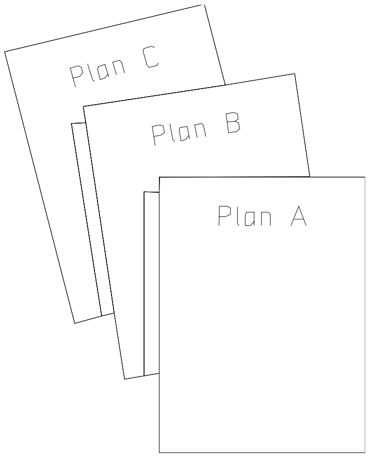
Location Sensing
(Part I)

"There will be obstacles. There will be doubters. There will be mistakes. But with hard work, there are no limits." —Michael Phelps

Overview

- Objective
  - To understand basics of localization techniques

- Content
  - Importance of location
  - Global positioning system (GPS)
  - Cell tower-based localization
  - Basics of indoor localization
  - The cricket indoor localization system

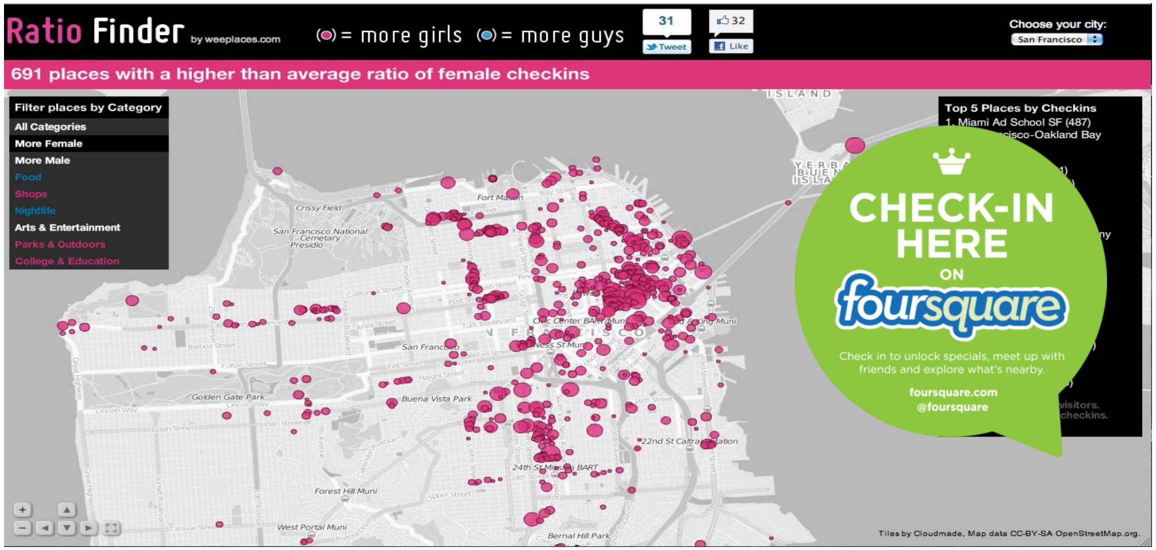


- After this module, you should be able to
  - Understand widely-used device localization techniques

Location

- The primary context of a mobile user.
- Location encodes rich amount of information.

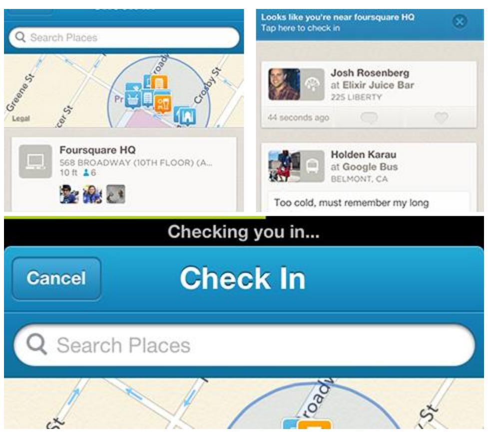
Value of Location



twitter

Example 1: Foursquare (Swarm)

- Location-based social network application
- Uses a gaming aspect
  - If a user checks in, they are awarded points and badges



Example 2: Sports Tracker

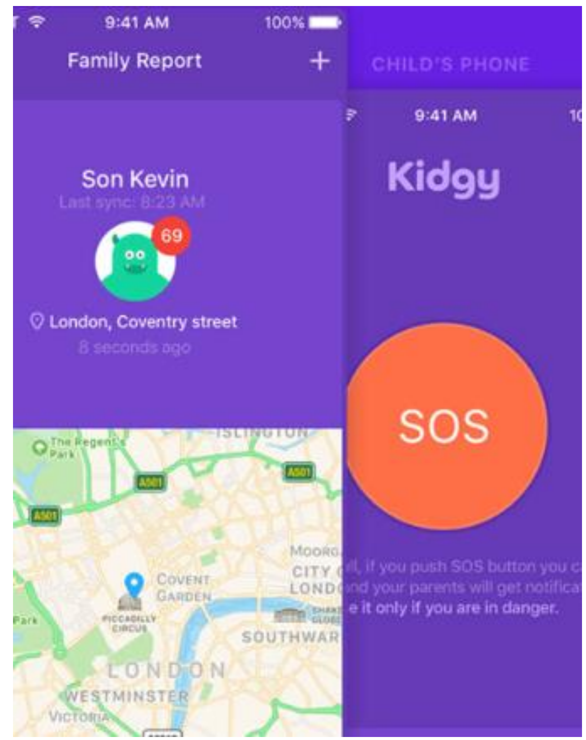
- Track the user's movement in real time
  - Record route using GPS and Google Maps
  - Estimate how many calories you've bunt
- Share their stats via social media

Example 3: Pokémon Go

- Augmented reality mobile game
- It uses the mobile device GPS to
  - Locate, capture, battle and train virtual creatures (called Pokémon)

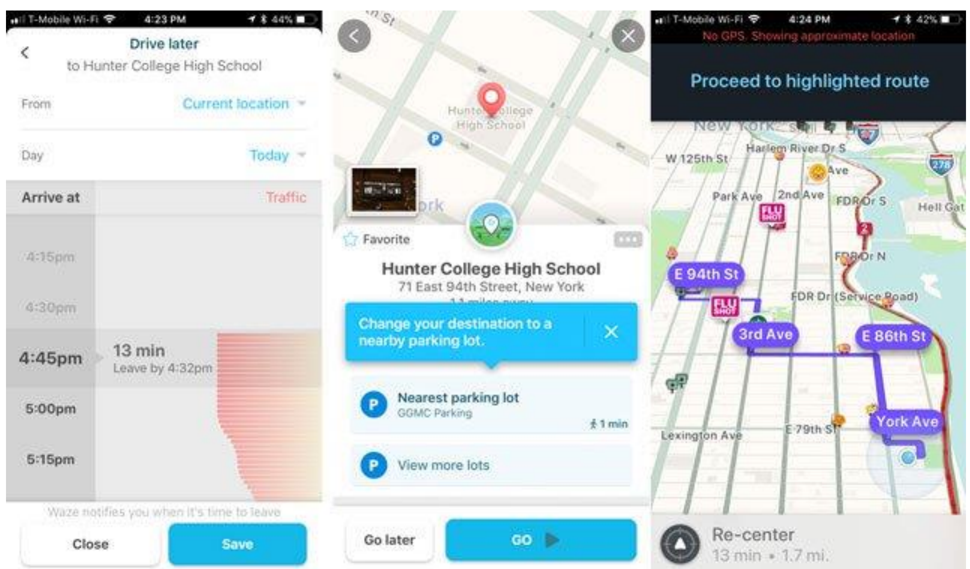
Example 4: Kidgy

- Keep track of your kids with geofencing
  - Mark specific zones on a digital map (safe, dangerous)
  - Track the child when he goes out of safe areas



Example 5: Waze

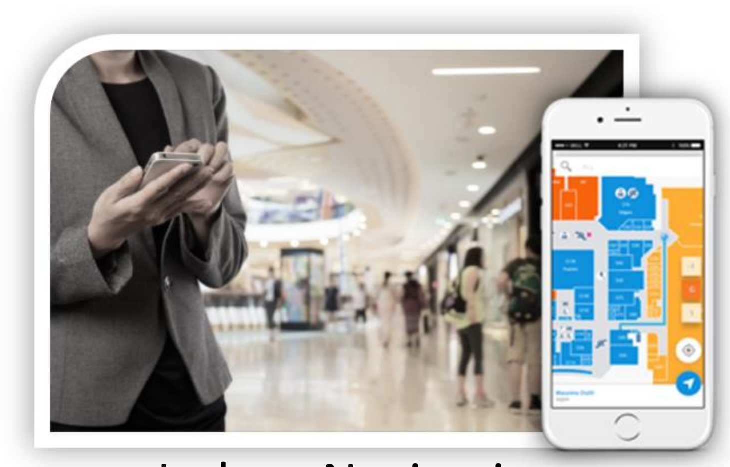
- It crowd-sources traffic information from other drivers using the app.
- Accurate, up-to-date traffic info and good rerouting to get you around severe traffic



Example 6: Urban Planning and Operation

- Capture traffic flows, taxi/bus demands, driver habits, micro events, etc. from a large collection of location data from various sources
- Use such insights to better plan and mange cities

Use Cases of Indoor Locations



- Indoor Navigation

- Space Planning

- Queue Detection

- Toilet Usage Monitoring

Device Positioning Systems:

Localization on Smartphones

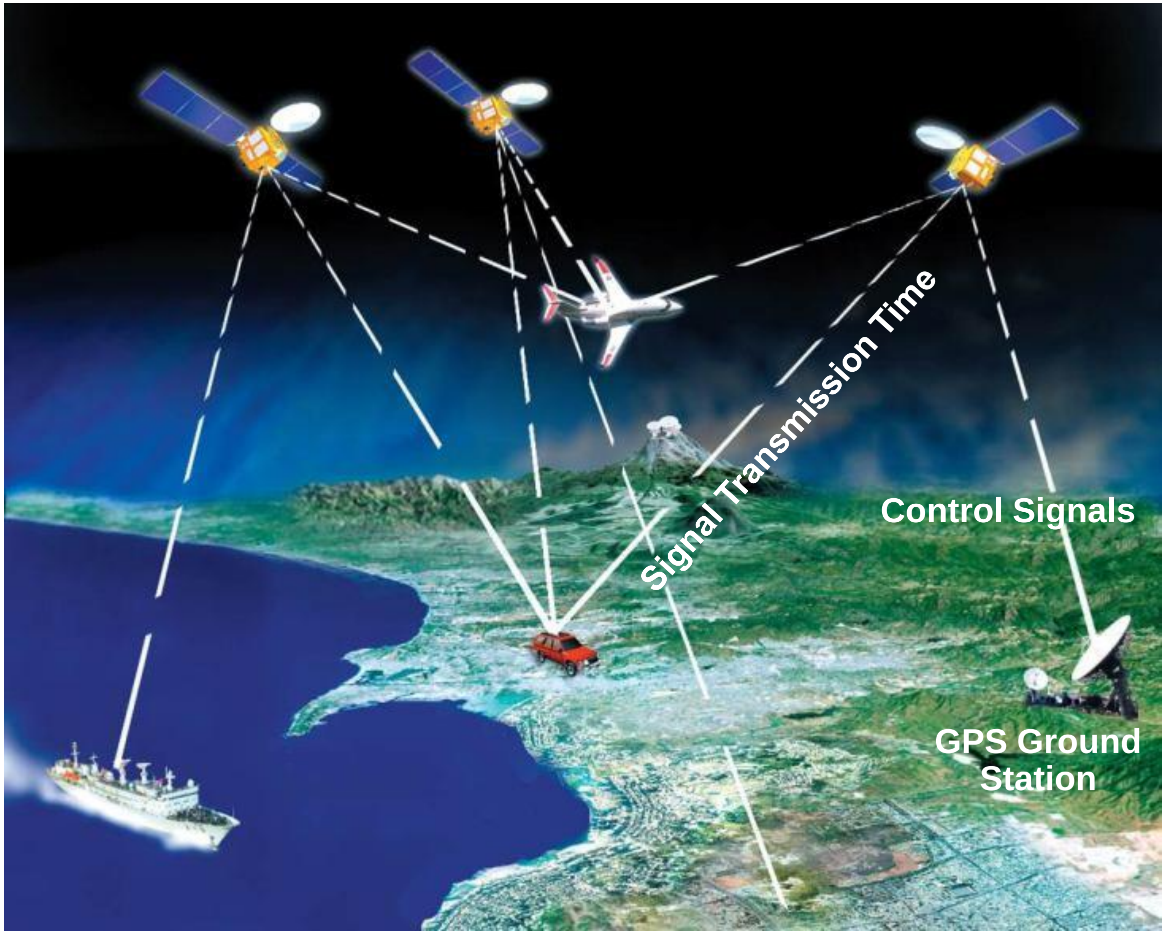
1. GPS Accuracy: 10m
2. Cellular Accuracy: 100m
3. WiFi+GPS+Cellular Accuracy: 10m-100m

Widely-deployable localization technologies have errors in the range of several meters

Where Do We Stand Today?

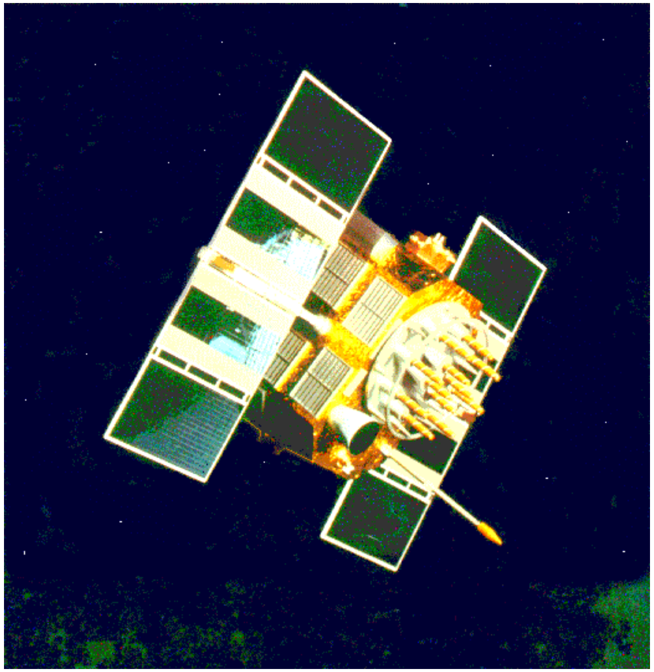
- GPS is hugely successful in cars and military.
- Cell tower-based location tracking is used for security and various analytics applications.
- Smartphones and robotics are rapidly advancing
  - Bringing new location-driven applications.
  - Bringing new challenges/opportunities in localization.

