

# COM-405: Mobile Networks

## Lecture 8.1: Wireless Sensing of Humans Haitham Hassanieh

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



**EPFL**

**SENS**  
Laboratory of SEnsing  
& Networking Systems

# Interest in Sensing the Human Body

## Heart Rate



## Breathing



## Locations



## Gestures



Heart Rate



Breathing



Locations

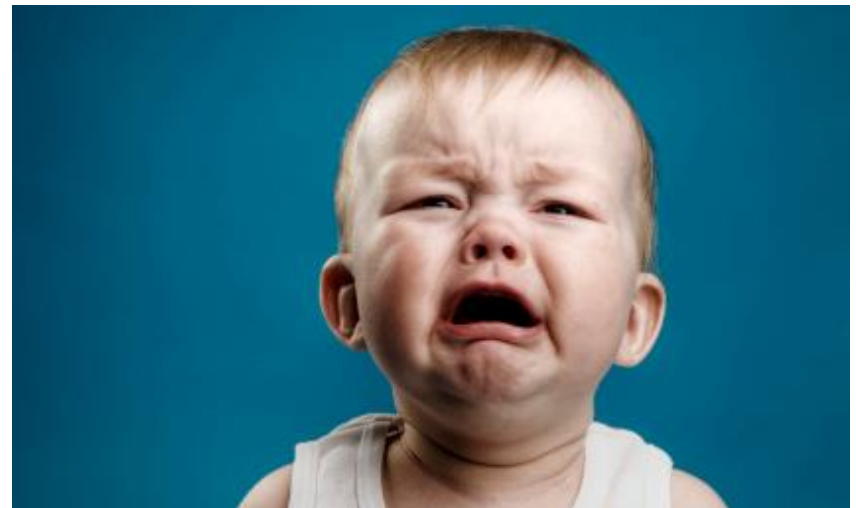


Gestures



On-body sensors can be cumbersome

Not suitable for elderly & babies



Heart Rate



Breathing



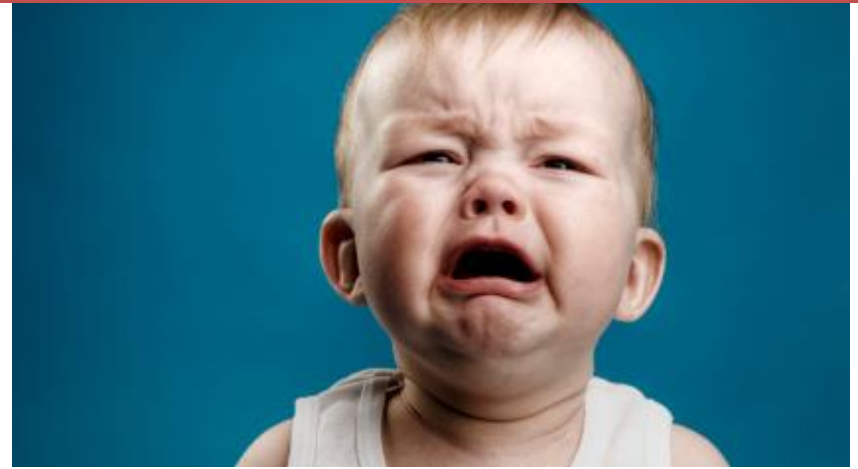
Locations

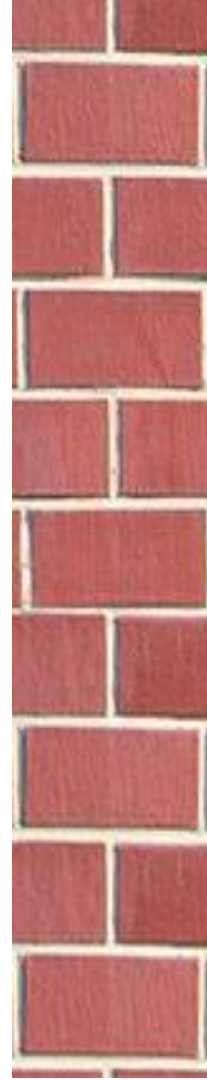
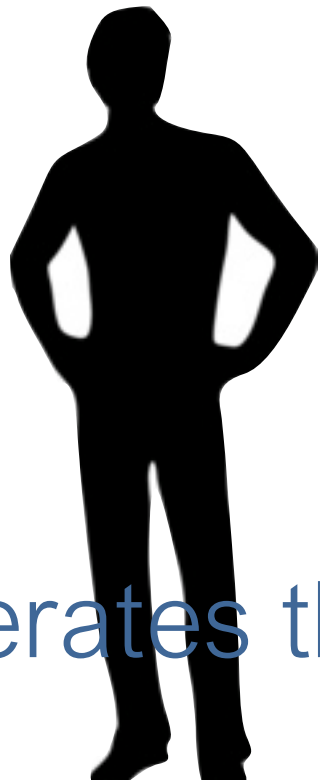


Gestures



Imagine enabling these applications without sensors on the human body

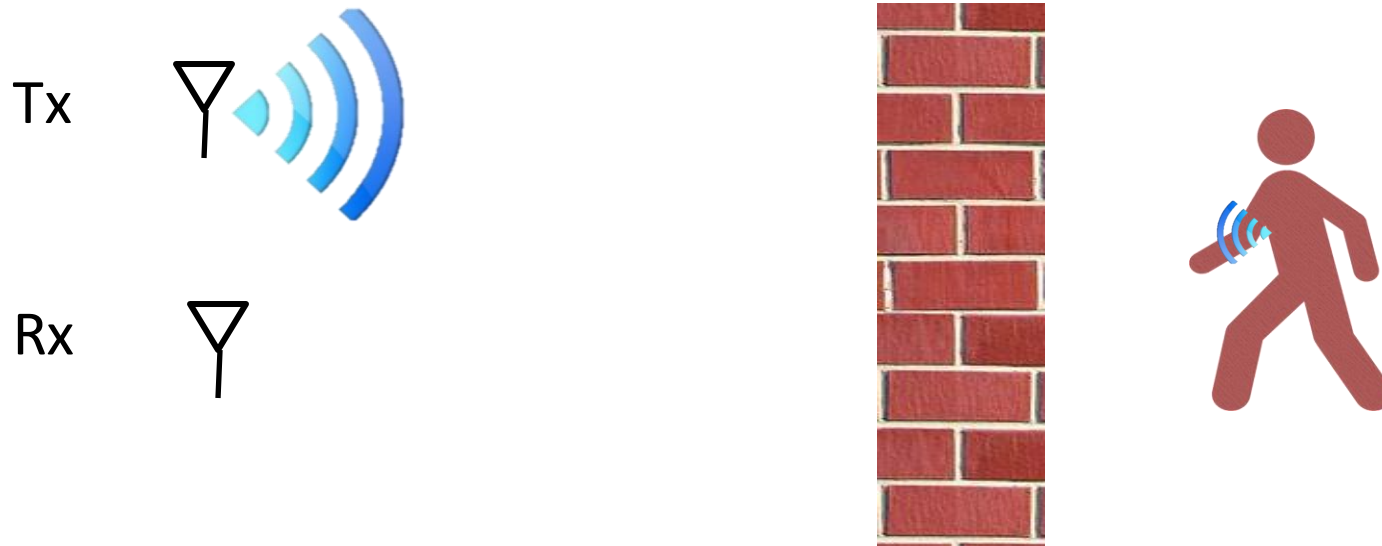




- Location
- Vital Signs
- Imaging

Operates through occlusions

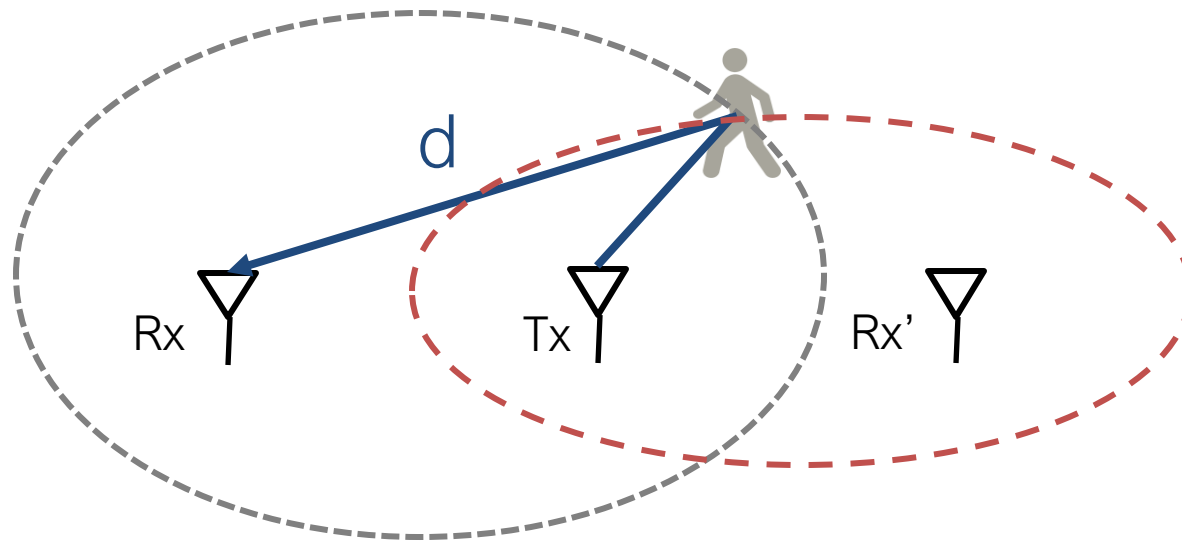
# Measuring Distances



Distance = Reflection time x speed of light

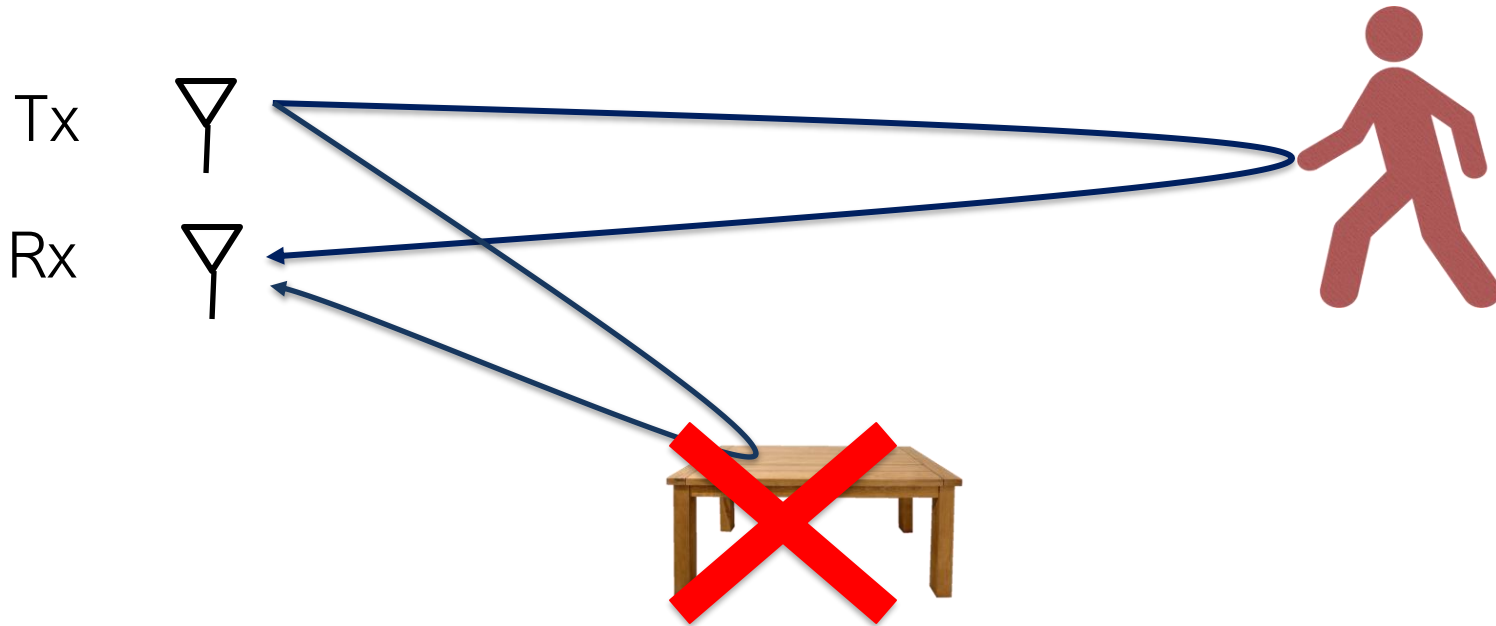
# Mapping Distance to Location

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:

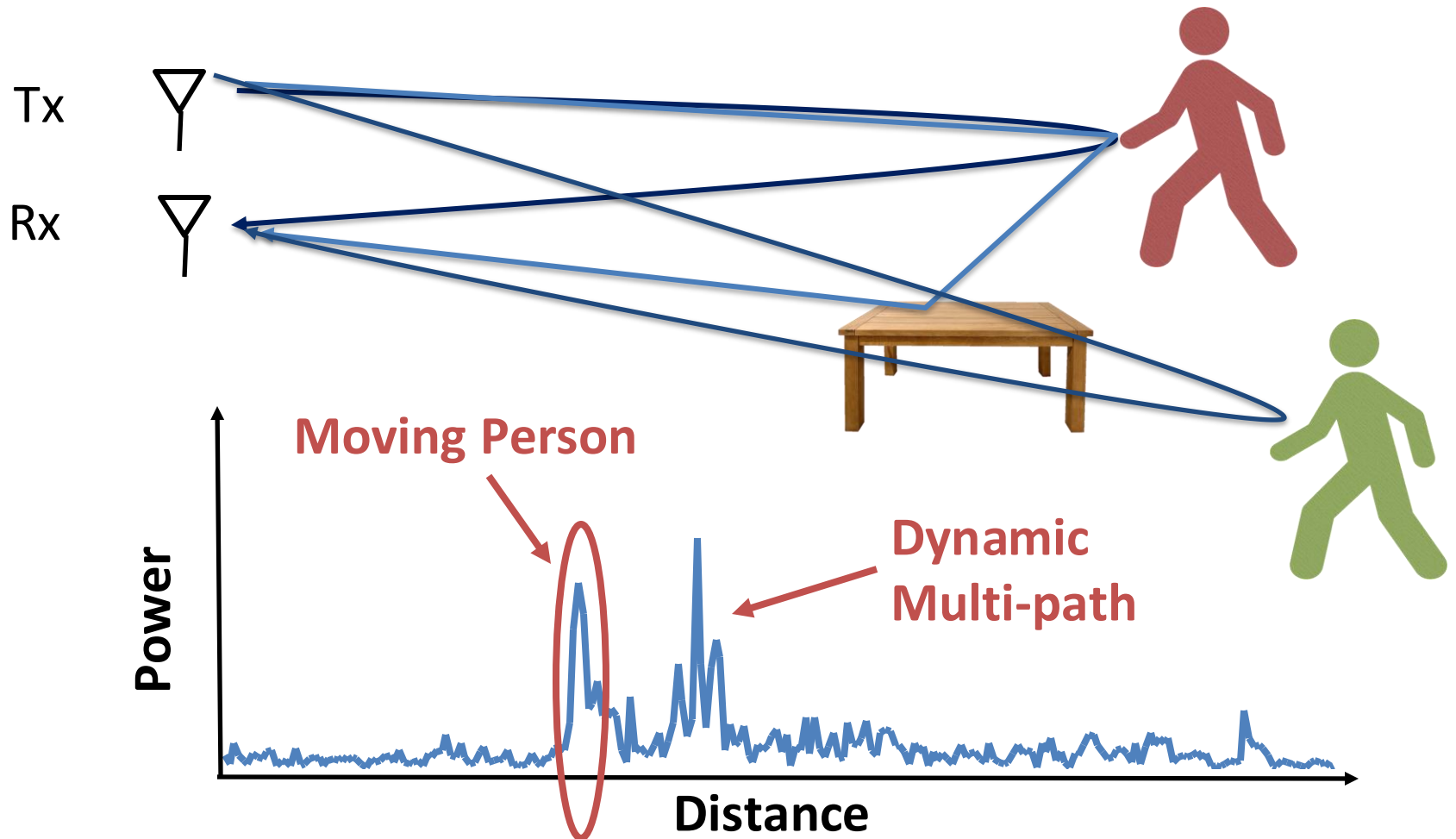
eliminated by subtracting consecutive measurements

