Localization (2)

Hua Huang

Department of Computer Science and Engineering

University of California, Merced

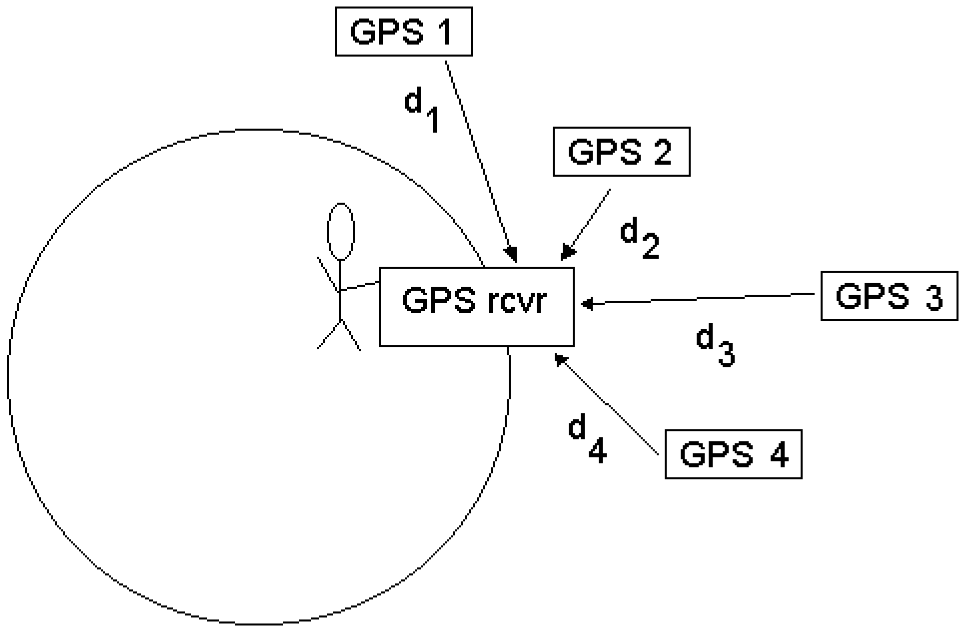
In this lecture

- The Global Positioning System (continued)
- Localization Applications

GPS Continued

Details of how GPS works

- The GPS calculates four unknowns **x, y, z, $\mathbf{t_B}$**, where **x, y, z** are the receiver's coordinates, and $\mathbf{t_B}$ is the time correction for the GPS receiver's clock.
- For satellite i, the position x_i, y_i, z_i is known



Solving for receiver position

$$\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}+ct_B=d_1$$

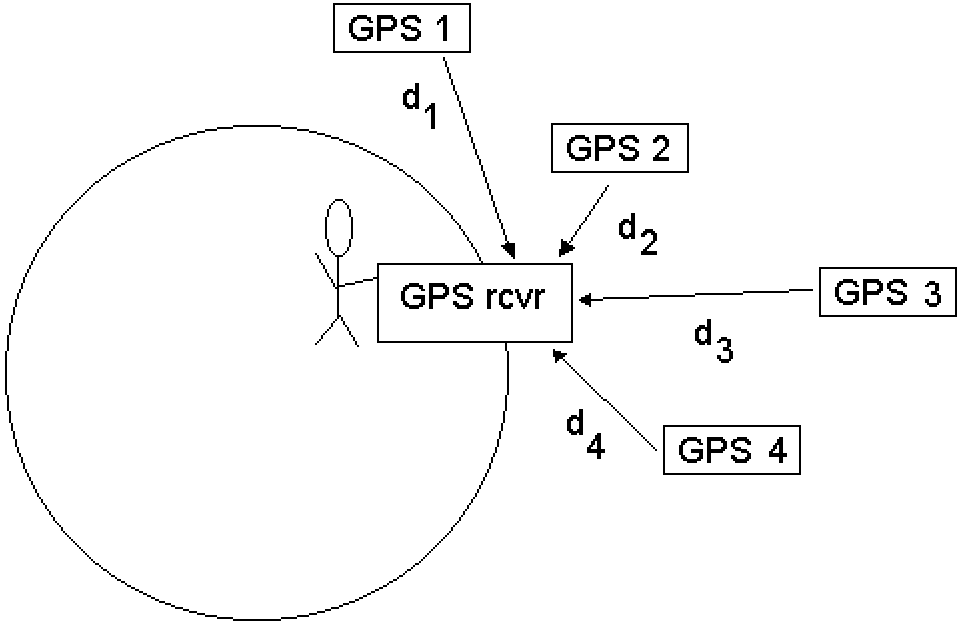
$$\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}+ct_B=d_2$$

$$\sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}+ct_B=d_3$$

$$\sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}+ct_B=d_4$$

- c: speed of light
- x_i: the satellite positions, sent to the receiver

A quadratic programming problem. Solved by mature solvers

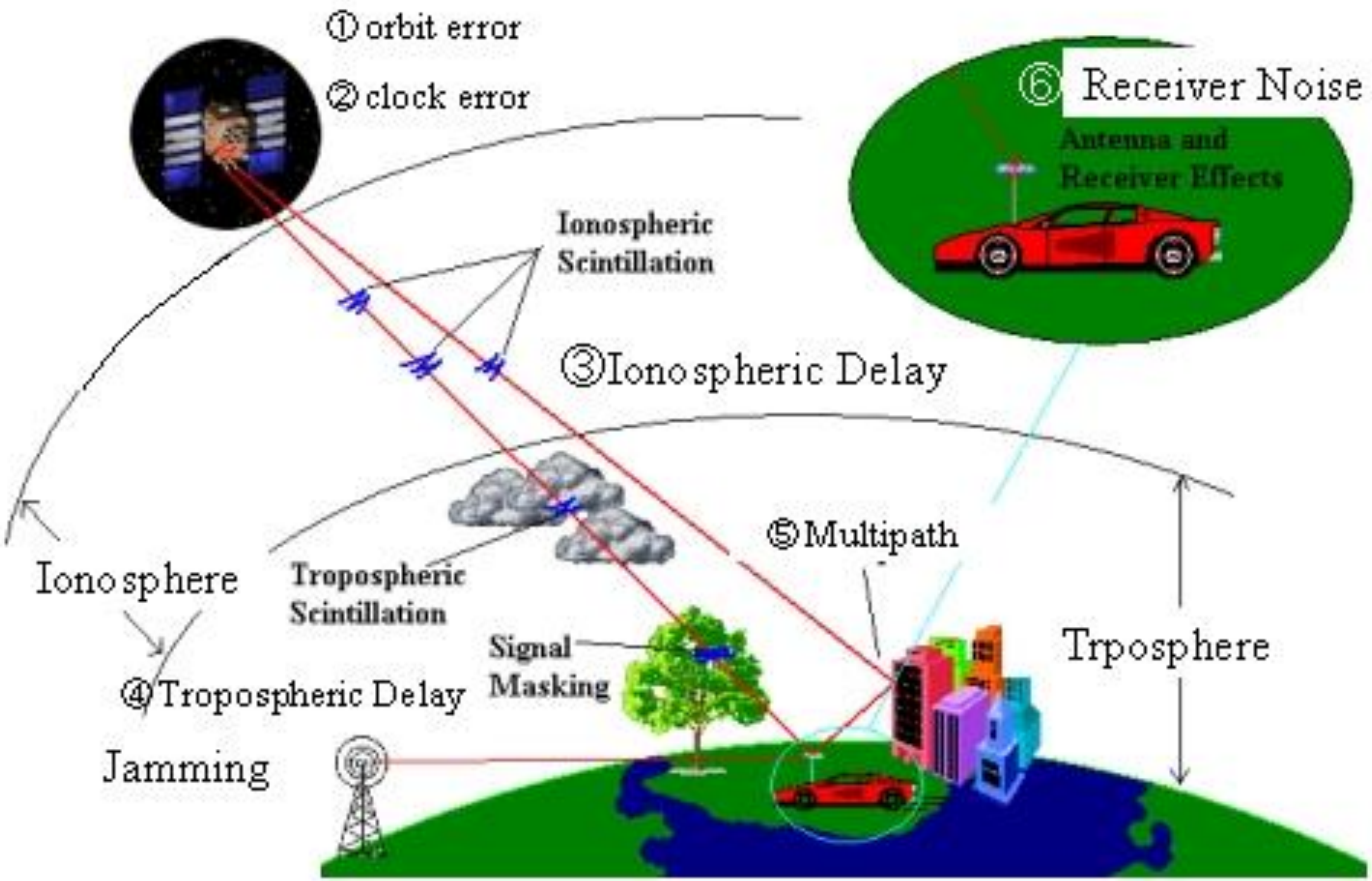


Reducing receiver energy consumption*

- Setting: localizing small and low-cost sensor nodes with limited computation and battery capacities
- Main idea:
  - Use elevation data of the earth to constrain search
    - Works like one more satellite, without the need for ranging
- Collect and store raw GPS samples for online processing
  - Dramatically reduce computation costs

*“Energy Efficient GPS Sensing with Cloud Offloading”, Sensys

Errors on GPS Signal



GPS error: Satellite clocks

- Satellites use atomic clocks, which are very accurate but can drift up to a millisecond. Errors: 1.5-3.6 meters

- Mitigation: minimized by calculating clock corrections (at monitoring stations) and transmitting the corrections along with the GPS signal to appropriately outfitted GPS receivers.

GPS error: Orbital Errors

- GPS receivers calculate coordinates relative to the known locations of satellites in space. Errors<1 meter

- Mitigation: The GPS Control Segment monitors satellite locations at all times, calculates orbit eccentricities, and compiles these deviations in documents called ephemerides.

- GPS receivers that are able to process ephemerides can compensate for some orbital errors.

GPS error: Upper Atmosphere (Ionosphere)

- As GPS signals pass through the upper atmosphere (the ionosphere 50-1000km above the surface), signals are delayed and deflected. Errors: 5-7 meters

- Mitigation: By modeling ionosphere characteristics, GPS monitoring stations can calculate and transmit corrections to the satellites, which in turn pass these corrections along to receivers.

GPS error: Lower Atmosphere (Troposhpere)

- The lower atmosphere delays GPS signals, adding slightly to the calculated distances between satellites and receivers. Errors: < 1 meter

GPS error: Multipath Effects

- Ideally, GPS signals travel from satellites through the atmosphere directly to GPS receivers.
- In reality, GPS receivers must discriminate between signals received directly from satellites and other signals that have been reflected from surrounding objects, such as buildings, trees, and even the ground. Errors: up to 1.2 meters

