6.808: Mobile and Sensor Computing

aka IoT Systems

http://6808.github.io

Lecture 4:
Device-Free Localization and Seeing Through Walls

Course Staff

Lecturer

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Logistics & Norms

1- Make sure your **name** displays

2- Turn on your **video**

3- **Mute** yourself

To ask questions:

Raise hand feature or write in chat

Announcements

1- Lab 0 checkoff by Wed

2- Lab 1 due March 4

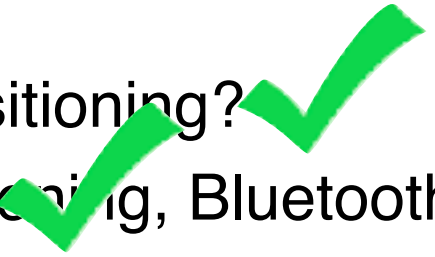
3- PSet 1 Due March 17

Objectives of the Three Lectures Series

Learn the fundamentals, applications, and implications of

wireless localization and sensing

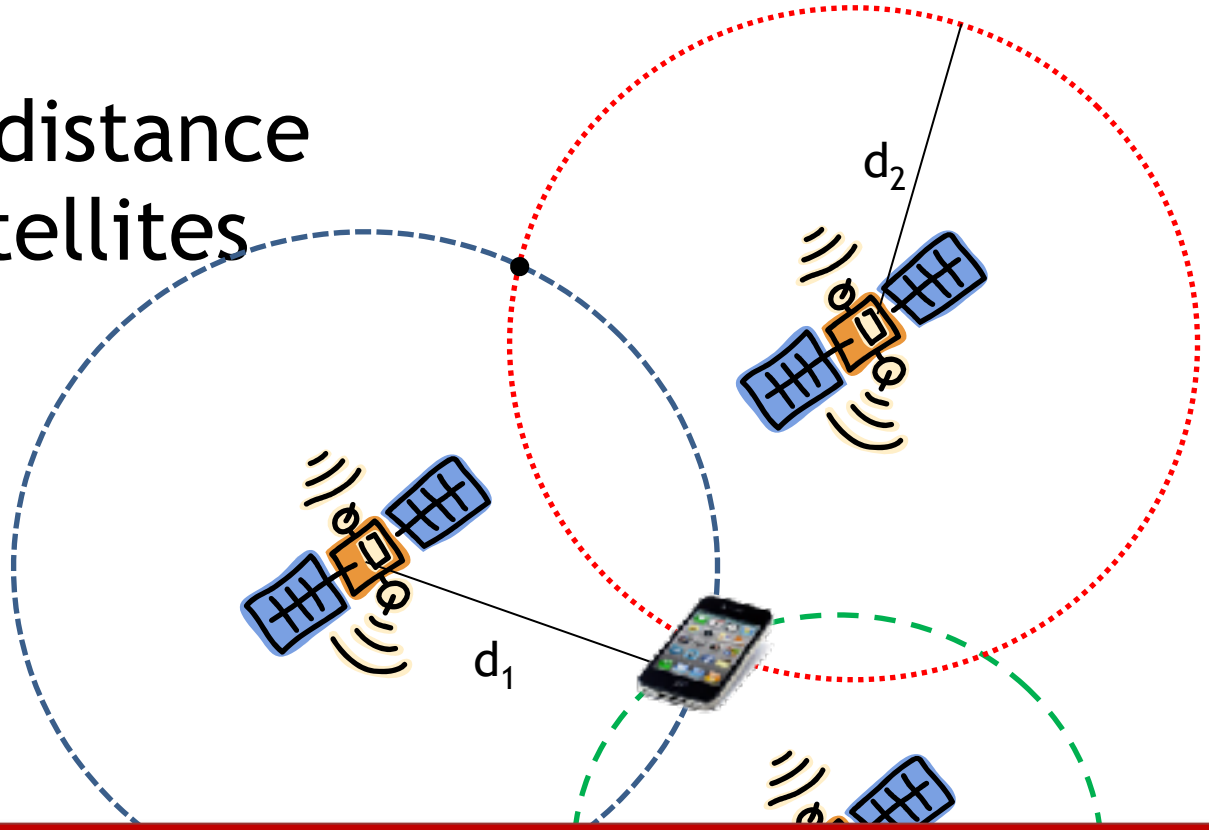
1. What are the unifying principles of wireless positioning?
2. How do practical systems like GPS, WiFi positioning, Bluetooth contact tracing work?
3. What is wireless (aka WiFi) sensing?
4. What are the industry opportunities and societal implications of wireless sensing (today and in the near+far future)?



this lecture

GPS

Compute the distance to the GPS satellites



distance = propagation delay x speed of light

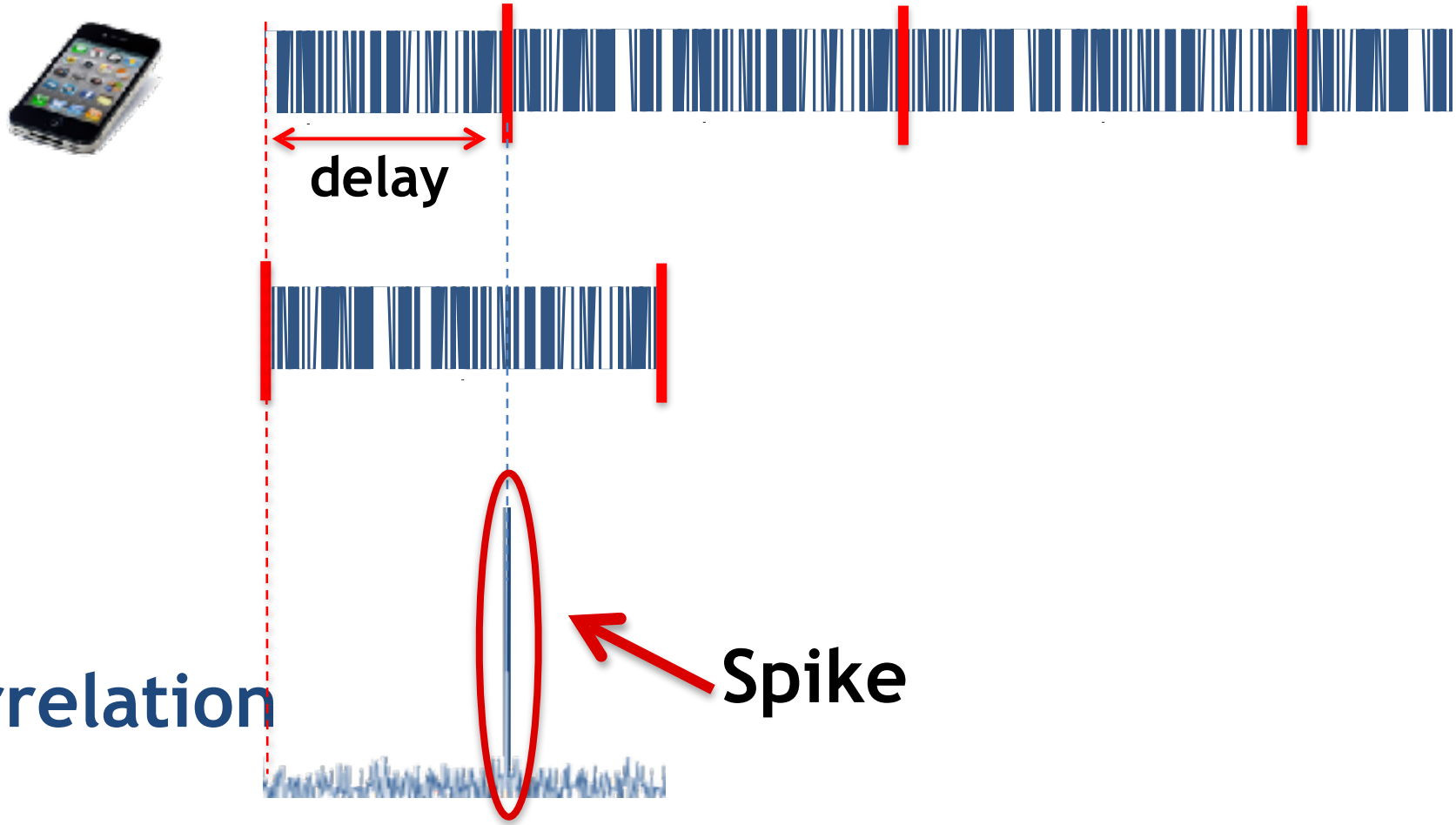
How to Compute the Propagation Delay?

Each satellite has its own code

How to Compute the Propagation Delay?

Code arrives shifted by propagation delay

How to Compute the Propagation Delay?



Spike determines the delay

use it to compute distance and localize

GPS Data Packet

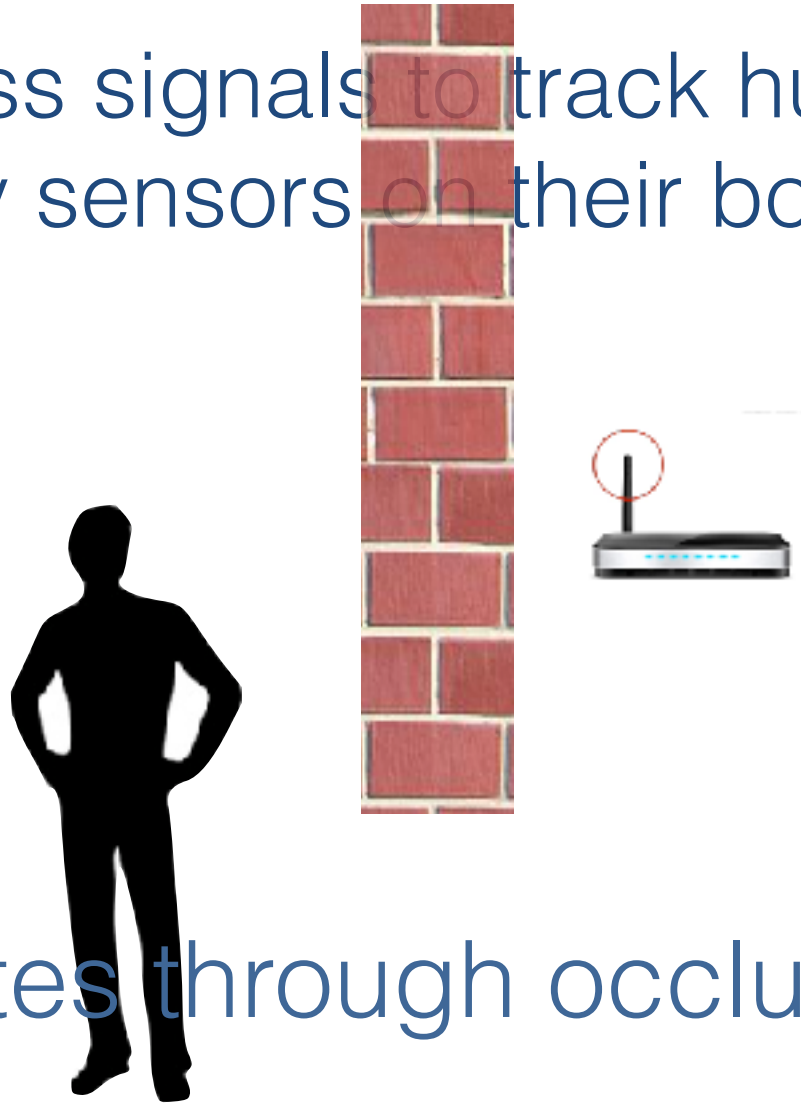
- Almanac & ephemeris data
  - Satellite location, clock, orbital parameters, etc.
  - Bitrate?
    - 50 bits/second
  - Takes about 12.5 minutes to download