Needs User to Move



Device in another room

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



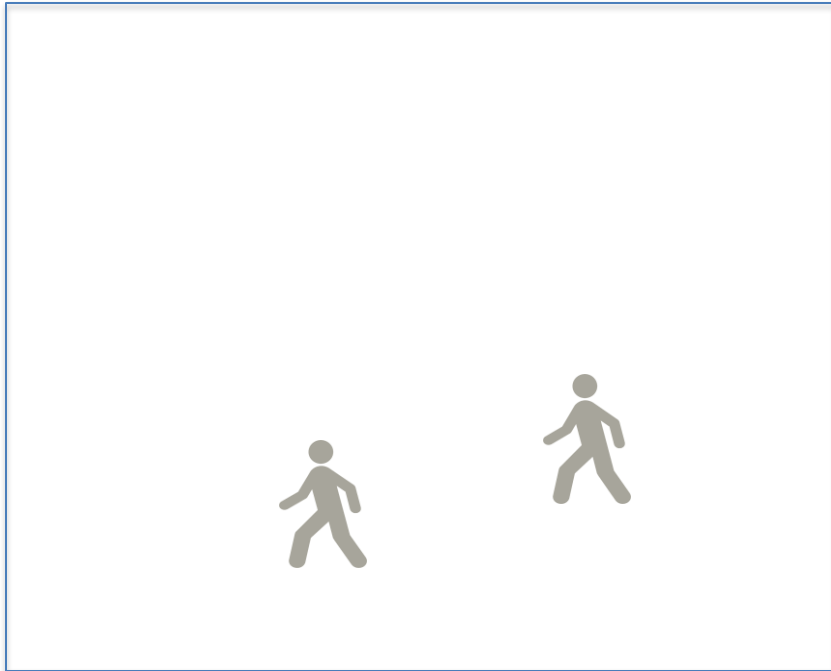
How can we deal with multi-path reflections when there are multiple persons in the environment?

Idea: Person is consistent across different vantage points while multi-path is different from different vantage points

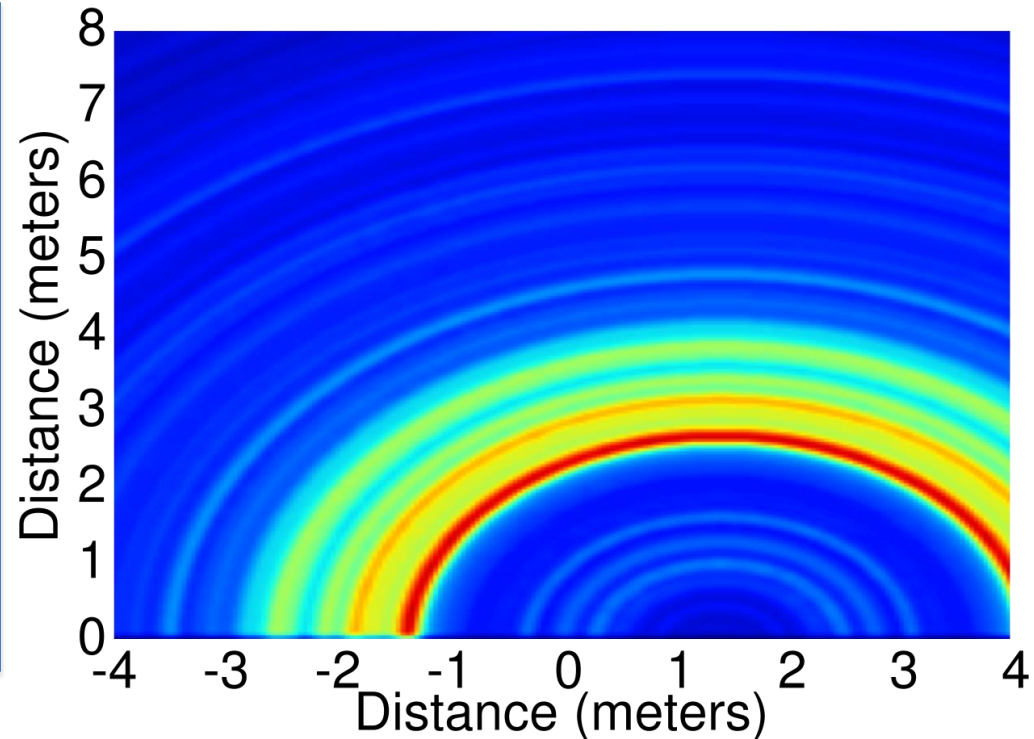
# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



Single Vantage Point

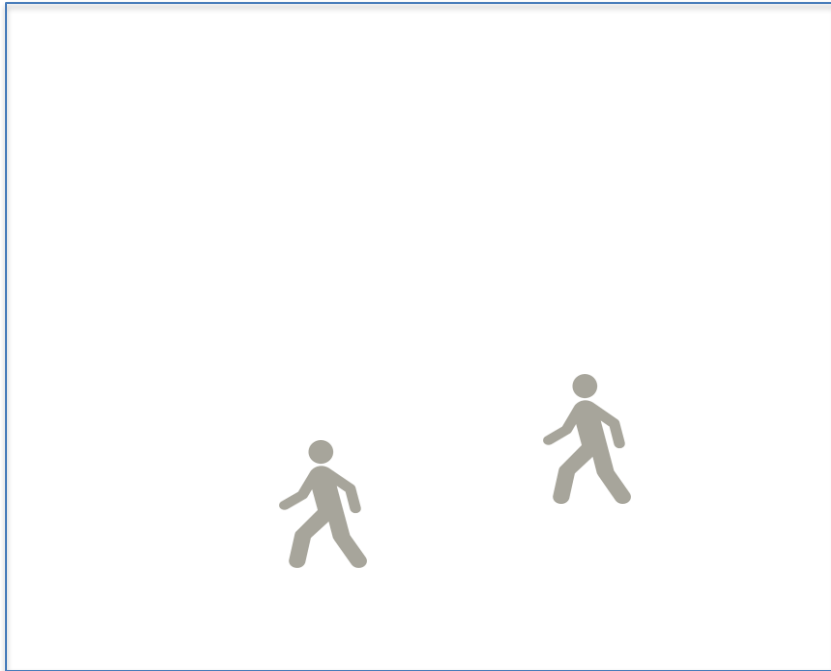


Mathematically: each round-trip distance can be mapped to an ellipse whose foci are the transmitter and the receiver

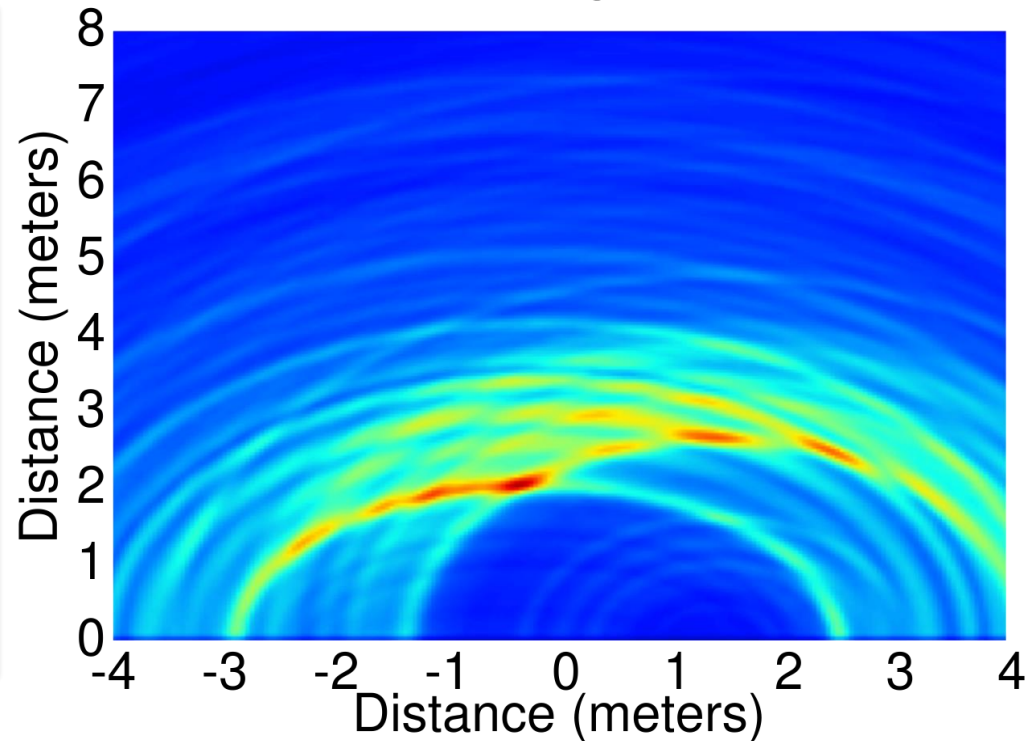
# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



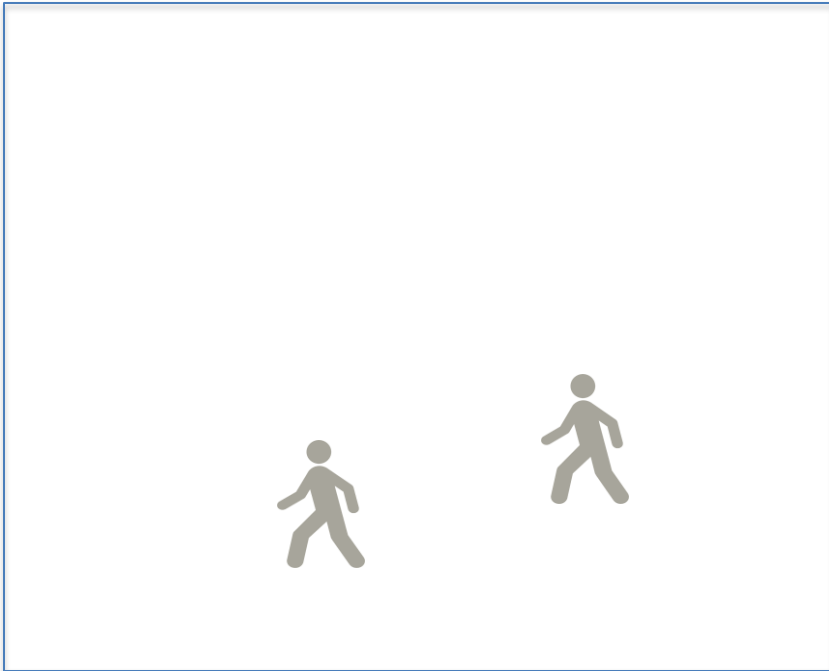
Two Vantage Points



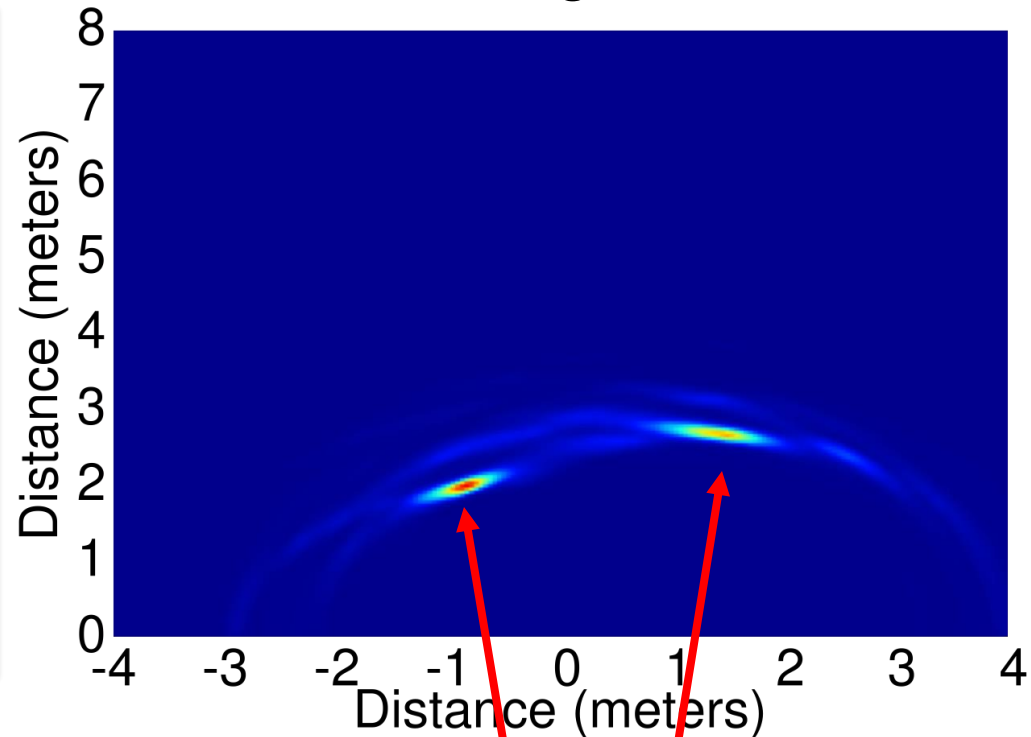
# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



16 Vantage Points

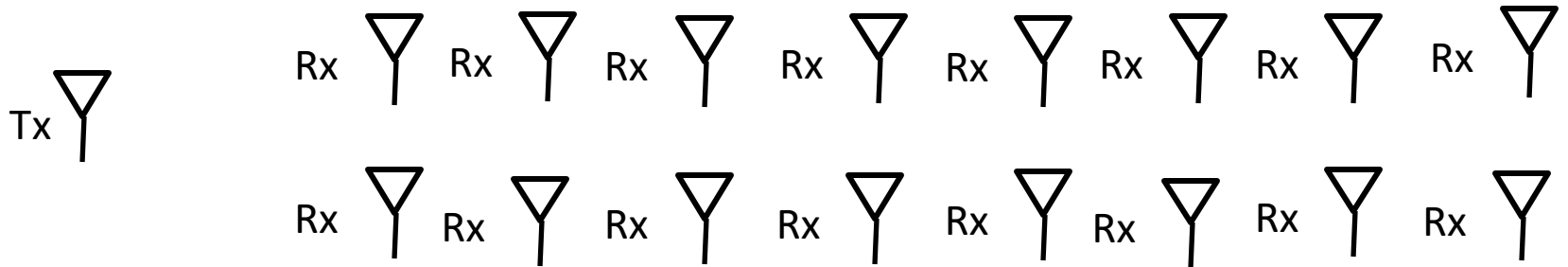


Localize the two users

How can we obtain 16 vantage points?

