CSE 162 Mobile Computing

Lecture 12: Localization

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An introduction to localization

What is localization?

- Get the location of a mobile device
  - Some devices, e.g., cell phones, are a proxy of a person’s location
- Get the location of wireless signal source
  - Wireless emitter
- Used to help derive the context and activity information
  - Location based services
  - Privacy problems

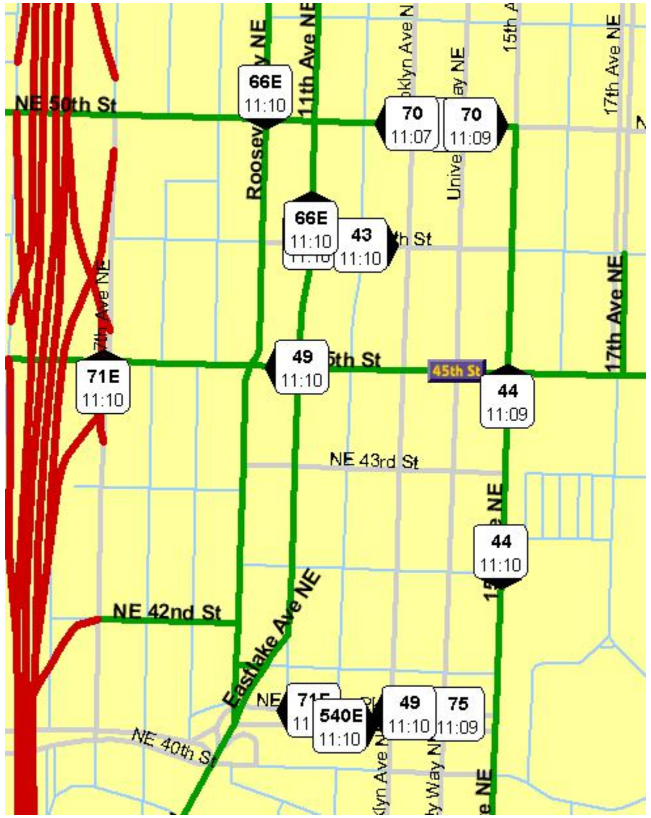
Localization

- Well studied topic (3,000+ PhD theses??)
- Application dependent
- Research areas
  - Technology
  - Algorithms and data analysis
  - Evaluation

Representing Location Information

- Absolute
  - Geographic coordinates (Lat: 33.98333, Long: -86.22444)
- Relative
  - 1 block north of the main building
- Symbolic
  - Home, road, bedroom, work

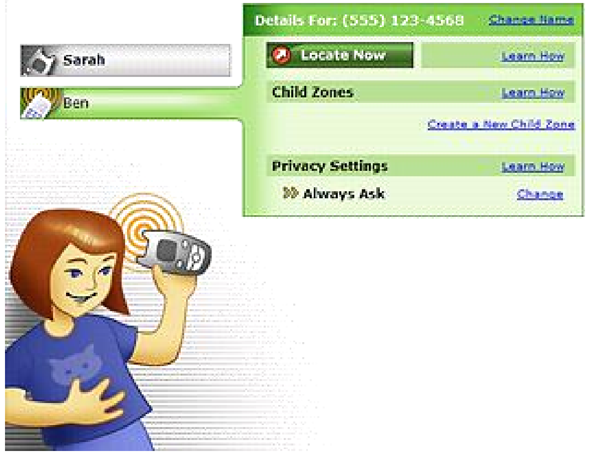
Some outdoor applications



Bus view

E-911

Car Navigation



Child tracking

Some indoor applications

Elder care

Indoor navigation:
mall, airport, museum, etc

Contact Tracing

No one size fits all!

- Accurate
- Low-cost
- Easy-to-deploy
- Ubiquitous

- Application needs determine technology

Lots of technologies!

