Multi-User Localization from Human Reflections

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Localization from Reflections Video



Applications

Smart Homes









Energy Saving



Gaming & Virtual Reality



Limitations of Past Work

Cannot localize multiple users



Cannot localize static users



Contributions

- Multi-user localization from human reflections
- Localizes both static and moving users
- Provides high localization accuracy of 12cm (i.e., half a foot)

Primer

How do these systems work?

Tx



Rx

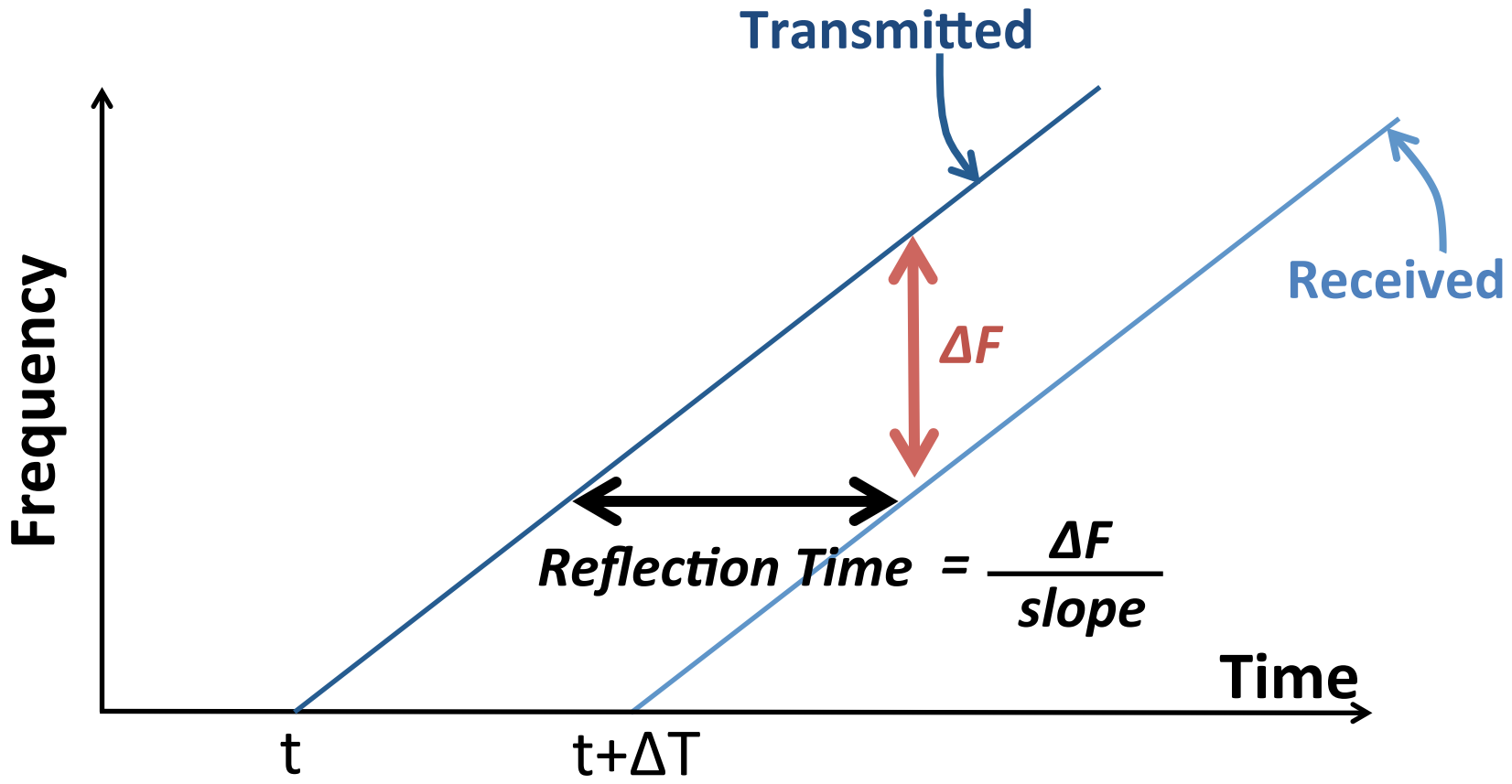






Distance = Reflection time x speed of light

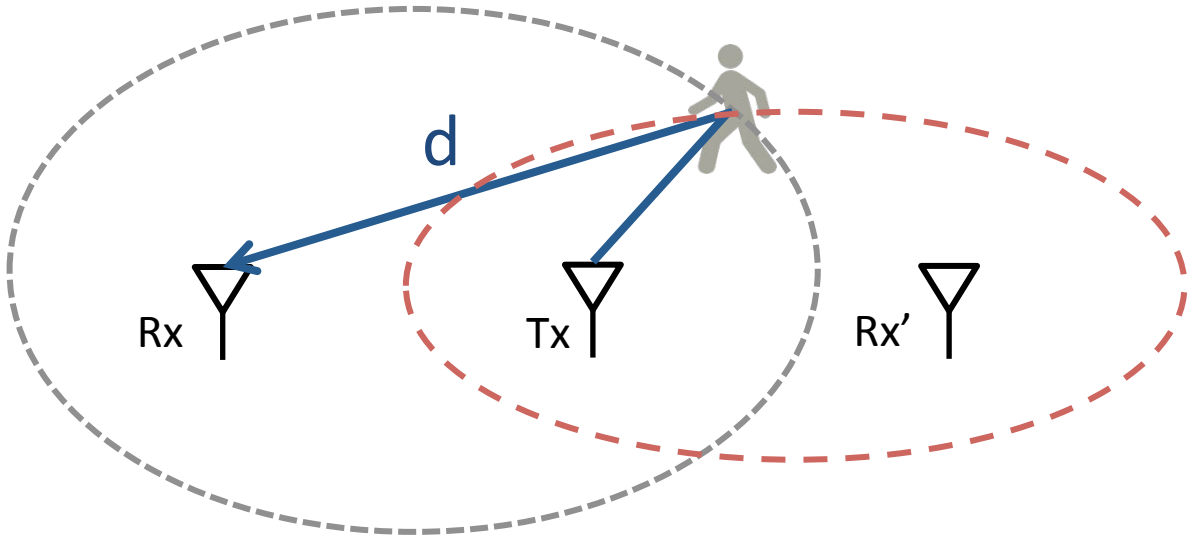
FMCW: Measure time by measuring frequency



ΔF → Reflection Time → Distance

Mapping Distance to Location

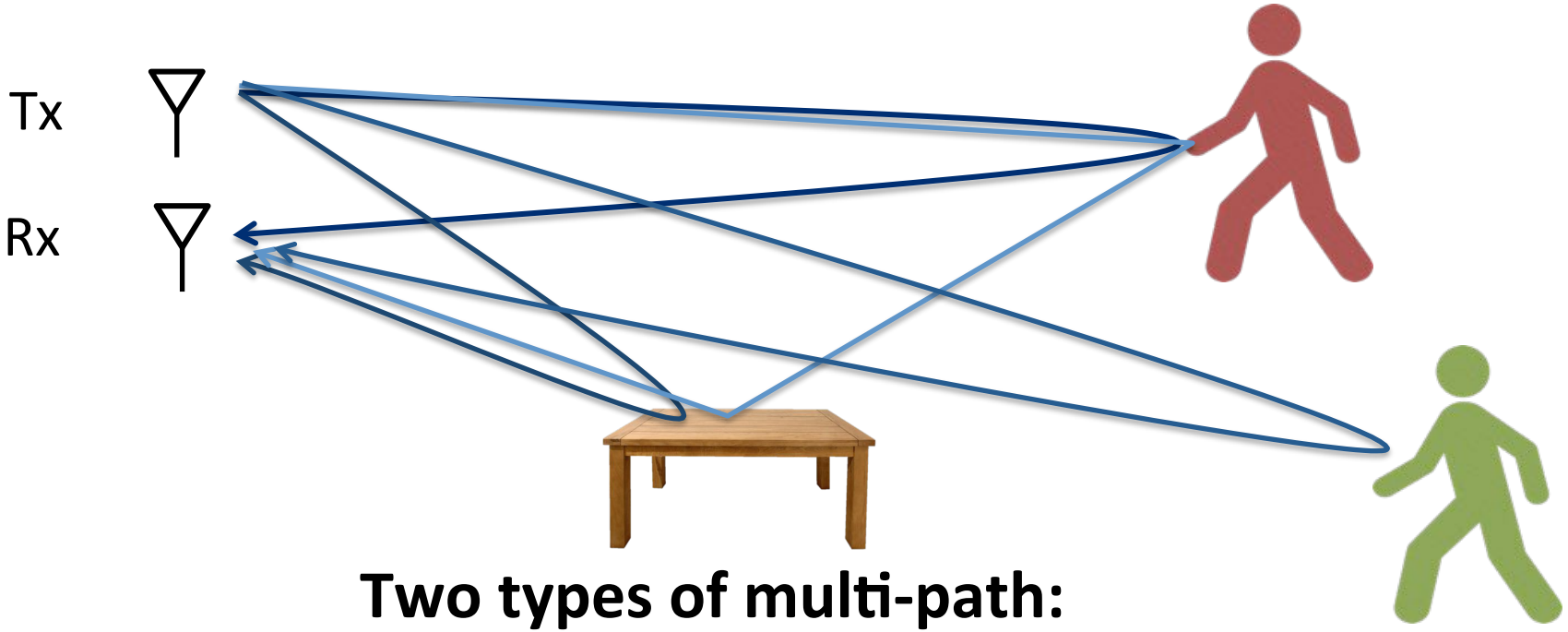
Person can be anywhere on an ellipse whose foci are (Tx,Rx)



By adding another antenna and intersecting the ellipses, they can localize the person

Why Are Past Systems Limited to a Single Moving User?

