GPS - Positioning Concepts And Errors And Accuracy of GPS Observation

System Description:

The Global Positioning System (GPS) consists of a constellation of radio-navigation satellites, a ground control segment that manages satellite operation and users with specialized receivers who use the satellite data to satisfy a broad range of positioning requirement. The system was established by the United States Department of Defense (DoD) to fulfill defense-positioning needs and as a by-product, to serve the civilian community.

The satellite constellation, consist of 21 satellite and three active spares positioned 20,000 km (about three times the earth's radius) above the earth. The satellites are distributed in a manner that ensures at least four satellites are visible almost anywhere in the world at any time. Each satellite receives and stores information from the control segment, maintains very accurate time through onboard precise atomic clocks and transmits signals to the earth.

The ground control segment operates the satellite system on an on-going basis. It consists of five tracking stations distributed around the earth of which one, located in Colorado Springs, is a Master Control Station. The control segment tracks all satellites, ensures they are operating properly and computes their position in space.

If a satellite is not operating properly the ground control segment may set the satellite "unhealthy" and apply measures to correct the problem. In such cases, the satellite should not be used for positioning until its status is returned to "healthy". The computed positions of the satellites are used to derive parameters, which in turn are used to predict where the satellites will be later in time. These parameters are uploaded from the control segment to the satellites and are referred to as broadcast ephemerides.

The user segment includes all those who use GPS tracking equipment to receive GPS signals to satisfy specific positioning requirements. A wide range of equipment designed to receive GPS signals is available commercially, to fulfill an even wider range of user applications. Almost all GPS tracking equipment have the same basic components: an antenna, an RF (radio frequency) section, a microprocessor, a control and display unit (CDU), a recording device, and a power supply. These components may be individual units, integrated as one unit, or partially integrated. Usually all components, with the exception of the antenna, are grouped together and referred to as a receiver. Some GPS receivers being marketed now in fact only consist of computer cards, which may be mounted in portable computers or integrated with other navigation systems.

GPS Signals:

Each GPS satellite continuously transmits signals, which contain a wealth of information. Depending on the type and accuracy of positioning being carried out, a user may only be interested in a portion of the information included in the GPS signals. Similarly, a given GPS receiver may only enable use of a portion of the available information. It is therefore important for users to understand the content and use of GPS signals. The information contained in GPS
signals includes the carrier frequencies, Coarse Acquisition (C/A) and Precise (P) codes and the satellite message. Descriptions of each of these signal components are as follows.

**Carrier Measurements**

Signals from GPS satellites are continuously transmitted on two carrier frequencies, 1575.42 MHz and 1227.60 MHz, and are referred to as L1 and L2 respectively. Since radio waves propagate through space at the speed of light, the wavelengths of the GPS carrier signals are computed as

\[ \lambda = \frac{c}{f} \]  

where \( \lambda \) is the wavelength (i.e. the length of one cycle) in metres, \( c \) is the speed of light (approximately \( 3 \times 10^8 \) m/s) and \( f \) is the carrier frequency in Hz (i.e. cycles per second). A snapshot of one section of carrier transmission illustrates the definition of wavelength and cycles.

The frequency and wavelength of the L1 and L2 carriers (computed using equation (2.1)) are given in Table 2.1.

GPS receivers, which record carrier phase, measure the fraction of one wavelength (i.e. fraction of 19 cm for the L1 carrier) when the receiver first locks onto a satellite and continuously measure the carrier phase from that time. The number of cycles between the satellite and receiver at initial start up (referred to as the ambiguity) and the measured carrier phase together represent the satellite receiver range (i.e. the distance between a satellite and a receiver). In other words,

\[ \text{Range} = \text{measured carrier phase} + (\text{Ambiguity} \times \text{wavelength}) + \text{errors} \]

or

\[ \Phi = p + N \lambda + \text{errors} \]

where \( \Phi \) is the measured carrier phase in metres, \( p \) is the satellite-receiver range in metres, \( N \) is the ambiguity (i.e. number of cycles) and \( \lambda \) is the carrier wavelength in metres.

