

CIS 3990

Mobile and IoT Computing

<https://penn-waves-lab.github.io/cis3990-24spring>

Lecture 3: Fundamentals of Localization (continued)

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Objectives of This Module

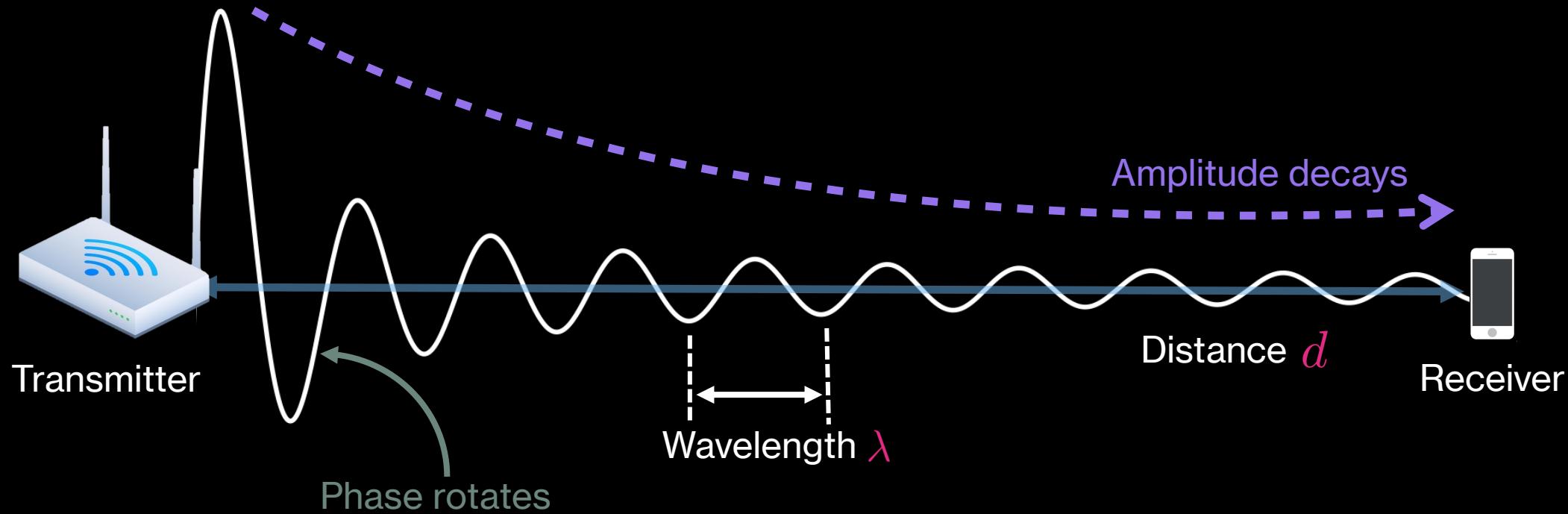
**Learn the fundamentals, applications, and implications of
localization, motion tracking, and sensing**

1. What are some motivating applications of localization and location-based services?
2. What are the unifying principles of positioning? → **Continue for today's lecture**
3. How do wireless positioning like GPS, Wi-Fi positioning, and Bluetooth ranging work?
4. What is wireless sensing?
5. How do visual positioning and tracking systems work?

Localization Methods (So Far)

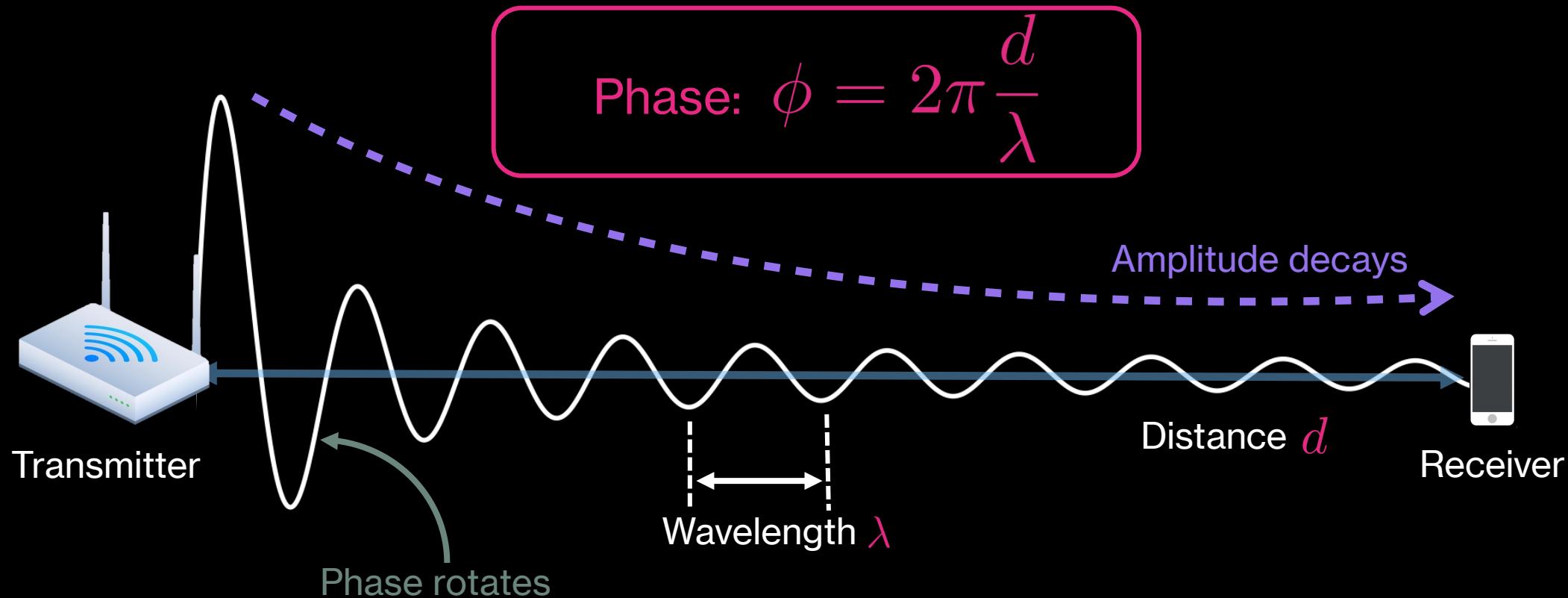
- Identify-based:
 - + Use the identity and known location of anchor objects
- Received Signal Strength (RSSI):
 - + Received signal amplitude is inversely proportional to the distance
 - + Fingerprinting method

