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Operational Satellite Navigation Systems

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Abstract**:** Global Navigation Satellite System (GNSS) or Satellite Navigation Systems (SNS) is the collective term, used to describe various satellite navigation systems, which provide three dimensional position, velocity and time across the globe, on the land, in the air, and at the sea in all weather conditions. The GNSS is successfully able to overcome the drawbacks imposed by the earlier radio navigation systems (such as Transit, and Omega). Currently, two fully operational GNSS are available across the world. These are the United States, Department of Defence's Global Positioning System (GPS) and Russian military controlled Global Navigation Satellite System (GLONASS). These two systems are continuously upgraded to meet the higher standards of reliability. This paper discusses about the features of Operational Global Satellite Navigation Systems.

Keywords: GNSS, GPS, GLONASS and SNS.

1.INTRODUCTION

All GNSS operate on the trilateration principle for obtaining the user positioning. In this, three minimum ranging sources from three satellites are required. The range measured from the satellite to user is called as pseudorange, because it includes the true error and errors such as the receiver clock bias and other errors. The pseudorange from each satellite define a sphere on which user position can be located in 3D and three such ranges from three satellites define three spheres. The intersection of these three spheres defines the user location. Measurement of another pseudorange from the fourth satellite is used for elimination of the receiver clock bias.

Let x_u , y_u , z_u and x_i , y_i , z_i (where i=1,2,3,4) be the coordinates of the user and the satellites in Earth Centered Earth Fixed (ECEF) coordinate system (Fig. 1).

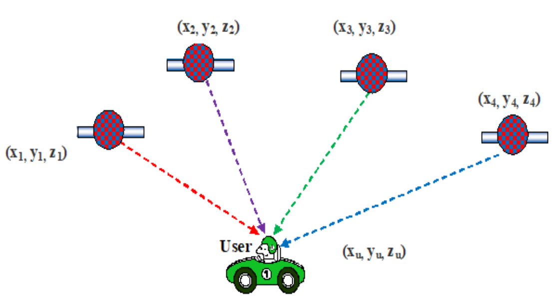

Fig.1 User position calculation

Assume that the satellite starts transmitting its signals at t_{svi} (i = 1 to 4) seconds and receive signals at t_{ui} seconds. Let t_{bias} is the time offset between the user and the satellite. Mathematically, the user position calculation can be written as,

$$(x_u-x_1)^2 + (y_u-y_1)^2 + (z_u-z_1)^2 = c^2 (t_{u1} - t_{sv1} + t_{bias})^2 \quad (1)$$
$$(x_u-x_2)^2 + (y_u-y_2)^2 + (z_u-z_2)^2 = c^2 (t_{u2} - t_{sv2} + t_{bias})^2 \quad (2)$$
$$(x_u-x_3)^2 + (y_u-y_3)^2 + (z_u-z_3)^2 = c^2 (t_{u3} - t_{sv3} + t_{bias})^2 \quad (3)$$
$$(x_u-x_4)^2 + (y_u-y_4)^2 + (z_u-z_4)^2 = c^2 (t_{u4} - t_{sv4} + t_{bias})^2 \quad (4)$$

where, 'c' is the free space velocity ($3 \times 10^8\ ms^{-1}$) of the GPS signal. By solving these equations simultaneously, the user position is obtained.

Some prominent features of GNSS which are useful in improving the performance are as follows[1].

a) Since GNSS are space based, problems associated with land based systems such as the ground reflections, electromagnetic interference, reflections from physical systems etc., are mostly minimized.
b) Forward Error Correction (FEC), pilot signals and high signal power in modern GNSS helps in improving accuracy and in indoor navigation.
c) In GNSS, multiple access schemes of modulations, which help to reduce the intentional interference, are incorporated.
d) The accuracy of GNSS can be further improved using differential techniques.

2. GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) was also known as Navigation Satellite Timing And Ranging (NAVSTAR) GPS. The GPS is the first fully operational GNSS, which is developed and operated by the U.S Department of Defense (DoD) since 1995[4]. Primarily GPS was developed for the U.S. military applications and later its applications were

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extended to civilians. Though they provided the GPS signals to the civilians, but the accuracy was degraded using a feature known as Selective Availability (SA). Due to the competition across the world, the SA was removed on 2nd May 2000. The GPS operates with the coordination of three important segments (Fig.2). These are;

a) Space segment
b) Control segment and
c) User segment

(a) Space segment

The space segment consists of nominally 24 satellites. The satellites are at an altitude of approximately 20,200 km above the earth. At this altitude the satellites are less affected by the irregularities caused by the unequal distribution of mass in the earth. The satellites travel at a velocity of 3.9 km/sec. The satellites launches are classified into various blocks. The satellites of Block I launched during 1978 to 1985 are no more in operation. Currently, the GPS constellation consists of 31 active satellites in various blocks (Table 1)