**Table 2.1 Carrier Frequencies and Wavelengths**

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Frequency (f)</th>
<th>Wavelength (( \lambda ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1575.42 MHz</td>
<td>19 cm</td>
</tr>
<tr>
<td>L2</td>
<td>1227.60 MHz</td>
<td>24 cm</td>
</tr>
</tbody>
</table>

Code and satellite messages are piggy-backed on the carrier signal through modulation. The L1 carrier is modulated by a coarse acquisition code referred to as the C/A code, a precise code and the satellite message. The L2 carrier is modulated by the P code and the satellite message.
Code Measurements:

It is the code measurements (also referred to as pseudorange measurements) that enable instantaneous position determinations using GPS satellites. The code is composed of a series of chips, which have values of 1 or 0. The C/A code has a frequency of 1.023 MHz (i.e. 1.023 million chips per second) and the P code has a frequency of 10.23 MHz.

The chip lengths of 293 m and 29.3 m for the C/A code and P code respectively were computed using equation (2.1), letting $\lambda$ be the chip length. Although the P code is generally ten times more accurate than the C/A code, it is unavailable for civilian use in 1993 when the full GPS constellation is complete (McNeff, 1991), meaning only C/A code is worthy of consideration for civilian GPS applications.

Code measurements are the difference in time between when the code is transmitted from a satellite and received at a GPS receiver, multiplied by the speed of light. That is,

\[
\text{measured code} = \text{speed of light} \times (\text{reception time} - \text{transmission time})
\]

or

\[
P = c (t_r - t_t) \quad \text{(in metres)}
\]  
(2.3)

where $P$ is the measured code, $c$ is the speed of light, $t_r$ is the signal reception time and $t_t$ is the signal transmission time. The code measurement is actually a direct measurement of satellite = receiver range ($p$), i.e. :

\[
\text{Measured code} = \text{range} + \text{error}
\]

or

\[
P = p + \text{errors} \quad \text{(in metres)}
\]  
(2.4)

Comparison of Code and Carrier Measurements:

At this point it is possible to make some brief comparisons of code and carrier measurements. Carrier wavelengths (19 cm for L1) are much shorter than the C/A code chip length (293 m) and consequently can be measured more accurately and used to achieve much higher positional accuracies than code measurements. Indeed the best relative accuracies achieved using code measurements are usually a few metres, and using carrier measurement are usually a few centimeters.

The problem with using carrier observations instead of code observations is evident upon comparison of equations (2.2) and (2.4). With code observations a direct measure of the satellite = receiver range is attained. With carrier observations, the ambiguity term (number of whole cycles) must be estimated before one may take advantage of the carrier accuracy. Ambiguity estimation leads to complexities in the use of carrier phase observations, which do not exist with code observations.

Satellite Message:

The satellite messages, which is modulated on both L1 and L2 frequencies, contains among other information, satellite broadcast ephemerides and health status. The ephemerides include the parameters necessary to compute a satellite's position in space for a given time and the health status indicates if a satellite is healthy. Almost all receivers use the broadcast.
ephemerides in conjunction with code observations, carrier observations or both to solve for a
GPS receiver's position in space.

**Types of GPS Positioning:**

Up to this point, the three segments of GPS have been described and the components of
signals broadcasted by the satellites have been explained. Major types of possible positioning
methods are as follows.

- **Single Point Positioning**
  1. Static mode
  2. Kinematic mode

- **Relative Point Positioning**
  1. Static mode
  2. Kinematic mode

- **Real-time data collection**

- **Post mission processing**

**Selective Availability and Anti-Spoofing:**

Two terms often associated with GPS status are selective availability (SA) and anti-
spoofing (AS). Both refer to techniques to limit the accuracies achievable for civilian users. Selective availability consists of the degradation of the broadcast orbit (i.e. the accuracy of the
satellites "known" position in space) and dithering of the satellite clocks. SA is currently being implemented. As a result of SA, single point positioning accuracies are limited to 100 m horizontally and 156 m vertically at the positioning accuracies are limited to 100 m horizontally and 156 m vertically at the 95% confidence level (U.S. DoD and DoT, 1986), instead of the 20-30 m and 30-45 m possible without SA (Cannon, 1991).

