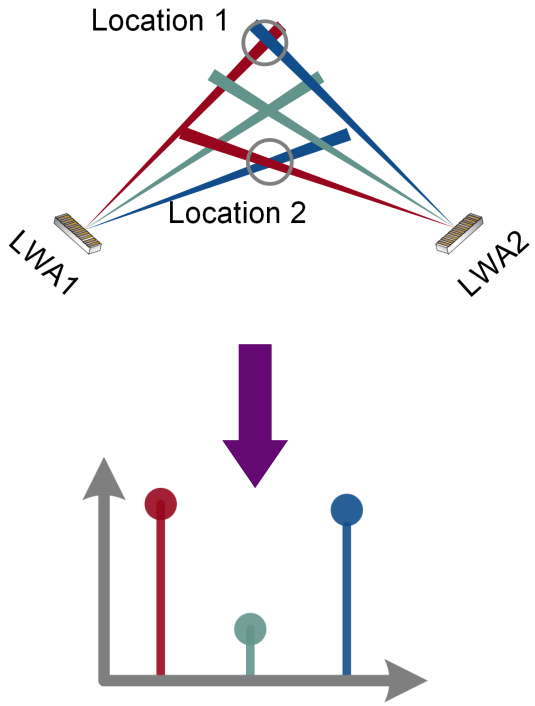
High-level Principle



Challenges

Challenge 1

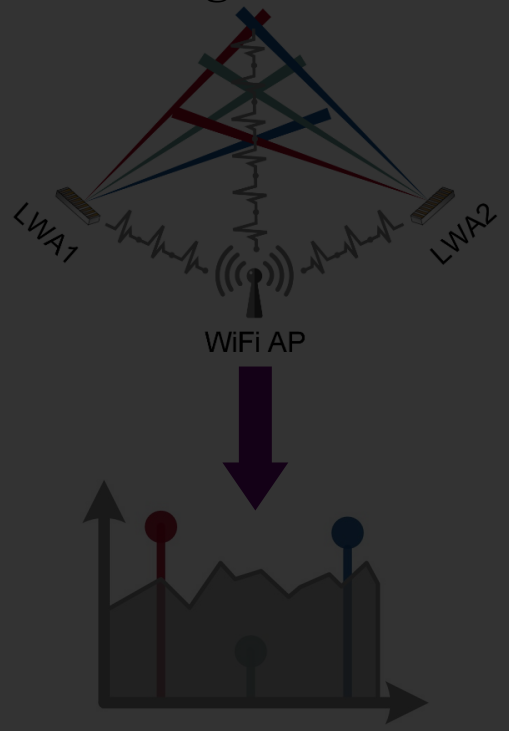
- **How to distinguish the two different LWAs?**



Different locations obtain the same frequencies, causing location ambiguity.

Challenge 2

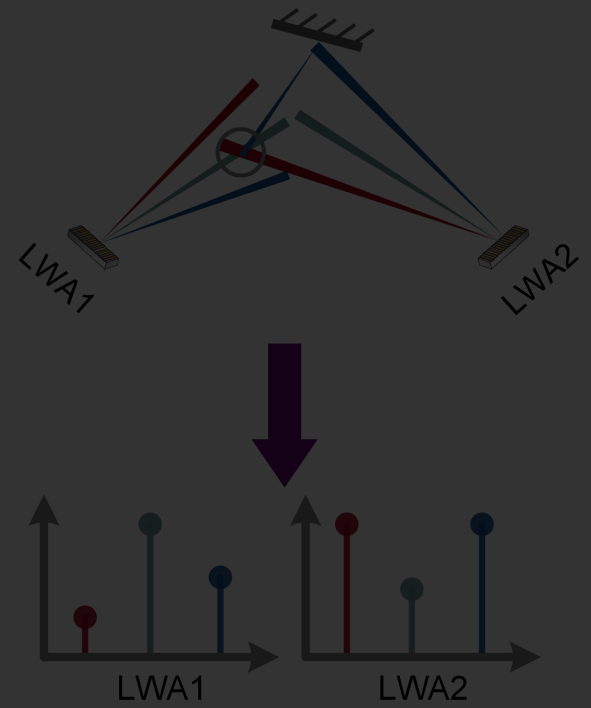
- **How to extract FSDM signal from WiFi signal?**



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

Challenge 3

- **How to mitigate the indoor multipath effect?**

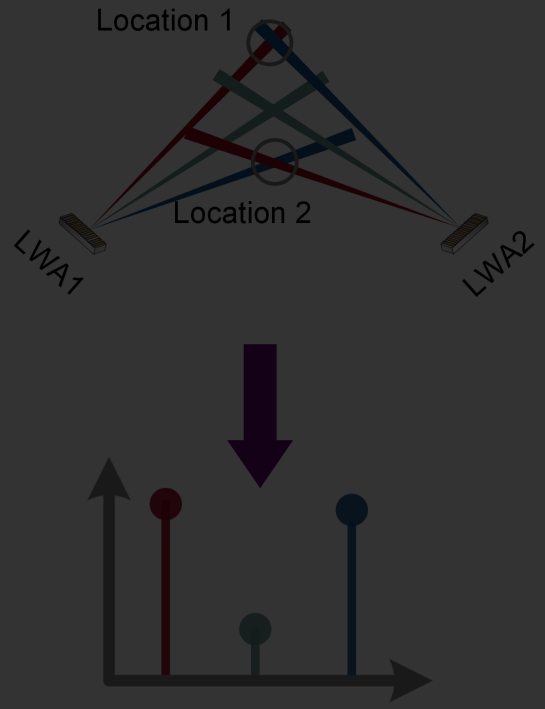


Indoor multipath effect affects the quality of receiving the FSDM signals.

Challenges

Challenge 1

- How to distinguish the two different LWAs?



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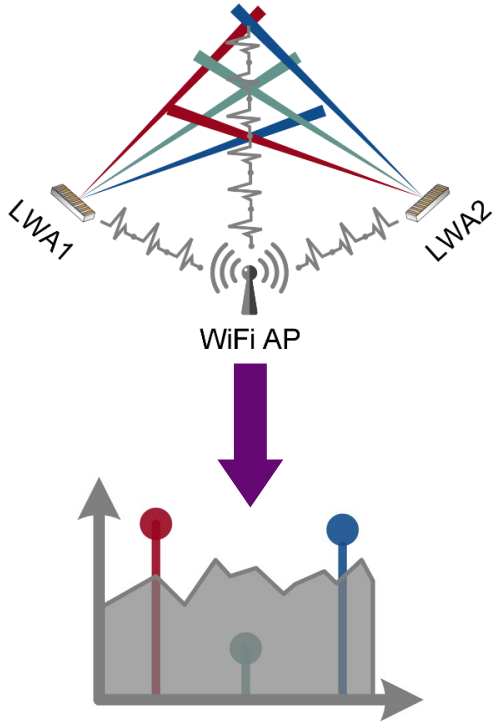
Challenge 2

- How to extract FSDM signal from WiFi signal?



