# Lecture 18: Localization algorithms

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CS 653 Spring 2014

March 27, Thursday

# Localization

- Mobile systems need a way to determine location.
- Location is useful for a variety of location-dependent applications
- Common ways of localization
  - Using fixed or known landmarks. Get distance / angle / signal strength / some other signature using these landmarks, and triangulate location. Most commonly used method
  - Start with known position, known velocity, and update position as you go along using velocity (also called dead reckoning). We won’t go into much depth on this.

# Localization using anchors

- Anchors with fixed or known positions, mobile node that needs to learn location.
- Beacons can be sent by anchors (in a coordinated or uncoordinated fashion) or by the mobile node
- Beacons can be RF or ultrasound or anything else
- From beacons, we can measure things such as
  - Time of arrival, or time difference of arrival (between two different beacons)
  - Signal strength or some other signature
  - Visibility or non-visibility of certain beacons
- From the above, we can infer
  - Distance to beacons
  - Angle of arrival
  - Approximate "area" or "logical space"

# Outdoor location systems

- Most systems send a signal, use the time taken for signal to travel, and map it to distance.
- RADAR: A fixed node emits radio signals that are reflected by the mobile object (say, airplane). If "t" is the time taken for the signal to go and come back, and "c" is the speed of light, then distance to the object is $d = 0.5 * c * t$.
- Radars can also estimate other aspects like velocity from the Doppler spread of the received signal, and angle of arrival of the signal

# Outdoor location systems: GPS

- GPS has many satellites orbiting the sky, emitting beacons with timing information (synchornized by very accurate atomic clocks)
- Satellite beacons have a timestamp, location of satellite, and an “almanac” of all other GPS satellites and their locations.
- Each satellite uses a unique code, and all satellite signals are transmitted using CDMA. The superset of codes are known to all receivers.
- Initially, GPS receiver searches all codes till it obtains a correlation with some code. After “locking on” to one satellite, it downloads the almanac and obtains the locations of other satellites.

# GPS (2)

- A GPS receiver obtains signals from multiple satellites, calculates the distances to those satellites, and triangulates itself.
- Let the location of mobile node be $(x,y,z)$ and its clock drift be "$dt$". Suppose the node obtains timestamp $t_i$ from satellite "$i$" located at $(x_i, y_i, z_i)$, at time "$t$" according to its clock.
- Then the actual time taken for the signal to travel from satellite is "$t + dt$". The distance $d_i$ to satellite "$i$" can be calculated as $d_i = (t + dt – t_i) * c$.
- We can get multiple equations of the form $(d_i)^2 = (x – x_i)^2 + (y – y_i)^2 + (z – z_i)^2$.
- If we have 4 such equations, we can solve for the 4 unknowns $x$, $y$, $z$, and the time drift of receiver clock $dt$.

# GPS (3)

- Inaccuracies in GPS due to atmospheric effects and clock inaccuracies.
- GPS does not work indoors and some outdoor places due to severe multipath that can distort the timing calculations.
- Need better ways for indoor localization that does not involve GPS.
- People are also exploring simpler / cheaper alternatives to GPS. E.g., place a large number of beacons at known locations. Mobile host can measure which beacons it can hear, and localize itself to the centroid of those beacons.

# Indoor localization using beacons

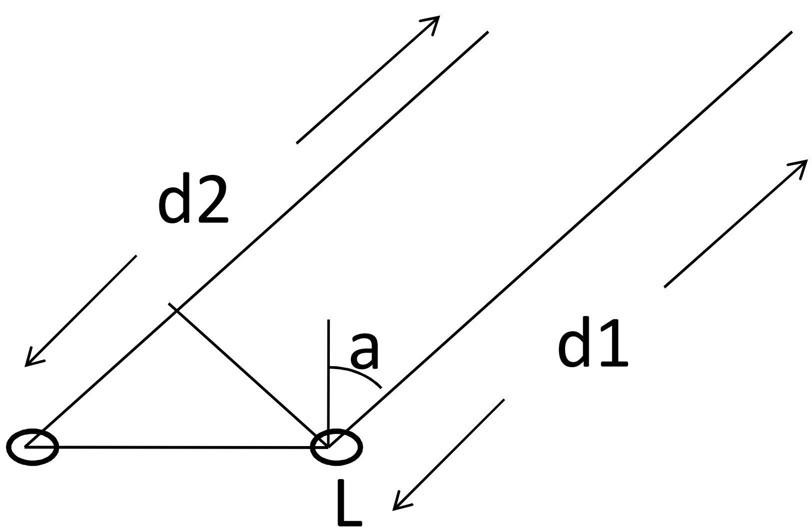
- Similar ideas from GPS can be extended. However, measuring time of arrival using RF signals might be hard because time values are likely to be very small at small indoor distances. So other ideas are needed.
- Example: Cricket localization system uses RF and ultrasound (US) beacons.
- Fixed nodes send RF and US beacons at one. The time difference between the arrival of both beacons dt is related to distance “d” and velocities v_RF and v_US as dt = d/v_RF – d/v_US. This time difference of arrival (TDOA) can be used to calculate distance, and then triangulate.

# Indoor localization using signal strength

- The signal strength of RF transmissions (from fixed to mobile or other way around) can be used to measure distance. Many indoor localization systems based on this idea.
- However, signal strength is only lossely coordinated with distance, and depends on the actual environment, multipath etc. Need extensive calibration for higher accuracy.
- Such systems need a RF signature database at various locations to match a mobile node to a location.
- Other ideas are to use light and other environmental sensors for building “location signatures”.

# Indoor localization using angle of arrival

- Using two antennas placed close to each other, one can estimate angle-of-arrival as shown below. Multiple such angle measurements can be used to triangulate location. This method is gaining traction with multiple antenna systems.




- If the distances to a far off anchor from two nodes (separated by L) are d1 and d2, and the angle of arrival is "a", then $d2 - d1 = L \sin(a)$. We can compute "a" from this equation, once we know d2-d1.
- Alternately, if we cannot measure d1 and d2, we can try to measure the phases of the signal p1 and p2. Since the phase changes by $2\pi$ over the wavelength of the wave (say $\lambda$), then we can get

$$d2 - d1 = (p2 - p1) * \lambda / 2\pi$$

# Other variations in localization algorithms

- Global vs. local coordinates.
  - Global coordinates. If you know the global coordinates of anchors, you can find global coordiantes of mobile host
  - Local coordinates that make sense only in a local setting. Find distances between enough pairs of nodes to fit the nodes into a "rigid graph"
- Incremental vs. concurrent
  - Incremental algorithms try to localize one node at a time.
  - Concurrent algorithms try to find solutions for all location variables using optimization techniques.