Anti-spoofing is the denial of access of the P code to civilian users (except those with special authorization from the U.S. DoD). Implementation of AS is planned to begin when the full GPS constellation is available at the end of 1993 (McNeff, 1991), although intermittent
testing of AS commenced in August 1992. When AS is activated, to deny access, the P code is replaced with a Y code on the L1 and L2 carriers. This Y code has similar properties to the P code, but is unknown to unauthorized users.
"Errors and Accuracy of GPS observation"

How Accurate Is A GPS Position?
Before talking about Errors and accuracy of GPS, we should know what ACCURACY and PRECISION mean?
The terms Accuracy and Precision are worthy of clarification. Accuracy refers to how close an estimate (or measurement) is to the true but unknown value, while precision refers to how close an estimate is to the mean estimate. This can also be understood from the following figure:

How accurate GPS position is? Is it accurate enough to find a City? How about a house? Could to measure the size of a manhole? How about a quarter? The simple answer is yes – to all of the above questions.

GPS positions vary in accuracy from 10's of meter’s, to cm's depending on what kind of GPS receivers, and how to use them.
The truth is that not everybody needs the highest accuracy of the GPS. Just as there are many different uses for GPS, each use needs a different accuracy. Each level of accuracy has some "Good News" and some "Bad News".

Accuracy levels:
To start, let's talk a little bit about accuracy. The latitude and longitude, or the ‘horizontal coordinates' are referred to as 2D coordinates. If we include the GPS height our position can now be called a 3D coordinate. The horizontal coordinates from GPS are more accurate than the heights. Why? Well, the satellites used to calculate position are spread throughout the sky, but none are visible below us. In general, the heights we get from GPS are about 1.6 times less accurate than the latitude and longitude. Now let's look at the 3 basic accuracy levels.

Single Point Positioning Accuracy - 10metres (2D), 16-m (3D)
A single point GPS position has a typical accuracy of around 10 metres or so. This position is computed from a single GPS receiver – errors and all. To review, the GPS receiver uses the radio signals sent from the satellites to measure the distance (satellite ranging) to each of at least 4 satellites.
Using these ranges plus the location of each satellite (known from the information broadcast from each satellite) and some fancy mathematics, the receiver can figure out its location. For example, if you look at the position computed by any small recreational GPS receiver, which can be held in the palm of your hand, you'll read on the screen a single coordinate (or unique address). The position might be wrong by about 10 m. This type of receiver is sold through most sports stores.

The Good News: This level of accuracy is very easy to get and the receiver is fairly inexpensive. As long as you are outside remember the GPS only works outside) and your view to the sky is not completely blocked (large buildings are a good example of things that block out the sky) you should be able to get a single point position. This type of position is even possible if you are in the woods.

The Bad News: Not much bad news here, except the accuracy. But it's plenty accurate enough to find your way back to your campsite at the end of a hike.

Differential Positioning Accuracy - 0.5m to 5m (2D), 0.8m to 8m (3D)

Differential GPS positioning accuracy varies from 0.5 metre to 5 metres depending on several key factors. Differential GPS, or DGPS as it's often called, requires the use of 2 different GPS receivers. One receiver, called the base or reference receiver, is placed at a point where the exact position (the Latitude and Longitude) is already known very accurately. The second receiver, called the roving receiver (or rover), is placed over the points or features to be positioned. At each point, the satellite data from at least 4 separate satellites is then stored in the receiver. At the same time, the base receiver tracks the same satellites at the same time. It too stores or records
similar data. In other words, both the base and rover receivers track the same satellites at the same time and store similar data, but at 2 different locations.
Later, the data from both receivers is transferred to a computer and special software is used to remove many of the errors in each of the positions. These 'differentially corrected' positions are accurate to somewhere between 0.5m and 5 m. This level of accuracy is sometimes called Mapping Quality because it is often the desired accuracy to locate features for a Geographic Information System (GIS) or for mapping purposes.
The Good News: The GPS receivers and software on the market today are very powerful and fairly easy to use making this level of accuracy very easy to achieve – if you are careful. Even higher accuracy may be achieved using survey grade receivers – see next section on Carrier Positioning.

