Localization:
Algorithms and System

Applications of Location Information

- Location aware information services
  - e.g., E911, location-based search, target advertisement, tour guide, inventory management, traffic monitoring, disaster recovery, intrusion detection
- Scientific applications
  - e.g., air/water quality monitoring, environmental studies, biodiversity
- Military applications
- Resource selection (server, printer, etc.)
- Sensor networks
  - Geographic routing
  - "Sensing data without knowing the location is meaningless." [IEEE Computer, Vol. 33, 2000]
- New applications enabled by availability of locations

Outline

- Localization in single hop wireless networks
  - Global positioning system (GPS)
  - War-driving
- Localization in multihop wireless networks
  - Sextant

Global Position Systems

- US Department of Defense wants very precise navigation
- In 1973, the US Air Force proposed a new system for navigation using satellites
- The system is known as Navigation System with Timing and Ranging: Global Positioning System or NAVSTAR GPS

GPS Operational Capabilities

Initial Operational Capability - December 8, 1993

Full Operational Capability declared by the Secretary of Defense at 00:01 hours on July 17, 1995

NAVSTAR GPS Goals

- What time is it?
- What is my position (including attitude)?
- What is my velocity?
- Other Goals:
  - What is the local time?
  - What is the distance between two points?
  - What is my estimated time arrival?

GPS System: Overview

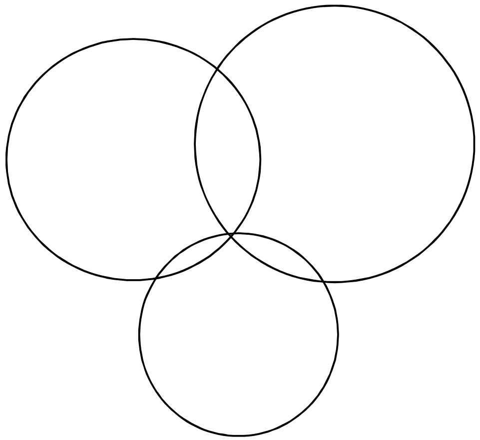
- GPS satellites are essentially a set of wireless base stations in the sky
- The satellites simultaneously broadcast beacon messages
- A GPS receiver measures time of arrival to the satellites, and then uses “triangulation” to determine its position

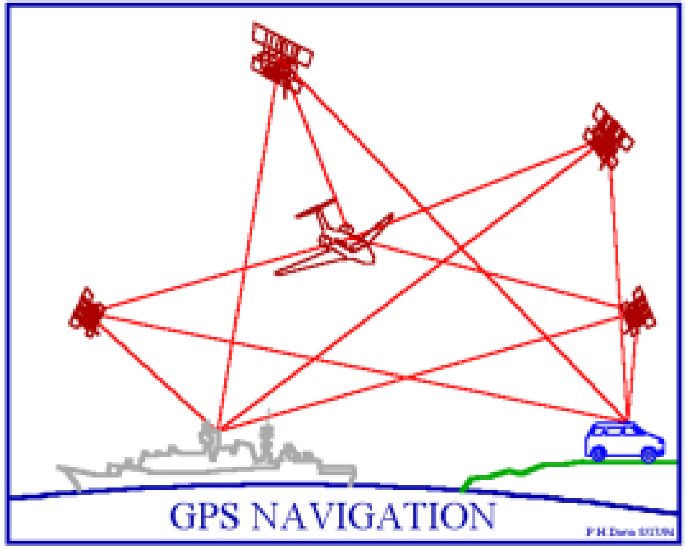
GPS System: Overview

- Assume receiver clock is sync'd with satellites

$$t^{R1} = t^{S} + \frac{\|p - p_1\|}{c} \longrightarrow \|p - p_1\| = c(t^{R1} - t^{S})$$

"Triangulation" determines position

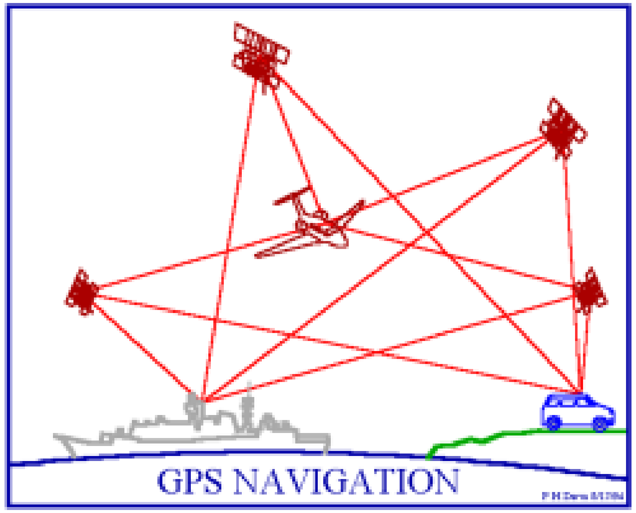




Why we need 4 satellites?