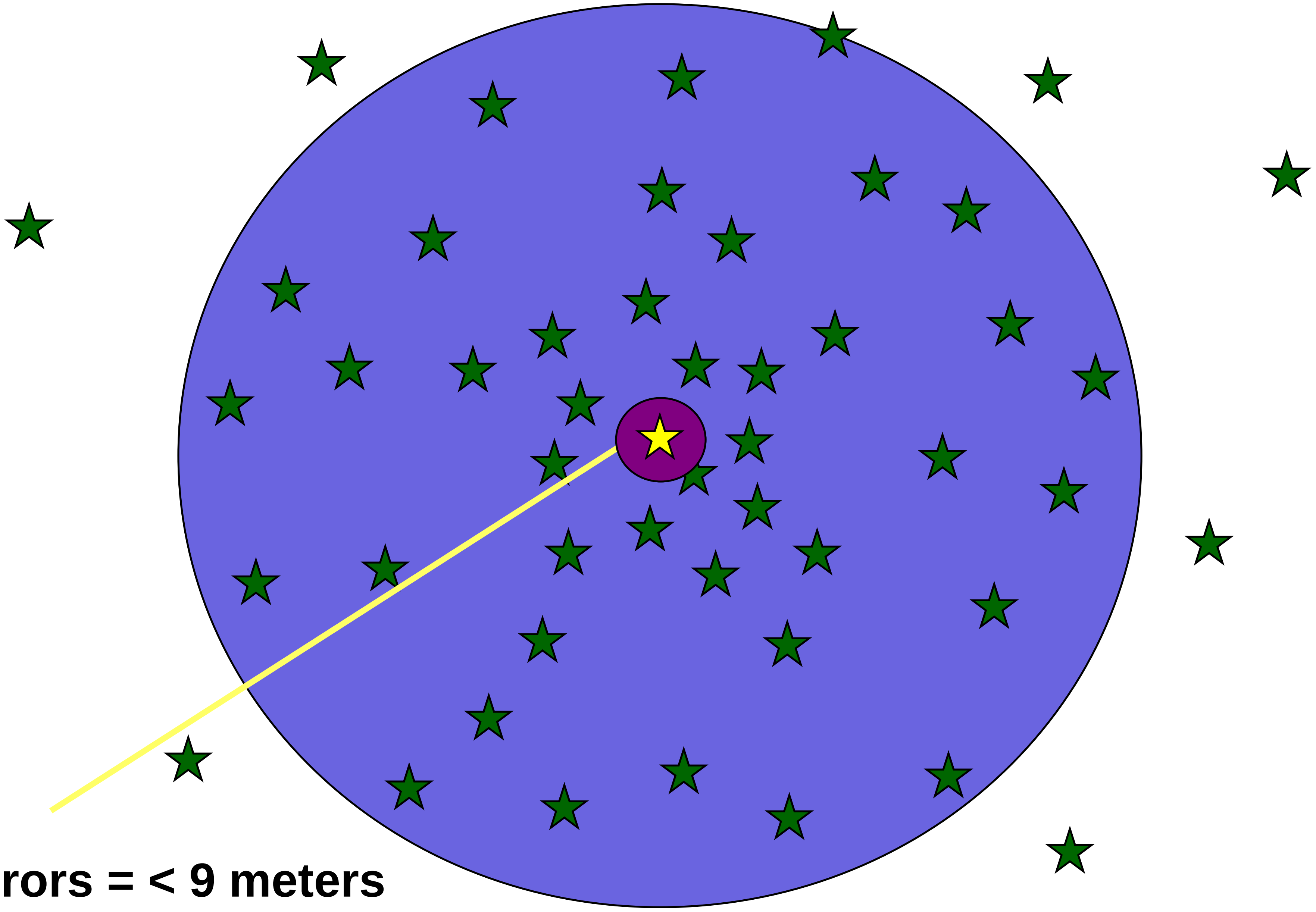
- Mitigation: use antenna technique to track signals that are at lest 15 degrees above horizon.

Sources of GPS Error

Source	Amount of Error
Satellite clocks:	1.5 to 3.6 meters
Orbital errors:	< 1 meter
Ionosphere:	5.0 to 7.0 meters
Troposphere:	0.5 to 0.7 meters
Receiver noise:	0.3 to 1.5 meters
Multipath:	0.6 to 1.2 meters

Errors are cumulative and increased by PDOP.

Receiver Errors are Cumulative!



System errors = < 9 meters

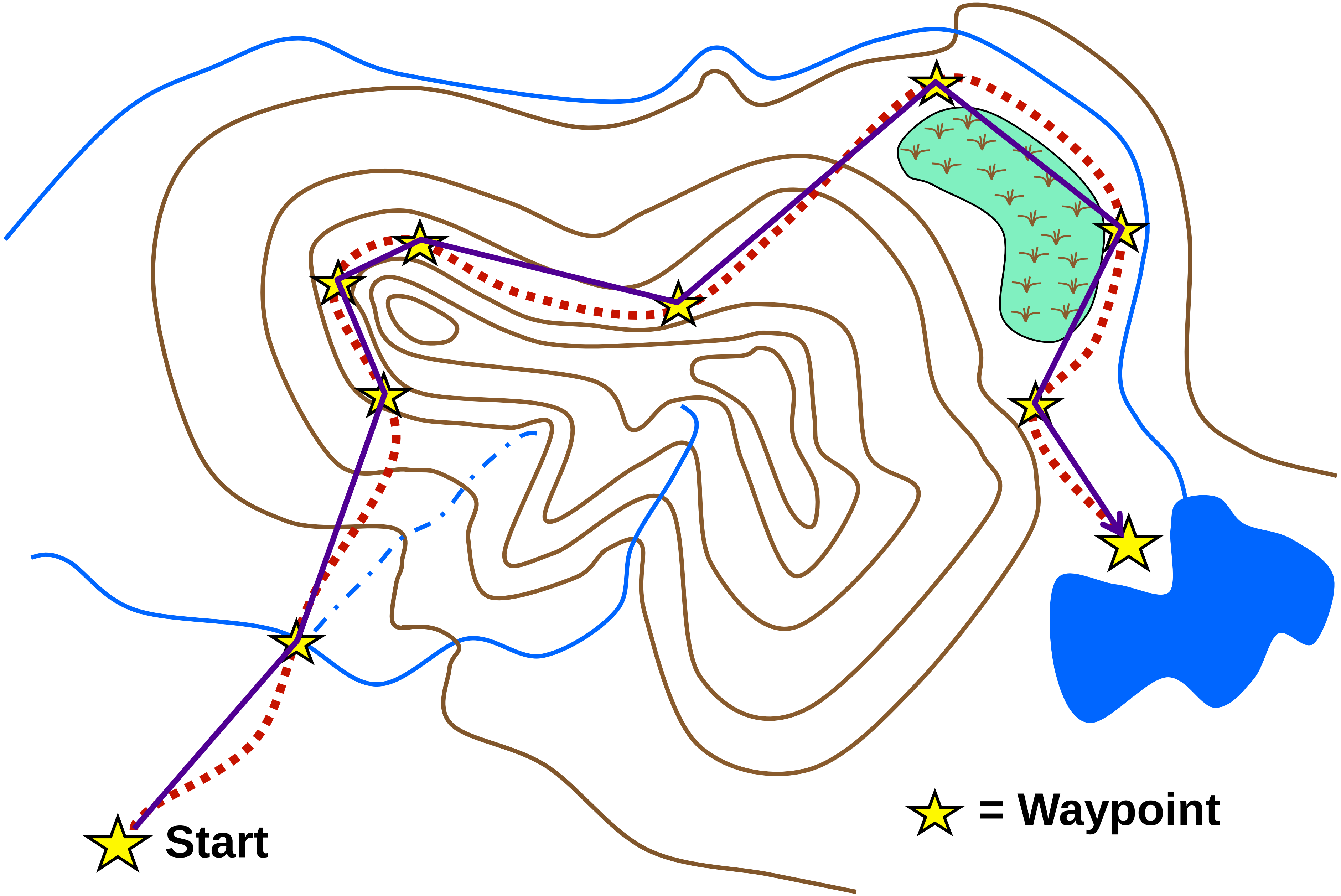
GPS position fix

- A position is based on real-time satellite tracking.
- It’s defined by a set of coordinates.
- A position represents only an *approximation* of the receiver’s true location.
- A position is not static. It changes constantly as the GPS receiver moves (or wanders due to random errors).
- A receiver must be in 2D or 3D mode (at least 3 or 4 satellites acquired) in order to provide a position fix.
- 3D mode dramatically improves position accuracy.

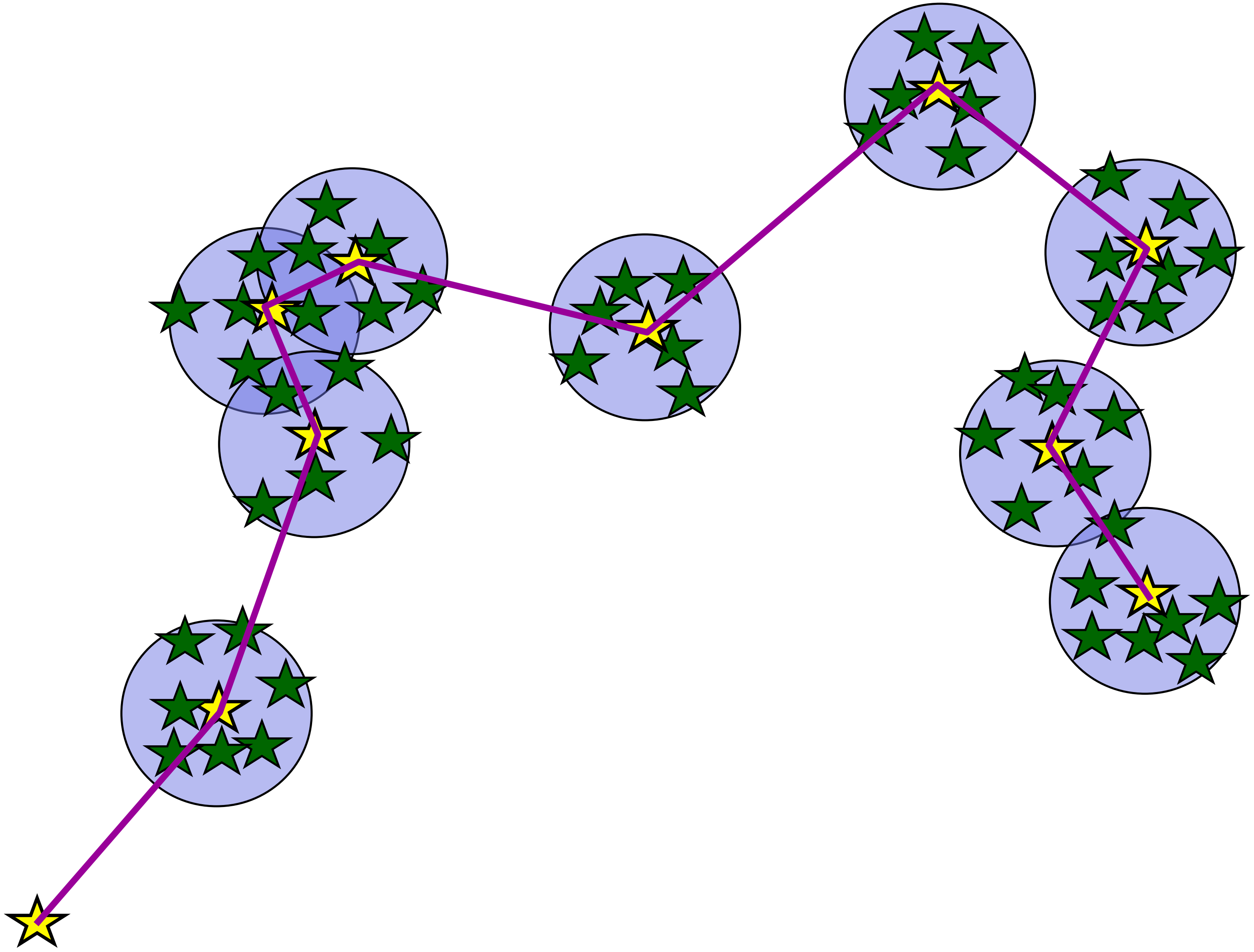
Waypoint

- A waypoint is based on coordinates entered into a GPS receiver’s memory.
- It can be either a saved position fix, or user entered coordinates.
- It can be created for any remote point on earth.
- It must have a receiver designated code or number, or a user supplied name.
- Once entered and saved, a waypoint remains unchanged in the receiver’s memory until edited or deleted.

