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Satellite-based Positioning, Navigation, and Timing (PNT)

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

This paper describes the Global Positioning System (GPS) satellite-based radio navigation system. The paper summarizes the space, control and user segments of the GPS, using one-way signal time of arrival measurements to multiple satellites in medium earth orbit to produce highly accurate positioning, and precise time dissemination. Further discussions on signaling waveform including Code Division Multiple Access (CDMA) and Direct Sequence Spread Spectrum (DSSS) techniques are covered. This document touches on the ubiquitous every day applications of the GPS that has improved many aspects of modern life.

The organization of this paper begins with a basic description of the GPS system, describes the method of using precise space borne atomic time standards to make pseudorange measurements from line of site between a user's receiver and satellites, requiring at least four satellites to solve for four unknowns (x, y, z, and time). With favorable geometry accurate positioning can be derives from range measurements to satellites. Time can be ascertained through calculating time uncertainty to on-orbit atomic clocks, with navigation messages providing corrections to account for factors such as relativistic effects. The paper further describes the utilization of spread spectrum techniques that can provide virtual gain for weak signals with excessive path loss resulting in signal power well below thermal background noise power. The next section describes GPS receiver basic operations. The paper concludes with modern day applications of the GPS including spacecraft orbital determination, environmental mapping, and precise timing.

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CONTENTS

FIGURES

1. INTRODUCTION

The Global Positioning System (GPS) is a satellite-based radio-navigation system owned and operated by the United States. The system, which provides users with positioning, navigation, and timing (PNT) services, was first approved by the Department of Defense in 1973. There are four components needed for GPS: known time of signal transmission, known satellite location, speed of the radio wave, and time of arrival.

The satellites send signals that are composed of the navigation message and carefully constructed navigation signals. The navigation signals allow the user receiver to make precise measurements of the signal arrival time. The navigation message carries the key information such as where the satellite is and when it broadcasted the information. A single satellite will broadcast a known transmission time and satellite location. The speed of the radio wave is close to the speed of light, with a travel time of approximately 70 milliseconds from medium earth orbit. The GPS receiver on Earth measures the delay of the signal by noting where the code transitions occur. Knowing the delay between when the signal was sent and when it was received, it is possible to calculate the distance between the receiver and the satellite. Knowing how far the receiver is from several known satellite positions, it is possible to determine the location of the receiver.

There are currently 31 U.S. operational satellites in orbit, in what is known colloquially as the GPS "Bird Cage." Generally speaking, satellites operate in three orbital regimes: Lower Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary/Geosynchronous Orbit (GEO). LEO satellites are not currently used for navigation due to limited time of view, raising and setting at a rate that has traditionally been too fast to be practical for radionavigation. During the time when GPS was being developed, if LEO satellites were to be used, the constellation would have required significantly more satellites, which, at the time (early 1970s), seemed impractical. The footprint of an individual LEO satellite is very small on the surface of the earth, so it follows that the amount of coverage per LEO satellite is also small. Moving out to the MEO satellites, the footprint and visibility for each satellite increases to a large fraction of the Earth's surface. A satellite in MEO can see about one-third of the Earth's surface. As a result, not as many satellites are needed in MEO in order to obtain full coverage of the Earth's surface. For these reasons, GPS chose MEO orbits for its constellation. GEO satellites are typically when a satellite needs to be fixed in a particular location in the sky to provide a constant directional angle to the GOE satellite from a point on the Earth's surface. Common applications for GEO satellites are communications. GEO satellites are also used to augment GPS, and this is done regionally. The United States, for example, has three satellites in GEO that serve the continental US local region and add augmentation information to GPS. This system is known as the Wide Area Augmentation System (WAAS).

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2. OVERVIEW OF GPS- SPACE, CONTROL, USER SEGMENTS

2.1 SPACE SEGMENT

For accurate satellite-based worldwide navigation, a minimum of 24 GPS Satellites are needed. With 31 currently in use today, improved accuracy is possible due to increased number of satellite in view for locations around the globe. The satellites are placed in a constellation, or orbit, at an altitude of 20,000 km above the Earth's surface, which is MEO. At this altitude, the satellites orbit at 3.9 Km per second and take 12 hours to complete one orbit.