GPS: Global Positioning System



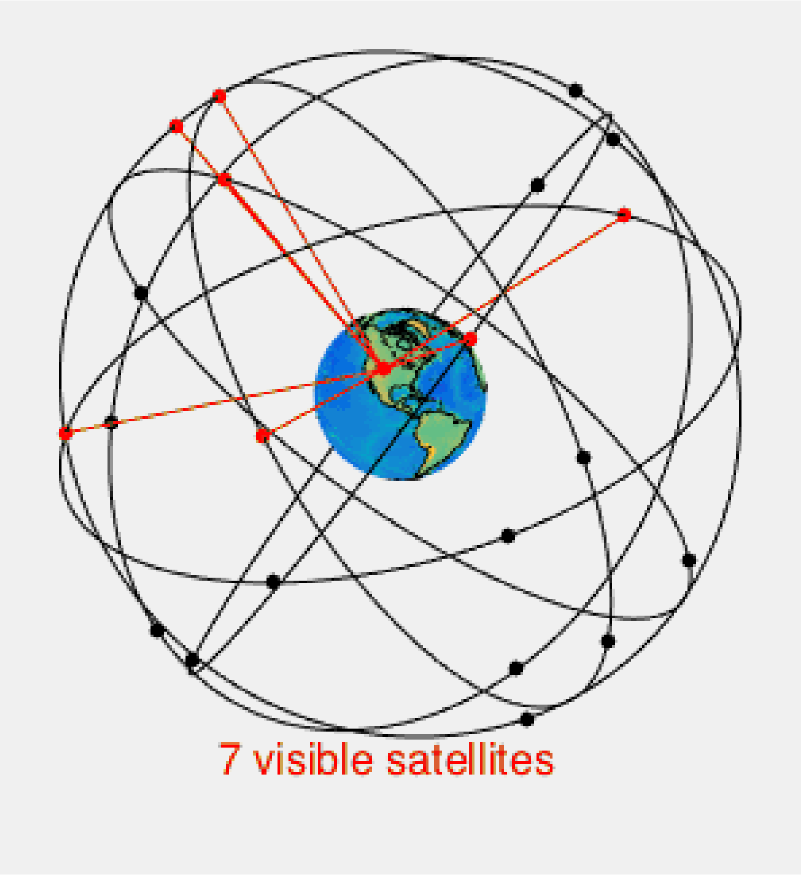
GPS Satellites = Space Vehicles (SVs)

- Solar powered
- Input signals:
  - Corrections from control stations
- Output signals:
  - X, Y, Z and t data streams sent continuously from SVs
  - L1 channel: C/A Code (Coarse Acquisition) – civil use
  - L2 channel: P-Code (Precise) – military / special licensees only

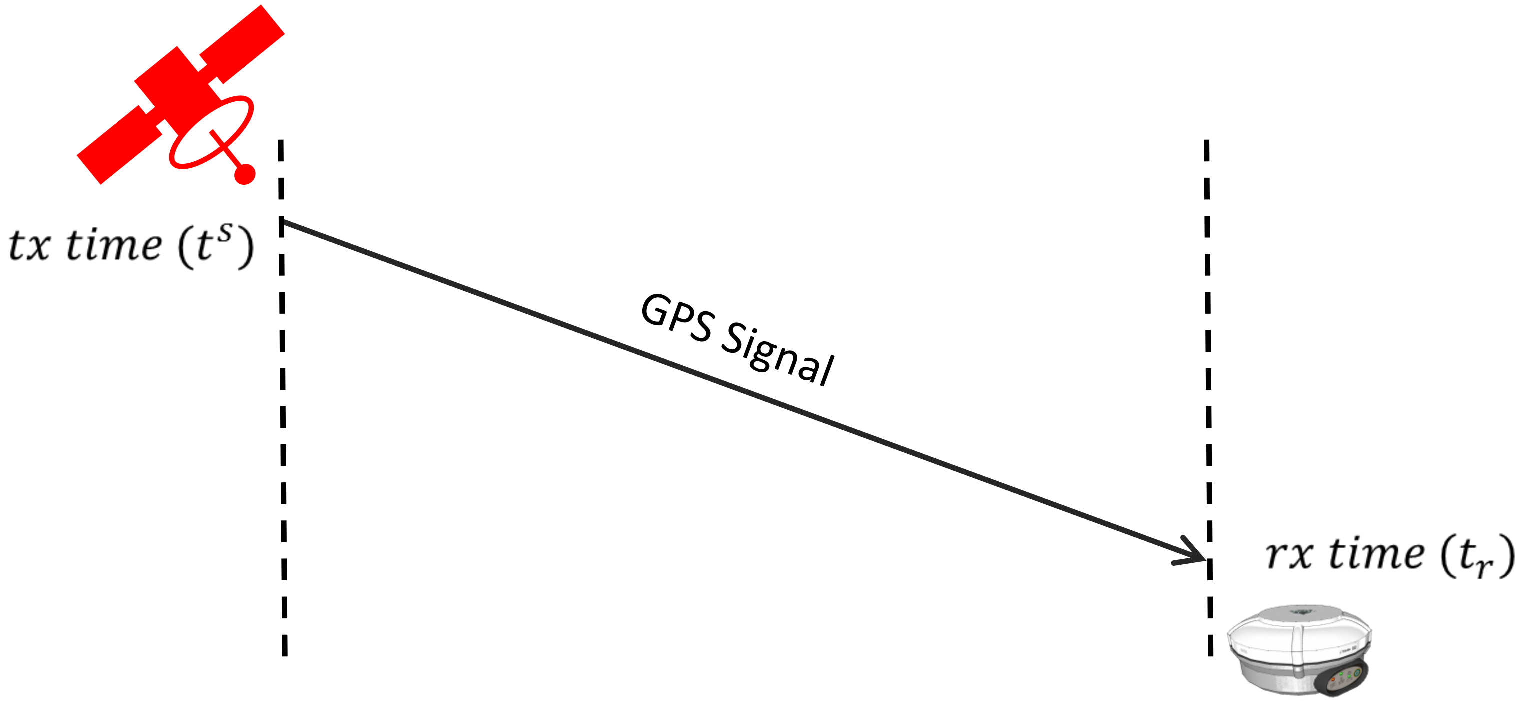


Satellite Constellation

- 24-satellite constellation
  (+3 backup=27)
- Elevation 12,000 mi
- 2 orbits/day (each)
- Six orbital planes:
  - 55° inclination from equator
  - 60° spacing about poles
  - 4 SVs/plane

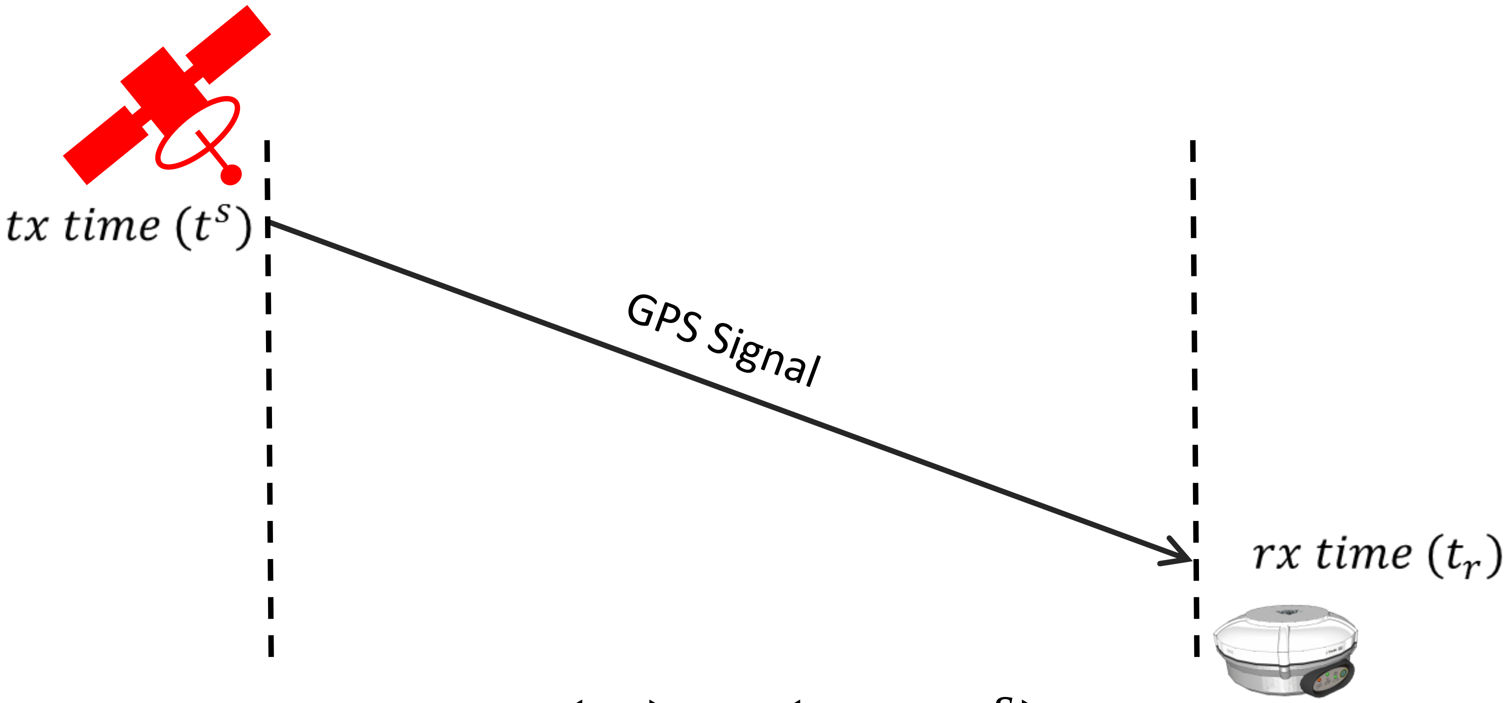


Basic GPS Localization



- Courtesy: Prof. Romit Roy Choudhury (UIUC)

