MAS.S61: Emerging Wireless & Mobile Technologies aka The "Extreme IoT" Class

Lecture 2:
Fundamentals of Wireless Sensing & Localization

Lecturers

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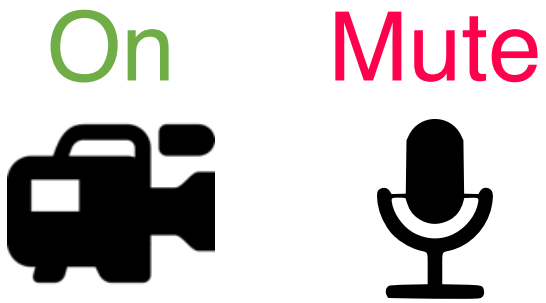
Website: http://www.mit.edu/~fadel/courses/MAS.S61/index.html

Logistics & Norm Settings

- What to do now?
  1. Turn on your video (if your connection allows it)
  2. Mute your mic (unless you are the active speaker)
  3. Open the “Participant” List
     - Make sure your full name is shown



- If you have a question:
  - Use the chat feature to either write the question or to indicate your interest in asking the question
  - We will be monitoring the chat
  - Unmute -> ask question -> mute again
  - Once done asking/answering, please state “Done” to clearly mark it (helps translation/moderation)
  - Same procedure for answering questions

- This lecture will be recorded. It will only be accessible to people in the class

Feedback on Class & Last Session

- Most excited about:
  - Building foundational technical abilities, seminar series with amazing guest lecturers, latest tech
- Most concerned
  - Virtual format and engagement with guest lectures, project and identifying teammates
- Liked about class #1:
  - motivating and exciting examples, interaction and dynamics
- Way to improve class #1:
  - might be a bit of a quiet group
  - 5min break earlier
  - Instructor could’ve been more prepared 💔

Main Components of IoT Systems

Axis #1:
Power/Energy

Focus of
Today's Lecture

Axis #3:
High-level Task
(Sensing, Actuation)

Axis #2:
Connectivity

Objectives of Today's Lecture

Learn the fundamentals, applications, and implications of **wireless localization and sensing**

1. What are the unifying principles of wireless positioning?
2. How do 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)?

What is Wireless Positioning (aka Localization)?

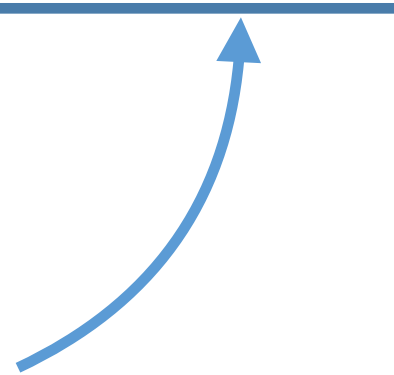
The process of obtaining a human or object's location using wireless signals

Applications:

- Navigation: both outdoors (GPS) and indoors (e.g., inside museum)
- Location based services: Tagging, Reminder, Ads
- Virtual Reality and Motion Capture
- Gestures, writing in the air
- Behavioral Analytics (Health, activities, etc.)
- Locating misplaced items (keys)
- Security (e.g., only want to give WiFi access to customers inside a store)
- Delivery drones

What are the different ways of obtaining location?

- Radio signals: GPS, Cellular, Bluetooth, WiFi
- Ultrasound signals: similar to those used in NEST
- Inertial
- Cameras, Vision, LIDAR



Focus of this lecture

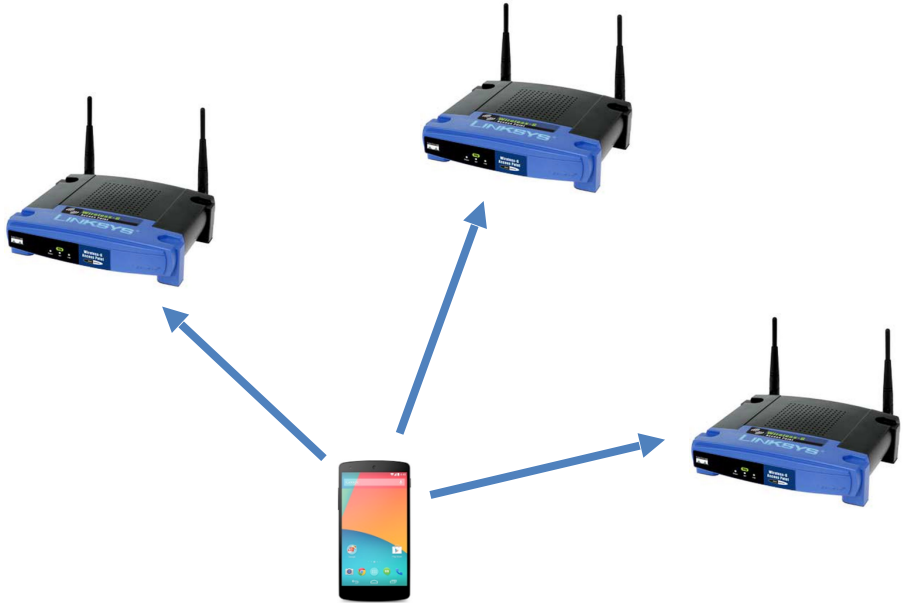
We will discuss the localization techniques in increasing order of sophistication

Who performs the localization process?

- Device based: A device uses incoming signal from one or more “anchors” to determine its own location

- Example: GPS

- Network based: Anchors (or Access points) use the signal coming from device to determine its location



- Example: Radar

1) Identity-based Localization

Idea: Use the identity and known location of anchor nodes

Example:

- Wardriving -- been used to improve the accuracy of GPS
- WiFi indoor localization

Localize by mapping to one of those locations.

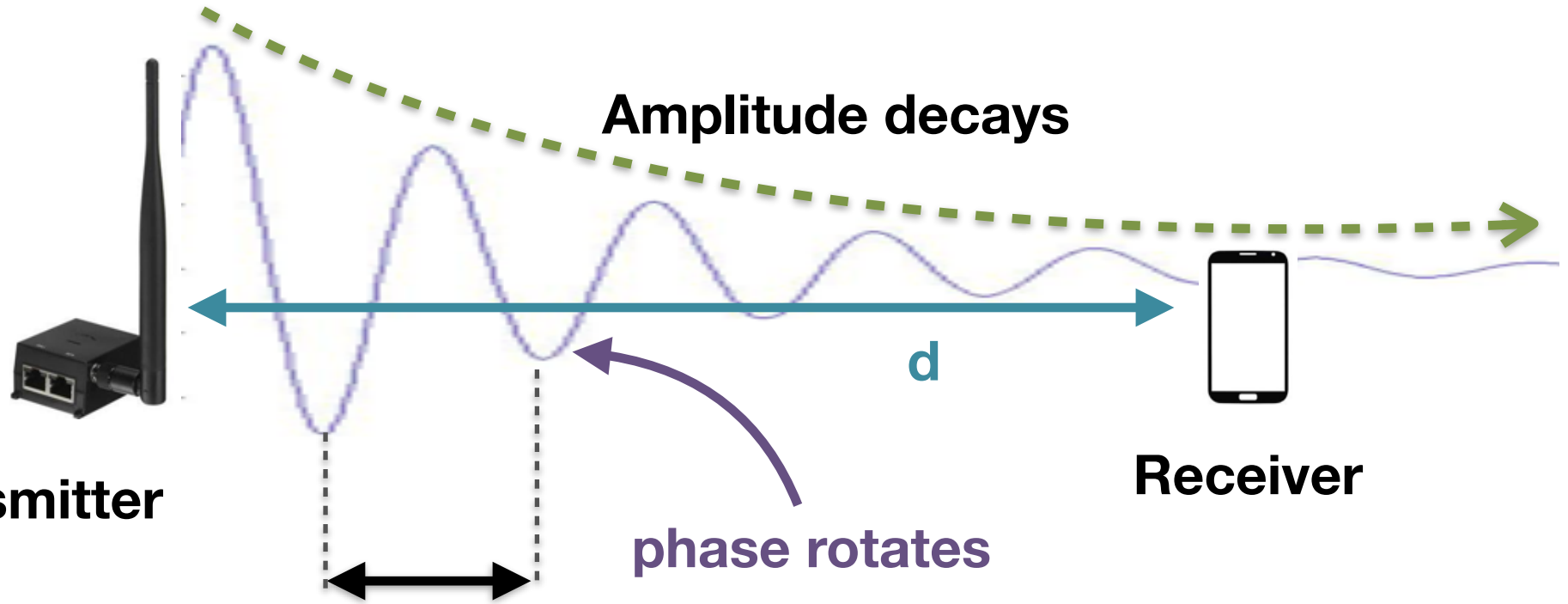
Pros? Cons?