The constellation, or “Bird Cage,” is divided into 6 orbital planes, with each orbit being able to support at least 4 satellites within it. This is done to ensure that at least 4 satellites are visible from the surface of Earth at any given time. Each orbital plane is placed 60 degrees relative to one another meaning that there is 60 degrees of arc between each orbital plane, giving full 360 degree coverage of the Earth. The constellation as a whole is then placed at an inclination of 55 degrees relative to the earth’s equator.

2.2 CONTROL SEGMENT

The control segment contains monitor stations, ground antennas, and the master control station. The monitor stations monitor the position of the GPS Satellites overhead. They also receive signals from the Satellites. The monitor stations then send the data collected to the Master Control Station. There are 16 monitor stations around the world, with 6 being monitored by the US Space Force and the other 10 by the National Geospatial Intelligence Agency or NGA.

The Master Control Station receives information from the monitor stations to control the constellation of satellites in orbit. Information on the position of the satellites is sent to the control station to determine if corrections need to be made. If there is a need for a correction, the Master Control Station will perform maintenance on the orbits of the constellation to keep it in optimal condition. The Master Control Station also creates commands and messages that are sent up to the satellites. The GPS constellation is currently being controlled through the Architectural Evolution Plan (AEP). AEP uses more modernized technologies to control and monitor the constellation of satellites. The system was implemented in 2007 and developed by the US Air Force. The Master Control Station is located in Colorado. There is an operational back-up station located in California as well.

The ground antennas are used to send commands and navigation data up to the satellites as well as collected measurements of the satellites position as well. The ground antennas are primarily used for sending commands from the Master Control Station up to the constellation. The antennas send signals in the S-Band frequency due to its ability to communicate with a directional signal as well as for its ability to communicate clear and quick responses. There are 4 GPS ground antennas on earth as well as another 7 that are operated by the Air Force Satellite Control Network (AFSCN).

2.3 USER SEGMENT

The User Segment of GPS consists of the receivers, processors, and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time. These receivers must decode and process the GPS satellite ranging codes and navigation data messages. Receivers can be stand-alone applications, or they can be integrated with or embedded into other systems.

This segment is used by land surveyors, aircraft, ships, agriculture and farming, navigation, shipping and delivery to name a few. The L1 frequency of GPS is intended for consumer/civilian use and has an accuracy of approximately 3-7 meters. A user device receives a signal from a satellite and uses transmitted information to calculate position and time. It only needs a one-way signal to operate.

Beginning in the 1990s, the consumer and commercial applications of GPS increased significantly. Finer accuracy and 24-hour performance became available. Consumer use of GPS has enabled the development of much smaller and more affordable GPS receivers.

3. PSEUDORANGE, TRILATERATION, AND MULTILATERATION

3.1 DEFINITION

For GPS, pseudoranges are invaluable measurements used to calculate a position on earth. The goal of pseudoranging is to align internal code replicas held by a receiver with the incoming received signal codes from the satellites. The receiver clock makes a mark on the incoming signal. That mark is then compared with the timestamp in the navigation message by the satellite. The measurement is called the *pseudorange* – as opposed to the ‘range’ – because it is the *true range* added to the *clock bias.*

In considering the clock bias, it is important to note that there will be a difference between the satellite time (which is much more accurate), and the user clock time. The user clock uses a different method of timekeeping, is much less precise, and a fraction of the cost. This factor must be included as a bias in the calculations.

The simplistic approach in solving this would be to take *time received* and subtract *time transmitted* and that would equal the *distance* divided by the *speed of light*. Nevertheless, since we need to account for the bias (being the small, yet important, difference between the two clocks), then we need to use a more complex equation.

Time Received (with bias) - *Time Transmitted = distance / speed of light + bias.*

3.2 ONE-WAY RANGING MEASUREMENTS: TRILATERATION & MULTILATERATION

Trilateration involves using three satellites and data from each satellite is combined to determine a point on the earth’s surface. It requires a minimum of three in this context, to calculate longitude, latitude, and altitude. However, that is not accurate enough for our purposes. Due to a lower accuracy clock in the receiver, a fourth is needed to achieve the goal. That is where multilateration comes into play. Multilateration includes four or more satellites. The benefits include more precision, and more information about elevation and altitude.