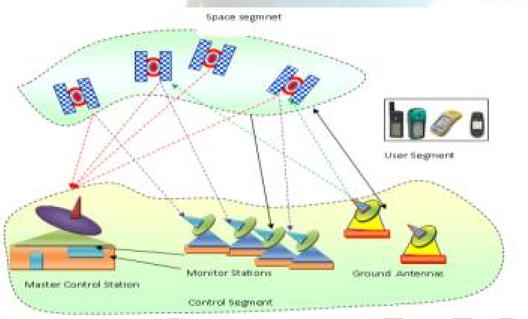

Fig.2 GPS architecture

The US DoD planned to launch 11 Block IIF satellites and 30 Block III satellites by the year 2030.

Table1: Current GPS satellite constellation

S.No.	Block number	Number of satellites
1	Block IIA	13
2	Block IIR	12
3	Block IIR	06
4	Block IIF	01

The satellites are placed in six nearly circular orbits. The orbits are equally spaced at 60° separation with a nominal inclination of 55° relative to the equator. The orbital period of satellite vehicles (SV's) is 12 sidereal hours or 11 hours 58 minutes and 2 seconds of solar time[5]. The satellites would consist of solar panels for power supply and a propulsion system for satellite orbit adjustments and stability control. Apart from this, each GPS satellite is identified by the following information[6].

a) Launch sequence number
b) Assigned pseudorandom noise (PRN) code
c) Orbital position number
d) National Aeronautics and Space Administration (NASA) catalogue number
e) International designations

(b) Control segment

The main function of control segment is to track satellites in the orbit, clock biases determination, time synchronization, and upload of data messages to the satellites. This segment consists of the following three sub-segments.

i) Monitor Stations (MS)
ii) Master Control Station (MCS)
iii) Ground Control Stations (GCS)

(i) Monitor Stations (MS)

The MS consists of accurate GPS receivers with precise atomic clocks to measure pseudoranges continuously from all the satellites in view. The pseudoranges are measured every 1.5 seconds. These measurements are smoothed and are transmitted to the MCS. The monitor stations are located at various places which include, Ascension Island, Diego Garcia, Kwajalein, Colorado Springs and Hawaii.

(ii) Master Control Station (MCS)

The major functions of MCS are;

i) To control the satellite and system operations
ii) To prepare the satellite almanac
iii) To monitor the health status
iv) To collect the tracking data from the MS
v) To calculate the satellite orbital and clock errors

(iii) Ground Antennas (GA)

The ground antennas upload the navigation data, orbital, clock corrections etc., provided by MCS, to the satellite via S-band radio links. The GCSs are located at the Ascension, Diego Garcia, and Kwajalein.

(c) User segment

The user segment comprises of GPS receivers. These are classified as single and dual frequency receivers. The dual frequency receivers are expensive but more accurate than

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single frequency receivers. Further, depending up on the type of application, the receiver design varies.

(d) GPS signals

A GPS signal from each satellite provides the users with the information to measure pseudorange. The satellites transmit signals in L-band such as L_1, L_2, L_3, and L_4 signals. The frequencies L_1 and are L_1 (1.575 GHz) and L_2 (1.227 GHz) .The L_1 signal is mainly used for civilian applications and the L_2 signal is used for military applications. The L_3 signal is associated with the nuclear detonation detection system and L_4 signal is used for other military purposes. The usage of two frequencies helps in the following two ways.

a) In case if the L_1 signal is lost, i.e. the receiver is being jammed on L_1, then the L_2 acts as the backup and
b) $L_1$and L_2 signals collectively provides dual frequency compensation for signal delay due to ionosphere.

3. GPS MODERNIZATION

Modernization program (GPS III) was approved by the U.S. congress in the year 2000 and is expected to be fully operational by the year 2030. The salient features of this program include the addition of new satellites and signals. The major objectives of the GPS modernization are as follows.

i) To provide with more signal power
ii) To provide with more secure new military code structure
iii) To provide with improved accuracy and integrity to the users
iv) To facilitate high level of continuity of service
v) To introduce more user equipment anti-jam capabilities
vi) To provide with better design-in flexibility for future changes

(a) Modern GPS satellites

The Modernization of GPS include the next generation Block III satellites. By introducing sufficient number of satellites with additional capabilities, the GPS horizontal accuracy will be improved to about 8.5m (95% of the time). With these upgradation, the expected standalone GPS horizontal accuracy will be 6m (95% of the time) or better. In the GPS III system architecture, space-based networks, inter satellite-cross links would allow the users to meet requirement of autonomous navigation. This means that the satellite has the capability to autonomously estimate clock and ephemeris error by using on-board cross-link range measurements. The first launch of a GPS III satellite is scheduled for the year 2014[7] .