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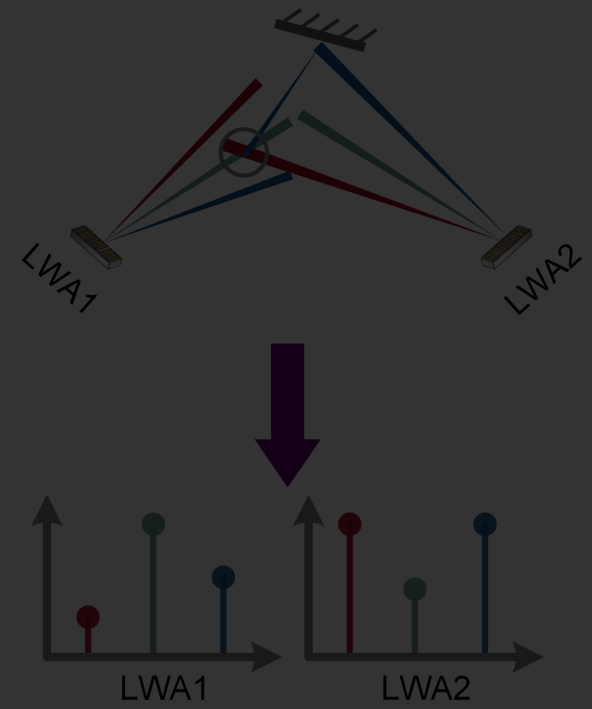

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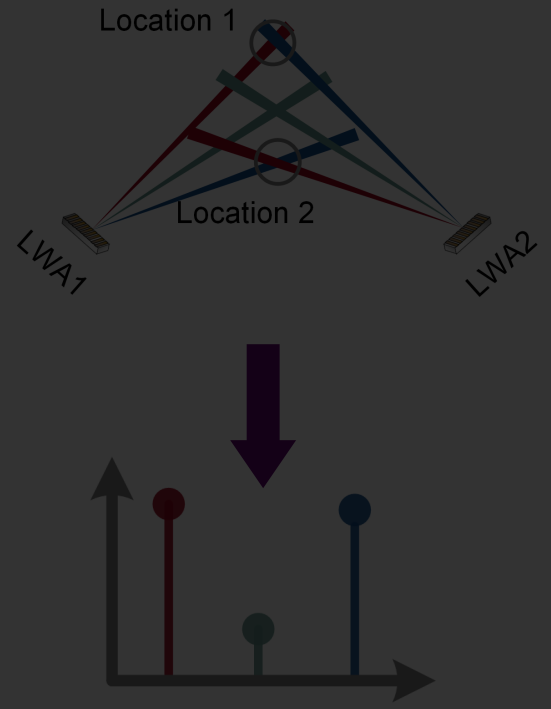

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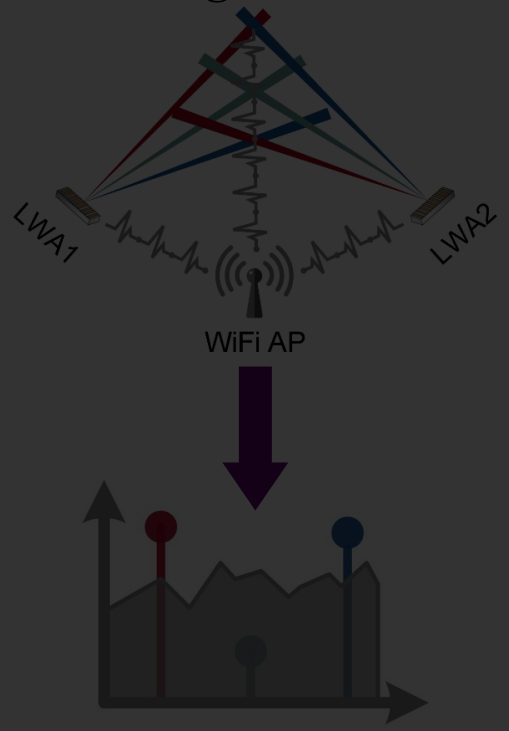


FSDM and WiFi signals operate within the same band, leading to interference.

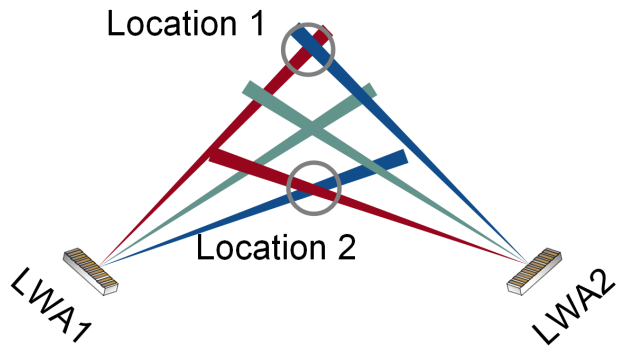
Challenge 3

- How to mitigate the indoor multipath effect?

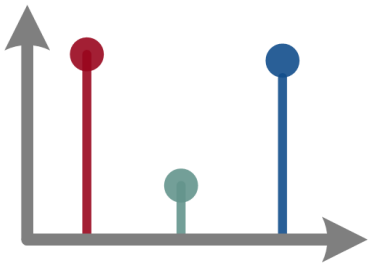
Indoor multipath effect affects the quality of receiving the FSDM signals.

How to distinguish the two different LWAs?

