CIS 7000-008: Special Topics on Wireless and Mobile Sensing

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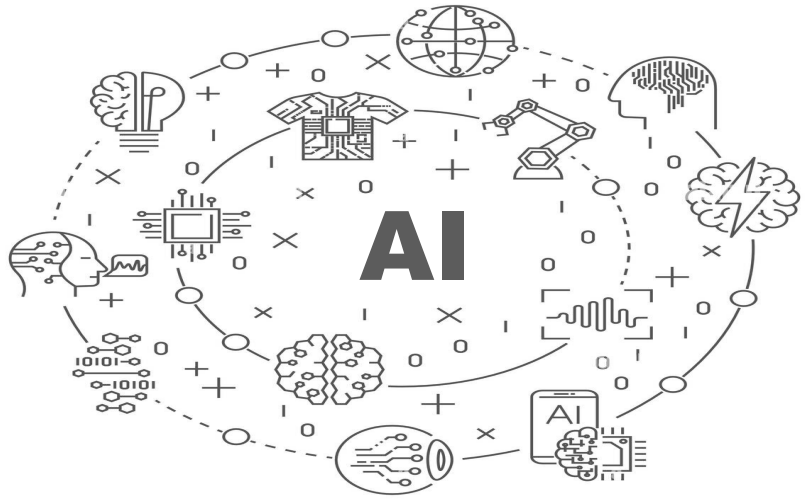
Lecture 2
Wireless Localization: WiFi



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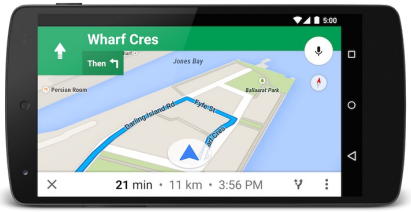
What is Wireless Localization / Positioning?

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

Applications:

- Navigation: outdoors (GPS) and indoors (e.g., 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)
- Location based security
- Delivery drones



What are different localization techniques?

- Radio signals: GPS, Cellular, Bluetooth, WiFi
- Ultrasound signals: Sonar
- Inertial sensors: IMU, gyroscope, magnetometer
- Visual signals: camera, LiDAR

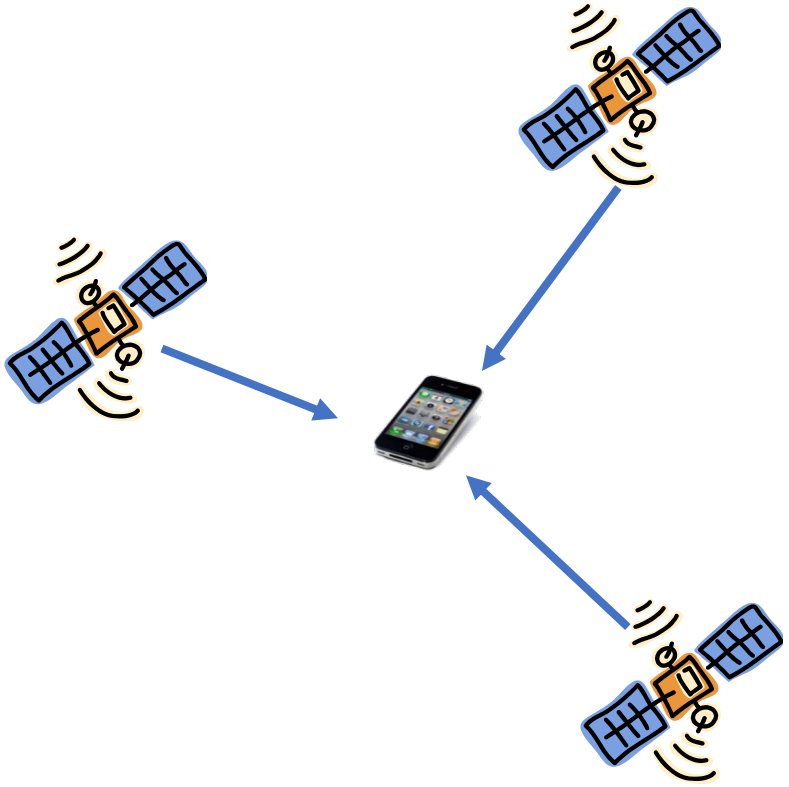
Wireless Localization

This Lecture: Focus on WiFi Localization

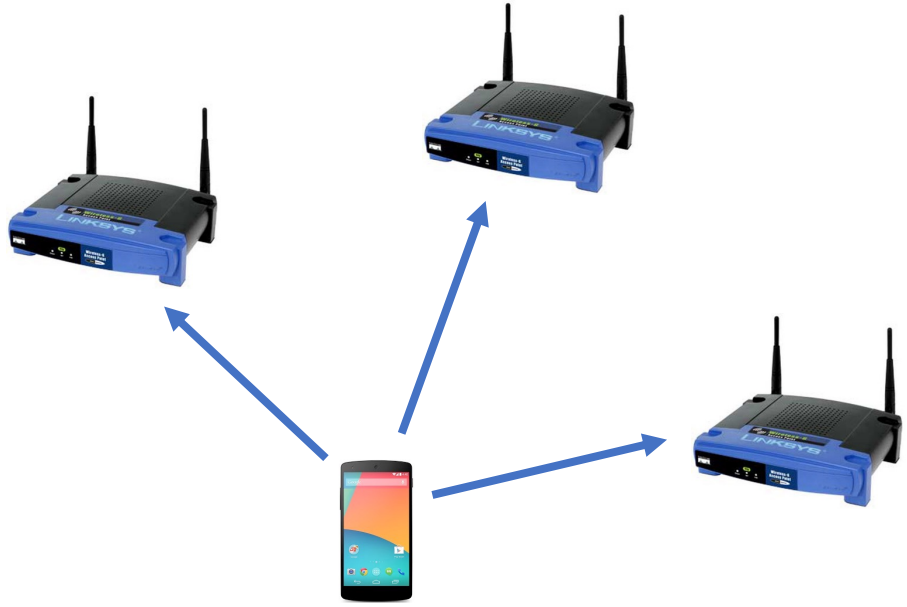
Future Lectures: Other wireless technologies

Who performs the localization?

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



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



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?

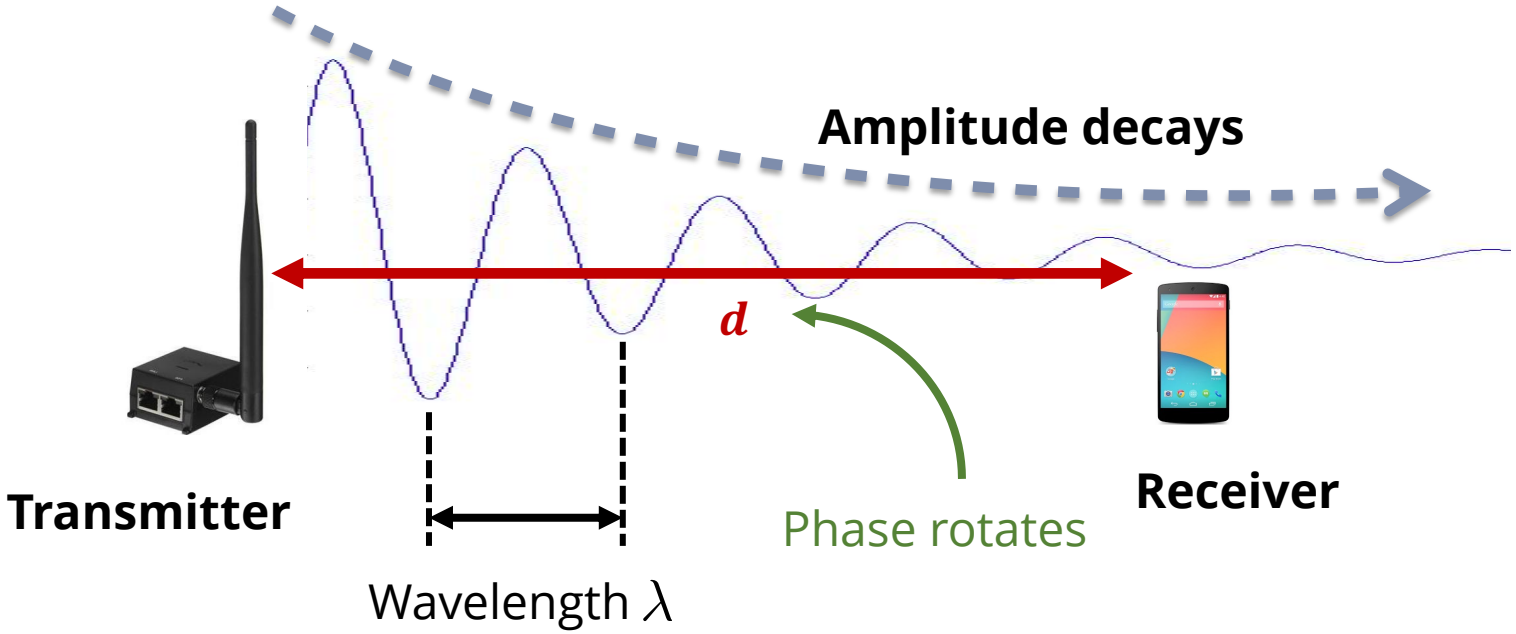
2. Received Signal Strength (RSSI)