GPS System: Overview

- In reality, receiver clock is not sync'd with satellites



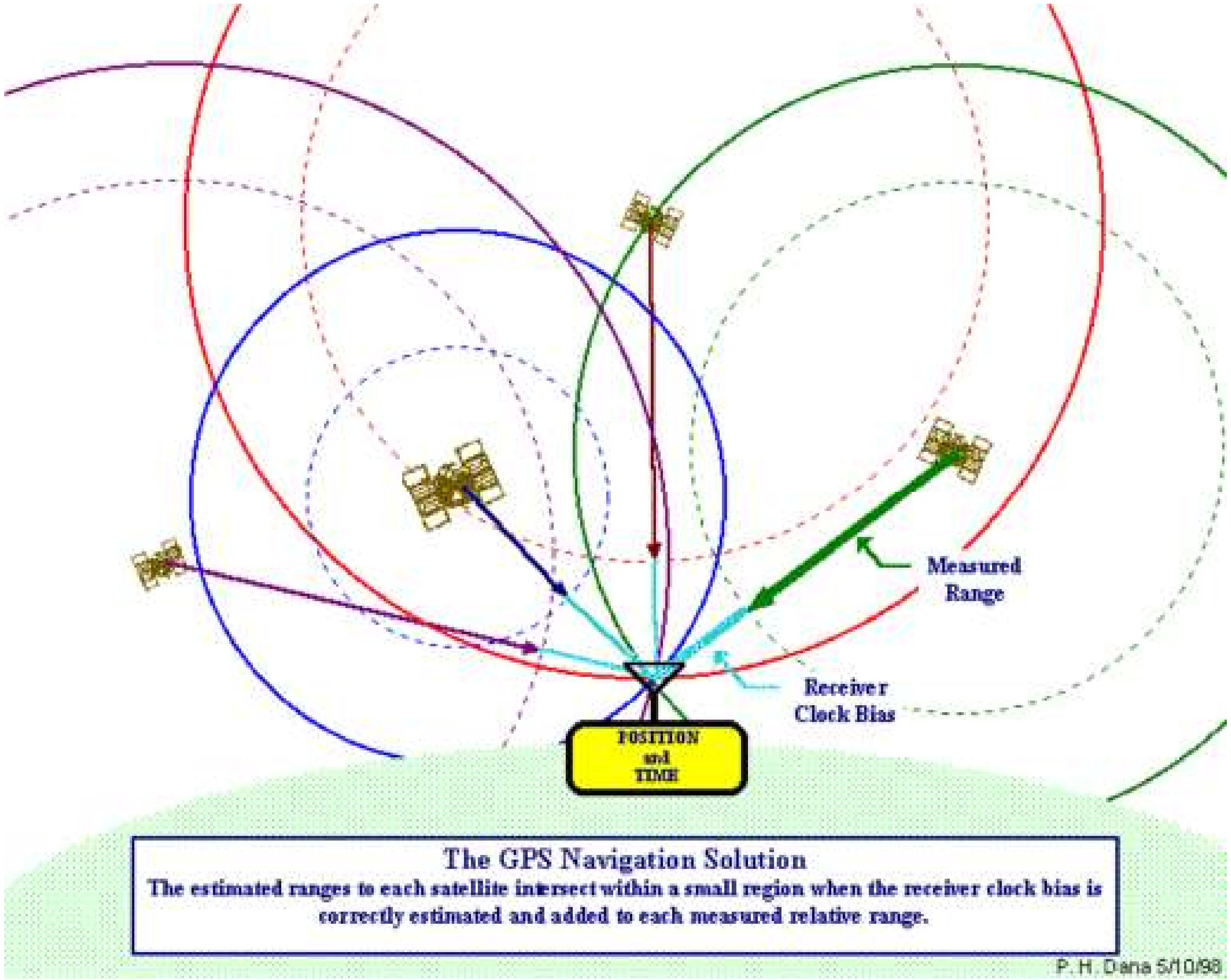
Thus need one more satellite to have the right number of equations to estimate clock

$$t^{R1} = t^S + \frac{d_1}{c} + \delta_{clock-drift} \longrightarrow \|p - p_1\| = c(t^{R1} - t^S - \delta_{clock-drift})$$

$$= c(t^{R1} - t^S) - c\delta_{clock-drift}$$

called pseudo range

We need to see 4 satellites in GPS



Each satellite timestamp transmission and receives measure received time

- Time of transmission
- Correct satellite location
- Speed of radio wave
- Time of arrival

GPS Satellite Transmissions

- Requirements
  - all 24 GPS satellites transmit on the same frequencies
  - resistant to jamming
  - resistant to spoofing
  - allows military control of access (selected availability)
  - satellites provide their positions

GPS Multiple Access and Identifying Codes

- All 24 GPS satellites transmit on the same two frequencies BUT use different codes
  - i.e., Modulation used is
    - Direct Sequence Spread Spectrum (DSSS) and
    - Code Division Multiple Access (CDMA)

