Localization through the GPS system

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Overview

- The Global Positioning System (GPS) is:
  - A worldwide radio-navigation system formed from a constellation of 24-31 satellites
  - Each satellite moves in its own orbit ~ 12,000 miles above the Earth
    - Medium Earth Orbit
  - Ground stations that make sure the satellites are working properly
    - Master Control Station, an Alternate Master Control Station, and a host of dedicated and shared Ground Antennas and Monitor Stations
  - GPS satellites each take 12 hours to orbit the Earth

More about GPS satellites

- GPS satellites are powered by solar energy
- Have backup batteries onboard to keep them running in the event of a solar eclipse, when there's no solar power
- Small rocket boosters on each satellite keep them flying in the correct path
- US Dept of Defense's official name for GPS satellites: NAVSTAR

[San Diego museum]

History and Trivia

- First GPS satellite launched in 1978
- A full constellation of 24 satellites was achieved in 1994
  - Only launch failure of 1 satellite (1981)
- Each satellite is built to last about 10 years
- Replacements are constantly being built and launched into orbit
- A GPS satellite weighs approximately 2,000 pounds and is about 17 feet across with the solar panels extended
- Transmit power is only 50 watts or less

History and trivia

- Korean airlines Flight 007 was shot down in 1983 after straying into USSR prohibited airspace
  - President Reagan issued directive to make GPS freely available for civilian use

- Initially highest quality signal was reserved for military use and the signal for civilians were intentionally degraded ("Selective Availability" or SA)

- In 2000, President Clinton ordered SA be turned off at midnight May 1, 2000
  - Accuracy improved from 1000 ft to 65 ft

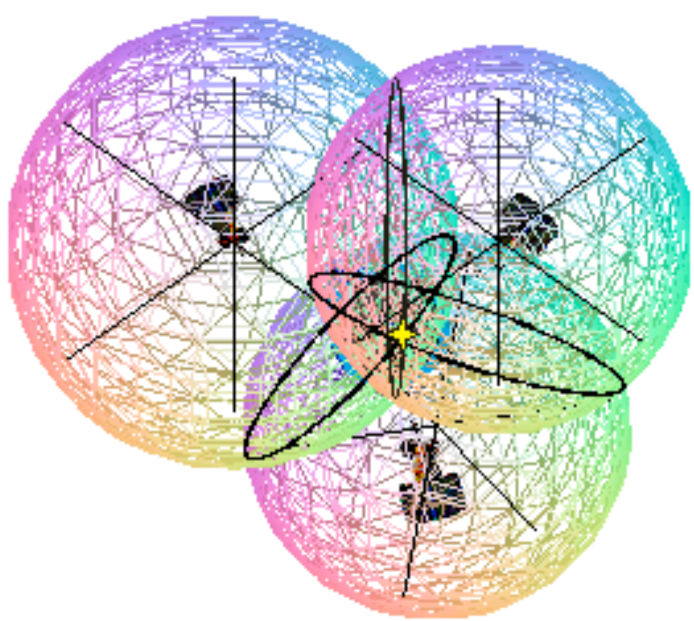
What a satellite transmits?

- GPS satellites transmit two low power radio signals, designated L1 and L2
- Civilian GPS uses the L1 frequency of 1575.42 MHz in the UHF band
- The signals travel by line of sight, meaning they will pass through clouds, glass and plastic but will not go through most solid objects such as buildings and mountains

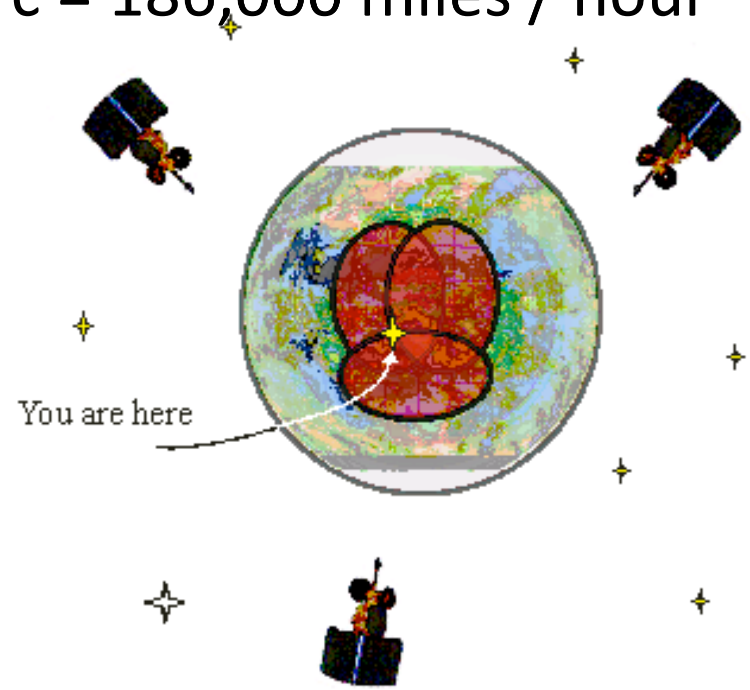
- A GPS signal contains three different bits of information
  - ID to identify which satellite is transmitting information. You can view this number on your GPS unit's satellite page, as it identifies which satellites it's receiving
  - Ephemeris data, which is constantly transmitted by each satellite, contains important information about the status of the satellite (healthy or unhealthy), current date and time. This part of the signal is essential for determining a position
  - Almanac data tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite transmits almanac data showing the orbital information for that satellite and for every other satellite in the system

How to calculate position?

