Comparison of Global Navigation Satellite Systems

Manuel Hernández-Pajares
UPC-IonSAT res. group
[contact e-mail : manuel@ma4.upc.edu]
https://scholar.google.es/citations?user=Tm-DcsMAAAAJ&hl=en

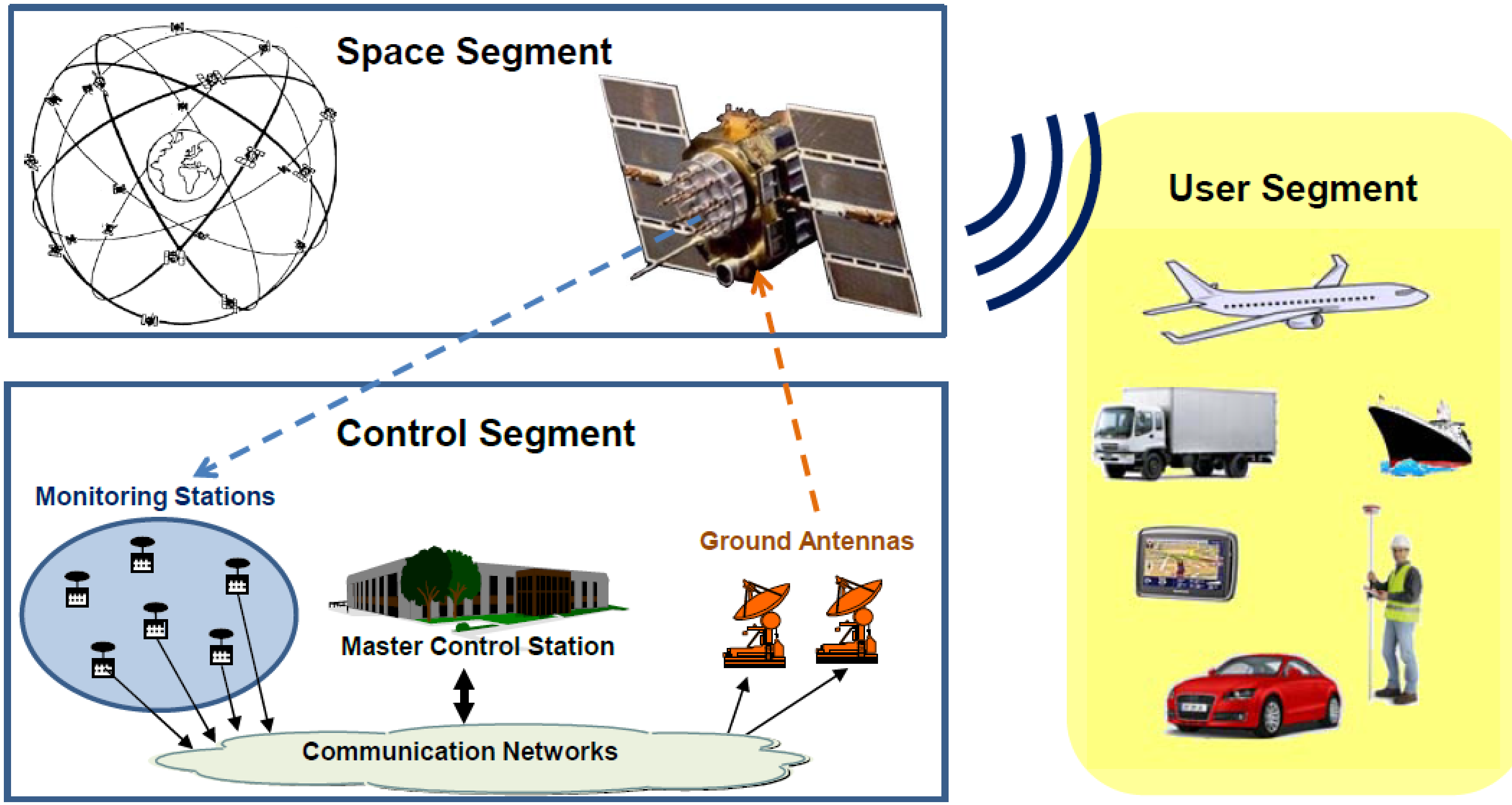
Based on *GNSS Data Processing*
Volume I: Fundamentals and Algorithms
J. Sanz Subirana, J.M. Juan Zornoza and M. Hernández-Pajares
ESA Communications, ISBN 978-92-9221-885-0 (two volumes), 2013

