CHARACTERIZATION OF GLOBAL SATELLITE NAVIGATION SYSTEM, (GNSS), AND THE MOST IMPORTANT INDIVIDUALL SATELLITE SYSTEMS (GPS, GLONASS GALILEO)

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In this article I will characterize global navigational system, GNSS, and the most important satellite systems used for world-wide navigation. Satellite navigation systems, using satellites on orbital planes, are invaluable in user positioning. As of this day there are only fully operational only two GNSS systems: American GPS and Russian GLONASS. EU and ESA are developing and constructing European satellite navigational system Galileo, which is about to enter full capability in 2020, and should be most accurate of them all. In this article I describe these systems, their creation, segments and use.

K e y w o r d s. GNSS, satellite, GPS, GLONASS, Galileo,

1 INTRODUCTION

Global Navigation Satellite System (GNSS) is the standard generic term for satellite navigation systems that provide autonomous geospatial positioning information with global coverage. This allows small electronic receivers to determine their location (longitude, latitude, and altitude) to within a few meters using time signals transmitted along a line-of-sight by radio from satellites. Receivers calculate the precise time as well as position, which can be used as a reference for scientific experiments. GNSS system includes several satellite constellations, aircraft receivers and system integrity monitoring, if necessary, supported with systems, which improve its accuracy to increase the required navigation performance. Global coverage for each system is generally achieved by a satellite constellation of 20–30 medium Earth orbit (MEO) satellites spread between several orbital planes. The actual systems vary, but use orbit inclinations of >50° and orbital periods of roughly twelve hours (at an altitude of about 20,000 kilometers).

2 GNSS CLASSIFICATION

As of October 2011, only the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS are fully globally operational GNSSs. China is in the process of expanding its regional Beidou navigation system into the global Compass navigation system by 2020. The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be fully operational by 2020 at the earliest. Several countries including France, Japan and India are in the process of developing regional navigation systems. [2]

Satellites use 5 basic orbital planes:

- low earth orbits – LEO
- Geosynchronous earth orbits – GEO
- medium earth orbits – MEO
- Sun synchronous orbits – SSO
- high earth orbits – HEO

They differ from one another by shape, height above the Earth's surface and inclination fig. 1 [5]

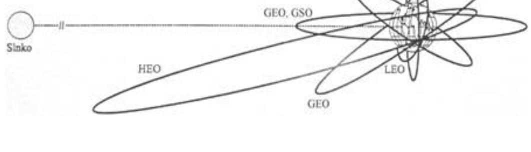

Fig. 1 Satellite orbital planes [5]

Satellite navigation systems that provide enhanced accuracy and integrity monitoring usable for civil navigation are classified as follows:

GNSS-1 is the first generation system and is the combination of existing satellite navigation systems (GPS and GLONASS), with Satellite-based augmentation system (SBAS) or Ground-based augmentation system (GBAS). In the United States, the satellite based component is the Wide Area Augmentation System (WAAS), in Europe it is the European Geostationary Navigation Overlay Service (EGNOS), and in Japan it is the Multi-Functional Satellite Augmentation System (MSAS). Ground based augmentation is provided by systems like the Local Area Augmentation System (LAAS).

GNSS-2 is the second generation of systems that independently provides a full civilian satellite navigation system, exemplified by the European Galileo positioning system. These systems will provide the accuracy and integrity monitoring necessary for civil navigation. This system consists of L1 and L2 frequencies for civil use and L5 for system integrity. Development is also in progress to provide GPS with civil use L2 and L5 frequencies (wavelengths of the frequencies are: 1176.45 MHz (L5), 1227.60 MHz (L2C), 1381.05 MHz (L3), and 1575.42 MHz (L1)), making it a GNSS-2 system. Core of these satellite navigation systems is currently made of these systems: GPS (U.S.), GLONASS (Russia), Compass (China), and Galileo (EU). As augmentation systems are used: Global Satellite Based Augmentation Systems (SBAS) such as Omnistar and StarFire, regional SBAS including WAAS (U.S.), EGNOS (EU), MSAS (Japan) and GAGAN (India). Regional Satellite Navigation Systems such as China's Beidou, India's yet-to-be-operational IRNSS, and Japan's proposed QZSS and many more... [1]

3 CHARACTERIZATION OF GPS, GLONASS AND GALILEO SYSTEMS

These chosen GNSS systems are the most wide-spread, and most important, not only in aviation, and that is why i selected them for detailed description in this article. Mostly i devote my attention to the European system Galileo, which will be crucial for navigation in Europe.