- How do today's systems use it?
  - A-GPS (Assisted GPS)
  - WiFi APs are mapped — war-driving

So Far
Device-based Localization

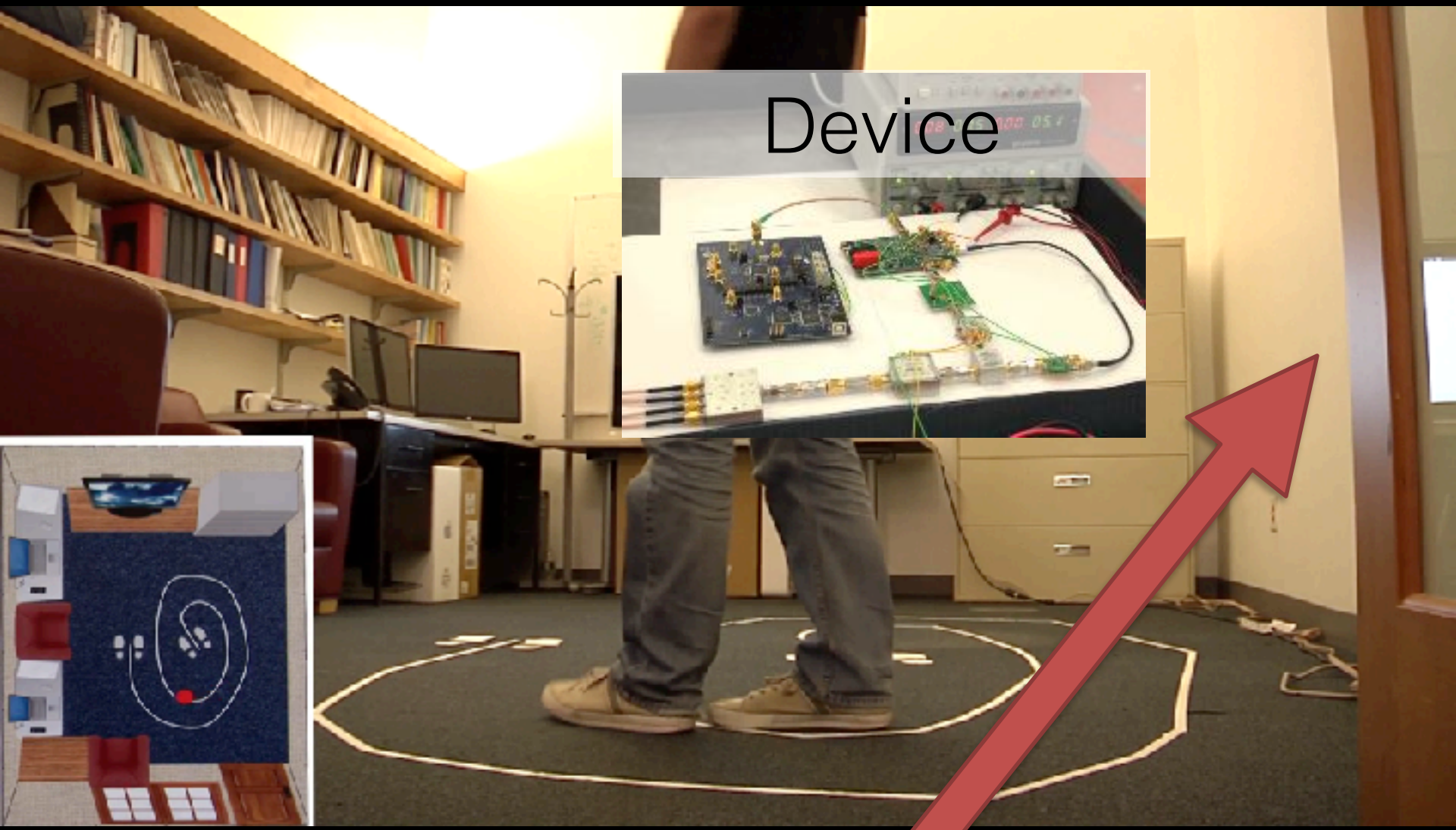
Next: Device-Free Localization (aka Wireless Sensing)

Using wireless signals to track humans without any sensors on their bodies



Operates through occlusions

Example: WiTrack


Device
Device in another room

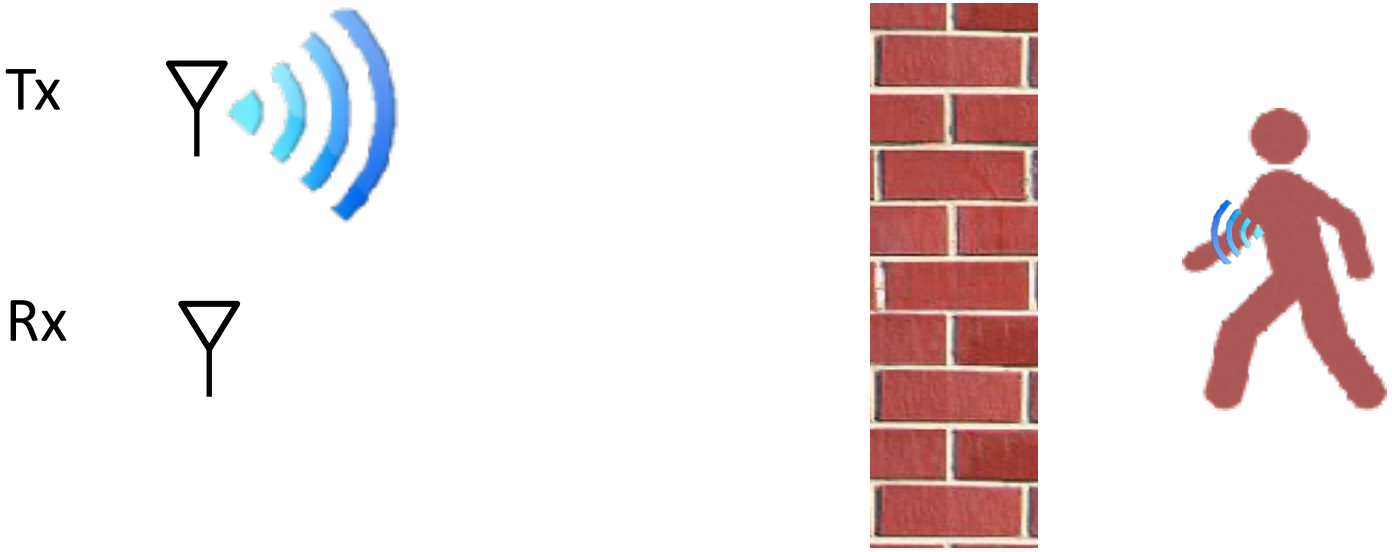
Applications

Smart Homes

Energy Saving

Gaming & Virtual Reality

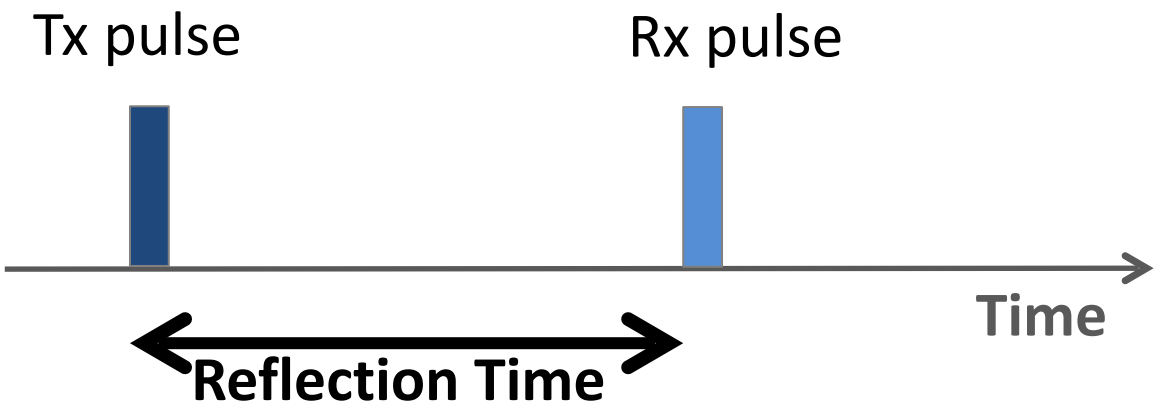
Measuring Distances



Distance = Reflection time x speed of light

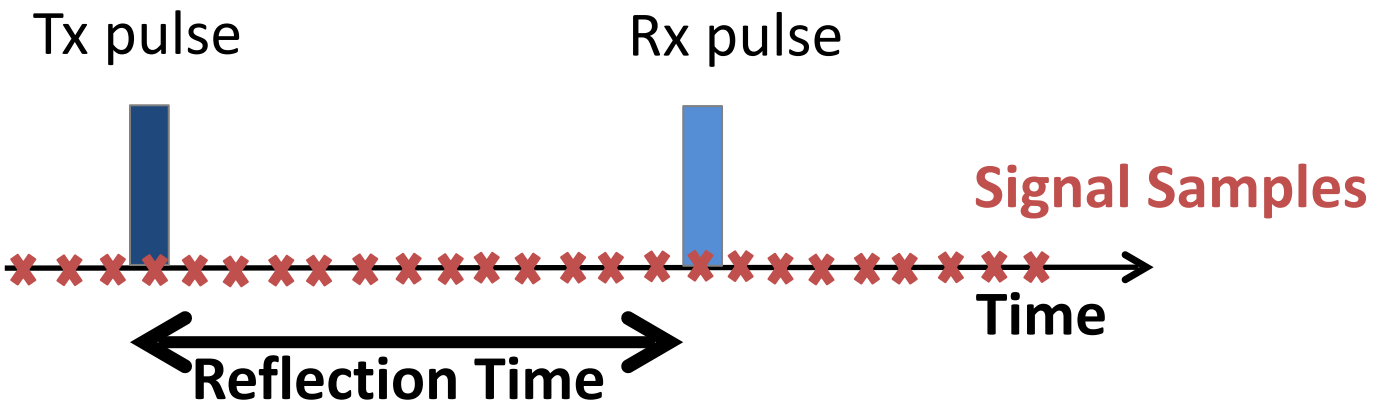
Measuring Reflection Time

Option1: Transmit short pulse and listen for echo



Measuring Reflection Time

Option1: Transmit short pulse and listen for echo



Capturing the pulse needs sub-nanosecond sampling

Why?

and why was this not a problem for Cricket?

Why was this not a problem for Cricket?

Capturing the pulse needs sub-nanosecond sampling

Why?

