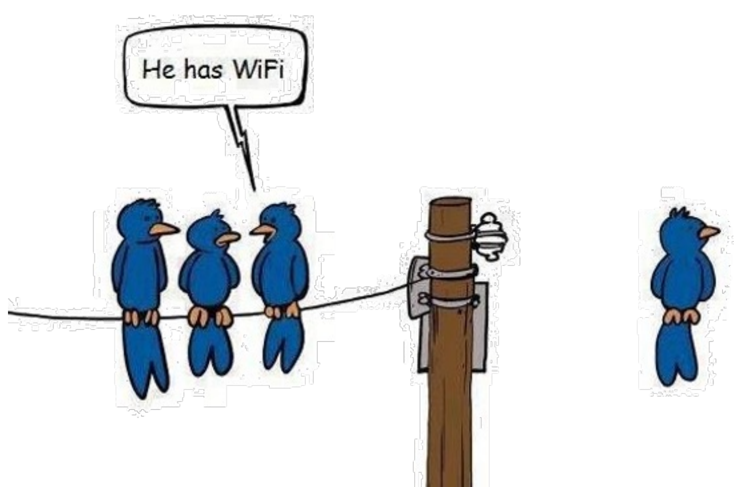
COM-405: Mobile Networks

Lecture 11.0: Wireless Sensing of Humans
Haitham Hassanieh

Some slides shamelessly stolen from Prof. Fadel Adib (MIT)



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Interest in Sensing the Human Body

Heart Rate

Breathing

Locations

Gestures

Heart Rate

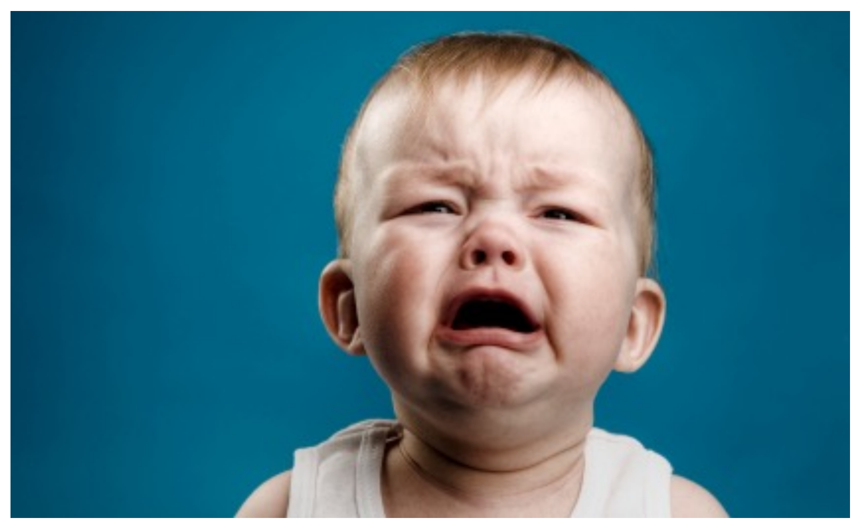
Breathing

Locations

Gestures

On-body sensors can be cumbersome

Not suitable for elderly & babies



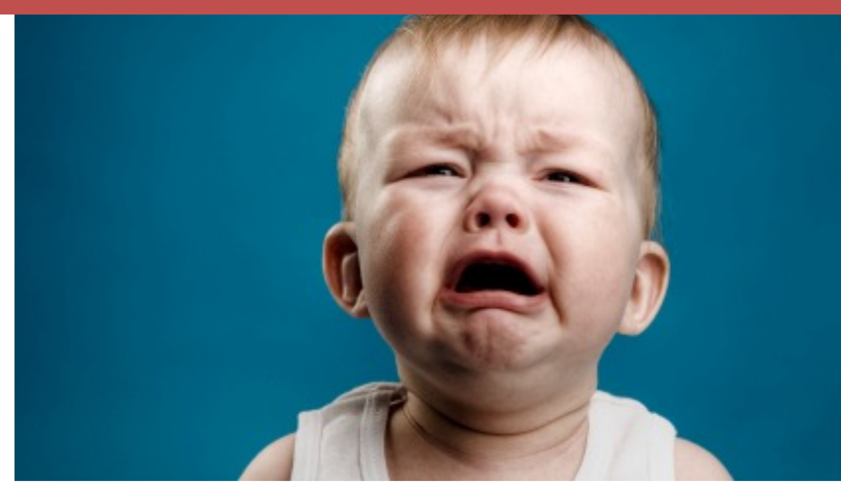
Heart Rate

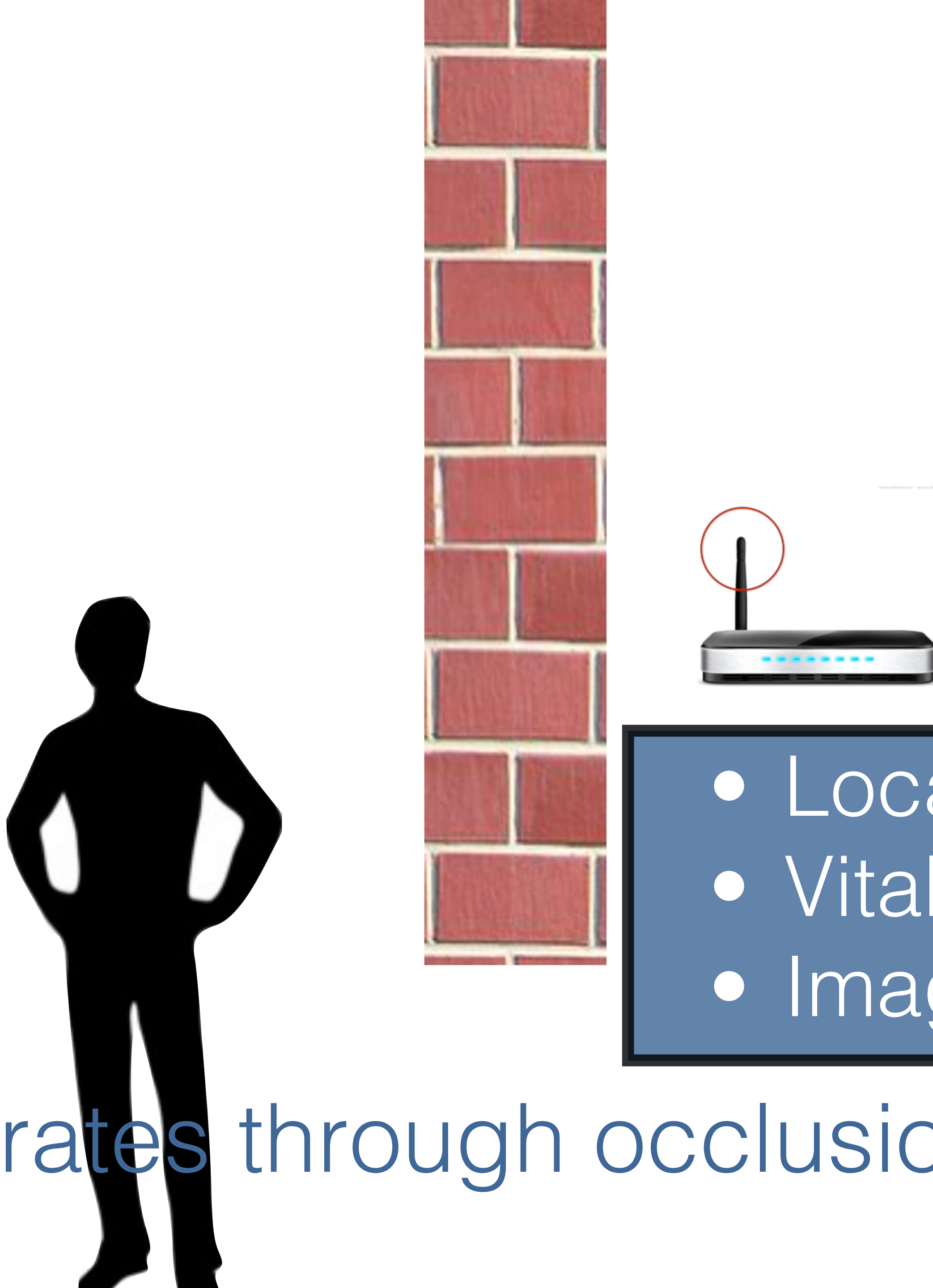
Breathing

Locations

Gestures

Imagine enabling these applications without sensors on the human body

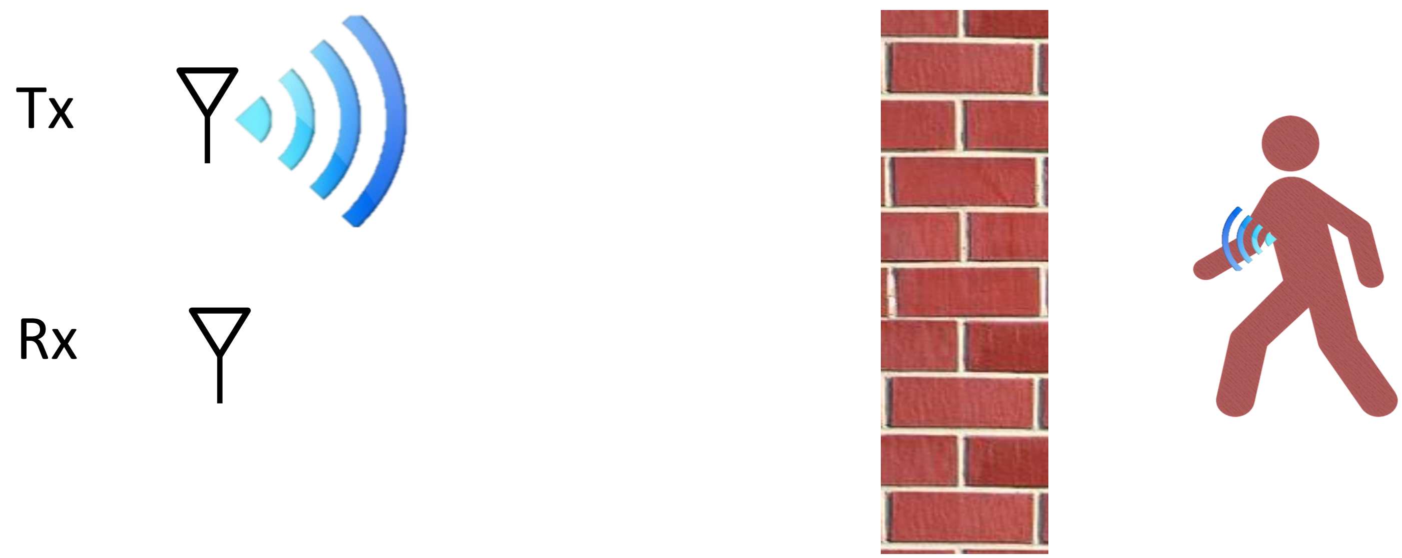




- Location
- Vital Signs
- Imaging

Operates through occlusions

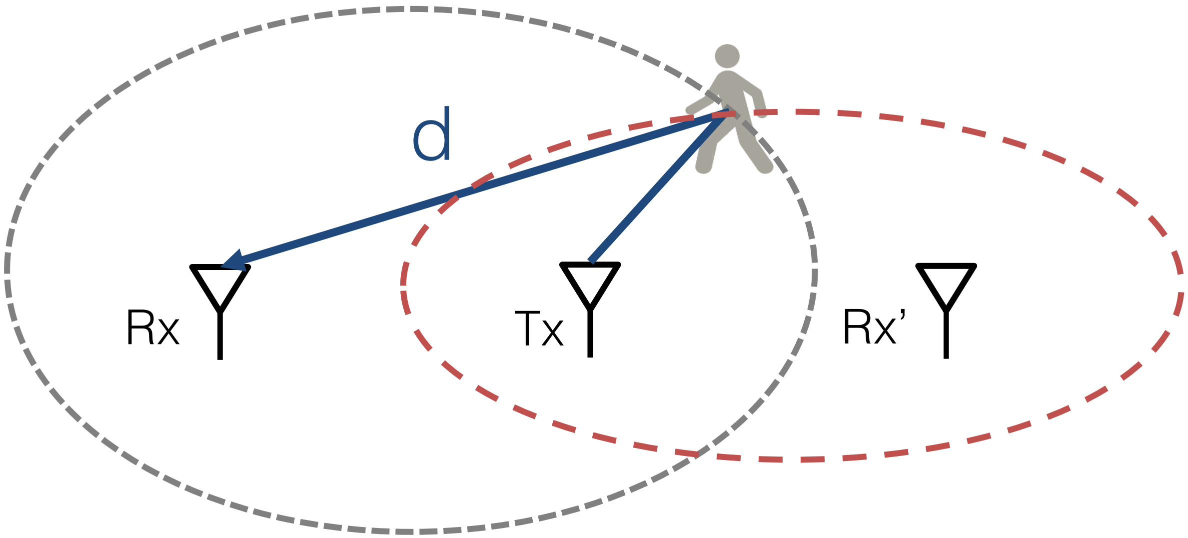
Measuring Distances



Distance = Reflection time x speed of light

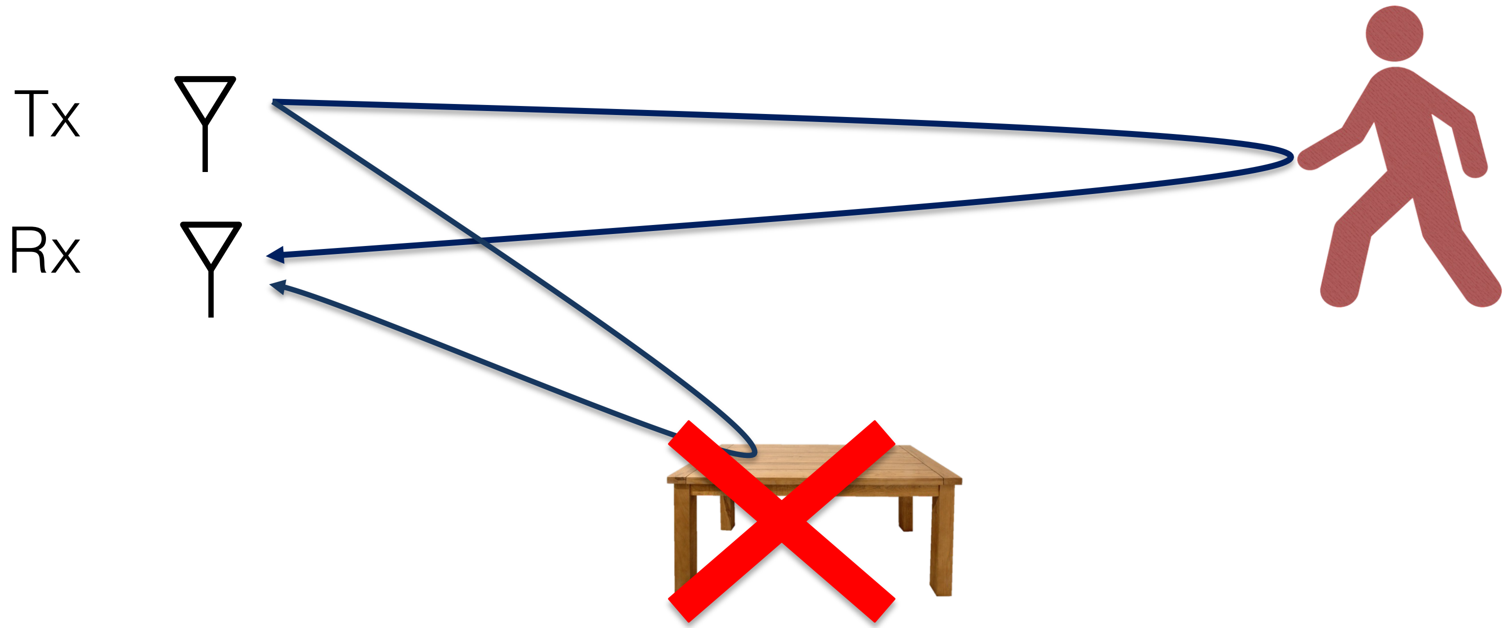
Mapping Distance to Location

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



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

Dealing with multi-path when there is one moving user



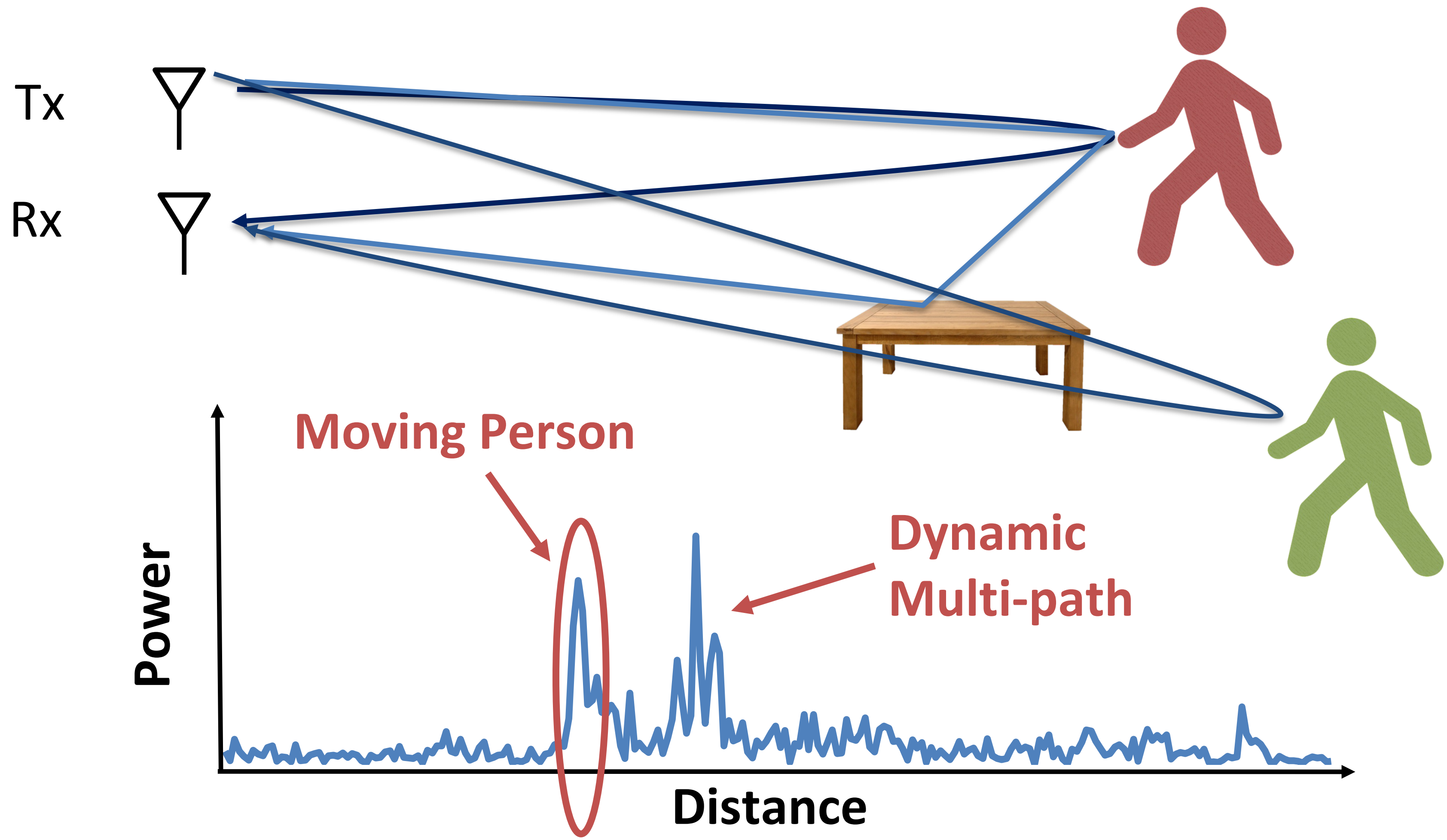
Direct furniture reflection:

eliminated by subtracting consecutive measurements

Needs User to Move

Device in another room

Fails for multiple people in the environment, and we need a more comprehensive solution