GPS

GPS - Global Positioning System (named by USArmy as **NAVSTAR GPS - NAV**igation **S**ignal for **T**iming, **A**nd **R**anging) has been developed since 1973 by USArmy, and up to this day is administered by the U.S. Department of Defense as the primary military system. Therefore, even though it is now the world's most used satellite system, its main drawback is the possibility of shutting it down or restricting it to exclusively military purposes in case of endangering the U.S. It is available worldwide since 1994. Work on the GPS system were divided into 3 phases:

Phase I: Verification of the system concept (1973 - 1979) – launch of 2 experimental NT satellites (Navigation Technology Satellites).

Phase II: Full system development (1979 - 1985) – launch of 11 block I satellites and construction of the control segment.

Phase III: Ongoing development and full operation capability (which is still in progress since 1986). Block I satellites replacement with Block II satellites. In 1993, reaching initial, (IOC - Initial Operational Capability - 18 satellites) and in 1994 full operational capability (FOC - Full Operation Capability - 24 satellites).

Satellites are broadcasting in the bands that are deliberately chosen to be minimally affected by meteorological factors. GPS has allocated five frequencies and each frequency corresponds to a transmission channel.

Band distribution of the receivers: one-frequency, two-frequency and multifrequency receivers.

Channel distribution of the receivers: one-channel, and multichannel receivers

Calculation principle distribution of the receivers: code, and phase and code receivers

GPS space segment consist of 32 MEO satellites (what is its limit state, because it was originally designed only for 24 satellites) on 6 different circular orbits with an inclination of 55° and height 20 200 km. The orbits are mutually separated by 60° and on each orbit there are originally 4, but now actually 5-6 irregularly deployed positions for satellites. Satellite orbital period is 11 hours and 58 minutes, during which each satellite makes two complete orbits each sidereal day, repeating its path every day.

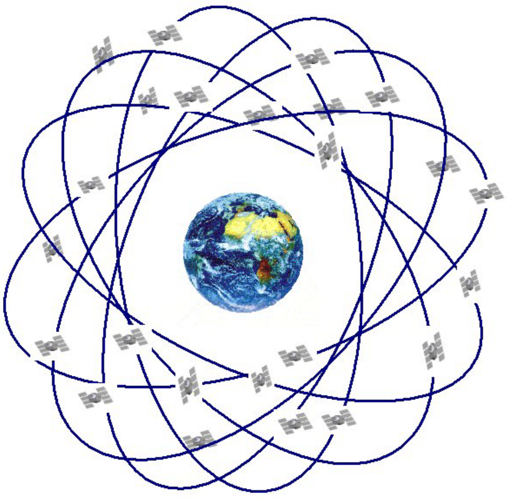

Fig. 2 Constellation of GPS satellites[6]

GPS ground control segment is composed of Master Control Station (MSC) located on Schriever air force base of the U.S. Air Force v Colorado Springs, Backup Master Control Station (BMCS), located in Gaithersburg, four Dedicated Ground Antenna located in various parts of the world, and six Dedicated Monitor Stations which communicate with the satellites. Ground control segment monitors the space segment, sending orders to satellites, making maneuvers with them and maintenance the atomic clock.

GPS user segment: Users with a GPS receiver receive signals from various satellites that are in the present moment on the horizon. Following the received data (timestamps from different satellites and knowledge of their position) and pre-defined parameters, the receiver calculates the position of the antenna, elevation, and shows the exact date and time. Communication takes place only from satellites to the user therefore the GPS receiver is passive.

Users using the GPS system can be divided into two groups:

- **Authorized users –** (military sector of the USA and selected allied armies) using Precise Positioning Service (PPS) service and those which have the decryption key to P(Y) code on L1 and L2 frequencies. Higher accuracy of the system is guaranteed for these users.

- **Other users** - (mostly civil sector) can use Standard Positioning Service (SPS) and have at their disposal C/A code on L1 frequencies. The receivers made in the USA may not be exported if they do not have limits set to 18 km (60,000 ft) and speeds up to 515 m / s (1,000 knots). These limits are designed to prevent possible misuse. [2]

GLONASS

Global navigation satellite system GLONASS (**GLO**bal’naja **NA**vigocionnaja **S**putnikovaja **S**istema) is the Russian alternative to system GPS. Its concept was made in the early 70’s of the last century, as a response to the American GPS system.

