MAS.S62:

Ocean IoT

Technologies, Industries, Sustainability

Lecture 4:
Fundamentals of Underwater Localization

Lecturer

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TA

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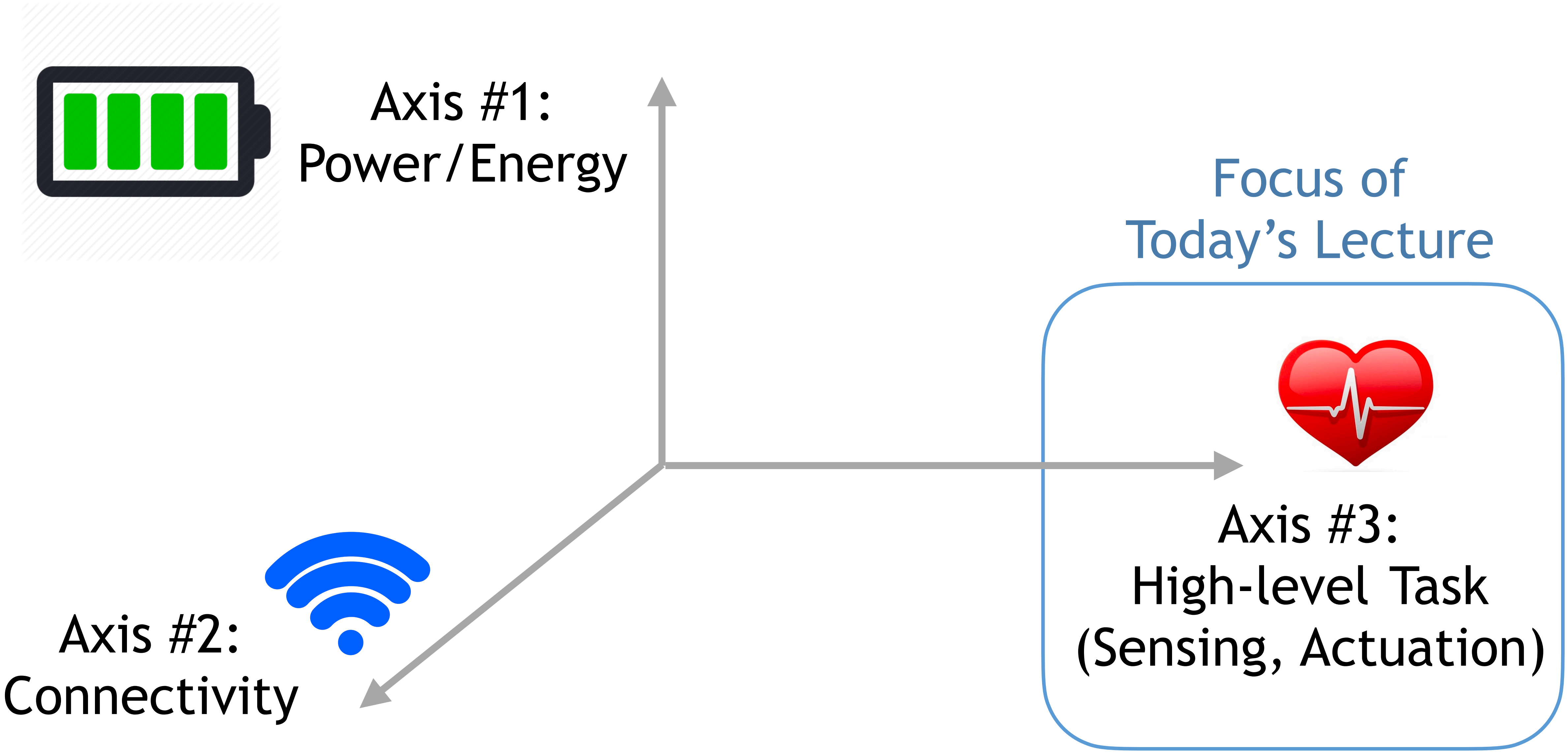
Feedback on Class

- Most excited about:
  - The project, innovative/state-of-the-art technologies and research, learning about wireless systems and signals, real-world applications
- Most concerned
  - Completing an innovative project despite challenges, giving good presentations and reviews
- Liked about classes so far:
  - Balance of technical (including background material) and applications, class interaction and dynamics
- Way to improve lectures:
  - Add slides on technical info after whiteboard derivations, timing for student presentations, seating for whiteboard derivation
- Exciting topics beyond class:
  - Animal detection/sensing

Main Components of (Ocean) IoT Systems



Objectives of Today's Lecture

Learn the fundamentals, applications, and implications of **underwater localization**

1. What are the unifying principles of underwater positioning?
2. How do systems like LBL, SBL, USBL work?

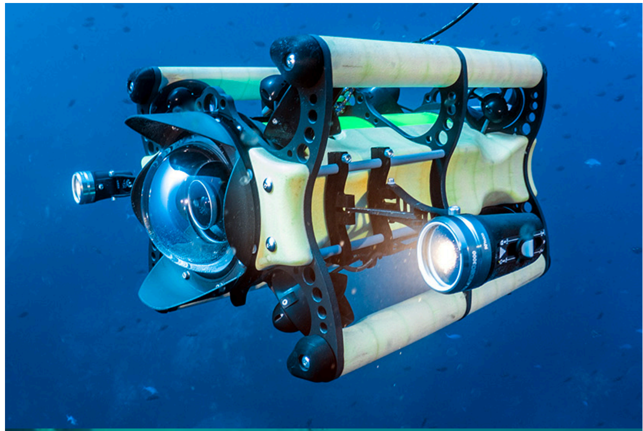
3. Feedback on reviewing
4. Pitches for project + early feedback

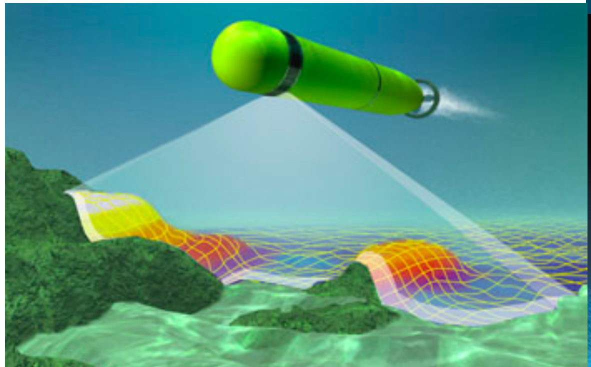
What is Underwater Positioning (aka Localization)?

The process of obtaining a sensor or underwater vehicle location

Applications:

- Underwater Navigation
- Underwater robot manipulation
- Seabed mapping
- Tagging animals to understand marine life/behavior/migration patterns
- Tracking animals for aquaculture
- Security (e.g., only want to allow affiliated drones to enter certain areas)
- Underwater asset tracking
- Spatiotemporal data for climate/weather





What is underwater positioning hard?

GPS doesn’t work underwater

How do Argo floats get their location?

They rise to the surface where they can get GPS

What are the different ways of obtaining location?

