# Welcome!

## CIS 7000: Special Topics on Mobile and IoT Sensing

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Lecture 2

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# Objectives of the Upcoming Three Lectures

Learn the fundamentals, applications, and implications of

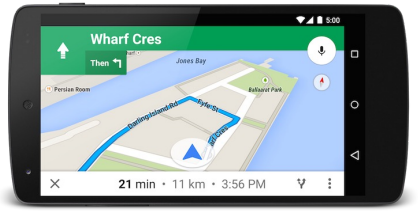
**wireless localization and sensing**

1. What are some motivating applications of localization and location services?
2. What are the unifying principles of wireless positioning?
3. How do systems like GPS, Wi-Fi positioning, Bluetooth ranging, and acoustic ranging work?
4. What is wireless (Wi-Fi) sensing?

# What is Wireless Positioning (aka Localization)?

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

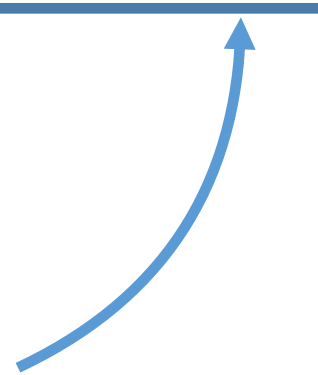
**Applications:**




- 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
- Contact tracing (Bluetooth, etc.)

# What are the different modalities of obtaining location?

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



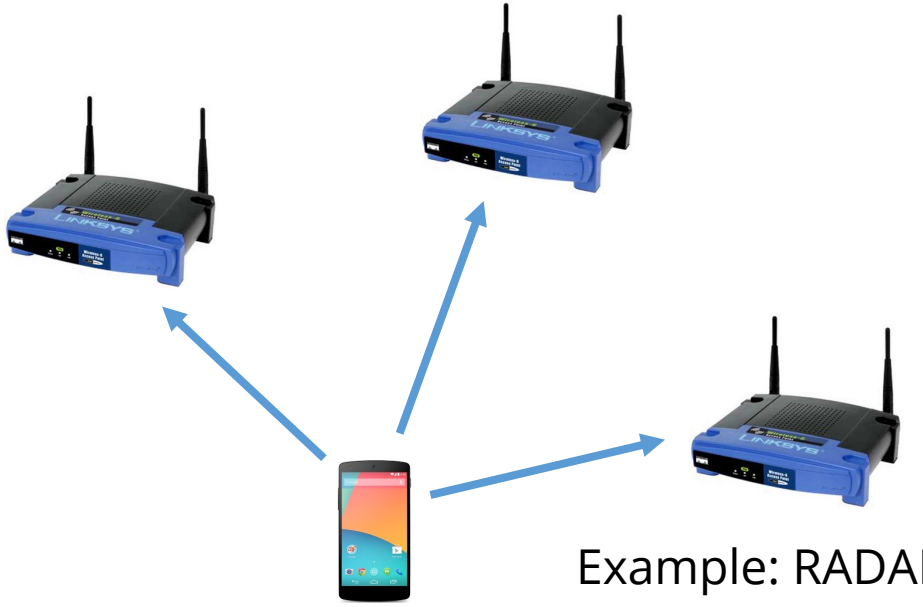

We will discuss the localization techniques in increasing order of sophistication

# Who performs the localization?

- **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

Device modification? Computation? Communication?

# 1. Identity-based Localization

**Idea:** use the identity and known location of anchor objects

**Examples:**

- WiFi indoor localization

**Localization by mapping to one of the known locations.**

Pros? Cons?

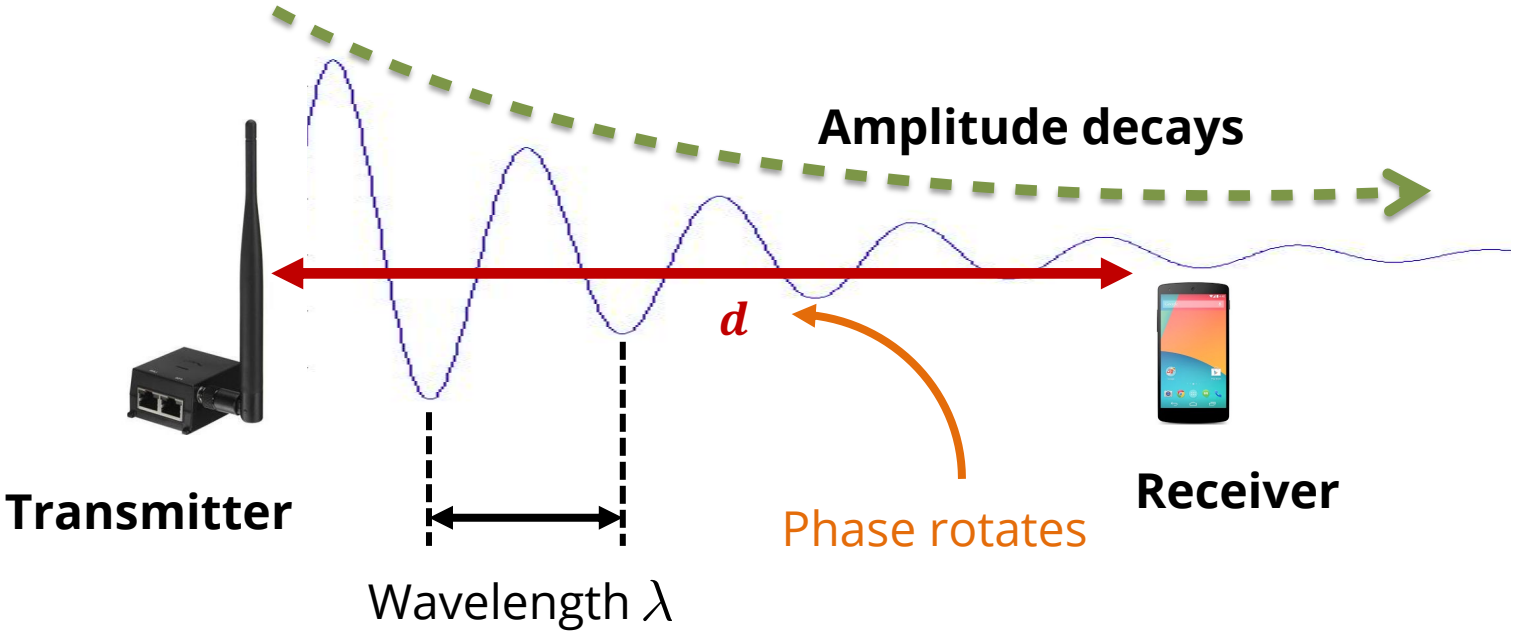
# 2. Received Signal Strength (RSSI)

**Idea:**

- higher received power ➔ closer
- lower received power ➔ farther

We could extract more information about the **exact distance** from the measured received power. Need to understand how the signals propagate.