GLONASS was fully functional satellite constellation until 1995, when after the collapse of the Soviet Union it began to decline, which resulted in loss of the coverage and only partial availability. Full functionality and availability was restored in 2011. GLONASS was, like the GPS system, at first available only for military use until 18 May 2007, when the President of the Russian Federation, Vladimir Putin, signed a document releasing the GLONASS for free use for the civilians.

GLONASS space segment: consists of 24 satellites, on 3 orbital planes, and of three backup satellites. These orbits are mutually separated by 120°, and the individual satellites in one orbit by 45°. Each satellite is operated on a circular orbit with a height of 19.100 km and inclination 64.8°, and the orbital period is approximately 11 hours and 15 minutes. For all satellites in each orbit, there are 8 balanced positions with numbering:

- Orbit 1: satellites 1-8
- Orbit 2: satellites 9-16
- Orbit 3: satellites 17-24

This constellation is characterized by the fact that every 8 sidereal days is a satellite on the same location above the Earth.

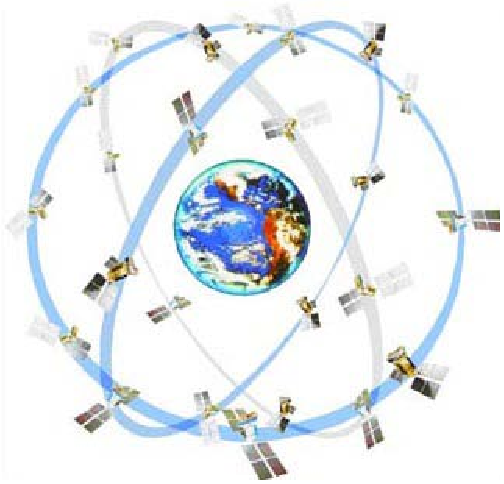

Fig. 3 Constellation of GLONASS satellites[7]

GLONASS ground control segment is entirely located in the former Soviet Union, and consists of several parts: the Master Control Station is located in the Moscow area - Krasnoznamensk, backup control centers in Moscow - Selkom area, Jenisejsk and Komsomolsk on Amure, telemetry and tracking stations are in St. Petersburg, Ussurijsk, Ternopil, Jenisejsk and Komsomolsk on Amure where are also located the monitoring stations. Ground control segment monitors the space segment, sending orders to satellites, making maneuvers with them and maintenance the atomic clock.

GLONASS user segment: Users that use a GLONASS receiver receive signals from GLONASS satellites that are in the present moment on the horizon. Following the received data (timestamps from different satellites and knowledge of their position) and pre-defined parameters, the receiver makes a calculation of the position of the antenna, elevation, and shows the exact date and time. GLONASS receiver is also passive.

Users using the GPS system can be divided into two groups, similar to those of the GPS system:

- **Authorized users** (military sector of the Russian federation and selected government organizations) using the High Positioning (HP) service. Higher accuracy of the system is guaranteed for these users.

- **Other users** (mostly civil sector) they can use Standard Positioning (SP) service with a lower accuracy.[3]

GALILEO

Galileo is a satellite navigation system currently being built by the European Union (EU) and European Space Agency (ESA). The main aim of Galileo is to provide a high-precision positioning system, upon which European nations can rely, independently from the Russian GLONASS, and US GPS. But despite the fact that Galileo will be fully independent system, it will be compatible with other systems. The main difference of the system is that is not a military system, but an open global system, which guarantees its functionality and signal availability even in the case of military conflict. This is important for its usability, for example in aviation. Positioning with the navigation system Galileo will have a better accuracy than one meter.

Program Galileo has three phases:

1. Definition of the program;

2. Development and validation on the orbital plane - the IOV phase (In-Orbit Validation), using test GIOVE (Galileo In-OrbitValidation Element) satellites and fully operational satellites;

3. Full deployment and operation.

Definition of the program, finished in 2003, provided basic specifications for the system. This will be verified by the IOV phase with the launch of four satellites (4 satellites are the minimum necessary to ensure accurate positioning) together with ground stations and control station.
IOV phase began with the launch of the first experimental Galileo satellite, GIOVE-A, in 28. December 2005. The objective of this mission was to characterize and validate the critical technologies required for Galileo, which were developed under ESA contracts. GIOVE-A remains in service, but has reached the end of its two-year design life.