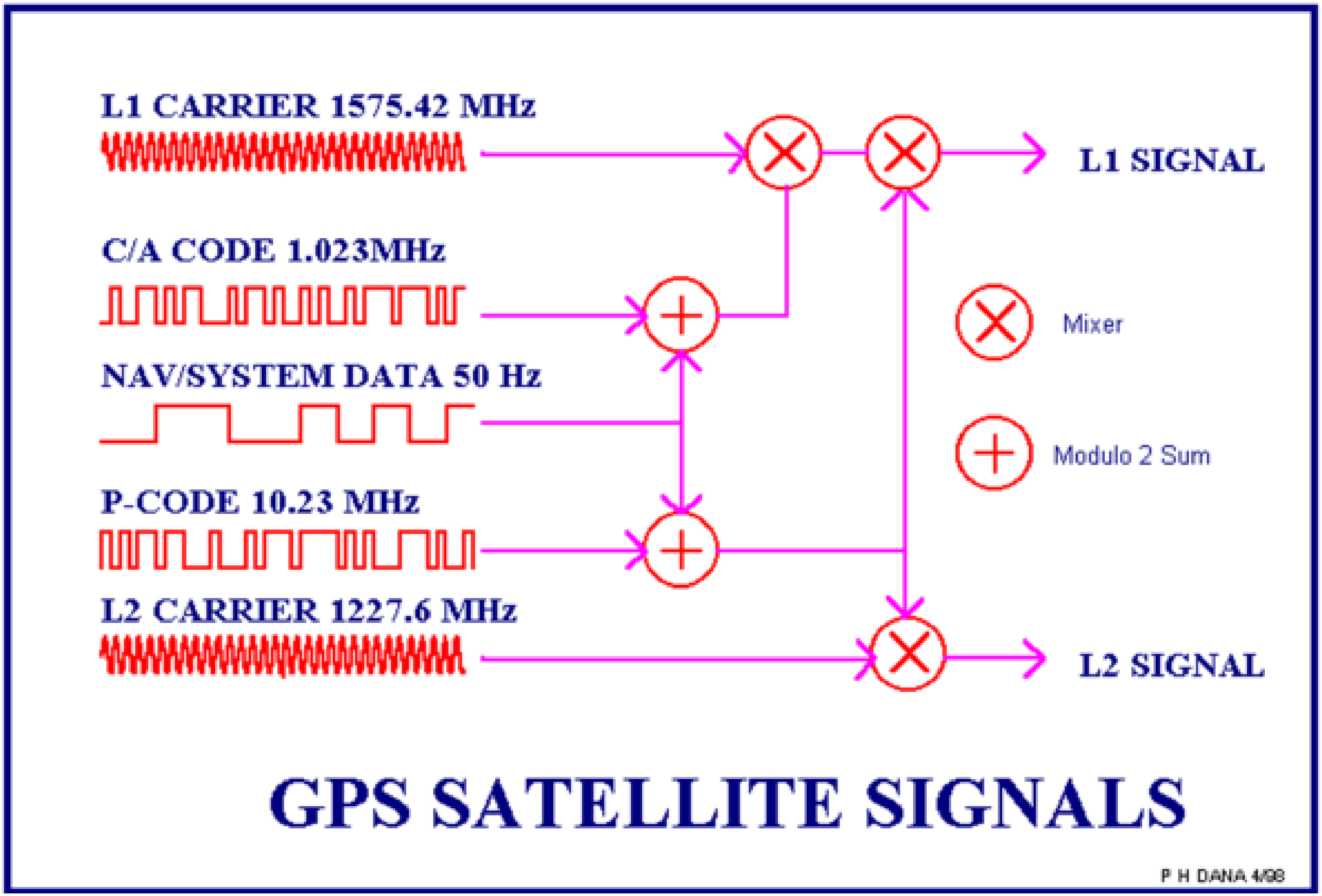
Navigation Message

- To compute position one must know the positions of the satellites
- Navigation Message (37,500 bits) - transmitted on both L1 and L2 at 50 bps
- Navigation message consists of:
  - satellite status to allow calculating position
  - clock information

GPS Identifying Codes

- Two types of clock signals
  - C/A Code - Coarse/Acquisition Code available for civilian use on L1 provides 300 m resolution
  - P Code - Precise Code on L1 and L2 used by the military provides 3 m resolution
  - Encrypted P Code provides selected availability and anti-spoofing

GPS Messages



GPS Receiver

- Typical receiver: C/A code on L1
- During the "acquisition" time you are receiving the navigation message also on L1
- The receiver then reads the timing information and computes the "pseudo-ranges"

Denial of Accuracy (DOA)

- The US military uses two approaches to prohibit use of the full resolution of the system
  - Anti-Spoofing (AS) - P-code is encrypted
  - Selective availability (SA)
    - noise is added to the clock signal
    - the navigation message has “lies” in it