Ambiguity between Different LWAs



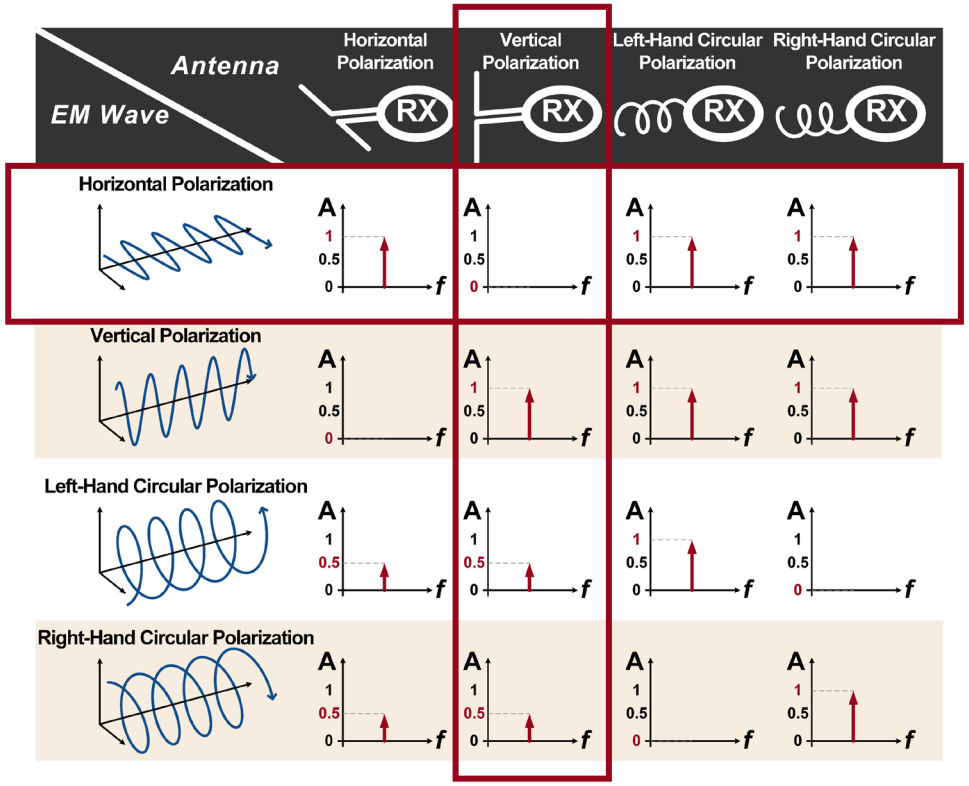
Different locations



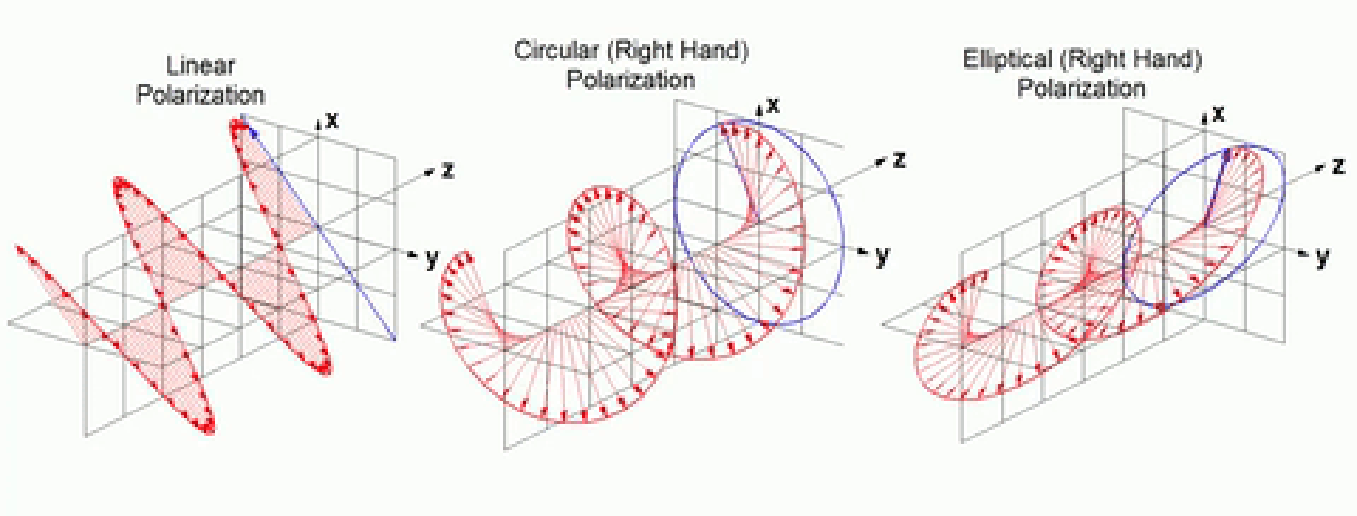
The same spectrums

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

Signal Polarization

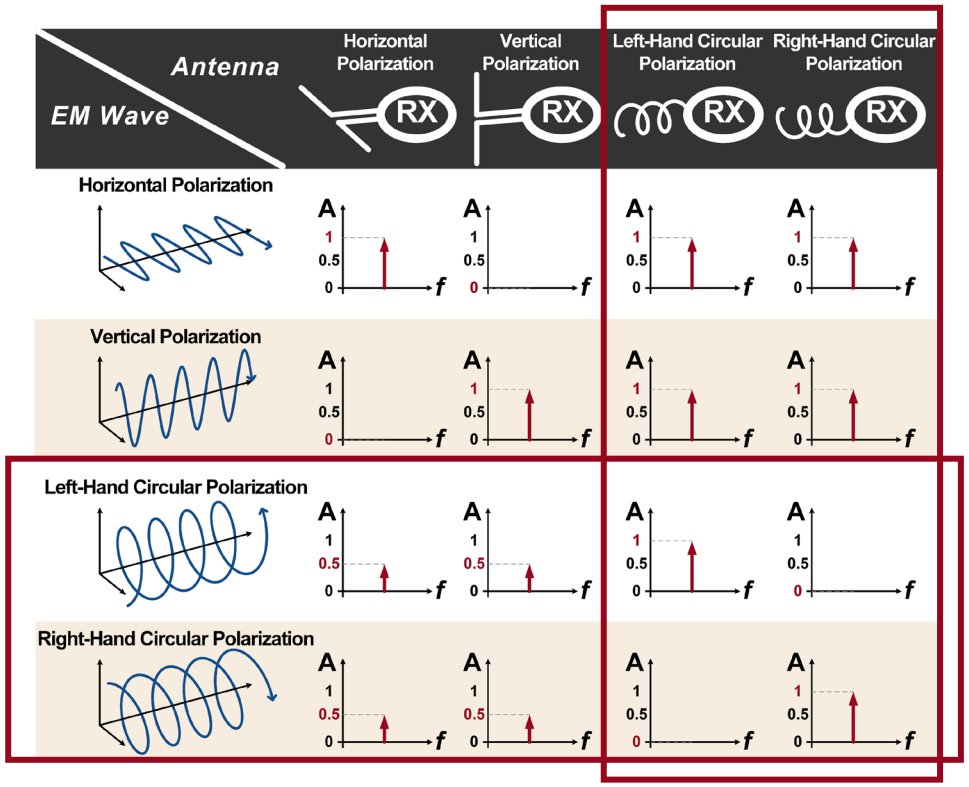


Polarization Mismatch



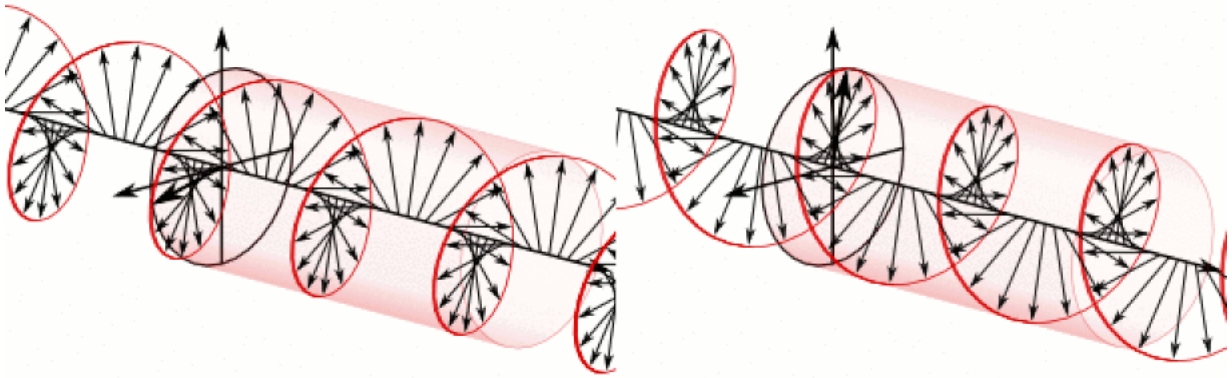
Solution: Exploiting orthogonal polarization to cancel the ambiguity between the two different LWAs

