CSE 162 Mobile Computing

Lecture 14: GPS

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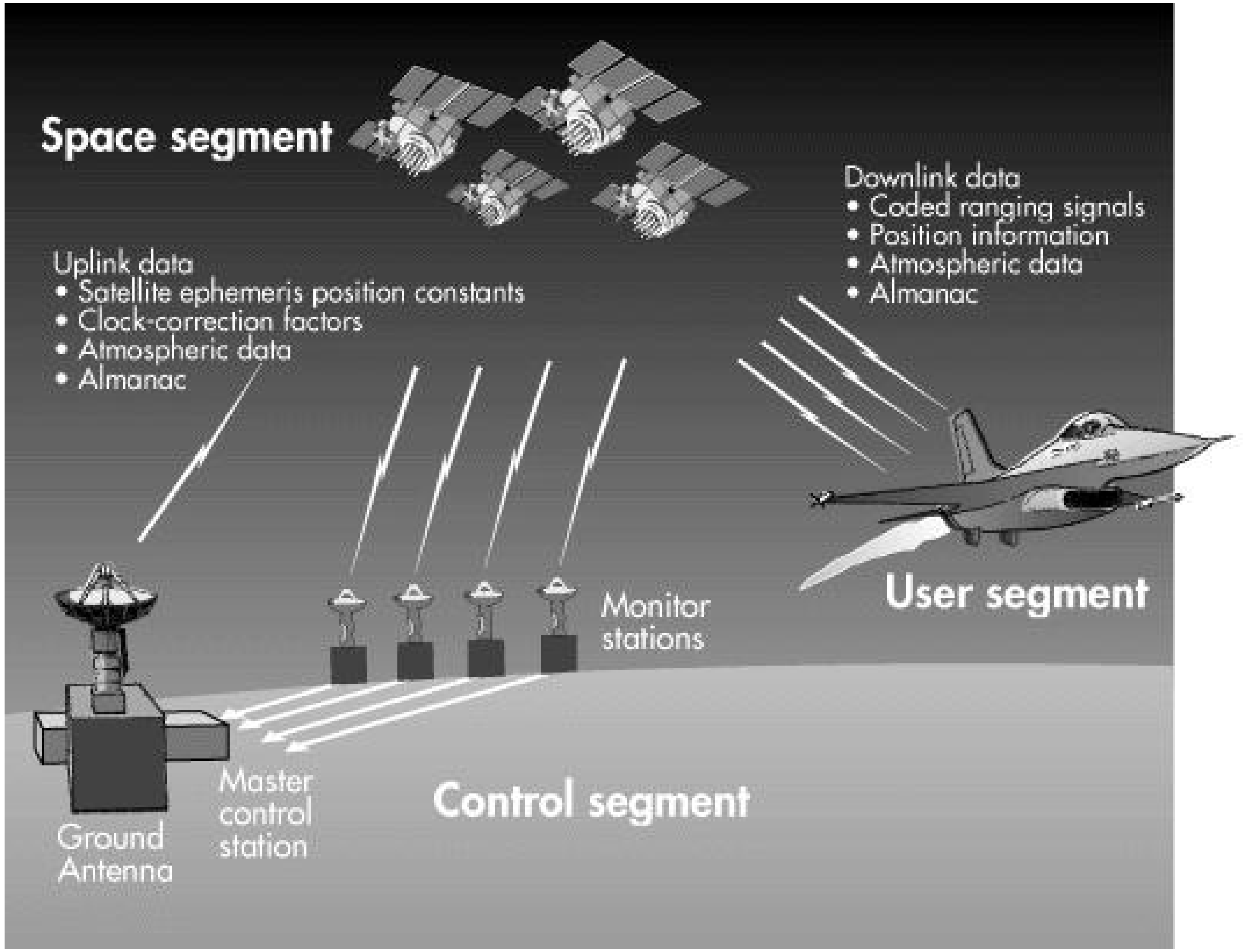
The Global Positioning System (GPS)

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.

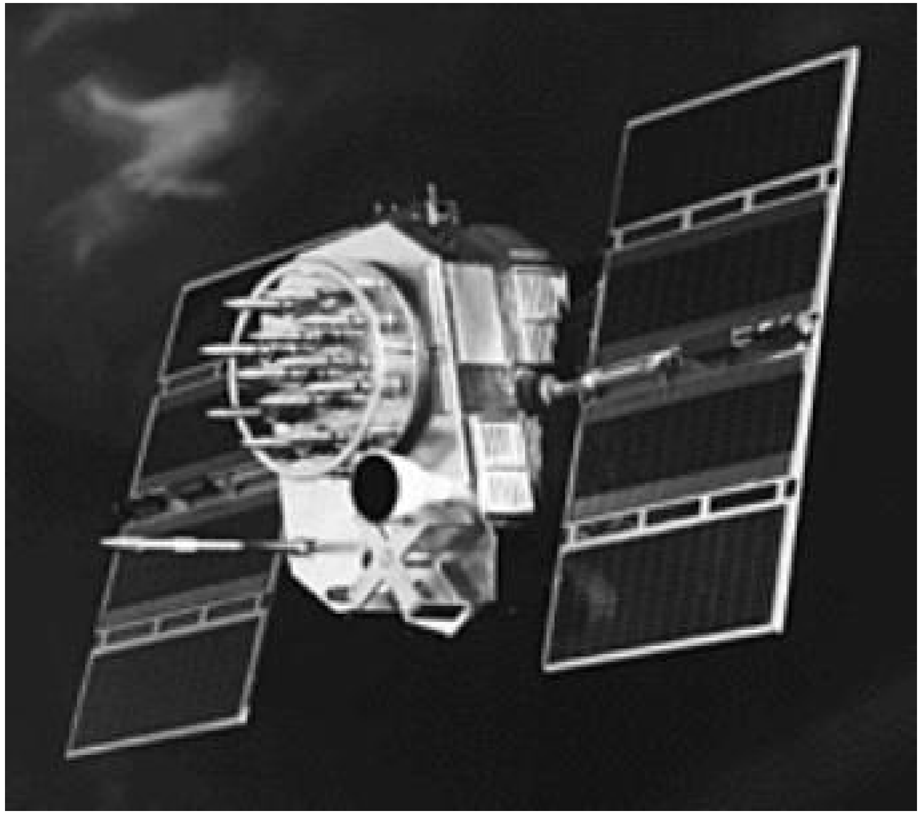
System Components

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



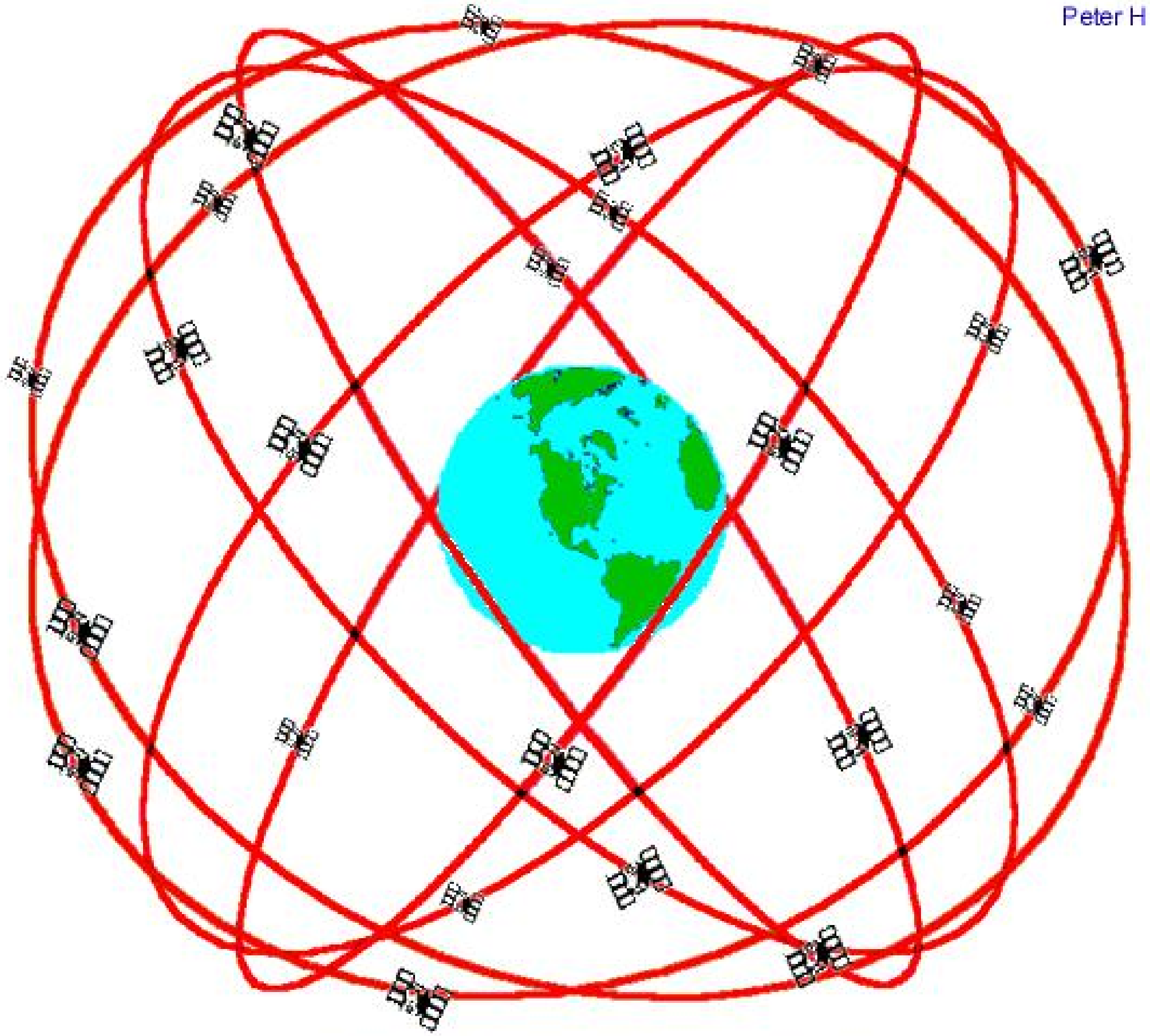
Two generations of GSP satellite vehicles (SVs)