GPS Operation

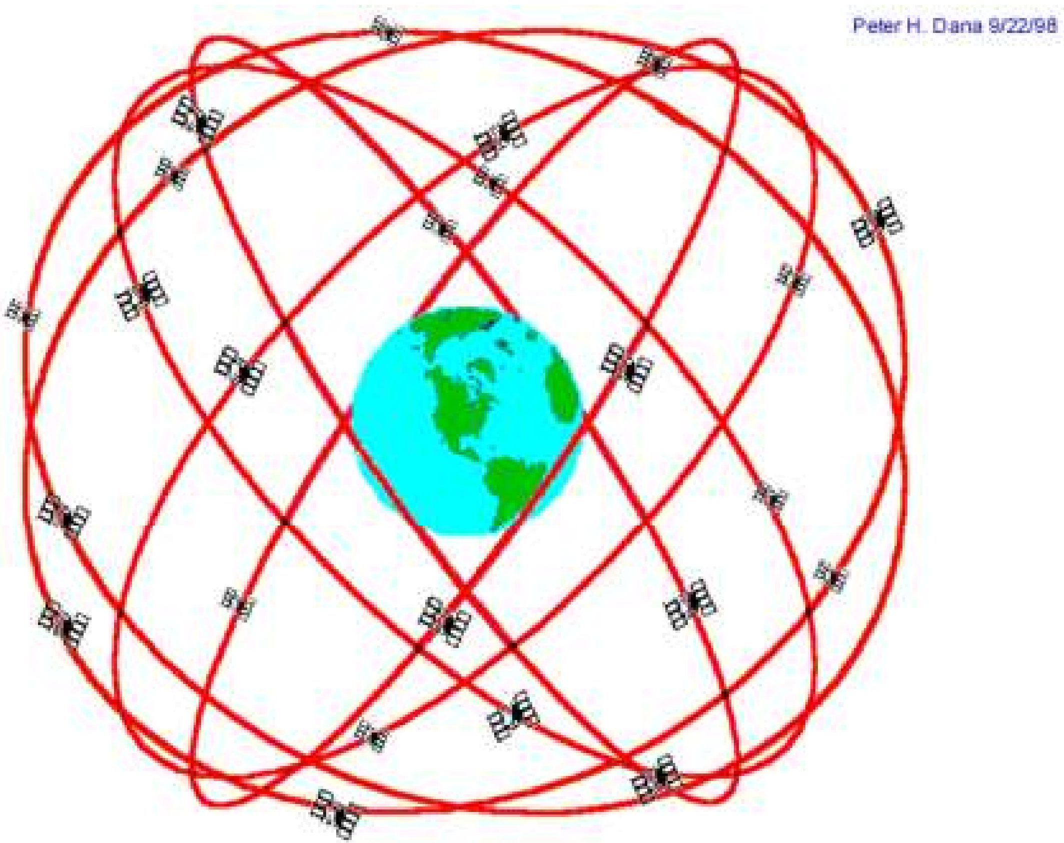
- Segments (components)
  - space segment: the constellation of satellites
  - control segment: control the satellites
  - user segment: users with receivers

Space Segment

Space Segment

- System consists of 24 satellites in the operational mode
  - 21 in use
  - 3 other satellites are used for testing
- Altitude: 20,200 Km with periods of 12 hr.
- Current Satellites: Block IIR- 25,000,000 2000 KG
- Hydrogen maser atomic clocks
  - these clocks lose one second every 2,739,000 million years

GPS Orbits



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Control Segment

Master Control Station is located at the Consolidated Space Operations Center (CSOC) at Flacon Air Force Station near Colorado Springs

Peter H. Dana 5/27/95

Global Positioning System (GPS) Master Control and Monitor Station Network

CSOC

- Track the satellites for orbit and clock determination
- Time synchronization
- Upload the Navigation Message
- Manage Denial Of Availability (DOA)

GPS: Summary

- GPS is among the simplest localization system in terms of topology
- Limitations of GPS
  - Hardware requirements vs. small devices
  - GPS jammed by adversaries
  - GPS spoofing
  - Obstructions to GPS satellites common
    - Each node needs LOS to 4 satellites
    - LOS hard to achieve in many environments, e.g., urban canyon, indoors, and underground

What other signals to use for localization?

Signals for localization

- RF signal: WiFi, bluetooth, sensor, UWB
- Acoustic signal
- Ultrasound
- Light
- Magnetic field
- …

Accuracy Characterization for Metropolitan-scale Wi-Fi Localization

Yu-Chung Cheng (UCSD, Intel Research)
Yatin Chawathe (Intel Research)
Anthony LaMarca (Intel Research)
John Krumm (Microsoft Research)

Motivation

- Limitations of GPS
  - Does not work indoors or in urban canyons
  - GPS devices are not nearly as prevalent as Wi-Fi
- Goals
  - High coverage and accuracy (<10m)
  - Both outdoor and indoor

Localization Using WiFi

- Wi-Fi is everywhere now
  - No new infrastructure
  - Low cost
  - APs broadcast beacons
  - "War drivers" already build AP maps
    - Calibrated using GPS
    - Constantly updated
- Position using Wi-Fi
  - Indoor Wi-Fi positioning gives 2-4m accuracy
  - But requires high calibration overhead: 10+ hours per building
- What if we use war-driving maps for positioning?
  - War-driving: driving around looking for wireless networks (coined by Pete Shipley)

Manhattan (Courtesy of Wigle.net)

Contribution

- Metropolitan-scale location with reasonable accuracy using 802.11 based positioning
- Evaluate several location algorithms
  - As the war driving data ages
  - When the calibration data is noisy
  - As the amount of calibration data is reduced

Why do we use RSS for localization using WiFi, not propagation delay?

Methodology

- Training phase
  - Collect AP beacons by "war driving" with Wi-Fi card + GPS
  - Each scan records
    - A GPS coordinate
    - List of Access Points
  - Covers one neighborhood in 1 hr (~1 km^2)
  - Build radio map from AP traces
- Positioning phase
  - Use radio map to position the user
  - Compare the estimated position w/ GPS

What would you do in positioning phase?