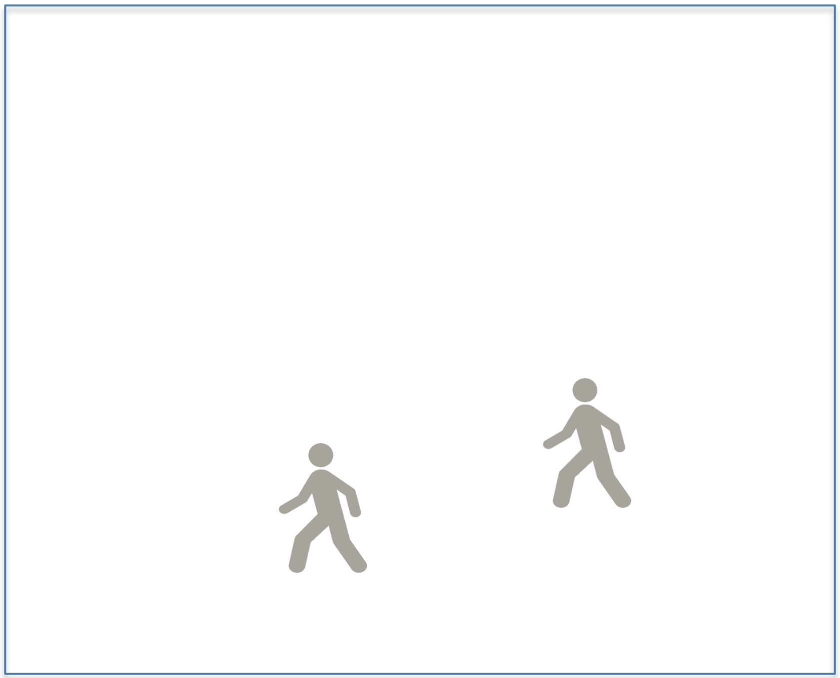
How can we deal with multi-path reflections when there are multiple persons in the environment?

<u>Idea:</u> Person is consistent across different vantage points while multi-path is different from different vantage points

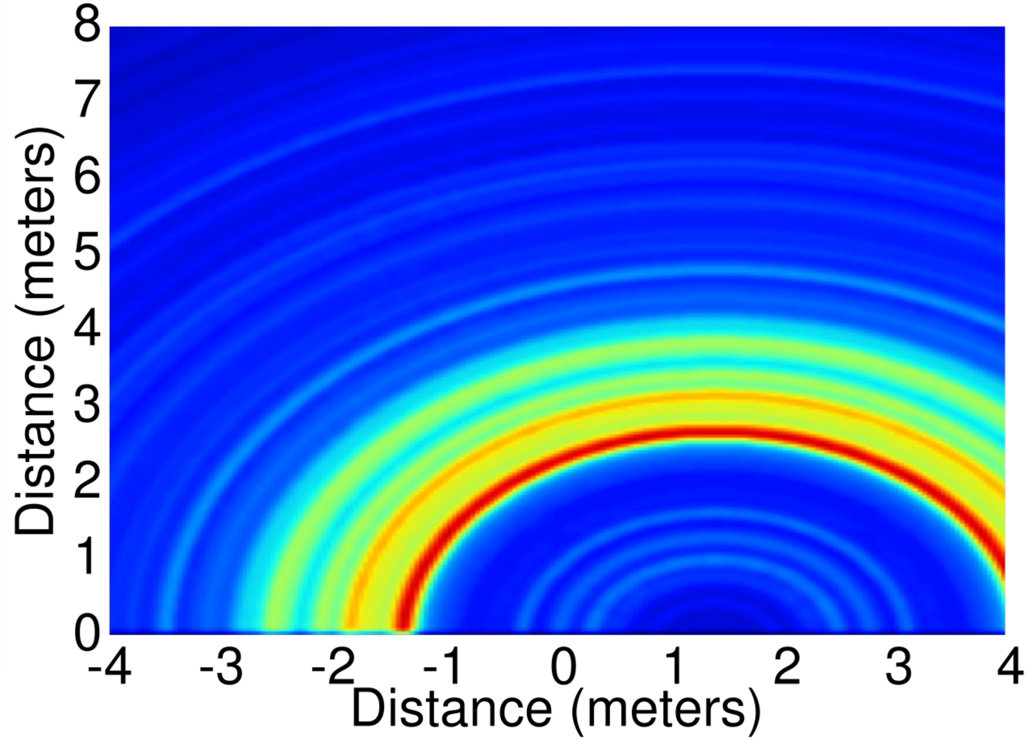
Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



Single Vantage Point

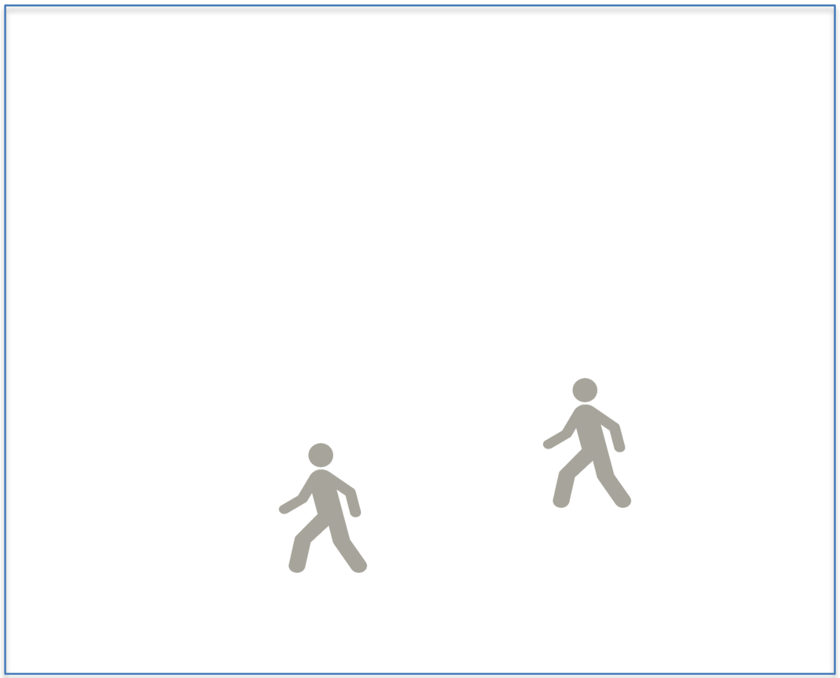


Mathematically: each round-trip distance can be mapped to an ellipse whose foci are the transmitter and the receiver

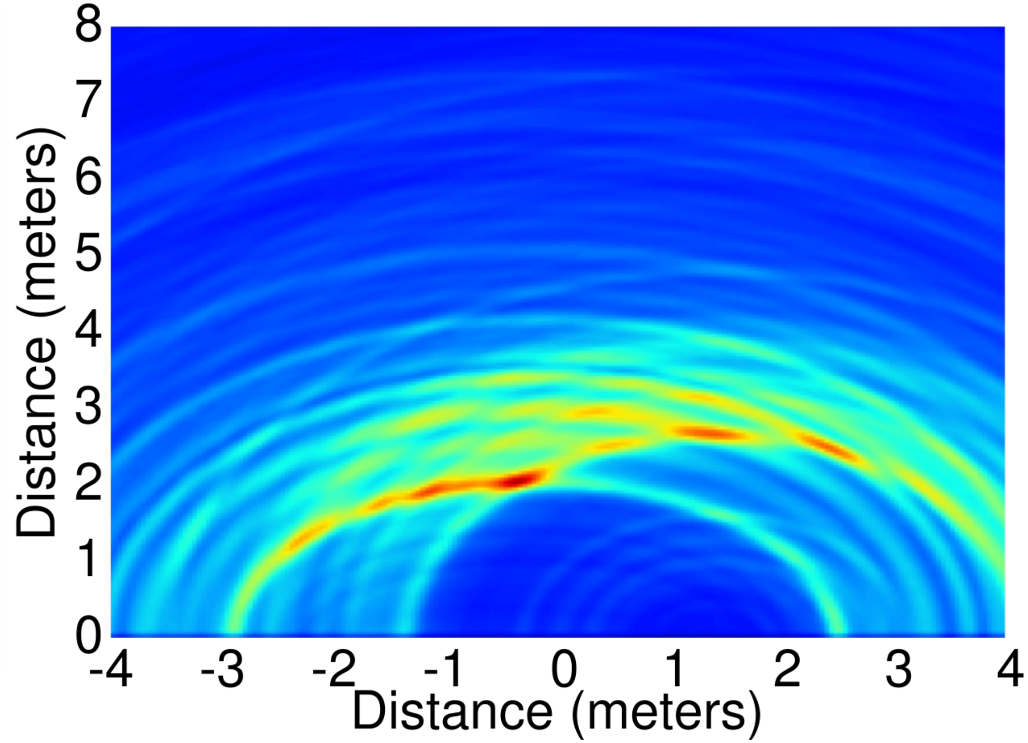
Combining across Multiple Vantage Points

<u>Experiment:</u> Two users walking

Setup



Two Vantage Points



Combining across Multiple Vantage Points

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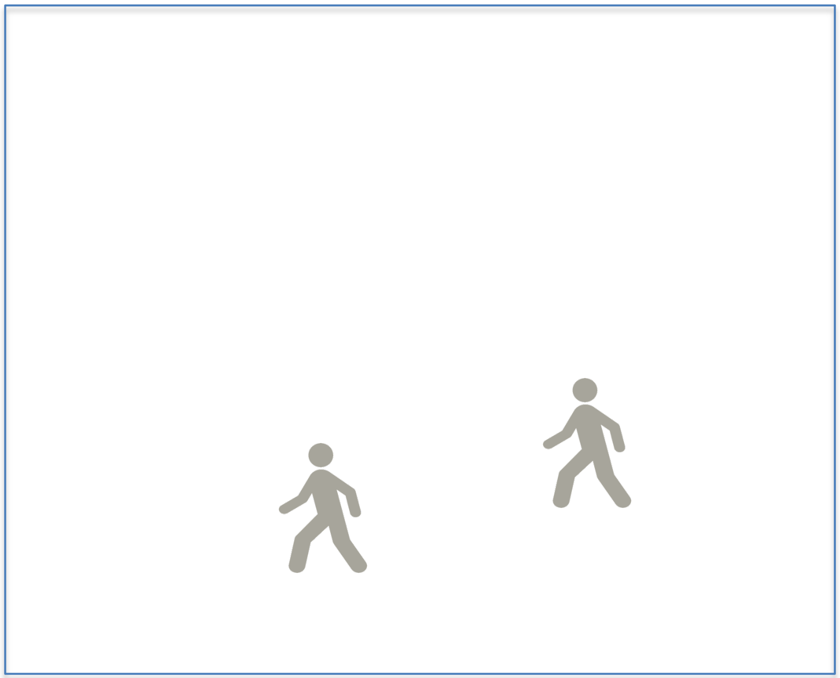
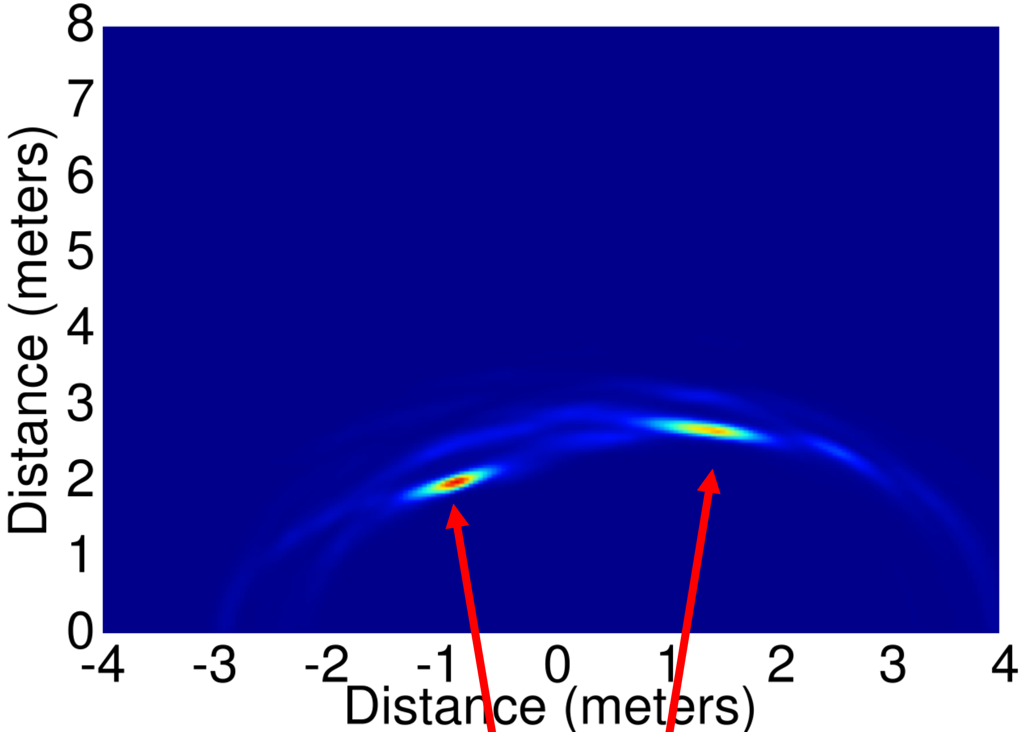


16 Vantage Points

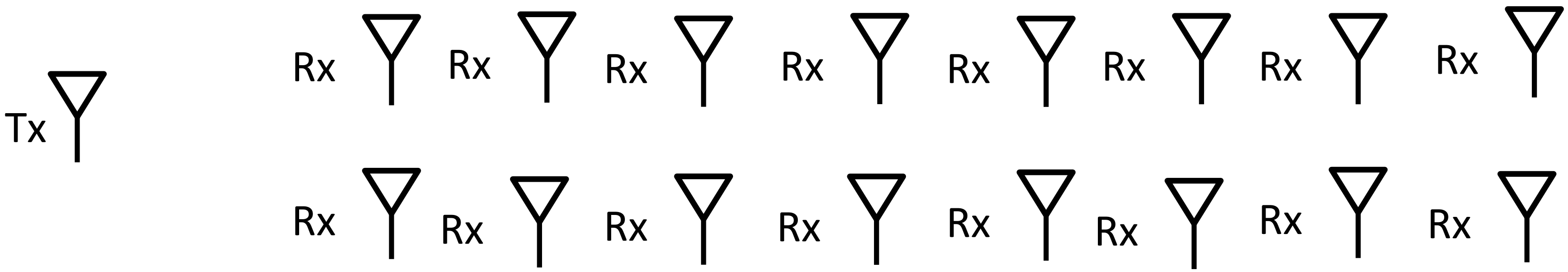


Localize the two users

How can we obtain 16 vantage points?