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 Propagation



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

2. Received Signal Strength (RSSI)

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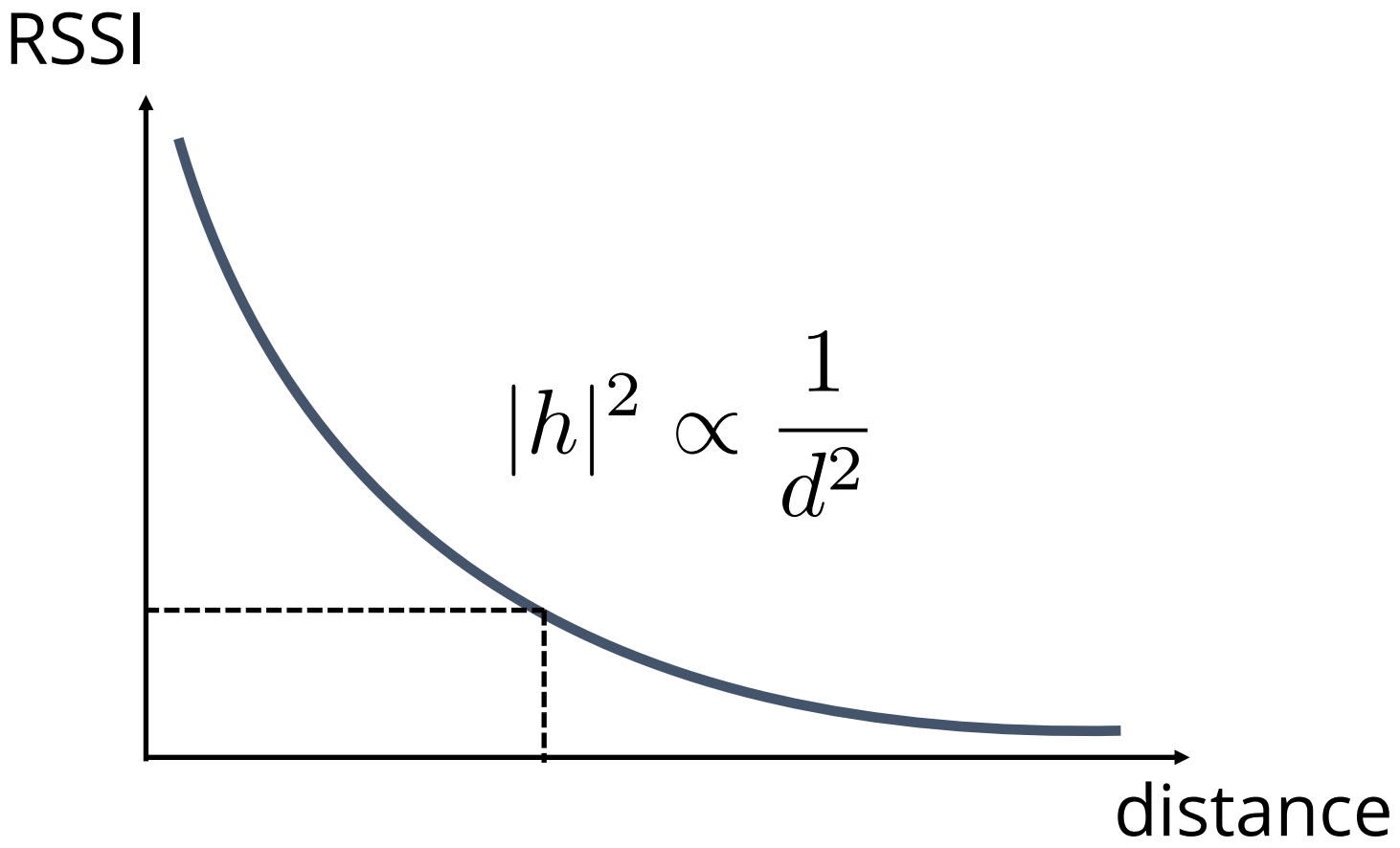
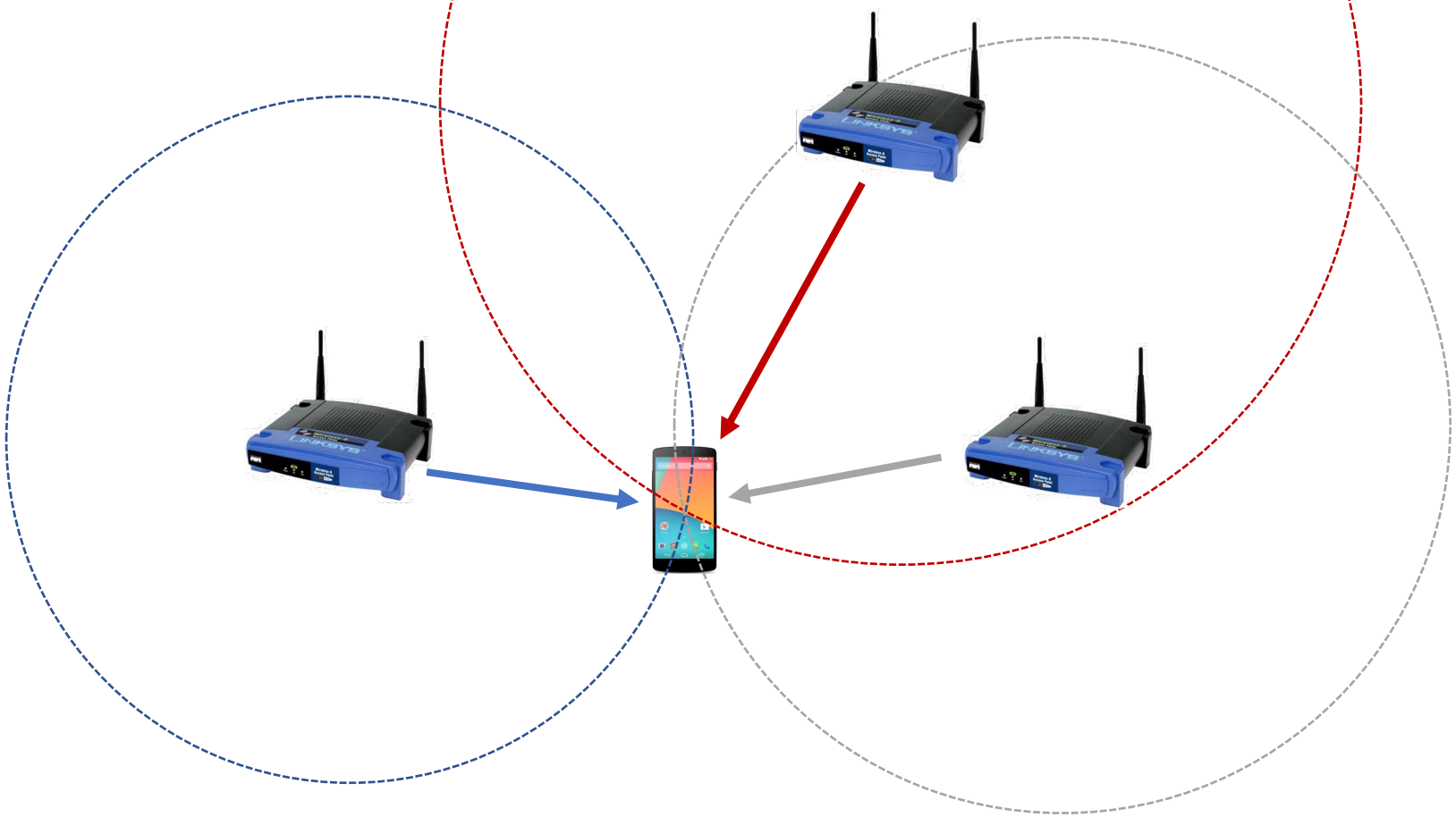