Signal Polarization



Polarization Mismatch

LHCP is orthogonal to RHCP

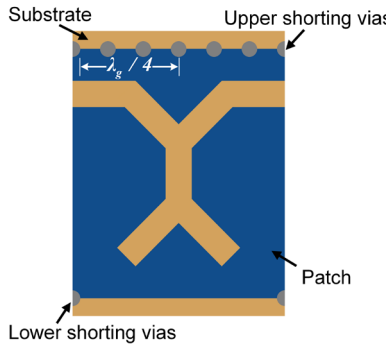


RHCP **LHCP**

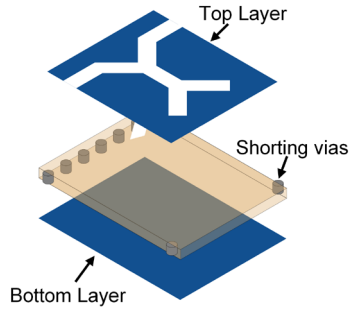
Solution: Exploiting orthogonal circular polarization (LHCP & RHCP) to cancel the ambiguity between the two different LWAs

CPLWA Design

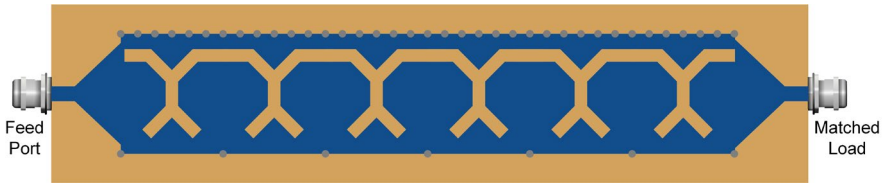
General View of CPLWA



Unit

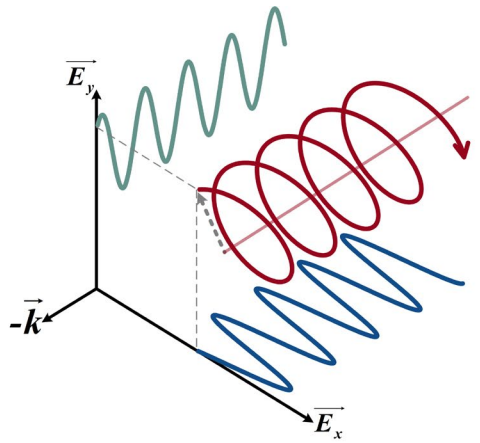


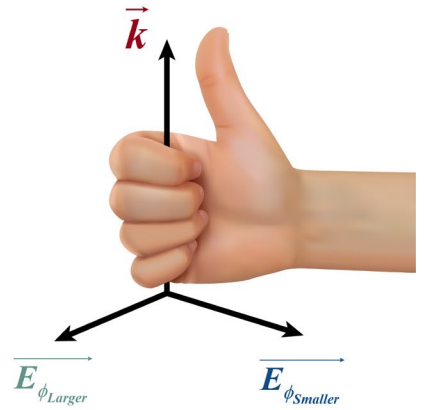
Layered structure



Complete design

CP signal synthesis

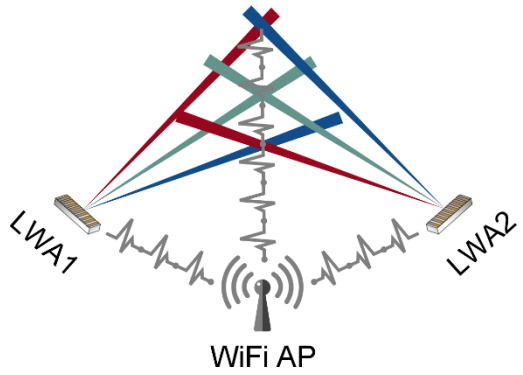




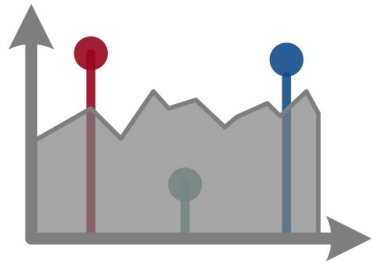
CPLWA: Orthogonal circular polarized signals can be generated by switching the signal feed port. The emitted signal is both CP and FSDM

How to extract FSDM signal from WiFi signal?

