Localization (1)

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In this lecture

- An introduction to localization
- The Global Positioning System (GPS)
- Localization Applications

An introduction to localization

What is localization?

- Get the location of a mobile device
  - Some devices, e.g., cell phones, are a proxy of a person’s location
- Get the location of wireless signal source
  - Wireless emitter
- Used to help derive the context and activity information
  - Location based services
  - Privacy problems

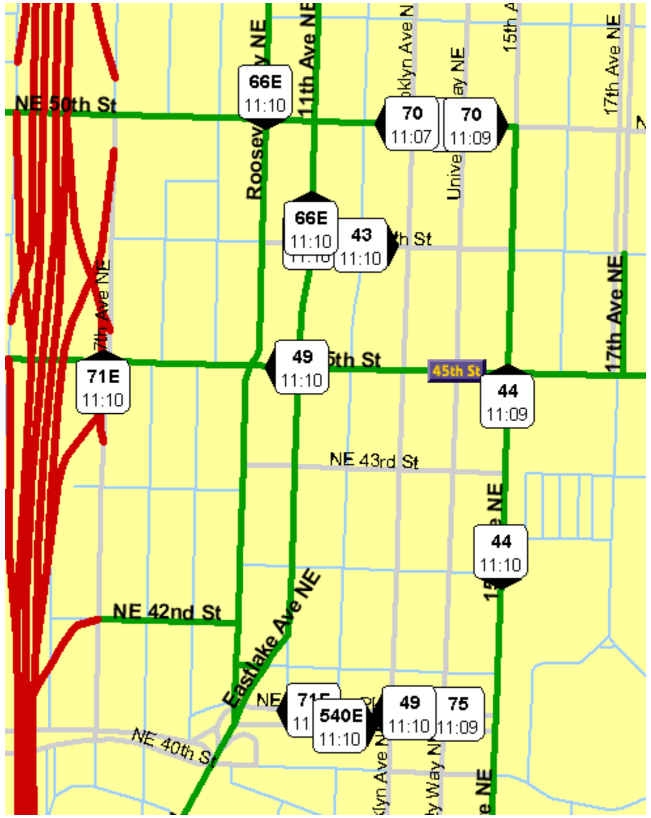
Localization

- Well studied topic (3,000+ PhD theses??)
- Application dependent
- Research areas
  - Technology
  - Algorithms and data analysis
  - Evaluation

Representing Location Information

- Absolute
  - Geographic coordinates (Lat: 33.98333, Long: -86.22444)
- Relative
  - 1 block north of the main building
- Symbolic
  - Home, road, bedroom, work

Some outdoor applications



Bus view

E-911

Car Navigation

Child tracking

Some indoor applications

Elder care

Indoor navigation:
mall, airport, museum, etc

Contact Tracing

No one size fits all!

- Accurate
- Low-cost
- Easy-to-deploy
- Ubiquitous

- Application needs determine technology

Lots of technologies!

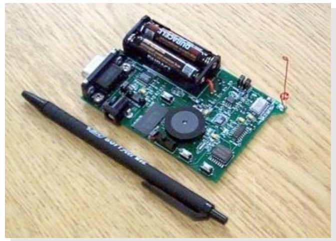
GPS

WiFi Beacons

Ultrasound

Floor pressure

VHF Omni Ranging



Ad hoc signal strength

Laser range-finding

Stereo camera

E-911

Ultrasonic time of flight

Array microphone

Infrared proximity

Physical contact

Wireless Technologies for Localization

Name	Effective Range	Pros	Cons
GSM	35km	Long range	Very low accuracy
LTE	30km-100km		
Wi-Fi	50m-100m	Readily available; Medium range	Low accuracy
Ultra Wideband	70m	High accuracy	High cost
Bluetooth	10m	Readily Available; Medium accuracy	Short range
Ultrasound	6-9m	High accuracy	High cost, not scalable
RFID & IR	1m	Moderate to high accuracy	Short range, Line-Of-Sight (LOS)
NFC	<4cm	High accuracy	Very short range

Localization Techniques

Algorithms to obtain locations

- Range-based algorithms
- Range-free algorithms
- Fingerprinting

Range Based Algorithms

- Rely on the distance (angle) measurement between nodes to estimate the target location
- Approaches
  - Proximity
  - Lateration
  - Hyperbolic Lateration
  - Angulation
- Distance estimates
  - Time of Flight
  - Signal Strength Attenuation

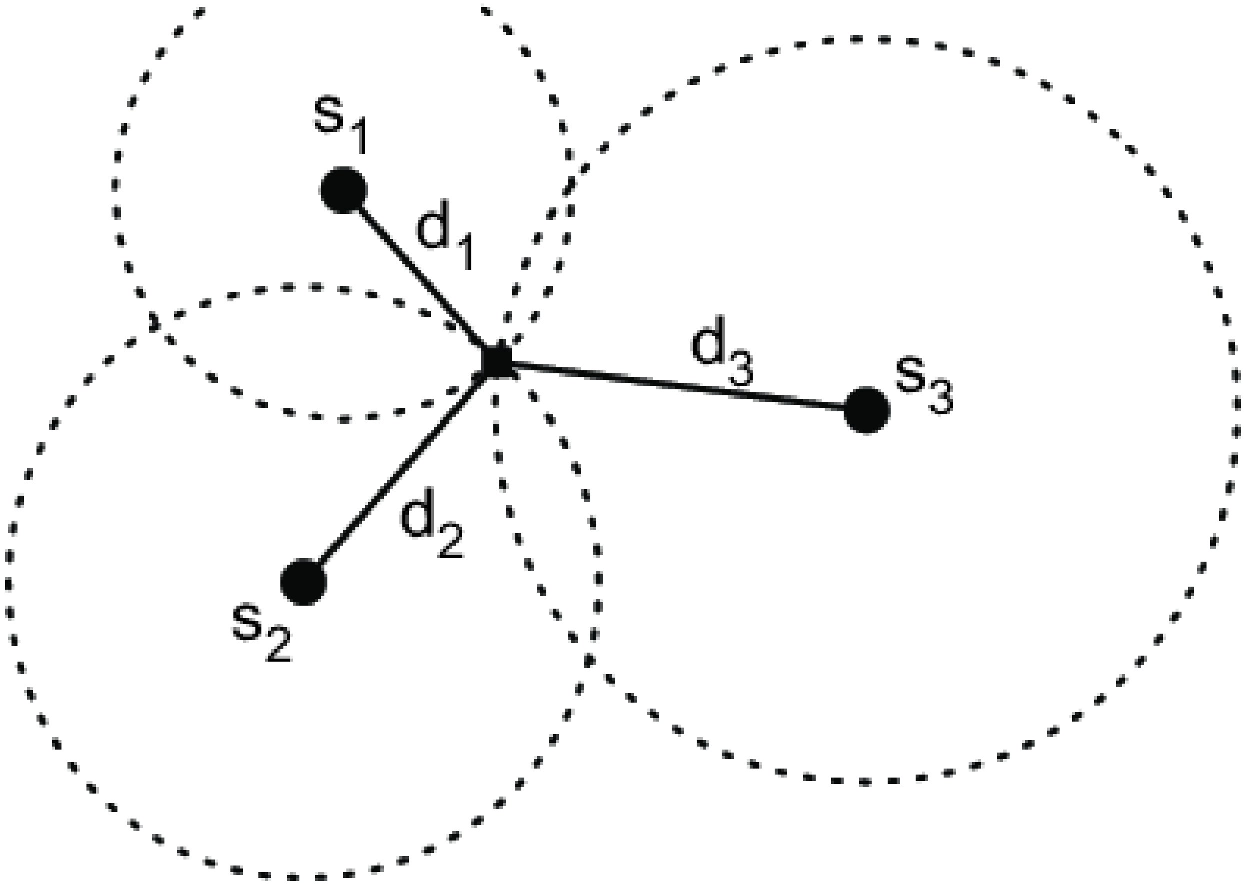
Approach: Proximity

- Simplest positioning technique
- Closeness to a reference point
- Based on loudness, physical contact, etc

- Examples
  - RFID Door Access Control System

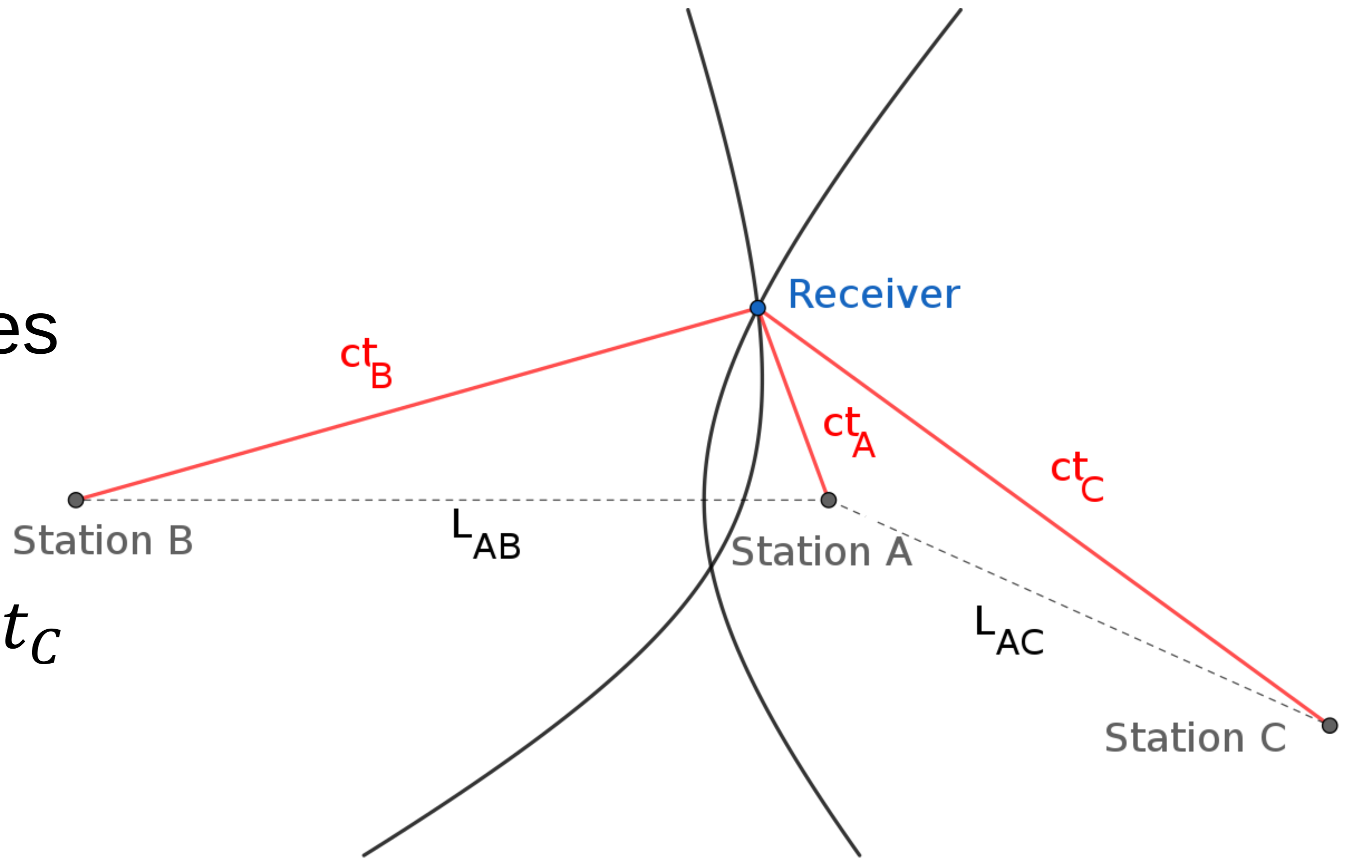
Approach: Lateration

- Method: Measure distance between device and reference points
  - s1, s2, s3 locations are known
  - Measure the distances d1, d2, and d3
  - Search for the most-likely location given the distances
- 3 reference points needed for 2D and 4 for 3D



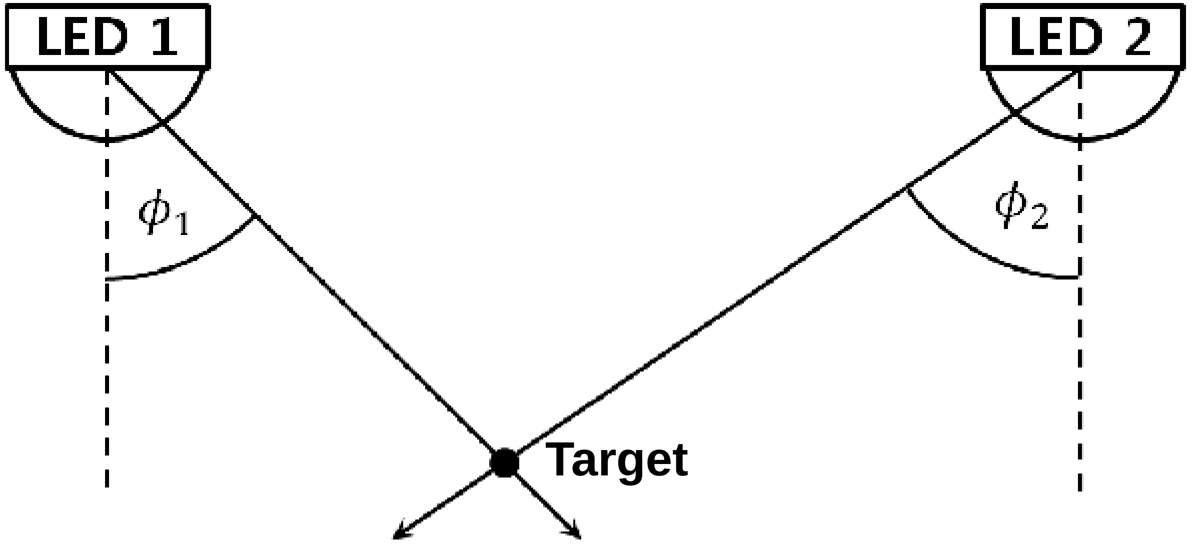
Approach: Hyperbolic Lateration

- Known: Station A, B, C locations
- Unknown: The signal traveling times to the receiver: ct_A, ct_B, ct_C
- Known: $ct_A - ct_B,\ ct_A - ct_C,\ ct_B - ct_C$
- Each time difference locates the receiver on a branch of a hyperbola



Approach: Angulation

- Use the location of the signal sources and the relative angles
- Uniquely identify the location of the target



Distance Estimation Techniques

Distance Estimation

- Multiply the radio signal velocity and the travel time
  - Time of arrival (TOA)
  - Time difference of arrival (TDOA)
- Compute the attenuation of the emitted signal strength
  - RSSI
- Problem: Multipath fading

Distance Estimation: TOA

- Distance
  - Based on one signal's travelling time from target to measuring unit
  - $d = v_{radio} * t_{radio}$
- Requirement
  - Transmitters and receivers should be precisely synchronized
  - Timestamp must be labeled in the transmitting signal

Distance Estimation: TDOA

- The transmitter sends a radio and a sound
- Receiver measurements: receiving time t1 and t2
- Known parameter: vr and vs
- How to estimate the distance?

Distance Estimation: TDOA

Let the transmission time be denoted t0. We have

d = (t1-t0)*v1

d = (t2-t0)*v2

Therefore : $\frac{d}{v_2} - \frac{d}{v_1} = t_2 - t_1$

Finally we get: $d = (t_2 - t_1) * v_1 * v_2 / (v_1 - v_2)$

Distance Estimation: RSSI

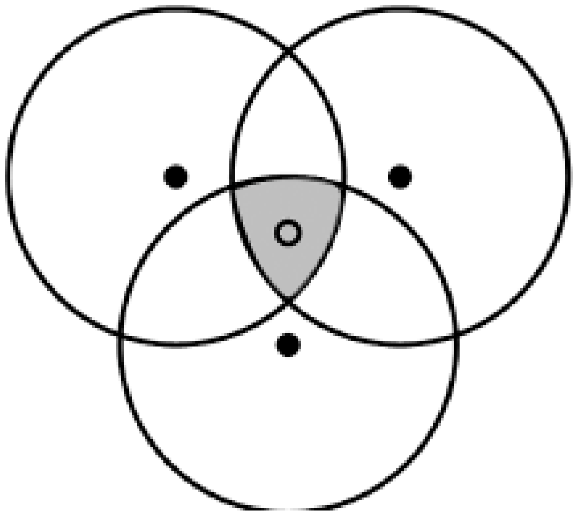
- Distance
  - Based on radio propagation model

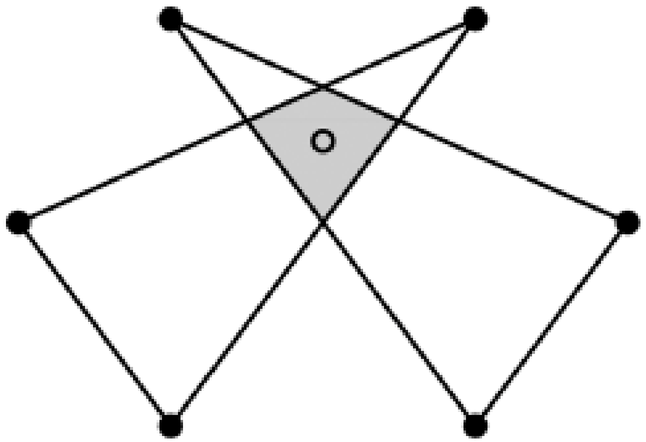
$$P(d) = P(d_0) - \eta 10 \log\left(\frac{d}{d_0}\right) + X_\sigma$$

- Requirement
  - Path loss exponent η for a given environment is known

Range Free Algorithms

- Rely on target object's proximity to anchors with known positions
  - Neighborhood: single/multiple closest BS
  - Area estimation:



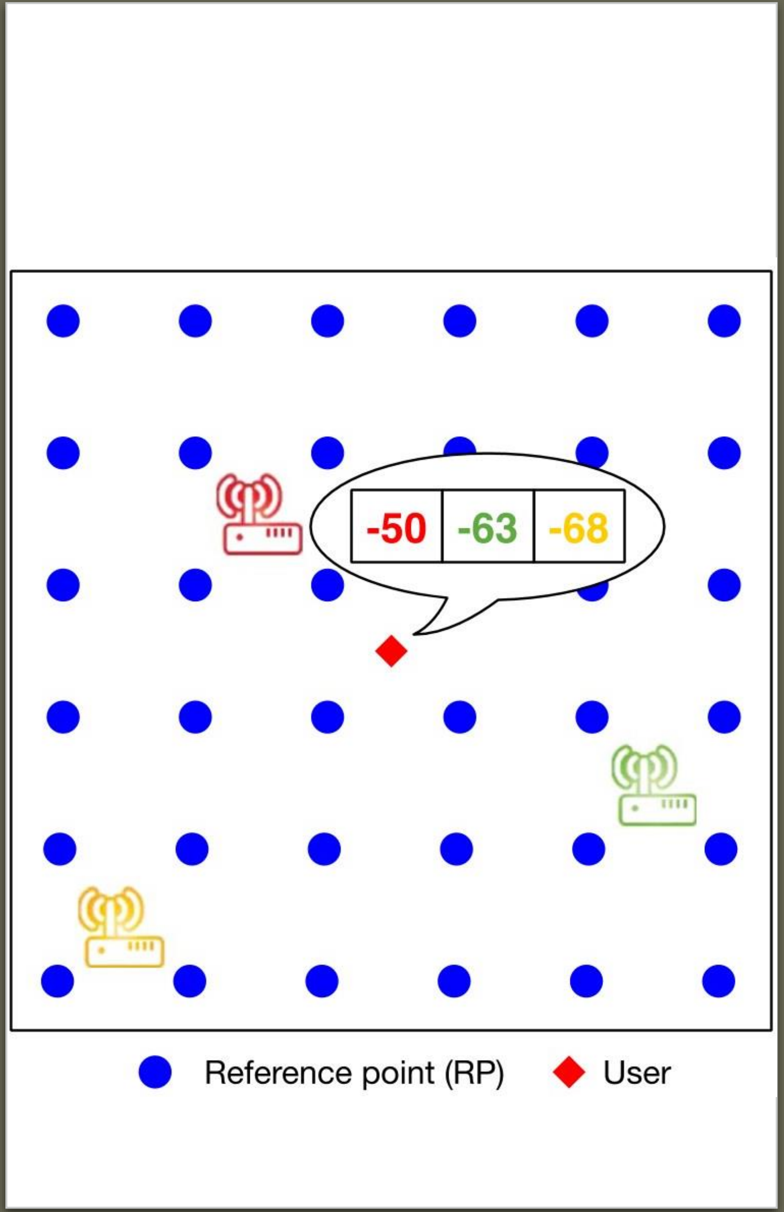


Fingerprinting

- Mapping solution
- Address problems with multipath
- Better than modeling complex RF propagation pattern

Fingerprinting: Steps

- Step1
  - Use war-driving to build up location fingerprints (i.e. location coordinates + respective RSSI from nearby base stations)
- Step2
  - Match online measurements with the closest *a priori* location fingerprints



Fingerprinting: Example

SSID (Name)	BSSID (MAC address)	Signal Strength (RSSI)
linksys	00:0F:66:2A:61:00	18
starbucks	00:0F:C8:00:15:13	15
newark wifi	00:06:25:98:7A:0C	23

Fingerprinting: Pros and Cons

- Pros
  - Physical model not required
- Cons
  - Requires a dense site survey
- Prerequisite:
  - Spatial differentiability
  - Temporal stability

Summary of Localization Techniques

	Measurement Scheme	Accuracy	Special Requirement
Range-based	TOA	Moderate	Synchronization, dense beacons
	TDOA	High	Synchronization, LOS, dense beacons
	AOA	High	Directional antenna
	RSSI	Moderate	No
Range-free	Neighborhood	Low	No
	Area estimation	Moderate	Dense Beacons
Fingerprinting	RSSI	High	No

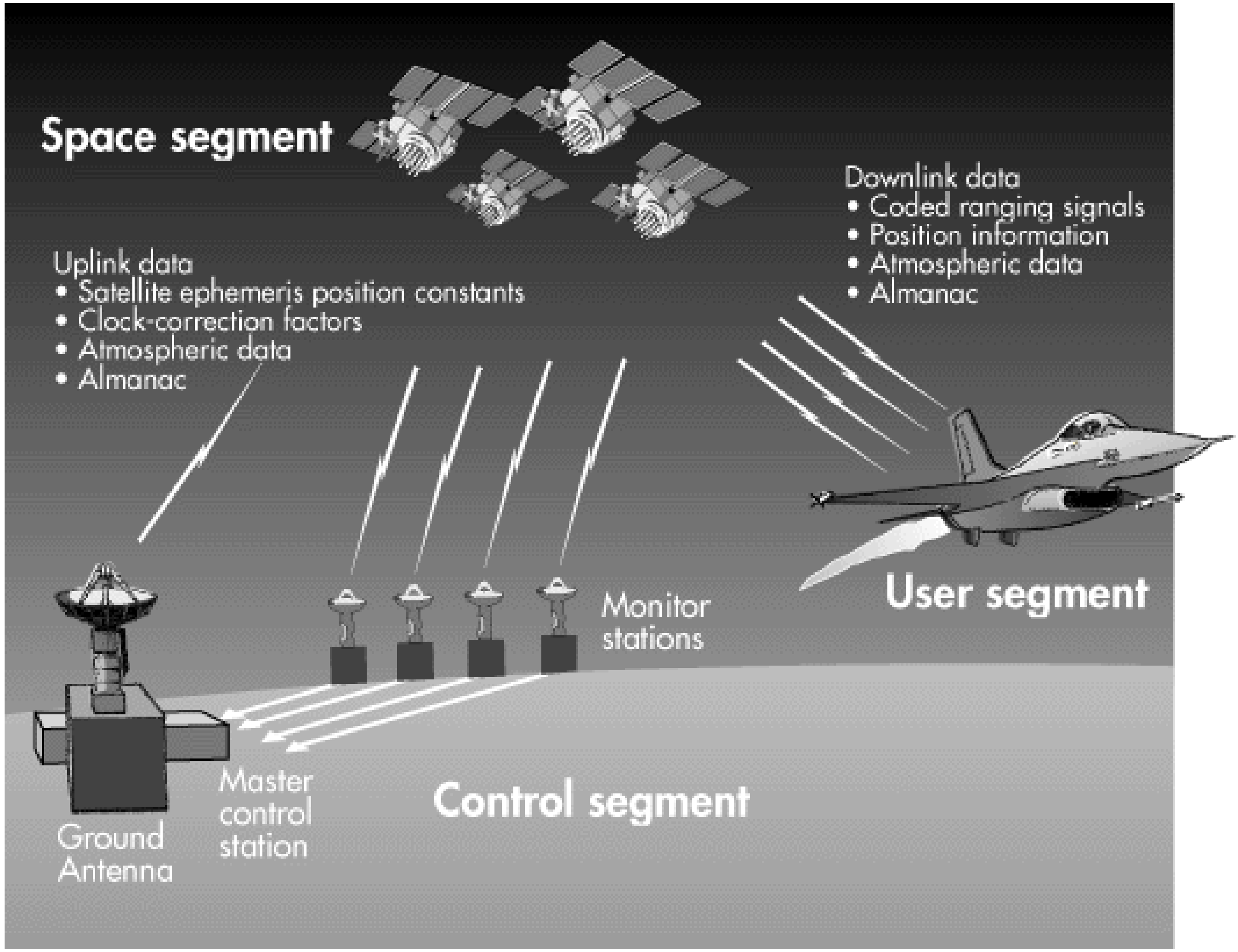
The Global Positioning System (GPS)

The History of GPS

- Feasibility studies begun in 1960s.
- Pentagon appropriates funding in 1973.
- First satellite launched in 1978.
- System declared fully operational in April 1995.

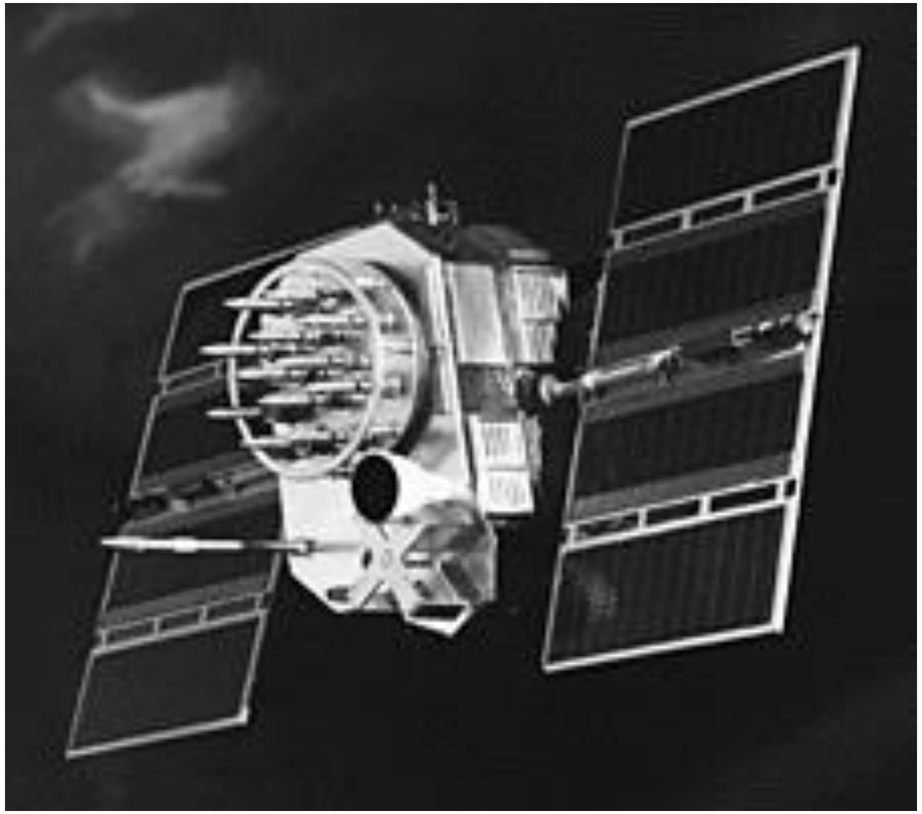
System Components

- space (GPS satellite vehicles)
- control (tracking stations)
- users

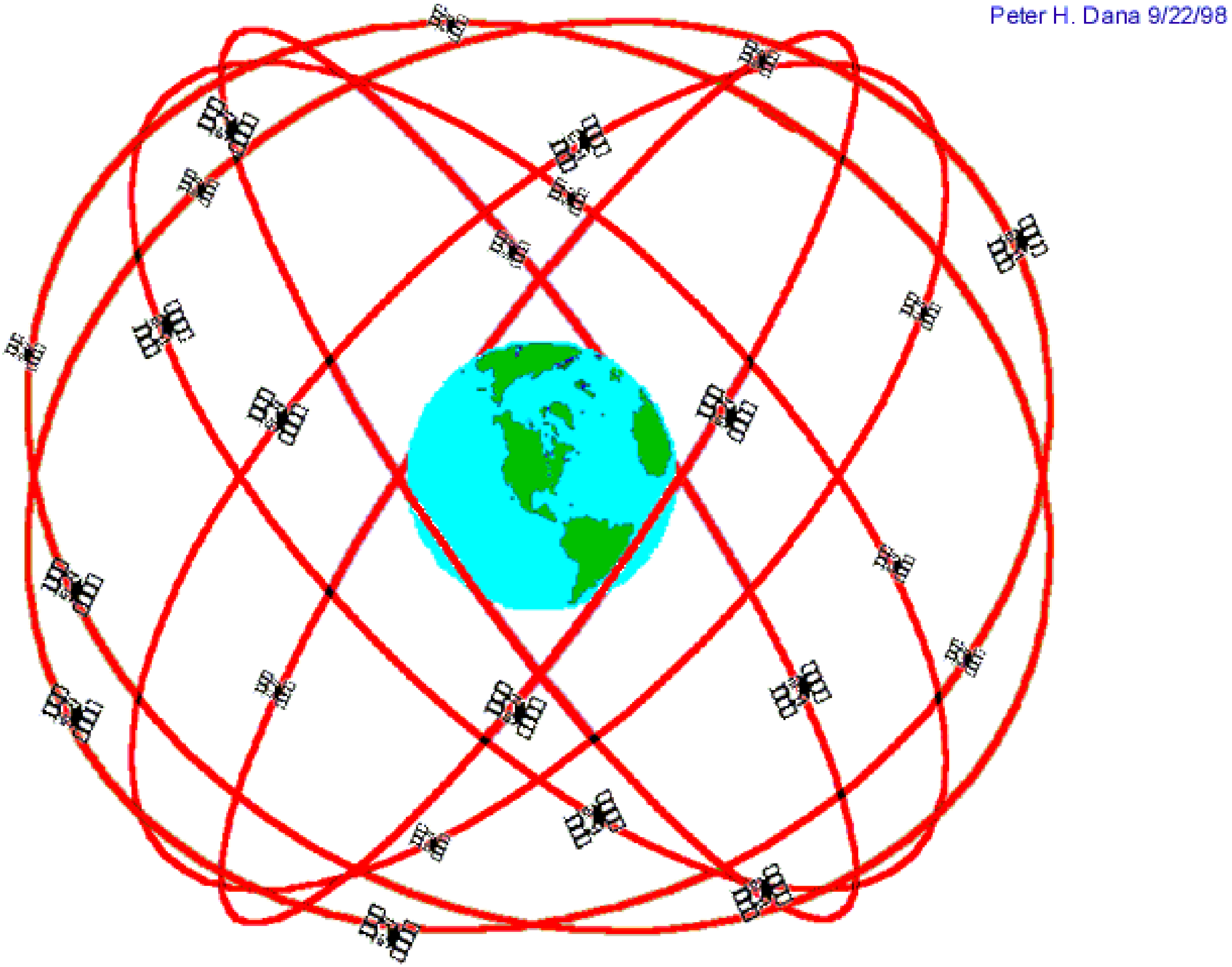


Two generations of GSP satellite vehicles (SVs)

GPS block I:
Experimental



GPS block II:
Full-scale operational



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

basic concept is that the GPS constellation replaces "stars" and gives us reference points for navigation

examples of some applications (users):

- navigation (very important for ocean travel)
- zero-visibility landing for aircraft
- collision avoidance
- surveying
- precision agriculture
- delivery vehicles
- emergency vehicles
- electronic maps
- Earth sciences (volcano monitoring; seismic hazard)
- tropospheric water vapor

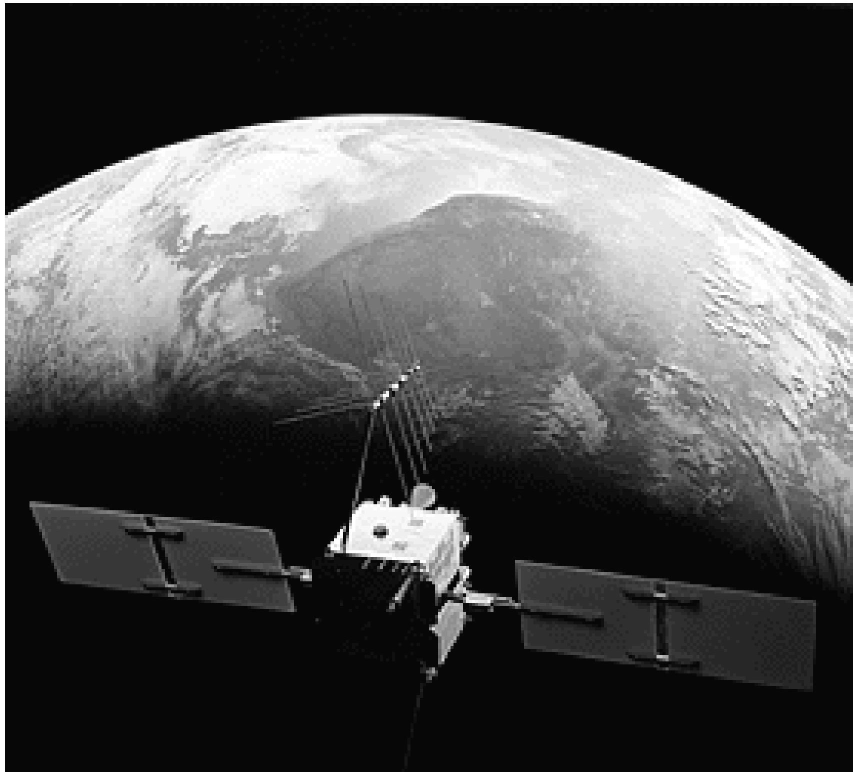
examples of applications

Four Basic Functions of GPS

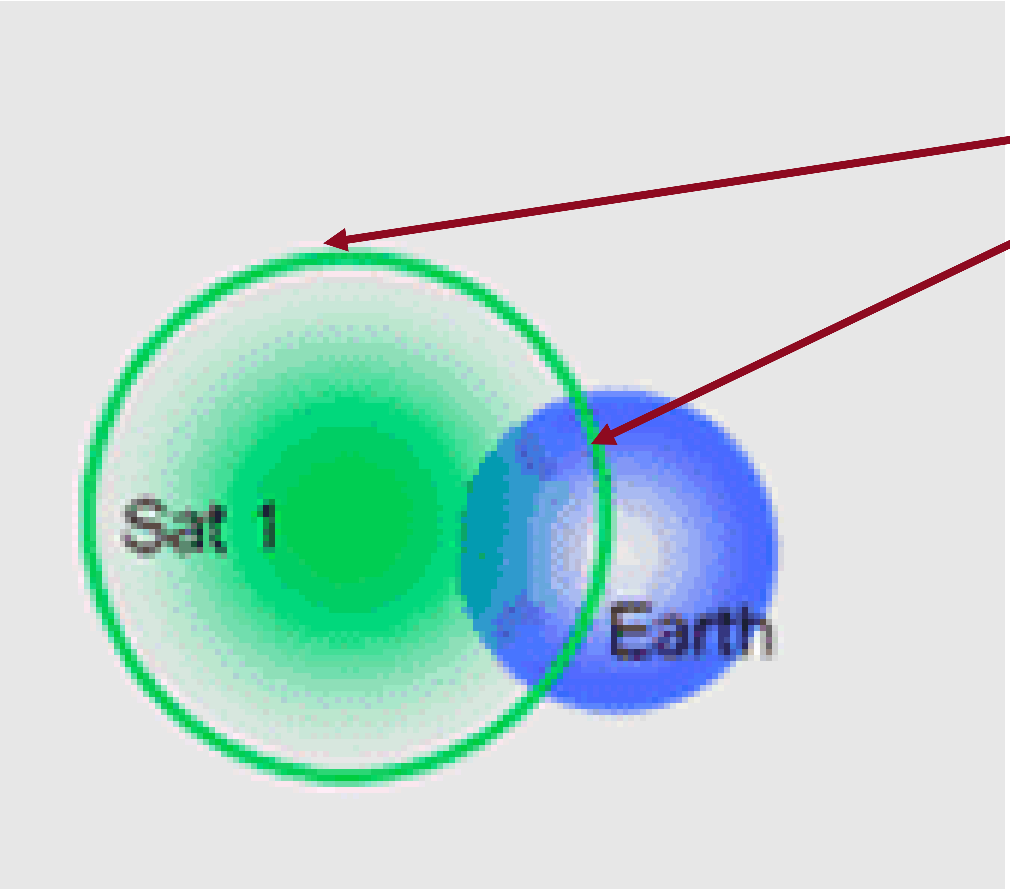
- Position and coordinates.
- The distance and direction between any two waypoints, or a position and a waypoint.
- Travel progress reports.
- Accurate time measurement.

How GPS works

- step 1: using satellite ranging
- step 2: measuring distance from satellite
- step 3: getting perfect timing
- step 4: knowing where a satellite is in space
- step 5: identifying errors

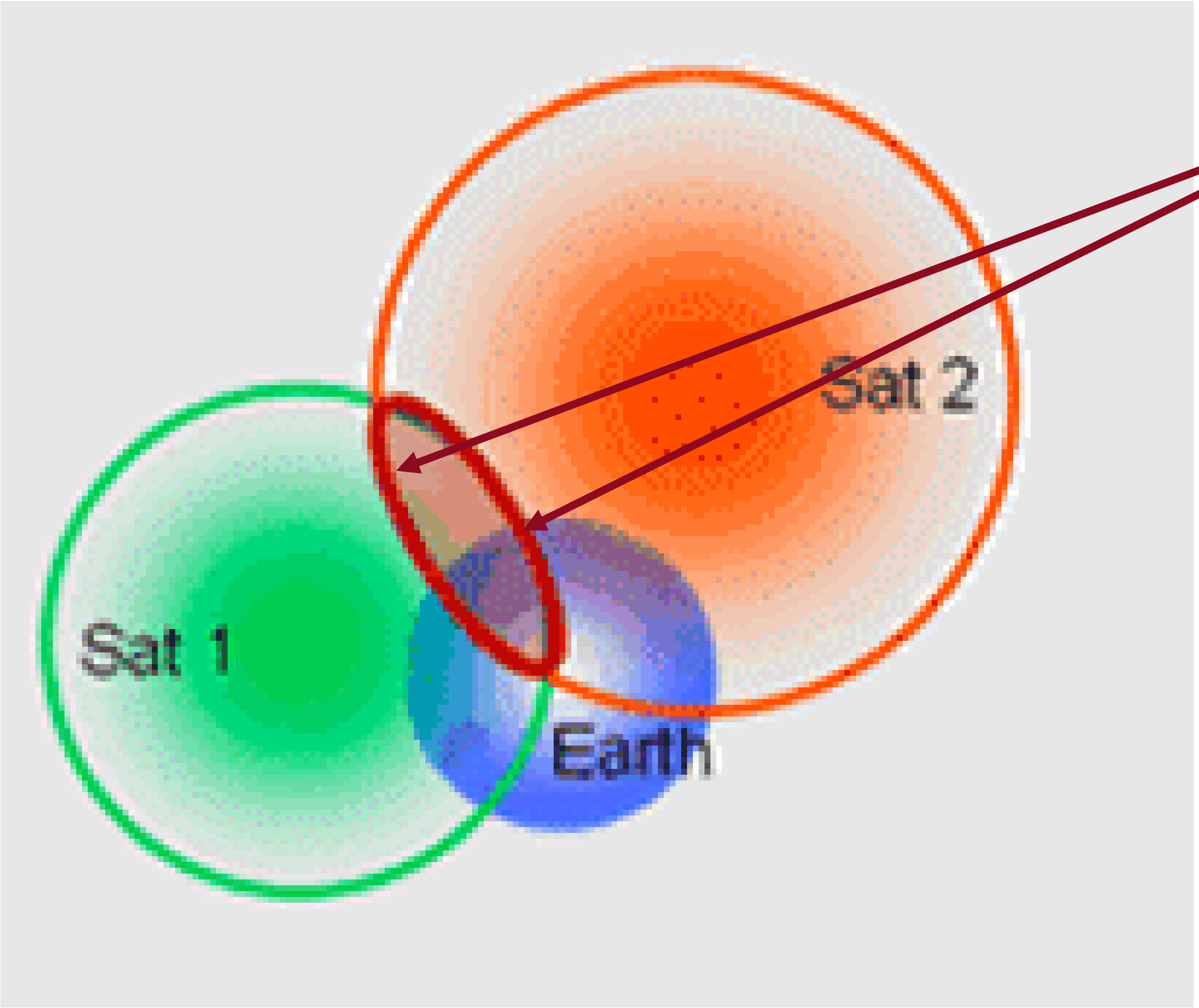


Signal From One Satellite



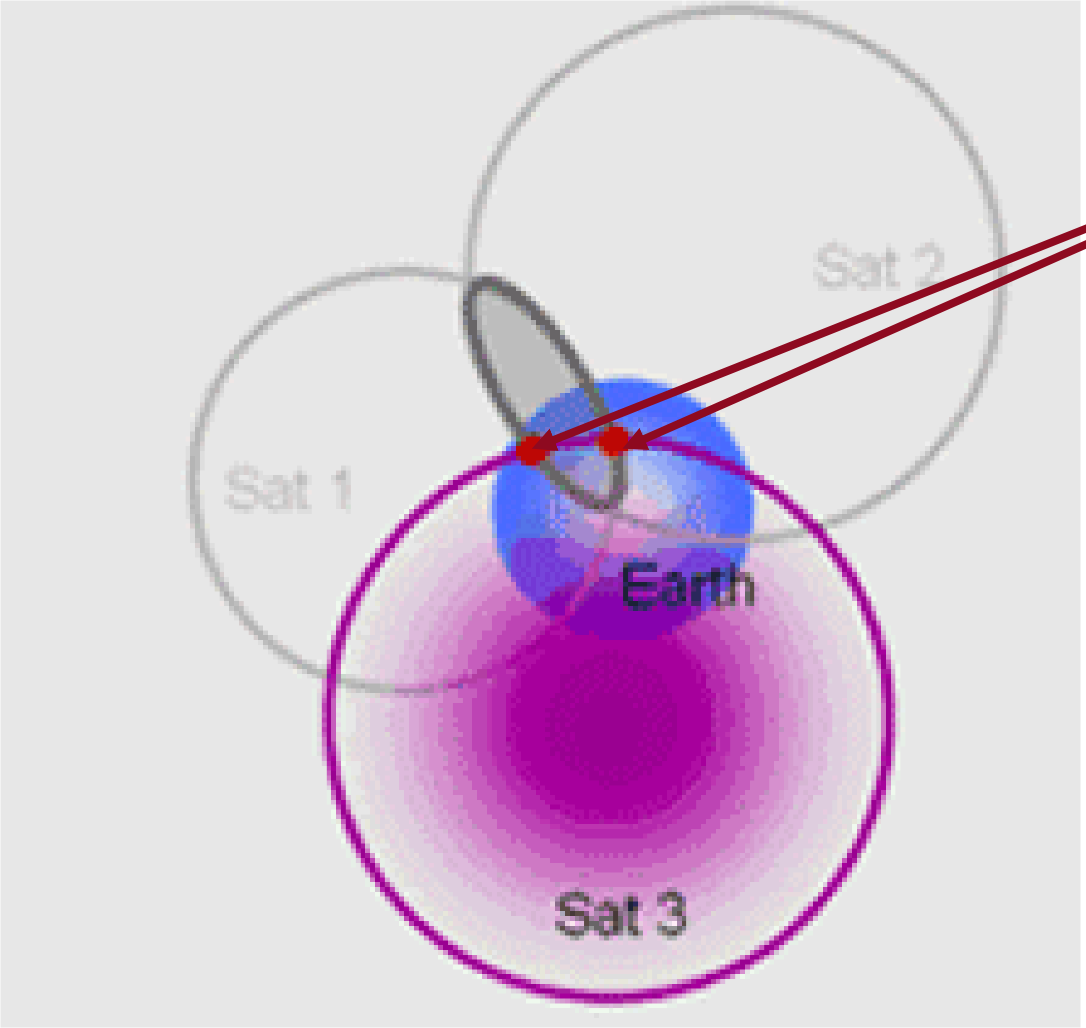