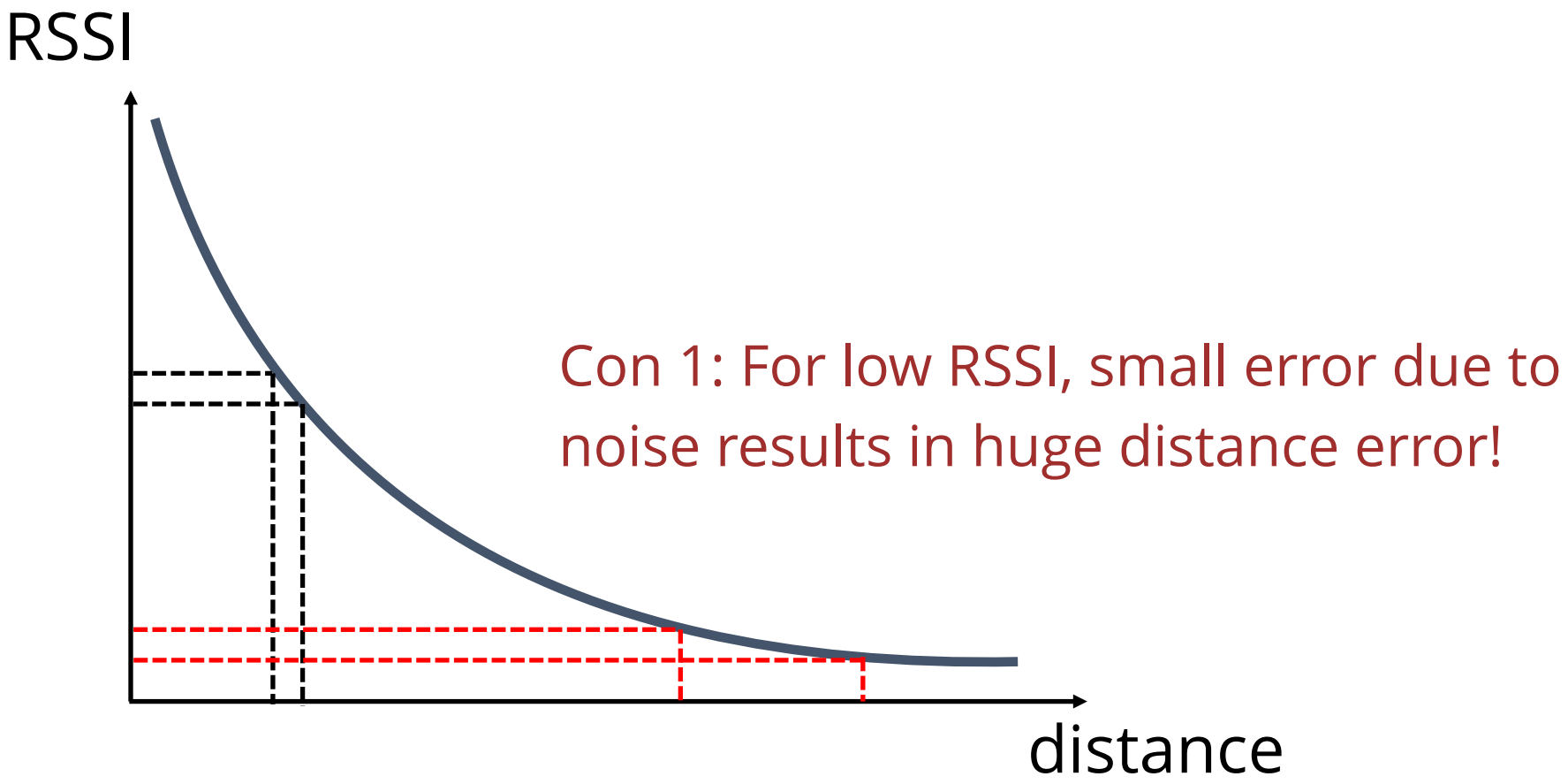
2. Received Signal Strength (RSSI)



