Global Positioning System

(GPS) Lectures

References

1- L.F.Wiederholt, "GPS SYSTEM SEGMENTS " lecturer. 2012

2- E. Calais," The Global Positioning System" Purdue University - EAS Department, Civil 3273 – ecalais@purdue.edu

3- Elliott D. Kaplan," Understanding GPS Principles and Applications" © 2006 ARTECH HOUSE, INC. 685 Canton Street, Norwood, MA

Lecture (7) GPS

Sources of Errors in GPS

At any single point in time, there will be several satellites from which a receiver may have a clear line of sight to receive signals and build its own navigation solution. However, these signals are prone to several sources of disturbance, causing errors in the measurements that are generated inside the receiver, which in turn degrades positioning accuracy. However, the sources of GPS errors are:

1. Dilution of Precision (Satellite Geometry)
2. Satellite Orbital Variations (Ephemeris)
3. Multipath Effect
4. Atmospheric Effects
5. Clock Inaccuracies and Rounding Errors

1. Dilution of Precision (Satellite Geometry)

As mentioned previously

- The Dilution of Precision (DOP) is, in turn, a measure of the geometry of the visible satellite constellation.
- Dilution of Precision (DOP) reflects each satellite's position relative to the other satellites being accessed by a receiver.
- It describes sensitivity of receiver to changes in the geometric positioning of the SVs. The higher the DOP value, the poorer the measurement.
- The cumulative UERE (User Equivalent Range Error) totals are multiplied by a factor of usually 1 to 6, which represents a value of the Dilution of Precision, or DOP.
- A low numeric Dilution of Precision value represents a good satellite configuration, whereas a higher value represents a poor satellite configuration.

2. Satellite Orbital Variations (Ephemeris)

- Slight shifts of the orbits are possible. These are caused by gravitational effects of the Earth and Moon and the pressure of solar radiation.
- Sun and moon have a weak influence on the orbits.
- The resulting error being not more than 2 m.

<u>Note that:</u>

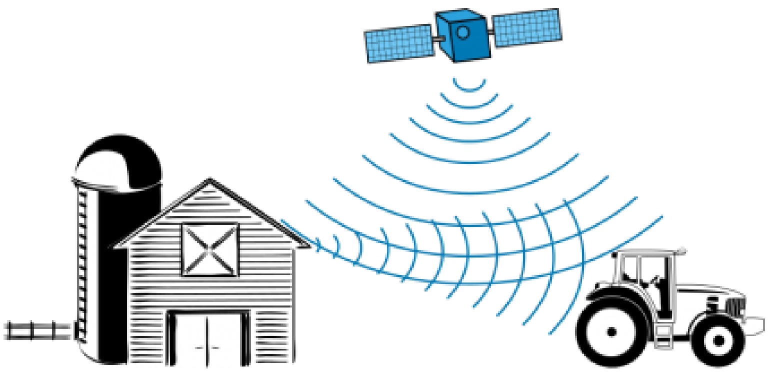
The accuracy of a GPS satellite's atomic clock is **one nanosecond** for each clock tick. That's pretty impressive stuff.

Using the trilateration of time signals in orbit, GPS receivers on the ground can obtain accurate positions. But due to the inaccuracy of the satellite's atomic clock **being synchronized**, this can offset a position measurement by 2 meters or so.

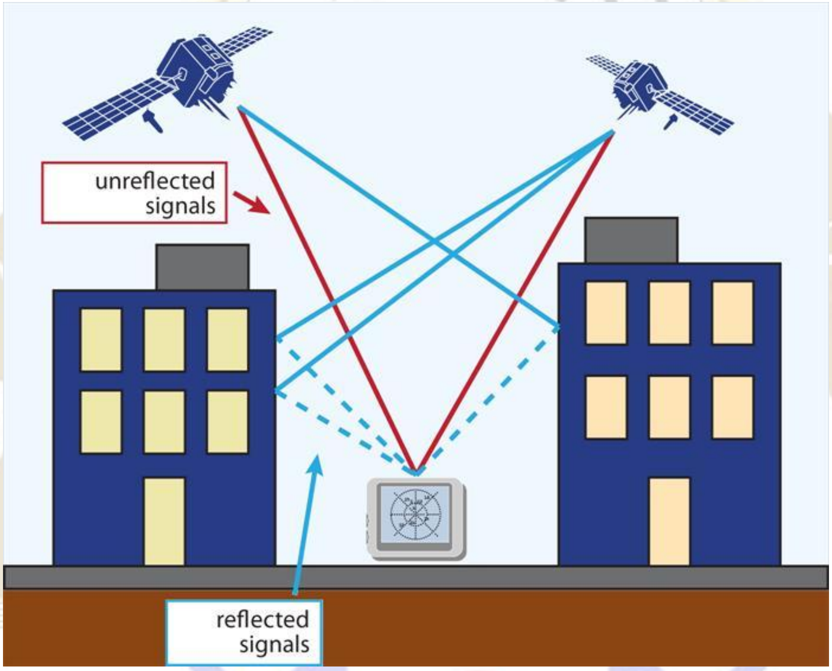
The ephemeris information contains details about that specific satellite's location. But if you don't know their exact location at a particular time, this can be a source of error.

