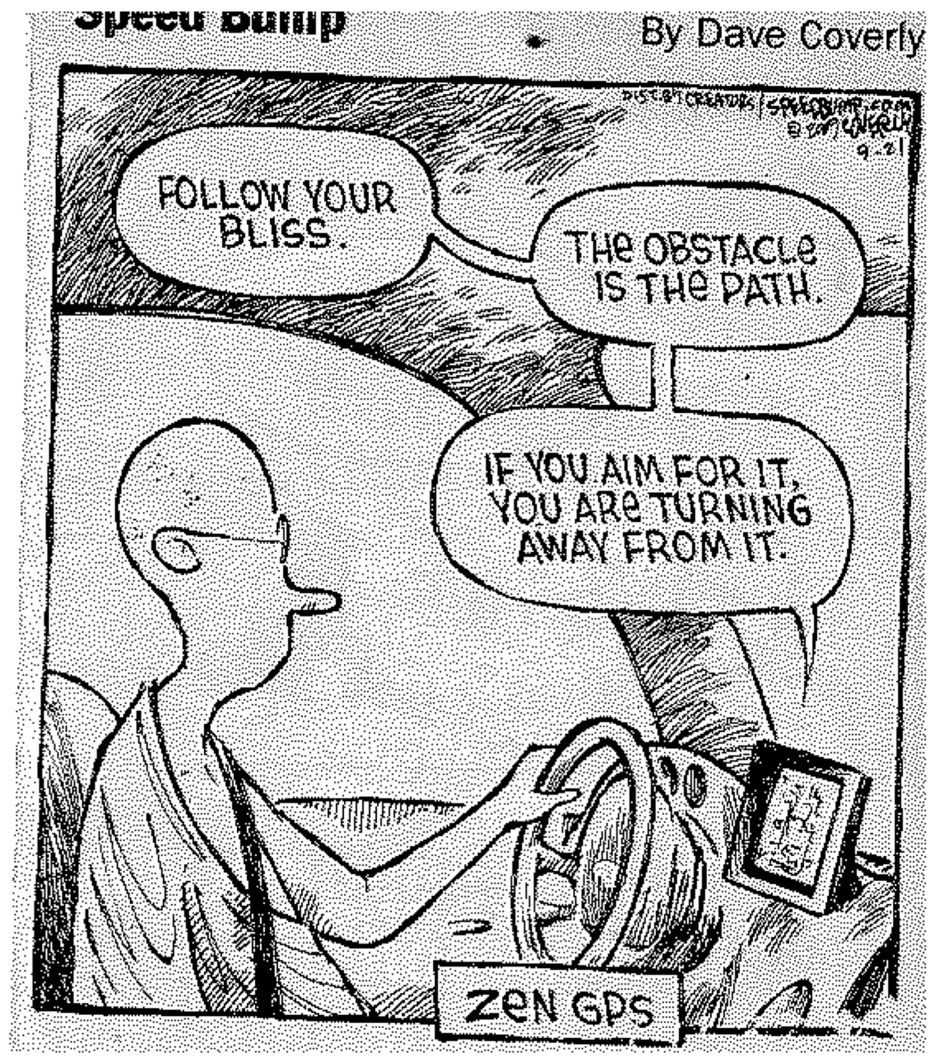
ASEN 5090 Lecture 3

GPS Basics



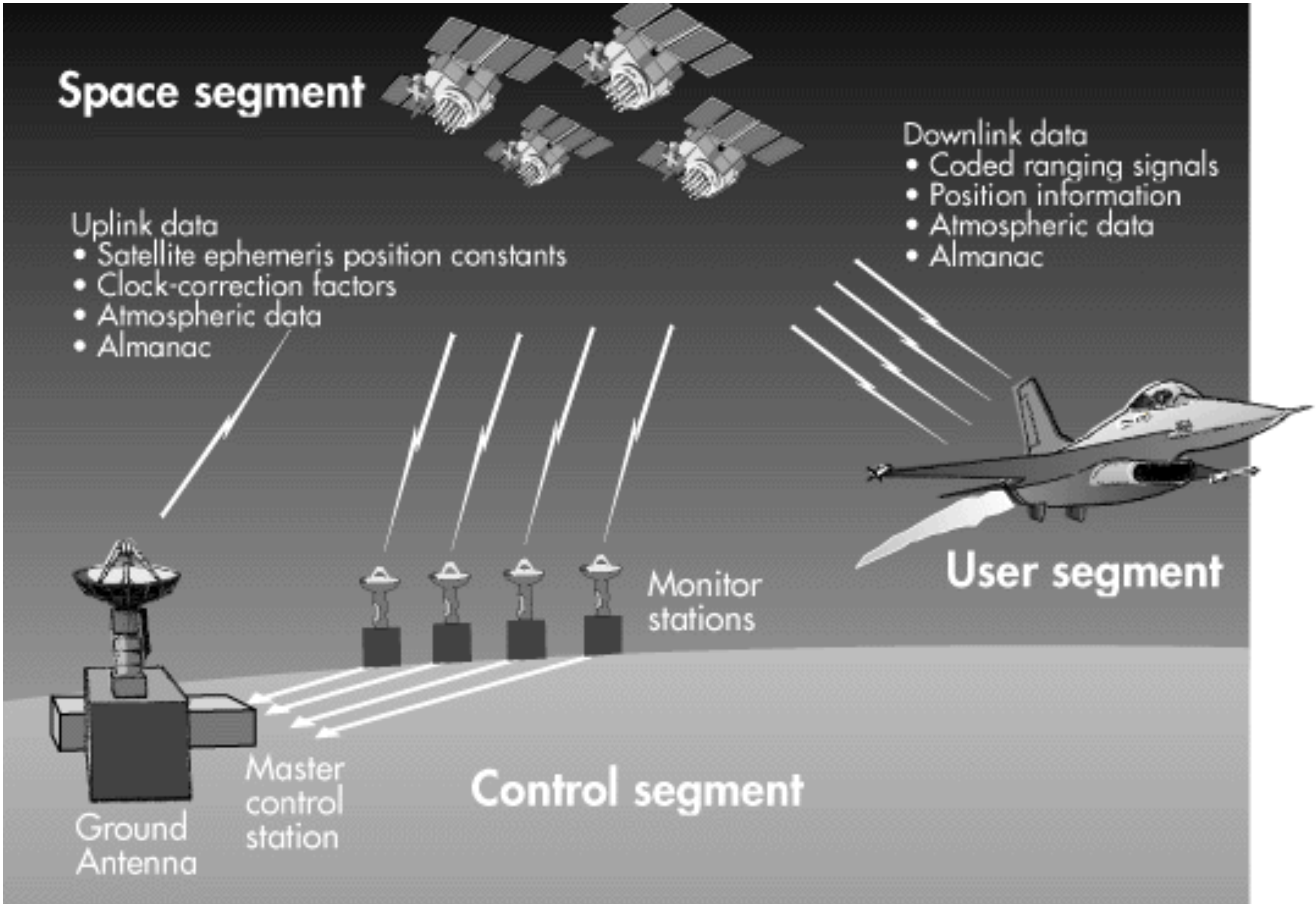
Outline

- Space Segment
- Control Segment
- User Segment
- Augmentations – WAAS, LAAS
- GPS Signals – carriers, codes
- Position solution – ranging and geometry

- Reading Assignment: Ch 2
- Questions to think about:
  - Why are PRN codes used?
  - What is needed to find position with GPS?

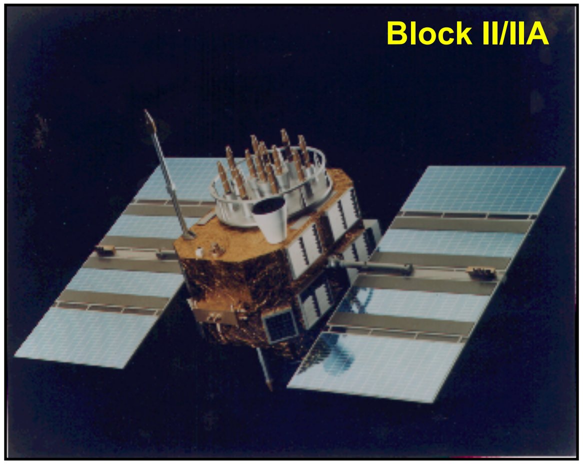
GPS JARGON

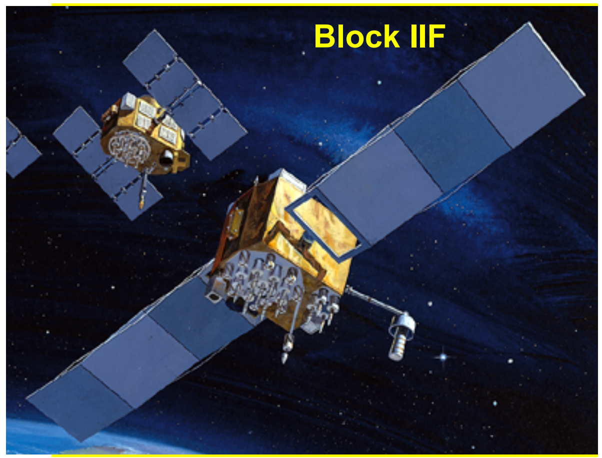
- PRN (pseudorandom noise) tells you which code is being generated by a certain satellite. The codes get reused, so PRN15 in 2008 will be a different spacecraft than it was in 1989.