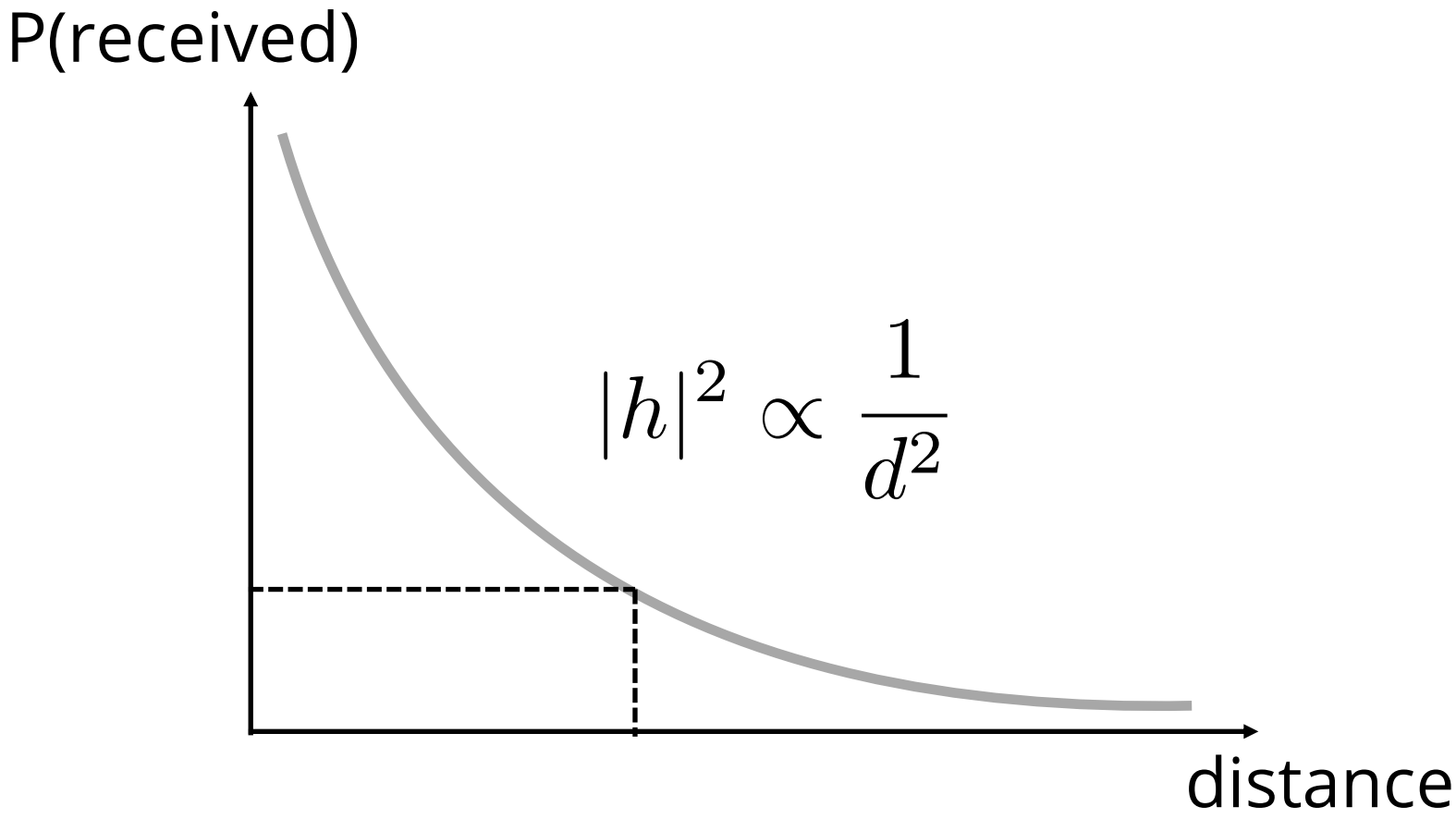
# Wireless Signal are Waves




**Channel equation:** $$h = \frac{1}{d} e^{j2\pi \frac{d}{\lambda}}$$

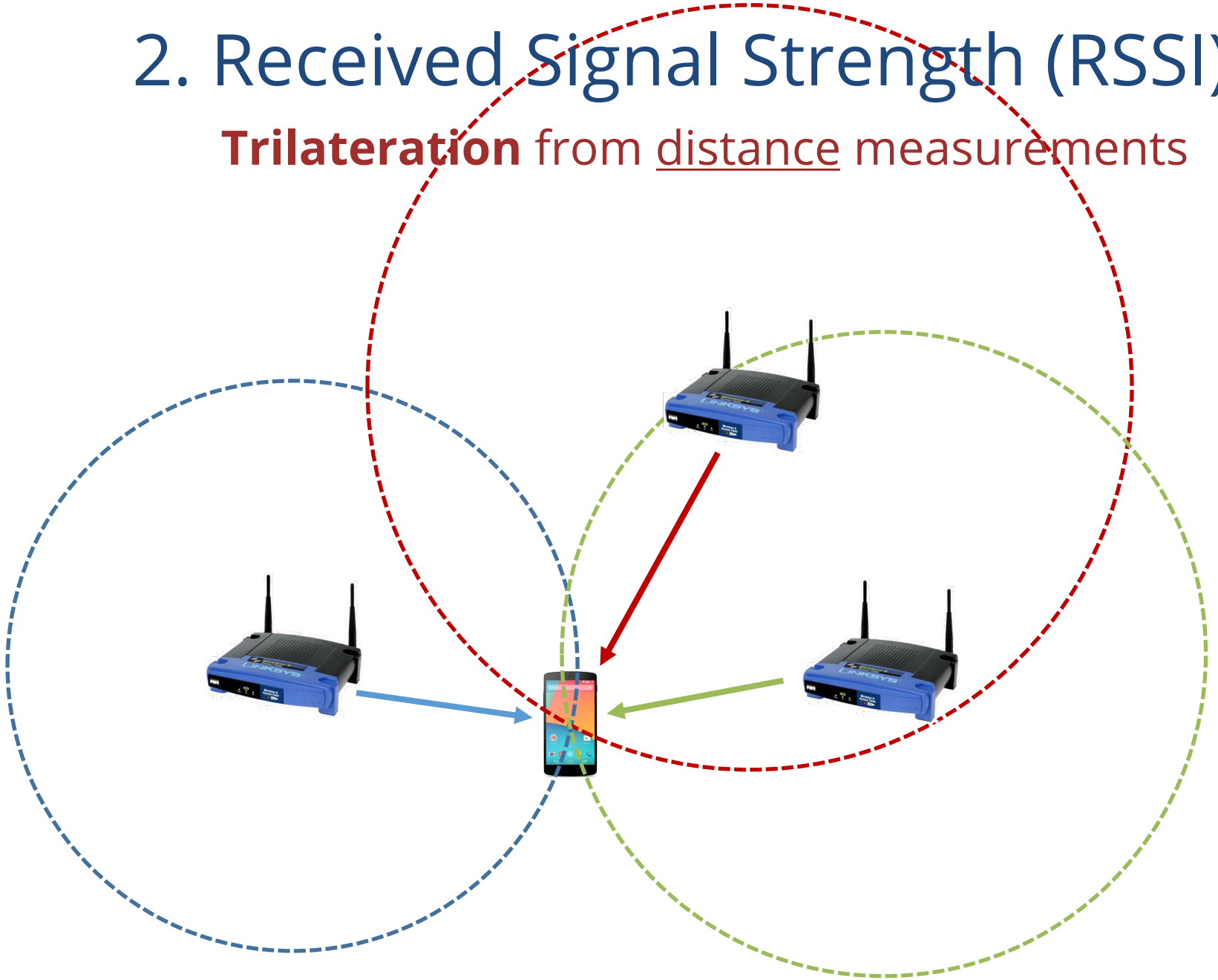