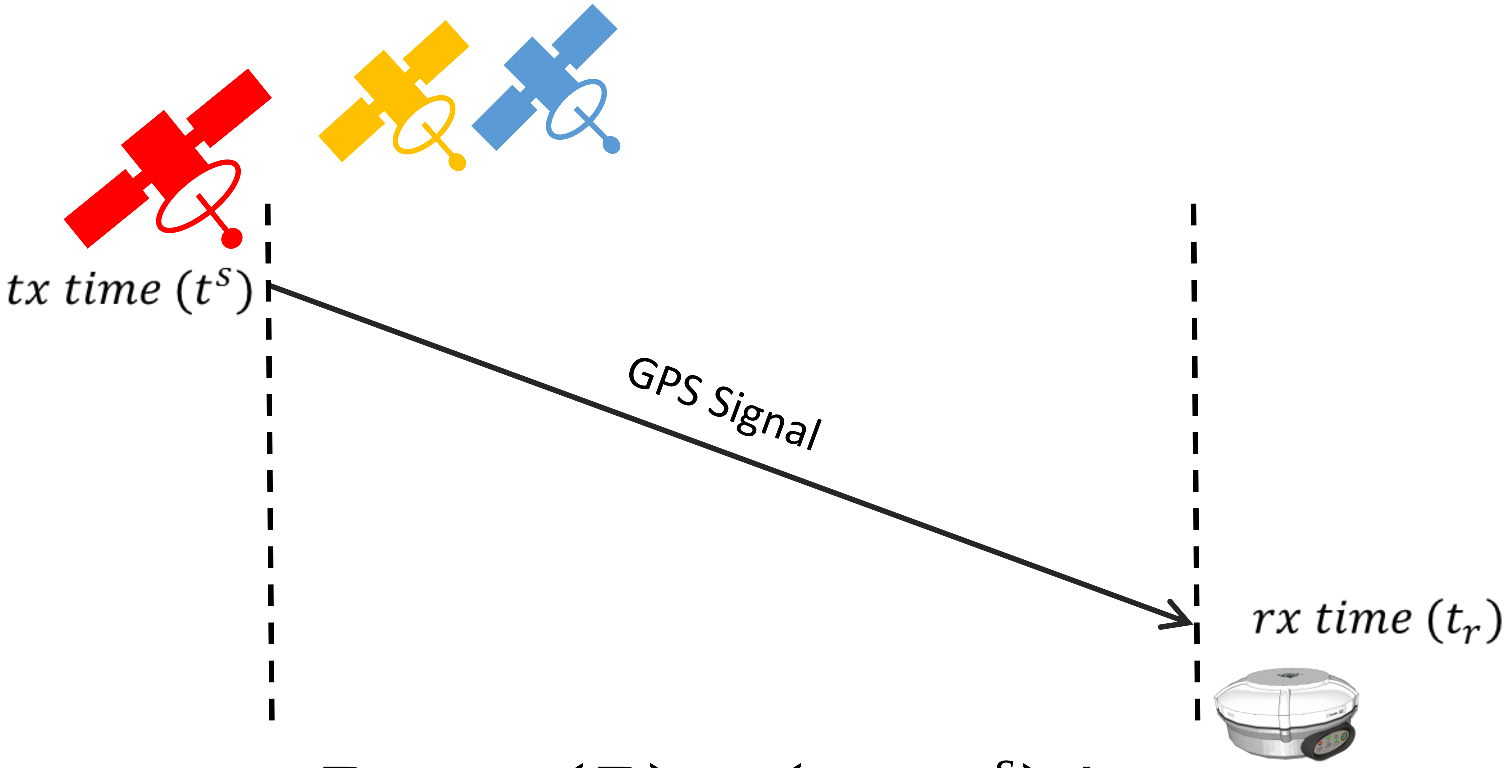
Basic GPS Localization



$$Range(R) = (t_r - t^s) * c$$

However, 3D location needs 3 equations … hence, use 3 satellites

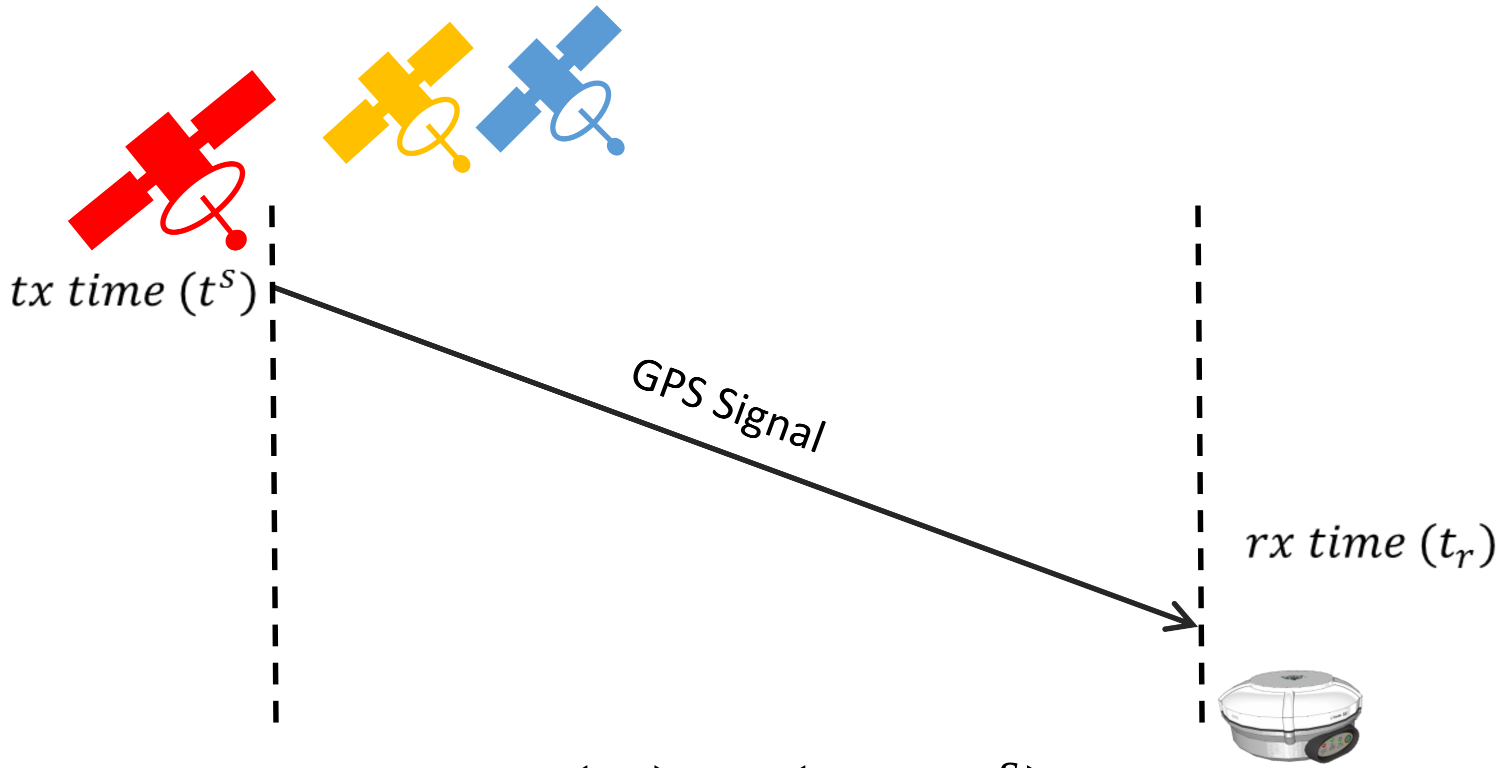
Basic GPS Localization



$$Range(R) = (t_r - t^s) * c$$

However, 3D location needs 3 equations … hence, use 3 satellites

Basic GPS Localization



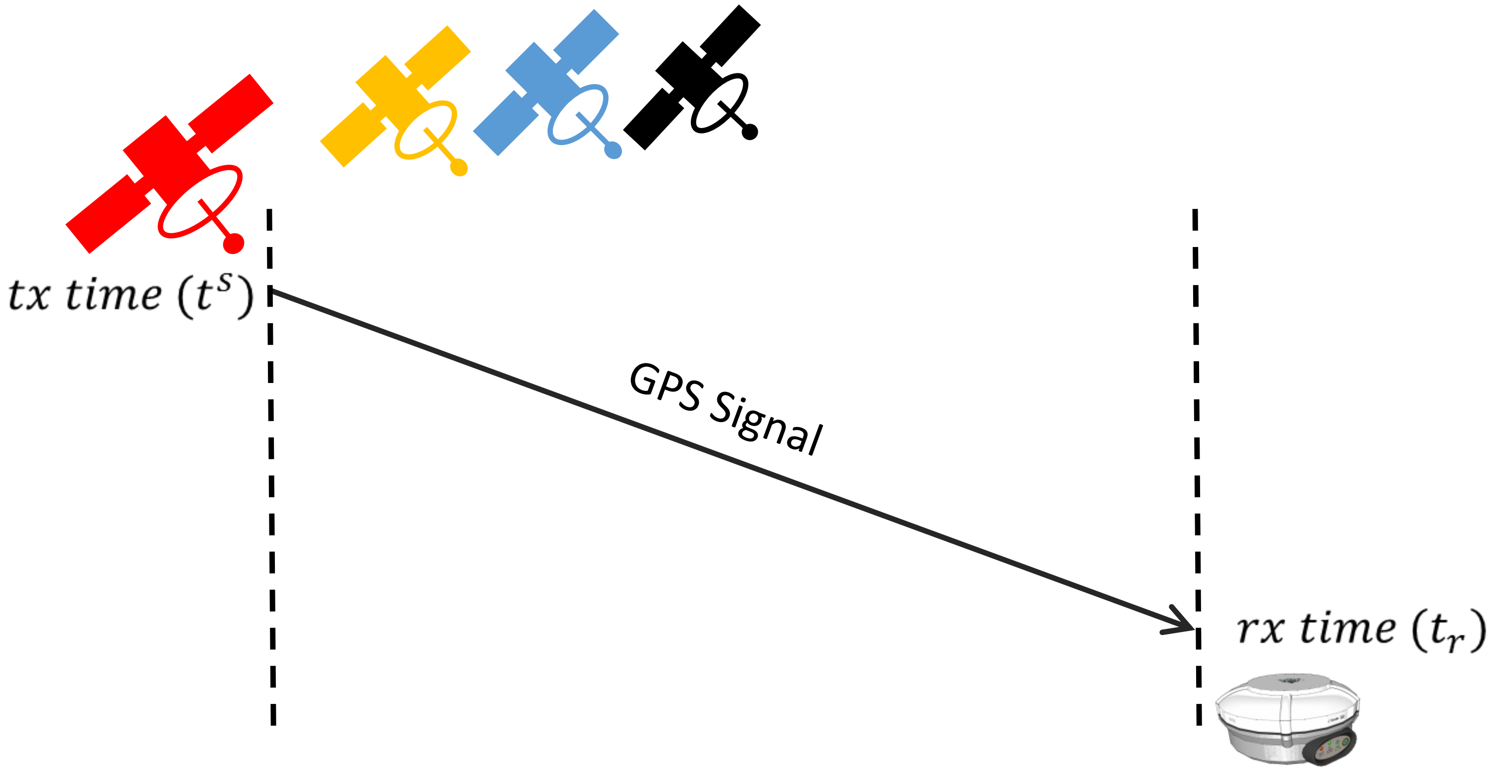
$$Range(R) = (t_r - t^s) * c$$

However, 3D location needs 3 equations … hence, use 3 satellites

$$\begin{bmatrix} \text{Satellite Geometry Matrix} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \end{bmatrix}$$

→ 300 Km of error due to unsynchronized clocks

Basic GPS Localization



$$Range(R) = (t_r - t^s) * c + \delta_{clk} * c$$

New unknown δ … use 4th satellite and estimate both location and δ

$$\begin{bmatrix} \text{Satellite Geometry Matrix} & \begin{matrix} c \\ c \\ c \\ c \end{matrix} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ \delta_{clk} \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix}$$

➡ **~10 m error**

Calculating Position

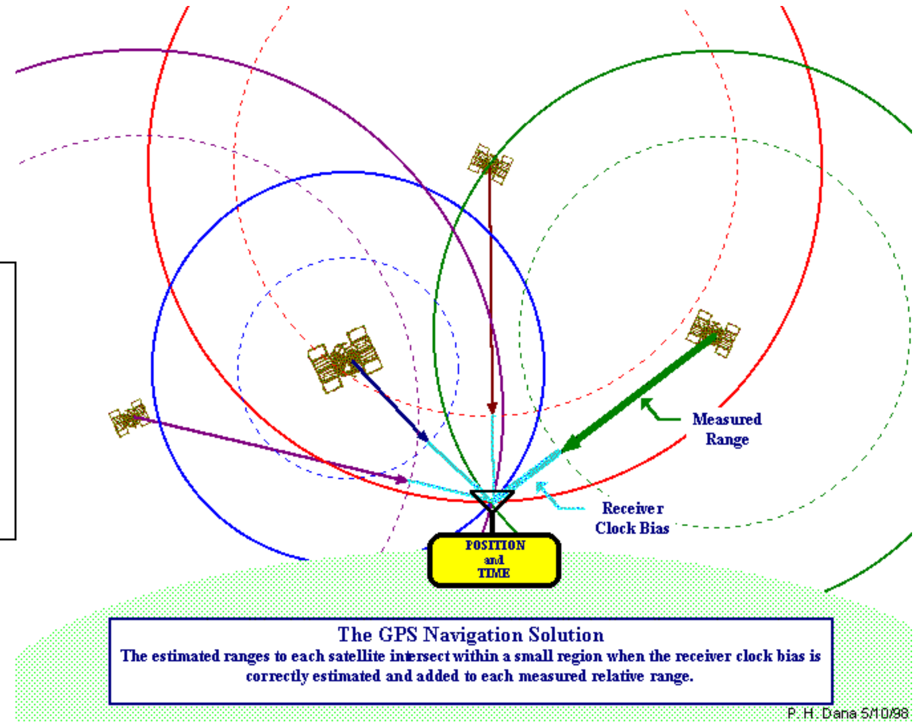
- The receiver position is calculated by solving a set of four Pythagorean equations:

$$(x1 - X)^2 + (y1 - Y)^2 + (z1 - Z)^2 = c(t_{s1} - t_{r1} - e)^2$$

$$(x2 - X)^2 + (y2 - Y)^2 + (z2 - Z)^2 = c(t_{s2} - t_{r2} - e)^2$$

$$(x3 - X)^2 + (y3 - Y)^2 + (z3 - Z)^2 = c(t_{s3} - t_{r3} - e)^2$$

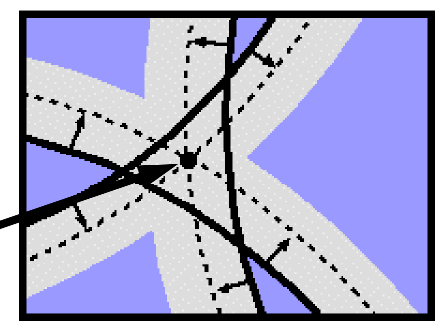
$$(x3 - X)^2 + (y3 - Y)^2 + (z4 - Z)^2 = c(t_{s4} - t_{r4} - e)^2$$



Where:

- X, Y, Z and e are unknown positions and time synchronization error at receiver
- $(x, y, z)_i$ are the four known satellite positions
- t_{si} and t_{ri} are the known times

Receiver must calculate actual position from best fit between multiple range calculations



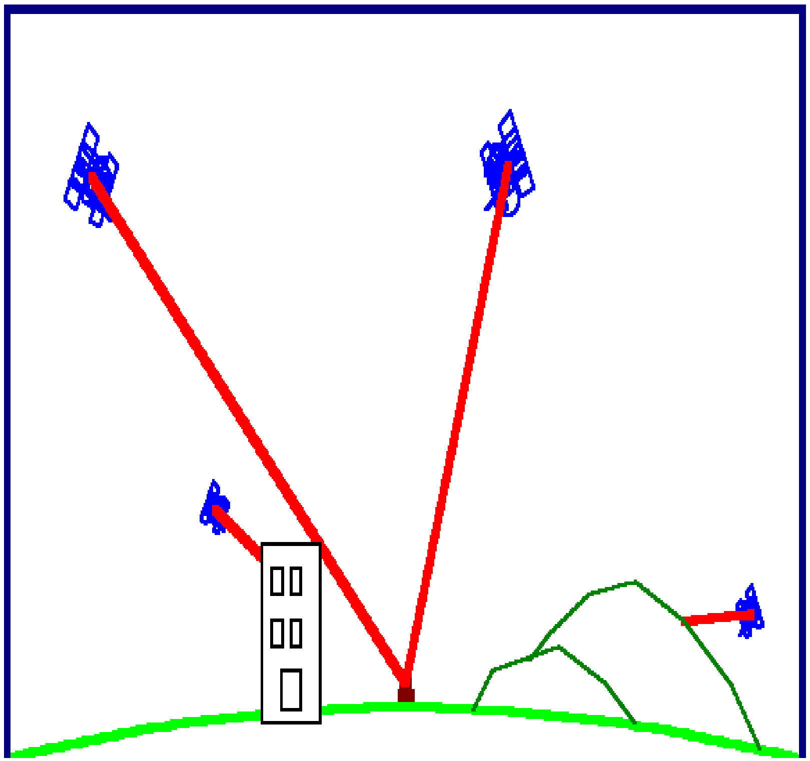
Three Okay, Four or More Better

- 4 satellites are needed for an accurate 3D position.
- 3 satellites are needed to acquire a 2D position.
- In reality, more satellites are needed due to various sources of error.
    - Satellite positions (geometry)
    - Weather
    - Multipath
    - Timing errors
- Typical error is 10+ meters.

GPS cannot “see” through objects!

