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
Spatial Information

- Sources of location information
  - Location of a device can be measured using positioning methods
  - Additional spatial information can be retrieved from a spatial information system
- Additional information
  - Geometric information
    - coordinate system and unit transformations
    - precision and accuracy of measurement
  - Region information
    - location hierarchies

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)

Quality of Position Information

Positioning accuracy:
  largest distance between an estimated position and the true position

Precision:
  the ratio with which a given accuracy is reached, averaged over many repeated attempts

Example:
  average error of less than 20cm in 95% of cases

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
  - Lateration: 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 3\textsuperscript{rd} from 1\textsuperscript{st} and 2\textsuperscript{nd}: 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

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

www.fws.gov/southeast/gis/training_2k5/GPS_overview_AR_04.ppt
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
  \[ \text{range} = \text{time delay} \times \text{speed of light} \]
- 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

Signal Structure

- Each satellite transmits its own unique code
- Two frequencies used
  - \( \text{L1 Carrier} \ 1575.42 \text{ MHz} \)
  - \( \text{L2 Carrier} \ 1227.60 \text{ MHz} \)
- Codes
  - CA Code use L1 (civilian code)
  - P (Y) Code use L1 & L2 (military code)
Three Satellite Ranges Known

20,000 Km radius

22,000 Km radius

21,000 Km radius

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.

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
- $1/100^{th}$ 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)

Satellite Positioning

- Also required in the equation to solve the 4 unknowns is the actual location of the satellite.
- Satellites are in relatively stable orbits and constantly monitored on the ground
- Satellite’s position is broadcast in the “ephemeris” data streamed down to receiver

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 affect 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!

CAESAR: Carrier Sense-based Ranging

- Question: can we use time of flight ranging using commodity WiFi hardware?
- Yes, but it gets a bit messy
  - Need to include SNR measurement
- Local station determines location of (mobile) remote stations
- Design criteria
  - Exploit standard 802.11 protocol implementations
  - Real time results
  - Low cost (low network usage, no additional hardware, minimal calibration)

CAESAR: Key Idea

- Time of flight from ACKs
  - Speed of light: \( c = \sim 300\text{m/s} \)
  - WLAN clock 44MHz
  - Resolution: \( 300/(2*44) = 3.4\text{m} \)
  - Distance \( d = c^2(t_{\text{MacIdle}}+t_{\text{SIFS}}+t_{\text{FD}})/2 \)

CAESAR: Adjustment to Noise

- Method depends on correct estimation of response time, which depends on the SNR
- Automatic gain control is used if
  - Preferred region (PR): no AGC
  - Strong signal detected (SSD): e.g. subtract 30dB from signal
  - Weak signal detected (WSD): may need adjust signal to to bring it into PR (or signal is not detected)
- Proposed solution:
  - Detect states SSD, WSD, and preferred range
  - Use different values for Time for Frame Detection (\( t_{\text{FD}} \))
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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)**

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)**
Effects of applying correction

![Graph showing signal strength as a function of distance with correction for walls]

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

Limits of Localization Using Signal Strength

- Measuring distance based on signal strength is an attractive idea for wireless sensor networks:
  - RSS does not require additional hardware
  - RSS declines with distance
  - Many different promising methods proposed
- Experimental study:
  - 802.11 technology with a range of methods and environments tested
  - Median localization error of 10ft and 97th percentile of 30ft
- Fundamental limitations that require
  - more complex environment models
  - additional infrastructure

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