# 2. Received Signal Strength (RSSI)

From power to distance



# 2. Received Signal Strength (RSSI)

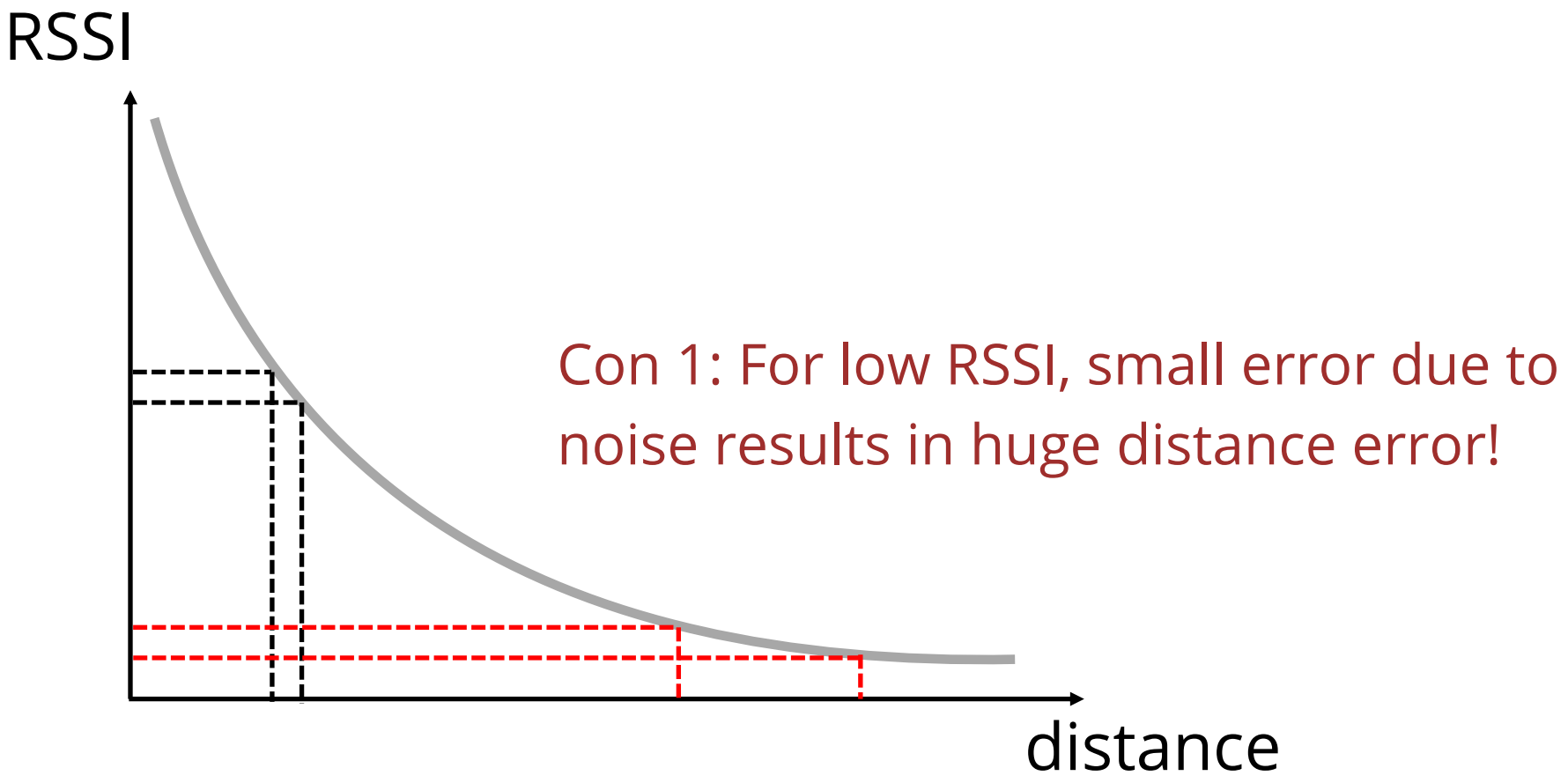
**Trilateration** from distance measurements



Pros? Cons?