# Achieving 16 vantage points

- Naïve solution: 1 Transmitter and 16 Receivers



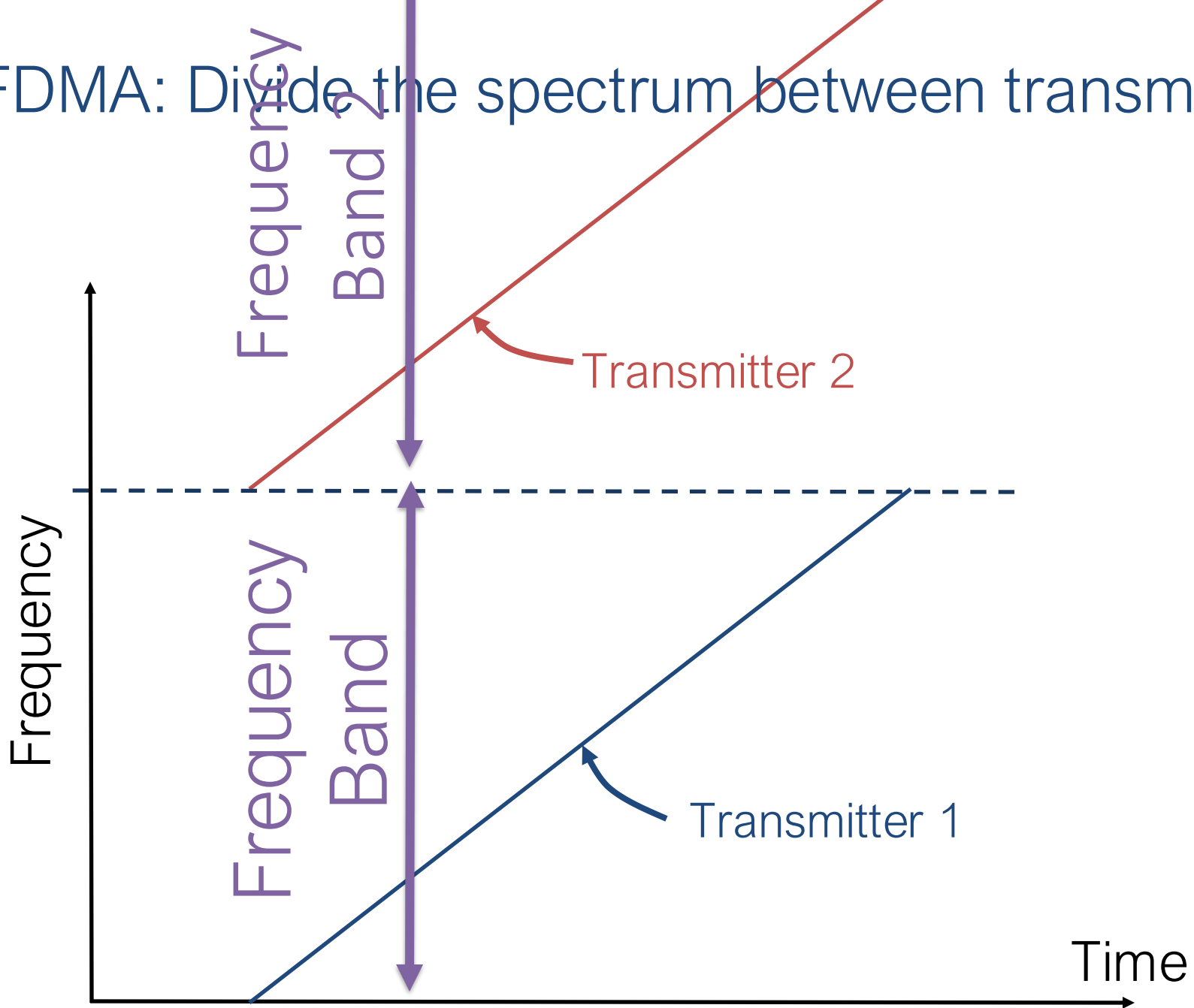
- Ideally: 4 Transmitters and 4 Receivers



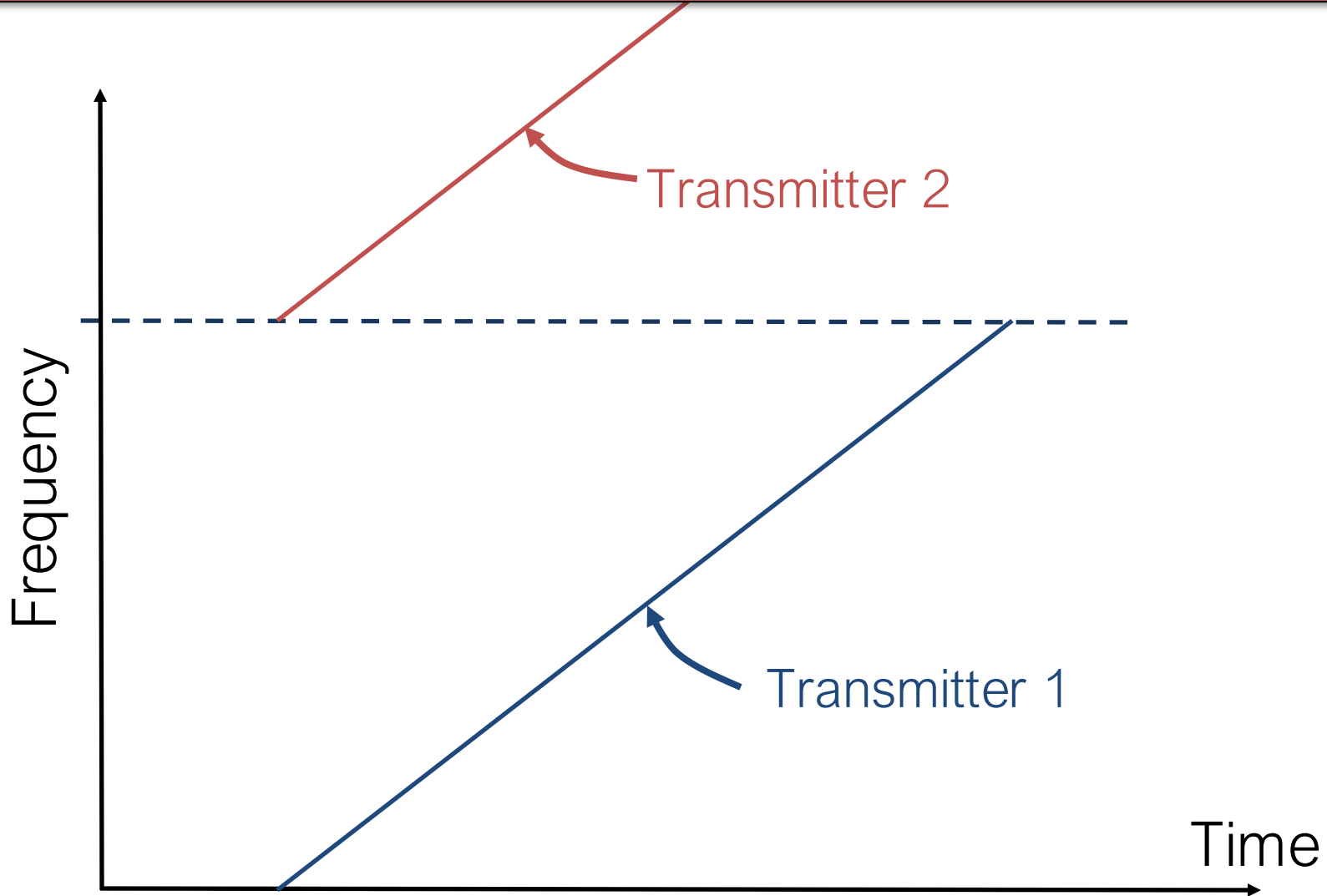
Problem: Different transmitters interfere with each other!

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

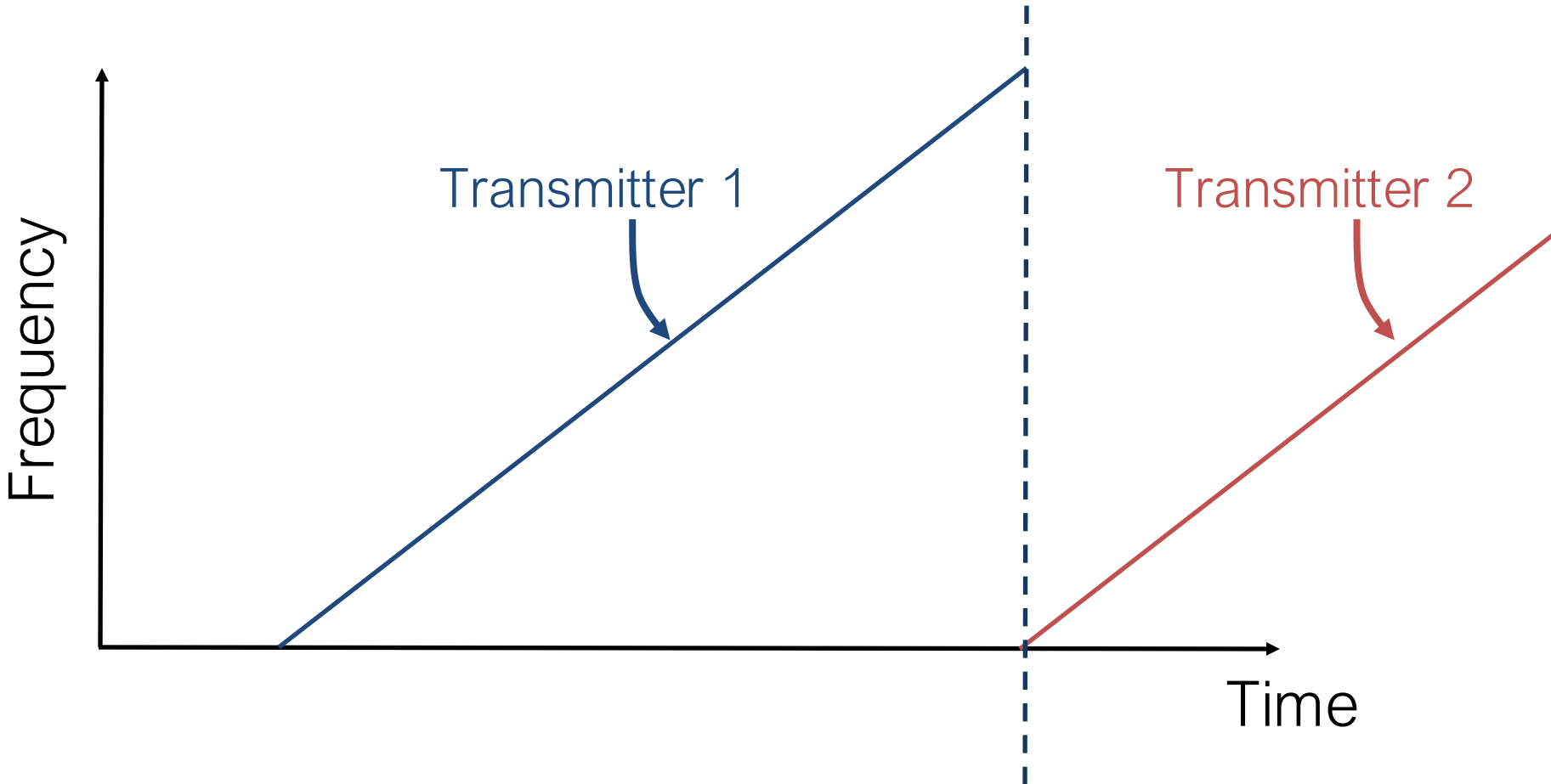
# FDMA: Divide the spectrum between transmitters



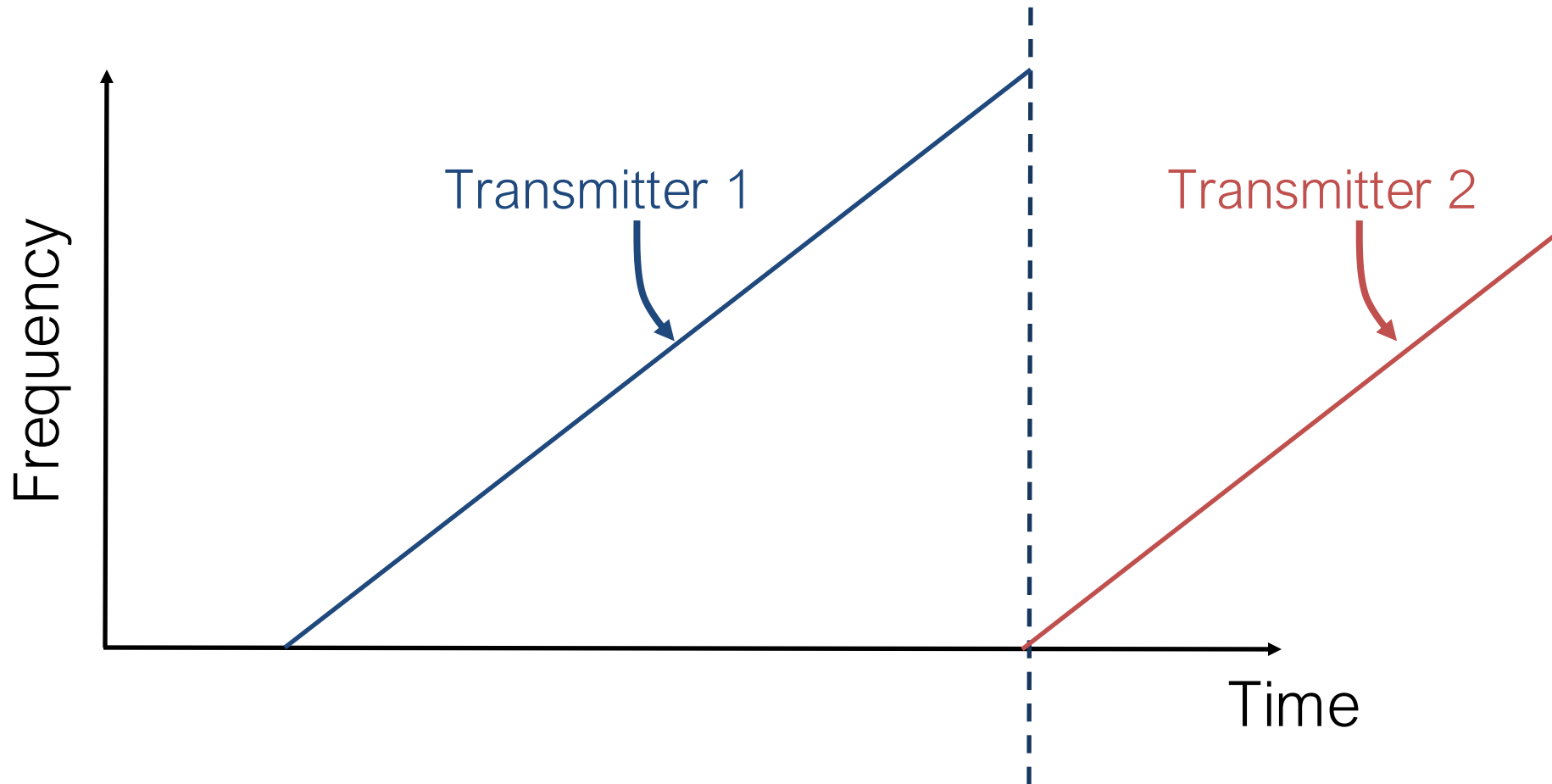
Would require N times the bandwidth!



