SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By
Prof. Radhakanta Koner
Department of Mining Engineering
Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 05
Satellite system in mining application

Lecture 11 A
GNSS in Mining

CONCEPTS COVERED

- Introduction to GNSS
- Primary uses of GNSS
- Basics of GNSS Trilateration
- GNSS Components
- GNSS signals
- Reference systems

CONCEPTS COVERED

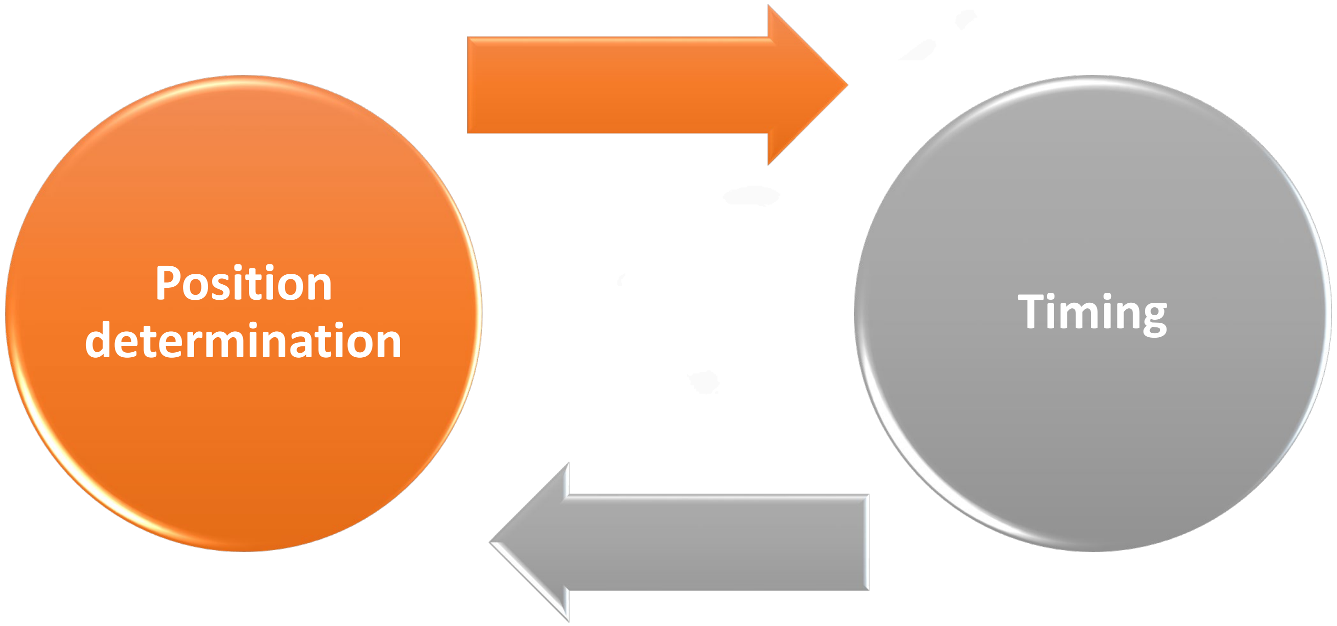
- Observation techniques
- GNSS positioning techniques
- Concept of GNSS
- Current and Developing status of GNSSs
- GNSS Applications

Global Navigation Satellite System (GNSS)

- GNSS stands for global navigation satellite system. A Global Navigation Satellite System (GNSS) consists of a constellation of satellites orbiting the Earth in very specific trajectories. For global coverage, it is estimated that a constellation requires 18 to 30 satellites.
- Navigation satellites provide orbit information and accurate timing (and other services) to radio receivers specifically designed to receive those satellite signals and decode the signal message contents. With the contents of the messages from at least four “visible” satellites, the position on or near most of the Earth’s surface can be calculated using a mathematical process known as trilateration.

Primary uses of GNSS

There are two primary uses for GNSS



Primary uses of GNSS

Position determination

Position of an object is its latitude (distance from the equator), longitude (distance from the Greenwich meridian in the UK) and elevation above (or below) mean sea level. This is known as "absolute position". The absolute position of a GNSS receiver can be determined when the signal from four (or more) GNSS satellites can be clearly received at the same time.

Primary uses of GNSS

Timing

- The signals, sent over radio waves, from GNSS satellites have extremely accurate time stamps (and other information) encoded into them. This is enabled by the use of incredibly accurate (and very high cost) atomic clocks on board each satellite.
- Once the GNSS receiver has determined its position, the GNSS receiver synchronizes its internal (much less accurate) clock with the satellite clocks. By maintaining that synchronization, the GNSS receiver clock is then considered to have a very accurate timing source.

Basics of GNSS Trilateration

- The signal from a single satellite provides a general location of a point around the perimeter of a circular area that covers approximately 35% of the Earth's surface.

- When a second satellite can be seen, the coverage of that satellite will overlap part of the first satellite coverage. This means that the GNSS receiver is at one of the two points of intersection of the perimeters of the coverage areas.

Basics of GNSS Trilateration

Basics of GNSS Trilateration

- When a third satellite can be seen, the point of intersection of all three coverage area perimeters will be the location of the GNSS receiver. That is, an accurate two-dimensional (longitude – X and latitude – Y coordinates) position of the GNSS receiver on the Earth's surface.

- When a fourth satellite can be seen, elevation or altitude can be determined with trigonometry using the X-Y coordinate