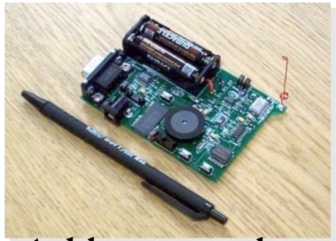
GPS

WiFi Beacons

Ultrasound

Floor pressure

VHF Omni Ranging



Ad hoc signal strength

Laser range-finding

Stereo camera

Ultrasonic time of flight

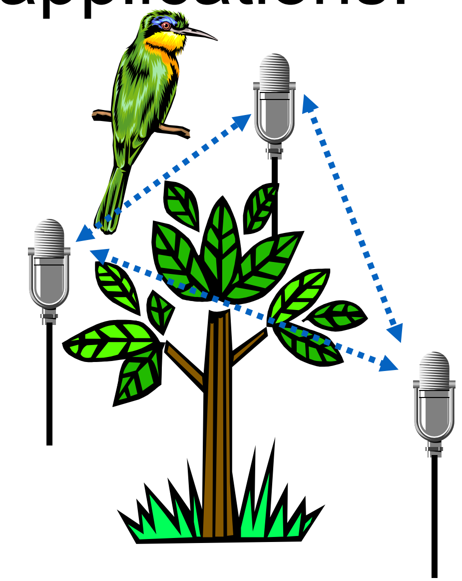
Infrared proximity

Array microphone

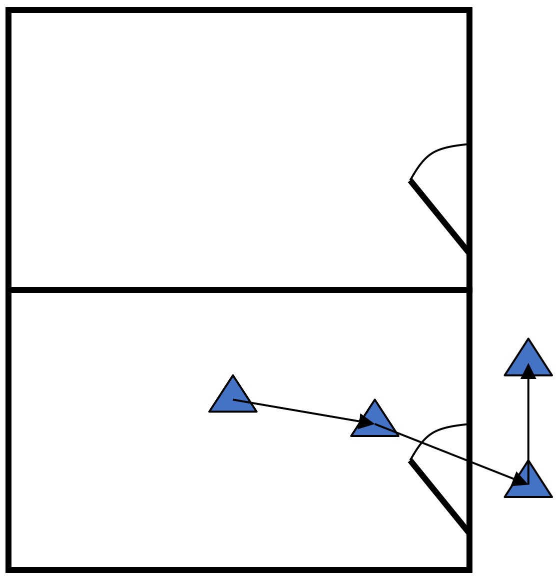
Localization Applications Design Principles

Variety of Applications

- Two applications:



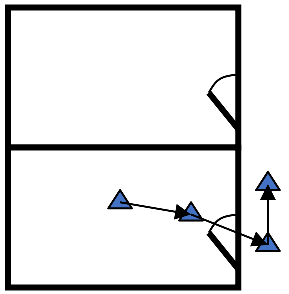
habitat monitoring:
Where is the bird?
What kind of bird is it?



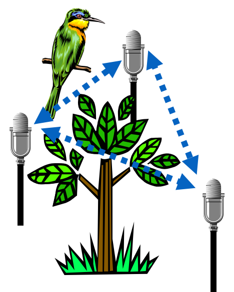
Asset tracking:
Where is the projector?
Why is it leaving the room?

Variety of Application Requirements

- Very different requirements!



- Outdoor operation
  - Weather problems
- Bird is not tagged
- Birdcall is characteristic but not exactly known
- Accurate enough to photograph bird
- Infrastructure:
  - Several acoustic sensors, with known relative locations; coordination with imaging systems



- Indoor operation
  - Multipath problems
- Assets are tagged
- Signals from asset tags can be engineered
- Accurate enough to track through building
- Infrastructure:
  - Room-granularity tag identification and localization; coordination with security infrastructure

Multidimensional Requirement Space

- Granularity & Scale
- Accuracy & Precision
- Relative vs. Absolute Positioning
- Dynamic vs. Static (Mobile vs. Fixed)
- Cost & Form Factor
- Infrastructure & Installation Cost
- Environmental Sensitivity
- Cooperative or Passive Target

Axes of Application Requirements

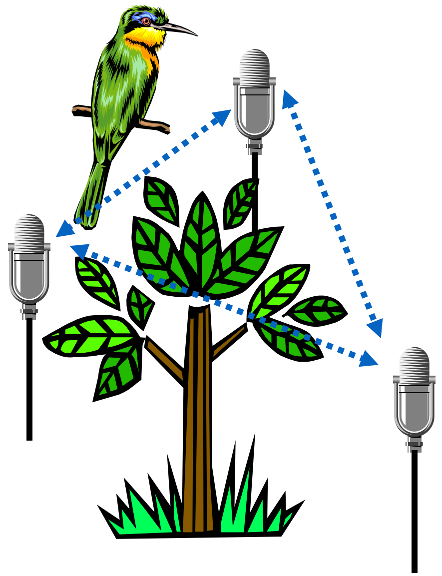
- Granularity and scale of measurements:
  - What is the smallest and largest measurable distance?
  - e.g. 50m (acoustics) vs. 25000km (GPS)
- Accuracy and precision:
  - How close is the answer to “ground truth” (accuracy)?
  - How consistent are the answers (precision)?
- Relation to established coordinate system:
  - GPS? Campus map? Building map?
- Dynamics:
  - Refresh rate? Motion estimation?

Axes of Application Requirements

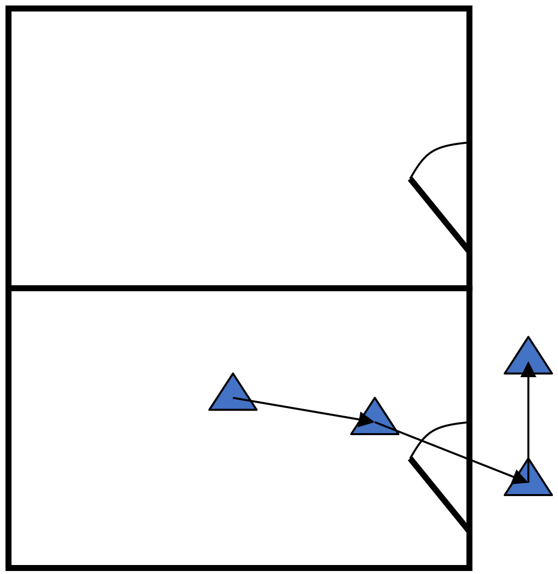
- Cost:
  - Node cost: Power? $? Time?
  - Infrastructure cost? Installation cost?
- Form factor:
  - How big
  - Think about tracking tags on wild animals
- Communications Requirements:
  - Network topology: cluster head vs. local determination
  - What kind of coordination among nodes?
- Environment:
  - Indoor? Outdoor? On Mars?
- Is the target known? Is it cooperating?