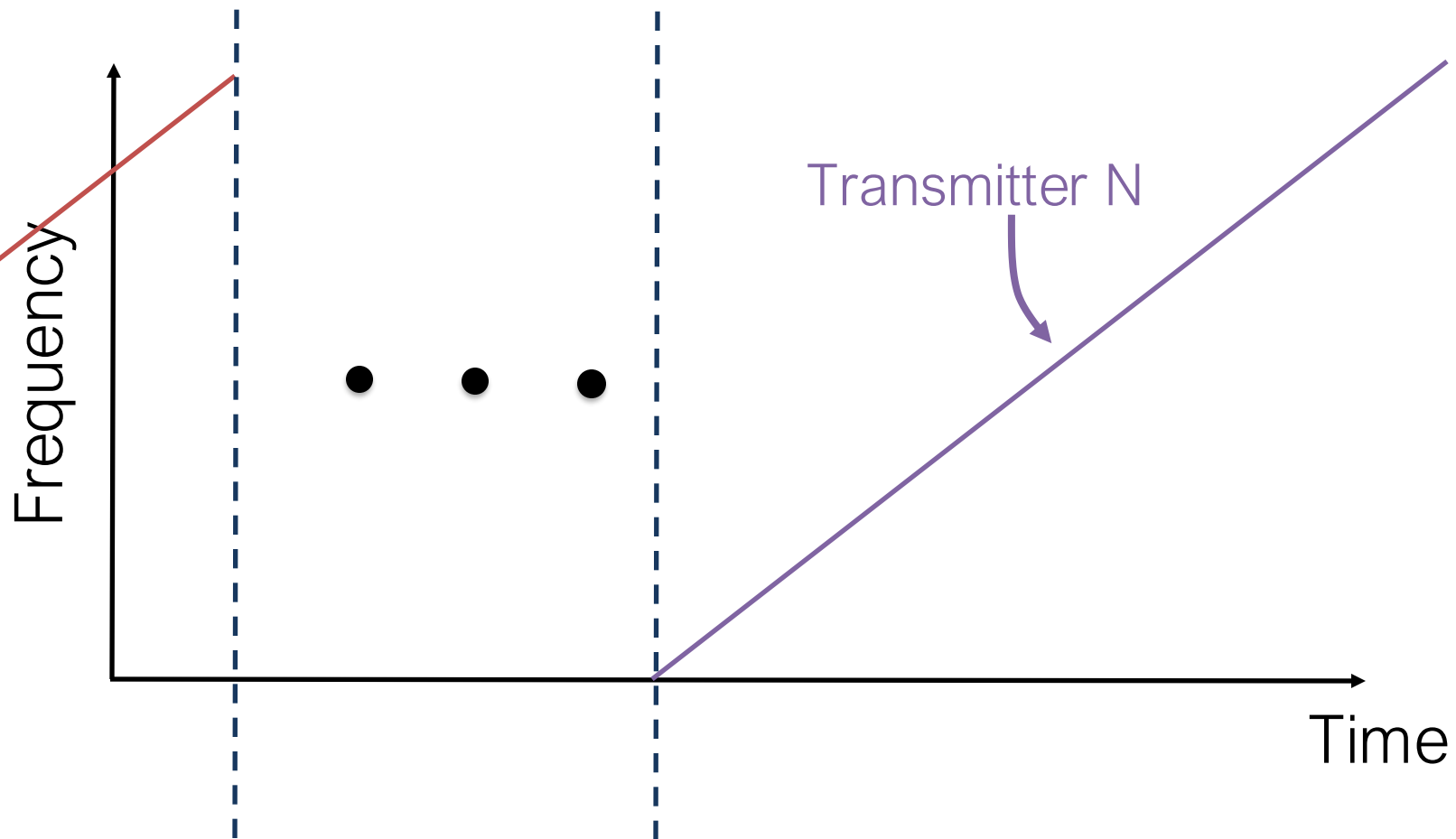
# TDMA: Transmitters take turns transmitting



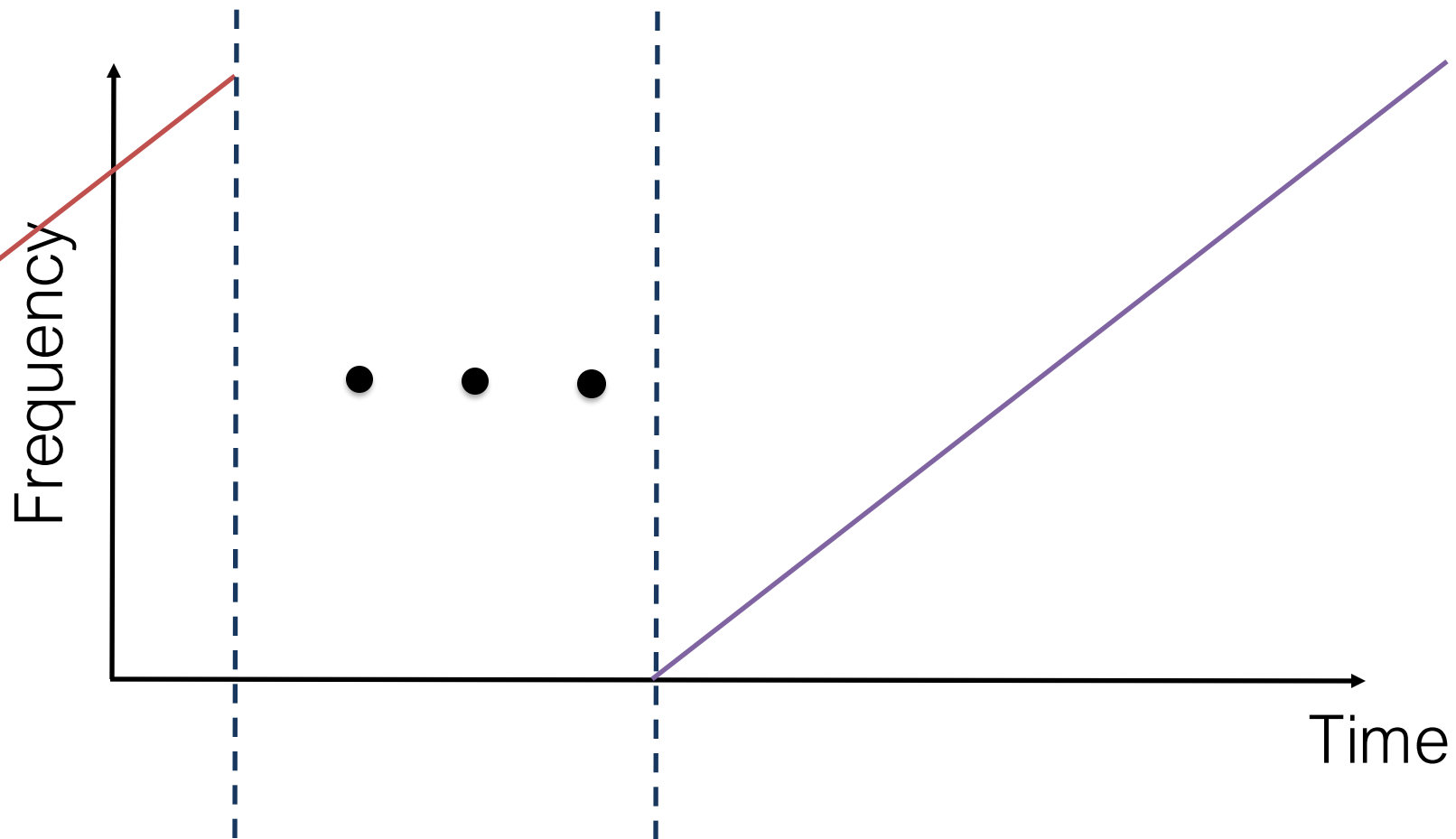
Would require N more time to localize



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

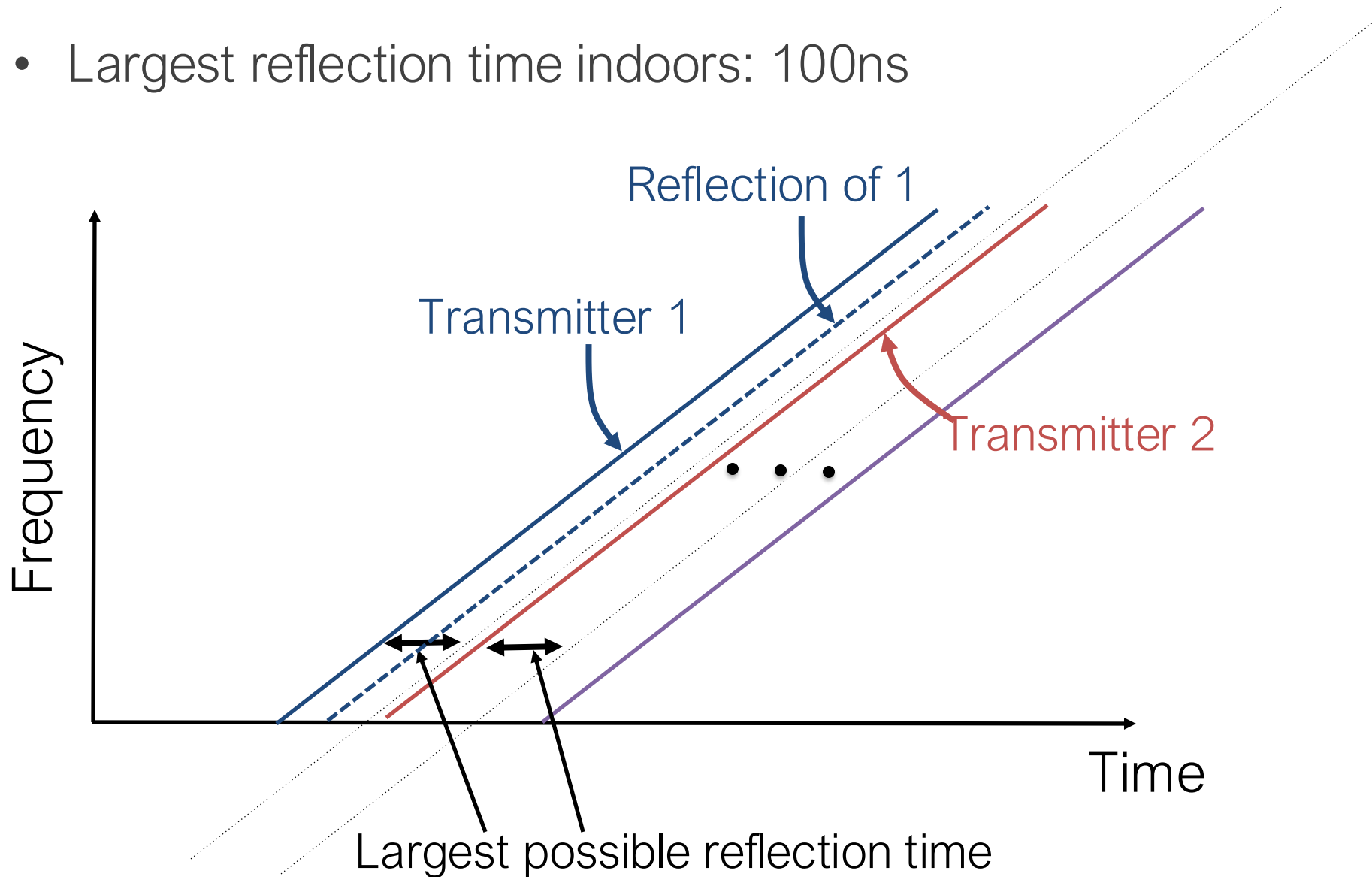


Ideally: Transmit in the same time and in the same frequency band without interfering