Multi-GHz samplers are expensive, have high noise, and create large I/O problem

Distance = time x speed

"smallest distance resolution"

"smallest time"

$$10cm = \Delta t \times (3 \times 10^8)$$

$$\Delta t = 0.3ns$$

0.3ns period => how many samples per second?

$$SamplingRate = \frac{1}{\Delta t}$$

3GSps! >> MSps for WiFi, LTE…

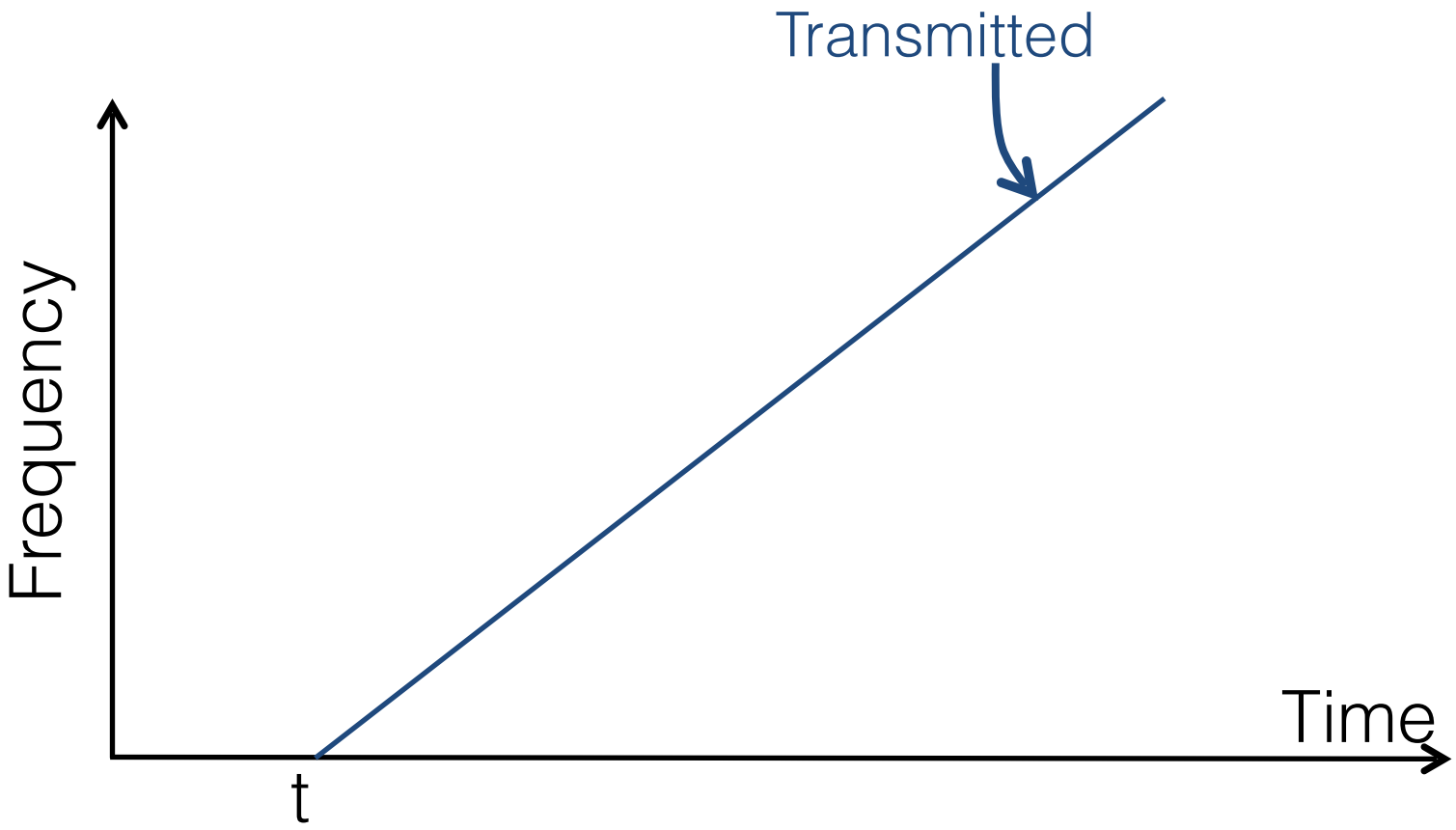
Why was this not a problem for Cricket?

because speed of ultrasound

$$10cm = \Delta t \times 345$$

$$SamplingRate = \frac{1}{\Delta t} \approx 3kbps$$

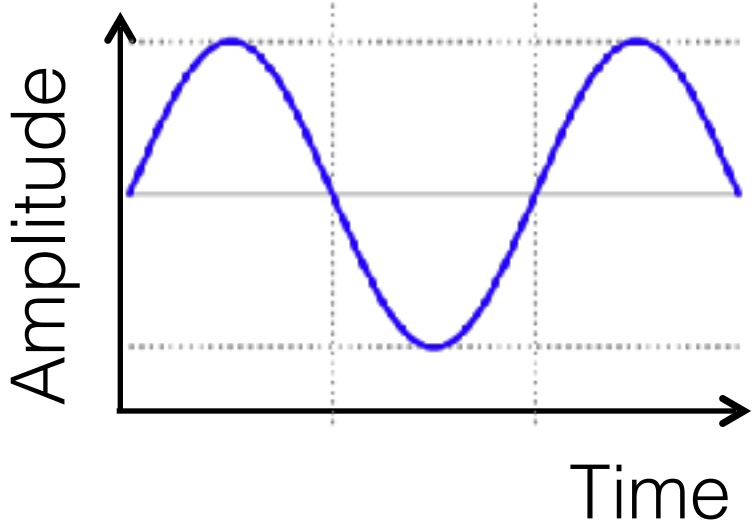
FMCW: Measure time by measuring frequency

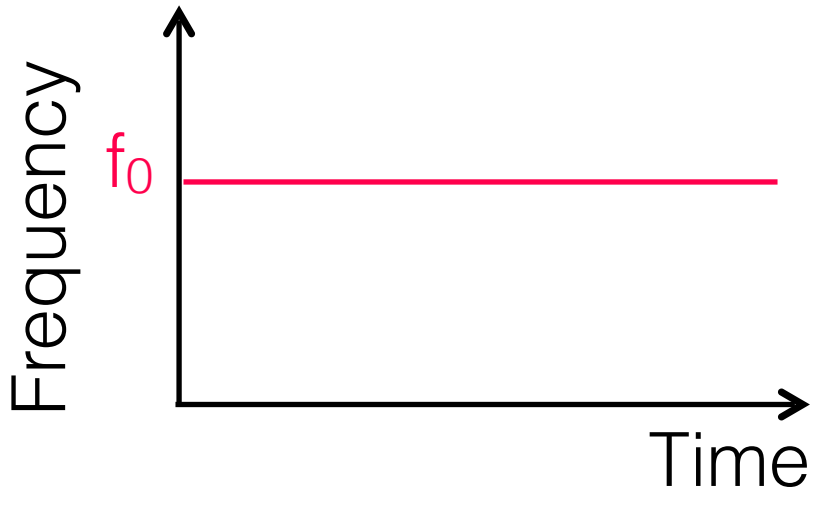


How does it look in time domain?

