http://www.mit.edu/~fadel/courses/MAS.s60/index.html

MAS.S60

How to Wirelessly Sense Almost Anything

Lecture 2:
Fundamentals of Wireless Sensing & Localization

Lecturers

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Last Updated 20 hours ago

2 minute read

WSJ

PS LOGGER FOR THE
ET OF ANIMALS

13 Comm

Personalized Prediction of Depression Treatment Outcomes With Wearables

Featured Neuroscience Psychology · September 18, 2022

Summary: A new multitask model artificial intelligence algorithm based on data from wearables predicts treatment outcomes on an individual basis for those with depression.

Source: WUSTL

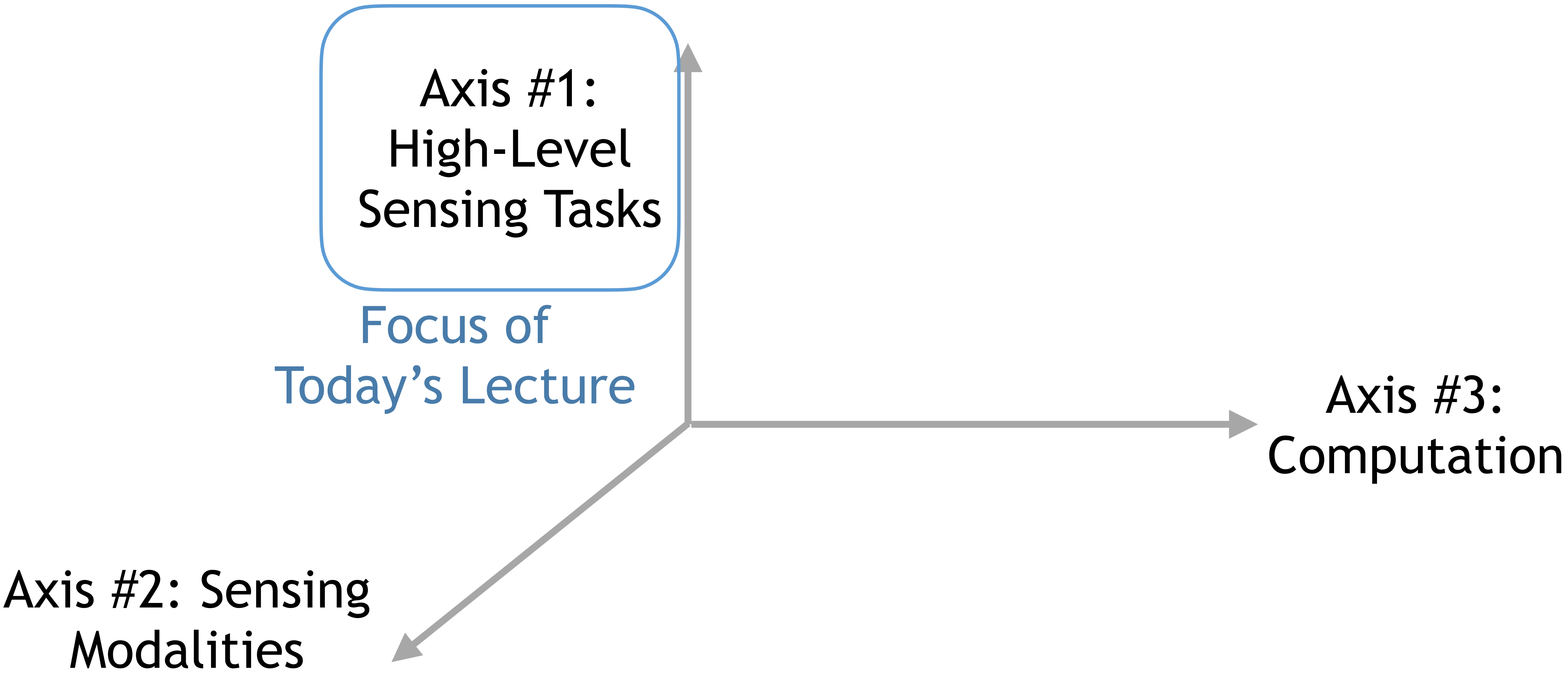
Push as Workforce Shrinks

Industrial automation climbs as country tries to extend manufacturing dominance despite labor challenges

By Jason Douglas Follow
Sept. 18, 2022 5:30 am ET

hub.com/trichl/TickTagOpenSource

Wireless Sensing Systems are designed along 3 axes



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. How do state-of-the-art positioning systems work?
4. What are the industry opportunities and societal implications of wireless positioning (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?

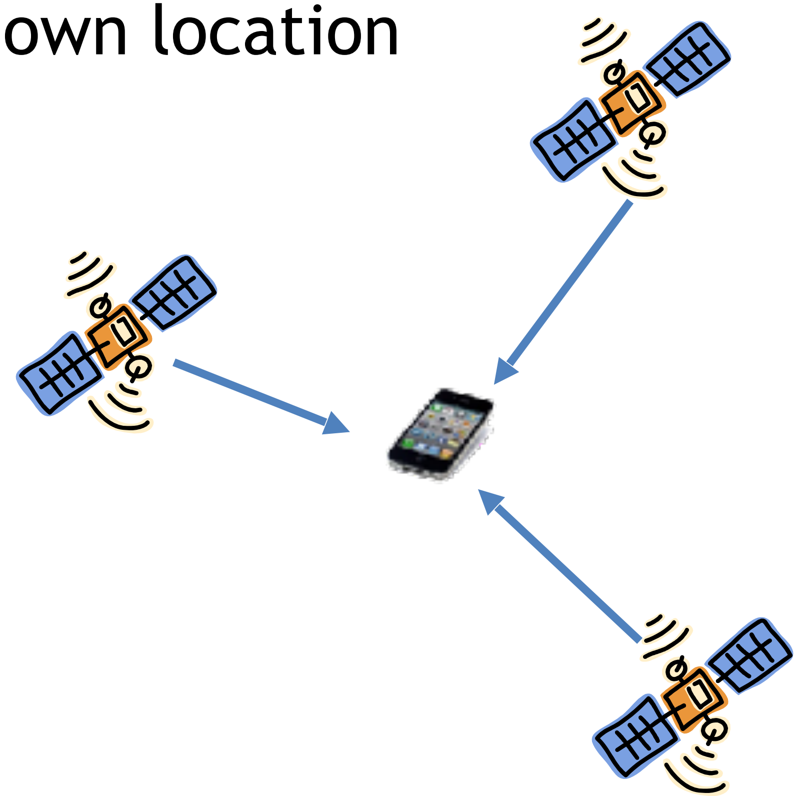
- Radio signals: GPS, Cellular, Bluetooth, WiFi
- Ultrasound signals: similar to those used in NEST
- Inertial
- Cameras, Vision, LIDAR

Focus of this lecture

We will discuss the localization techniques in increasing order of sophistication

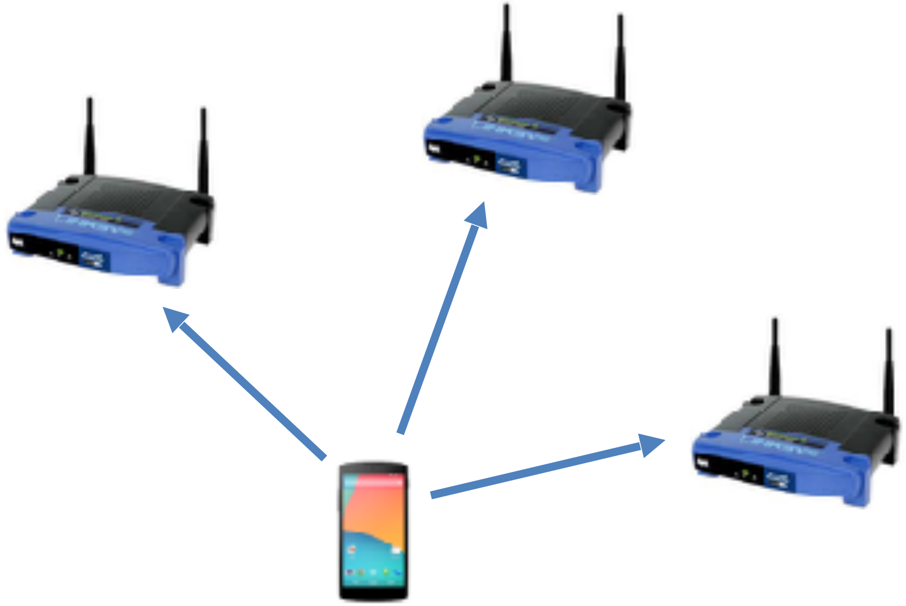
Who performs the localization process?

- 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?