Localization Algorithms

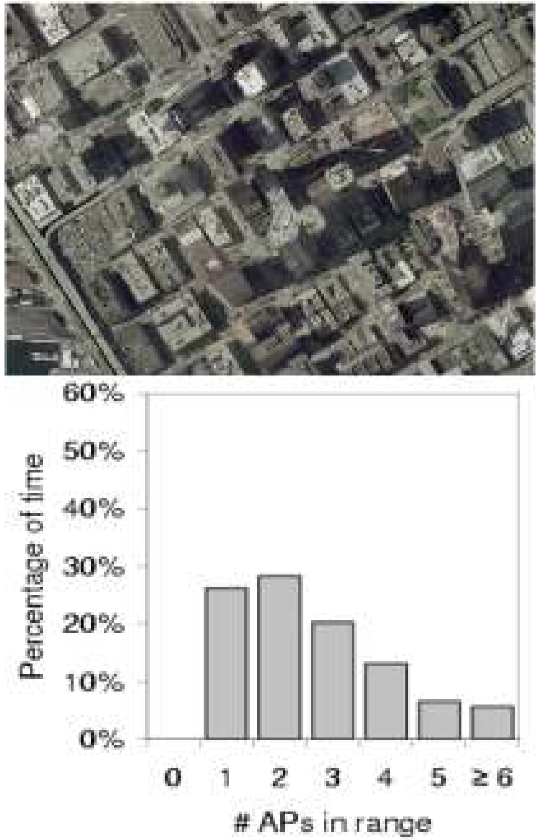
- Centroid
  - A weighted average of positions of all heard APs
    - What should be the weights?
- Fingerprinting
  - User hears APs with some signal strength signature
  - Find top k fingerprints that are the closest match in terms of APs seen and corresponding RSS
    - k=4 works well in practice
    - RADAR: compare using absolute signal strengths [Bahl00]
    - RANK: compare using relative ranking of signal strengths [Krumm03]
  - Determine the user's location as the average of the k fingerprints' locations
- Particle Filters: probabilistic approximation algorithm for Bayes filter

Evaluation

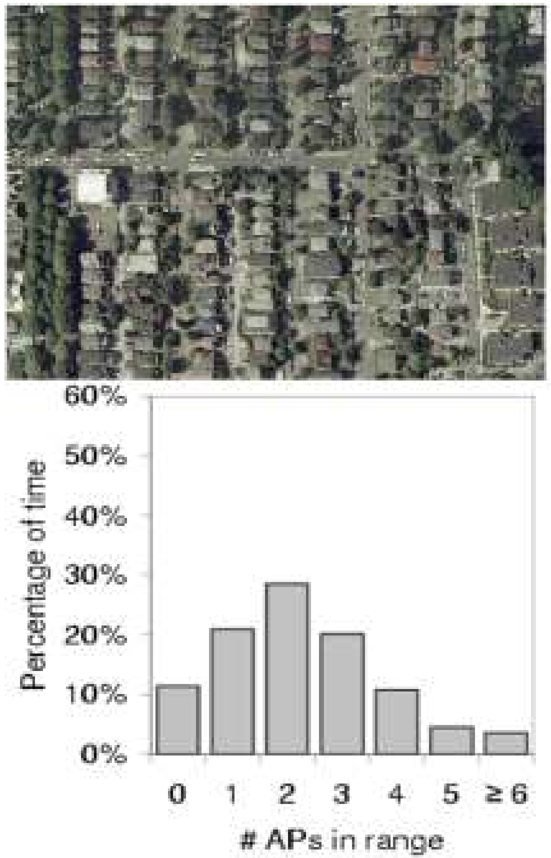
- Choice of algorithms
  - Naïve, Fingerprint, Particle Filter
- Environmental Factors
  - AP density: do more APs help?
  - #APs/scan?
  - AP churn: does AP turnover hurt?
  - GPS noise: what if GPS is inaccurate?

- In your course project, please also try to identify a list of questions you want to answer in your evaluation

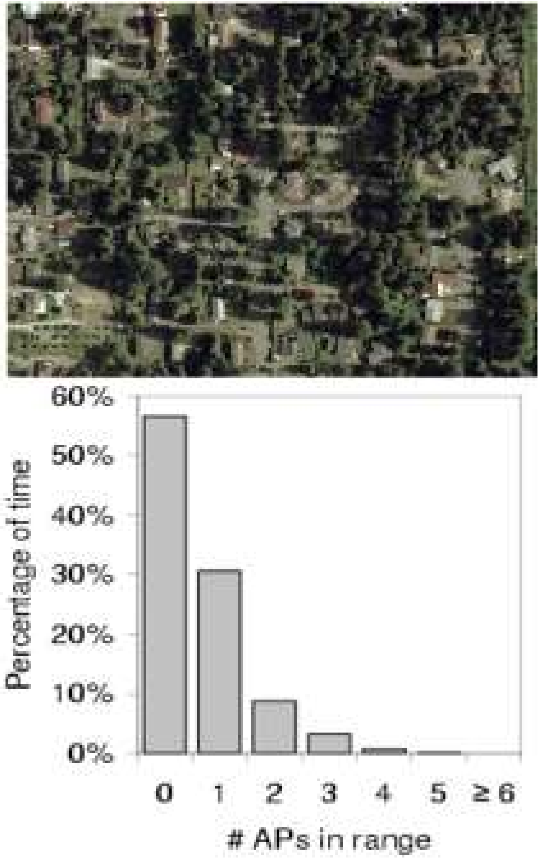
Downtown vs. Urban Residential vs. Suburban