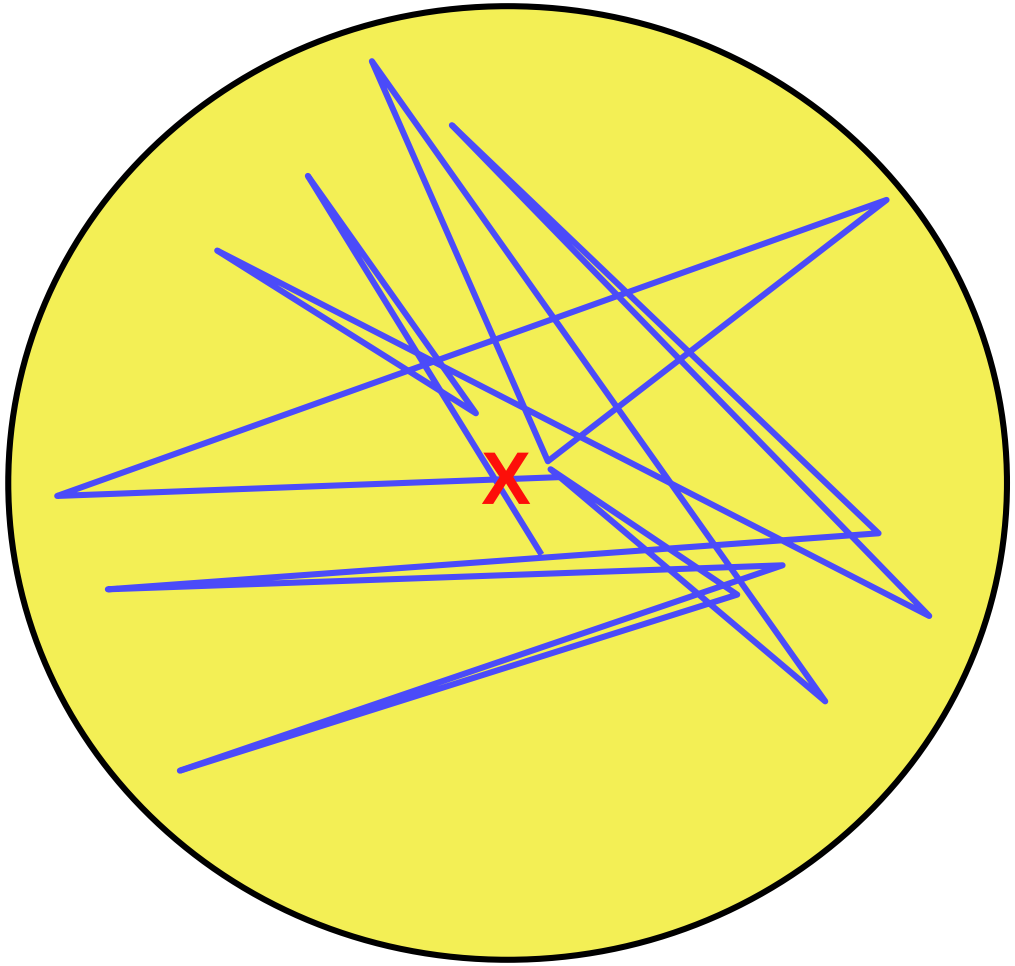
Planning a Navigation Route



How A Receiver Sees Your Route



GPS Waypoint Circle of Error

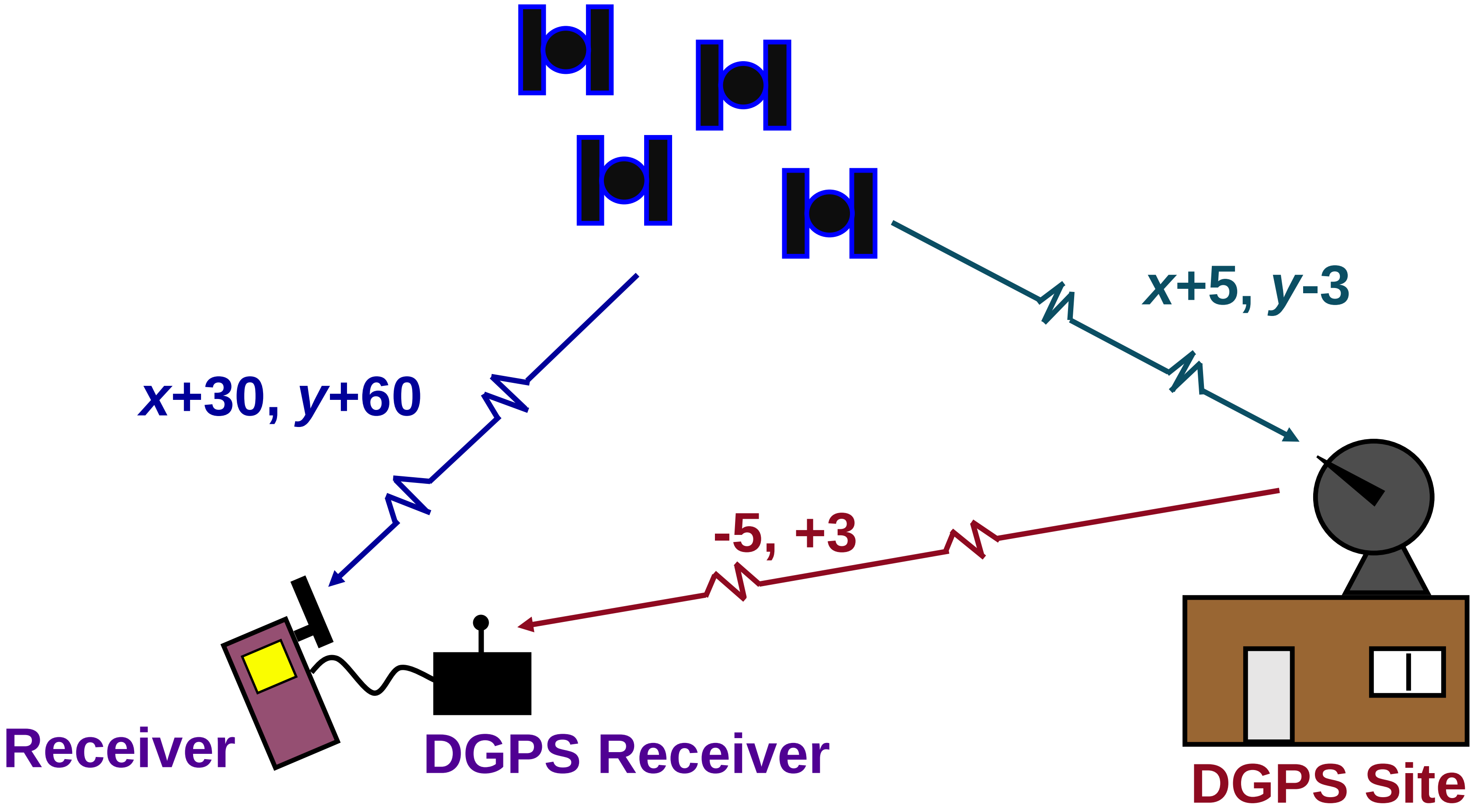


Differential GPS

- Improves nominal GPS accuracy of 15m to up to 3cm

- Basic idea:
  - Use a network of fixed reference ground-based stations to broadcast the difference between GPS result and the ground-truth position
  - The GPS receiver use this difference to correct its own errors.

Real Time Differential GPS



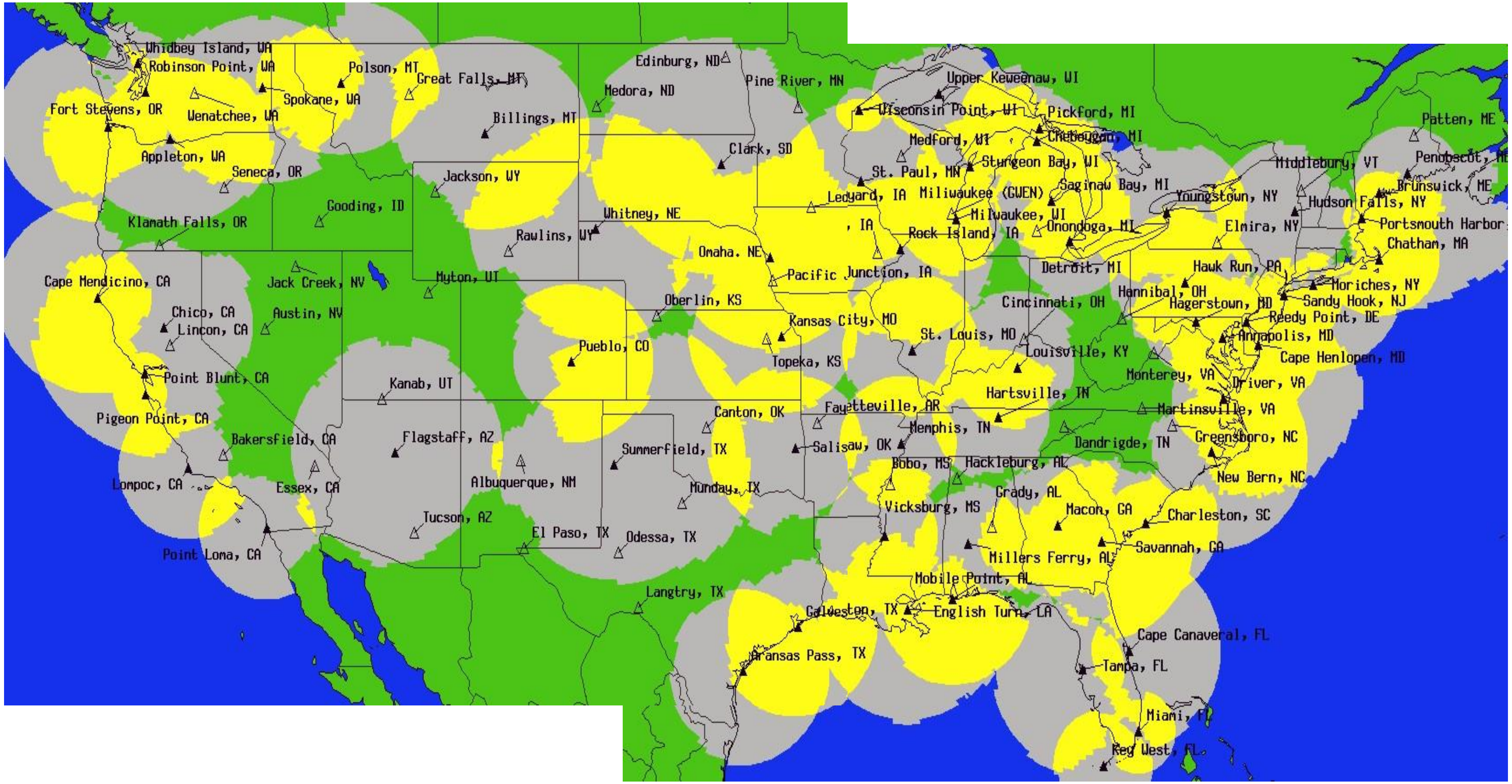
True coordinates = *x*, *y*

Correction = -5, +3

DGPS correction = *x*+(30-5) and *y*+(60+3)

Corrected coordinates = *x*+25, *y*+63

National Differential Global Positioning System Coverage



Yellow areas show overlap between NDGPS stations. Green areas are little to no coverage.

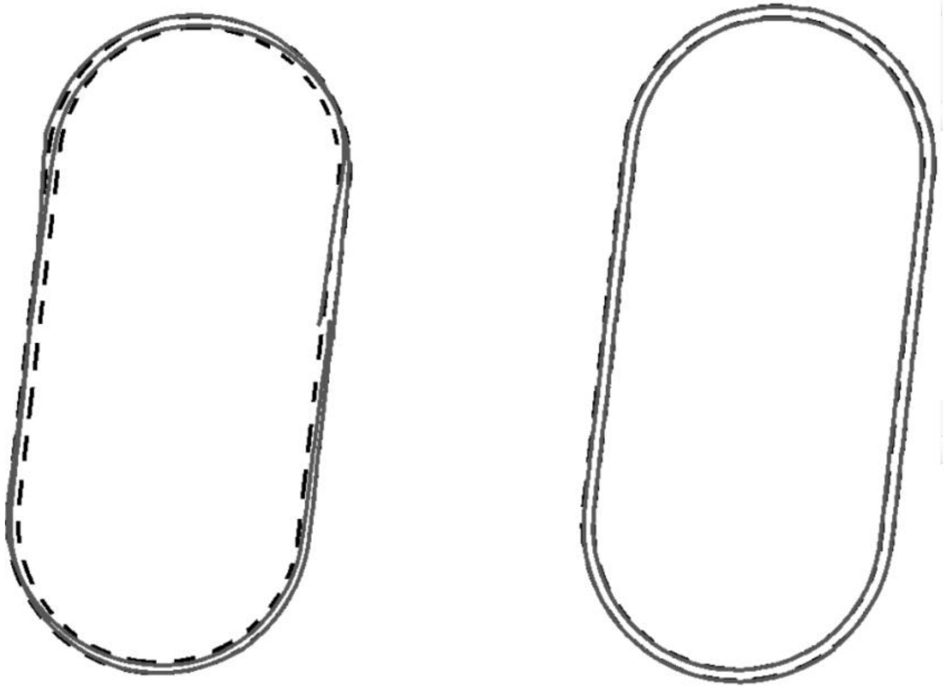
Exercise

Find the ground truth coordinate for receiver 1

	Lat_meas	Long_meas	alt_meas	Lat_ground	Long_ground	Alt_ground
DGPS	37.0366833	35.3744433	60	37.0367146	35.3744596	64.5
Receiver 1	37.03671	35.3744467	65			

