

# **mmTAI: Biometric-assisted Multi-person Tracking with mmWave Radar**

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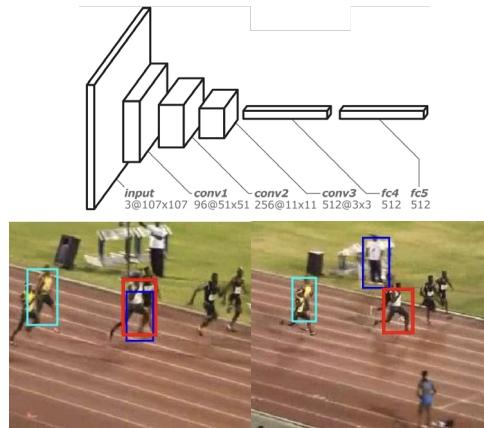
# Device-free Multi-person Tracking



**Benefits:** Tracking is crucial in smart homes and elderly care scenarios.

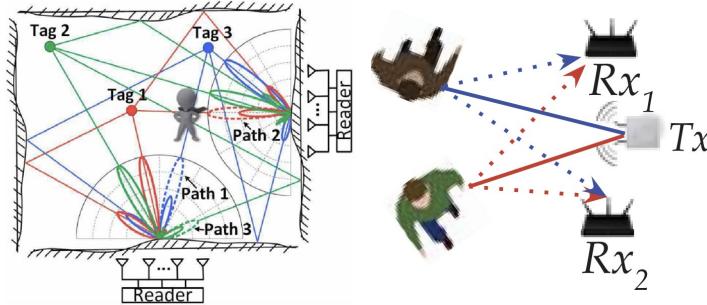
# Related Work

## Vision-based



H.Nam et al., CVPR 2016

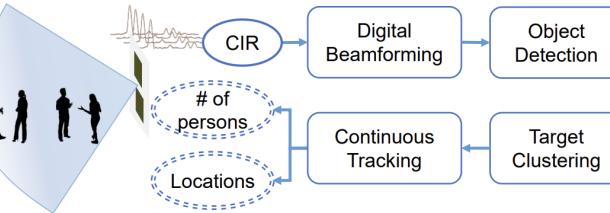
## RF-based



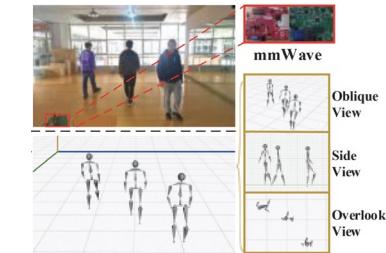
D-Watch, TON 2017

WiPolar, IMWUT 2020

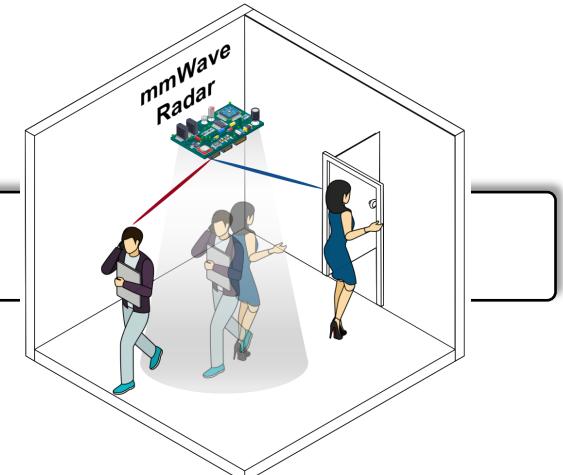
## mmWave-based



mmTrack, INFOCOM 2020



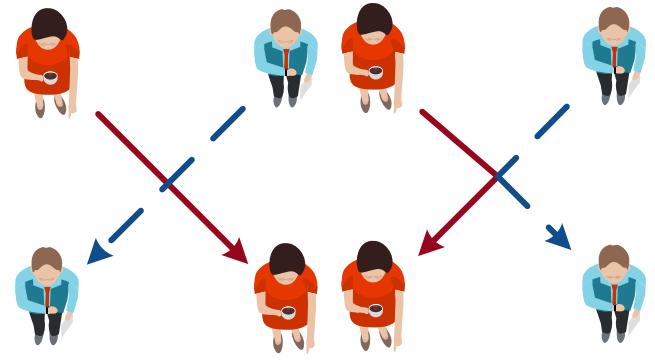
$m^3$ Track, MobiSys 2022



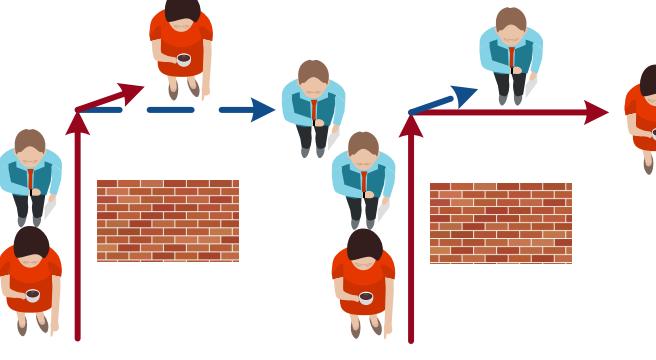
**Problem:** Cannot resolve trajectory ambiguity.