GPS block I:
Experimental



GPS block II:
Full-scale operational

Peter H. Dana 9/22/98



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

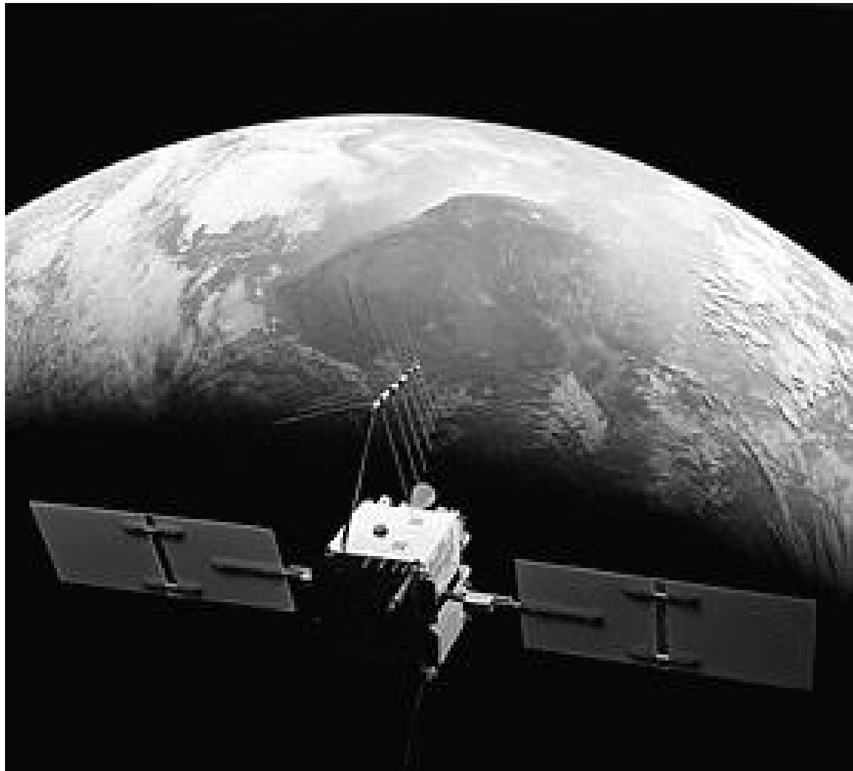
examples of applications

Four Basic Functions of GPS

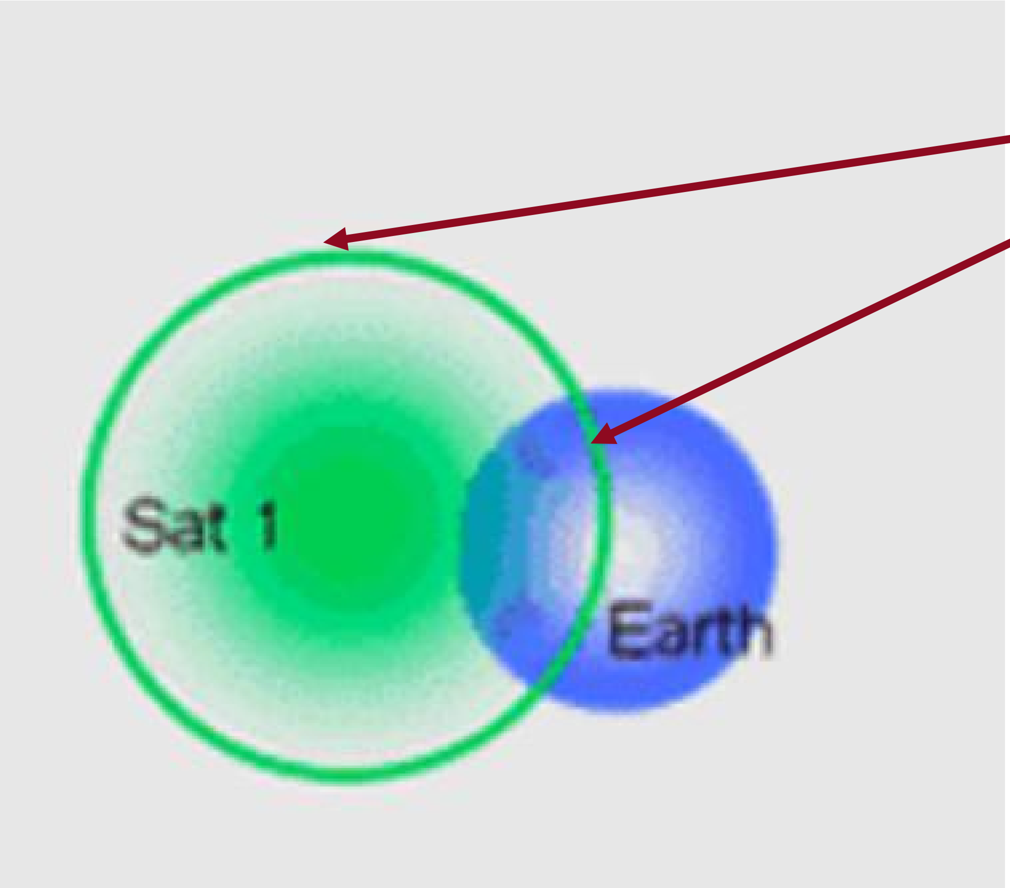
- Position and coordinates.
- The distance and direction between any two waypoints, or a position and a waypoint.
- Travel progress reports.
- Accurate time measurement.

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

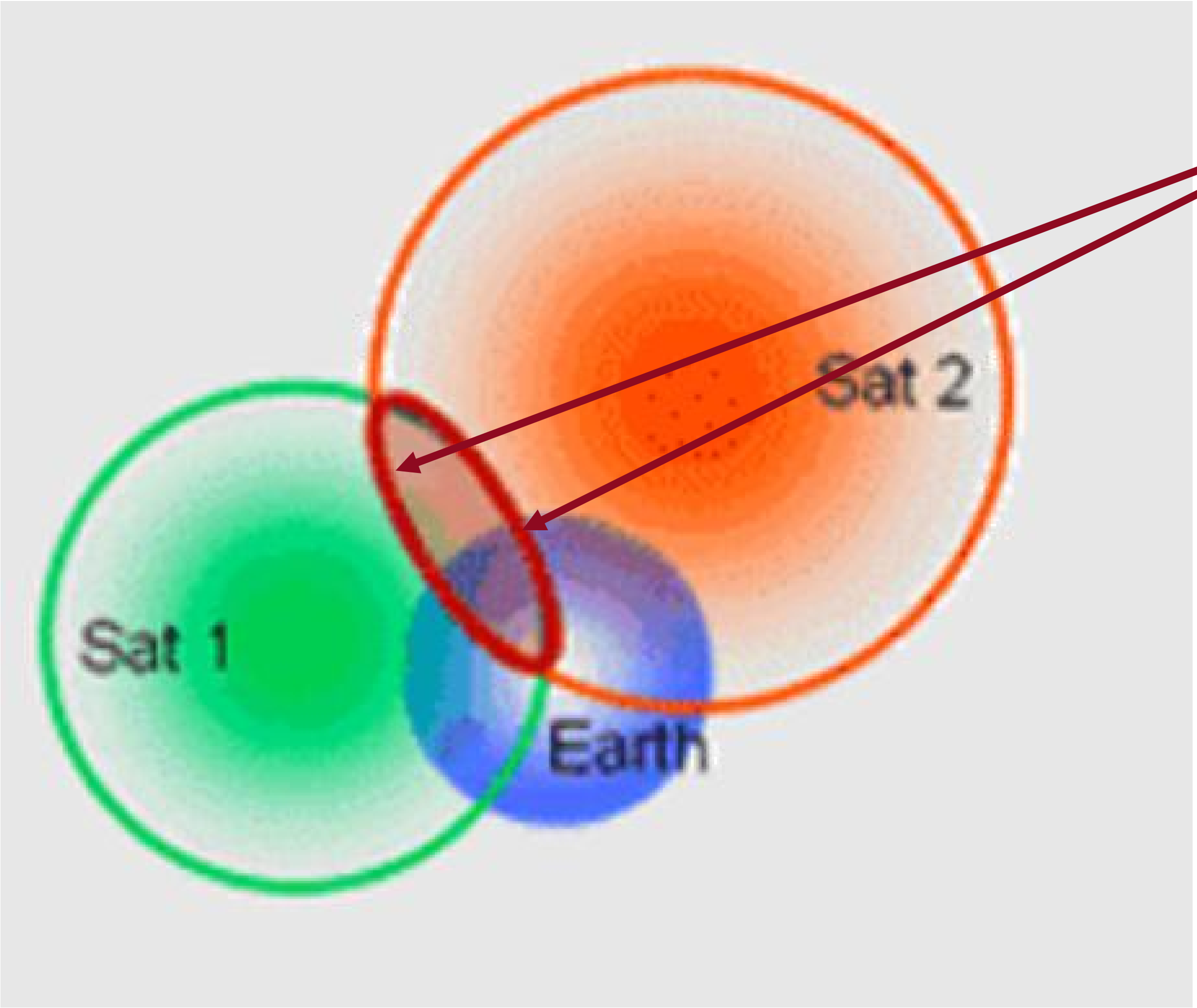


Signal From One Satellite



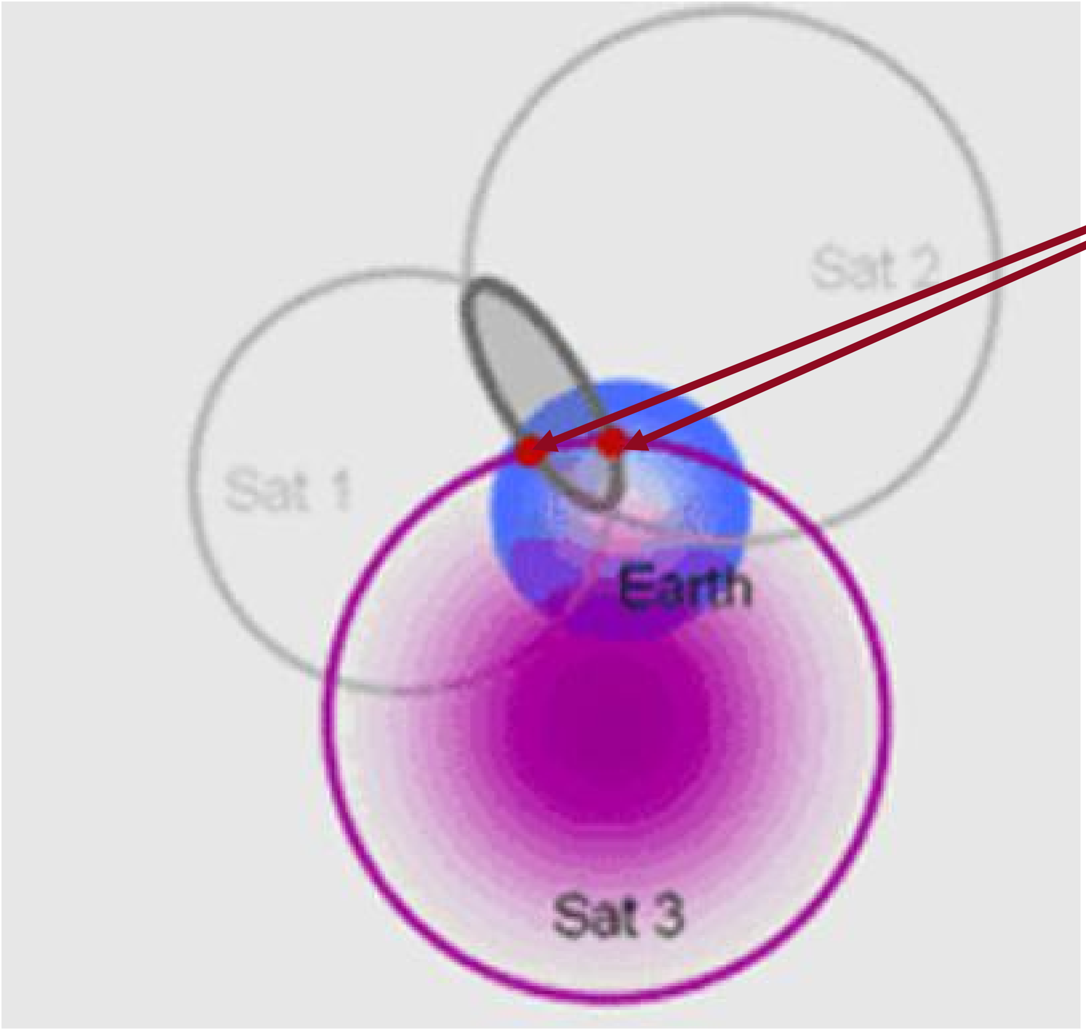
The receiver is somewhere on this sphere.