GNSS Components

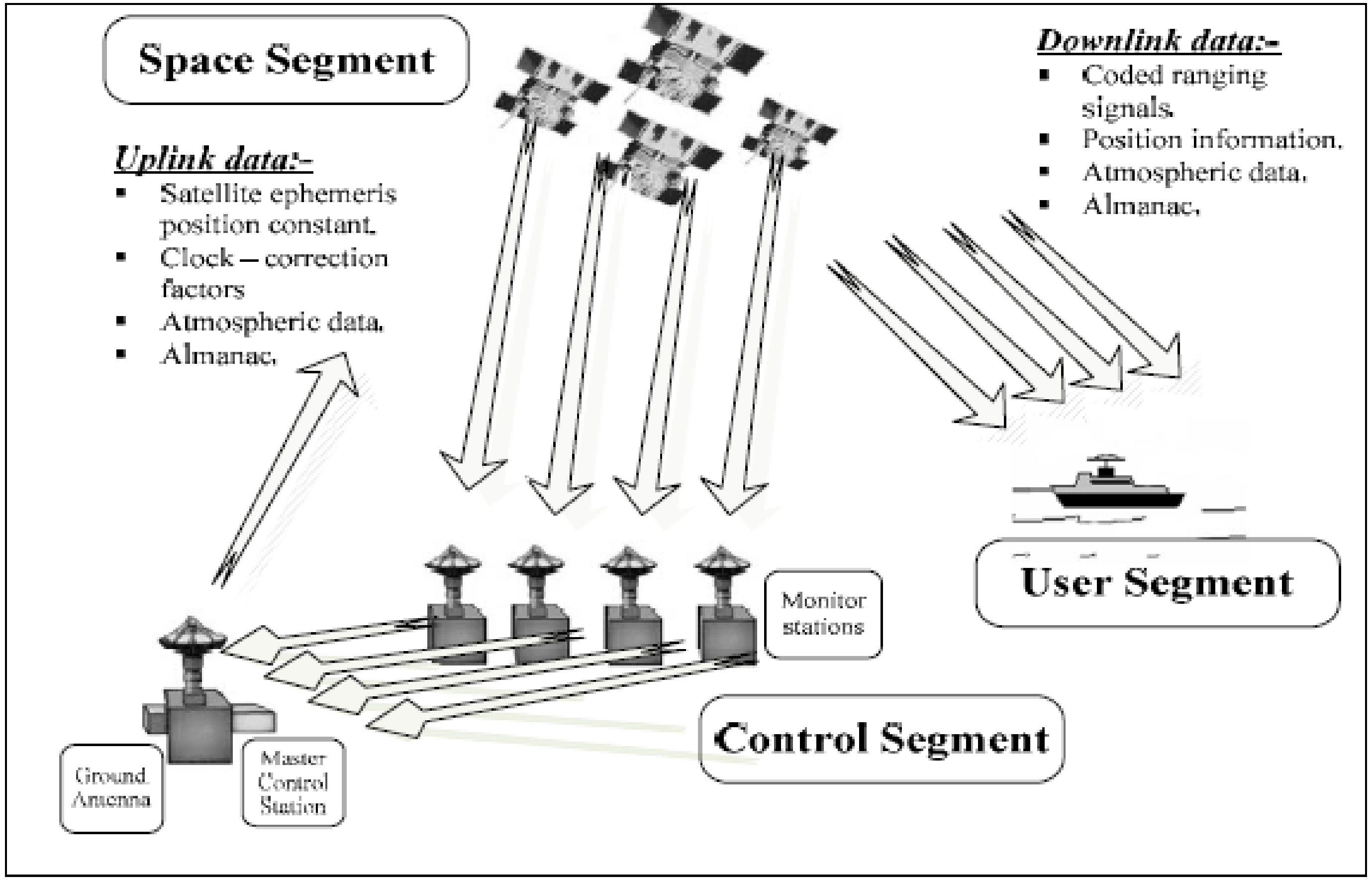
The GNSS consists of three main satellite technologies: GPS, Glonass, and Galileo. Each of the consists mainly of three segments: (a) space segment, (b) control segment, and (c) user segment. These segments are almost similar in the three satellite technologies, which are all together make up the GNSS.

space segment

control segment

user segment

Global Positioning System



GPS segments

Global Positioning System

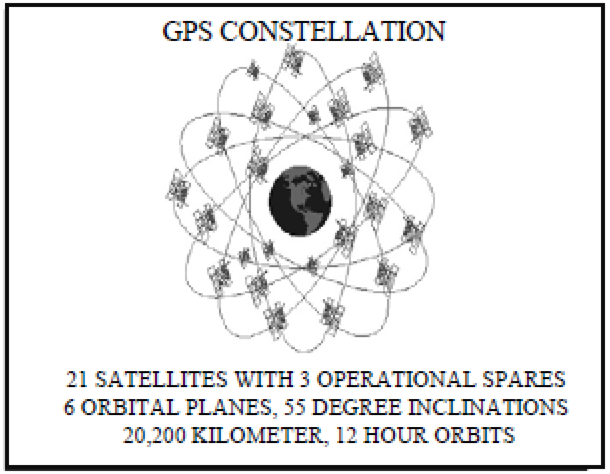
The United States Department of Defence (DoD) has developed the Navstar GPS, which is an all-weather, space-based navigation system to meet the needs of the USA military forces and accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis

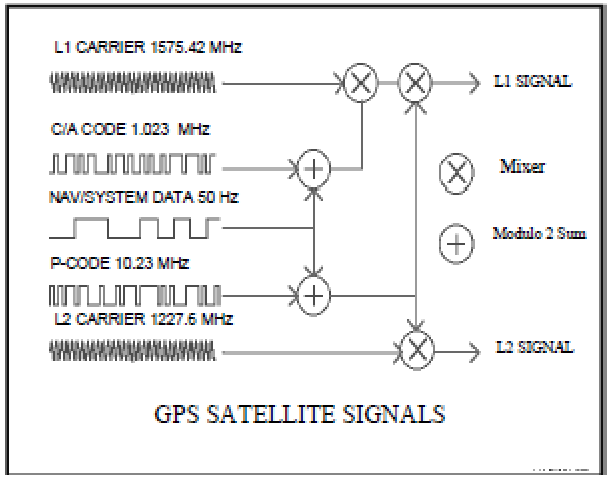
Global Positioning System

GPS comprises three main components

Space segment

- **The Space Segment of the system consists of the GPS satellites.**
- **These space vehicles (SVs) send radio signals from space as shown in the figure below.**





GPS Constellation and GPS Satellite Signals

Global Positioning System

Control segment

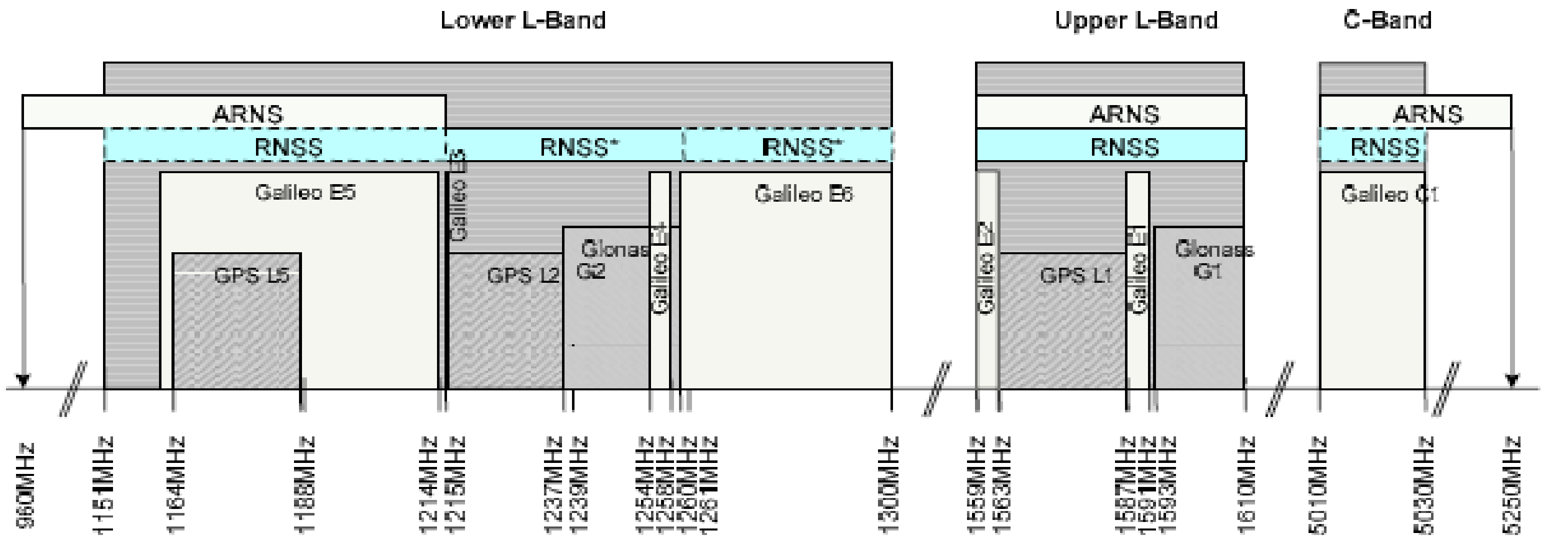
- The Control Segment consists of a system of tracking stations located around the world.
- The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in the State of Colorado, USA.