# Ambiguity in Multi-person Tracking

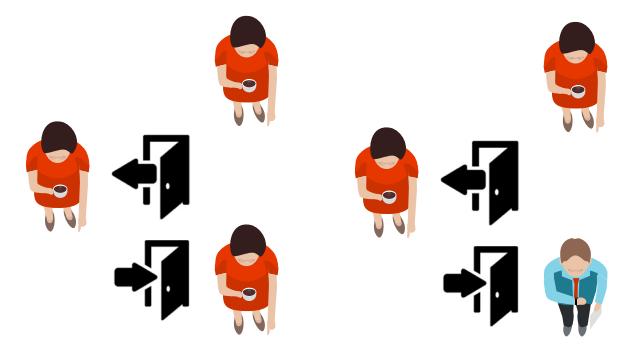
## Crossover



## Blockage

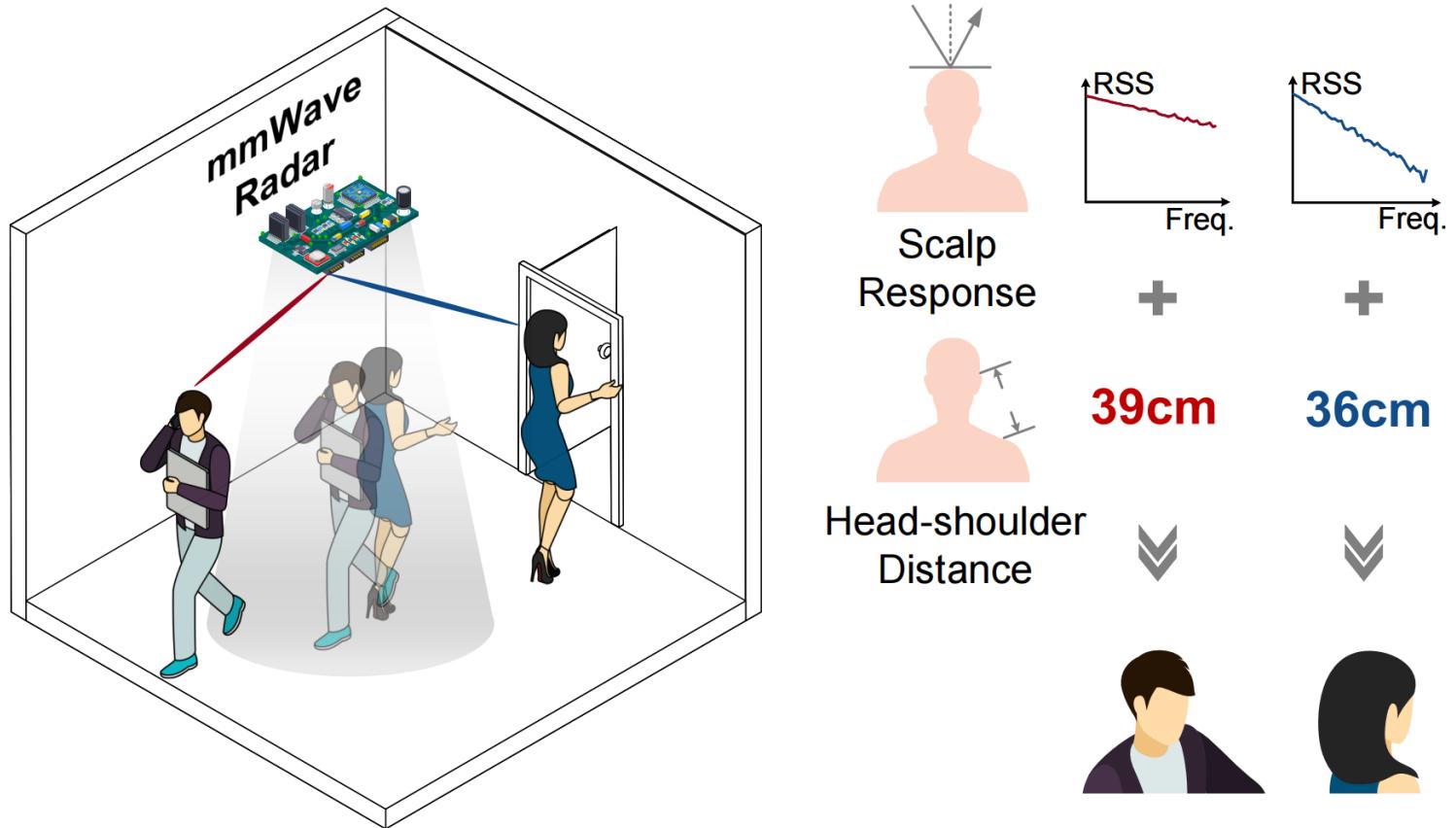


## Joining/Leaving



**Different trajectories lead to the same point clouds.**

# Our Solution



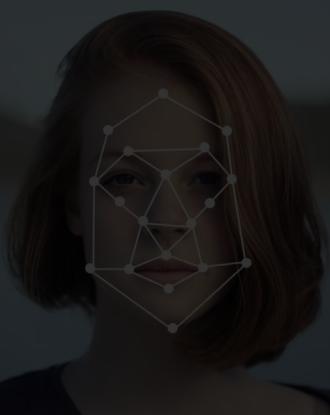
**Solution:** Simutaneously **differentiate** and track the persons.

# Key Insight – Biometric-assisted Differentiation

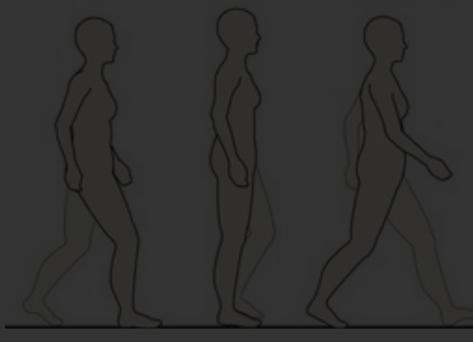
## Fingerprint



## Face



## Gait



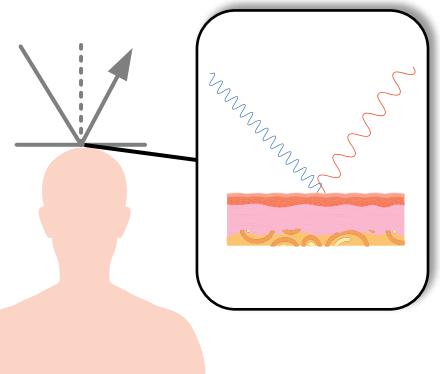
## Checklist

1. differentiating among persons
2. invariant during a short period
3. accessible to the mmWave radar
4. compatible with radar resolution
5. instantly obtainable
6. robust to posture and motion

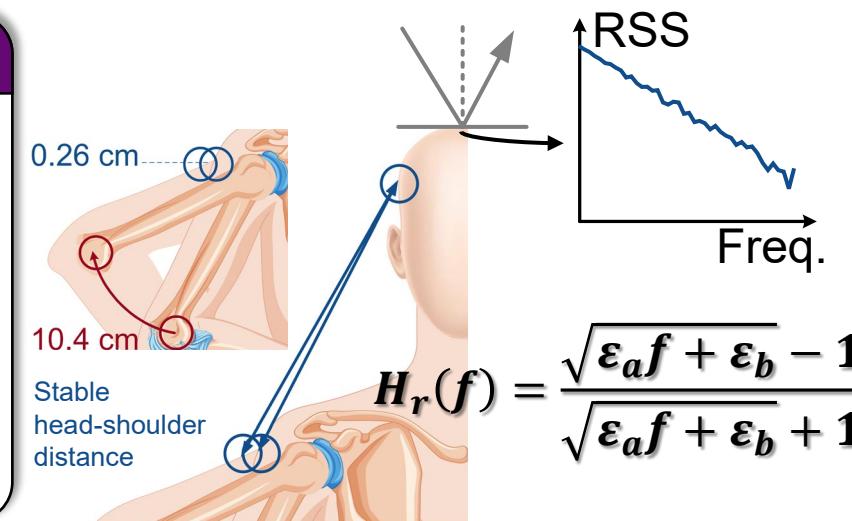
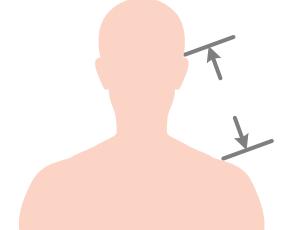
## Vital Sign



