MAS.S66
Computational Wireless Sensing

Lecture 2: Localization

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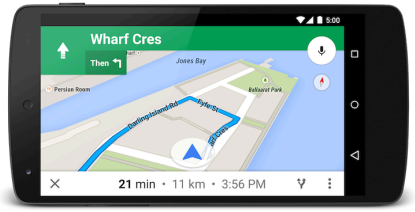
What is Wireless Positioning (aka Localization)?

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

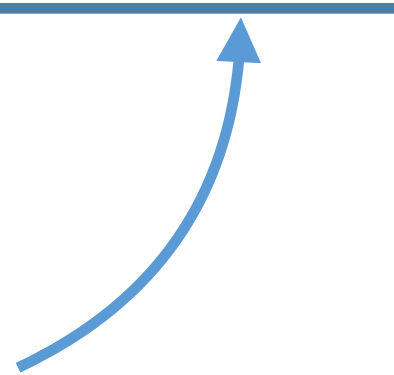
Applications:



- 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

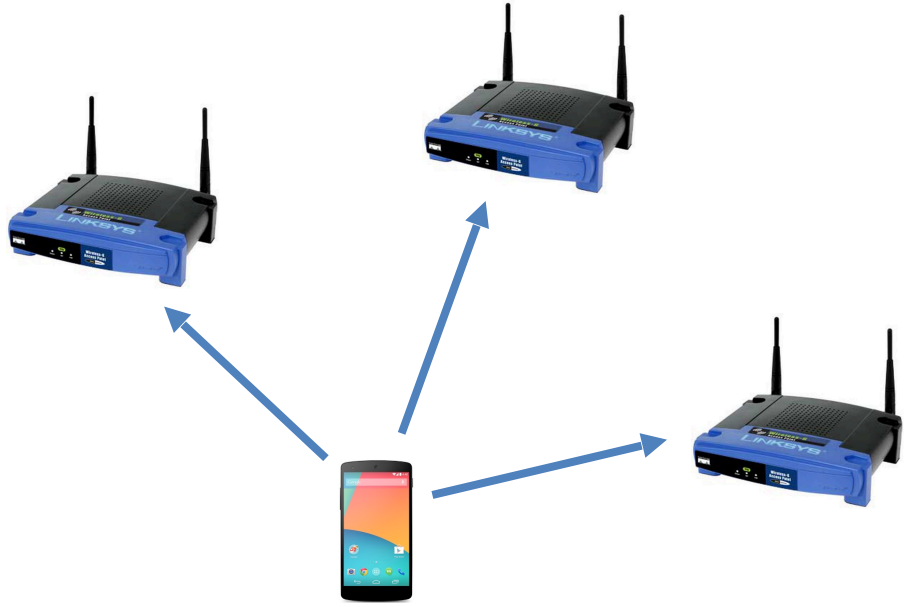
We will discuss the localization techniques in increasing order of sophistication

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.

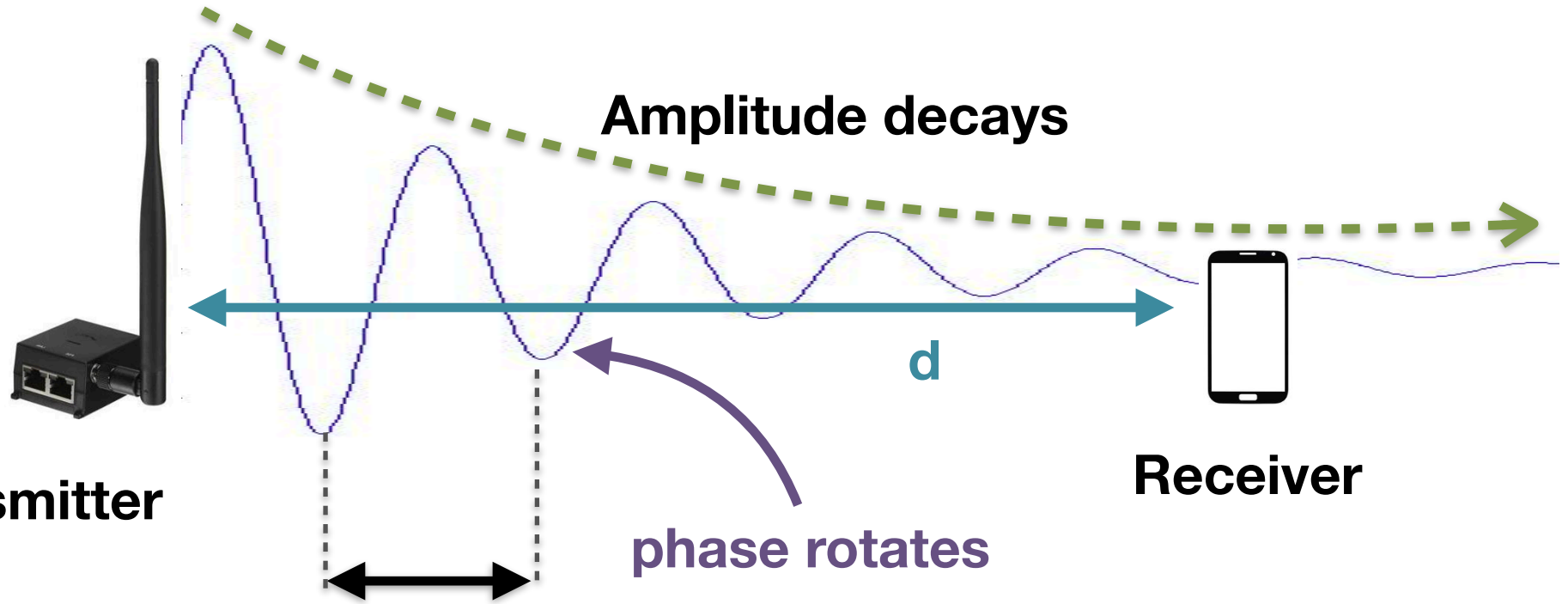
Pros? Cons?

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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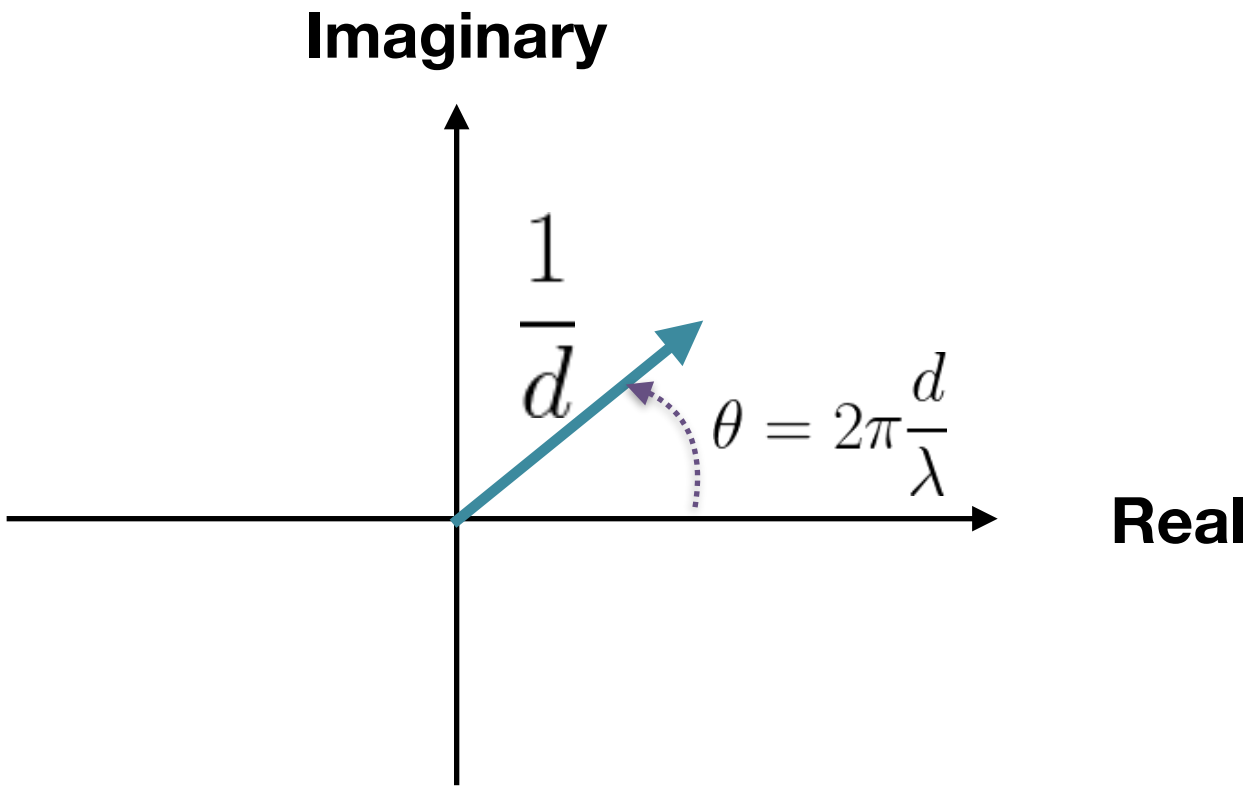
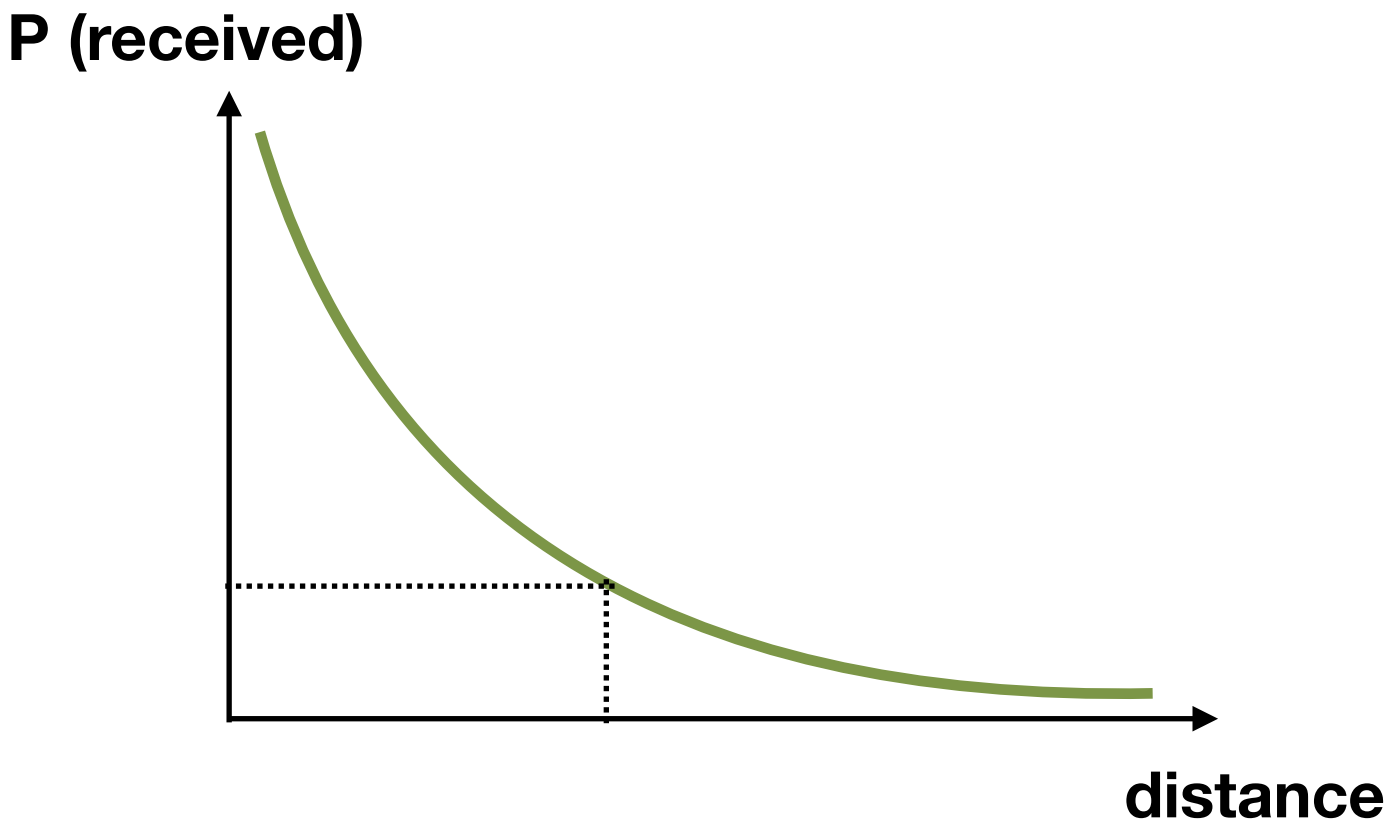