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

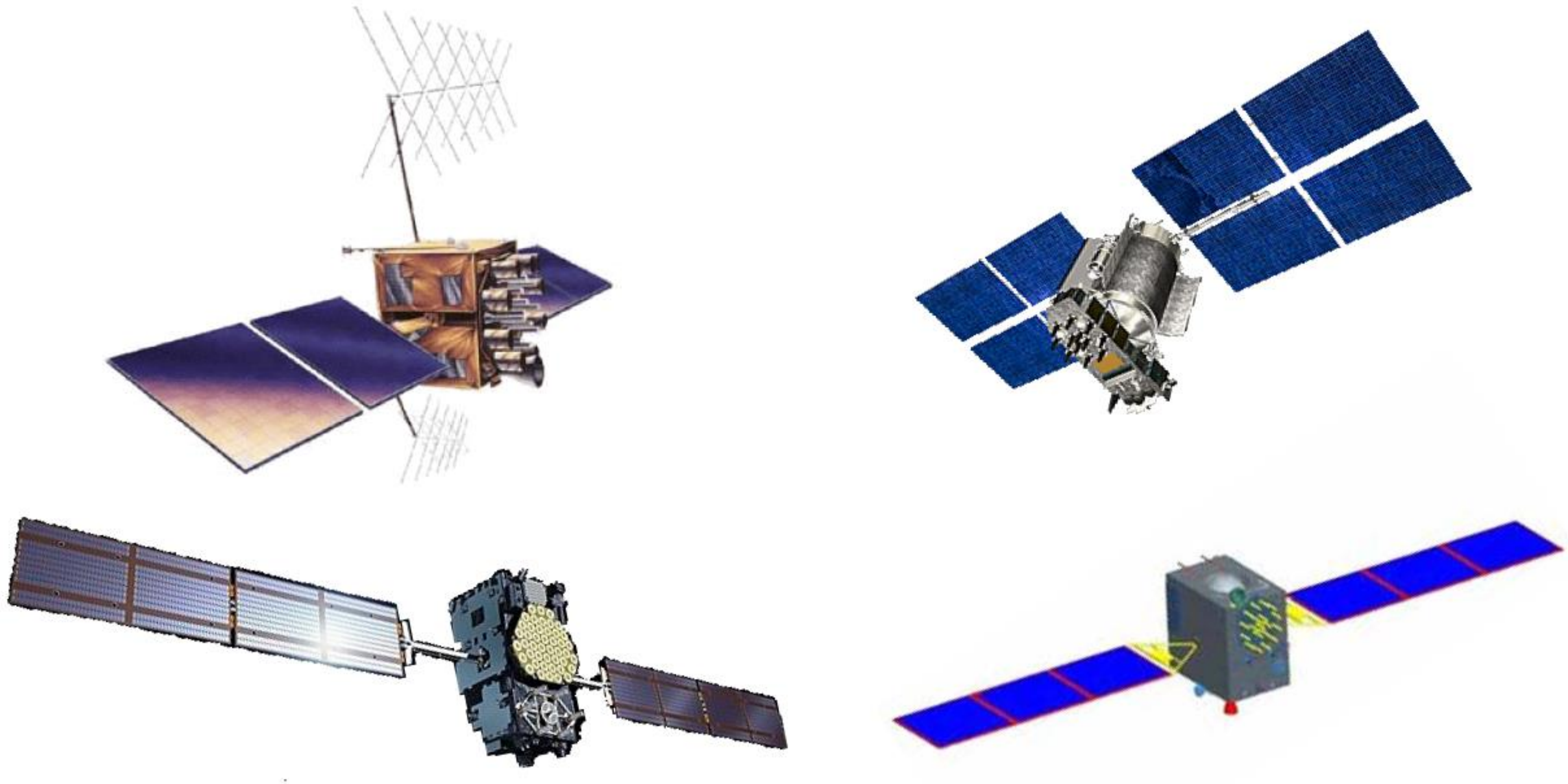
Global Navigation Satellite Systems

- Global Navigation Satellite System (GNSS) is a generic term denoting a satellite navigation system (e.g. GPS, Glonass, Galileo and Beidou) that provides continuous positioning over the globe.
- A GNSS basically consists of three main segments: the space segment, which comprises the satellites; the control segment (also referred to as the ground segment), which is responsible for the proper operation of the system; and the user segment, which includes the GNSS receivers providing positioning, velocity and precise timing to users.

Global Navigation Satellite Systems (2/3)



Global Navigation Satellite Systems (3/3)



GNSS satellites: GPS IIR-M (top left), Glonass-M (top right), Galileo IOV (bottom left) and Beidou-M (bottom right).

GPS

- The GPS satellites are arranged in six equally spaced orbital planes surrounding Earth, each with four `slots' occupied by baseline satellites.
- This 24-slot arrangement ensures there are at least four satellites in view from virtually any point on the planet.
- The satellites are placed in a Medium Earth Orbit (MEO) orbit, at an altitude of 20 200km and an inclination of 55 deg. relative to the equator.
- Orbits are nearly circular, with an eccentricity of less than 0.02, a semi-major axis of 26 560km and a nominal period of 11 hours, 58 minutes and 2 seconds (12 sidereal hours), repeating the geometry each sidereal day.

GLONASS

- The nominal Glonass constellation consists of 24 MEO satellites deployed in three orbital planes with eight satellites equally spaced in each plane.
- The orbits are roughly circular, with an inclination of about 64.8 deg, and at an altitude of 19 100km with a nominal period of 11 hours, 15 minutes and 44 seconds, repeating the geometry every eight sidereal days.
- Due to funding problems, the number of satellites decreased from the 24 available in 1996 to only 6 in 2001.