Achieving 16 vantage points

- Naïve solution: 1 Transmitter and 16 Receivers

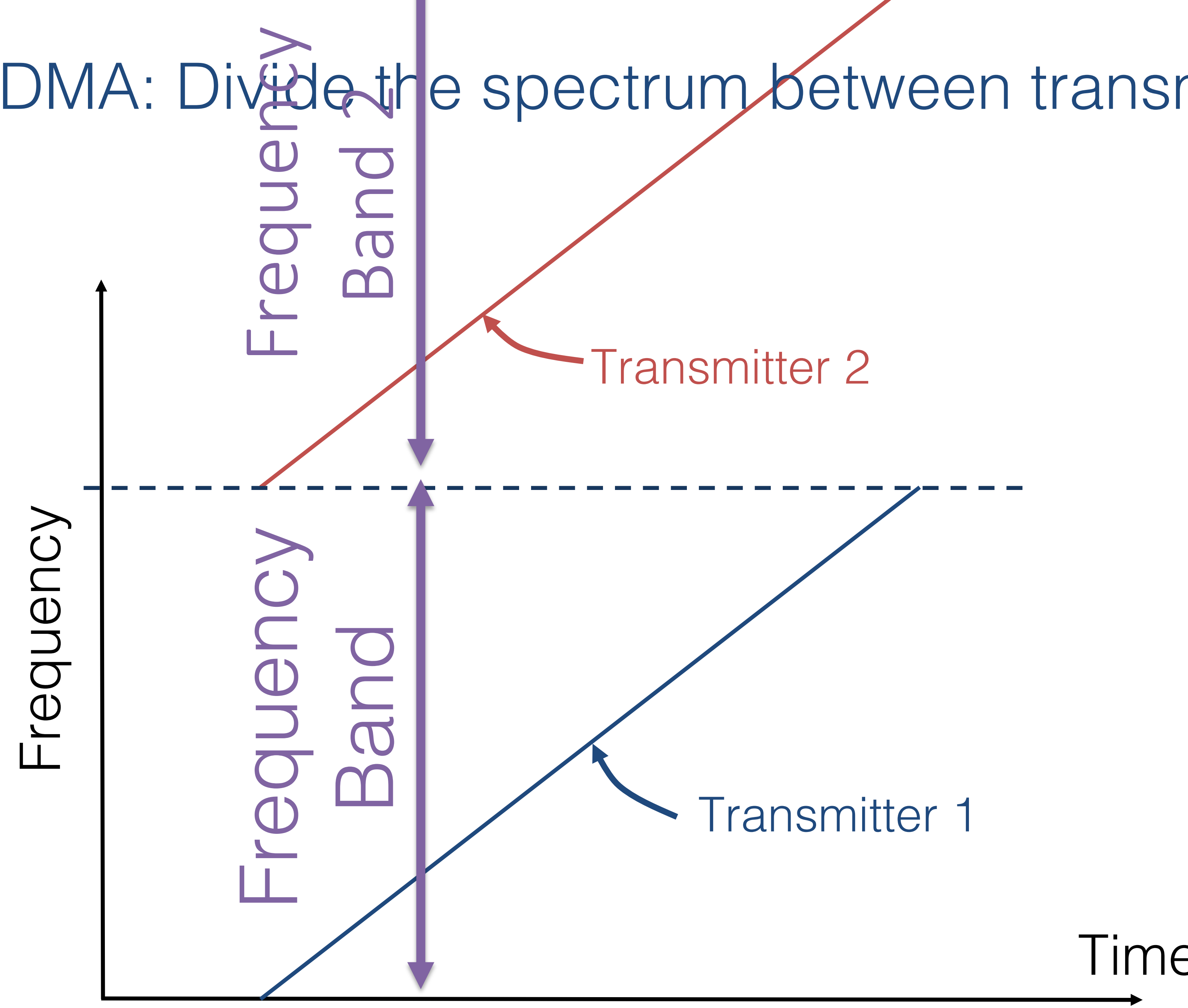


- Ideally: 4 Transmitters and 4 Receivers

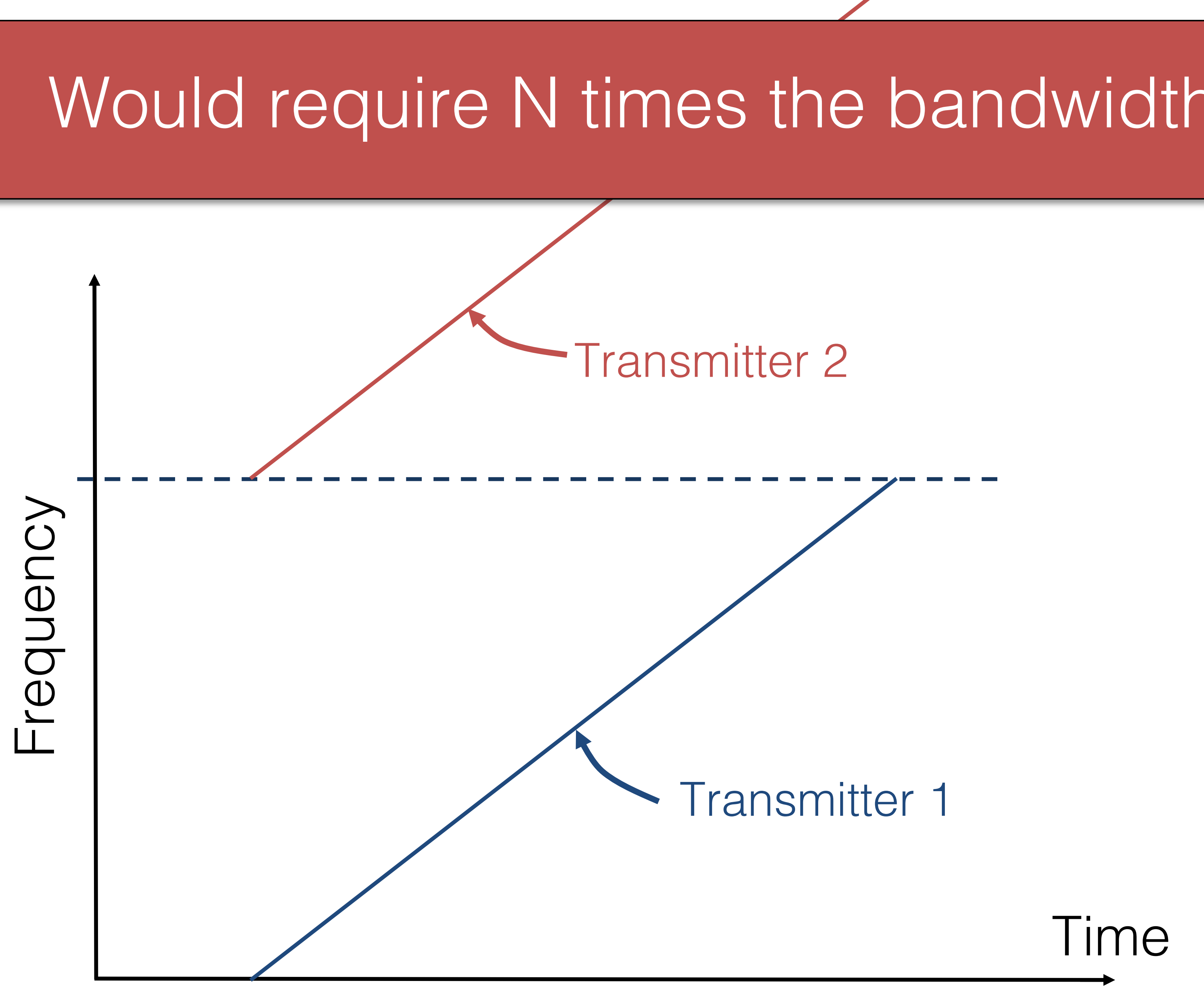
<u>Problem:</u> Different transmitters interfere with each other!

Let us look at standard mechanisms that are used to deal with interference

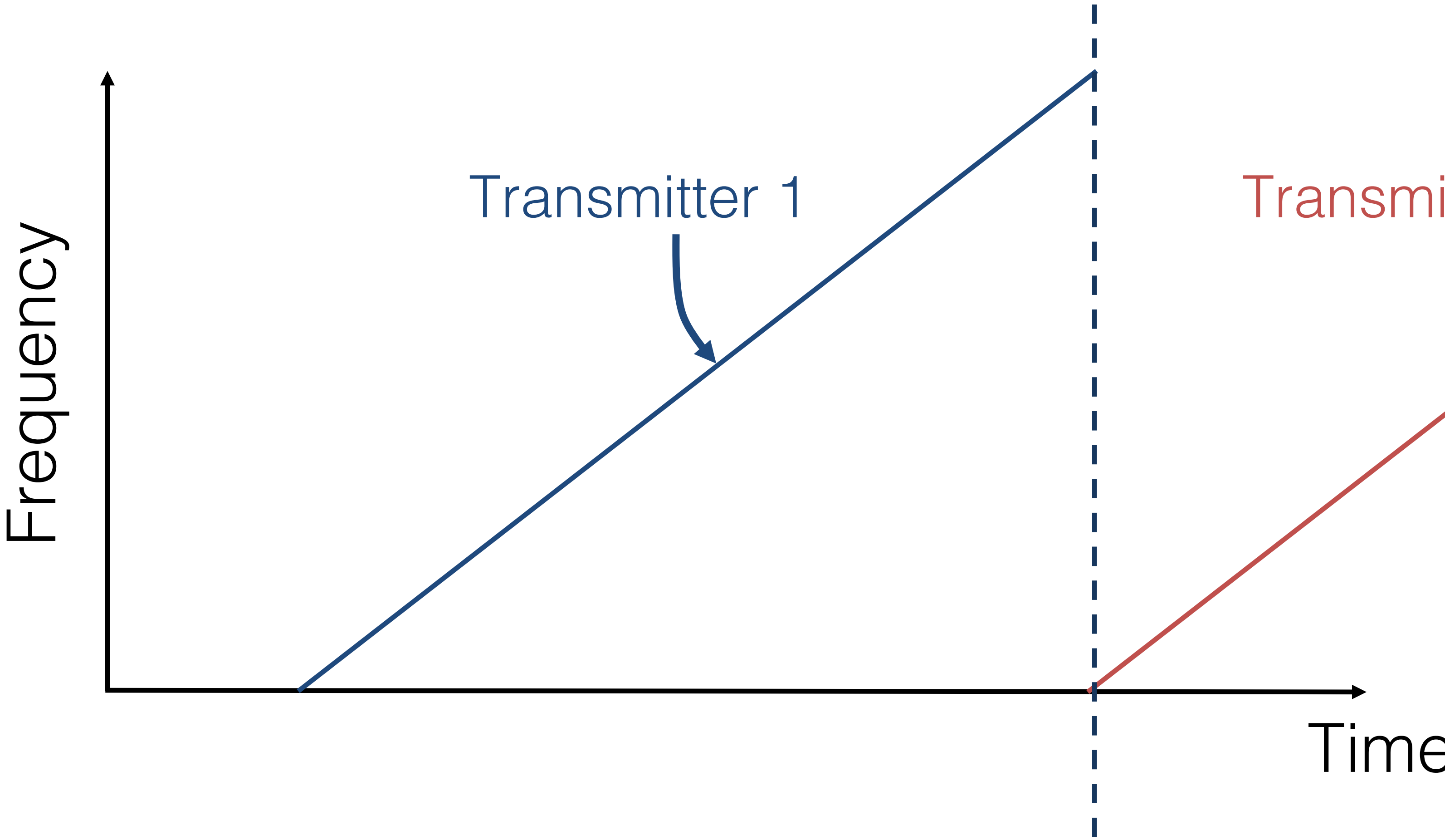
FDMA: Divide the spectrum between transmitters



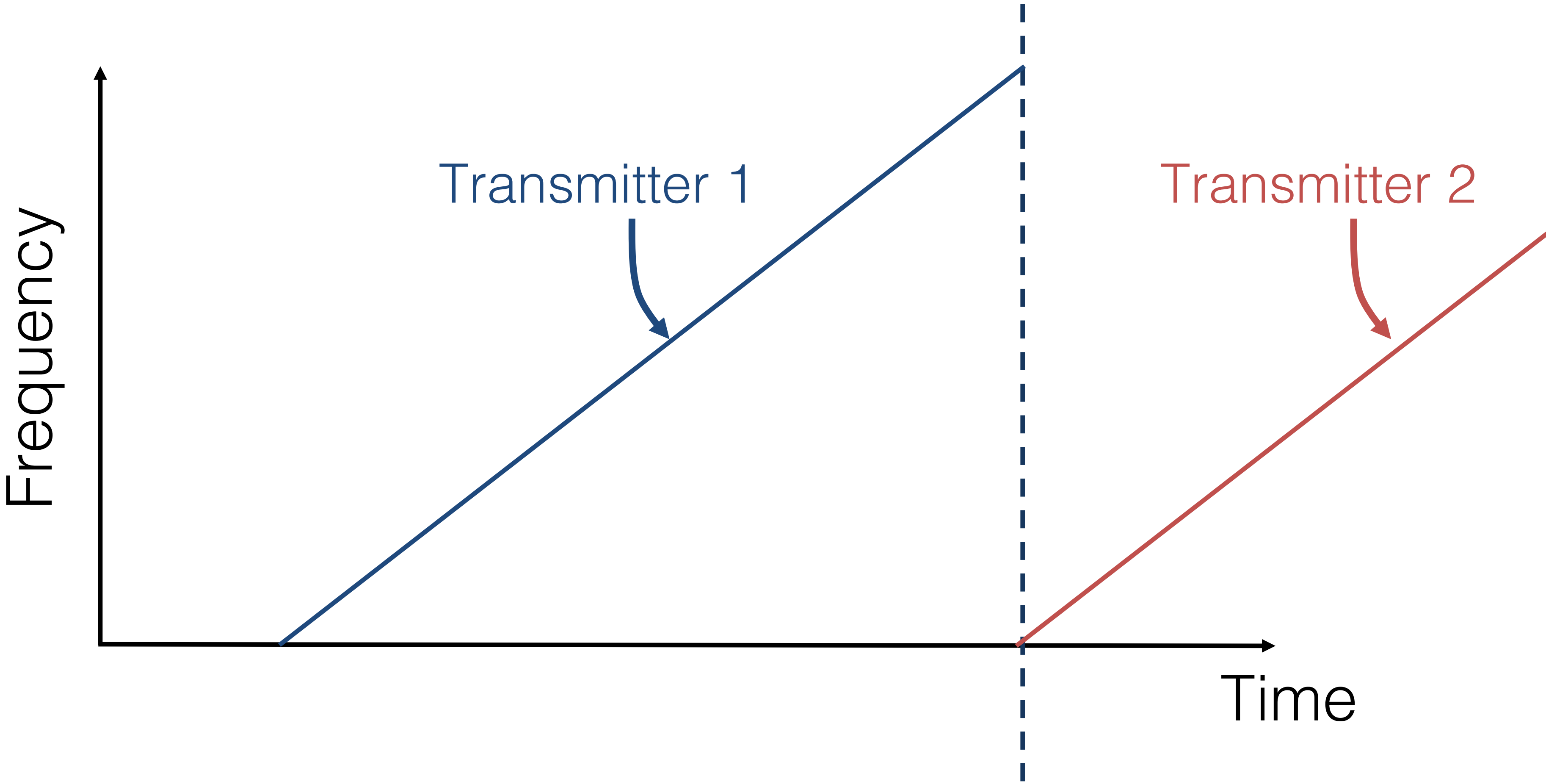
Would require N times the bandwidth!



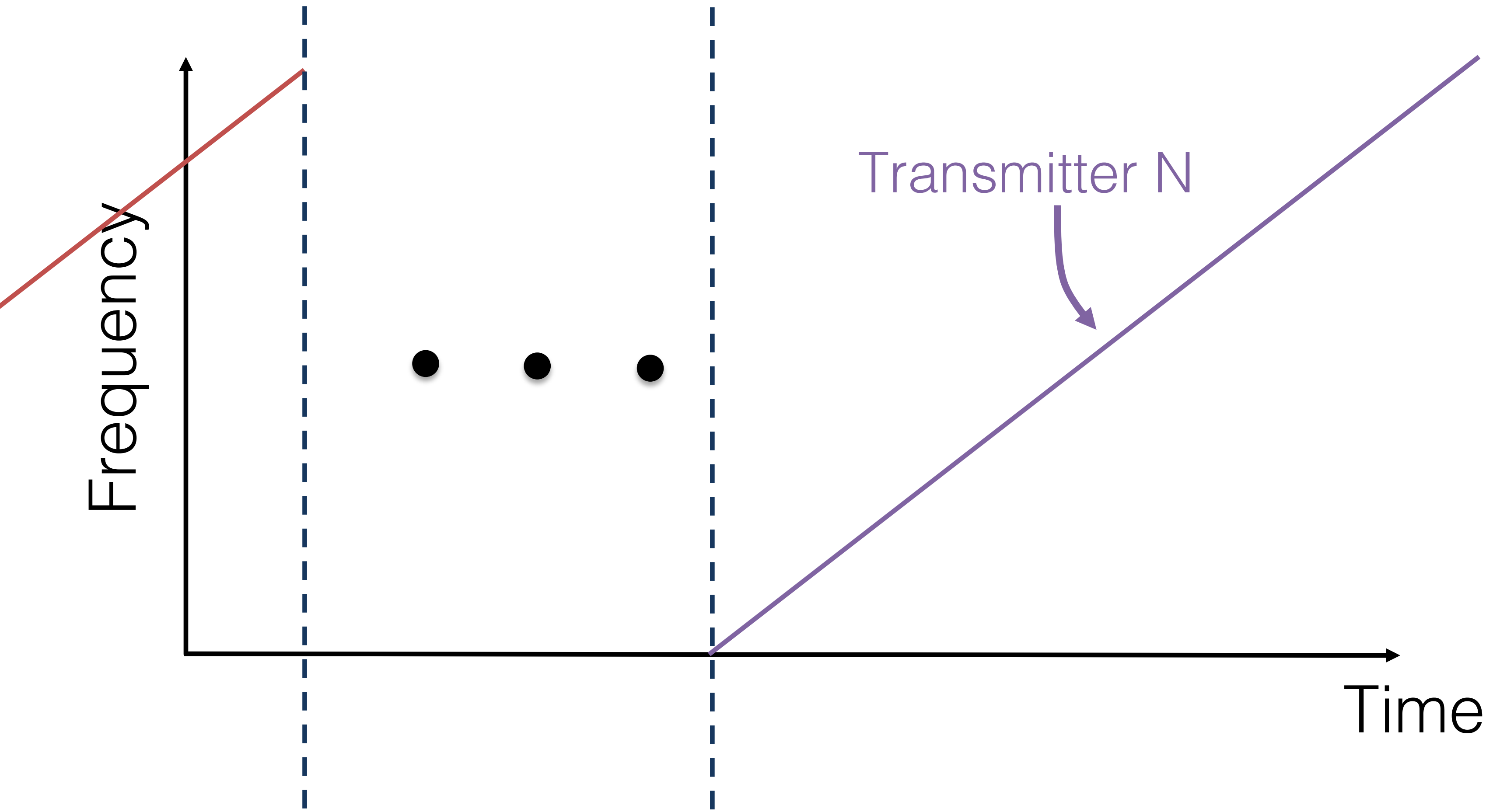
TDMA: Transmitters take turns transmitting