There are four similar equations to be solved, because there are four unknowns {x,y,z,b} when solving with four satellites. As was mentioned before, there needs to include a clock bias (bu) term. The set of equations showing each equation is for a different satellite is shown below:

$$\tau^{(1)} = \sqrt{\left(x_u - x^{(1)}\right)^2 + \left(y_u - y^{(1)}\right)^2 + \left(z_u - z^{(1)}\right)^2} + b_u - B^{(1)} + \varepsilon_u^{(1)}$$
$$\tau^{(2)} = \sqrt{\left(x_u - x^{(2)}\right)^2 + \left(y_u - y^{(2)}\right)^2 + \left(z_u - z^{(2)}\right)^2} + b_u - B^{(2)} + \varepsilon_u^{(2)}$$
$$\tau^{(3)} = \sqrt{\left(x_u - x^{(3)}\right)^2 + \left(y_u - y^{(3)}\right)^2 + \left(z_u - z^{(3)}\right)^2} + b_u - B^{(3)} + \varepsilon_u^{(3)}$$
$$\tau^{(4)} = \sqrt{\left(x_u - x^{(4)}\right)^2 + \left(y_u - y^{(4)}\right)^2 + \left(z_u - z^{(4)}\right)^2} + b_u - B^{(4)} + \varepsilon_u^{(4)}$$

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4. NAVIGATION SOLUTION AND SOLVING FOR POSITION USING THREE RANGE MEASUREMENTS, AND A FOURTH TO RESOLVE TIME UNCERTAINTY

4.1 INTRODUCTION TO EQUATIONS VARIABLES

As mentioned in the previous section, four pseudorange equations are required to solve for the location and time of the user. The equations include the range estimate and a variable for state augmentation in the case that the user clock is offset. The equation to solve for these variables is as follows:

$$\tau^{(i)} = \sqrt{(x_u - x^{(i)})^2 + (y_u - y^{(i)})^2 + (z_u - z^{(i)})^2} + b_u + \gamma_u^{(i)}$$

Where the variables are:

- τ is the pseudorange measurement for the i^{th} satellite
- b_u is the clock bias adjustment made by the receiver to align for the intersection of satellite signals
- x_u, y_u, z_u is the user state estimate for position
- $\sqrt{(x_u - x^{(i)})^2 + (y_u - y^{(i)})^2 + (z_u - z^{(i)})^2}$ is the euclidean distance formula of user position in x,y,x, subtracted by the i^{th} satellite ephemeris
- $\gamma_u^{(i)}$ is the error of satellite clock relative to the master clock and the remaining error from atmospheric delay suffered by the user to the i^{th} satellite

Note that the variables in the equation are in respect to the earth centered earth fixed coordinate reference frames (ECEF).

4.2 LINEARIZING THE PSEUDORANGE EQUATIONS

An important step towards solving the four or more pseudorange equations for the state estimates is to linearize them. To do this, we can solve for them in respect to an assumed location instead of solving globally. The following figure shows a simplified case of using assumed locations for measurements in the east west direction, however, the same idea holds for adding another dimension.

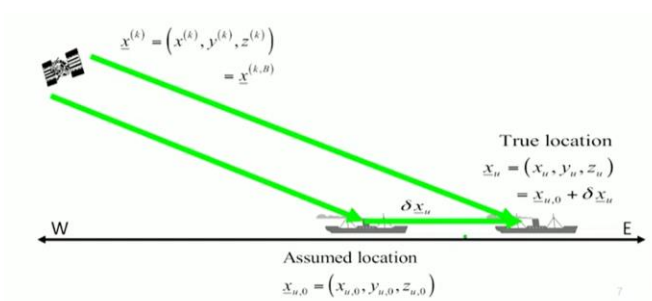

Figure 1. x^k represents the location of the satellite. $x_{u,o}$ represents the assumed location of the user. x_u represents the true location of the user [2].

After an assumed location is established, we use the error between the assumed and true locations to solve for x_u-- making it $x_u=x_{u,o}+x_u$. In the case that the assumed location is too far off, the process will iteratively take new assumed locations until the estimation of the true location becomes satisfactory. The next step is to find out what the error is and that can be solved by examining the parallel rays of the satellite to assumed location and satellite to true location. The rays of the assumed location are found with the Euclidean distance formula with respect to the satellite broadcast signal and the true location is found with respect to the satellite's true position. The two parallel rays will give you a simple triangle geometry between the two location points with one side as the difference between the two location's distance. Then the difference can be further reduced using trigonometry with the angle of ray height at the horizon and the user position. This makes the location estimate linearized and the result is as shown in the following figure.