Returning to our two Applications…

- Choice of mechanisms differs:



Passive habitat monitoring:
Minimize environ. interference
No two bird songs are the same



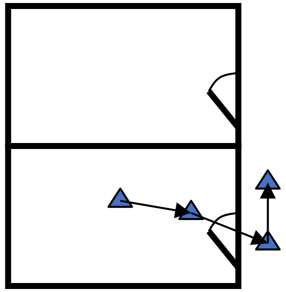
Asset tracking:
Controlled environment
We know exactly what tag is like

Variety of Localization Mechanisms

- Very different mechanisms indicated!

- Bird is not tagged
  - Passive detection of bird presence
- Birdcall is characteristic but not exactly known
- Bird does not have radio; Acoustic based ranging
- Passive target localization
  - Requires
    - Sophisticated detection
    - Coherent beamforming
    - Large data transfers

- Asset is tagged
  - Projector might know it had moved
- Signals from asset tag can be engineered
- Tag can use radio signal for ranging
- Cooperative Localization
  - Requires
    - Basic correlator
    - Simple triangulation
    - Minimal data transfers



Wireless Technologies for Localization

Name	Effective Range	Pros	Cons
GSM	35km	Long range	Very low accuracy
LTE	30km-100km		
Wi-Fi	50m-100m	Readily available; Medium range	Low accuracy
Ultra Wideband	70m	High accuracy	High cost
Bluetooth	10m	Readily Available; Medium accuracy	Short range
Ultrasound	6-9m	High accuracy	High cost, not scalable
RFID & IR	1m	Moderate to high accuracy	Short range, Line-Of-Sight (LOS)
NFC	<4cm	High accuracy	Very short range

Localization Algorithms

Algorithms to obtain locations

- Range-based algorithms
- Range-free algorithms
- Fingerprinting

Range Based Algorithms

- Rely on the distance (angle) measurement between nodes to estimate the target location
- Approaches
  - Proximity
  - Lateration
  - Hyperbolic Lateration
  - Angulation
- Distance estimates
  - Time of Flight
  - Signal Strength Attenuation

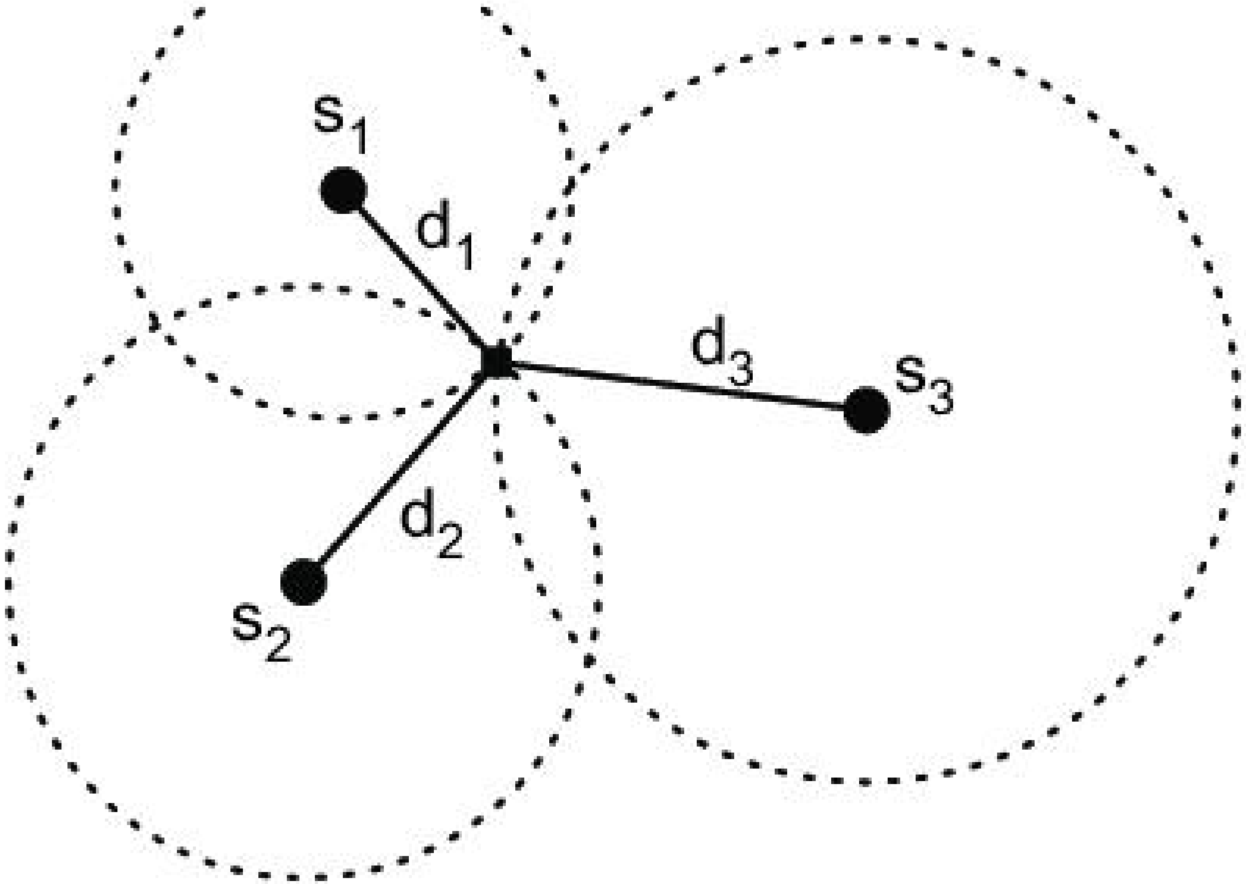
Approach: Proximity

- Simplest positioning technique
- Closeness to a reference point
- Based on loudness, physical contact, etc