## Scalp Response



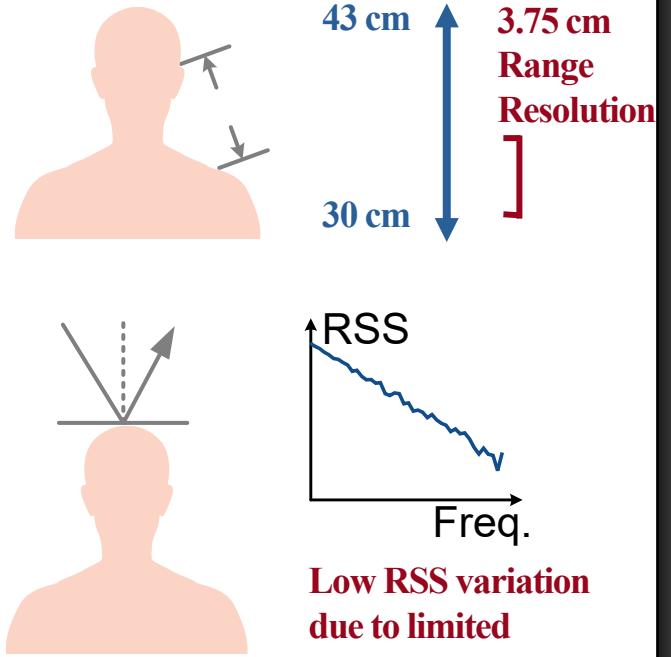
## Head-shoulder Distance



# Challenges

## Challenge 1

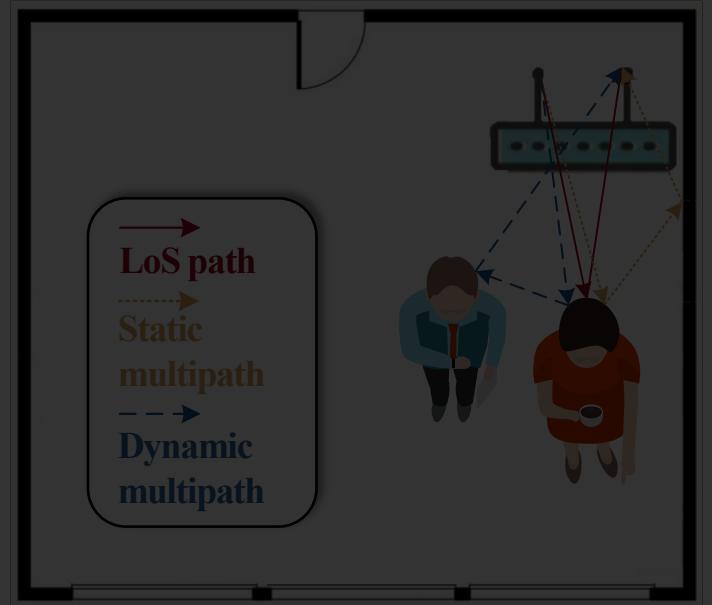
- Subtle biometric features.



**The resolution of mmWave radar is limited for biometric feature measurement.**

## Challenge 2

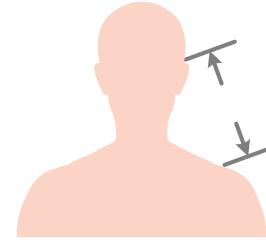
- Dynamic interference on measured biometric features.



**The interference results in varying biometric measurements of the same person.**

# How to Extract the Subtle Biometric Features?

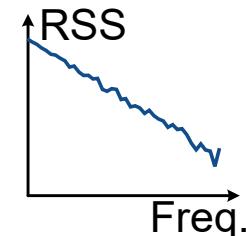
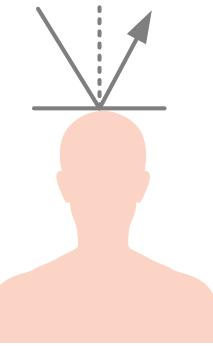
## Head-shoulder Distance



$$\frac{c}{2B} = 3.75 \text{ cm}$$

430 mm  
300 mm  
20 mm Standard Deviation

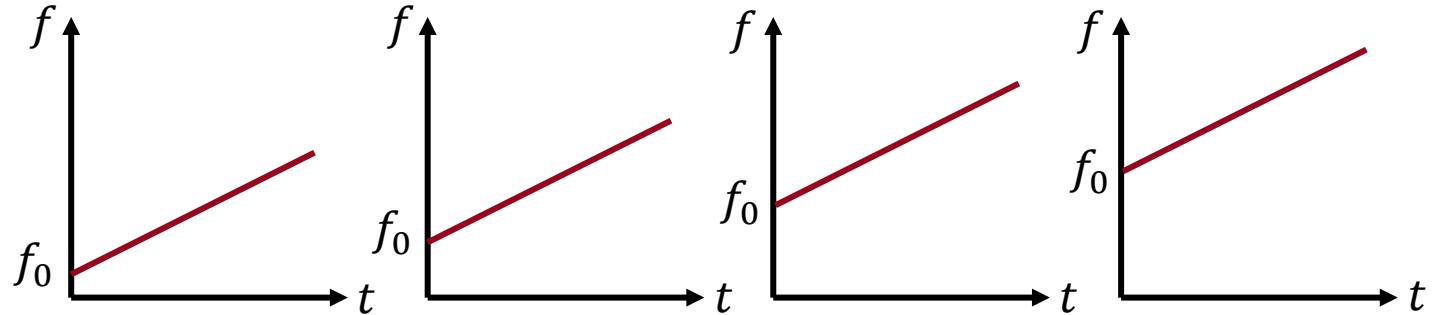
## Scalp Response



Low RSS variation due to limited frequency range

**Solution:** Multiple measurements

## Solution: Multi-chirp Consolidation



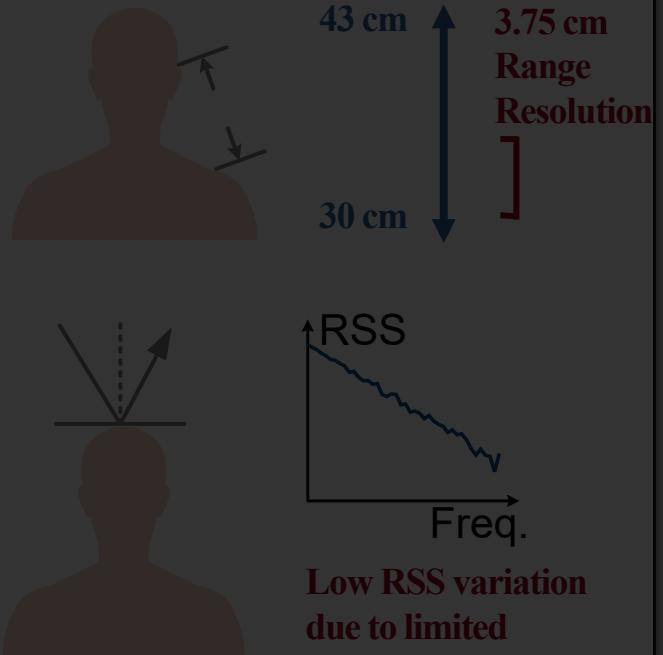
$f_0$	60.0 GHz	60.1 GHz	60.2 GHz	60.3 GHz
Phase $\varphi$	2.00	2.30	2.60	2.90

$$\varphi = \frac{1}{B} \int_{f_0}^{f_0+B} \frac{4\pi f d}{c} df \rightarrow \frac{\partial \varphi}{\partial f} = \frac{4\pi d}{c} \rightarrow d = \frac{c}{4\pi} \frac{\Delta \varphi}{\Delta f_0}$$