# 2. Received Signal Strength (RSSI)

**Pros:** Very simple, no hardware modifications




Con 1: For low RSSI, small error due to noise results in huge distance error!

# 2. Received Signal Strength (RSSI)

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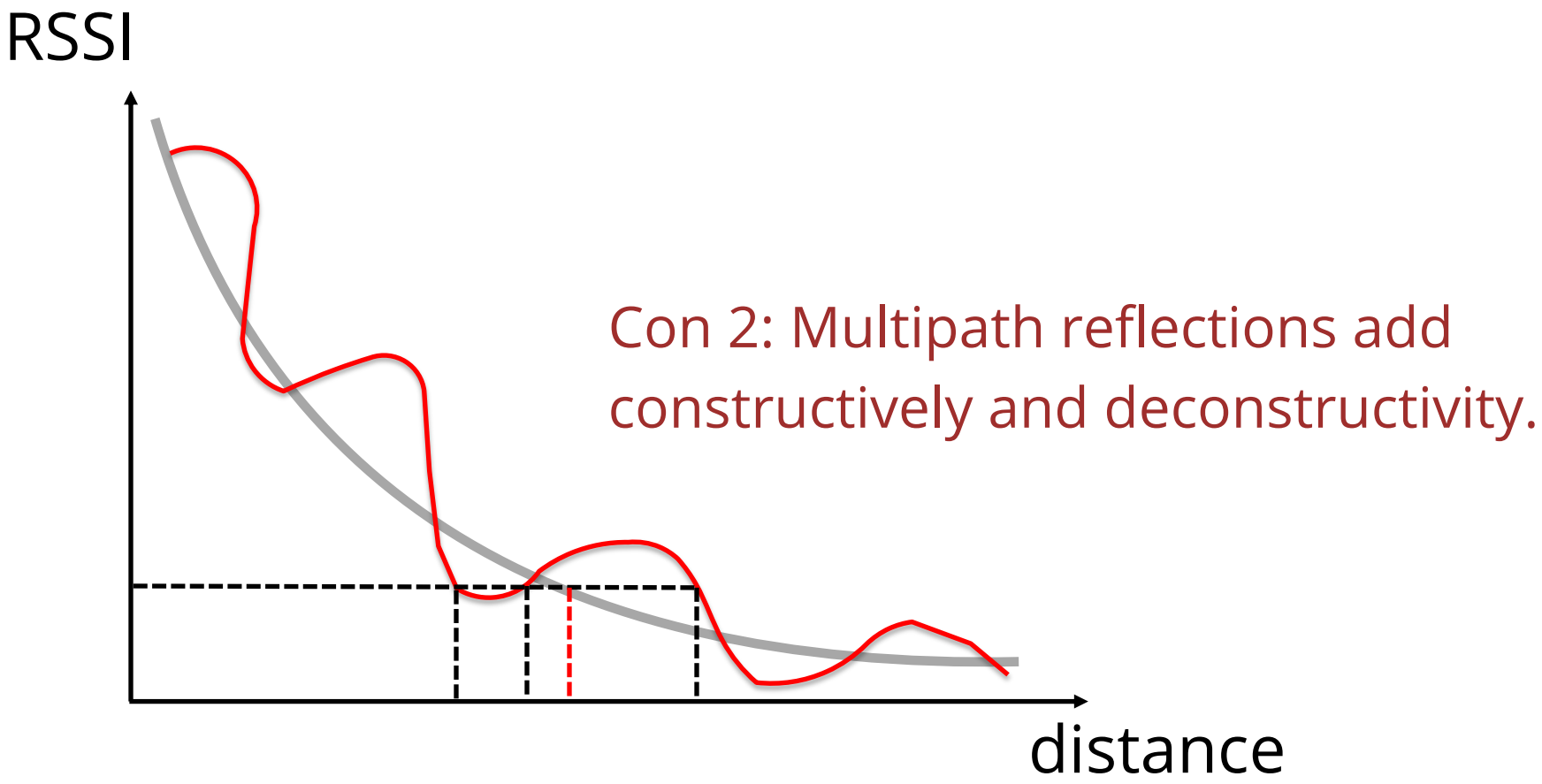
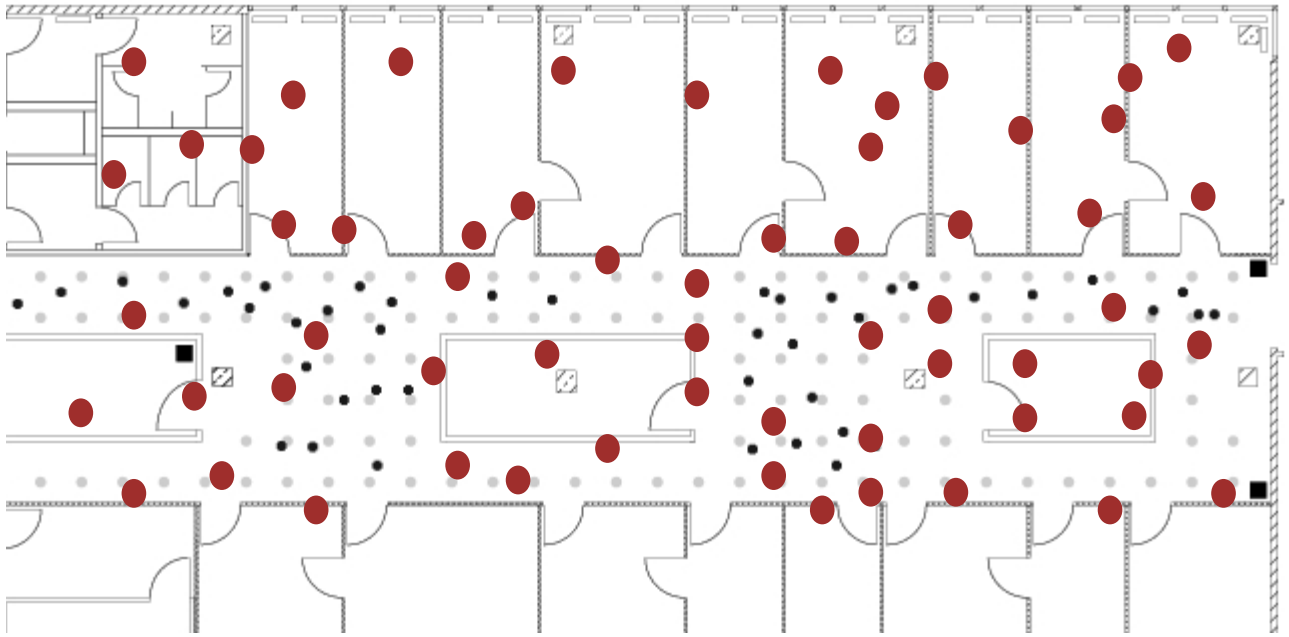



Con 2: Multipath reflections add constructively and deconstructivity.