Wireless Signal are Waves



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

3. Phase of the signal



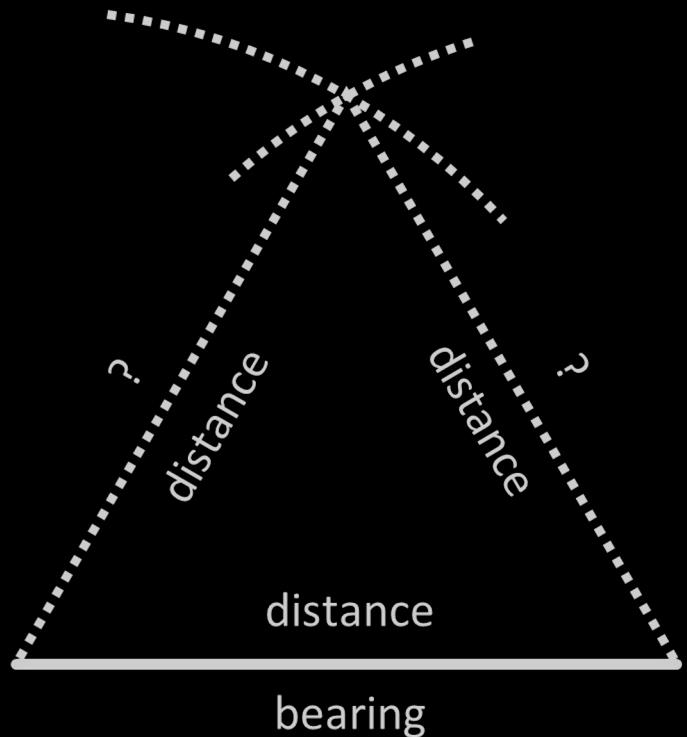
Pros: Can get highly accurate distance measurement

Cons: Cycle Ambiguity

Localization with Geometry

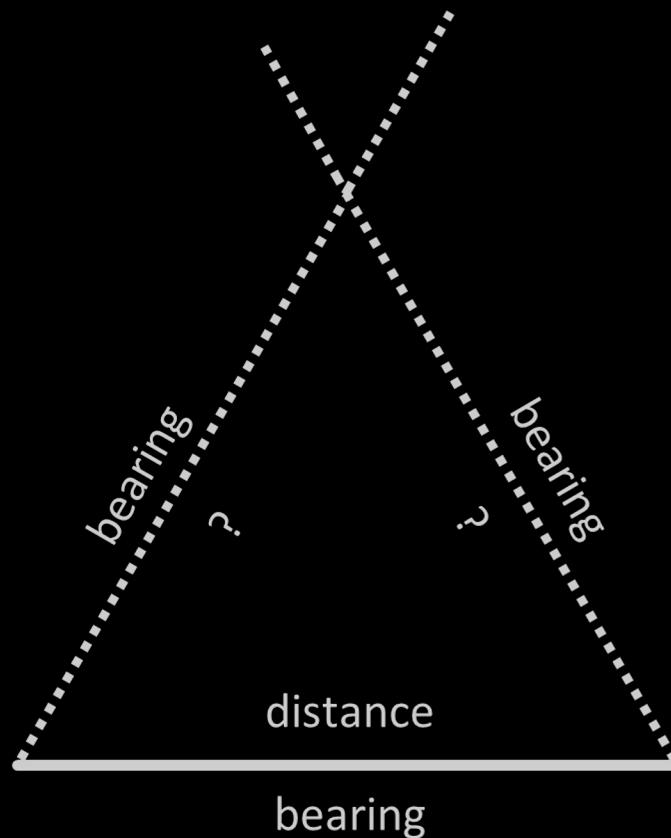
Trilateration

(2 missing bearings)