# Challenges

## Challenge 1

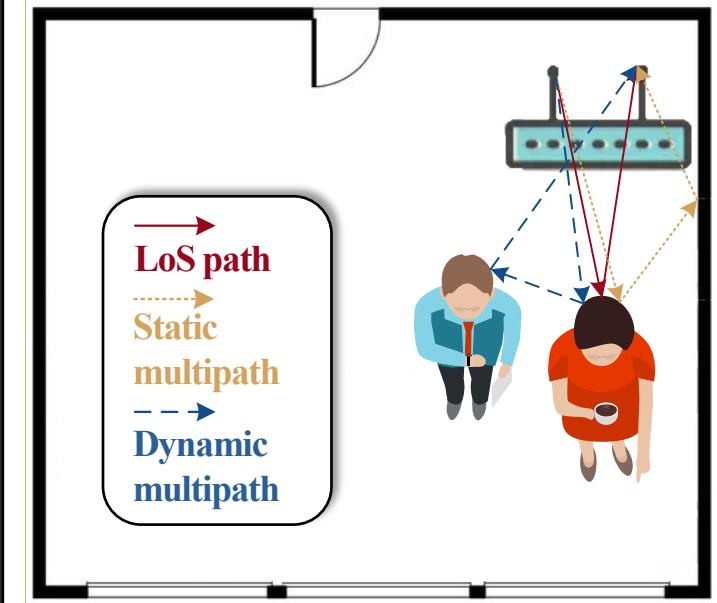
- Subtle biometric features.



**The resolution of mmWave radar is limited for biometric feature measurement.**

## Challenge 2

- Dynamic interference on measured biometric features.



**The interference results in varying biometric measurements of the same person.**

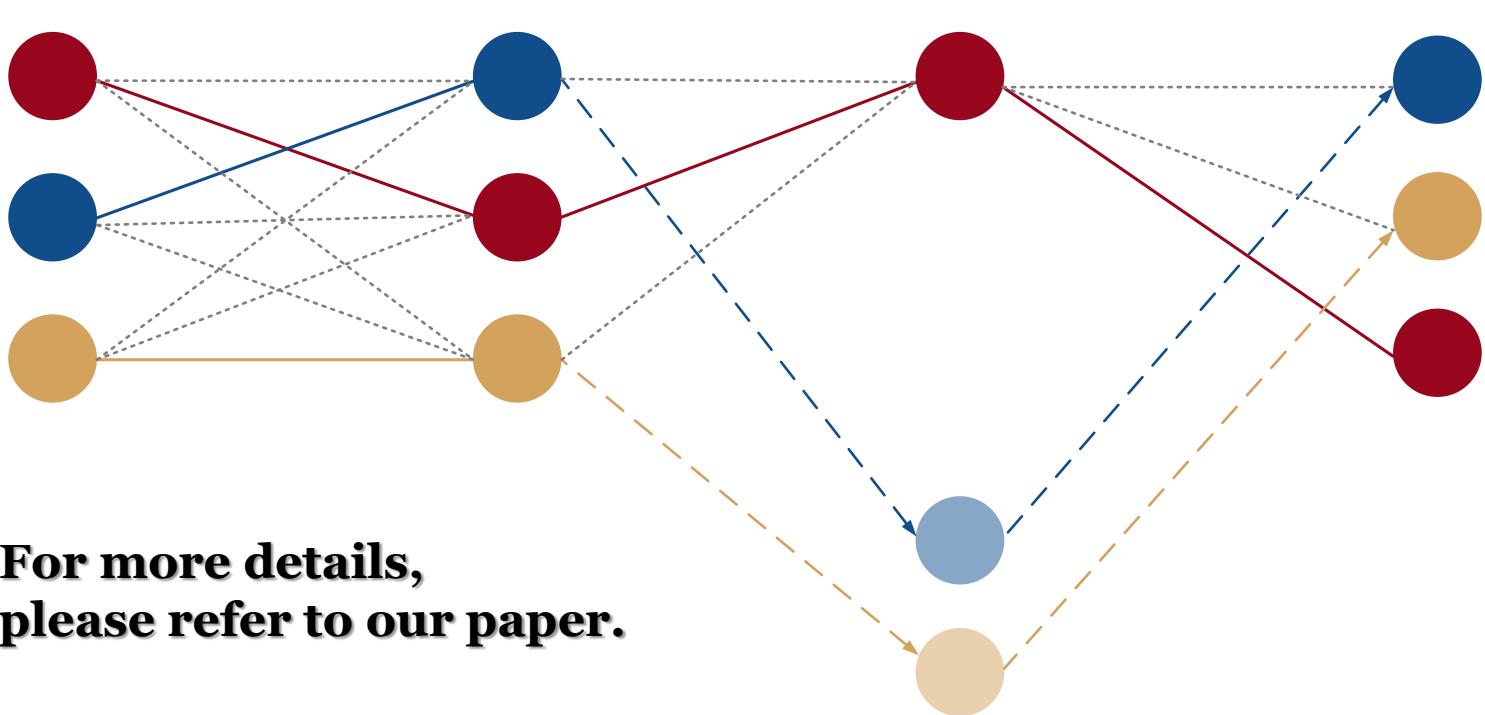
# How to Mitigate the Dynamic Interferences?



