
18-759: Wireless Networks

Lecture 30: Localization

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Outline

- **Properties of localization procedures**
- **Approaches**
 - » Proximity
 - » Trilateration and triangulation (GPS)
 - » Finger printing (RADAR)
 - » Hybrid systems

Properties of localization procedures

- Physical position vs data types
- Reference systems
- Processing: localized vs centralized
- Data quality
 - » Accuracy and precision
 - » Scale
- Deployment aspects
 - » Limitations
 - » Cost
- ➔ Very diverse systems – lots of research

Data types

- Many ways to measure location, e.g.
 - » GPS location of a mobile phone
 - » Area where an access point has sufficient reception
- Corresponding data types
 - » point locations in terms of coordinates:
physical or geometric locations
 - » extended region locations given by names:
symbolic locations

Location-awareness

- **Location model: data structure that organizes locations**
- **Location-based routing**
 - » symbolic location model
 - » geometric location model
 - » hybrid location model

Examples

- » **symbolic location model:**
address hierarchy
DH.Floor2.2105
- » **geometric location model:**
GPS coordinate
(12.3456°N, 123.456°E)
- » **hybrid location model:**
combination of address and coordinate
DH.Floor2.2105.Seat(0,4)

Approaches

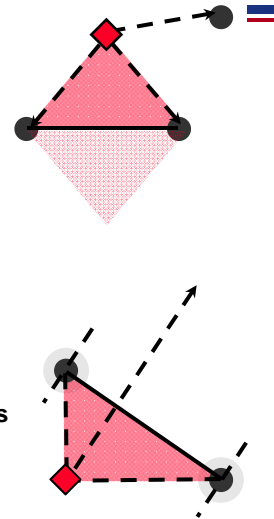
- **Proximity**
 - » estimate distance between two nodes
- **Trilateration and triangulation**
 - » using elementary trigonometric properties: a triangle is completely determined,
 - if all two angles and a side length are known
 - if the lengths of all three sides are known
 - » infer a 3d position from information about two triangles
- **Fingerprinting (scene analysis)**
 - » using radio characteristics of a location as fingerprint to identify it
- **Hybrid methods: combine multiple sources of information**

Proximity and Distance

- **Binary nearness: using finite range of wireless communication and/or threshold**
 - » within range of a beacon signal from a source with known position
 - » yields region locations, e.g.: cell in cellular network
- **Distance measurement (ranging)**
 - » Received signal strength
 - » Time of flight (time of arrival)
 - » Time difference of arrival

Measuring Location: Trigonometry Basics

- **Triangles in a plane**
 - » **Lateralation: distance measurement to known reference points**
 - a triangle is fully determined by the length of its sides
 - Time of Flight (e.g. GPS, Active Bat)
 - Attenuation (e.g. RSSI)
 - » **Angulation: measuring the angle with respect to two known reference points and a reference direction or a third point**
 - a triangle is fully determined by two angles and one side as shown
 - Phased antenna arrays
 - aircraft navigation (VOR)



Mathematical Background

- Computing positions between three known positions (x_i, y_i) and an unknown position (x_u, y_u) given distances r_i btw (x_i, y_i) and (x_u, y_u)
- Yields three equations $(x_i - x_u)^2 + (y_i - y_u)^2 = r_i^2$
- Linear equations by subtracting 3rd from 1st and 2nd: quadratic terms x_u^2 and y_u^2 disappear
 - » $2(x_3 - x_1)x_u + 2(y_3 - y_1)y_u = (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)$
 - » $2(x_3 - x_2)x_u + 2(y_3 - y_2)y_u = (r_2^2 - r_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2)$
- In 3D: yields two points
- Positioning with imprecise information:
 - » Add redundancy: over determined solution
 - » Least squares estimates

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GPS

- Radio-based navigation system developed by DoD
 - » Initial operation in 1993
 - » Fully operational in 1995
- System is called NAVSTAR
 - » NAVigation with Satellite Timing And Ranging
 - » Referred to as GPS
- Series of 24 satellites, in 6 orbital planes
- Works anywhere in the world, 24 hours a day, in all weather conditions and provides:
 - » Location or positional fix
 - » Velocity, direction of travel
 - » Accurate time

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www.fws.gov/southeast/gis/training_2k5/GPS_overview_APR_04.ppt 12

GPS involves 5 Basic Steps

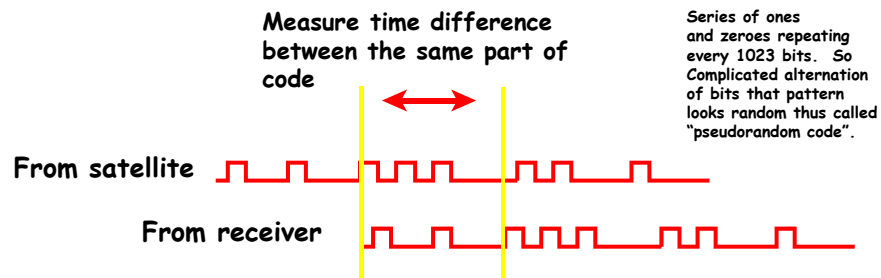
- **Trilateration**
 - » Intersection of spheres
- **Satellite Ranging**
 - » Determining distance from satellite
- **Timing**
 - » Why consistent, accurate clocks are required
- **Positioning**
 - » Knowing where satellite is in space
- **Correction of errors**
 - » Correcting for ionospheric and tropospheric delays

How GPS works?