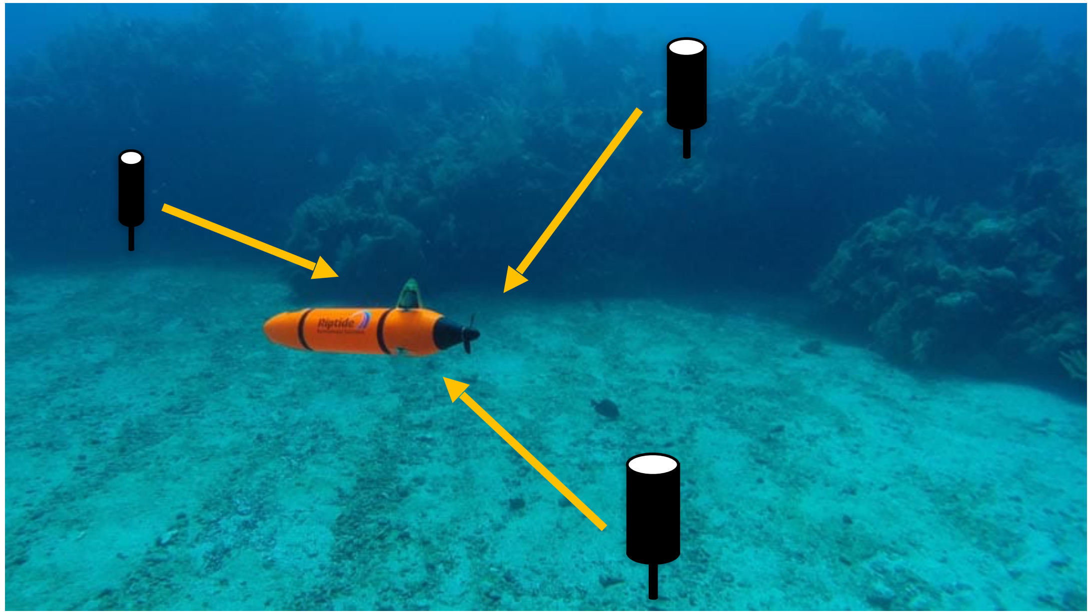
- Acoustic & ultrasonic signals
- Inertial (dead-reckoning)
- Optical (Cameras, Vision, LIDAR)

Focus of this lecture

We will discuss the localization techniques in increasing order of sophistication

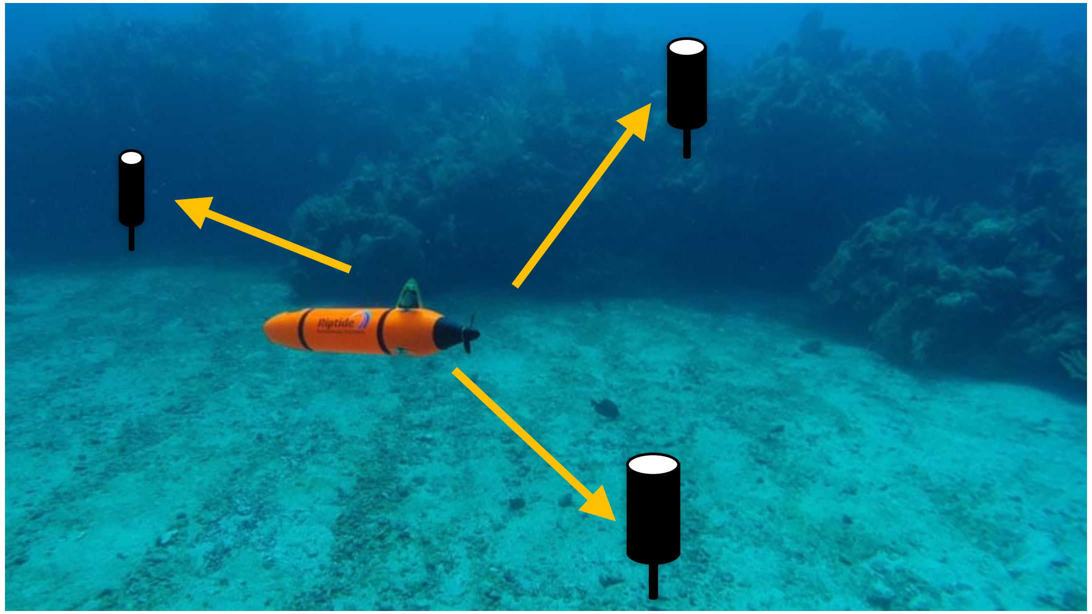
Who performs the localization process?

- Device based (Distributed): A device uses incoming signal from one or more "anchors" to determine its own location



- Example: GPS-like

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



- Example: SONAR

1) Identity-based Localization

Idea: Use the identity and known location of anchor nodes

Also called: Area Localization Scheme (ALS) or Direct Beaconing Localization system (UDB)

Non-ocean Example:

- Wardriving -- been used to improve the accuracy of GPS
- WiFi indoor localization

Localize by mapping to one of those locations.

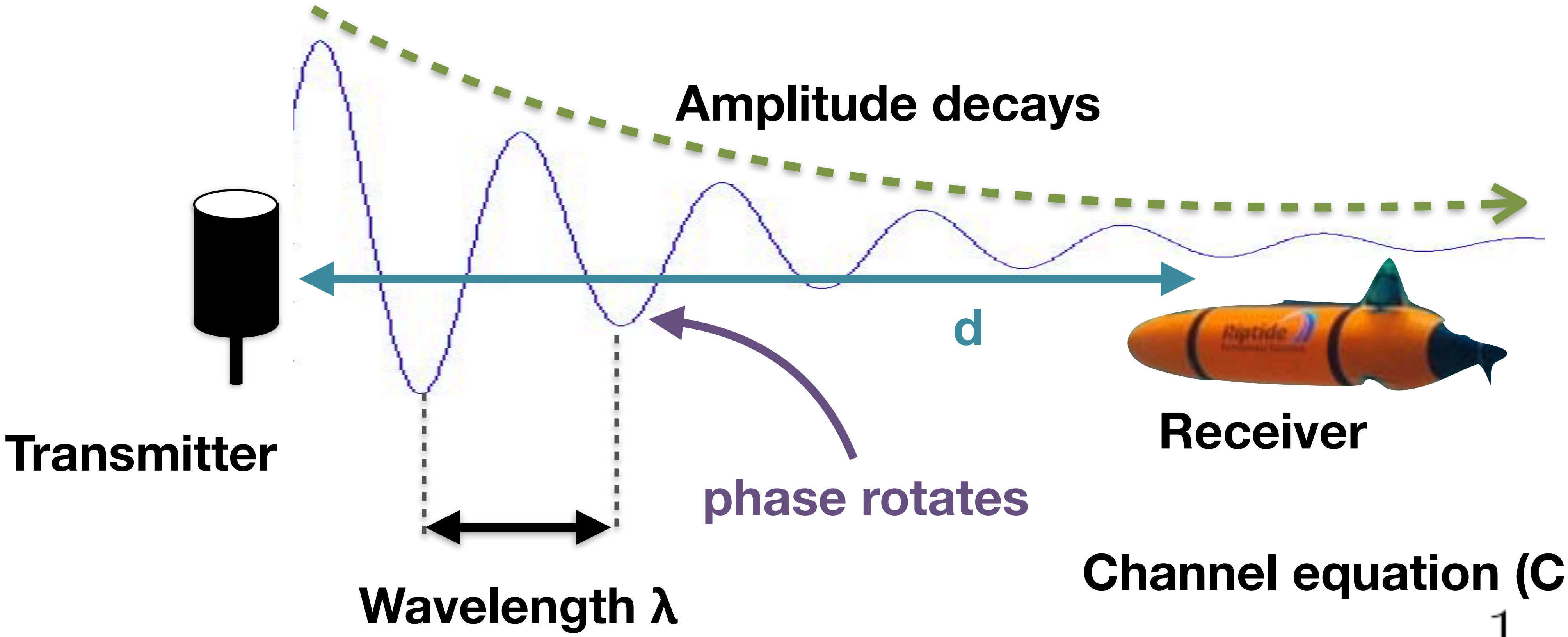
Pros? Cons?