GIOVE-B was launched in 27. April 2008. His mission continued with the work started by GIOVE-A, using a satellite more closely representative of the design of those planned for the operational Galileo constellation. GIOVE-B carries a high-precision passive maser clock - the most accurate clock ever flown in space - and is capable of triple-channel transmission of navigation signals. The satellite will be able to transmit a signal complying with a specific standard (known as MBOC), in accordance with an agreement reached only a few months ago by the European Union and the United States for their respective systems.

The first pair of satellites for Europe's Galileo global navigation satellite system, IOV phase, were launch into orbit by the first Russian Soyuz vehicle ever launched from Europe's Spaceport in French Guiana in 29. October 2011. The next two Galileo satellites, completing the IOV quartet, are scheduled for launch in summer 2012. After their launch the verification of the Galileo concept will start with both segments: space segment and related ground infrastructure. After completion of the IOV phase, the remaining satellites will be installed to achieve full operational capability (FOC) and after launching all 30 satellites and their deployment, the full operation of system Galileo can start.

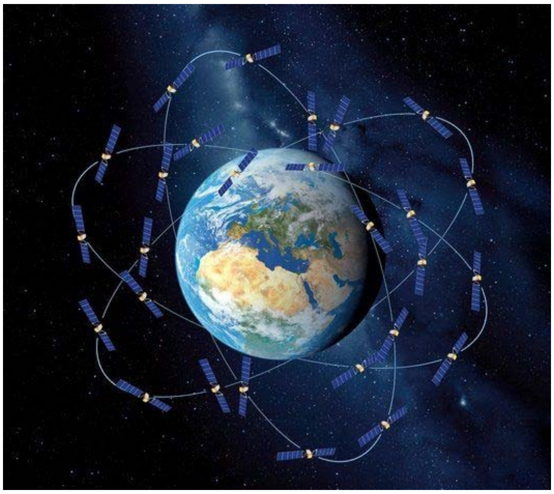

Fig. 4 Constellation of Galileo satellites[8]

Space segment: The fully deployed Galileo system will consist of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes at 23 222 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees to the equator. Once this is achieved, the Galileo navigation signals will provide good coverage even at latitudes up to 75 degrees north, which corresponds to the North Cape, and beyond. The orbital period of one satellite will be approximately 14 hours, and for the most locations on Earth, there will be visible 6 – 8 satellites together, which will ensure high accuracy of the system. The large number of satellites together with the optimization of the constellation, and the availability of the three active spare satellites, will ensure that the loss of one satellite has no discernible effect on the user. System Galileo will be compatible with the Russian GLONASS system, and US GPS system, which will even more enhance its accuracy and use.

Ground control segment: The core of the Galileo ground segment will be the two control centers (located in Germany - Munich and Italy - Fucino). Each control center will manage 'control' functions supported by a dedicated Ground Control Segment (GCS) and 'mission' functions, supported by a dedicated Ground Mission Segment (GMS). The GCS will handle spacecraft housekeeping and constellation maintenance while the GMS will handle navigation system control.

The GCS will use a global network of nominally five TTC stations to communicate with each satellite on a scheme combining regular, scheduled contacts, long-term test campaigns and contingency contacts.

The Galileo Mission Segment (GMS) will use a global network of nominally thirty Galileo Sensor Stations (GSS) to monitor the navigation signals of all satellites on a continuous basis, through a comprehensive communications network using commercial satellites as well as cable connections in which each link will be duplicated for redundancy. The prime element of the GSS is the Reference Receiver. The GMS communicates with the Galileo satellites through a global network of Mission Up-Link Stations (ULS), installed at five sites, each of which will host a number of 3-metre antennas. ULSs will operate in the 5 GHz Radionavigation Satellite (Earth-to-space) band.

The GMS will use the GSS network in two independent ways. The first is the Orthography Determination and Time Synchronization (OD&TS) function, which will provide batch processing every ten minutes of all the observations of all satellites over an extended period and calculates the precise orbit and clock offset of each satellite, including a forecast of predicted variations (SISA - Signal-in-Space Accuracy) valid for the next hours. The results of these computations for each satellite will be up-loaded into that satellite nominally every 100 minutes using a scheduled contact via a Mission Up-link Station. The second use of the GSS network is for the Integrity Processing function (IPF), which will provide instantaneous observation by all GSSs of each satellite to verify the integrity of its signal. The results of these computations, for the complete constellation, will be up-loaded into selected satellites and broadcast such that any user will always be able to receive at least two Integrity Messages.