# 2. Received Signal Strength (RSSI)

**Solution:** Fingerprinting

Measure and records RSSI fingerprints at each location



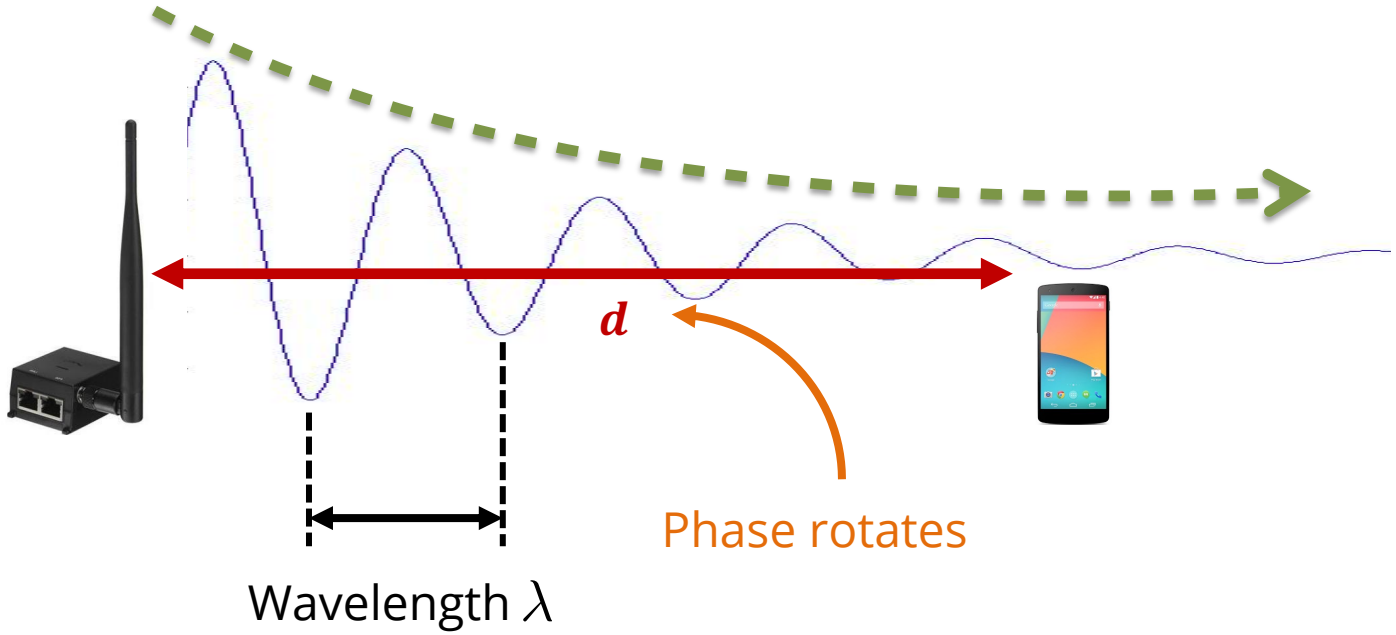
**Pros:** Works with multipath,  No need to know AP locations!

**Cons:** Changes in environment/movement ➔ change RSSI!

Continuous training is needed. Lots of effort!

# 3. Phase of the signal

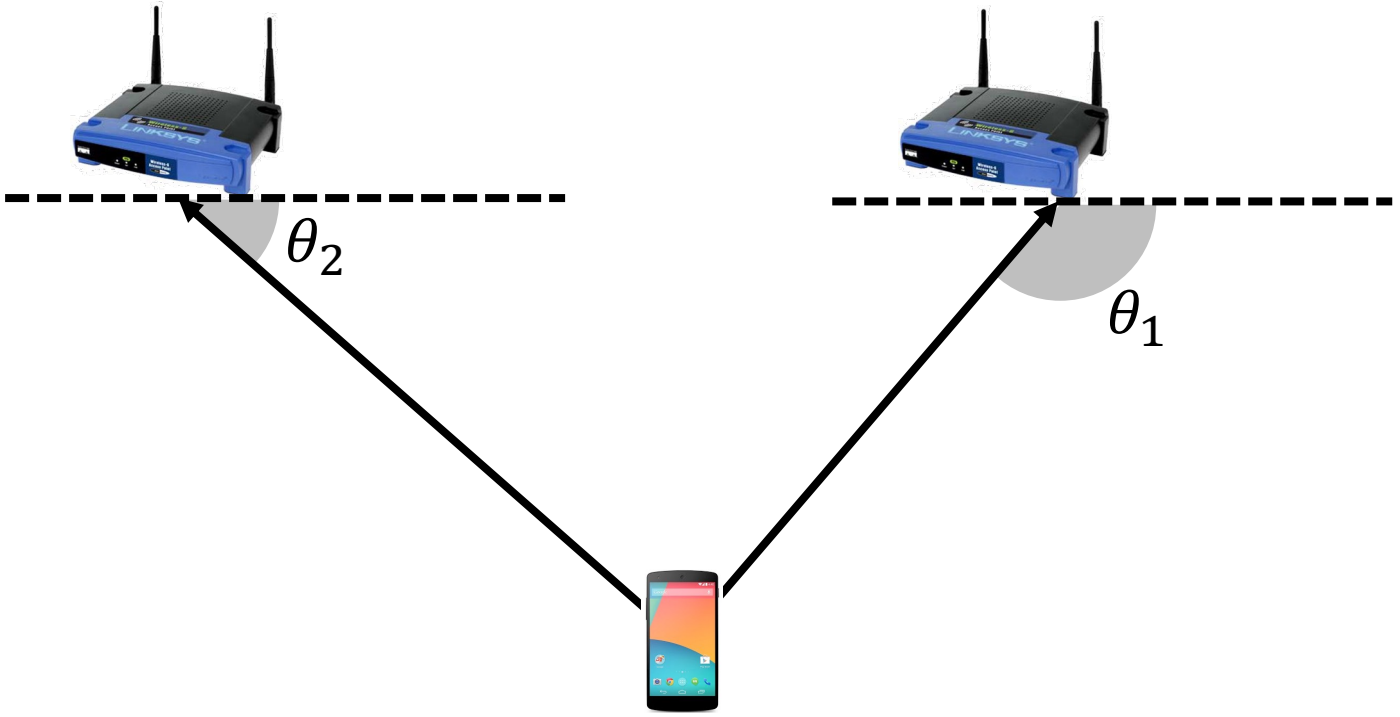
**Phase:** $\phi = 2\pi \frac{d}{\lambda}$