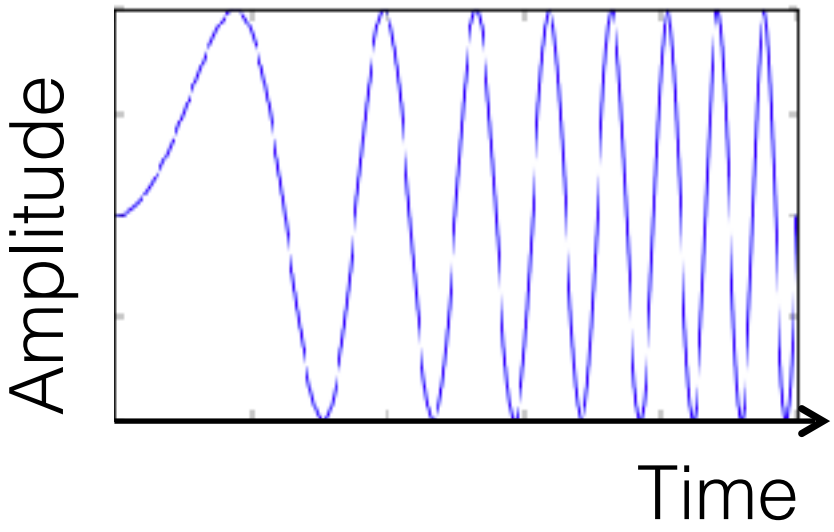
More intuitive understanding of FMCW

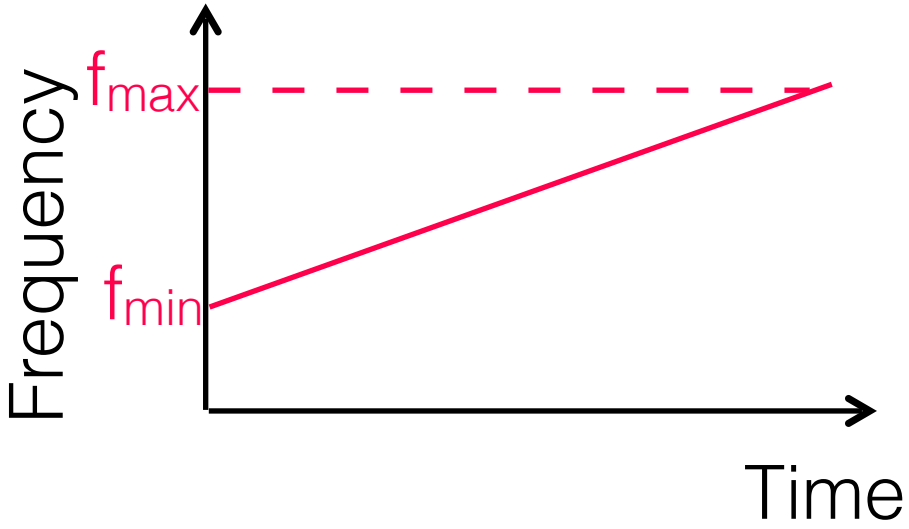
Wireless Signal at frequency f_0



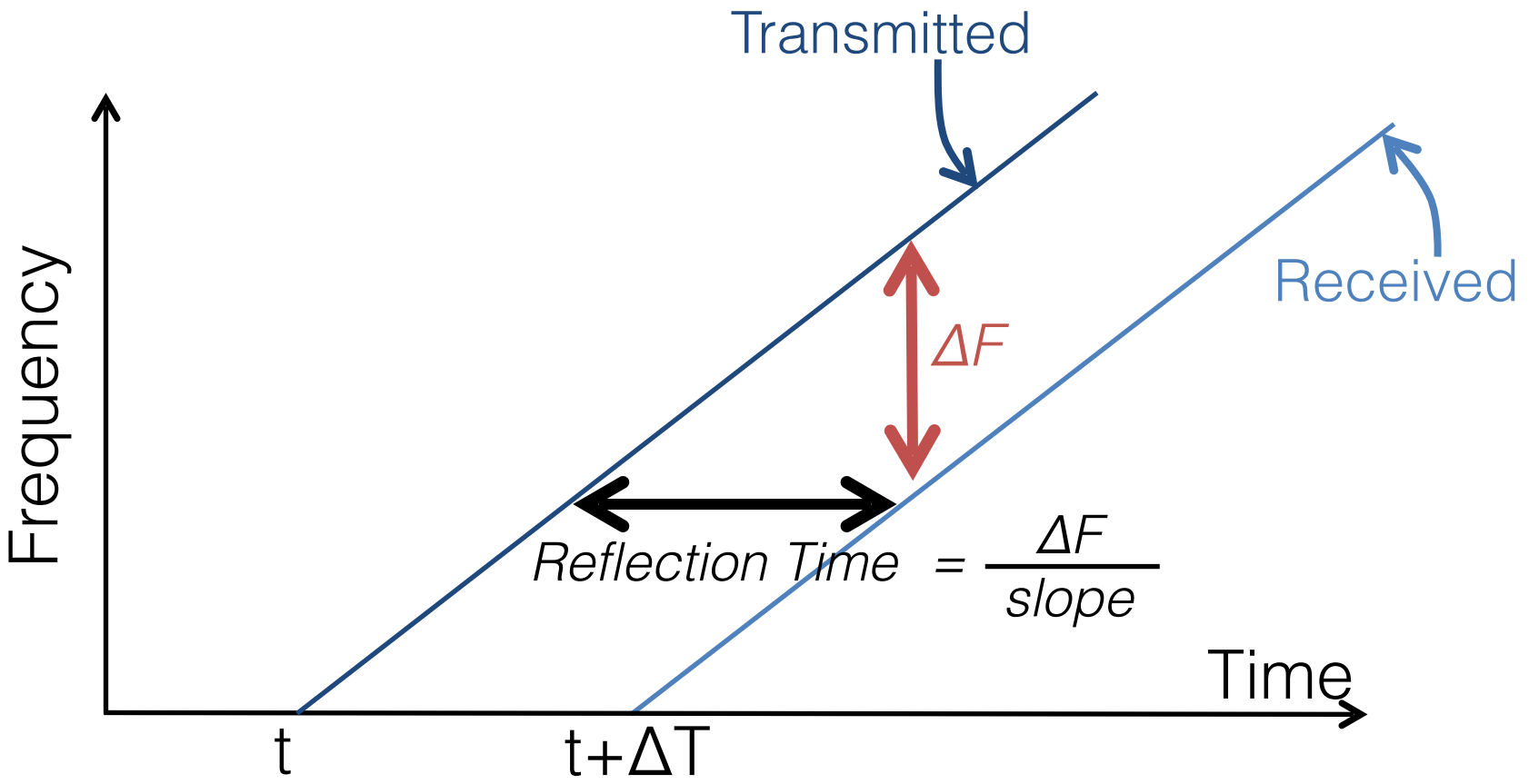


FMCW signal





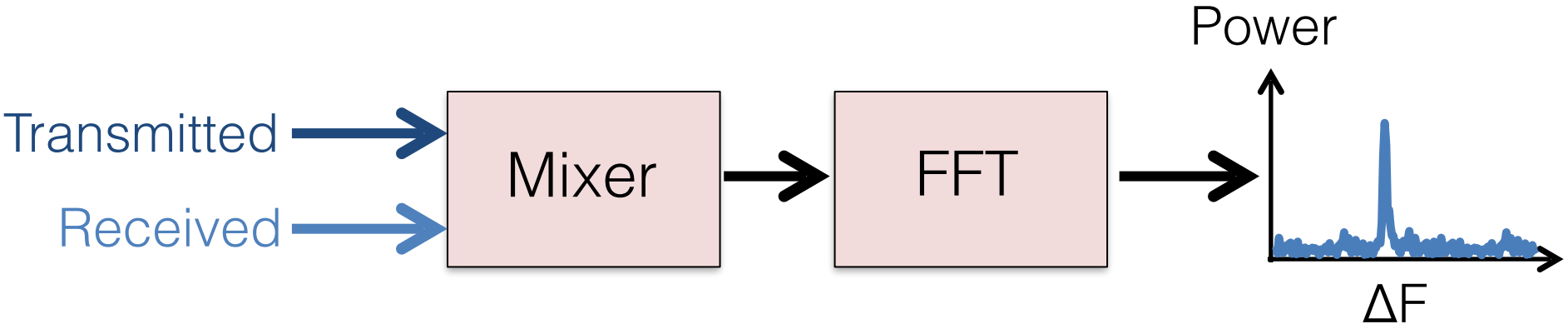
FMCW: Measure time by measuring frequency



How do we measure ΔF?

Measuring ΔF

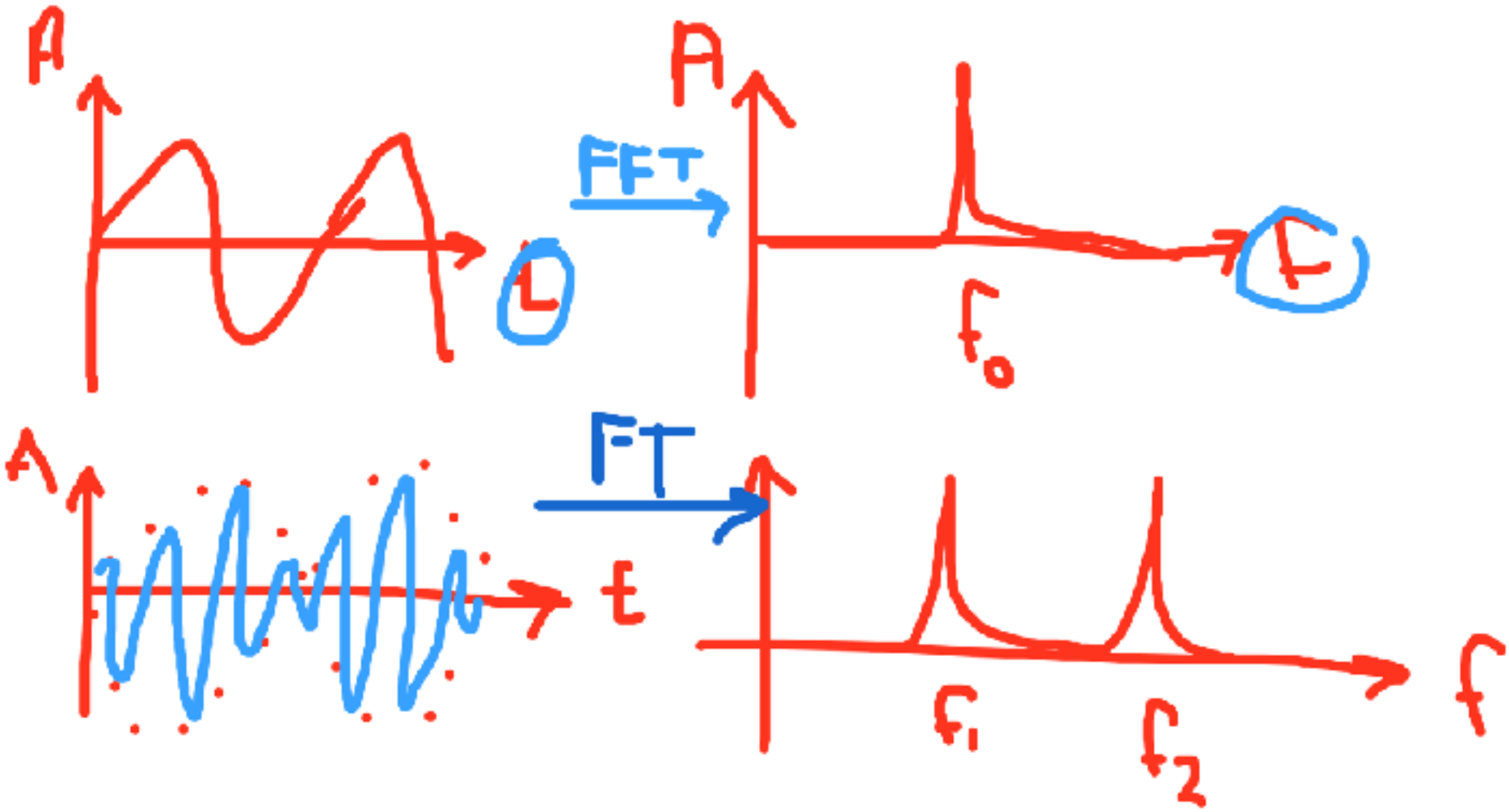
- Subtracting frequencies is easy (e.g., removing carrier in WiFi)
- Done using a mixer (low-power; cheap)



Signal whose frequency is ΔF

let's talk about FFTs a bit — freq

Basics of Fourier Transform



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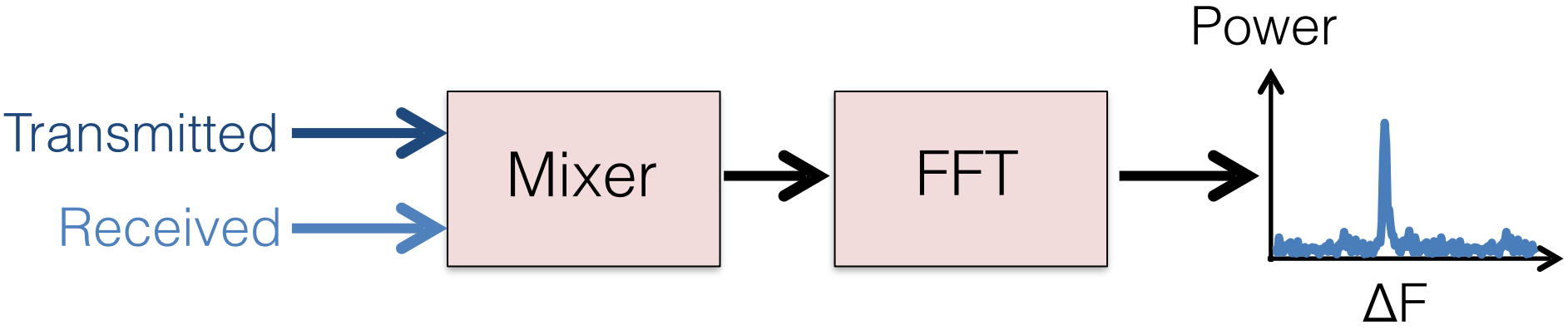
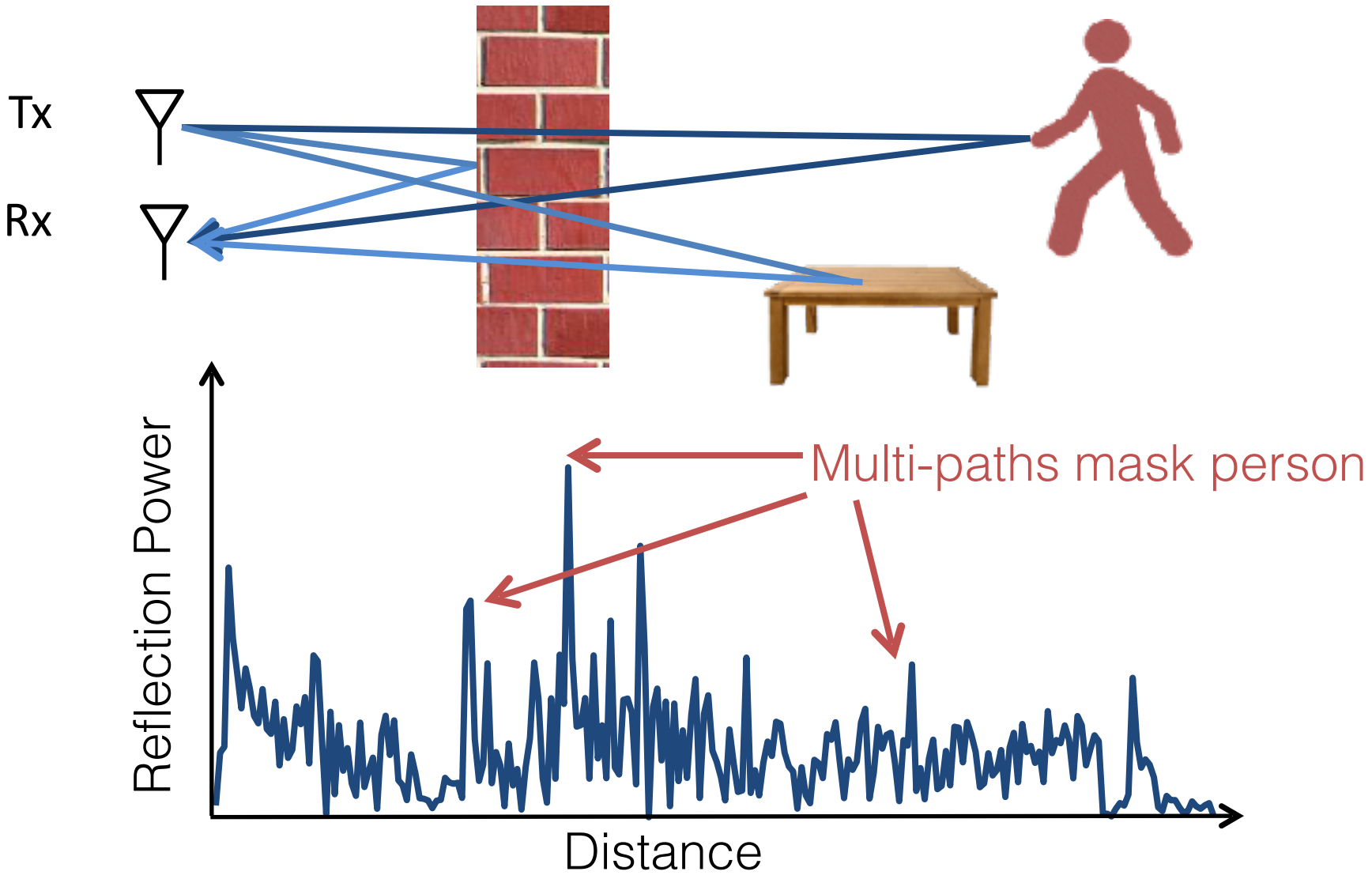