Trilateration

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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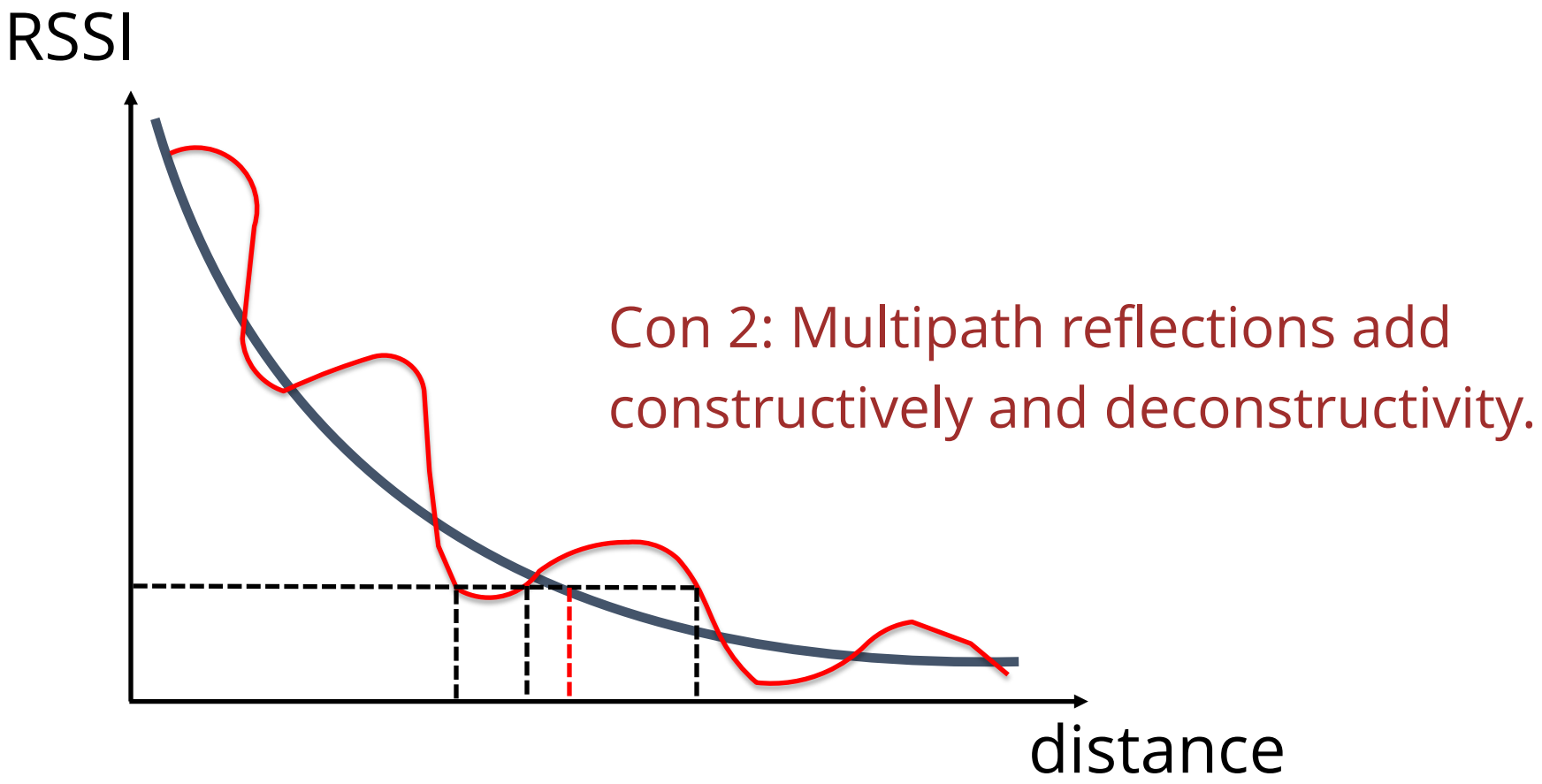
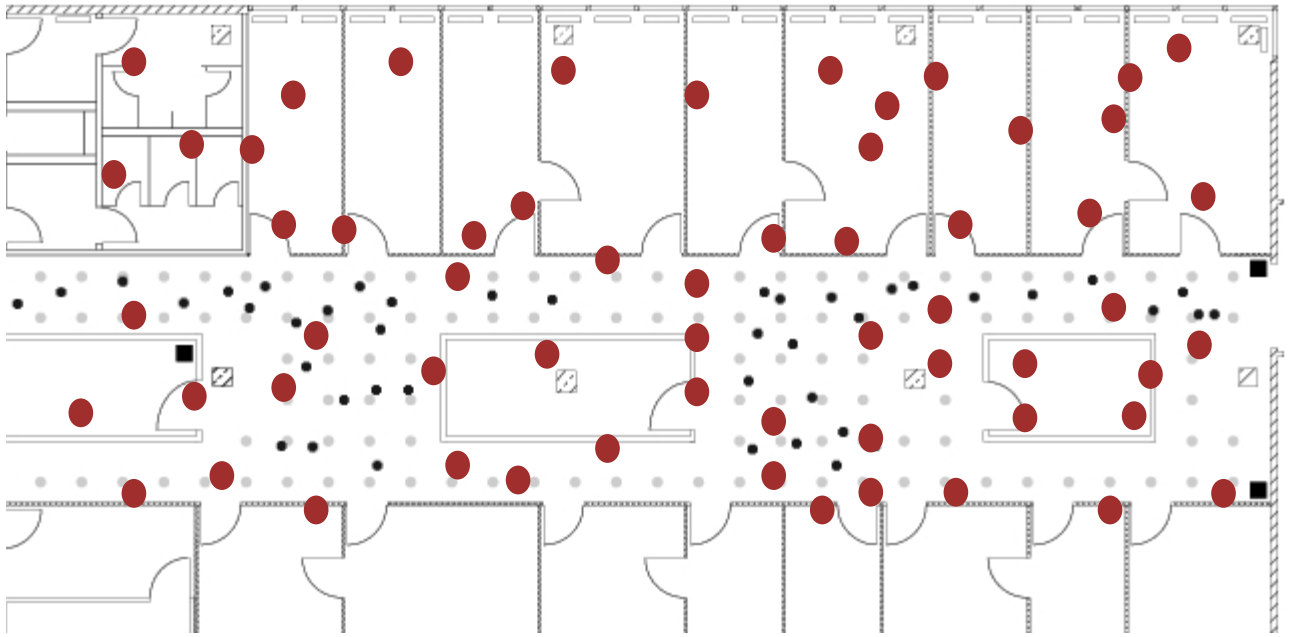


Con 2: Multipath reflections add constructively and deconstructivity.

2. Received Signal Strength (RSSI)

Solution: Fingerprinting

Measure and records RSSI fingerprints at each location

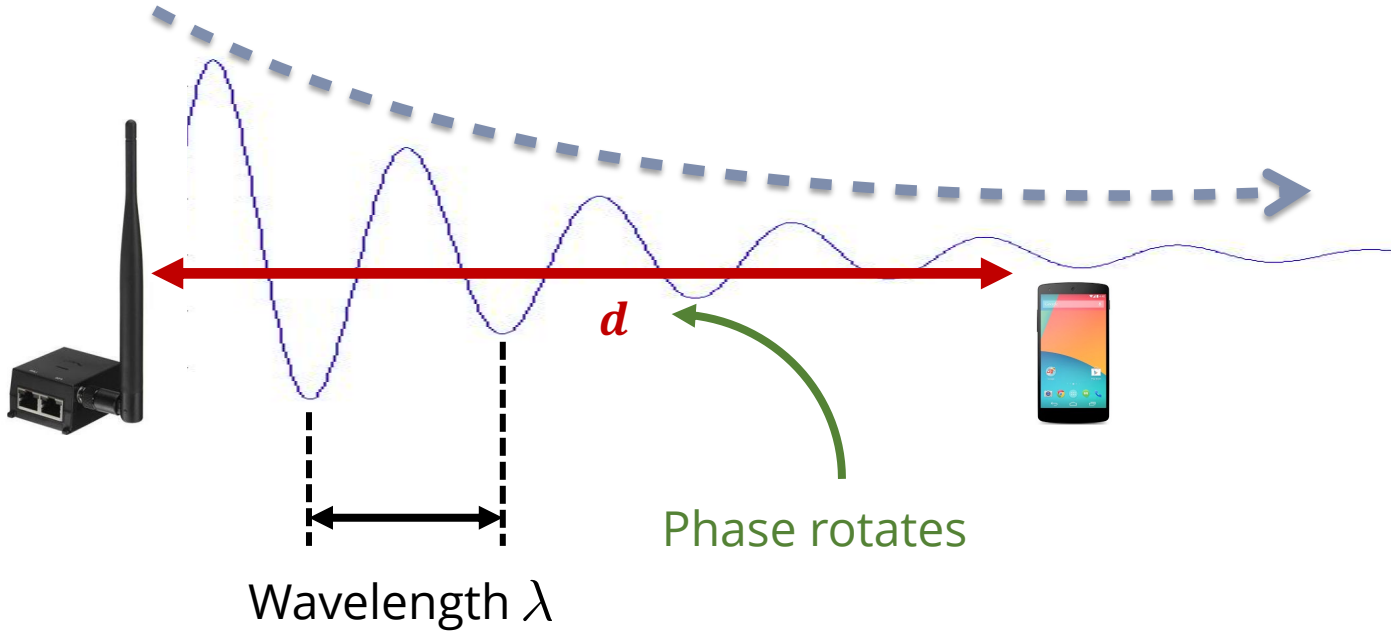


Pros: Works with multipath, No need to know AP locations!

Cons: Changes in environment/movement ➔ change RSSI!

Continuous training is needed. Lots of effort!