- A total of 24 operational satellites plus 2 in maintenance were again available in December 2011, restoring the full constellation

Galileo

- The planned Galileo constellation in Full Operational Capability (FOC) phase consists of 27 operational and 3 spare MEO satellites at an altitude of 23 222 km and with an orbit eccentricity of 0.002.
- 10 satellites will occupy each of three orbital planes inclined at an angle of 56 deg. on the equator.
- The satellites will take about 14 hours, 4 minutes and 45 seconds to orbit Earth, repeating the geometry each 17 revolutions, which involves 10 sidereal days.
- This constellation guarantees, under nominal operation, a minimum of six satellites in view from any point on Earth's surface at any time, with an elevation above the horizon of more than 10.

Galileo (2/2)

- The Galileo Deployment Plan has two main phases:

  (1) the In-Orbit Validation (IOV) phase with a reduced constellation of four operational satellites and their related ground infrastructure (2012);

  (2) the FOC that involves the deployment of the remaining ground and space infrastructure, including an intermediate initial operational capability phase (by 2014-2016) with 18 satellites in operation (the 4 IOV satellites plus 14 others).

- Completion of the FOC phase is expected by 2019-2020.

Beidou

- The Beidou (Compass) constellation (Phase III) will consist of 35 satellites, including 5 Geostationary Orbit (GEO) satellites and 30 non-GEO satellites in a nearly circular orbit.
- The non-GEO satellites include 3 Inclined Geosynchronous Satellite Orbit (IGSO) ones, with an inclination of about 55, and 27 MEO satellites orbiting at an altitude of 21 528km in three orbital planes with an inclination of about 55 and with an orbital period of about 12 hours and 53 minutes, repeating the ground track every seven sidereal days.
- The GEO satellites, orbiting at an altitude of about 35 786 km, are positioned at 58:75E, 80E, 110:5E, 140E and 160E, respectively, and are expected to provide global navigation service by 2020.