**Cons:** Cycle Ambiguity

# 4. Angle of Arrival (AoA)

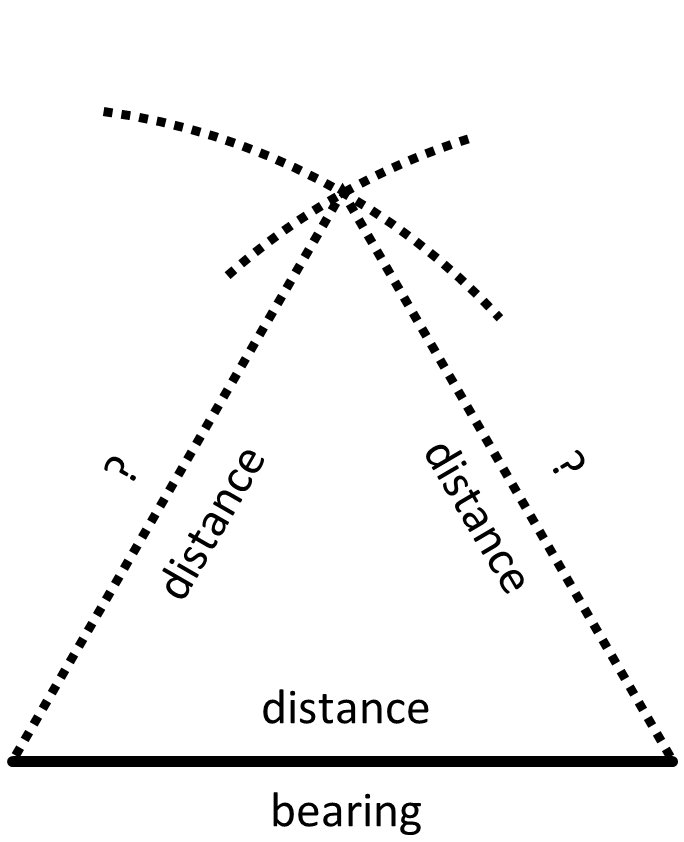
**Triangulation** from angular measurements



# Triangulation and Trilateration

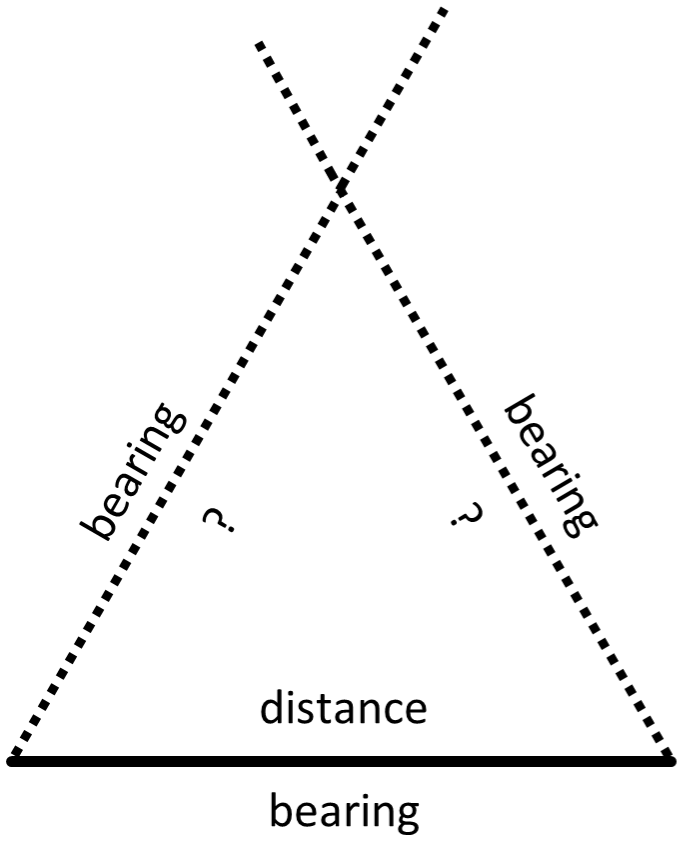
**Trilateration**

(2 missing bearings)

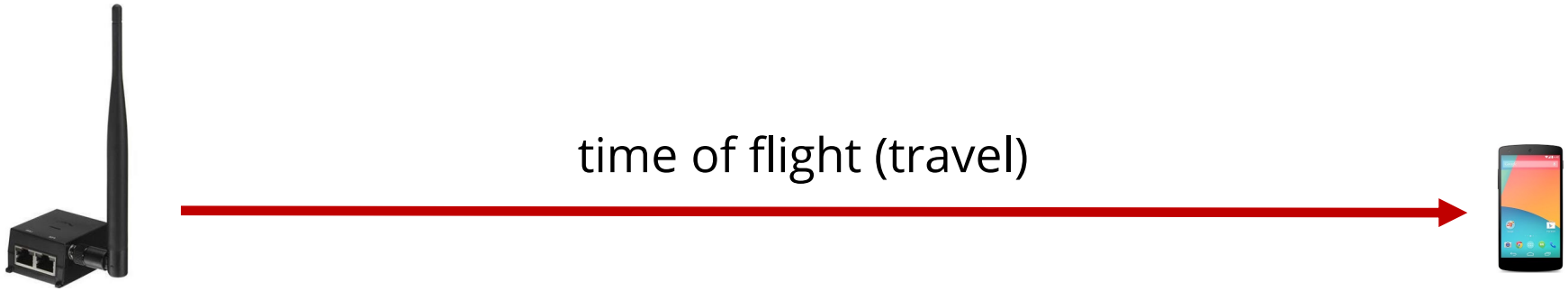



**Triangulation**

(2 missing distances)