Low-cost Differential GPS*

- Use multiple GPS receivers with known relative positions
- Sub-meter accuracy

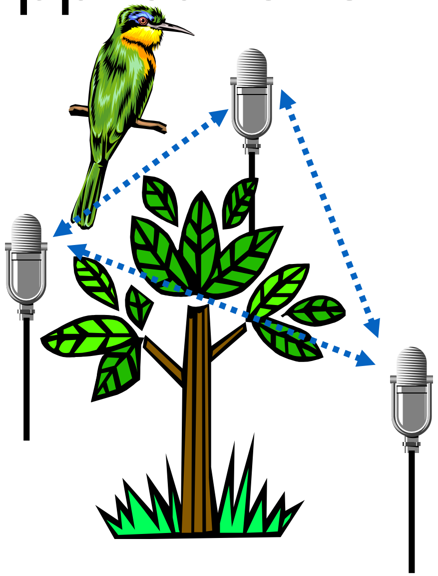


*High-Accuracy Differential Tracking of Low-Cost GPS Receivers, Mobisys

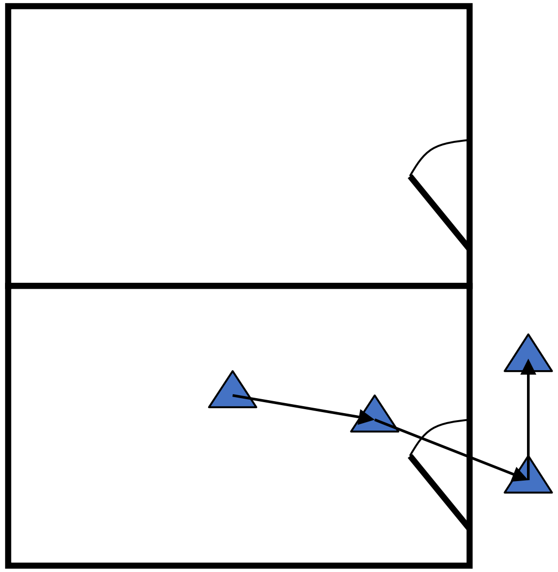
Localization Applications Design Principles

Variety of Applications

- Two applications:



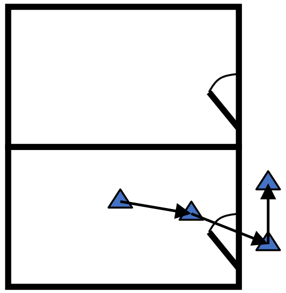
habitat monitoring:
Where is the bird?
What kind of bird is it?



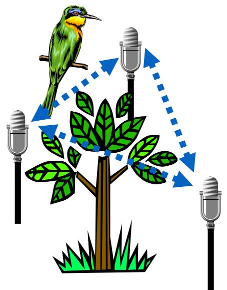
Asset tracking:
Where is the projector?
Why is it leaving the room?

Variety of Application Requirements

- Very different requirements!



- Outdoor operation
  - Weather problems
- Bird is not tagged
- Birdcall is characteristic but not exactly known
- Accurate enough to photograph bird
- Infrastructure:
  - Several acoustic sensors, with known relative locations; coordination with imaging systems



- Indoor operation
  - Multipath problems
- Assets are tagged
- Signals from asset tags can be engineered
- Accurate enough to track through building
- Infrastructure:
  - Room-granularity tag identification and localization; coordination with security infrastructure

Multidimensional Requirement Space

- Granularity & Scale
- Accuracy & Precision
- Relative vs. Absolute Positioning
- Dynamic vs. Static (Mobile vs. Fixed)
- Cost & Form Factor
- Infrastructure & Installation Cost
- Environmental Sensitivity
- Cooperative or Passive Target

Axes of Application Requirements

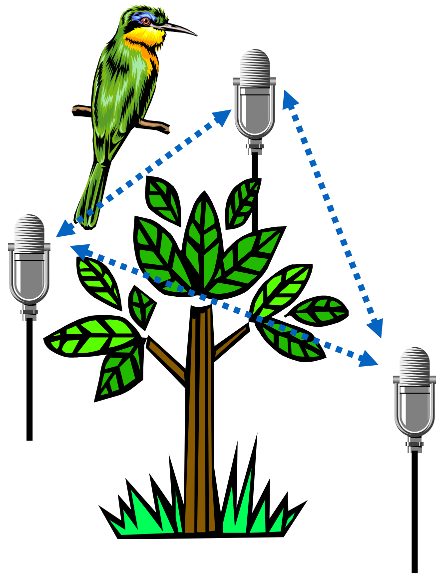
- Granularity and scale of measurements:
  - What is the smallest and largest measurable distance?
  - e.g. 50m (acoustics) vs. 25000km (GPS)
- Accuracy and precision:
  - How close is the answer to "ground truth" (accuracy)?
  - How consistent are the answers (precision)?
- Relation to established coordinate system:
  - GPS? Campus map? Building map?
- Dynamics:
  - Refresh rate? Motion estimation?

Axes of Application Requirements

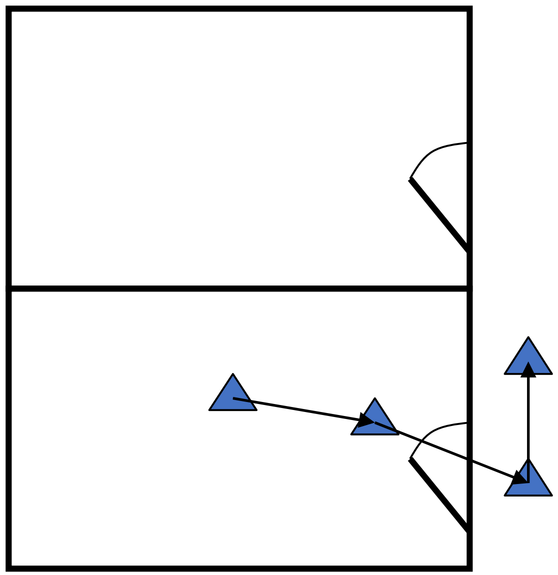
- Cost:
  - Node cost: Power? $? Time?
  - Infrastructure cost? Installation cost?
- Form factor:
  - How big
  - Think about tracking tags on wild animals
- Communications Requirements:
  - Network topology: cluster head vs. local determination
  - What kind of coordination among nodes?
- Environment:
  - Indoor? Outdoor? On Mars?
- Is the target known? Is it cooperating?

Returning to our two Applications…

- Choice of mechanisms differs:



Passive habitat monitoring:
Minimize environ. interference
No two bird songs are the same



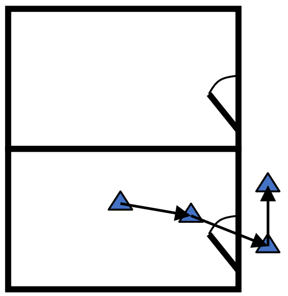
Asset tracking:
Controlled environment
We know exactly what tag is like

Variety of Localization Mechanisms

- Very different mechanisms indicated!

- Bird is not tagged
  - Passive detection of bird presence
- Birdcall is characteristic but not exactly known
- Bird does not have radio; Acoustic based ranging
- Passive target localization
  - Requires
    - Sophisticated detection
    - Coherent beamforming
    - Large data transfers

- Asset is tagged
  - Projector might know it had moved
- Signals from asset tag can be engineered
- Tag can use radio signal for ranging
- Cooperative Localization
  - Requires
    - Basic correlator
    - Simple triangulation
    - Minimal data transfers



Mobile Localization using Motion Sensing

User tracking in campus, is GPS the solution?

Pros: Good accuracy

Cons: Poor battery lifetime

Is GSM the solution?

Pros: Long battery lifetime

Cons: Poor accuracy

What about WiFi Localization?

E.g., SkyHook:

Basic Idea:

1. Several trucks war-drive a place
2. Create Radio map = <Location: WiFi IDs>
3. Distribute map to phones
4. Phone user goes to war-driven region, overhears WiFi IDs
5. Reverse Look Up IDs against radio map
6. Obtains location

Is Wifi the solution?

Middle Ground

Lower Accuracy than GPS, Longer Battery lifetime

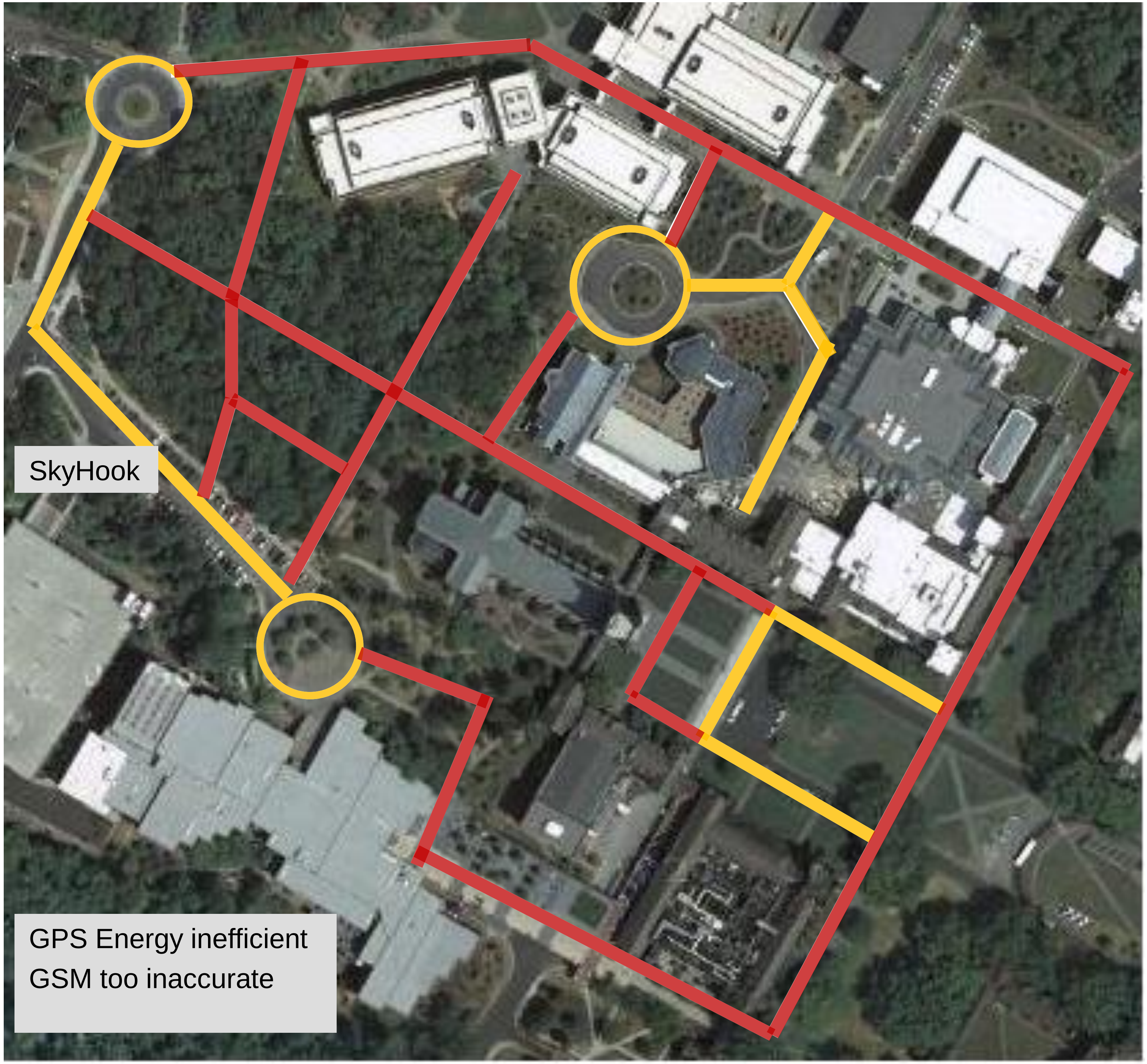
Better Accuracy than GSM, Shorter Battery lifetime

but …

At the cost of:

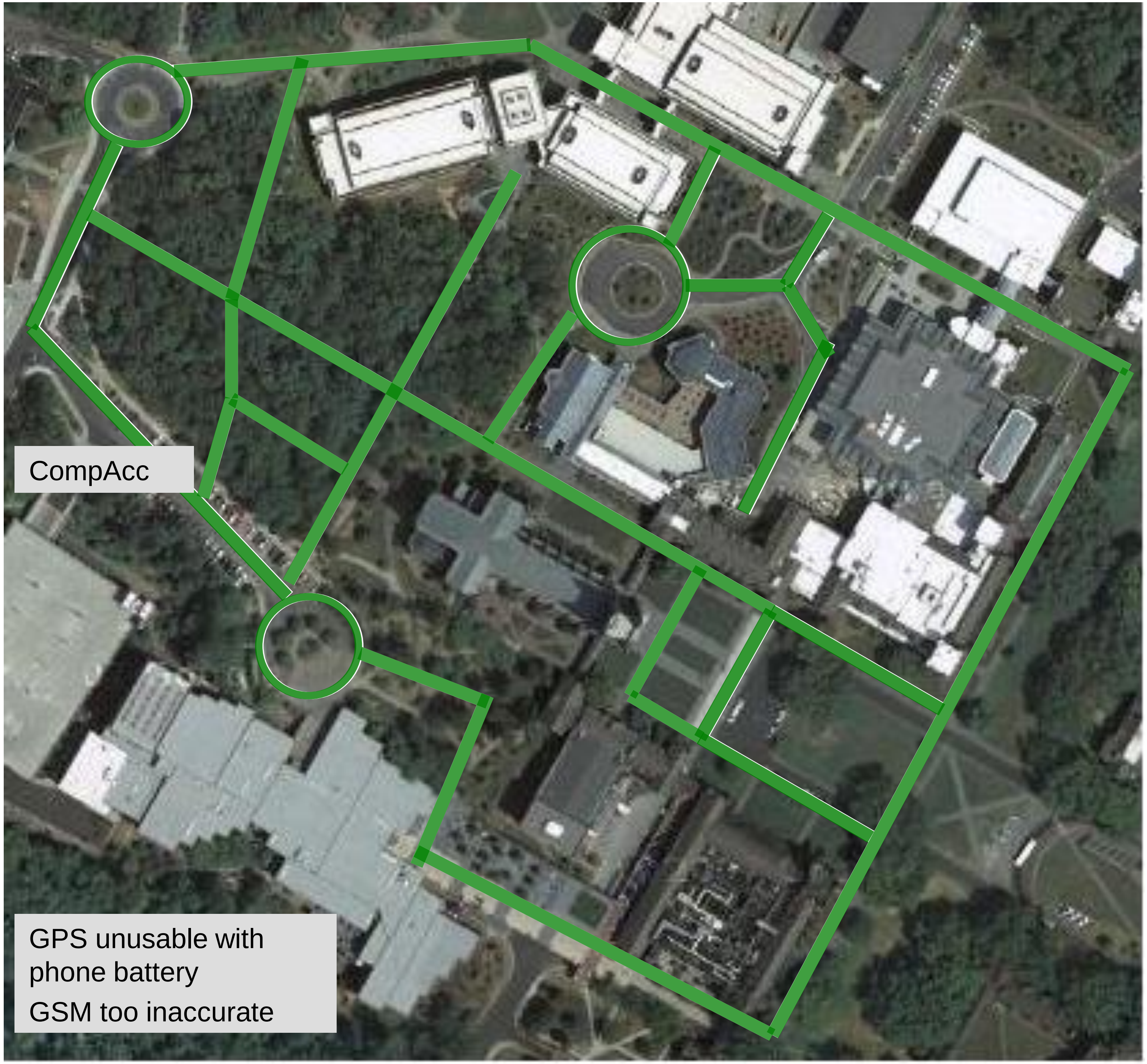
- Degraded location accuracy: walking paths ~ 60m
- Reliance on infrastructure (APs)
- War-driving ($$ + carbon footprint)

"NYTimes: Skyhook fleet 500 trucks/drivers"



GPS
No Eng. Eff. & Acc.
Solution

WiFi
Better than GPS Eng.
Eff.



Eng. Eff. & Acc.
Solution

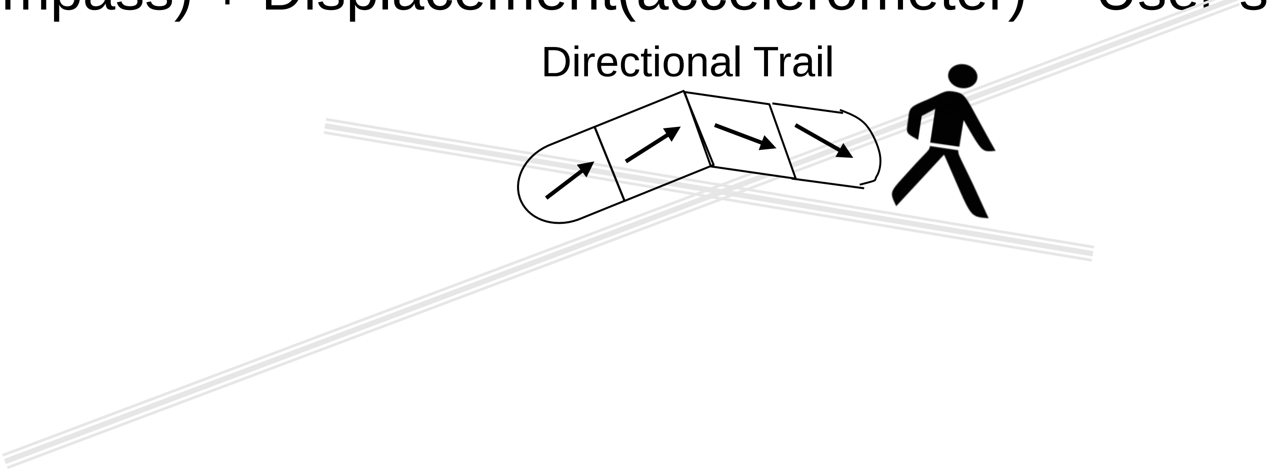
Contents

Goals

- No War-Driving
  - Cannot drive walking paths (campus, parks, …)
  - Expensive / Environment unfriendly
- No reliance on WiFi infrastructure
  - Rural regions / developing countries
- Good accuracy (~GPS)
- Improve energy-efficiency
  - Better than Skyhook, GPS

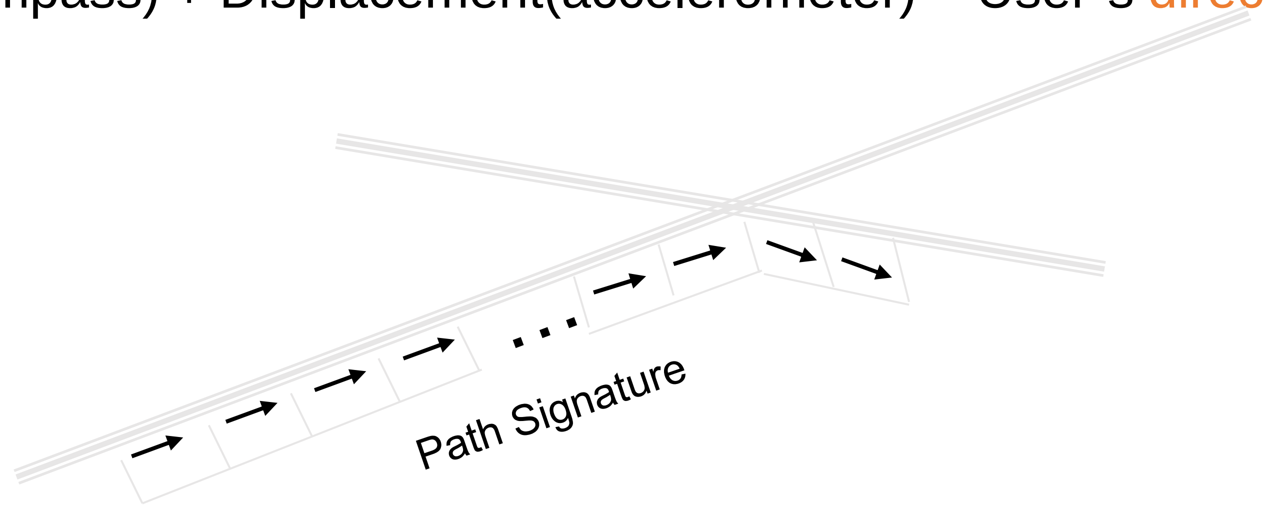
CompAcc: Basic Idea

- Direction(compass) + Displacement(accelerometer) = User's directional trail



CompAcc: Basic Idea

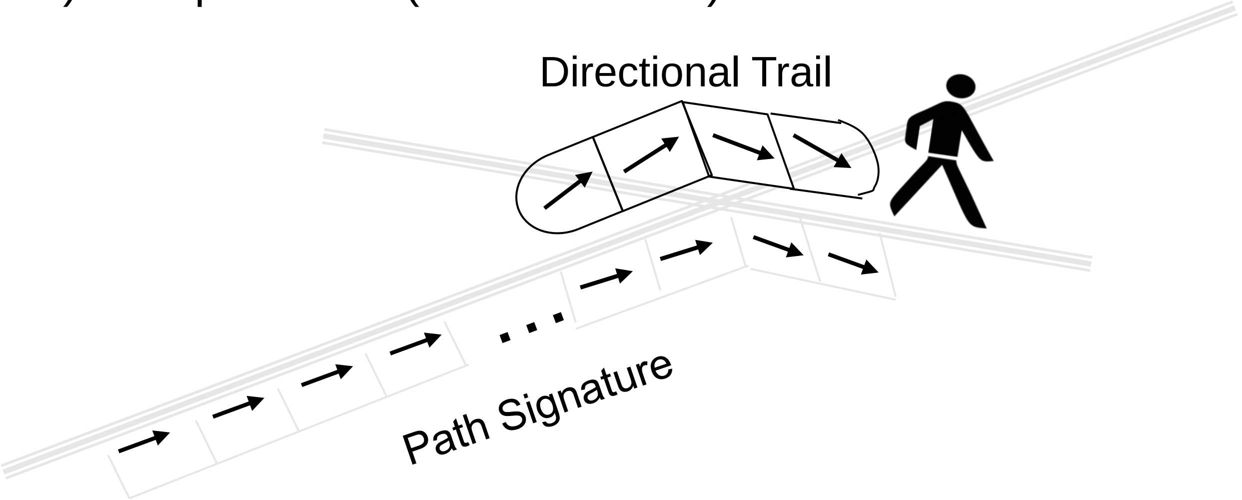
- Direction(compass) + Displacement(accelerometer) = User's directional trail



- Compute path signatures
  - Derived from a local electronic map (Google Maps)