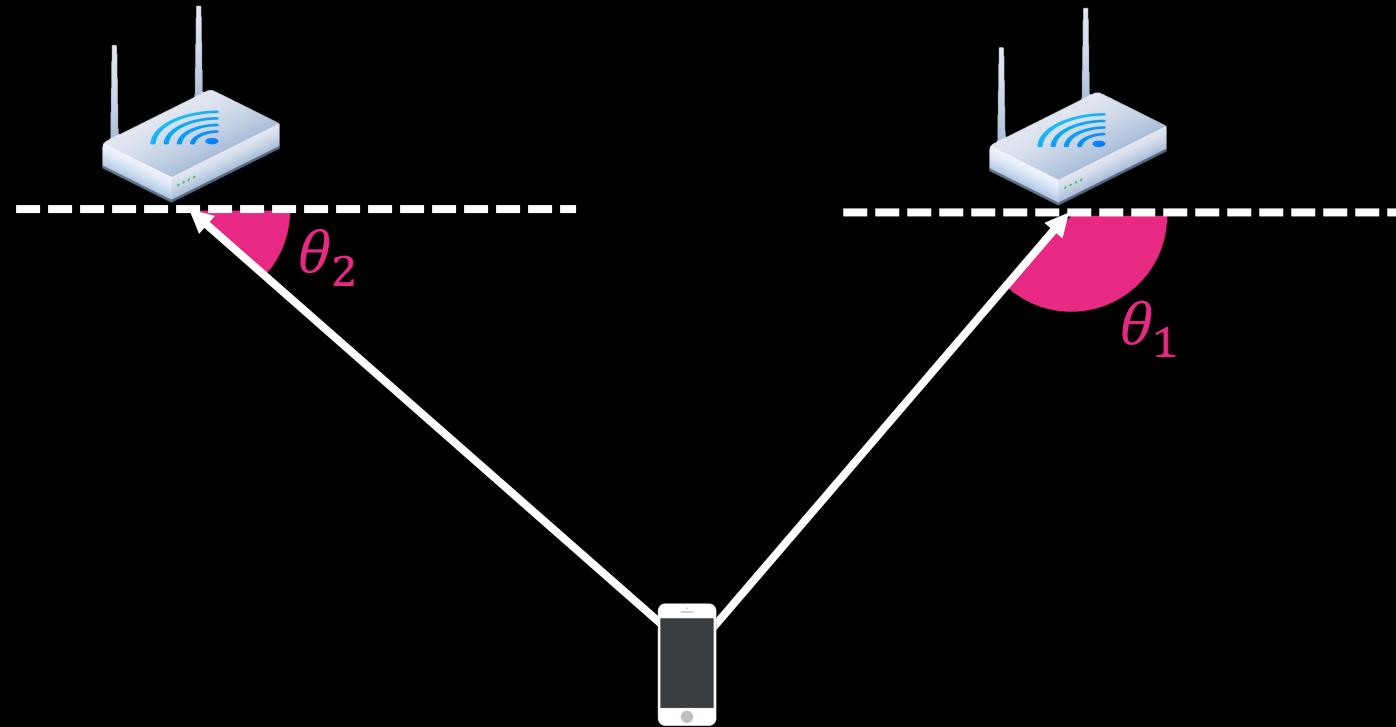
Triangulation

(2 missing distances)

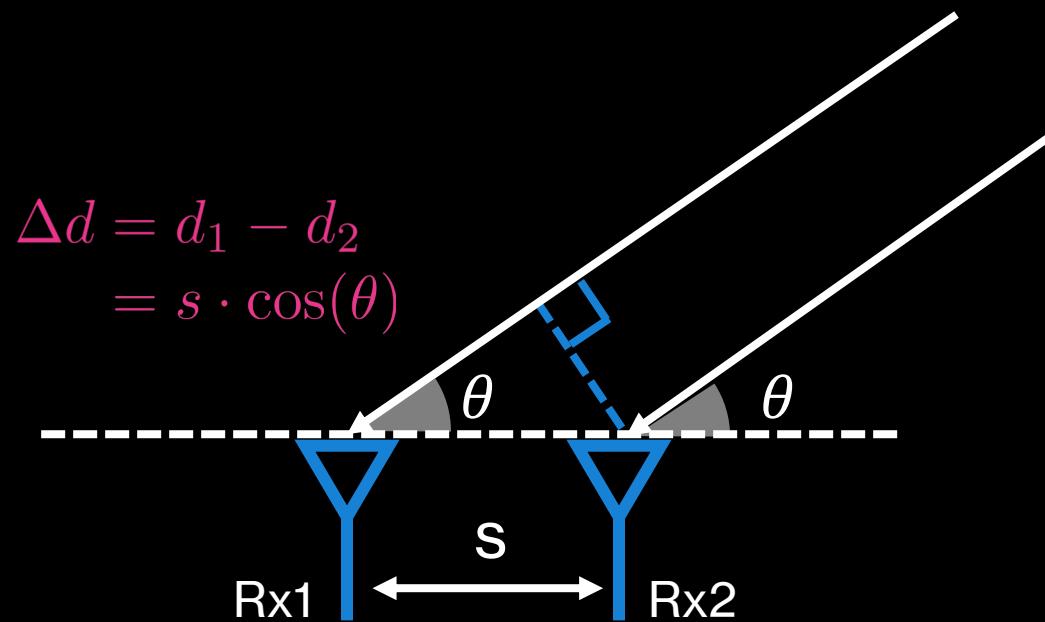


4. Angle of Arrival (AoA)

Triangulation from angular measurements



How can we measure the AoA?



$$\begin{aligned}\Delta d &= d_1 - d_2 \\ &= s \cdot \cos(\theta)\end{aligned}$$

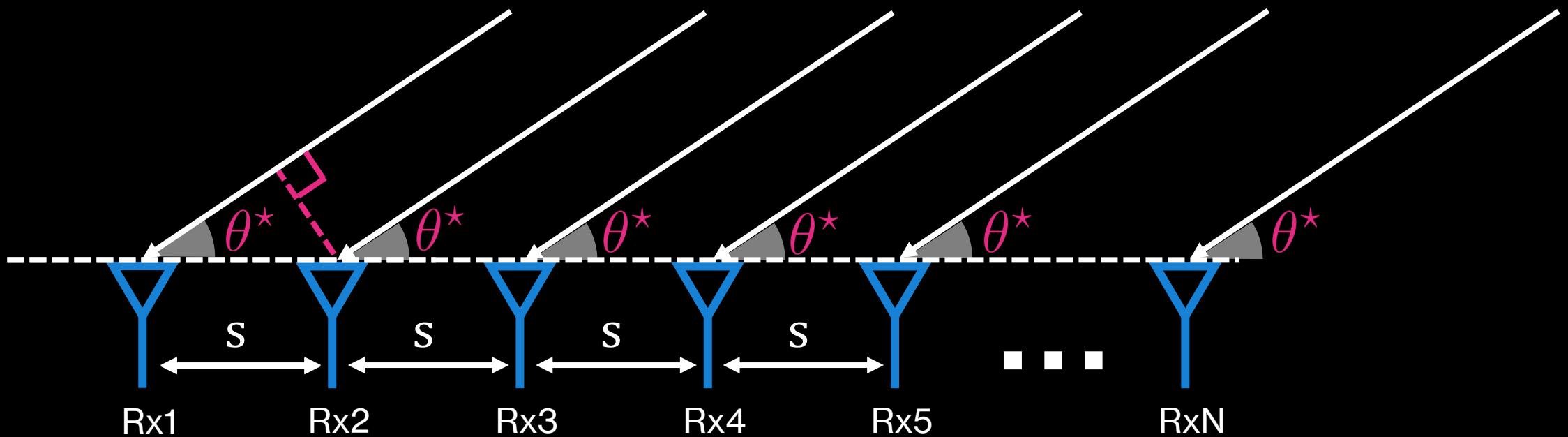
$$\Delta\phi = \frac{2\pi(d_1 - d_2)}{\lambda} = \frac{2\pi s \cos(\theta)}{\lambda}$$

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

Pros: More accurate than RSSI. Simple!