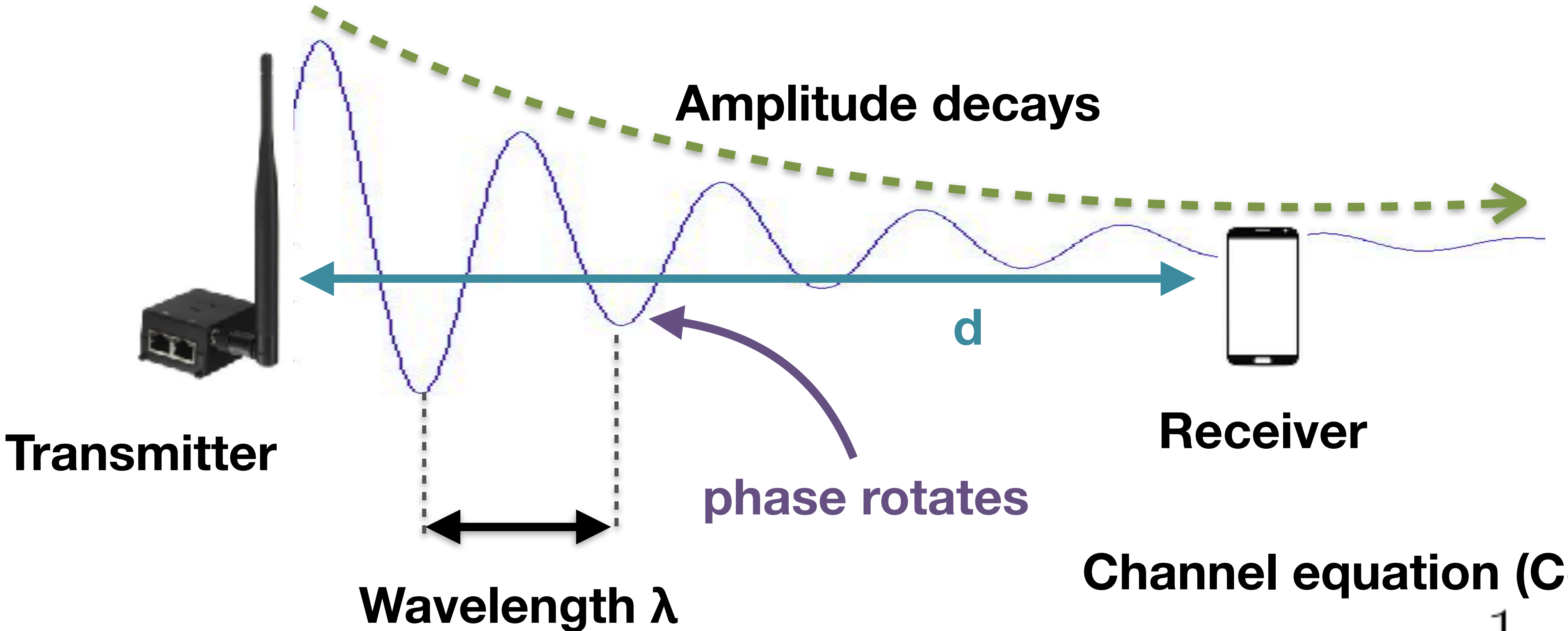
2) Received Signal Strength (RSSI)

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

Wireless Signals are Waves



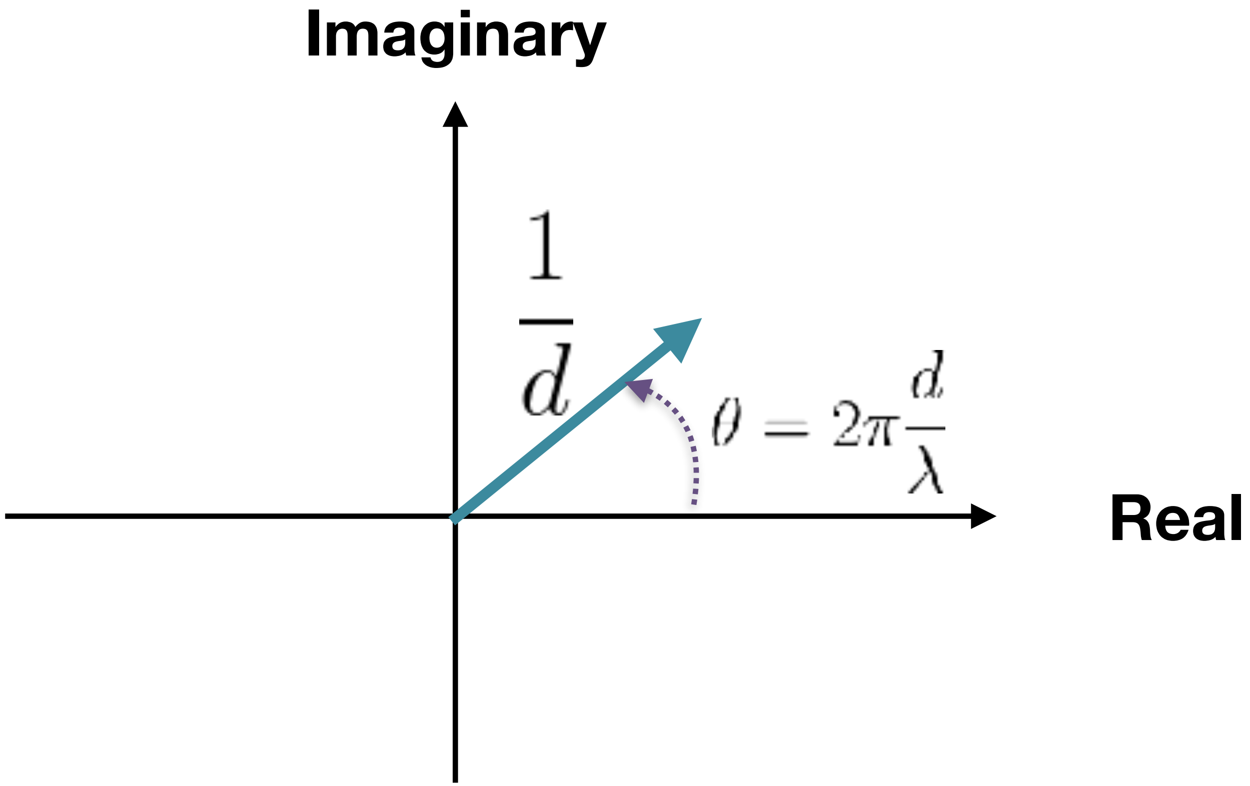
Channel equation (Complex number)

$$h = \frac{1}{d} e^{j 2\pi \frac{d}{\lambda}}$$

Wireless Signals are Waves

Channel equation (Complex number)

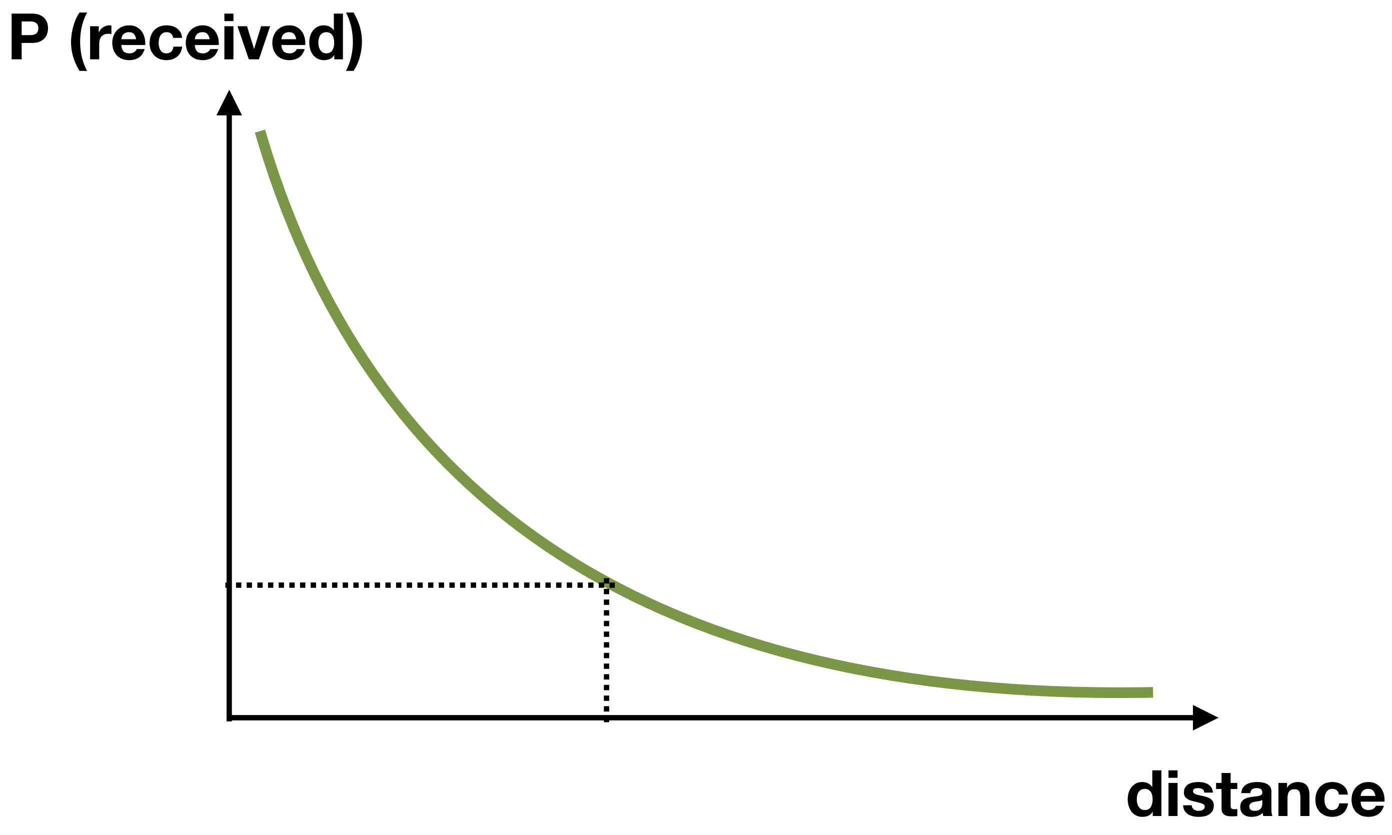
$$h = \frac{1}{d} e^{j2\pi \frac{d}{\lambda}}$$