2) Received Signal Strength (RSSI)

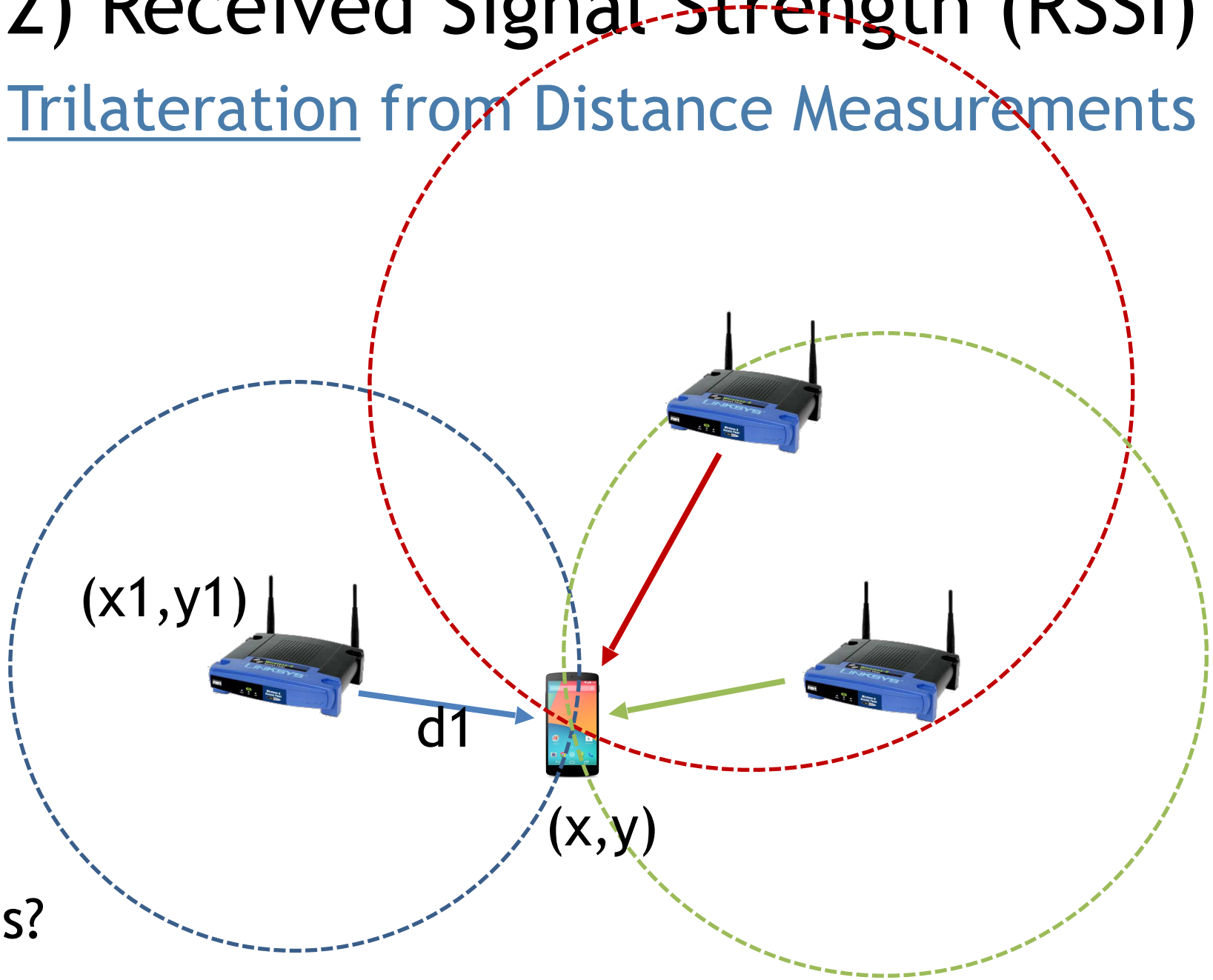
From power to distance

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

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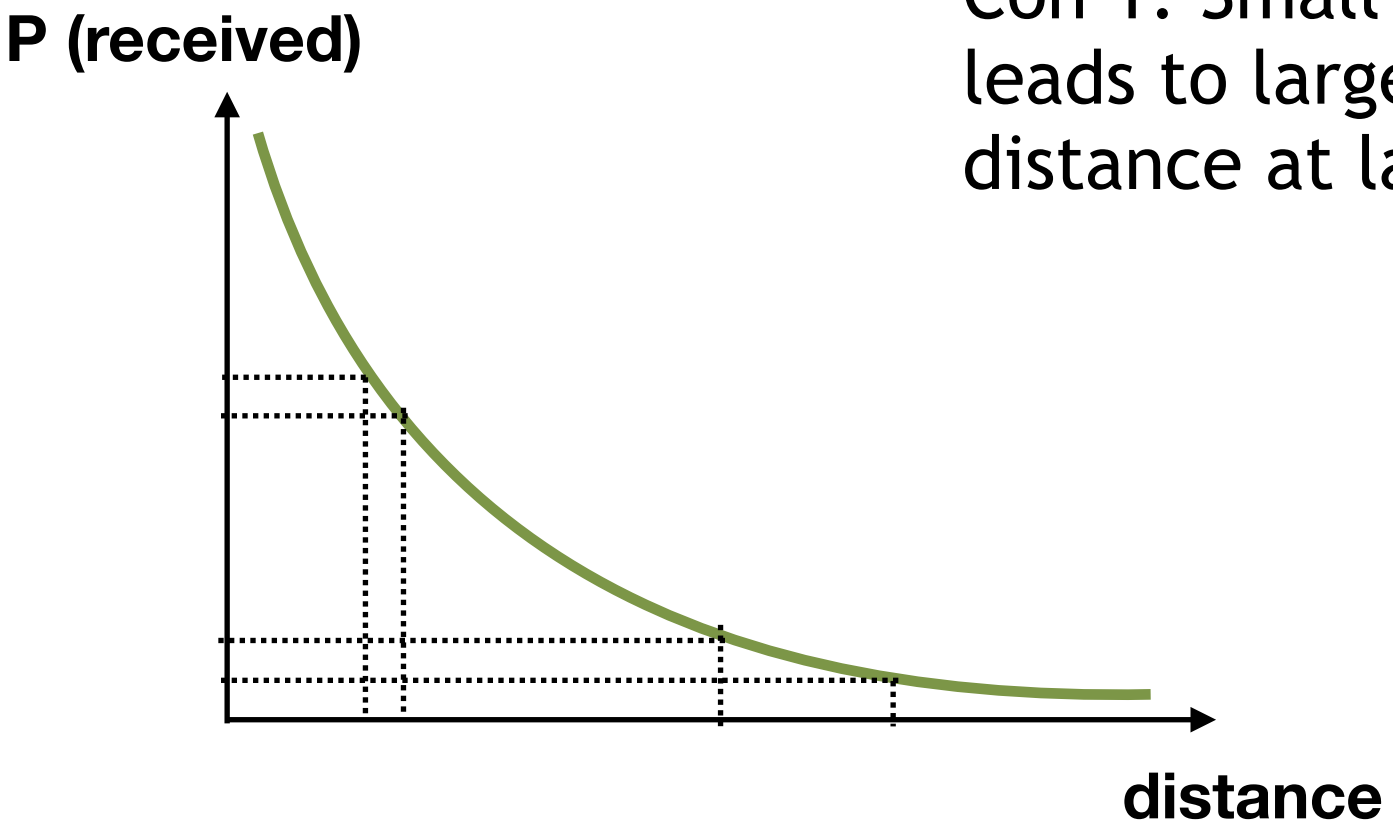
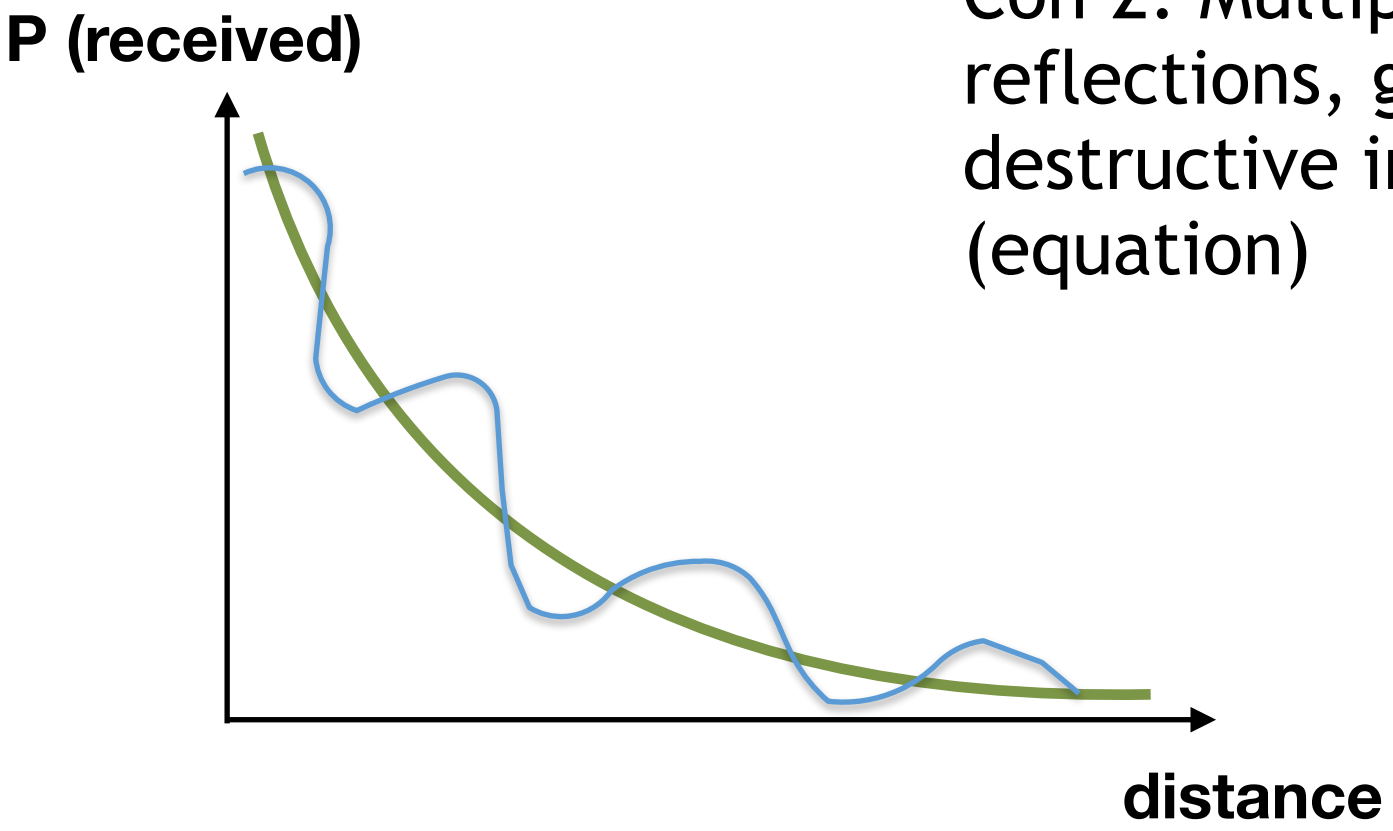