Time

 $t$  $t + 1$  $t + 2$  $t + 3$ 

Matching

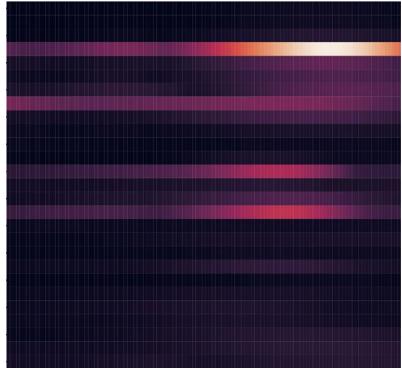


**Observation:**  
The interferences  
are invariant  
within a short  
period.

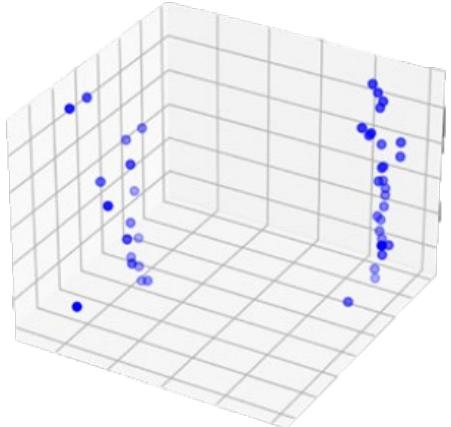
**For more details,  
please refer to our paper.**

# mmTAI Design Overview

## Human Detection

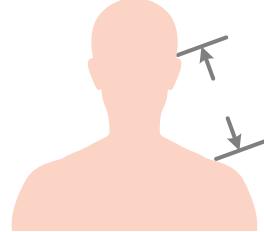


Radar Signal Preprocessing

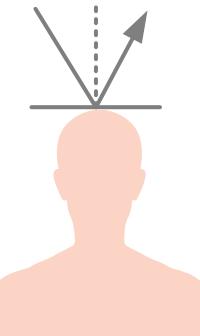


Point Cloud Generation  
and Clustering

## Biometric Feature Measurement

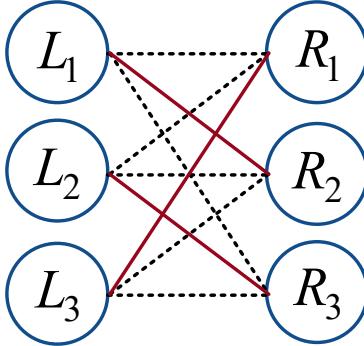


Head-shoulder Distance  
Estimation

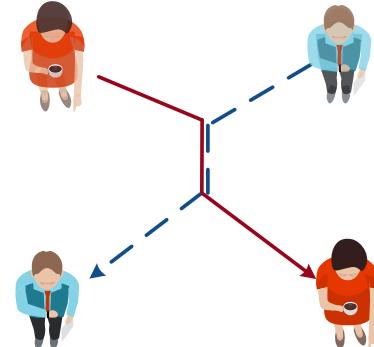


Scalp Distance Estimation

## Multi-person Tracking



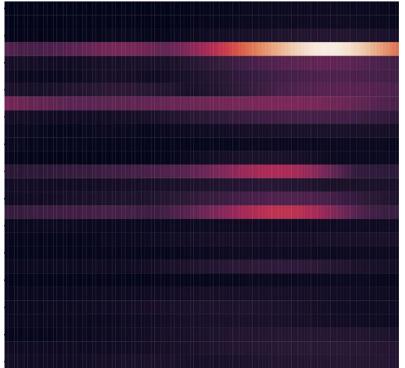
Short-time Person Matching



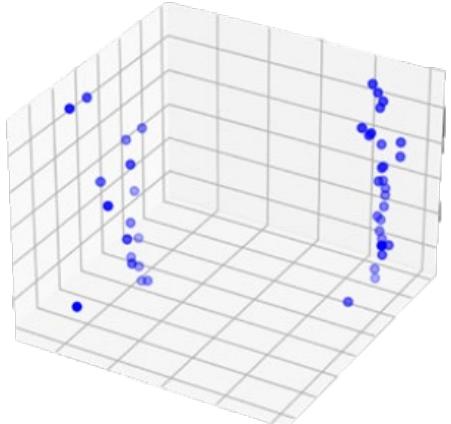
Trajectory Re-association

# mmTAI Design Overview

## Human Detection

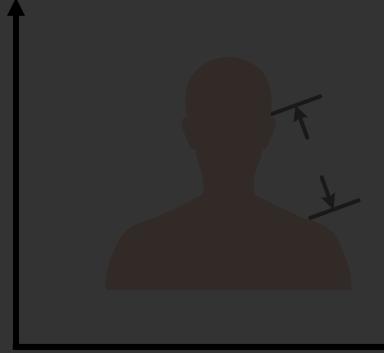


### Radar Signal Preprocessing

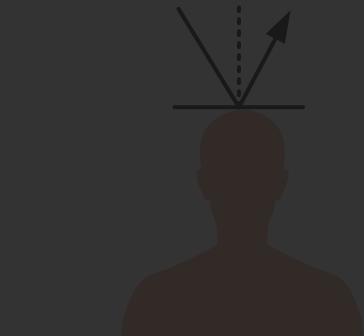


### Point Cloud Generation and Clustering

## Biometric Feature Measurement

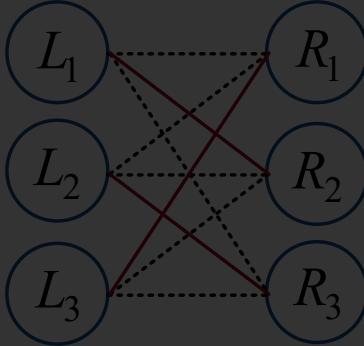


### Head-shoulder Distance Estimation

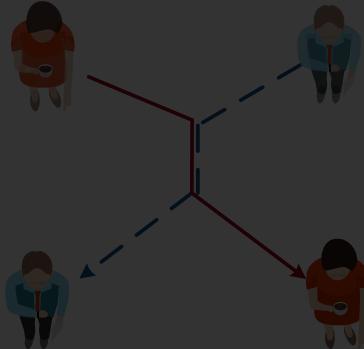


### Scalp Distance Estimation

## Multi-person Tracking



### Short-time Person Matching



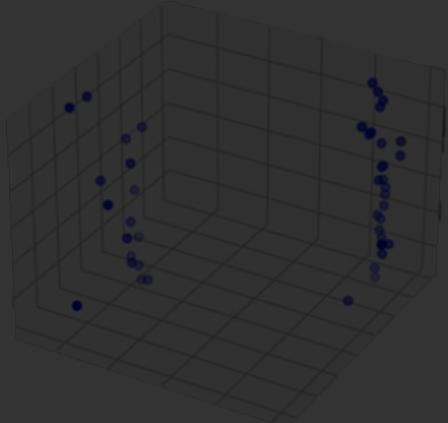
### Trajectory Re-assocation

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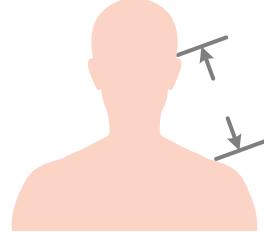