- SVN (satellite vehicle number) tells you exactly which spacecraft it is. This number is never reused, as you need it to know the design specifications of the satellite.
- Constellation status is maintained by the Coast Guard website, Notice Advisory to Navstat Users (NANU)

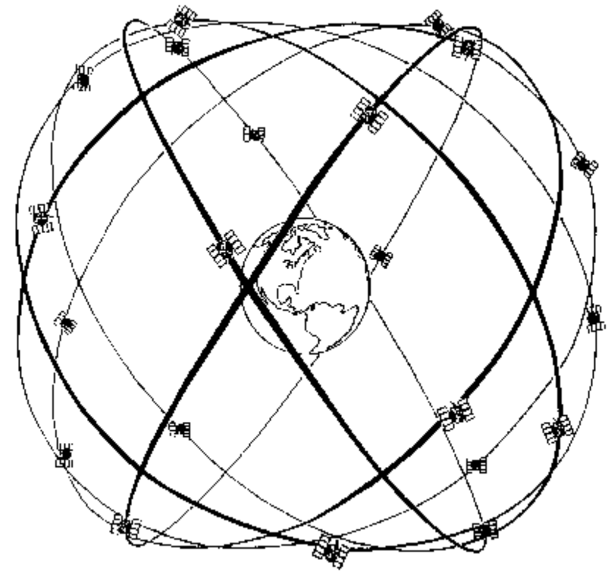


Space segment
Uplink data
• Satellite ephemeris position constants
• Clock-correction factors
• Atmospheric data
• Almanac
Downlink data
• Coded ranging signals
• Position information
• Atmospheric data
• Almanac
User segment
Monitor stations
Ground Antenna
Master control station
Control segment