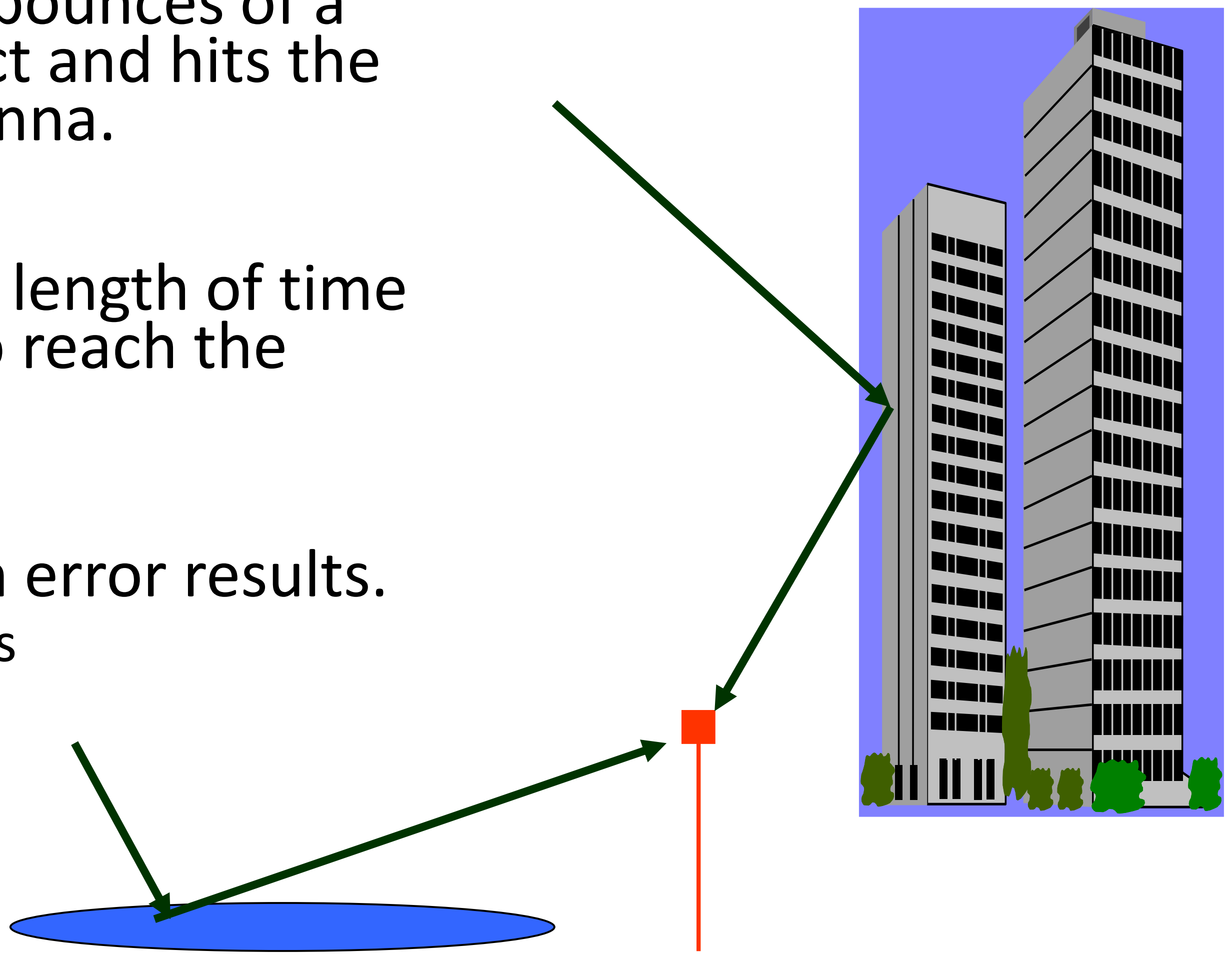
- Some of the newer satellites and receivers can receive through thinner solid objects like cars, building walls and forest canopy.

- Terrain and larger buildings are still too big.

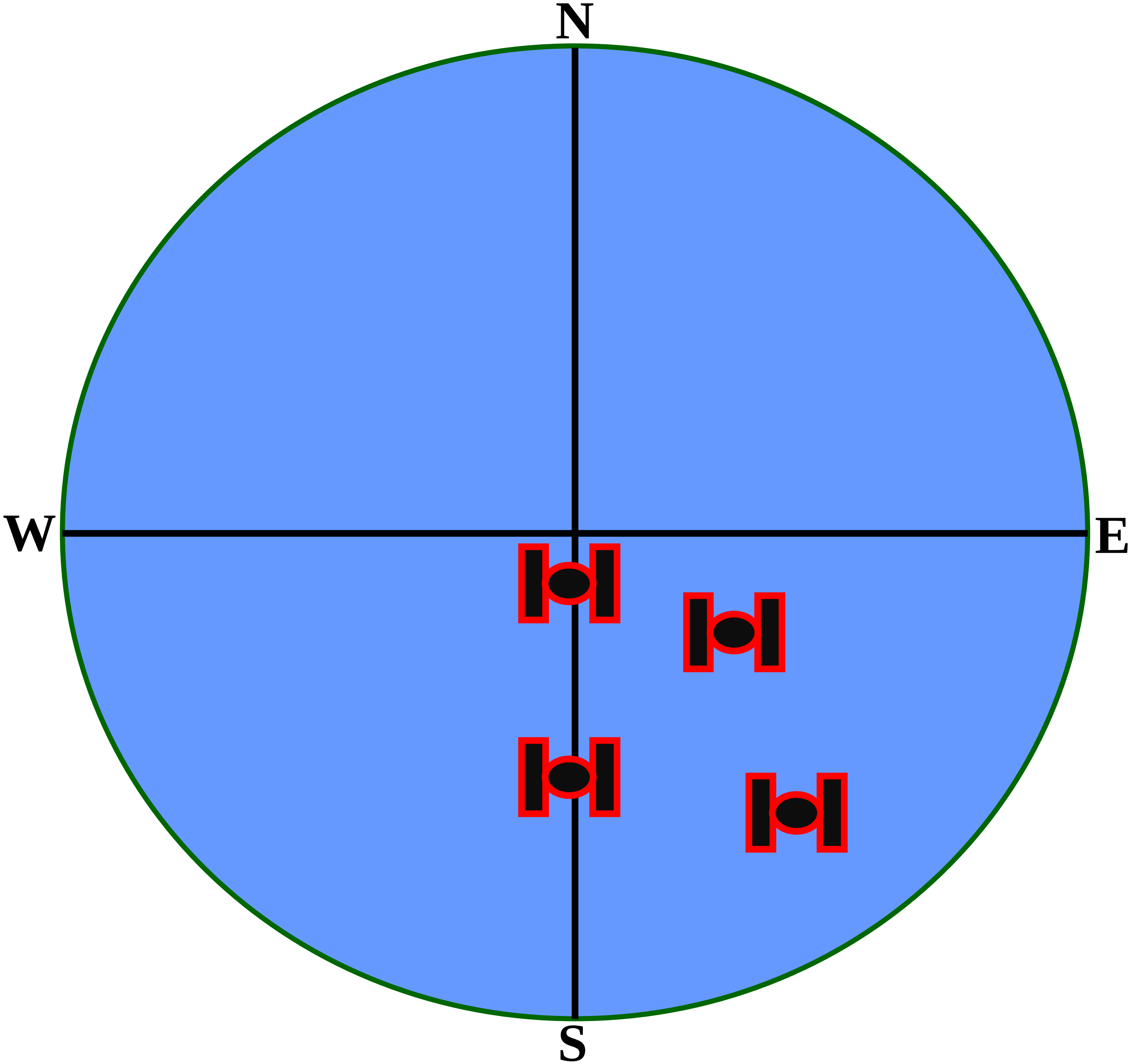


Multipath Error

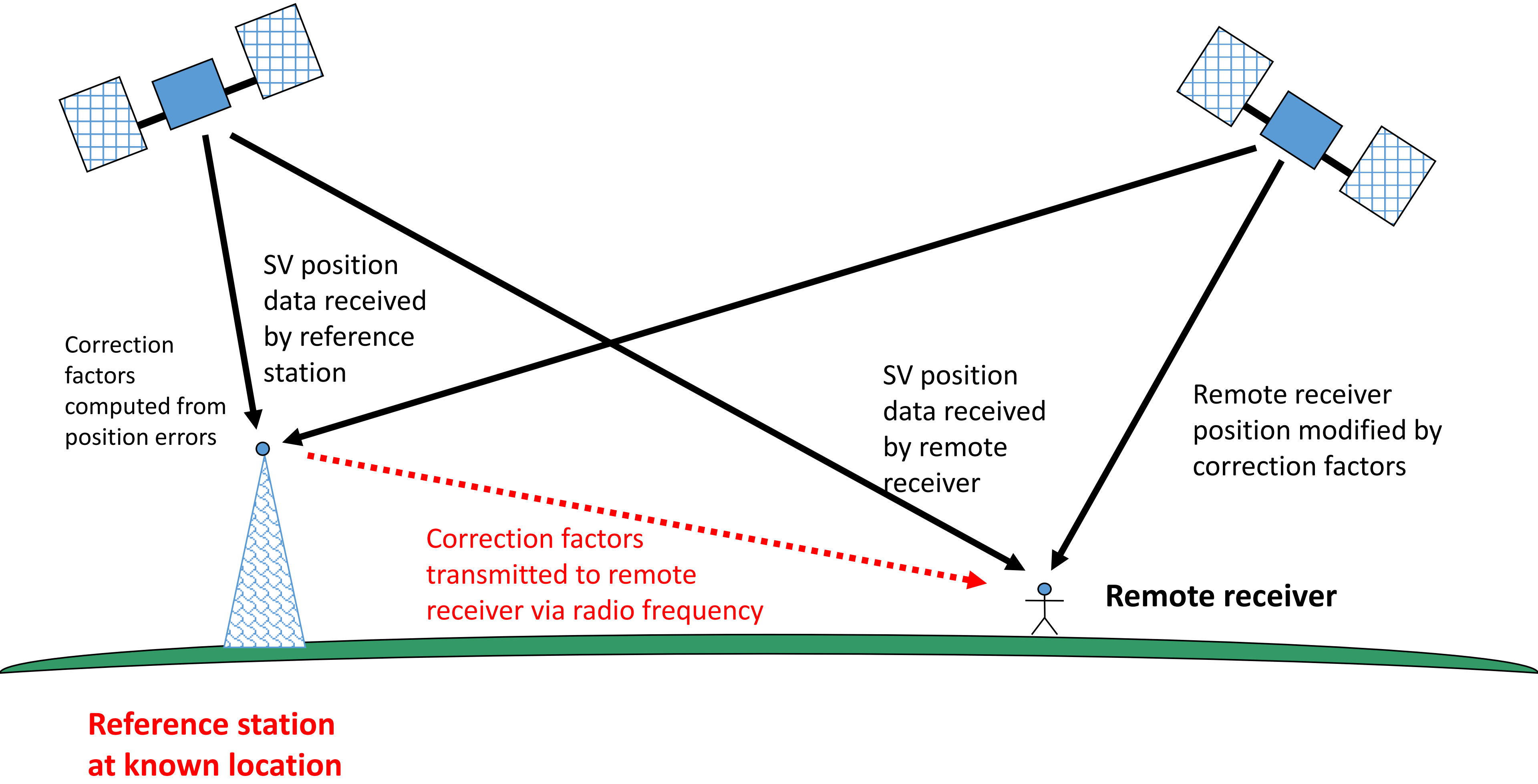
- A signal that bounces of a smooth object and hits the receiver antenna.
- Increases the length of time for a signal to reach the receiver.
- A big position error results.
  - Gravel roads
  - Open water
  - Snow fields
  - Rock walls
  - Buildings



