UNIT 2

GNSS BASICS

SYLLABUS

GNSS Basics
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GNSS BASICS

GNSS SYSTEMS

Although you may already be familiar with the term "GPS" (Global Positioning System), you may not have heard the term "GNSS" (Global Navigation Satellite System), which is used to describe the collection of satellite positioning systems that are now operating or planned.

GPS (United States): GPS was the first GNSS system. GPS was launched in the late 1970s by the United States Department of Defense. It uses a constellation of 27 satellites, and provides global coverage.

GLONASS (Russia): GLONASS is operated by the Russian government. The GLONASS constellation consists of 24 satellites and provides global coverage.

Galileo (European Union): Galileo is a civil GNSS system operated by the European Global Navigation Satellite Systems Agency (GSA). Galileo will use 27 satellites with the first Full Operational Capability (FOC) satellites being launched in 2014. The full constellation is planned to be deployed by 2020.

BeiDou (China): BeiDou is the Chinese navigation satellite system. The system will consist of 35 satellites. A regional service became operational in December of 2012. BeiDou will be extended to provide global coverage by end of 2020.

IRNSS (India): The Indian Regional Navigation Satellite System (IRNSS) provides service to India and the surrounding area. The full constellation of seven satellites is planned to be deployed by 2015.

QZSS (Japan): QZSS is a regional navigation satellite system that provides service to Japan and the Asia-Oceania region. The QZSS system is planned to be deployed by 2018.

OVERVIEW OF GNSS SEGMENTS

GNSS SEGMENTS

GNSS consists of three segments: the space segment, the control segment, and the user segment as shown in Figure 2.1.

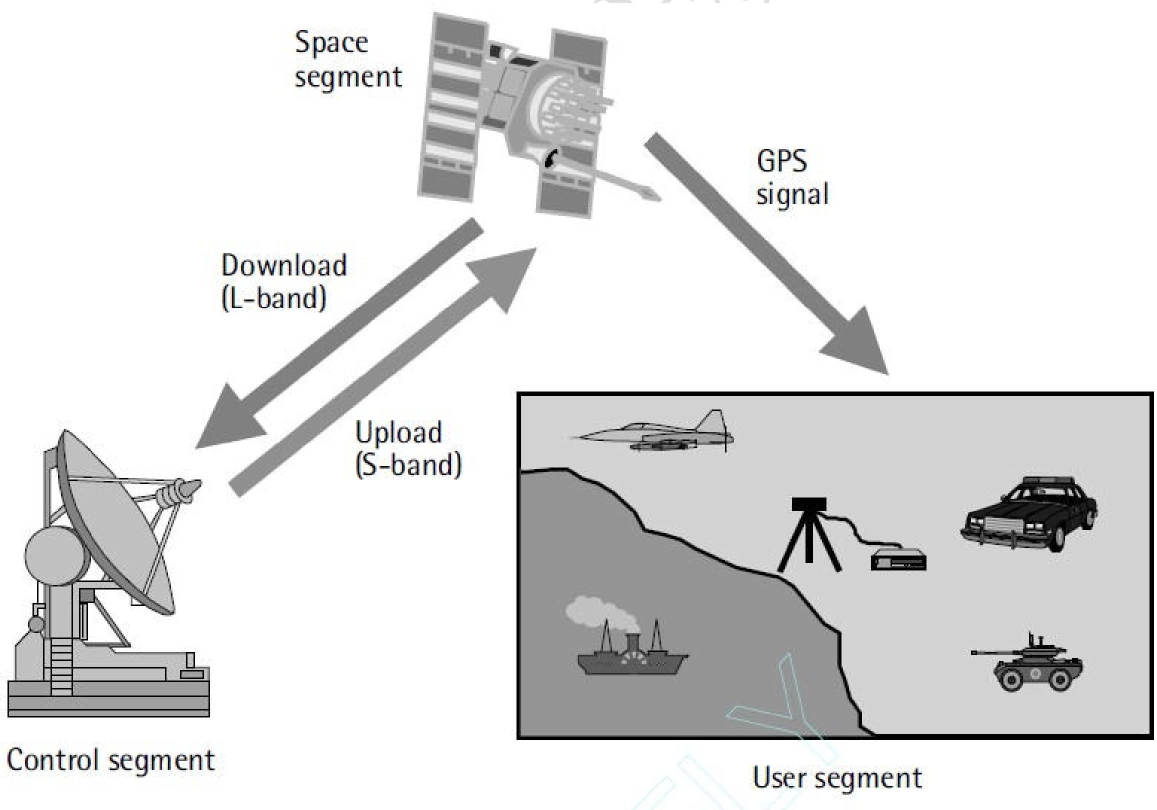

Fig. 2.1 GPS Segments

THE SPACE SEGMENT

The space segment consists of the 24-satellite constellation introduced in the previous section as shown in Figure 2.2.

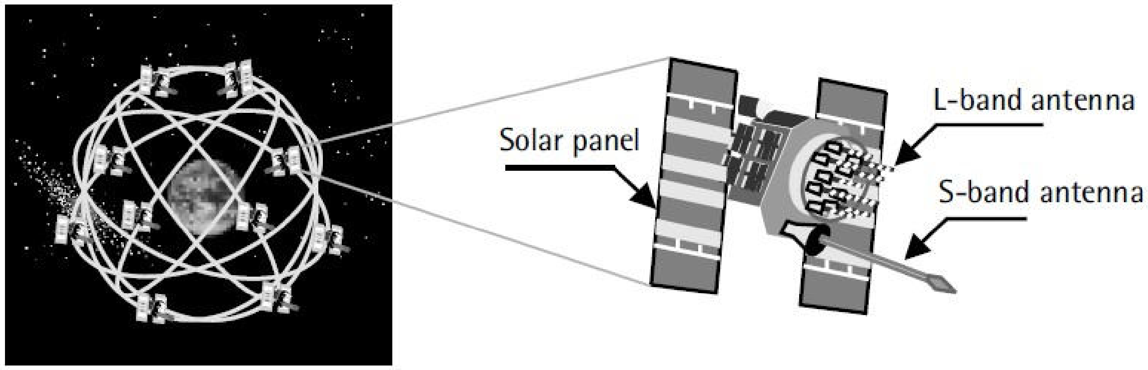

Fig. 2.2 GPS Constellation

Each GNSS satellite transmits a signal, which has a number of components: two sine waves (also known as carrier frequencies), two digital codes, and a navigation message.

The codes and the navigation message are added to the carriers as binary bi phase modulations.

The carriers and the codes are used mainly to determine the distance from the user's receiver to the GNSS satellites.

The navigation message contains, along with other information, the coordinates (the location) of the satellites as a function of time.

The transmitted signals are controlled by highly accurate atomic clocks onboard the satellites.

The U.S. government baseline configuration for the constellation consists of 24 satellites.

Within this configuration, the satellites are positioned in six Earth-centered orbital planes with four satellites in each plane.

The nominal orbital period of a GNSS satellite is one-half of a sidereal day or 11 hours, 58 minutes.

The orbits are nearly circular and equally spaced around the equator at a 60° separation with a nominal inclination relative to the equatorial plane of 55°.

The orbital radius (i.e., nominal distance from the center of mass of the Earth to the satellite) is approximately 26,600 km.

This satellite constellation provides a 24-hour global user navigation and time determination capability.

THE GROUND SEGMENT OR THE USER SEGMENT

The Ground Segment or the User Segment includes all military and civilian users.

With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals, which can be used to determine his or her position anywhere in the world.

GPS is currently available to all users worldwide at no direct charge.

The user receiving equipment comprises the user segment.

Each set of equipment is typically referred to as a GNSS receiver, which processes the L-band signals transmitted from the satellites to determine user Position Velocity and Time (PVT).

Technology trends in component miniaturization and large-scale manufacturing have led to a proliferation of low-cost GPS receiver components.

GPS receivers are embedded in many of the items we use in our daily lives.

These items include cellular telephones, PDAs, and automobiles.

Selection of a GNSS receiver depends on the user's application (e.g., civilian versus military, platform dynamics, and shock and vibration environment).

THE CONTROL SEGMENT

The control segment comprises a ground-based network of master control stations, data uploading stations and monitor stations.

In the case of GPS, two master control stations (one primary and one backup), four data uploading stations and 16 monitor stations, located throughout the world.

In each GNSS system, the master control station adjusts the satellites' orbit parameters and onboard high-precision clocks when necessary to maintain accuracy.

Monitor stations, usually installed over a broad geographic area, monitor the satellites' signals and status, and relay this information to the master control station.

The master control station analyses the signals then transmits orbit and time corrections to the satellites through data uploading stations.

The control segment of the GPS system consists of a worldwide network of tracking stations, with a master control station (MCS) located in the United States at Colorado Springs, Colorado.

The primary task of the operational control segment is tracking the GNSS satellites in order to determine and predict satellite locations, system integrity, behavior of the satellite atomic clocks, atmospheric data, the satellite almanac, and other considerations.

This information is then packed and uploaded into the GNSS satellites through the S-band link.

The CS is responsible for maintaining the satellites and their proper functioning.

This includes maintaining the satellites in their proper orbital positions (called Station keeping) and monitoring satellite subsystem health and status.

The CS also monitors the satellite solar arrays, battery power levels, and propellant levels used for maneuvers.

Furthermore, the CS activates spare satellites (if available) to maintain system availability.

The CS updates each satellite's clock, ephemeris, and almanac and other indicators in the navigation message at least once per day.

Updates are more frequently scheduled when improved navigation accuracies are required.

The ephemeris parameters are a precise fit to the GNSS satellite orbits and are valid only for a time interval of 4 hours with the once-per-day normal upload schedule.

Depending on the satellite block, the navigation message data can be stored for a minimum of 14 days to a maximum of a 210-day duration.

Almanac data is used to predict the approximate satellite position and aid in satellite signal acquisition.

The almanac is a reduced precision subset of the ephemeris parameters.

The almanac consists of 7 of the 15 ephemeris orbital parameters.

Furthermore, the CS resolves satellite anomalies, controls SA and AS and collects pseudorange and carrier phase measurements at the remote monitor stations to determine satellite clock corrections, almanac, and ephemeris.

To accomplish these functions, the CS is comprised of three different physical components: the master control station (MCS), monitor stations, and the ground antennas as shown in Figure.

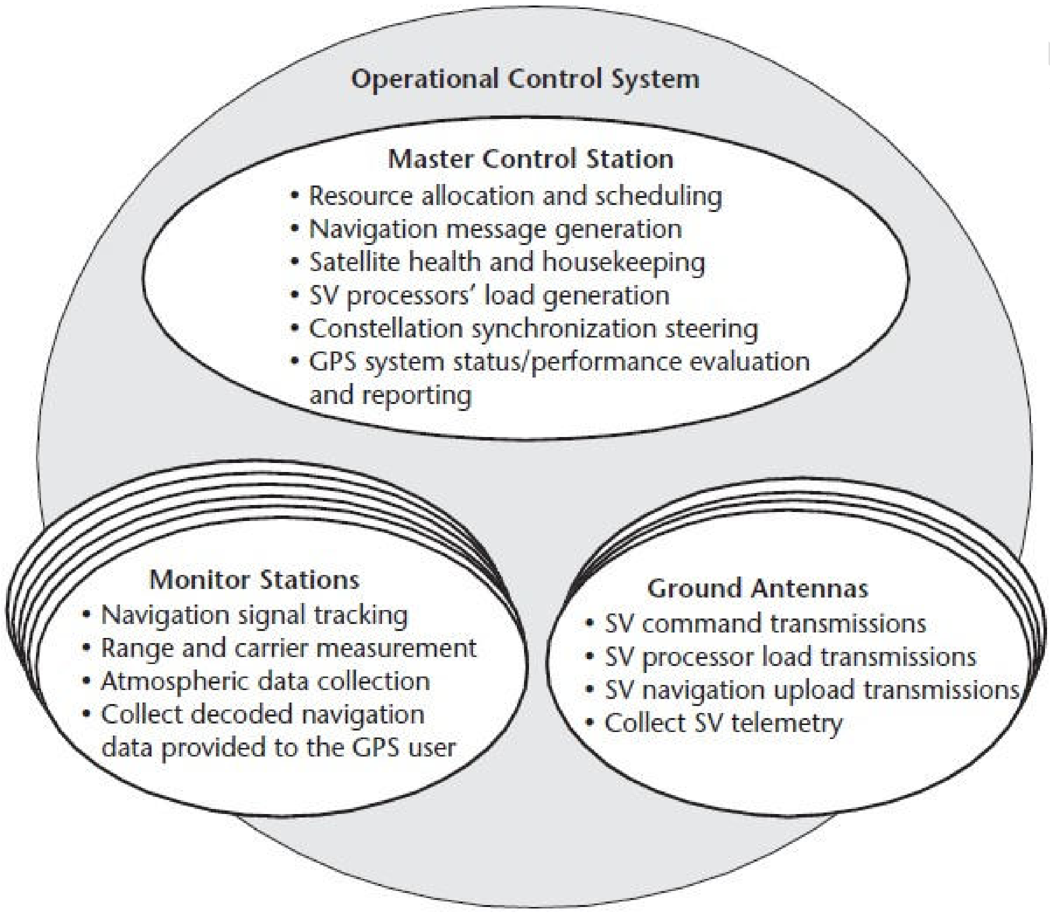

Fig.2.3 Control Segment Components

GPS

The Global Positioning System (GPS) is part of a satellite-based navigation system developed by the U.S. Department of Defense under its NAVSTAR satellite program.

GPS Orbits The fully operational GPS includes 24 or more (32 currently) active satellites approximately uniformly dispersed around six circular orbits with four or more satellites each.

The orbits are inclined at an angle of 55◦ relative to the equator and are separated from each other by multiples of 60◦ right ascension.

The orbits are nongeostationary and approximately circular, with radii of 26,560 km and orbital periods of one-half sidereal day (≈11.967 h).

Theoretically, three or more GPS satellites will always be visible from most points on the earth's surface, and four or more GPS satellites can be used to determinean observer's position anywhere on the earth's surface 24 h per day.

GPSSignals EachGPSsatellite carries a cesium and/or rubidium atomic clock to provide timing information for the signals transmitted by the satellites.

Internal clock correction is provided for each satellite clock.

Each GPS satellite transmits two spread spectrum, L-band carrier signals—an L1 signal with carrier frequency $f1$ = 1575.42 MHz and an L2 signal with carrier frequency $f2$ = 1227.6 MHz.

These two frequencies are integral multiples $f1 = 1540f0$ and $f2 = 1200f0$ of a base frequency $f0$ = 1.023 MHz.

The L1 signal from each satellite uses *binary phase-shift keying* (BPSK), modulated by two *pseudorandom noise* (PRN) codes in phase quadrature, designated as the C/A-code and P-code.

The L2 signal from each satellite is BPSK modulated by only the P-code.

Code-Division Multiplexing Knowledge of the PRN codes allows users independent access to multiple GPS satellite signals on the same carrier frequency.

The signal transmitted by a particular GPS signal can be selected by generating and matching, or correlating, the PRN code for that particular satellite.

All PRN codes are known and are generated or stored in GPS satellite signal receivers carried by ground observers.

A first PRN code for each GPS satellite, referred to as a *precision code* or *P-code*, is a relatively long, fine-grained code having an associated clock or chip rate of $10f0 = 10.23$ MHz.

A second PRN code for each GPS satellite, referred to as C*oarse Acquisition code* or *C/A-code*, is intended to facilitate rapid satellite signal acquisition and handover to the P-code.

It is a relatively short, coarser-grained code having an associated clock or chip rate $f0 = 1.023$ MHz.

The C/A-code for any GPS satellite has a length of 1023 chips or time increments before it repeats.

The full P-code has a length of 259 days, during which each satellite transmits a unique portion of the full P-code.

The portion of P-code used for a given GPS satellite has a length of precisely one week (7.000 days) before this code portion repeats.

Navigation Signal The GPS satellite bit stream includes navigational information on the ephemeris of the transmitting GPS satellite and an almanac for all GPS satellites, with parameters providing approximate corrections for ionospheric signal propagation delays suitable for single-frequency receivers and for an offset time between satellite clock time and true GPS time.

The navigational information is transmitted at a rate of 50 baud.

Selective Availability Selective availability (SA) is a combination of methods available to the U.S. Department of Defense to deliberately derating the accuracy of GPS for "nonauthorized" (i.e., non-U.S. military) users during periods of perceived threat.
The horizontal-position accuracy, as degraded by SA, currently is advertised as 100 m, the vertical-position accuracy as 156 m, and time accuracy as 334 ns—all at the 95% probability level.

The initial satellite configuration used SA with pseudorandom dithering of the onboard time but this was discontinued on May 1, 2000.

Precise Positioning Service (PPS) is the full-accuracy, single-receiver GPS positioning service provided to the United States and its allied military organizations and other selected agencies.

Standard Positioning Service without SA Standard Positioning Service (SPS) provides GPS single-receiver (standalone) positioning service to any user on a continuous, worldwide basis.

SPS is intended to provide access only to the C/A-code and the L1 carrier.

GLONASS

A second configuration for global positioning is the Global Orbiting Navigation Satellite System (GLONASS), placed in orbit by the former Soviet Union, and now maintained by the Russian Republic.

GLONASS Orbits GLONASS also uses 24 satellites, but these are distributed approximately uniformly in three orbital planes (as opposed to six for GPS) of eight satellites each (four for GPS).

Each orbital plane has a nominal inclination of 64.8◦ relative to the equator, and the three orbital planes are separated from each other by multiples of 120◦ right ascension.

GLONASS orbits have smaller radii than GPS orbits, about 25,510 km.

GLONASS has a satellite period of revolution of approximately 8/17 of a sidereal day.

A GLONASS satellite and a GPS satellite will complete 17 and 16 revolutions, respectively, around the earth every 8 days.

GLONASS Signals The GLONASS system uses frequency-division multiplexing of independent satellite signals.

Its two carrier signals corresponding to L1 and L2 have frequencies $f1 = (1.602 + 9k/16)$ GHz and $f2 = (1.246 + 7k/16)$ GHz, where $k = 0, 1, 2, \ldots, 23$ is the satellite number.

These frequencies lie in two bands at 1.597–1.617 GHz (L1) and 1.240–1.260 GHz (L2).

The L1 code is modulated by a C/A-code (chip rate = 0.511 MHz) and by a P-code (chip rate = 5.11 MHz).

The L2 code is presently modulated only by the P-code.

The GLONASS satellites also transmit navigational data at a rate of 50 baud.

Because the satellite frequencies are distinguishable from each other, the P-code and the C/A-code are the same for each satellite.

The methods for receiving and analyzing GLONASS signals are similar to the methods used for GPS signals.
GLONASS does not use any form of SA.

GALILEO

The Galileo system is a satellite-based navigation system currently under development.

It is being developed by the European Commission's Galileo Signal Task Force (STF), which was established by the European Commission (EC) in March 2001.

The STF consists of experts nominated by the European Union (EU) member states, official representatives of the national frequency authorities, and experts from the European Space Agency (ESA).

Galileo Navigation Services

Galileo provides the following four navigation services plus one search and rescue (SAR) service.

1. *Open Service (OS)* The OS provides signals for positioning and timing, free of direct user charge, and is accessible to any user equipped with a suitable receiver, with no authorization required.

2. *Safety of Life Service (SOL)* The SOL service is intended to increase public safety by providing certified positioning performance, including the use of certified navigation receivers.

3. *Commercial Service (CS)* The CS service is intended for applications requiring performance higher than that offered by the OS.

   Users of this service pay a fee for the added value.

4. *Public Regulated Service (PRS)* The PRS is an access-controlled service for government-authorized applications.

   It will be used by groups such as police, coast guards, and customs.

   The signals will be encrypted, and access by region or user group will follow the security policy rules applicable in Europe.

Search and Rescue (SAR) It will feature near real-time reception of distress messages from anywhere on Earth, precise location of alerts (within a few meters).

Galileo Signal Characteristics

Galileo will provide 10 right-hand circularly polarized navigation signals in three frequency bands.

The various signals fall into four categories: F/Nav, I/Nav, C/Nav, and G/Nav.

The F/Nav and I/Nav signals are used by the Open Service (OS), Commercial Service (CS) and Safety of Life (SOL) service.

The I/Nav signals contain integrity information, while the F/Nav signals do not.

The C/Nav signals are used by the Commercial Service (CS).

The G/Nav signals are used by the Government.

It contains two signals, denoted E5a and E5b, which are respectively centered at 1176.45 and 1207.140 MHz.

Each signal has an in-phase component and a quadrature component.

Both components use spreading codes with chipping rate of 10 Mcps (million chips per second).

INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM (IRNSS) : NAVIC (NAVIGATION WITH INDIAN CONSTELLATION; ALSO, NĀVIK 'SAILOR')

Navic is an independent regional navigation satellite system being developed by India.

It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, which is its primary service area.

IRNSS will provide two types of services, namely, Standard Positioning Service (SPS) which is provided to all the users and Restricted Service (RS), which is an encrypted service provided only to the authorised users.

The IRNSS System is expected to provide a position accuracy of better than 20 m in the primary service area.

Some applications of IRNSS are:

- Terrestrial, Aerial and Marine Navigation
- Disaster Management
- Vehicle tracking and fleet management
- Integration with mobile phones
- Precise Timing
- Mapping and Geodetic data capture
- Terrestrial navigation aid for hikers and travellers
- Visual and voice navigation for drivers

The system will be under complete Indian control, with the space segment, ground segment and user receivers all being built in India.

IRNSS Architecture

The constellation consists of 7 satellites.

Three of the seven satellites are located in geostationary orbit (GEO) at longitudes 32.5° E, 83° E, and 131.5° E, approximately 36,000 km above Earth's surface.

The remaining four satellites are in inclined geosynchronous orbit (GSO).

The **IRNSS Ground Segment** consists of:

- ISRO Navigation Centre
- IRNSS Spacecraft Control Facility
- IRNSS Range and Integrity Monitoring Stations
- IRNSS Network Timing Centre
- IRNSS CDMA Ranging Stations

- Laser Ranging Stations
- Data Communication Network

The ground segment is in charge of estimating and predicting IRNSS satellites position, calculation of integrity, ionospheric and clock corrections and running the navigation software.

The **IRNSS User segment**: the IRNSS user segment is made of the IRNSS receivers. They will be dual-frequency receivers (L5 and S band frequencies) or single frequency (L5 or S band frequency) with capability to receive ionospheric correction.

IRNSS Services and Performances

There will be two kinds of services

- Special Positioning Service (SPS)
- Precision Service (PS)

Both services will be carried on L5 (1176.45 MHz) and S band (2492.028 MHz). The navigation signals would be transmitted in the S-band frequency and broadcast through a phased array antenna to keep required coverage and signal strength.
The Performances expected for the IRNSS system are: Position accuracy around 20 m over the Indian Ocean Region (1500 km around India) and less than 10 m accuracy over India.

IRNSS Development

The Indian government approved the project in May 2006, with the intention of the system to be completed and implemented by 2015.

BEIDOU

The BeiDou Navigation Satellite System (BDS) has been independently constructed and operated by China with an eye on the needs of the country’s national security and economic and social development.

As a temporal-spatial infrastructure of national significance, the BDS provides all-time, all-weather and high-accuracy positioning, navigation and timing services to global users.

Since provision of services, BDS has been widely used in

1. Transportation
2. Agriculture
3. forestry
4. fisheries
5. hydrological monitoring
6. meteorological forecasting
7. communication
8. power dispatching
9. disaster relief
10. public security

Beidou Architecture

BDS is mainly comprised of three segments: a space segment, a ground segment and a user segment.

The BDS space segment consists of a number of satellites located in the Geostationary Earth Orbit (GEO), Inclined Geo-Synchronous Orbit (IGSO) and Medium Earth Orbit (MEO).

The BDS ground segment consists of various ground stations, including master control stations, time synchronization/uplink stations, monitoring stations, as well as operation and management facilities of the inter-satellite link.

The BDS user segment consists of various kinds of BDS basic products, systems, and services as well as those compatible with other navigation systems, including basic products such as chips, modules and antennae, terminals, application systems and application services.

The BeiDou Navigation Satellite System (BDS) has 3 of the following segments:

a) **Space Segment:** The space segment is a hybrid-based navigation constellation comprising of MEO, IGSO and GEO satellites.
b) **Ground Segment:** The ground segment comprises several ground stations, which include master control stations, time-based synchronization and uplink stations, as well as numerous interception stations.

c) User segment: The user segment comprises modules, antennas and chips, as well as terminals, application systems and its services, which may be harmonious with other GNSS systems.

Table 2.1. Comparison of all GNSS Constellations

System	BeiDuo	Galileo	GLONASS	GPS	NAVIC	QZSS
Owner	China	EU	Russia	United States	India	Japan
Coverage	Regional (Global by 2020)	Global by 2020	Global	Global	Regional	Regional
Coding	CDMA	CDMA	FDMA	CDMA	CDMA	CDMA
Orbital altitude	21,150 km (13,140 mi)	23,222 km (14,429 mi)	19,130 km (11,890 mi)	20,180 km (12,540 mi)	36,000 km (22,000 mi)	32,000 km (20,000 mi)
Period	12.63 h (12 h 38 min)	14.08 h (14 h 5 min)	11.26 h (11 h 16 min)	11.97 h (11 h 58 min)	1436.0m (IRNSS-1A) 1436.1m (IRNSS-1B) 1436.1m (IRNSS-1C) 1436.1m (IRNSS-1D) 1436.1m (IRNSS-1E) 1436.0m (IRNSS-1F) 1436.1m (IRNSS-1G)	
Revolutions per sidereal day	17/9	17/10	17/8	2		
Number of satellites	5 geostationary orbit (GEO) satellites, 30 medium Earth orbit (MEO) satellites	24 by design, 14 operational, 4 commissioning, 30 operational satellites budgeted	28 (at least 24 by design) including:[17] 24 operational 2 under check by the satellite prime contractor 2 in flight tests phase	31 (at least 24 by design)[18]	3 geostationary orbit (GEO) satellites, 5 geosynchronous (GSO) medium Earth orbit (MEO) satellites	In 2011 the Government of Japan has decided to accelerate the QZSS deployment in order to reach a 4-satellite constellation by the late 2010s, while aiming at a final 7-satellite constellation in the future
Frequency	1.561098 GHz (B1) 1.589742 GHz (B1-2) 1.20714 GHz (B2) 1.26852 GHz (B3)	1.164–1.215 GHz (E5a and E5b) 1.260–1.300 GHz (E6) 1.559–1.592 GHz (E2-L1-E11)	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	1176.45 MHz(L5 Band) 2492.028 MHz (S Band)	
Status	22 satellites operational, 40 additional satellites 2016-2020	18 satellites operational 12 additional satellites 2017-2020	Operational	Operational	7 satellites fully operational	
Precision	10m (Public) 0.1m (Encrypted)	1m (Public) 0.01m (Encrypted)	4.5m – 7.4m	15m (Without DGPS or WAAS)	10m (Public) 0.1m (Encrypted)	1m (Public) 0.1m (Encrypted)

USER POSITION CALCULATIONS WITH NO ERRORS

User Position Calculations

ρ_r = pseudorange (known),
x, y, z = satellite position coordinates (known),
X, Y, Z = user position coordinates (unknown),

where x, y, z, X, Y, Z are in the earth-centered, earth-fixed (ECEF) coordinate system.

Position calculation with no errors is

$$\rho_r = \sqrt{(x-X)^2 + (y-Y)^2 + (z-Z)^2}.$$

Squaring both sides yields

$$\begin{aligned}\rho_r^2 &= (x-X)^2 + (y-Y)^2 + (z-Z)^2 \\ &= \underbrace{X^2 + Y^2 + Z^2}_{r^2 + C_{rr}} + x^2 + y^2 + z^2 \\ &\quad -2Xx - 2Yy - 2Zz,\end{aligned}$$

$$\rho_r^2 - (x^2 + y^2 + z^2) - r^2 = C_{rr} - 2Xx - 2Yy - 2Zz,$$

where *r* equals the radius of earth and *Crr* is the clock bias correction.

The four unknowns are *(X, Y, Z, Crr)*.

position *(x, y, z)* is calculated from ephemeris data.

For four satellites, the above Eq becomes

$$
\begin{aligned}
\rho_{r_1}^2 - (x_1^2 + y_1^2 + z_1^2) - r^2 &= \mathrm{Crr} - 2Xx_1 - 2Yy_1 - 2Zz_1,\\
\rho_{r_2}^2 - (x_2^2 + y_2^2 + z_2^2) - r^2 &= \mathrm{Crr} - 2Xx_2 - 2Yy_2 - 2Zz_2,\\
\rho_{r_3}^2 - (x_3^2 + y_3^2 + z_3^2) - r^2 &= \mathrm{Crr} - 2Xx_3 - 2Yy_3 - 2Zz_3,\\
\rho_{r_4}^2 - (x_4^2 + y_4^2 + z_4^2) - r^2 &= \mathrm{Crr} - 2Xx_4 - 2Yy_4 - 2Zz_4,
\end{aligned}
$$

With four unknown state vectors X, Y, Z and Crr

We can rewrite the four equations in matrix form as

$$
\begin{bmatrix}
\rho_{r_1}^2 - (x_1^2 + y_1^2 + z_1^2) - r^2\\
\rho_{r_2}^2 - (x_2^2 + y_2^2 + z_2^2) - r^2\\
\rho_{r_3}^2 - (x_3^2 + y_3^2 + z_3^2) - r^2\\
\rho_{r_4}^2 - (x_4^2 + y_4^2 + z_4^2) - r^2
\end{bmatrix}
=
\begin{bmatrix}
-2x_1 - 2y_1 - 2z_1 \; 1\\
-2x_2 - 2y_2 - 2z_2 \; 1\\
-2x_3 - 2y_3 - 2z_3 \; 1\\
-2x_4 - 2y_4 - 2z_4 \; 1
\end{bmatrix}
\begin{bmatrix}
X\\ Y\\ Z\\ C_{rr}
\end{bmatrix}
$$

or

$$
\overbrace{Y}^{4\times 1} = \overbrace{M}^{4\times 4}\overbrace{\chi_\rho}^{4\times 1},
$$

where

$$
\begin{aligned}
Y &= \text{ vector (known)},\\
M &= \text{ matrix (known)},\\
\chi_\rho &= \text{ vector (unknown)}.
\end{aligned}
$$

Then we premultiply both sides of above equation with M^{-1}

$$
\begin{aligned}
M^{-1}Y &= M^{-1}M\chi_\rho\\
&= \chi_\rho\\
&= \begin{bmatrix} X\\ Y\\ Z\\ C_{rr} \end{bmatrix}.
\end{aligned}
$$

TIME REFERENCE

GNSS Systems strongly rely on measuring the time of arrival of radio signals propagation. Thus, each GNSS System has its own time reference from which all elements of the Space, Control and User segments are time synchronized, as well most of the GNSS-based applications.

The most relevant GNSS time references are briefly described below.

GPS Time (GPST)

GPS Time (GPST) is a continuous time scale (no leap seconds) defined by the GPS Control segment on the basis of a set of atomic clocks at the Monitor Stations and onboard the satellites.

It starts at 0^h UTC (midnight) of January 5th to 6th 1980.

GPS time is synchronised with the UTC (Coordinated Universal Time) and is kept within 25 ns.

GLONASS Time (GLONASST)

GLONASS Time (GLONASST) is generated by the GLONASS Central Synchroniser with accuracy better than 1 microsecond.

Galileo System Time (GST)

Galileo System Time (GST) is a continuous time scale maintained by the Galileo Central Segment and synchronised with TAI (International Atomic Time) with a nominal offset below 50 ns.

BeiDou Time (BDT)

BeiDou Time (BDT) is a continuous time scale starting at 0^h UTC on January 1st, 2006 and is synchronised with UTC within 100 ns

DILUTION OF PRECISION (DOP)

Several external sources introduce errors into a GNSS position estimated by a GNSS receiver.

One important factor in determining positional accuracy is the constellation, or geometry, of the group of satellites from which signals are being received.

An indicator of the quality of the geometry of the satellite constellation is the Dilution of Precision or DOP.

Dilution of precision (**DOP**), or **geometric dilution of precision** (**GDOP**), is a term used in satellite navigation to specify the error propagation as a mathematical effect of navigation satellite geometry on positional measurement precision.

DOP only depends on the position of the satellites: how many satellites you can see, how high they are in the sky, and the bearing towards them.

This is often referred to as the geometry.

The term DOP means Dilution of Precision and is a value of probability for the geometrical effect on GPS accuracy

The computed position can vary depending on which satellites are used for the measurement.

Different satellite geometries can magnify or lessen the position error.

A greater angle between the satellites lowers the DOP, and provides a better measurement.

A higher DOP indicates poor satellite geometry (Figure 2), and an inferior measurement configuration, or in other words.

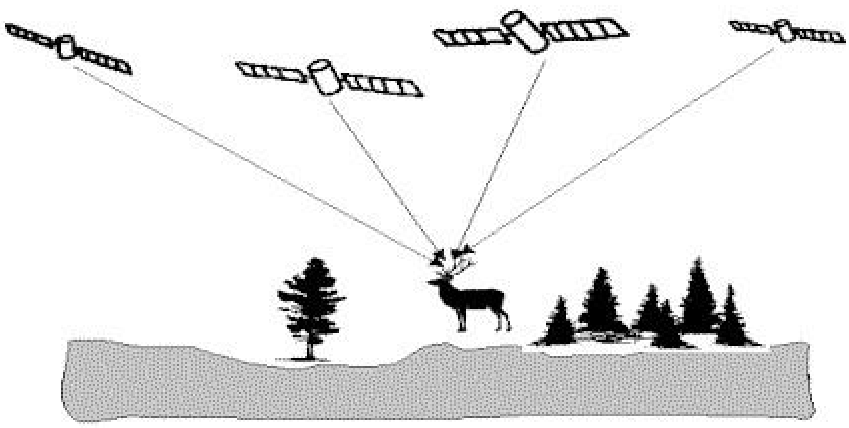

Fig.2.4 Example of Good Dilution of Precision

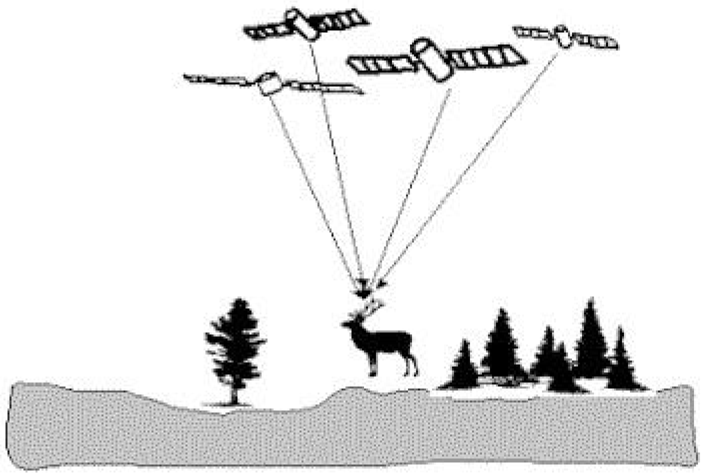

Fig. 2.5 Example of poor Dilution of Precision

Dilution of Precison components

GEOMETRIC DOP (GDOP)

This value describes **how many** satellites are spread evenly throughout the sky.

The more the satellites directly above you and the less on the horizon, the lower the GDOP value is.

GDOP is computed from the geometric relationships between the receiver position and the positions of the satellites the receiver is using for navigation.

GDOP Components are:

- HDOP = Horizontal DOP (Latitude, Longitude)
- VDOP = Vertical Dilution of Precision (Height)

HORIZONTAL DOP (HDOP)

The effect of the DOP on the horizontal position value.

The more visible satellites low in the sky, the better the HDOP and the horizontal position (Latitude and Longitude) are.

VERTICAL DOP (VDOP)

The effect of the DOP on the vertical position value.

The more visible satellites low in the sky, the better the VDOP and the vertical position (Altitude) are.

GNSS APPLICATIONS

1. Navigation

- Automobiles can be equipped with GNSS receivers at the factory or as aftermarket equipment. Units often display moving maps and information about location, speed, direction, and nearby streets and points of interest.

- Air navigation systems usually have a moving map display and are often connected to the autopilot for en-route navigation.
- Boats and ships can use GNSS to navigate all of the world's lakes, seas and oceans.

- Heavy equipment can use GNSS in construction, mining and precision agriculture. The blades and buckets of construction equipment are controlled automatically in GNSS-based machine guidance systems.
- Agricultural equipment may use GNSS to steer automatically, or as a visual aid displayed on a screen for the driver.
- Cyclists often use GNSS in racing and touring.

  GNSS navigation allows cyclists to plot their course in advance and follow this course, which may include quieter, narrower streets, without having to stop frequently to refer to separate maps.

- GNSS equipment for the visually impaired is available.
- Spacecraft use GNSS as a navigational tool.
- The addition of a GNSS receiver to a spacecraft allows precise orbit determination without a ground tracking station.

2. **Surveying and mapping**

- Geophysics and geology — High precision measurements of crustal strain can be made with differential GNSS by finding the relative displacement between GNSS sensors.
- Multiple stations situated around an actively deforming area (such as a volcano or fault zone) can be used to find strain and ground movement. These measurements can then be used to interpret the cause of the deformation, such as an active volcano.
- Archaeology — As archaeologists excavate a site, they generally make a three-dimensional map of the site, detailing where each artifact is found.
- Surveying — Survey-Grade GNSS receivers can be used to position survey markers, buildings, and road construction.

<u>Other uses</u>

- Military precision-guided munitions – Many types of munitions use GNSS to guide them to their target.
- Precise time reference – Many systems that must be accurately synchronized use GNSS as a source of accurate time.
- Mobile satellite communications – Satellite communications systems use a directional antenna (usually a "dish") pointed at a satellite. The antenna on a moving ship or train, for example, must be pointed based on its current location. Modern antenna controllers usually incorporate a GNSS receiver to provide this information.
- Emergency and location-based services – GNSS functionality can be used by emergency services to locate cell phones.
    - Location-based games – The availability of hand-held GNSS receivers has led to games such as geocaching, which involves using a hand-held GNSS unit to travel to a specific longitude and latitude to search for objects hidden by other geocachers.
- Aircraft passengers – Most airlines allow passenger use of GNSS units on their flights, except during landing and take-off, when other electronic devices are also restricted. Even though consumer GNSS receivers have a minimal risk of interference, a few airlines disallow use of hand-held receivers during flight. Other airlines integrate aircraft tracking into the seat-back television entertainment system, available to all passengers even during takeoff and landing.
- GPS tracking systems use GNSS to determine the location of a vehicle, person, pet or freight, and to record the position at regular intervals in order to create a log of movements. The data can be stored inside the unit or sent to a remote computer by radio or cellular modem. Some systems allow the location to be viewed in real time on the Internet with a web browser.
- Geo-fences can enable or disable devices based on their location.
- GNSS road pricing systems charge road users using data from GNSS sensors inside vehicles.
- Weather prediction (GNSS radio occultation) – Measurement of atmospheric bending of GNSS satellite signals by specialized GNSS receivers in orbital satellites can be used to determine atmospheric conditions such as air density, temperature, moisture and electron density.
- Photographic geocoding – Combining GNSS position data with photographs taken with a (typically digital) camera allows to view the photographs on a map or to look up the locations where they were taken in a gazetteer.
- It is possible to automatically annotate the photographs with the location they depict by integrating a GNSS device into the camera so that co-ordinates are embedded into photographs.
- Skydiving – Most commercial drop zones use a GNSS to aid the pilot to "spot" the plane to the correct position to allow all skydivers on the load to be able to fly their canopies back to the landing area.
- Wreck diving – A popular variant of scuba diving is known as wreck diving. In order to locate the desired shipwreck on the bottom of the ocean floor, GPS is used to navigate to the approximate location, and then the shipwreck is found using an echosounder.
- Social networking – A growing number of companies are marketing cellular phones equipped with GPS technology, offering the ability to pinpoint friends on custom created maps, along with alerts that inform the user when the party is within a programmed

range. Not only do many of these phones offer social-networking functions, they offer standard GPS navigation features such as audible voice commands for in-vehicle GPS navigation.

END OF UNIT 2