(b) Modern GPS signals

As stated, the GPS modernization has plan to introduce new signals for civilian, aviation and military users. Fig. 2.3 shows, the three stages of GPS modernization plans with GPS signal spectra. The features of modern GPS signals are discussed below[9].

(i) New civil signal on L_1 (L_1C)

The L_1C signal is proposed to be broadcasted on the L_1 frequency along with the existing C/A signal. This signal provides backward compatibility, enables greater civil interoperability with proposed European Satellite navigation system-Galileo's L_1 signal. The L_1C will be transmitted from the GPS III satellites[8].

(ii) New civil signal on L_2 (L_2C). The L_2C signal provides improved accuracy of navigation, an easy-to-track facility and acts as a redundant signal in case of localized interference. This signal was first transmitted by one of the block IIR-M GPS satellites in the year 2005[8].

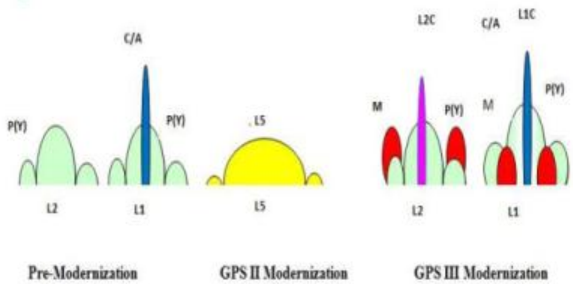

Fig.3 Spectrum of GPS original and modernized signals

(iii) Signal for civil aviation (L_5)

A new civilian safety of life signal known as L_5 at 1176.45MHz is introduced. This signal is located in the Aeronautical Radio Navigation Services (ARNS) band, a frequency band that is available worldwide[10]. This signal has improved signal structure for better performance, higher transmitted power than that of L_1 and L_2 signals. The L_5 signal is robust and was made available with first block IIF satellites. This signal also has a wide broadcast bandwidth (20 MHz) and a higher chipping rate (10.23 MHz), which provide higher accuracy under noisy and multipath conditions[11].

(iv) Military signal on L_1 and L_2 (M-code)

Two new military codes (M-codes) would be made available on both the L_1 and L_2 frequencies. These codes are intended to be broadcast from a high gain directional antenna. These

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codes provide an improved anti-jamming and secure access of the military GPS signals. The M-code is designed to be autonomous which means that the user position can be calculated using only the M-code signal[12].

4.GLOBAL NAVIGATION SATELLITE SYSTEM

The second fully operational GNSS is known as Globalnaya Navigationnaya Sputnikovaya Sistema or Global Navigation Satellite System (GLONASS). This system is designed and developed by the Ministry of Defense of Russia. It is controlled for the Russian Federation Government by the Russian Space Forces (RSF) (GLONASS Interface Control Document, 1997). This system is operated by the Coordination Scientific Information Center (CSIC) of the Ministry of Defense of the Russian Federation. Like GPS, GLONASS architecture consists of three segments. They are the space, control and user segments.

(a) Space segment

The GLONASS satellites are upgraded with the advent of 3 generations. The 1st generation satellites were 3-axis stabilized. These satellites consist of propulsion systems which permit the relocation of the satellites. The first satellite was launched in the year 1982. The 2nd generation satellites are known as GLONASS-M satellites. The 3rd generation satellites are known as GLONASS-K satellites. Presently, the satellite constellation has full operational capability with 24 satellites. The constellation incorporatesing the antipodal satellites to transmit on the same frequency[13]. The satellites are placed at an altitude of 19,100 km above the earth, at an inclination angle of 64.8 ^{o} to the equatorial plane. The GLONASS satellites are deployed in the 3 orbital planes and are separated by 120° as shown in Fig.4. The satellites within the same orbit plane are separated by 45°[14]. Each of the GLONASS satellite is identified by a particular slot number. The orbital period of the satellites is 11 hours and 15 minutes. The GLONASS time is generated on the basis of the GLONASS Central Synchronizer (CS) time. Similar to GPS, the GLONASS time is based on an atomic time scale.

(b) Ground control segment

Main functions of GCS are;

i) To measure and predict each satellite ephemeris and monitor the GLONASS signals
ii) To control the uplink of predicted satellites
iii) To upload the data and the almanac of all the satellites to each satellite, etc.

The GLONASS GCS ensures the synchronization of the on-board time and the ground segment time[16]. The GCS controls the satellite movement with the use of radio commands. The GCS and the time standards are located in the capital city, Moscow. The number and also the global distribution of the tracking stations have been improved significantly since 2006.