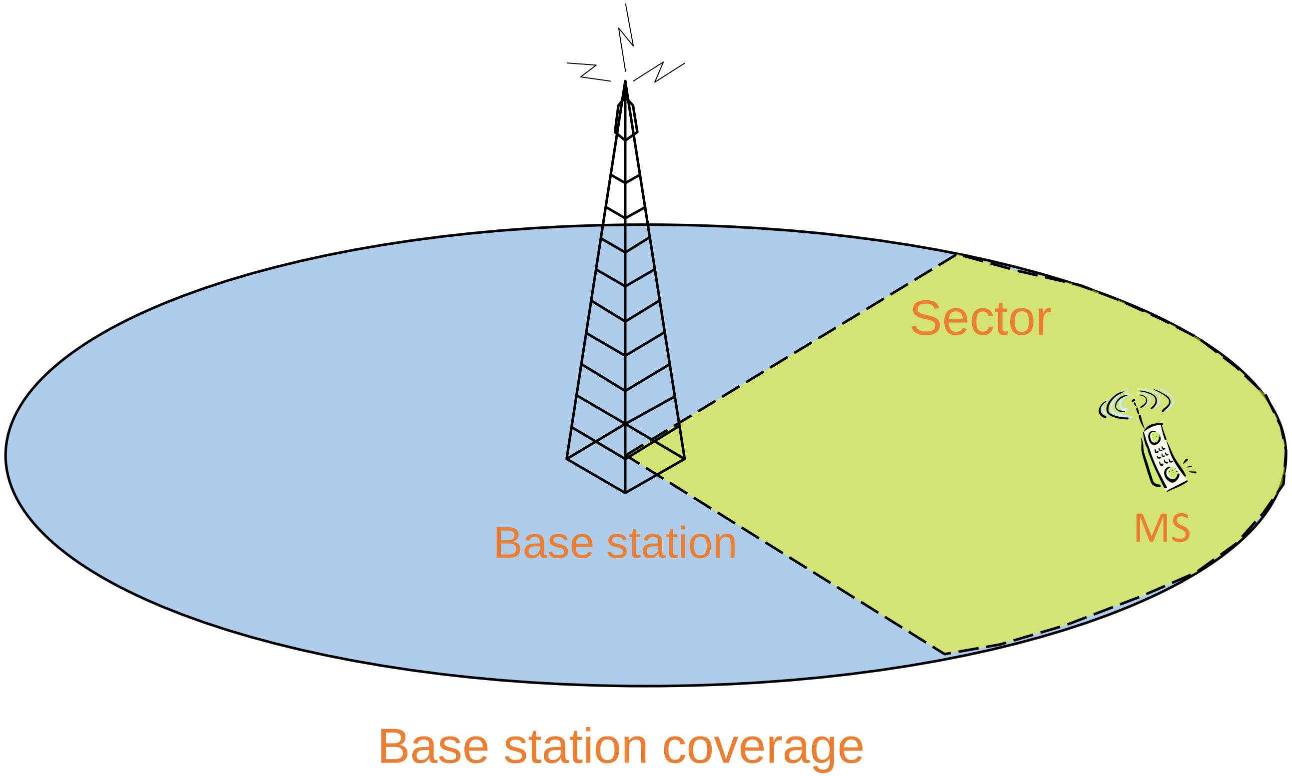
Poor Satellite Geometry



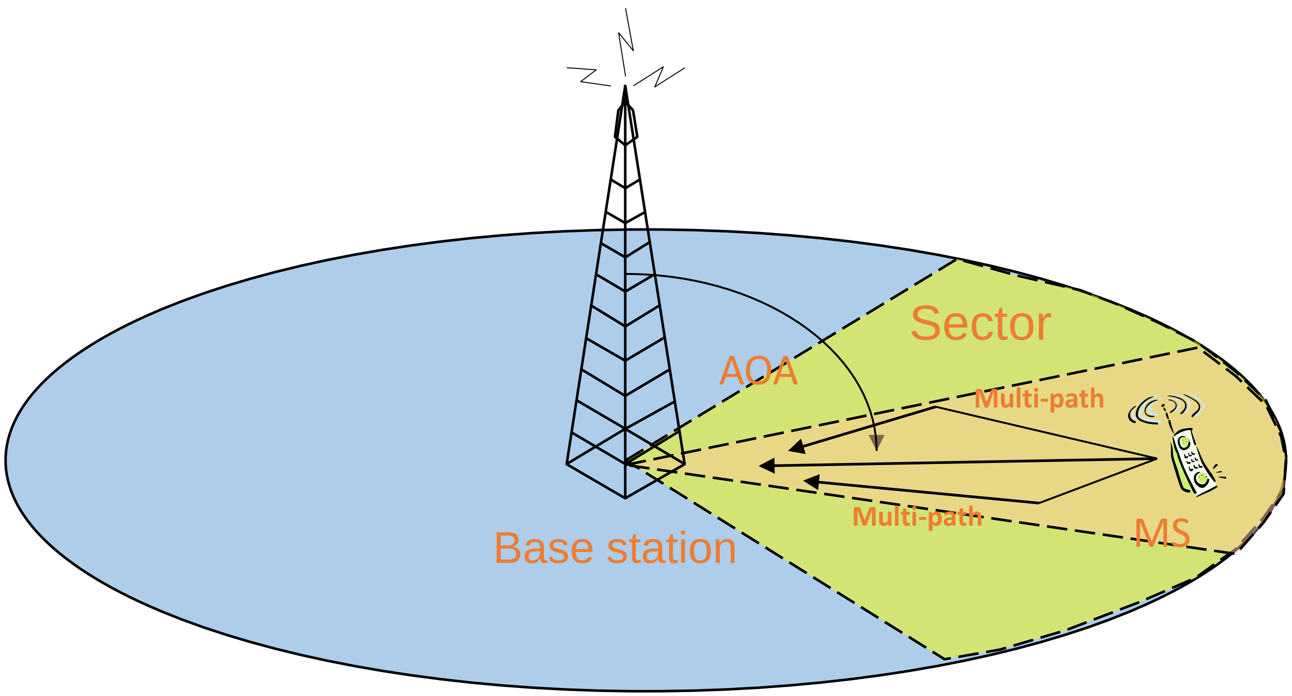
Differential GPS



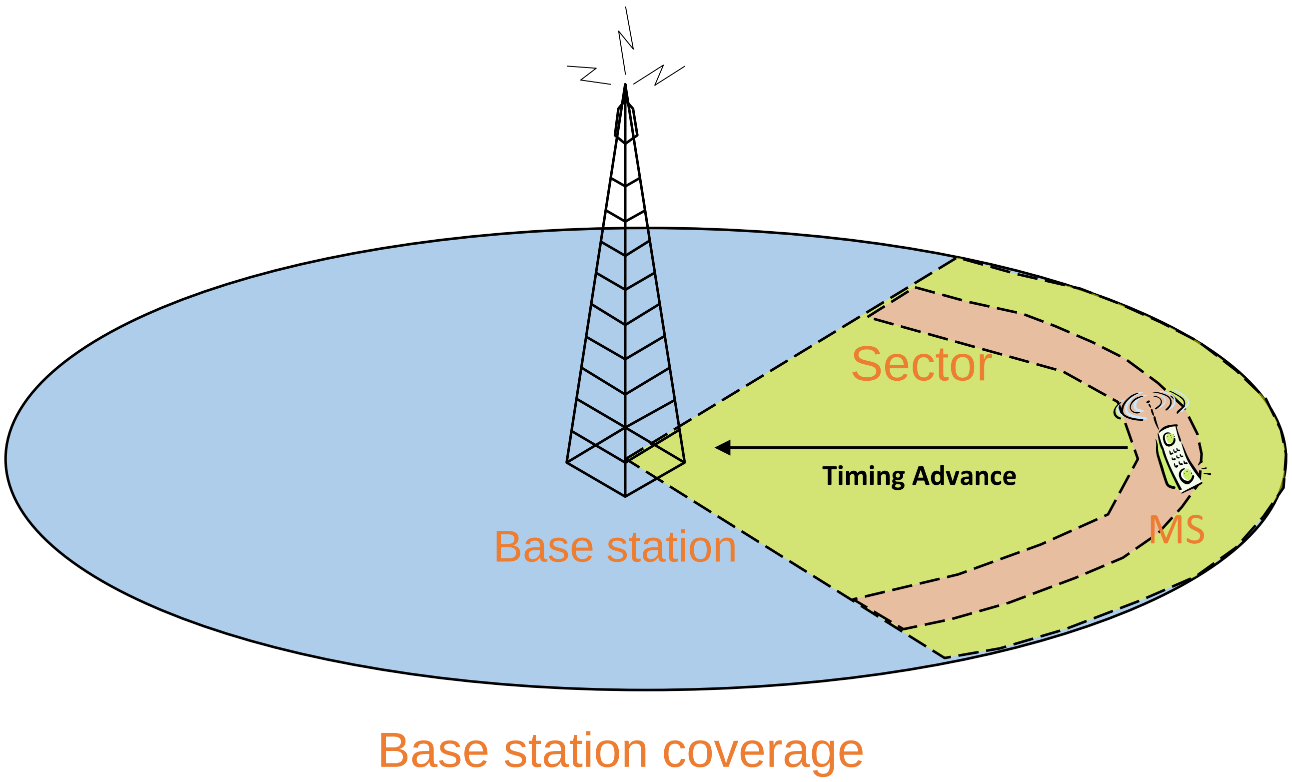
Cell Tower-Based Positioning: Cell ID



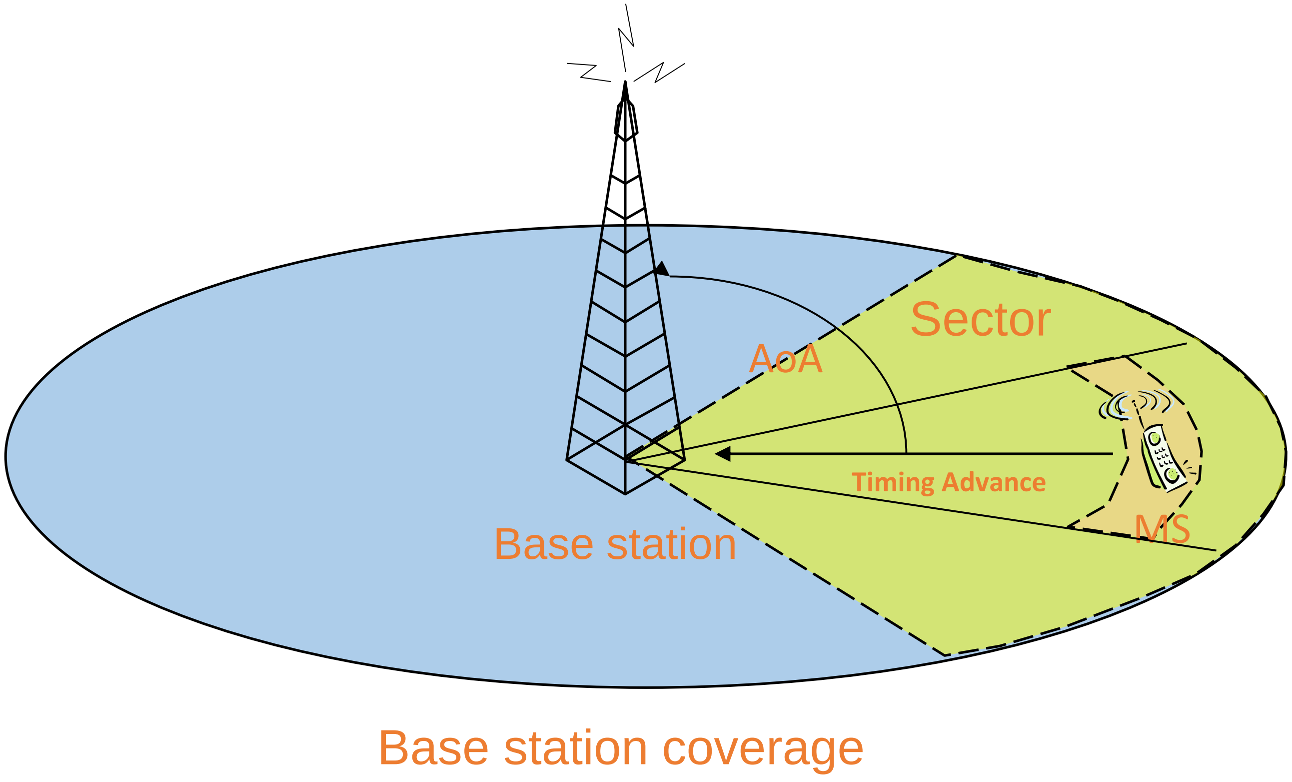
Angle of Arrival (AOA)



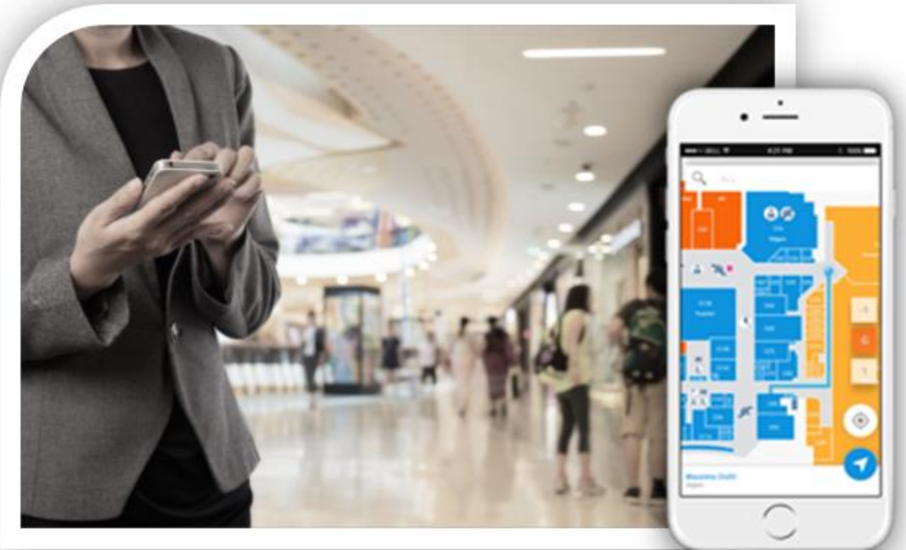
Time of Arrival (ToA)



Hybrid AoA + ToA



Localization in Indoor Complexes?

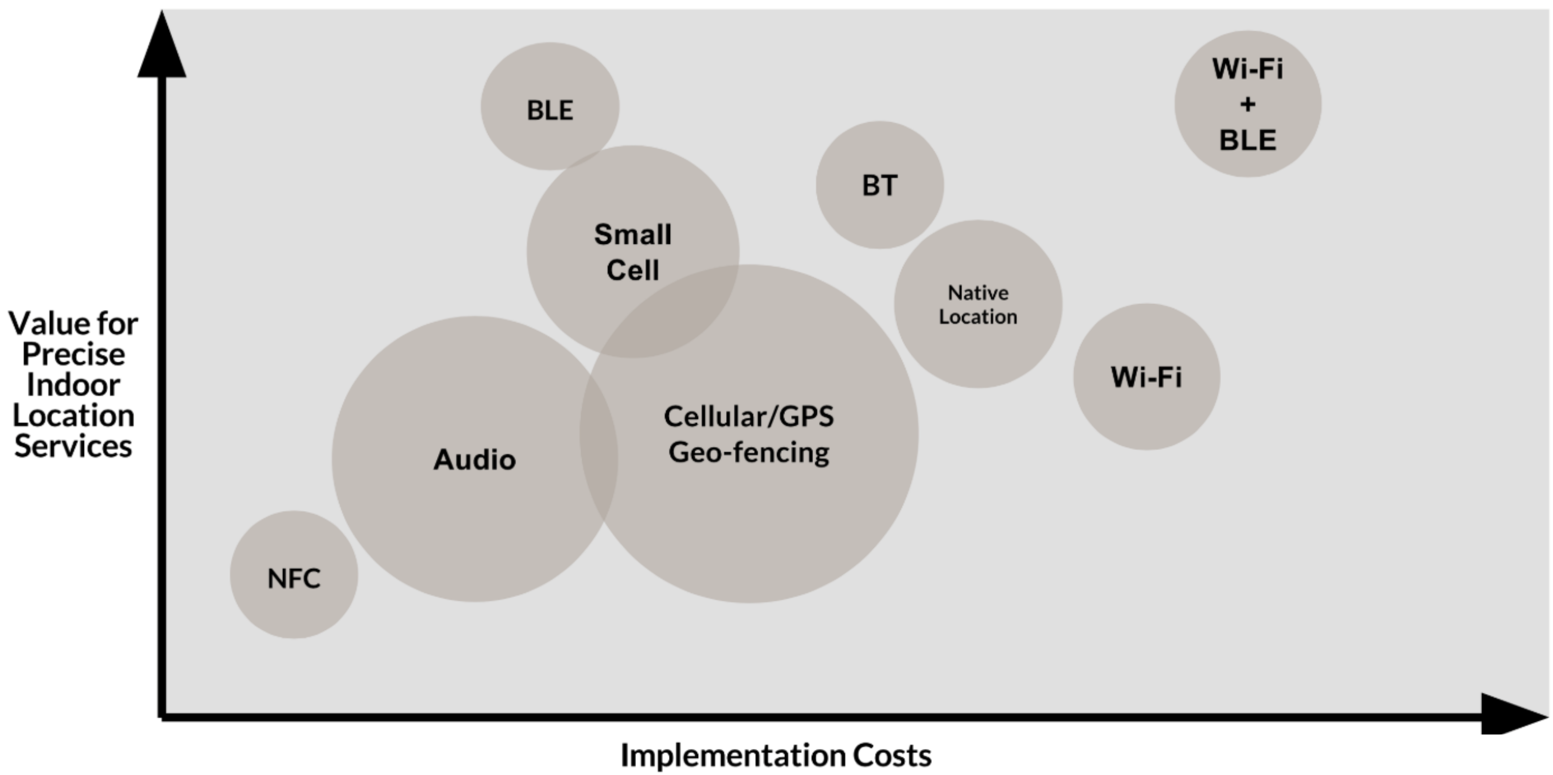



Area 1B

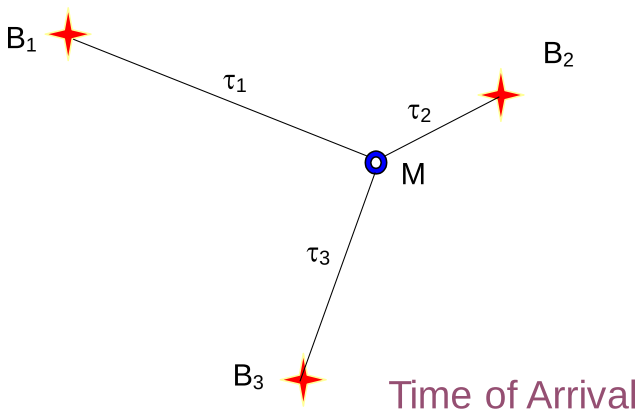

General
15
All Gates
Odd Size Baggage
All Gates

Indoor Positioning Systems

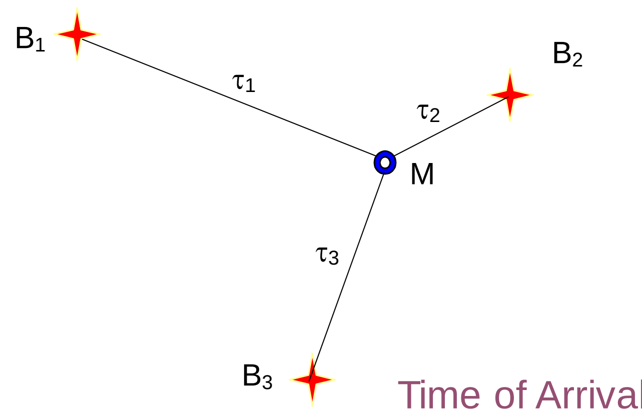
- Distinguished by their underlying signaling techniques
  - IR, RF, Ultrasonic, Wi-Fi, BLE, UWB, RFID