User segment: With Galileo receiver, users will be able to receive signals from various satellites and following the received data and pre-defined parameters, the receiver calculates the position of the antenna, elevation, and shows the exact date and time.

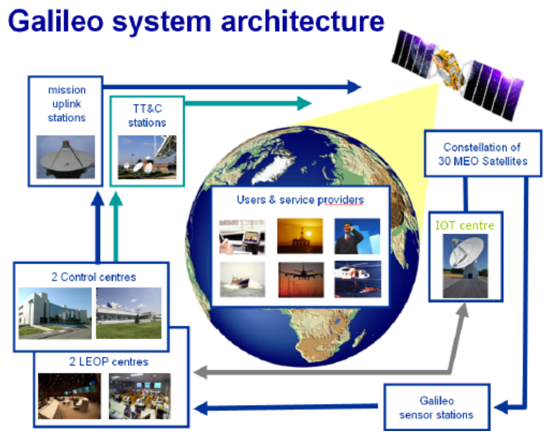

Fig. 5 Galileo system architecture[9]

The Galileo system will have five main services:

- **The Open Service** (OS) results from a combination of open signals (The signals will use two bands: 1164-1214 MHz and 1563-1591 MHz. The receivers will have a horizontal accuracy better than 4 m and vertical better than 8 m), free of user charge, and provides position and timing performance competitive with other GNSS systems.

- **The Safety-of-Life Service** (SoL) improves the open service performance through the provision of timely warnings to the user when it fails to meet certain margins of accuracy (integrity). It is envisaged that a service guarantee will be provided for this service.

- **The Commercial Service** (CS) provides access to two additional signals, to allow for a higher data throughput rate and to enable users to improve accuracy. The signals are encrypted. It is envisaged that a service guarantee will be provided for this service.

- **The Public Regulated Service** (PRS) provides position and timing to specific users requiring a high continuity of service, with controlled access. Two PRS navigation signals with encrypted ranging codes and data will be available.

- The Galileo support to the **search and rescue service** represents the contribution of Europe to the international COSPAS/SARSAT co-operative effort on humanitarian Search and Rescue activities. Galileo is to play an important part of the Medium Earth Orbit Search and Rescue system (MEOSAR).

Each Galileo satellite will broadcast 10 different navigation signals to offer OS, SOL, CS, and SAR and PRS services. OS will use the L1, E5a and E5b frequencies. Charged services will have the possibility of using dual - frequency, or triple - frequency, which will ensure centimeter accuracy and eliminate errors caused by ionosphere. [4]

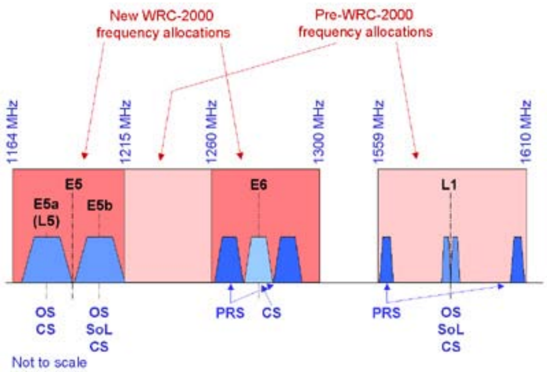

Fig. 6 Galileo frequencies[10]

4 CONCLUSION

Positioning and navigation is a function that has always been of major importance in sustaining human activities, whether to explore new lands, for controlling aviation or transportation, or in conducting warfare. In the past fifty years navigation and positioning methods have made a quantum leap and can be applied with significantly low-cost and low-power miniature devices accessible to individuals. A leap in these technologies occurred with the introduction of the Global Positioning System (GPS) by the United States and GLobal Orbiting NAvigation Satellite System (GLONASS) by the former Soviet Union in the 1980s. This has resulted in rapid and revolutionary adaptation of satellite based navigation and positioning systems worldwide. Soon after the introduction of GPS and GLONASS, the European Union have initiated its system Galileo, which should be the most accurate of them all. The development and successful commercialization of satellite-based navigation and positioning methods for numerous applications in the late 1990s is currently resulting in scores of applications and devices based on GNSS.

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