Dealing with multi-path is easy when there is one moving user



Two types of multi-path:

1. Direct furniture reflection:

eliminated by subtracting consecutive measurements

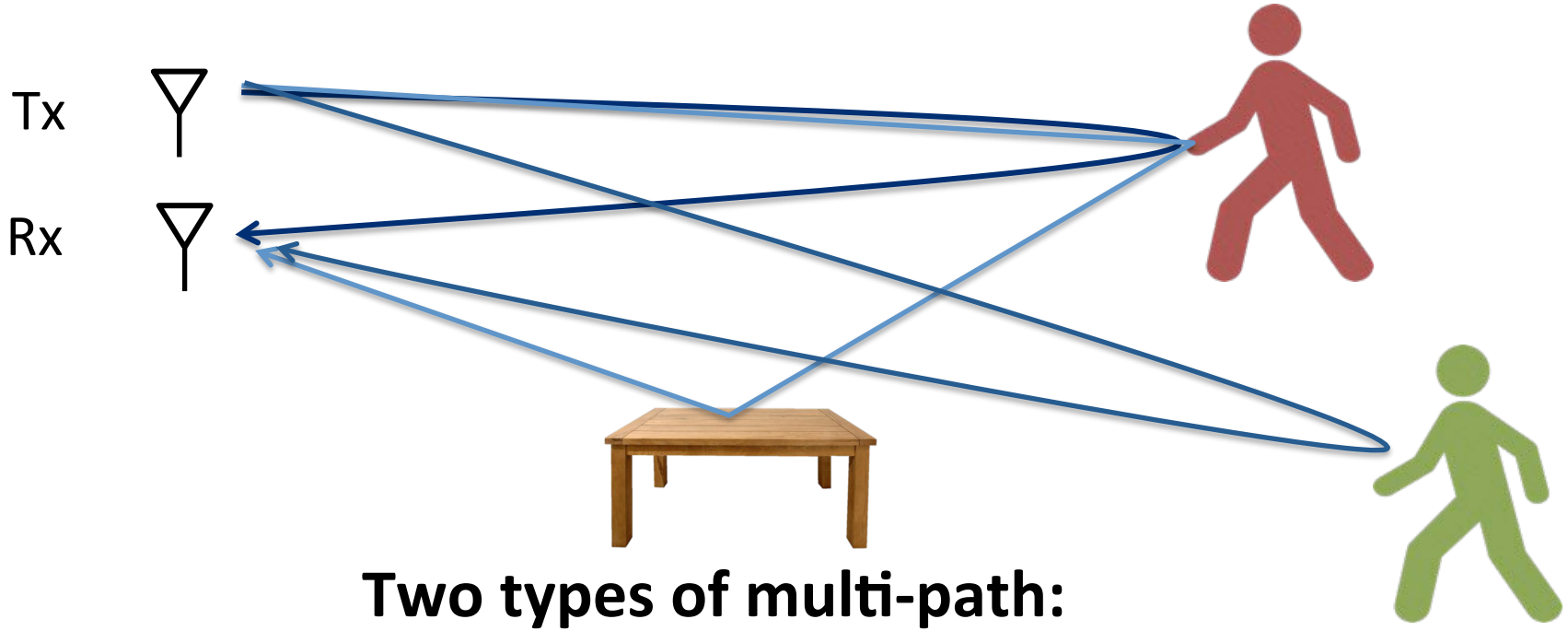
Needs User to Move

2. Indirect reflections:

eliminated by choosing shortest round-trip distance

Fails for multiple users

Need new mechanisms to eliminate muti-path



Two types of multi-path:

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Fails for multiple users

How can we deal with multi-path reflections when there are multiple users in the environment?

Idea: Person is consistent across different vantage points while multipath is different from different vantage points

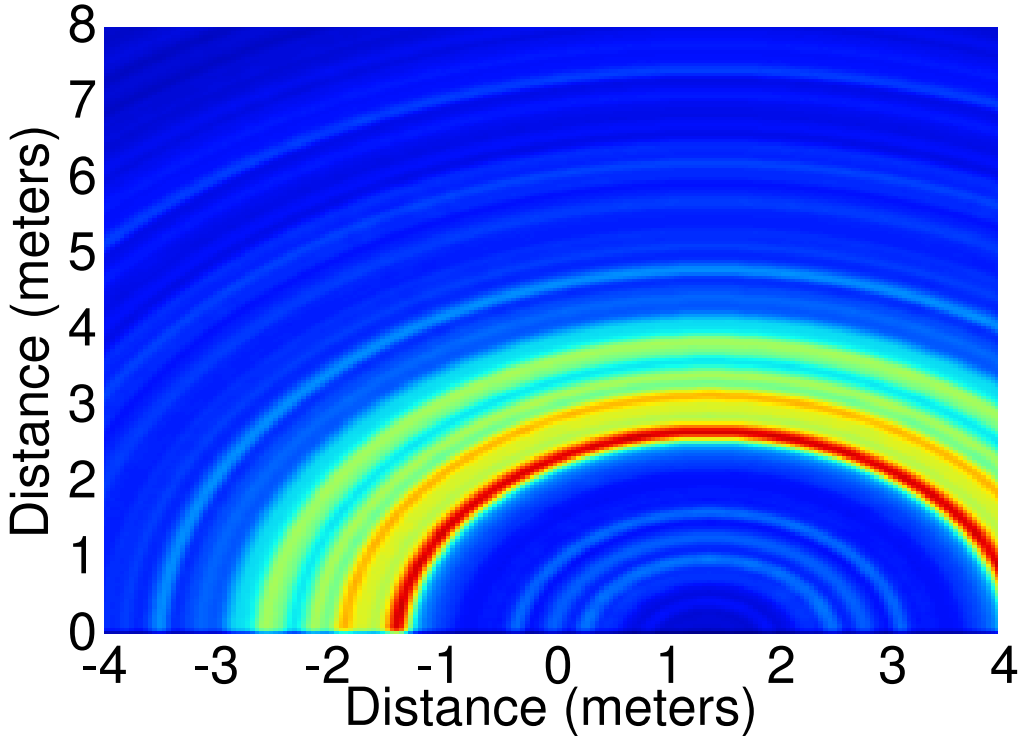
Combining across multiple vantage points

Experiment: Two users walking

Setup



Single Vantage Point



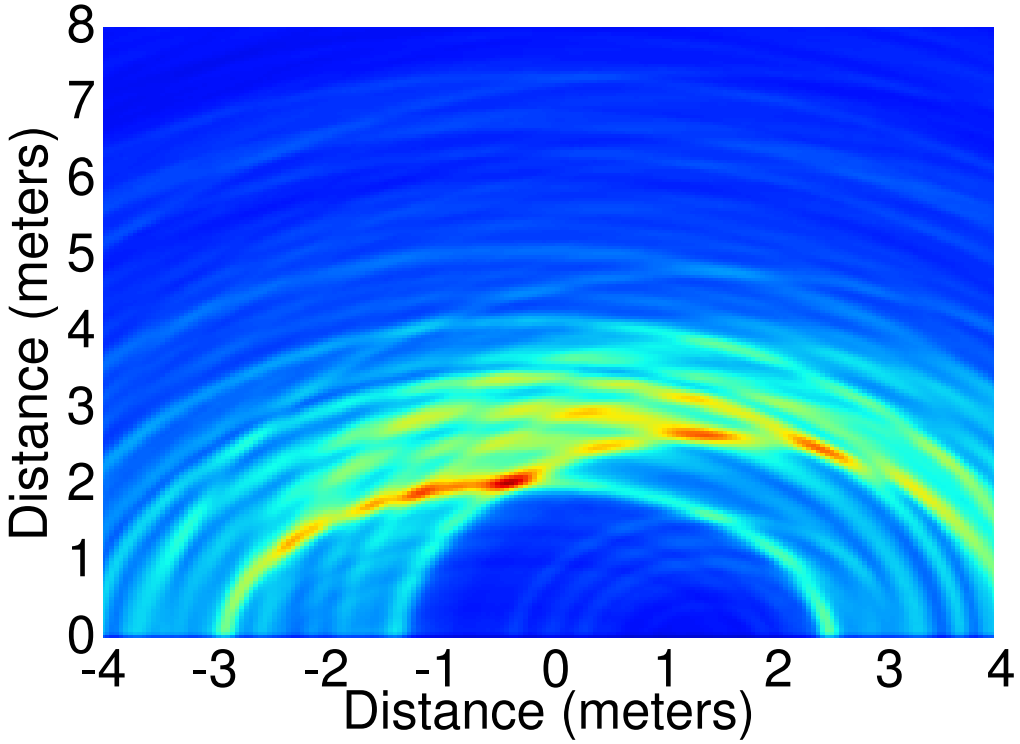
Combining across multiple vantage points

Experiment: Two users walking

Setup



Two Vantage Points



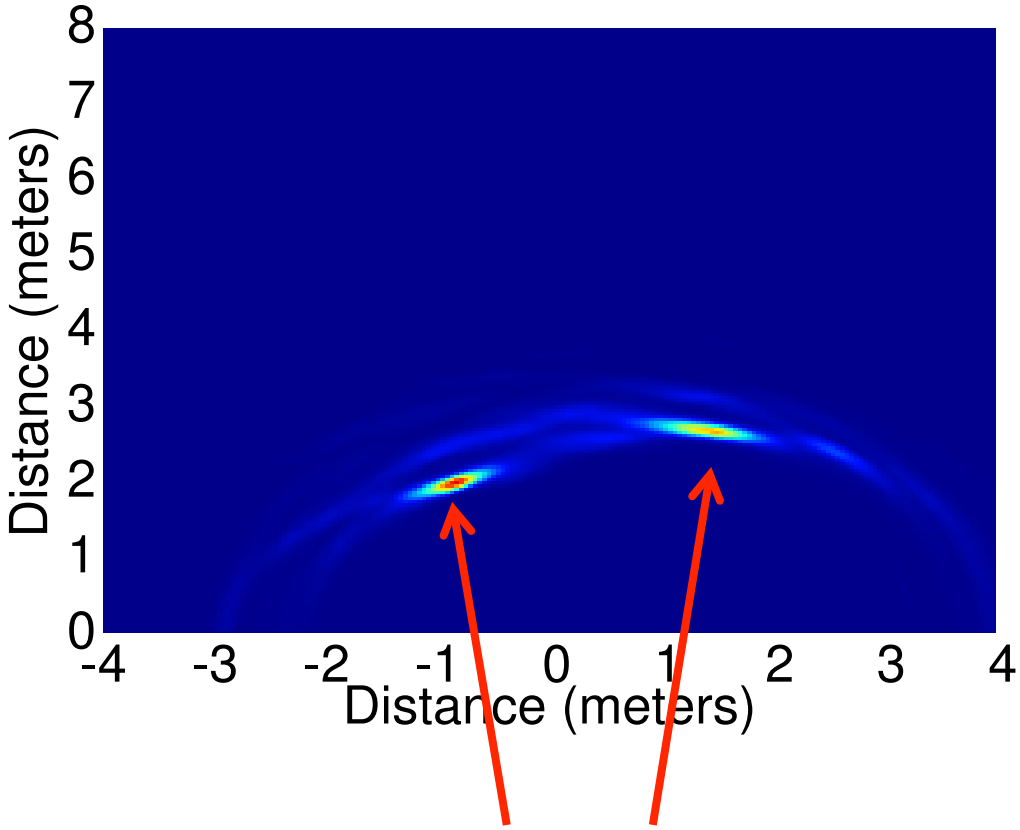
Combining across multiple vantage points

Experiment: Two users walking

Setup



16 Vantage Points

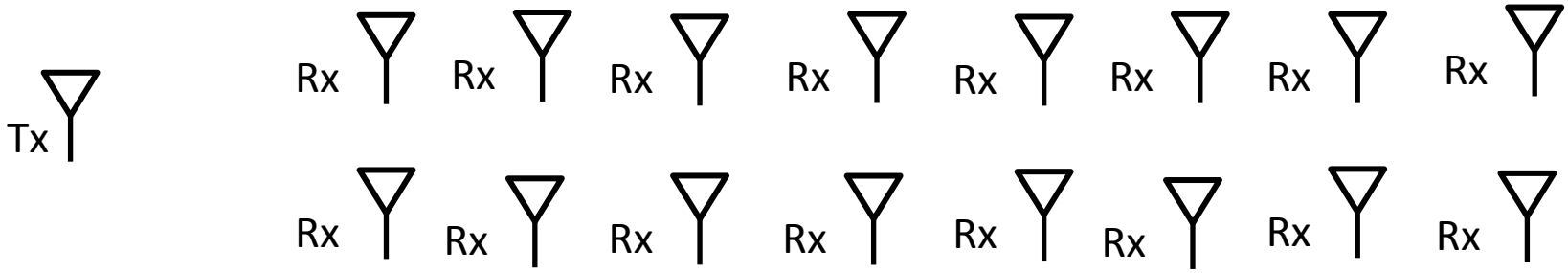


Localize the two users

How can we obtain 16 vantage points?