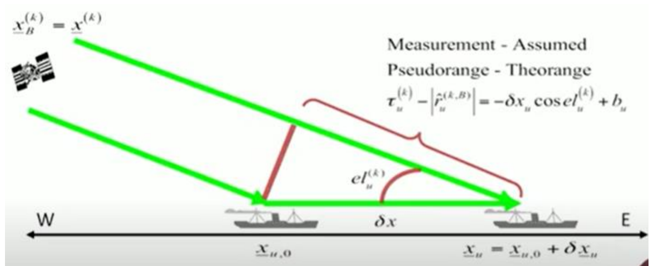

Figure 2. The linearized version of the pseudorange is called the theorange. The figure shows u(k) as the linearized version of the pseudorange equation with the difference of true and assumed location, the trigonometry to reduce that difference, and the clock offset, bu.

4.3 SOLVING THE LIENARIZED EQUATIONS

Now that we have linearized the pseudorange equations, we can bring in more satellites- four or more- to solve for all the variables. These satellites must be at sufficiently different angles and distances to solve for each variable. We can also add on complexity by considering the azimuth angles to bring in positioning for the full 3 dimensions of location. The new reference frame is East-North-Up.

As with problems involving linear equations, we can solve it using matrices. In figure 3, the matrix is displayed in multiple forms. The first matrix system is τ =A*x where τ represents the pseudorange difference values, A is the coefficients calculated using the assumed angles and x represents the difference from the true to the assumed point's time and distance. The matrix equation below that is a shorthand representation with G^i being the assumed angle coefficient of the i^{th} measurement. This matrix solves for the estimates and is called the "geometry matrix".

$$\begin{bmatrix} \delta\tau^{(1)} \\ \delta\tau^{(2)} \\ \vdots \\ \delta\tau^{(K)} \end{bmatrix} = \begin{bmatrix} -\cos el_u^{(1)} \sin az_u^{(1)} & -\cos el_u^{(1)} \cos az_u^{(1)} & -\sin el_u^{(1)} & 1 \\ -\cos el_u^{(2)} \sin az_u^{(2)} & -\cos el_u^{(2)} \cos az_u^{(2)} & -\sin el_u^{(2)} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ -\cos el_u^{(K)} \sin az_u^{(K)} & -\cos el_u^{(K)} \cos az_u^{(K)} & -\sin el_u^{(K)} & 1 \end{bmatrix} \begin{bmatrix} \delta E_u \\ \delta N_u \\ \delta U_u \\ \delta b_u \end{bmatrix}$$

$$\begin{bmatrix} \delta\tau^{(1)} \\ \delta\tau^{(2)} \\ \vdots \\ \delta\tau^{(K)} \end{bmatrix} = \begin{bmatrix} \tilde{G}^{(1)} \\ \tilde{G}^{(2)} \\ \vdots \\ \tilde{G}^{(K)} \end{bmatrix} \begin{bmatrix} \delta E_u \\ \delta N_u \\ \delta U_u \\ \delta b_u \end{bmatrix}$$

East-North-Up (ENU) reference frame

$$\delta\tau^{(k)} - \tilde{G}^{(k)} \begin{bmatrix} \delta E_u & \delta N_u & \delta U_u & \delta b_u \end{bmatrix}^T$$

Figure 3. The first matrix equation is the change in pseudorange equation equal to the assumed angle coefficients times the change in assumed and user estimates [2].

These equations can also be rewritten in the ECEF reference frame as:

$$\begin{bmatrix} \delta\tau^{(1)} \\ \delta\tau^{(2)} \\ \vdots \\ \delta\tau^{(K)} \end{bmatrix} = \begin{bmatrix} -\underline{1}_u^{(1)} & 1 \\ -\underline{1}_u^{(2)} & 1 \\ \vdots & \vdots \\ -\underline{1}_u^{(K)} & 1 \end{bmatrix} \begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix} + \begin{bmatrix} \tilde{\nu}_u^{(1)} \\ \tilde{\nu}_u^{(2)} \\ \vdots \\ \tilde{\nu}_u^{(K)} \end{bmatrix}$$

$$\delta\underline{\tau} = G\delta\underline{x}_u + \underline{\tilde{\nu}}_u$$

Figure 4. The linearized pseudoequations in ECEF reference frame with an added error term [2].