Radar Signal Preprocessing

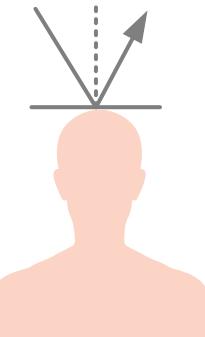


Point Cloud Generation  
and Clustering

## Biometric Feature Measurement

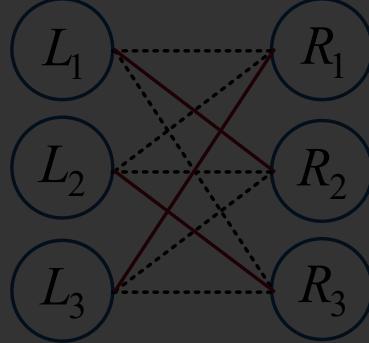


Head-shoulder Distance  
Estimation

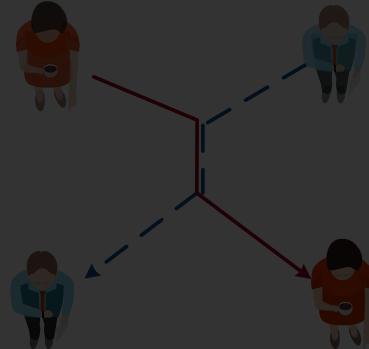


Scalp Distance Estimation

## Multi-person Tracking



Short-time Person Matching



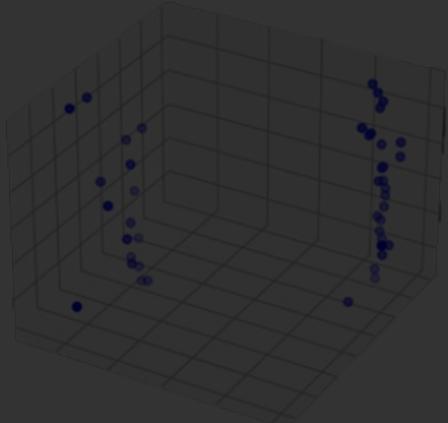
Trajectory Re-association

# mmTAI Design Overview

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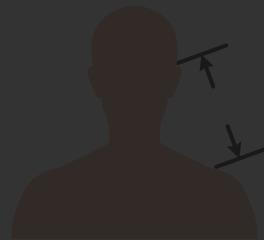


Radar Signal Preprocessing

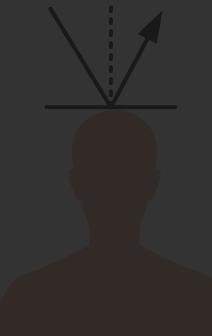


Point Cloud Generation  
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## Biometric Feature Measurement

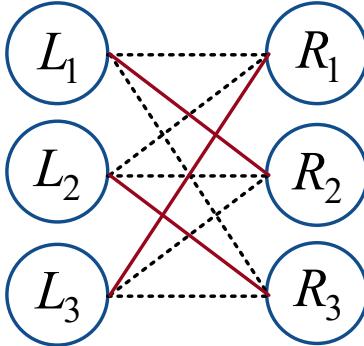


Head-shoulder Distance  
Estimation

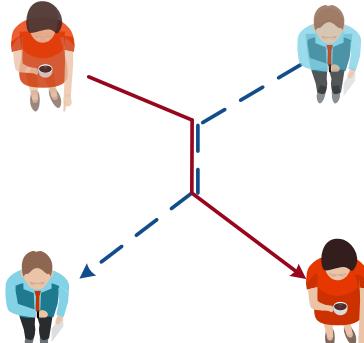


Scalp Distance Estimation

## Multi-person Tracking



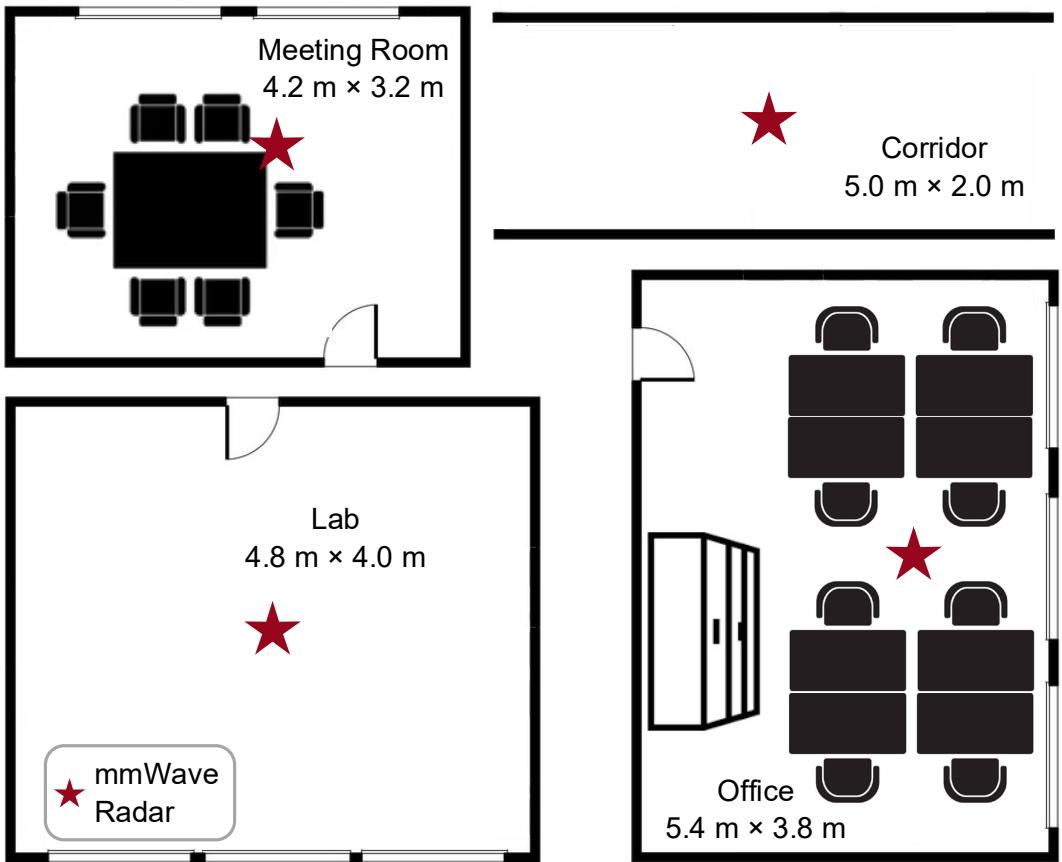
Short-time Person Matching



Trajectory Re-association

# Implementation

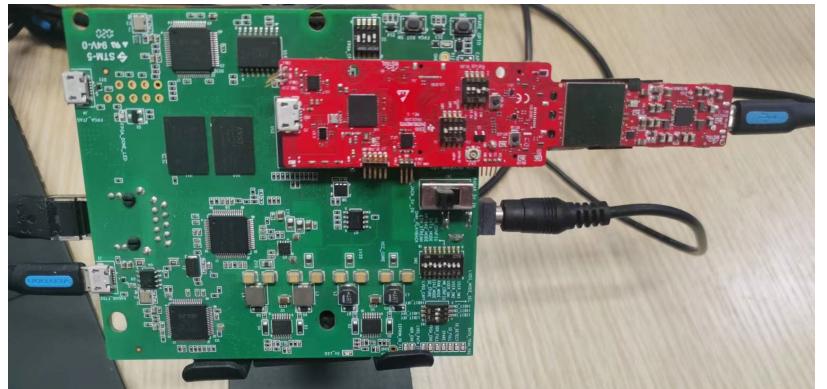
## Scenarios



(The radar is placed on the ceiling, right towards the floor)