Achieving 16 vantage points

- Naïve solution: 1 Transmitter and 16 Receivers



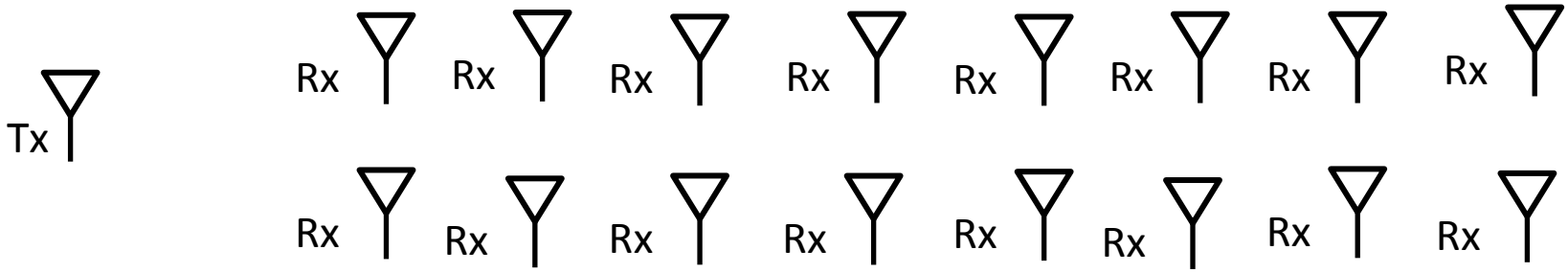
- Ideally: 4 Transmitters and 4 Receivers



Scales with the square root of the number of vantage points

Achieving 16 vantage points

- Naïve solution: 1 Transmitter and 16 Receivers

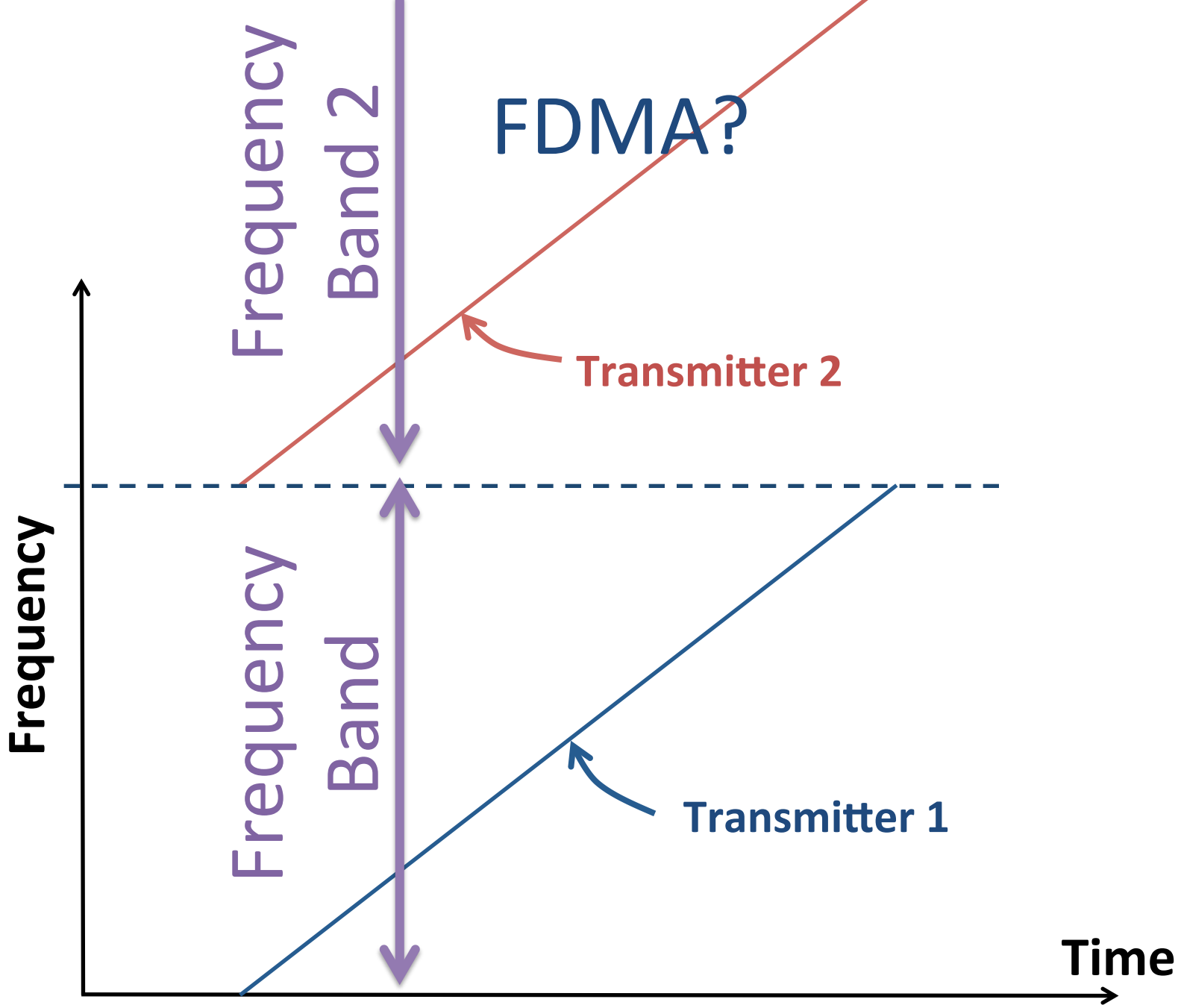


- Ideally: 4 Transmitters and 4 Receivers

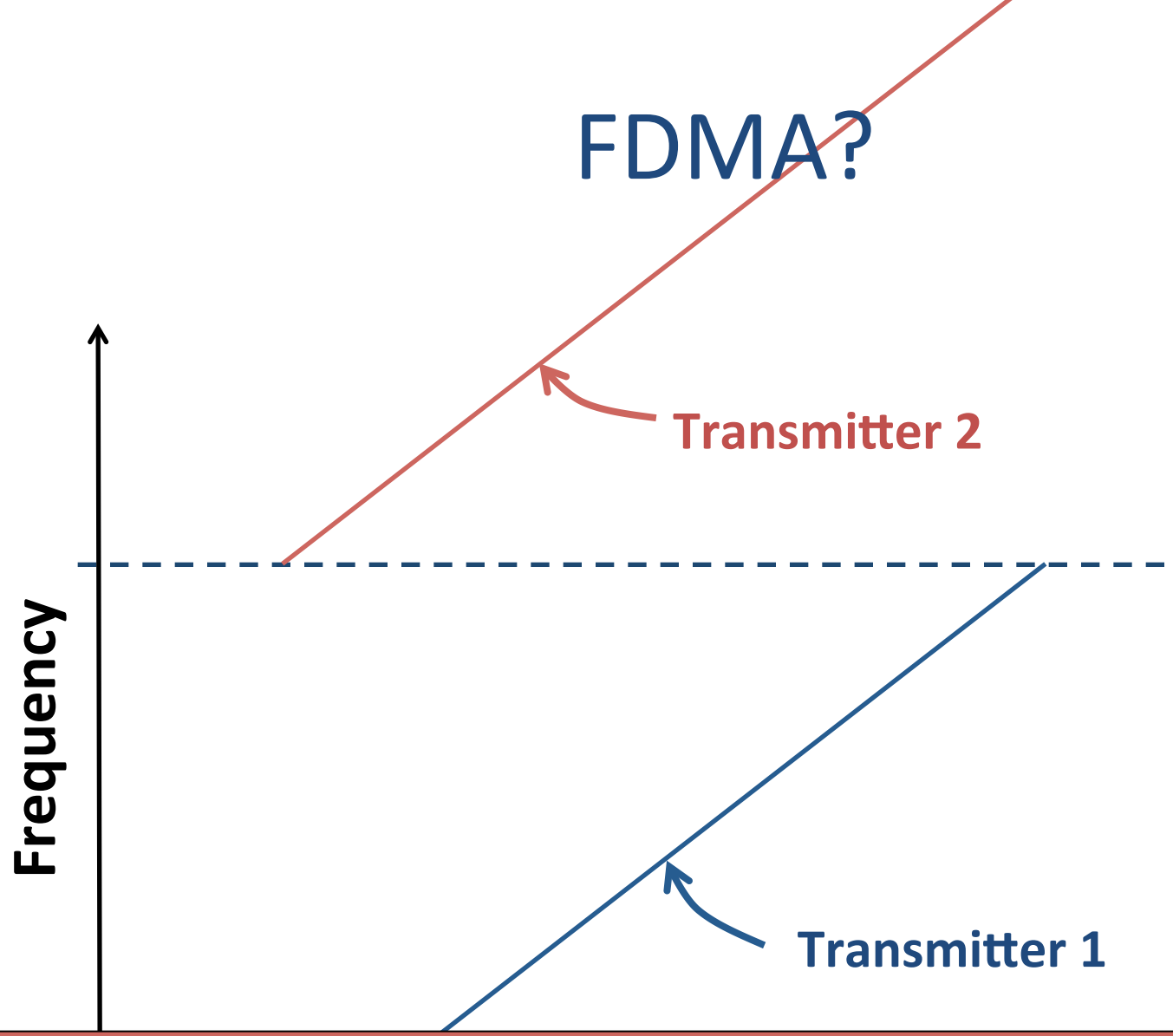


Problem: Different Transmitters interfere with each other!

How can these different transmitters share the medium without interference?