Downtown
(Seattle)

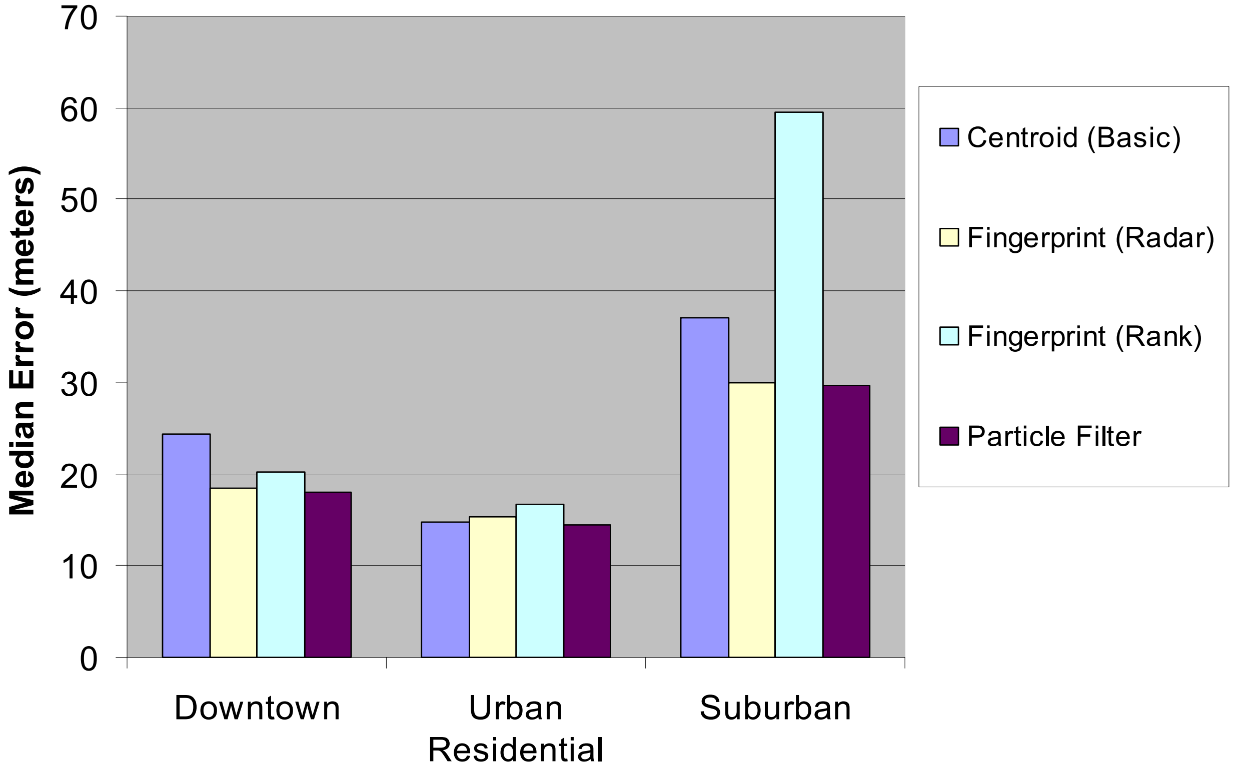


Urban Residential
(Ravenna)



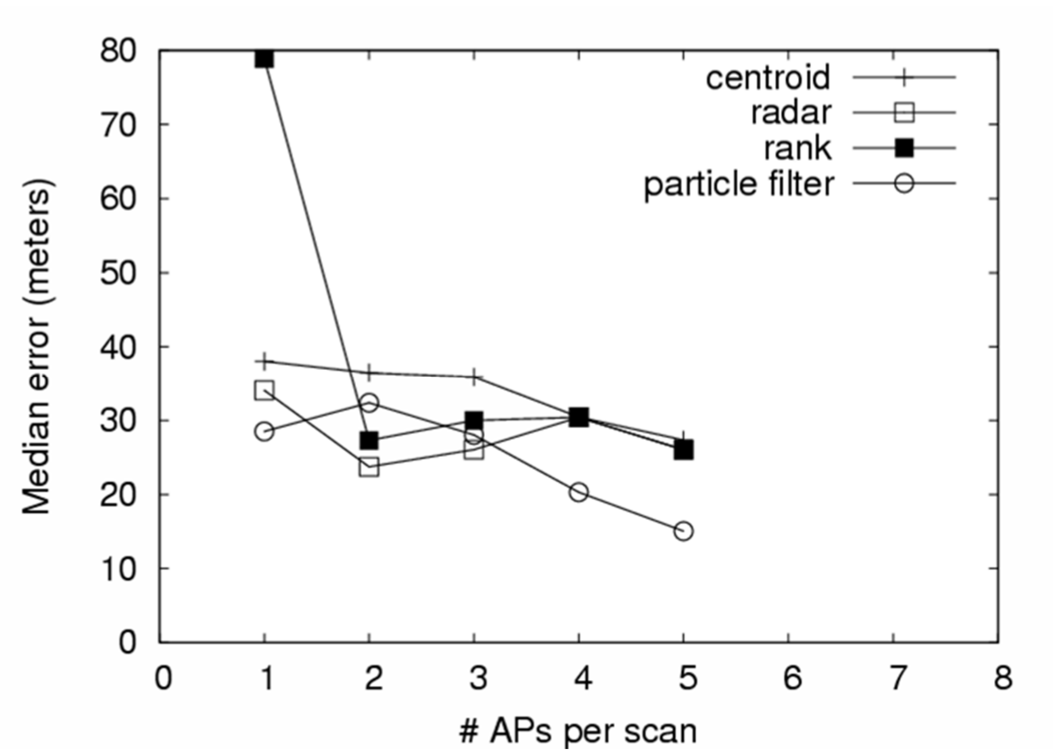
Suburban
(Kirkland)