2) Received Signal Strength (RSSI)

Idea: Higher power -> closer; lower power-> further

In fact, we can extract more information about exact distance from measured power. Need to understand more about wireless signals

Wireless Signals are Waves



Channel equation (Complex number)

$$h = \frac{1}{d} e^{j2\pi \frac{d}{\lambda}}$$

Wireless Signals are Waves

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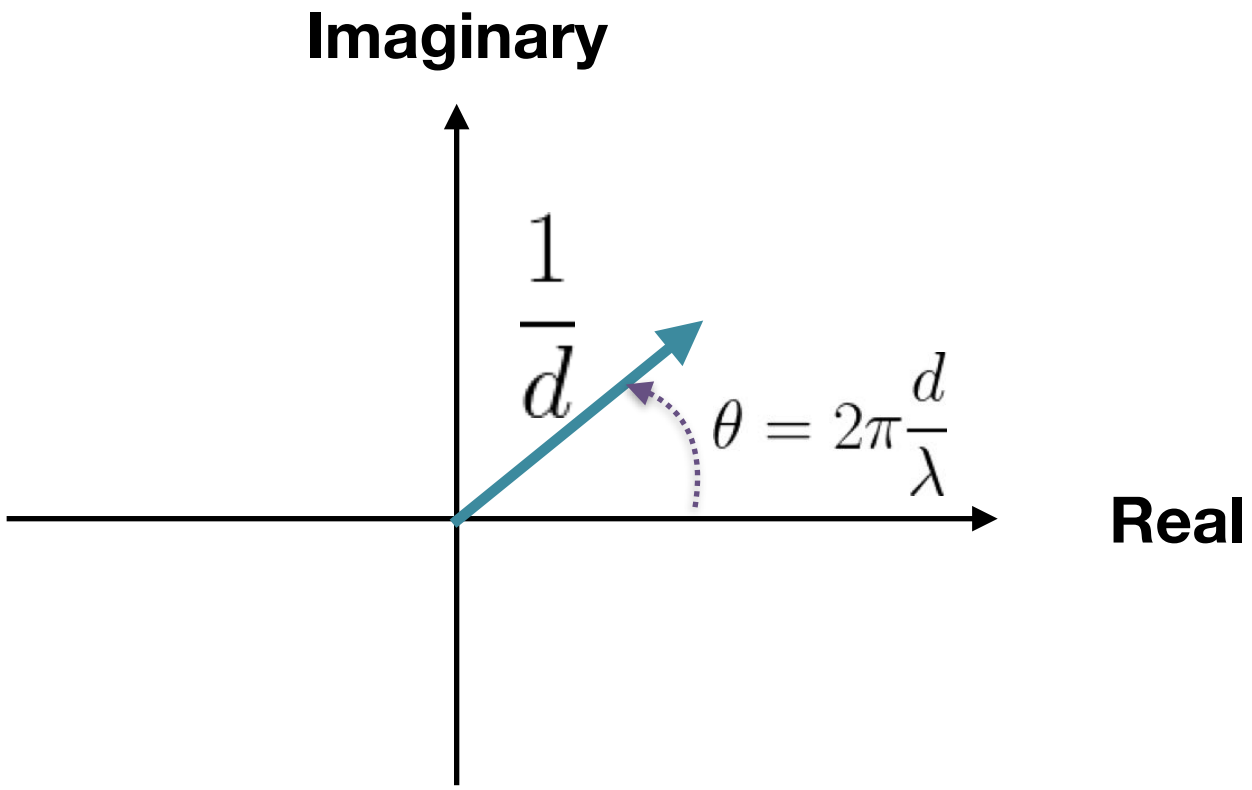
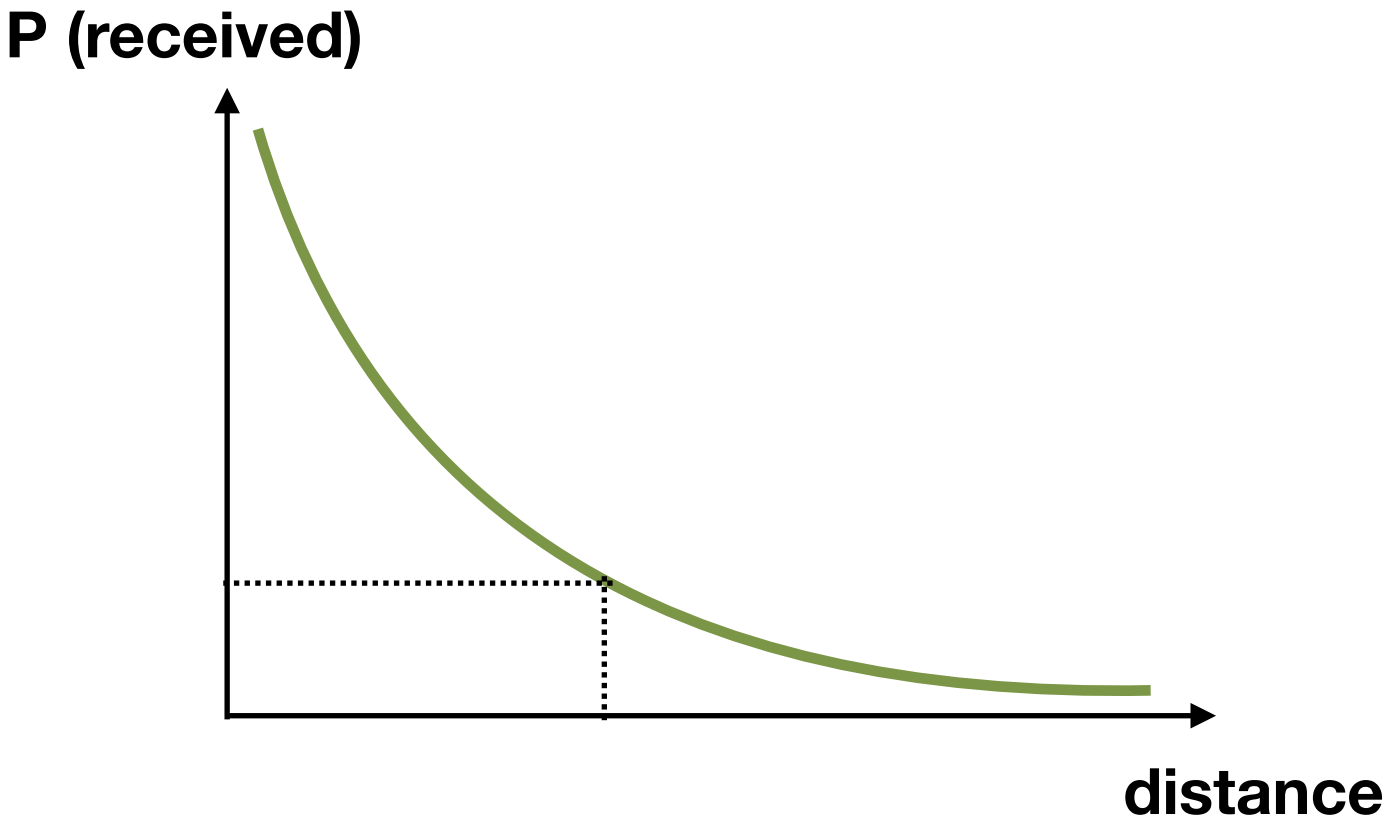


2) Received Signal Strength (RSSI)