GPS Space Segment



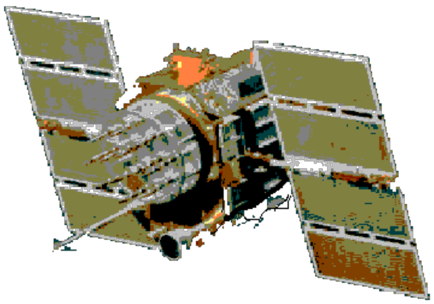




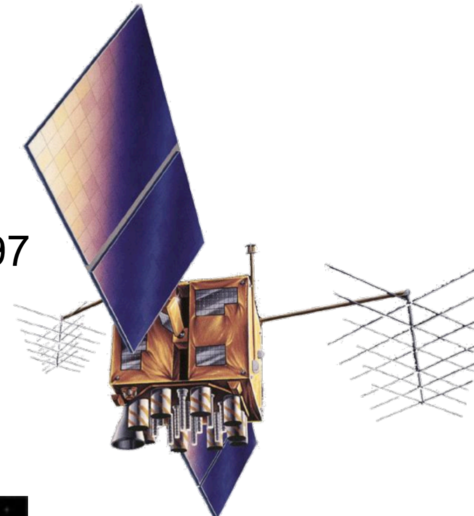
- 24-satellite (nominal) constellation
- Six orbital planes inclined at 55 deg, four satellites per plane
- Not geosynchronous.
- Semi-synchronous, nearly circular orbits (20,200 km altitude)
- Redundant cesium and/or rubidium clocks on board each satellite
- Antenna array pointed at the earth

GPS Constellation Status, April 2012

34 satellites on-orbit: 31 active, 3 Residual



Block II/IIA
Boeing (Rockwell)
Launched 1989 – 1997
10 Current

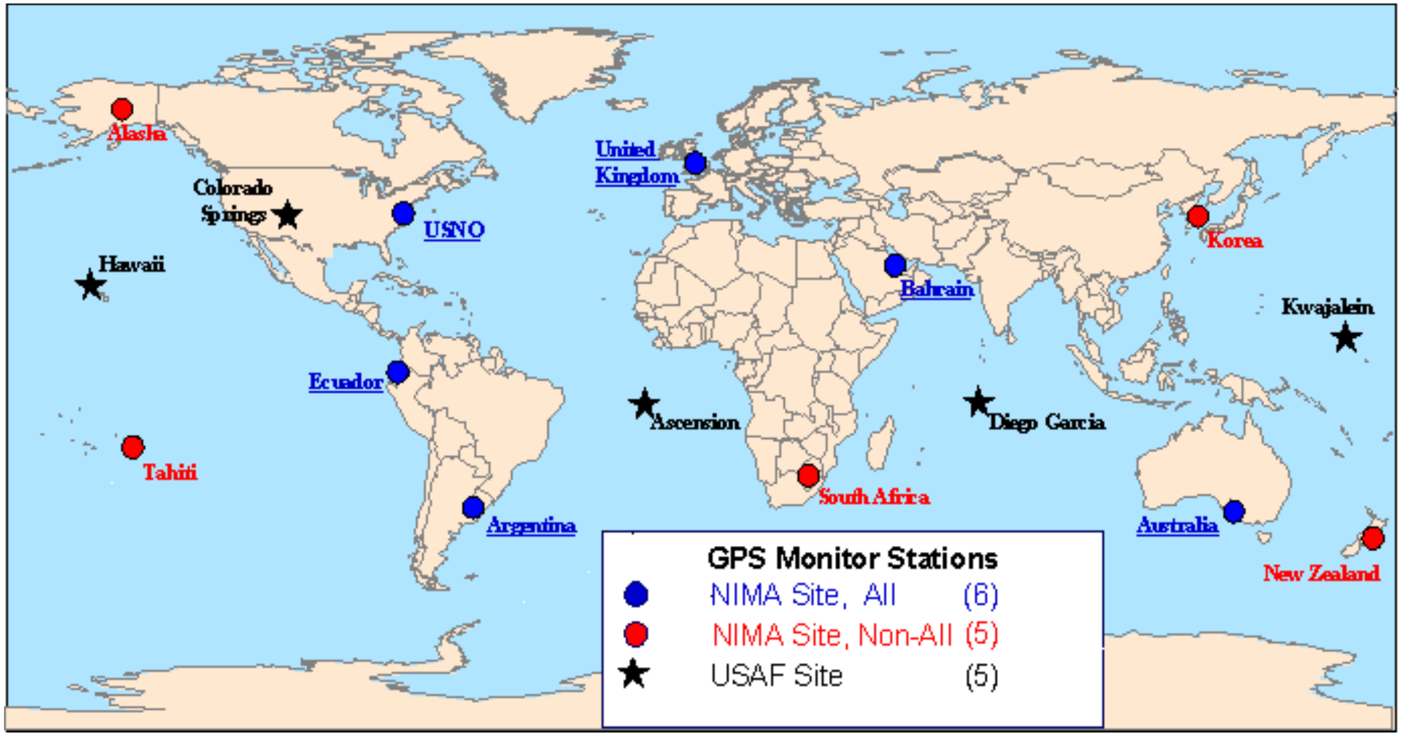


Block IIR/IIR-M
Lockheed Martin
Launched 1997 – 2009
12+7 Current

Block IIF
Boeing
First Launch May 2010
2 Current
Next launch in Oct

Block IIIA
Lockheed Martin
Contract announced 5/2008

Control Segment – Monitor Stations



- Original U.S. Air Force GPS Monitor Stations
  - Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs
- New monitoring stations incorporated 2005
  - Cape Canaveral (USAF)
  - Washington, DC, UK, Argentina, Ecuador, Bahrain, and Australia (NGA)