(c) User segment

The user segment consists of the compatible GLONASS receivers. Like GPS, this also finds applications in several areas such as, transportation, commerce, sports and recreation, guidance of military weapons, communication network timing etc.

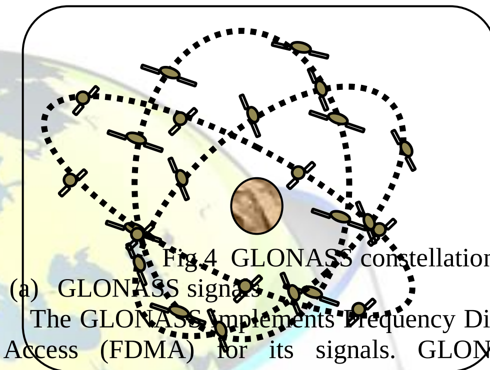

Fig.4 GLONASS constellation

(a) GLONASS signals

The GLONASS implements Frequency Division Multiple Access (FDMA) for its signals. GLONASS satellites continuously transmit coded signals and can be received by the compatible receivers in two frequency bands 1602.5625 - 1615.5 MHz and 1240 - 1260 MHz.

Table 2 : Comparison of important features of GPS and GLONASS

S. No.	Parameter	GPS	GLONASS
1	Operator	DoD, USA (Military Control)	Ministry of Defense, Russia (Military Control)
2	Current Status of SV's	31 satellites	24 satellites
3	Altitude	20,200 Kms	19,100 Kms

4	Operating frequency (MHz)	L1 = 1575.42 L2 = 1227.6 for all the satellites	L1 = 1602-1615.5 Δf = 0.5625 L2 = 1246 – 1256.5 Δf = 0.4375 Each SV has diff. freq.
5	Services offered	C/A code: for Civilians P: code : for Military	Safety-of-life and Sub meter real time accuracy
6	Orbit Inclination	55°	65°
7	Technique	Spread Spectrum, CDM	Spread Spectrum, FDM
8	Modulation	BPSK	BPSK
9	Time	GPS time synchronized with UTC (USNO)	GLONASS time synchronized with UTC
10	Clock rate i) C/A code ii) P code	1.023 Mbits/sec 10.23 Mbits/sec	0.511 Mbits/sec 5.11 Mbits/sec
11	Coordinate system	WGS-84 ECEF	SGS-90 (PZ-90) ECEF

5. CONCLUSIONS

The GNSS has become a critical part in the lives of human beings. Even though, GPS is the first fully operational satellite navigation system, the GLONASS is also widely used across the world. Also, if the GNSS receiver is compatible enough to receive both the GPS and GLONASS signals. then it is expected to provide better accuracy, as the satellite visibility will be more with both the satellite constellations.

6. REFERENCES

1. Kaplan, Elliott, D.(1996), "Understanding GPS Principles and Applications", Artech House, Boston.
2. Sergey Revnivykh," GLONASS Status Update"UN/Zambia/ESA Regional Workshop on the Applications of Global Navigation Satellite System Technologies in Sub-Saharan Africa, 26 - 30 June 2006.
3. Parkinson, B.W., and Spilker, J.J. Jr. (1996a), "Global Positioning System: Theory and Applications", Vol. I, American Institute of Aeronautics and Astronautics, Inc., Washington, DC.
4. Misra,P., and Enge,P.(2001),"Global Positioning System Signals, Measurements, and Performance", Ganga Jamuna Press, MA, USA.
5. Leick, Alfred, "GPS Satellite Survey", Wiley publications, 3rd edition, 2004.
6. Hofmann-Wellenhof, B., Lichtenegger, H., and Wasle, E. (2008),"GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more", Springer-Verlag Wien New York
7. (http://www.spacedaily.com/reports/ Lockheed_Martin_Delivers_Key_GPS_ III_Test_Hardware_Ahead_of_Schedule_999.html)
8. http://www.insidegnss.com/pdf/08-leveson-v5Web.pdf.
9. http://www.insidegnss.com/node/97.
10. http://www.gpsworld.com/gnss-system/gps-modernization/the-modernized-l2-civil-signal-730
11. http://waas.stanford.edu/~wwu/papers/gps/PDF/EngeAIAC03.pdf.
12. http://www.mitre.org/work/tech_papers/tech_papers_00/betz_overview/betz_overview.pdf.
13. http://www.http://glonass-iac.ru/en/GLONASS/ .
14. http://www.spaceandtech.com/spacedata/constellations/glonass_consum.shtml.
15. Hofmann-Wellenhof, B., Lichtenegger, H., and Collins, J. (2001), "Global Positioning System Theory and Practice", 5th edn., Springer-Verlag Wien New York.
16. http://www.iss-reshetnev.com/images/File/magazin/2007/m2-screen_en.pdf