Cons: Fail with multiple signal sources / multipath; half-circle vision

How can we measure the AoA?

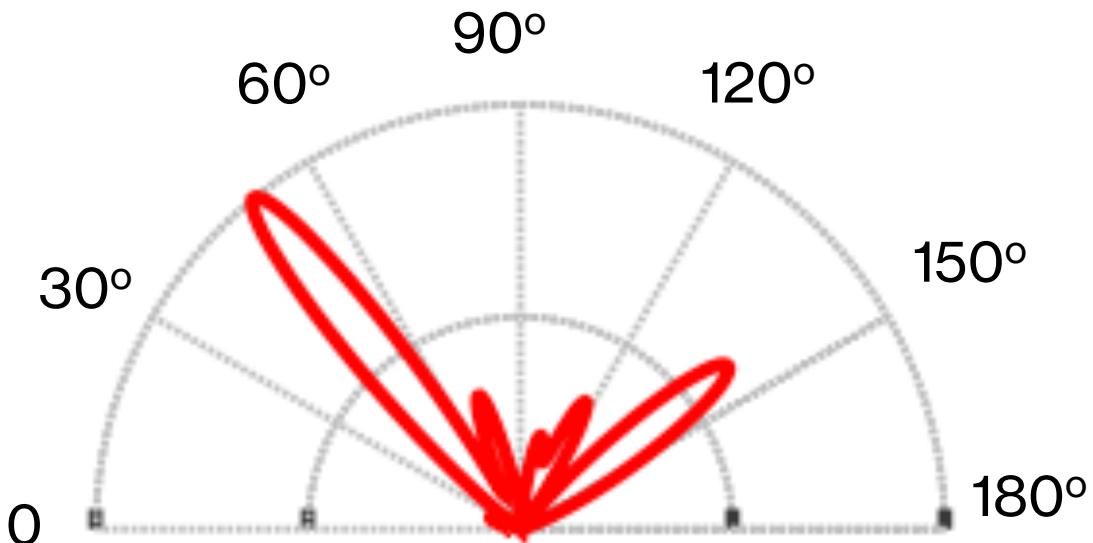


Multipath profile
(delay-and-sum):
$$P(\theta) = \left\| \sum_{k=1}^N h_i \exp\left(-j2\pi \frac{ks \cos(\theta)}{\lambda}\right) \right\|^2$$

How can we measure the AoA?

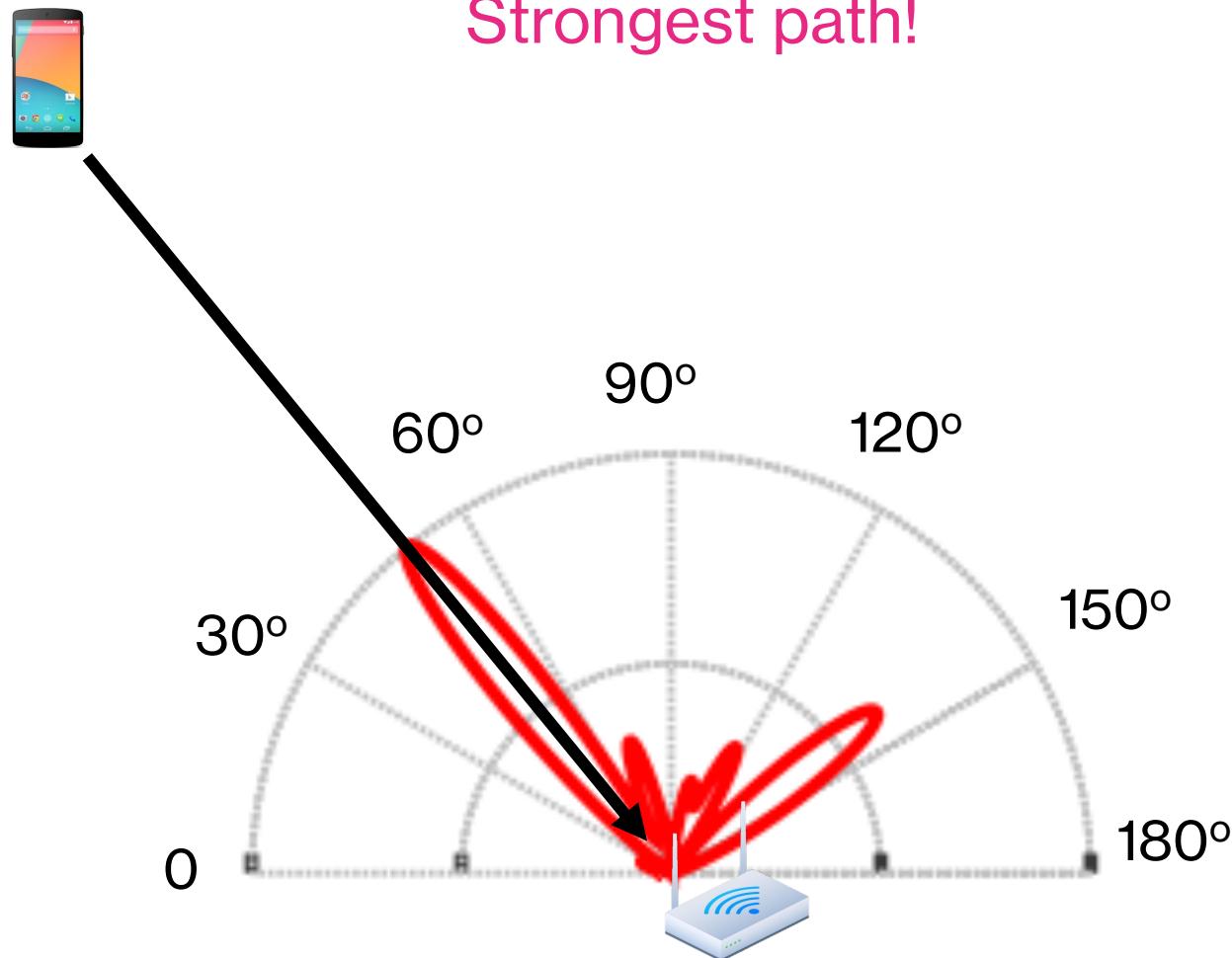
Multipath profile
(delay-and-sum):

$$P(\theta) = \left| \sum_{k=1}^N h_i \exp\left(-j2\pi \frac{ks \cos(\theta)}{\lambda}\right) \right|^2$$



How can we measure the AoA?