- **Range from each satellite calculated**
 - range = time delay X speed of light*
- **Technique called trilateration is used to determine your position or “fix”**
 - » Intersection of spheres
- **At least 3 satellites required for 2D fix**
- **However, 4 satellites should always be used**
 - » The 4th satellite used to compensate for inaccurate clock in GPS receivers
 - » Yields much better accuracy and provides 3D fix

Determining Range

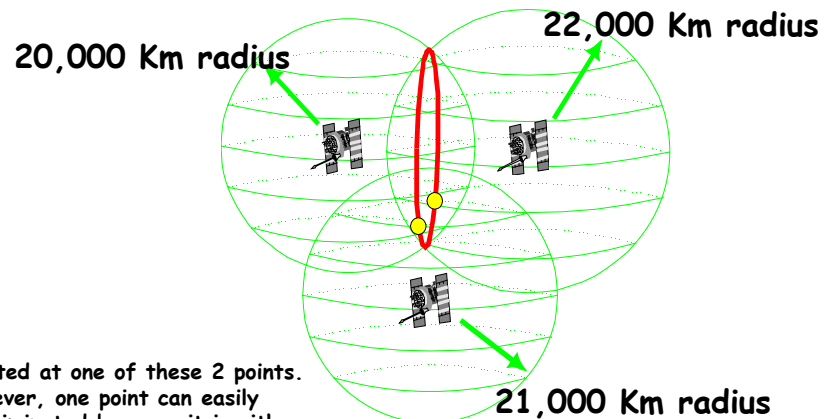
- Receiver and satellite use same code
- Synchronized code generation
- Compare incoming code with receiver generated code



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Three Satellite Ranges Known



Located at one of these 2 points. However, one point can easily be eliminated because it is either not on earth or moving at impossible rate of speed.

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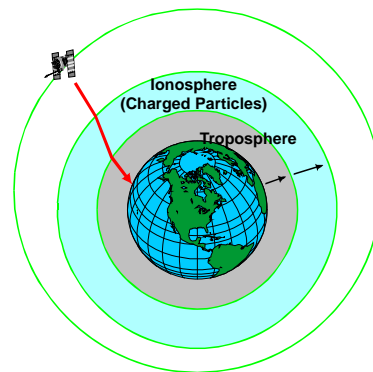
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Accurate Timing is the Key

- Satellites have very accurate atomic clocks
- Receivers have less accurate clocks
- Measurements made in nanoseconds
 - » 1 nanosecond = 1 billionth of a second
- 1/100th of a second error could introduce error of 1,860 miles
- Discrepancy between satellite and receiver clocks must be resolved
- Fourth satellite is used to solve the 4 unknowns (X, Y, Z and receiver clock error)

Sources of Errors

- Largest source is due to the atmosphere
 - » Atmospheric refraction
 - Charged particles
 - Water vapor
- Other sources:
 - » Geometry of satellite positions
 - » Multi-path errors
 - » Satellite clock errors
 - » SV position or “ephemeris” errors
 - » Quality of GPS receiver

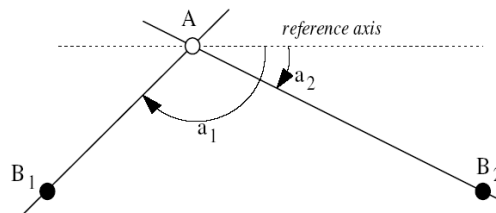


How about Indoors?

- We can use received WiFi signal strength (RSS) to measure distance to APs with known location!
- Does not work in practice: too many factors affects RSS: objects, people, ...
 - » Triangulation based on RSS tends to results tend to give large, unpredictable errors
- How about using time of arrival?
 - » E.g., based on sound, radar-like techniques, ...
 - » Works better, but it is still hard
 - » Can work well but often requires special infrastructure
 - » Reflections can also create inaccuracies: longer path!