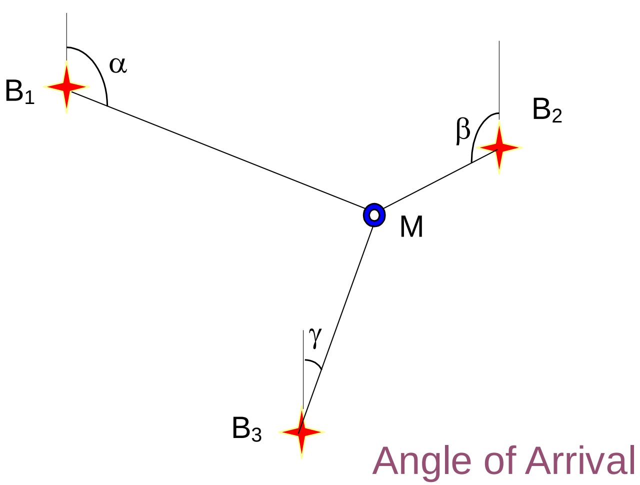
Common Localization Approaches



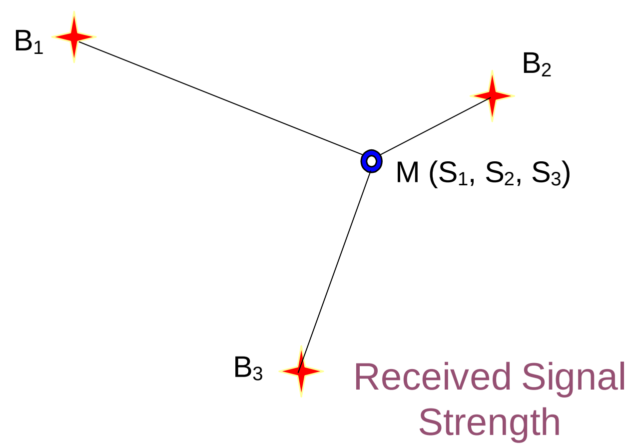
(a) Proximity



(b) Trilateration



(c) Triangulation



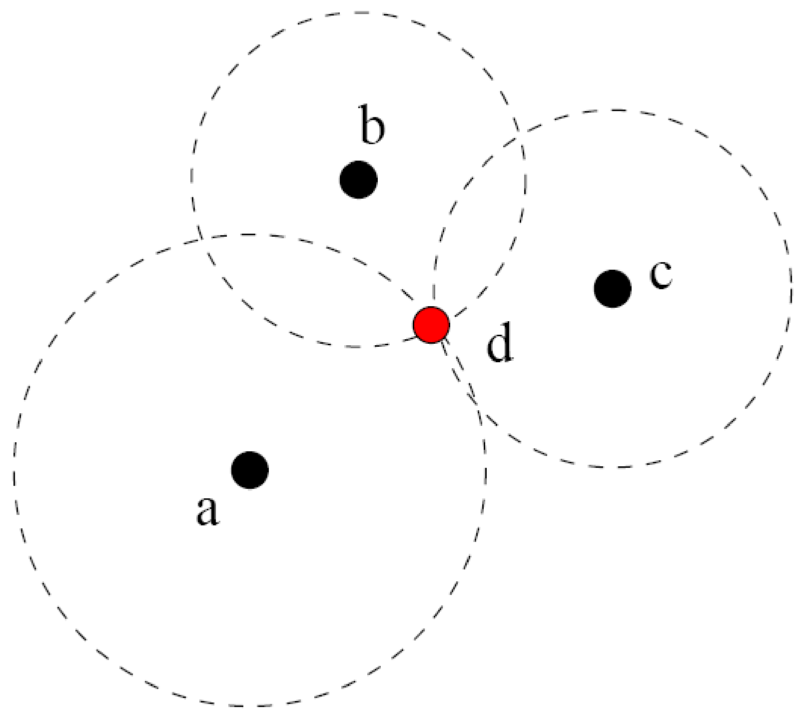
(d) RSSI-based

Proximity

- Measure distance between device and reference points (as in GPS)
- Use the location of the closest reference point as its location
- When is this useful?
  - Think about a case where a device needs to know which room it is in (not the exist coordinates).

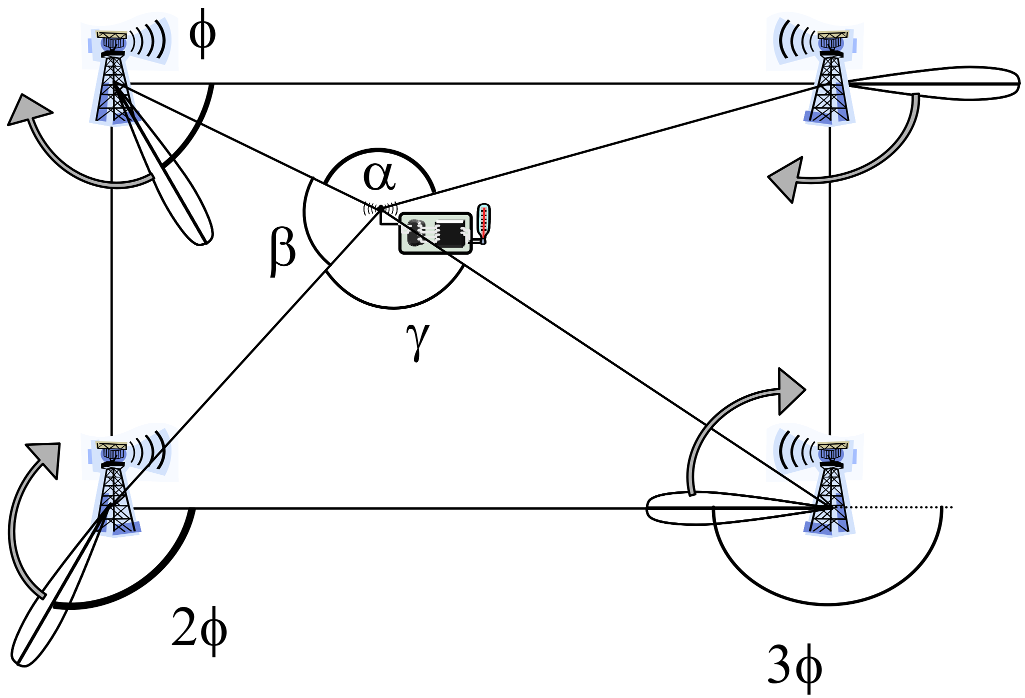
Trilateration

- Measure distance between device and reference points (as in GPS)
- 3 reference points needed for 2D and 4 for 3D



Triangulation

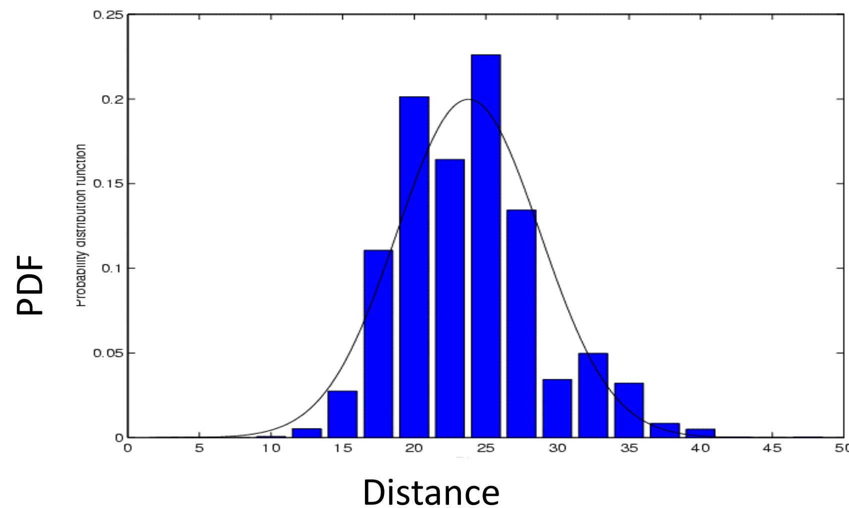
- Measure which direction the reference signal comes from (i.e., the angle of arrival) to estimate its location



RSSI Model-Based Localization

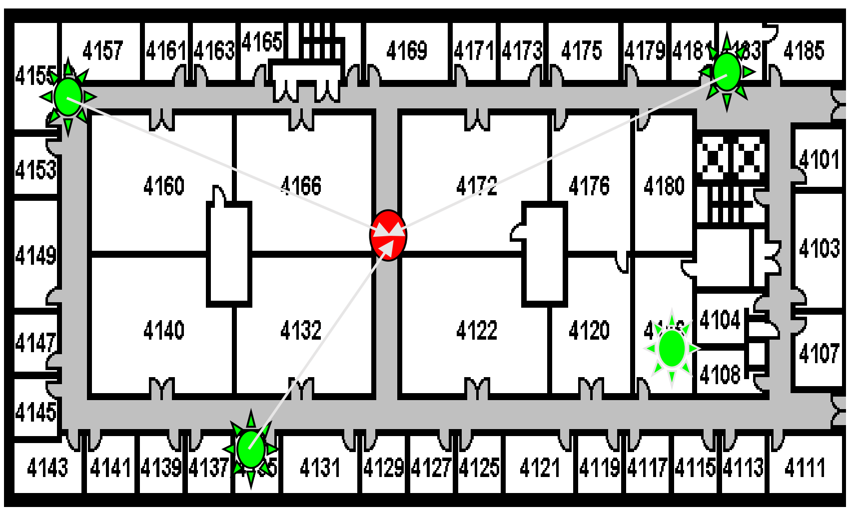
- Received Signal Strength Indicator (RSSI)
  - Send out signal of known strength
  - Use received signal strength and path loss coefficient to estimate distance

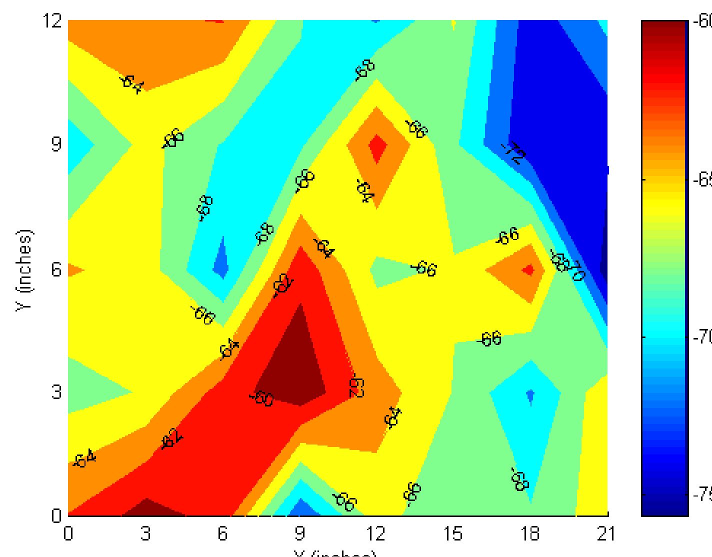
$$P_{\mathrm{recv}} = c\frac{P_{\mathrm{tx}}}{d^{\alpha}} \Leftrightarrow d = \sqrt[\alpha]{\frac{cP_{\mathrm{tx}}}{P_{\mathrm{recv}}}}$$



RSSI Fingerprint-based Localization

- RSSI Fingerprints: signal strength characteristics at selected locations
- Use prebuilt fingerprints to determine a location of a device