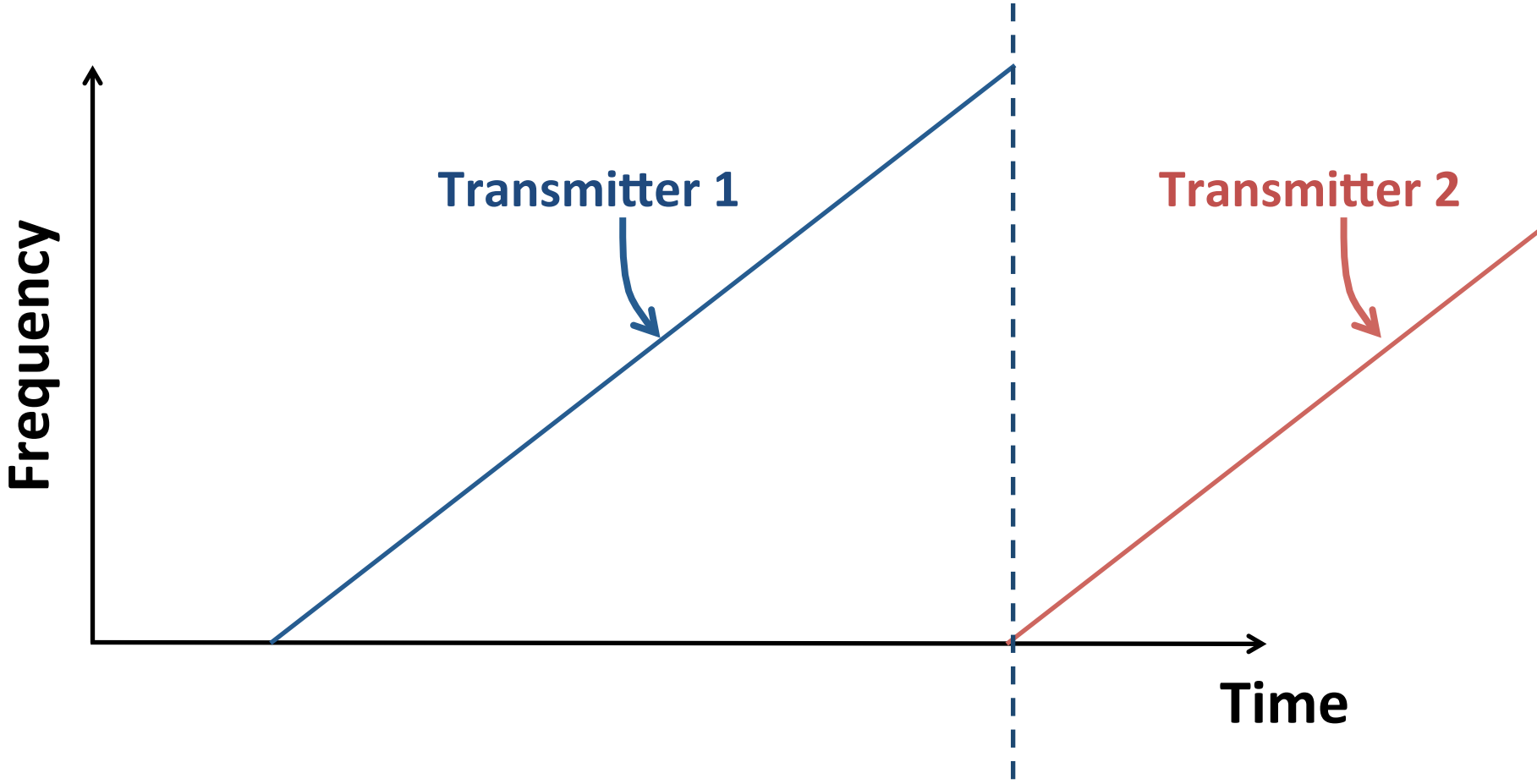

FDMA?
Frequency Band 2
Transmitter 2
Frequency Band
Transmitter 1
Frequency
Time

FDMA?

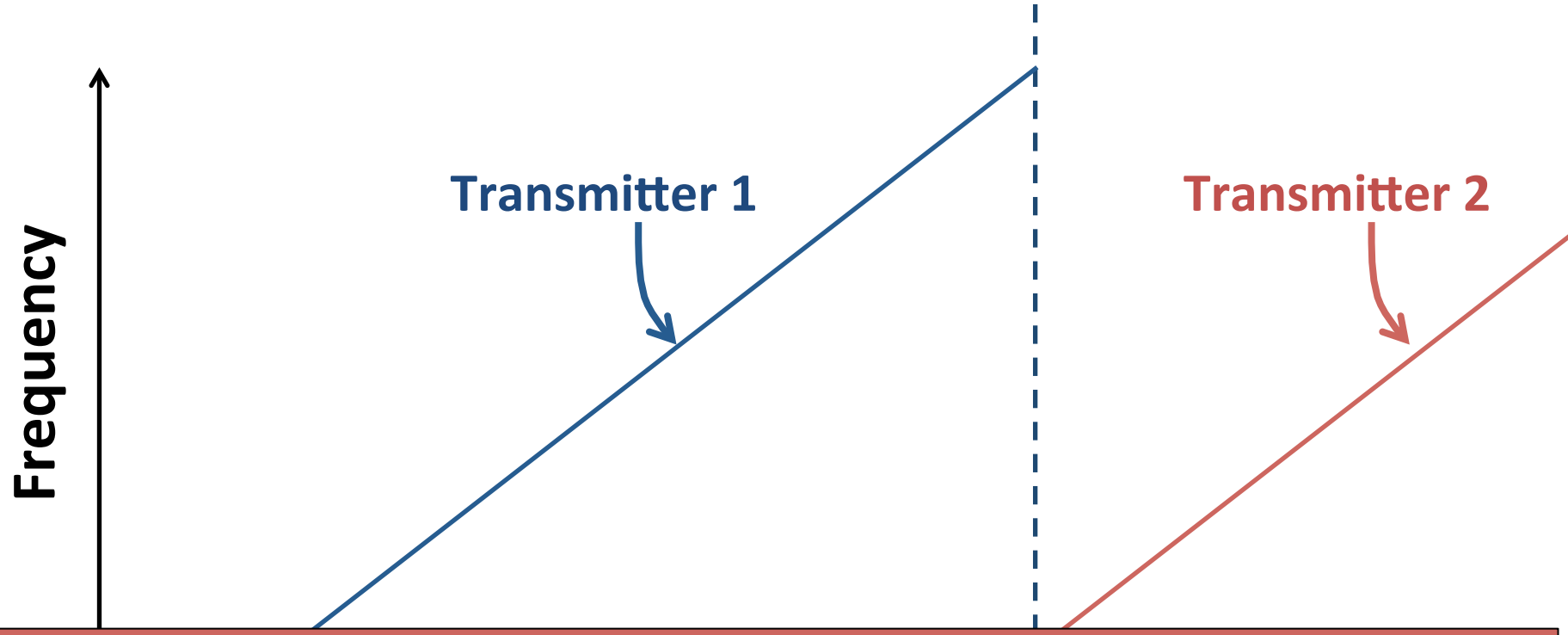


Would require N times the bandwidth!

TDMA?

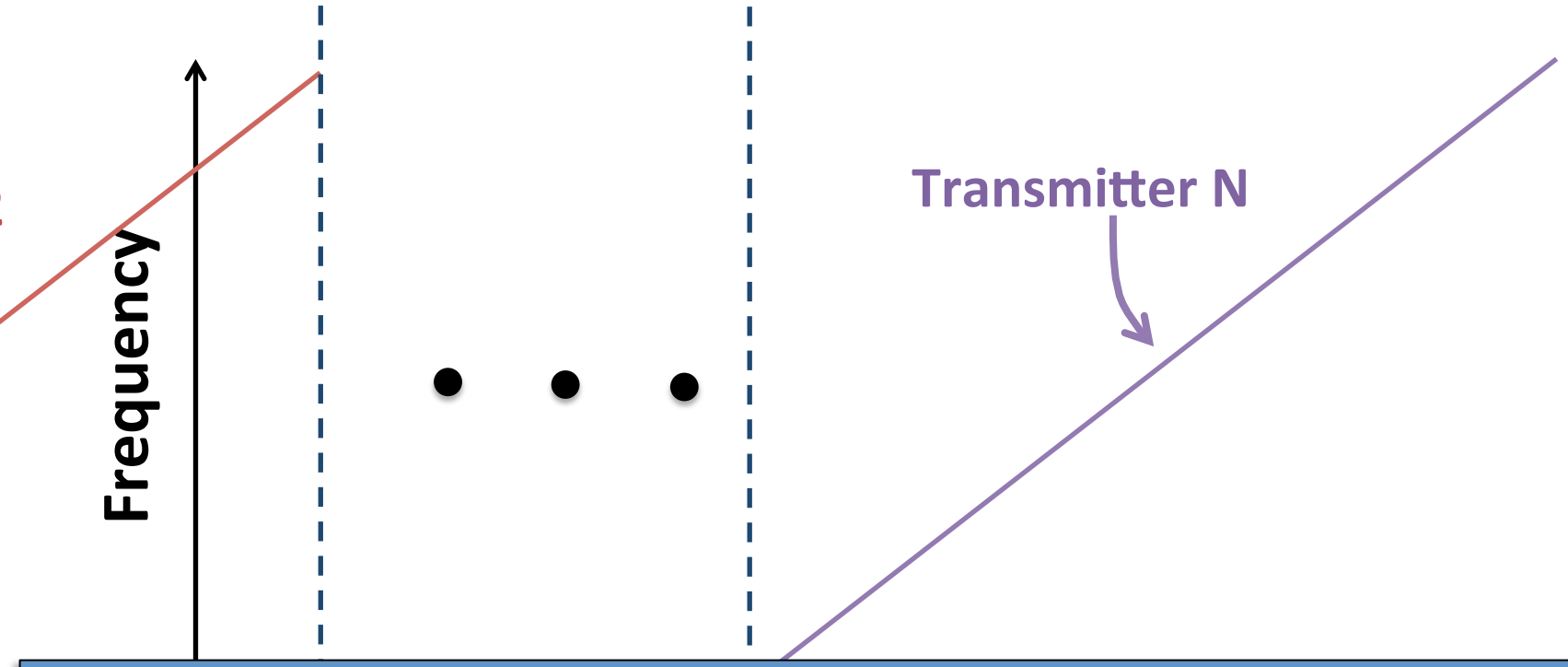


TDMA?