Which is the Line-of-Sight Path (Direct Path)?

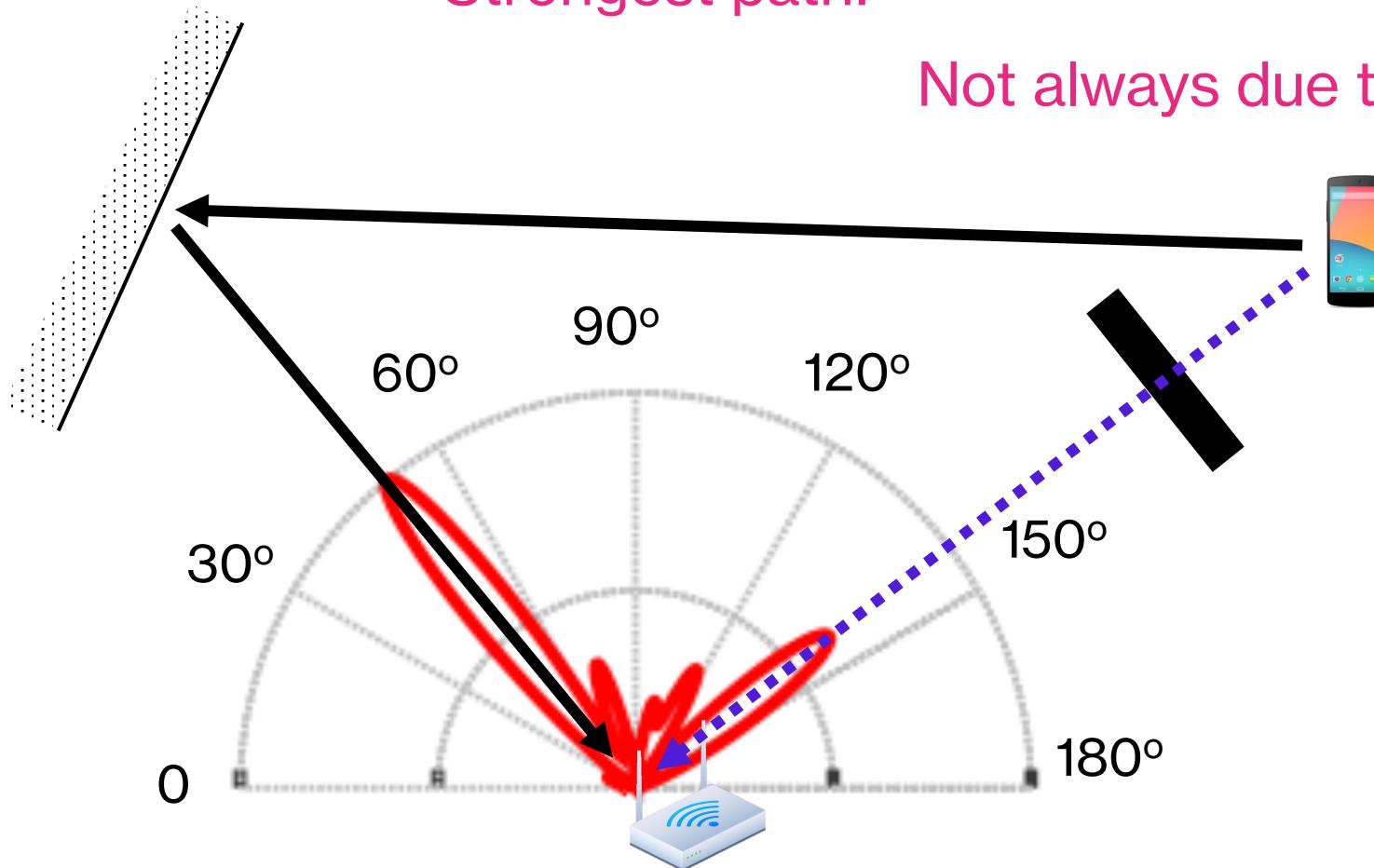


How can we measure the AoA?

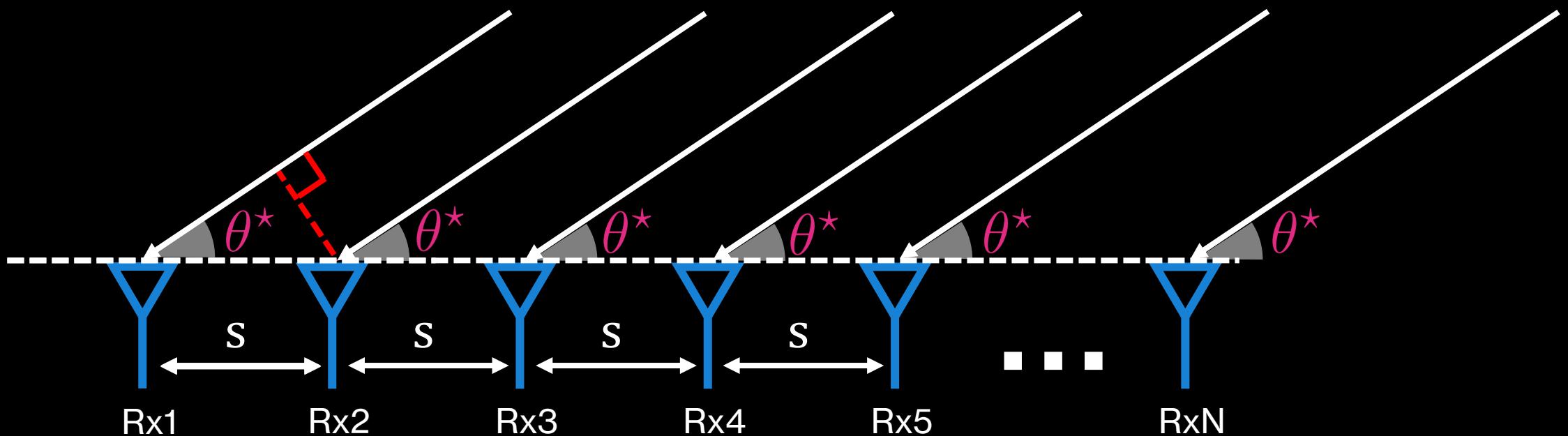
Which is the Line-of-Sight Path (Direct Path)?