## mmWave Device

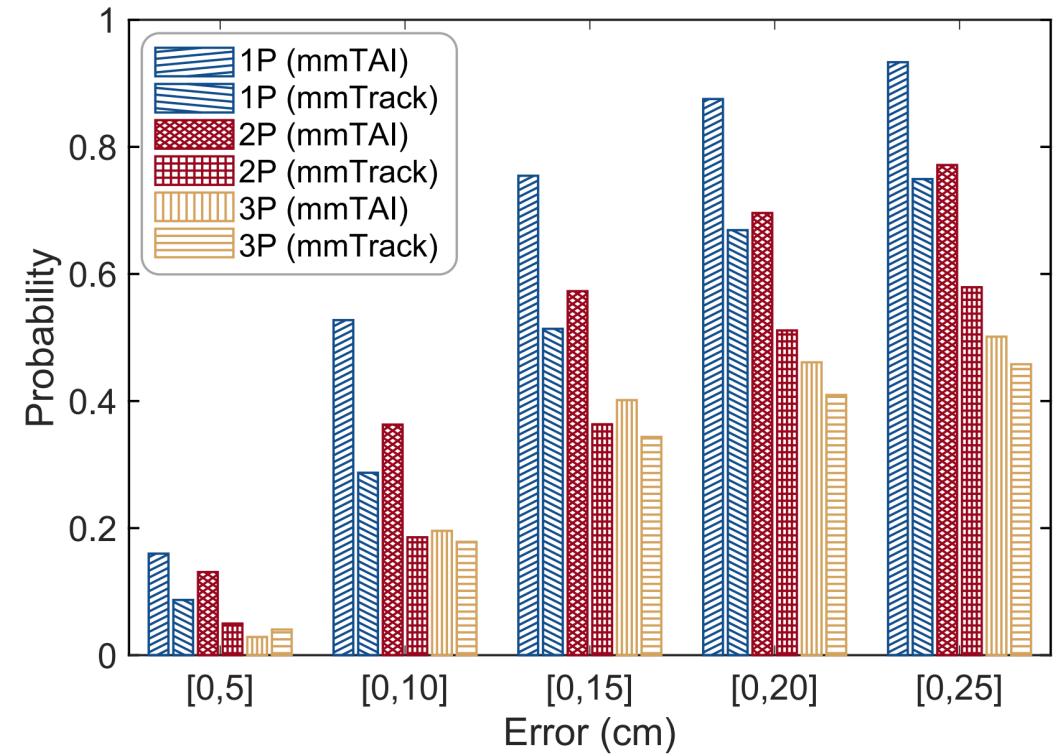
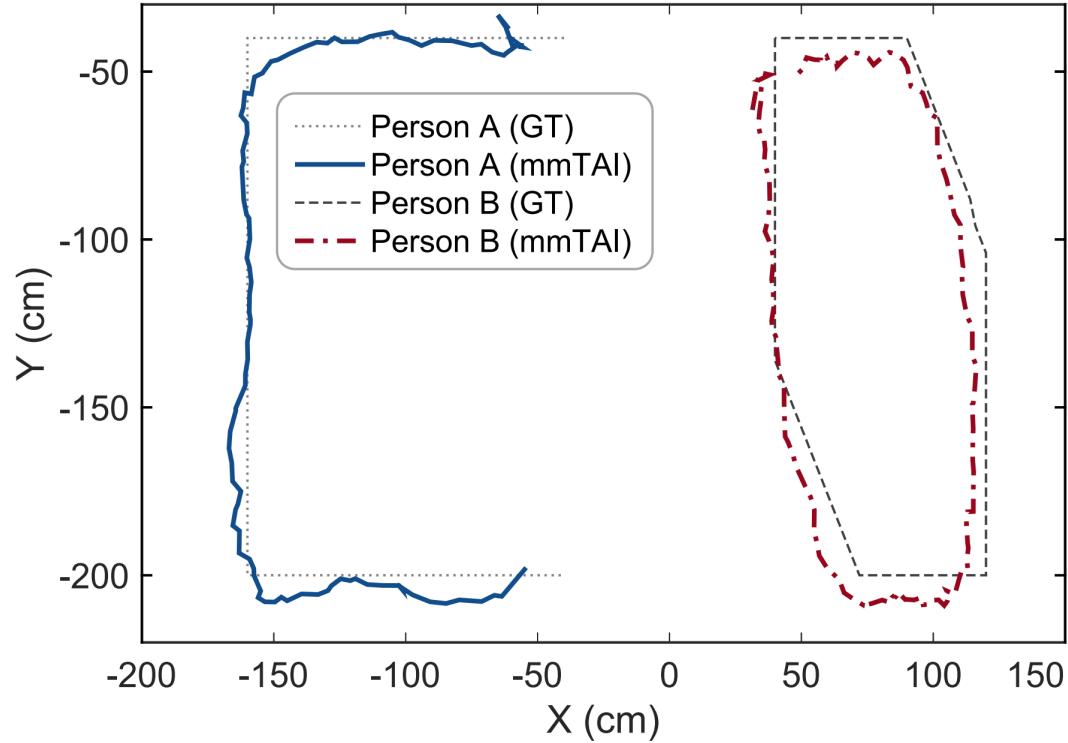
TI DCA 1000 + IWR6843AOPEVM  
60 – 64 GHz, 3 TX, 4 RX  
100 samples / second