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)

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

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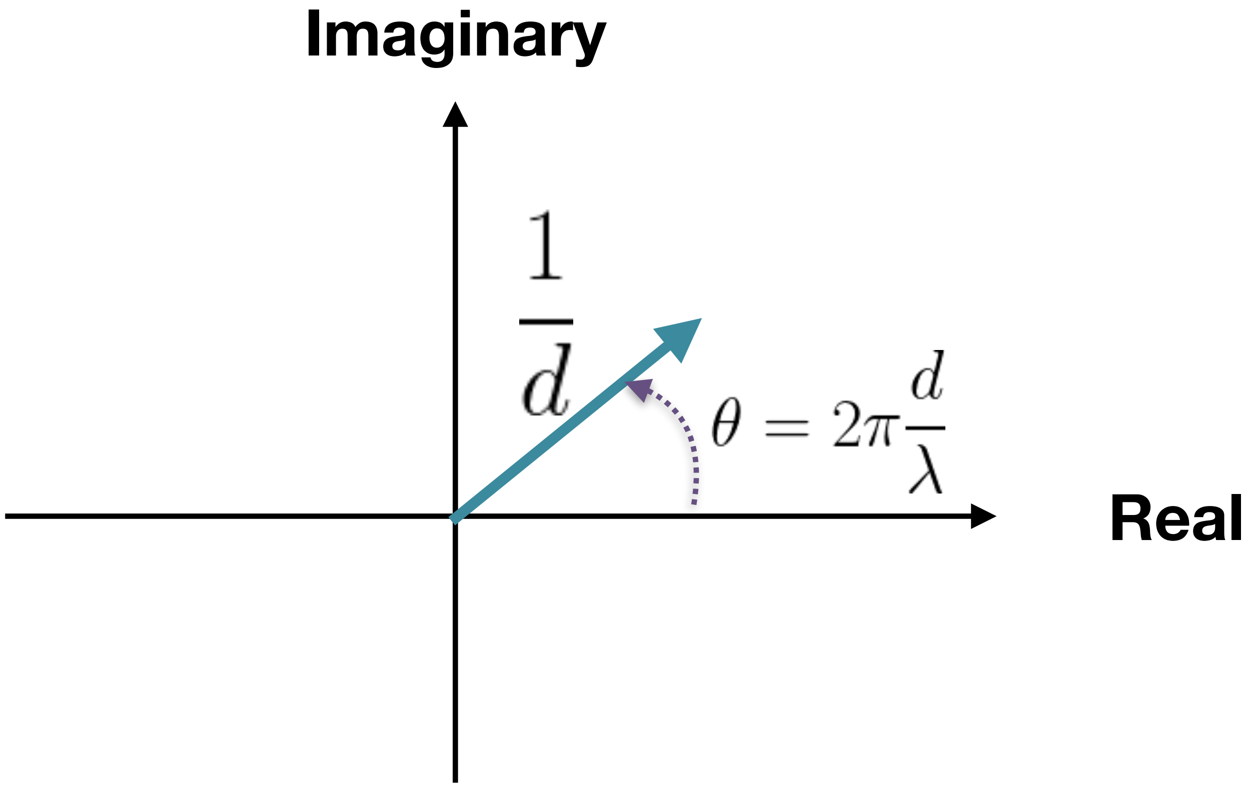
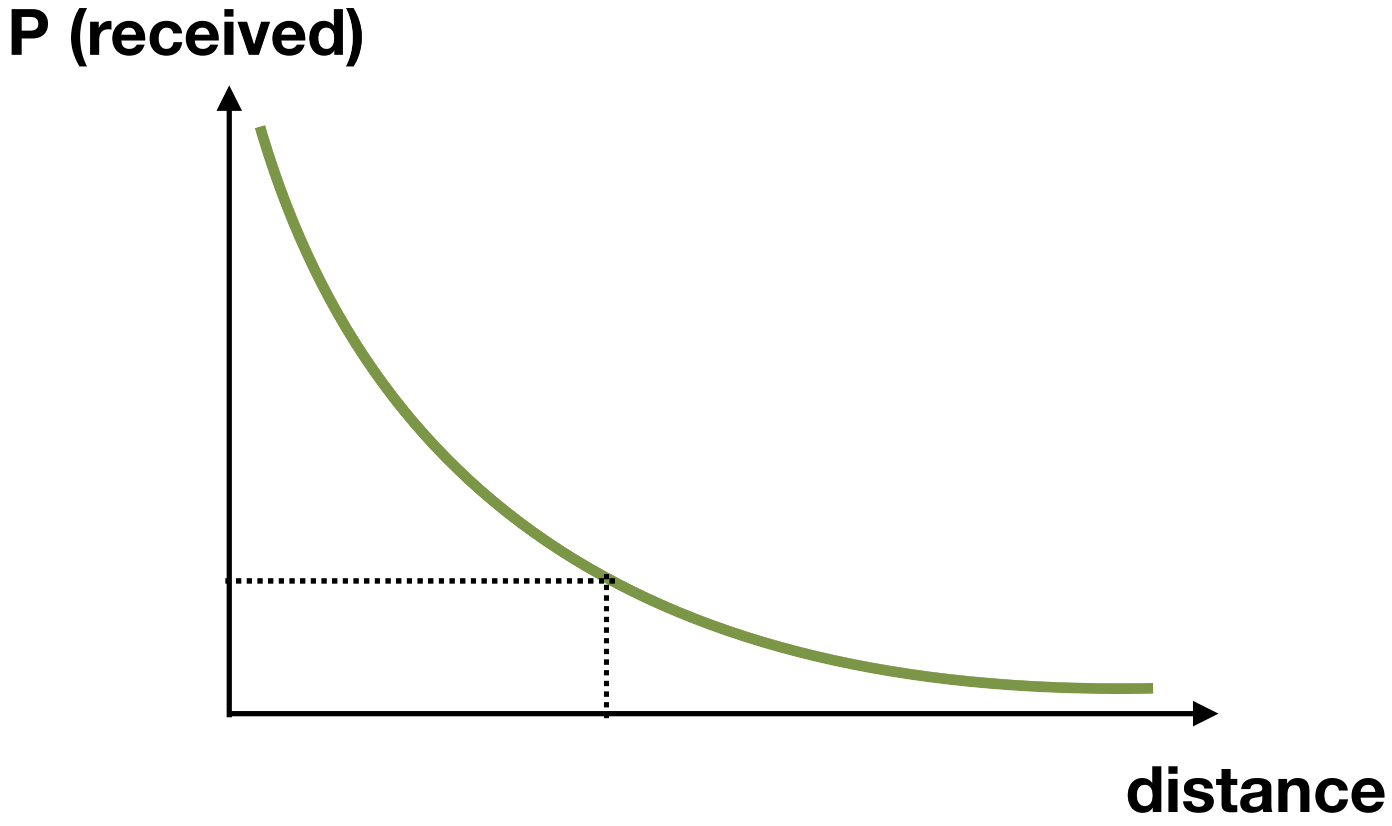


2) Received Signal Strength (RSSI)

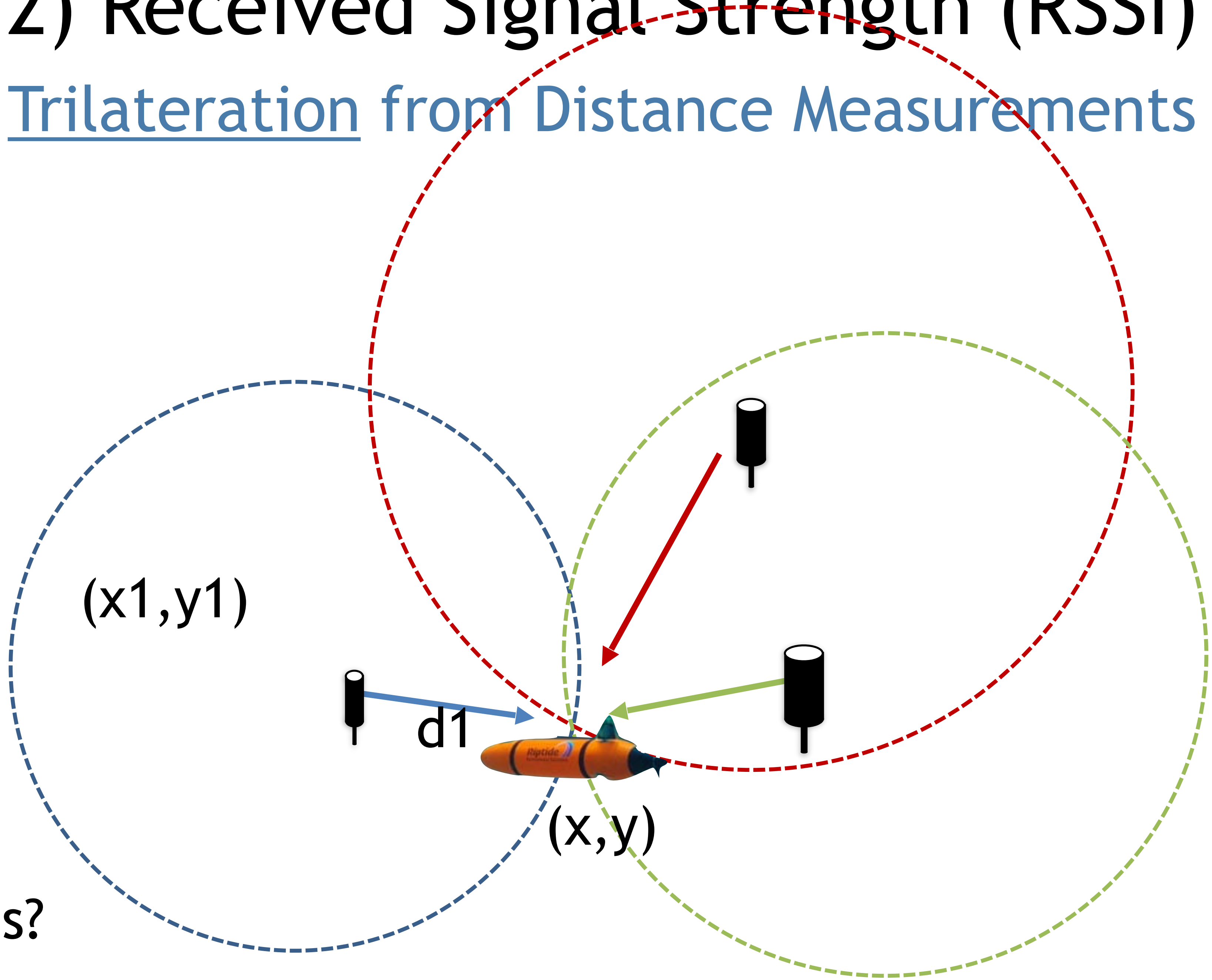
From power to distance

Power is proportional to $1/d^2$



2) Received Signal Strength (RSSI)

Trilateration from Distance Measurements



Pros? Cons?

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From power to distance

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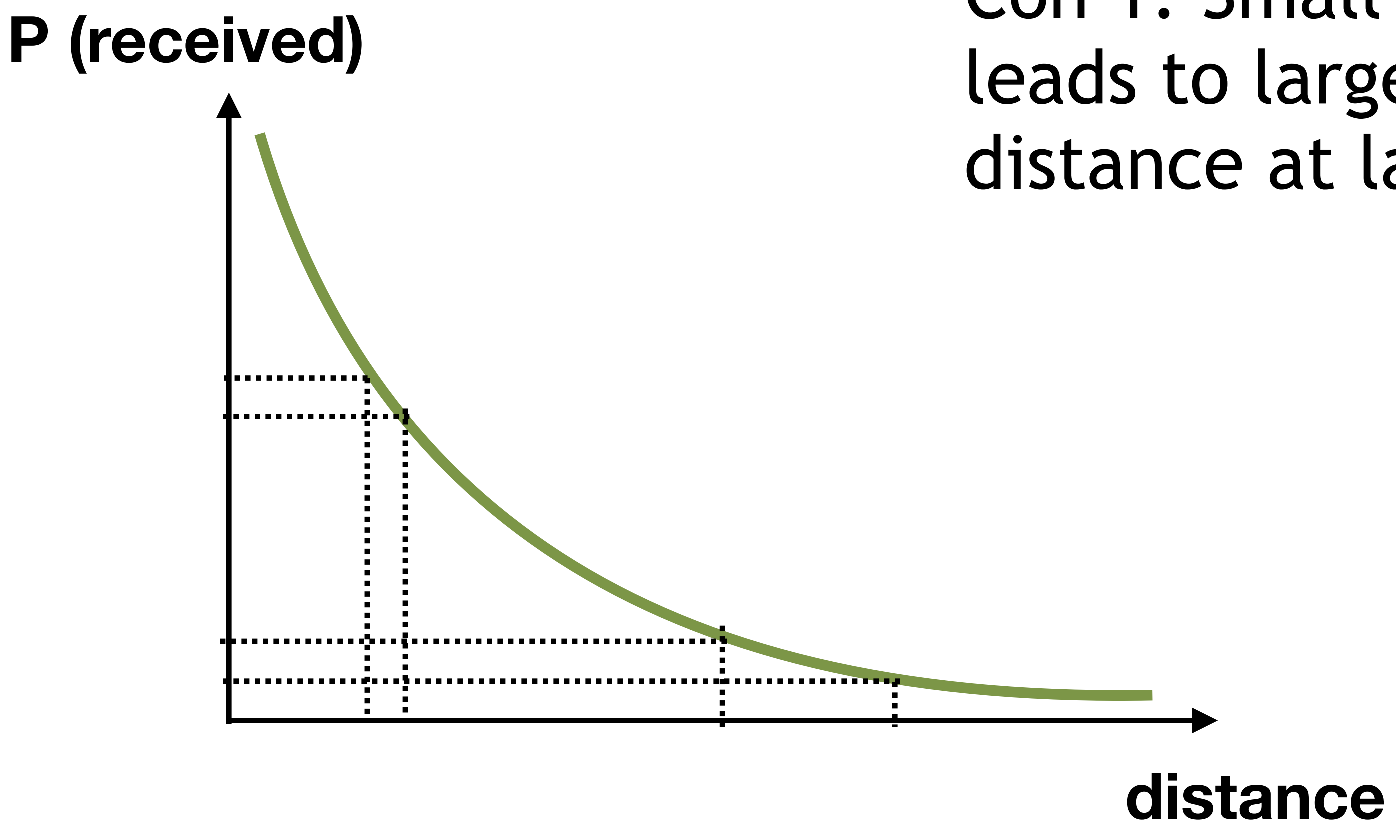
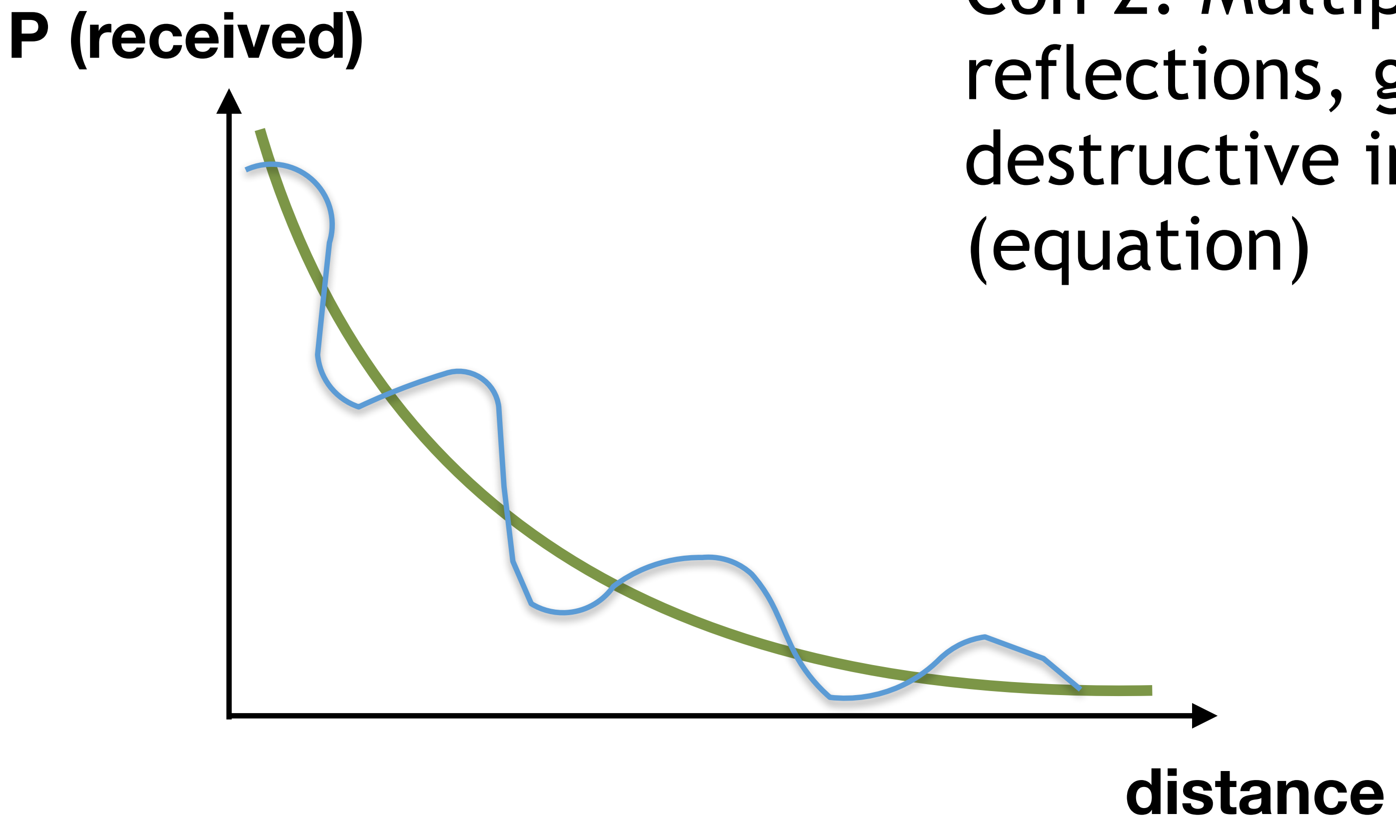