Strongest path!

Not always due to blockage!



How can we measure the AoA?



Pros: Works with multipath

Cons: Requires more hardware! Far-field approximation.

5. Time-of-Flight (ToF)



Distance = Time of flight × speed of light

Measure ToF → Get distance → Trilateration

5. Time-of-Flight (ToF)



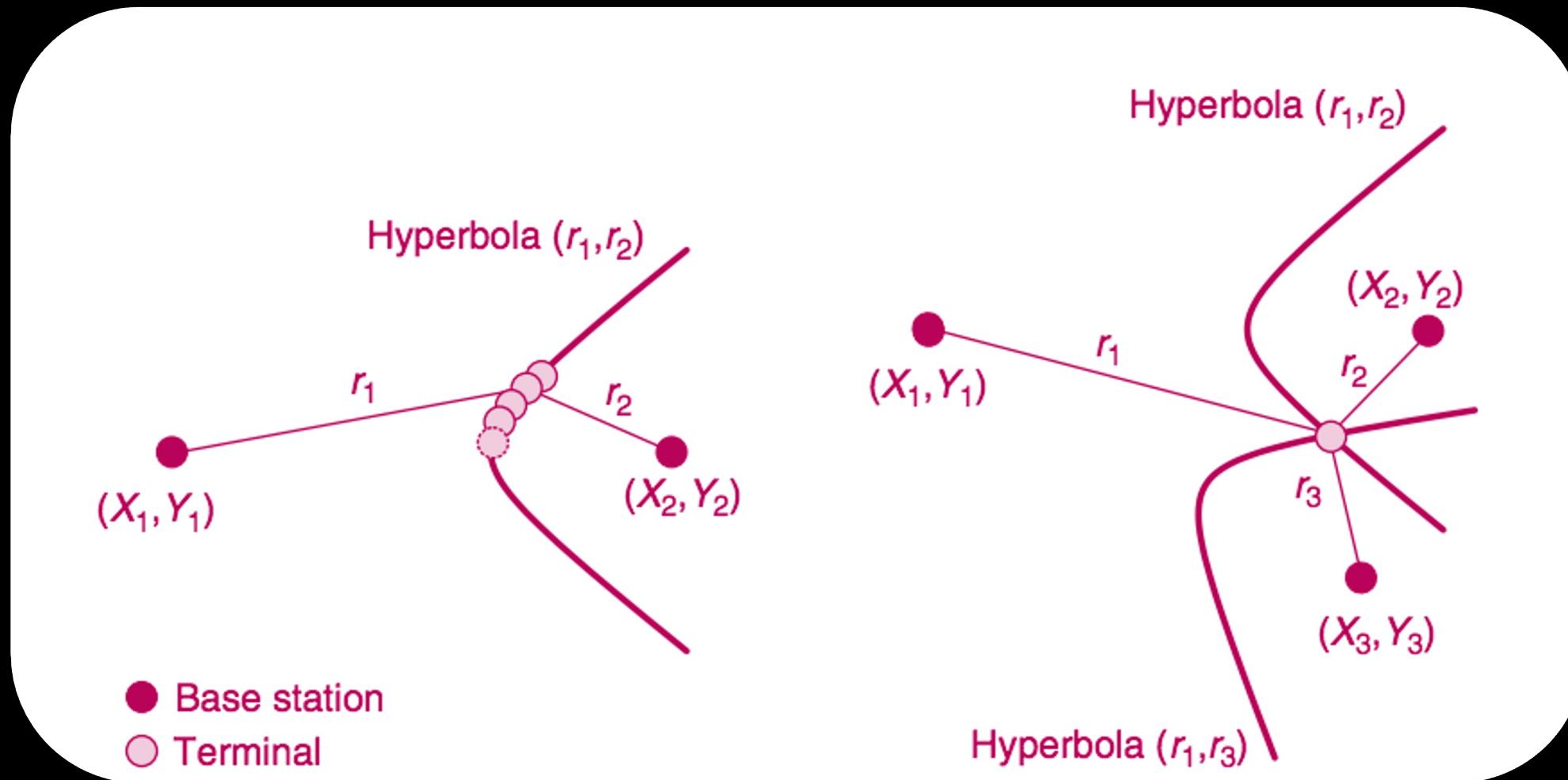
Challenge:

- How do you know when signal was transmitted?