2) Received Signal Strength (RSSI)

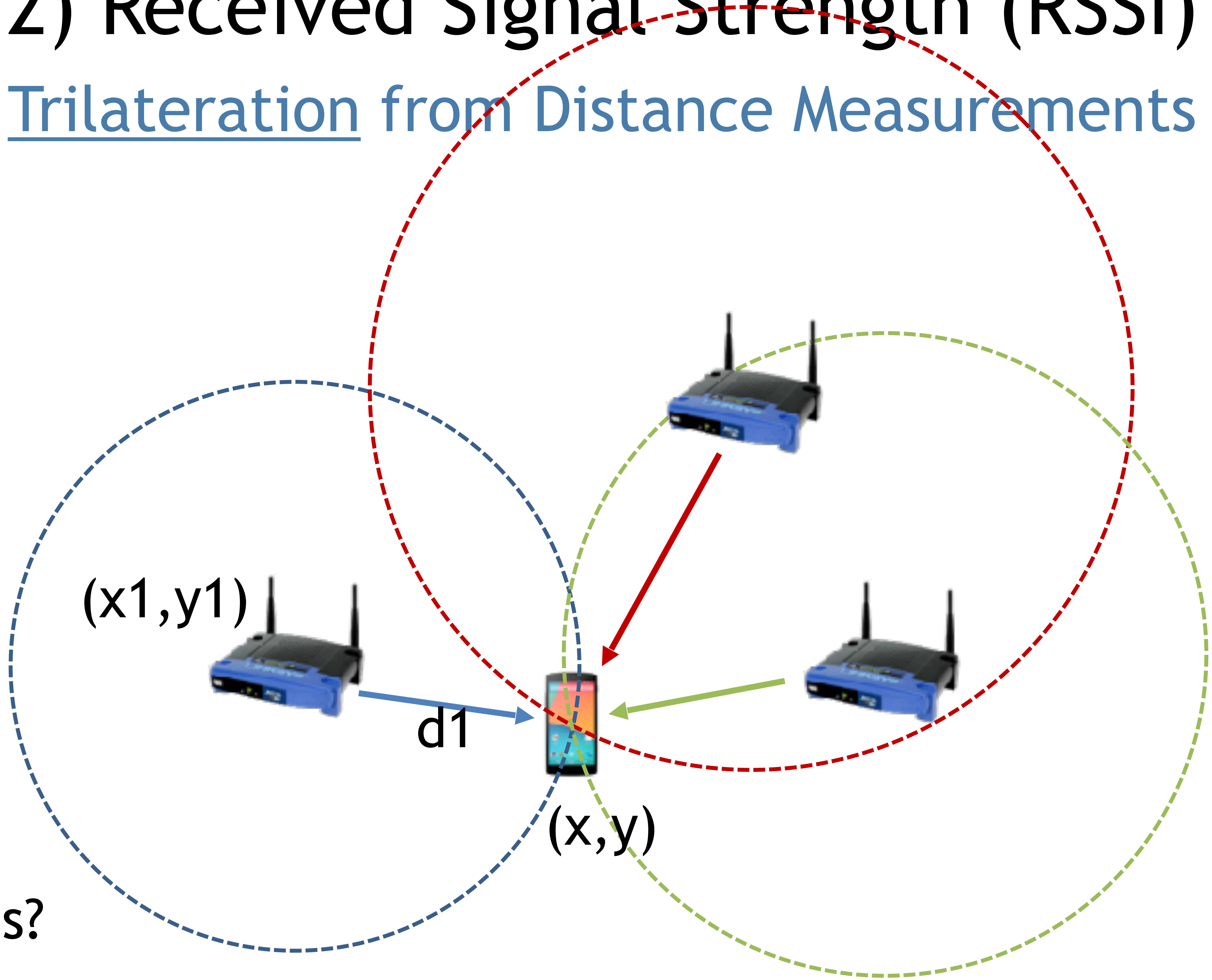
From power to distance

Power is proportional to $1/d^2$



2) Received Signal Strength (RSSI)

Trilateration from Distance Measurements

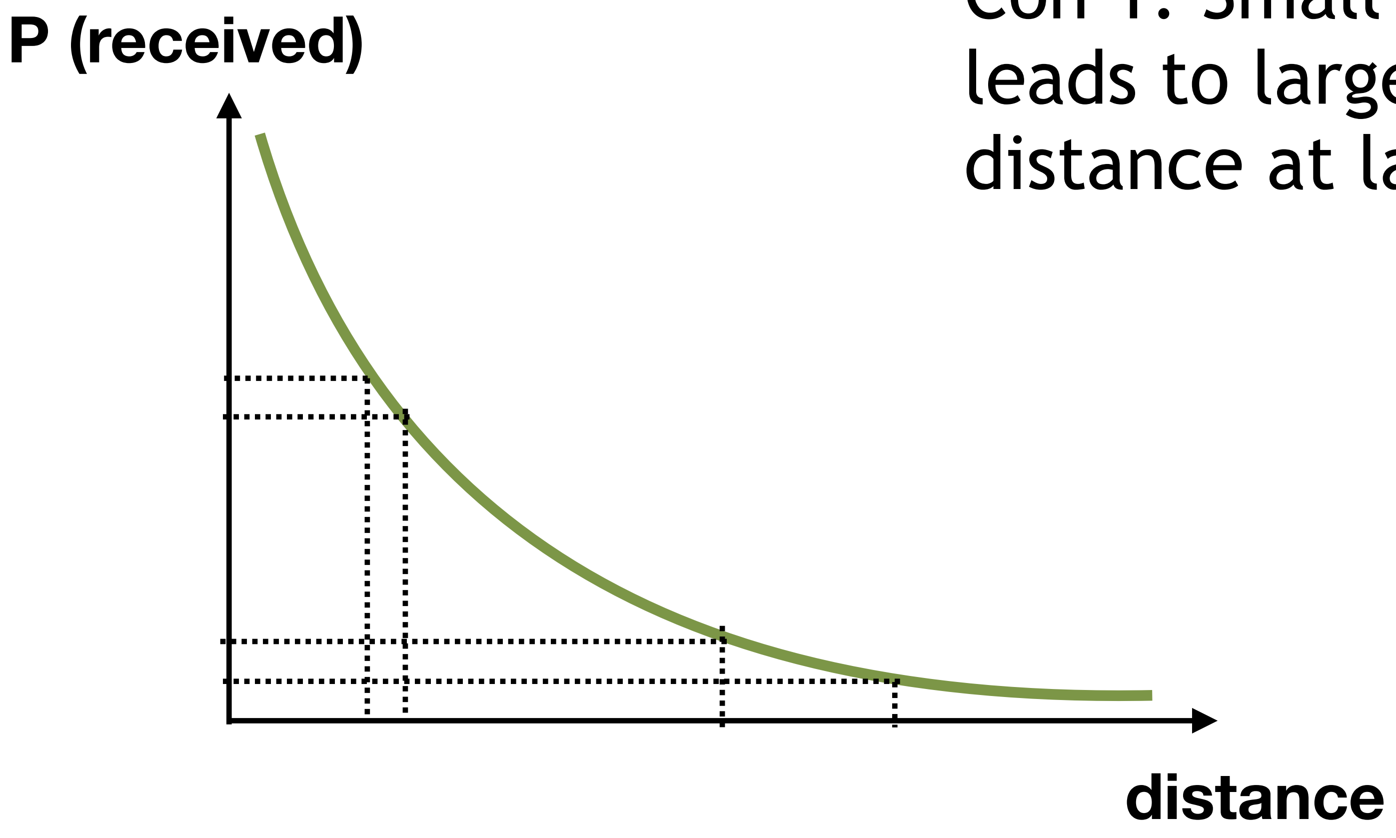


Pros? Cons?