Con 1: Small change in power leads to large deviations in distance at larger distances

2) Received Signal Strength (RSSI)

From power to distance

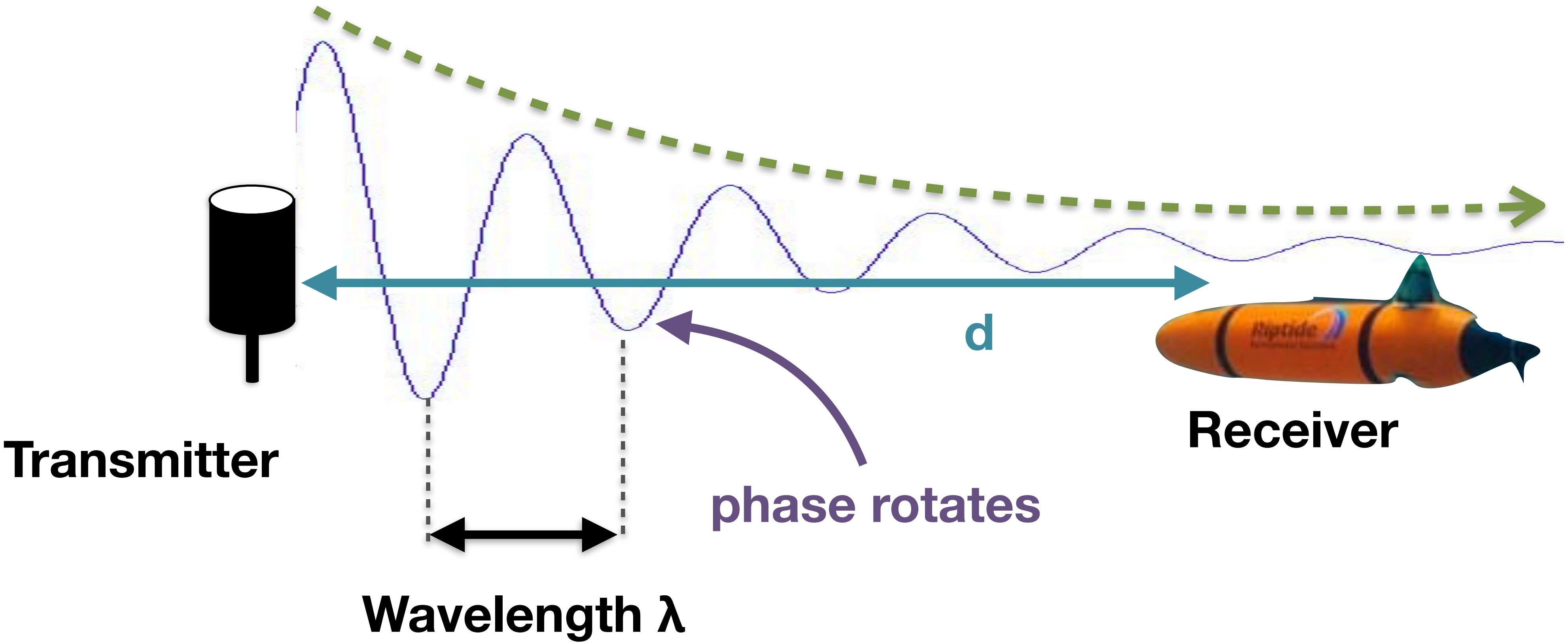
Power is proportional to $1/d^2$



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

3) Use the Signal "Phase"

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

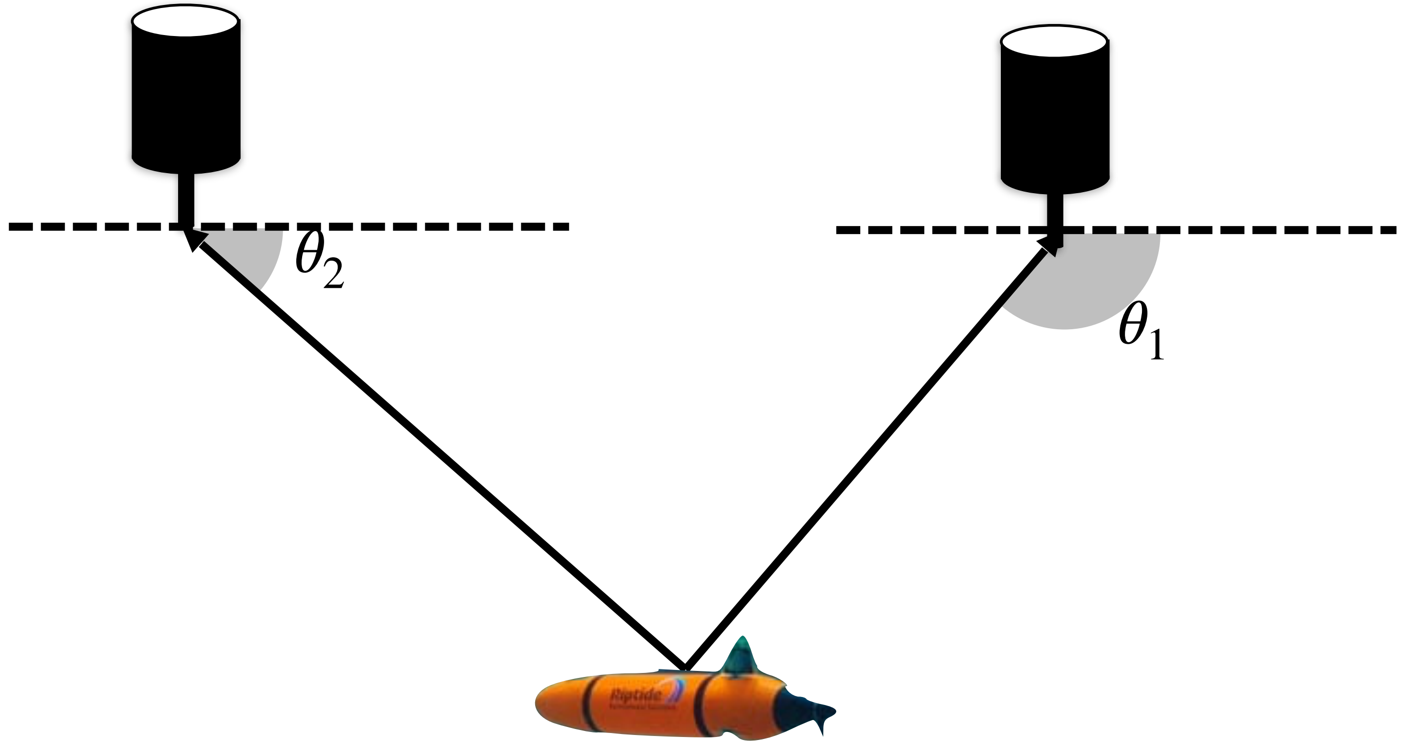


Pros? Cons?