Baseline Results



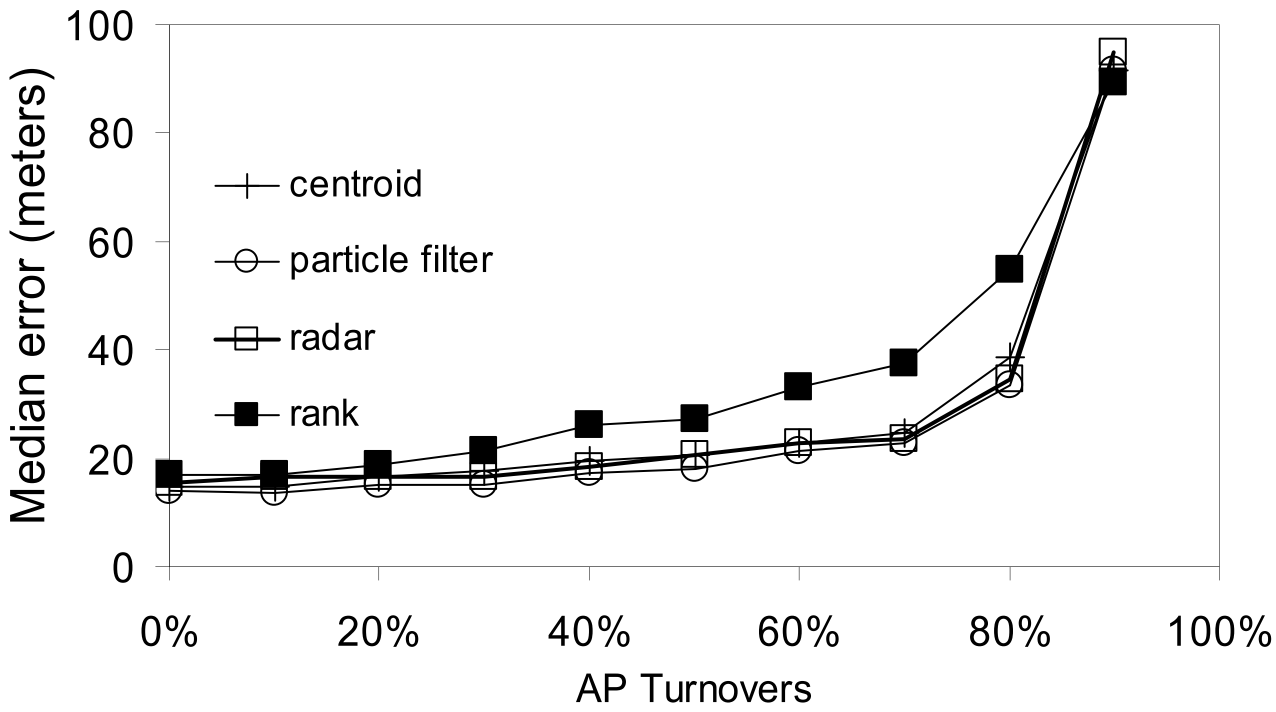
- AP density (horizontal/vertical) matters
- The effects of algorithms is larger in sparse topologies
- Rank tends to perform worst