Techniques can get accurate ToF:

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

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



Localization Methods

- Identity-based
- Received Signal Strength (RSSI)
- Phase of the signal
- Angle of arrival (AoA)
- Time of flight (ToF)
- Time difference of arrival (TDoA)

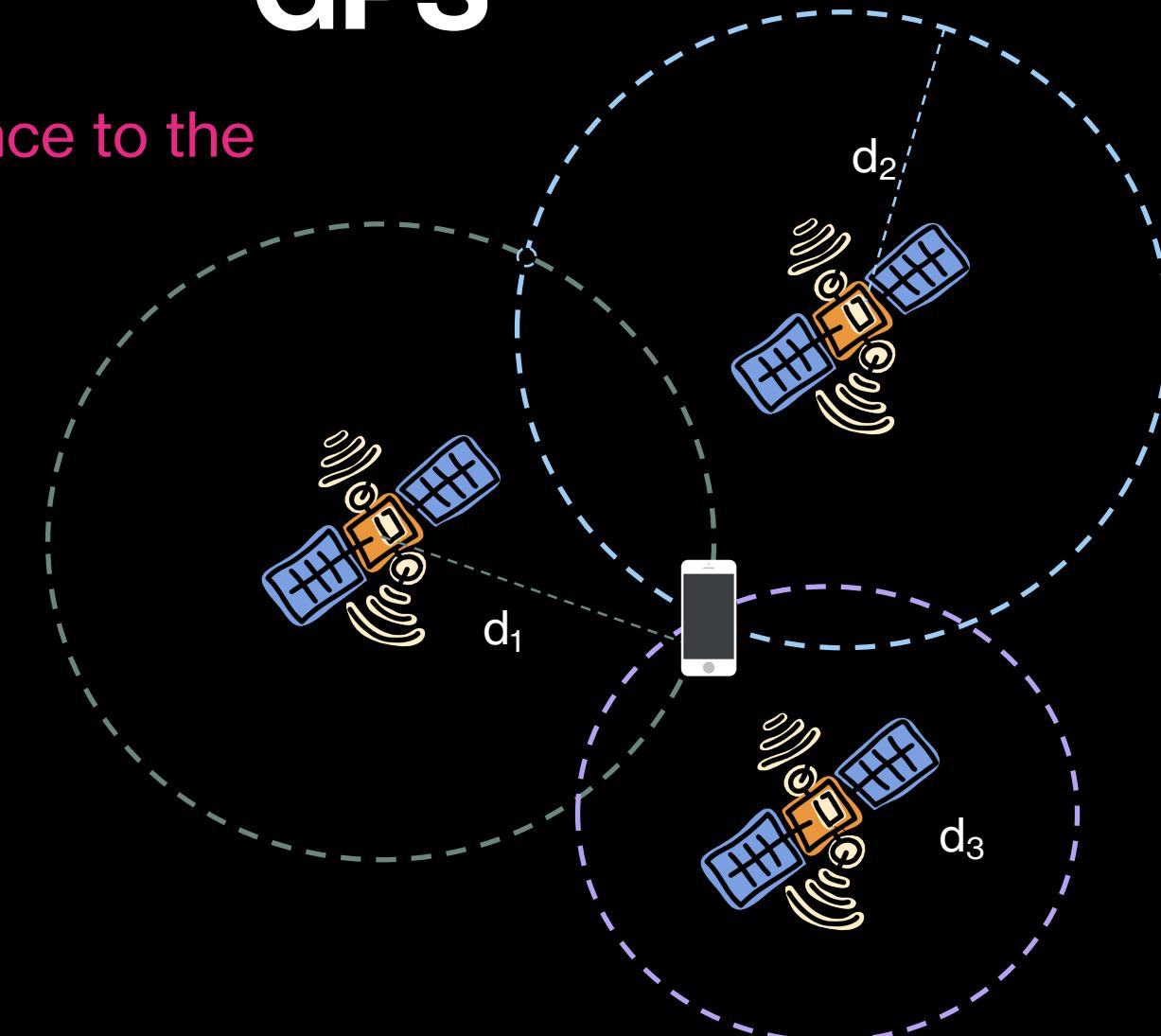
State-of-the-Art Techniques?

Sophisticated **Combinations** of these techniques:

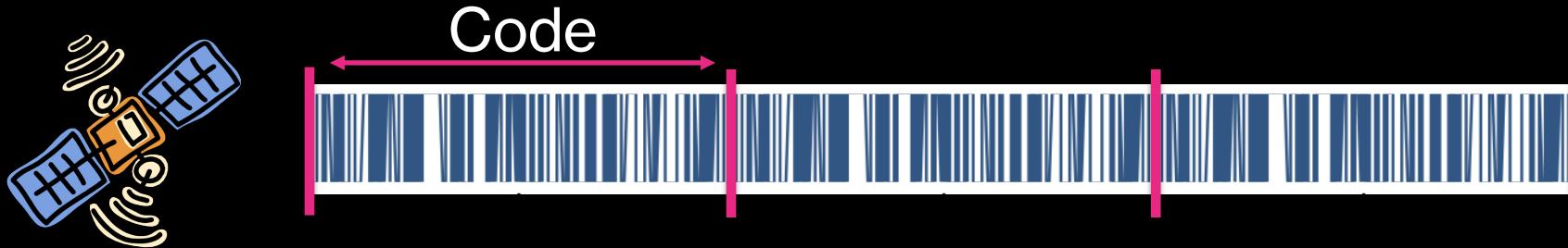
- Combine AoA with ToF
- Use circular antennas and combine with inertial sensing
- Perform synthetic aperture radar
- Synthesize measurements from multiple frequencies
- ...