3. Phase of the signal



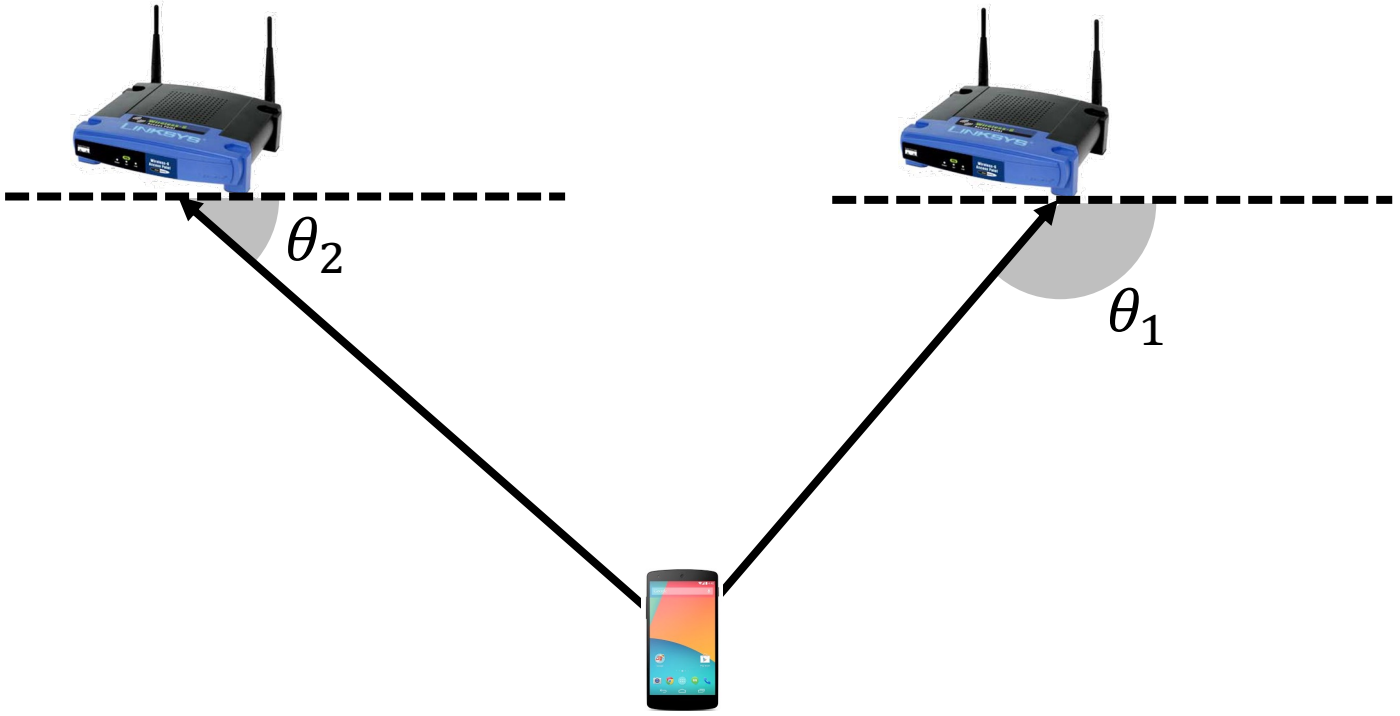
Channel equation: $h = \frac{1}{d} e^{j2\pi \frac{d}{\lambda}}$

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

Cons: Phase Ambiguity

4. Angle of Arrival (AoA)

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

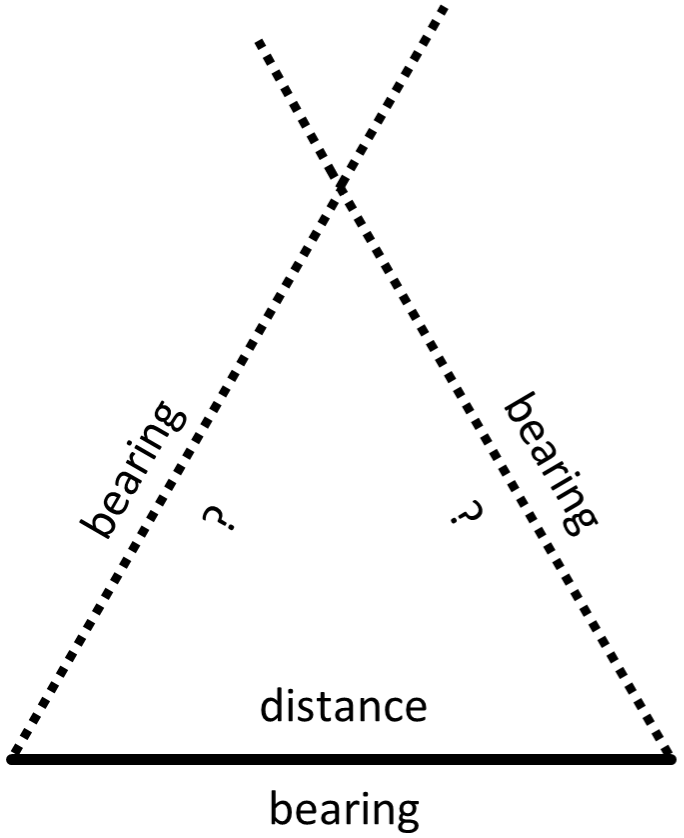


Triangulation

Triangulation and Trilateration

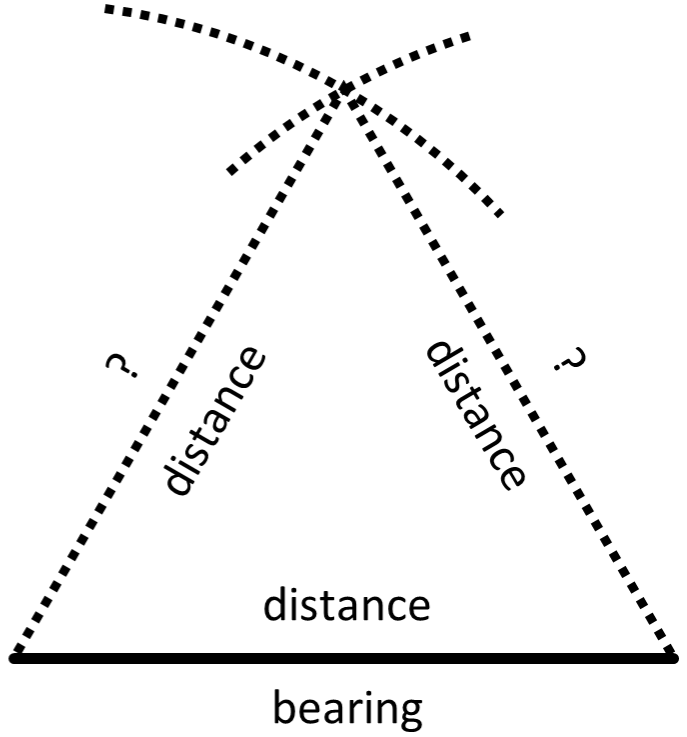
Triangulation

(2 missing distances)



Trilateration

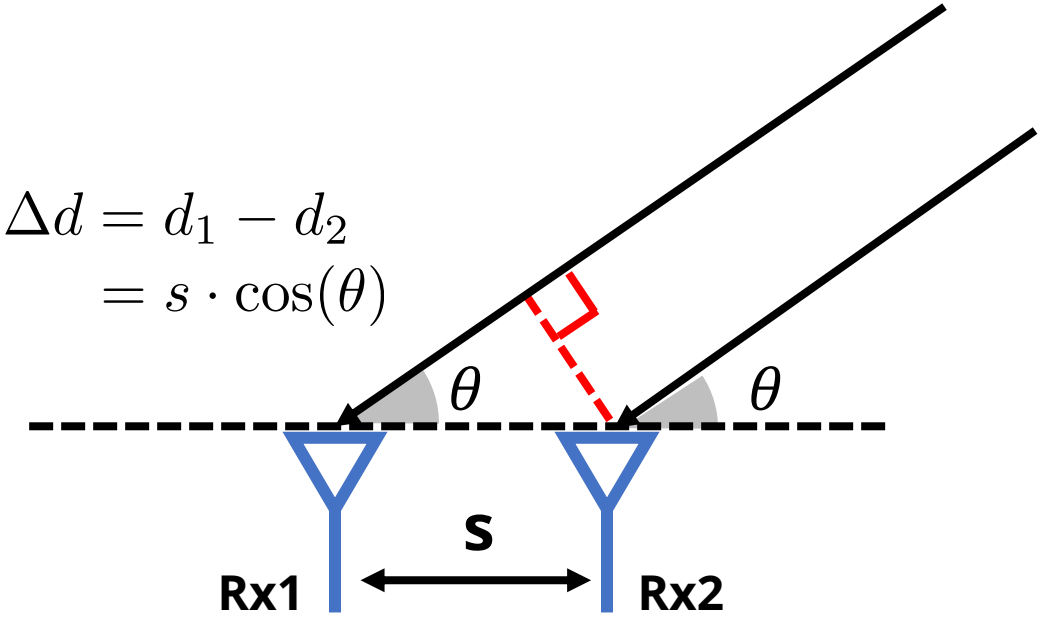
(2 missing bearings)



4. Angle of Arrival (AoA)

How to measure the angle?