Bad News: This level of accuracy requires either 2 GPS receivers or one roving receiver and data from a second ‘base' source. In either case, this method is more expensive, not as simple to use and may require some practice or perhaps even some training to get the most of the system and use the GPS hardware (the receiver) equipment and software properly.

Carrier Positioning Accuracy < 1cm - 30 cm (2D), 1.6cm to 45cm (3D)

**Graphic of a quarter-sized object**

This is the highest level of accuracy possible using the GPS and is the technique that land surveyors and engineers generally use. This method is often referred to as "Survey grade" GPS. The method is exactly the same as "Differential Positioning” with a few notable exceptions.

Two receivers are used; one receiver over a known location (the base or reference receiver) and the second (Rover or roving receiver) is placed over the new or unknown location. The receivers track and record data from the same satellites at the same time recording similar information. The data is eventually transferred from the receivers to a computer. Specialized software is used to ‘correct' the data.

The main differences are:
GPS receiver type – a ‘survey grade' receiver must be used. These receivers are somewhat larger and usually much more expensive than those used for single point positioning.

Satellite visibility – an unobstructed, clear view of the sky, no trees or branches can come between the receiver and the satellites.

The positions we get from this method are typically accurate to a cm or less.
In our discussion of measuring distances using patterns of numbers, we assumed that you and your friend started counting numbers simultaneously. If your watch is one second off, this will translate into 344 meters of error in measuring distance, because sound travels 344 meters in one second. With satellites, the electronic signals travel about 300,000,000 meters per second (the speed of light). So the errors in the satellite clock and the receiver clock contribute profoundly to errors in distance measurements.

**Satellite Clock:**
One billionth of a second (one nanosecond) of inaccuracy in a satellite clock results in about 30 centimeters (one foot) of error in measuring the distance to that satellite. For this reason, the satellites are equipped with very accurate (Cesium) atomic clocks. Even these very accurate clocks accumulate an error of 1 billionth of a second every three hours. To resolve the satellite clock drifts, they are continuously monitored by ground stations and compared with the master control clock systems that are combinations of more than 10 very accurate atomic clocks. The errors and drifts of the satellites' clock are calculated and included in the messages that are transmitted by the satellites. In computing the distance to the satellites, GPS receivers subtract the satellite clock errors from the reported transmit time to come up with the true signal travel time.

Even with the best efforts of the control centers in monitoring the behavior of each satellite clock, their errors cannot be precisely determined. Any remaining satellite clock errors accumulate typically to about a few nanoseconds, which cause a distance error of about one meter.

**Receiver Clock:**
Similar to satellite clock errors, any error in the receiver clock causes inaccuracy in distance measurements. However, it is not practical to equip receivers with very accurate atomic clocks. Atomic clocks weigh more than 20 kilograms, cost about US$50,000, and requires extensive care in temperature control.
Assume that at a given time our receiver clock has an error of one millisecond, causing a distance error of about 300,000 meters. If the distances to all satellites are measured exactly at the same time, then they are all off by the same amount of 300,000 meters. We can, therefore, include the receiver clock error as one of the unknowns that we must solve for. Now we have four unknowns: three components of position and the new unknown of receiver clock error. We will need four equations in order to solve for the four unknown. Measuring distances to four satellites can provide us such four necessary equations. Instead of three satellites before, now we need four, but in return we can use inexpensive clocks in our GPS receivers.

Note that the concept of receiver clock being one of the unknowns is valid only if we take measurements to all satellites exactly at the same time. If distances to all satellites are not measured at the same time, then for each measurement we have a different clock.

