18-759: Wireless Networks
Lecture 21: Localization

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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

Outline

- Properties of localization procedures
- Approaches
  - Proximity (CAESAR)
  - Trilateration and triangulation (GPS)
  - Finger printing (RADAR)
  - Hybrid systems
- Other direct methods

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)

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
CAESAR

- Carrier sense-based ranging:
- Combines time of flight and SNR measurement
- Local station determines location of (mobile) remote stations
- Design criteria
  » Exploit 802.11 protocol
  » Real time
  » 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: \( \frac{300}{2\times44} = 3.4\text{m} \)
  » Distance
    \[
    d = c\left(\frac{t_{\text{MacIdle}}-t_{\text{SIFS}}-t_{\text{FD}}}{2}\right)
    \]

CAESAR: Adjustment to Noise

- Method depends on correct estimation of response time
- Automatic gain control is used if
  » Strong signal detected (SSD): e.g. subtract 30dB from signal
  » Weak signal detected (WSD): quantization method takes longer (or signal is not detected)
- Suggested solution:
  » Detect states SSD, WSD, and preferred range
  » Use three different values for \( t_{\text{FD}} \)

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 \(r_i\) between \((x_i, y_i)\) 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
  \[
  2(x_3 - x_2)x_u + 2(y_3 - y_2)y_u = (r_2^2 - r_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2)
  \]
  \[
  2(x_3 - x_1)x_u + 2(y_3 - y_1)y_u = (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)
  \]
- Positions with imprecise information
  - Redundancy: overdetermined 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_APR_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

Measure time difference between the same part of code

From satellite

From receiver

Signal Structure

- Each satellite transmits its own unique code
- Two frequencies used
  - L1 Carrier 1575.42 MHz
  - L2 Carrier 1227.60 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 using “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

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

Other Direct Methods

- Active Badge: infrared beacons in rooms
- Active Office: location of specific device
  - arrays of ultrasound receivers
  - central controller sending radio signal
  - time difference of arrival (95%, 8cm)
- Cricket
  - device queries anchors
  - anchors provide ultrasound and radio signal for TDoA
- Overlapping connectivity
- Approximate point in triangle
- Angle of arrival: narrow, rotating beams
Literature