Critical Role of the Control Segment

- Takes GPS ranging data. Assuming positions of tracking stations are known, computes orbital parameters.
- In same process, estimates the bias and drift of each satellite's clock relative to GPS time.
- Uploads new orbits and clocks so that they can be broadcast on the GPS signal.
- GPS orbits can be computed very simply. There are two forms used in this class.
- The GPS almanac (1 km) is NOT for positioning. It is primarily used by the receiver to aid tracking (I.e. tells it which satellites should be visible).
- The GPS broadcast ephemeris (1 meter) is for low-accuracy, real-time positioning.
- The GPS precise ephemeris (2 cm) is not broadcast by the DoD. It is generated by geodesists, and will not be used in this class; it is used extensively in ASEN 6090.

GPS User Segment

- GPS receivers are specialized "radios" that track GPS signals and produce position and velocity solutions
  - Wide range of cost/sophistication depending on the application
- Signals from 4 or more GPS satellites are required, but 8-10 are typically available at any time
- Many civil (SPS) receivers track only the L1 C/A signal
- Precision civil users track both L1 and L2, without the P(Y) codes.
- PPS receivers have special keys that allow tracking of the military P(Y) code over both L1 and L2

Military Spacecraft
(~$1,000,000)

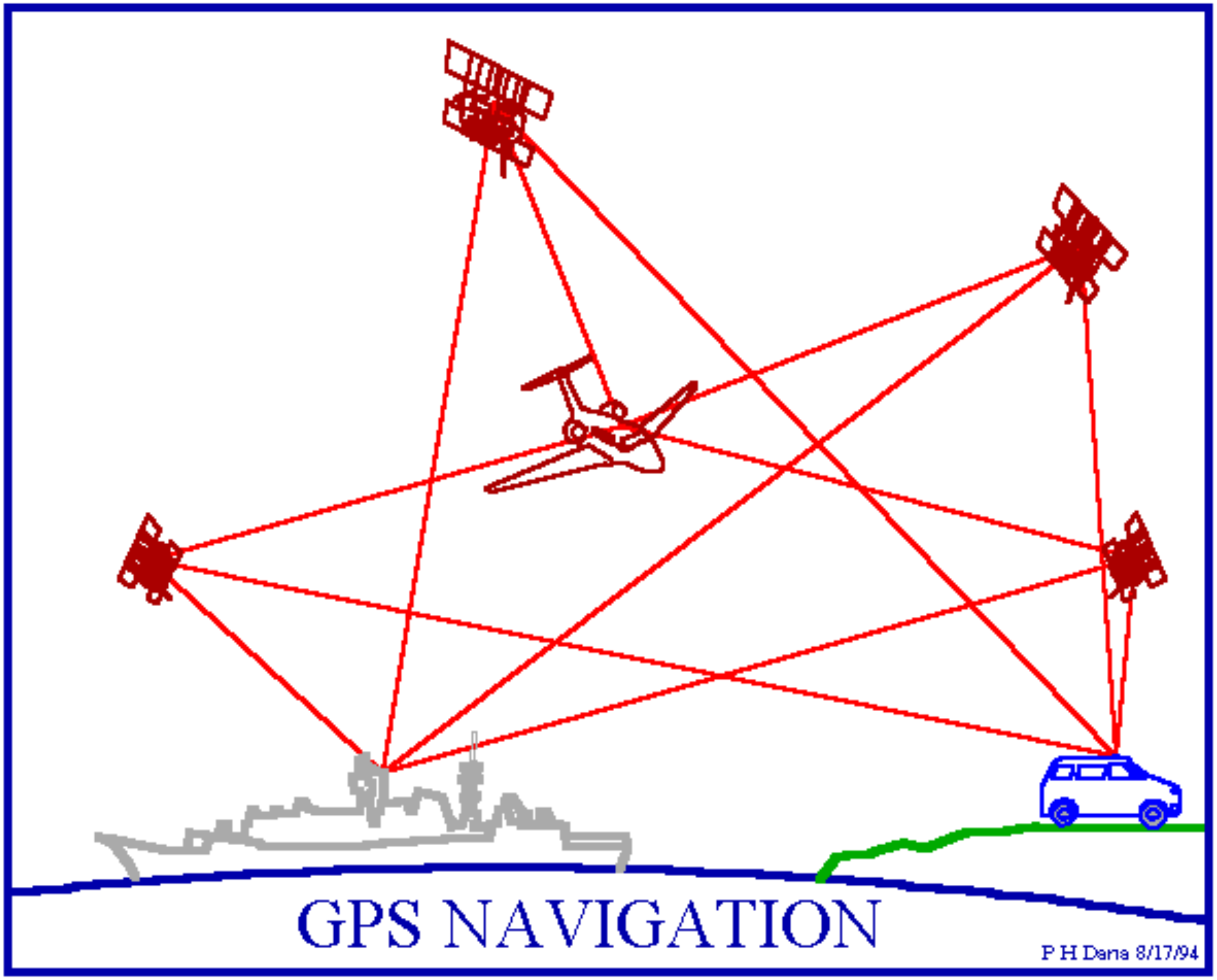
courtesy General Dynamics

Consumer Recreation
(~$100)

courtesy Trimble

Surveying/Science

($10,000)