4) Use Angle of Arrival (AoA)

<u>Triangulation</u> from Angular Measurements

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

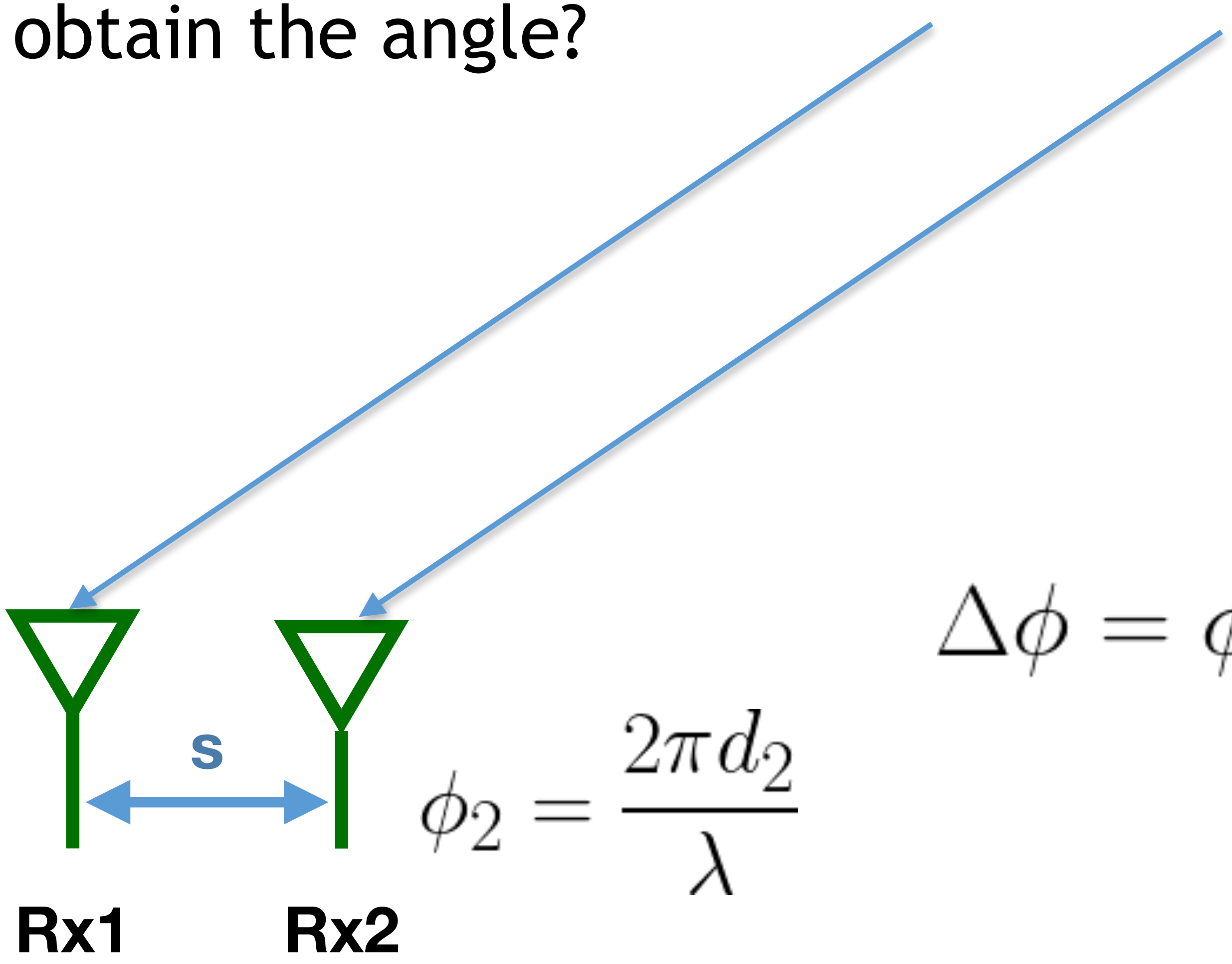


4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

How can we obtain the angle?

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



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

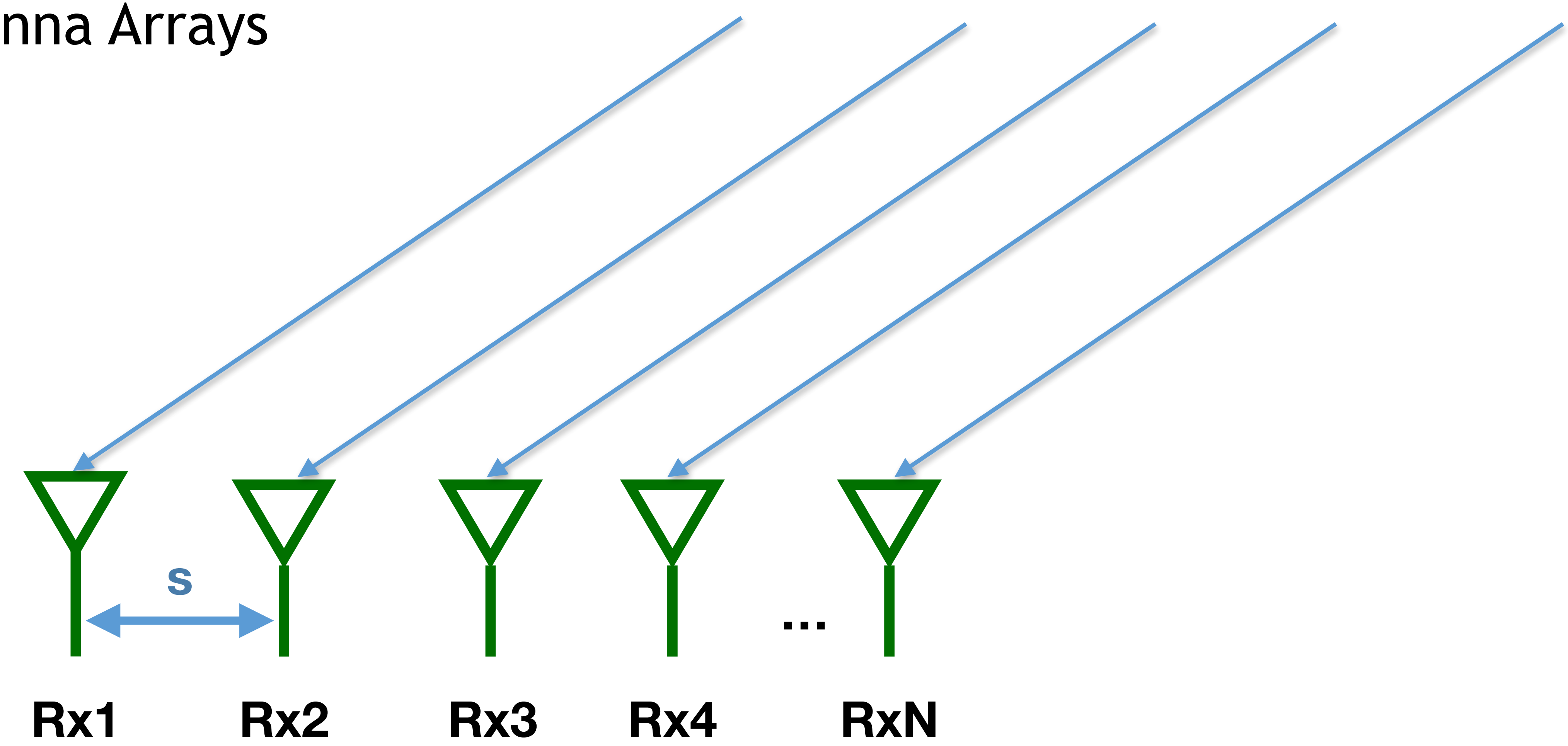
$$\Delta\phi = \phi_1 - \phi_2 = \frac{2\pi s \cos\theta}{\lambda}$$

Issues?