Signal whose frequency is ΔF

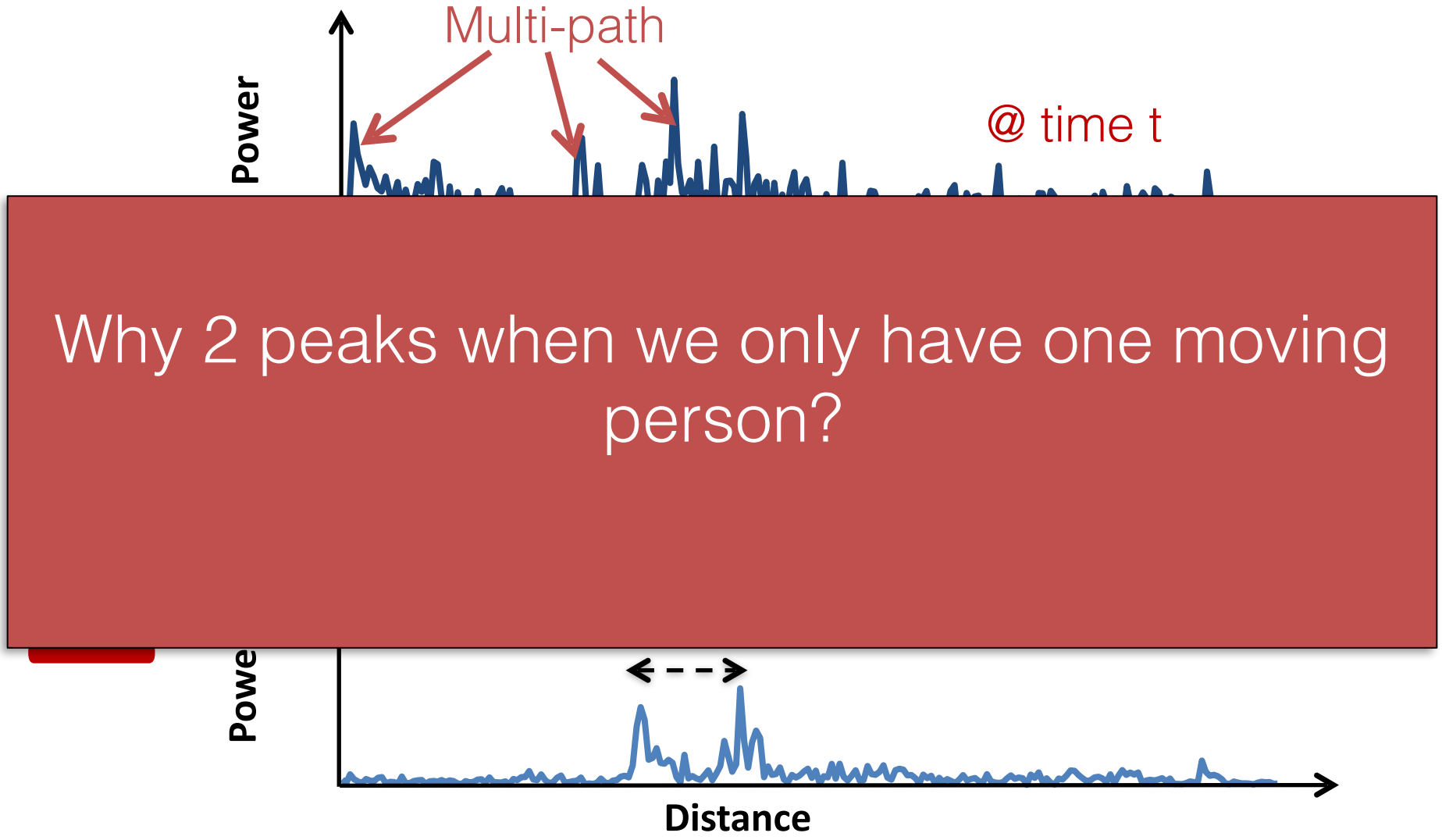
ΔF →Reflection Time → Distance

Challenge: Multipath➔ Many Reflections



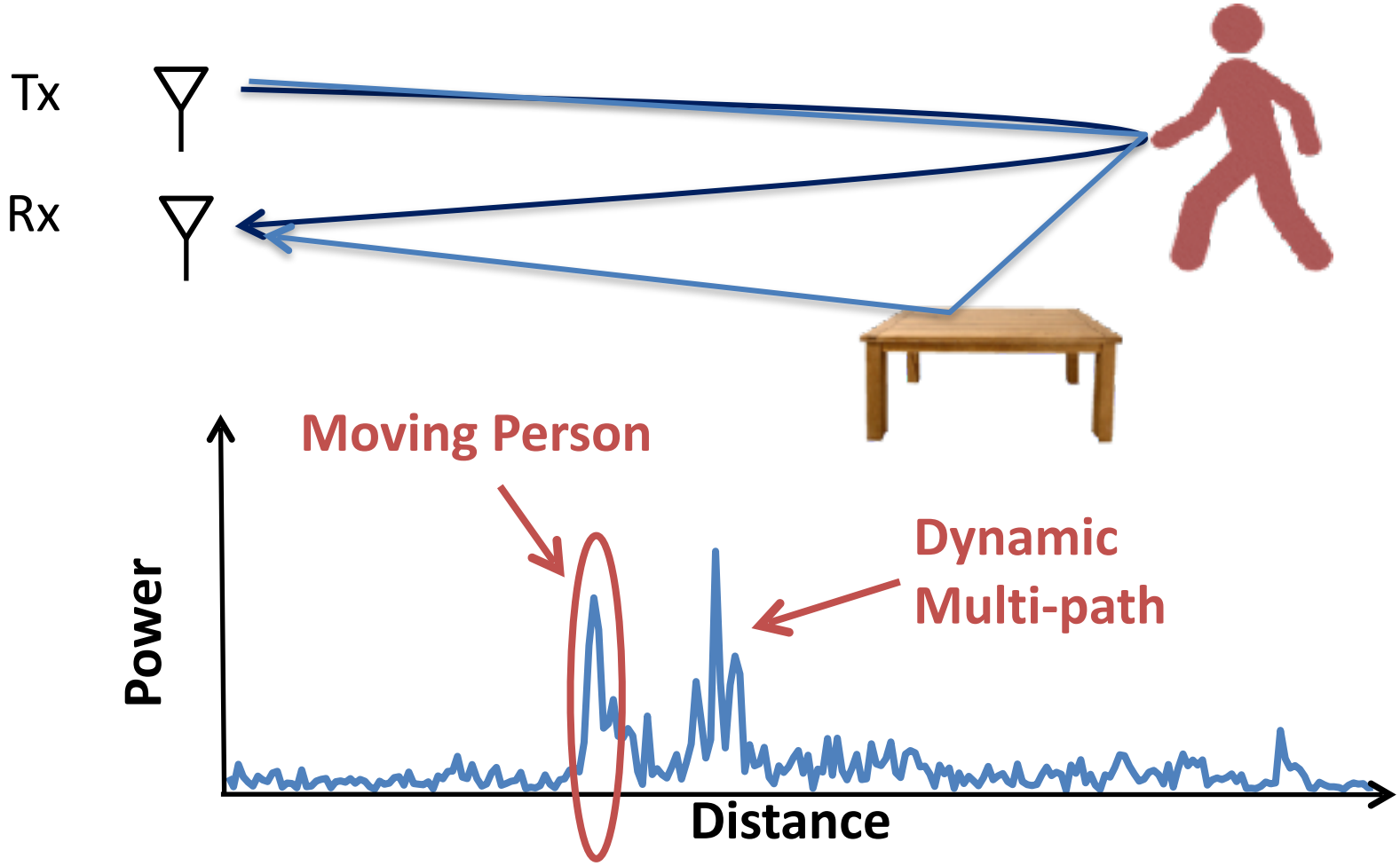
Static objects don't move

➔ Eliminate by subtracting consecutive measurements



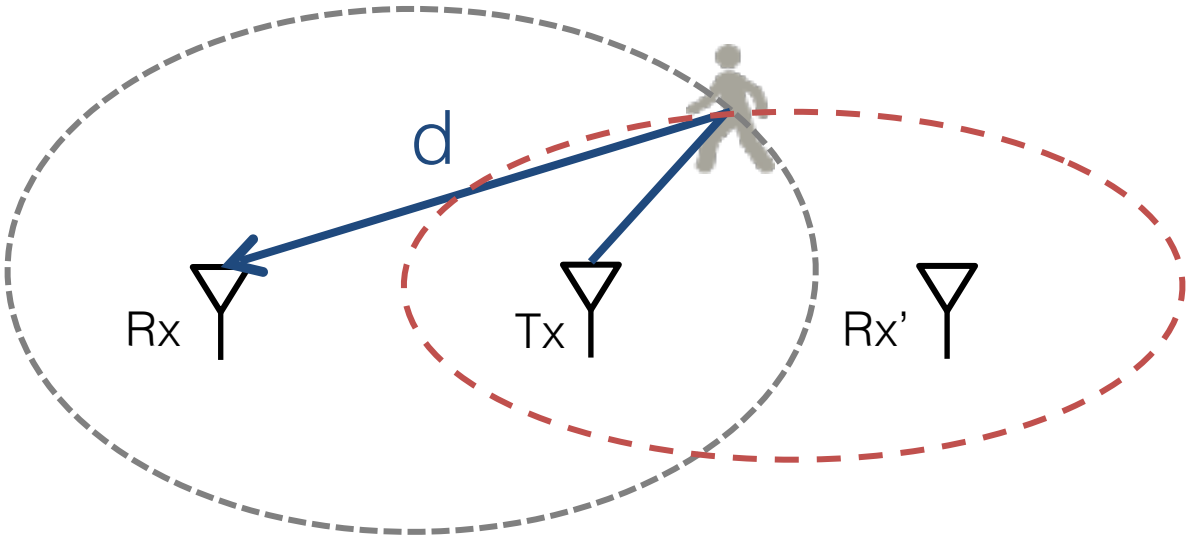
Why 2 peaks when we only have one moving person?