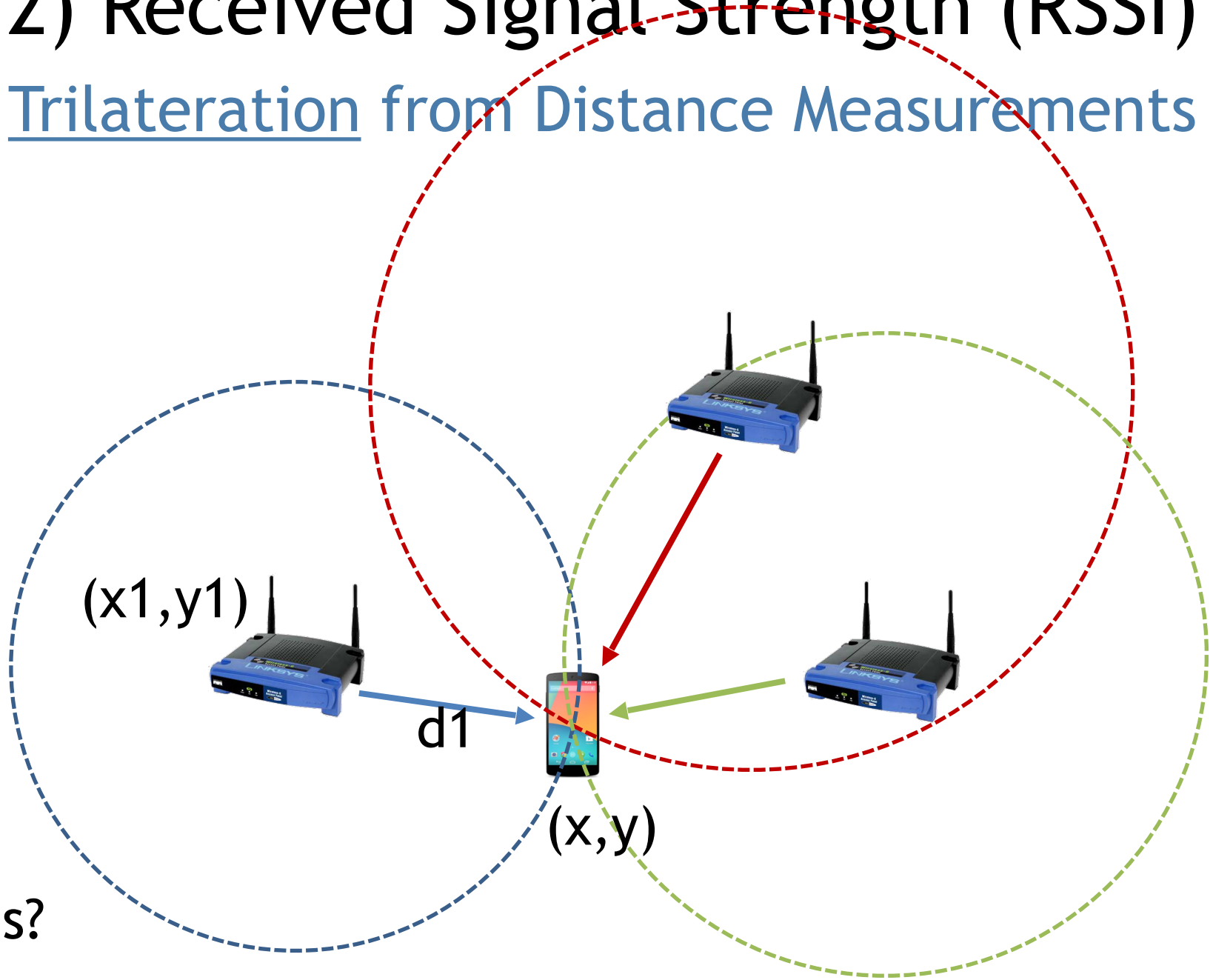
From power to distance

Power is proportional to $1/d^2$



2) Received Signal Strength (RSSI)

Trilateration from Distance Measurements

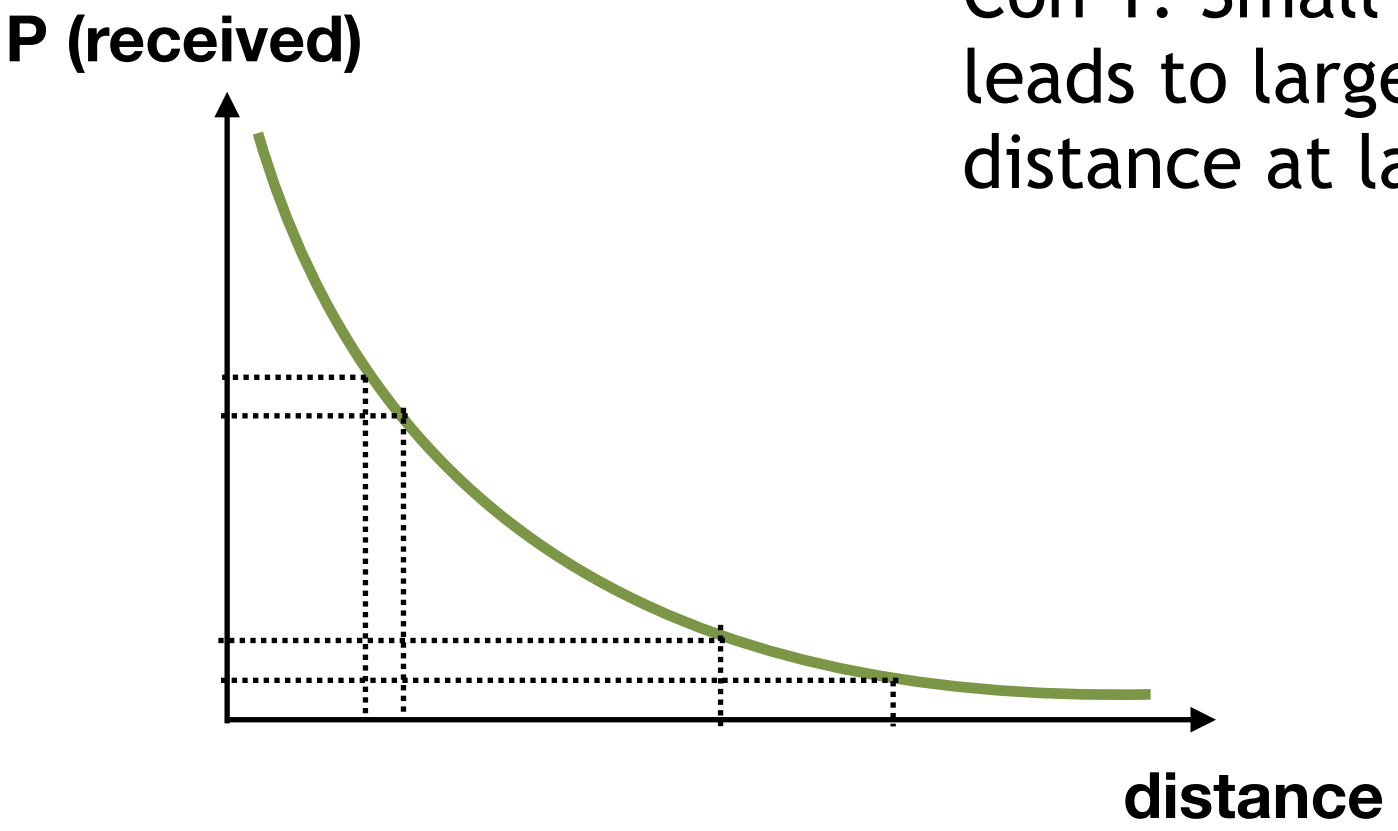


Pros? Cons?

2) Received Signal Strength (RSSI)

From power to distance

Power is proportional to $1/d^2$

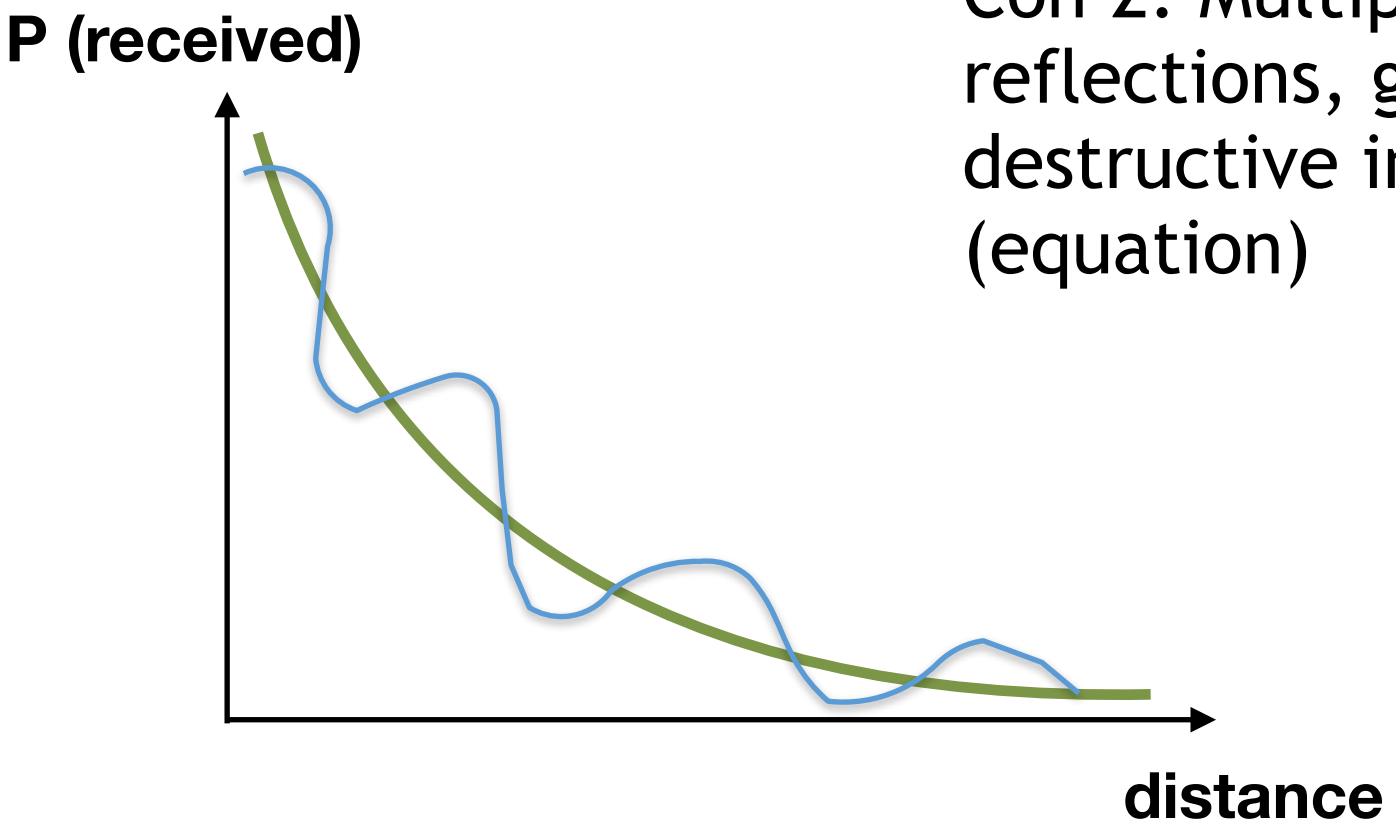


Con 1: Small change in power leads to large deviations in distance at larger distances

2) Received Signal Strength (RSSI)

From power to distance

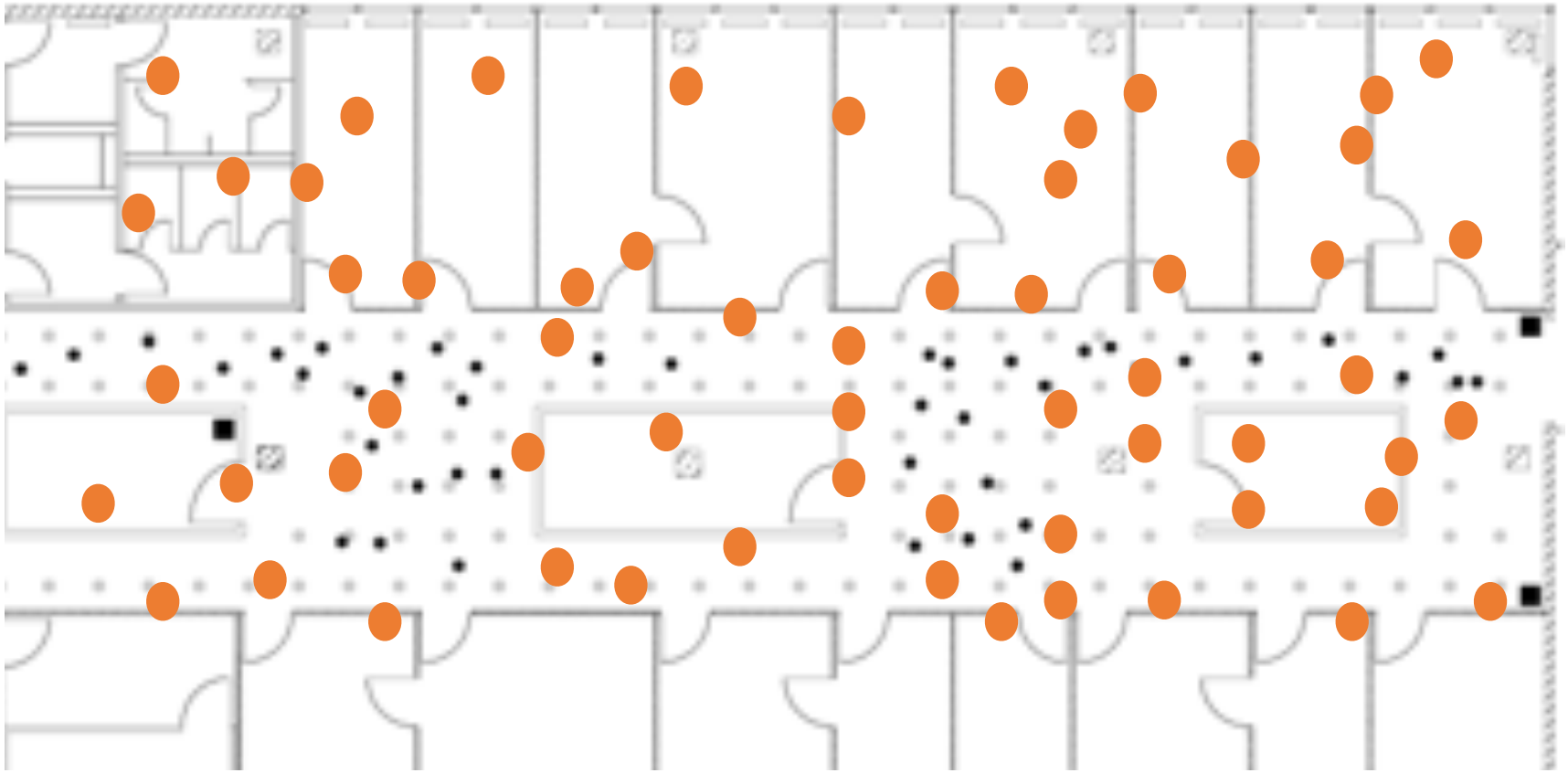
Power is proportional to $1/d^2$



Con 2: Multipath: Due to reflections, get constructive and destructive interference (equation)

2) Received Signal Strength (RSSI)