GPS

Compute the distance to the
GPS satellites

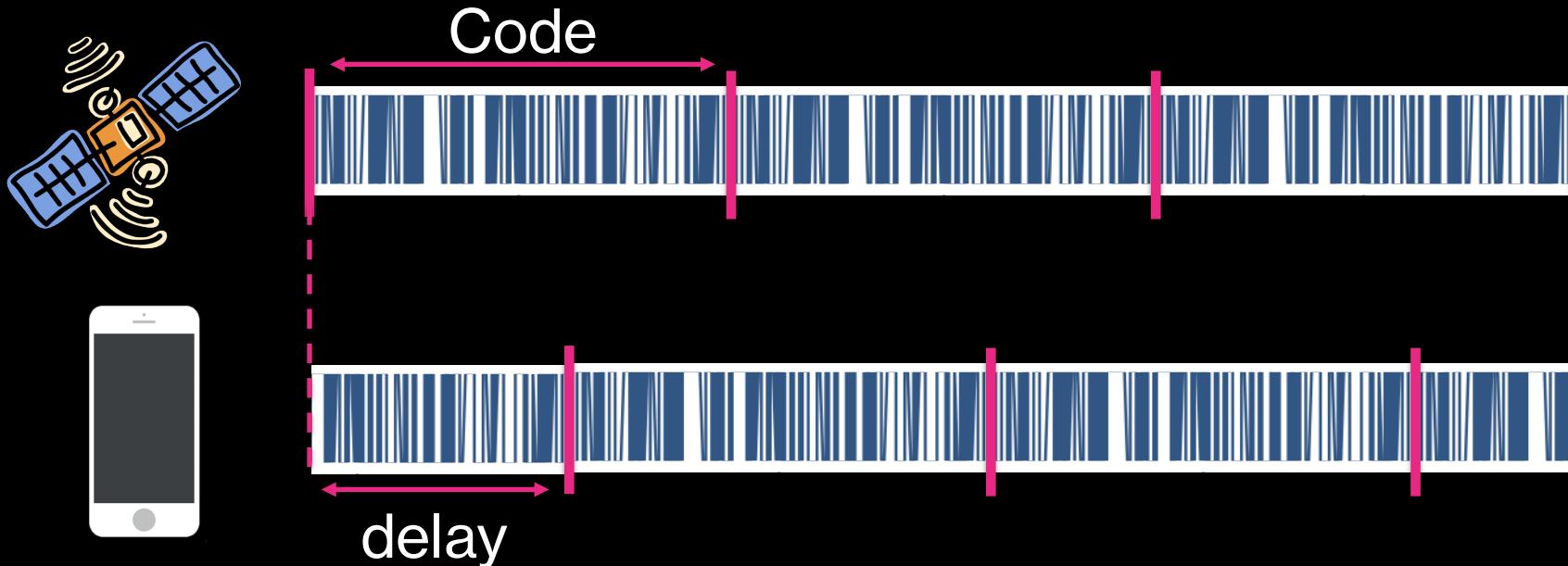


How to Compute the Propagation Delay?



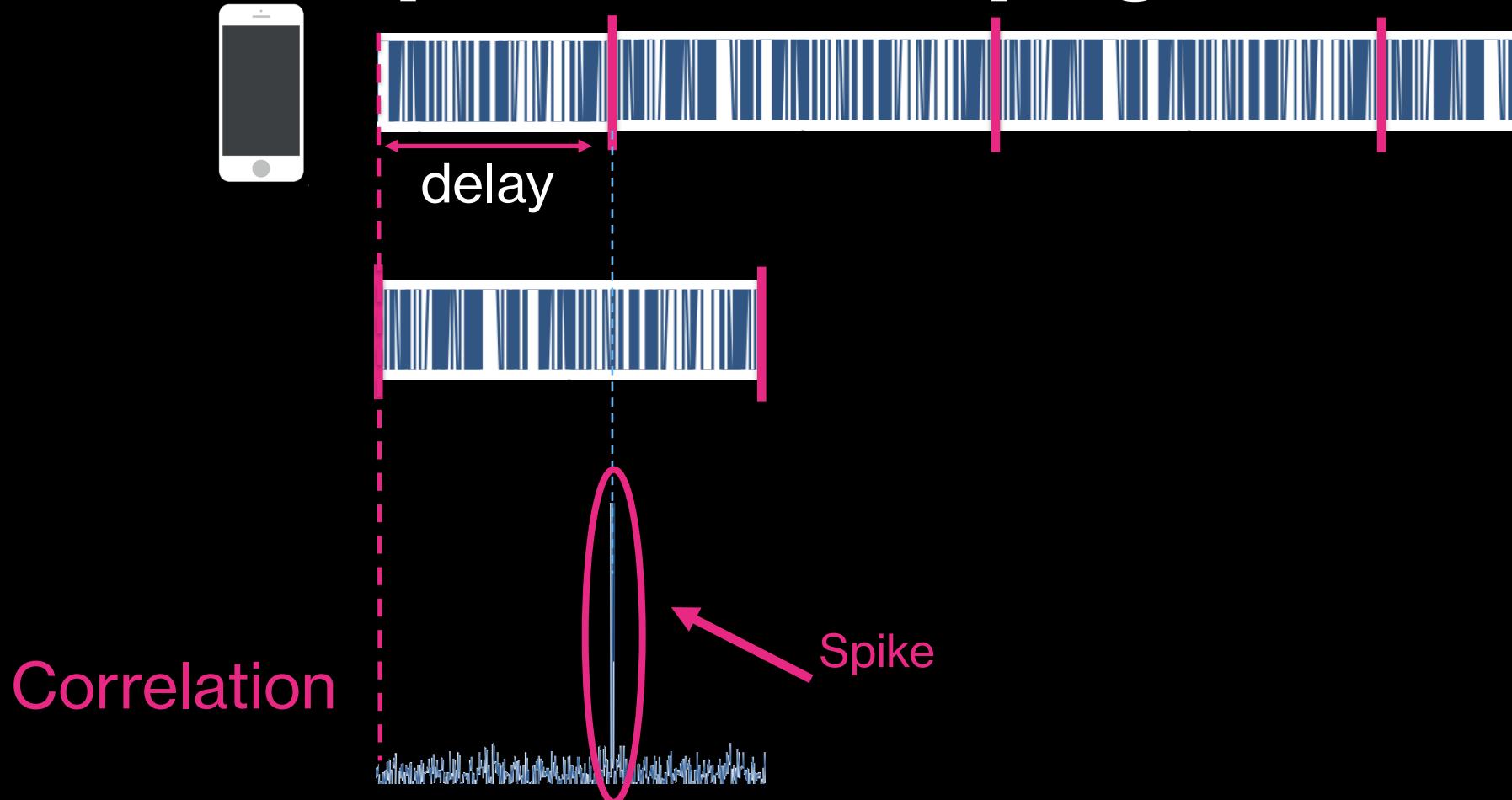
Each satellite has its own code

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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iOS Lab 0 is out

- **Topic:** Get familiar with Xcode IDE and develop an OpenWeather API
- **Due:** Mon Feb 5th, 11:59 pm

Next Lecture

- **Time:** Wed Jan 31st
- **Topic:** Device-free localization
- **Reading & Questions:** WiTrack (details on the course website)