Making simultaneous measurements to four satellites, we not only compute the three dimensions of our position, but we also find the error in our receiver clock with very good accuracy. A typical clock has a drift of about 1000 nanoseconds every second, but we can now adjust the receiver time to the accuracy of the GPS clock. This will make the inexpensive clock of the receiver as good as an atomic clock. Receivers correct their clock every second and provide a corrected time signal for outside use for those who need accurate time. If we put a receiver in a precisely known location, then we need to track only one satellite to continuously calculate the receiver clock error and adjust it.

Four is the minimum number of satellites that we need to compute position and time. The more satellites we have the more accurate results we can get. This is discussed later in the GDOP section.

**Satellite Orbit Error:**
As we discussed before, the accuracy of our computed position also depends on how accurately we know the location of the satellites (the points of references). The orbits of satellites are monitored continuously from several monitoring stations around the earth and their predicted orbital information is transmitted to the satellites, which they in turn transmit to the receivers. The history of GPS has shown, thus far, that the accuracy of the orbital prediction is in the order of a few meters. This will create about a few meters of error in computing our position.

**Atmospheric Errors: Ionosphere and Troposphere:**

**Ionosphere:**
In computing distances to satellites, we first measure the time it takes for the satellite signal to reach the receiver and then we multiply this by the speed of light. The problem is that the speed of light varies due to atmospheric conditions. The upper layer of the atmosphere, called the ionosphere, contains charged particles that slow down the code and speed up the carrier.

The magnitude of the effect of the ionosphere is much more during the day than during the night. The magnitude also has a cyclical period of 11 years that reaches a maximum and a minimum. For the current cycle, the ionosphere will reach its peak magnitude in 1998 and its minimum in 2004. The cycle will then be repeated. The effects of the ionosphere, if not mitigated, can introduce measurement errors greater than 10 meters.

Some receivers use a mathematical model for the effects of the ionosphere. With the approximate knowledge of the density of the charged particles in the ionosphere (broadcast by
satellites), the effect of the ionosphere can be reduced by about 50%. The remaining error is still significant.

The impact of the ionosphere on electronic signals depends on the frequency of the signal. The higher the frequency, the less is the impact. So if we transmit the patterns simultaneously via two different frequencies, the ionosphere may delay the code on one frequency, for example, by 5 meters and on the other frequency, say, by 6 meters. We cannot measure the magnitude of these delays, but we can measure their difference by observing the difference on their arrival time, which in this case translates into 1 meter of effective distance between them. By measuring this difference and using known formula for frequency dependency of the ionosphere delay, ionosphere effect can be removed.

It is exactly for this reason that all GPS satellites transmit information in two frequencies, called \textit{L1} and \textit{L2}. Precision receivers track both signals to remove the effect of the ionosphere. All non-precision receivers track only the L1 signal. This is one of the main distinguishing features between different types of receivers. The L1 receivers are also called single frequency receivers, while the receivers that track L1 and L2 are called dual frequency receivers. Dual frequency receivers practically remove the ionosphere effects.

Since the L2 signal is not entirely available to the general public, sophisticated techniques have been implemented in receivers to extract the code and carrier information, even with the partial availability of the L2 signal. These techniques fully satisfy the requirements of the users for non-military applications, while not compromising the Anti Spoof policy and security objectives of the US Department Of Defense (DOD).

There has been some discussion on allowing a different frequency for civilian applications to separate the DOD and civilian requirements. We believe, however, that the existing system fully satisfies the civilian requirement, particularly since advancements in electronics integration have made the technology affordable for broad civilian applications.

\textit{Troposphere:}

The lower level of the atmosphere, which contains water vapors, is called the troposphere. It has the effect of slowing down both code and carrier. The effects of the troposphere cannot be removed using dual frequency systems. The only way to remove the effects of the troposphere is by measuring its water vapor content, temperature and pressure, and applying a mathematical model that can compute the delay of the troposphere.