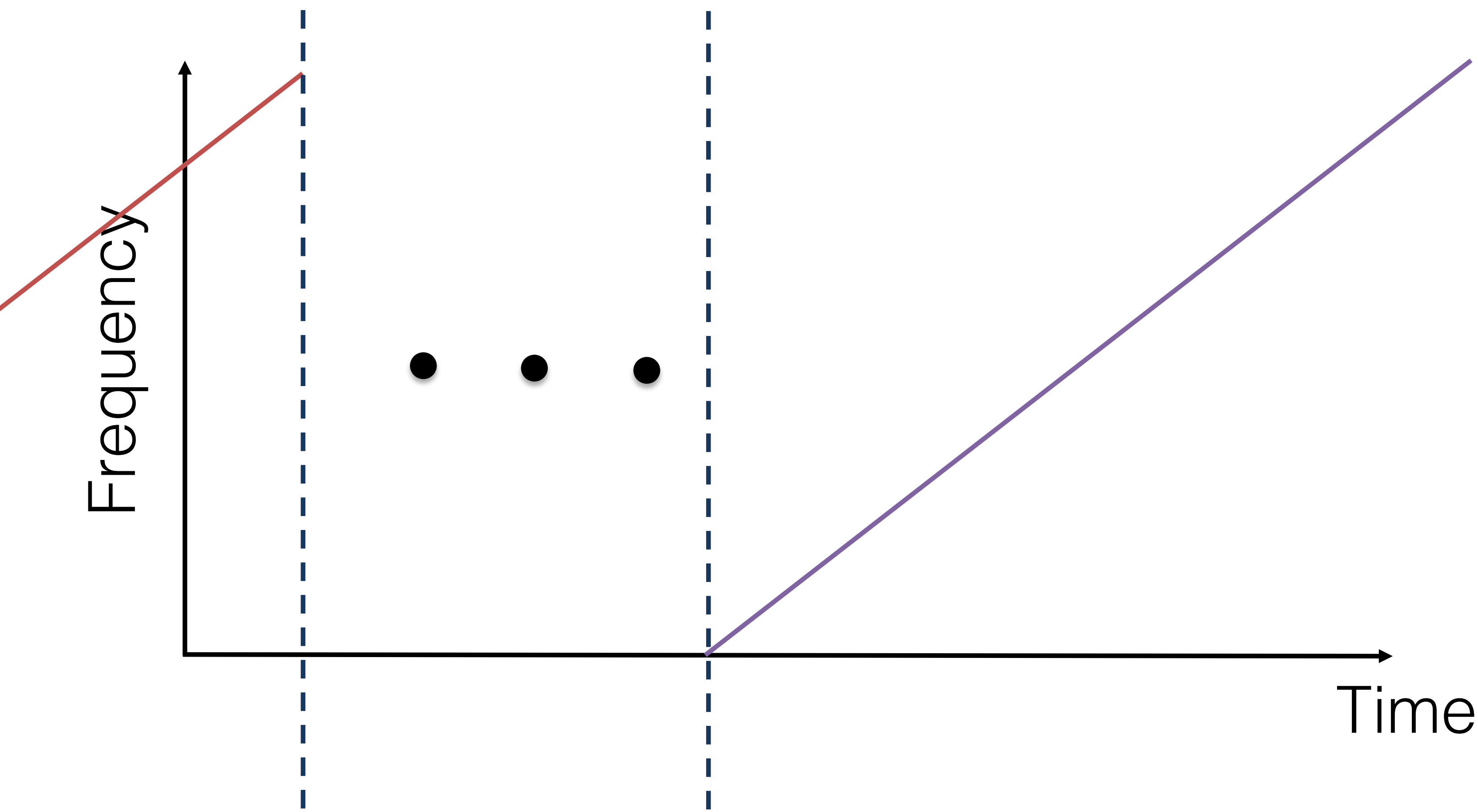
Would require N more time to localize



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

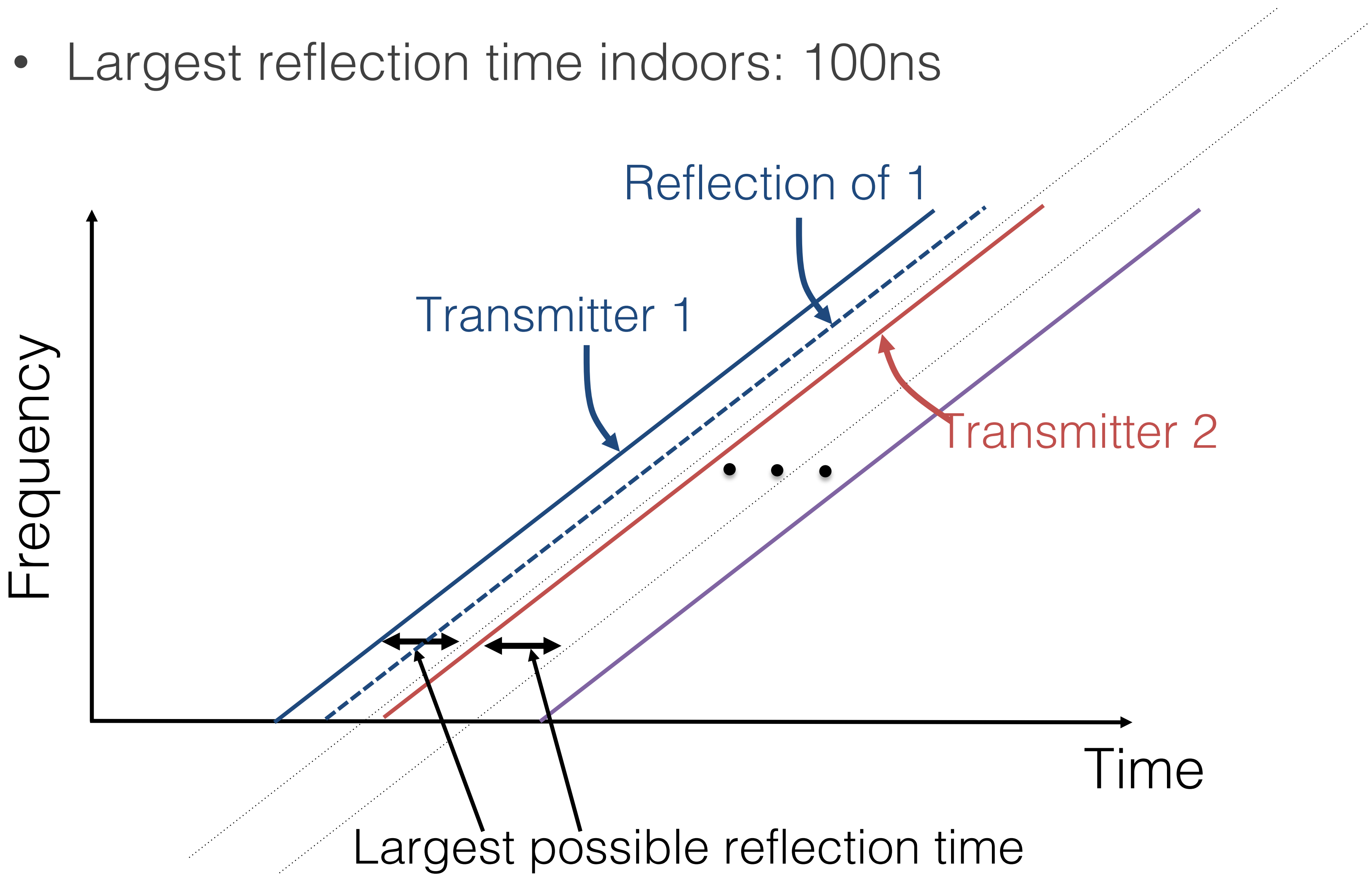


Ideally: Transmit in the same time and in the same frequency band without interfering

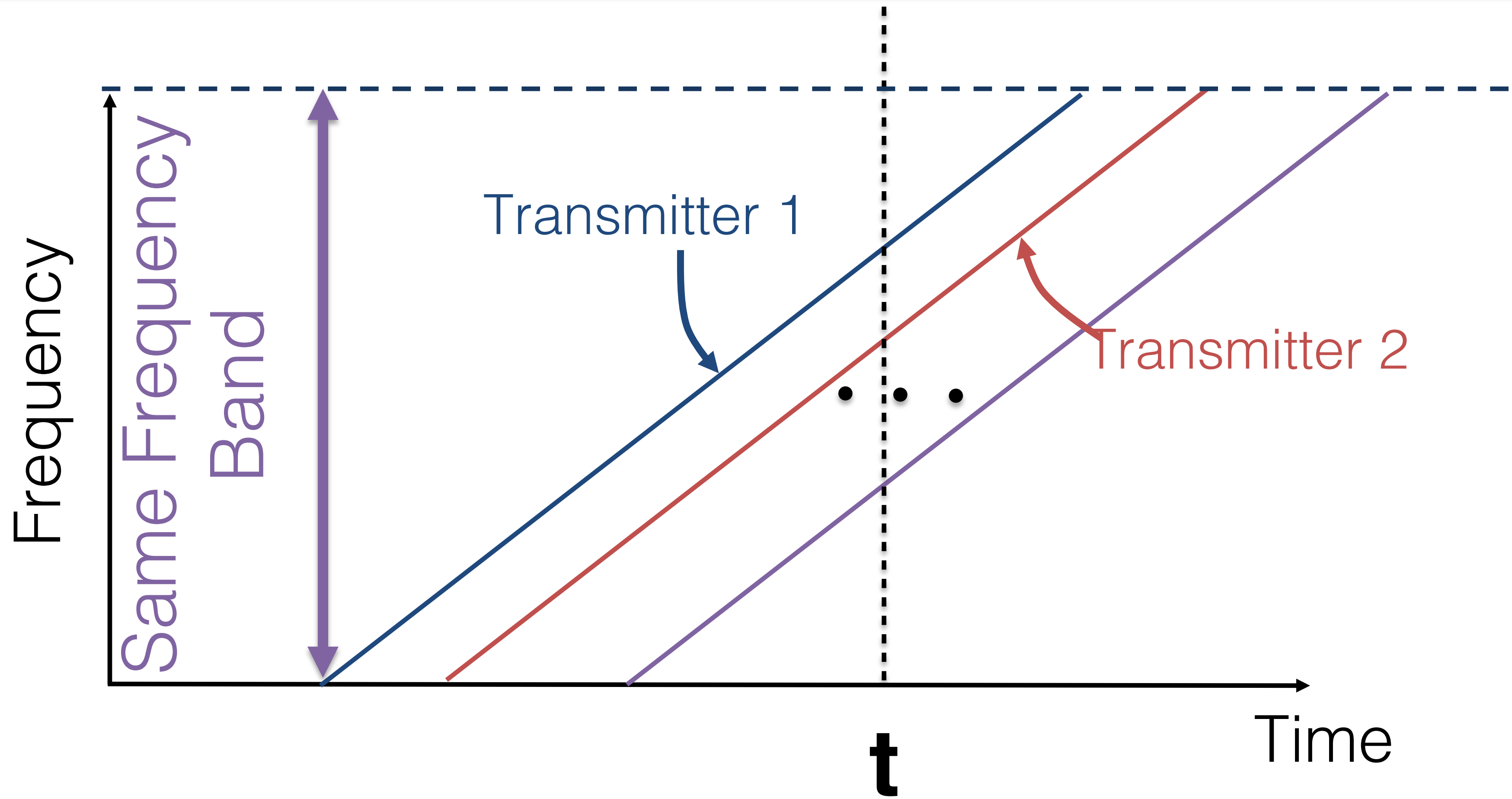


Objective: Transmit and Get Reflection

- Largest reflection time indoors: 100ns

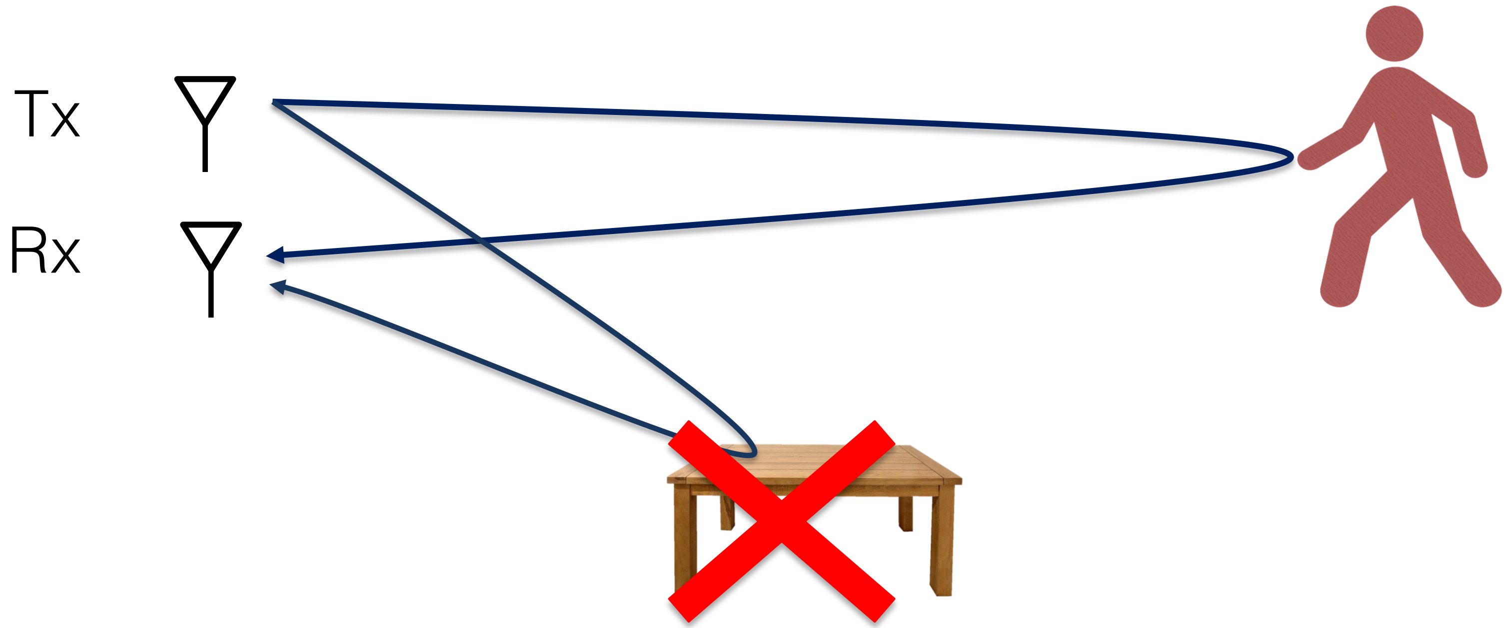


Multi-shift FMCW enables multiple transmissions at the **same time** and in the **same frequency band** without interference



How can we localize static users?