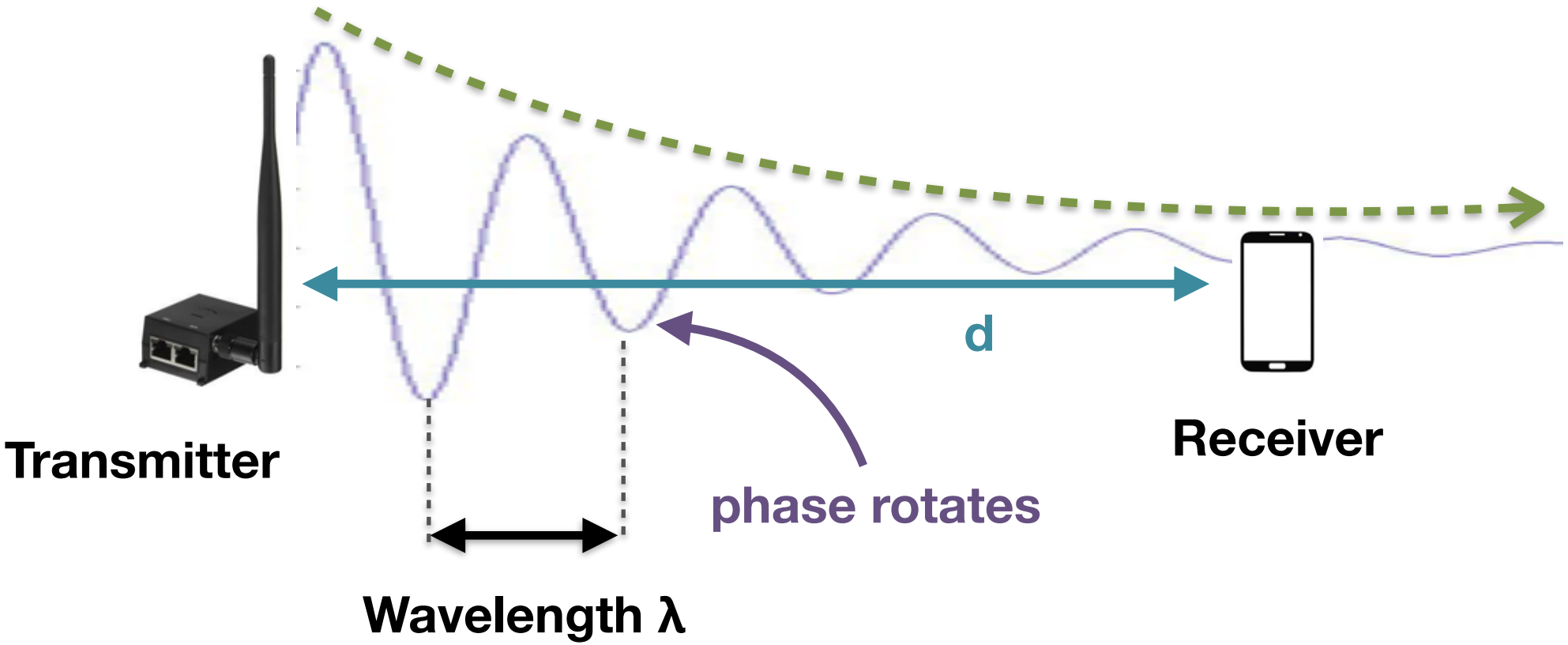
Solution: Fingerprinting
i.e., measuring device records signal strength fingerprints at each location



Pros? Cons?

3) Use the Signal “Phase”

Phase $\phi = 2\pi \frac{d}{\lambda}$

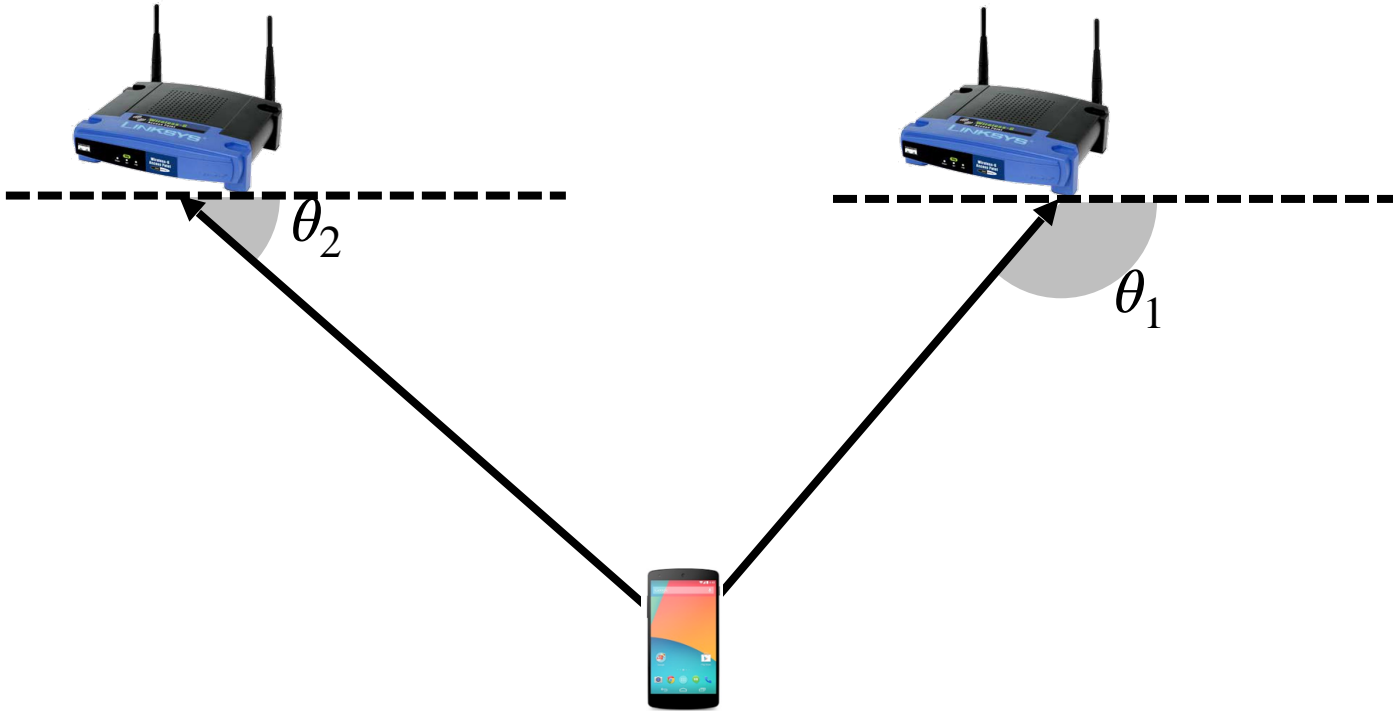


Pros? Cons?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

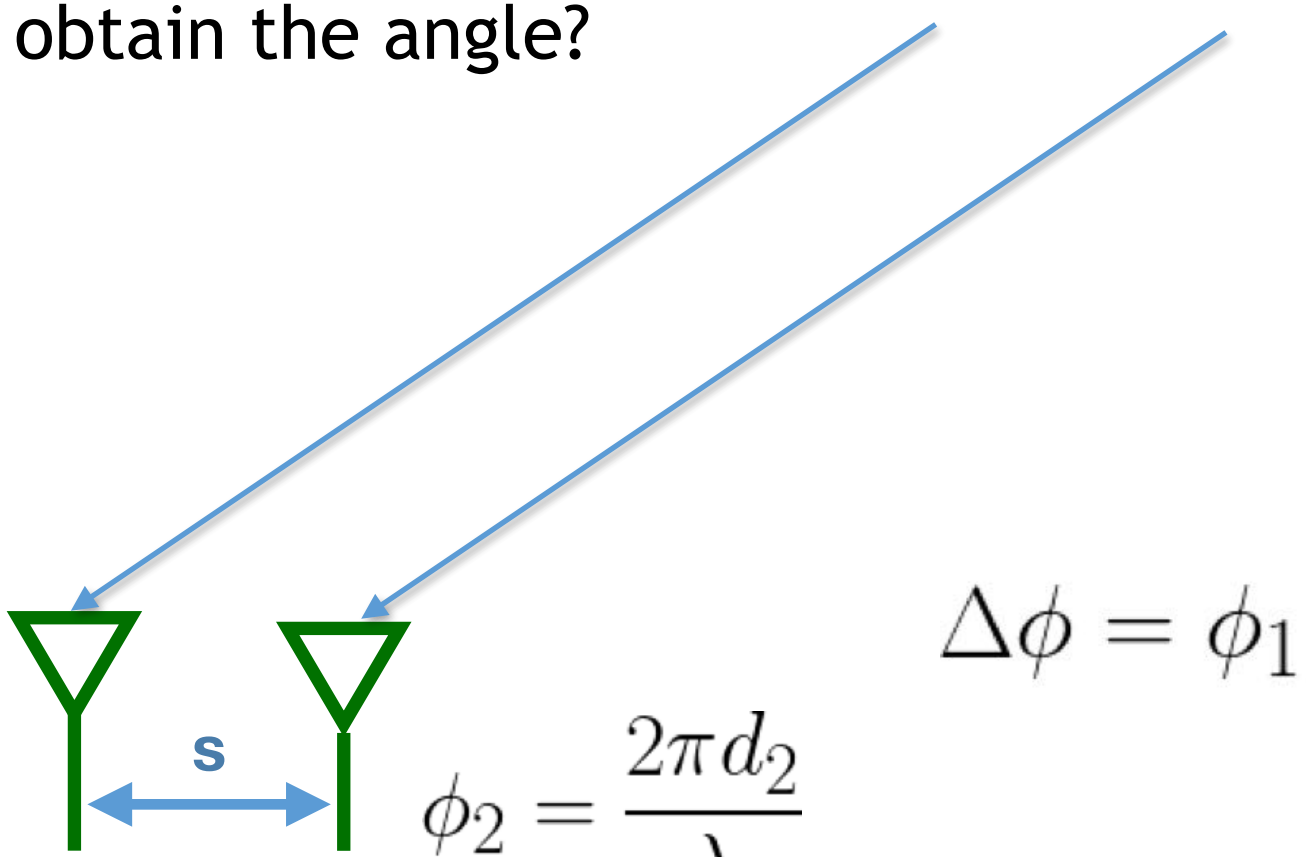
Measure Angle of Arrival (AoA) from device to each AP