Con 1: Small change in power leads to large deviations in distance at larger distances

2) Received Signal Strength (RSSI)

From power to distance

Power is proportional to $1/d^2$

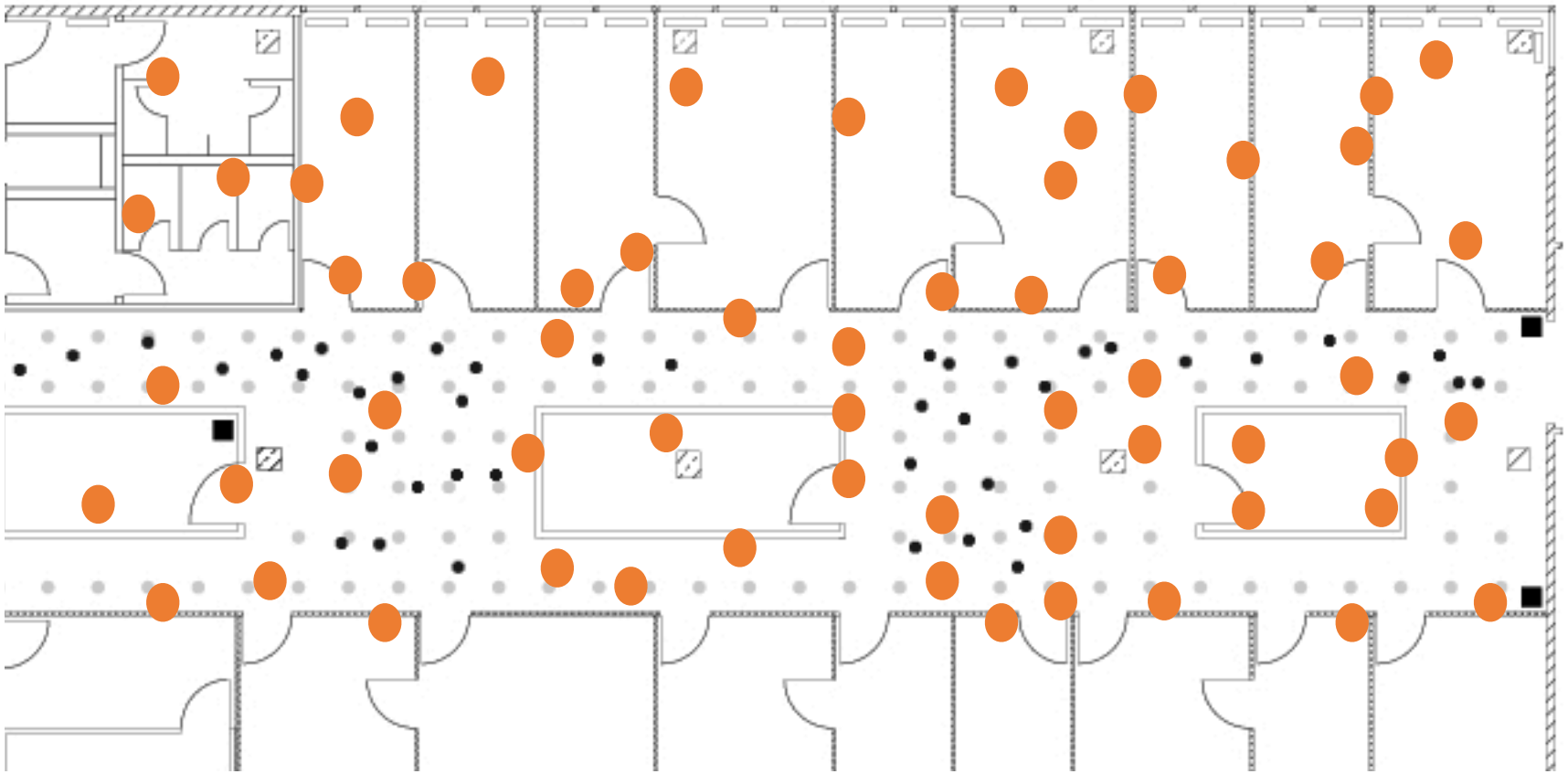


Con 2: Multipath: Due to reflections, get constructive and destructive interference (equation)

2) Received Signal Strength (RSSI)