Dealing with multi-path when there is one moving user

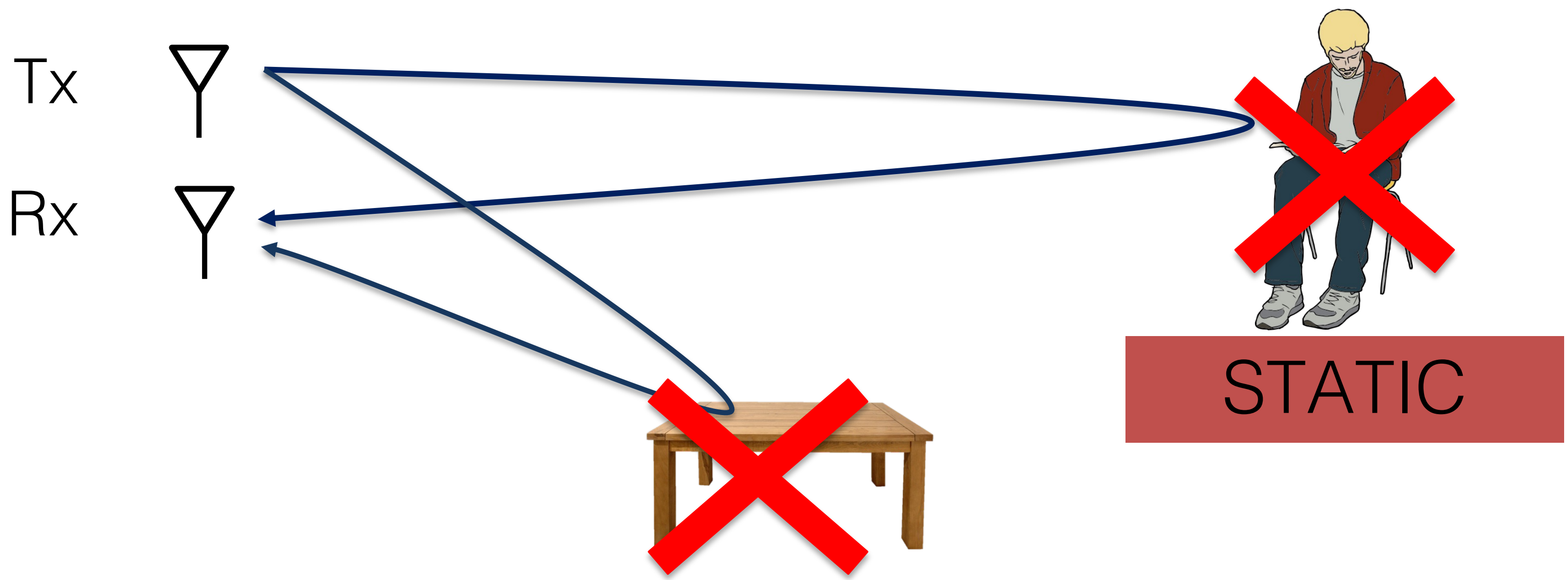


1. Direct furniture reflection:

eliminated by subtracting consecutive measurements

Needs User to Move

Dealing with multi-path when there is one moving user



1. Direct furniture reflection:

eliminated by subtracting consecutive measurements

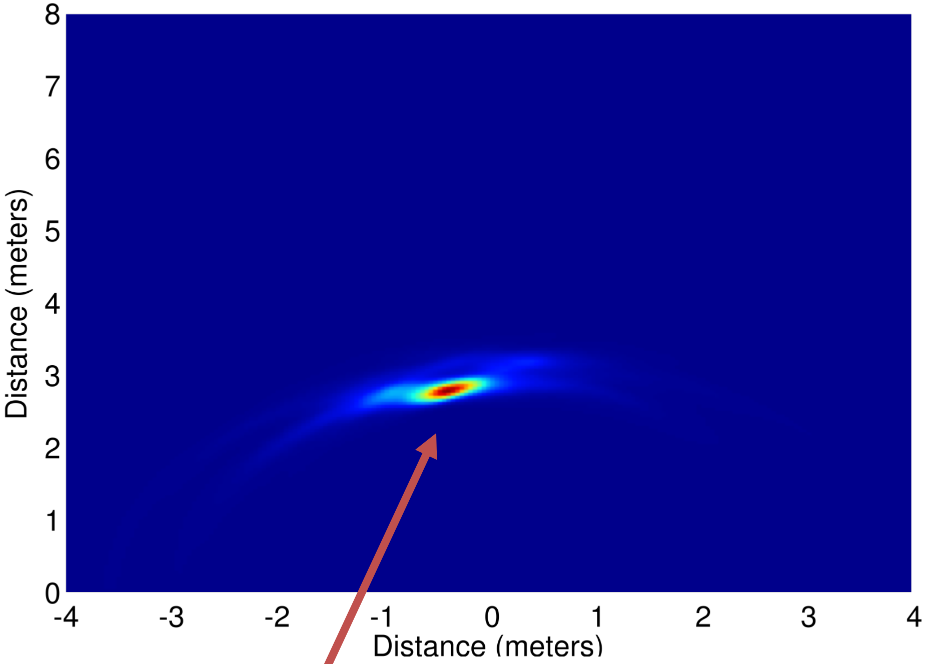
Needs User to Move

Exploit breathing motion for localize static users

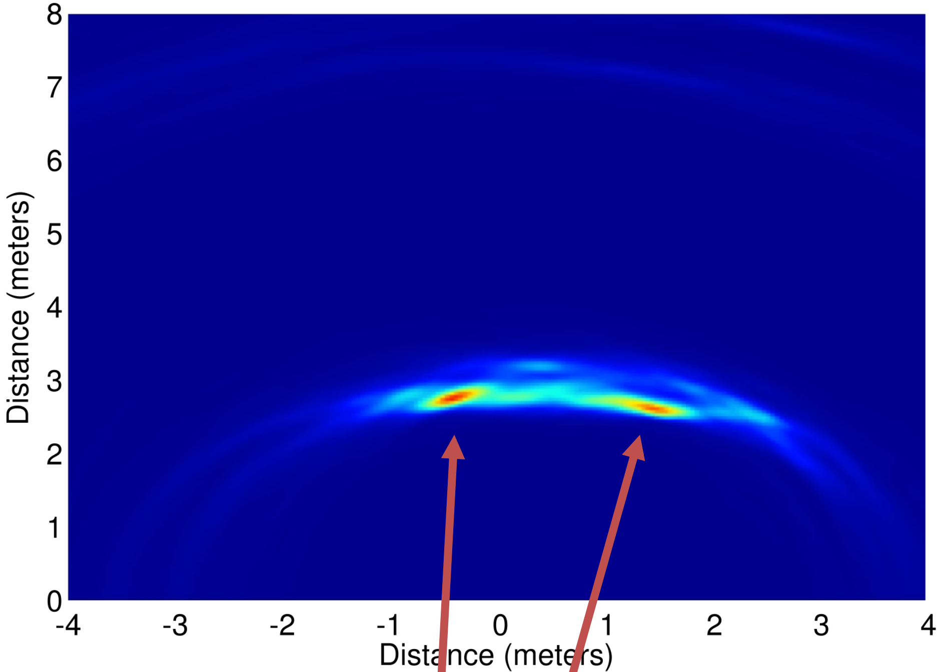
- Breathing and walking happen at different time scales
  - A user that is pacing moves at 1m/s
  - When you breathe, chest moves by few mm/s
- Cannot use the same subtraction window to eliminate multi-path

User Walking at 1m/s

30ms subtraction window



3s subtraction window

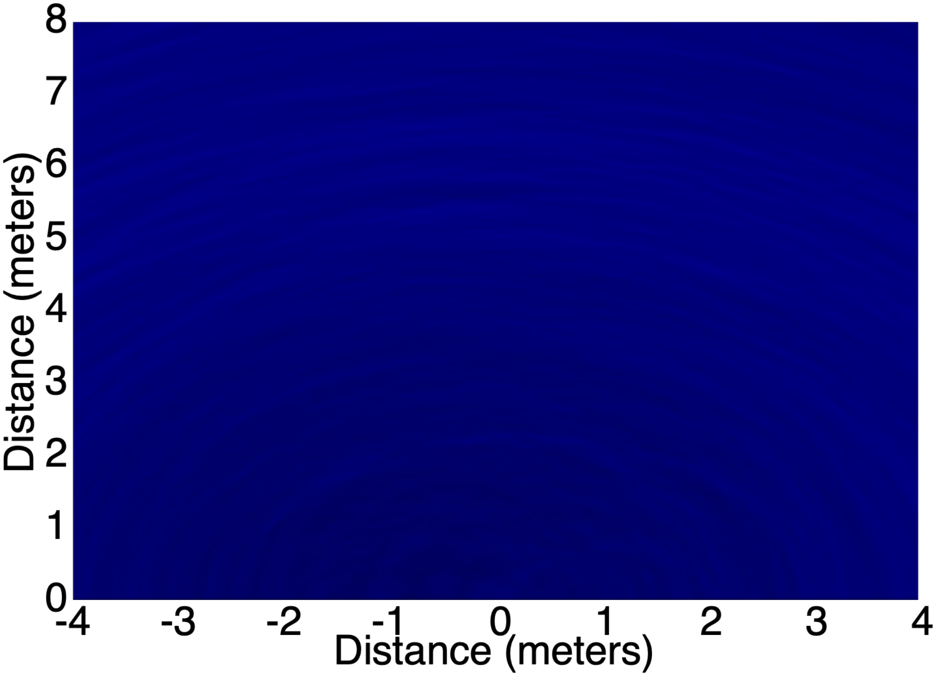


Localize the person

Person appears in two locations

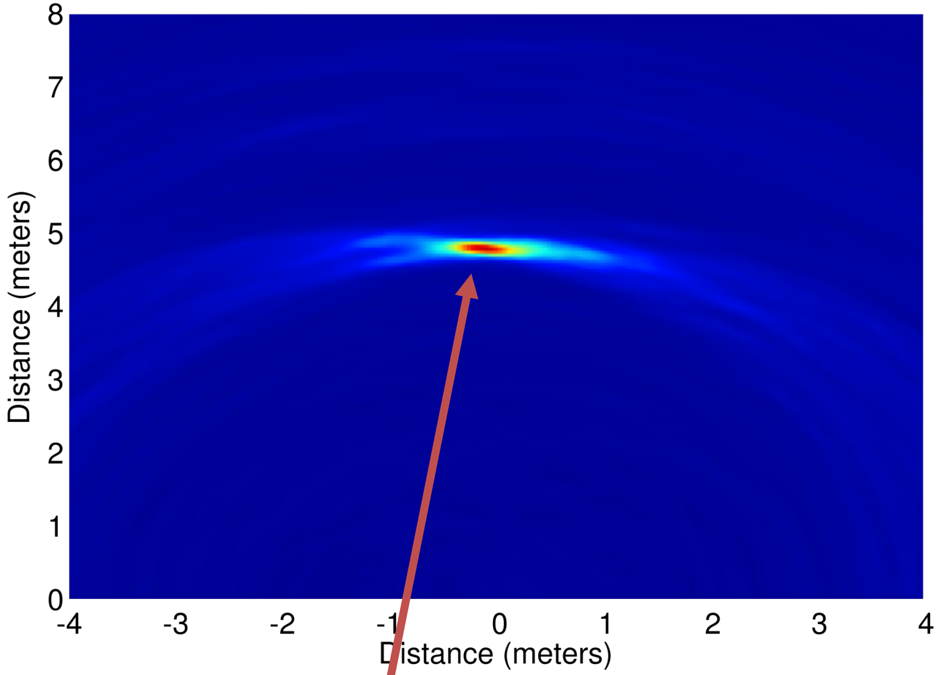
User Sitting Still (Breathing)

30ms subtraction window



Cannot localize

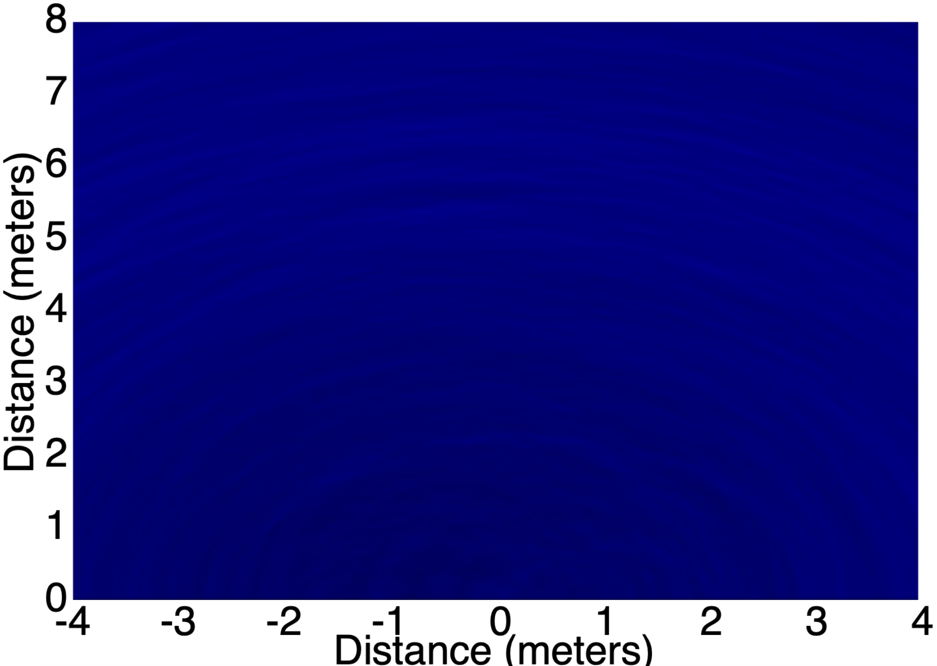
3s subtraction window



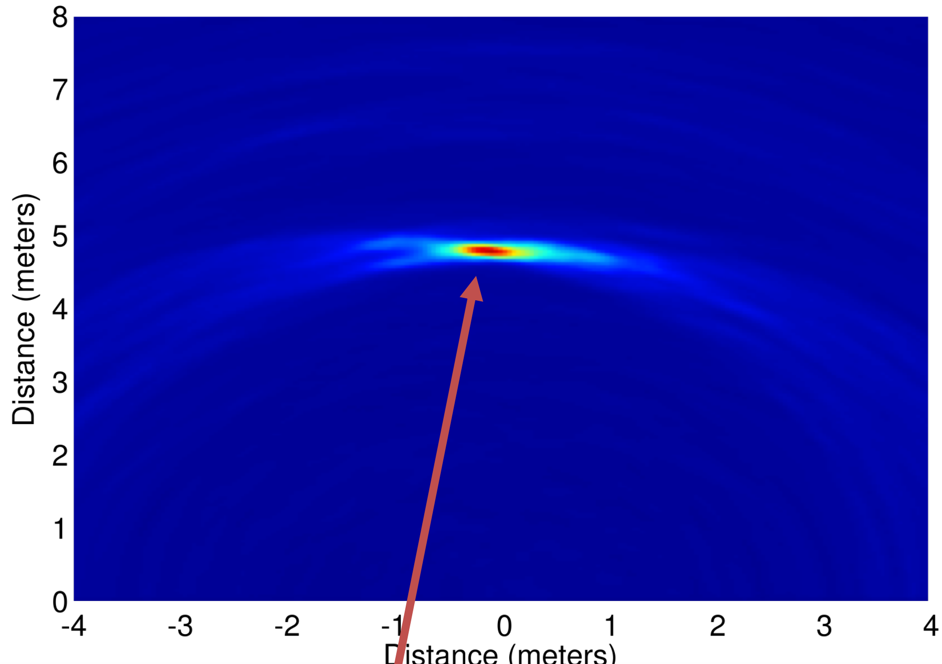
Localize the person

User Sitting Still (Breathing)

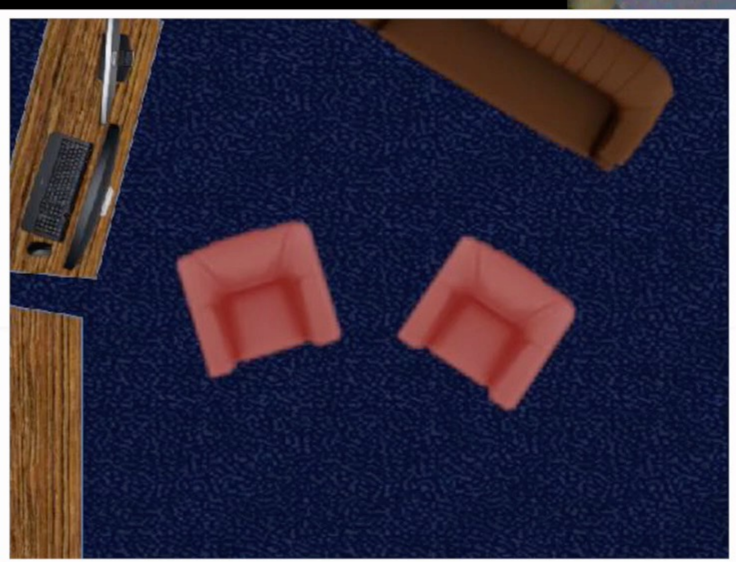
30ms subtraction window



3s subtraction window



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

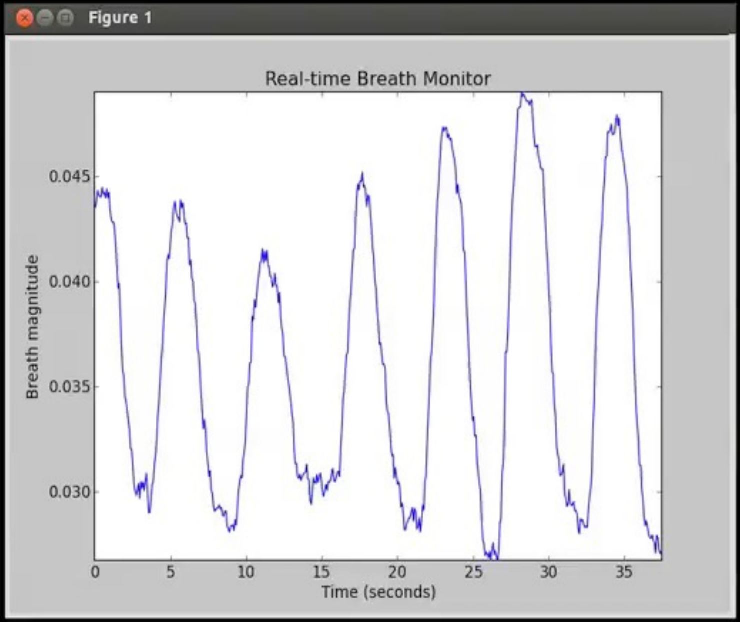
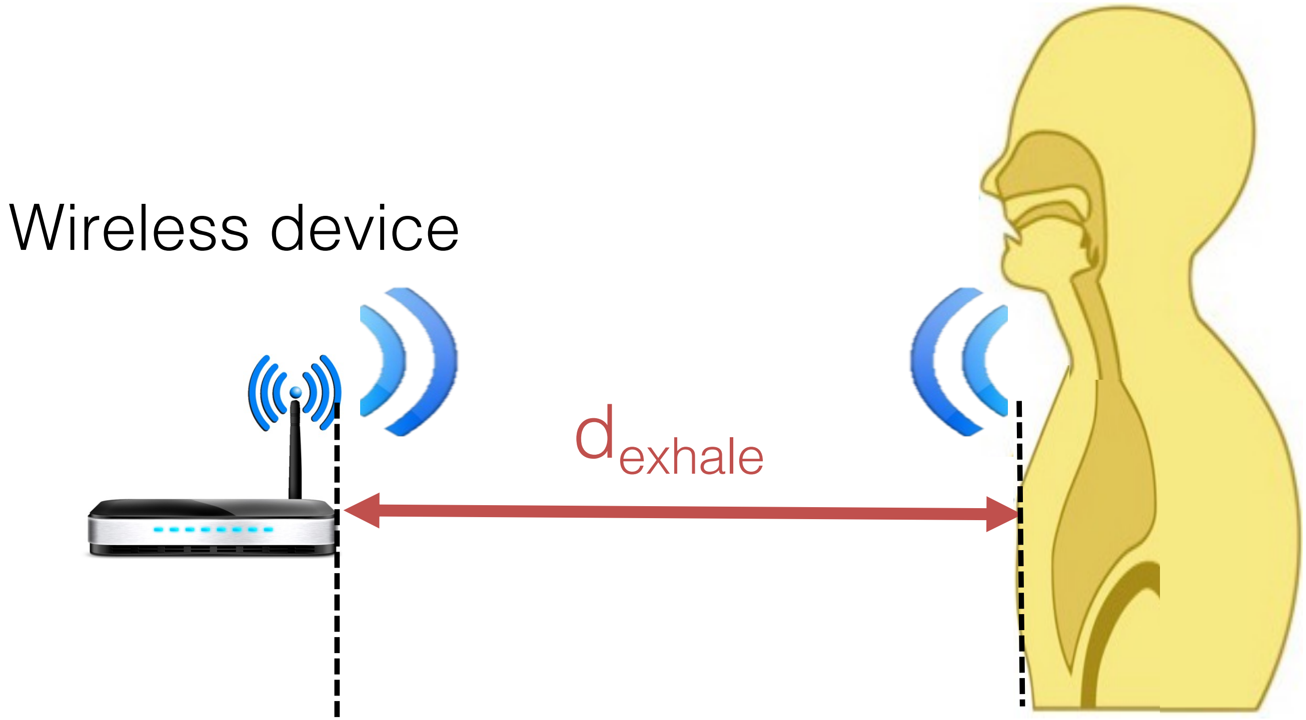
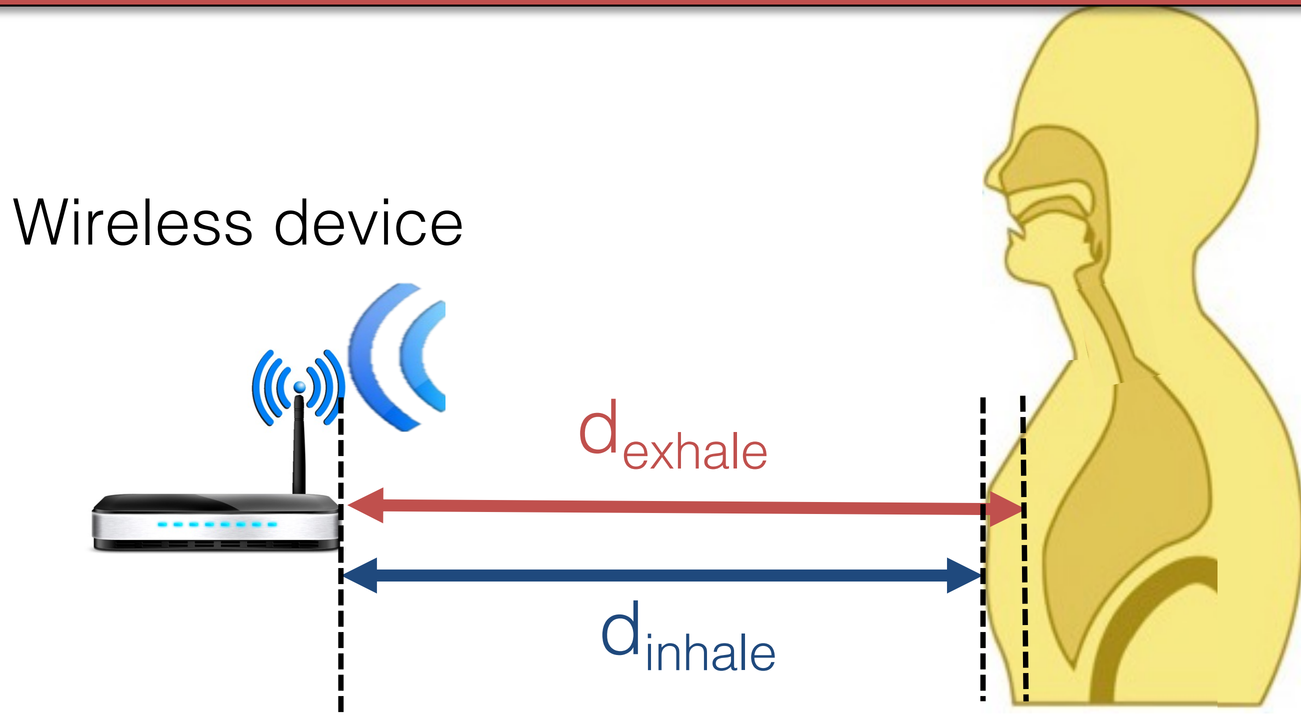