2) Received Signal Strength (RSSI)

From power to distance

Power is proportional to $1/d^2$

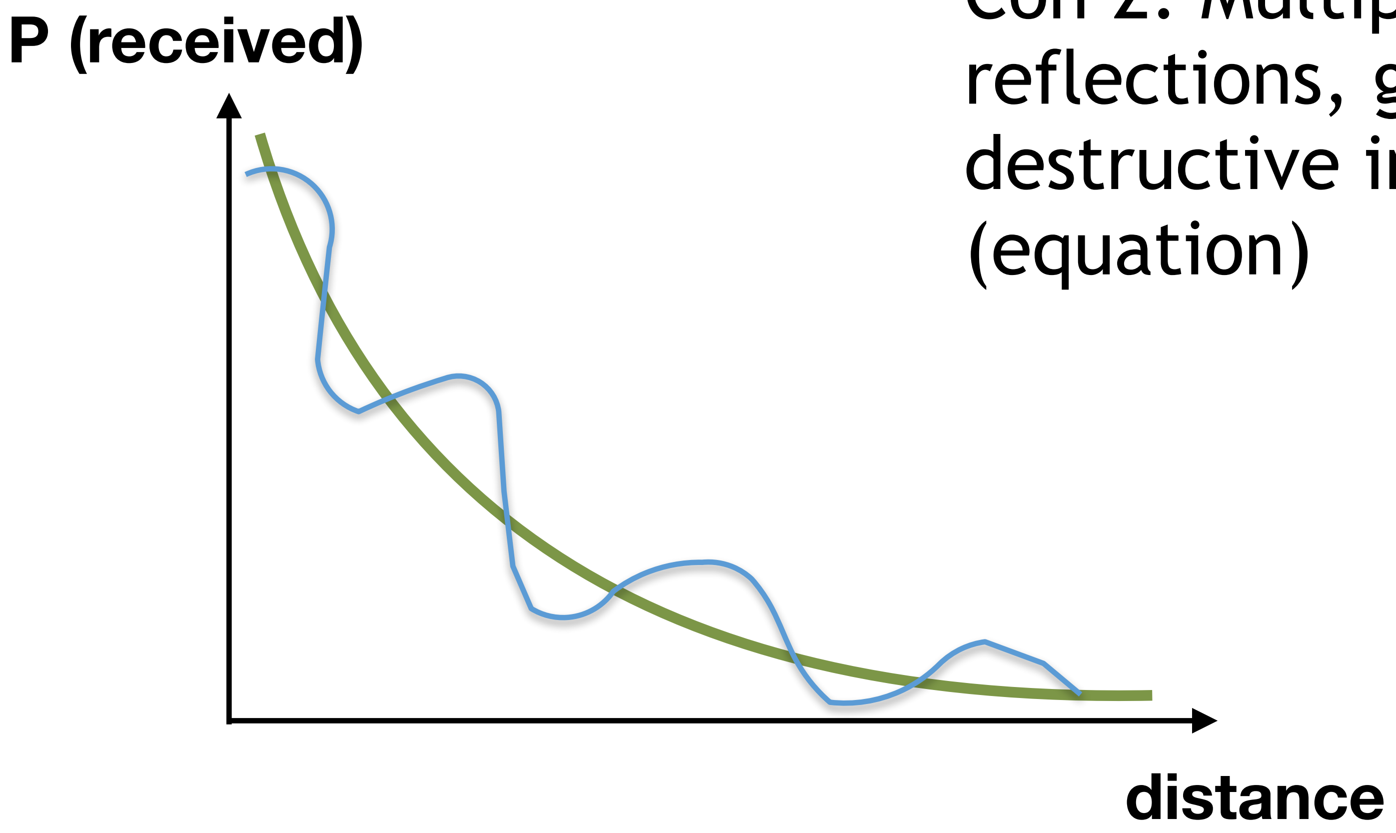


Con 1: Small change in power leads to large deviations in distance at larger distances

2) Received Signal Strength (RSSI)

From power to distance

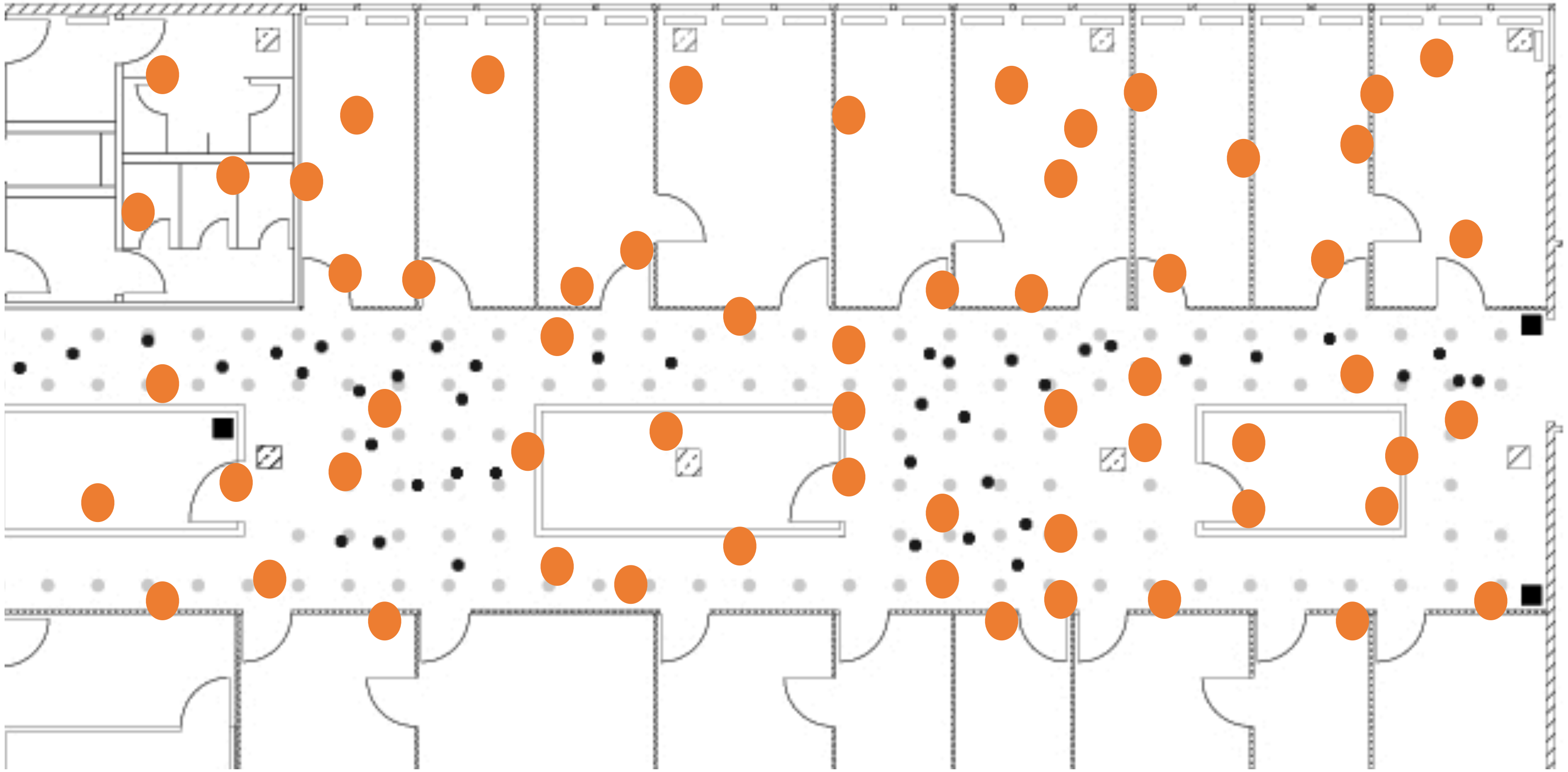
Power is proportional to $1/d^2$



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

2) Received Signal Strength (RSSI)

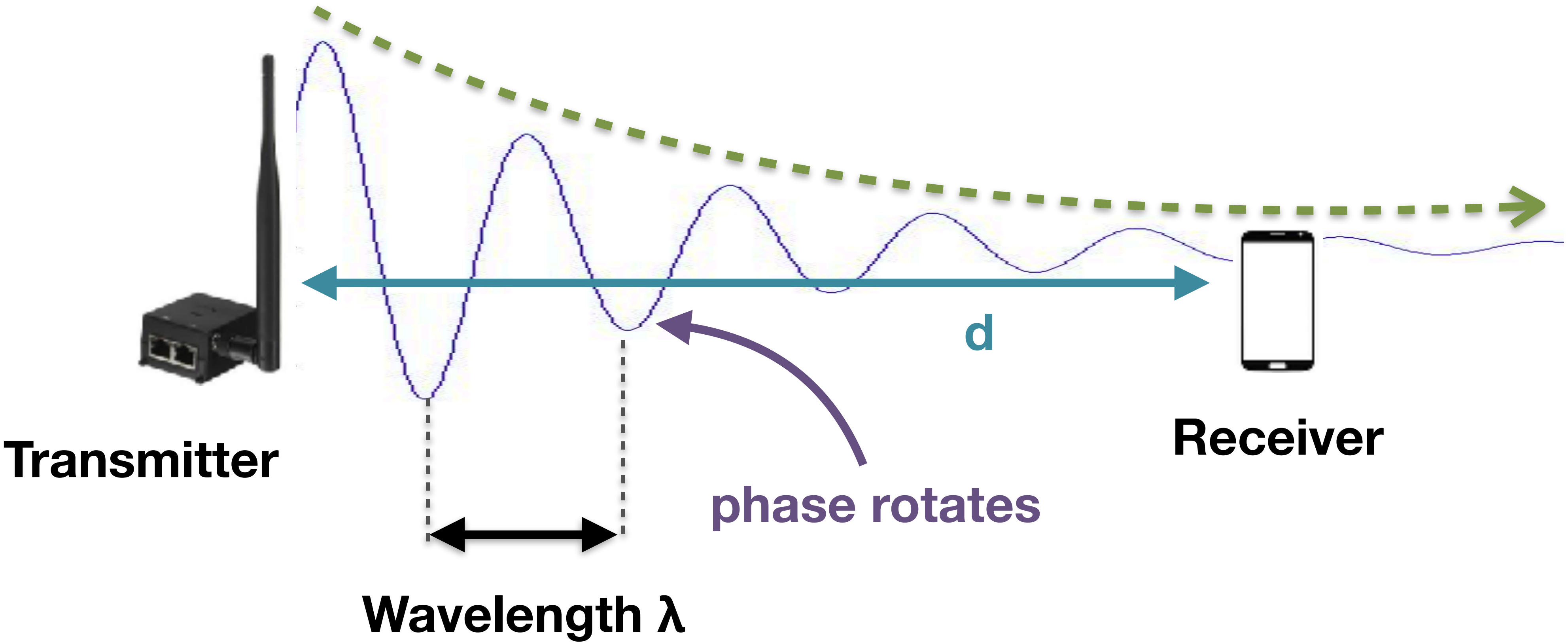
Solution: Fingerprinting
i.e., measuring device records signal strength fingerprints at each location



Pros? Cons?