Signal Extraction from the Interfered Frequency Band



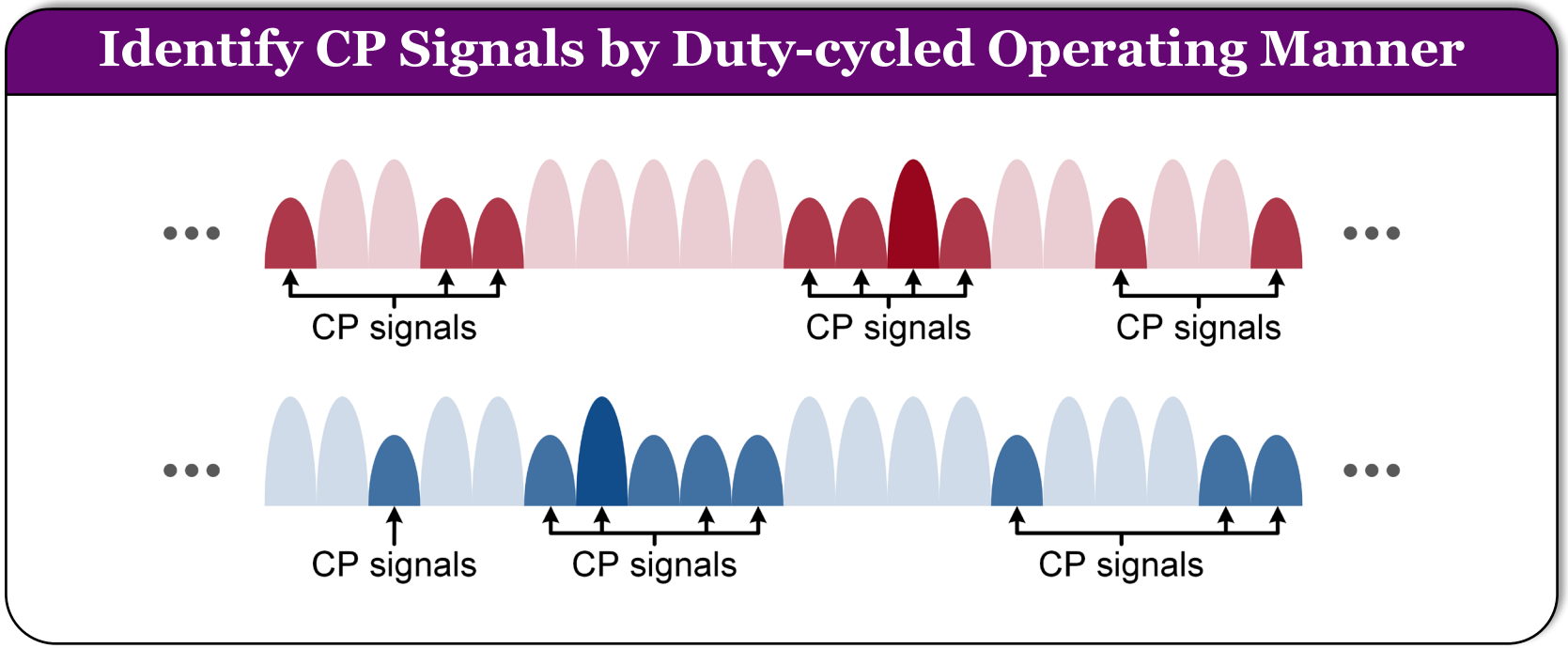
WiFi and FSDM signals in the same space



Overlapped noisy spectrum

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

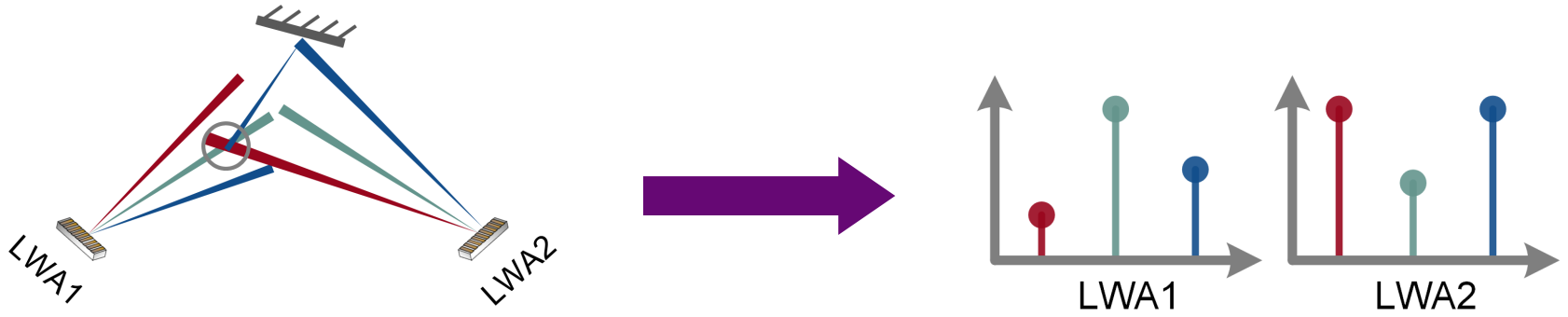
Duty-cycled Operating Manner



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

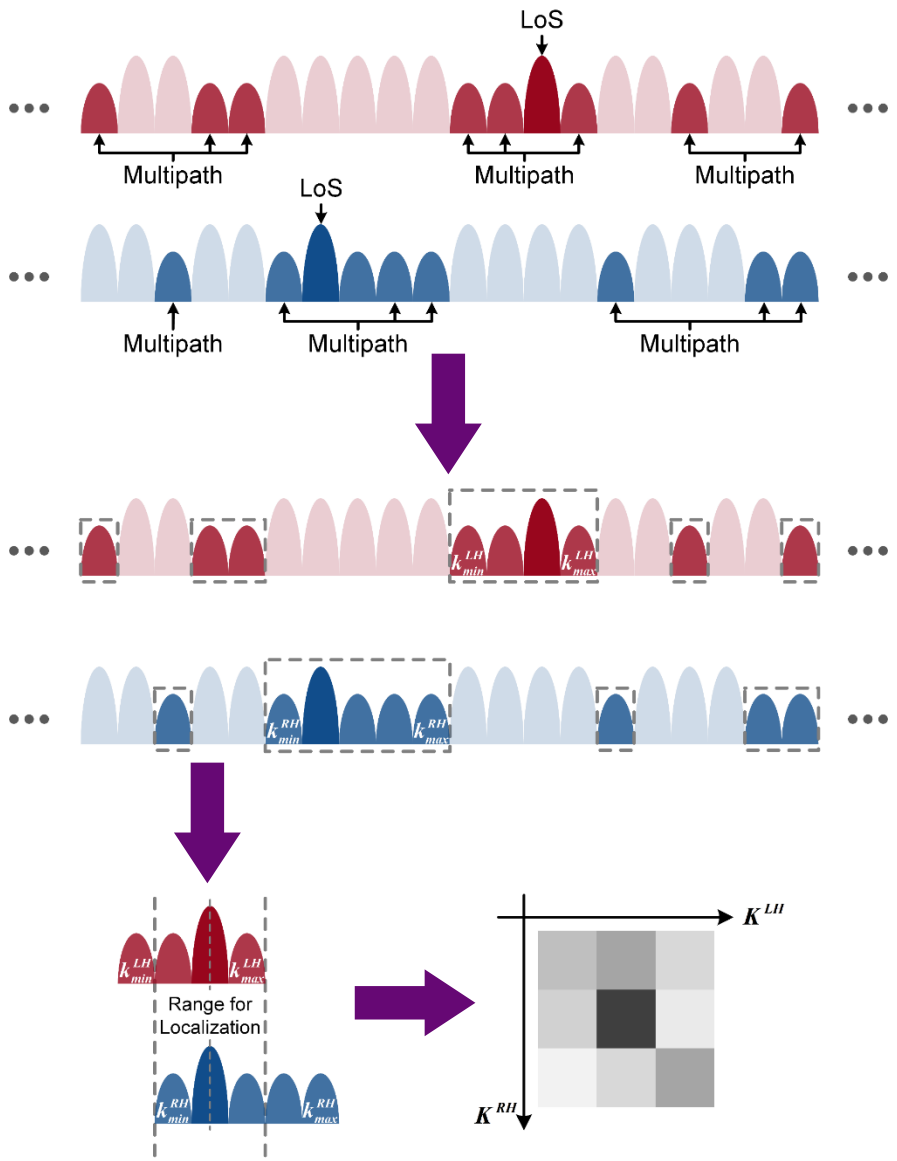


Undesired reflection

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



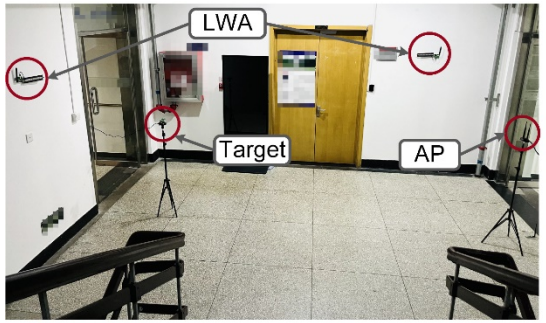
Workflow of Selecting Correct Frequencies

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.