The last term $\gamma_u^{(i)}$ is the term that comes from noise plus other sources of error from the i^{th} satellite to the user.

Finally, we can solve for the estimates of the user. In the case that we are using exactly four satellites to solve the equations, we can multiply the inverse of G, the assumed angles coefficients to the right hand side. That will give the location and time of the user. In the case that we have more than four satellites, we have an over specified situation that has more G matrix rows than columns. This can be fixed by multiplying the pseudoinverse of the G transpose times G. This gives the least squares formula and that provides the minimum values of each satellite squared. The time and position solutions of the user can be then be ascertained.

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5. DIRECT SEQUENCE SPREAD SPECTRUM BASICS, LINK BUDGET/SIGNAL POWER AT THE RECEIVER, PROCESSING GAIN

The GPS satellite's antenna pattern projects energy of the l band signal onto the earth's sphere that provides power that is significantly below the radio frequency background noise. For this reason, Direct Sequence Spread Spectrum (DSSS) technology is required to detect the signals from beneath the background noise in order for a user to receive and process the GPS signals. A representation of a binary phase shift keyed DSSS signal is shown in Figure 5:

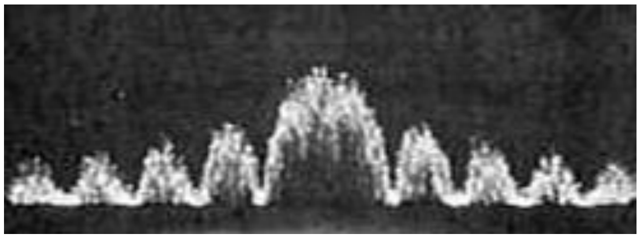

Figure 5. The Binary Phase Shift Keying (BPSK) modulated signal. Chipping rate for GPS C/A code is 1.024 MHz. Modulated null-to-null radio frequency bandwidth is twice the code chipping rate, or 2.048 MHz that contains more than 90% of the signal energy and is defined as the signal modulated bandwidth. BPSK spectrum is represented by the $(\sin x/x)^2$ or $(\text{sinc})^2$ function.

5.1 LINK BUDGET

An example budget for the link, based on a presumed 26 dBW transmission power level (Effective Isotropic Radiated Power or EIRP) which is the satellite RF power output and transmit antenna gain can be expressed as:

- EIRP
  - Satellite Power Amplifier transmitter power: (25 Watts) 14.25 dBW
  - RF Losses in transmission path: 1.25 dB
  - Antenna Gain (with respect to an isotropic radiator, circularly polarized): 13 dBic
  - Satellite EIRP (with respect to a circularly polarized isotropic radiator): (400 Watts) 26 dBW
- Path Loss
  - Path Length or R: 2.4E+07 meters (13,000 nmi)
  - L1 Wavelength or λ = speed of light/L1 frequency = 3E+08/1575.42E+6: 19.0424 cm
  - Path Loss =20 log $4\pi R/\lambda$: 184 dB
- Received Signal Power
  - Signal Power = EIRP (dBW) - Path Loss(dB): - 158 dBW
- Thermal Noise Power
  - Receive Noise Power = kTB: -141 dBW
  - Where:

    k is Boltzmann's Constant: 1.38E-23

    T is system noise temperature (62.33 deg F) = 290 deg K

    B is Noise Bandwidth: 2 MHz

- Link Budget:
  - Signal Power (dBW) – Receive Noise Power (dBW): -17 dB

5.2 PROCESSING GAIN

Using the above link budget analysis the GPS signal is so weak that under non spread spectrum conditions the signal is not detectable as it is buried below the natural thermal noise. Spread spectrum techniques allow for the desired signal energy in the entire 2 MHz Modulated RF Bandwidth to be compared to only 1 Hz of noise Bandwidth. The DSSS post correlation process allows for compression of the entire RF power across the modulated RF spectrum to be concentrated to a 1 Hz bandwidth, while comparing only 1 Hz of noise (or interference power) to the signal power:

Thermal Noise Power (1 Hz Bandwidth):

- Receive Noise Power in 1 Hz BW = kT: -204 dBW

Direct Sequence Spread Spectrum Link Budget (Carrier to Noise ration or C/No):