Figure 1
Real-time Breath Monitor
Breath magnitude
0.045
0.040
0.035
0.030
0
5
10
15
20
25
30
35
Time (seconds)



Wireless device
d_{exhale}

<u>Problem:</u> Localization accuracy is only 12cm and cannot capture vital signs



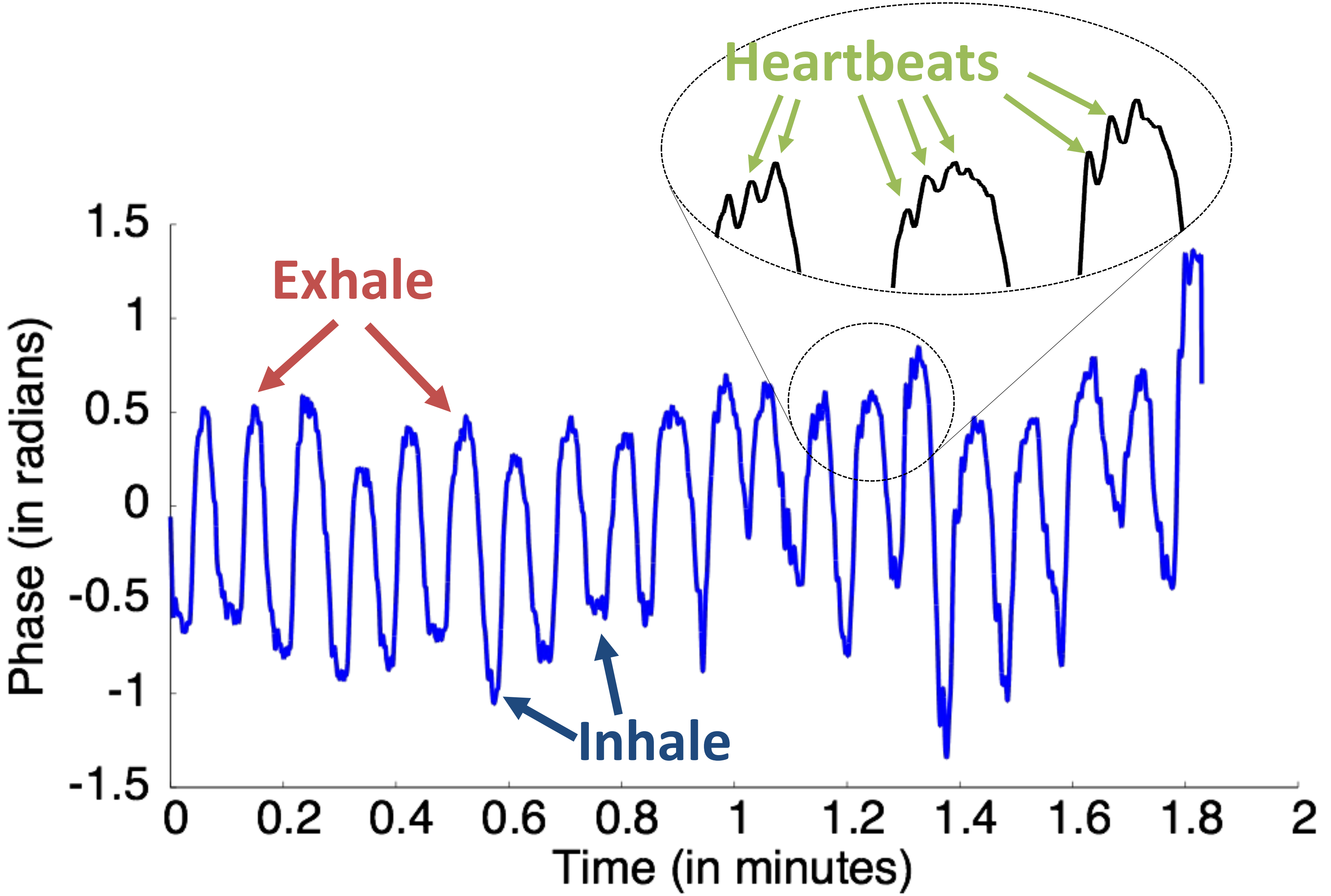
FMCW: Frequency Modulated Carrier Wave

- Mix TX and RX Signal: $y_b(t) = y(t) \times x^*(t) = \sum_i A_i e^{-j2\pi(\alpha\tau_i t + f_0\tau_i)}$

Phase

Frequencies at $f = \alpha\tau_i$

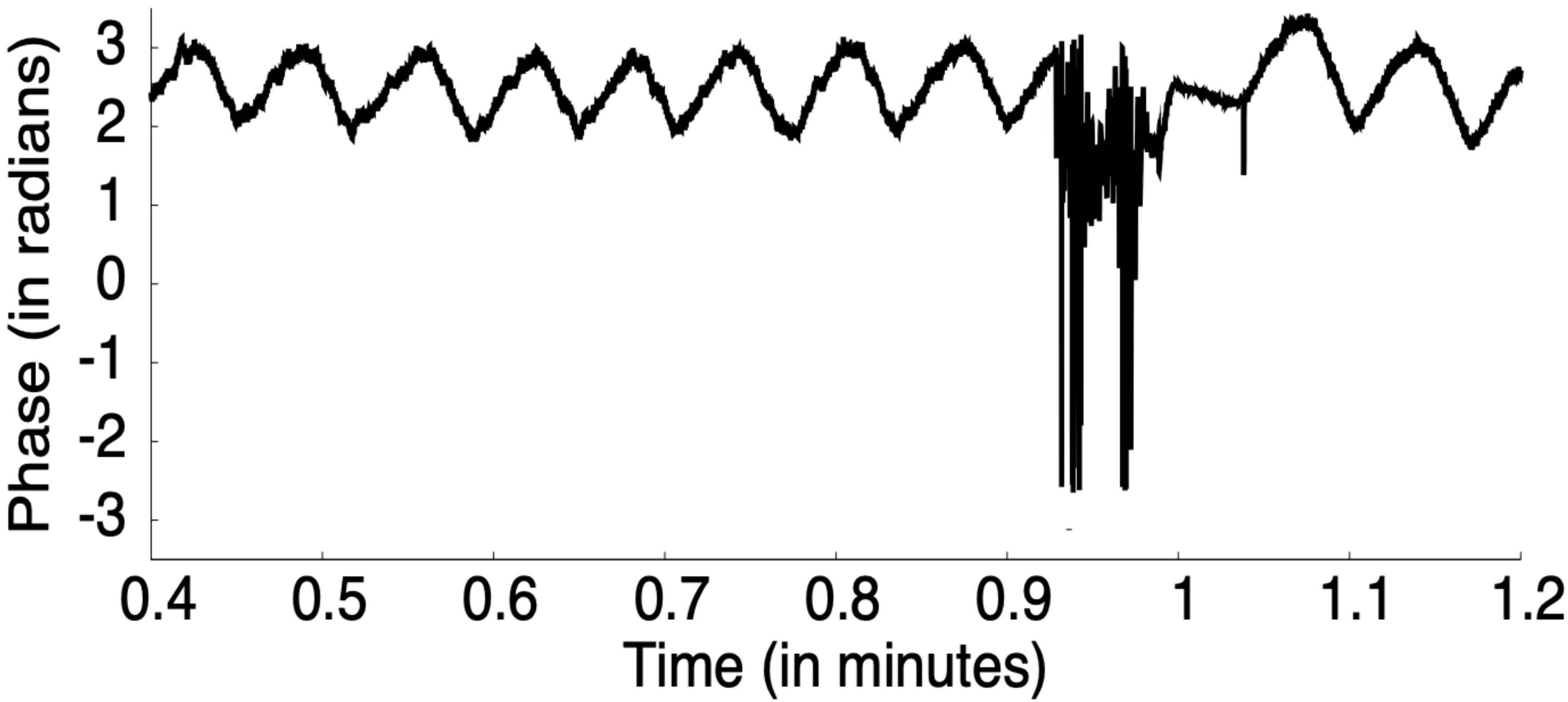
- Phase of peak = $f_0\tau_i$
  - Phase wraps around 2pi
  - Use peak position ΔF= alpha x τ_i for course estimate of τ_i
  - Use peak phase $f_0\tau_i$ for fine estimate of τ_i



Heartbeats
Exhale
Inhale
Phase (in radians)
Time (in minutes)
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

What happens when a person moves his limb?

What happens when a person moves his limb?



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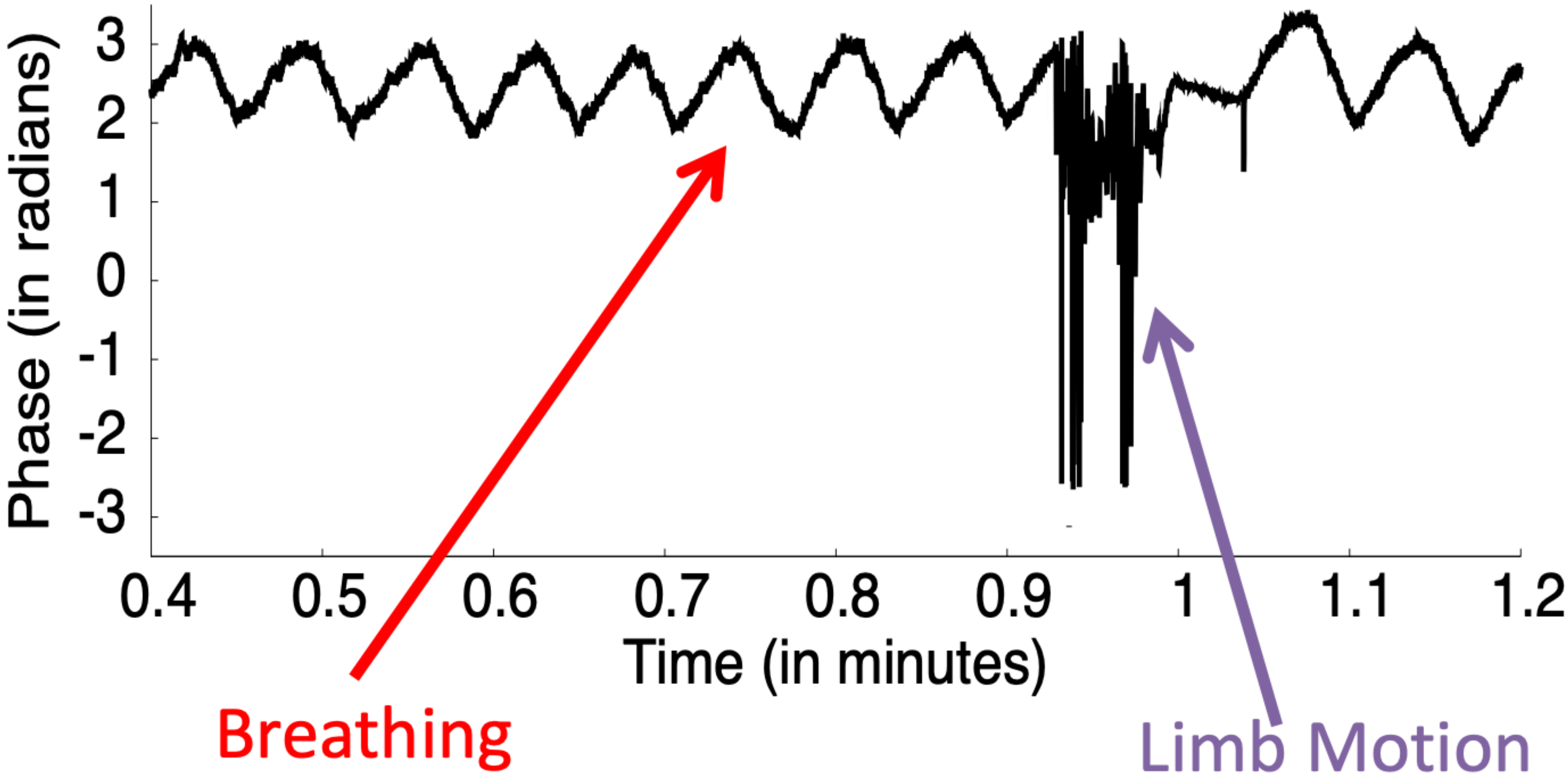
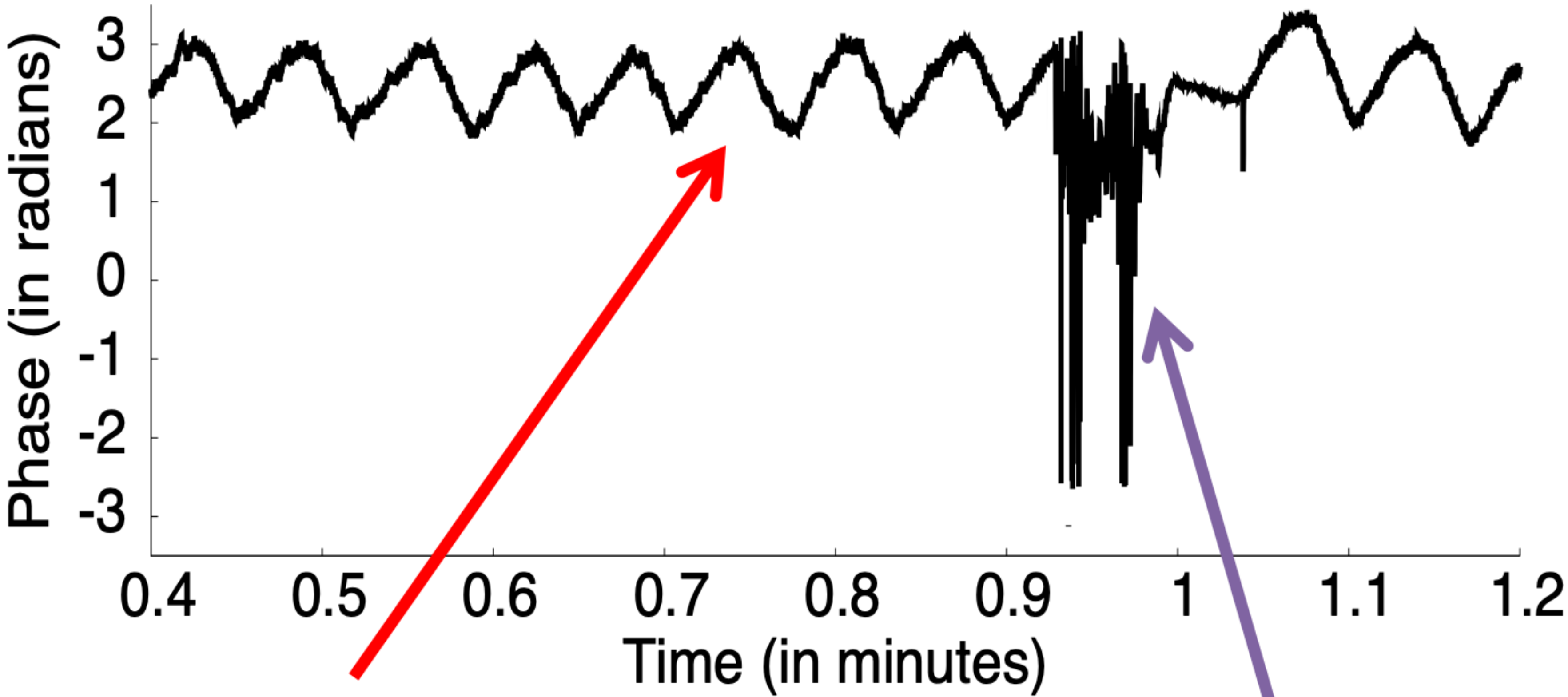