The receiver is somewhere on this sphere.

Signals From Two Satellites



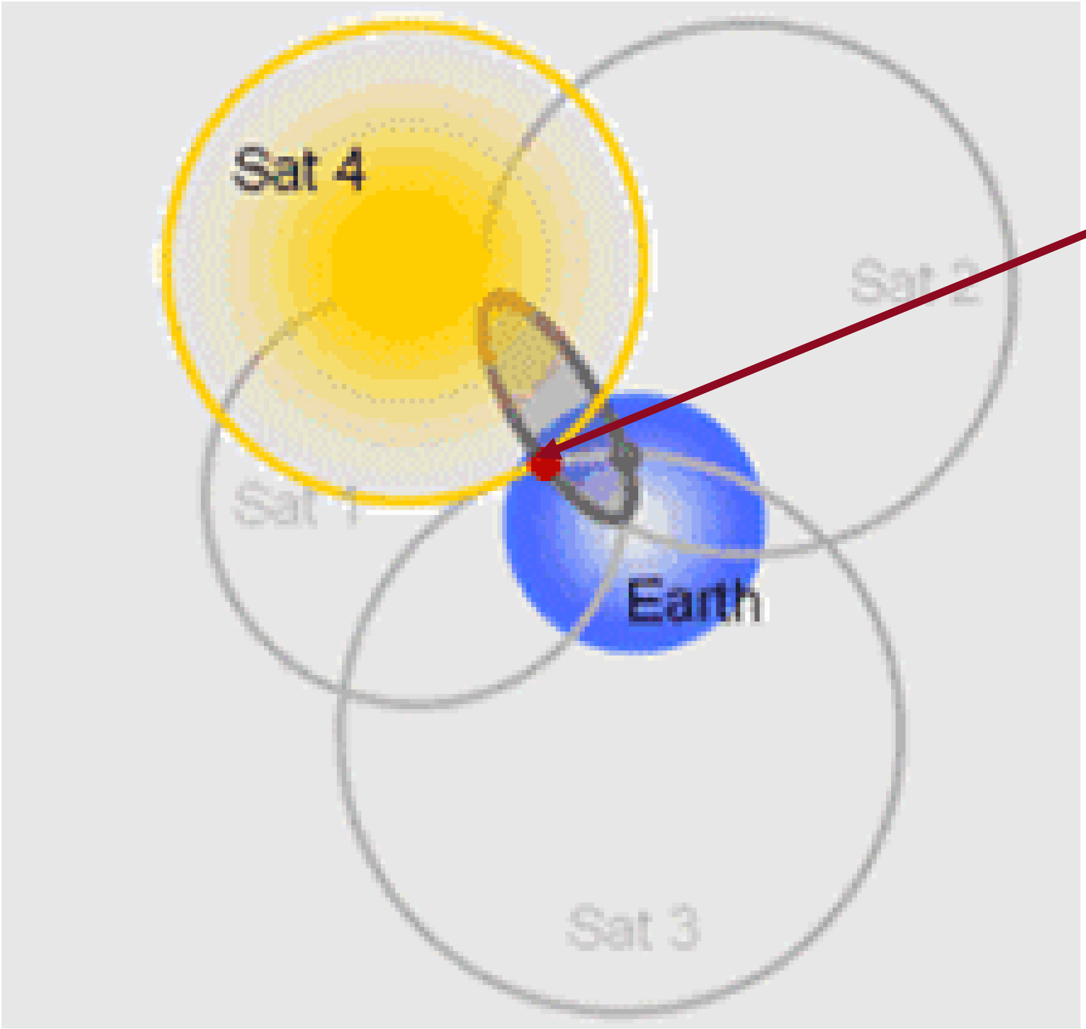
The receiver is somewhere on this circle.

Signals From Three Satellites



The receiver is somewhere between these two points.

Signals From Three Satellites



The receiver is here.