$$\Delta d = d_1 - d_2 = s \cdot \cos(\theta)$$



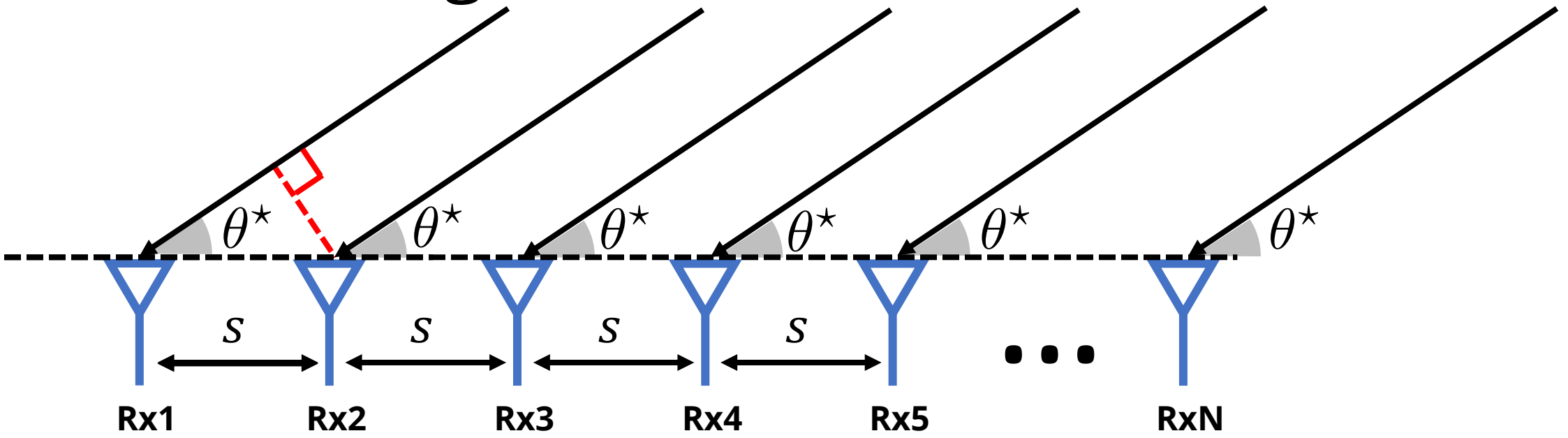
$$\phi_1 = \frac{2\pi d_1}{\lambda} \qquad \phi_2 = \frac{2\pi d_2}{\lambda}$$

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

Pros: More accurate than RSSI, Simple!

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

4. Angle of Arrival (AoA)



Multipath profile (delay-and-sum):

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

4. Angle of Arrival (AoA)

Multipath profile:

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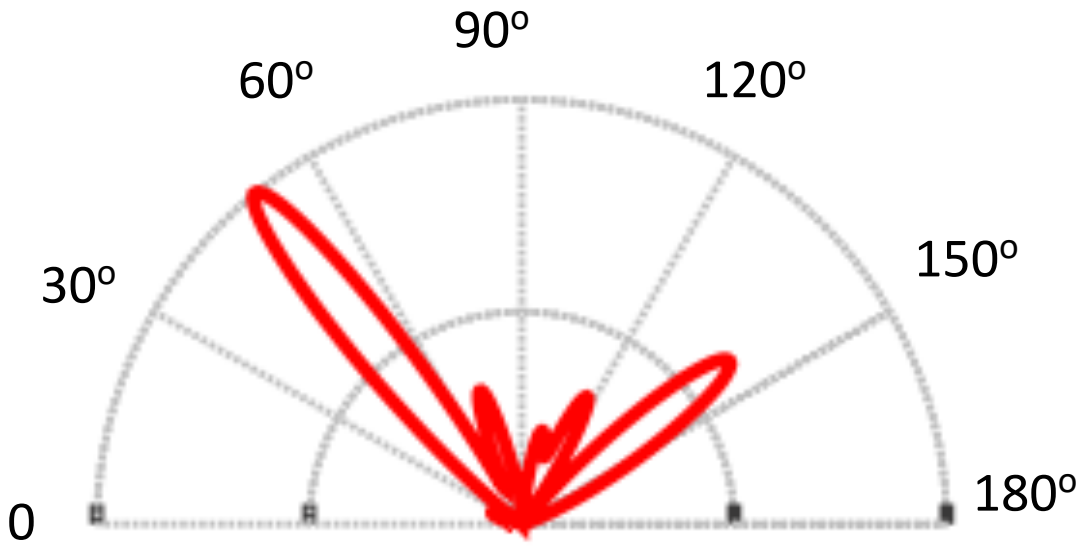
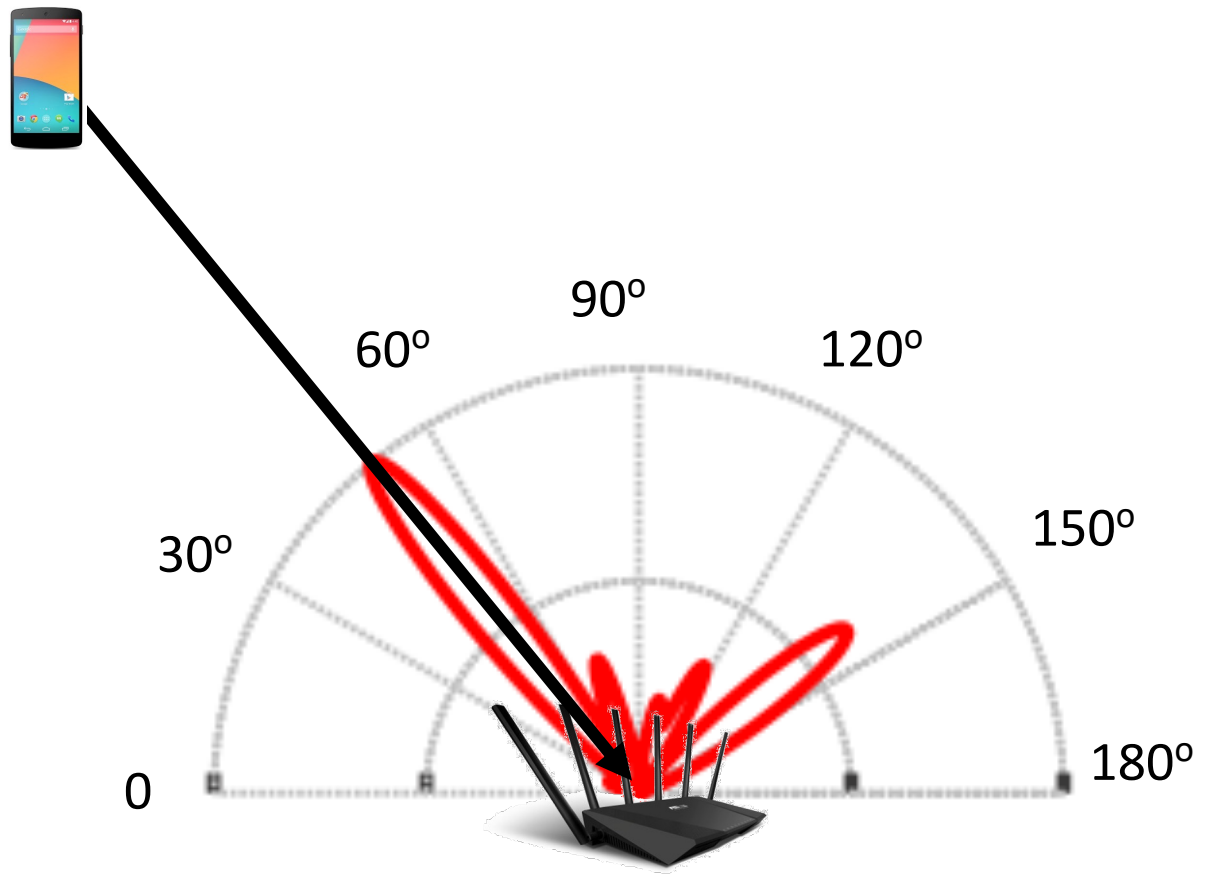


4. Angle of Arrival (AoA)

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

Strongest Path!