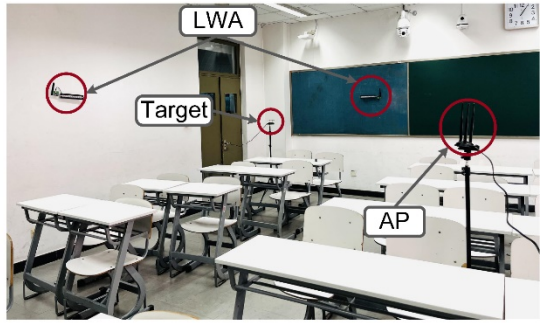
For more detail, please refer to our paper.

Implementation

Hall and Classroom Scenarios

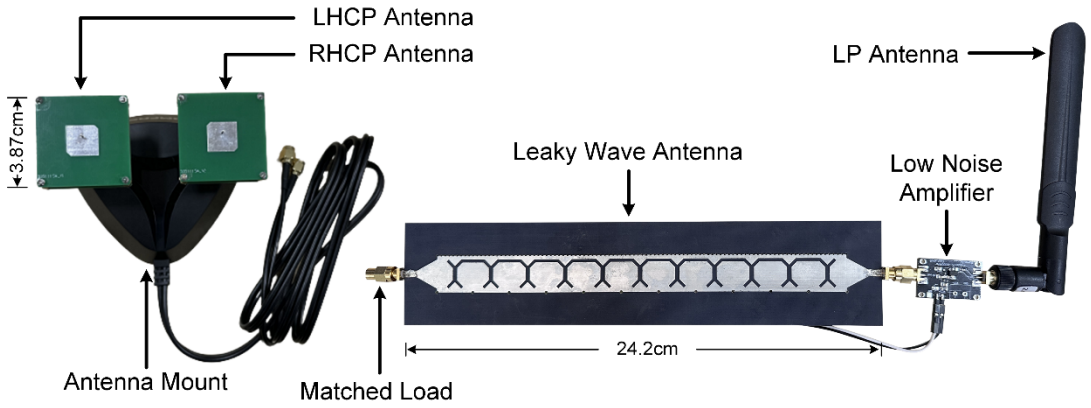


(Hall: 6.2 m × 4.5 m)



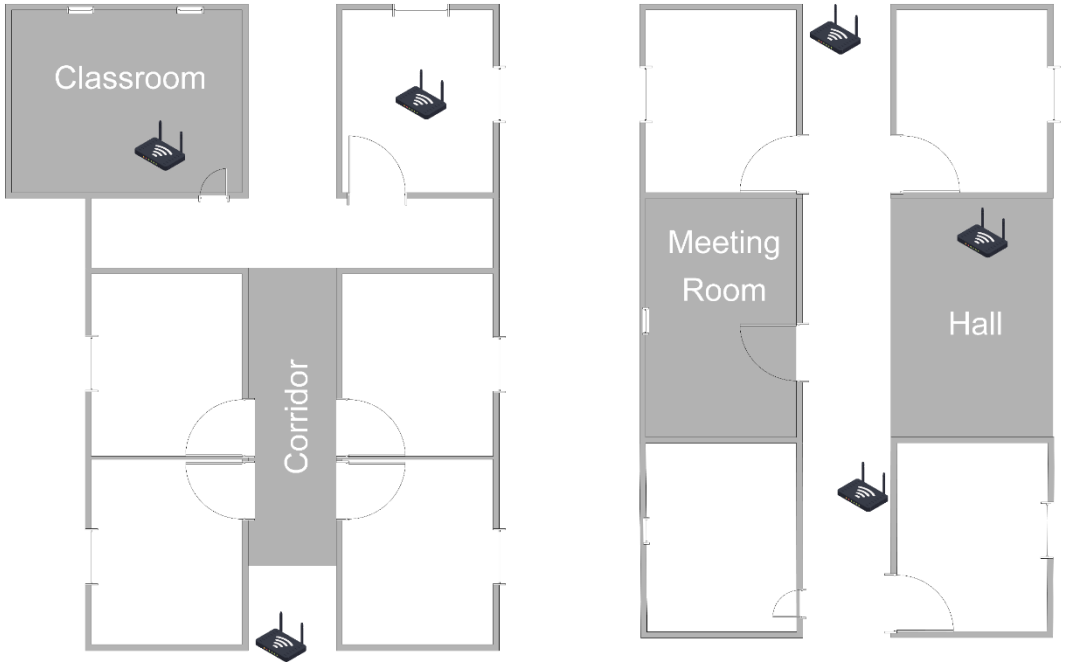
(Classroom: 10.6 m × 7.1 m)

Localized Target and the LWA

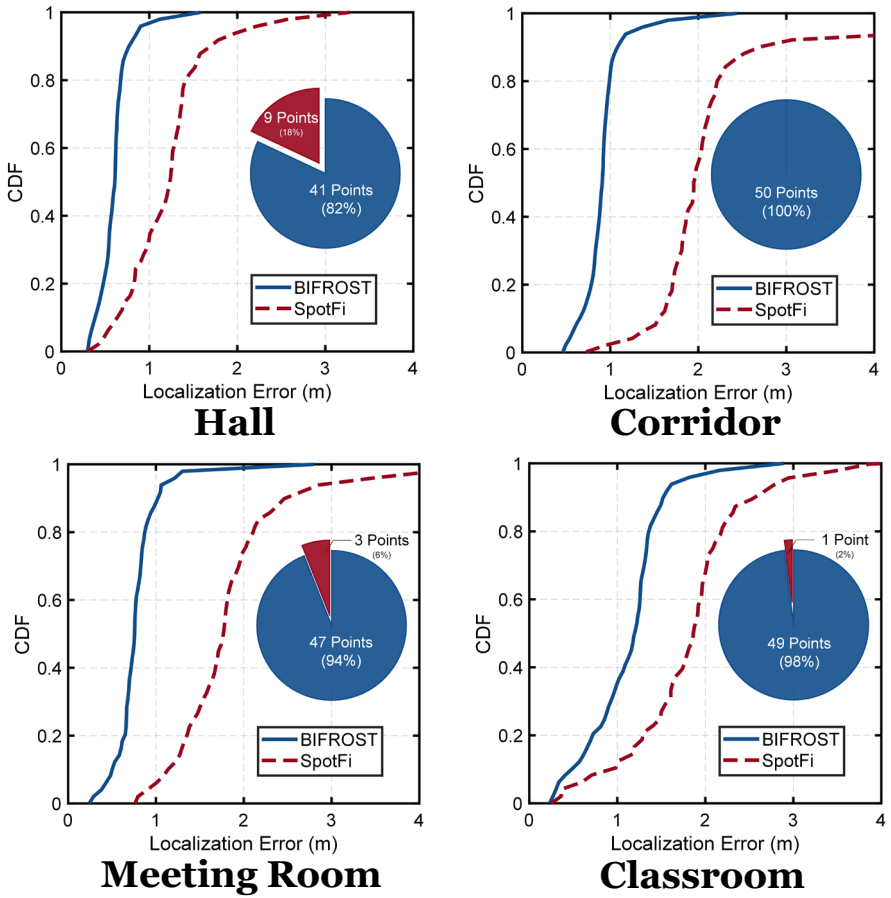


(Frequency Band: 5.17 GHz ~ 5.33 GHz)