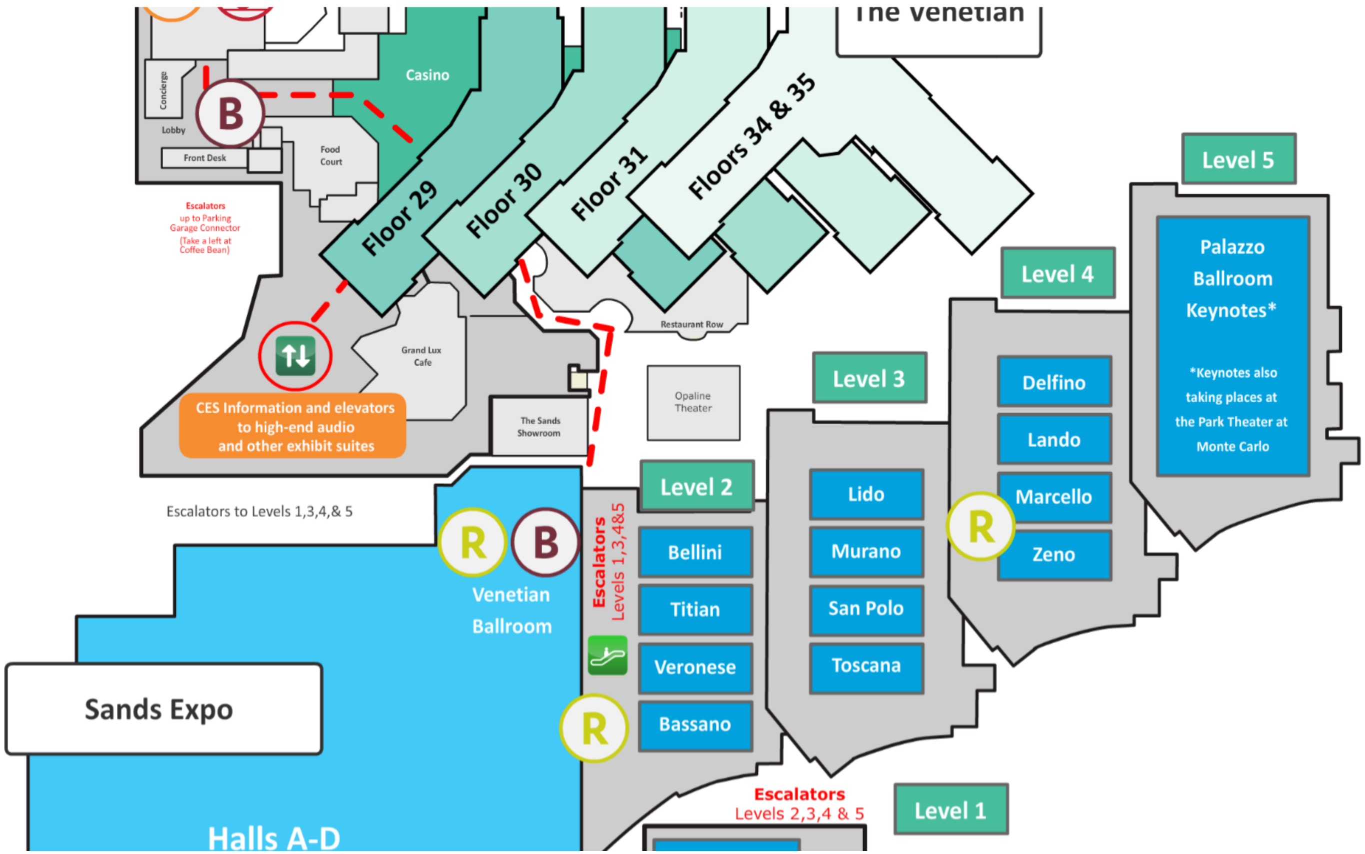
The Cricket Indoor Location System

http://cricket.csail.mit.edu/

[MobiCom 2000]

Motivation

How do I get to Youngki's office?
How do I get to Samsung's booth at CES?

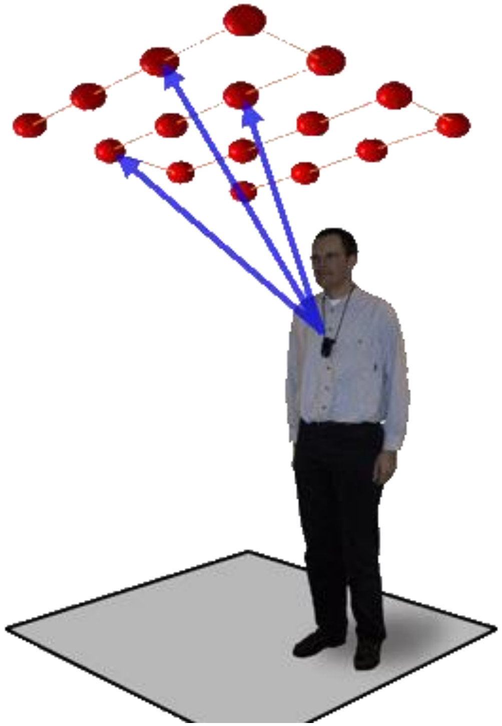


Goals

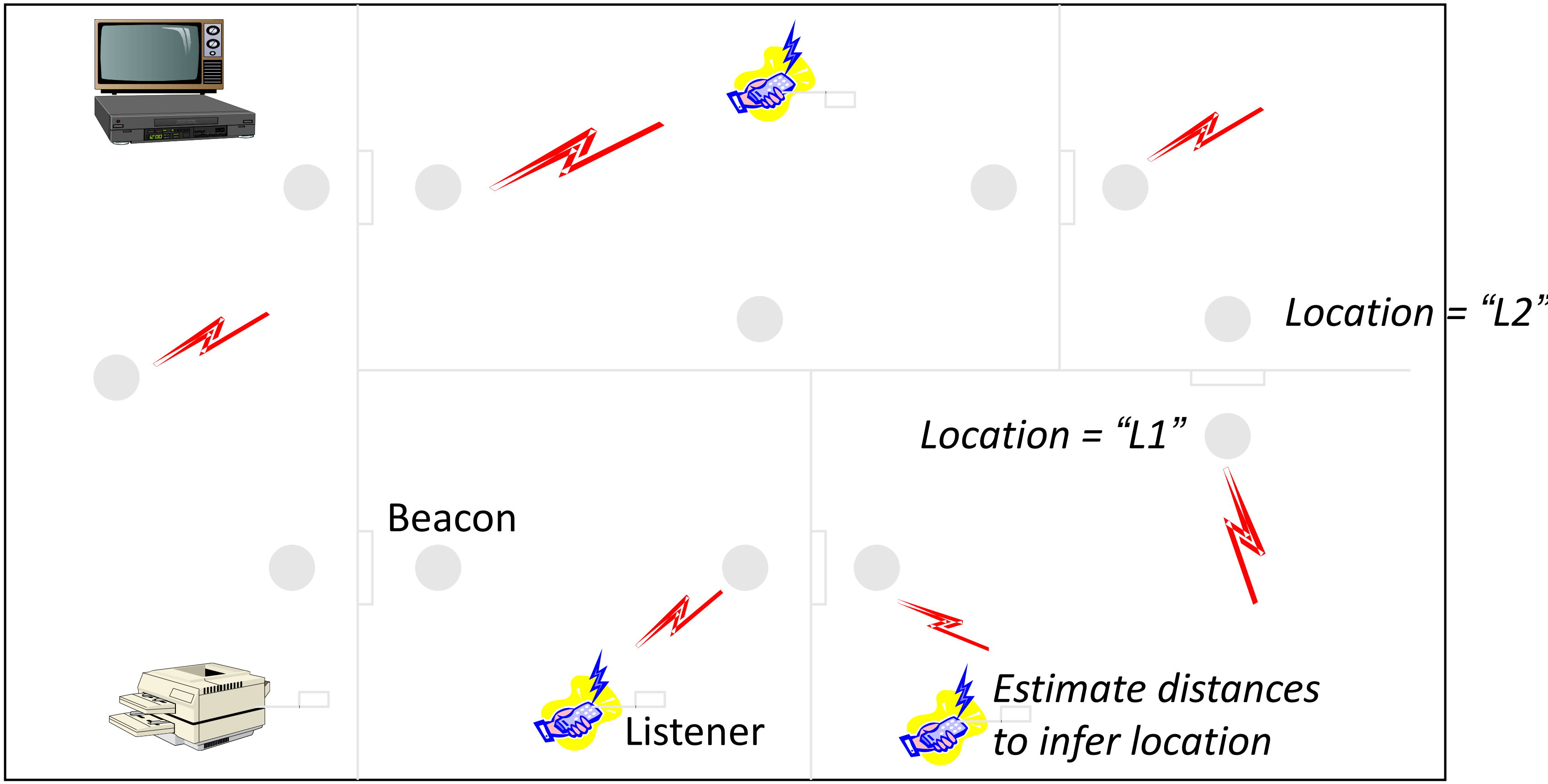
- Provide mobile devices with knowledge of “symbolic spaces” they inhabit.
  - E.g., in a classroom, in the corridor, etc.
- Preserve user privacy
  - No signaling from tracked mobile clients.
  - No measurements on the infrastructure

Prior Work: Active Bat

- Ultrasonic sounds is emitted by the client.
- Time of flight of ultrasonic pings (i.e., Trilateration)
- 3cm resolution

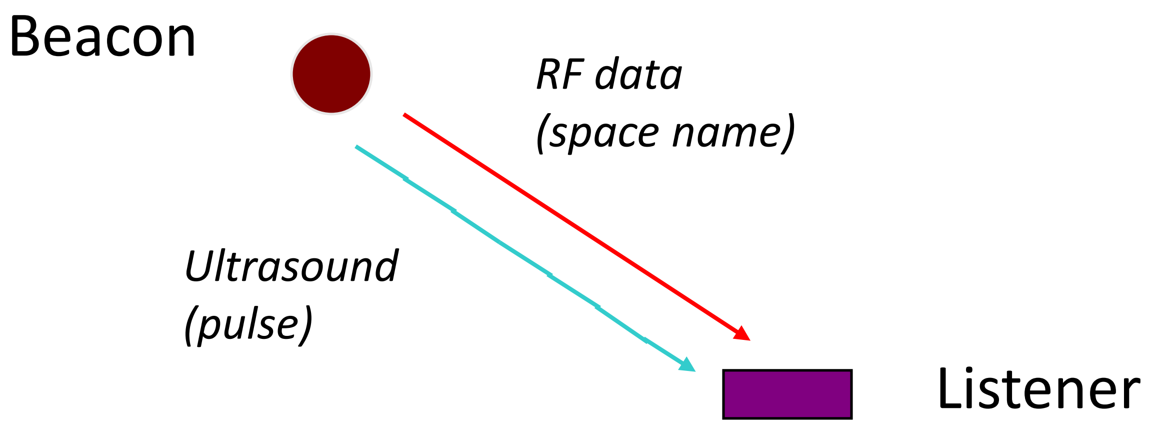


Cricket Architecture



- Passive listeners + active beacons preserves privacy
- No central beacon control or location database
- Straightforward deployment and programmability

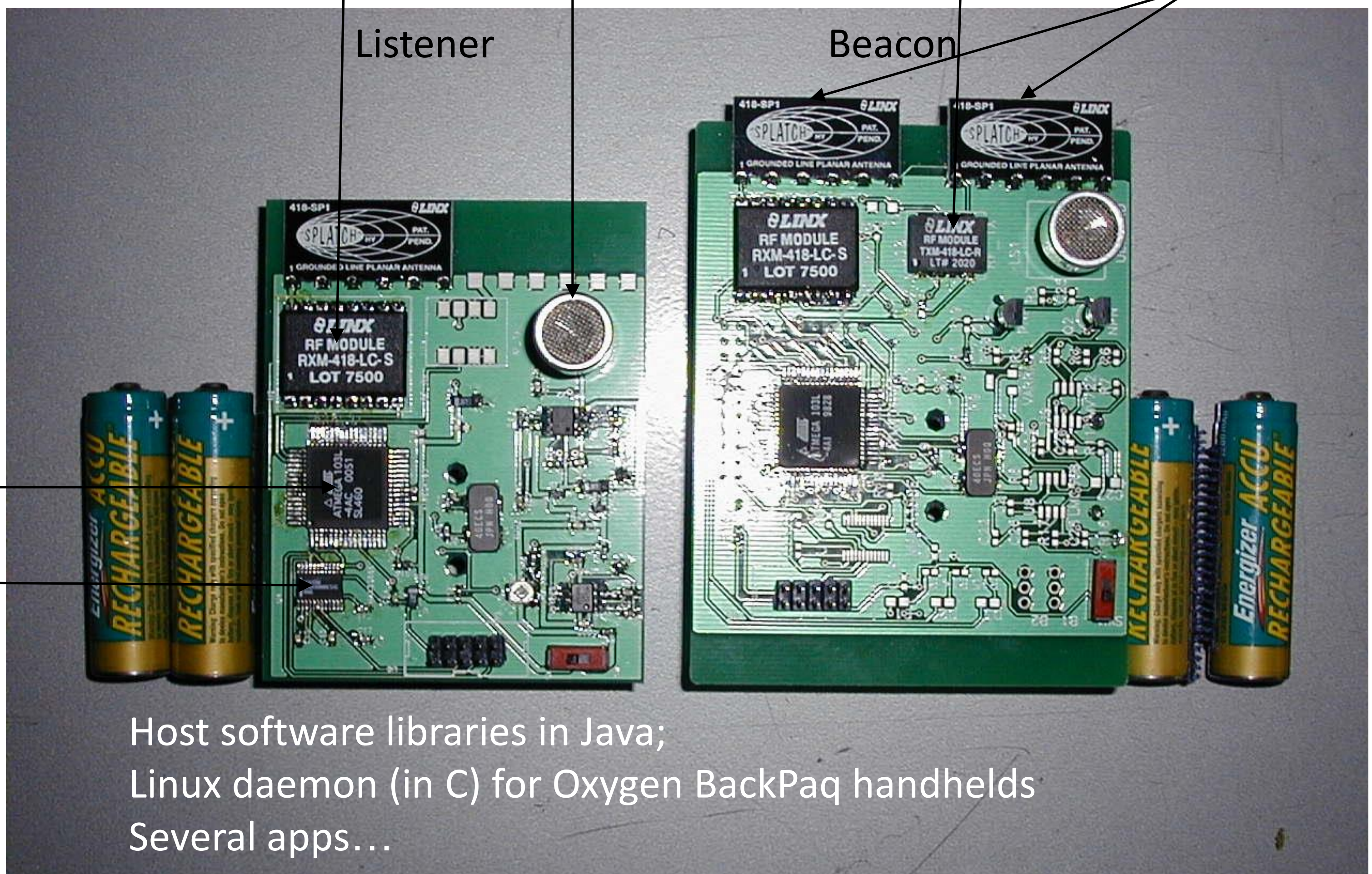
Key Idea: Time Difference of Arrival between RF and Ultrasound Signals



- The listener measures the time gap between the receipt of RF and ultrasonic signals
  - A time gap of x ms roughly corresponds to a distance of y feet from beacon
  - Velocity of ultra sound << velocity of RF