4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

How can we obtain the angle?



$$\phi_1 = \frac{2\pi d_1}{\lambda} \qquad \phi_2 = \frac{2\pi d_2}{\lambda}$$

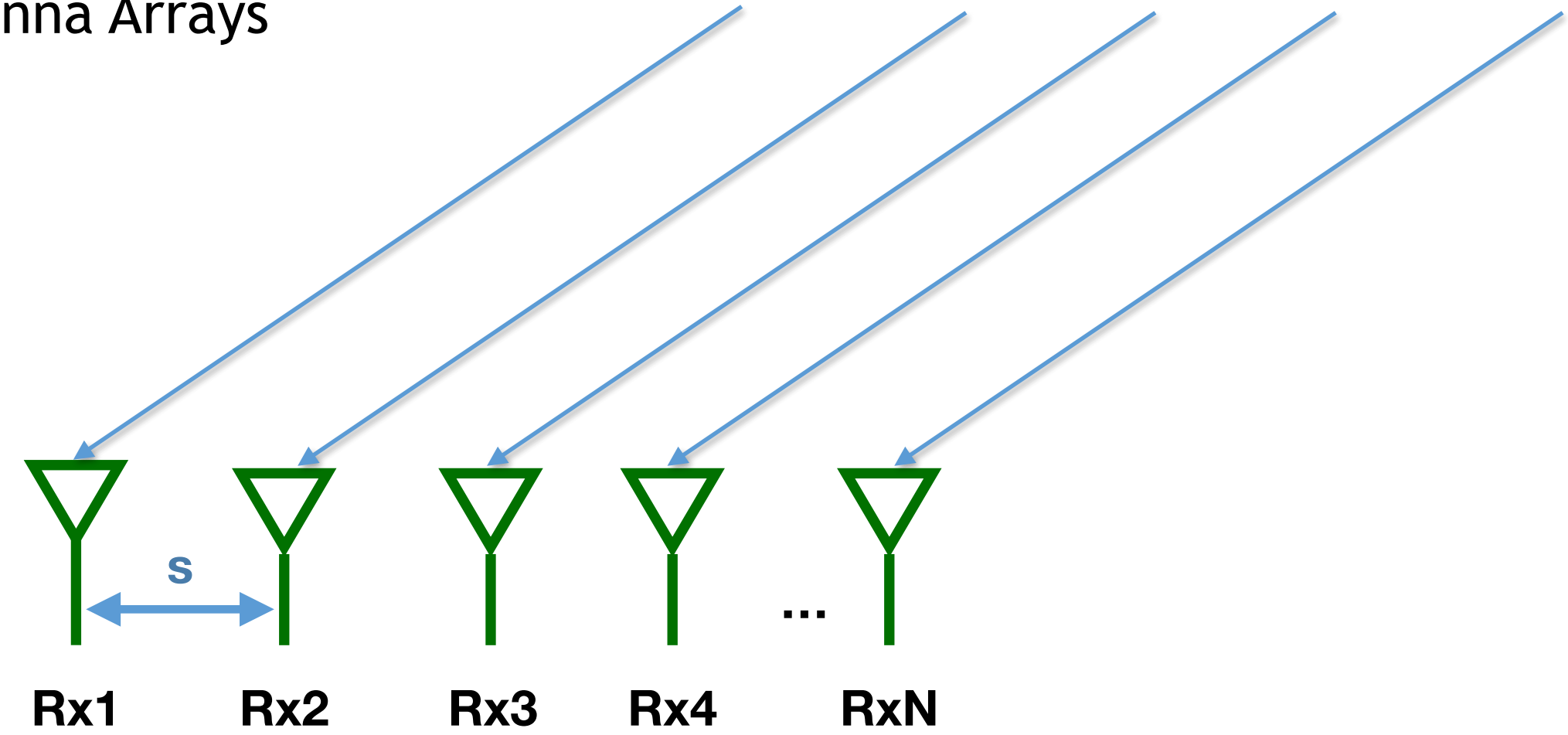
$$\Delta\phi = \phi_1 - \phi_2 = \frac{2\pi s \cos\theta}{\lambda}$$

Issues?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

Use Antenna Arrays



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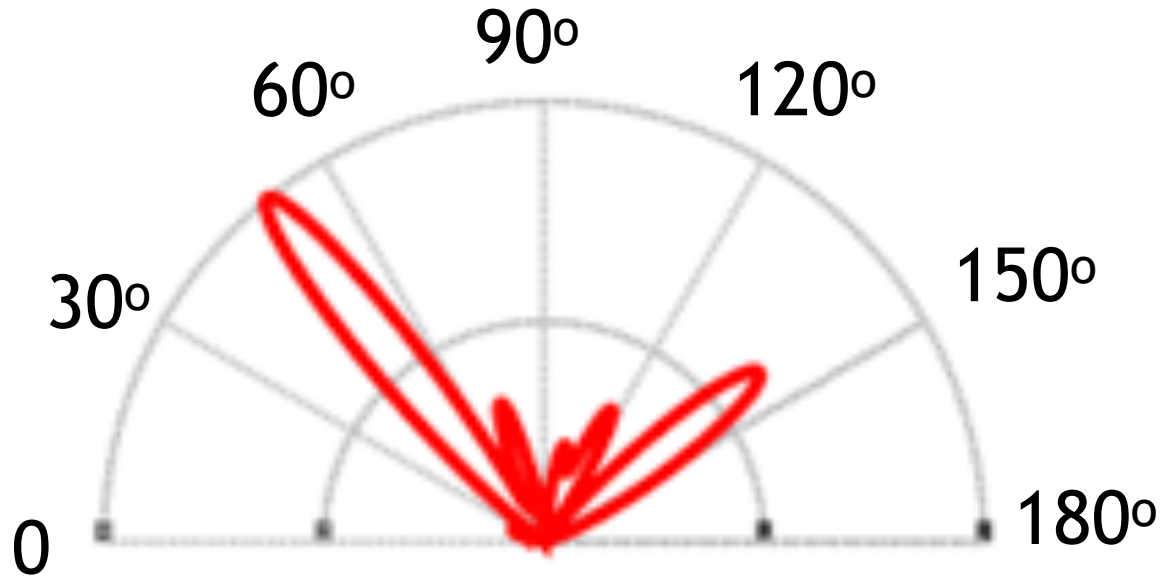
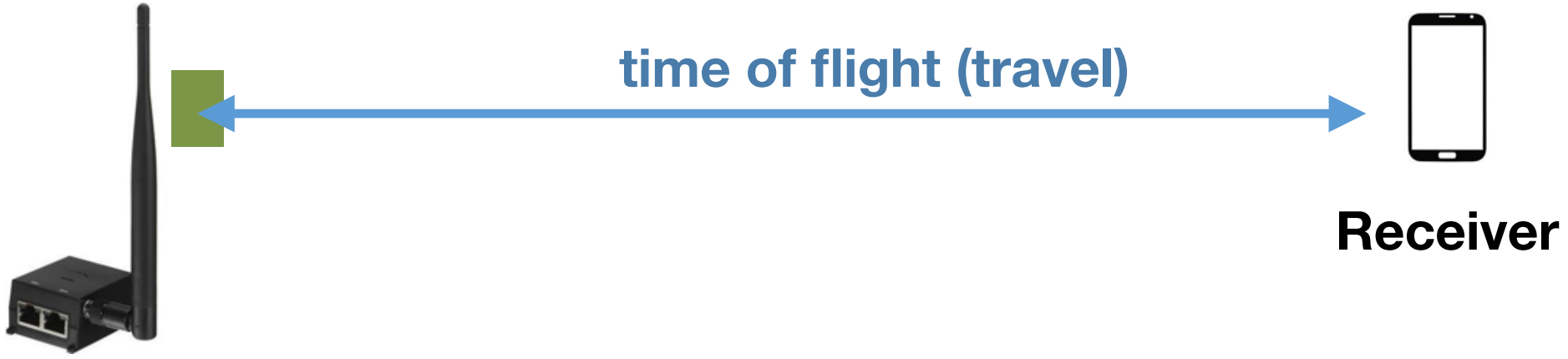


How do we know which direction corresponds to the direct path?