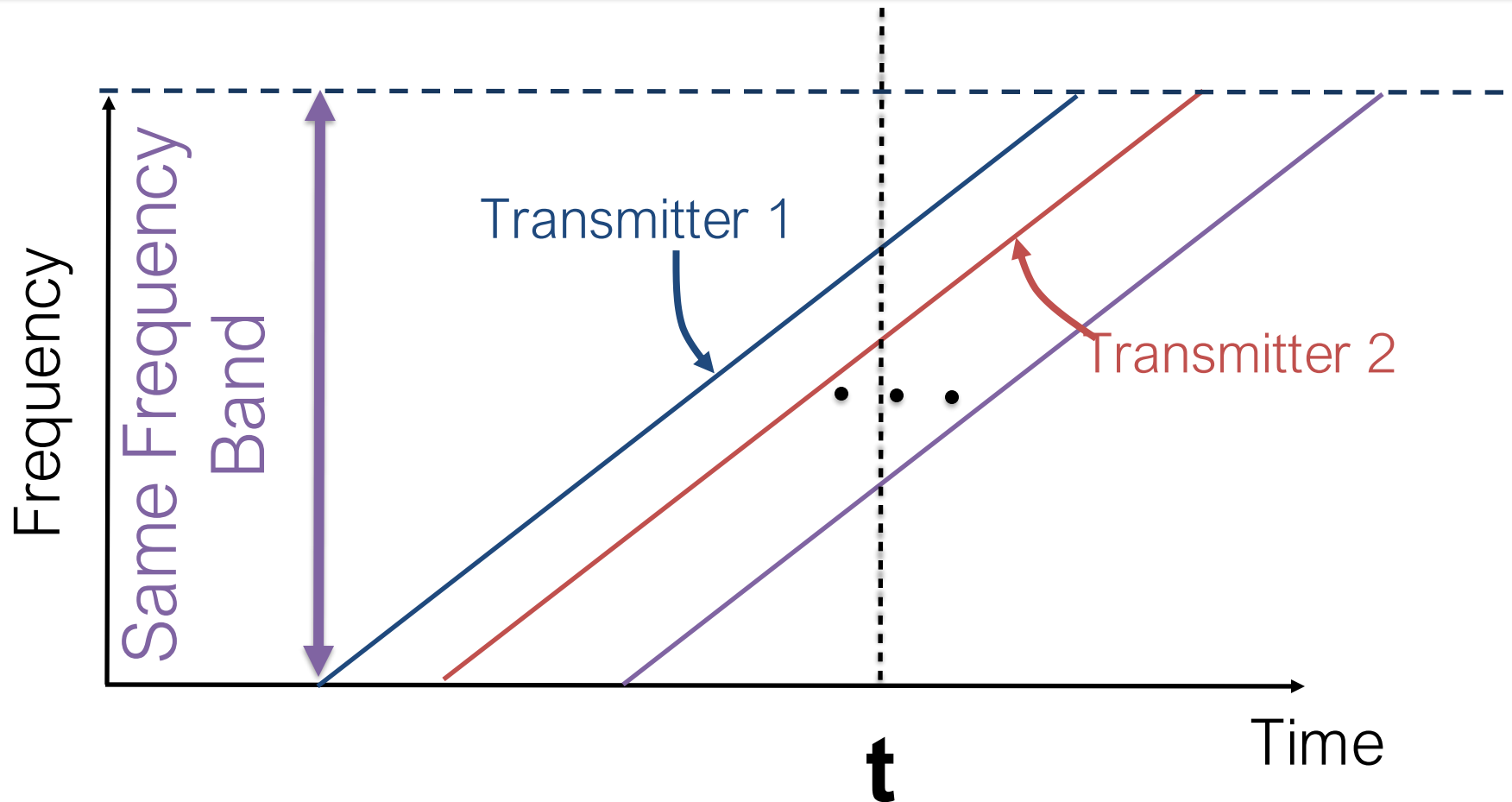


# Objective: Transmit and Get Reflection

- Largest reflection time indoors: 100ns

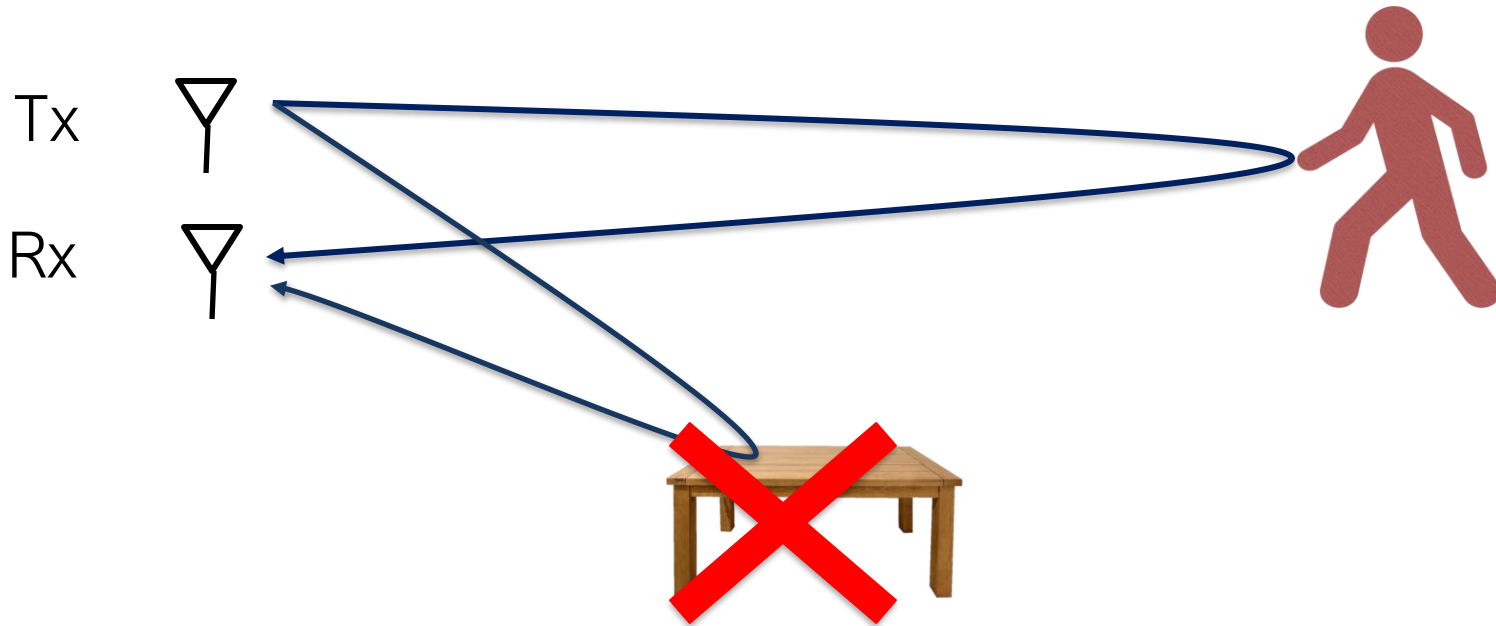


Multi-shift FMCW enables multiple transmissions at the **same time** and in the **same frequency band** without interference



How can we localize static users?

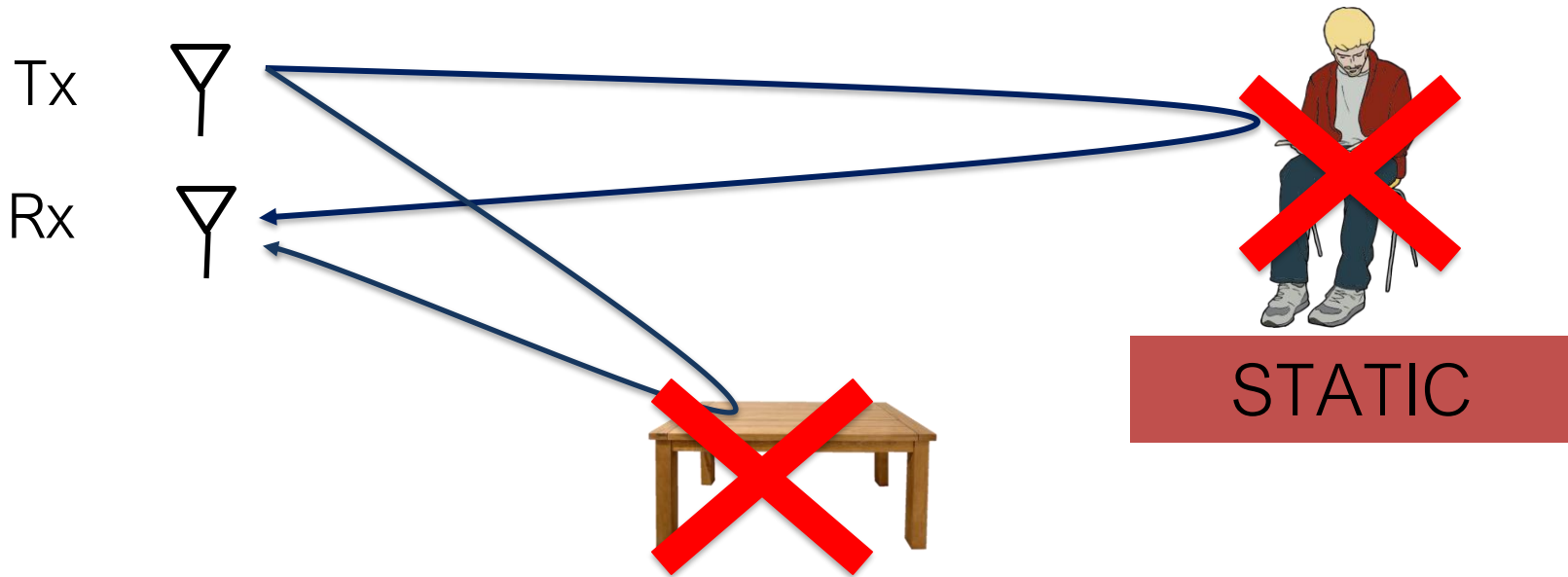
# Dealing with multi-path when there is one moving user



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:  
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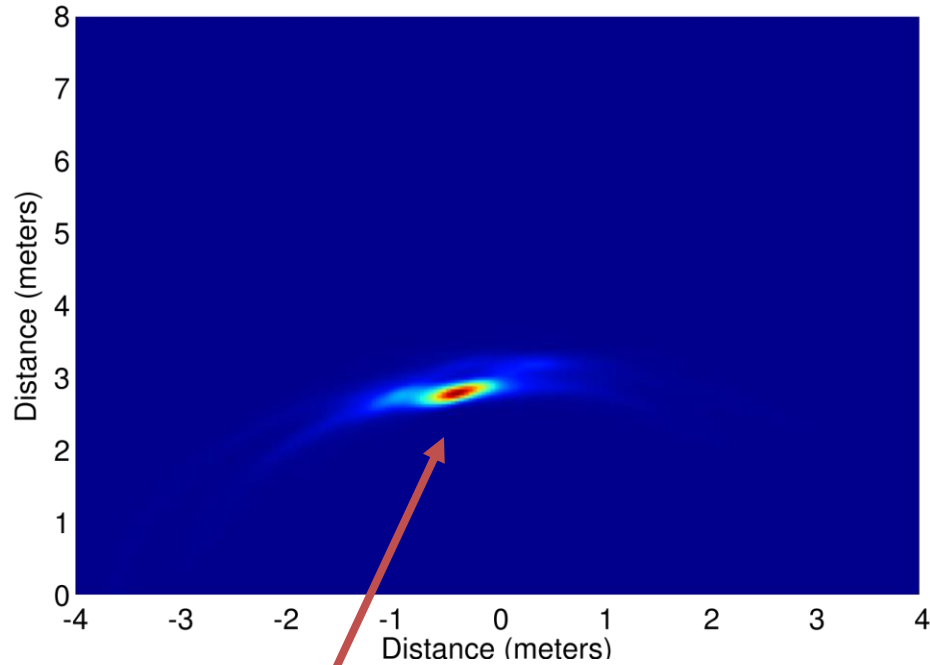
Needs User to Move

# 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

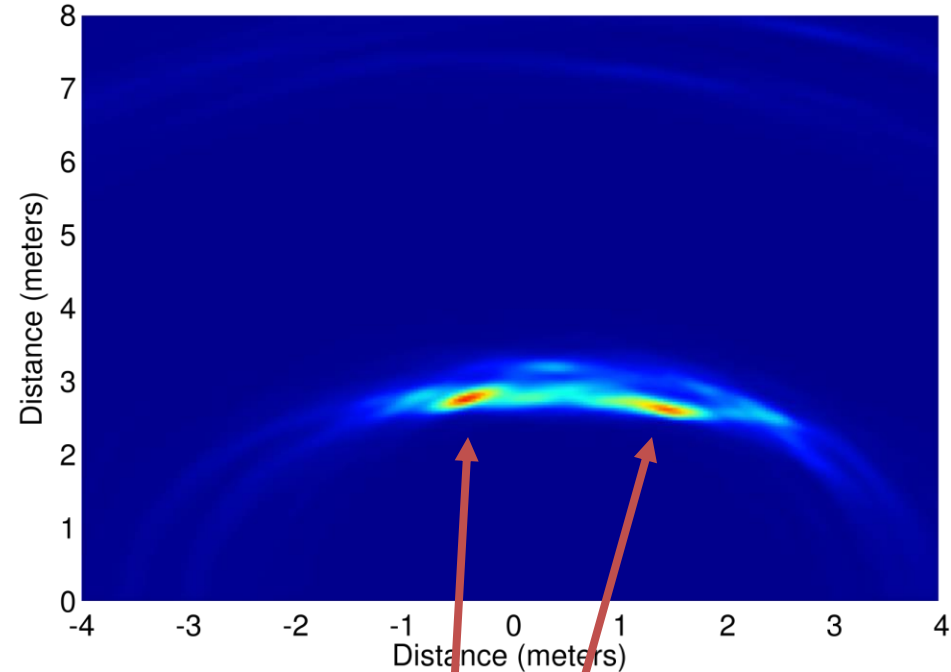
# User Walking at 1m/s

30ms subtraction window



Localize the  
person

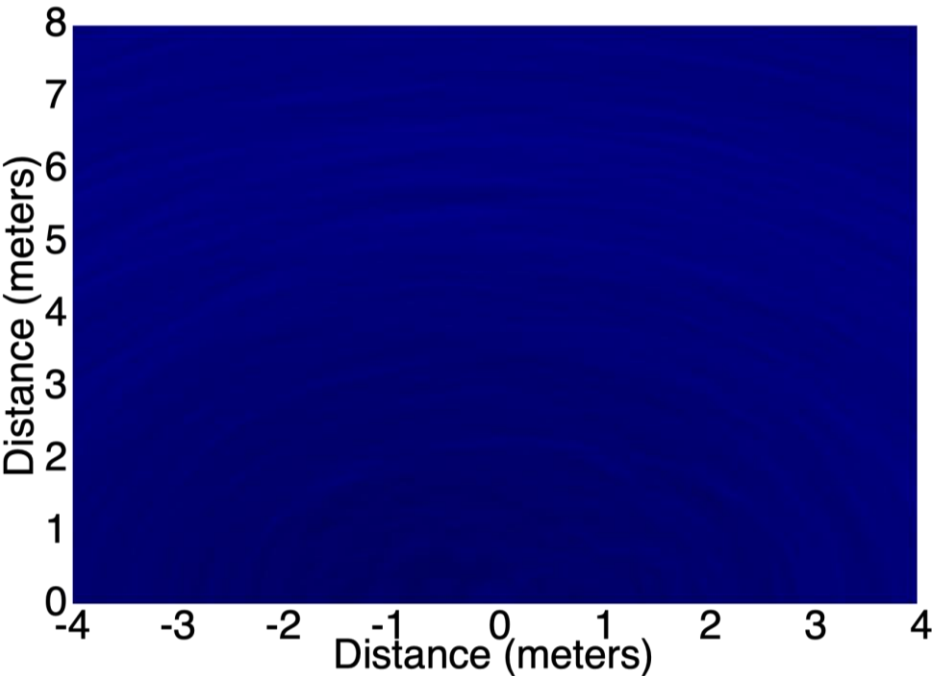
3s subtraction window



Person appears in two  
locations

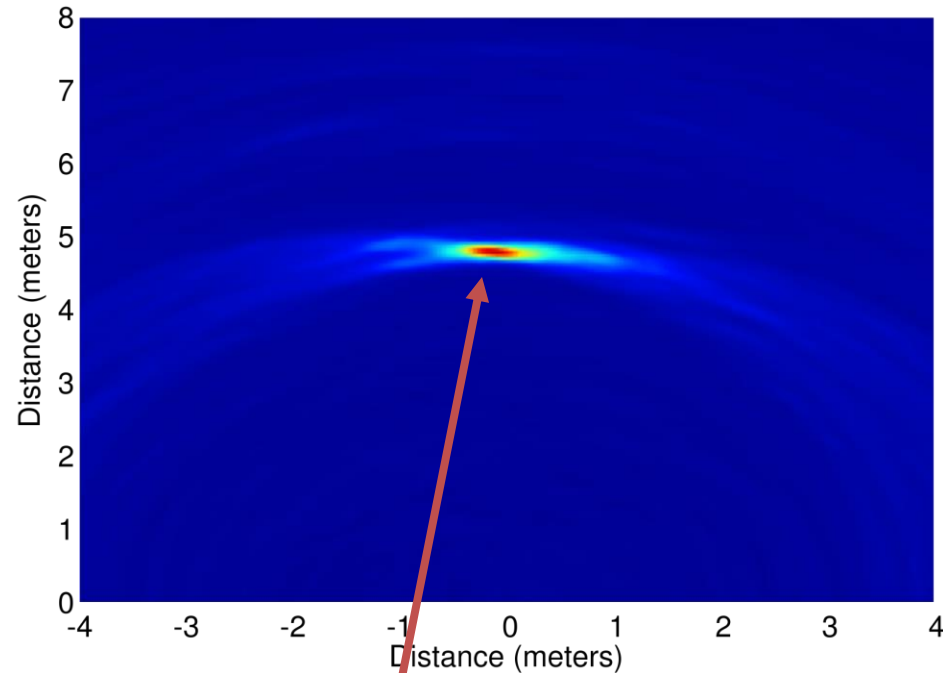
# User Sitting Still (Breathing)