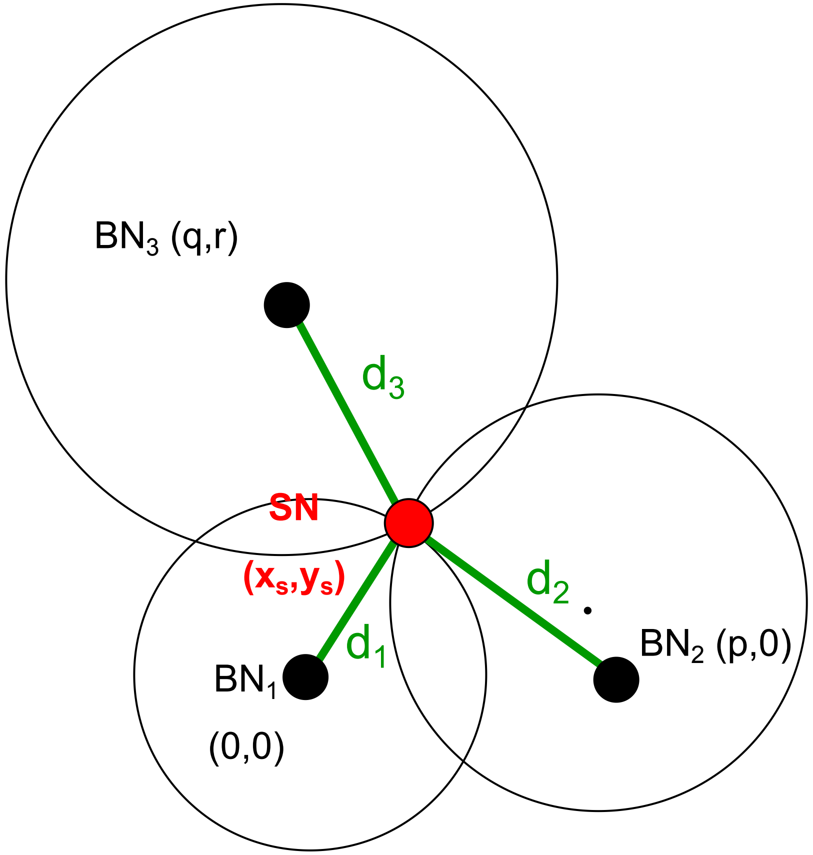
- Examples
  - RFID Door Access Control System

Approach: Lateration

- Method: Measure distance between device and reference points
  - s1, s2, s3 locations are known
  - Measure the distances d1, d2, and d3
  - Search for the most-likely location given the distances
- 3 reference points needed for 2D and 4 for 3D



- Assuming accurate distance measurements between nodes, apply the trilateration technique to determine the SN coordinates (unknown) using the three BNs coordinates and the r distances.
- Without loss of generality, let the cooridnates of the references be (0,0),(0,p),(q,r)



By definition:

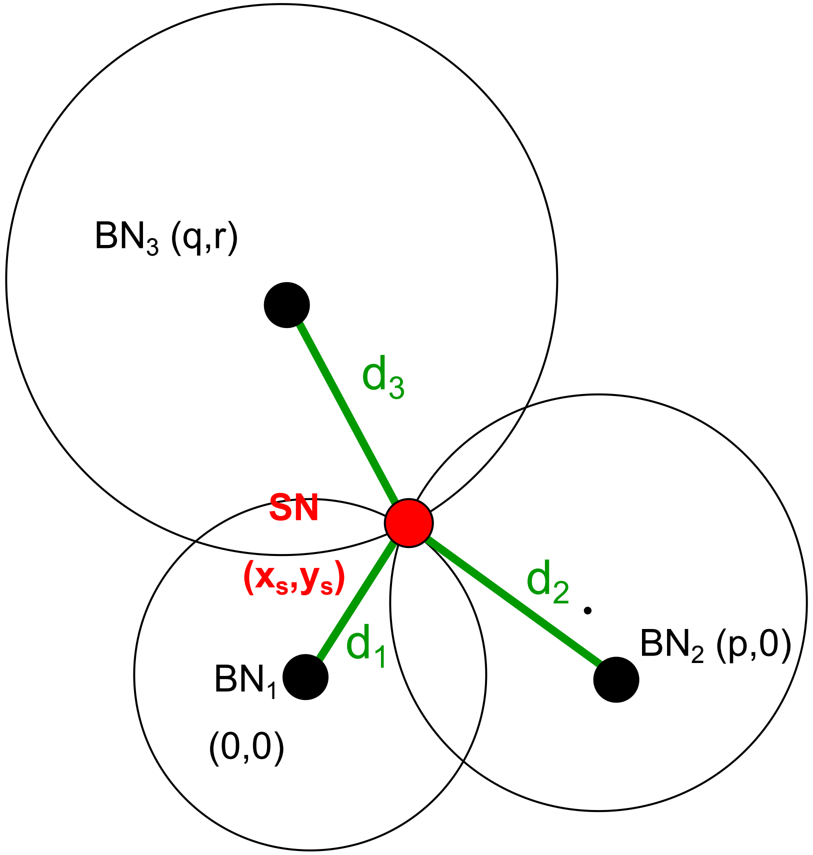
$$d_1^2 = x^2 + y^2$$
$$d_2^2 = (x-p)^2 + y^2$$
$$d_3^2 = (x-q)^2 + (y-r)^2$$

- By subtracting the second equation from the first, ***x*** is attained.