Periodic

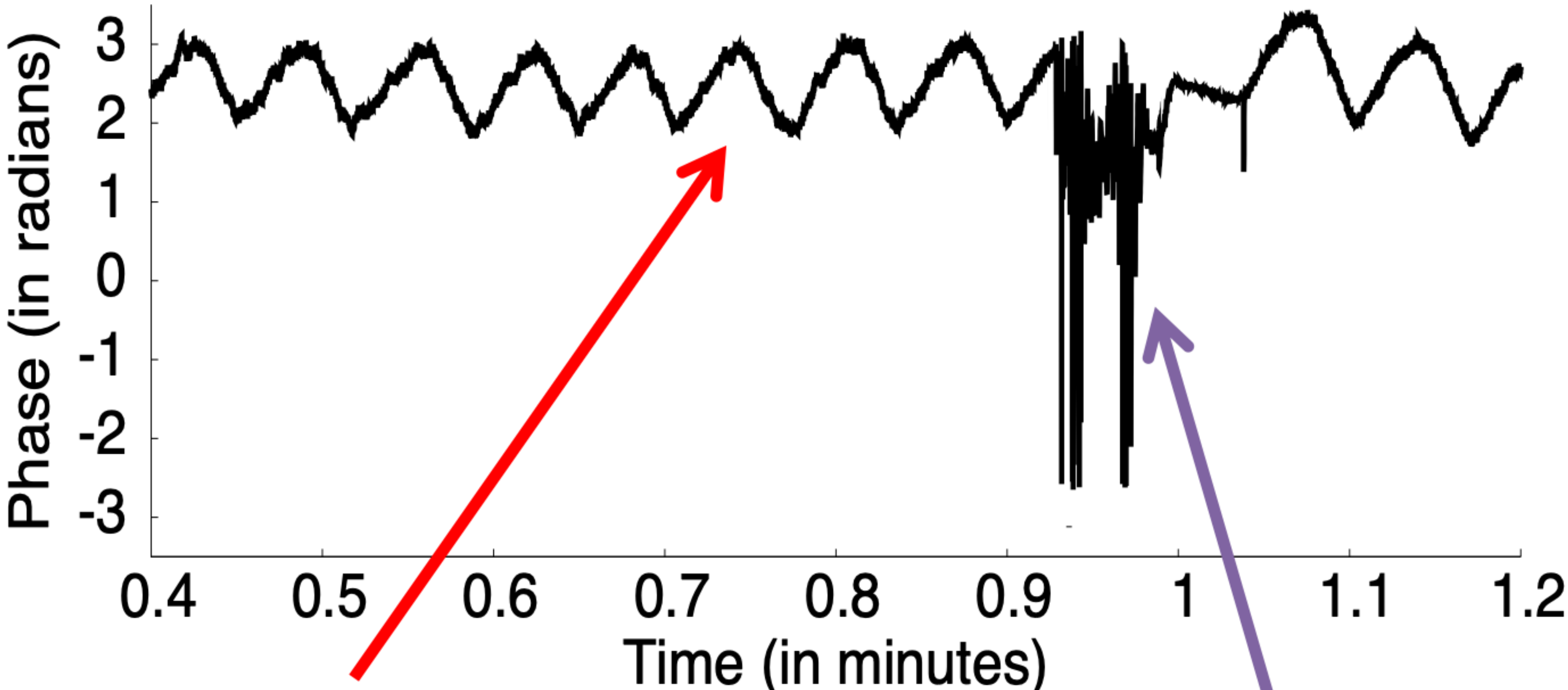
Not periodic

What happens when a person moves his limb?



Use periodicity test to eliminate variations that are not due to breathing/heartbeats

What happens when a person moves his limb?

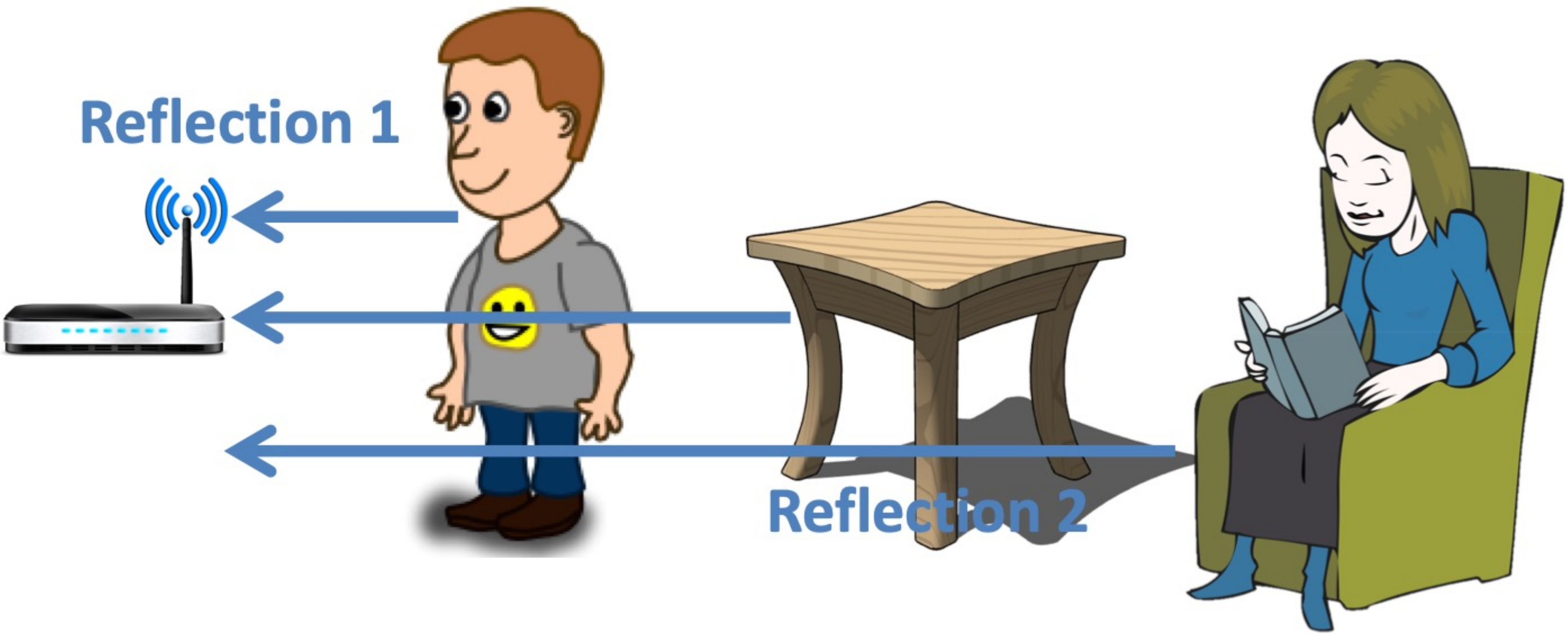


Band-pass filter the cleaned signals to extract breathing and heart rate

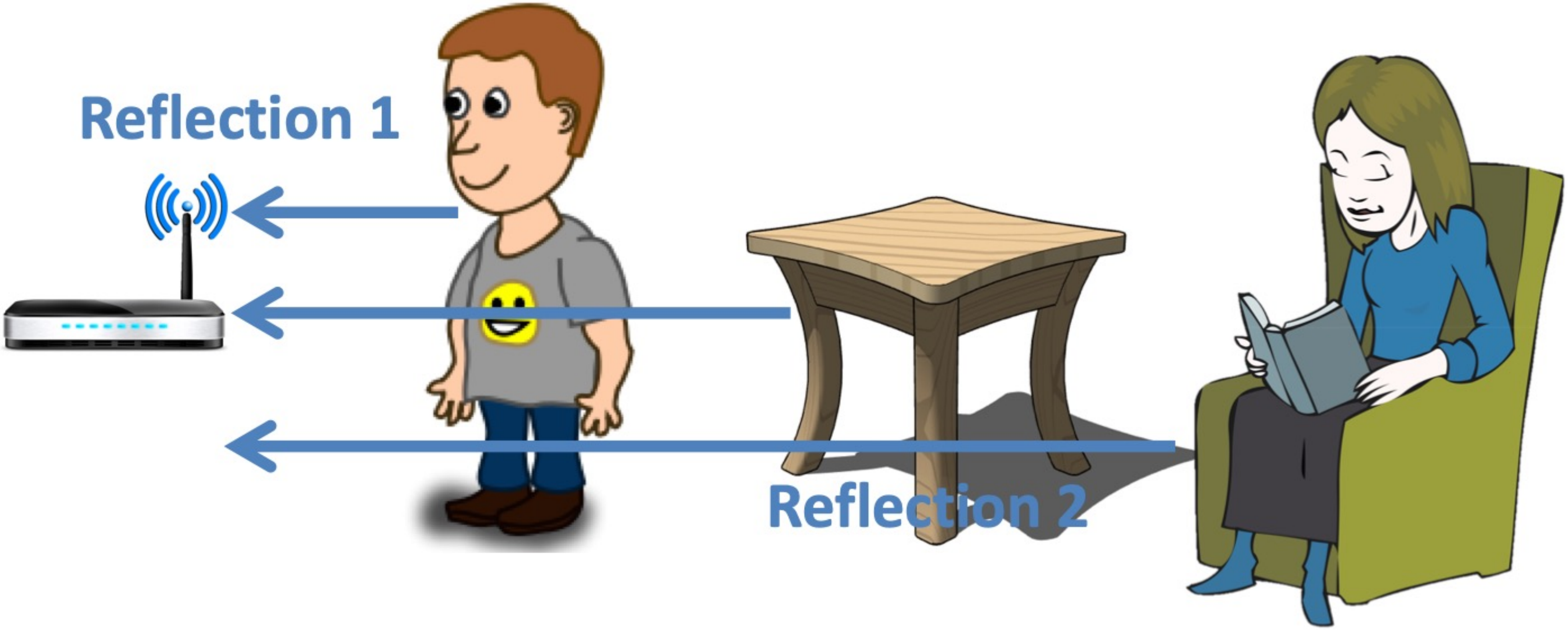
What happens with multiple users in the environment?

Reflections from different objects collide

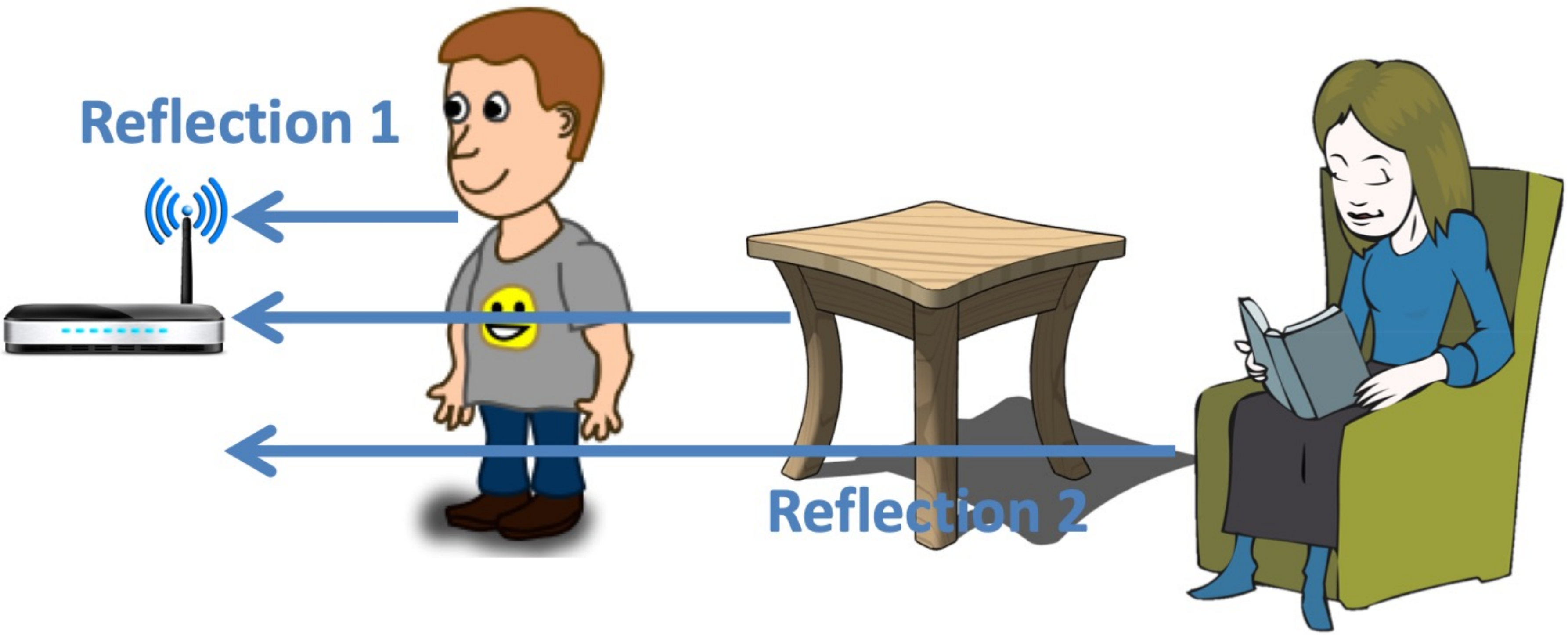
Problem: Phase becomes meaningless!



Idea: Wireless localization can be used to locate various devices



Solution: Use wireless localization as a filter to isolate reflections from different positions



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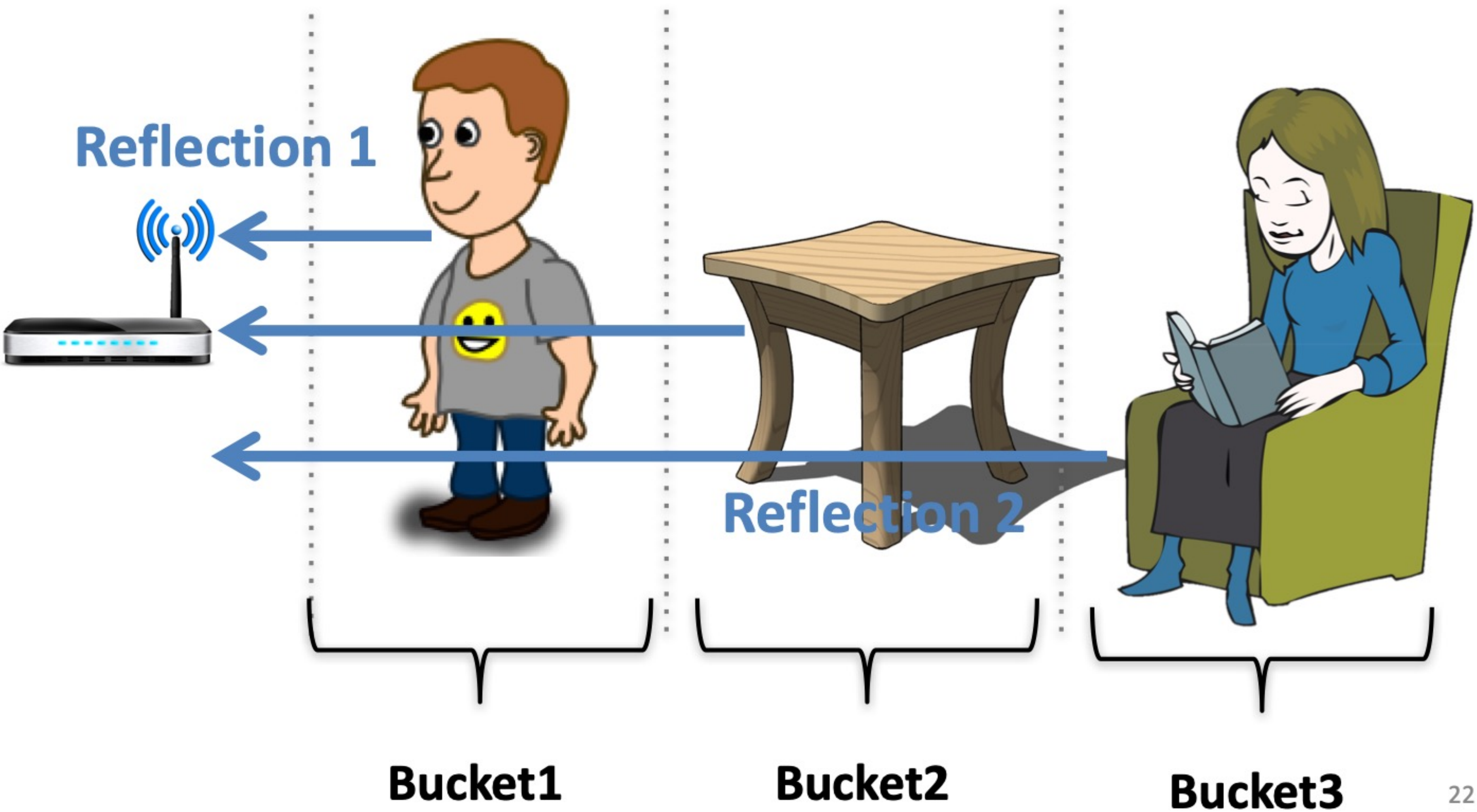


Putting It Together

Step 1: Transmit a wireless signal and capture its reflection

Step 2: Isolate reflections from different objects based on their positions

Step 3: Zoom in on each object’s reflection to obtain phase variations due to vital signs