The direct reflection arrives before dynamic multipath!



Mapping Distance to Location

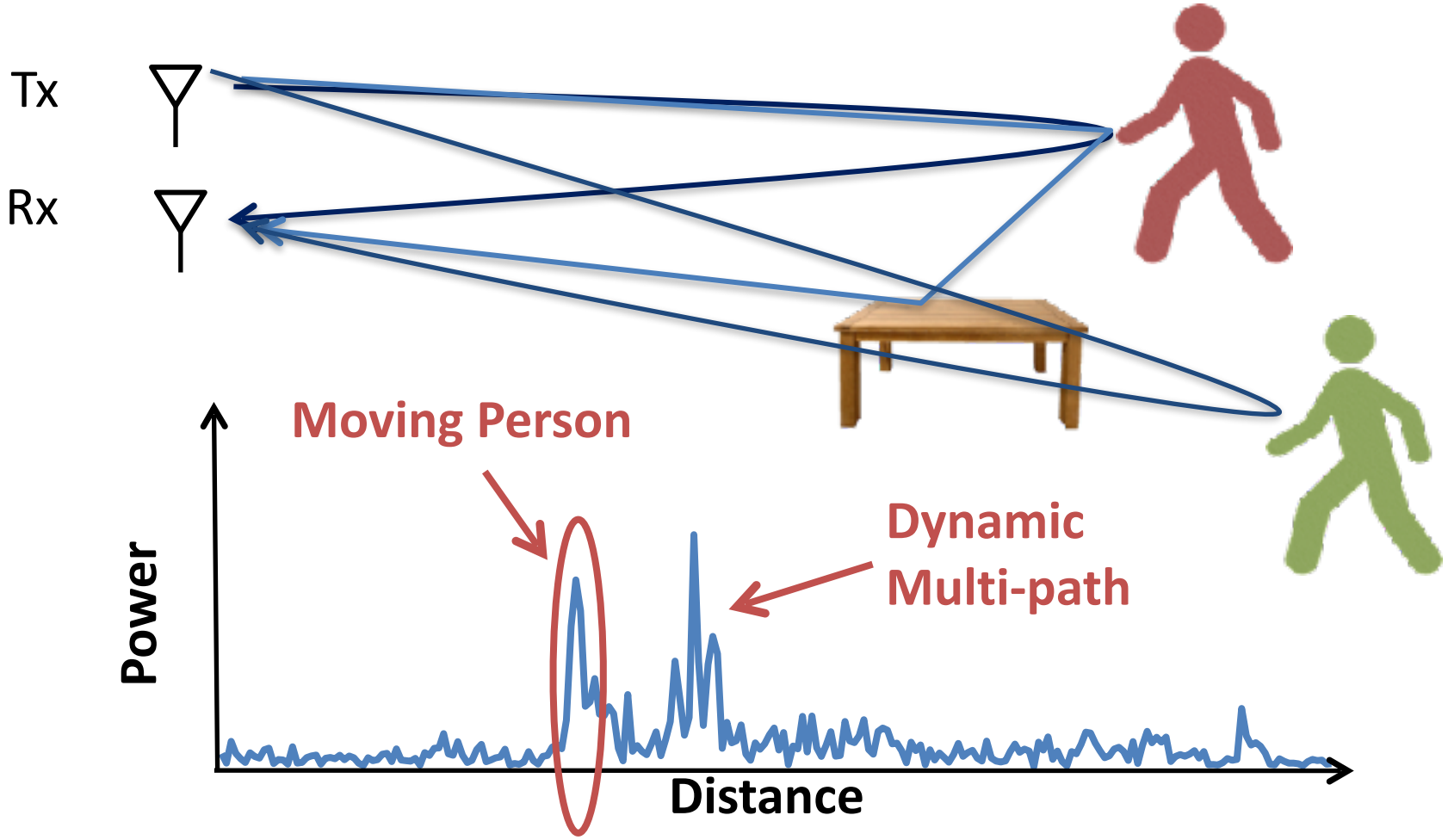
Person can be anywhere on an ellipse whose foci are (Tx,Rx)



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

From Location to tracking (over time)

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?

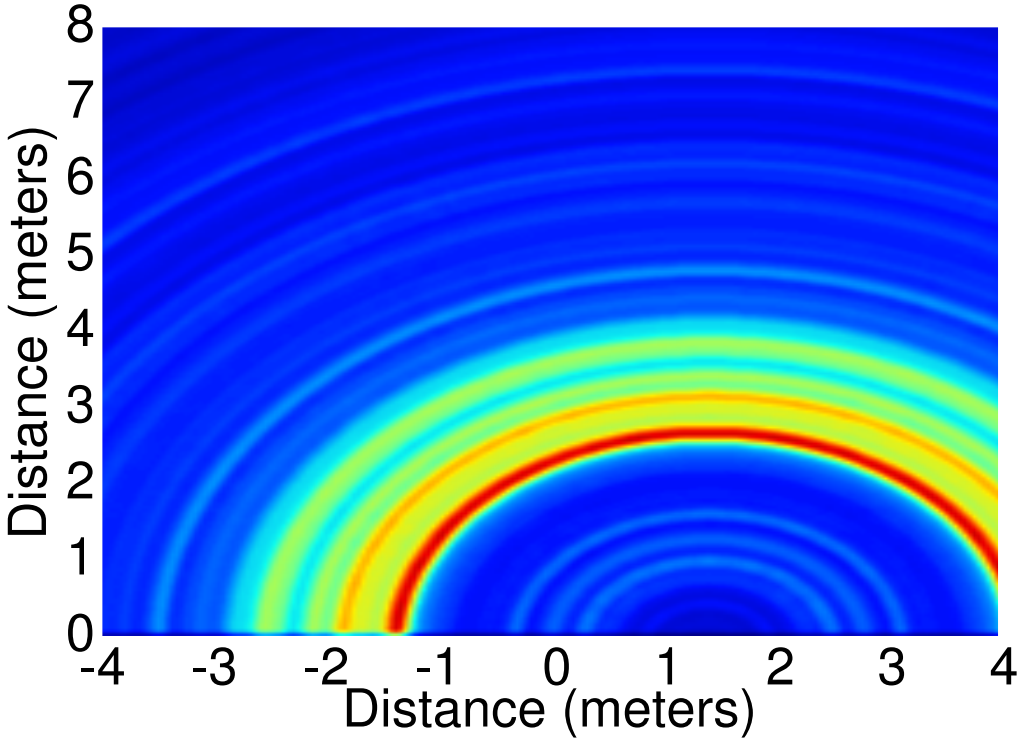
Idea: Person is consistent across different vantage points while multi-path is different from different vantage points