# 5. Time-of-Flight (ToF)




Distance = Time of flight × speed of light

Measure ToF → Get distance → Trilateration

# 5. Time-of-Flight (ToF)

Measure Time of Flight (ToF) from device to each AP

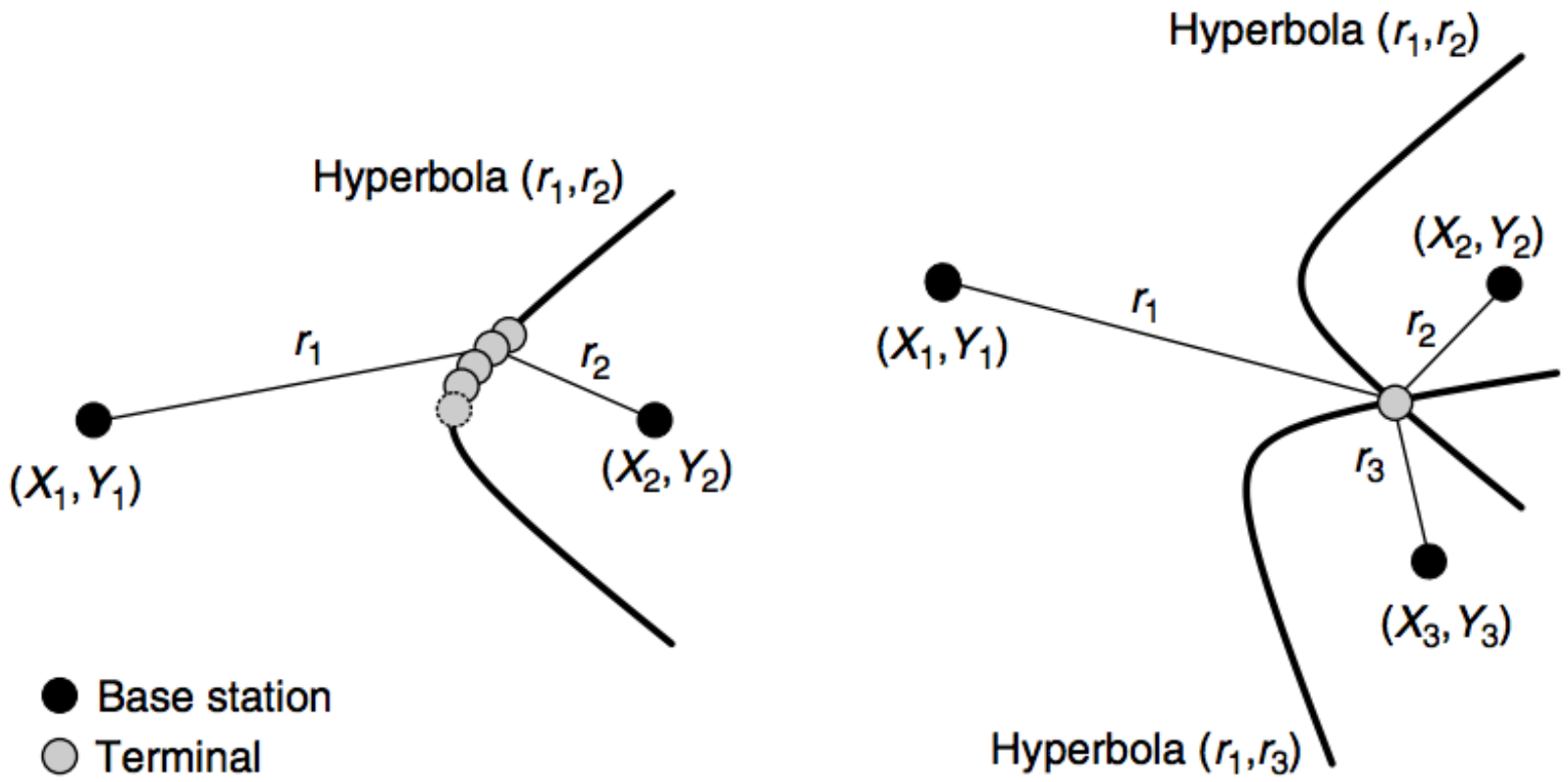
**Challenge:**

- How do you know when signal was transmitted?

- Techniques to can get accurate ToF:

  - UWB: Ultra-Wide Band (e.g., Apple AirTag)
  - FMCW: Frequency Modulated Carrier Wave