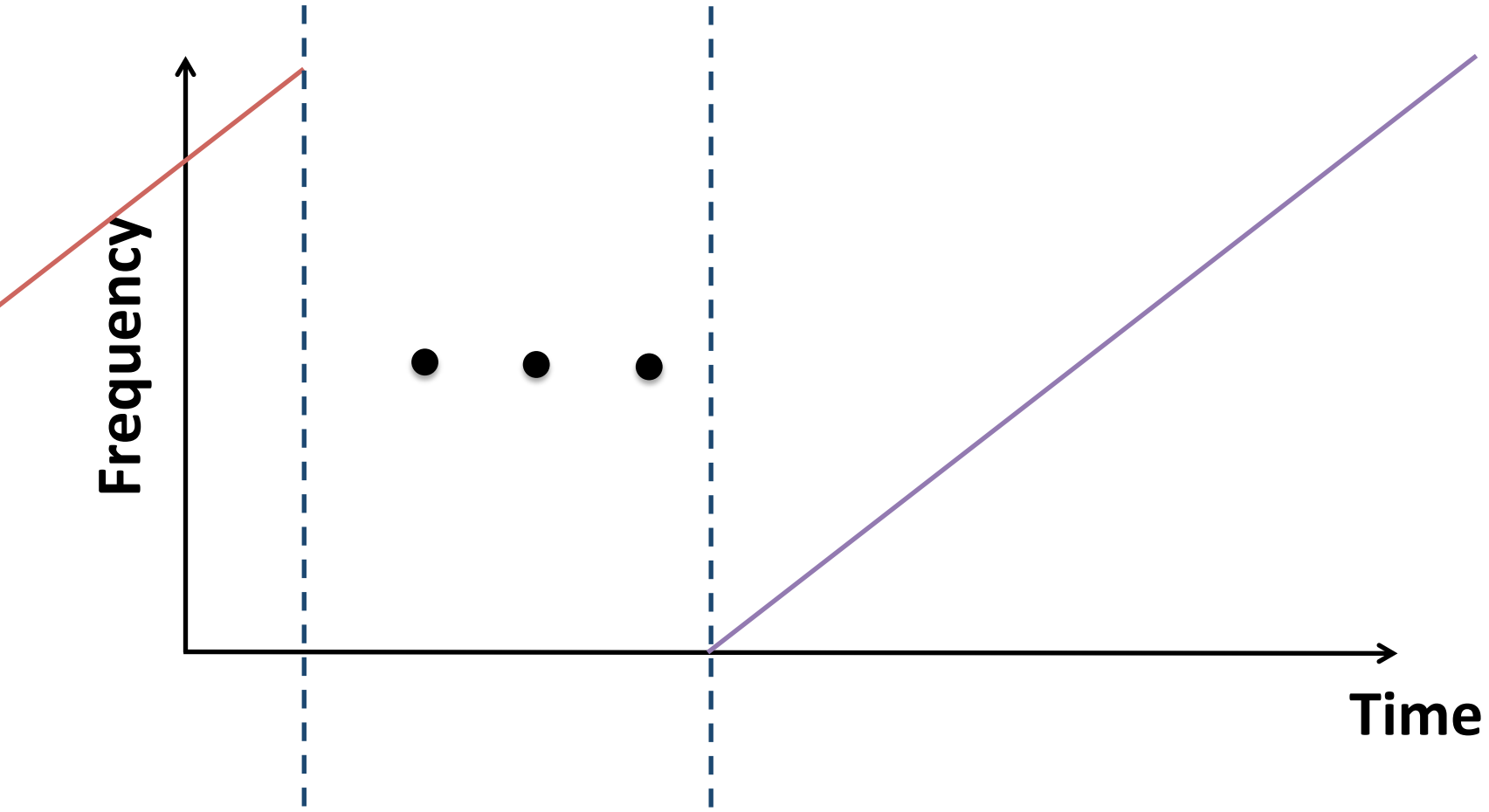
Would require N more time to localize

TDMA?



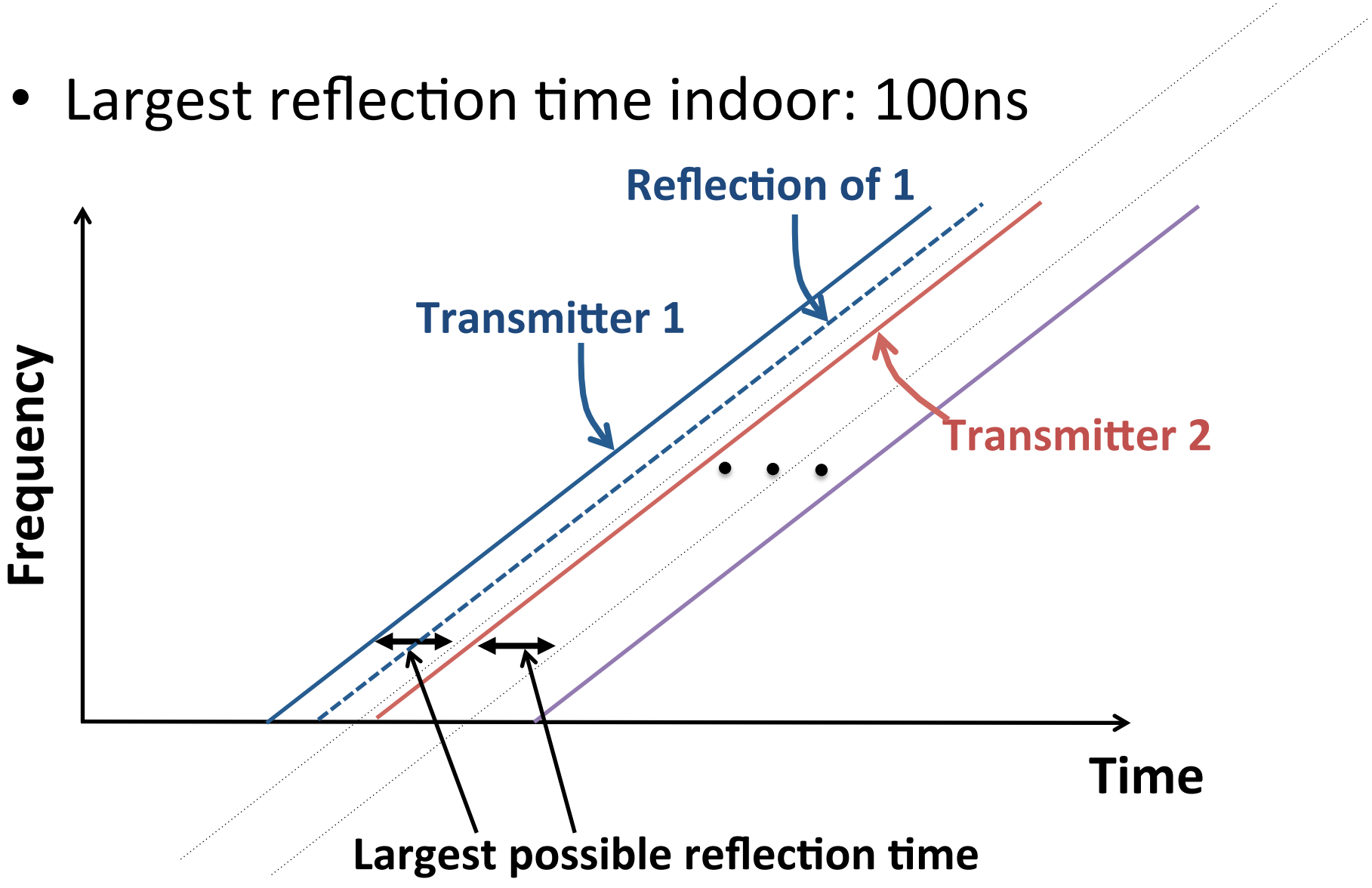
Ideally: Transmit in the same time and in the same frequency band without interfering

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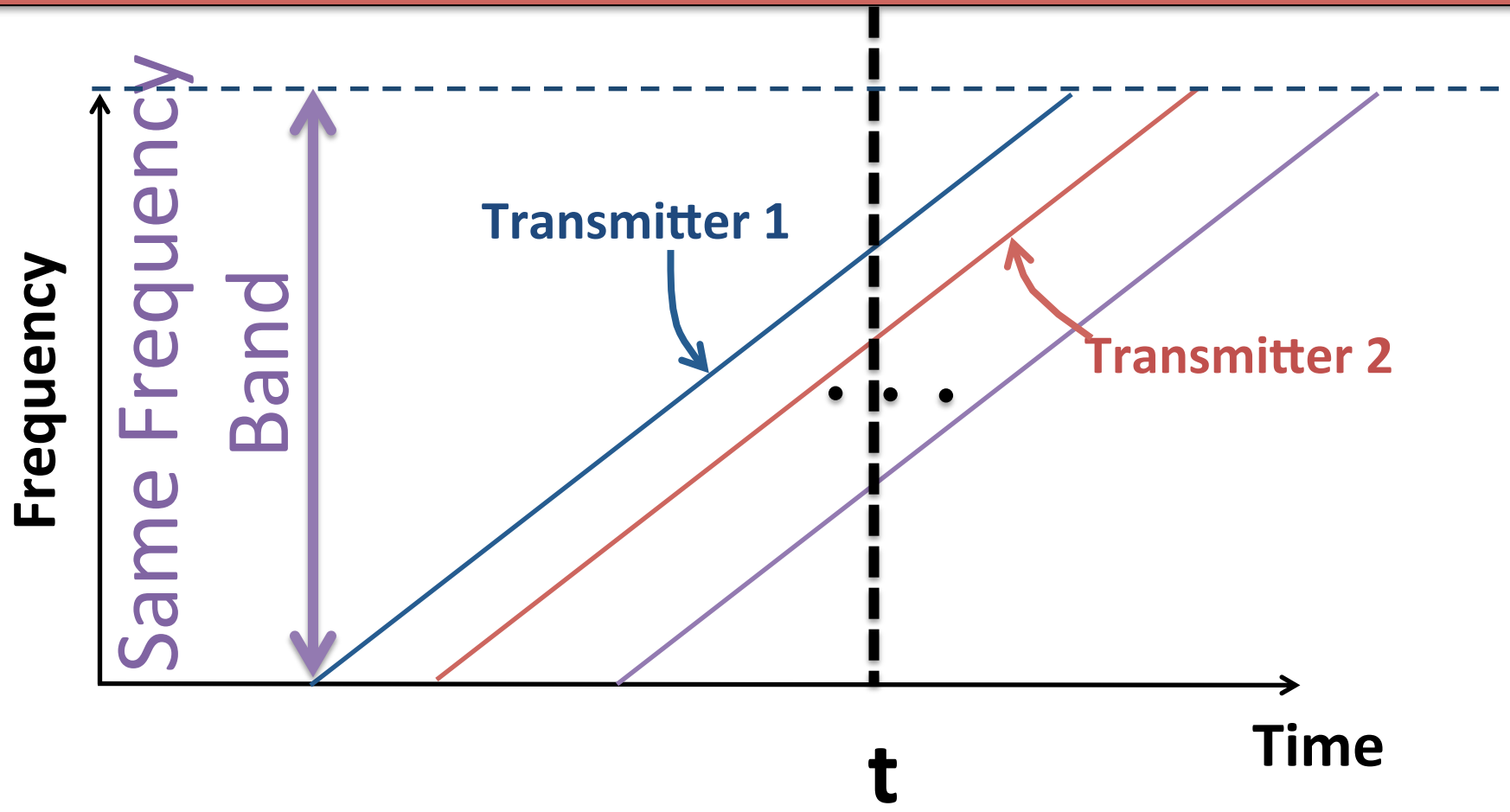


Objective: Transmit and Get Reflection

- Largest reflection time indoor: 100ns



Multi-shift FMCW enables multiple transmissions at the **same time** and in the **same frequency band** without interference