## Data Processing

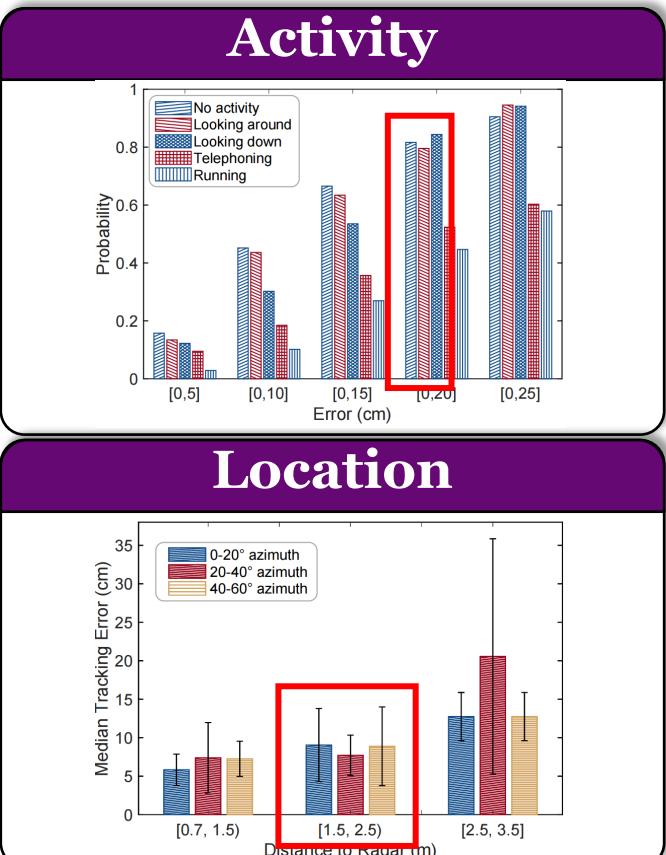
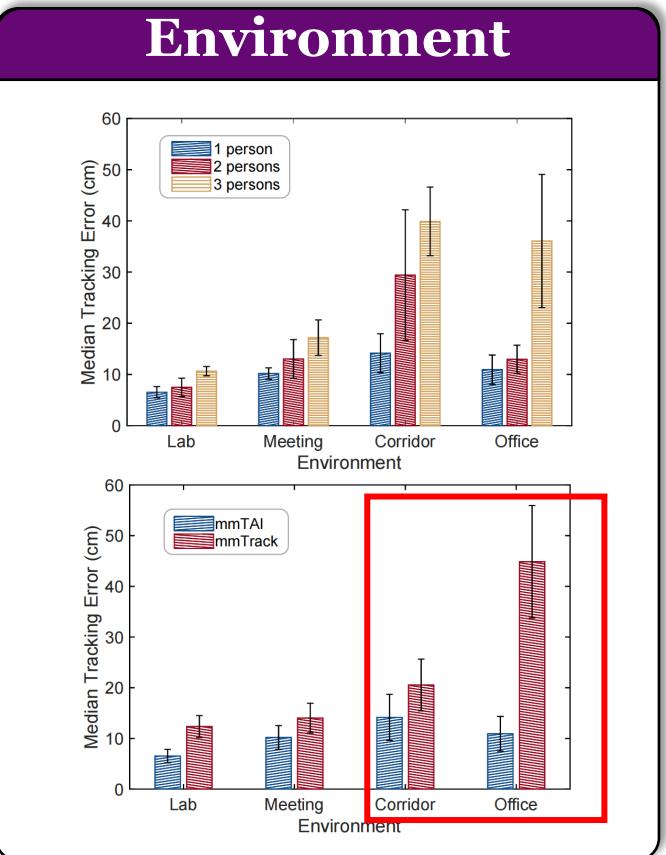
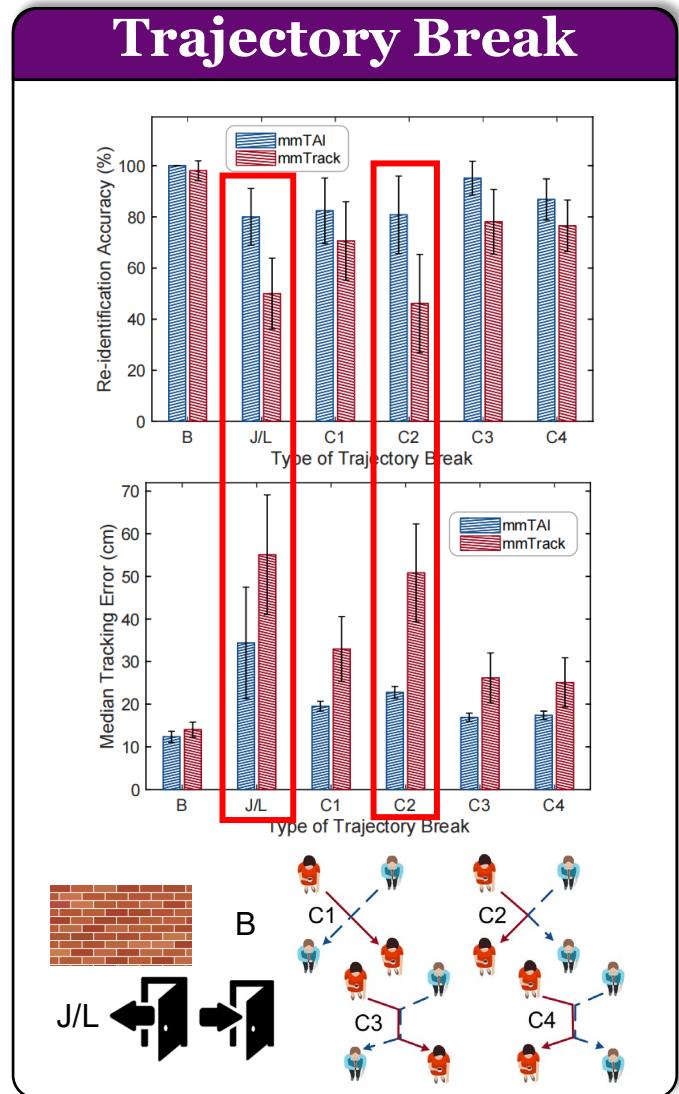
PC (CPU: Intel i7-12700H)  
Real-time processing on CPU for up to  
11 persons in the tracking area

# Overall Performance



The median error of mmTAI is 12.33cm,  
35.88% less than that of mmTrack in the lab scenario.

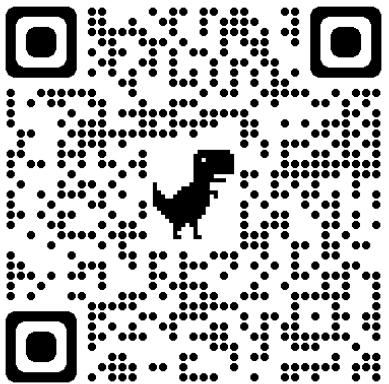
# Impacting Factors



The effectiveness of mmTAI is verified under a wide range of practical conditions.

# Conclusion

- mmTAI mitigates the ambiguity with biometric-assisted methods, to **enhance mmWave-based multi-person tracking**.
- The key innovation is the extraction of the **biometric features**, which is related to the **principle of RF signal reflection** and embodies the concept of **RF computing**.
- Among the multi-person tracking methods without the burden of training and running deep learning models, mmTAI achieves the **state-of-the-art localization error**.



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