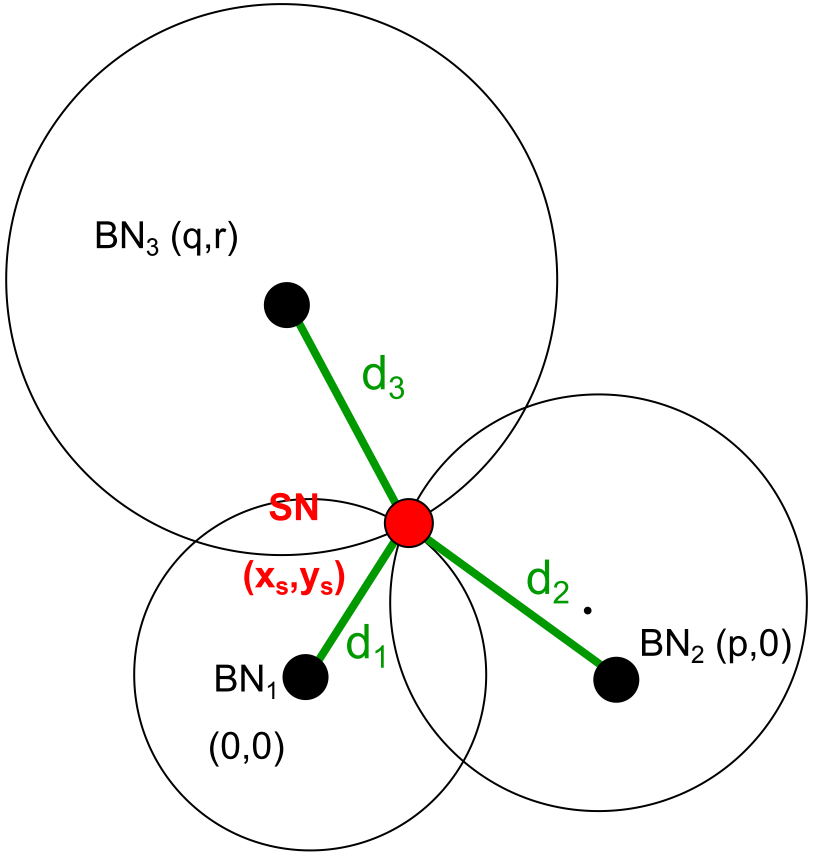
$$x = \frac{d_1^2 - d_2^2 + p^2}{2p}$$

- Substituting this value back into the first equation will result in values for ***y***.

$$y = \pm\sqrt{d_1^2 - \left(\frac{d_1^2 - d_2^2 + p^2}{2p}\right)^2}$$



To determine which value of ***y*** correctly describes the point in question, ***x*** and ***y*** are substituted into the third equation.