\textit{Multipath:}

In measuring the distance to each satellite, we assume that the satellite signal travels directly from the satellite to the antenna of the receiver. But in addition to the direct signal, there are reflected signals, from the ground and the objects near the antenna, which also reach the antenna through indirect paths and interfere with the direct signal. The compound signal creates an uncertainty about the true signal arrival time, much the same way as the echo from nearby mountains may cause uncertainty in the exact time you hear your friend's voice. If the indirect path is considerably longer than the direct path (more than 10 meters) such that the two patterns of signals can be separated, then the multipath effect can be substantially reduced by signal processing techniques.
Global Positioning System

**Receiver Errors:**
Receivers may introduce some errors by themselves in measuring code or carrier. In high quality receivers, however, these errors are negligible (less than one millimeter) for carrier phase and a few centimeters for code phase.

**Geometric Dilution of Precision (GDOP):**
We have been talking about the errors in measuring distances to satellites, which are commonly referred to as ranging or range errors. The question is what is the relationship between the range error and the error in computed position. Or, in other words, how many meters of error are introduced in our computed position as a result of one meter of error in measuring distances to the satellites?

The answer is that it depends on the number and the geometry of the satellites used. If four satellites are clustered near each other, then one meter of error in measuring distance may result in tens or hundreds of meters of error in position. But if many satellites are scattered around the sky, then the position error may be less than 1.5 meters for every meter of error in measuring distances. The effect of the geometry of the satellites on the position error is called Geometric Dilution Of Precision (GDOP), which can roughly be interpreted as the ratio of the position error to the range error.

Imagine the tetrahedron that is formed by lines connecting the receiver to each satellite used. The larger the volume of this tetrahedron, the smaller (better) the GDOP. In most cases, the larger the number of satellites the smaller the GDOP.

**Selective Availability: The Man-Made Errors:**
Errors in the satellite clock, the satellite orbit, the ionosphere, the troposphere, the multipath, and the receiver typically amount to less than 10 meters of range error, which, under typical GDOPs of about 2, results in a position accuracy of about 20 meters. The US Department of Defense has determined that providing this level of precision to the general public is against the US national interest. Therefore, DOD has introduced man-made intentional errors to degrade the position accuracy of GPS to about 100 meters. This intentional degradation is called Selective Availability (SA) and is implemented by tethering the satellite clocks and reporting the orbit of the satellites inaccurately. Military receivers are equipped with special hardware and codes that
can mitigate the effect of SA. SA can be turned ON or OFF through ground commands by the GPS system administrators.

**Summary**

- We can adjust the receiver time to the accuracy of the GPS clock. This will make the inexpensive clock of the receiver as good as an atomic clock.
- Four is the minimum number of satellites that we need to compute position and time. (But the more satellites we have the more accurate results we can get.)
- Dual frequency receivers practically remove the ionosphere effects.
- If the signal indirect path is considerably longer than the direct path, more than 10 meters, then the multipath effect can be substantially reduced by signal processing techniques.

**Sources of Inaccuracy: The Cures**

Assume you have two receivers not too far from each other. The errors due to the satellite clock, the satellite orbit, the ionosphere, the troposphere and SA affect both receivers the same way and with the same magnitude. If we knew the exact location of one receiver, we could use that information to calculate errors in the measurement and then report these errors (or correction values) to the other receiver, so that it could compensate for them. This technique is called Differential mode.

The distance between the base and rover receivers is called "baseline". When the baseline is small, i.e. when the receivers are very close to each other, the range errors for the two receivers are nearly identical; therefore, we could use the range errors calculated by the base to correct for
the rover position. As the baseline gets longer, the correlation between the range errors becomes weaker. In other words, there will be some residual errors in the computed position of the rover that depend on its proximity to base. As a rule of thumb, you can expect an additional one-millimeter of error or uncertainty for every kilometer of baseline when dual frequency receivers are used. This is abbreviated as 1 ppm (one part per million). For single frequency receivers this error increases to 2 ppm.