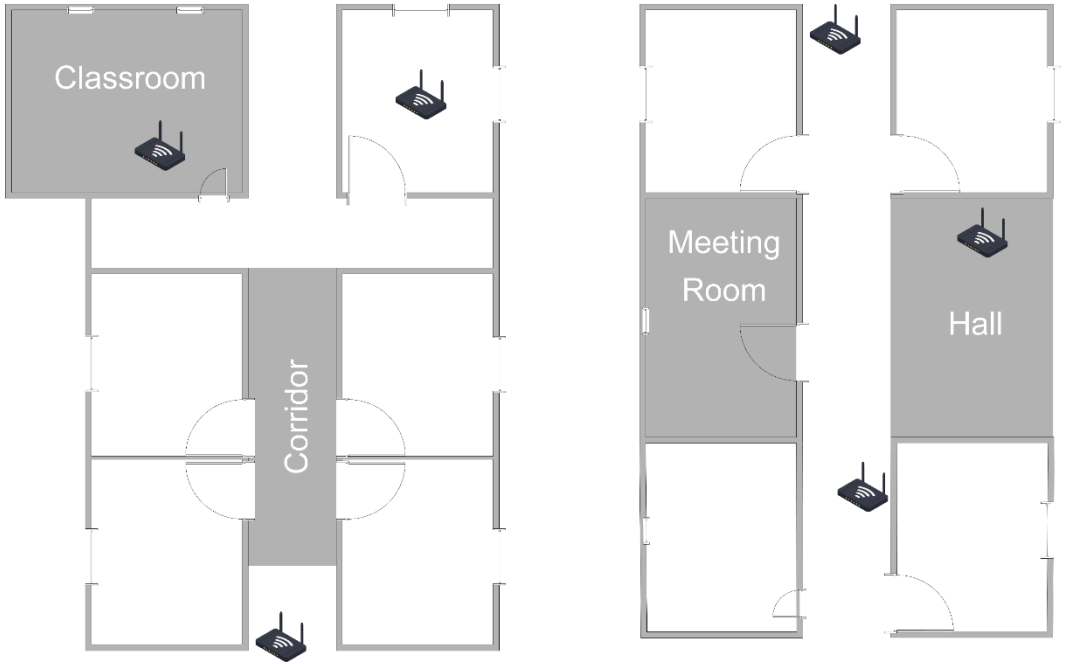
The Realistic AP Deployment



Overall Performance

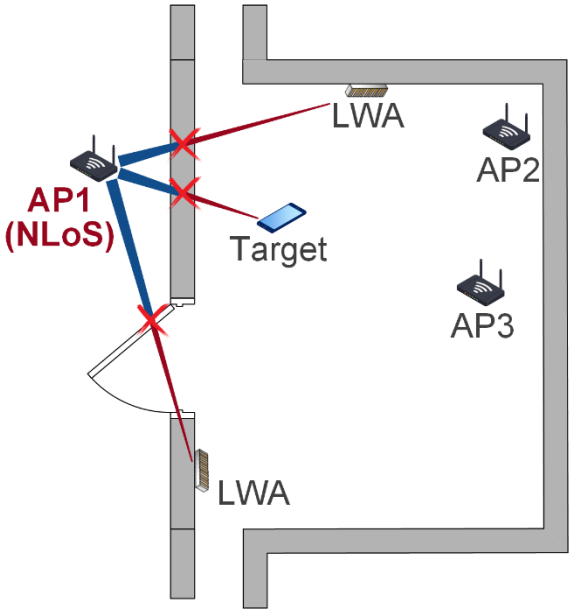


The Realistic AP Deployment

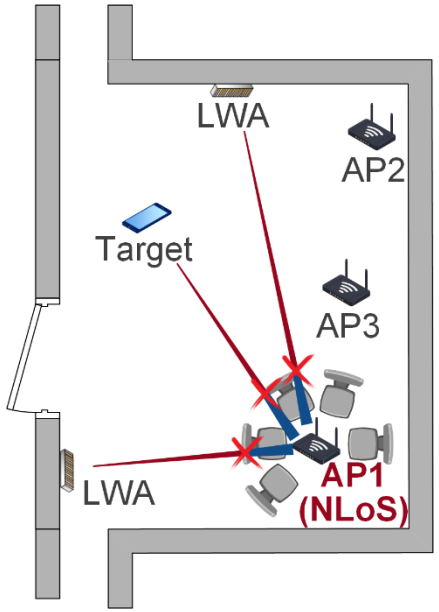


The median error of BIFROST is 0.81m, 52.35% less than that of SpotFi *in the arguably realistic indoor settings.*