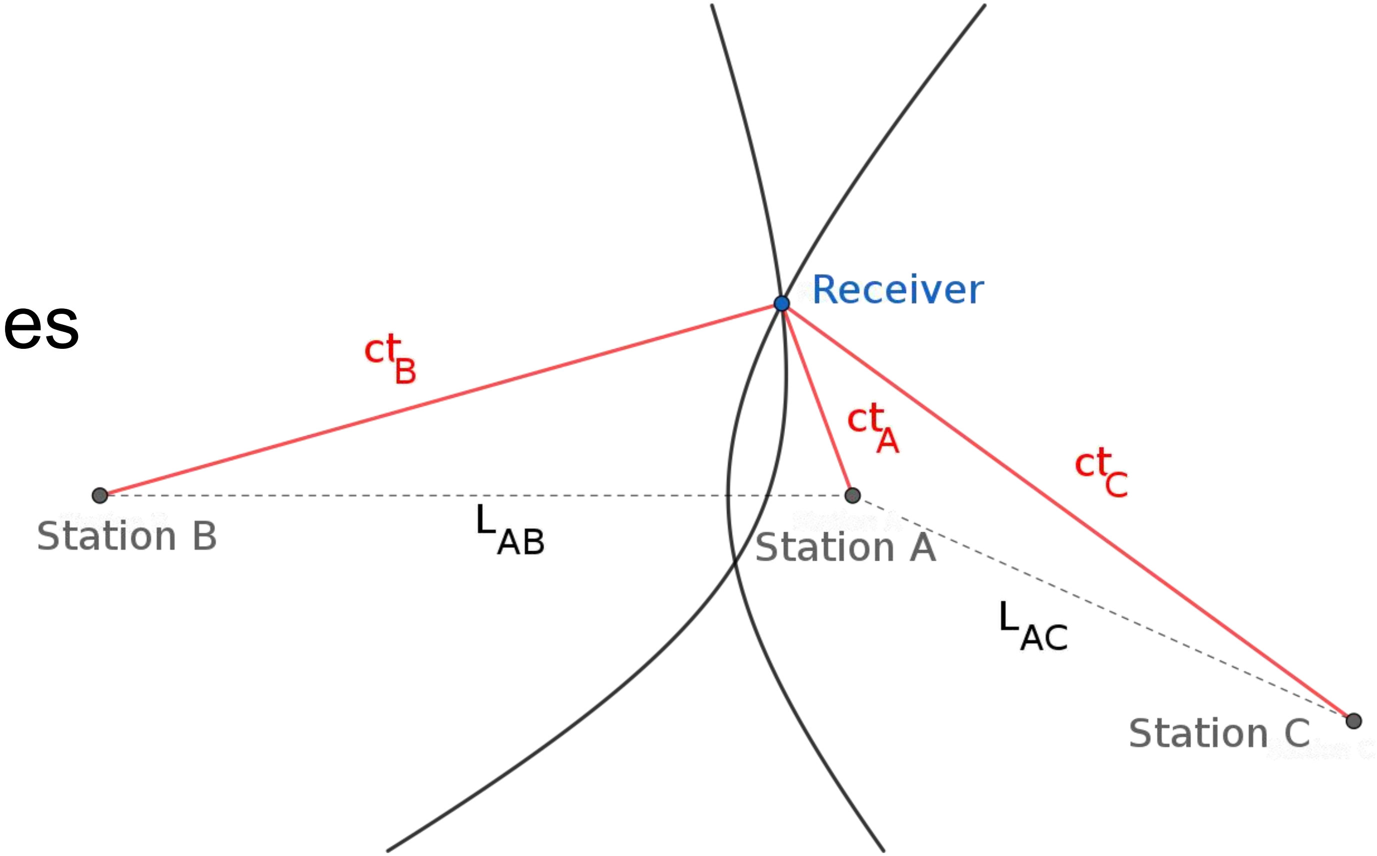
Approach: Hyperbolic Lateration

- Known: Station A, B, C locations

- Unknown: The signal traveling times to the receiver: ct_A, ct_B, ct_C

- Known: $ct_A - ct_B, ct_A - ct_C,$ $ct_B - ct_C$

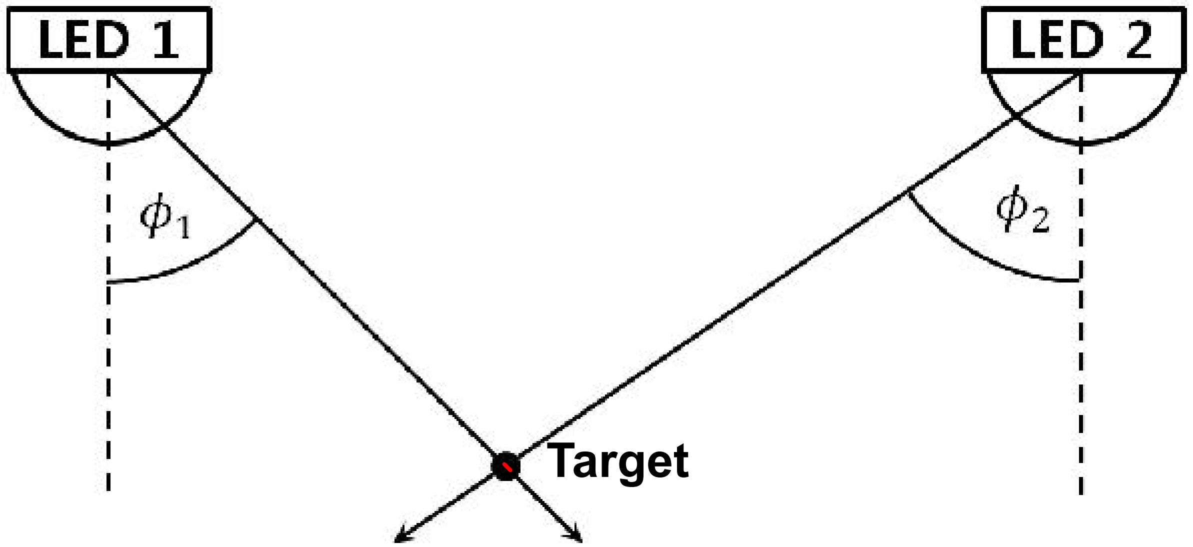
- Each time difference locates the receiver on a branch of a hyperbola



Approach: Triangulation

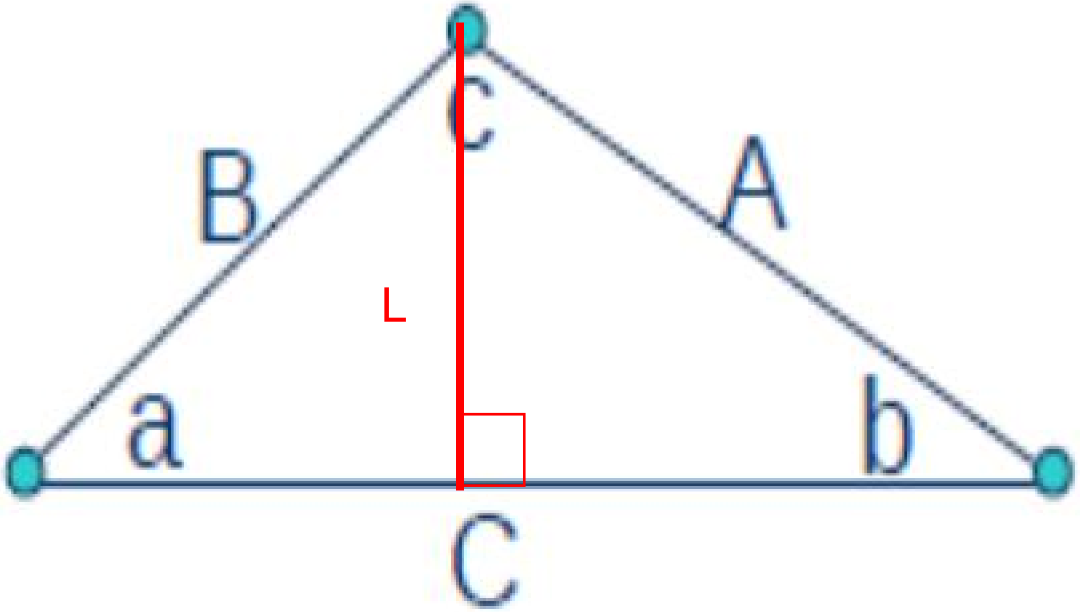
- Use the location of the signal sources and the relative angles
- Uniquely identify the location of the target

- How to do it mathematically?