30ms subtraction window



Cannot localize

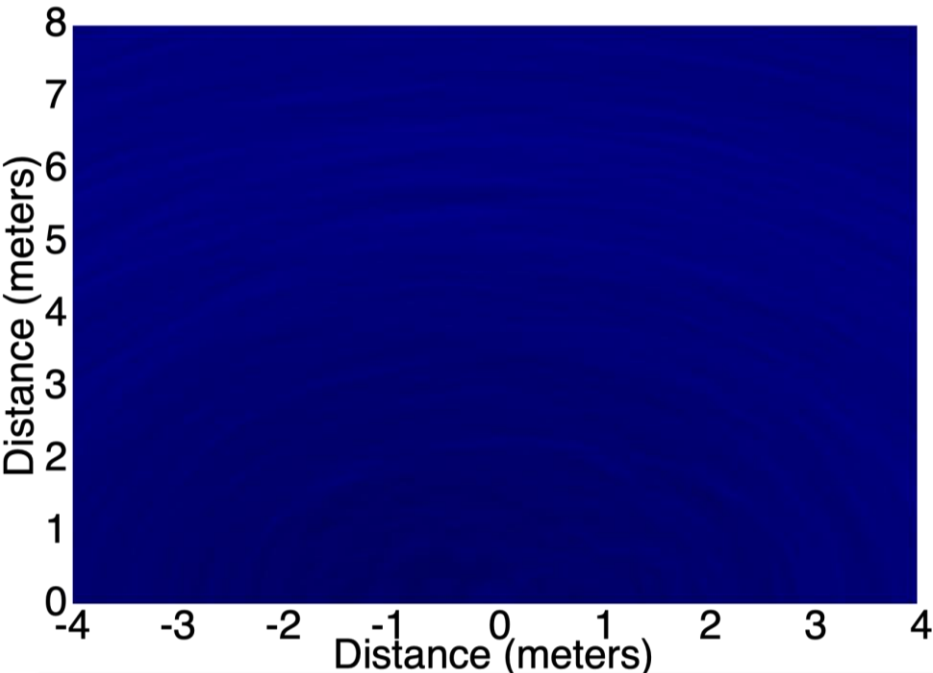
3s subtraction window



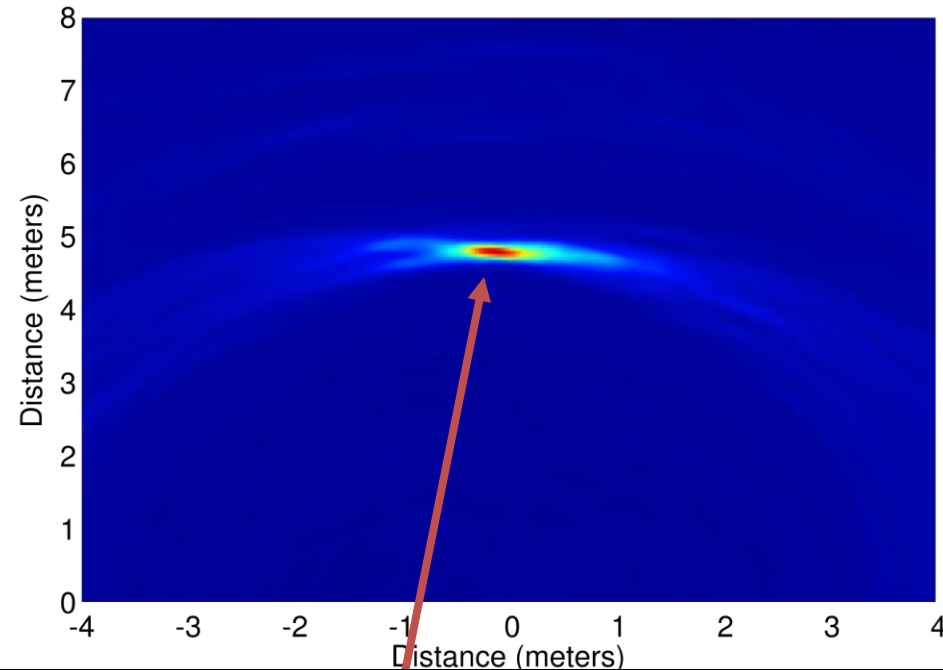
Localize the  
person

# User Sitting Still (Breathing)

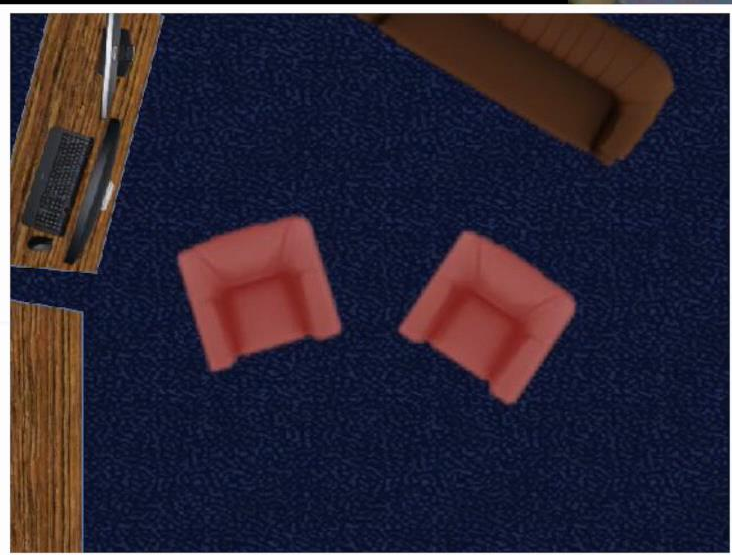
30ms subtraction window

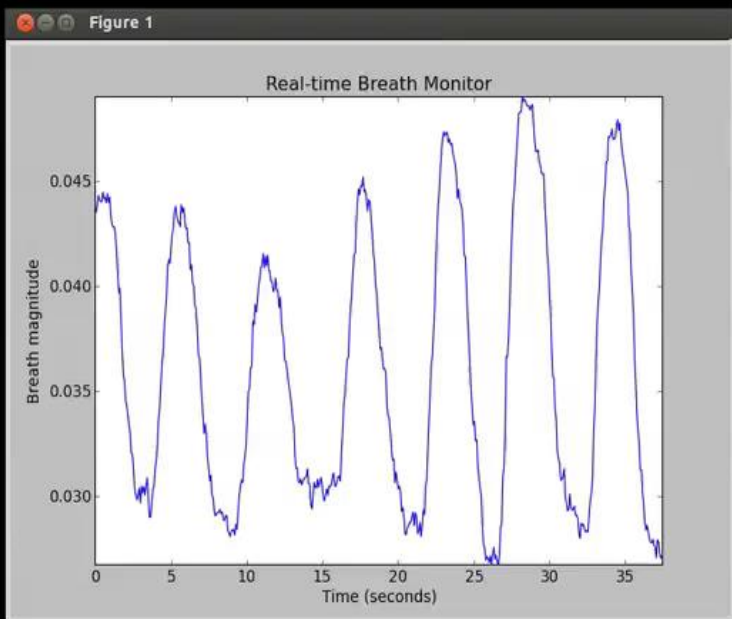


3s subtraction window

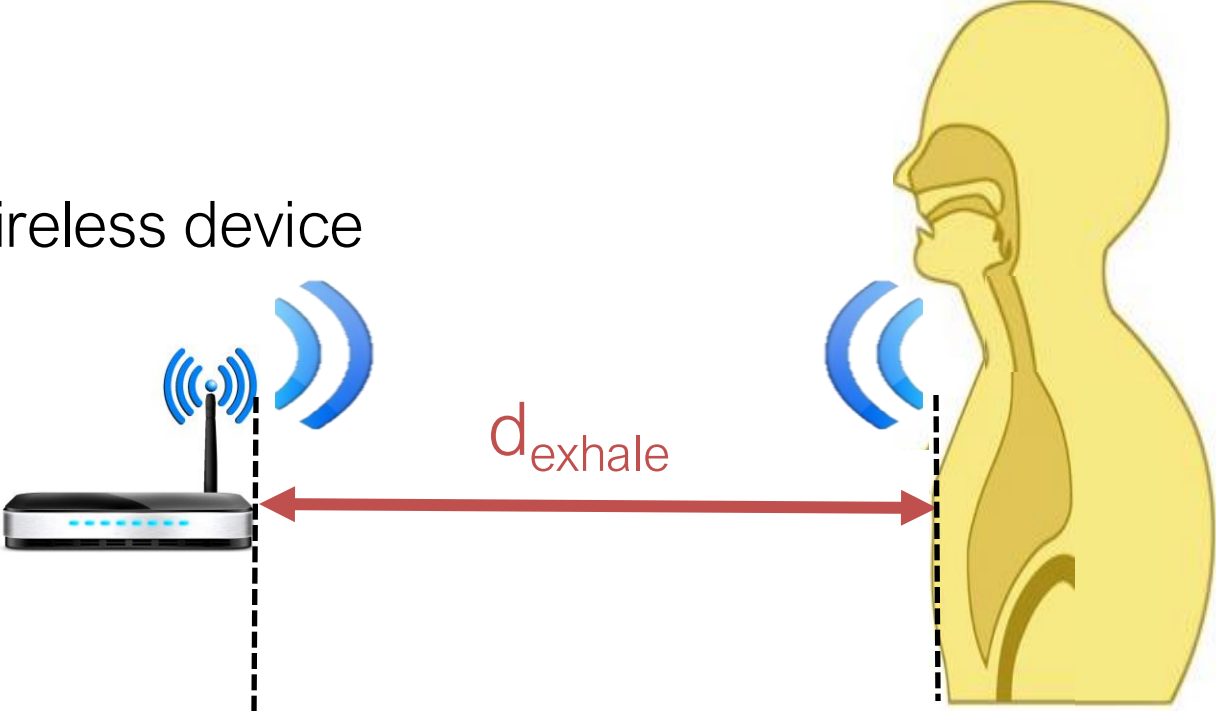


Use multi-resolution subtraction window to eliminate multi-path while being able to localize both static and moving users