GPS NAVIGATION
P H Dana 8/17/94

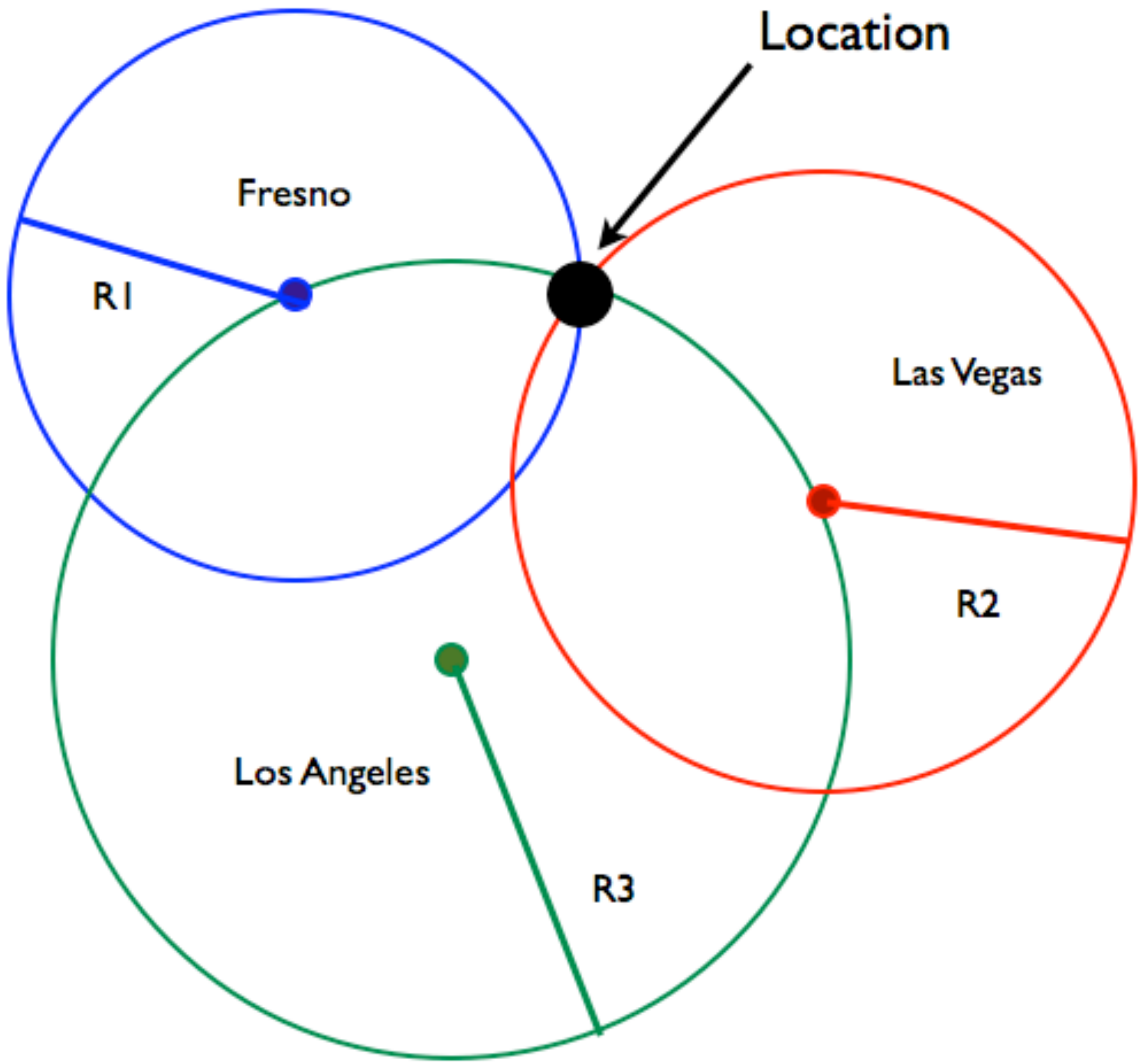
GPS Augmentations

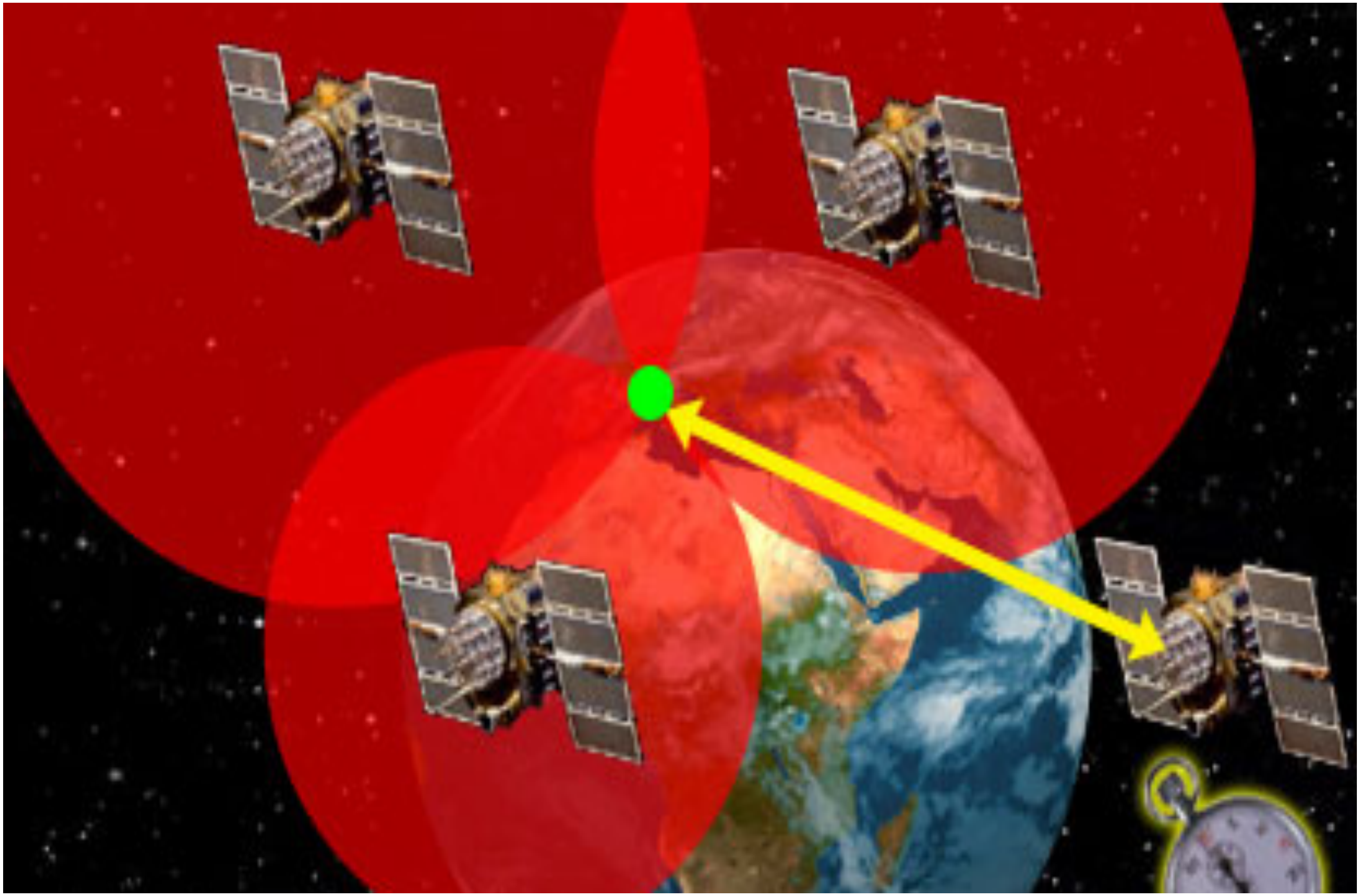
- WAAS
  - WAAS provides augmentation information to GPS receivers to enhance the accuracy and reliability of position estimates
  - Space Based Augmentation System (SBAS) covering nearly all of the National Airspace System (NAS)
  - Commissioned July 2003
- LAAS
  - Augmentation to GPS that focuses its service on the airport area (approximately a 20-30 mile radius)
  - Broadcasts correction message via a very high frequency (VHF) radio data link from a ground-based transmitter

Fundamentals of Satellite Navigation

- Satellite based navigation is fundamentally based on:
  - The precise measurement of time

    (you have to agree on what you mean by time!)
  - The constancy of the speed of light
- GPS and other systems use the concept of trilateration:
  - Satellite (transmitter) positions are known
  - Receiver position is unknown
  - Satellite-to-receiver range measurements are used to estimate position


Location
Fresno
R1
Las Vegas
R2
Los Angeles
R3



GPS Signals

- Codes
  - C/A Code – 1.023 MHz Coarse Acquisition code, repeats @ 1 ms
  - P(Y) Code – 10.23 MHz, Encrypted
  - M Code – New Military Split spectrum
  - L2C, L5C – New Civil codes
- Carriers
  - L1 1575.42 MHz – C/A and P(Y)
  - L2 1227.6 MHz – P(Y) only
  - L5 1176.45 MHz – LC
- Navigation Data
  - 50 bps
  - Satellite ephemeredes and almanacs
  - Satellite clock parameters
  - Ionospheric model for single frequency users
  - Health and status

Position Solution

- The position solution involves an equation with four unknowns:
  - Receiver position (x, y, z) (in what reference frame)
  - Receiver clock correction (correction to what?)
    - ➢ *Position accuracy of ~1 m implies knowledge of the receiver clock to within ~3 ns*
  - GPS accuracy is based almost entirely on knowing satellite orbits and satellite clocks.

- Requires simultaneous measurements from at least four satellites
  - The receiver makes a range measurement to the satellite by measuring the signal propagation delay
  - A data message modulated on the ranging signal provides the precise location of the satellite and corrections for the satellite clock. GPS accuracy is based almost entirely on knowing these two things.