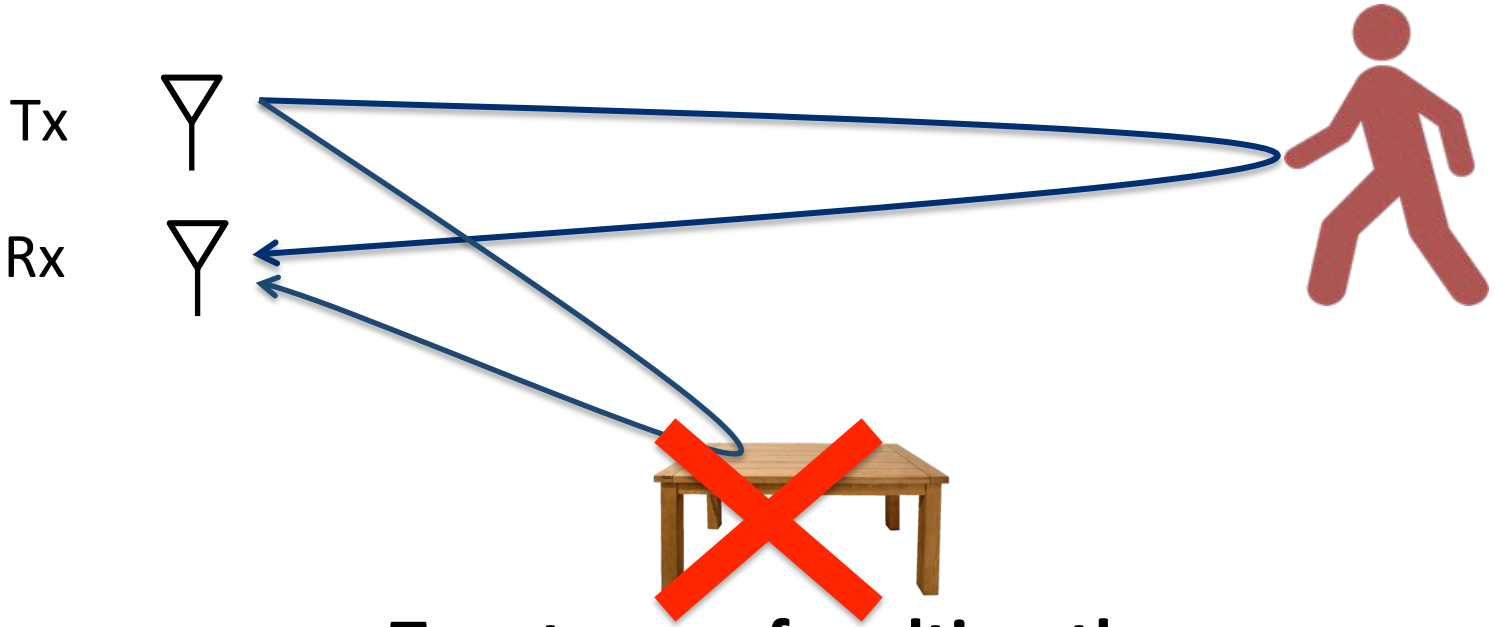


Localize Multiple Users

- Transmit from multiple antennas using multi-shift FMCW
- Combine measurements from different vantage points to eliminate multi-path

How can we localize static users?

Dealing with multi-path is easy when there is one moving user



Two types of multi-path:

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eliminated by subtracting consecutive measurements

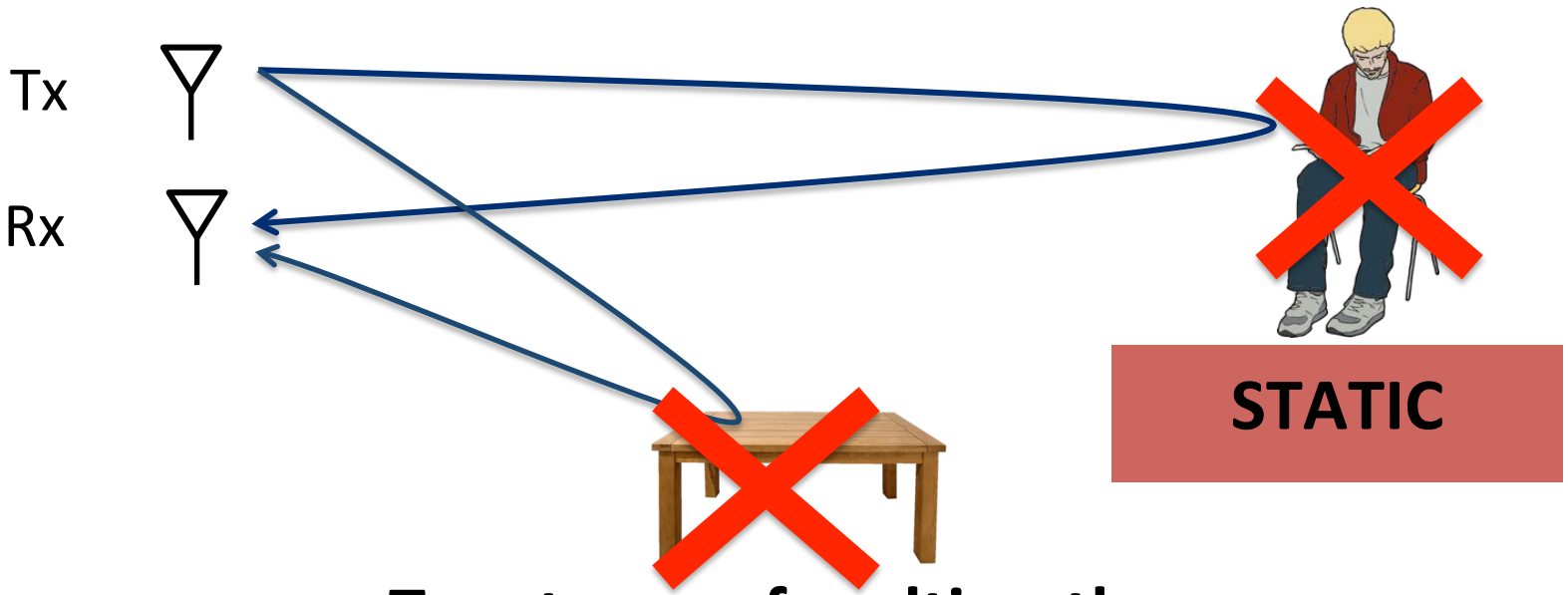
Needs User to Move

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Fails for multiple users

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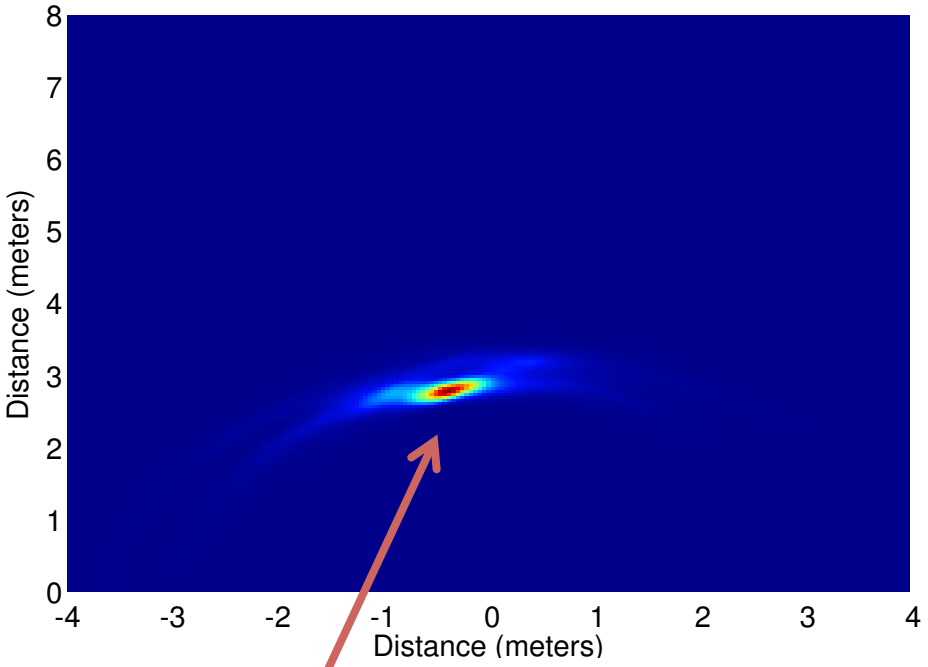
Fails for multiple users

Exploit breathing motion for localize static users

- Breathing and walking happen at different time scales
  - A user that is pacing moves at 1m/s
  - When you breathe, chest moves by few mm/s
- Cannot use the same subtraction window to eliminate multi-path

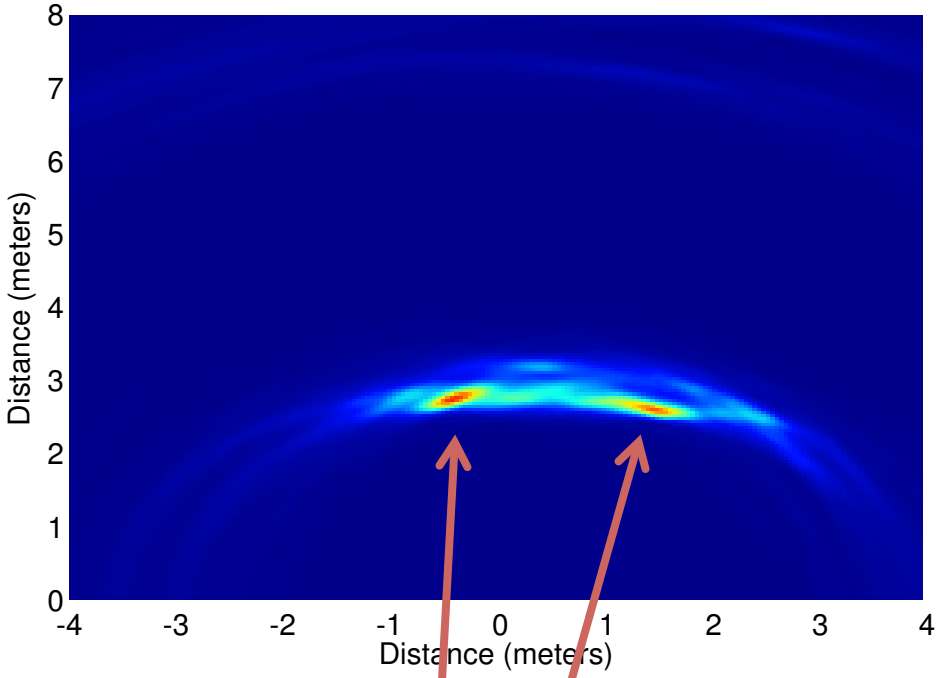
User Walking at 1m/s

30ms subtraction window



Localize the person

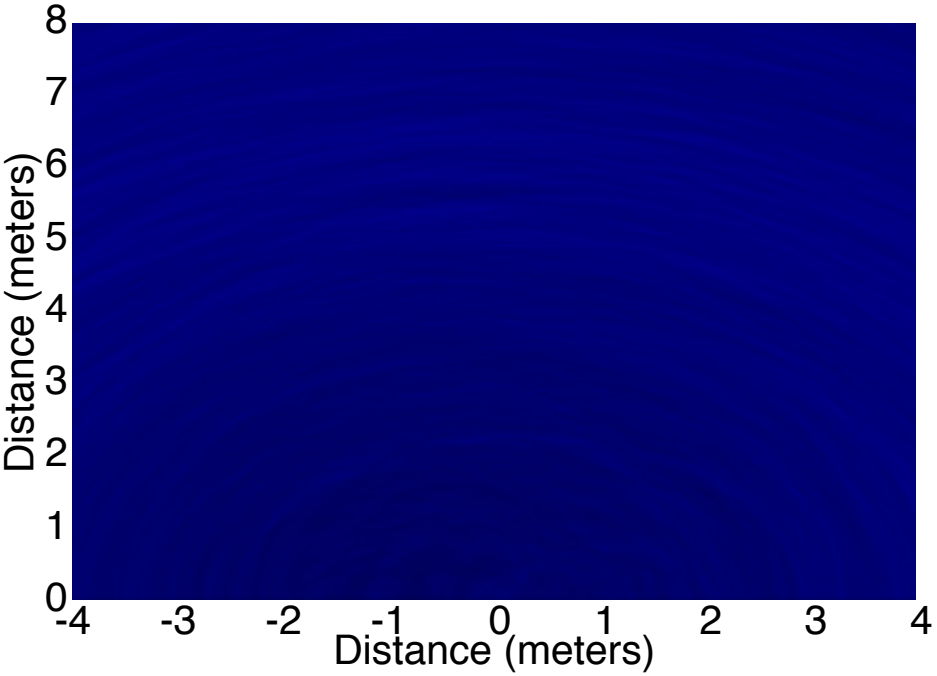
3s subtraction window



Person appears in two locations

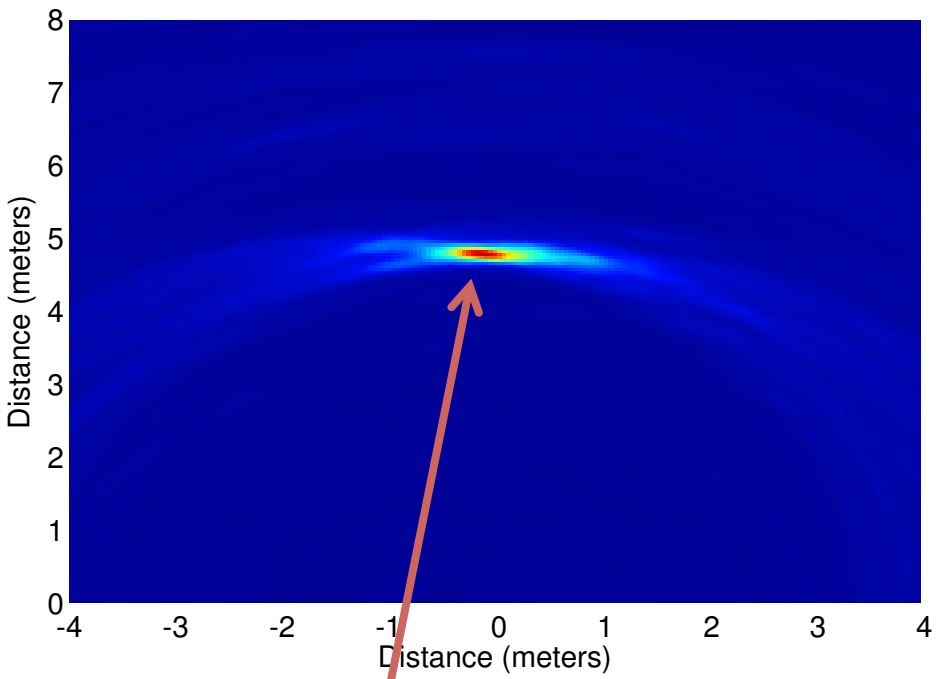
User Sitting Still (Breathing)

30ms subtraction window



Cannot localize

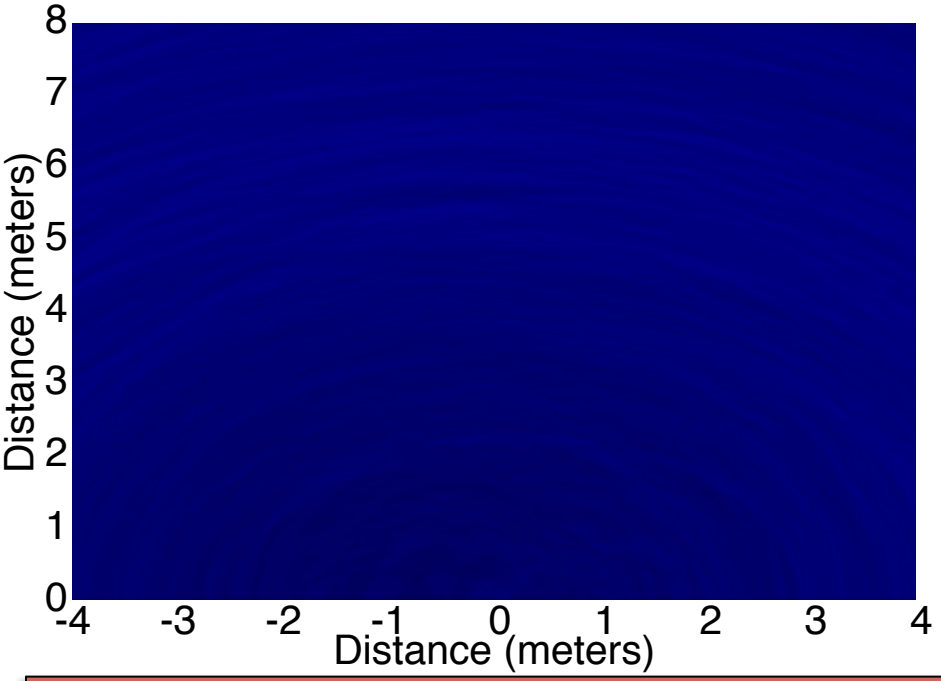
3s subtraction window



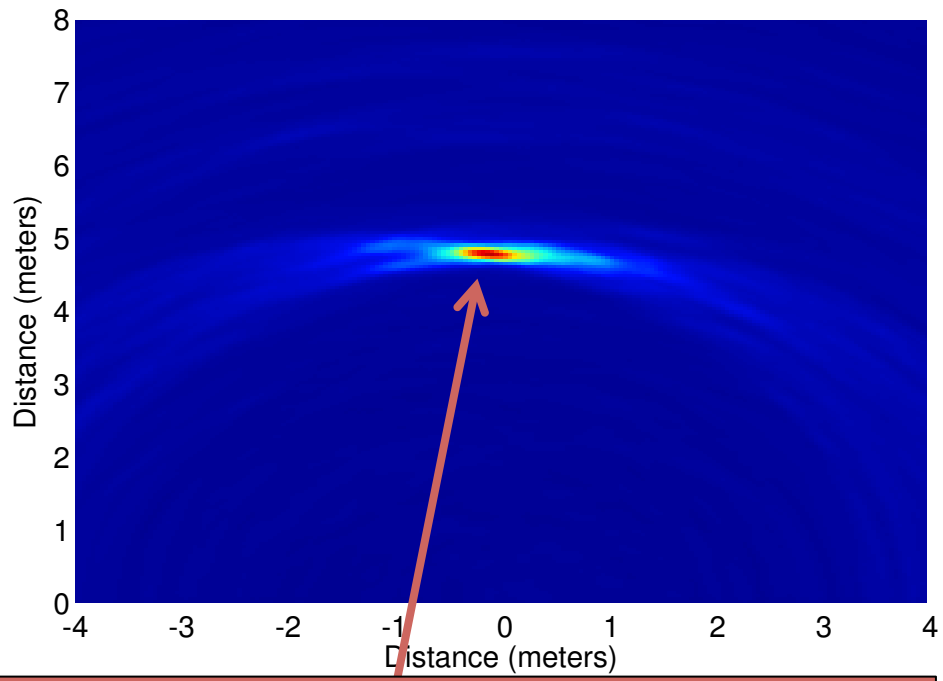
Localize the person

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30ms subtraction window



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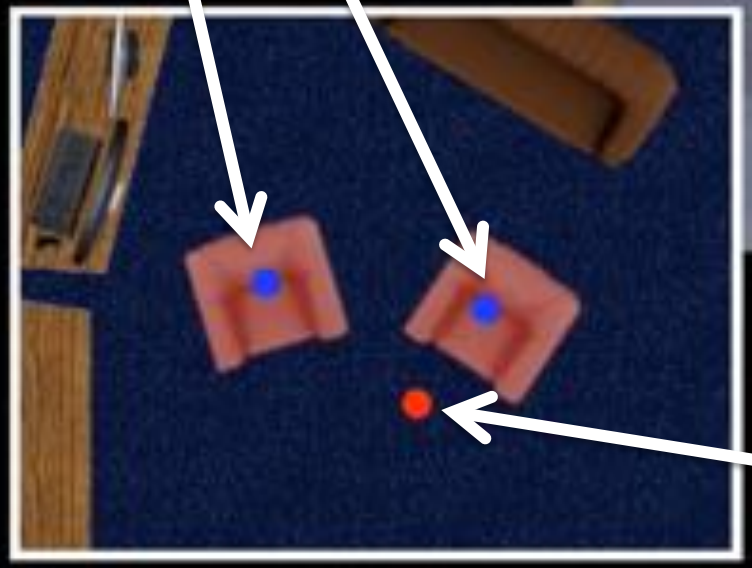


Use multi-resolution subtraction window to eliminate multi-path while being able to localize both static and moving users