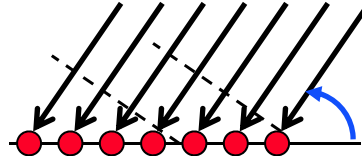
Angle of Arrival (AoA)

- A measures the direction of the incoming signal using a radio array.
- By using 2 anchors, A can determine its position
- Alternatively: the anchor measure the angle of A's signal and coordinate



Angle of Arrival Techniques

- Antenna arrays are increasingly popular
- They are usually used to steer the signal, but can be used to identify the angle at which it arrives
- Difference in arrival time can be used to measure angle



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Location Fingerprinting

- **Fingerprint Methods for Recognizing Locations**

- » **Examples**

- Visual identification of places from photos
- Recognition of horizon shapes
- Measurement of signal strengths of nearby networks (e.g. RADAR)

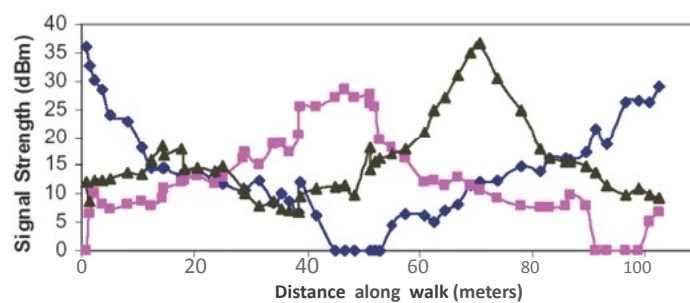
- » **Method: computing the difference between a feature set extracted measurements with a feature database**

- » **Advantages: passive observation only (protect privacy, prevent communication overhead)**

- » **Disadvantage: access to feature database needed**

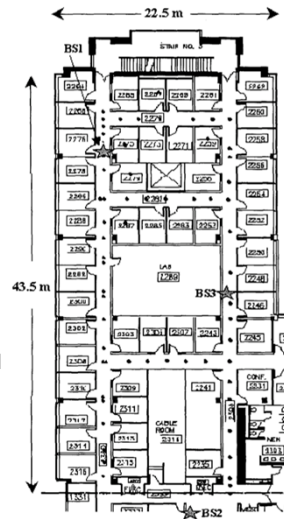
RADAR: Key Idea

- **RSS from multiple APs tends to be unique to a location**



RADAR Approach

- Scenario: floor layout with three base stations (in the hallways)
- Empirical method
 - » offline phase: database is constructed
 - collect signal strength measurements from all three base stations at 70 distinct locations
 - store each of the 70 measurement triples together with the spatial location and orientation in a database
 - » online phase: position can be determined
 - measure the current signal strength from all three base stations
 - find the most similar triple(s) in the database
 - » Resolution 2.94m (50th percentile)



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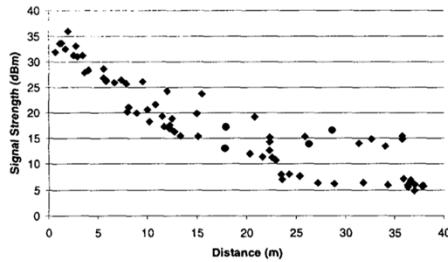
Model-Based Radio Map

- Model set-up phase has high cost
- Alternative use radio propagation model and floor plan (instead of measurements)
 - » Considered models
 - Rayleigh fading model: small-scale rapid amplitude fluctuation to model multi-path fading
 - Rician distribution model: like Rayleigh but with additional LoS component
 - Floor Attenuation Factor propagation model: large scale path loss with building models
 - Wall Attenuation Factor model: considers effects from walls between transmitter and receiver
 - » Resolution 4.3m (50th percentile)

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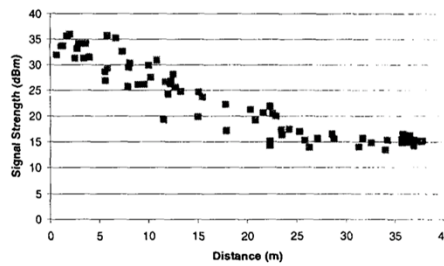
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Effects of applying correction



signal strength
as a function of
distance

with correction
for walls

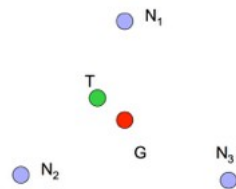


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Localization

- Find nearest neighbor in single space (NNSS)
 - » Default metric is Euclidean distance
- Physical coordinates of NNSS → estimated user location
- Refinement: k-NNSS
 - » Average the coordinates of k nearest neighbors

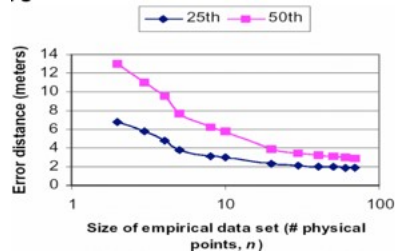
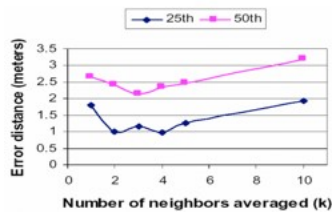


- N1, N2, N3: neighbors
- T: true location of user
- G: Guess based on averaging

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Results



Median error distance is 2.13 meters when averaging is done over 3 neighbors

Diminishing as the number of physical points mapped increased

Hybrid Technologies

- **Cell phones: have many other sensors**
 - » Accelerometer, compass, ...
- **Can be used to estimate the user's walking speed, direction, ...**
- **This information can be combined with finger printing based techniques**
- **Especially useful if finger printing provides accurate location in specific points**
 - » When entering a store, escalator, elevators
 - » Can use the other sensors starting with these well-known locations

Literature

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