Signals From Two Satellites



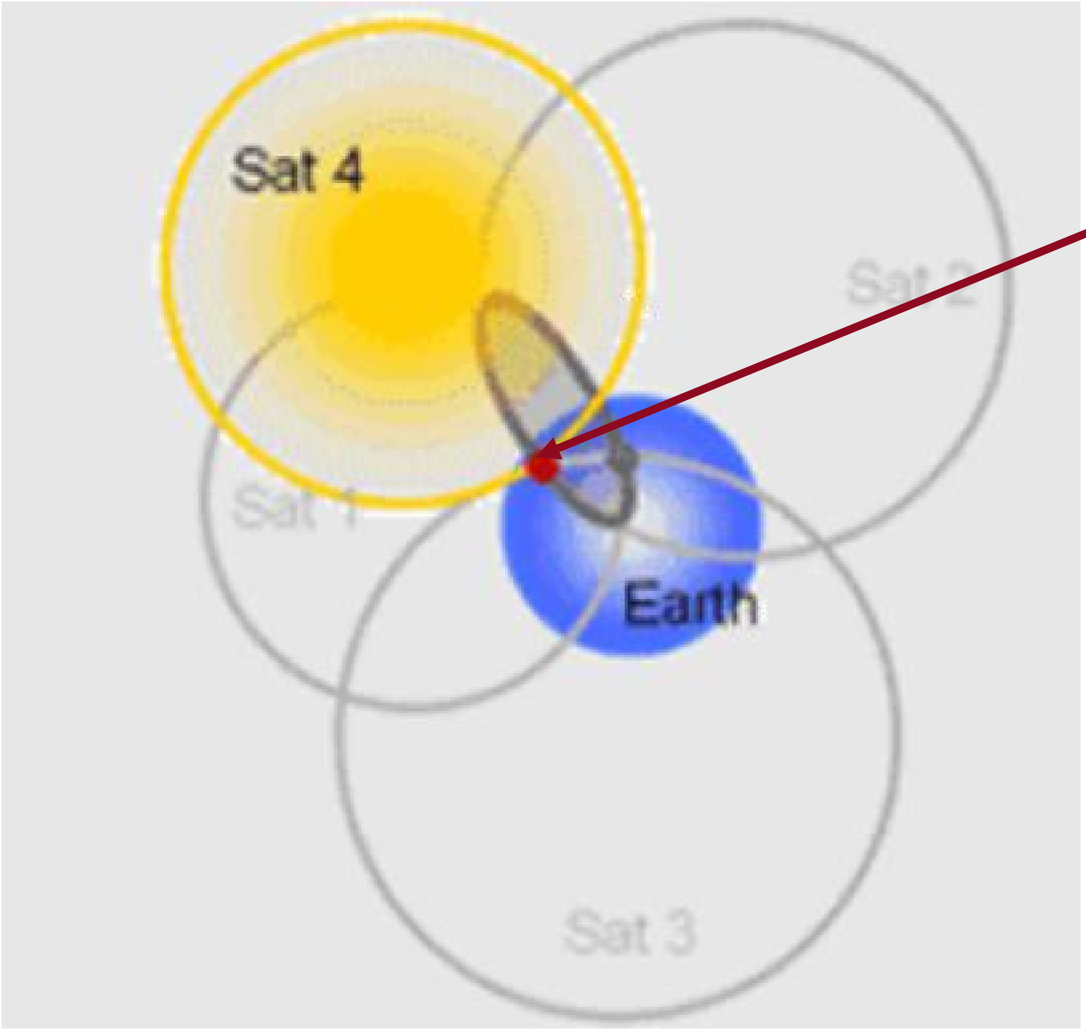
The receiver is somewhere on this circle.

Signals From Three Satellites



The receiver is somewhere between these two points.

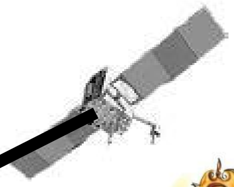
Signals From FourSatellites



The receiver is here.

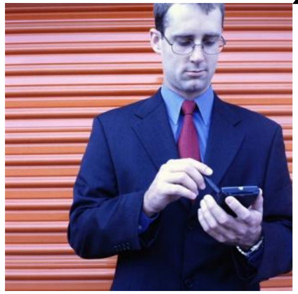
Travel time

Signal leaves at 8:03:02.12



For example: 13,000 some miles

Radio waves travel about 186,000 miles (300,000 km) per second.



Signal arrives at 8:03:02.19

High accuracy is needed

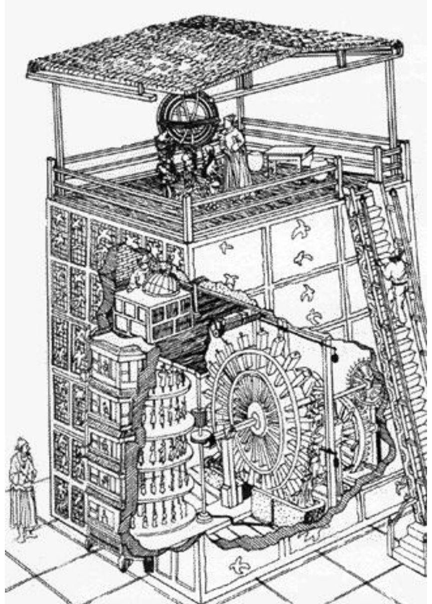
8:03:02.19

\- 8:03:02.12

0:00:00.07

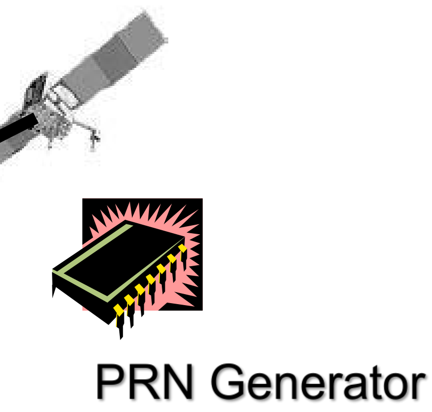
7 hundredths of a second difference for the 13,000 mile (i.e. 20,000 km) distance

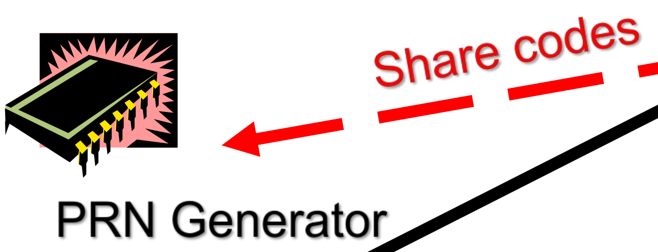
Takes some really good clocks



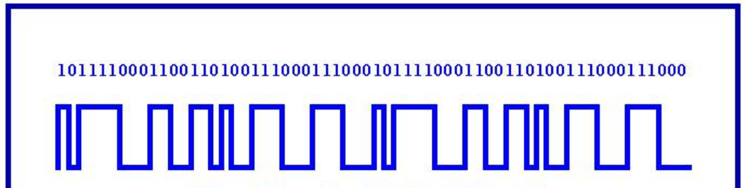
Su Sung water clock tower

So how do you measure the time difference (ranging)?



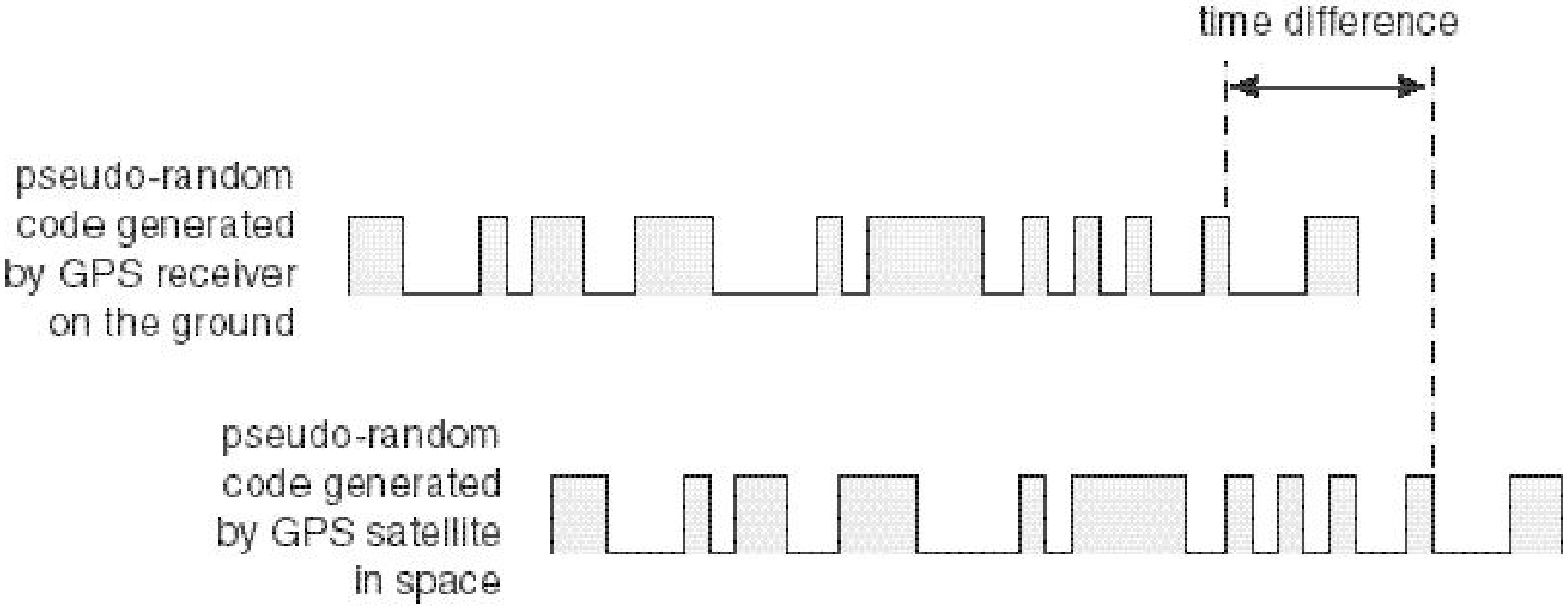


- If we wanted to see just how delayed the satellite's version was, we could start delaying the receiver's version until they fell into perfect sync.
- The amount we have to shift back the receiver's version is equal to the travel time of the satellite's version.