Measurement Equation

- GPS receiver measures "Pseudorange" by measuring the transit time of the signal:

$$\rho_r^s = c\left(t_r - t^s\right)$$

time of signal reception, (based on receiver clock, can be significantly in error)

time of transmission, encoded in signal by GPS satellite clock (known precisely)

Measurement Equation (cont)

- Measured pseudorange to a satellite is comprised of:

$$R_r^S = \rho_r^S - c\delta^S + c\delta_r + \rho_{trop} + \rho_{iono} + \rho_{multi} + \rho_{rel} + \varepsilon$$

  - true range
  - receiver clock error
  - satellite clock error (known)
  - ionosphere and troposphere delays (estimated or measured)
  - other errors (satellite ephemeris and clock mis-modeling, measurement errors, multipath, receiver noise)

$$\rho_r^s(t_r) = \left| \vec{X}^s(t^s) - \vec{X}_r(t_r) \right|$$

Solution Accuracy

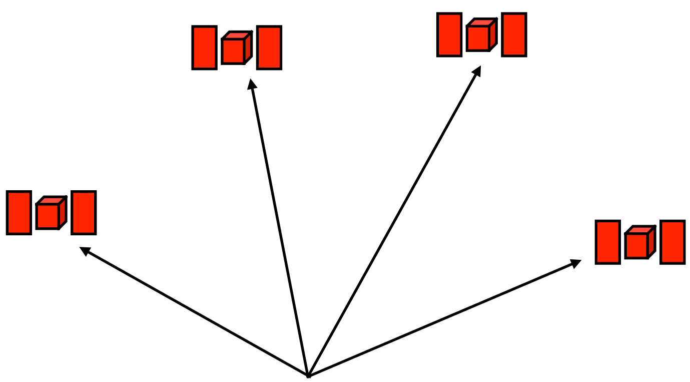
- Two primary factors affect the fundamental position and time accuracy possible from the system:
  - Ranging error – a function of the quality of the broadcast signal and data
  - Geometry – the distribution of satellites in the sky
- The actual positioning accuracy achieved depends on many other factors:
  - The design of the receiver (receiver/antenna noise levels, modeling errors, etc.)
  - Environmental effects such as ionosphere and troposphere signal delays, field of view obstructions, multipath signals, and jamming/interference.

Ranging Error

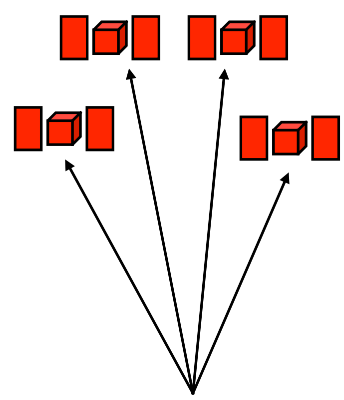
- User Range Error (URE)
  - A measure of the accuracy of the pseudorange along the line-of-sight direction from a particular satellite to the user
  - Indication of signal quality
- Composite of several factors
  - stability of particular satellite's clock
  - predictability of the satellite's orbit

Geometry – Dilution of Precision

- Geometric Dilution of Precision (GDOP) is a measure of the quality of the receiver-to-GPS satellite range geometry
  - Related DOPs exist for position, horizontal, vertical, and time dilutions of precision
- Used in conjunction with the URE to forecast navigation and timing performance, weight measurements
- For GPS, DOP can range from 1 to infinity, with values in the 2-3 range being typical