3. Multipath Effect

- One possible error source in GPS calculations is the multipath effect. Multipath occurs when the GPS satellite signal (radio waves) **bounces off of nearby structures** like buildings and mountains or other elevations..
- These reflected signals can create interference and introduce errors in the calculation of the receiver's position, leading to inaccuracies in the GPS measurements.

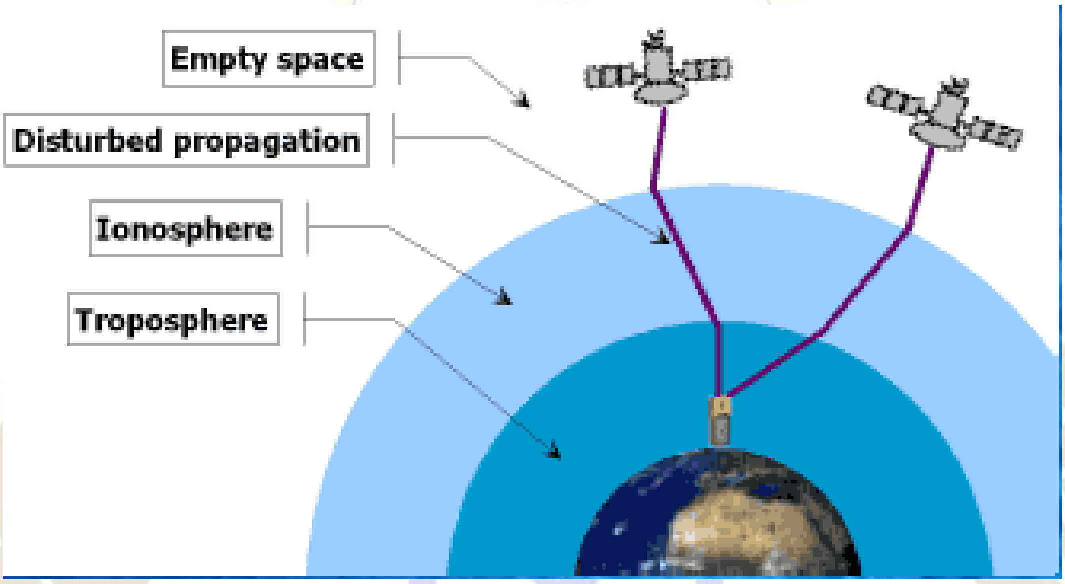


- The reflected signal takes more time to reach the receiver than the direct signal.
- The resulting error typically lies in the range of a few meters.



4. Atmospheric Effects

- Another problem area is the ***atmosphere*** itself, through which the satellite signals must pass.
- The ***atmosphere*** (*the troposphere and ionosphere*) can **change the speed of propagation of a GPS signal**.
- The speed of radio waves (i.e., the speed of light) is a constant at 300,000 km/sec. That's not strictly true. It ***is*** true in the perfect vacuum of space.
- The signal has to travel through some 300 kilometers of the Earth's atmosphere to reach us.
- The two most troublesome components of the atmosphere **are** the **ionosphere** and the **troposphere,** as shown in figure below.



- The **ionosphere** is a layer of electrically charged particles between around 70 and 400 kilometers altitude.
- The **troposphere** is simply what we ***usually*** think of as the atmosphere, extending from the surface up to between eight and 16 kilometers altitude.
- Each of these literally "drag" radio waves down, causing them to bend a tiny, but significant, amount. This "bending" of radio waves is called ***refraction***.
- Further complicating the problem is the fact that the ionosphere and troposphere each refract differently.
- The problem with the ionosphere is the electrically charged particles that "drag" on the incoming signal. In the troposphere, the problem is with the water vapor content which does the same thing, just at a different rate.
- The amount of refraction is constantly changing with changing atmospheric conditions.
- There are a couple of ways to deal with refraction to minimize propagation speed error.
  - First, the satellite's NAV-msg includes an atmospheric refraction model that compensates for as much as 50-70% of the error.

- A more effective method for **ionospheric refraction** is to use a ***dual-frequency*** receiver which simultaneously collects the signals on both the Ll and L2 carriers. Because the amount of refraction that a radio wave experiences is inversely proportional to its frequency, using two different frequencies transmitted through the same atmosphere at the same time makes it relatively easy to compute the amount of refraction taking place and compensate for it.
- Unfortunately, **tropospheric refraction** is not frequency-dependent and so cannot be corrected by this method.

- Depending on conditions, this type of GPS error could offset the position anywhere from 5 meters.