A Short Repeating PRN Code Sample

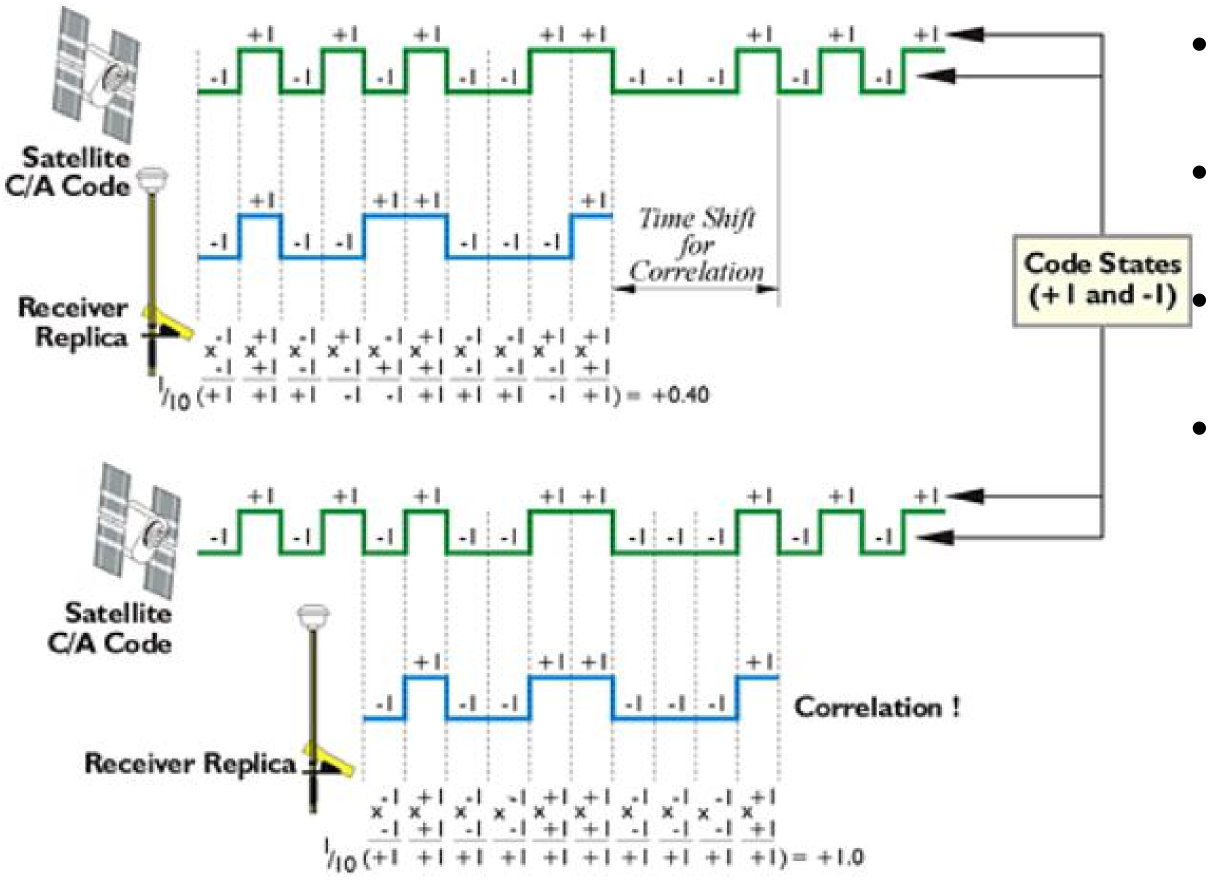
GPS Ranging



http://maps.unomaha.edu/Peterson/gis/notes/GPS.pdf

- The local receiver and the satellite generate the same pseudo-random code at the same time.
- Upon revceiving the signal from the satellite, the difference of the two signal is compared.
- The time difference times speed of light determins the distance to satellite.

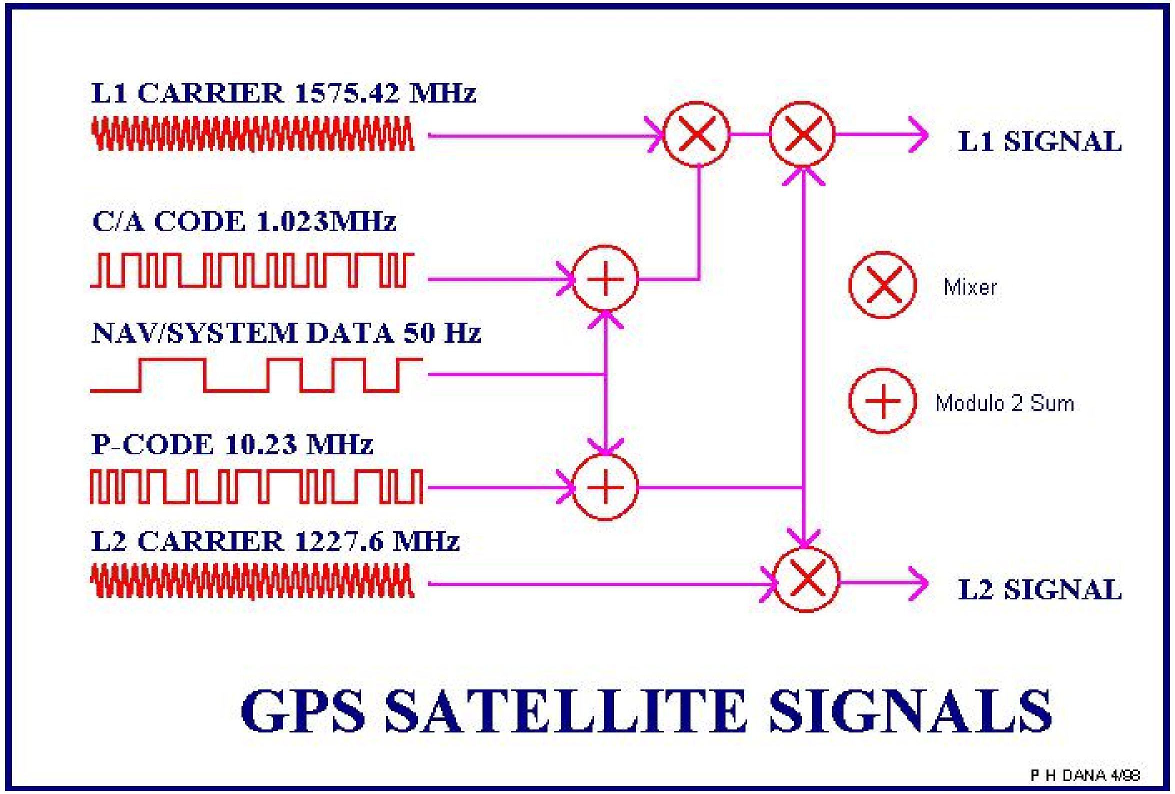
Algorithm Implementation



- The signals time slices are charaterized as +1 and –1 states.
- We multiply each time slices and sum them up.
- We time shift the receiver replica of the signal to find the best correlation.
- When th sum of product of the two signal equals to 1, we have a perfect match

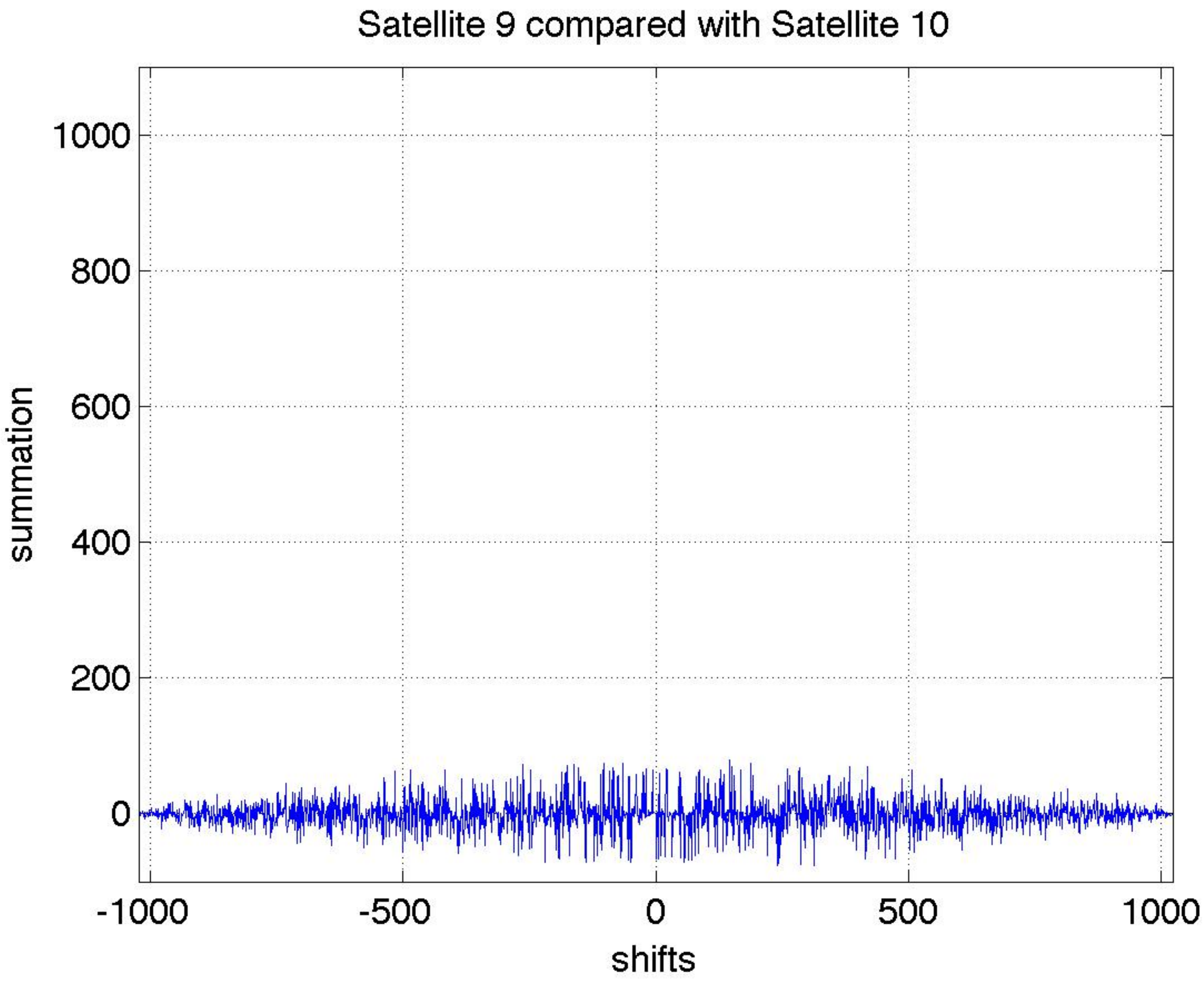
https://www.e-education.psu.edu/geog862/book/export/html/1407

So what do the real signals look like?