5) Measure the Time-of-Flight (ToF)

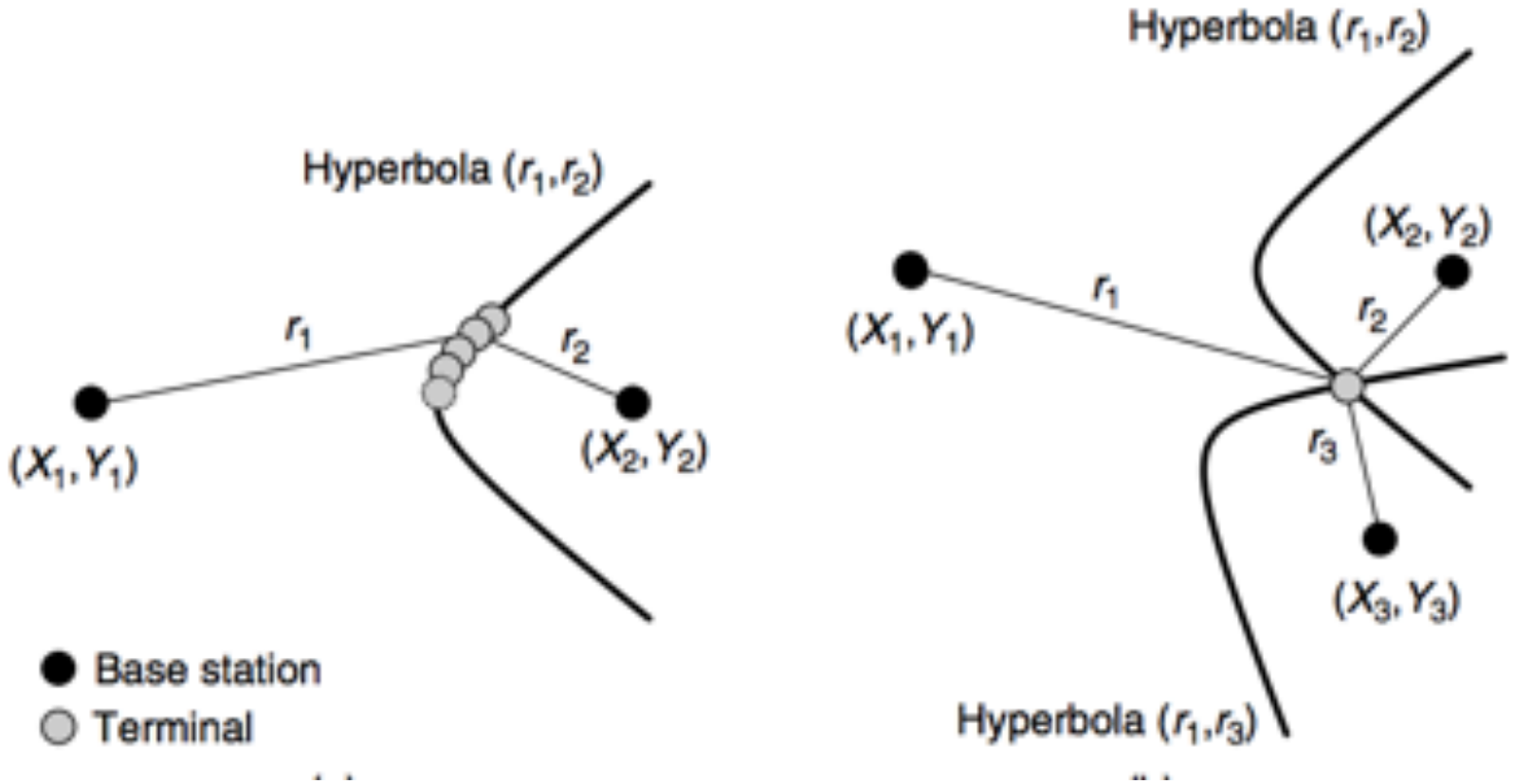


Distance = Time of flight x speed of travel

Can use trilateration (intersection circles/spheres)

How do we know when the signal was transmitted?

6) Time-difference-of-arrival (TDoA)



State-of-the-Art Techniques?

- Sophisticated Combinations of these techniques, e.g.,:
- Combine AoA with time-of-flight
- Use circular antennas and combine with inertial sensing
- Perform synthetic aperture radar and DTW
- Synthesize measurements from multiple frequencies
- …

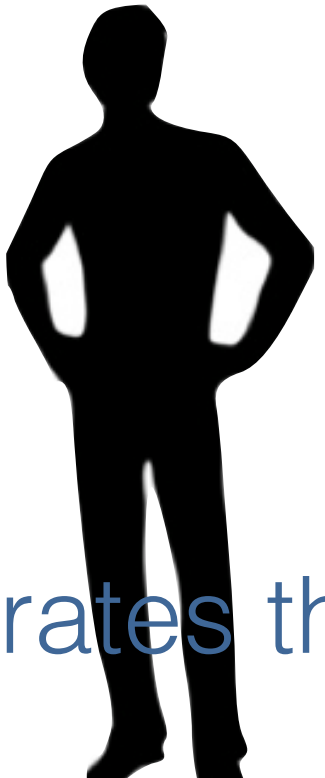
- Optional Readings
  - Indoor Positioning Systems:
    - RADAR [2000]; Cricket [2000]
  - Outdoor Positioning:
    - GPS

So Far

Device-based Localization

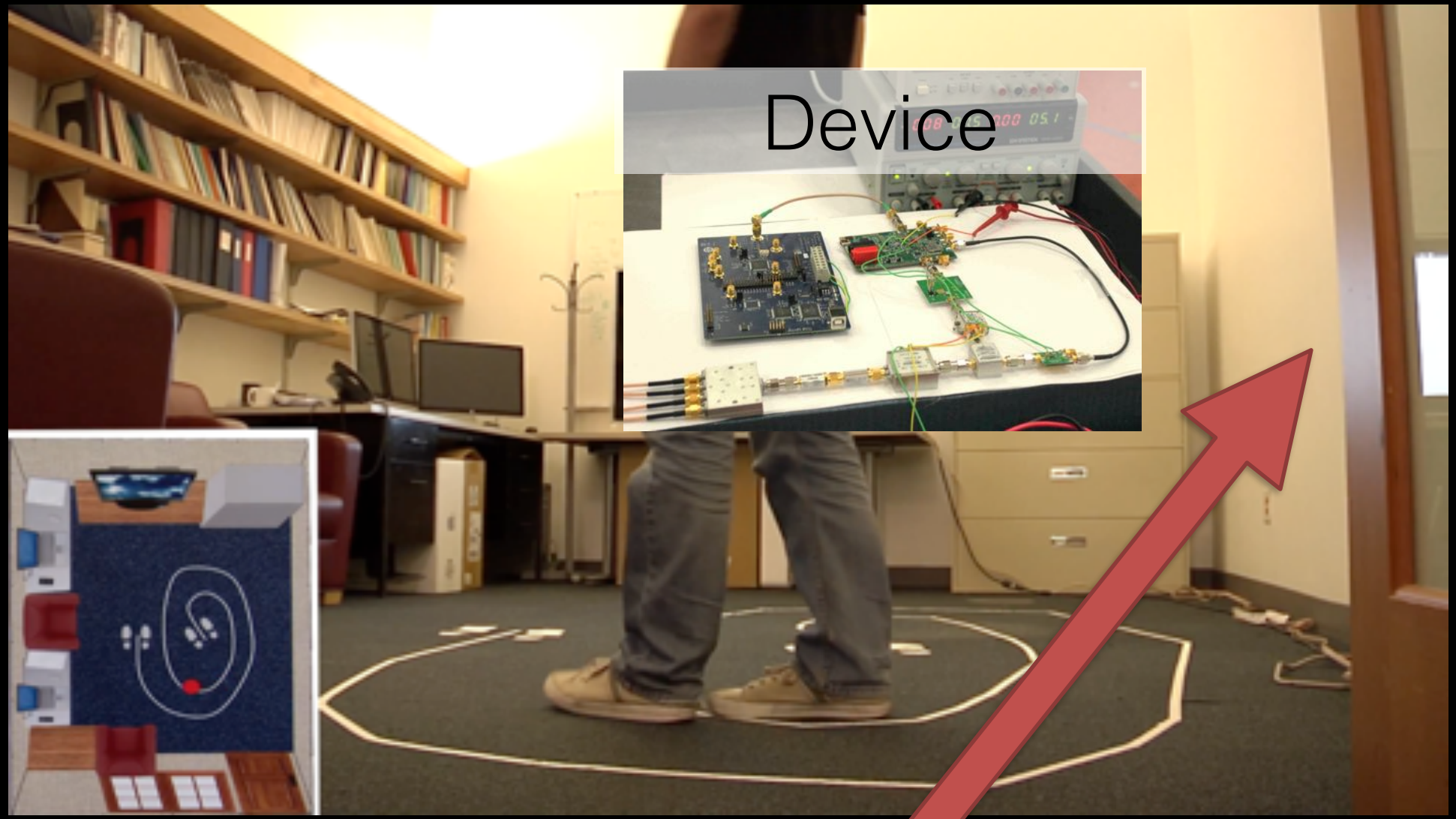
Next: Device-Free Localization (aka Wireless Sensing)