4) Use Angle of Arrival (AoA)

Triangulation from Angular Measurements

Use Antenna Arrays



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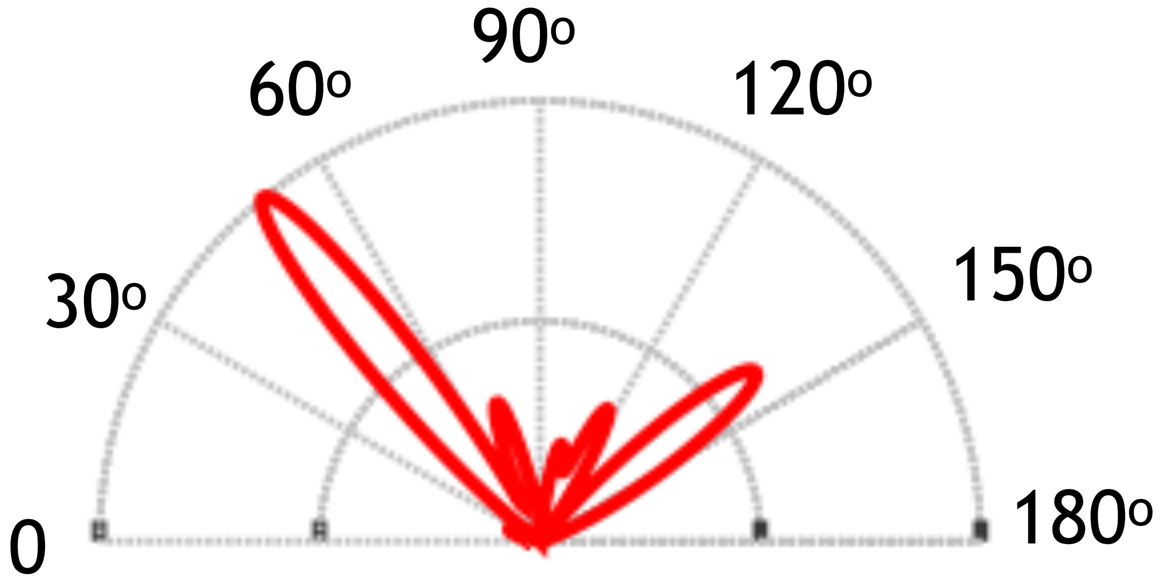
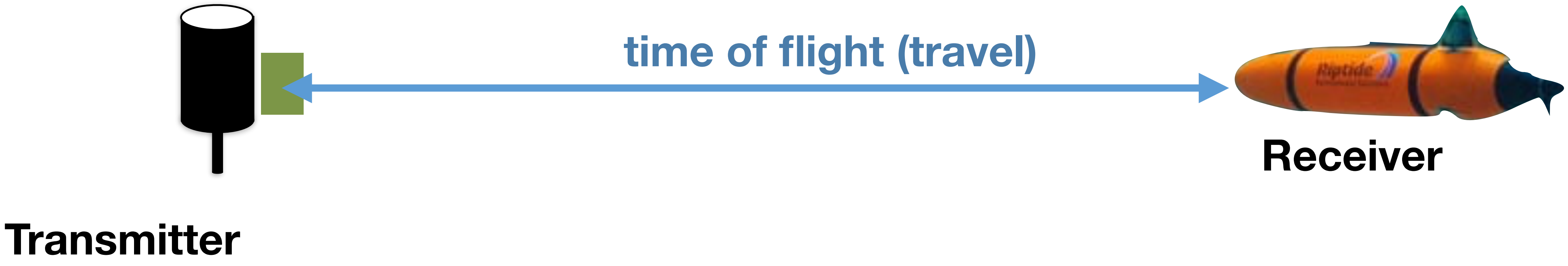


How do we know which direction corresponds to the direct path?

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

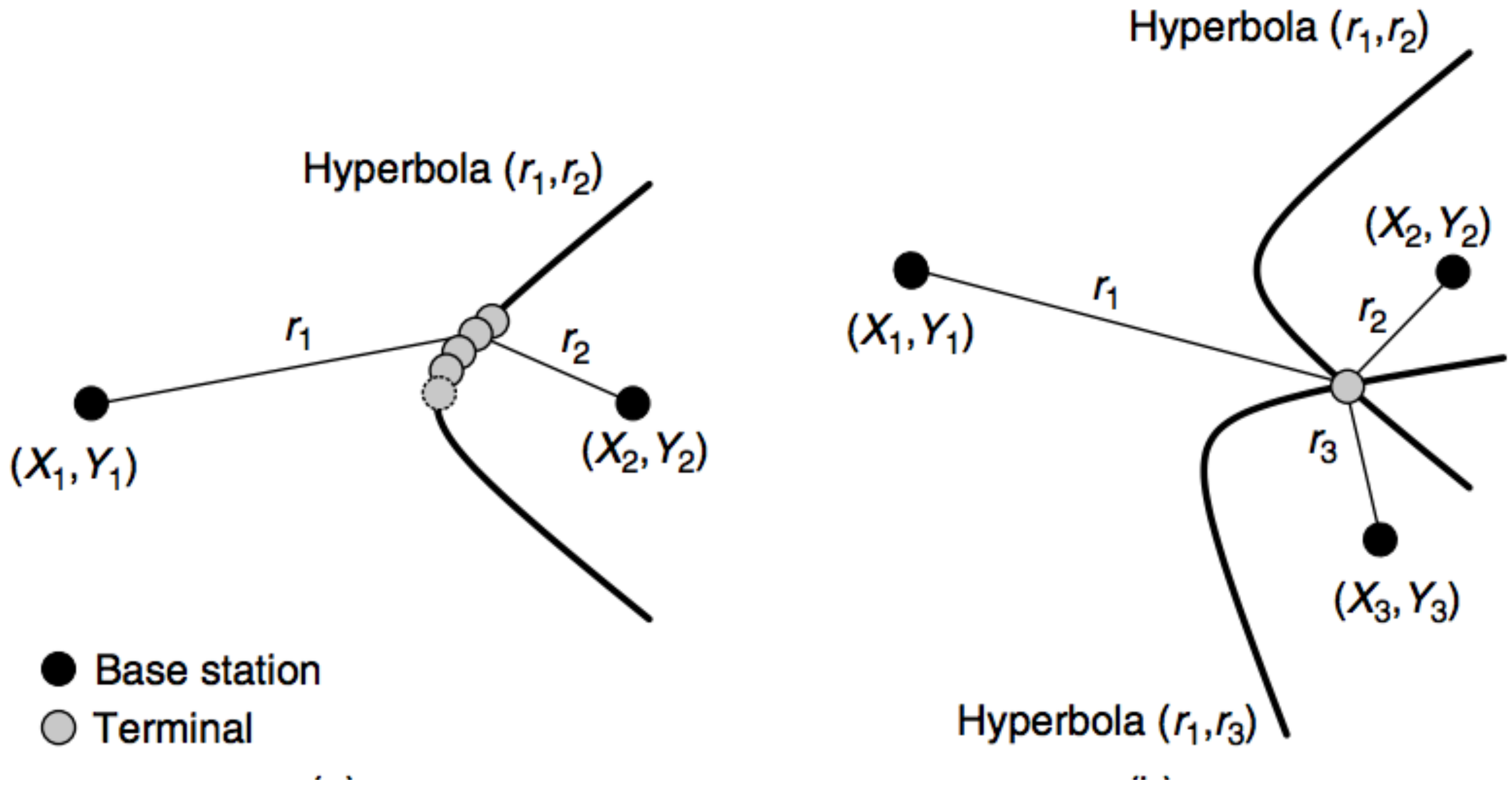


Distance = Time of flight x speed of travel

Can use trilateration (intersection circles/spheres)

How do we know when the signal was transmitted?