Multi-Person Localization Video



Sitting subjects



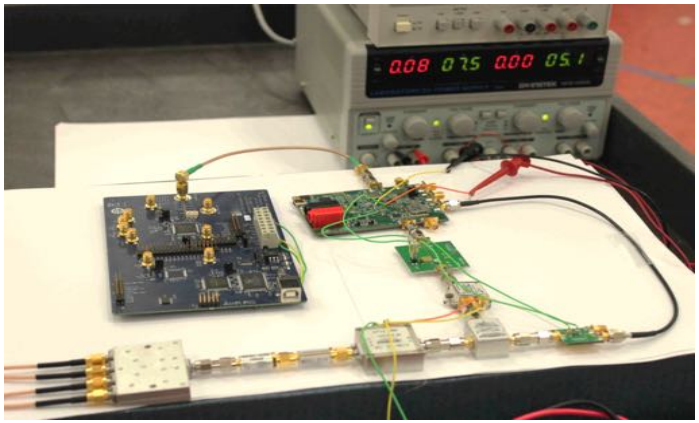
Walking person

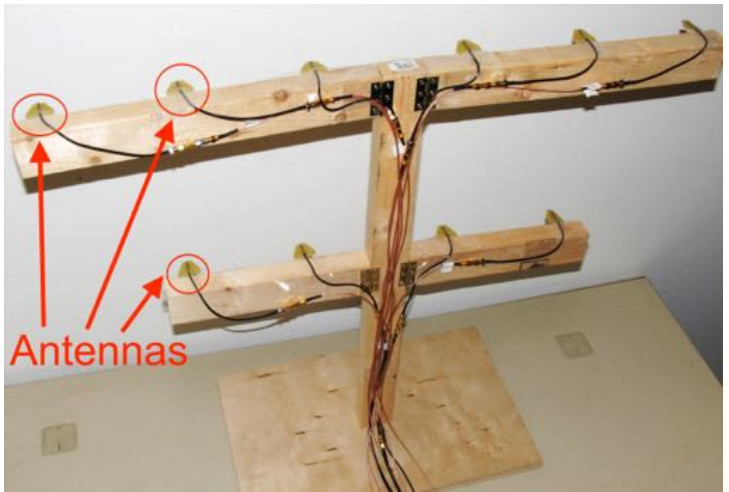
WiTrack2.0 output

Implementation & Evaluation

Implementation

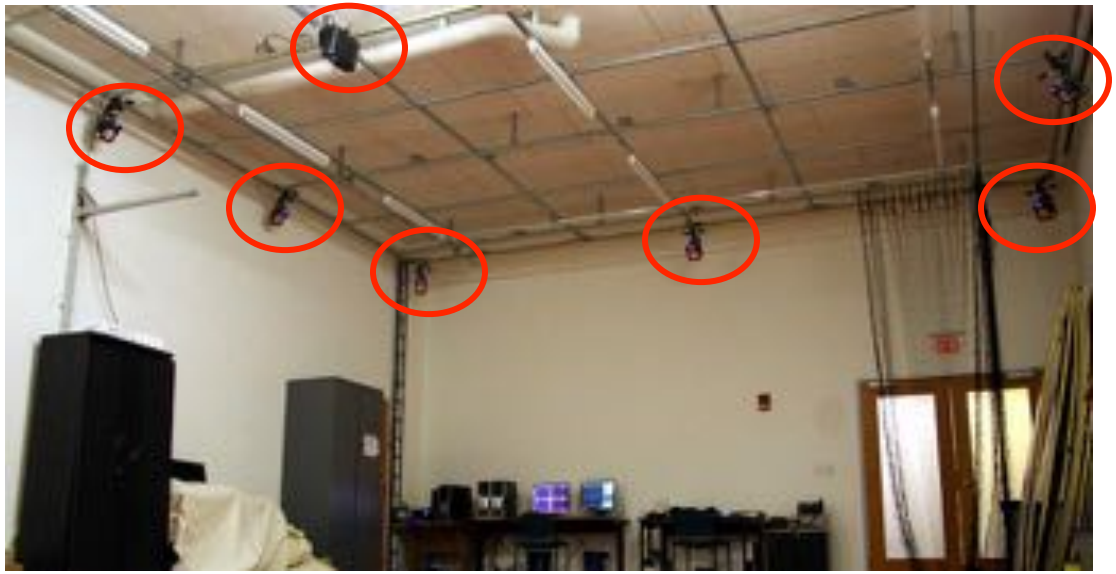
- Built FMCW front-end
  - Connected to USRP
- Band: 5.5-7.2GHz
- Transmit 70uW
  - 1000x lower power than WiFi AP
- 5 Tx, 5 Rx antennas





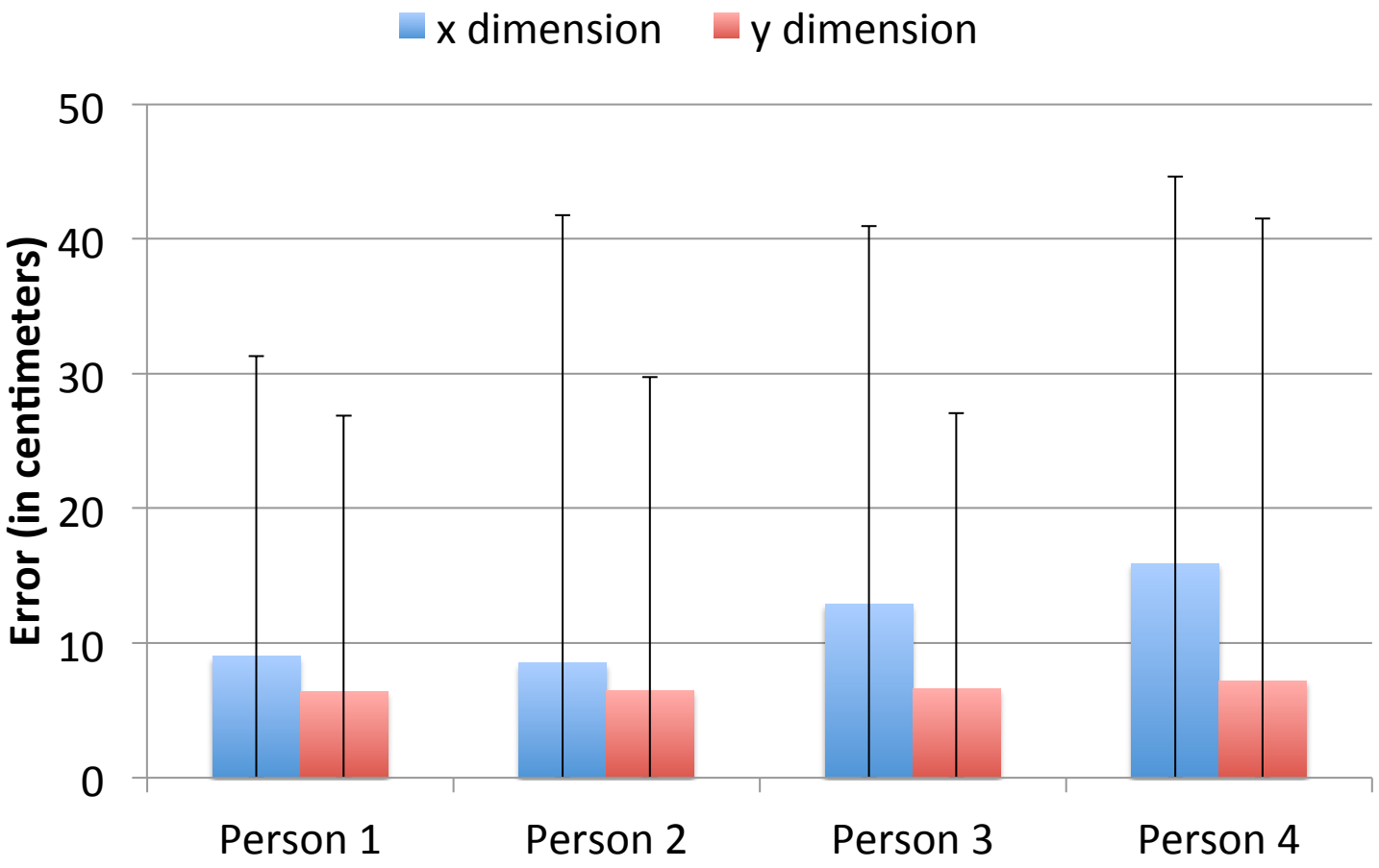
Ground Truth via VICON

- Array of infrared cameras
- Infrared markers to provide sub-cm accuracy



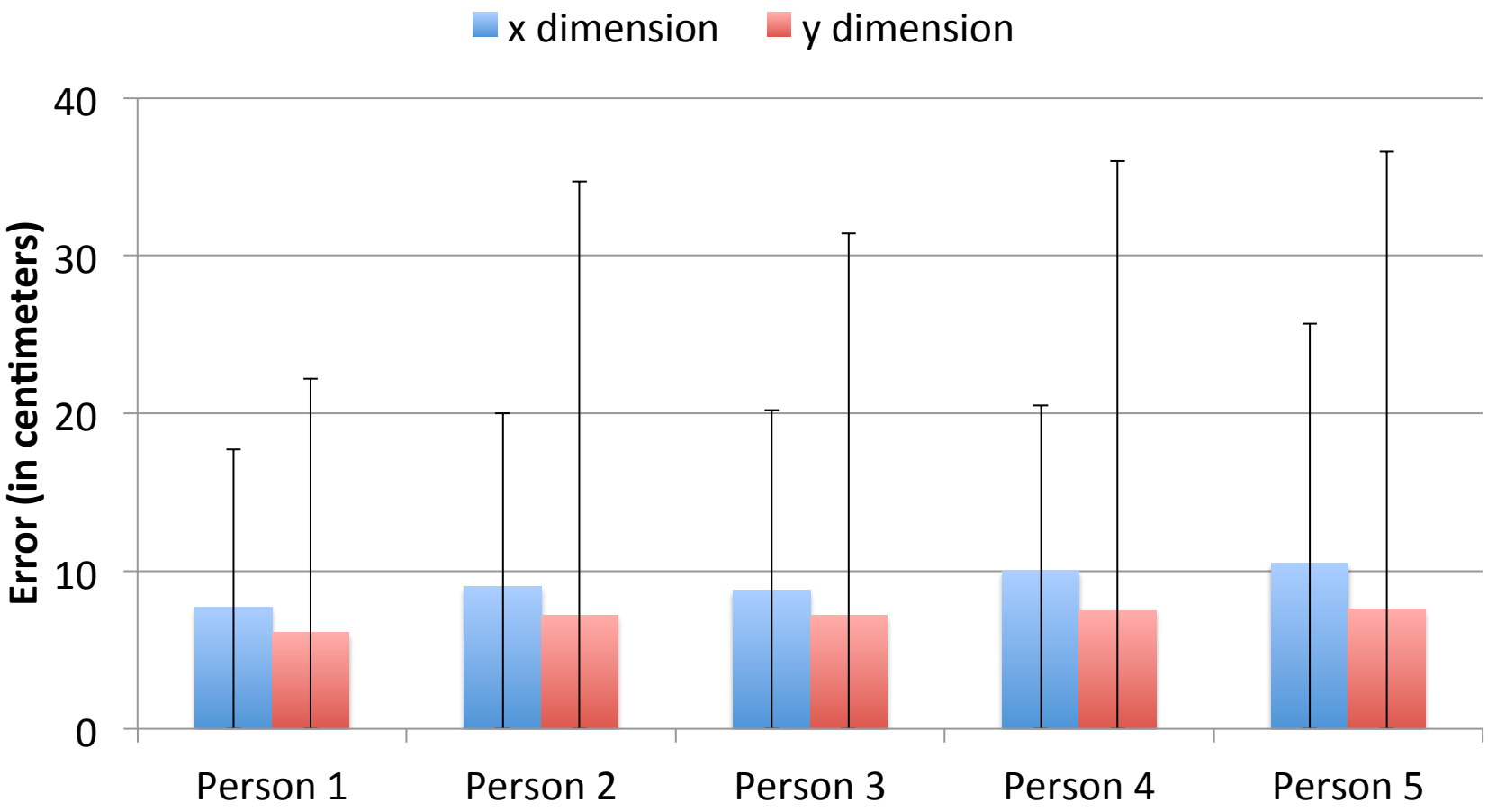
Accuracy of Localizing Moving Users

100 experiments where users walk around randomly in the room



Accuracy of Localizing Static Users

100 experiments where users sit down in different locations in the room



Past Work

- **Device-Free Detection and Localization**
  - WiVi [SIGCOMM'13], RTI [TMC'13], WiSee [MobiCom'13], WiTrack [NSDI'14], AllSee [NSDI'14], Ichnaea [J-STSP'14]

- **RF-based localization: localizes an RF transceiver**
  - ArrayTrack [NSDI'13], PinPoint [NSDI'13], PinIt [SIGCOMM'13], Zee [MobiCom'12], EZ [MobiCom'10], VOR [MobiCom'04], Cricket [MobiCom'00], RADAR [INFOCOM'00]

- **Radar Systems**
  - FMCW [ARRAY'10, ITIP'12, TGRS'12, RADAR'13]

Reflection-based Human Localization

Accurate localization of multiple users & static users

- Exploit properties of indoor multi-path
- Multi-resolution subtraction window

Limitations

- Lack of identification
- Current implementation: a maximum of 5 people given the compact setup

Demo (Breathing and Heart Rate)

For more information (Videos and animated slides), check out:

http://witrack.csail.mit.edu