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

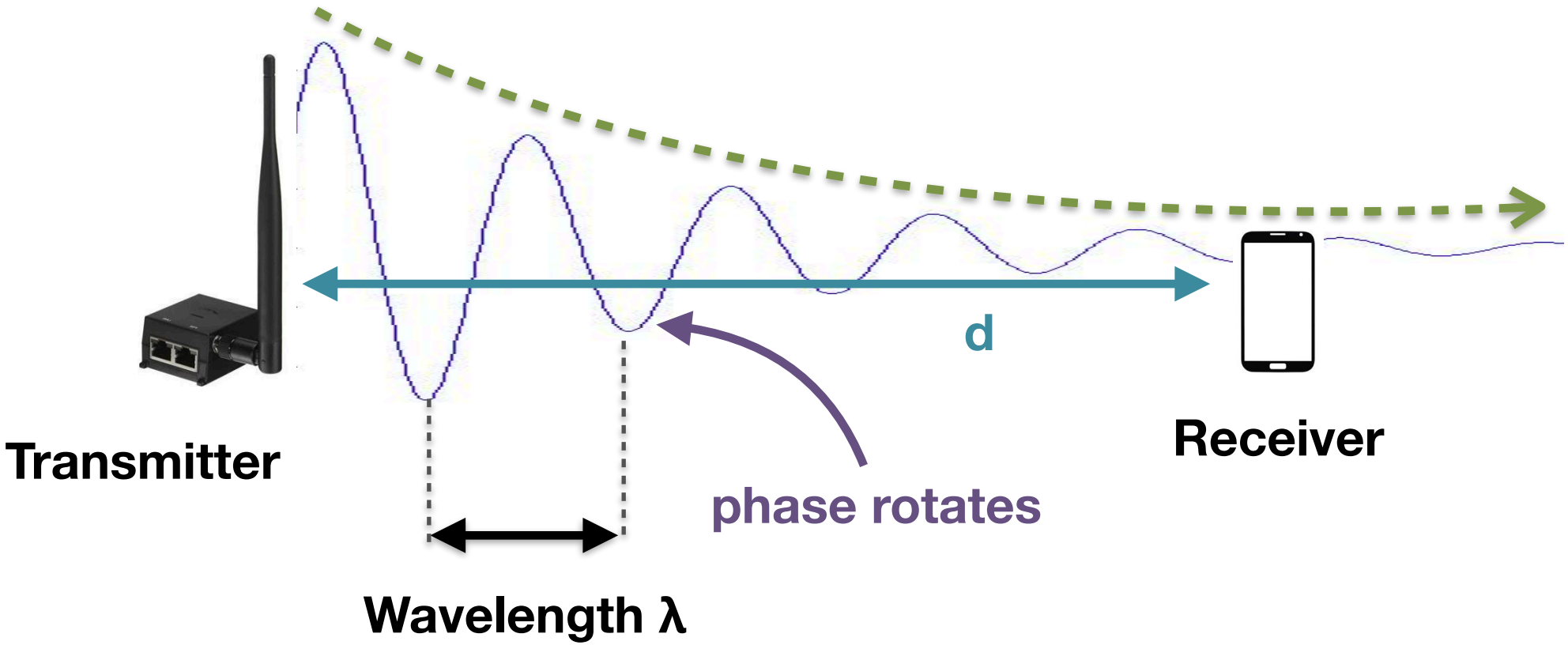
Database



Pros? Cons?

3) Use the Signal “Phase”

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

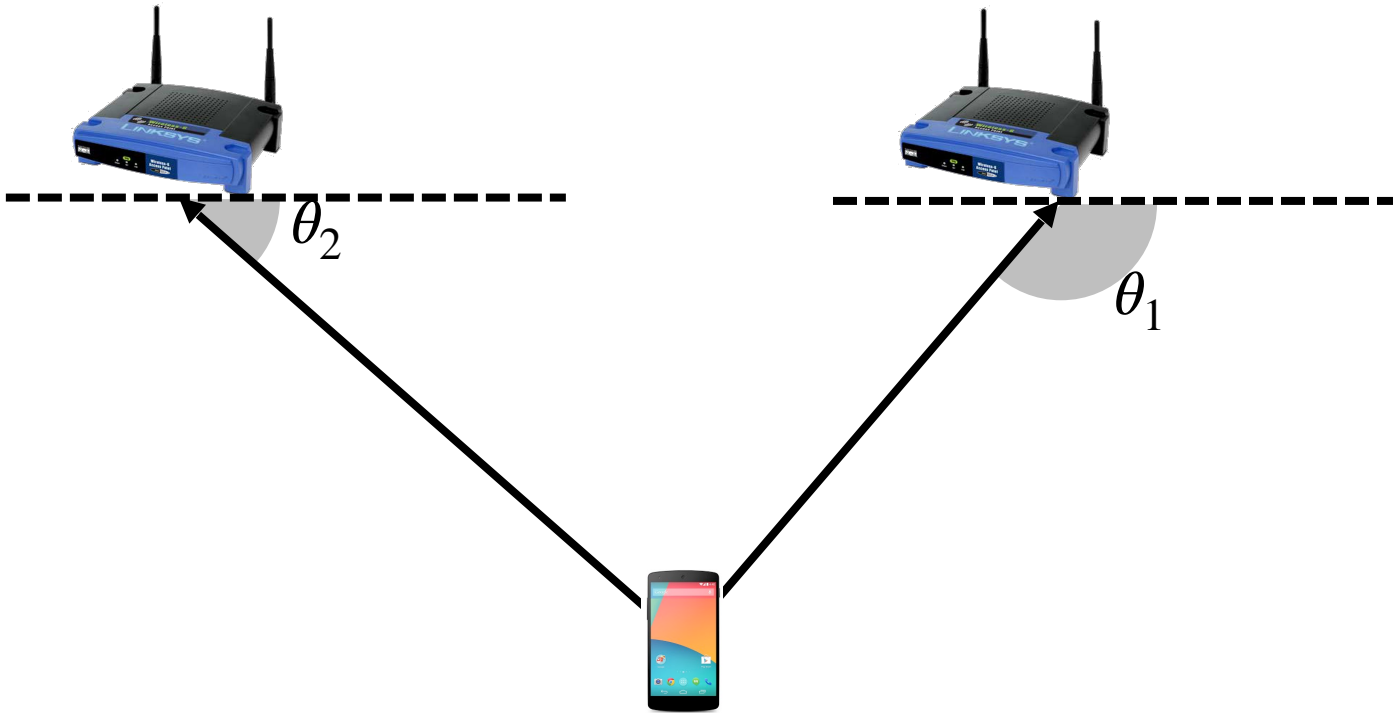


Pros? Cons?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

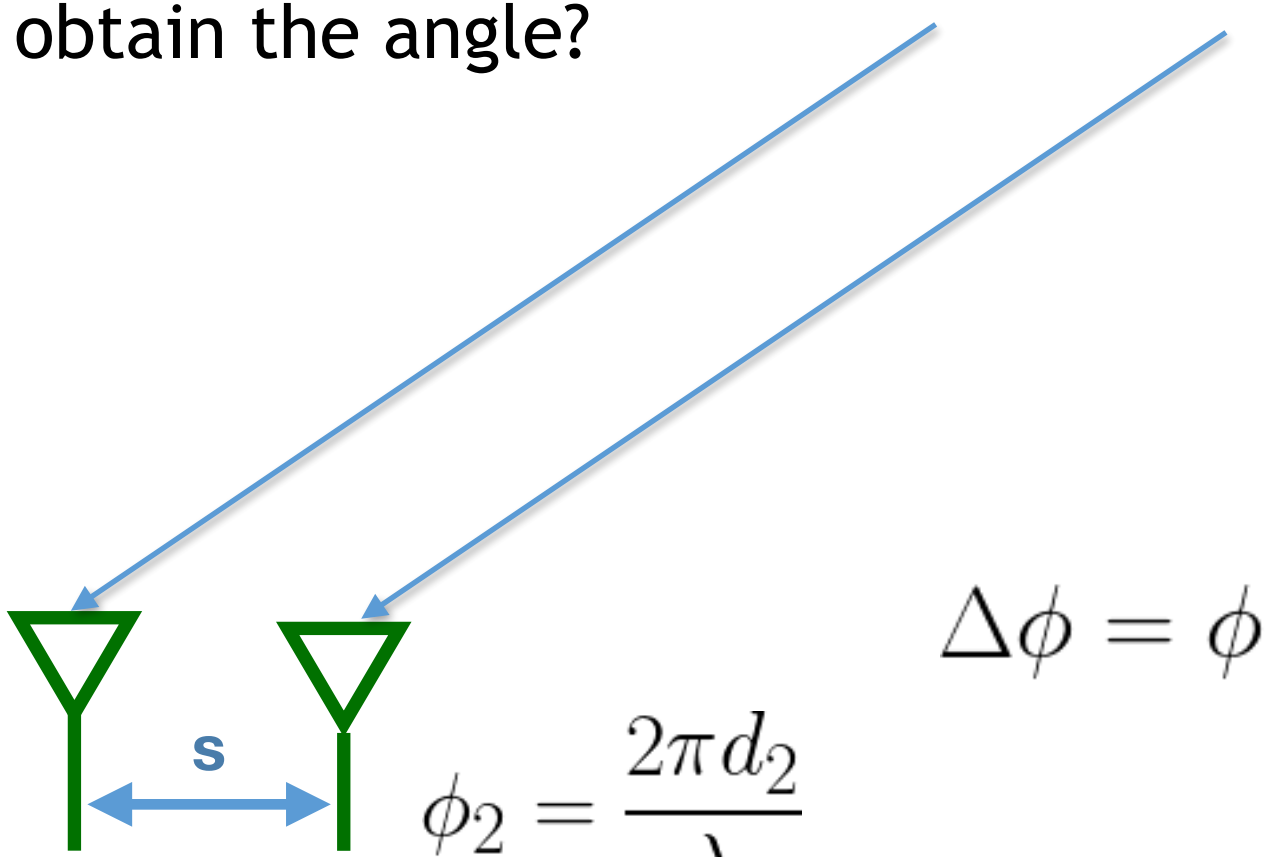
Measure Angle of Arrival (AoA) from device to each AP



4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

How can we obtain the angle?