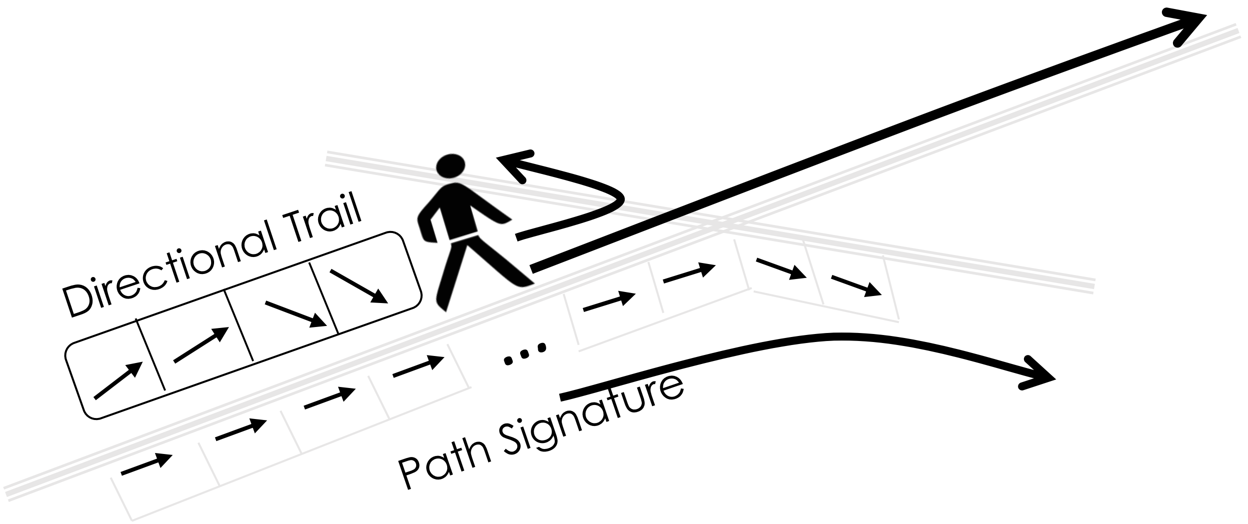
CompAcc: Basic Idea

- Direction(compass) + Displacement(accelerometer) = User's directional trail

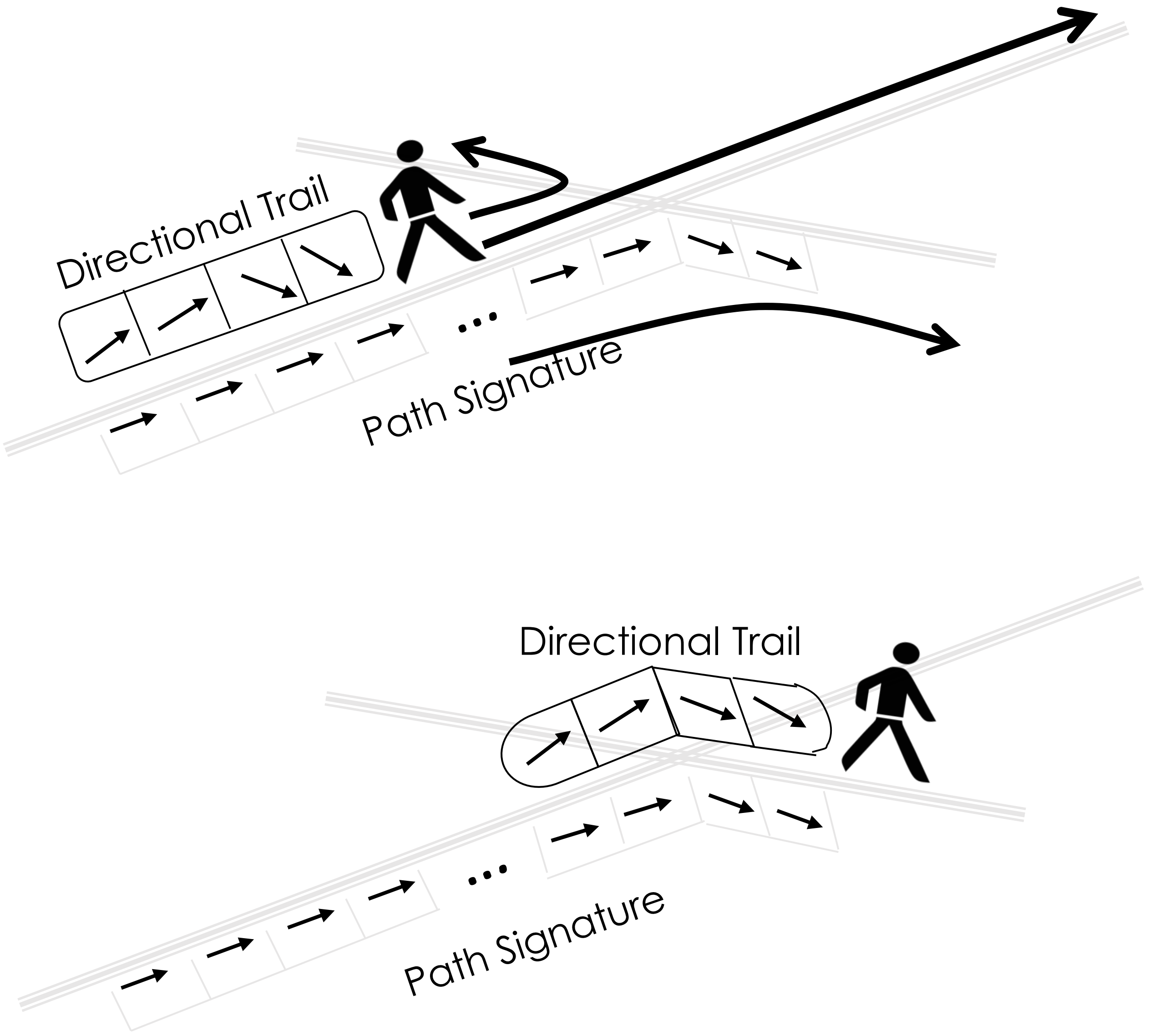


- Compute path signatures
  - Derived from a local electronic map (Google Maps)
- Compare directional trail with path signatures
  - Best match provides the user location

Correct location errors at turns



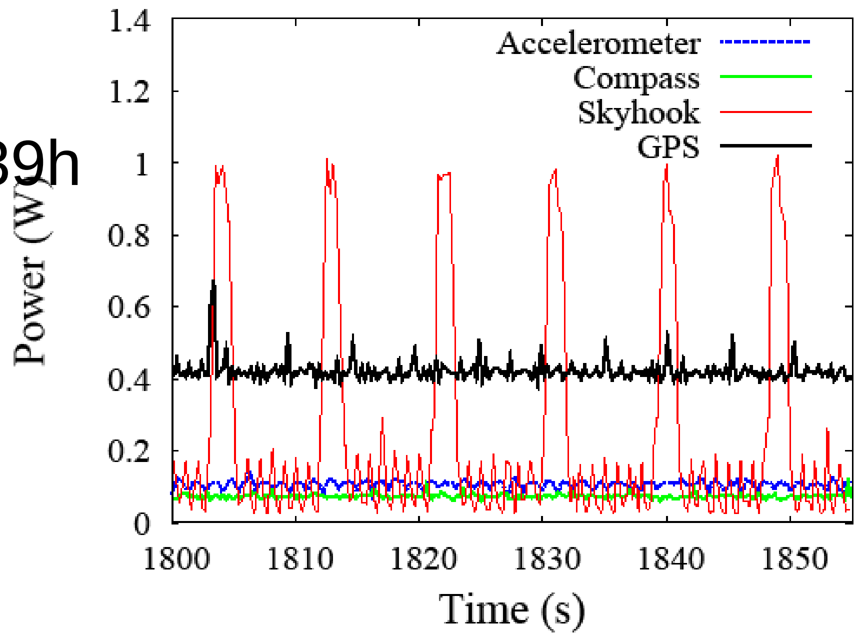
Correct location errors at turns



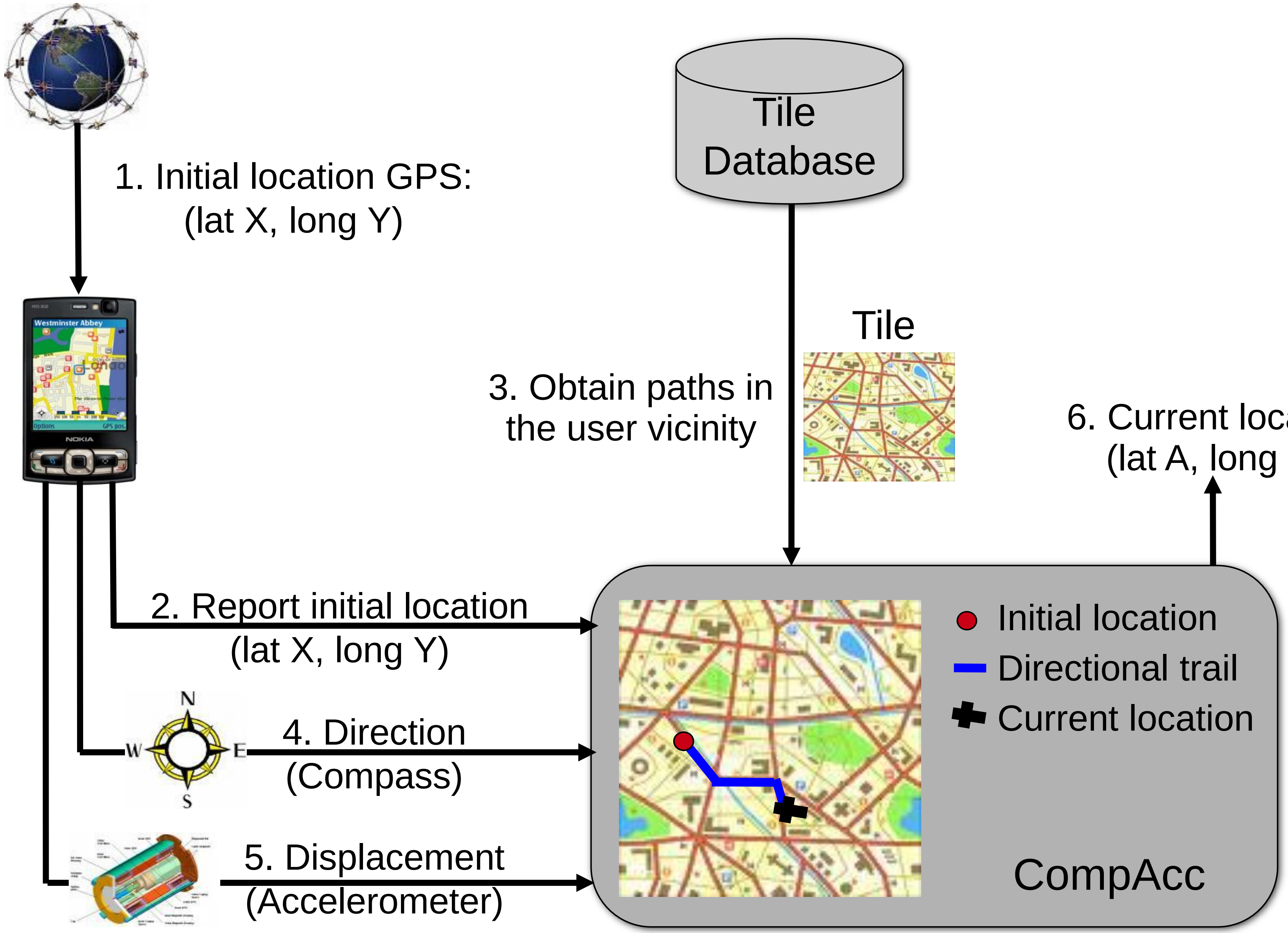
Advantages

- No war-driving
- No reliance on WiFi infrastructure
  - Maps available ubiquitously

- Improves battery lifetime
  - GPS ~10h
  - WiFi ~16h
  - Accelerometer ~ 39h
  - Compass ~48h