# 6. Time-Difference-of-Arrival (TDoA)



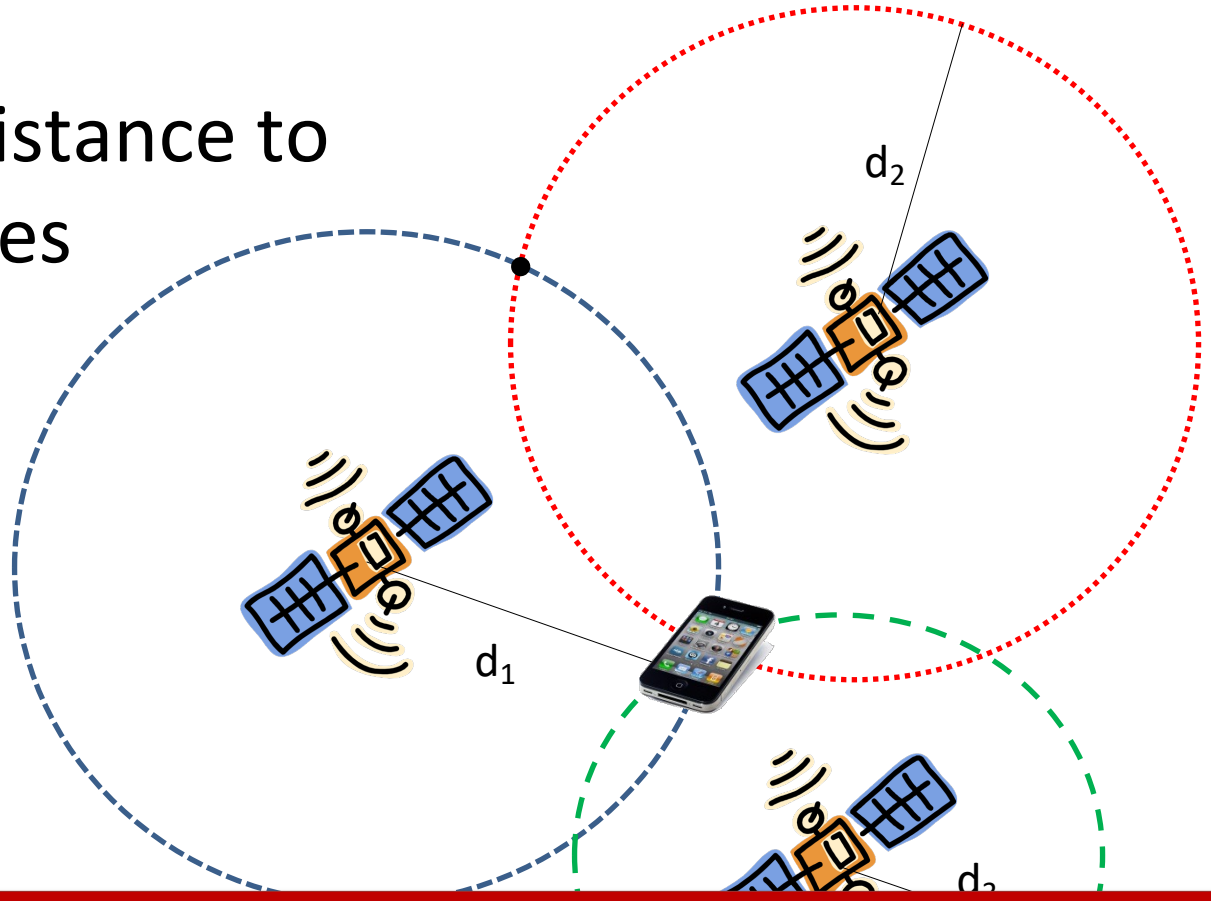
# State-of-the-Art Techniques?

Sophisticated Combinations of these techniques, e.g.,:

- Combine AoA with ToF
- Use circular antennas and combine with inertial sensing
- Perform synthetic aperture radar
- Synthesize measurements from multiple frequencies
- …

# GPS

Compute the distance to the GPS satellites




**distance = propagation delay x speed of light**

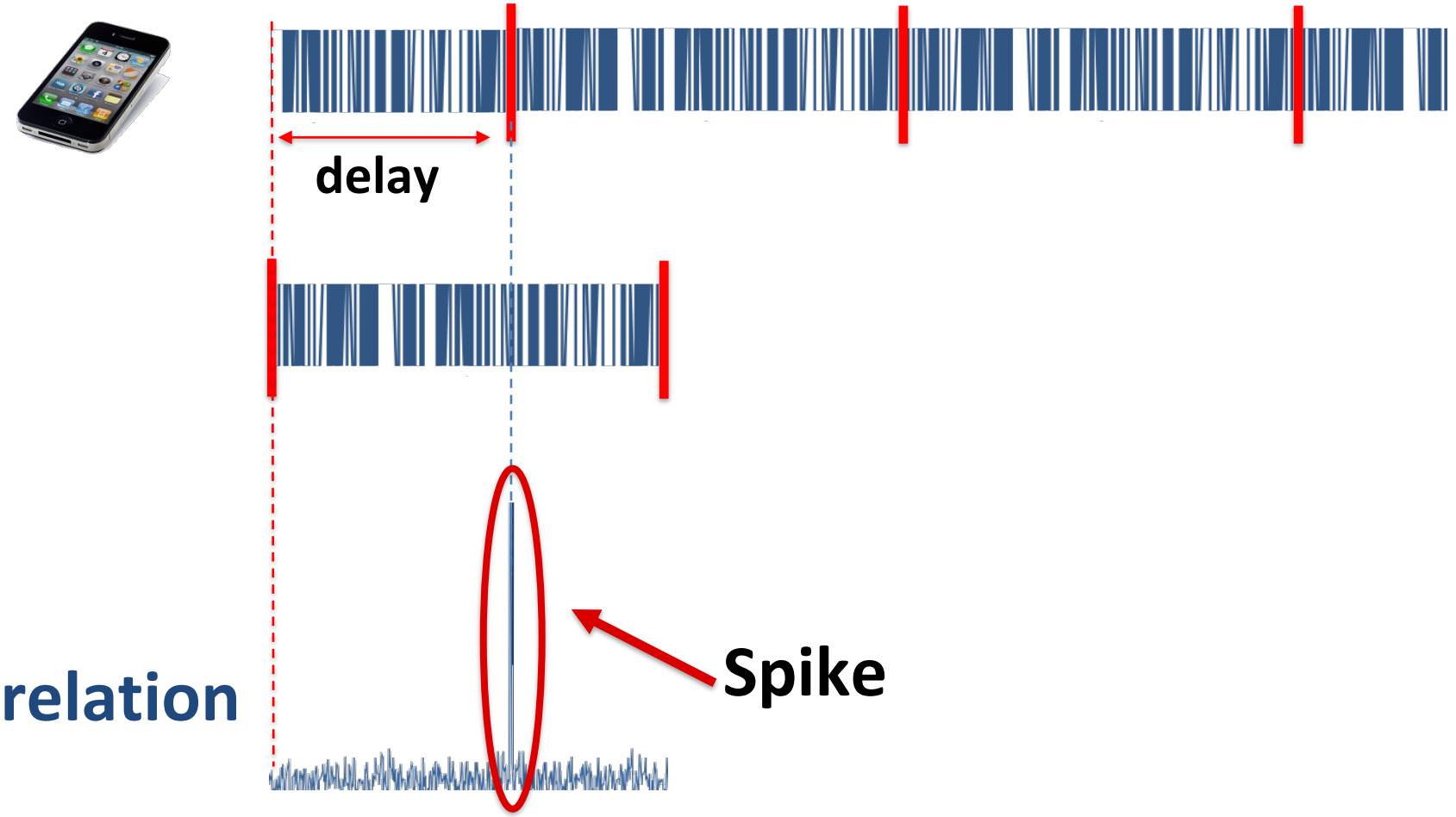
# How to Compute the Propagation Delay?


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

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next lecture (case studies)

# Next class

- Mon Sep 11
- Device-based Localization
  - Required: Cricket
  - Optional: RADAR

- Lab 0 is out. Due on Sep 17