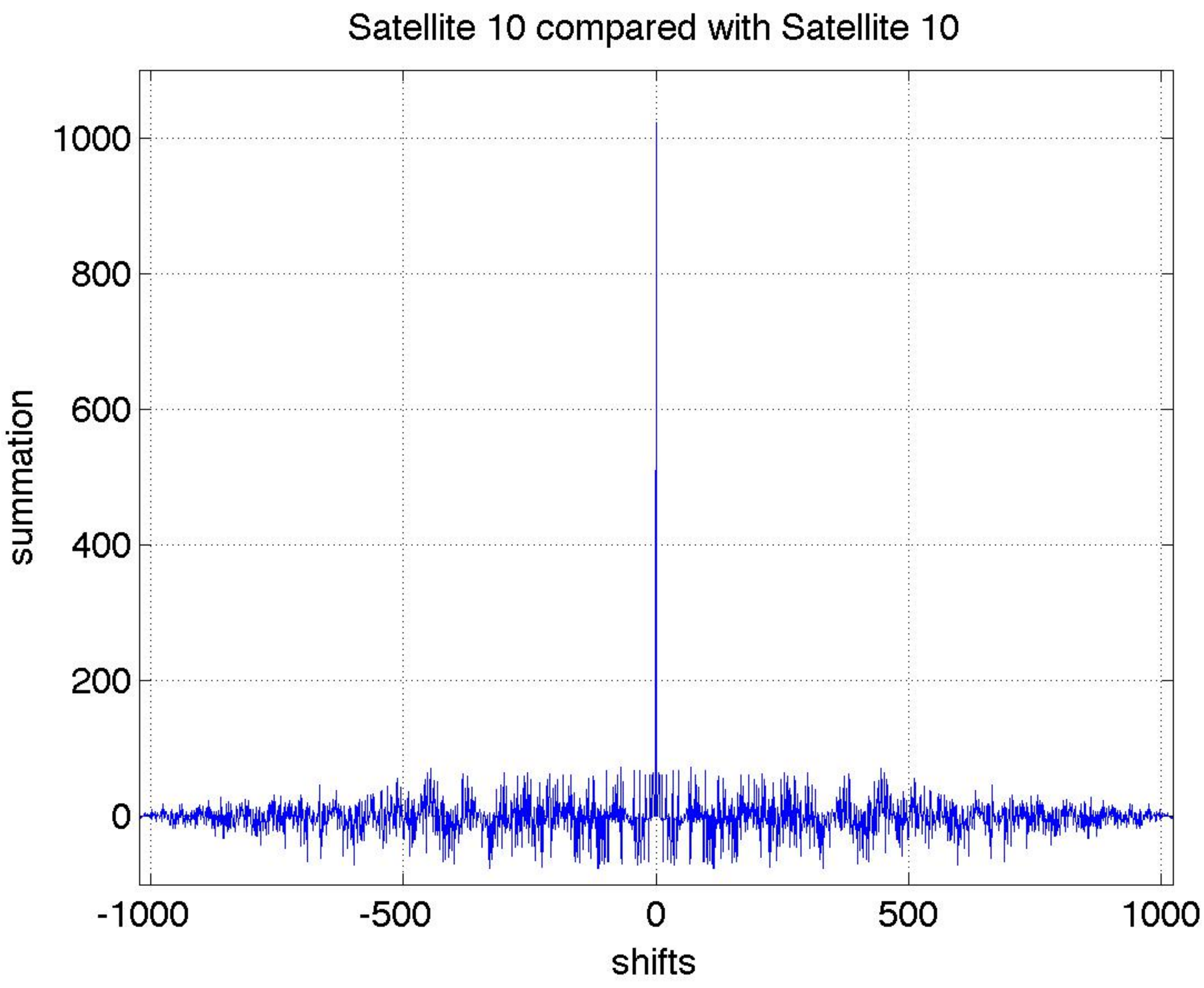


The information is sent either C/A (Course Acquisition Code)
or P codes (Precision Code).
The C/A code is broadcast on L1 Carrier Frequency. 1-5 meter accuracy.
P Code – Precision Code is used by the military (L1 and L2).

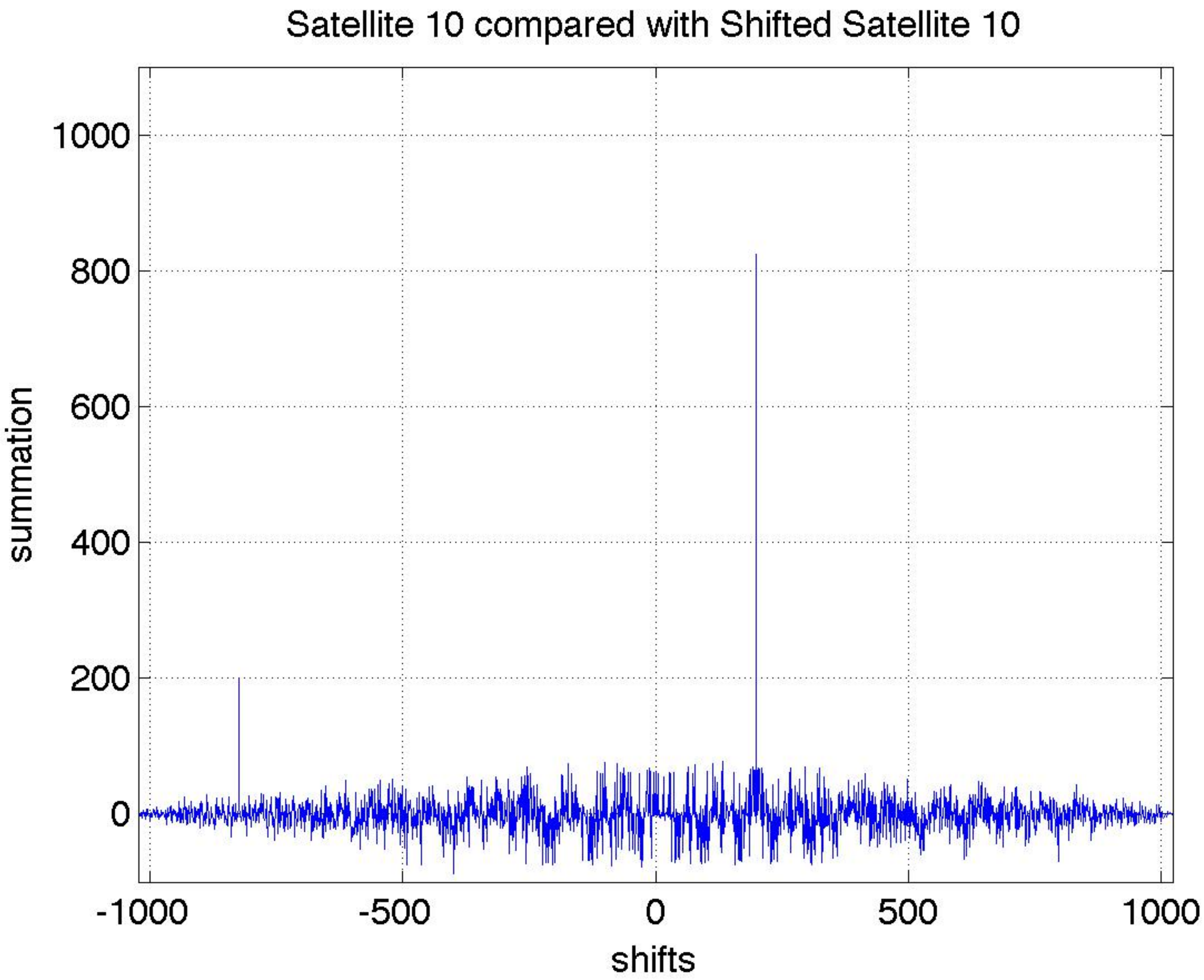
Satellite 9 compared to Satellite 10 code



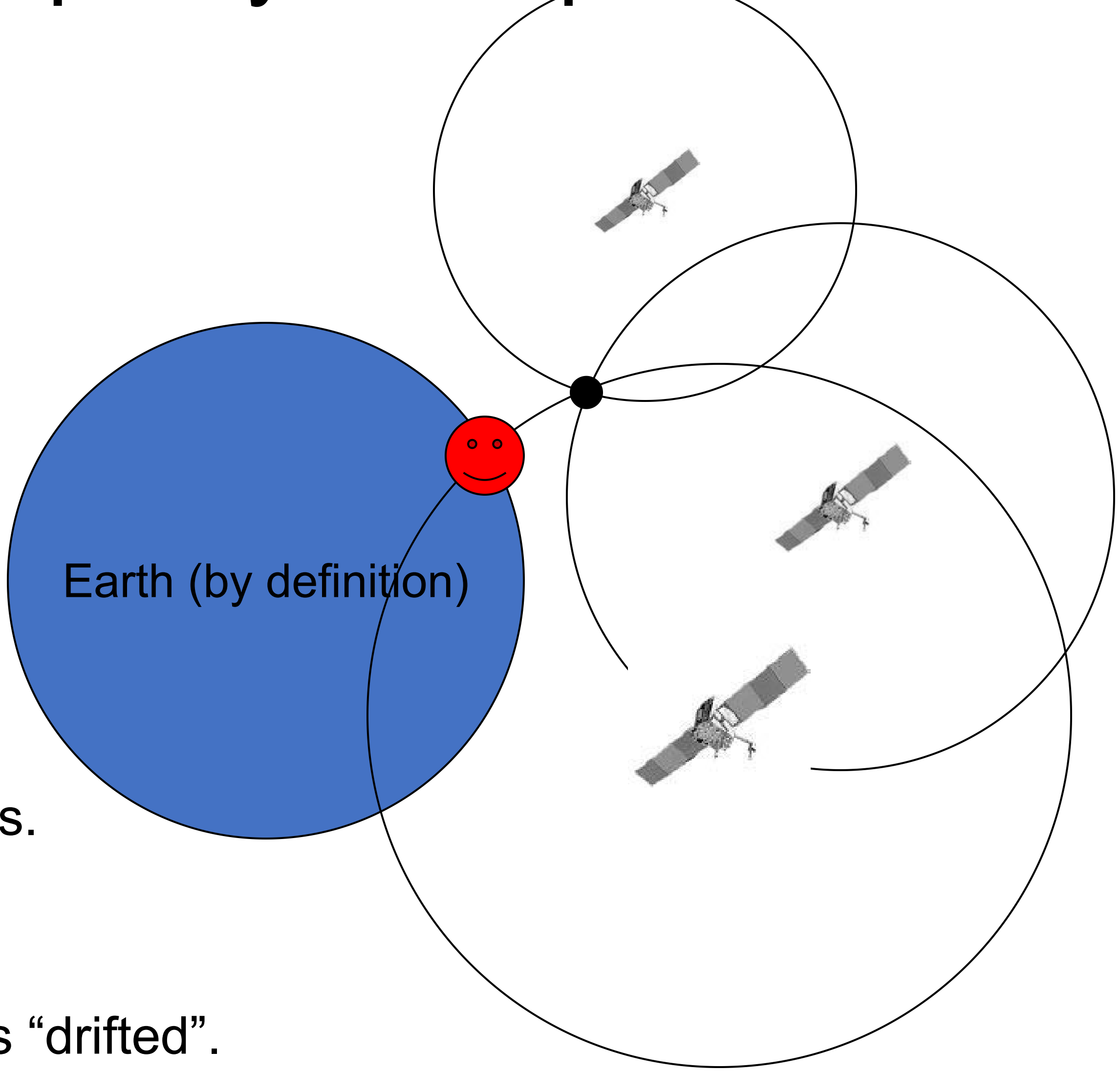
Satellite 10 compared to Satellite 10 code



Satellite 10 compared to Satellite 10 code that has been shifted by 200.