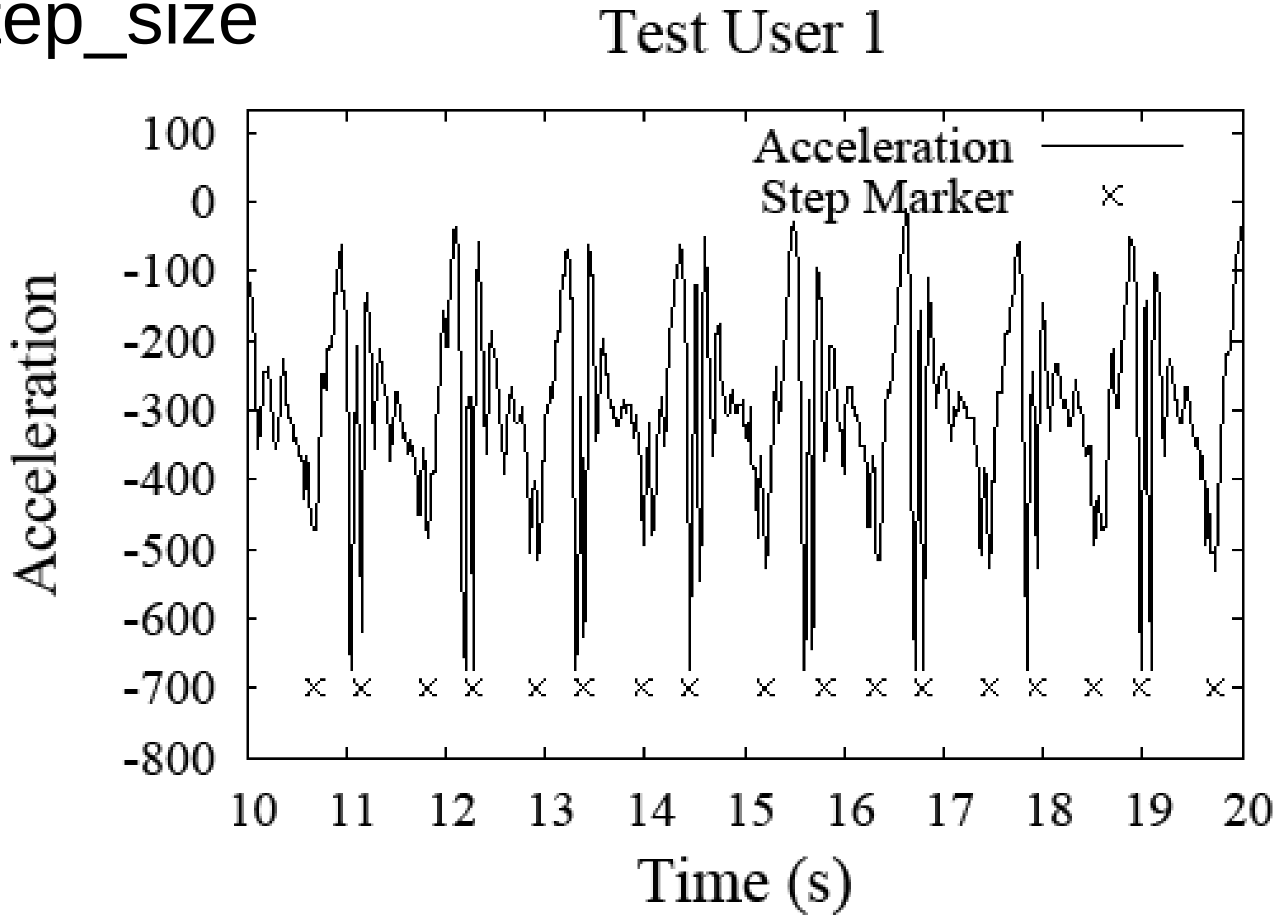


Architecture

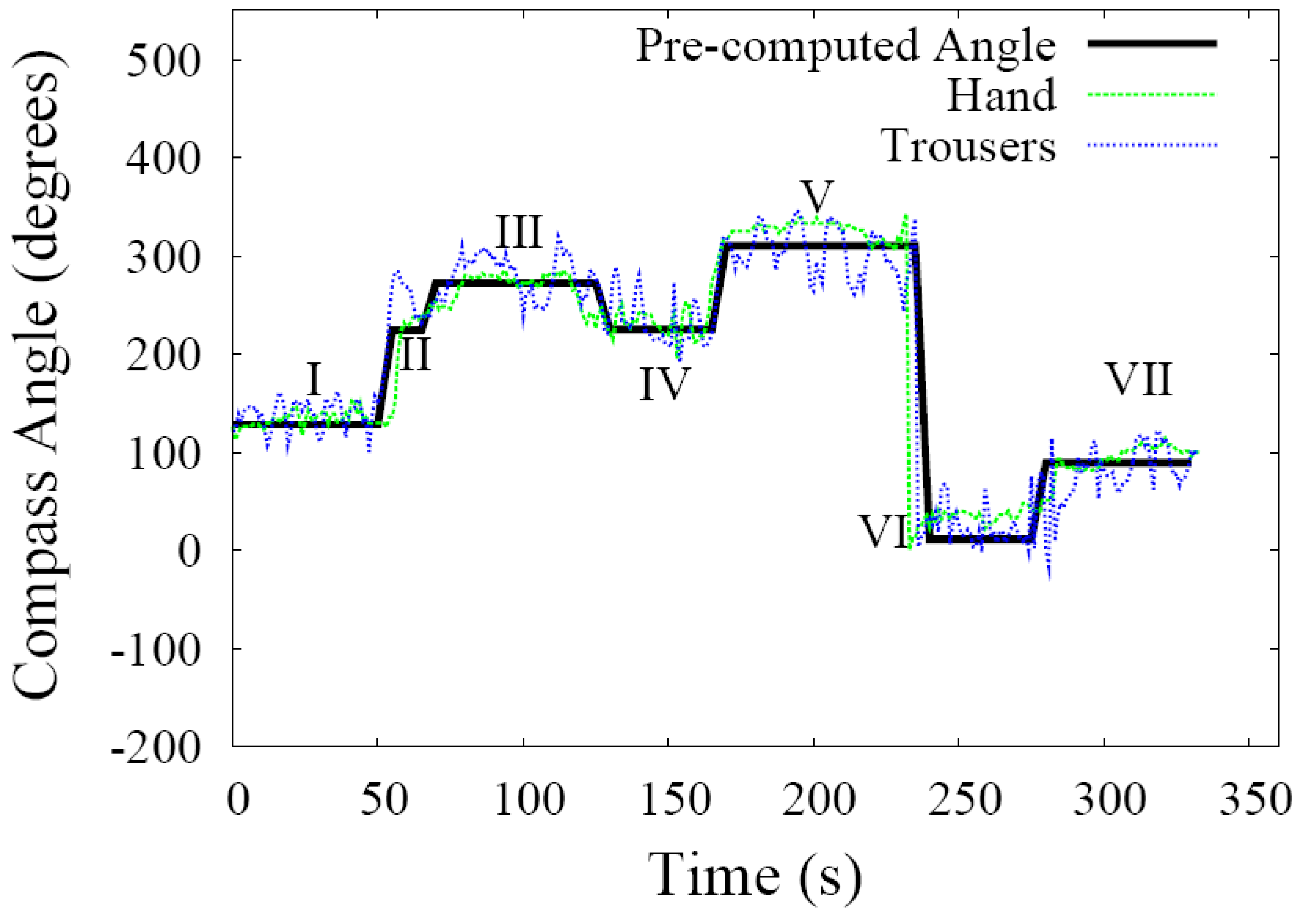


Directional trail: displacement

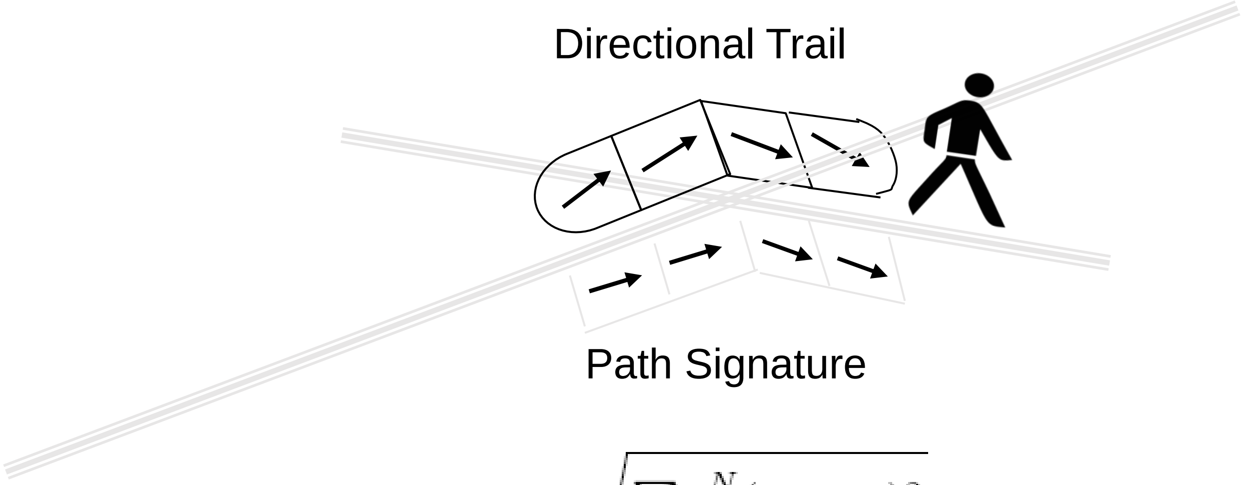
- Accelerometer based step count
- displacement = step_count * step_size



Directional trail: direction



Matching Directional Trail with Path Signatures



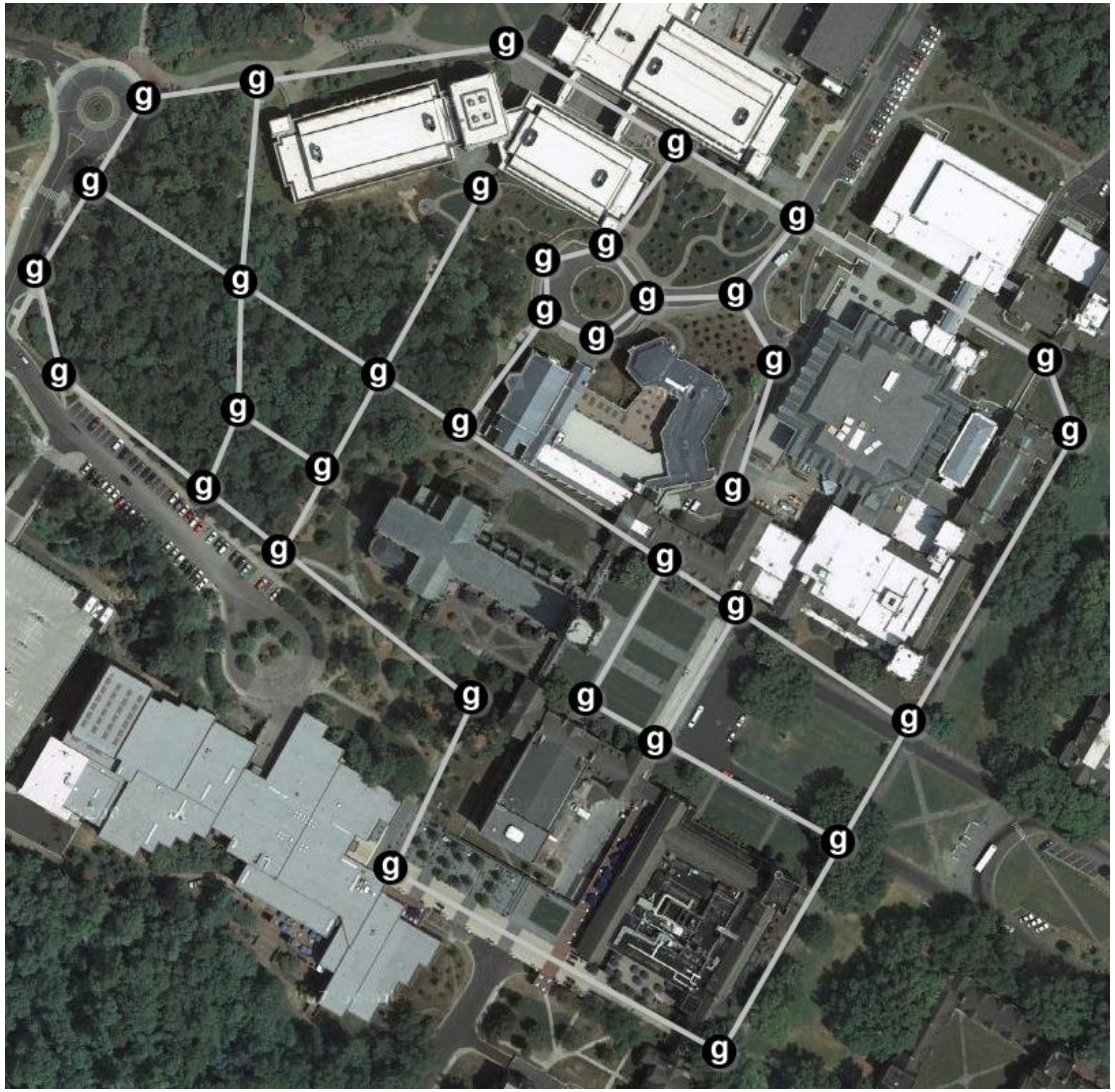
$$\phi_0 = \sqrt{\frac{\sum_{i=0}^{-N}(c_i - p_i)^2}{N}}$$