- C/No (dB): Signal Power (dBW)- Receive 1 Hz Noise Power (dBW): +46 dB

DSSS techniques use a Pseudo-random Noise (PN) encoded sequence that is composed of many "chips" to represent a single information "bit". The chips are clocked at many times the baseband signal data rate (for GPS L1 C/A code the RD bandwidth is 2 MHz while the baseband data rate is only 50 bps). Demodulated processing gain is the ratio of the RF modulated chipping rate as compared to baseband data rate. It is typically expressed in dB using the following expression:

DSSS Processing Gain: $G_p(dB) = 10 \log (BW_{RF}/R_{info})$

Where:

- G_p is Processing Gain of the system
- BW_{RF} is RF Modulated Bandwidth of the system

For *Binary Phase Shift Keying or BPSK:*

$BW_{RF} = 2\ R_c = 2$ MHz (R_c is the "chipping rate" or 1 MHz)

R_{info}, baseband information rate for GPS is: 50 bps

Therefore DSSS Processing Gain, G_p(dB) for GPS is: 46 dB

Note that for the example above both DSSS C/No and processing gain, (G_p) just happen to be the same value, however this is merely coincidental. DSSS processing and C/No are both related to the gain of spreading modulated signals, with processing gain related to post data demodulation gain, while C/No is related to the power of spreading signal bandwidth under uncorrelated white noise RF interference (post correlator signal to noise ratio). Therefore, there is not a direct correlation between the DSSS processing gain and the DSSS C/No per se. This can be seen for the example of the military's P(Y)-code 20 MHz RF bandwidth signal that would have similar satellite signal level, spread across 20 MHz (instead of 2 MHz for C/A code) resulting in a similar C/No, while G_p for P(Y)-code would be an order of magnitude (10 dB) larger than C/A code.

A positive link budget (C/No) does not constitute signal reception data demodulation necessarily as there will be a cutoff at a C/No that can be approximated in the following manner:

G_p + *(Link Budget) = Residual* G_p

For our example: *Residual* G_p = 29 dB

To determine expected C/No interference signal breakpoint, the following expression can be used:

C/No - (Residual G_p) = Minimum Useable C/No

For this example *Minimum Useable C/No* = *+17 dB* (Note: again the coincidental value of Link Budget and *Minimum Useable C/No* - except for sign differences. Also, note that this value is a theoretical minimum, while in practice effects such as correlation loss and Analog to Digital Converter (ADC) Effective Number of Bits (ENoB) may result in losses that increase this minimum.

5.3 DSSS CHANNEL ACCESS

Not only does the GPS DSSS signal construct allow for processing gain to permit receivers to detect signals that are below noise, the DSSS chips (PRN) sequence is encoded to permit Code Division Multiple Access (CDMA) operation allowing all of the satellites' broadcast signals to share the same radio frequency spectrum .The PRN generator for GPS C/A code uses the "Gold codes". This code or sequence is named after its inventor, Dr. Robert Gold who devised this code while working at Magnavox in the late 1960s. Gold codes have excellent autocorrelation properties while possessing very low cross correlation properties to facilitate CDMA. A CDMA architecture permits spectrum sharing with each satellite being identified by its own unique code. CDMA is in widespread use today in the cell phone communications industry for the very same reasons it has been used for GPS.

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6. GPS RECIEVER BASICS

A GPS receiver, for the most part, can be broken down into the following components:

- An Antenna, which receives extremely weak satellite signals.
- A RF Front End consisting of a Low Noise Amplifier (LNA) and a RF filter to reject out of band signal interference.
- An RF/Intermediate Frequency (RF/IF) down converter that mixes the RF frequency with a Local Oscillator (LO) frequency to produce an IF output.
- An IF stage that filters out unwanted image and spurious frequencies allowing only the appropriate intermediate frequency to pass to the next stage.
- An Analog to Digital Converter (ADC).
- A Digital Signal Processor (DSP) that performs parallel processing to correlate all-in-view satellite pseudo random noise (PRN) codes. Data is output and referred to as navigation data.
- A Controller or Navigation Processor that calculates position, time, velocity and other characteristics using the navigation data. [6]

GPS modules evaluate weak antenna signals from at least four satellites to determine a correct three-dimensional position, also known as multilateration. Satellite visibility and geometry affect the quality of GPS measurements, introducing performance parameters. The basic performance parameters used to make such comparisons between multiple GPS receivers are position accuracy, velocity accuracy, time accuracy, and Time to First Fix (TTFF).