3) Use the Signal "Phase"

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

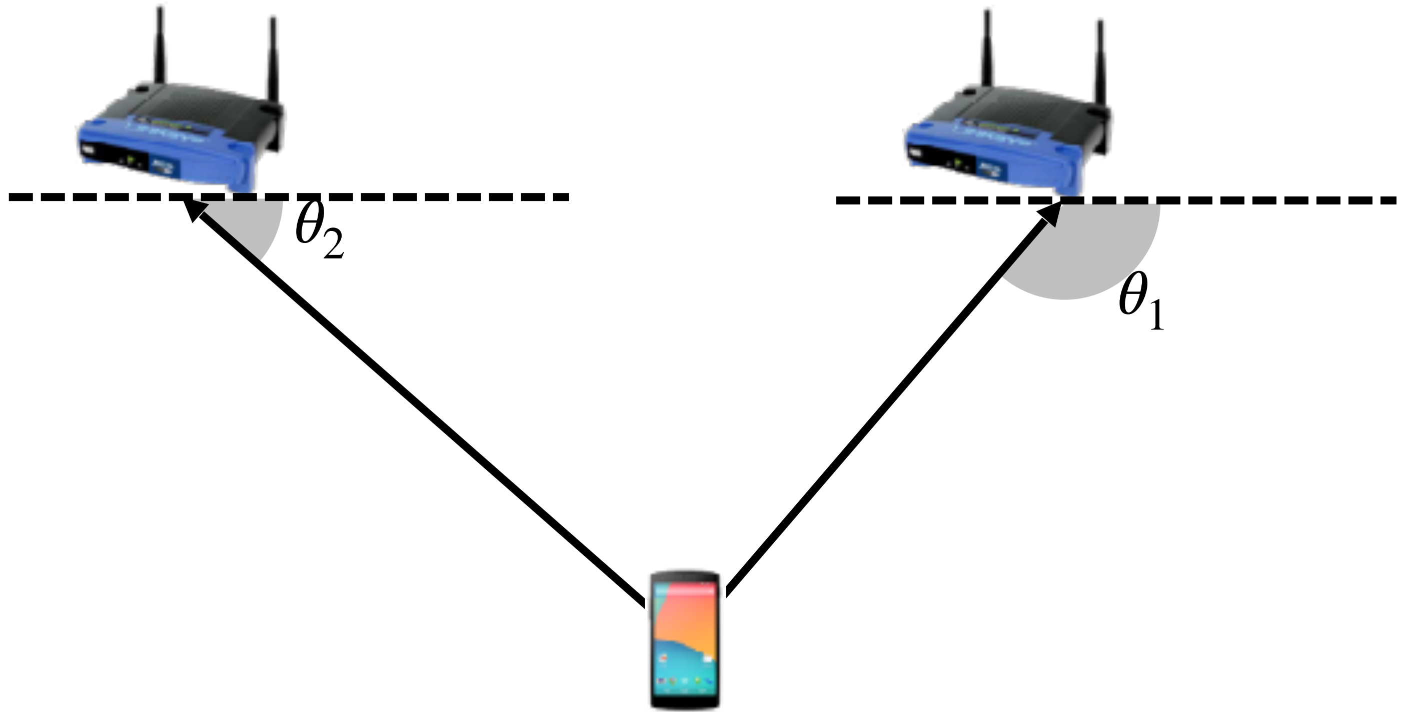


Pros? Cons?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

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

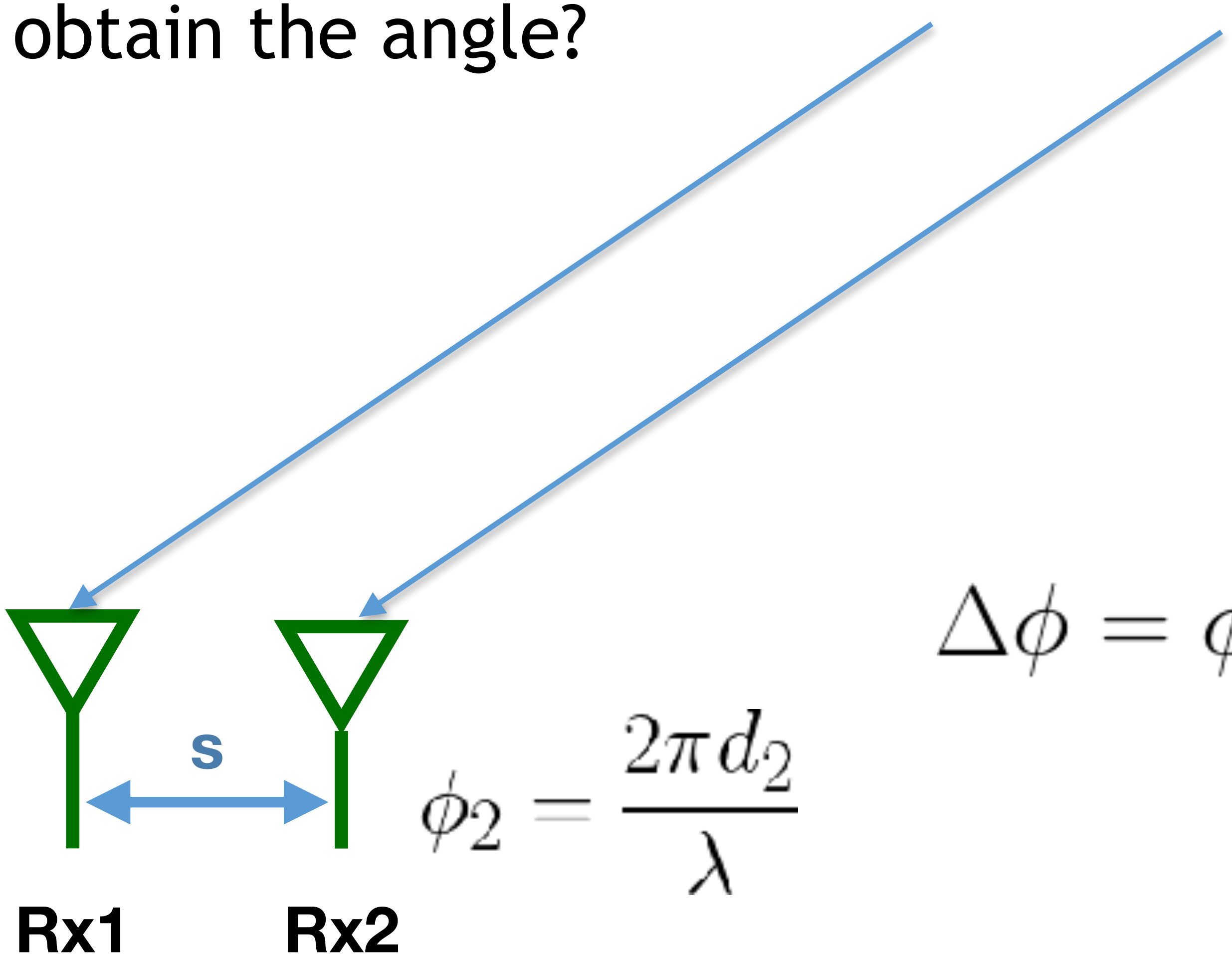


4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

How can we obtain the angle?