Dissimilarity Metric:

c_i = compass readings
p_i = path computed direction
N = directional trail size

Contents

Experiment Site



Results

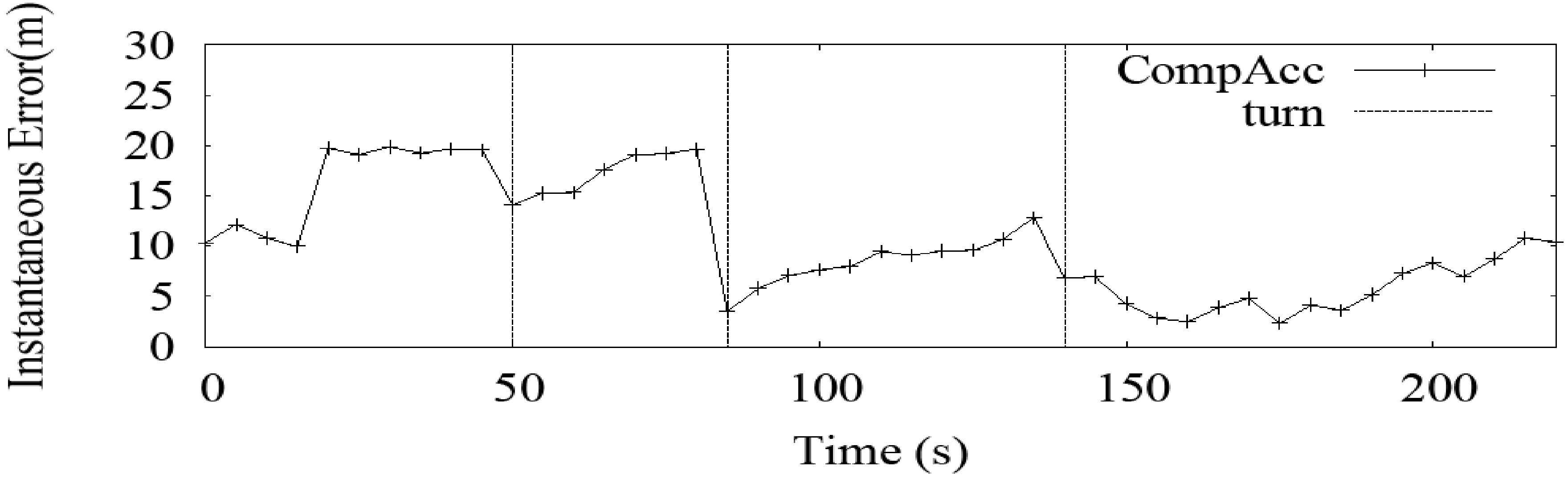
- Compared 3 localization schemes
  - CompAcc
  - WiFi-War_Drive (Skyhook)
  - Wifi-War-Walk (We war-droved walking paths in campus)

- Metrics

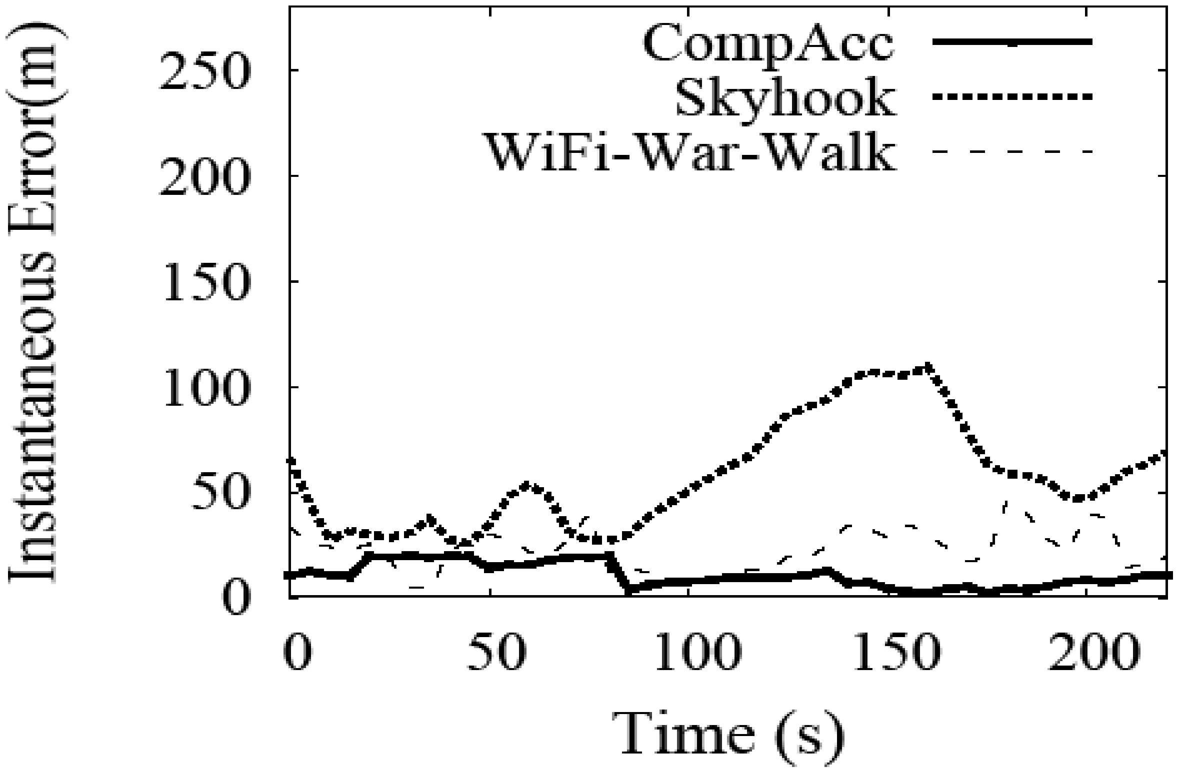
  Instantaneous Error = distance(estimated, real)

  Average Localization Error (ALE) = Average Instantaneous Error

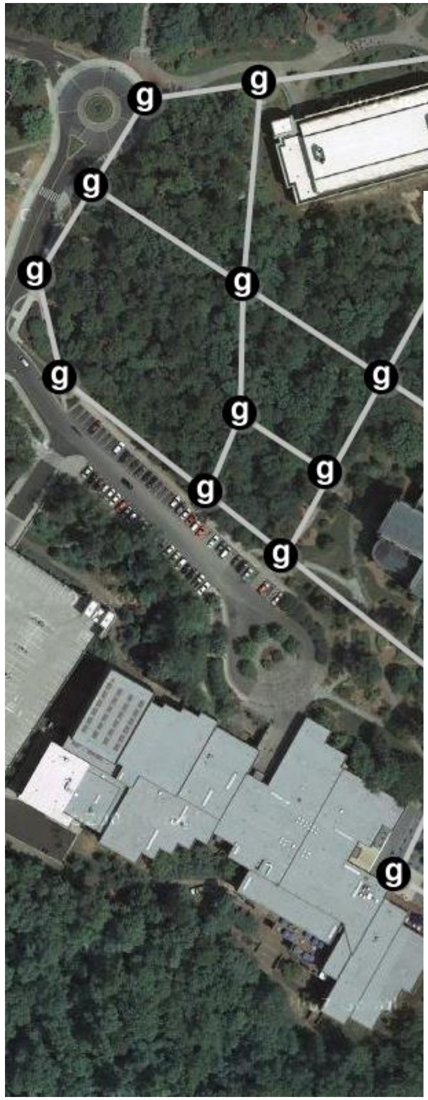
CompAcc Instantaneous Error

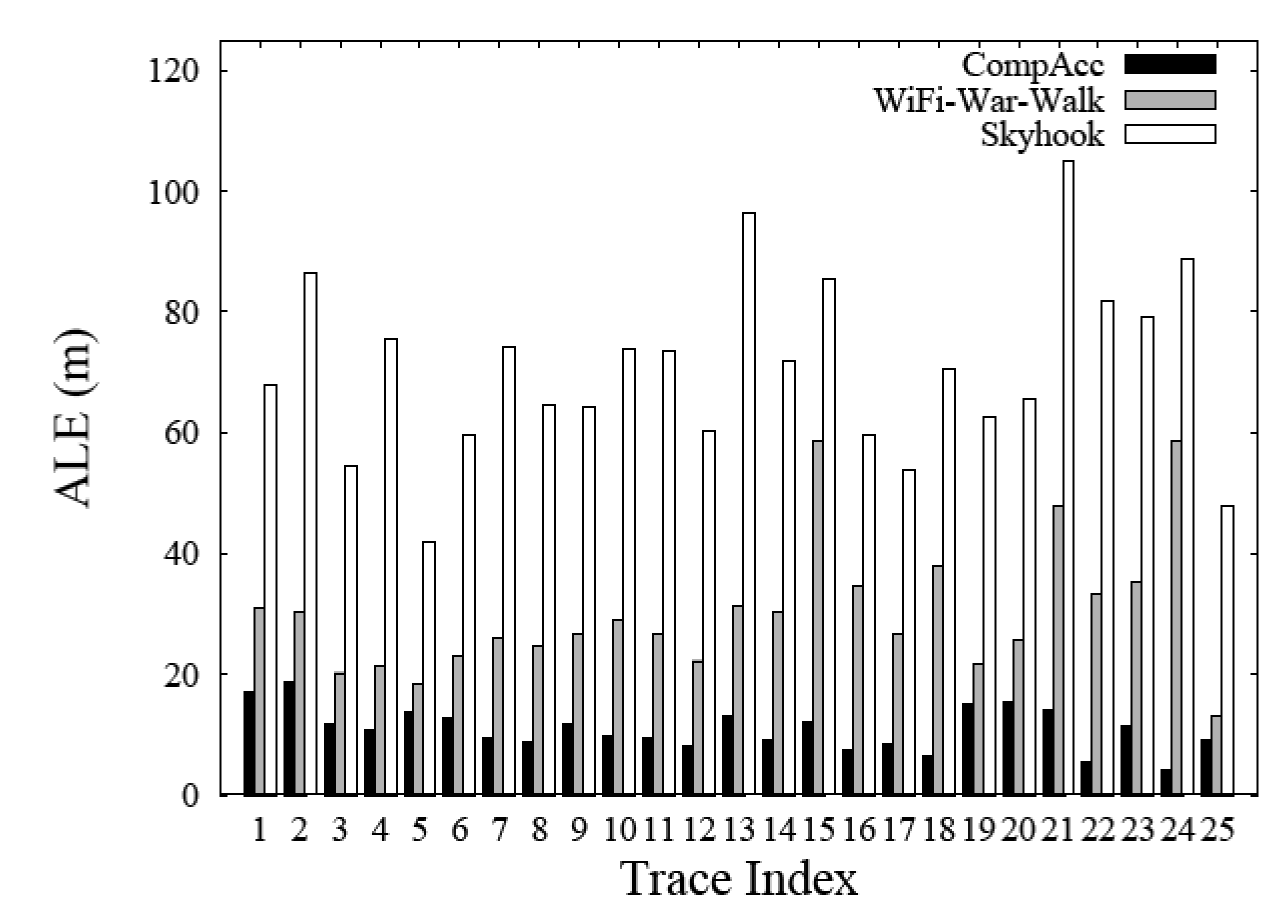


CompAcc Instantaneous Error



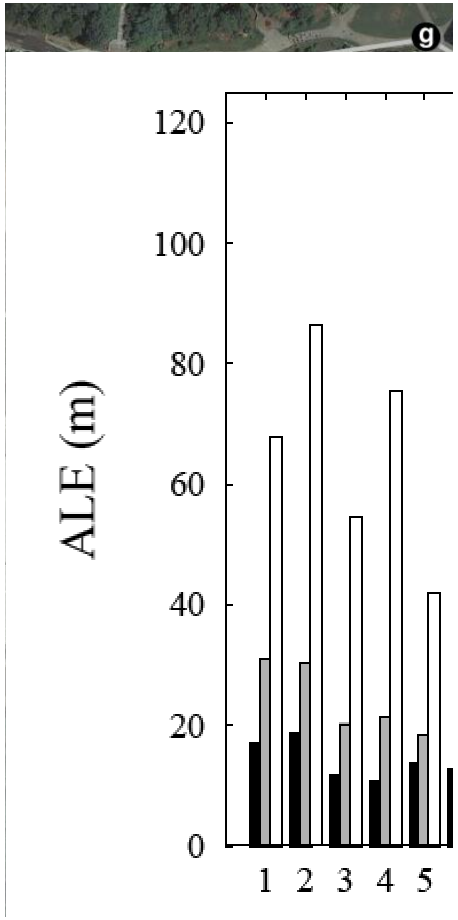
Results





CompAcc
WiFi-War-Walk
Skyhook
ALE (m)
0
20
40
60
80
100
120
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Trace Index

Results



Average ALE
GPS: 10m
CompAcc: 11m
WiFi-War-Walk: 30m
Skyhook: 70m

Energy
GPS: 10h
CompAcc: 23h
WiFi-War-Walk:16h
Skyhook:16h