The differential mode will remove most of all errors except multipath and receiver errors. These errors are local to each receiver and will not be canceled by the differential mode. The receiver error (or noise) is typically about 10 cm for the code phase and about 1-mm for the carrier phase. In high quality receivers these errors are even smaller by several times. The multipath error, on the other hand, could be as much as several meters for the code phase and several centimeters for the carrier phase. Therefore, if we somehow deal with the multipath errors, we can obtain millimeter level accuracy with carrier phase and decimeter accuracy with code phase.

**Multipath:**
There are two techniques available to mitigate the effects of multipath: a) Signal processing technique and b) Multipath Rejection Choke Rings.

Signal Processing Technique — In this method, the data is analyzed to separate the direct signal from the indirect signal(s). You can imagine the echo of your voice in a canyon. If the indirect path is substantially longer than the direct path, then you may be able to distinguish the two and concentrate on the direct path. But if the difference is small, the echoed signal may be so close to the direct signal that you cannot separate them. With GPS signals, the signal processing technique is ineffective if the difference between the direct path and the indirect path is less than a few meters. Removing a multipath signal comes at the expense of removing part of the direct signal too, which in turn increases noise. Oftentimes, the more we try to remove the short distance multipath, the more noise we add.

Multipath rejection choke rings — This technique works only for the multipath signals reflected from objects below the antenna. The reflected signal that hits the bottom side of the antenna can be rejected. This technique will do nothing for the reflected signals that hit the antenna on top, for example a signal that is reflected off a building above the antenna.

Fortunately most of the times the signals that are reflected from objects above the antenna have a multipath distance of more than 10 meters and signal processing techniques can mitigate them. For signals that are reflected off the ground, the multipath distance is in the order of a few meters and signal-processing techniques cannot do much to address them, but choke rings can. Because of the complimentary nature of the two techniques, we can mitigate both "near" and "far" multipaths.

**Choke Ring:**
A choke ring ground plane consists of several concentric thin walls, or rings, around the center where the antenna element is located. The area between the rings creates "grooves". The principle of the operation of choke ring ground planes is as follows. The signal received by the antenna is composed of two components: Direct and reflected. The grooves have no effect on the direct signal other than decreasing the antenna gain at low elevation angles; for high elevation angles the choke ring ground plane works almost like a flat ground plane. But the grooves have much effect on reflected signal from underneath.

The electromagnetic field of the reflected signal in the vicinity of the choke ring ground plane can be viewed as the sum of a primary and a secondary field waves. The objective of the choke ring ground plane is for the primary and secondary reflected signals to substantially cancel each other and the direct signal to the antenna to remain as the dominant signal. If the amplitude of the primary and the secondary waves are equal and the phase difference between them is 180 degrees, then the two components of the reflected signal cancel each other at the antenna output and multipath is suppressed. So, a given choke ring has optimum effect only at the particular frequency that has resonance behavior. For a given choke ring ground plane, the complete suppression of multipath only occurs at certain elevation angles; at other angles, the multipath is suppressed partially. The maximum suppression usually occurs at angles close to zenith, and minimal suppression at angles close to the horizon.

Choke rings are typically designed for one frequency. If a choke ring is designed for L1 then it has no effect on L2, while if it is designed for L2 then it has some benefits for L1. Recently, dual-frequency choke rings have been introduced that allow separate optimization for L1 and L2.

Summary:

- Because of the complimentary nature of the choke ring and the signal processing methods, we can mitigate both "near" and "far" multipaths.
- Choke rings are typically designed for one frequency. If a choke ring is designed for L1 then it has no effect on L2, while if it is designed for L2 then it has some benefits for L1. New dual-frequency choke rings allow separate optimization for L1 and L2.
Fig. 1: The Global Positioning System (GPS), 21 satellites configuration
Fig. 2. Basic principle of positioning with GPS.
Fig. 3 The space, Control and User Segment of GPS

Fig. 4 Arrangement of satellites in full constellation