User segment

- The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert space vehicle (SV) signals into position, velocity, and time estimates.

GNSS SIGNALS

Each satellite system has specific signal characteristics, but each system attempts to be compatible with the others in order to prevent the interferences and attenuation between the signals. It is important to consider that the processing of all signals should be performed using the same receiver, thus a complex receiver design is supposed to be designed and built.



Reference Systems

Coordinate system

The definition of reference coordinate system is crucial for the description of satellite motion.

In satellite geodesy, two reference systems are required

(a) Space-fixed, inertial reference system for the description of satellite motion, and

(b) Earth-fixed, terrestrial reference system for the positions of the observation stations

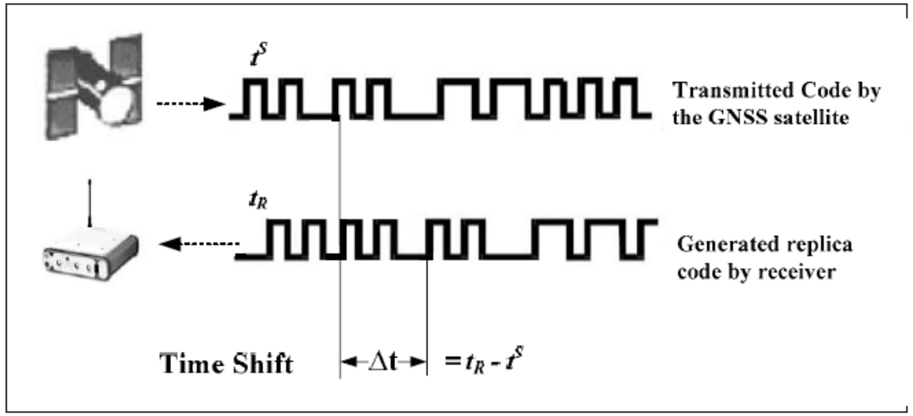
Reference Systems

Coordinate system

The position of the receiver is calculated with respect to the instant position of the satellite. By considering the range vector relation between satellite and receiver, the coordinate of the satellite and receiver should be expressed in the same coordinate system.

Observation Techniques

The basic concept of GNSS is to measure the signal traveling time between an artificial satellite and a receiver. By multiplying this time by the light velocity (c), we get the range between the satellite and the receiver.



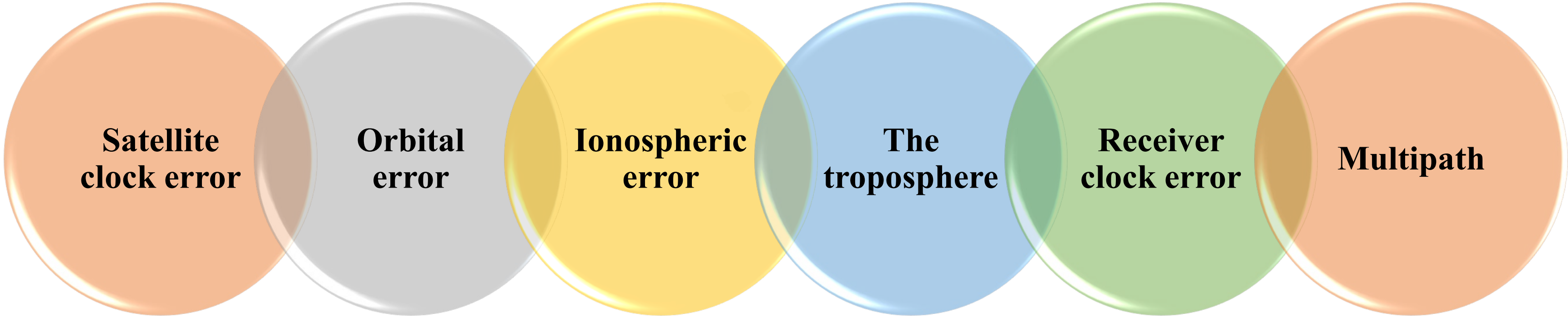
$$Range = c.(t_R - t^S) = \Delta t_R^S \cdot c$$

Observation Techniques

The time or phase measurement performed by the receiver is based on the comparison between the received signal at the antenna of the receiver and the generated reference signal by the receiver. The two signals are affected by the clock's errors. Therefore, the range measured is not true and it is called pseudorange. Since the signal travels through the atmospheric layers, further noise should be modelled in order to compute the precise range.

GNSS observable errors

The code and phase measurements are affected by noise and errors due to the propagation of signals through atmospheric layers and due to the noise measurements.



GNSS Positioning Techniques

There are two main types of positioning techniques in GNSS measurements are single point positioning and differential positioning.

Single Point Positioning

The basic concept of point position depends on the trilateration between the receiver and satellite. Range measurements from 4 satellites are needed to determine the four unknown X, Y, Z, and receiver clock offsets (Δδ).

GNSS Positioning Techniques

There are two main types of positioning techniques in GNSS measurements are single point positioning and differential positioning.

Single Point Positioning

The basic concept of point position depends on the trilateration between the receiver and satellite. Range measurements from 4 satellites are needed to determine the four unknown X, Y, Z, and receiver clock offsets ($\Delta\delta$).

GNSS Positioning Techniques

The analytical solution for receiver A and 4 satellites could be written as below.

$$R_A^1(t) = \sqrt{\left(X^1(t) - X_A\right)^2 + \left(Y^1(t) - Y_A\right)^2 + \left(Z^1(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^2(t) = \sqrt{\left(X^2(t) - X_A\right)^2 + \left(Y^2(t) - Y_A\right)^2 + \left(Z^2(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^2(t) = \sqrt{\left(X^3(t) - X_A\right)^2 + \left(Y^3(t) - Y_A\right)^2 + \left(Z^3(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^4(t) = \sqrt{\left(X^4(t) - X_A\right)^4 + \left(Y^4(t) - Y_A\right)^2 + \left(Z^4(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

GNSS Positioning Techniques

Observable difference

By considering all the systematic and random errors on the observation, we can write the math model for observable differences in code and phase measurements, respectively, as below.

$$R_A^1(t_0) = \rho_A^1(t_0) + \Delta\rho_A^1(t_0) + c\delta^1(t_0) - c\delta_A(t_0) + I_A + T_A + \varepsilon$$

$$\lambda\phi_A^1(t_0) = \rho_A^1(t_0) + \Delta\rho_A^1(t_0) + \lambda N_A^1 + c\delta^1(t_0) - c\delta_A(t_0) - I_A + T_A + \varepsilon$$

Where Δp_R^S is the orbital error, I is the ionosphere error, T is the troposphere error and ε is the other types of noise and errors such as the ones due to multipath.

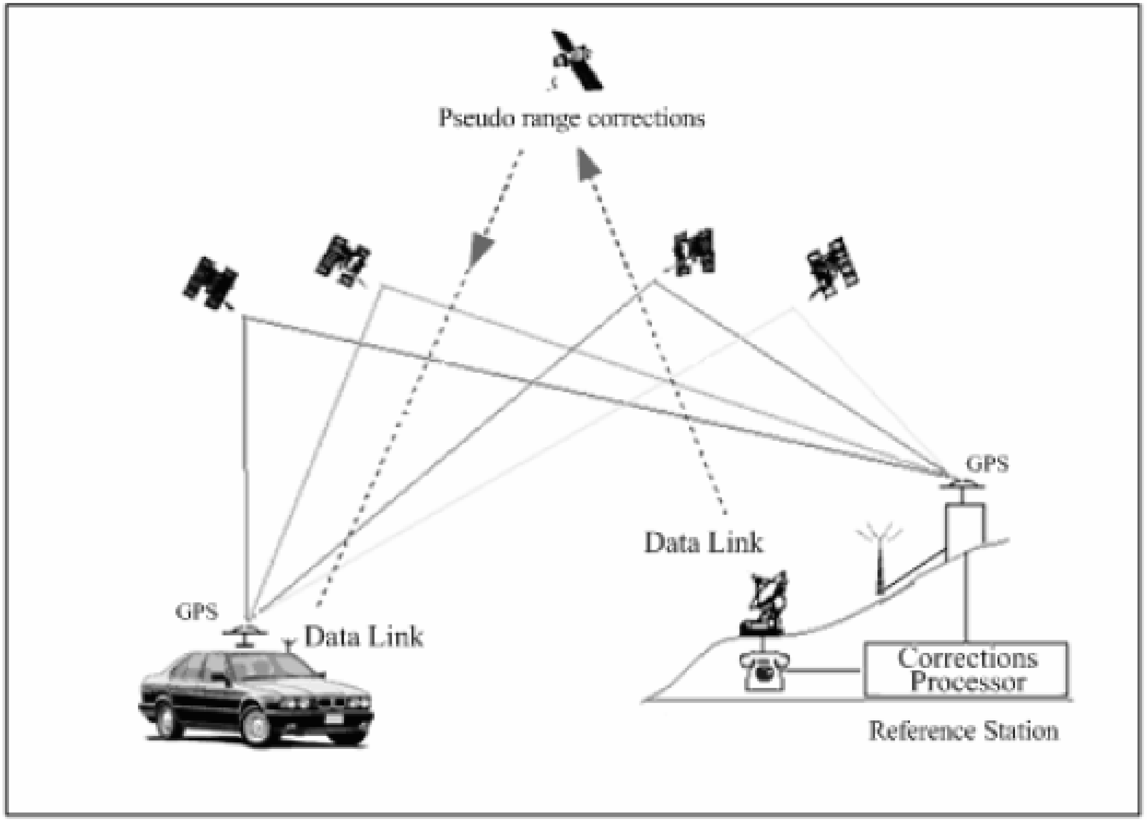
GNSS Positioning Techniques

Differential position

- There is an increase interest in differential positioning due to the numerous advantages of wireless communications and networks. Most of the errors that affect GNSS are common between the receivers, which observe the same set of satellites. Thus, by making differential measurements between two or more receivers, most of these errors could be cancelled.
- The basic concept of differential position is the calculation of position correction or range correction at the reference receiver and then sending this correction to the other receiver via a radio link. This way most of the errors are cancelled.

GNSS Positioning Techniques

Differential position



GNSS Positioning Techniques

Wide Area Differential GNSS (WADGNSS)

- **WADGNSS is a scheme that would allow the user to perform differential positioning and obtain reliable position with high accuracy in real time over a sizeable region. WADGNSS consists of a master control station and number of local or Global monitor stations and communication link.**

- **The monitor stations gather the data from the GNSS satellite, and then send them to the master control station. The master control estimates the ionosphere parameter, troposphere parameters, satellite ephemeredes, and clock errors. All these corrections are transmitted to the user via the Internet, wireless communications, or satellite communications.**

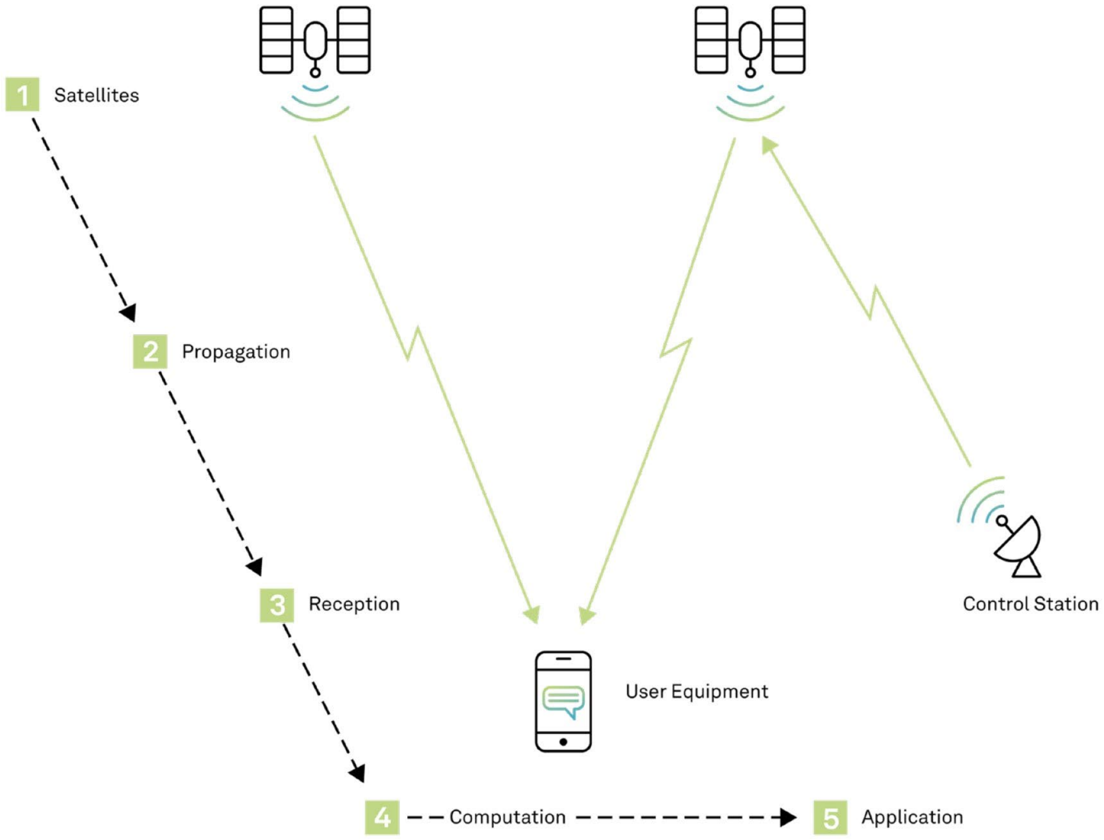
GNSS Positioning Techniques

Wide Area Augmentation System (WAAS)

- Wide Area Augmentation System (WAAS) is a new augmentation to the United States Department of Defense's (DoD) Global Positioning System (GPS) that is designed to enhance the integrity and accuracy of the basic GPS capability

- The WAAS uses geostationary satellites to receive data measured from many ground stations, and it sends information to GPS users for position correction. Since WAAS satellites are of the geostationary type, the Doppler frequency caused by their motion is very small. Thus, the signal transmitted by the WAAS can be used to calibrate the sampling frequency in a GPS receiver. The WAAS signal frequency is at 1575.42 MHz. The WAAS services will be available on both L1 and L5.

GNSS concepts



STEP 1 — SATELLITES

GNSS satellites orbit the Earth. The satellites know their orbit ephemerides (the parameters that define their orbit) and the time very accurately. Ground-based control stations adjust the satellites' ephemerides and time, when necessary.

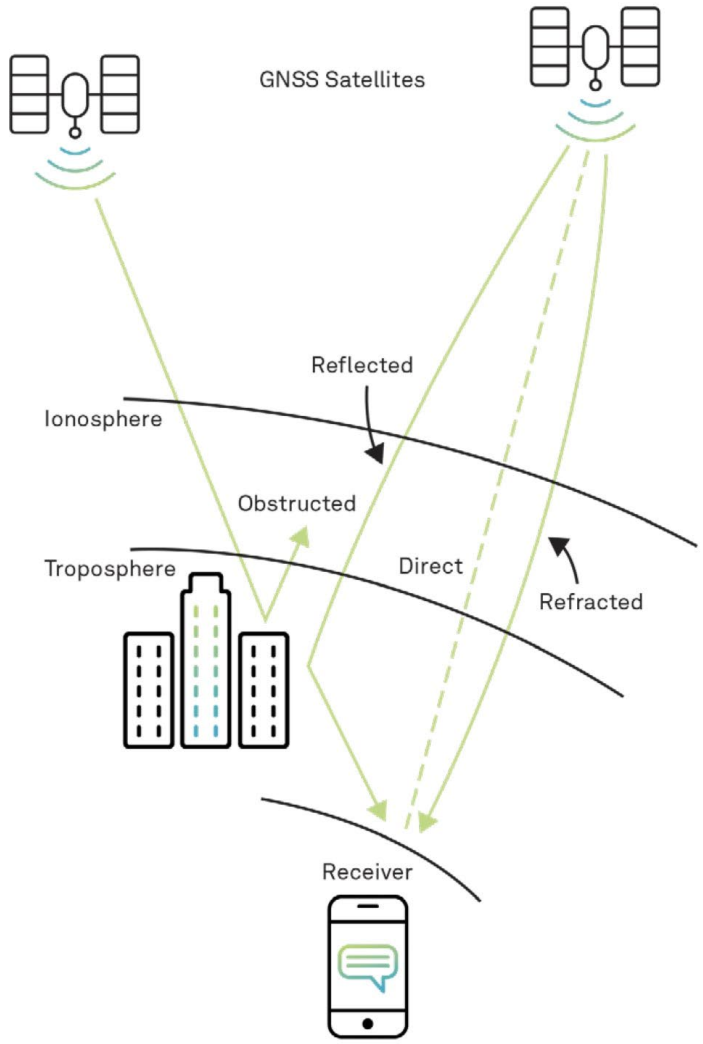
GPS satellite

Satellite orbits

- **GNSS satellites orbit well above the Earth's atmosphere. GPS and GLONASS satellites orbit at altitudes close to 20,000 km (12,500 miles). BeiDou and Galileo satellites orbit higher, around 21,500 to 36,000 km (13,400 to 22,400 miles) for BeiDou and 23,000 km (14,300 miles) for Galileo. GNSS orbits are more or less circular, highly stable, and predictable.**

STEP 2 — PROPAGATION:

- GNSS satellites regularly broadcast their ephemerides and time, as well as their status. GNSS radio signals pass through layers of the atmosphere to the user equipment.

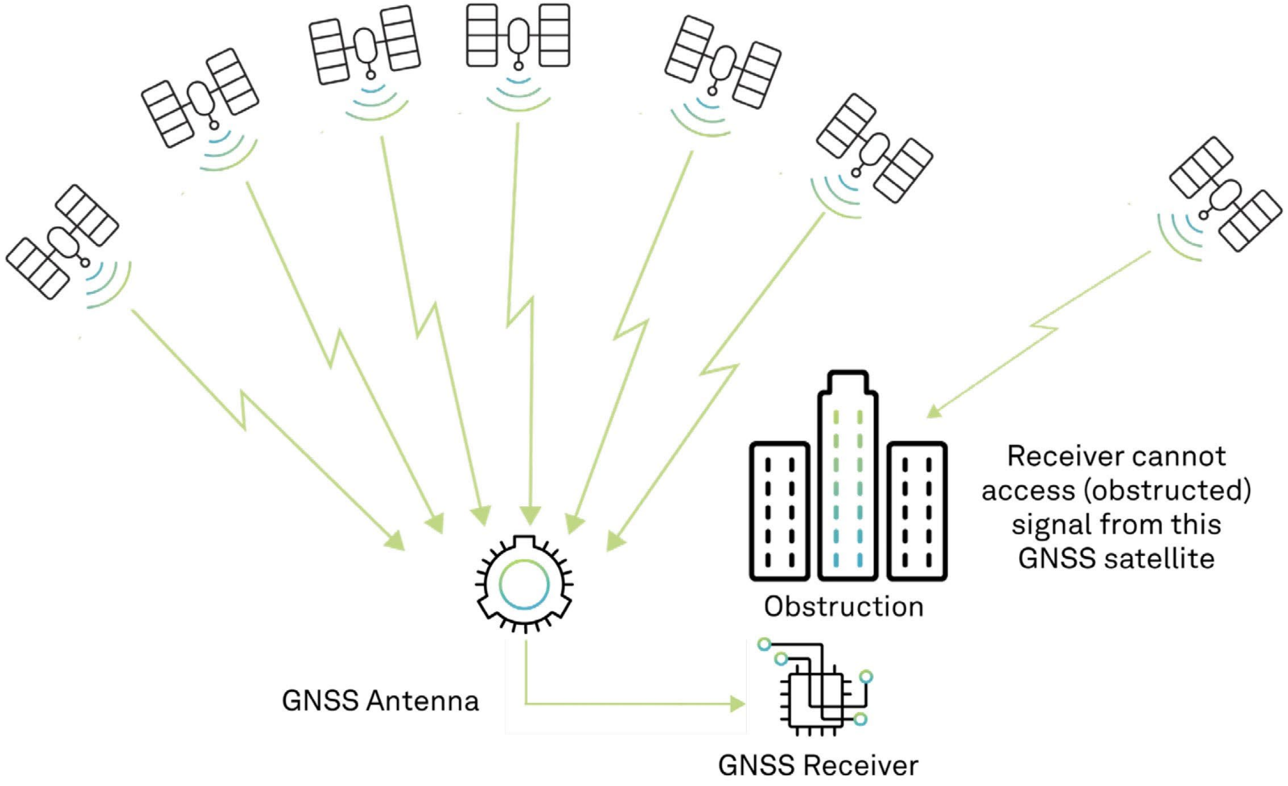


STEP 3 — RECEPTION:

- GNSS user equipment receives the signals from multiple GNSS satellites and, for each satellite, recovers the information that was transmitted and determines the time of propagation (the time it takes the signals to travel from the satellite to the receiver).

- To determine a position and time, GNSS receivers need to track at least four satellites from one of the GNSS constellations. This means there needs to be a line of sight between the receiver's antenna and the four satellites.

STEP 3 — RECEPTION



GNSS reception

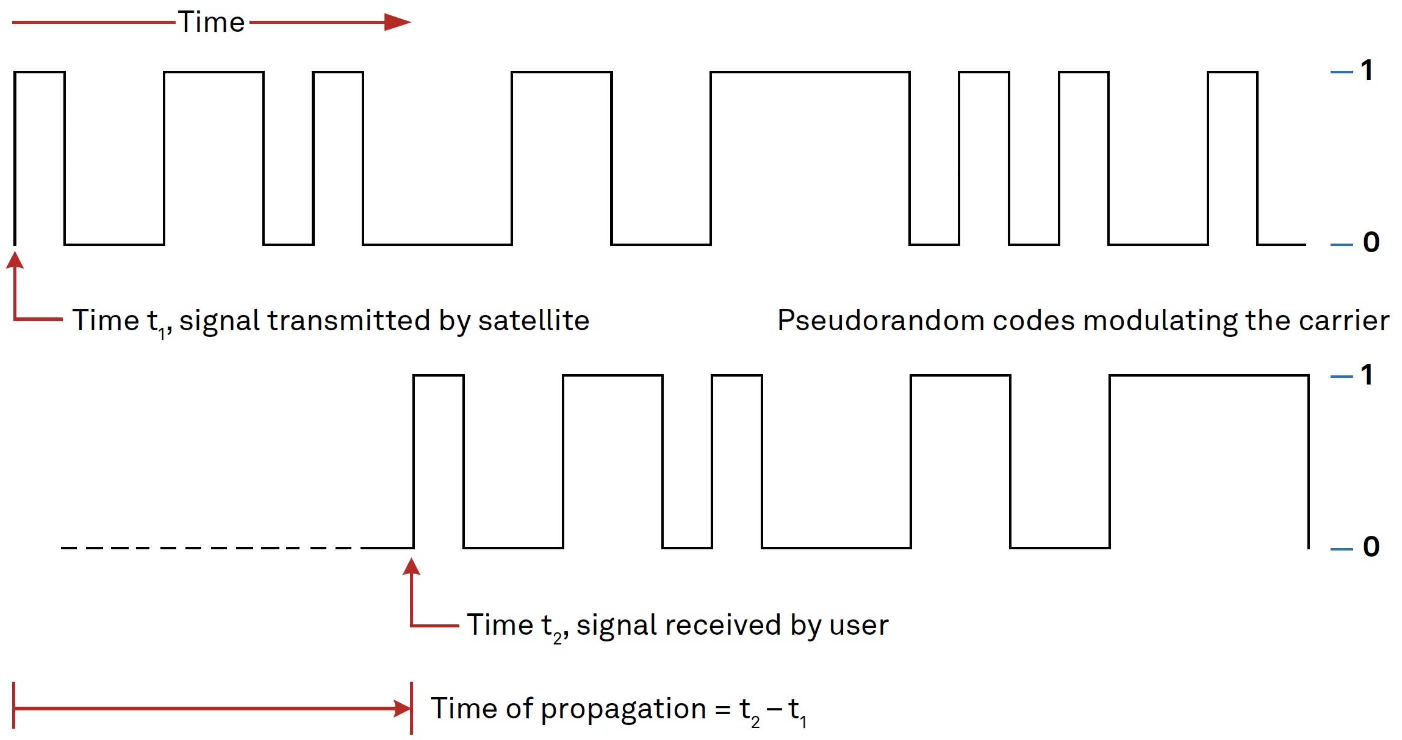


Figure illustrates the transmission of a pseudorandom code, a series of zeroes and ones. Since the receiver knows the pseudorandom code for each satellite, it can determine the time it received the code from a particular satellite. By comparing the time the signal was received with the transmission time stored in the satellite message, the receiver can determine the time of propagation.

STEP 4 — COMPUTATION

GNSS equipment uses the recovered information to compute time and position.

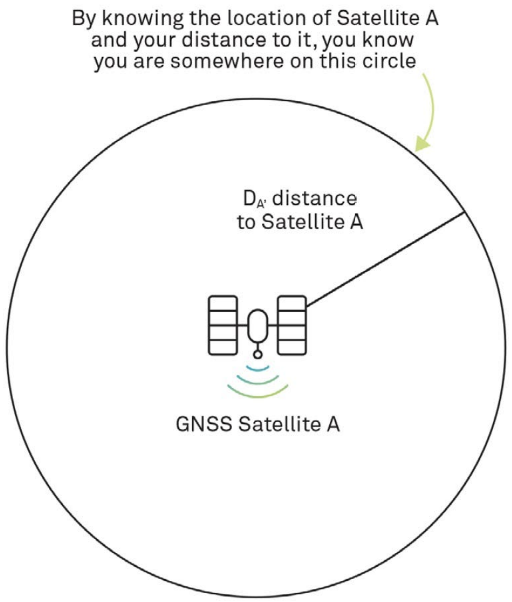
- If we knew the exact position of three satellites and the exact range to each of them, we would geometrically be able to determine our location. We have suggested that we need ranges to four satellites to determine position.

- **For each satellite being tracked, the receiver calculates how long the satellite signal took to reach it, as follows:**

Propagation Time = Time Signal Reached Receiver – Time Signal Left Satellite

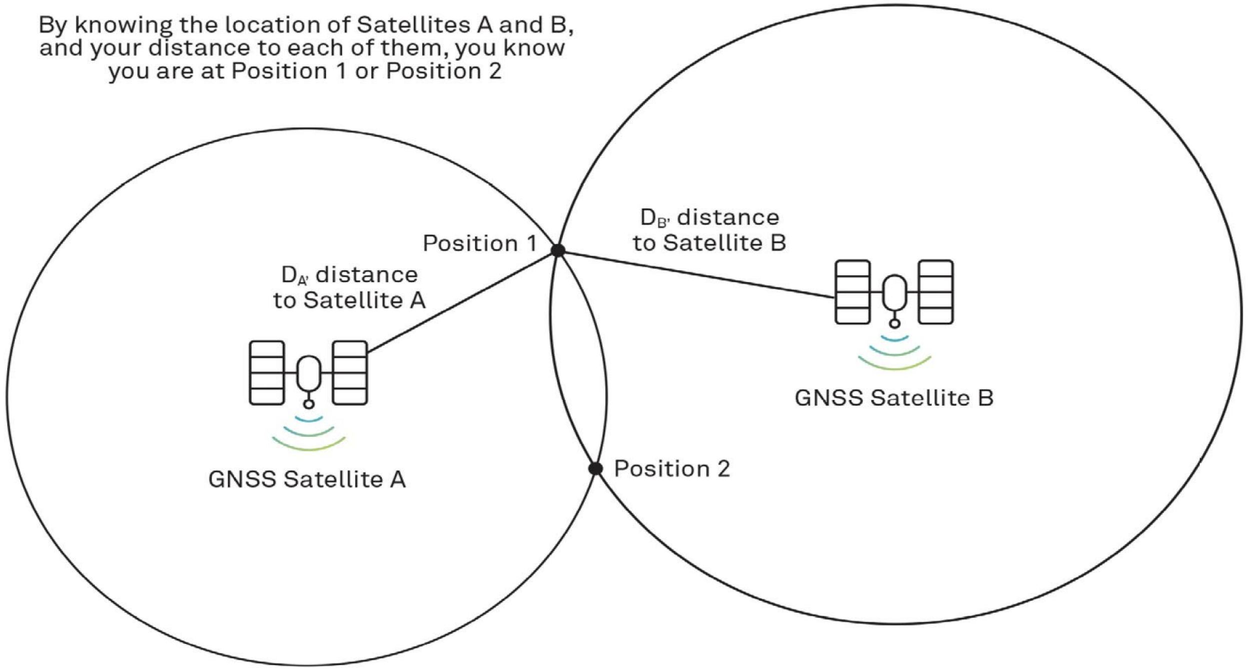
- Multiplying this propagation time by the speed of light gives the distance to the satellite.

- By determining the amount of time it took for the signal from Satellite A to arrive at the receiver and multiplying this time by the speed of light.
- Satellite A communicated its location (determined from the satellite orbit ephemerides and time) to the receiver, so the receiver knows it is somewhere on a circle with a radius equal to the range and centered at the location of Satellite A, as illustrated in Figure.



Ranging to first satellite

- **The receiver also determines its range to a second satellite, Satellite B. Now the receiver knows it is at the intersection of two circles, at either Position 1 or 2, as shown in Figure.**



Ranging to second satellite

STEP 5 — APPLICATION

- GNSS user equipment provides the computed position and time to the end-user application for use in navigation, surveying, mapping and more.

- Once the errors have been accounted for in the GNSS equation, the receiver can determine its position and time and pass this information on to the end-user application.
- The GNSS technology market is a ubiquitous, multi-billion-dollar industry.
- Applications range from simple hand-held meter-level (yard-level) navigation aids to robust, centimeter-level (inch-level) positioning solutions for survey, military and autonomous applications.

Concept of GNSS Positioning

GNSS Measurements

- **Pseudo-range:**

Measures the difference between the receiver clock at signal reception and the satellite clock at signal transmission, scaled by the speed of light. It reflects the satellite-receiver distance with precision in the range, considering clock asynchrony and other delays.

- **Doppler:**

The Doppler effect-induced change in received frequency indicates range-rate or line-of-sight velocity. This provides valuable information about the velocity component along the line of sight.

Concept of GNSS Positioning

GNSS Measurements

- ### Carrier Phase:

Measures the instantaneous beat phase and accumulated zero-crossings after mixing with a reference signal. Changes in carrier phase over time reflect (pseudo)range changes with exceptional precision, approximately two orders higher than the pseudo-range. Interrupted tracking may lead to cycle slips in measurements.

Current and Developing GNSSs

GNSSs and regional navigation satellite systems (RNSSs) commonly consist of three components:

- The space segment comprises a constellation of satellites orbiting above the Earth's surface that transmit ranging signals on at least two frequencies in the microwave part of the radio spectrum.

- The control segment is responsible for maintaining the health of the system by monitoring the broadcast signals and computing and uploading to the satellites required navigation data. It consists of a group of globally (or locally)-dispersed monitoring stations, ground antennas for communicating with the satellites, and a master control station with a backup facility at a different location.

Currently, there are six GNSSs/RNSSs in operation. The four GNSSs are: GPS (US), GLONASS (Russia), BeiDou (China), and Galileo (EU); and the two RNSSs: QZSS (Japan) and IRNSS/NavIC (India). For an overview summary, see Table.

System	GPS	GLONASS	BeiDou	Galileo	QZSS	NavIC
Owner	USA	Russia	China	European union	Japan	India
Coverage	Global	Global	Global	Global	Regional	Regional
Orbit	MEO	MEO	MEO,GSO,GEO	MEO	GSO,GEO	GSO,GEO
Nominal no.of satellites	24	24	35(27MEO,3GSO, 5GEO)	24	4(3GSO,1GEO) 7 in the future	8(5GSO,3GEO)
Precision	5m(no DGPS or WAAS)	4.5-7.4m	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)

BEIDOU NAVIGATION SATELLITE SYSTEM (BDS)

- BeiDou, or BDS, is a regional GNSS owned and operated by the People's Republic of China. China is currently expanding the system to provide global coverage with 35 satellites by 2020. BDS was previously called Compass.

GALILEO

- Galileo is a global GNSS owned and operated by the European Union. The EU declared the start of Galileo Initial Services in 2016 and plans to complete the system of 24+ satellites by 2020.

GLONASS

It is a global GNSS owned and operated by the Russian Federation. The fully operational system consists of 24+ satellites.

Indian Regional Navigation Satellite System (IRNSS) / Navigation Indian Constellation (NAVIC)

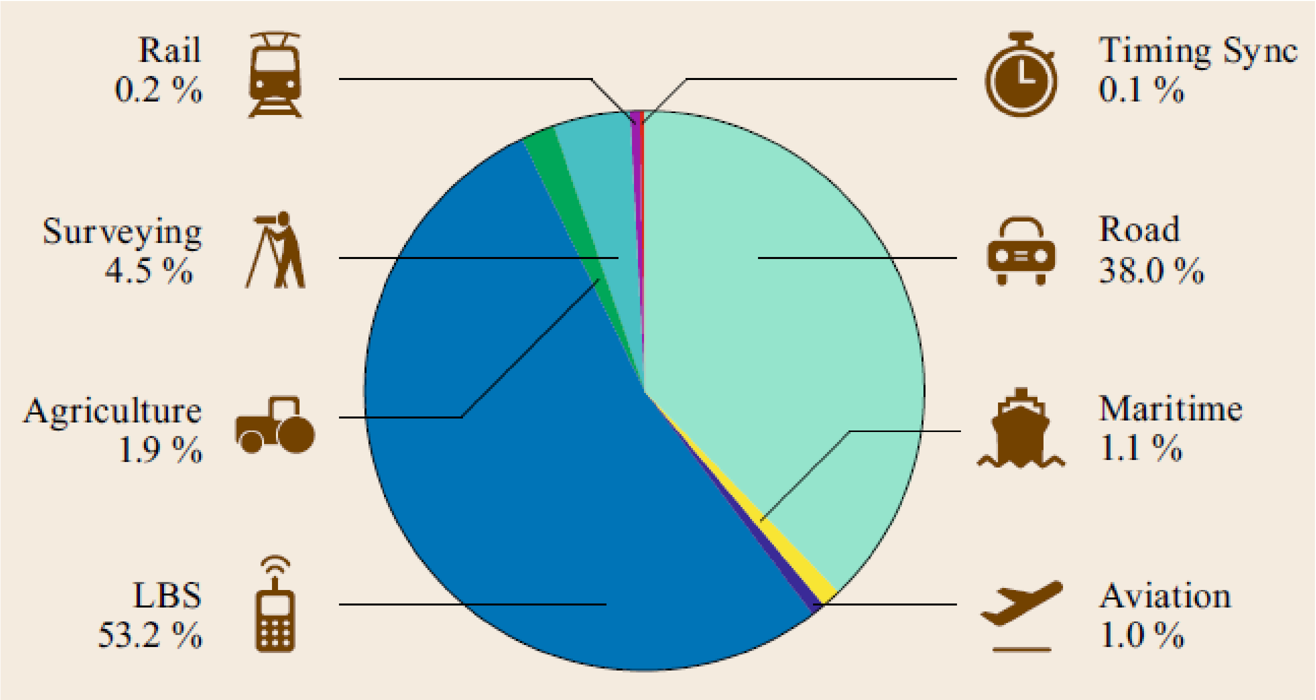
IRNSS is a regional GNSS owned and operated by the Government of India. IRNSS is an autonomous system designed to cover the Indian region and 1500 km around the Indian mainland. The system consists of 7 satellites and should be declared operational in 2018. In 2016, India renamed IRNSS as the Navigation Indian Constellation (NavIC, meaning "sailor" or "navigator").

QUASI-ZENITH SATELLITE SYSTEM (QZSS)

- QZSS is a regional GNSS owned by the Government of Japan and operated by QZS System Service Inc. (QSS). QZSS complements GPS to improve coverage in East Asia and Oceania. Japan plans to have an operational constellation of 4 satellites by 2018 and expand it to 7 satellites for autonomous capability by 2023.

GNSS for Science and Society at Large

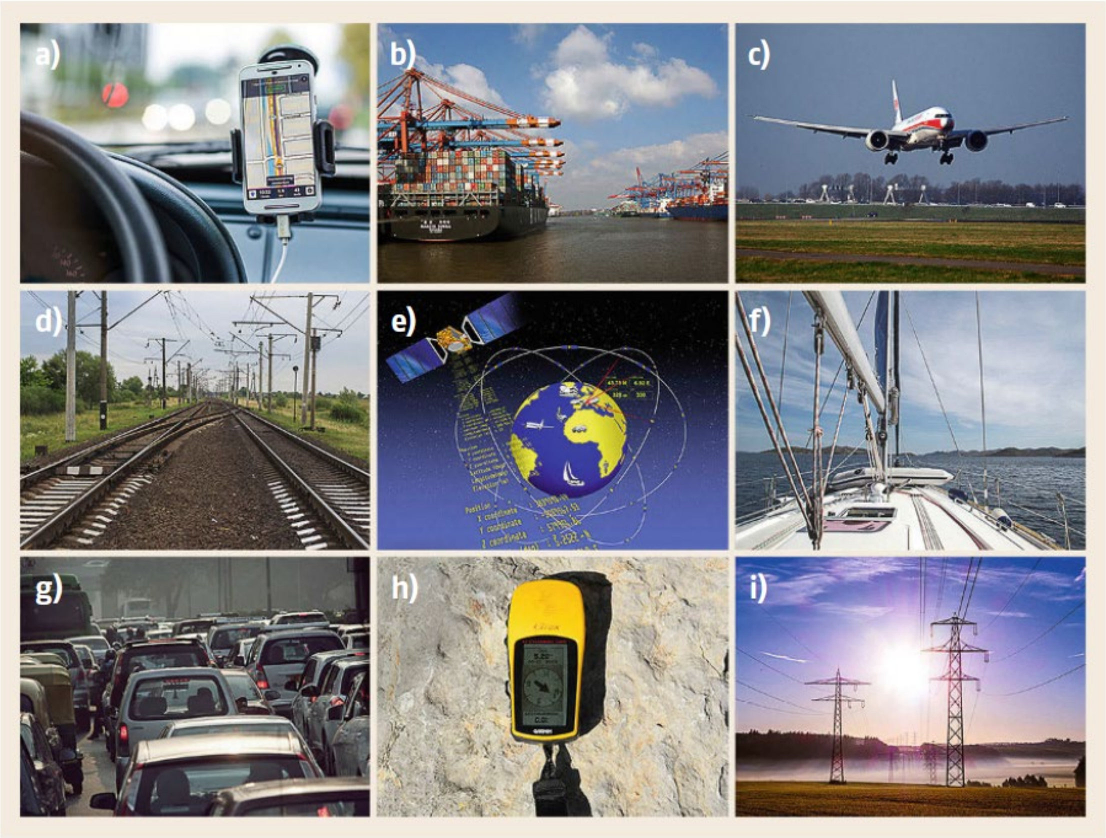
GNSS is used for many types of applications, covering the mass market, professional and safety-critical applications as well as a whole range of scientific applications.



Distribution of cumulative global revenue from GNSS chipset sales projected for 2013–2023 period

GNSS for Science and Society at Large

GNSS is used for many types of applications, covering the mass market, professional and safety-critical applications as well as a whole range of scientific applications.



Examples of everyday GNSS applications.

REFERENCES

- https://novatel.com/an-introduction-to-gnss/basic-concepts/application
- FontShen, N.; Chen, L.; Liu, J.; Wang, L.; Tao, T.; Wu, D.; Chen, R. A Review of Global Navigation Satellite System (GNSS)-Based Dynamic Monitoring Technologies for Structural Health Monitoring. Remote Sens. 2019, 11, 1001. https://doi.org/10.3390/rs11091001
- Hofmann-Wellenhof, B.; Lichtenegger, H.;Wasle, E. GNSS–Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and More; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2007; pp. 161–191.

REFERENCES

- Shrestha, R. and Awasthi, E.B., A Scientific Report on “How Nepal can be benefitted from different GNSS systems available worldwide”.
- Teunissen, P.J. and Montenbruck, O. eds., 2017. Springer handbook of global navigation satellite systems (Vol. 10, pp. 978-3). Cham, Switzerland: Springer International Publishing.
- https://www.advancednavigation.com/tech-articles/global-navigation-satellite-system-gnss-and-satellite-navigation-explained/
- https://www.princeton.edu/~alaink/Orf467F07/GNSS.pdf

CONCLUSION

- Provided an introduction to Global Navigation Satellite Systems (GNSS).
- Explored the primary use of GNSS technology.
- Discussed the fundamental principle of trilateration used in GNSS for determining positions.
- Explored the key components that constitute a GNSS system.
- Explored the signals transmitted by Global Navigation Satellite Systems (GNSS) for positioning and navigation.
- Discussed the reference systems utilized in GNSS technology for accurate positioning measurements.

CONCLUSION

- Explored the methodologies and techniques employed to observe and analyze GNSS signals for navigation and positioning purposes.
- Provided an overview of the fundamental concept of GNSS technology, which enables precise positioning and navigation using satellite signals.
- Introduced the concept of determining precise positions using GNSS technology.
- Discussed existing and emerging GNSS systems.
- Explored the diverse practical applications of GNSS technology across various industries.


THANK YOU