- Two spheres intersect as a circle
- Three spheres intersect in two points
- If received time, t, and transmit time, ti, then sphere has radius of (t – ti)c, where c = 186,000 miles / hour



Three spheres



Intersection of the spheres

How accurate clocks needed?

- 3 x 10^8 meters /second
- If we want 10 meter accuracy, should need 10^-7 second accuracy = 1

How to calculate position?

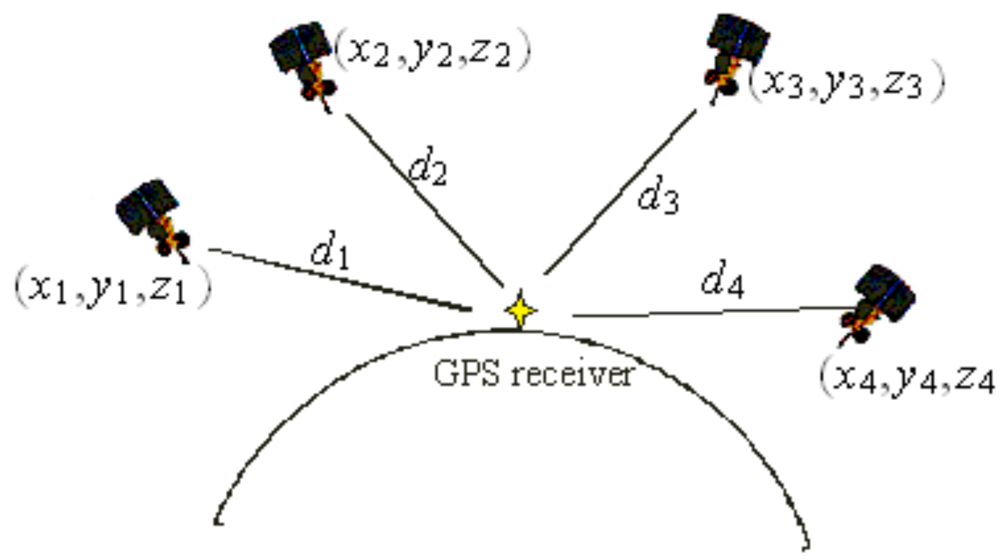
- Trilateration
  - 4 satellites instead of 3
  - (x, y, z, and t)

  - If satellite at xi, yi, zi, and sent at ti
  - Then, satellite distance is (t – ti)c
    - c = 186,000 miles / hour

The math

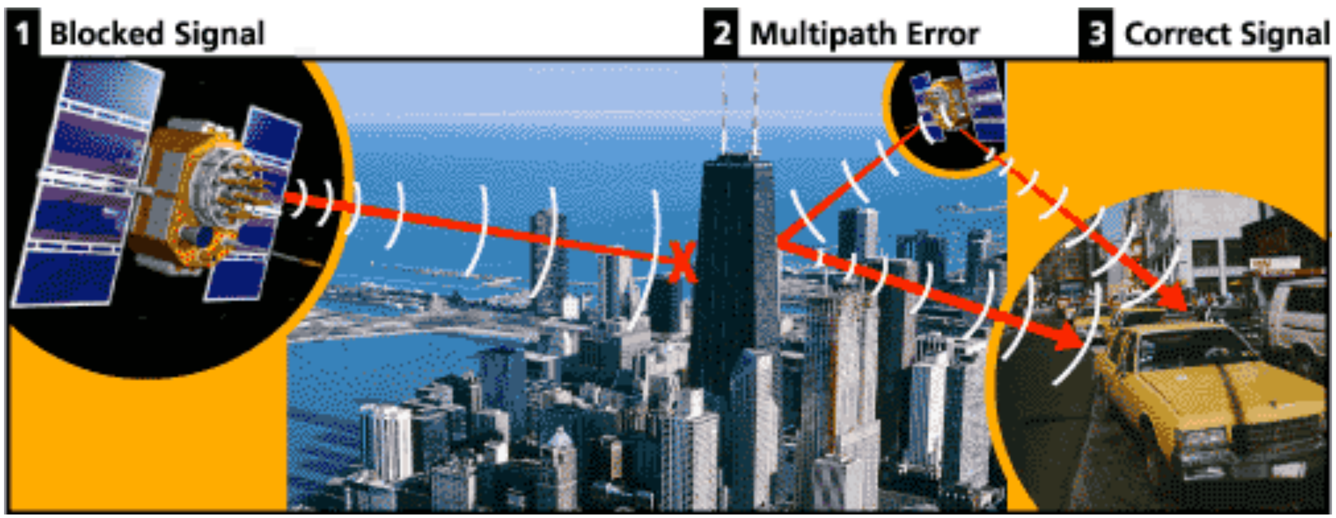
- xi, yi, zi are positions of satellite i
- di is the distance of receiver from satellite i
- tB is the clock offset of the receiver from correct GPS time
- Assumption: All satellites have identical clocks

$$\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}+ct_B=d_1$$
$$\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}+ct_B=d_2$$
$$\sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}+ct_B=d_3$$
$$\sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}+ct_B=d_4$$



Errors in GPS signals

- Ionosphere and troposphere delays — The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error



- Signal multipath — This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors

Errors in GPS signals

- Receiver clock errors — A receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have very slight timing errors
- Orbital errors — Also known as ephemeris errors, these are inaccuracies of the satellite's reported location
- Number of satellites visible — The more satellites a GPS receiver can "see," the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground
- Satellite geometry/shading — This refers to the relative position of the satellites at any given time. Ideal satellite geometry exits when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping
- Intentional degradation of the satellite signal — Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. Department of Defense. SA was intended to prevent military adversaries from using the highly accurate GPS signals. The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.

A view of multiple GPS satellites