Remember the pesky clock problem?

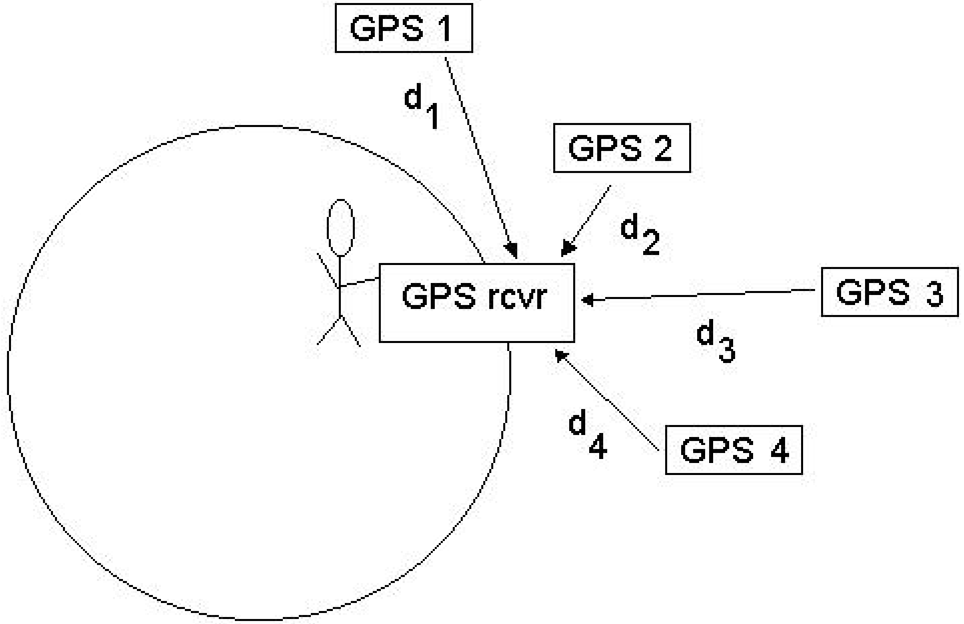


Satellites have expensive clocks.
Our receiver doesn't!

Key idea: user clock is "drifted".
So our distance is off – but by a constant amount!
Treat it as another unknown variable

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

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

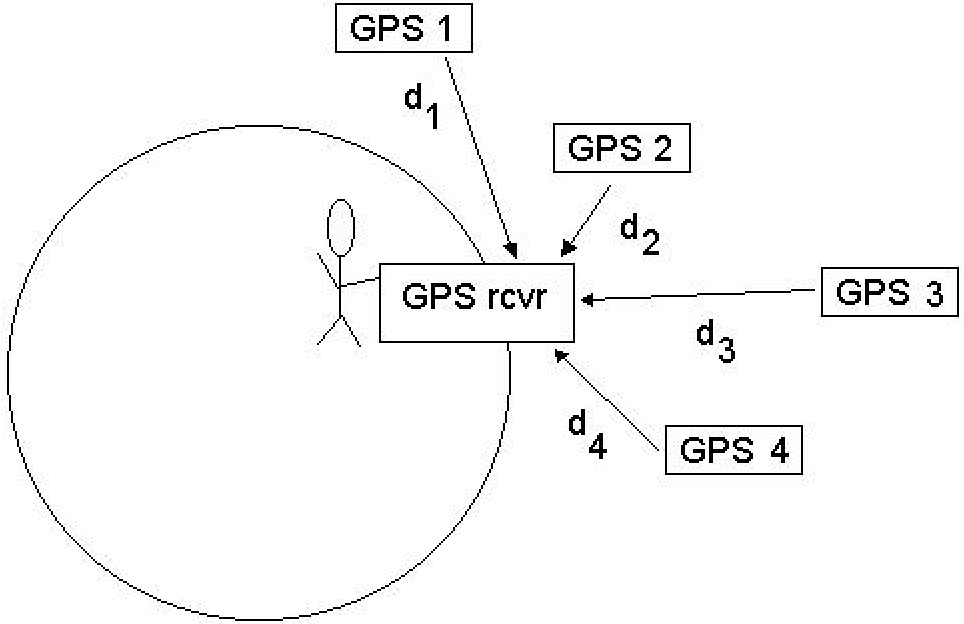
$$\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}+ct_B=d_2$$

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

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

- c: speed of light
- x_i: the satellite positions, known to the receivers

A quadratic programming problem. Solved by mature solvers



Satellite position information

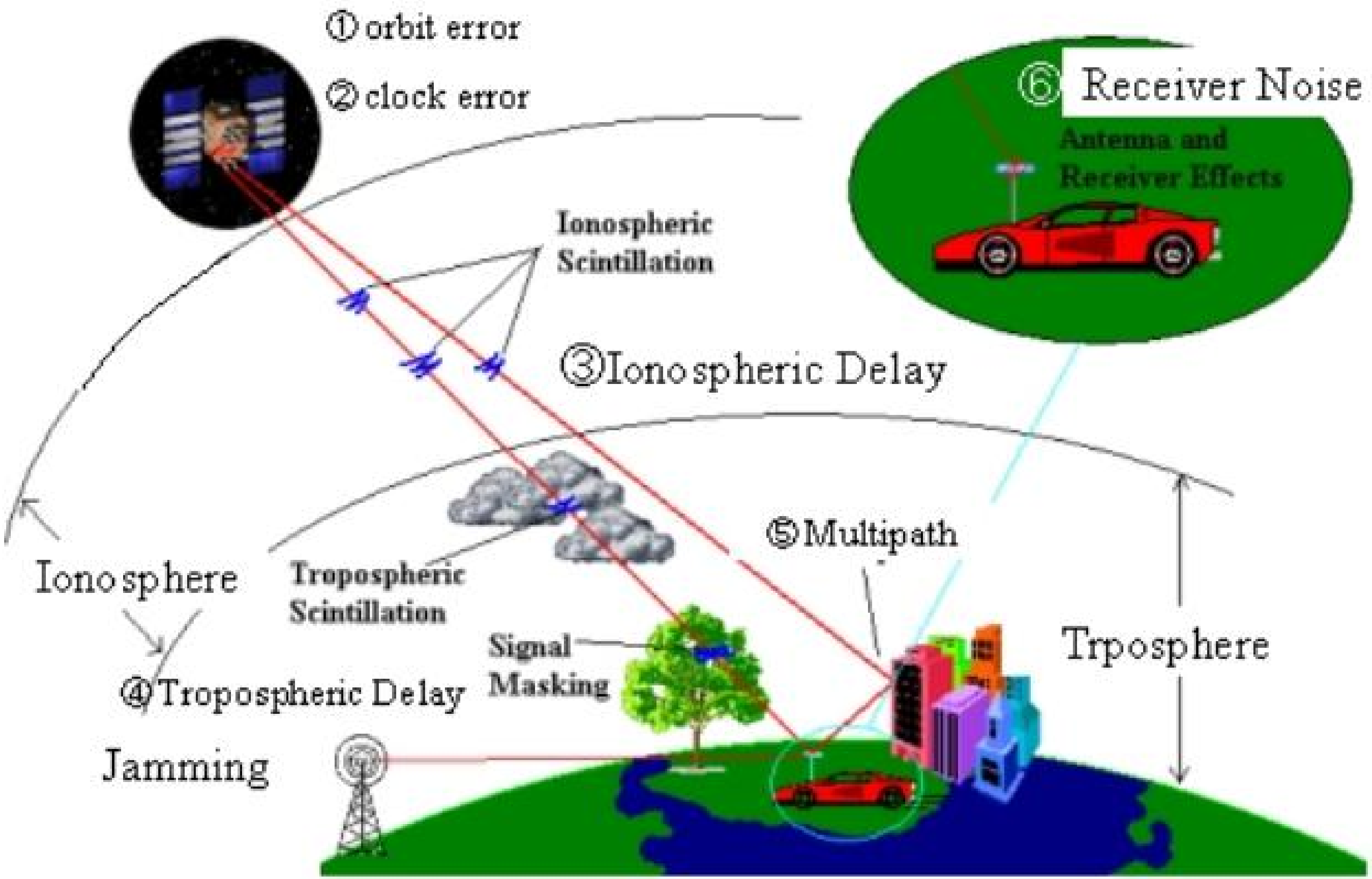
- GPS satellites transmit information about their location (current and predicted), timing and "health" via what is known as **ephemeris** data.
- This data is used by the GPS receivers to estimate location relative to the satellites and thus position on earth.

Adafruit Ultimate GPS Module

- -165 dBm sensitivity, 10 Hz updates, 66 channels
- 5V friendly design and only 20mA current draw
- Breadboard friendly + two mounting holes
- RTC battery-compatible
- Built-in datalogging
- PPS output on fix
- Internal patch antenna
- u.FL connector for external active antenna

https://www.adafruit.com/product/746

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 (Troposphere)

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

- Note: weather conditions, such as clouds, storms, and rains, have limited impacts on accuracy

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.