The receiver position accuracy depends on User Range Error (URE), Control Segment errors. User Equipment (UE) error (UEE) of the URE is the contribution allocated to the receiver. For moving platforms, dynamic positioning accuracy measurements must consider the effect of vehicle motion on calculations such as UEE, filtering algorithms and coordinate transformations. To help mitigate error in position accuracy for example due to ionospheric delay, satellites can transmit signals at different frequencies which can be analyzed with dual frequency receivers to measure the delay rather than estimate it as must be done for a single frequency receiver. Velocity is calculated by measuring the frequency shift of the carrier doppler. The signal in space has a User Range Rate Error (URRE) smaller or equal to 0.006 m/sec over a 3-second interval with 95% probability. Time accuracy relies on the Precise Time and Time Interval (PTTI) interface, that can provide accurate time and time interval (pulse) output for which the receiver has compensated for errors by reading and processing satellite navigation message data that contains correction data. Line-of-site errors are limited to nanoseconds. For comparison, errors of microseconds can affect the accuracy significantly, especially if these errors occur for multiple satellites that a GPS receiver is tracking. GPS can routinely deliver a time transfer accuracy on the order of 10's of nanoseconds relative to Coordinated Universal Time (UTC).[2]

Time-To-First-Fix (TTFF) is the time elapsed required for a receiver to calculate the first position solution after gathering satellite signals and navigation data. Even though a GPS receiver must collect a complete ephemeris from each individual GPS satellite to tell its correct position, reading the almanac from just one satellite is still valuable. A receiver that has been in operation and still stores ephemeris or almanac from previous observations performs what is known as a warm start or normal start. This has a smaller TTFF (2-5.5 minutes) compared to a receiver at cold start. A receiver with no previous observations is said to have a cold start (12.5 minutes). Lastly, the fastest TTFF is known as hot start (about 10 seconds). This happens when a receiver is provided with a standby capability to maintain oscillator power, time, position, and the satellites' ephemeris and almanac. [7]

7. APPLICATIONS OF GPS/GNSS

GPS is an open access infrastructure that enhances many of the devices and systems that we have in society. Basic things like accurate location and timing are accessible to everyone all over the world and these things have impacts on almost everything in society. From economy, to agriculture, to construction and so much more, GPS has seamlessly improved the efficiency and effectiveness of technologies available to humankind. In the following section, we will discuss a few of the fields that GPS has a major influence on.

7.1 SPACECRAFT ORBIT AND TRAJECTORY DETERMINATION

Some space missions choose to use GPS to determine their positioning instead of the typical two-way communications channel that uses a ground station or relay satellite. Implementing GPS increases the autonomy of the spacecraft and enables for new spaceflight operations. It also deletes the need for expensive on-board clocks, improves quick trajectory maneuver and performance.

7.2 ENVIORNMENT

GPS helps provide accurate mapping of environmental problem locations. Once GPS receivers are placed, GPS data provides views into hard to reach wilderness, inform environmental scientists about the health of the environment, and predict how it will change. The data that can be gathered include meteorology, tidal wave proliferation, endangered species population tracking, tectonic plate movements and more. All this information comes in an efficient digital form that can be processed and analyzed by environmental scientists quickly. [7]

7.3 TIMING

GPS satellites contain multiple atomic clocks that can provide precise time data. Precision in time is critical for many fields such as communication systems, electrical power grids, and financial networks. The applications of GPS timing are evident in daily life. The U.S. Federal Aviation Administration (FAA) uses the precise timing sent from GPS to synchronize all reporting of hazardous weather situations. Additionally, the use of GPS time in seismic monitoring networks has allowed scientists and researchers to seamlessly integrate and synchronize devices that monitor and locate the epicenters of earthquakes. GPS continues to benefit civilian users in their daily lives. Wireless phones rely on an infrastructure that uses GPS to discipline clocks in order to synchronize devices across networks. Businesses rely on the consistency and accuracy of GPS timing to timestamp significant transactions.

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14. ABSTRACT

The Global Positioning System (GPS) is a satellite-based radio navigation system that uses multiple satellites in view of a receiver on earth to produce precise positioning based on signal propagation speed, distance to the satellites, and precise time. This paper describes the different segments of the GPS: Space, Control, and User. We also discuss the measurements that determine precise location information. Additionally, we discuss the radio signal and factors of interference. Finally, we conclude with use cases for modern applications of GPS.

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