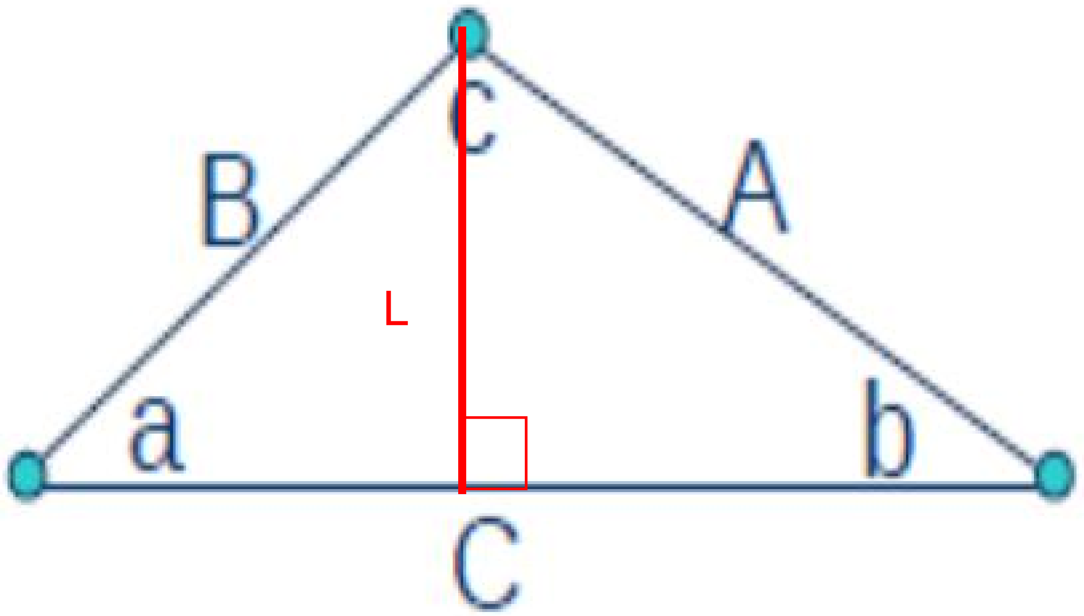
Question

- Angles a and b are known. Distance C is known.
- What is L?



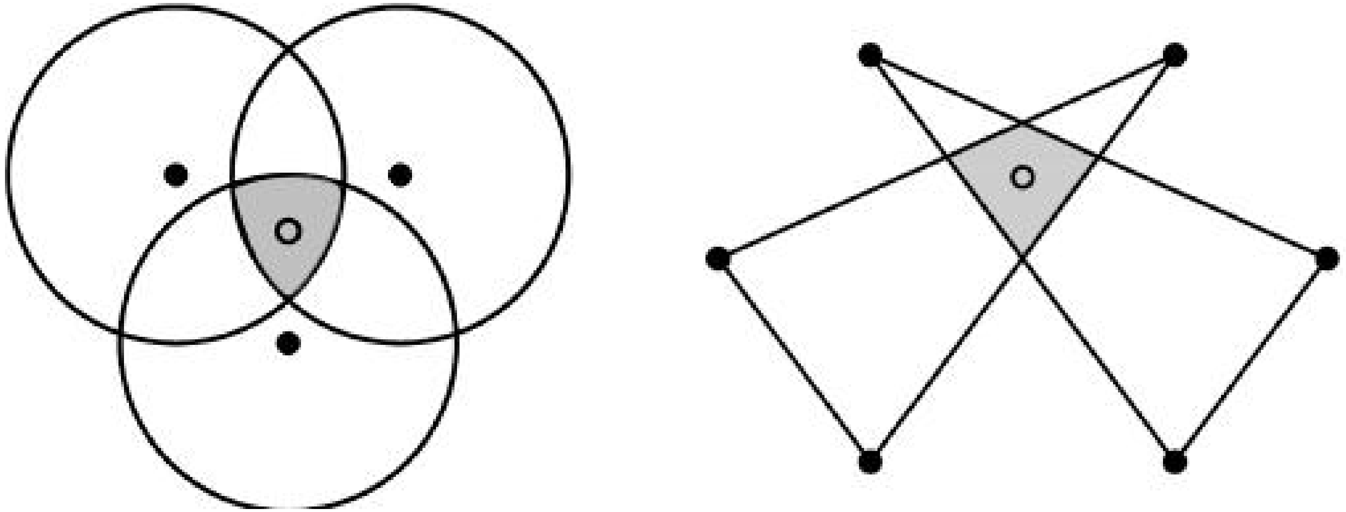
Question

- L/tan(a)+L/tan(b)=C
- L=C/(1/tan(a)+1/tan(b))