GPS error: Wireless Interference

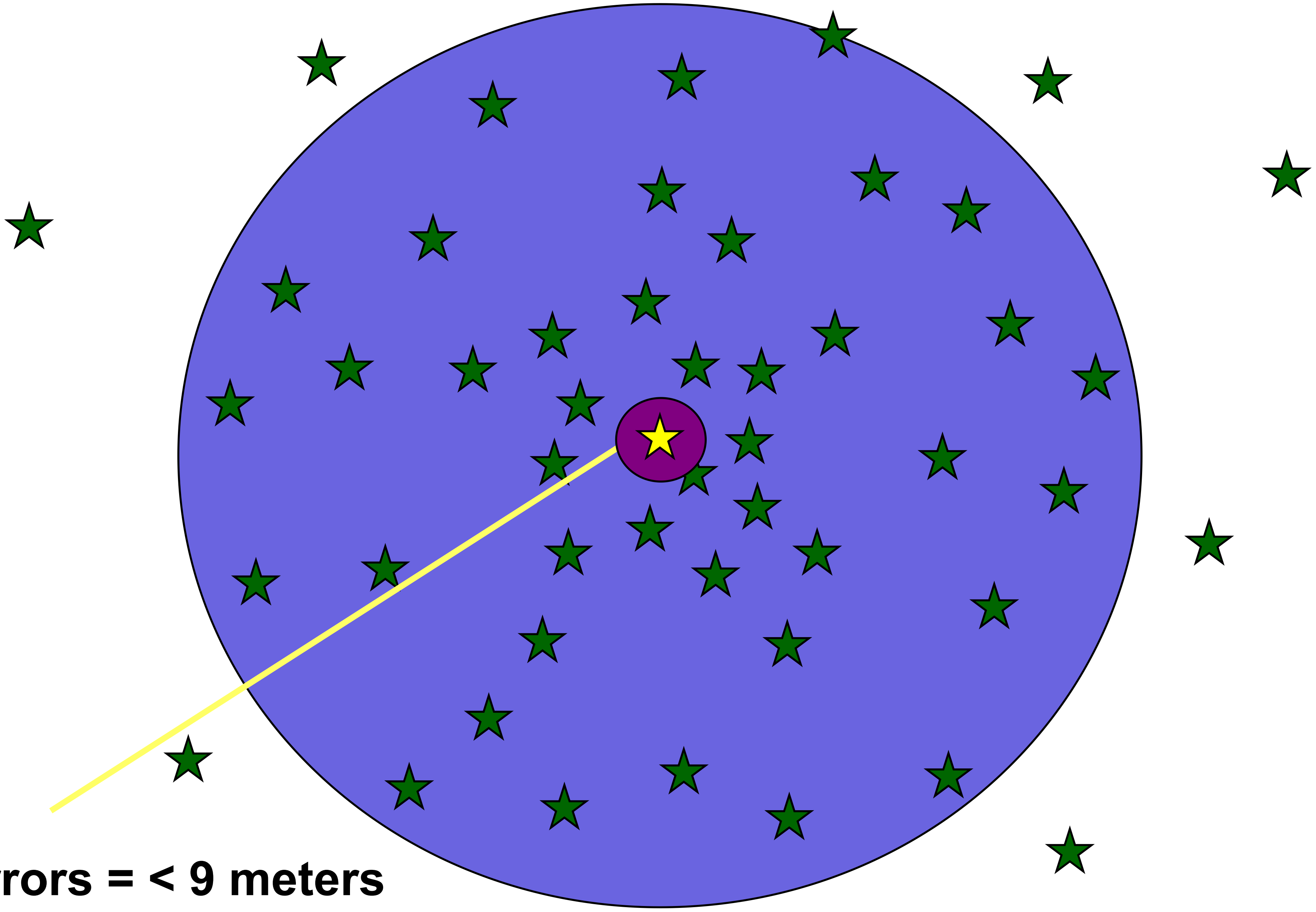
- Like any other wireless systems, GPS signals are susceptible to interference. Error: from small to unbounded.

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!

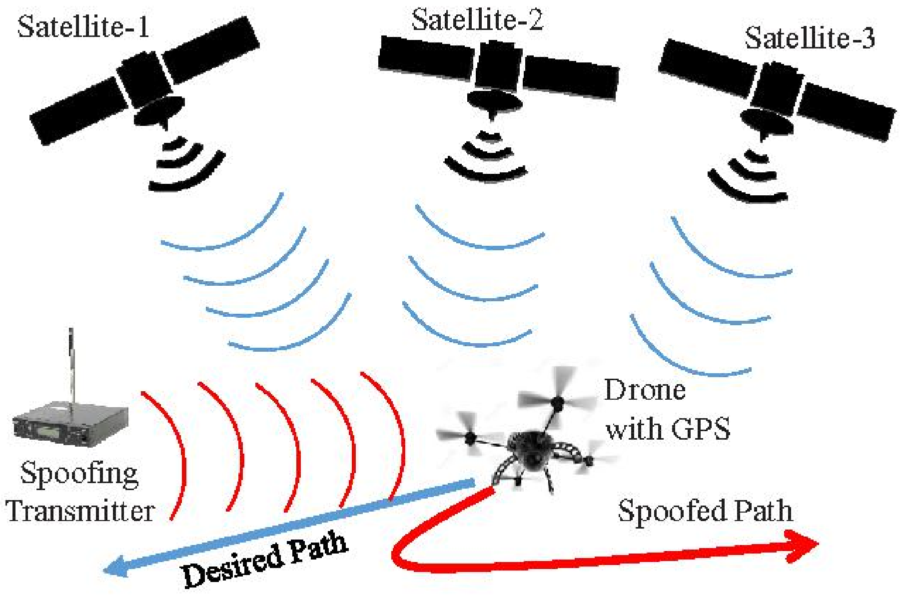


System errors = < 9 meters

Which sources of errors?

- GPS navigation errors in a city with tall buildings

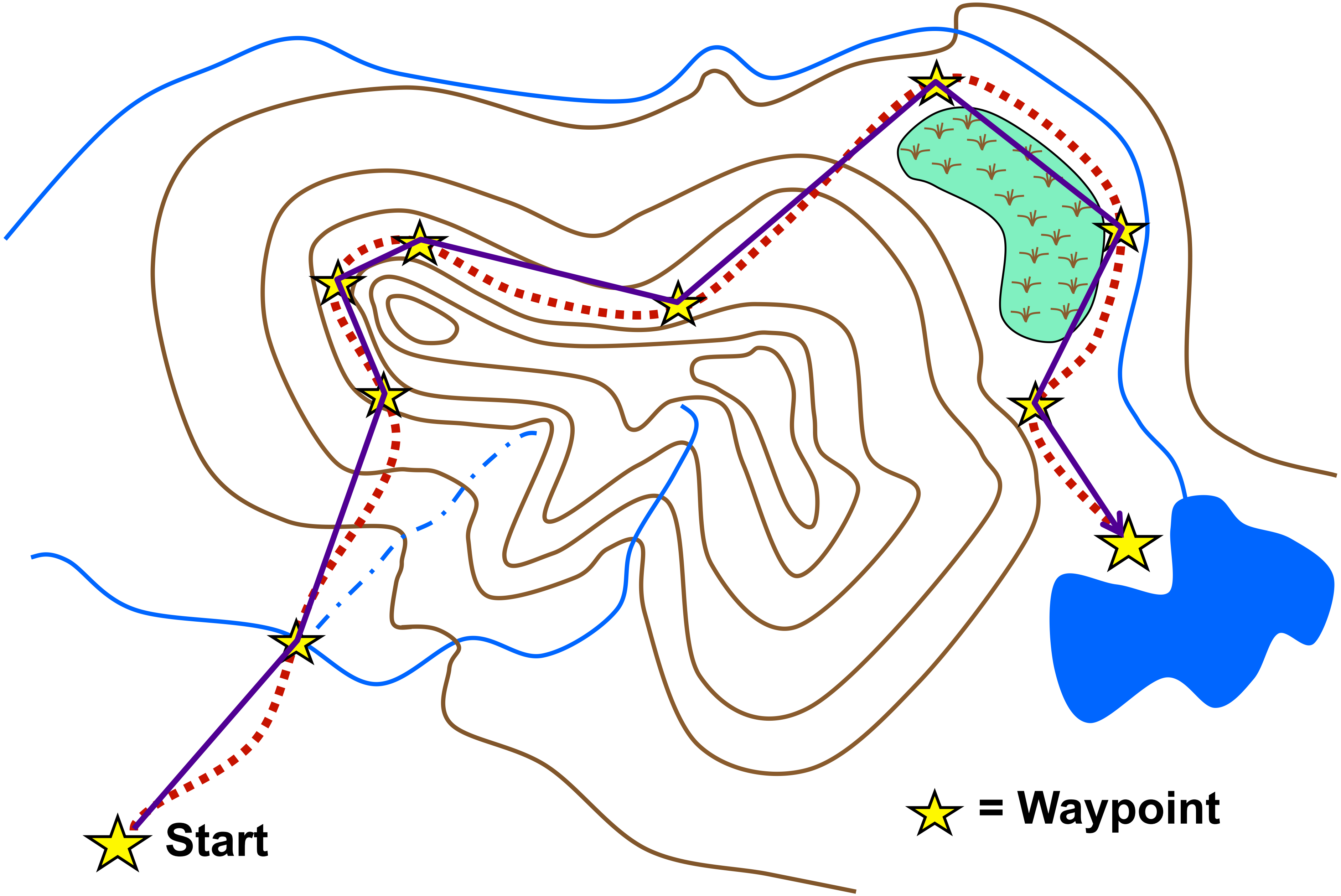
- Drone GPS spoofing



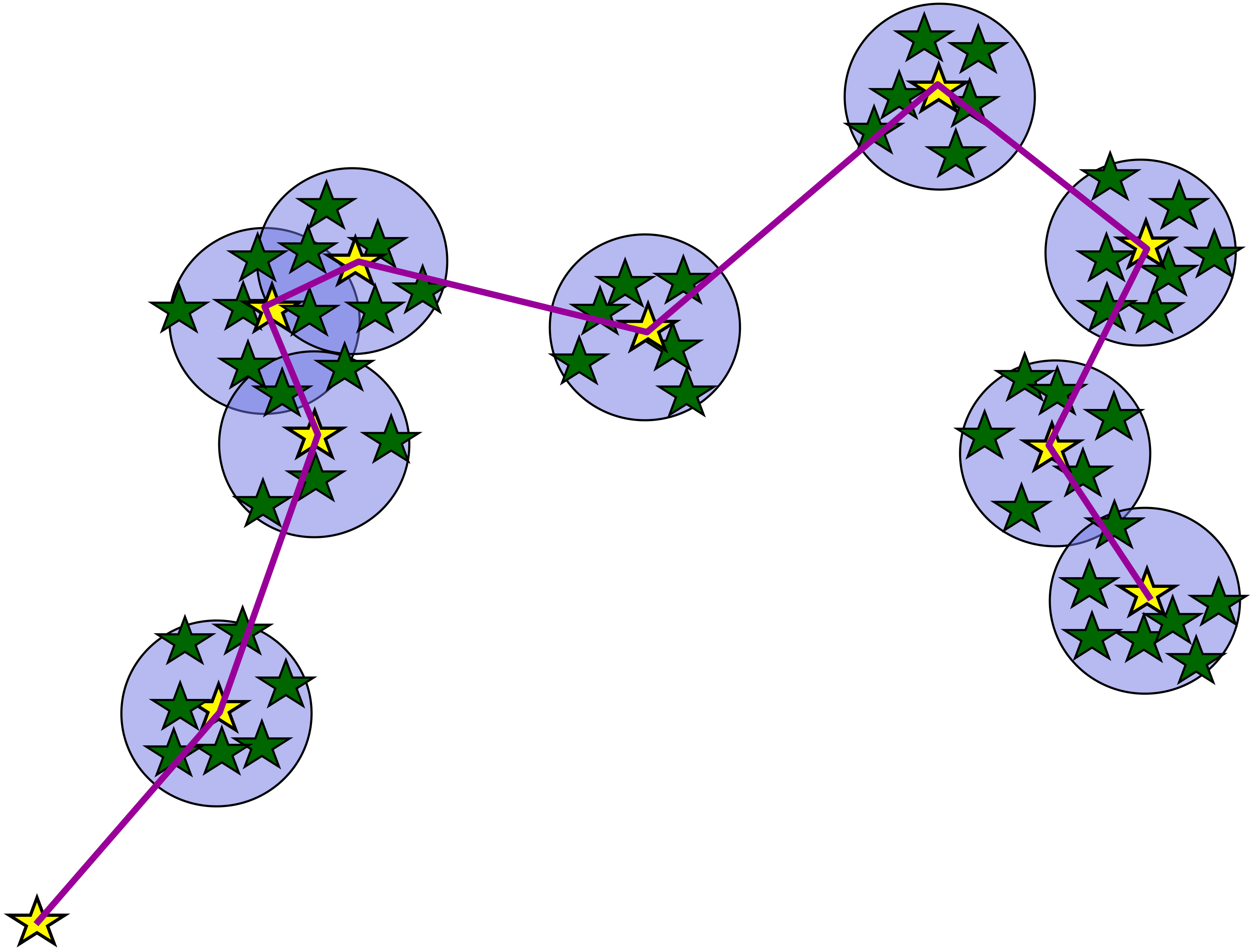
Waypoint

- A waypoint is based on coordinates entered into a GPS receiver’s memory.
- 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