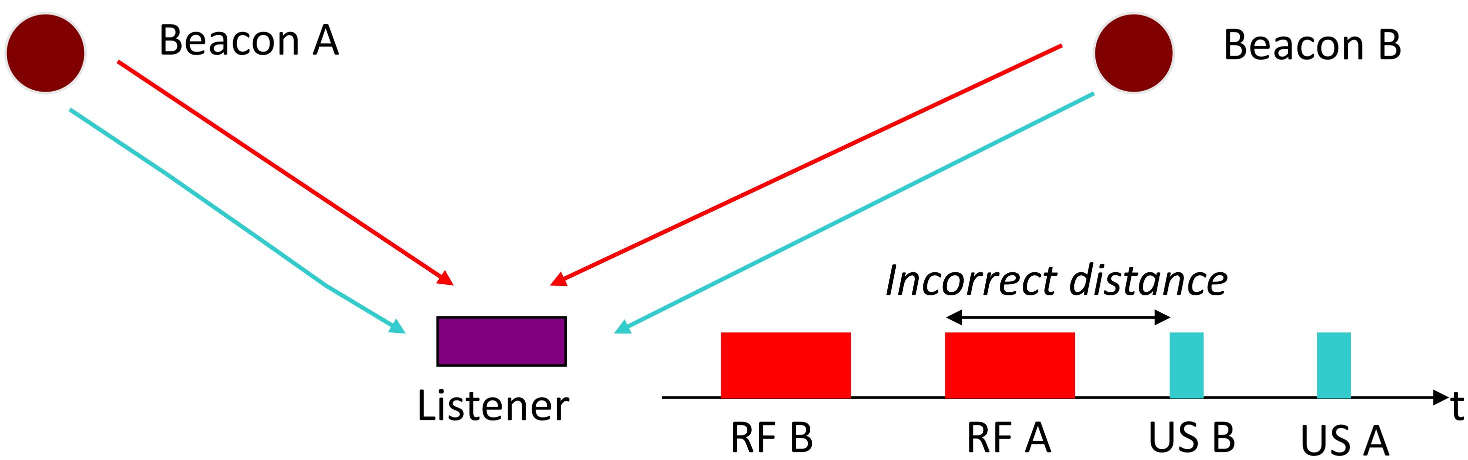
Deployment

Cricket v1 Prototype



Host software libraries in Java;
Linux daemon (in C) for Oxygen BackPaq handhelds
Several apps…

Multiple Beacons Cause Complications



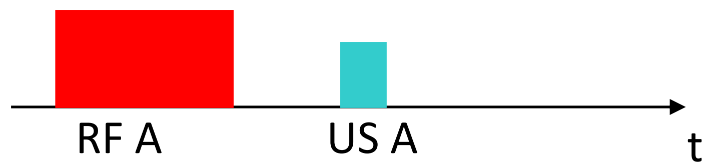
- Beacon transmissions are uncoordinated
- Ultrasonic signals reflect heavily
- Ultrasonic signals are pulses (no data)

These make the correlation problem hard and can lead to incorrect distance estimates

Solution

- Carrier-sense + randomized transmission
  - Reduce chances of concurrent beaconing
- Bounding stray signal interference
  - Envelop all ultrasonic signals with RF
- Listener inference algorithm
  - Processing distance samples to estimate location

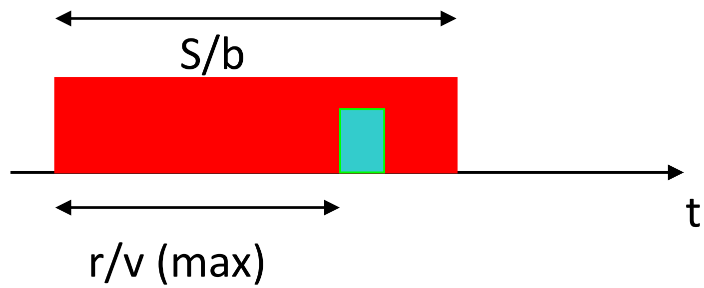
Bounding Stray Signal Interference



- Engineer RF range to be <u>larger</u> than ultrasonic range
  - Ensures that if listener can hear ultrasound, corresponding RF will also be heard

Bounding Stray Signal Interference

S = size of space advertisement
b = RF bit rate
r = ultrasound range
v = velocity of ultrasound

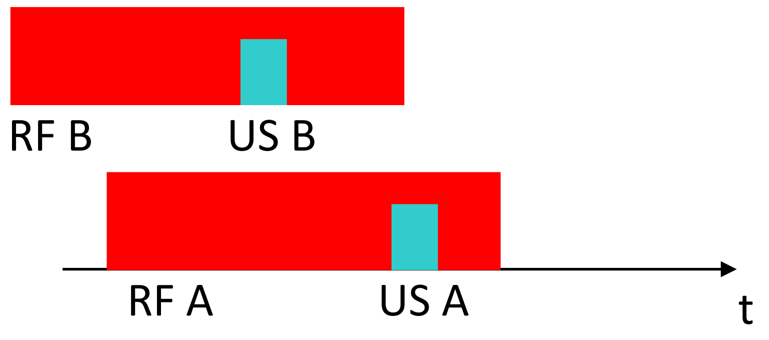


$$\frac{S}{b} > \frac{r}{v}$$

(RF transmission time)   (Max. RF-US separation at the listener)

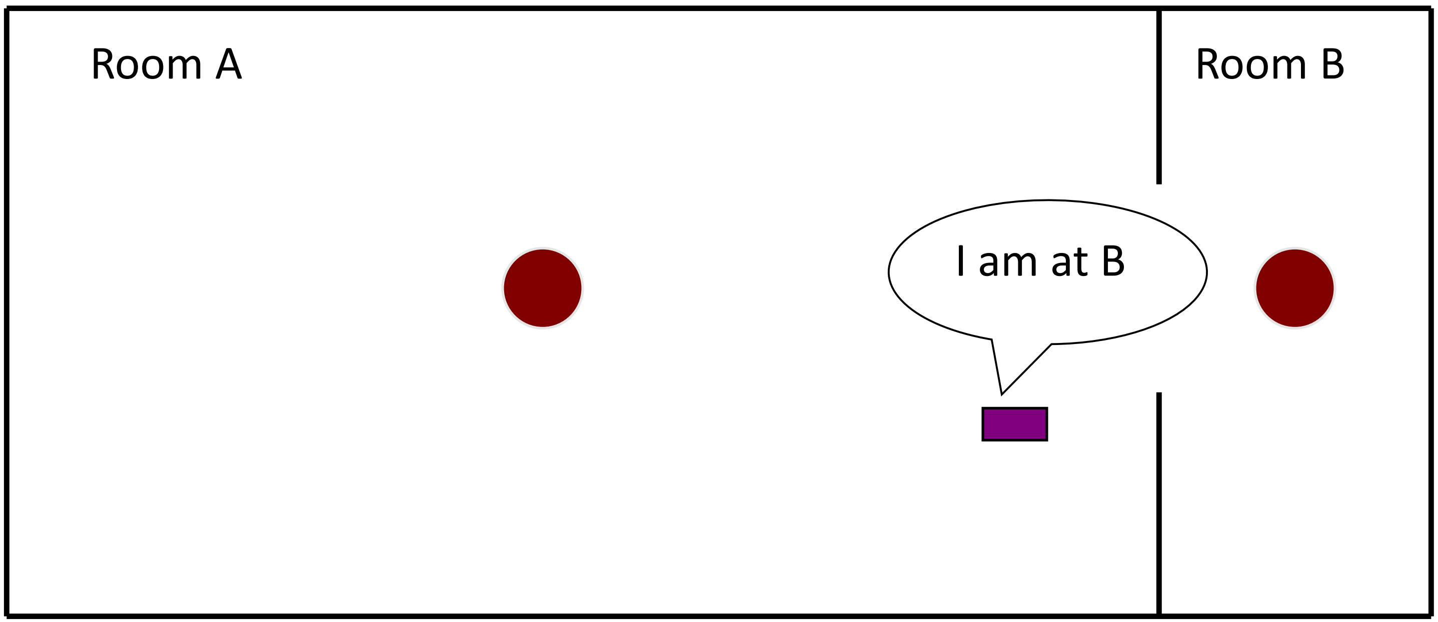
- No "naked" ultrasonic signal can be valid!

Bounding Stray Signal Interference

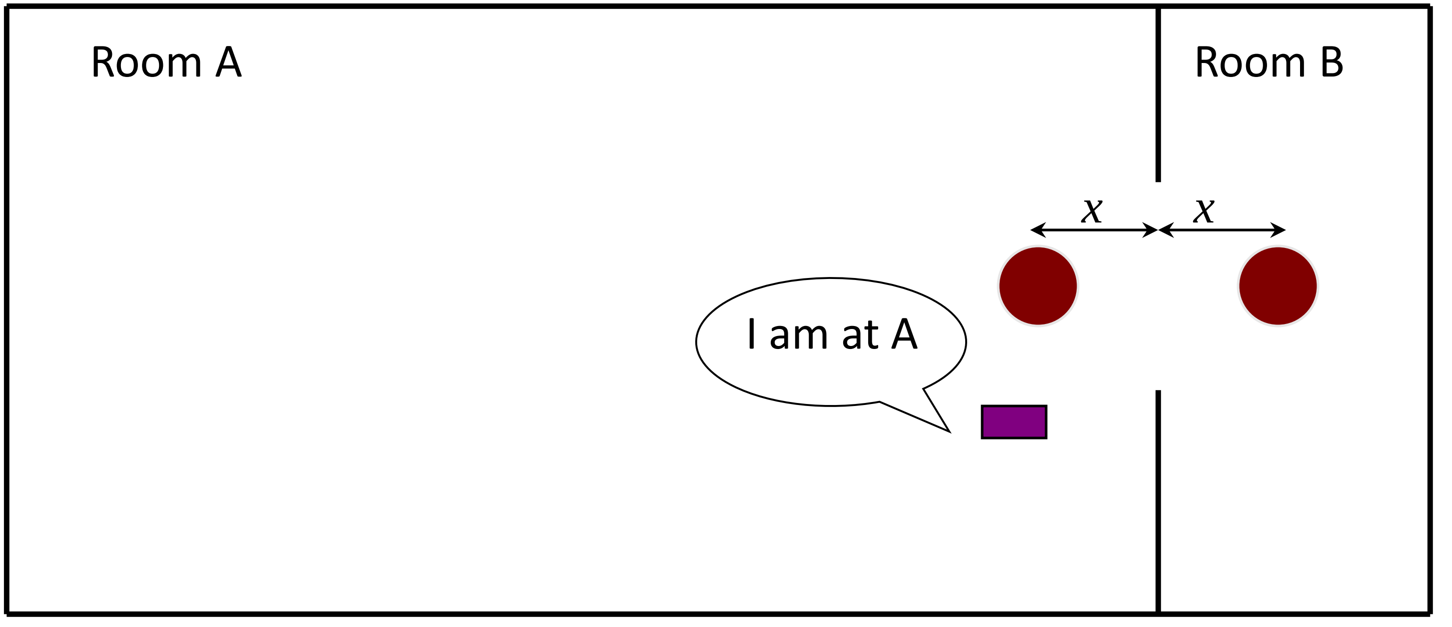


- Envelop ultrasound by RF
- Interfering ultrasound causes RF signals to collide
- Listener does a block parity error check
  - The reading is discarded...

Deployment Problem: Closest Beacon May Not Reflect Correct Space



Correct Beacon Placement

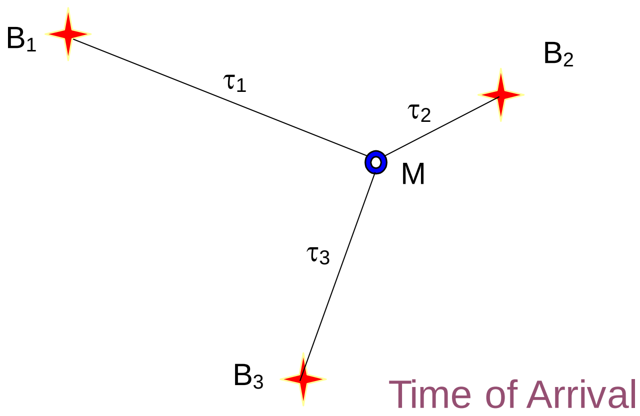


- Position beacons to detect the boundary
- Multiple beacons per space are possible

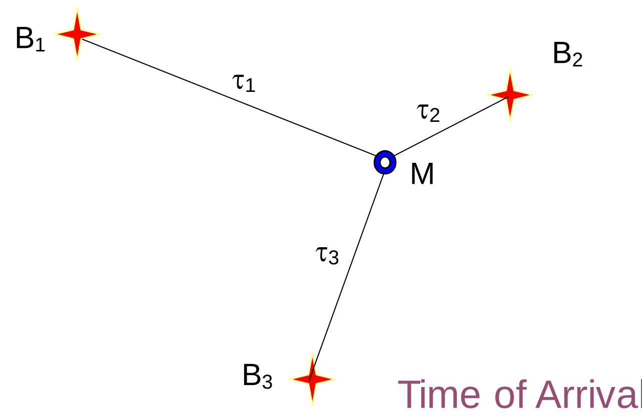
Results Reported

- Linear distances to within 6cm precision
- Spatial resolution of about 30cm
- Several applications (built, or being built)
  - Stream redirection, active maps, Viewfinder, Wayfinder, people-locater, smart meeting notifier,…

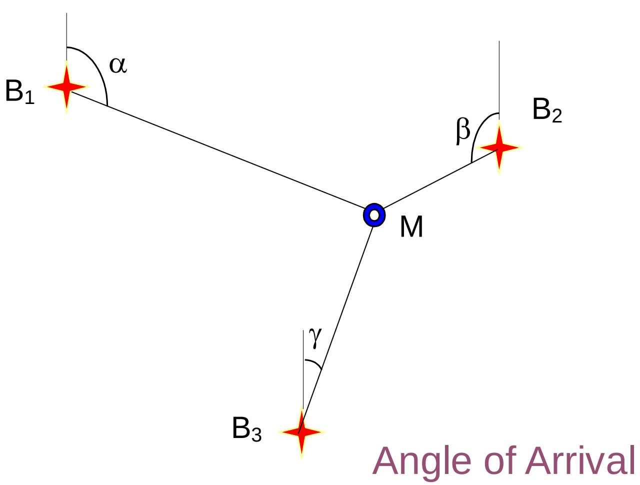
Summary



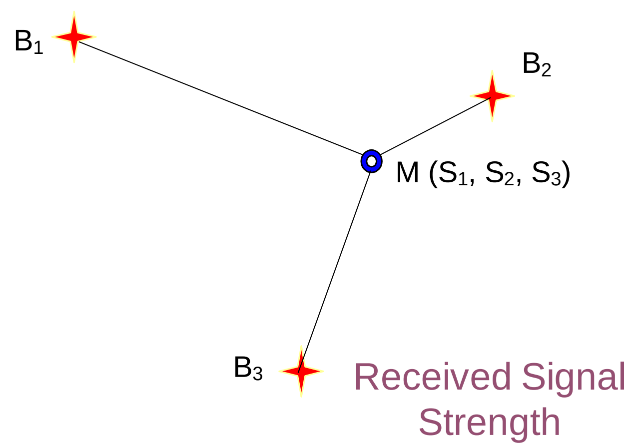
(a) Proximity



(b) Trilateration



(c) Triangulation



(d) RSSI-based