Effect of APs per scan



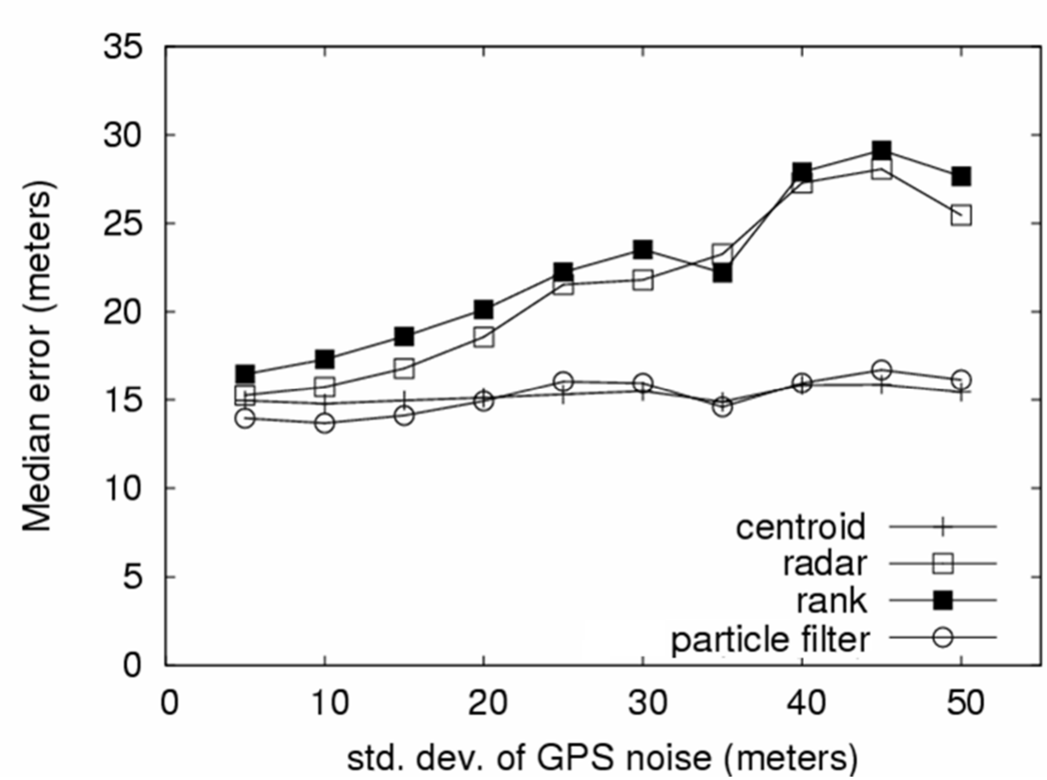
- More APs/scan → lower median error
- Rank does not work with 1 AP/scan

Effects of AP Turnovers



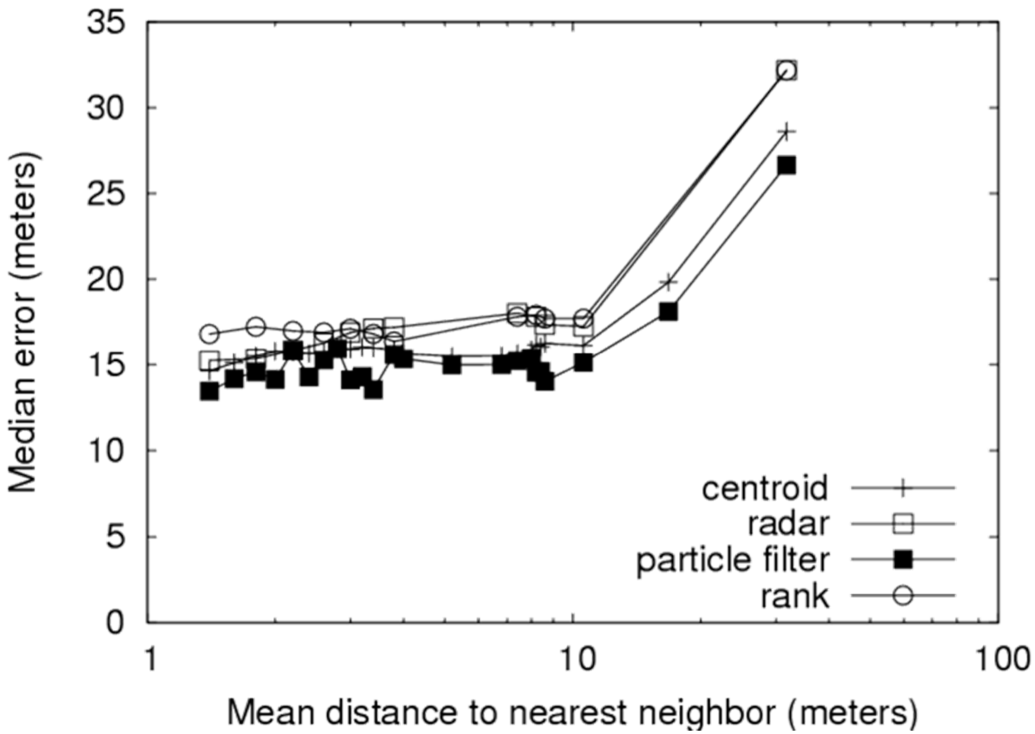
Minimal effect on accuracy even with 50% AP turnover

Effects of GPS noise



Particle filter & centroid are less sensitive to GPS noise

Scanning density



- 1 scan per 10 meters is good == 25 mph driving speed at 1 scan/sec
- More war-drives do not help

Summary

- Wi-Fi-based location has low calibration overhead
  - 1 neighborhood in 1 hour
- Positioning accuracy depends mostly on AP density
  - Urban 13~20m, suburban ~40m
  - Dense AP records get better accuracy
  - In urban area, simple algo. (centroid) yields same accuracy as other complex ones
  - Rank fingerprint algorithm is usually among the worst
- AP turnovers & low training data density do not degrade accuracy significantly
  - Low calibration overhead
- Noise in GPS only affects fingerprint algorithms