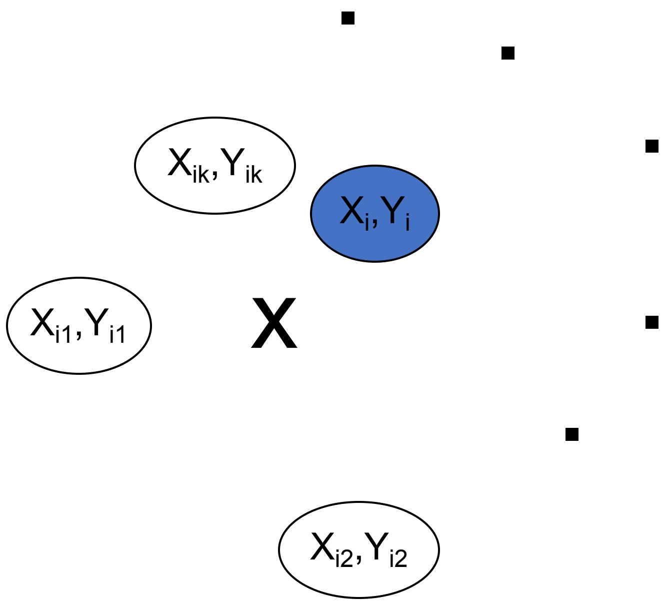
Range Free Algorithms

- Rely on target object's proximity to anchors with known positions
  - Neighborhood: single/multiple closest BS
  - Area estimation:



Range-free Localization Techniques
Centroid Algorithm

- Nodes localize themselves to the centroid of their proximate reference points



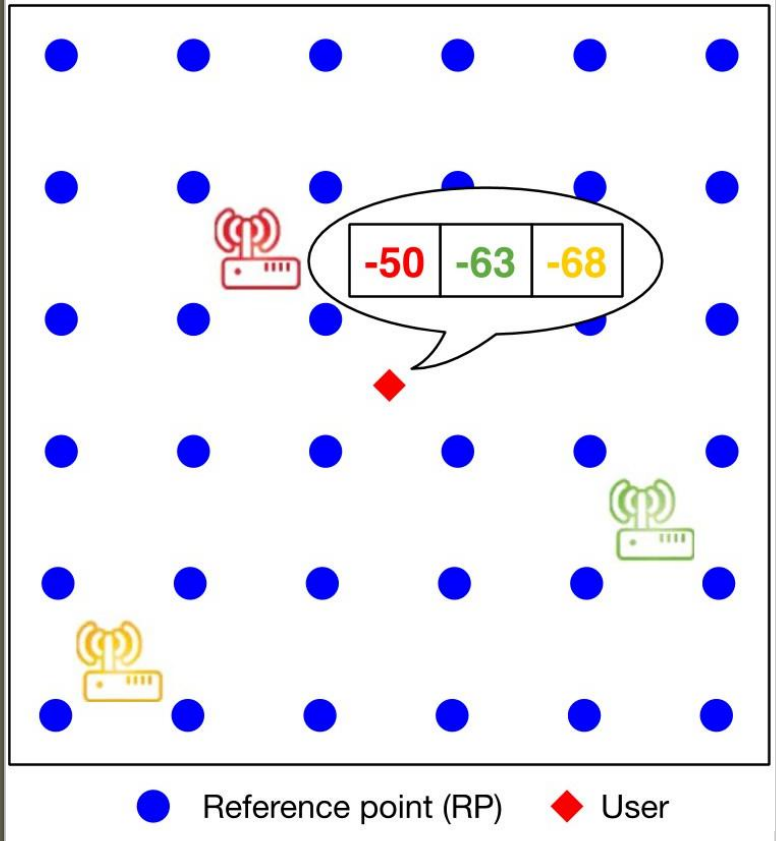
$$(X_{est},Y_{est})=\left(\frac{X_{i1}+\ldots+X_{ik}}{k},\frac{Y_{i1}+\ldots+Y_{ik}}{k}\right).$$

Fingerprinting

- Mapping solution
- Address problems with multipath
- Better than modeling complex RF propagation pattern

Fingerprinting: Steps

- Step1
  - Use war-driving to build up location fingerprints (i.e. location coordinates + respective RSSI from nearby base stations)
- Step2
  - Match online measurements with the closest *a priori* location fingerprints



Fingerprinting: Example

SSID (Name)	BSSID (MAC address)	Signal Strength (RSSI)
linksys	00:0F:66:2A:61:00	18
starbucks	00:0F:C8:00:15:13	15
newark wifi	00:06:25:98:7A:0C	23

Fingerprinting: Pros and Cons

- Pros
  - Physical model not required
- Cons
  - Requires a dense site survey
- Prerequisite:
  - Spatial differentiability
  - Temporal stability

Concluding Remarks
Pros and Cons

- Two main types of distributed localization algorithms:
  - Range-based
    - Estimating the coordinates based on the collected information of distances or angles among nodes
    - Merit: Relatively high accuracy
    - Drawback: Costly (Hardware, Power consumption)
  - Range-free
    - Estimating the coordinates based on the connectivity relations
    - Merit: Cost-effective
    - Drawback: Not as accurate (But: coarse accuracy is sufficient for some applications)

Hardware/Energy Cost vs Location Precision

Summary of Localization Algorithms

	Measurement Scheme	Accuracy	Special Requirement
Range-based	TOA	Moderate	Synchronization, dense beacons
	TDOA	High	Synchronization, LOS, dense beacons
	AOA	High	Directional antenna
	RSSI	Moderate	No
Range-free	Neighborhood	Low	No
	Area estimation	Moderate	Dense Beacons
Fingerprinting	RSSI	High	No