4. Angle of Arrival (AoA)

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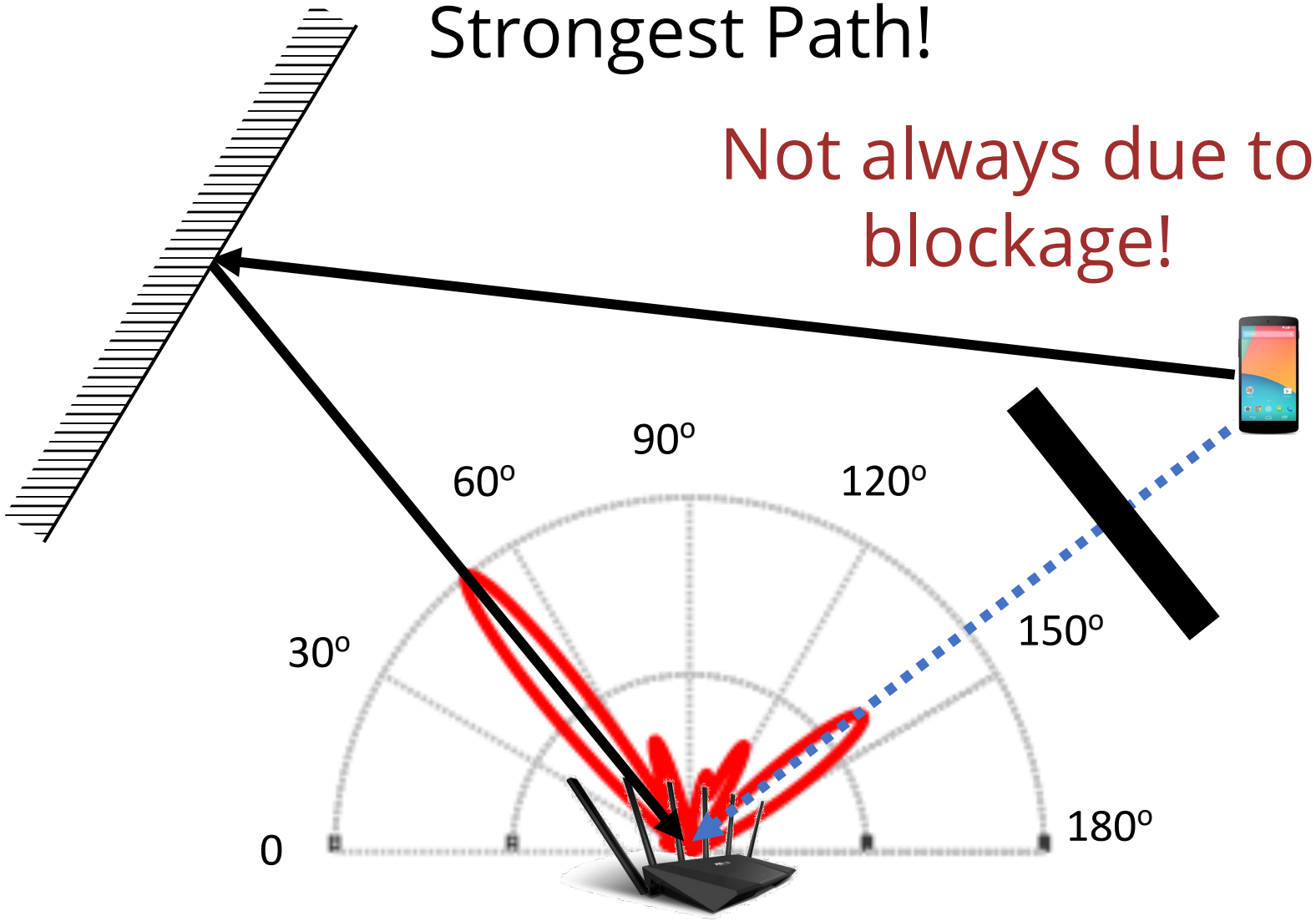
Strongest Path!

Not always due to blockage!



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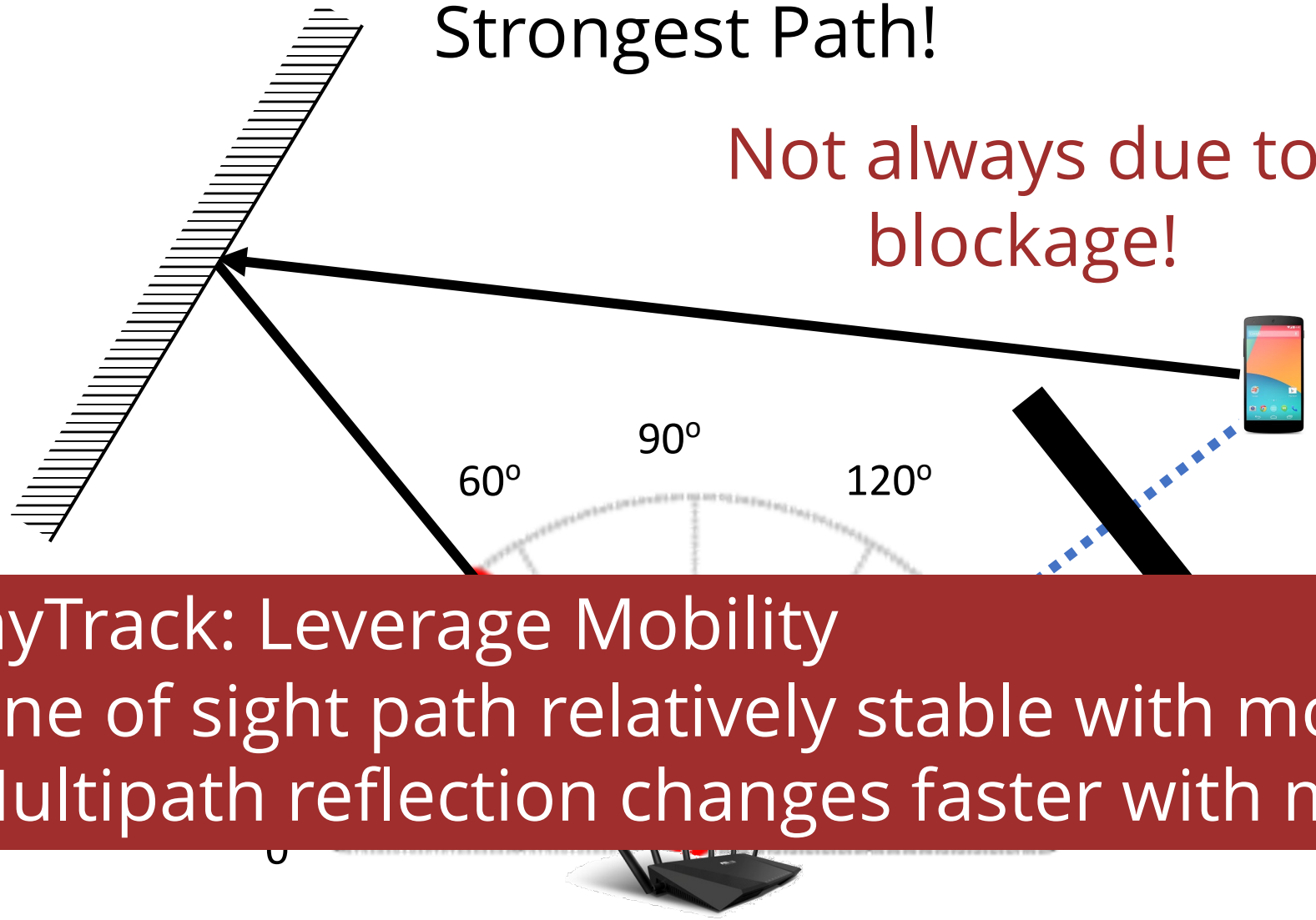
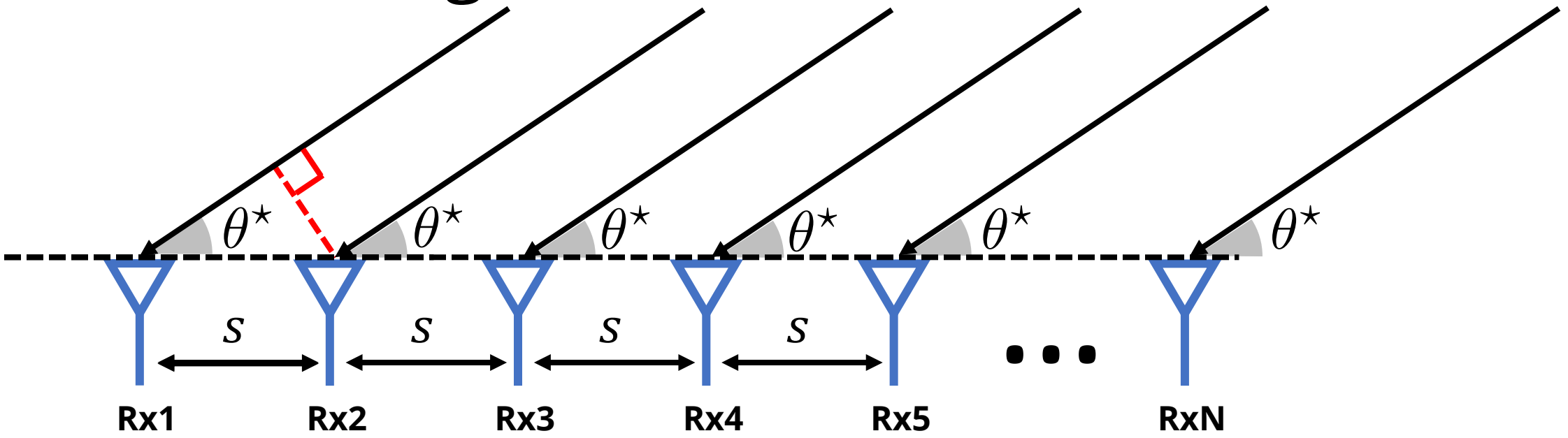