$$\phi_1 = \frac{2\pi d_1}{\lambda}$$



$$\phi_2 = \frac{2\pi d_2}{\lambda}$$

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

Issues?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

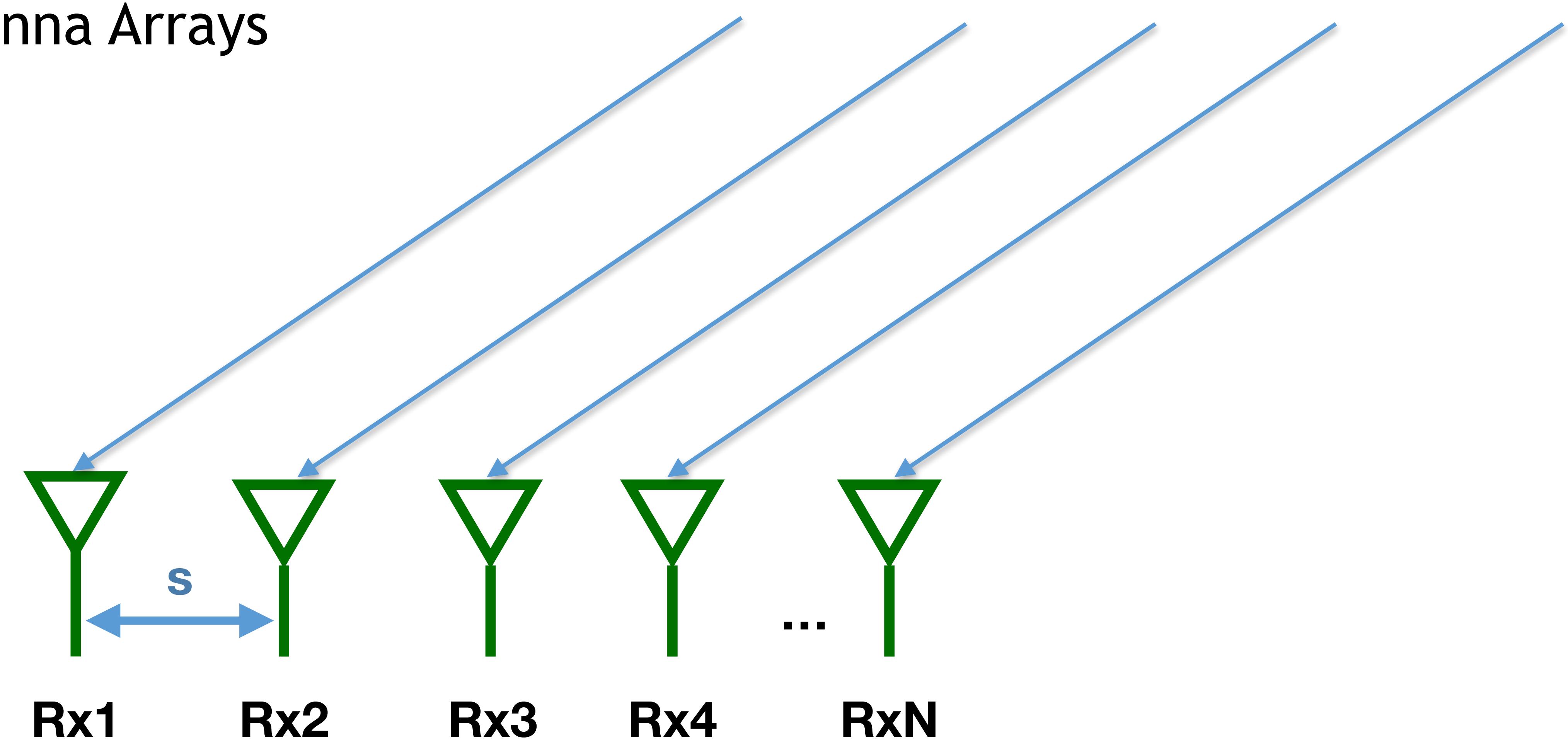
Issues

- Multipath
- Nonuniform resolution
- Half-circle vision

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

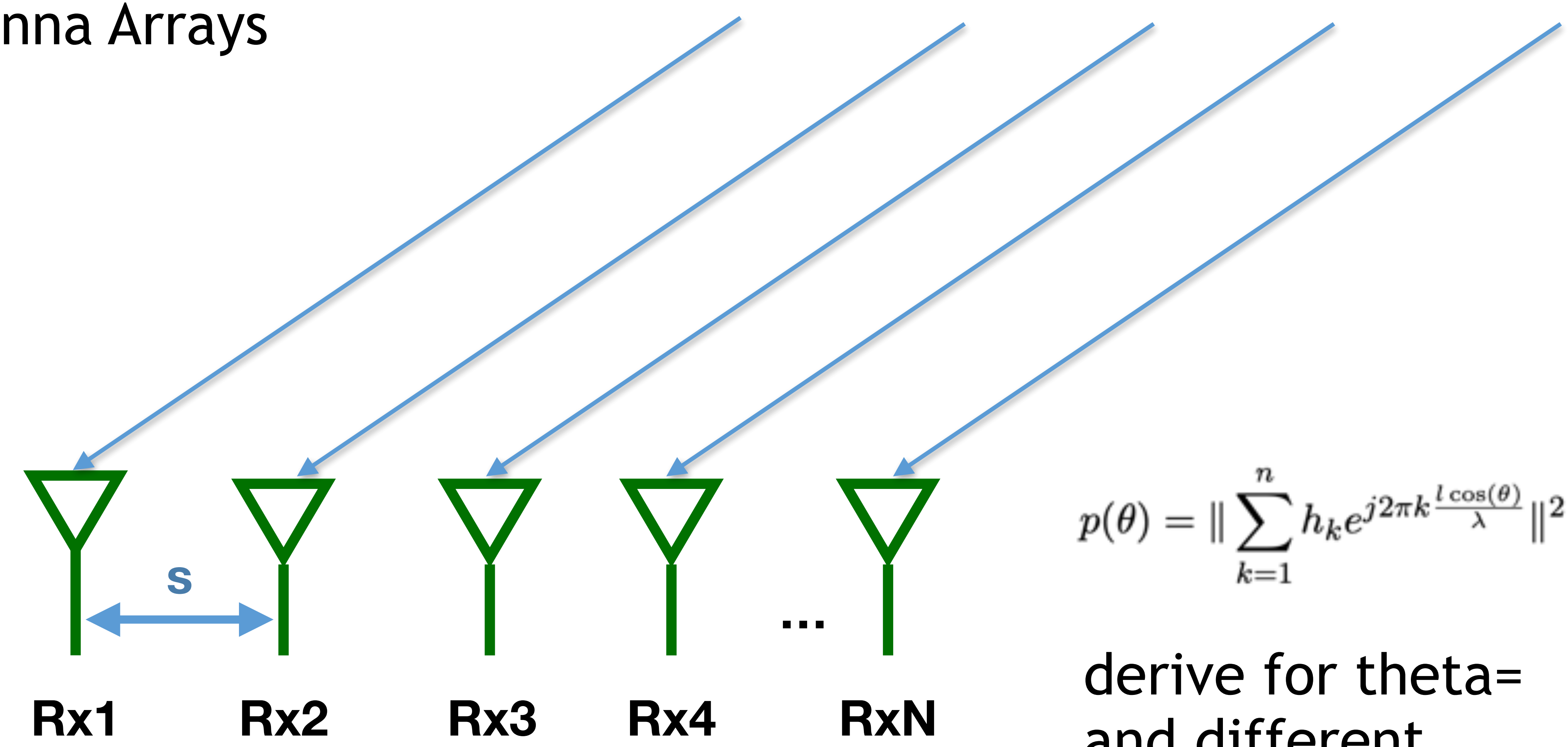
Use Antenna Arrays



4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

Use Antenna Arrays



$$p(\theta) = \| \sum_{k=1}^{n} h_k e^{j2\pi k \frac{l\cos(\theta)}{\lambda}} \|^2$$

derive for theta=
and different

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

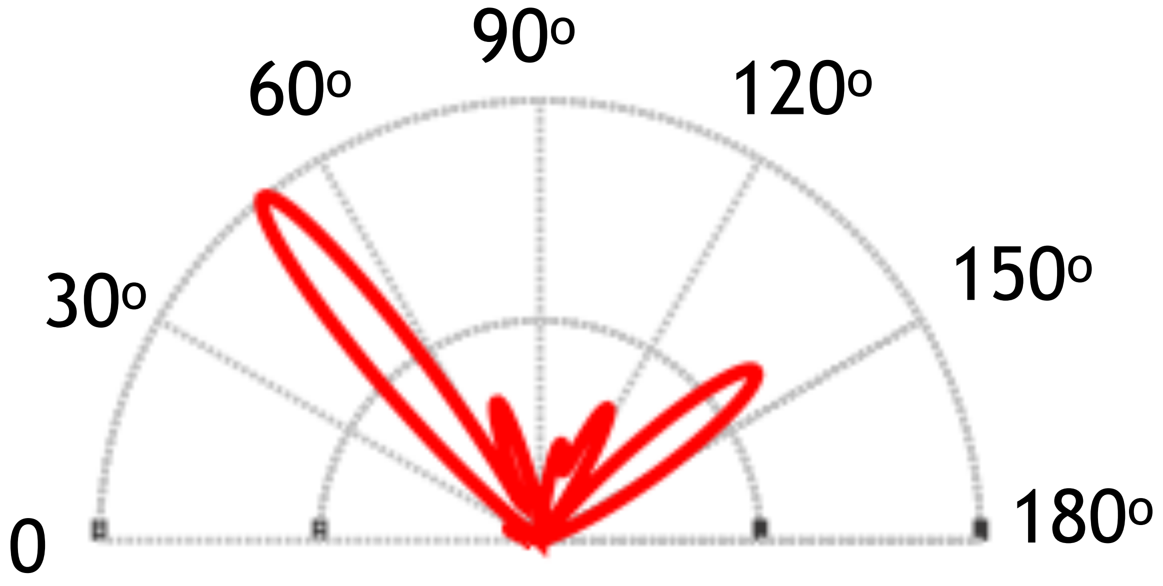
Use Antenna Arrays

$$
\begin{aligned}
p(\theta) &= \| \sum_{k=1}^{n} h_k e^{j2\pi k \frac{l\cos(\theta)}{\lambda}} \|^2 \\
&= \| \sum_{k=1}^{n} \frac{1}{d_k} e^{\Phi_k} e^{j2\pi k \frac{l\cos(\theta)}{\lambda}} \|^2 \\
&= \| \sum_{k=1}^{n} \frac{1}{d_k} e^{-2\pi j \frac{d_1 + (k-1) l \cos(\theta^*)}{\lambda}} e^{j2\pi k \frac{l\cos(\theta)}{\lambda}} \|^2 \\
&= \| \sum_{k=1}^{n} \frac{1}{d_k} e^{-2\pi j \frac{d_1 - l\cos(\theta^*)}{\lambda}} e^{j2\pi k \frac{l}{\lambda}(\cos(\theta) - \cos(\theta^*))} \|^2 \\
&\approx \| \frac{1}{d_1} e^{-2\pi j \frac{d_1 - l\cos(\theta^*)}{\lambda}} \sum_{k=1}^{n} e^{j2\pi k \frac{l}{\lambda}(\cos(\theta) - \cos(\theta^*))} \|^2 \ (\text{approximating } \tfrac{1}{d_k} \text{ by } \tfrac{1}{d_1})
\end{aligned}
$$