6) Time-difference-of-arrival (TDoA)



Names of the Existing Systems

Baseline (difference between anchor nodes)

1. Long Baseline (LBL)	anchors are deployed and separated
2. Short baseline (SBL)	anchors are on ship, separated by a bit
3. Ultra-short baseline (USBL)	anchors are tightly close to each other (on ship)

Challenges?

- Multipath
- Channel changes quickly
- Temperature and conductivity change speed
- Doppler shift

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

- **Summary:**
  - Most of you wrote good summaries
  - A missing element from most reviews is **<u>context</u>** in terms of "**<u>what was new</u>**" in this paper?
    - Some said the paper proposed a new system/ technology: piUSBL. Is this true?
    - Some focused more on the system and less on the evaluation (1 sentence for evaluation+results), which is as important. Remember, the summary should cover the whole paper.

Feedback on reviews

- Pros/Cons:
  - Remember you're not reviewing the "English" but the scientific research
    - Don't make them about typos/writing style/clarity, e.g., abstract or future work. Make them about the system itself - look at lecture 1.
  - Itemize them, include 2-4 full-sentences as a bulleted list describing the pros and cons
  - Think **in-depth** about the pros and cons of the paper

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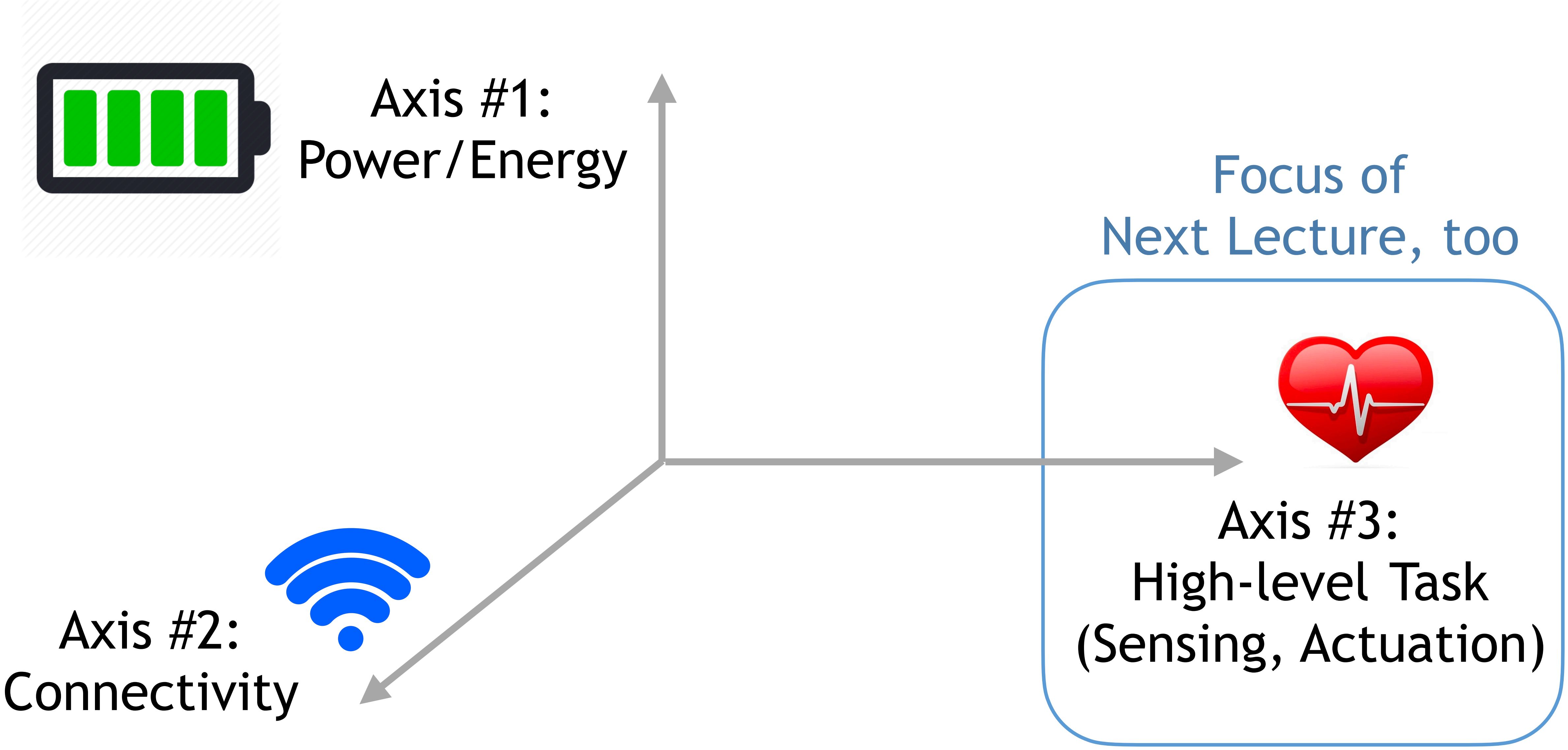
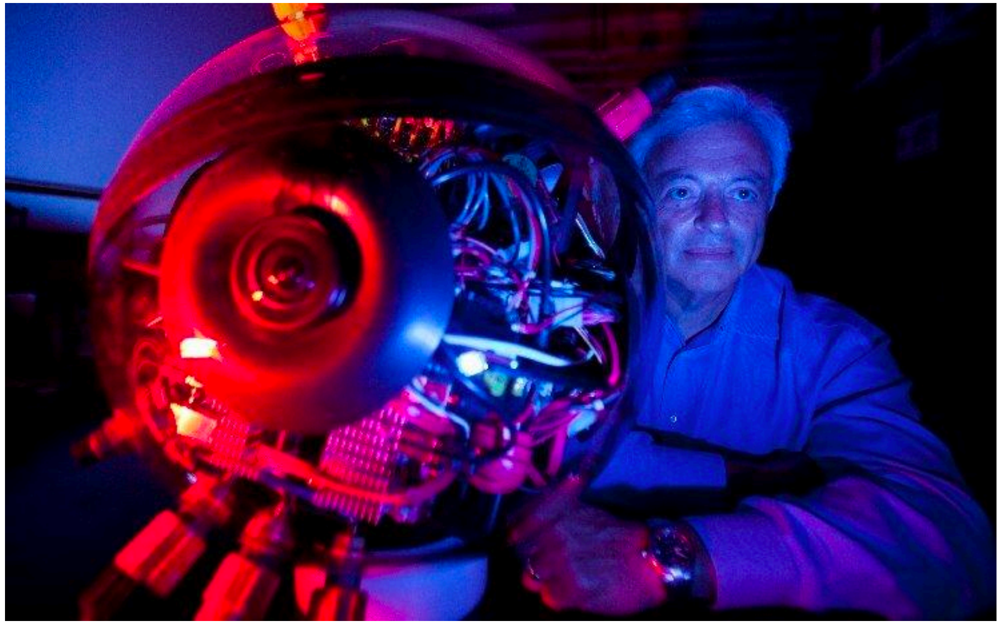


Next Class: Underwater Imaging

1) Required

- Underwater dual-magnification imaging for automated lake plankton monitoring (Typical Review required)
- Underwater Optical Imaging: The Past, the Present, and the Prospects, IEEE JOE 2014 (Think about how you might review a "review" paper)



Dr. Jules Jaffe, UCSD Scripps

2) Optional

- UWStereoNet: Unsupervised Learning for Depth Estimation and Color Correction of Underwater Stereo Imagery, ICRA 2020
- Visual tracking of deepwater animals using machine learning-controlled robotic underwater vehicles, WACV 2021
- An Optical Imaging System for Capturing Images in Low-Light Aquatic Habitats Using Only Ambient Light, DIY Oceanography, 2020