ArrayTrack: Leverage Mobility

- Line of sight path relatively stable with mobility
- Multipath reflection changes faster with mobility

4. Angle of Arrival (AoA)

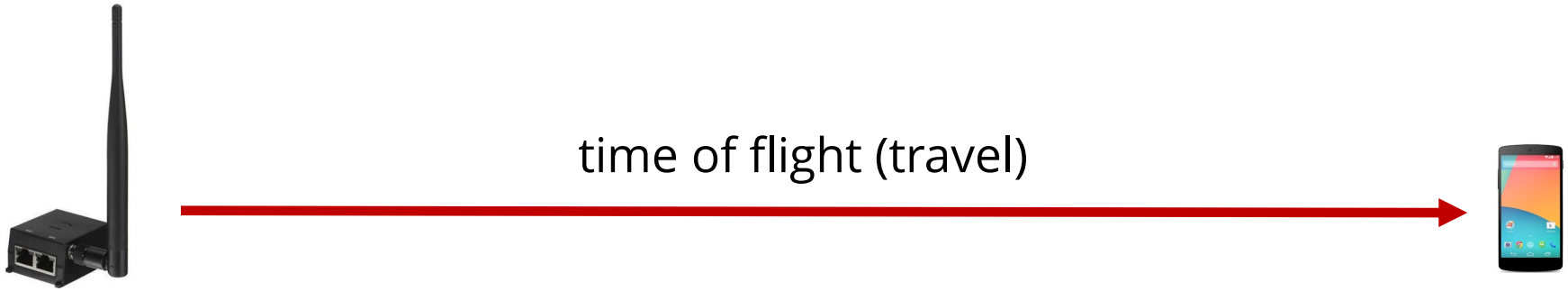


Pros: Works with multipath,

Cons: Requires more hardware!

Far-field approximation: it assumes device is sufficiently far such that wavefront is parallel

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

Challenges:

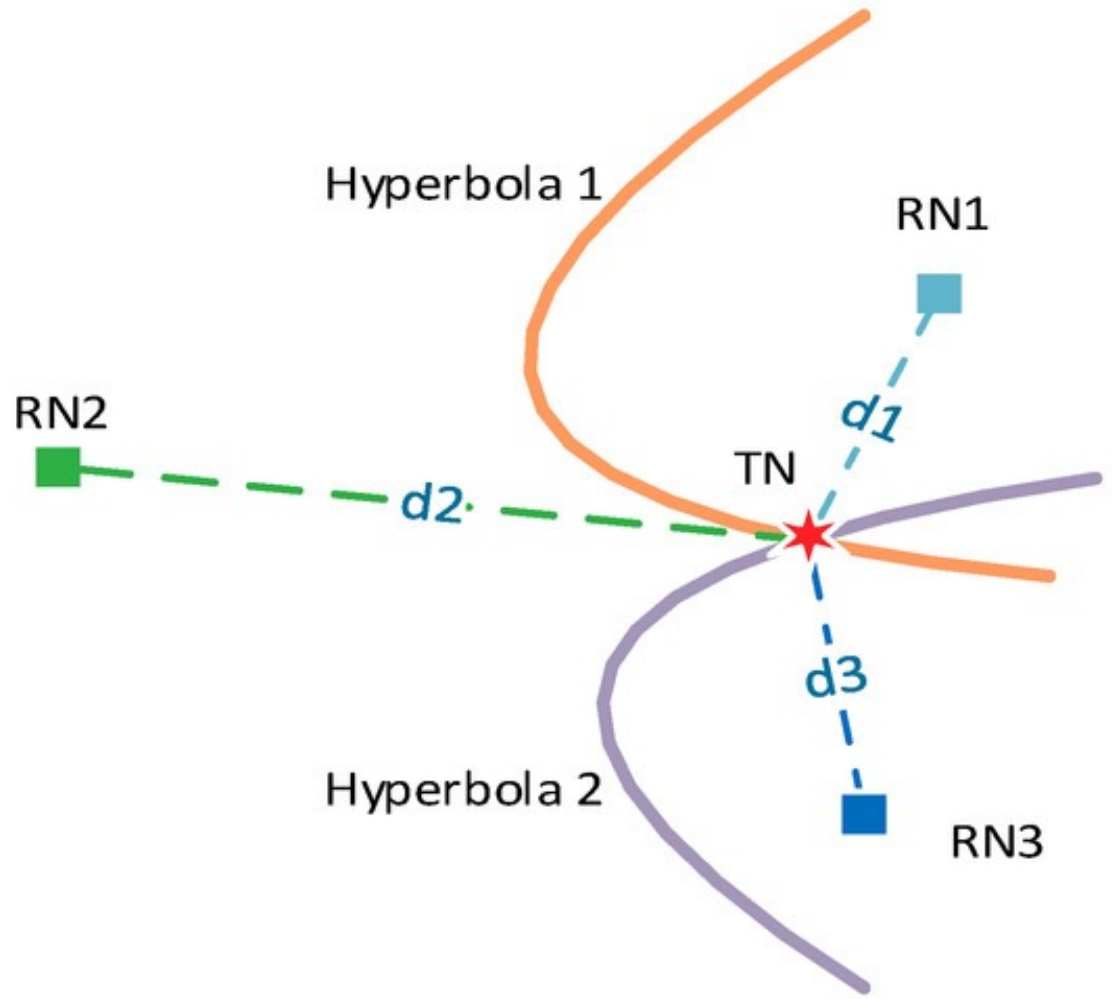
- How do you know when signal was transmitted? Not Practical!

- Other systems than WiFi can get accurate ToF:

  - UWB: Ultra-Wide Band
  - FMCW: Frequency Modulated Carrier Wave

Not Supported in WiFi
(Will discuss in future lectures)

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



Today

Wireless Localization:

- Identity
- RSSI
- Phase
- AoA
- ToF
- TDoA

Next class

- Mon Jan 23rd
- Wireless Localization: RFID
  - Required: ArrayTrack
  - Optional: Cricket, RADAR