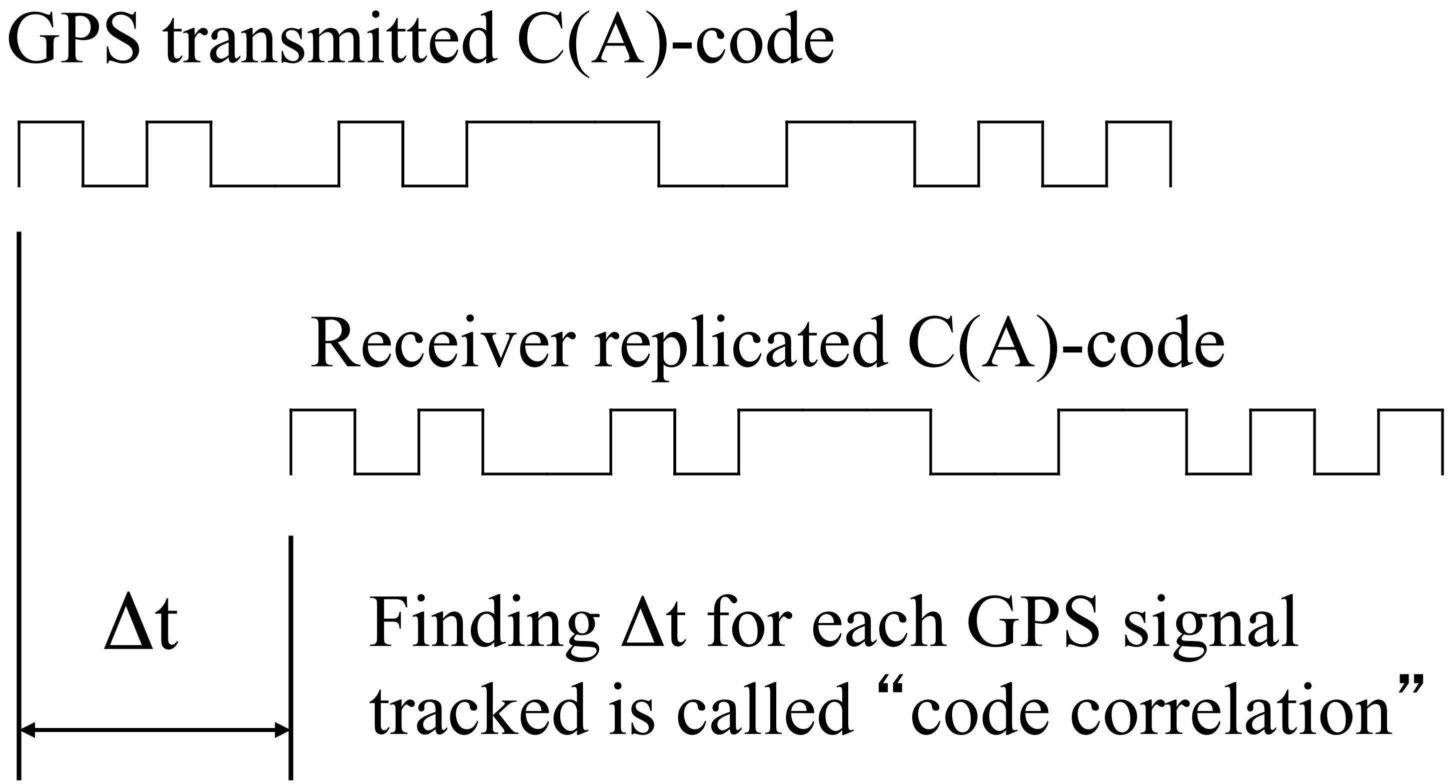


Good GDOP

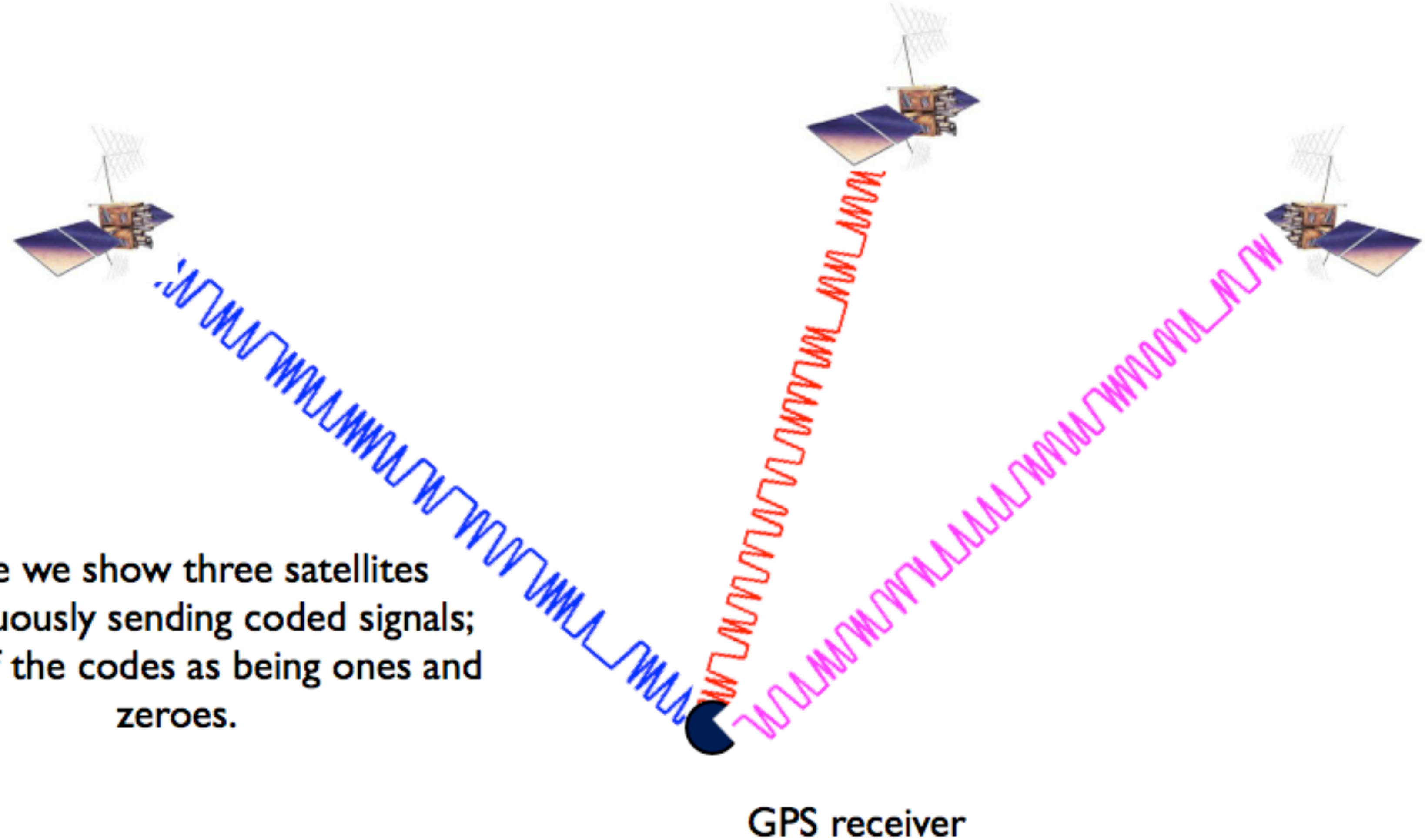


Poor GDOP

Pseudorange



- Δt is proportional to the GPS-to-receiver range
- Four pseudorange measurements can be used to solve for receiver position



Here we show three satellites continuously sending coded signals; think of the codes as being ones and zeroes.

The receiver is going to try to decrypt each of the GPS signals separately.

Here the receiver compares the blue coded signal to all the known codes.

it isn't this one.

it isn't this one either

at first this one looks wrong too

but then we can see that they are identical, but shifted by 10

It is this time shift the receiver uses to figure out how far away the satellite 3 is from the receiver - and how big the radius is for that sphere.

Next week….

- We will start getting into the details of what the user does, the constellation, control segment, and signals..

- HW#2 posted (problems 2.1 and 2.2) and is due a week from Monday. (one week later for CAETE)