4) Use Angle of Arrival (AoA)

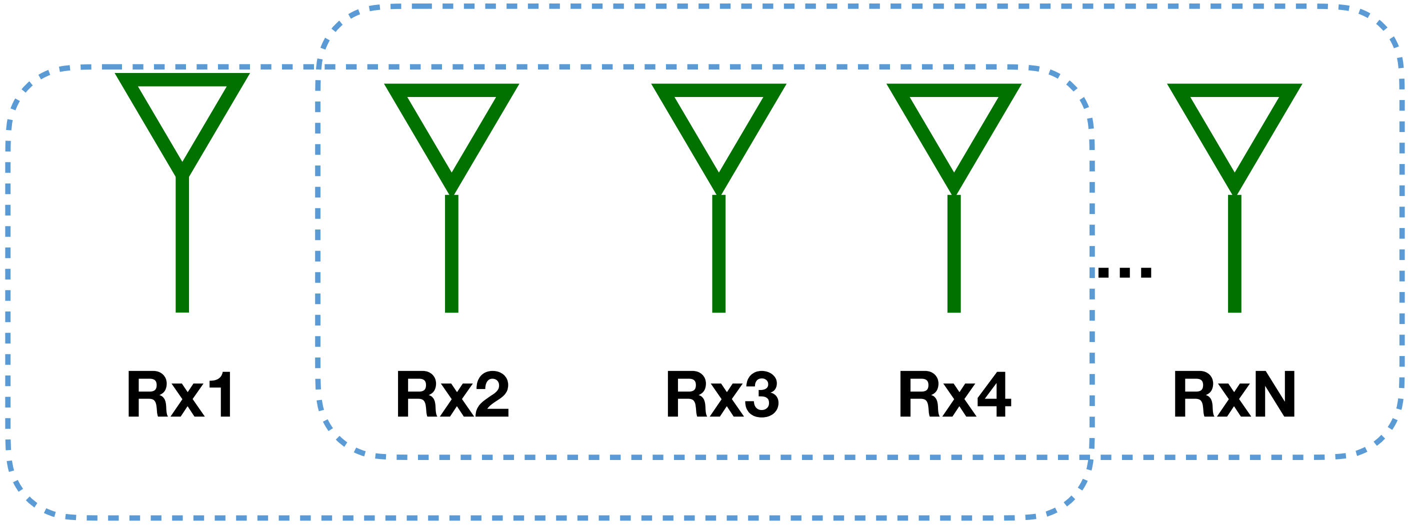
Triangulation from Angular Measurements

Use Antenna Arrays

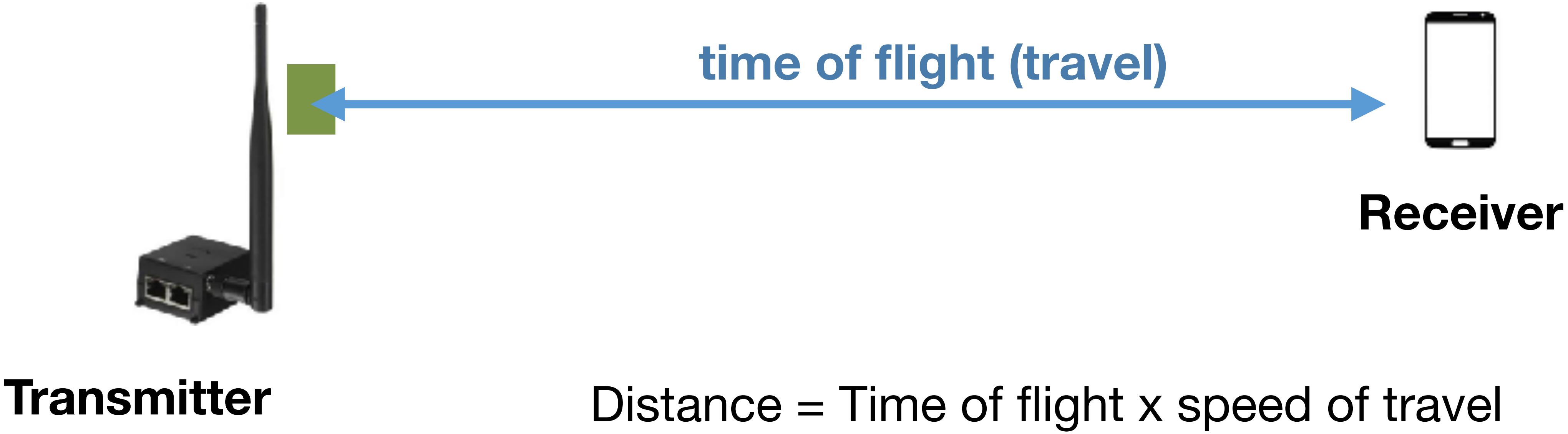


How do we know which direction corresponds to the direct path?

ArrayTrack dealing with Multipath



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



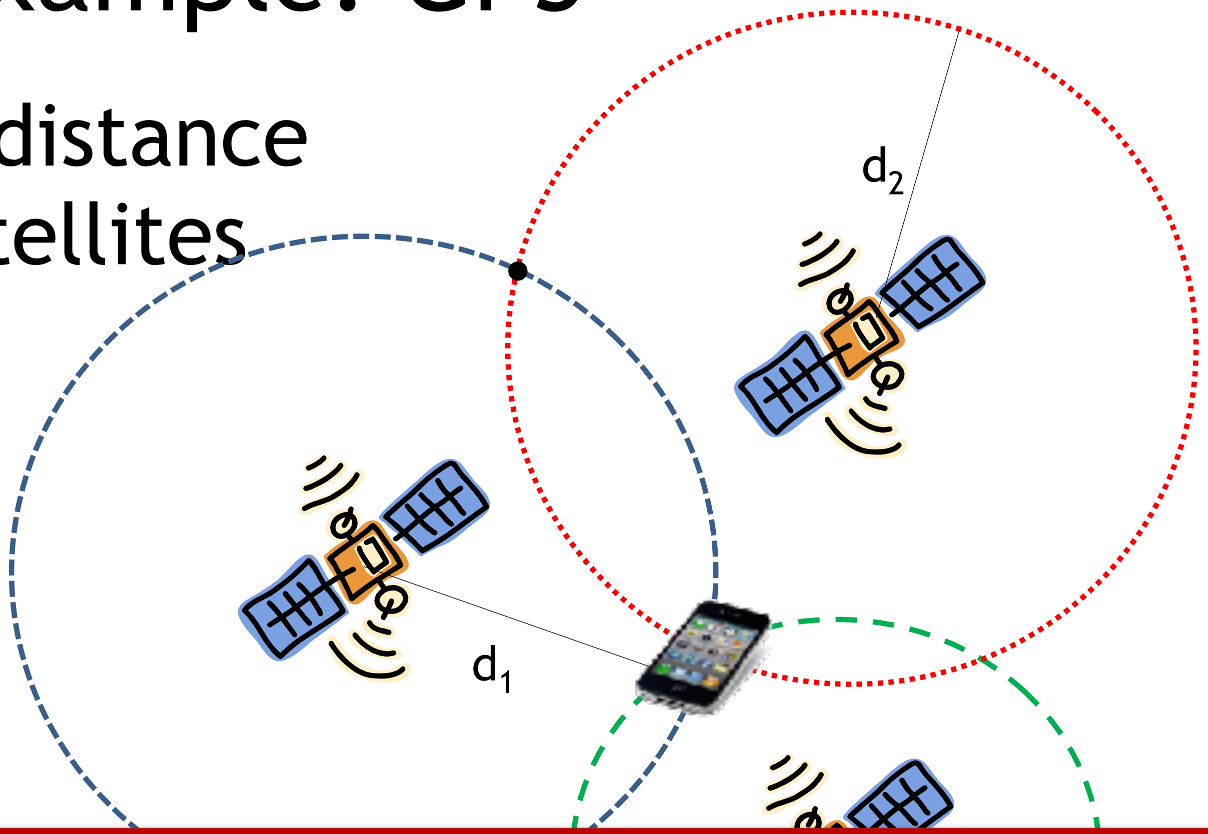
Distance = Time of flight x speed of travel

Can use trilateration (intersection circles/spheres)

How do we know when the signal was transmitted?