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

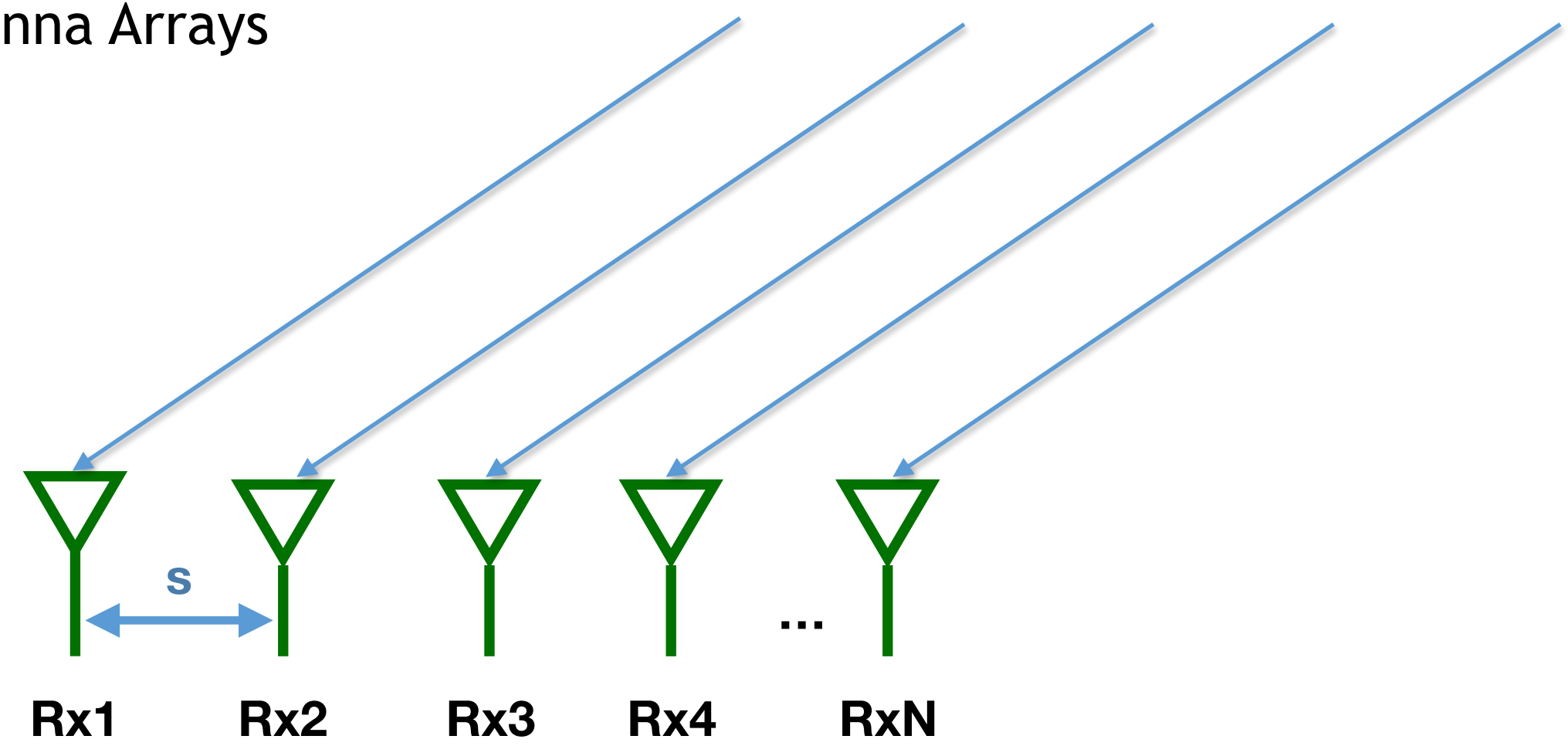
$$\Delta\phi = \phi_1 - \phi_2 = \frac{2\pi s \cos\theta}{\lambda}$$

Issues?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

Use Antenna Arrays



4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

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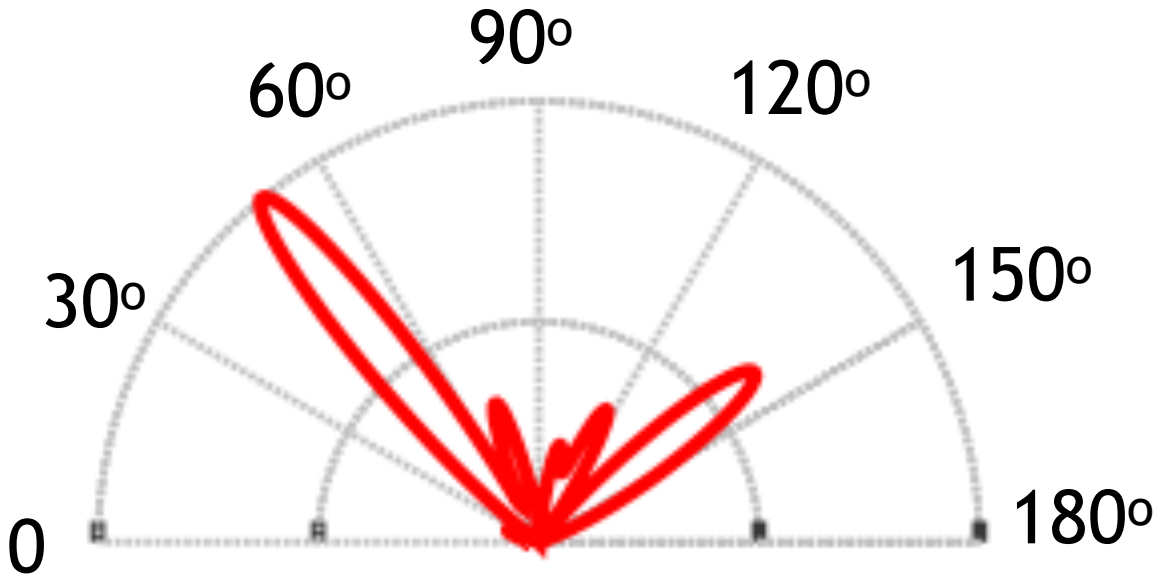


How do we know which direction corresponds to the direct path?

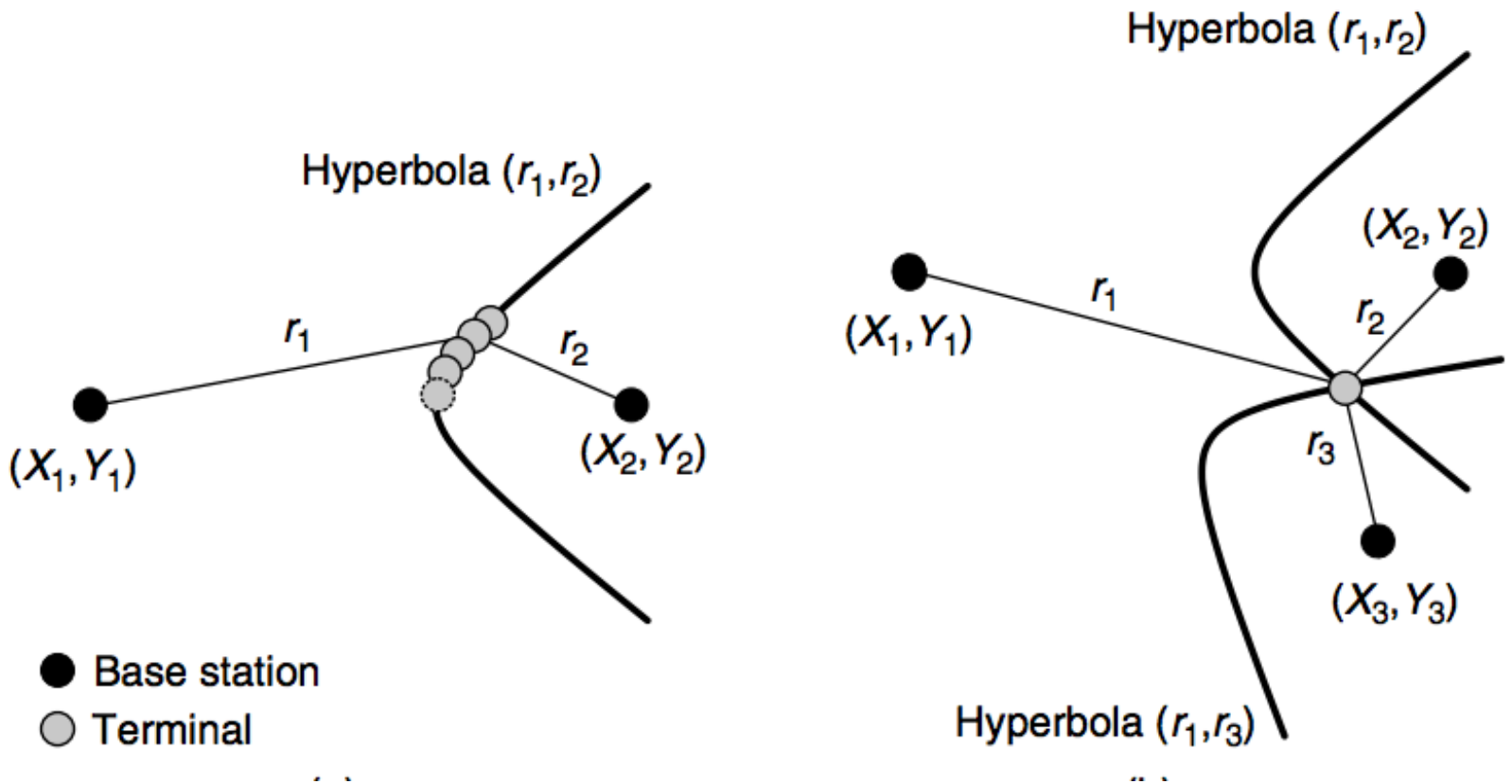
5) Measure the Time-of-Flight (ToF)