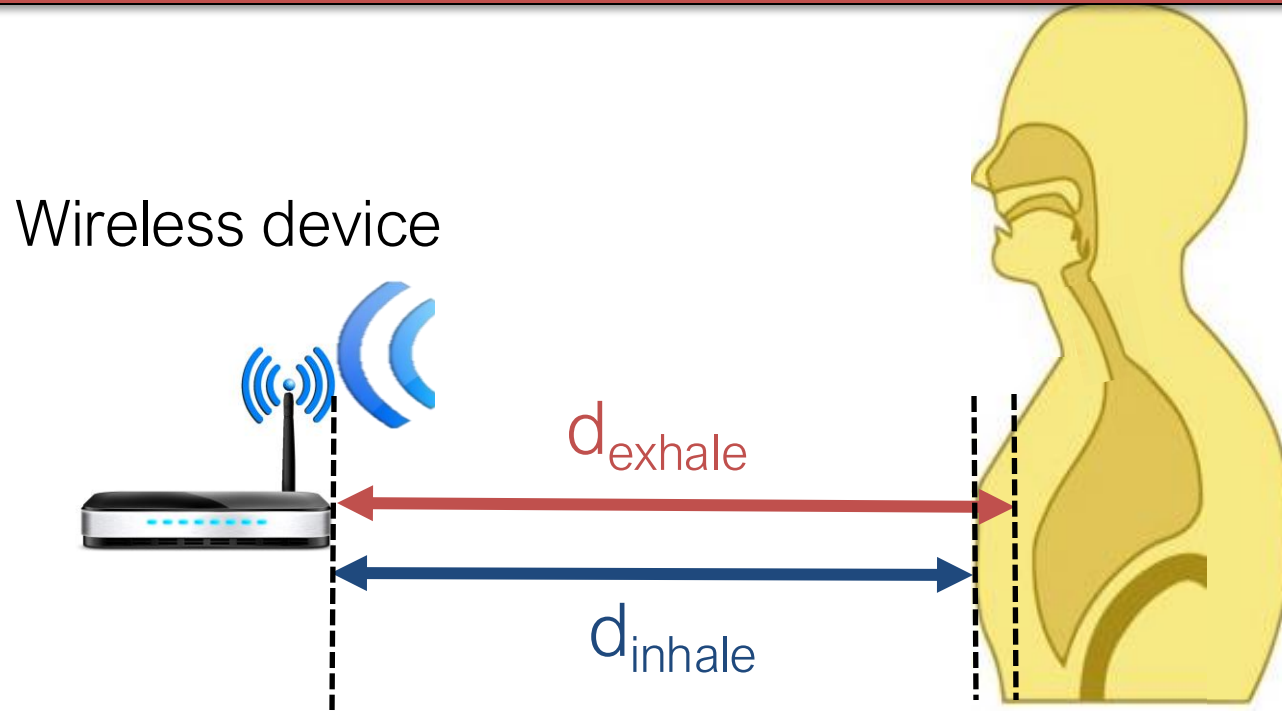




Wireless device

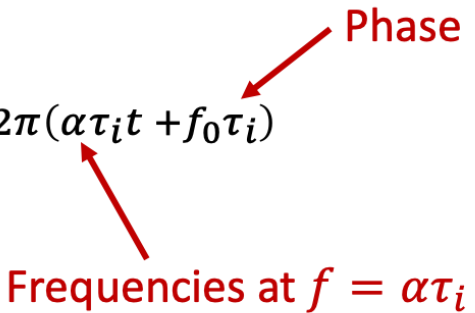


Problem: Localization accuracy is only 12cm and cannot capture vital signs



# FMCW: Frequency Modulated Carrier Wave

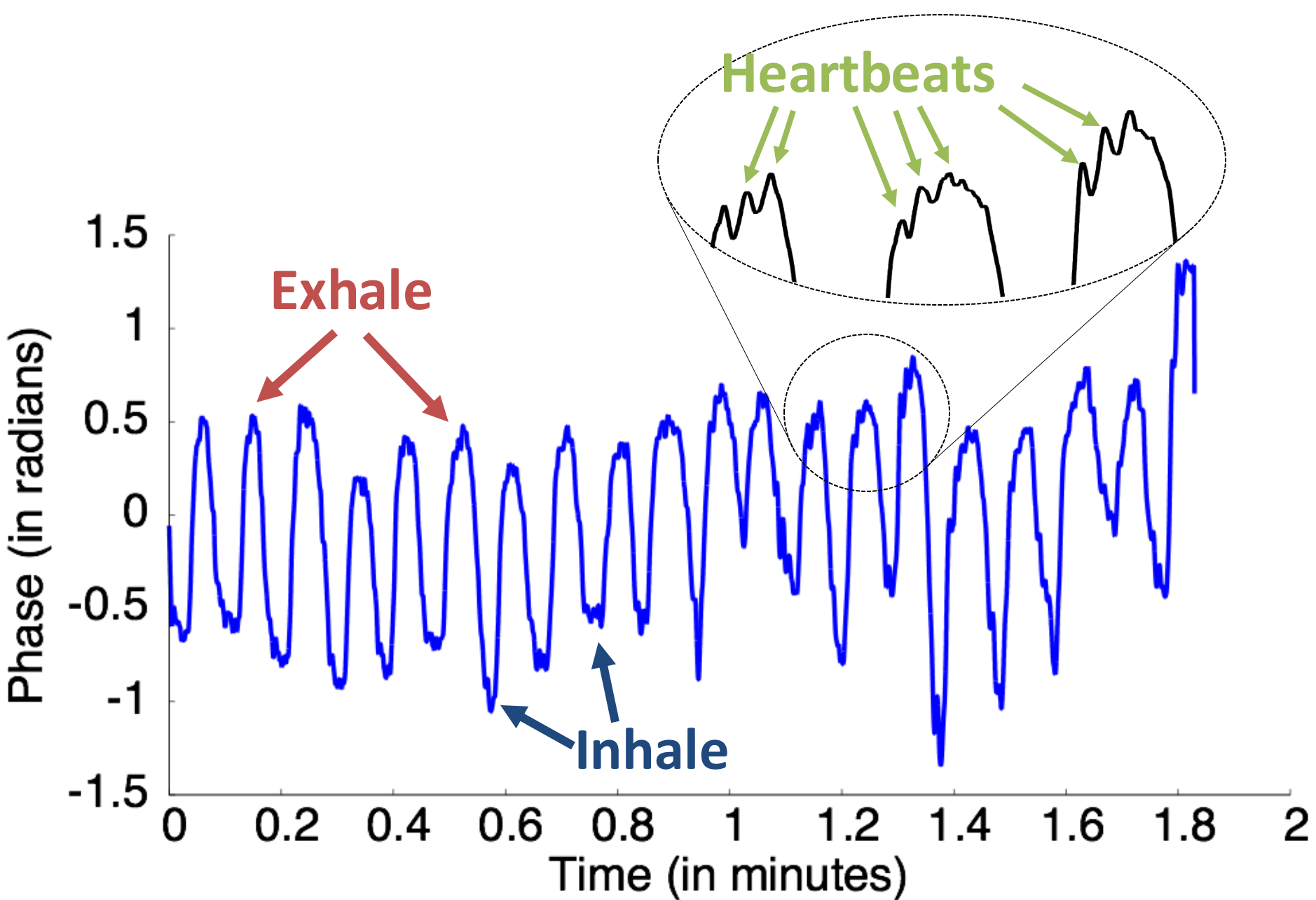
• Mix TX and RX Signal:  $y_b(t) = y(t) \times x^*(t) = \sum_i A_i e^{-j2\pi(\alpha\tau_i t + f_0\tau_i)}$



Phase

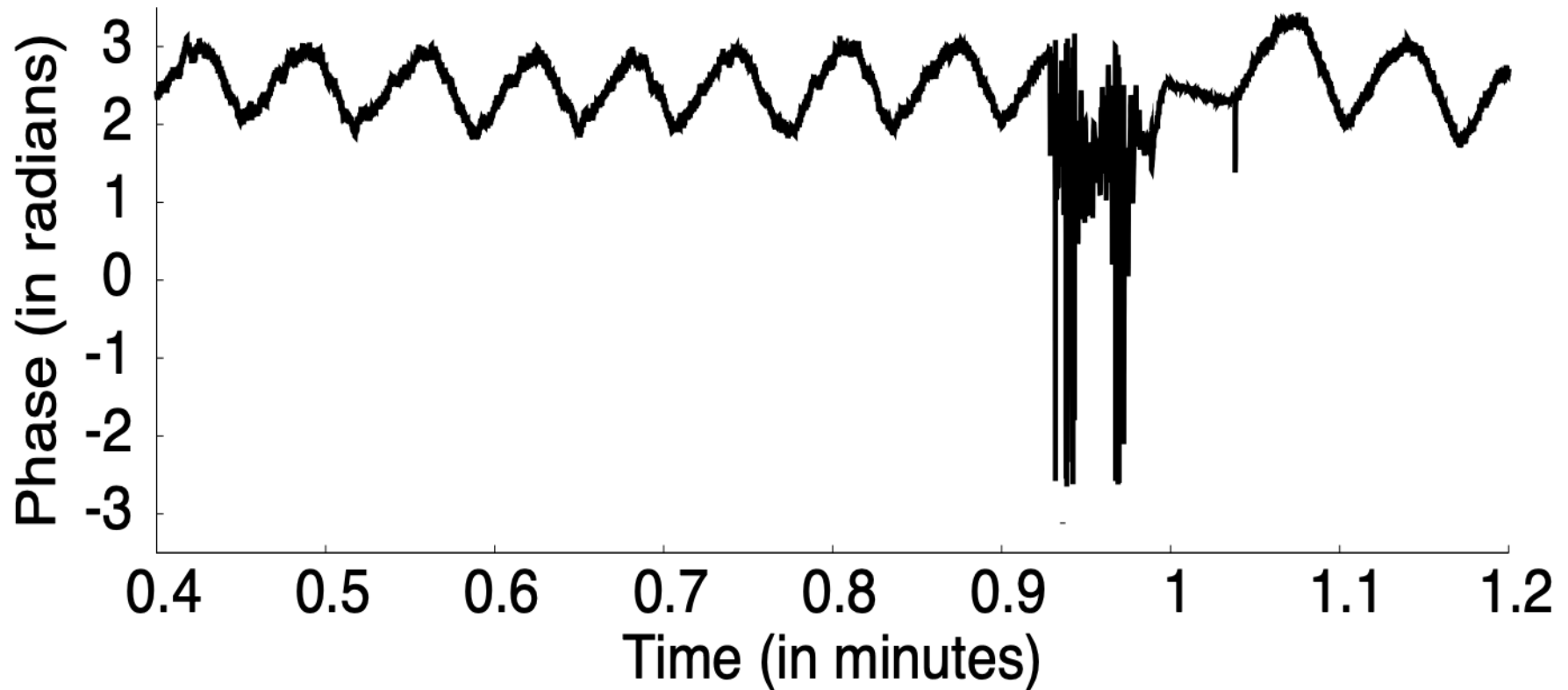
Frequencies at  $f = \alpha\tau_i$

- Phase of peak =  $f_0\tau_i$ 
  - Phase wraps around  $2\pi$
  - Use peak position  $\Delta F = \alpha \times \tau_i$  for course estimate of  $\tau_i$
  - Use peak phase  $f_0\tau_i$  for fine estimate of  $\tau_i$

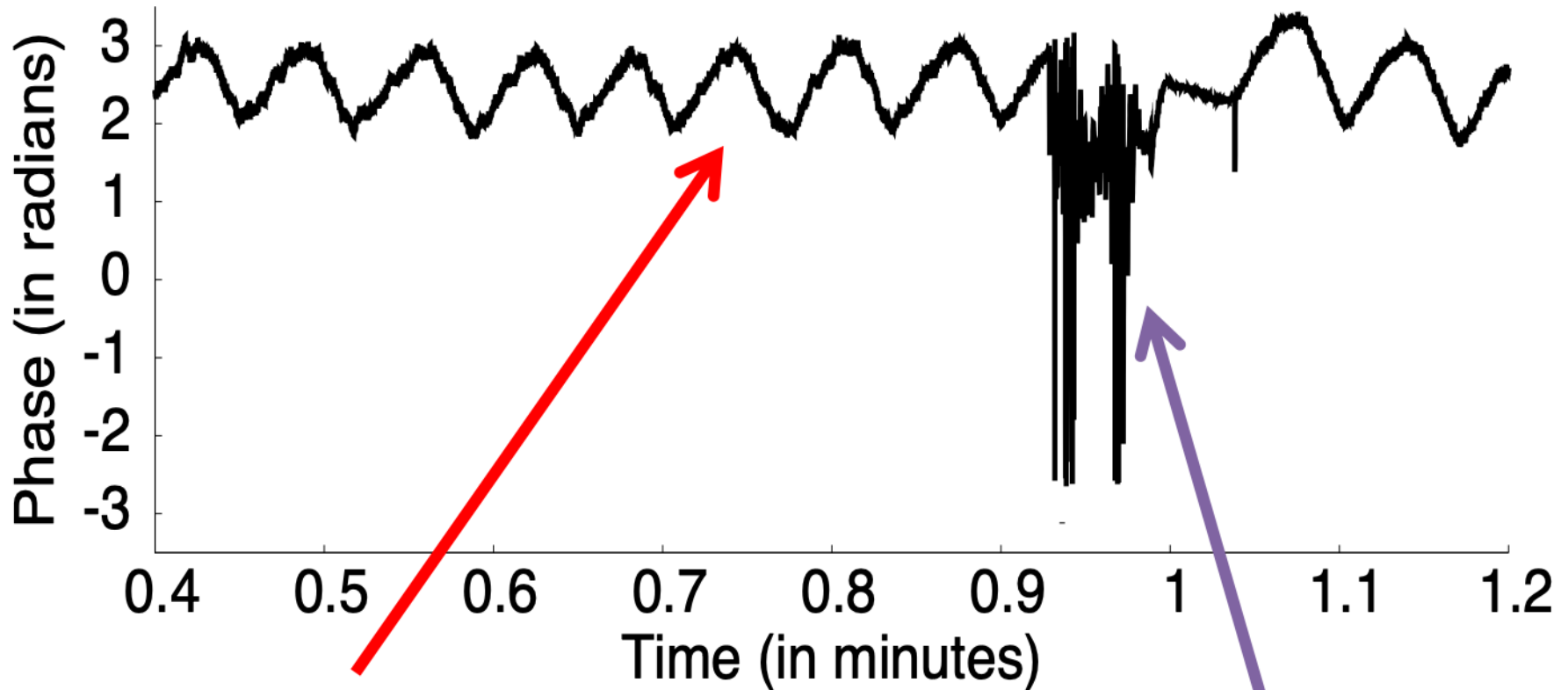


What happens when a person moves  
his limb?

# What happens when a person moves his limb?



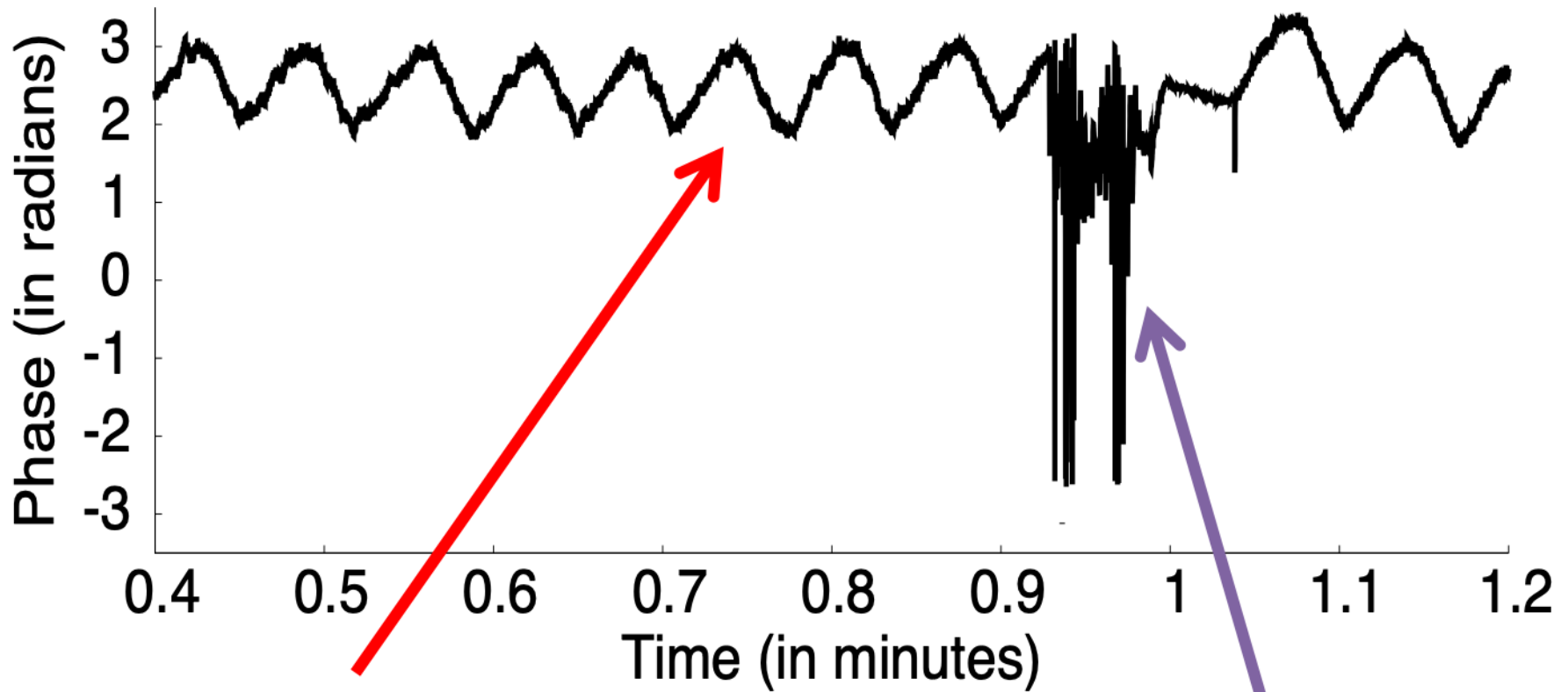
# What happens when a person moves his limb?