Step 4: Use frequency analysis to separate breathing and heart rate signals

Through-wall breath monitoring of multiple users

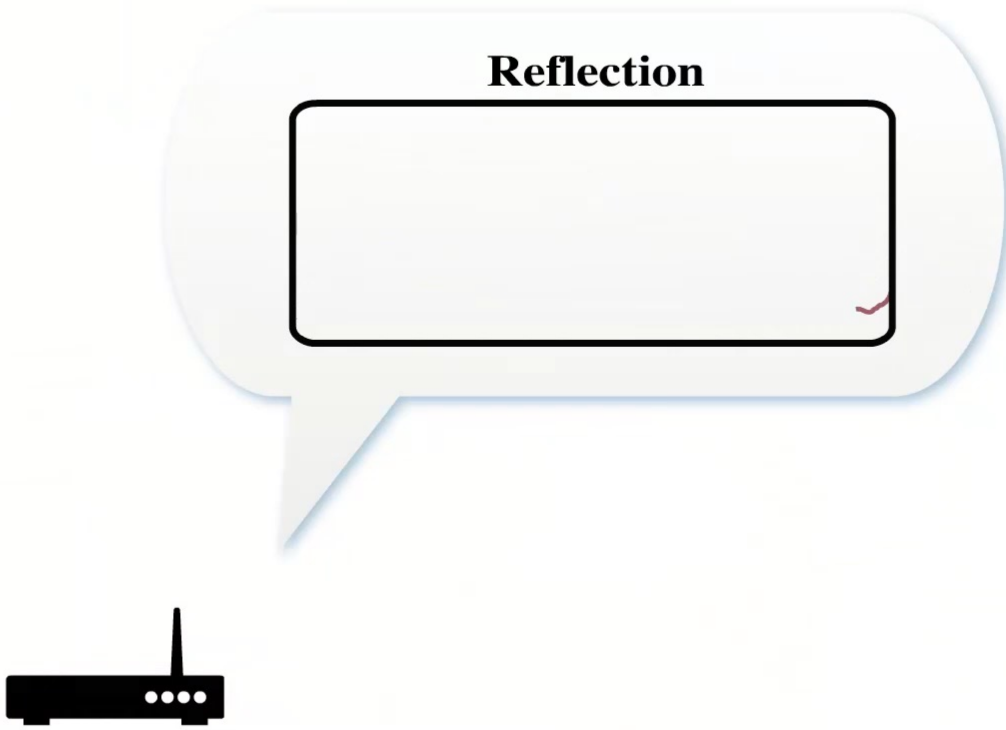
It captures chest motion using wireless signal reflections

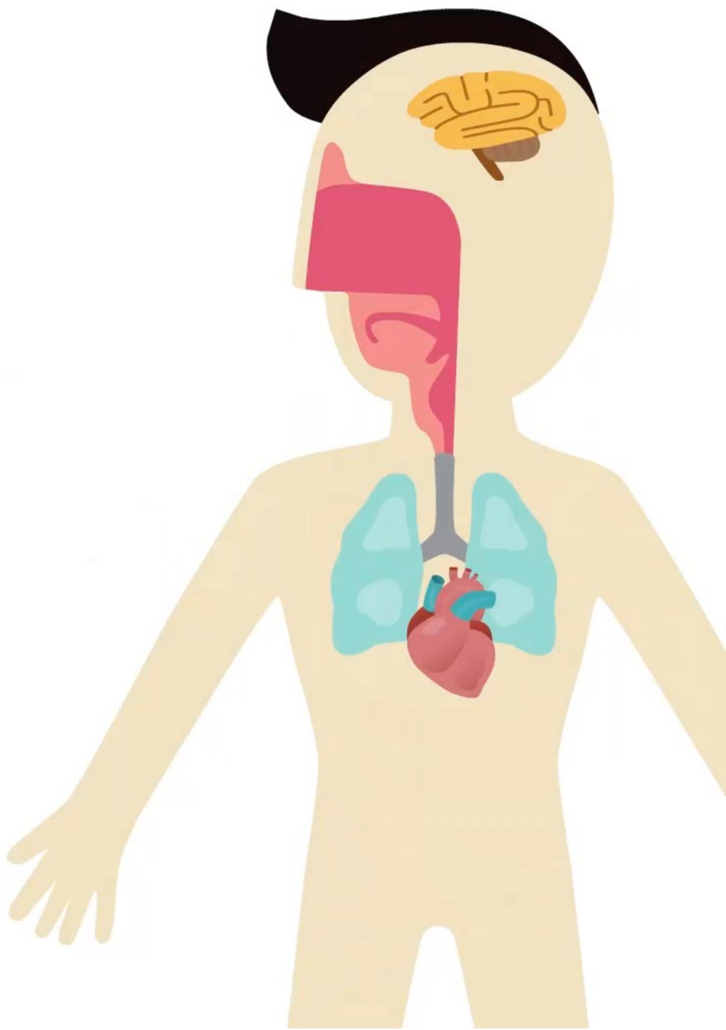
Device is behind the wall

Baby Monitoring

Input signal

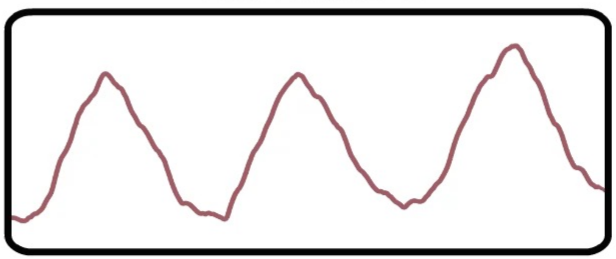
Wireless reflection of the human body



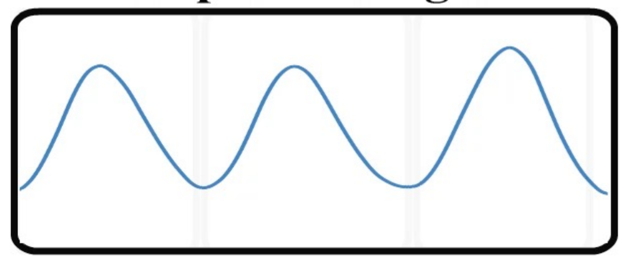


Emotion recognition using wireless signals

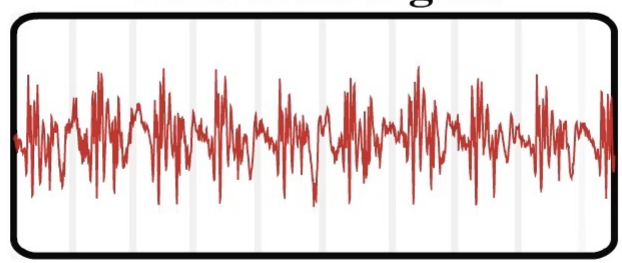
Reflection



Respiration Signal

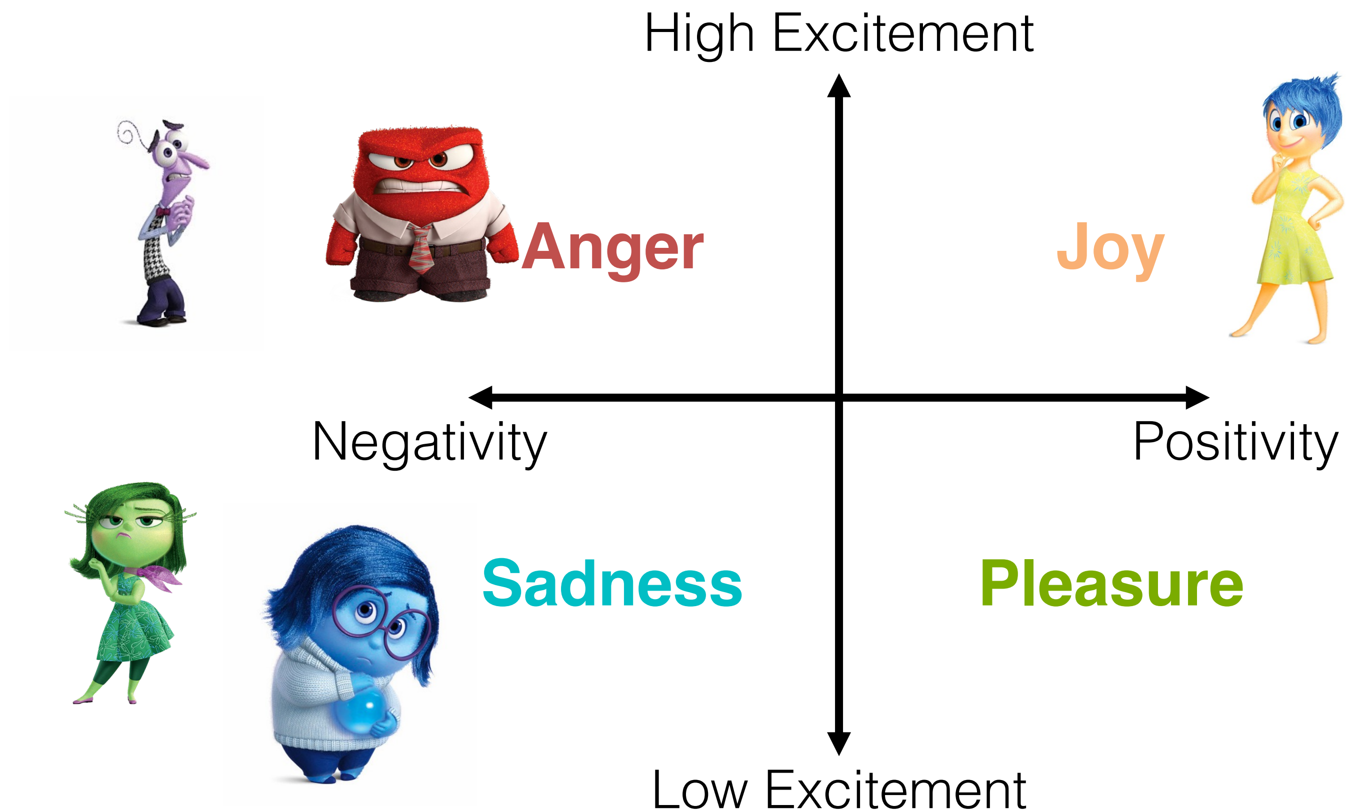


Heartbeat Signal



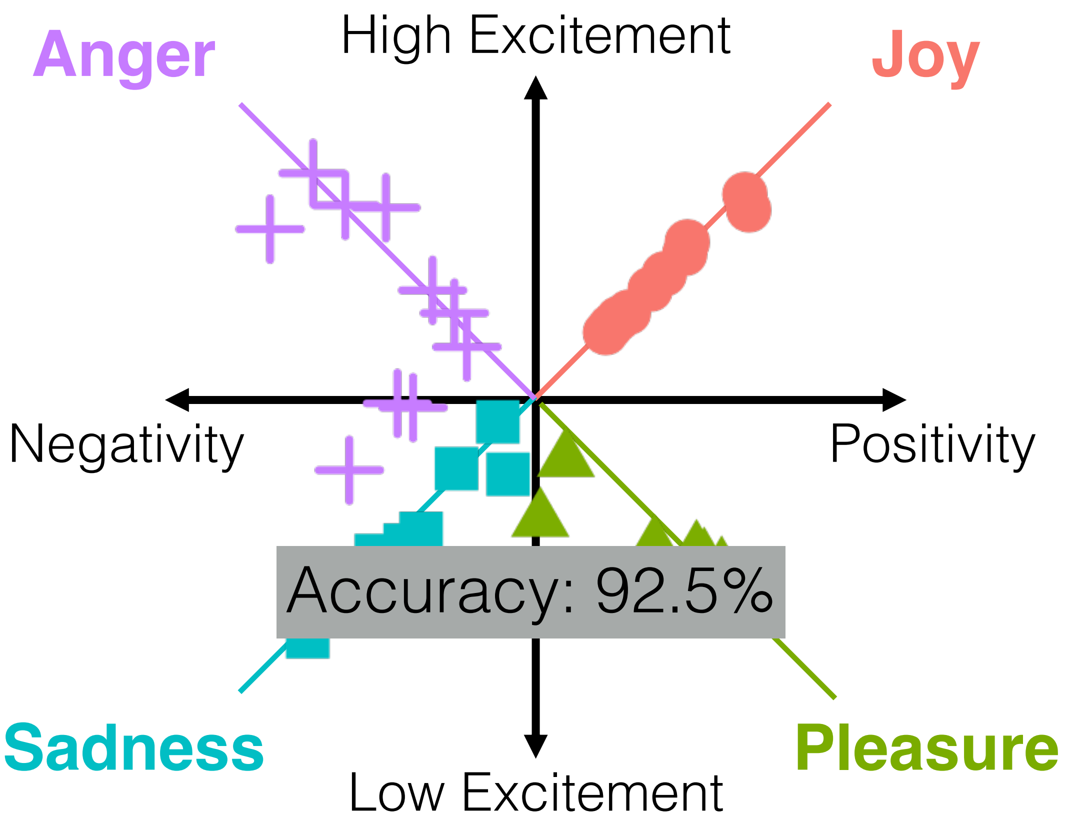
Emotion Model

- Standard 2D emotion model
- Classify into **anger**, **sadness**, **pleasure** and **joy**

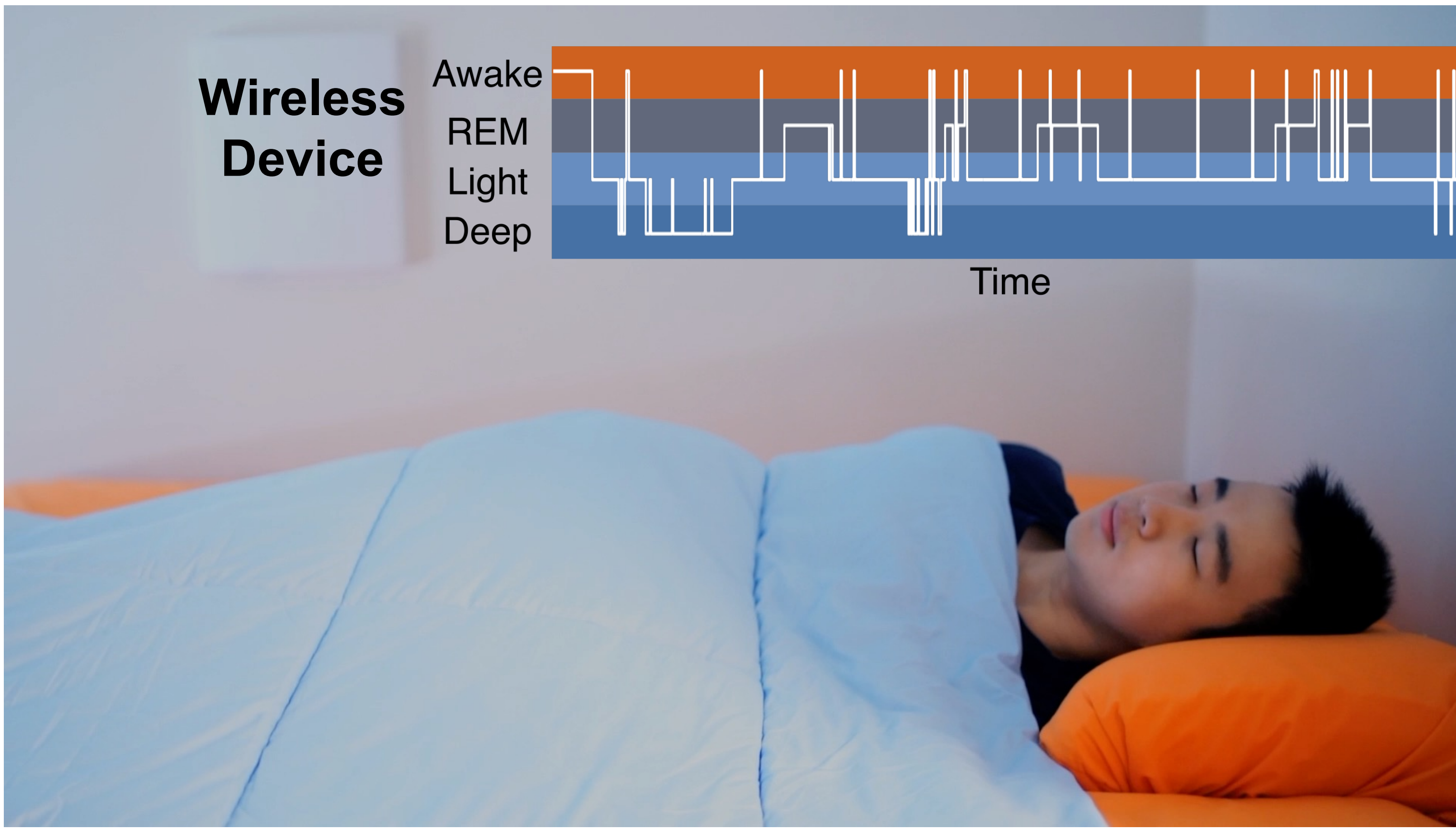


Person-dependent Classification

- Train and test on the same person



Wireless Sensing Sleep Stages



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Amazon's Halo Rise is a $140 bedside sleep tracker that works by sensing you breathe

No cameras or wearables necessary.

Amazon

Cherlynn Low | @cherlynnlow | September 28, 2022 12:26 PM

Biotech & Health

Google's Soli radar returns to track sleep on the new Nest Hub

Brian Heater @bheater / 2:00 PM GMT+1 • March 16, 2021

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Image Credits: Google

Talk about surprise comebacks. This morning Google announced the arrival of the next-gen Nest Hub. In spite of rebranding from Google Home Hub back in 2019, the smart screen hasn't seen many changes since its 2018 introduction. Today's arrival doesn't represent a huge upgrade from its predecessor, but it does support a familiar — and largely forgotten — face.

We haven't heard a peep from Project Soli since the technology was introduced with the Pixel in late-2019. The miniature, motion-sensing radar tech was positioned to be a major selling point, finally arriving on a device some four years after being announced. Applications were relatively few and far between — including gesture detection and a weird, one-off Pokémon app.