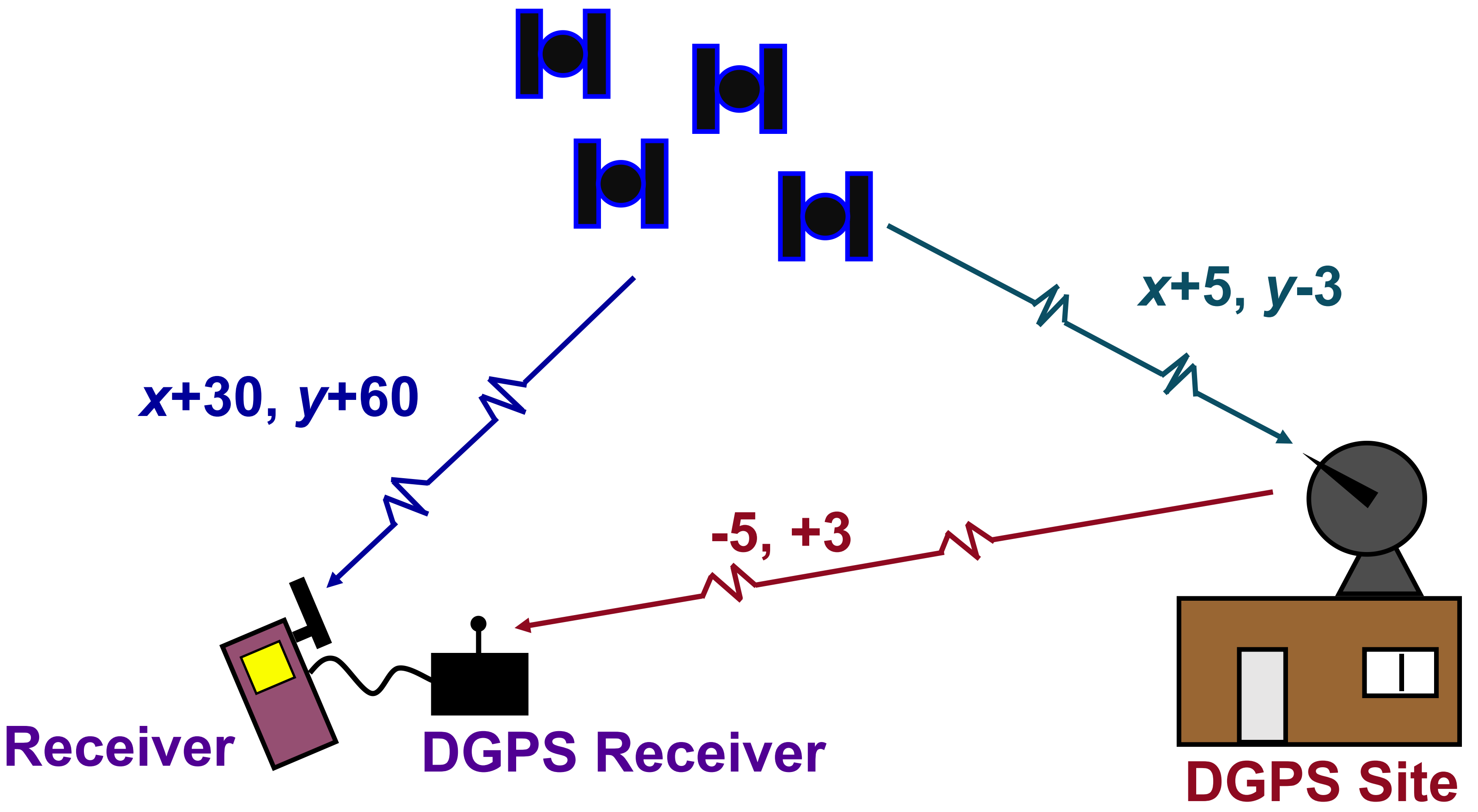


Differential GPS

- 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



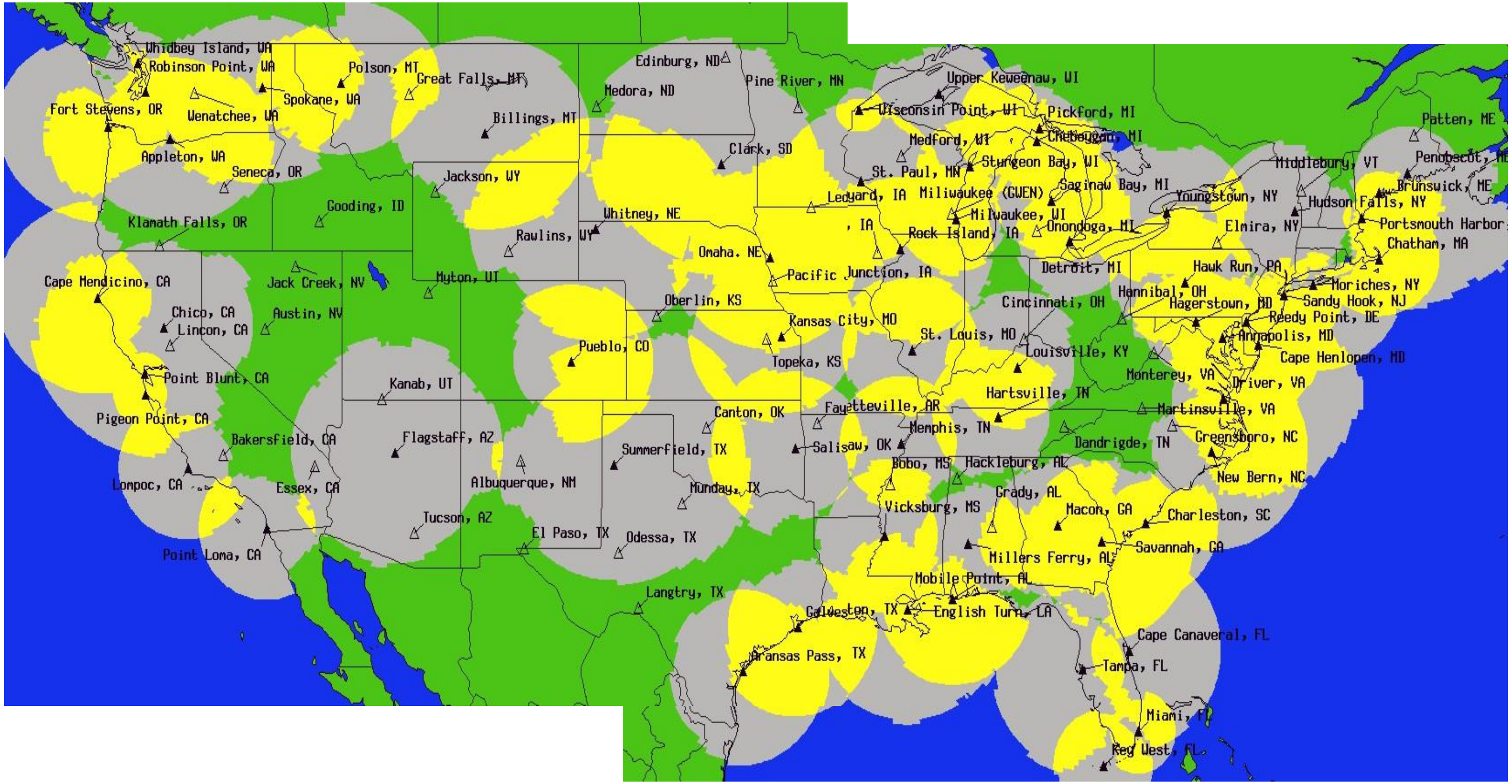
True coordinates = *x*, *y*

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

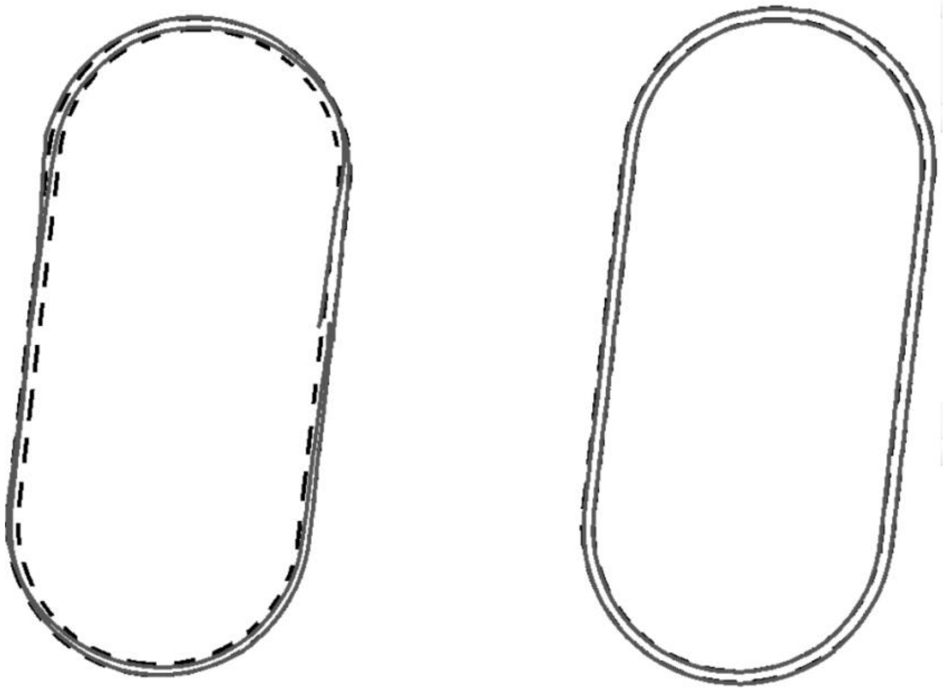
	Lat_meas	Long_meas	alt_meas	Lat_ground	Long_ground	Alt_ground
DGPS	37.0366833	35.3744433	60	37.0367146	35.3744596	64.5
Receiver 1	37.03671	35.3744467	65			

Question

- What types of errors can be mitigated by DGPS
    - ∅ Satellite clocks
    - ∅ Orbital errors
    - ∅ Ionosphere
    - ∅ Troposphere
    - ∅ Receiver noise
    - ∅ Multipath

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