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
- …

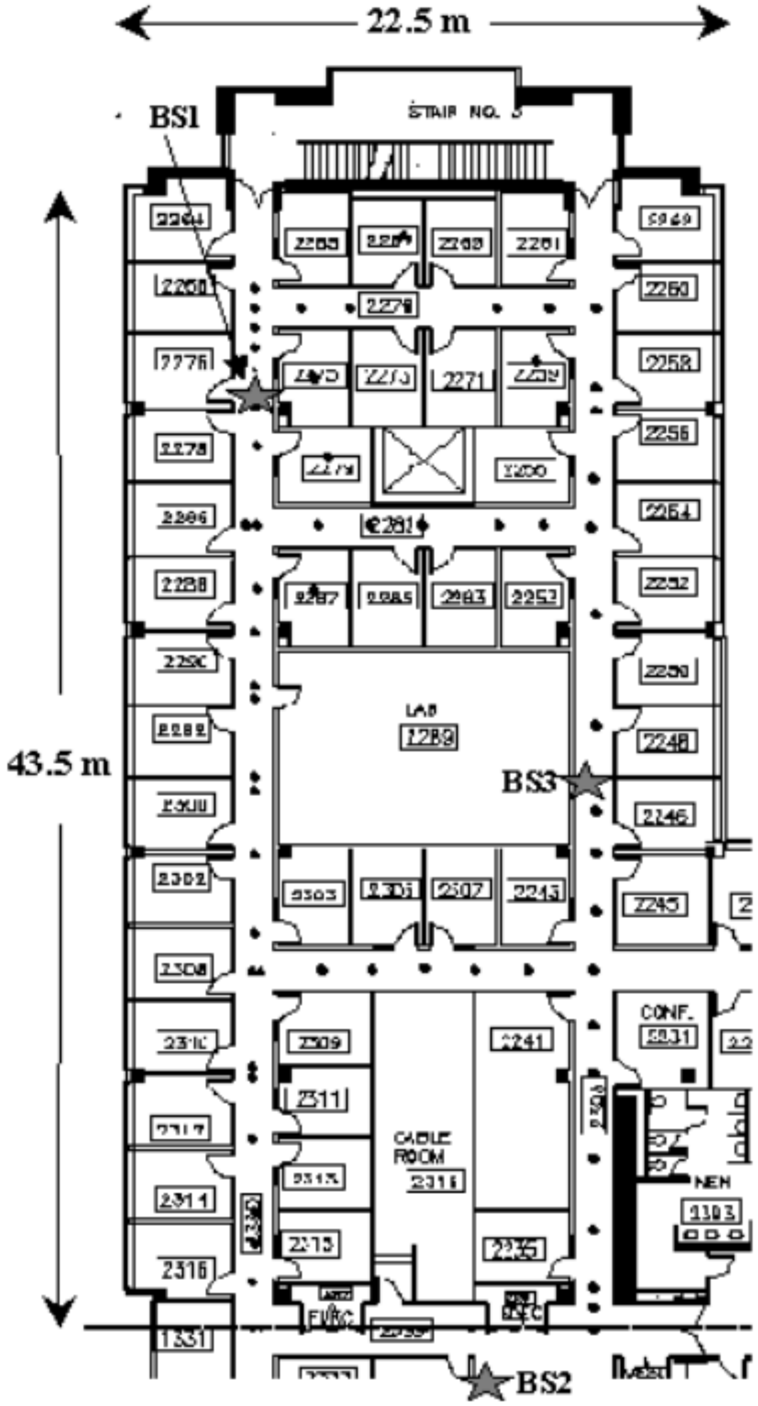
- So Far: Localization Primitives

- Rest of this Lecture: Case Studies
  - Indoor Positioning Systems:
    - RADAR [2000]; Cricket [2000]
  - Outdoor Positioning:
    - GPS

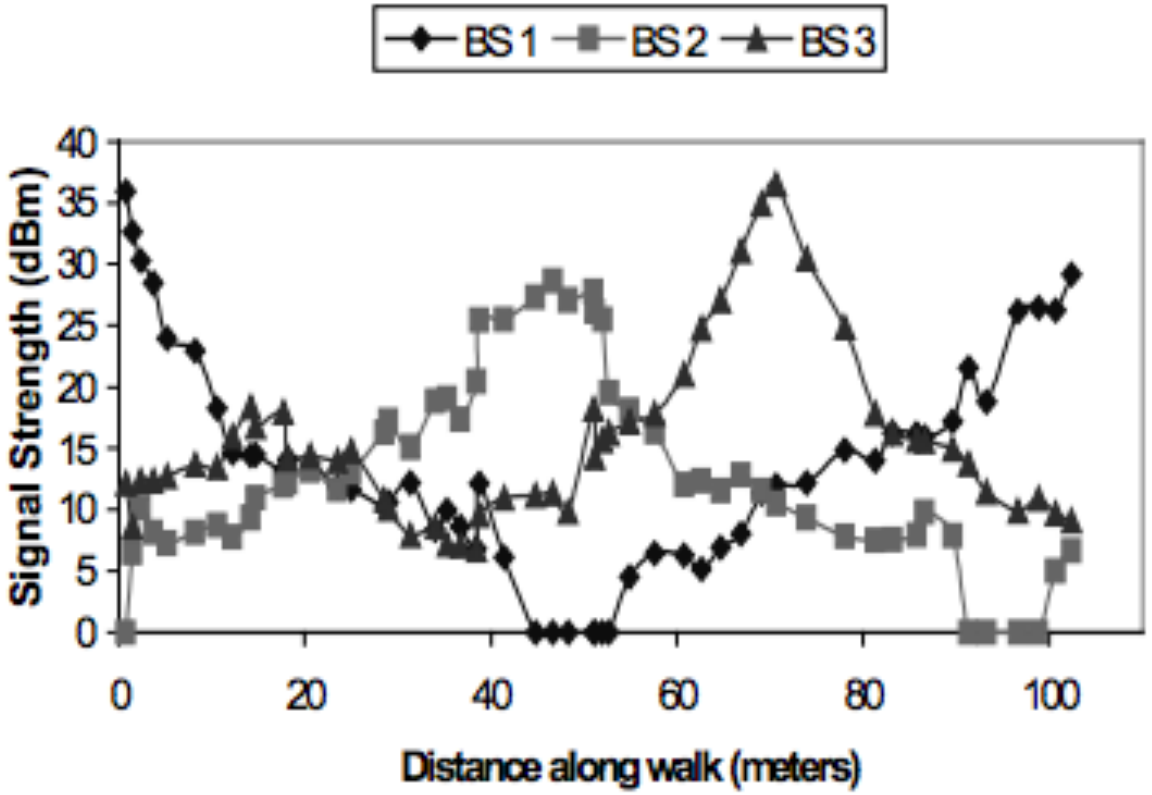
Case Study 1: RADAR [INFOCOM ’00]

Why are we reading this paper?

- First paper to propose using wireless LANs for indoor location estimation
- Measurement-based / analysis paper (not system)
- Key idea: which of the localization primitives?
- Pioneering idea; with many enhancements it’s a viable approach today in many settings


22.5 m
43.5 m
BS1
BS2
BS3
LAB
CABLE ROOM
CONF.