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



Operates through occlusions

Example: WiTrack


Device
Device in another room

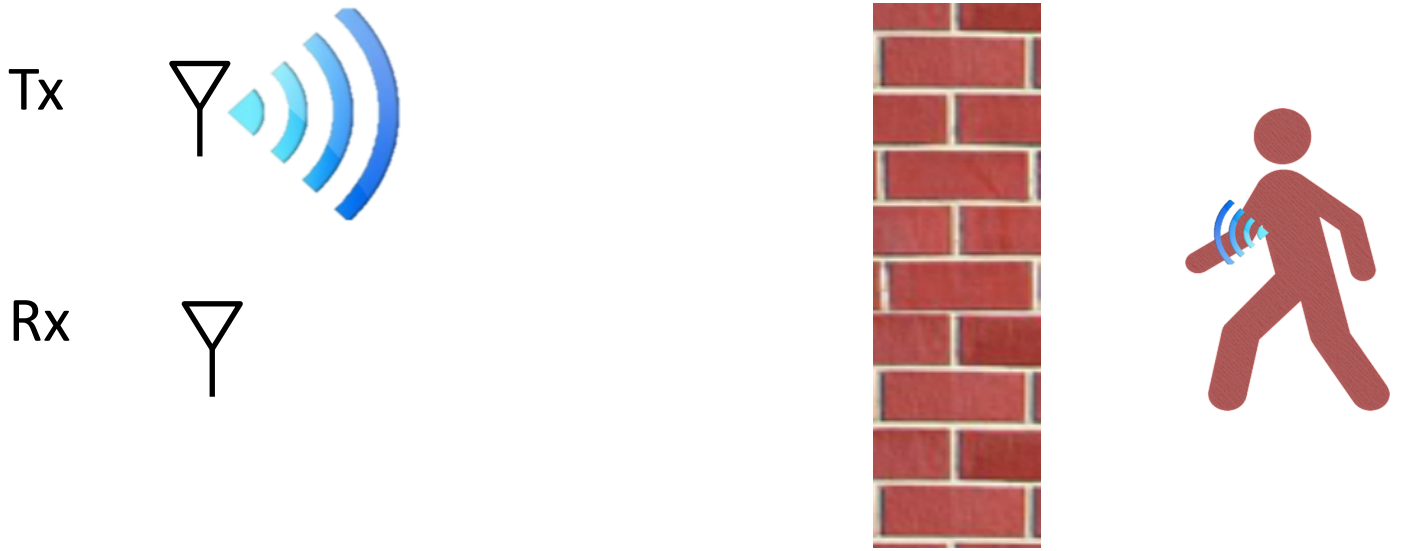
Applications

Smart Homes

Energy Saving

Gaming & Virtual Reality

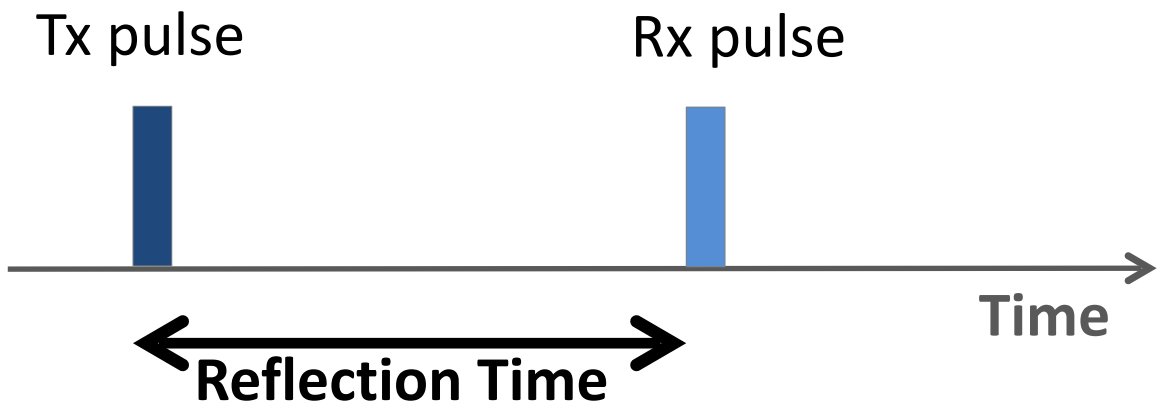
Measuring Distances



Distance = Reflection time x speed of light

Measuring Reflection Time

Option1: Transmit short pulse and listen for echo



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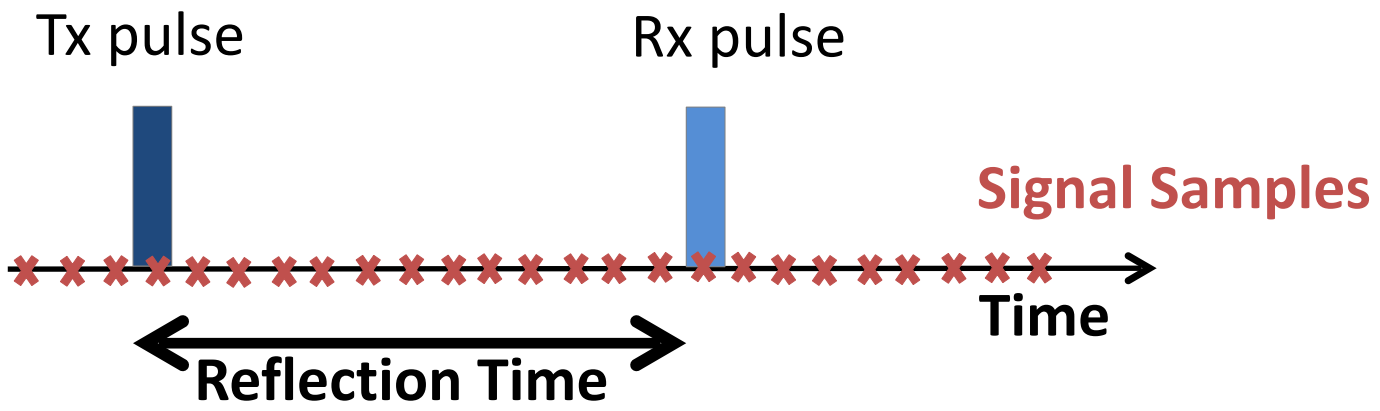

Capturing the pulse needs sub-nanosecond sampling

Why?

Would it also be a problem for acoustic or ultrasound-based methods?

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 ultrasound-based methods (e.g., Cricket)?

because speed of ultrasound

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

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

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