Combining across Multiple Vantage Points

Experiment: Two users walking

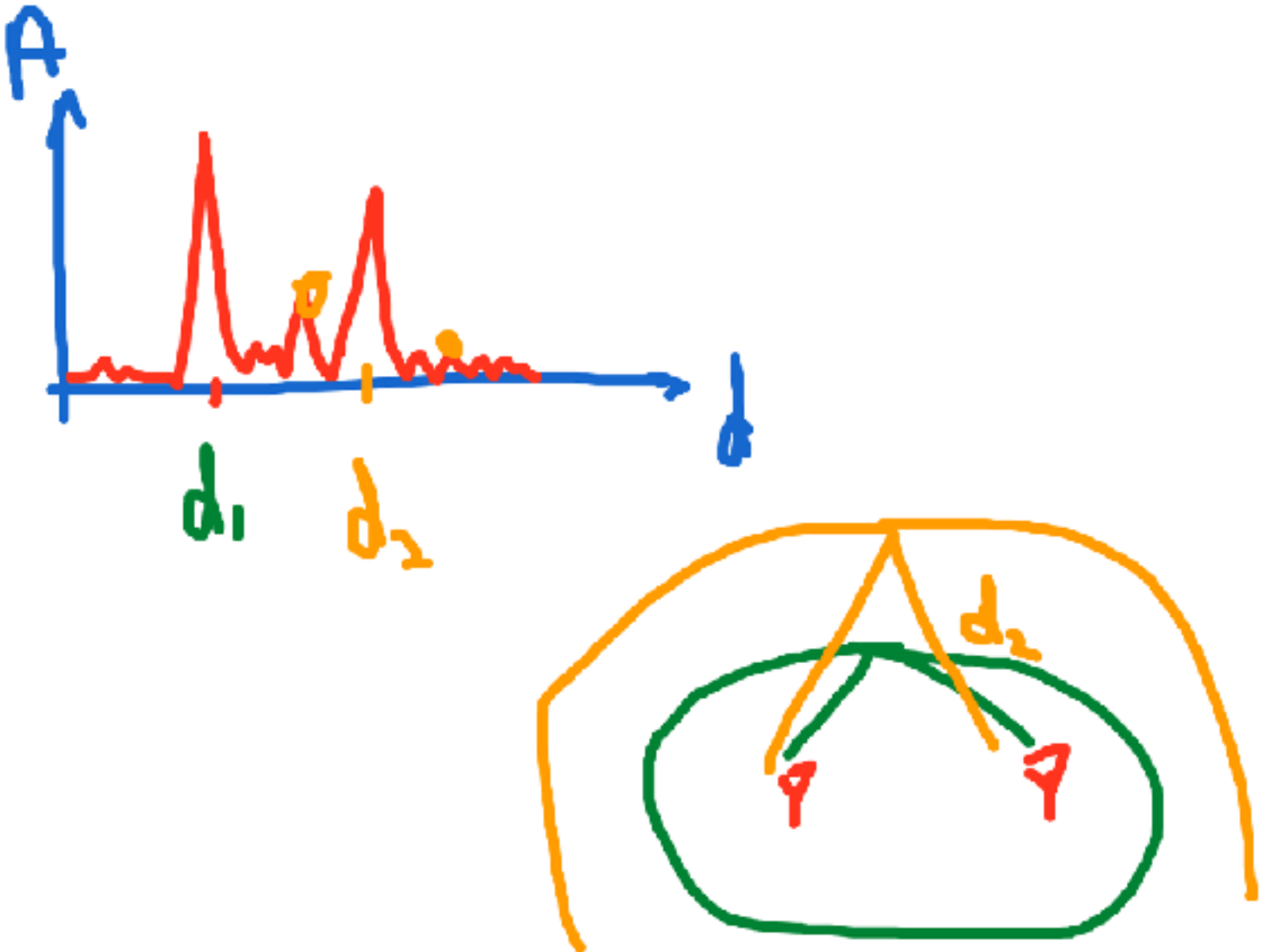
Setup

Single Vantage Point



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

Mapping 1D to 2D heatmap



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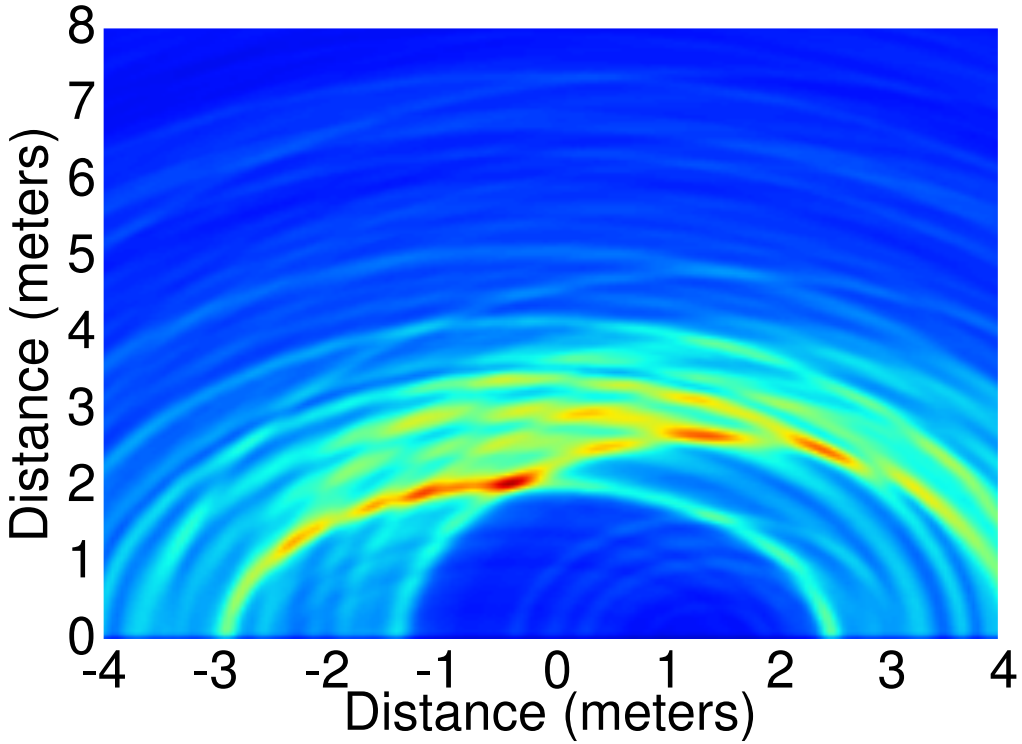
Two Vantage Points



Combining across Multiple Vantage Points

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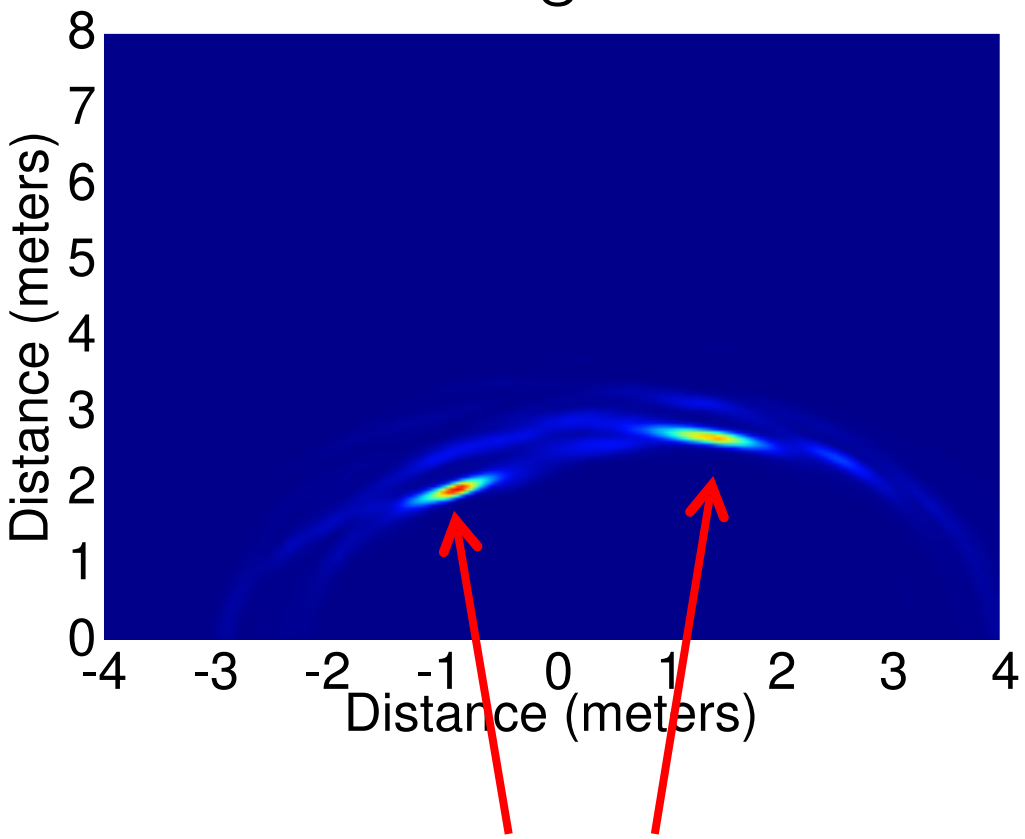
Setup

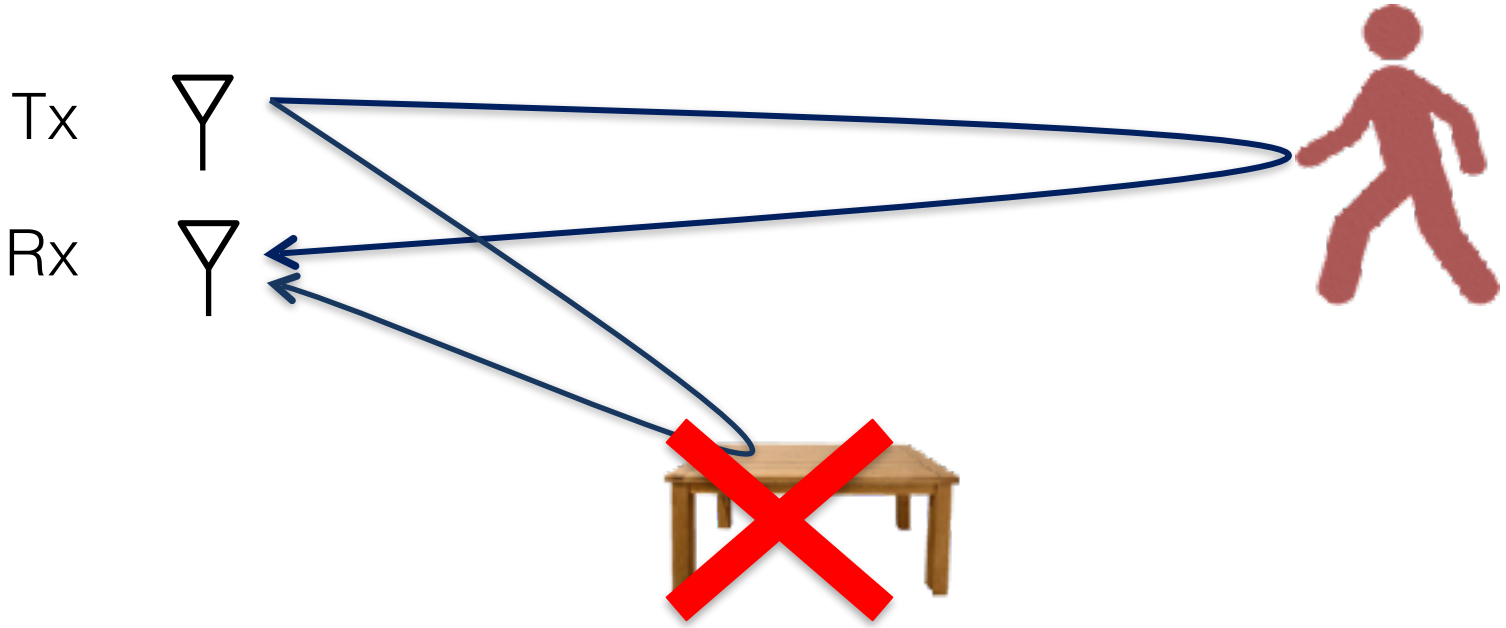
16 Vantage Points



Localize the two users

How can we localize static users?

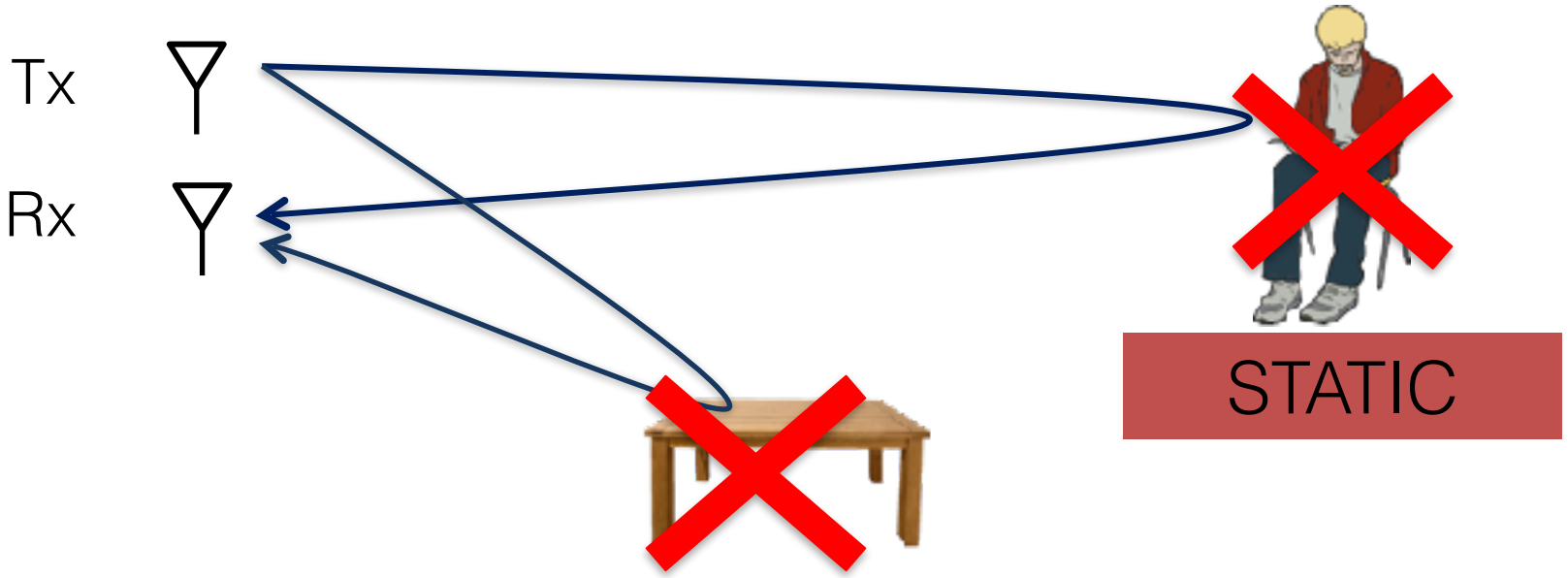
Dealing with multi-path when there is one moving user