Signal strength at the base stations as user walks



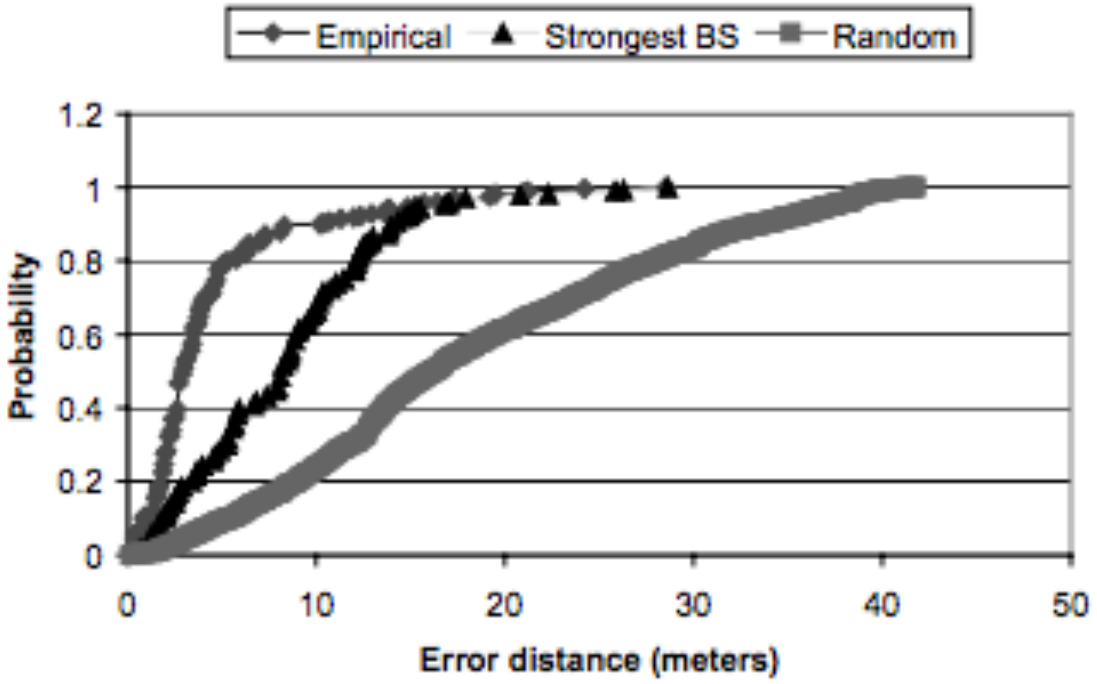
Approach

- Summarize signal strength samples at base stations
- Metric for determining best match
- Determine “best match”

Approach

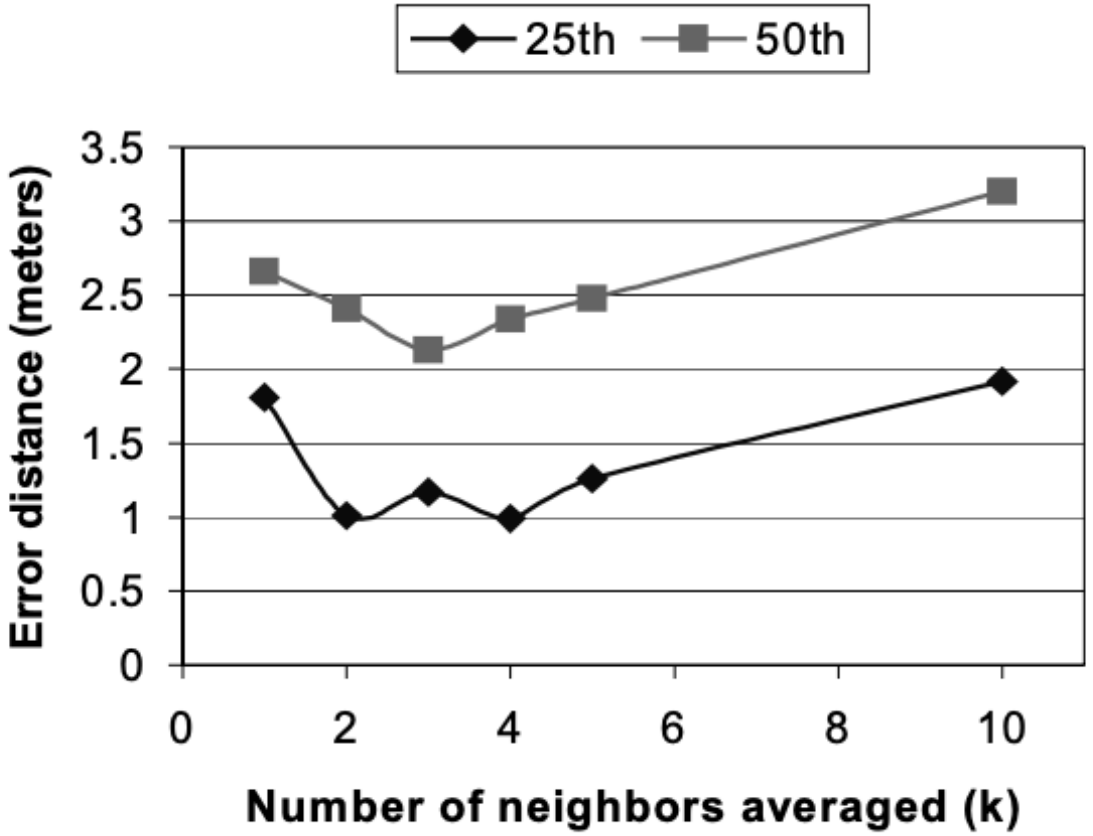
- Summarize signal strength samples at base stations
  - Mean signal strength over a time window
- Determine “best match”
  - Empirical method
  - Signal propagation model
- Metric for determining best match
  - Nearest neighbor in signal space, i.e., Euclidean distance between ss’ and ss vectors

Evaluation



- Critique the evaluation?

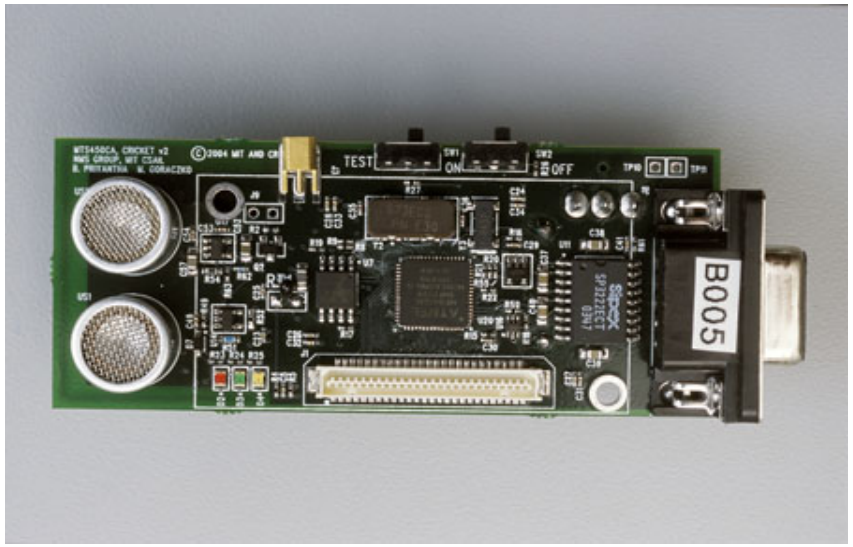
Averaging multiple nearest neighbors

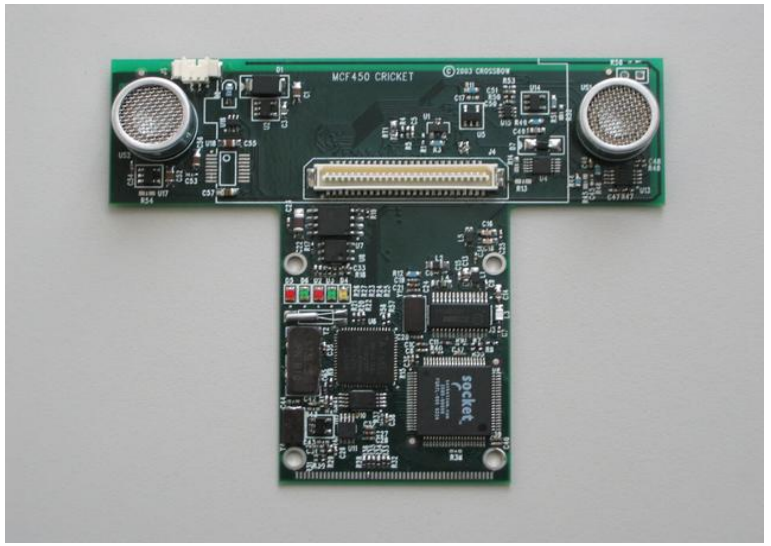


Why does the graph look like this?

Case Study 2: Cricket [MobiCom ’00]

A general-purpose indoor location system for mobile and sensor computing applications

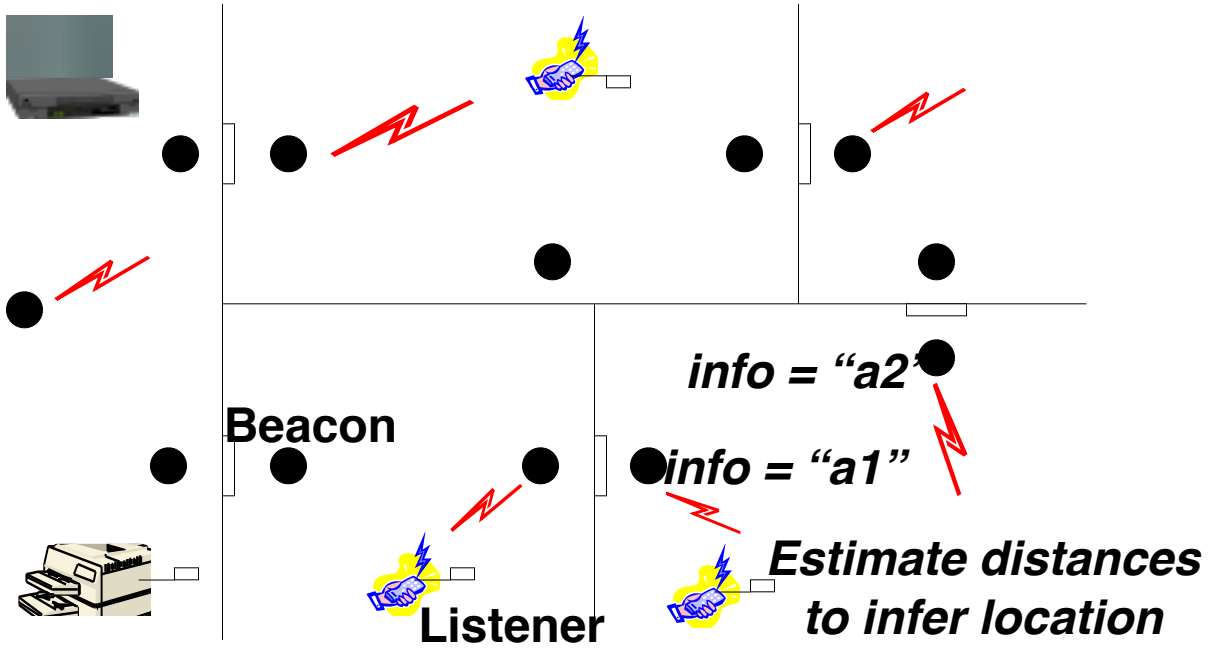




Cricket Design Goals

- Must work well indoors
- Must scale to large numbers of devices
- Should not violate user location privacy — location-support rather than track
- Must be easy to deploy and administer
- Should have low energy consumption