Example: GPS

Compute the distance to the GPS satellites



distance = propagation delay x speed of light

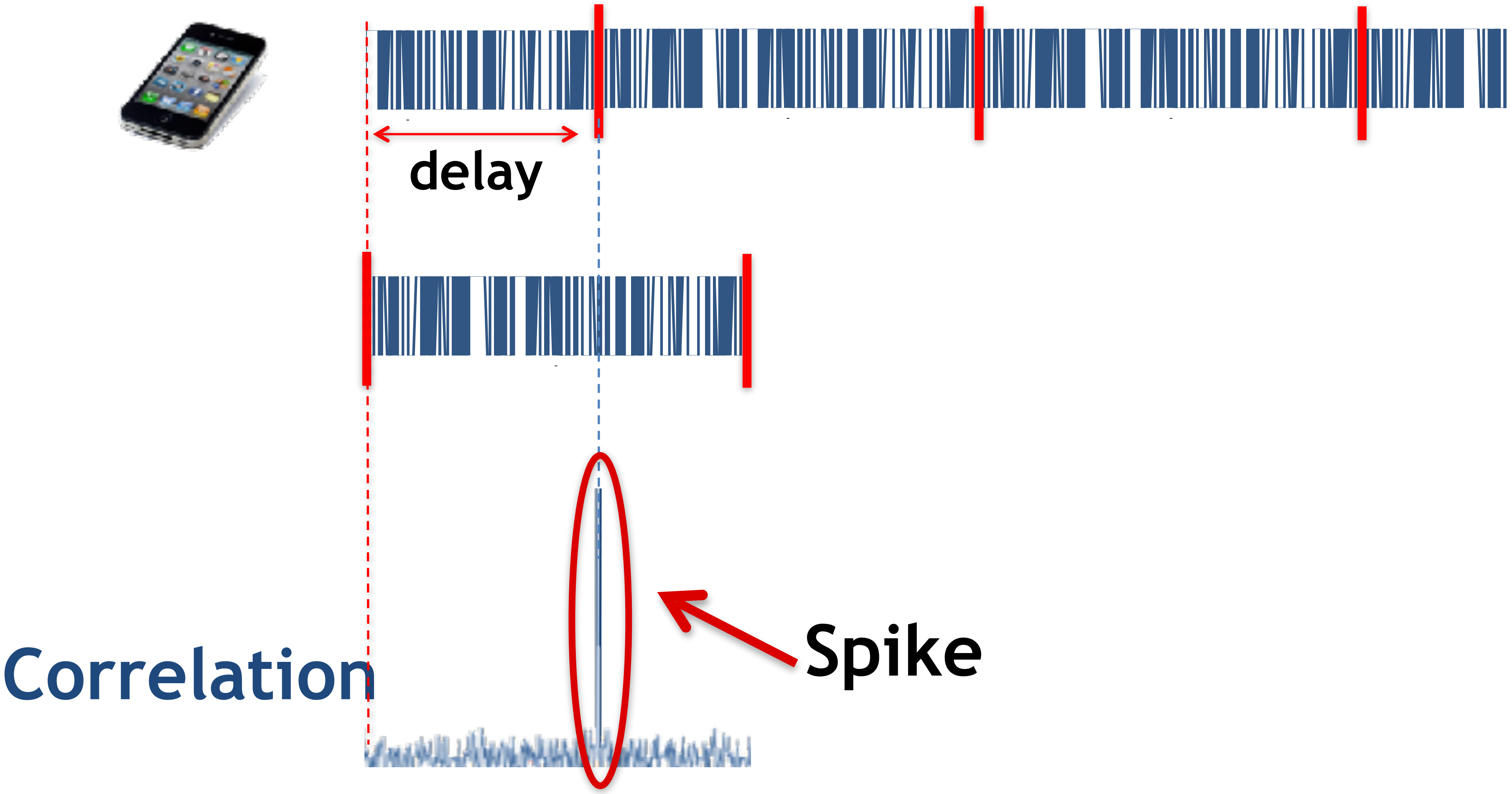
How to Compute the Propagation Delay?

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

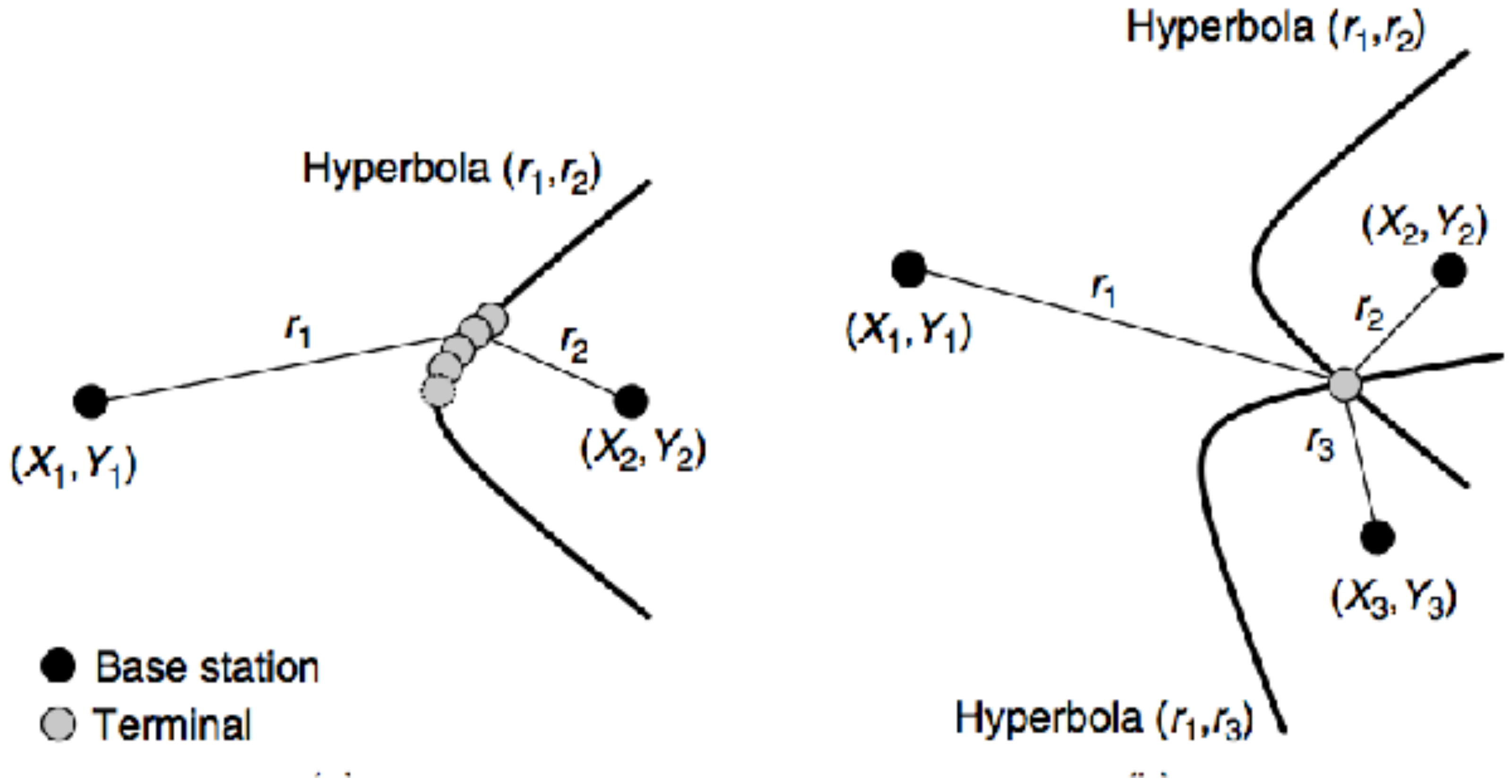
use it to compute distance and localize

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

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
- …

Feedback on reviews

- Overall: very good reviews by (almost) everyone!
- Summary: Good length
- Pros/Cons:
  - Itemize them, include 2-4 in a bulleted list.
  - Each pro/con should be a full sentence of a complete idea (in-depth about the techniques)
    - Not good: they used a good method for localization
    - Good: the method for suppressing multipath using multiple subarrays is novel and effective
  - You can have one pro or con about exposition (e.g., writing style / clarity / figures / typos). The rest should be about the system itself
- Suggestions for improvement
  - Make it about the system rather than about the paper itself
  - Go beyond what is straightforward (more evaluation/APs or less hardware) to something that is more fundamental/insightful (e.g., use packet)

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This Class (Localization)

1) Required Readings

- **Chapter on Localization -** Covers fundamentals
- **ArrayTrack paper -** State-of-the-art localization system

What to submit? For localization paper: summary (2 paragraphs); for the ArrayTrack paper: a review

2) Optional Readings

- **Cricket -** More than 100,000 deployed (hospitals); Cited > 5,000 times
- **Radar paper** - Transitioned to real-world products (Microsoft, many startups); Started a new field; Cited > 10,000 times
- **SpotfFi paper** - another state-of-the-art localization paper
- **Chronos paper** - another state-of-the-art localization system
- **GPS** - how it works

Next Class: Contactless Wireless Sensing

1) Required

- WiTrack: Fundamentals of seeing through walls
- Vital-Radio: Smart homes that monitor breathing & heart rate

2) Optional

- RFCapture: Capturing Human Figure through a Wall
- EQ-Radio: Emotion Recognition using Wireless Signals
- WiStress: Stress Monitoring using Wireless Signals
- WiVi: See through Walls with WiFi
- Through-Wall Human Pose Estimation Using Radio Signals
- RF-Based 3D Skeletons
- Artificial intelligence-enabled detection and assessment of Parkinson’s disease using nocturnal breathing signals
- WiSee: Whole-home gesture recognition using wireless signals
- Learning Sleep Stages from Radio Signals: A Conditional Adversarial Architecture

Introductions

- Name
- Position (undergrad year, grad year, postdoc, industry)
- Major
- Why are you interested in this class?