We eliminated direct table reflections by subtracting consecutive measurements

Needs User to Move

Dealing with multi-path when there is one moving user



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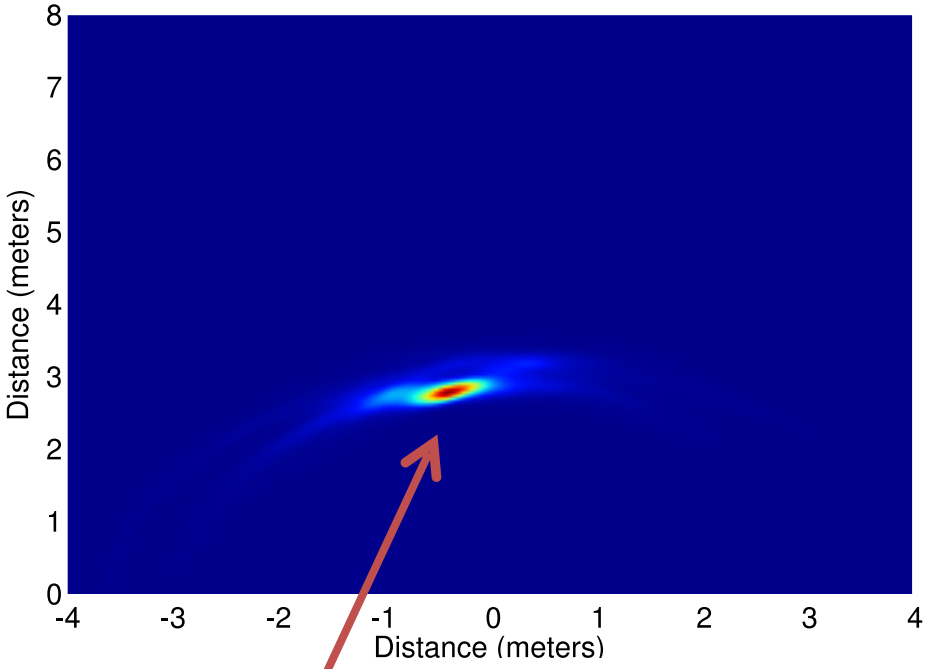
Needs User to Move

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

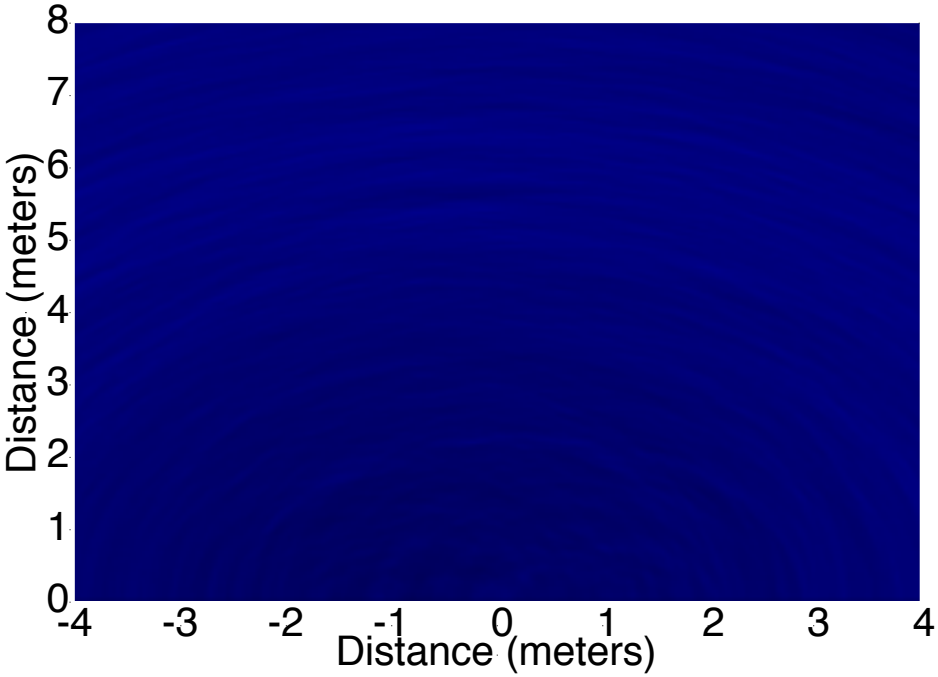
30ms subtraction window

User walking @ 1m/s



Localize the person

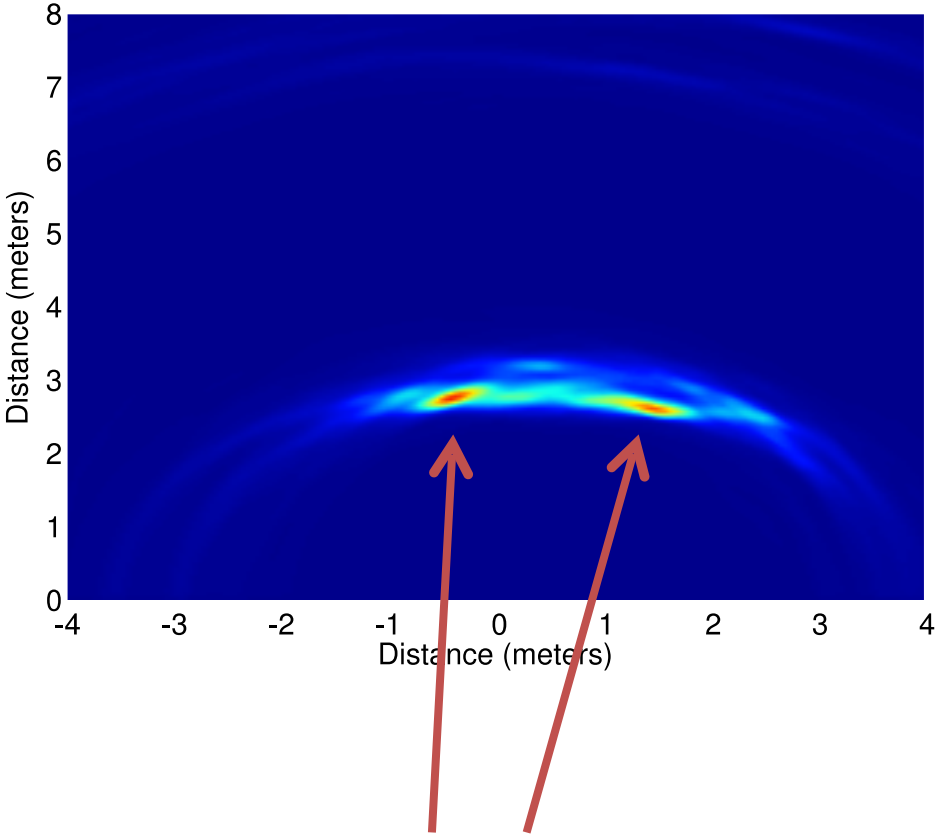
User Still (Breathing)



Cannot localize

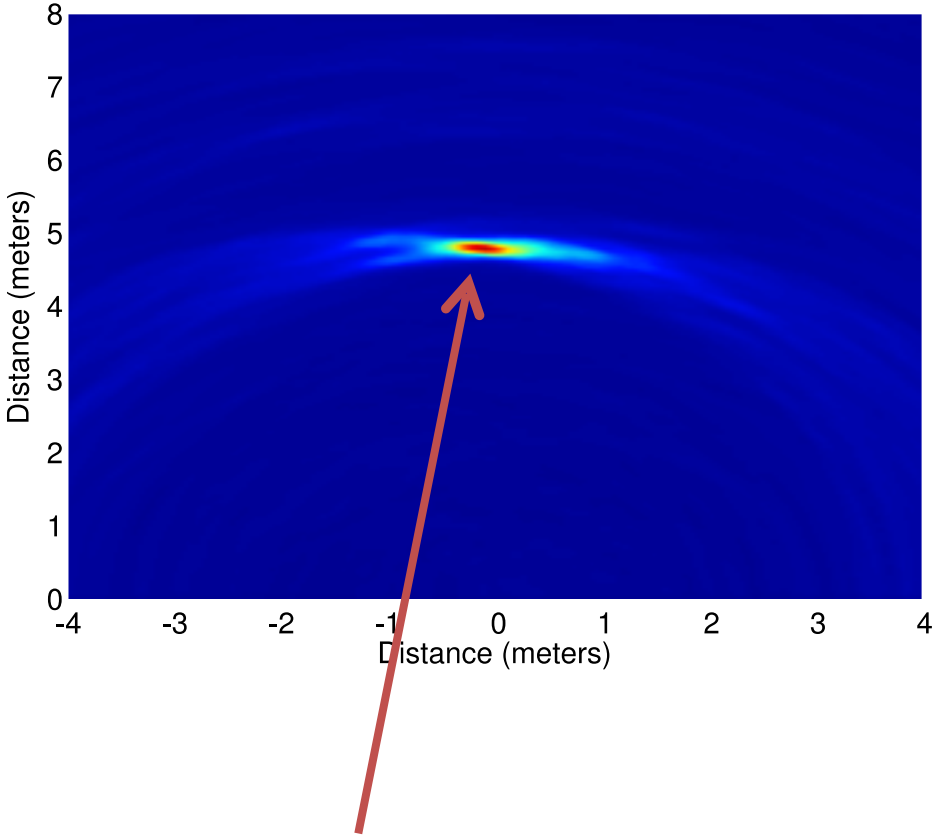
3s subtraction window

User walking



Person appears in two locations

User Still (Breathing)



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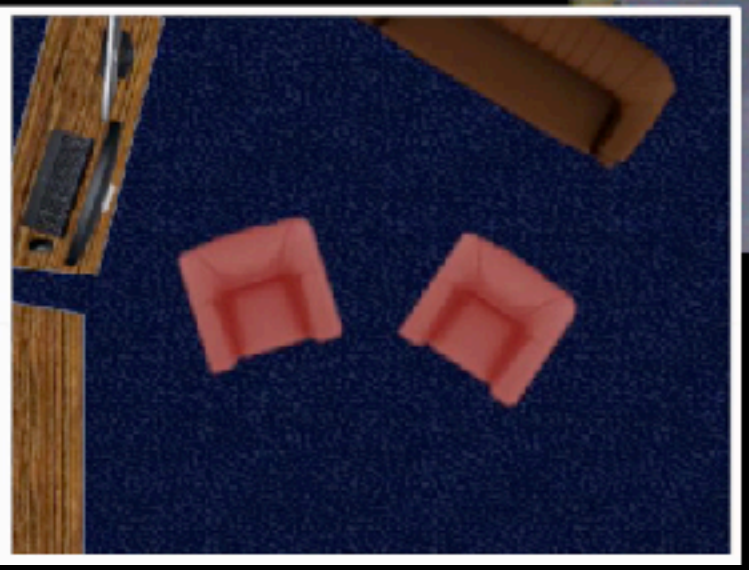

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Packages shipping - Feel free to take a photo/short clip of you receiving/opening the package