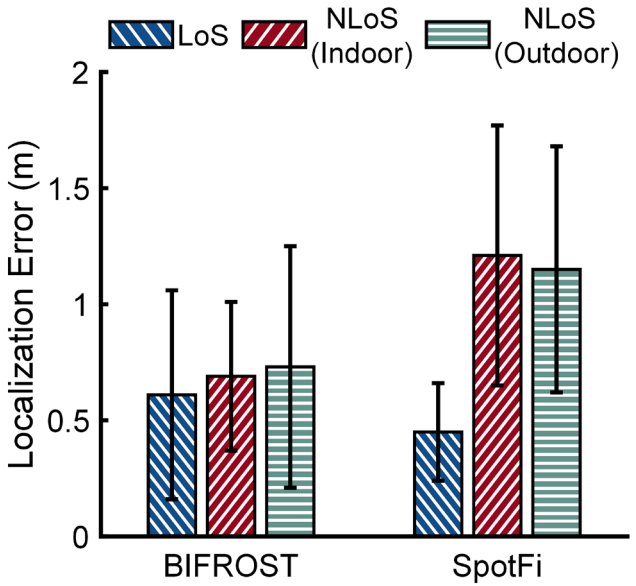
Performance in NLoS



The NLoS AP outdoors



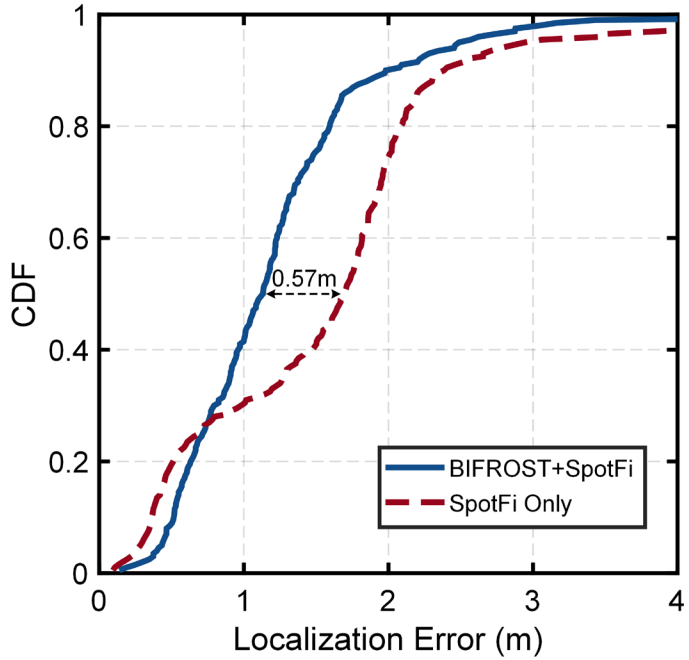
The NLoS AP indoors



Performance comparison

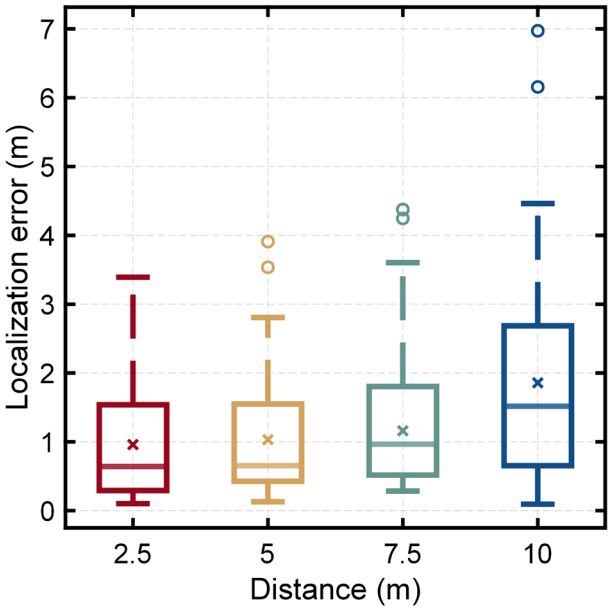
BIFROST provides stable performance when the AP is in LoS and NLoS. In NLoS scenarios, BIFROST achieves more accurate results than SpotFi.

Performance Enhancement

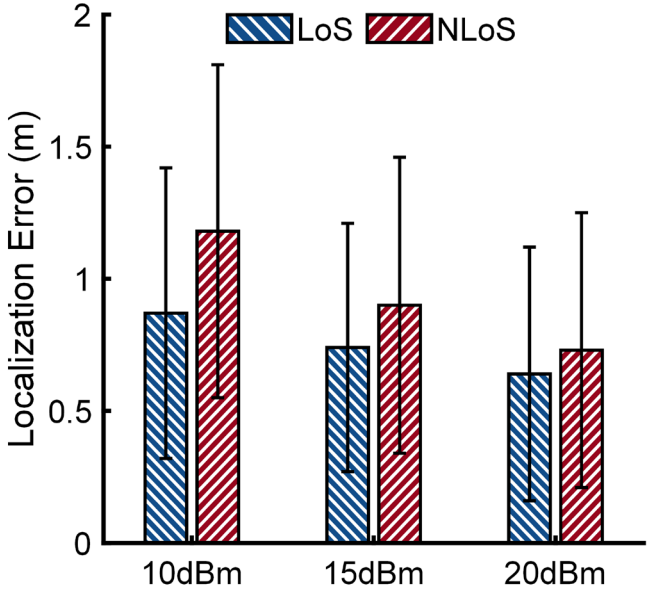


BIFROST can enhance localization accuracy of existing localization techniques and achieve 33.54% error reduction (From 1.70m to 1.13m).

Impacting Factors



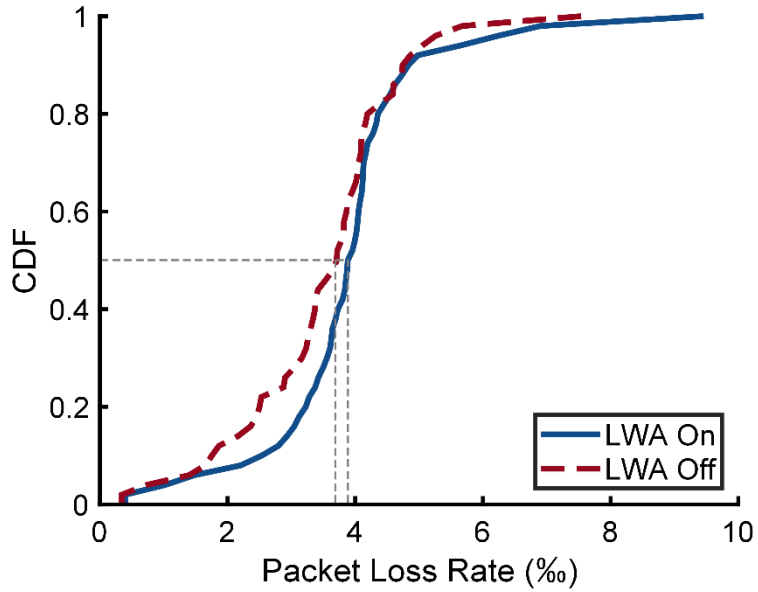
Distance between AP and LWAs



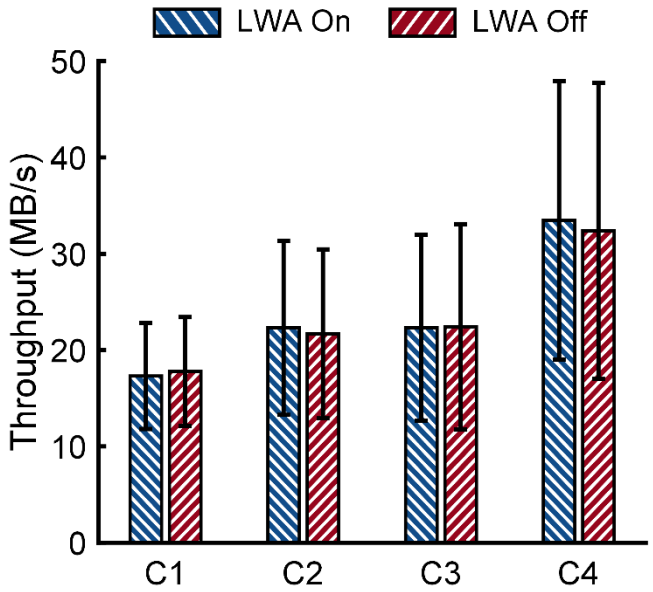
Transmission power

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

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

Conclusion

- BIFROST tackles a significant problem, namely the limited availability of LoS signals, to **enhance the availability of indoor 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/