**Breathing**  
**Periodic**

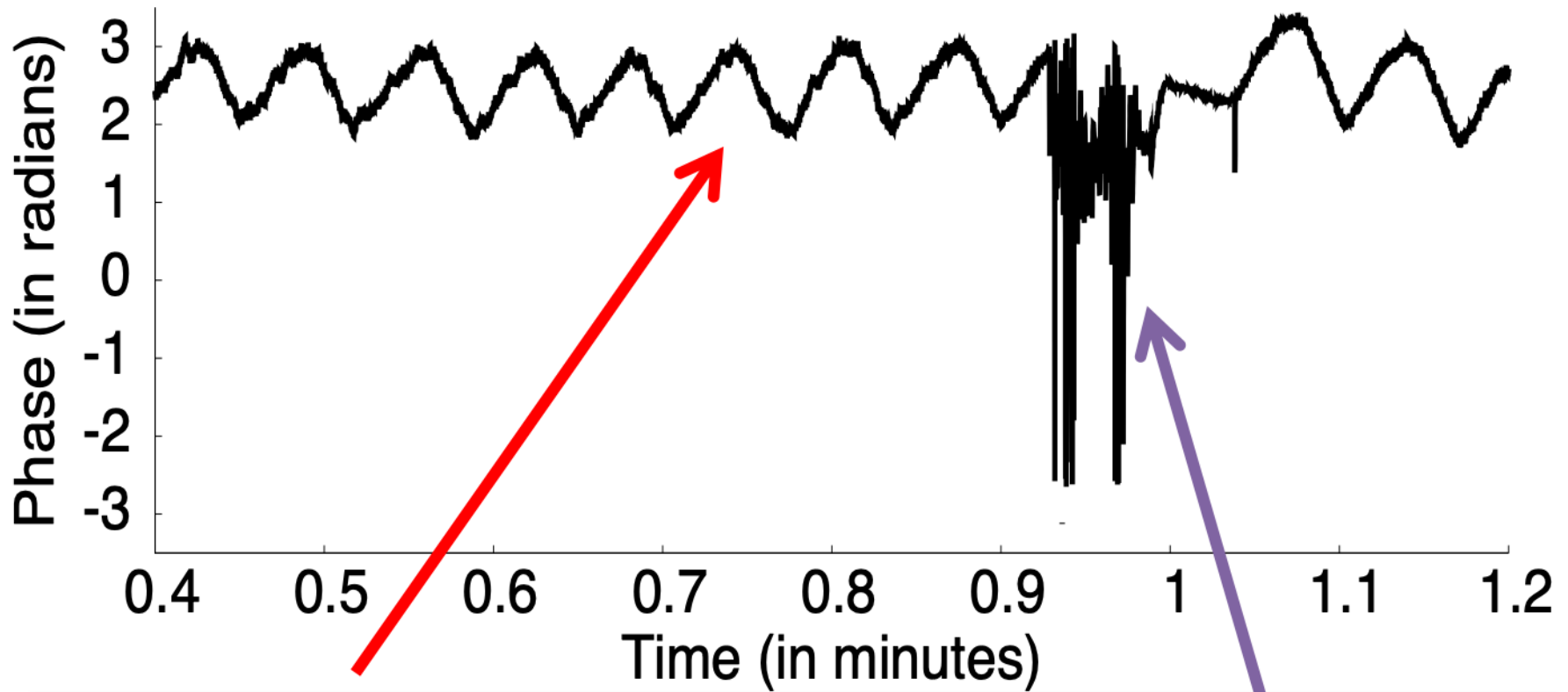
**Limb Motion**  
**Not periodic**

# 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?

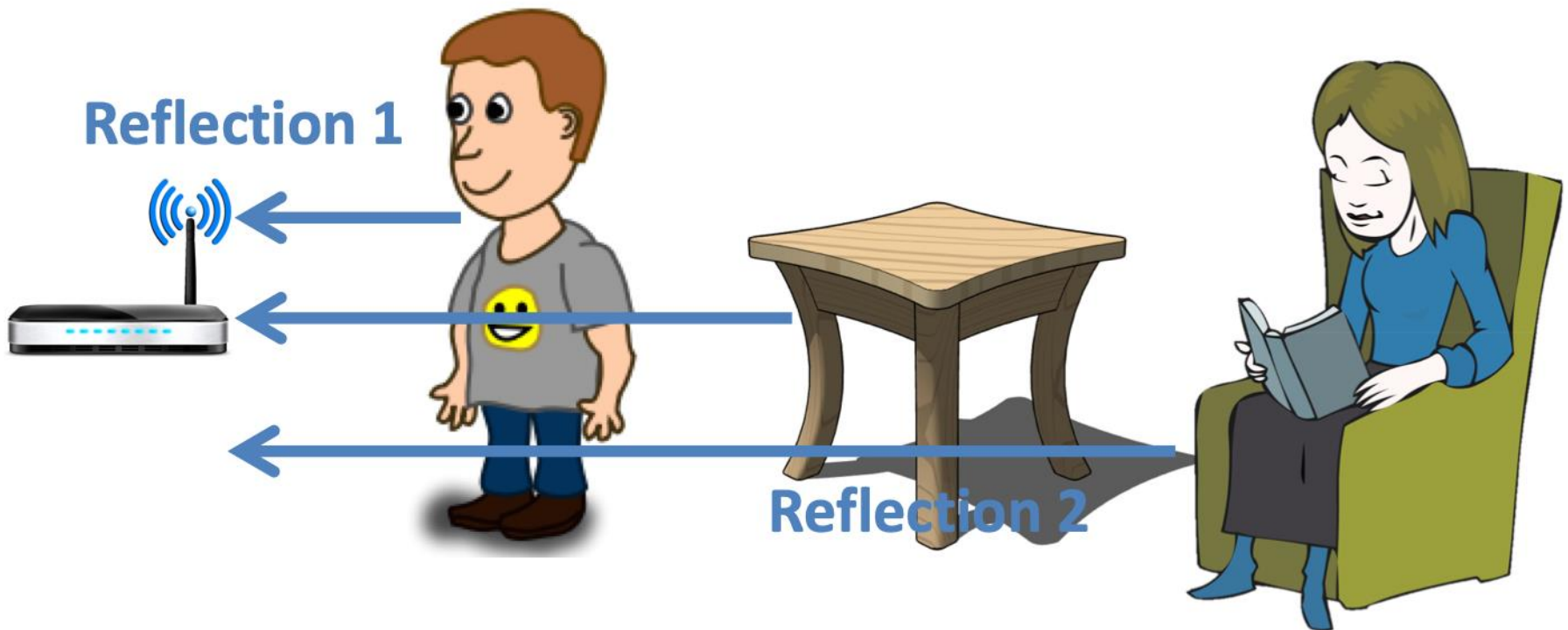


**Band-pass filter the cleaned signals to extract breathing and heart rate**

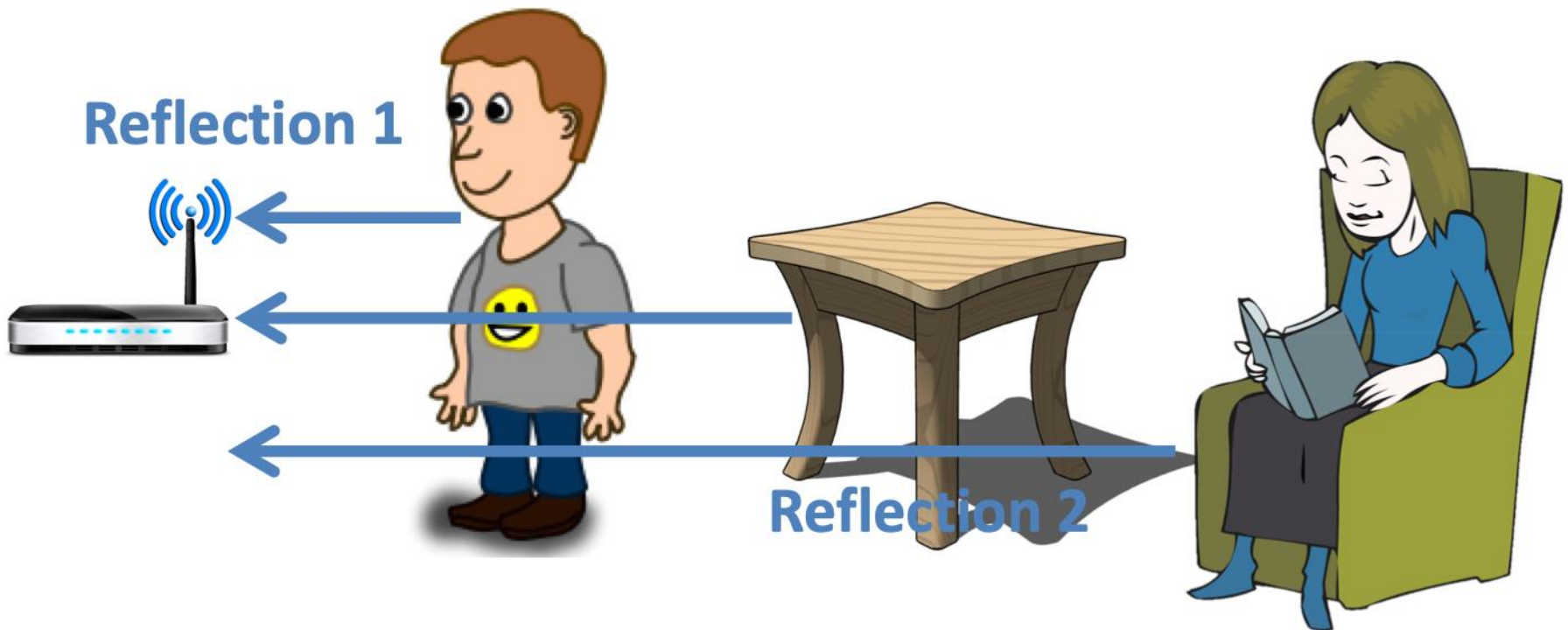
**What happens with multiple users in the environment?**

Reflections from different objects **collide**

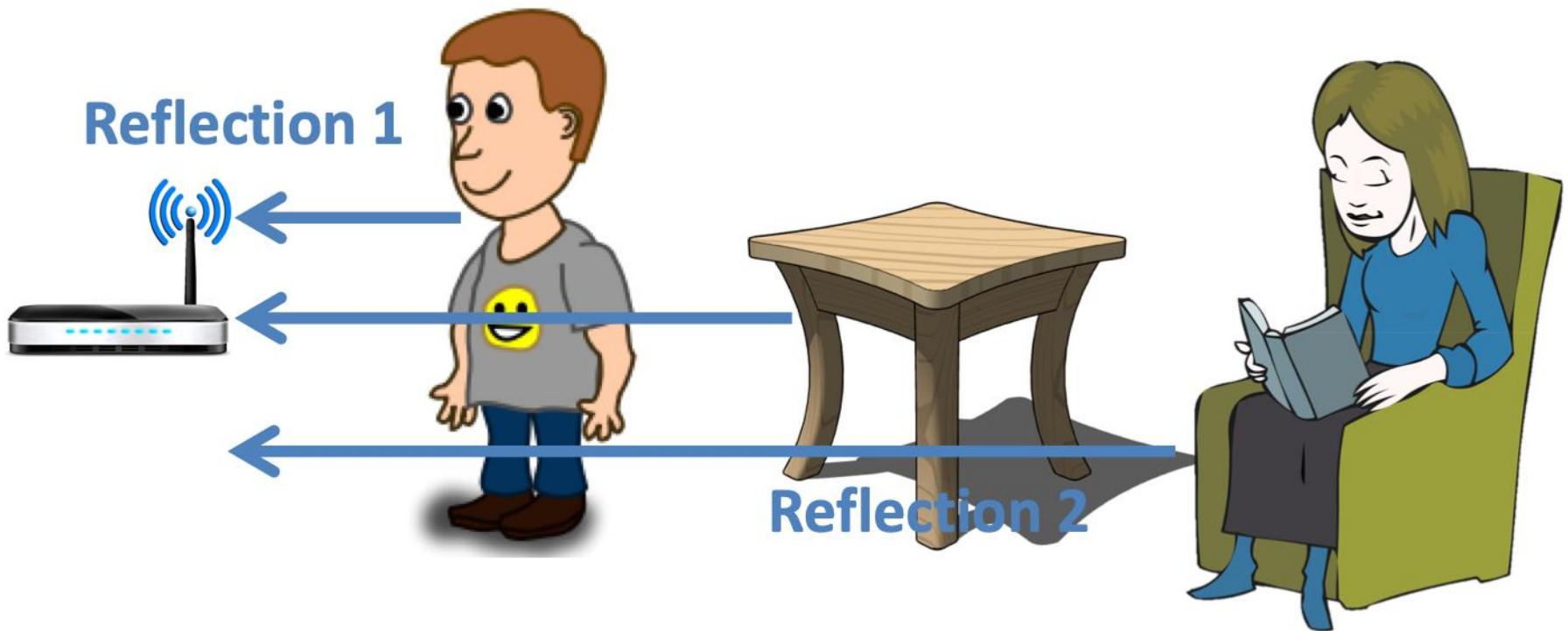
**Problem: Phase becomes meaningless!**



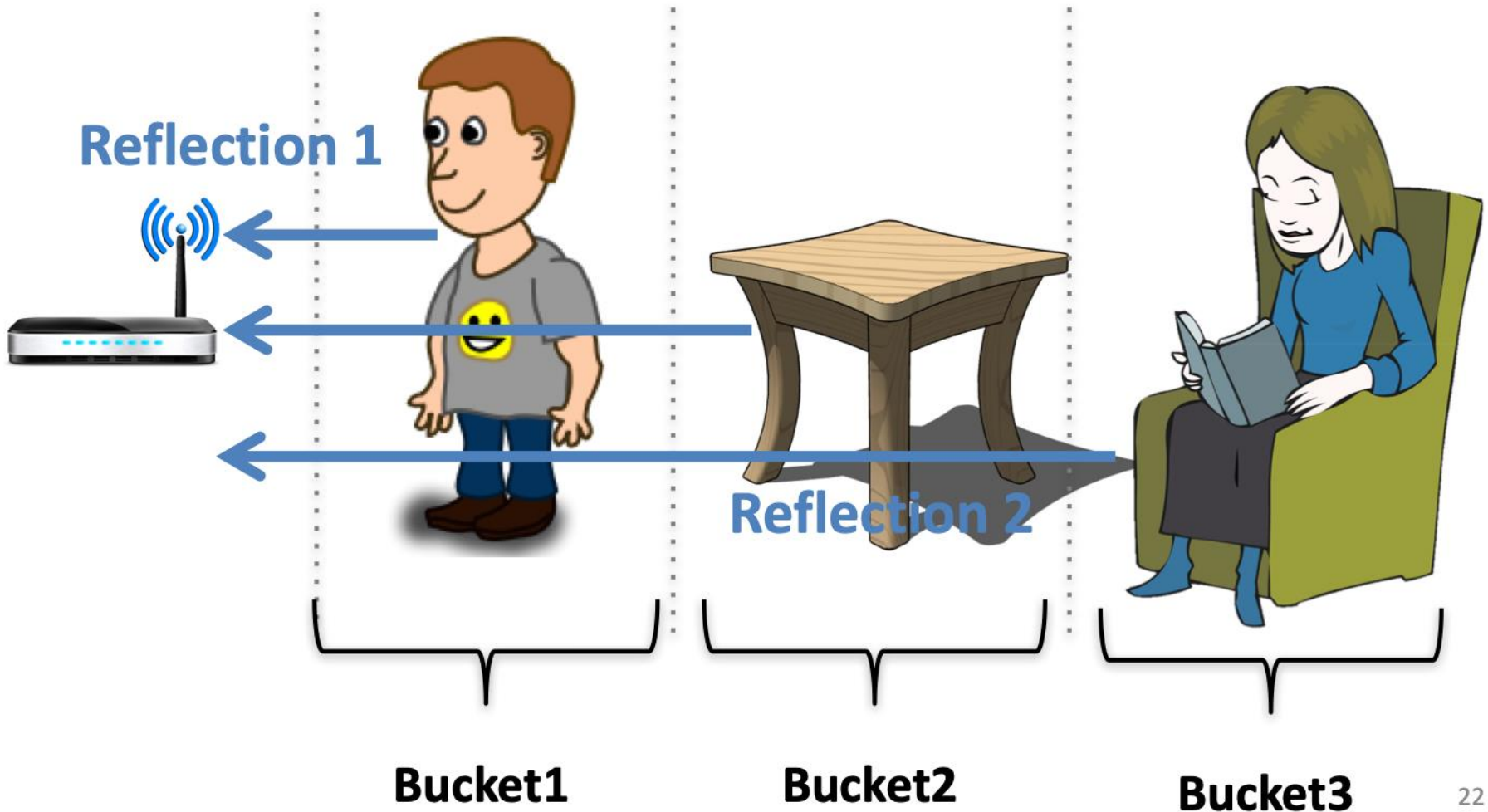
Idea: **Wireless localization** can be used to locate various devices



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



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



# 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