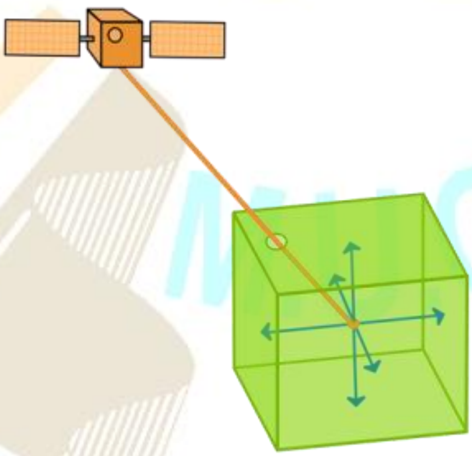
5. Clock Inaccuracies and Rounding Errors (Receiver Error)

Timing errors due to inaccuracies in both the satellite and receiver clocks, as well as relativity effects, can result in position errors of up to two meters.

Error	VALUE (Approx)
Ionosphere	4.0 meters
Clock	2.1 meters
Orbit	2.1 meters
Troposphere	0.7 meters
Receiver	0.5 meters
Multipath	1.0 meter
TOTAL	10.4 meters

Selective Availability (SA)

- SA is the intentional degradation of the signals by a time varying bias.
- SA is controlled to limit accuracy for non-U.S. military and government users.
- SA bias on each satellite signal is different, and so the resulting position solution is a function of the combined SA bias from each Space Vehicle (SV) used in the navigation solution.
- SA therefore affects the precision of all measurements, code and carrier phase.
- All things considered, this significantly reduced GPS accuracy.
- At the time, differential GPS was able to correct. But after 2000, this source of GPS error no longer was much of a concern as the selective availability switch was turned off.
- It is possible to summaries SA as:
    - Intentional degradation of GPS accuracy.
    - 50 m of error horizontally and 100 m vertically.
    - Accounted for most error in standard GPS.
    - Turned off May 2, 2000.



Methods of Correcting GPS Errors.

1. Real Time Correction.
2. Post-Processing Correction.

The techniques like Real Time Correction and Post-Processing Correction, positions can improve to sub-meter accuracy.

1. Real Time Correction

- The base station calculates and broadcasts corrections for each satellite as it receives the data.
- The correction is received by the roving receiver via a radio signal and applied to the position it is calculating.
- As a result, the position displayed on the roving GPS receiver is a differentially corrected position.

2. Post Processing Correction

- Differentially correcting GPS data by post-processing uses a base GPS receiver that logs positions at a known location and a rover GPS receiver that collects positions in the field.
- The files from the base and rover are transferred to the office processing software, which computes corrected positions for the rover's file.
- This resulting corrected file can be viewed in or exported to a GIS.

Converting Decimal to/from Degree Minute Seconds

Usually in GPS the coordinated are written in the form Degrees Minuets Seconds as:

$$Degree^o\ Minutes'\ Seconds''$$

These coordinates can be transforms from its degree minuets seconds form to decimal format and vice versa.

Converting Decimal to Degree Minute Seconds

Example: transform the following decimal 42.3601 to degree minuets seconds format.

<u>*Solution:*</u>

1- The integer value of any given decimal number is the same degree value.

Degree = 42

2- The minuets equal the integer number resulted from multiplying the fraction of the given decimal number by 60.

$$0.3601 \times 60 = 21.606$$

Minuets = 21

3- The seconds equal the number resulted from multiplying the fraction resulted from the minutes by 60.

$$Seconds = 0.606\ \times 60 = 36.36$$

The required converted number is $\mathbf{42^o\ 21'\ 36.36''}$

Converting Degree Minute Seconds to Decimal

$$Decimal = Degree + \frac{Minutes}{60} + \frac{Seconds}{3600}$$

Example: Convert the following $39°25'30''$ to decimal.

<u>*Solution:*</u> $Decimal = 39 + \frac{25}{60} + \frac{30}{3600} = 39.425$

Satellite Time and Location (Ephemeris)

The accuracy of a GPS satellite's atomic clock is **one nanosecond** for each clock tick. That's pretty impressive stuff.

Note that the almanac is the same for all satellites whereas the ephemeris is unique to each satellite.

What is the purpose of each one?

Ephemerides:

- contains information on week number, satellite accuracy and health, age of data, satellite clock correction coefficients, orbital parameters
- valid two hours before and two hours after time of ephemeris (toe). The toe can be thought of as when the data was computed from the GNSS control segment
- Used for real time satellite coordinate computation which is required in position computation

Almanac:

- contains less accurate orbital information than ephemerides
- valid for a period of up to 90 days
- Used to speed up time to first fix by 15 seconds (compared to not having almanac stored)

Thus, the receiver is capable of computing a position without having an almanac present. The almanac helps out with fixing the satellites for the first time but that is about it. The ephemerides however are vital for positioning computation.

The ephemerides are also used for post-processing as like was stated earlier, the ephemerides allow for the satellite position computation which is required in order to use trilateration to compute the receiver's position. Thus, it is very common for clients to log the ephemerides of each constellation they are tracking with the receiver. For brevity we will just refer to the GPS ephemeris from the RAWEPHEM message. We recommend clients to log this message with the ONCHANGED trigger. Here is why: