IX. Satellite Navigation Systems

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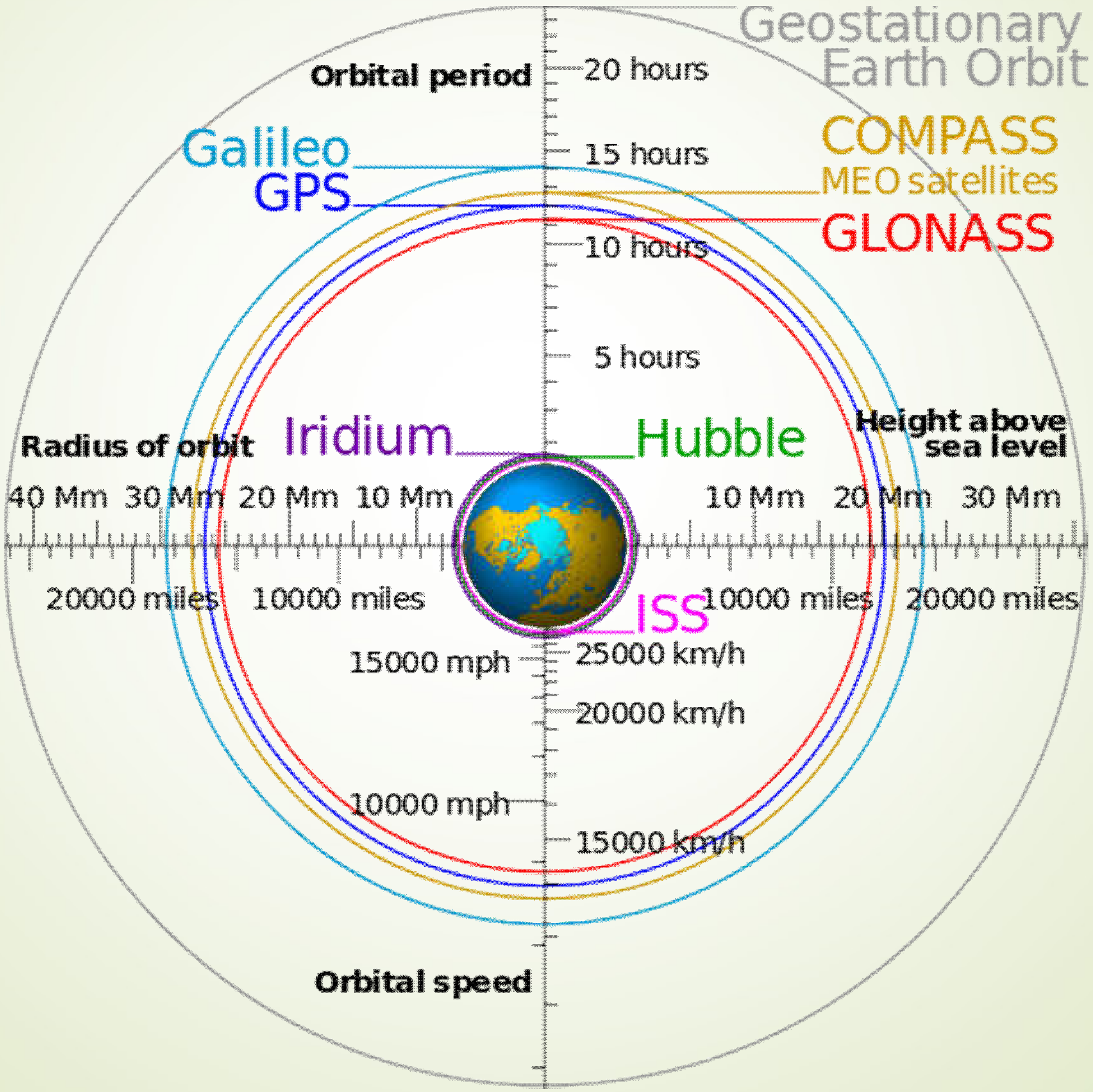
Satellite navigation systems



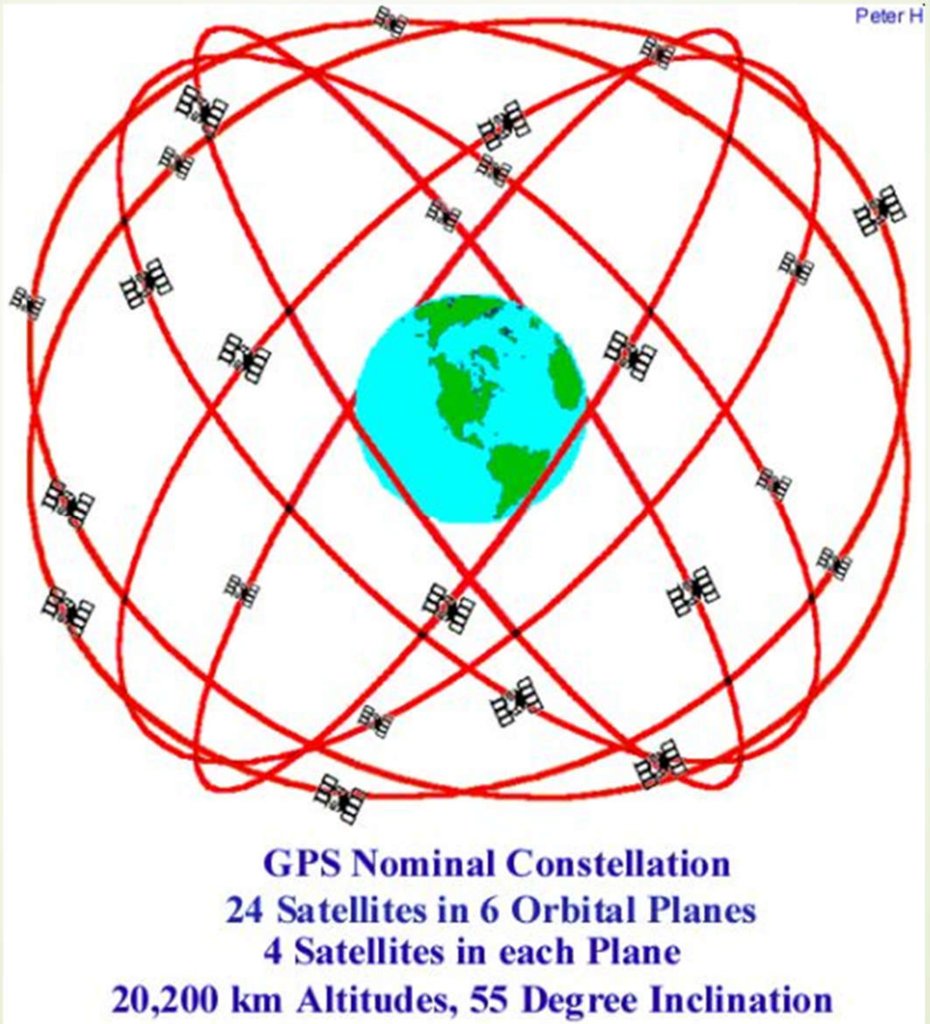
1. GPS (Global Positioning System)

- Global Positioning System (GPS) is the name of a satellite radio navigation system for determining the position, speed and time with an accuracy of 1 nanosecond at any point on the globe and orbit around the Earth in real time.
- The US military calls the system "NAVSTAR GPS" - "Navigation Signal Timing and Ranging Global Positioning System".

1. GPS

- The system consists of a minimum of 24 satellites located in 6 orbits at an altitude of about 20,000 kilometers and a ground control center with observation stations located at various points on Earth.
- The principle of operation is based on measuring the distance from the place whose coordinates we are looking for to a group of satellites whose coordinates are precisely determined and known. The distance is calculated based on the propagation time of the radio signal from the satellite to the user.

1. GPS


Peter H
GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

1. GPS

- The Global Positioning System is designed and controlled by the US Department of Defense. It can be used for free by anyone.
- The global positioning system is divided into three segments: space, control and user.

1. GPS

1.1. Space segment

- The space segment consists of a minimum of 24 operational GPS satellites located in 6 geocentric orbital planes, containing 4 satellites each with an orbital inclination relative to the equator at an angle of 55°.
- The satellites are positioned so that at any moment and at any point on Earth, at least 4 of them are visible.
- Each satellite carries 4 atomic clocks on board and completes one complete revolution of its orbit in 11 hours and 58 minutes (half a sidereal day).

1. GPS

1.1. Space segment

- GPS satellites broadcast a signal on two carrier frequencies: L1 (1575.42 MHz) and L2 (1227.60 MHz), which are multiples of the standard frequency (10.23 MHz) of the onboard atomic clocks and are C/A modulated - ("coarse acquisition") and P- ("precise") codes.
- The purpose of using two frequencies is to eliminate the error caused by the delay of the signal as it passes through the ionosphere.
- Of these frequencies and codes, only L1 and C/A-code are available to civilian users, the rest are reserved for military purposes.

1. GPS

1.2. Control segment

- The control segment consists of 5 observing ground stations located around the world, ground antennas and one main control center in Colorado Springs, which control the operation of each satellite and are responsible for measuring the parameters of the satellites' orbits and the deviation of the clocks, predicting the parameters of the orbits, the synchronization of atomic clocks, the submission of data for retransmission from the satellites.

1. GPS

1.3. User segment

- The consumer segment consists of GPS receivers used for both military and civilian applications. The GPS receiver decodes a time signal provided by the atomic clocks of several satellites and calculates its position using trilateration (a method similar to but different from triangulation).
- GPS receivers are mainly used for navigation in road, marine and aviation transport, in agriculture, as well as for accurate timing and synchronization in some areas of industry.

1. GPS

1.4. Operating principle

- The principle of operation of GPS is based on the so-called trilateration method, by which the position of a point is determined as the point of intersection of several circles (or spheres) with a known radius and known coordinates of the center.
- In the context of GPS, each satellite can be defined as the center of a sphere with coordinates - satellite position and radius - the distance from the satellite to the receiver. To determine the position of a receiver, it must have the distance to the satellites and their exact coordinates.

1. GPS

1.4.1. Determining the distance to the receiver

- The distance from each satellite to the user is calculated as the time it takes the signal to travel the distance from the satellite to the receiver multiplied by the speed of light (the speed at which electromagnetic waves travel).
- The time for which the signal reaches the user is the difference between the time of receiving and sending the signal.
- For several reasons, the distance calculated in the receiver contains errors and is not the real value. This is called the pseudo-distance and is used to determine the position.

1. GPS

1.4.1. Determining the distance to the receiver

- To calculate the time interval for the propagation of the radio signal from the satellite to the user, the receiver and the satellite generate the same time-synchronized code.
- Because GPS satellites send a known, repeating 1023-bit, pseudo-random code, receivers are capable of generating that same code. In this case, the measurement of signal travel time is reduced to measuring the delay of the received code relative to the one generated at the receiver.

1. GPS

1.4.1. Determining the distance to the receiver

- The accuracy of the measurement depends mainly on the stability of the on-board frequency standard.
- Receivers and satellites need extremely accurate clocks to be able to generate synchronized signals.
- Therefore, a very stable frequency generator implemented with an atomic clock is used as the main element of the satellite navigation equipment.

1. GPS

1.4.1. Determining the distance to the receiver

- Because of their high cost, however, cheaper but less accurate quartz clocks are used in receivers.
- If the receiver and satellite clocks were perfectly synchronized, then all spheres centered - satellite positions and radius - the distances to them would intersect at one point, which is also the sought position.
- In imprecise clocks, these spheres do not intersect at the same point, due to the error in determining their radii.

1. GPS

1.4.2. Determining the position of the satellites

- In order to be able to determine the coordinates of the objects, in addition to the distance to the satellites, it is necessary to know their exact current location.
- Information about this is contained in the navigation message broadcast by them, which transmits the orbital parameters necessary to determine the exact location, the parameters for the accuracy of the clocks, for their corrections and an estimate of the accuracy of the position.
- The coordinates of each satellite are calculated in the receiver based on these parameters.

1. GPS

1.4.3. Determining the position of the receiver

- The position of each receiver is defined as a point in the three-dimensional space of the earth and consists of three coordinates - latitude, longitude and altitude.
- To determine its exact position, each receiver must solve an equation with three unknowns, called the navigation equation.
- To these unknowns is added the clock error in the receiver to avoid the problem of insufficient precision.

1. GPS

1.4.3. Determining the position of the receiver

- Thus, the GPS receiver needs a clock that is not very precise, but stable enough, and the positioning algorithm compensates for the clock error and allows the distances to be corrected to calculate the exact position.
- When using this method to determine the position of a receiver in three-dimensional space, with four unknowns, at least four GPS satellites are required.
- Using more than four contributes to greater position accuracy.

1. GPS

1.5. Application

- GPS is a system designed by the US military and is primarily used for military purposes. It is used anywhere the US military is deployed to determine the position of combat units, control combat missiles, and more.
- In addition to military purposes, the system is also widely used by civilian users, as it makes it possible to determine the position and time with very high accuracy. An important feature of the system is that it can be used free of charge, which makes it useful for the consumer market.

1. GPS

1.5. Application

- Some of the main application areas of GPS are:
  - Navigation in transport - used for navigation in road, sea and air transport, route optimization. There are currently a large number of relatively inexpensive receivers and applications that are used for car navigation.
  - GPS tracking and control of vehicles, people and animals
  - In science and research - in geography, cartography, geology, geodesy, archeology, etc.

1. GPS

1.5. Application

- In agriculture - for land planning, navigation of agricultural machines, etc.
- In communications - for synchronizing communication systems
- For tourism and sports - orienteering, mountain rescue services
- To determine the exact time, etc.

2. GLONASS (Global Navigation Satellite System)

- The Russian GLONASS system uses the same positioning principle as the American system. In October 1982, the first GLONASS satellite was launched into orbit around the Earth, but the system was not put into operation until 1993.
- Satellites of the Russian system continuously broadcast signals with standard accuracy (ST) - in the 1.6 GHz range and with high accuracy (BT) - in the 1.2 GHz range.
- Reception of signals with ST is available to every user of the system and provides determination of horizontal and vertical coordinates, the velocity vector, as well as time.

2. GLONASS

- For example, to accurately indicate coordinates and time, information from no less than four satellites from the GLONASS system must be accepted and processed.
- The entire GLONASS system consists of twenty-four satellites that are in circular orbits at an altitude of about 19,100 km. The rotation period of each of them is 11 hours and 15 minutes. All satellites are located in three orbital planes - in each 8 devices. The configuration of their deployment provides global coverage of the navigation field, not only on the surface of the earth, but also in outer space.

2. GLONASS

- The GLONASS system includes a Control Center and a network of measurement and control stations located throughout the territory of Russia.
- Each user receiving a navigation signal from GLOGASS satellites must have a navigation receiver and processing equipment that allows to calculate own coordinates, time and speed.
- To implement the GLONASS system and to ensure its financing, the equipment from this navigation system is installed on all new vehicles: airplanes, ships, land transport, etc.

GLONASS

3. Galileo

- Galileo is a European satellite navigation system project, designed as an alternative to the US-controlled GPS and Russia's GLONASS, respectively. The project started in 2003 and is a joint venture of the European Union and the European Space Agency.
- In addition to the countries of the European Union, China, Israel, Morocco, Saudi Arabia, South Korea also participate in the project. In addition, negotiations are underway with representatives of Argentina, Australia, Brazil, Chile, India, Malaysia, Russia and Ukraine.
- Since 2016, the Galileo system has been providing services to users.

3. Galileo

- Galileo uses satellites located in three orbital planes. The orbits are at average distances from the earth, according to the classification of the International Telecommunication Union, of about 20,000 km.
- The distance from the surface of the Earth to each satellite (the orbits are circular) is 23222 km or a little more.
- The orbital planes are highly inclined (56°) relative to the plane of the Earth's equator and to each other.
- This allows for very accurate location determination when navigating in high latitudes.

3. Galileo

- The accuracy with which the corresponding coordinates are determined in the entire system, regardless of location, is about 1 m.
- It is planned that the satellites will be 30 in total (at the moment there are 26, of which 22 are working). Operational satellites should be 27. The remaining three should be spare (one for each orbit), but active and ready without delay to replace one of the main ones.

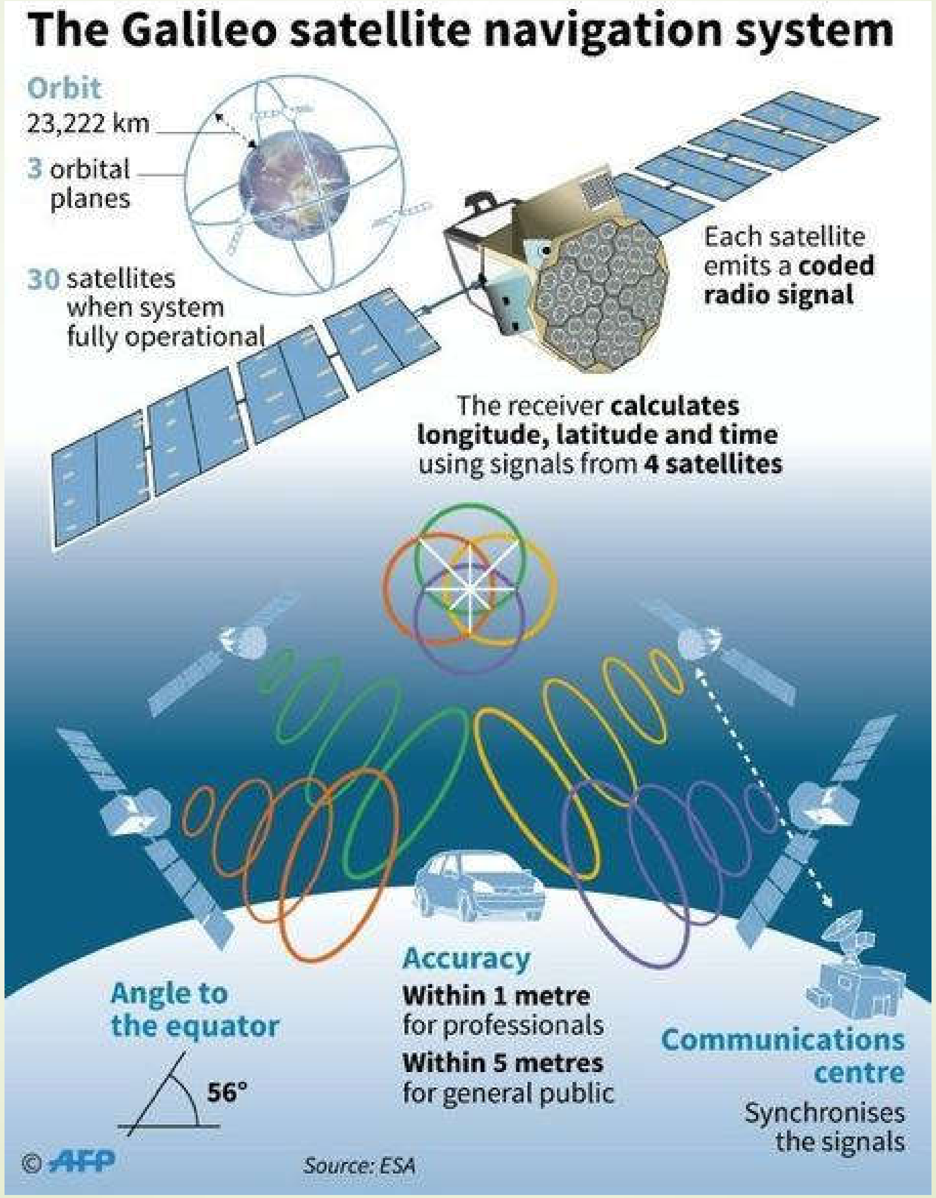
3. Galileo

- The system has two ground control centers - Galileo Control Centers (GCC). They receive the information from twenty ground base stations, called sensor stations - Galileo Sensor Stations (GSS).
- The main tasks of control centers are twofold:
  - The first is determining the integrity and validity of the satellite information received from the sensor stations.
  - The second task is extremely important for the operation of the system - synchronizing the signals for the exact time of all satellites and the clocks of the earth stations.

3. Galileo

- The frequency bands in which Galileo operates are 1.2 GHz and 1.5 GHz.
- The exact frequency bands for Open Service (OS) are 1164-1214 MHz and 1563-1591 MHz.
- Frequencies in the band 1260-1300 MHz are also used for commercial paid services (Commercial Service - CS).
- The receivers can be compatible with those of the GPS system. There is an agreement with the US for joint use and terminals that work simultaneously in both systems, i.e. more than 50 satellites will be usable.

Galileo



The Galileo satellite navigation system
Orbit
23,222 km
3 orbital planes
30 satellites when system fully operational
Each satellite emits a coded radio signal
The receiver calculates longitude, latitude and time using signals from 4 satellites
Angle to the equator
56°
Accuracy
Within 1 metre for professionals
Within 5 metres for general public
Communications centre
Synchronises the signals
© AFP
Source: ESA

4. BeiDou

- The Chinese BeiDou satellite navigation system costs 10 billion USD and is made up of 35 satellites that provide global navigation coverage.
- In 2000 the BeiDou-1 satellites providecoverage of China, and the second-generation BeiDou-2 covers the Asia-Pacific region in 2012.
- The launch of satellites from BeiDou-3, which provides global coverage, began in 2015 and end in 2020.

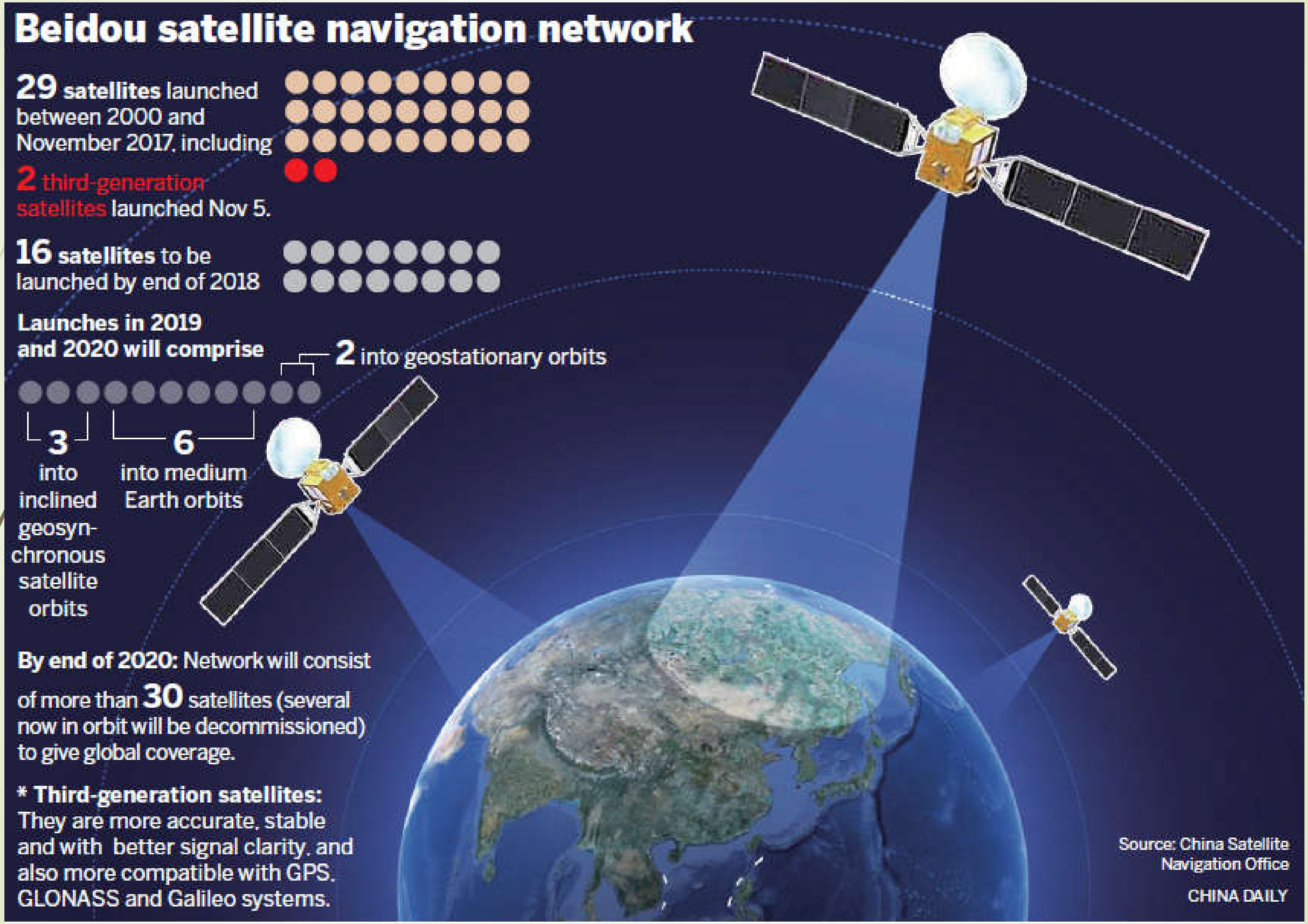
4. BeiDou

- Of the 35 satellites - 5 are in geostationary orbit, 3 are in inclined geostationary orbit, and the remaining 27 are in mean Earth orbit (in three planes with a nominal altitude of 21,528 km and a nominal period of 12 hours and 53 minutes, inclined at 55° relative to the equator).
- The ground segment uses a classical centralized scheme involving a network of unidirectional measurement stations that continuously monitor the navigation signals of all satellites and transmit all observations to all satellites for processing by the system control center that generates the precise orbit and clock data for each satellite.

4. BeiDou

- Like GPS and other systems, BeiDou is used for military purposes, but it can also be used by businesses and end users.
- At least 70% of smartphones in and from China now support BeiDou. In China, the system is mandatory for buses and trucks.

BeiDou



Beidou satellite navigation network
29 satellites launched between 2000 and November 2017, including
2 third-generation satellites launched Nov 5.
16 satellites to be launched by end of 2018
Launches in 2019 and 2020 will comprise
2 into geostationary orbits
3 into inclined geosyn-chronous satellite orbits
6 into medium Earth orbits
By end of 2020: Network will consist of more than 30 satellites (several now in orbit will be decommissioned) to give global coverage.
* Third-generation satellites: They are more accurate, stable and with better signal clarity, and also more compatible with GPS, GLONASS and Galileo systems.
Source: China Satellite Navigation Office
CHINA DAILY

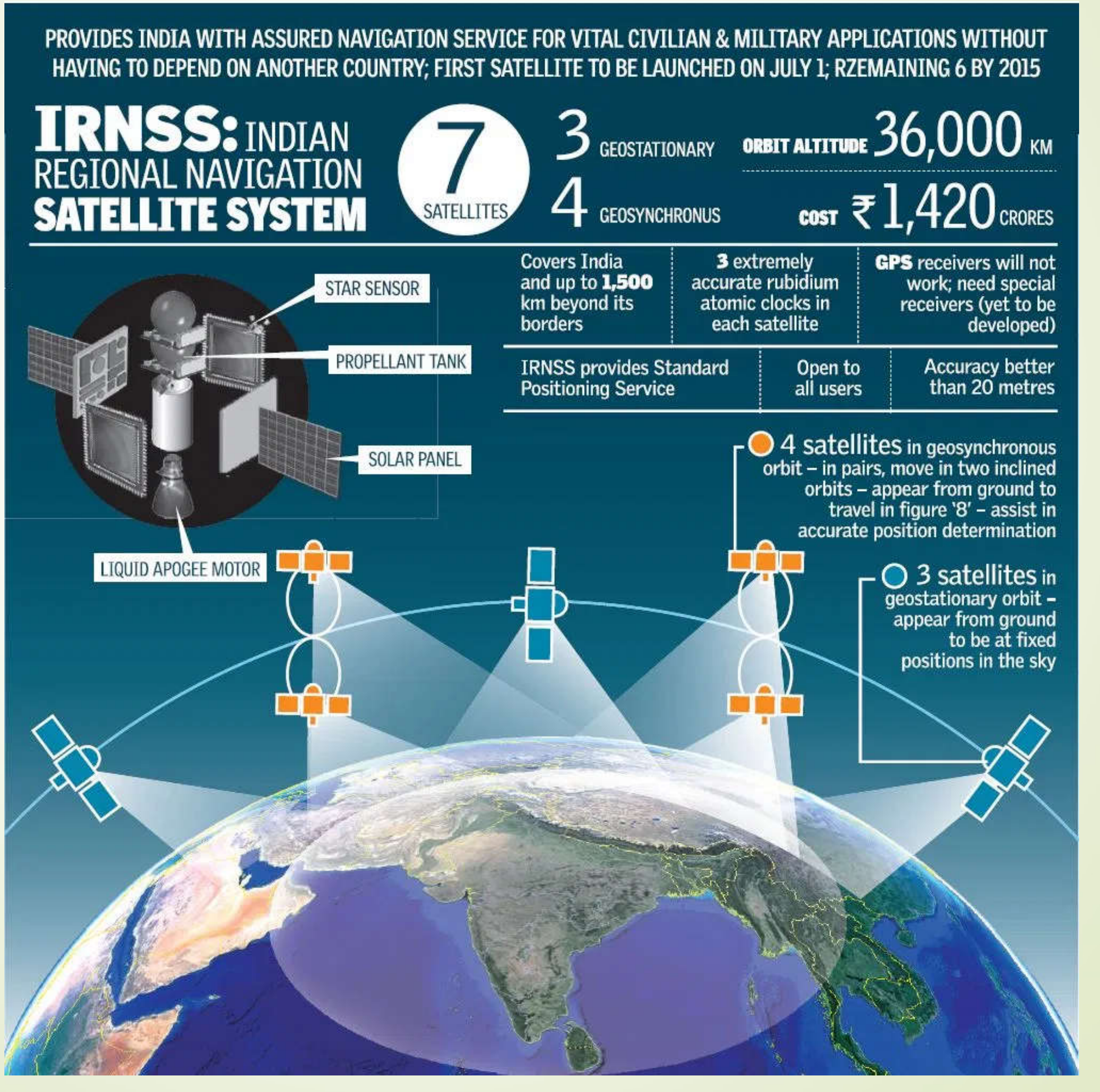
5. IRNSS (Indian Regional Navigation Satellite System)

- In 2006, India also took the decision to create own navigation system IRNSS. Seven satellites are planned to be launched into geosynchronous orbits. The work on the development of the Indian system is carried out by the state-owned company ISRO. All system hardware is developed only by Indian companies.
- In 2013, the first of the planned seven satellites that form the basis of India's IRNSS navigation system was launched into orbit. Three of the seven satellites are located in geostationary orbit, and the remaining four - in geosynchronous orbit.

5. IRNSS

- The IRNSS is designed to cover the Indian region and 1,500 km around mainland India.
- Apart from military navigation, IRNSS also provides civil services related to transport management, monitoring and positioning of various means of transport. Signals intended for military purposes are encrypted.
- The cost of the project amounts to approximately 237 million USD.

IRNSS

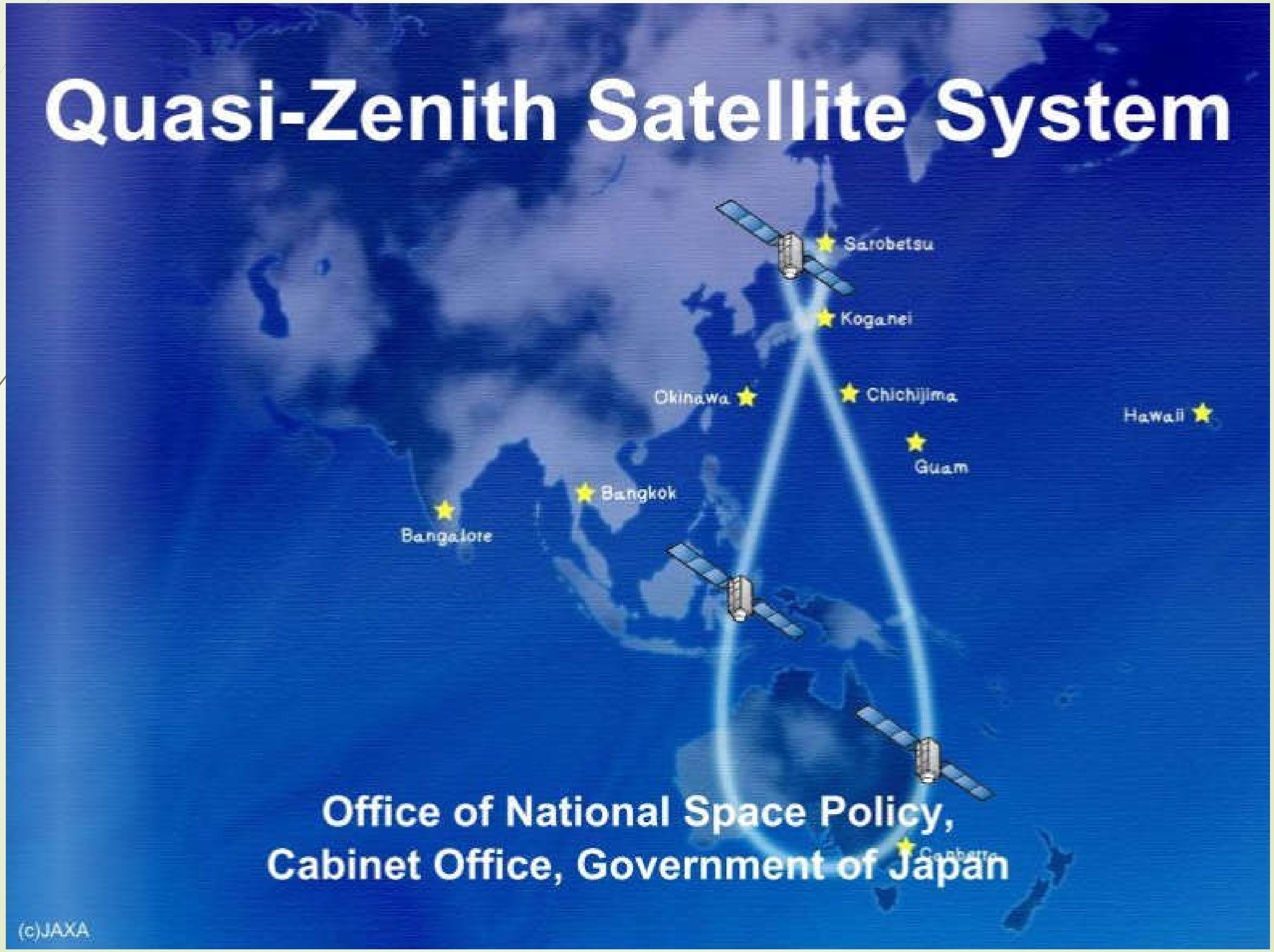


PROVIDES INDIA WITH ASSURED NAVIGATION SERVICE FOR VITAL CIVILIAN & MILITARY APPLICATIONS WITHOUT HAVING TO DEPEND ON ANOTHER COUNTRY; FIRST SATELLITE TO BE LAUNCHED ON JULY 1; RZEMAINING 6 BY 2015
IRNSS: INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM
7 SATELLITES
3 GEOSTATIONARY
4 GEOSYNCHRONUS
ORBIT ALTITUDE 36,000 KM
COST ₹1,420 CRORES
Covers India and up to 1,500 km beyond its borders
3 extremely accurate rubidium atomic clocks in each satellite
GPS receivers will not work; need special receivers (yet to be developed)
IRNSS provides Standard Positioning Service
Open to all users
Accuracy better than 20 metres
STAR SENSOR
PROPELLANT TANK
SOLAR PANEL
LIQUID APOGEE MOTOR
4 satellites in geosynchronous orbit – in pairs, move in two inclined orbits – appear from ground to travel in figure '8' – assist in accurate position determination
3 satellites in geostationary orbit – appear from ground to be at fixed positions in the sky

6. Quasi-Zenith Satellite System (QZSS)

- QZSS is a regional satellite navigation project owned by the Government of Japan and operated by QZS System Service Inc. (QSS).
- QZSS complements the GPS system to improve coverage in East Asia and Oceania.
- Japan currently has 4 operational satellites, with plans to increase to 7 by 2024.
- The QZSS ground segment includes the main control station in Tsukuba, two tracking and communication control stations in Okinawa, and eight monitoring stations whose locations have been selected to provide maximum monitoring.

Quasi-Zenith Satellite System



7. Assisted GPS (A-GPS)

- Assisted Global Positioning System (A-GPS) helps mobile devices locate satellites.
- In cases where A-GPS is used, the device receives useful satellite information from an auxiliary data server over the cellular network.
- If the device is not receiving auxiliary data, then it tries to find available satellites.

7. Assisted GPS (A-GPS)

- Through the auxiliary data, the device can pick up a group of satellites worth paying attention to, these are the satellites that are located on the same side of the planet as the device.
- A-GPS greatly increases the speed of location calculation.
- A-GPS is available in all countries and does not depend on specific provider services. A-GPS uses 3G and 2G cellular network connection, and GPRS and EGPRS connection for packet data transfer.
- Wireless LAN (WLAN) access points are not supported when using A-GPS.