Cricket Architecture



Passive listeners + active beacons scales well, helps preserve user privacy

Decentralized, self-configuring network of autonomous beacons

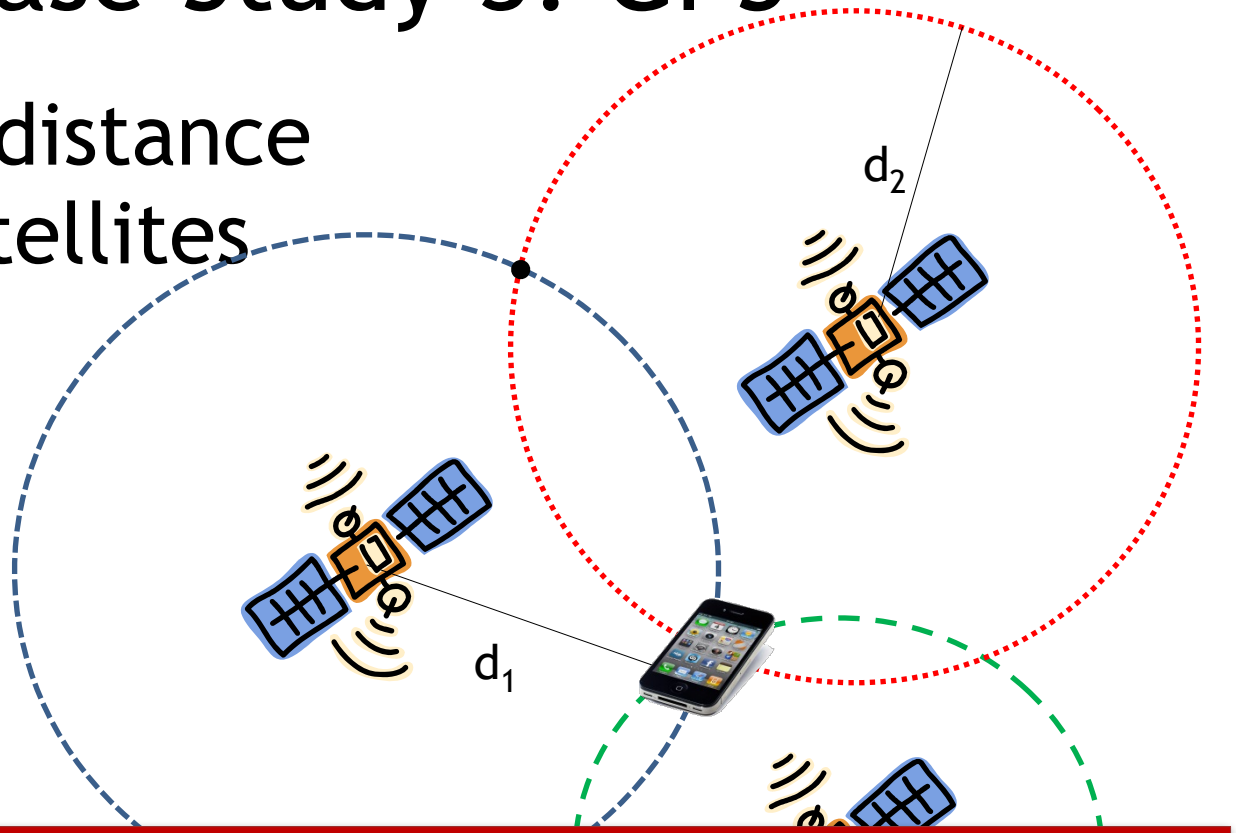
Cricket Localization Primitive

- Combine ultrasound + RF
  - use time difference between them (similar to lightening+thunder)
- How to avoid/minimize interference?
  - “Long radio”: b < S/tau
- How to localize?
  - majority (pick beacon with highest freq of occurrence)
  - minmean (pick beacon with smallest mean distance)
  - minmode (pick beacon with smallest mode distance)

How to improve?

Case Study 3: GPS

Compute the distance to the GPS satellites



distance = propagation delay x speed of light

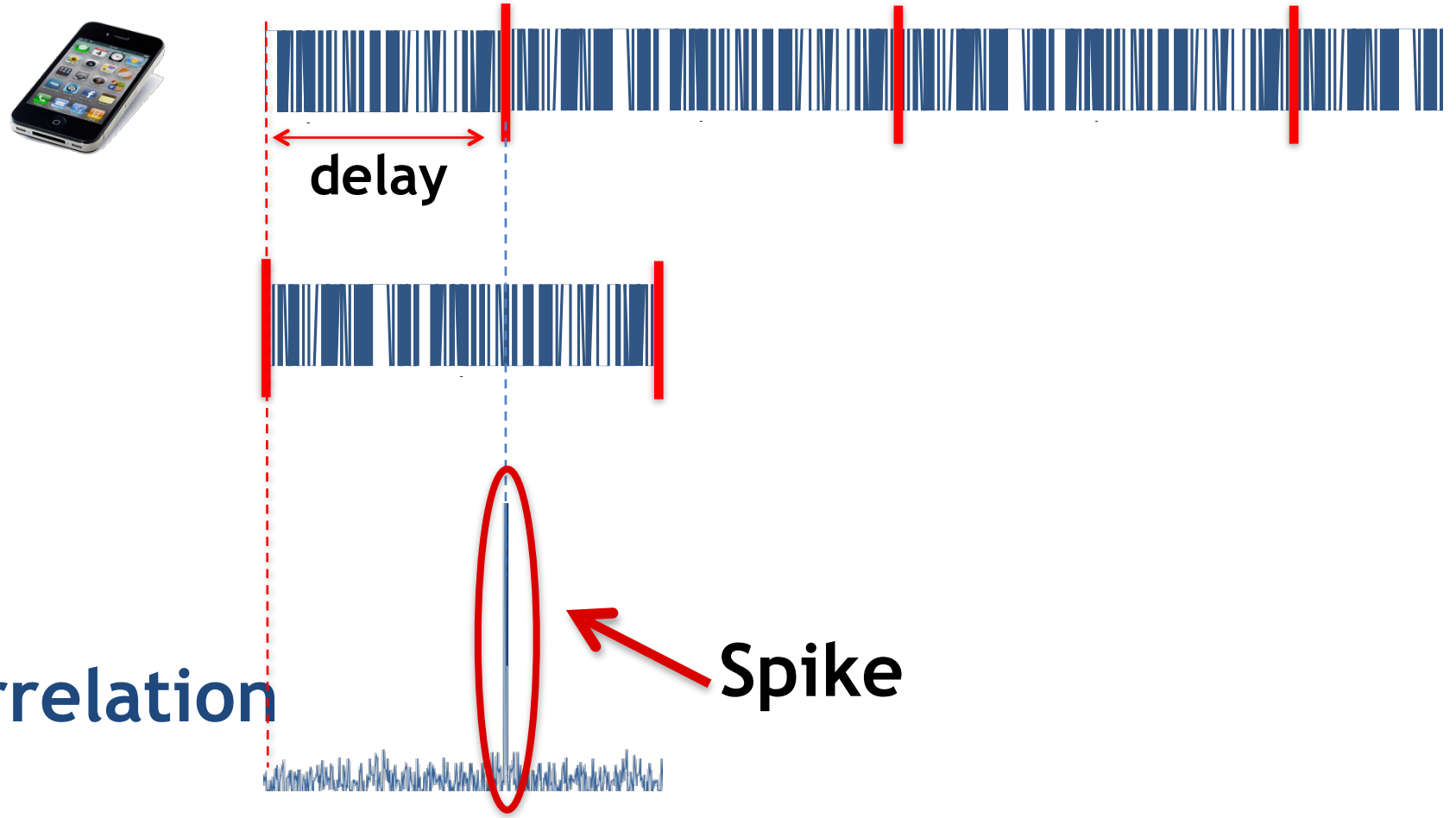
How to Compute the Propagation Delay?

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

Localization Primitives & Systems

- Applications
- Modalities
- Network vs device-based
- Increasing levels of sophistication
- Case Studies from early IPS: RADAR, Cricket
- GPS

Feedback on reviews

- Summary: Too long/too short
- Pros/Cons:
  - Itemize them, include 2-4
  - Don’t make them about typos/writing style/clarity, e.g., abstract or future work. Make them about the system itself
- Suggestions for improvement
  - Make it about the system rather than about the paper itself