Beidou (2/2)

- The previous Phase II involves a reduced constellation of four MEO, five GEO and ve IGSO satellites to provide regional coverage of China and surrounding areas.
- The initial Phase II operating service with 10 satellites started on 27 December 2011.

The Satellites

- Satellites have various structures and mechanisms to keep them in orbit, communicate with the control segment and broadcast signals to receivers.
- The satellite clocks are one of the critical components of GNSSs.
- For this reason, satellites are equipped with very high-stability atomic clocks (rubidium, caesium, hydrogen).

GPS Satellites

- GPS satellites are divided into blocks.
- Each block comprises a set of satellites usually launched within a certain time interval.
- <u>Block I, Navigation Development Satellites</u>:
  - Eleven satellites of this kind were launched between 1978 and 1985.
  - The Selective Availability (S/A) capability was not yet implemented then.
  - They weighed about 845 kg and had a planned average lifetime of 4-5 years, although some of them lasted for 10 years.

GPS Satellites (2/5)

- Blocks II and IIA, Operational Satellites:
  - These consist of 28 satellites in total, launched from 1989 on, and many still operating.
  - They weigh about 1 500 kg each and have a planned average lifetime of 7.5 years.
  - Since 1990, an improved version has been used, namely Block IIA (advanced), with the capability of mutual communication.
  - They are able to supply positioning services for 180 days without contact with the control segment.
  - However, under normal operating mode, they must communicate daily.

GPS Satellites (3/5)

- Block IIR, Replacement Operational Satellites:
  - These satellites were produced to replace the II/IIA series as they gradually degraded or exceeded their intended design lifetime.
  - The `R' in Block IIR stands for replenishment.
  - They weigh about 2 000 kg each and have a planned average lifespan of 10 years.
  - These satellites are capable of autonomously determining their orbits and generating their own navigation messages.
  - They are able to measure the distances between them and to transmit observations to other satellites or to the control segment (designed for up to half year of autonomous operation).

GPS Satellites (4/5)

- Block IIF, Follow-on Operational Satellites:
  - The first satellite (SVN62) was launched on 28 May 2010.
  - The IIF series expand on the capabilities of the IIR-M series with the addition of a third civil signal (L5) in a frequency band protected for safety-of-life applications.
  - Their theoretical average lifetime is about 15 years, and they have inertial navigation systems.
- Block III Satellites:
  - These satellites will introduce signicant enhancements in navigation capabilities, by improving interoperability and jam resistance.
  - They will provide the fourth civil signal on the L1 band (L1C).

GPS Satellites (5/5)

- GPS satellites are identied in different ways: by their position in the orbital plane, their NASA reference number, their assigned Pseudo-Random Noise (PRN) code, their Space Vehicle Number (SVN), etc.
- Full Operational Capability (FOC): The GPS constellation achieved FOC in March 1994, when 24 Block II/IIA satellites were operational in their assigned orbits. Nevertheless, FOC was not declared until 17 July 1995.

Glonass Satellites

- Prototypes (Generation Zero):
  - The first prototypes of the Glonass (Uragan) satellites were placed into orbit in October 1982, with 18 launched between 1982 and 1985 (Block I).
- First Generation:
  - The first were launched between 1985 and 1990.
  - They are divided into different blocks (Block IIa, IIb and IIv), with different design lifetimes (from the two-year design of Block IIb to the three-year design of Block IIv, although many spacecraft reached up to 4.5 years).
  - They are all three-axis stabilised with about 1250 kg.
  - They have improved time and frequency standards compared with the previous prototypes.

Glonass Satellites (2/4)

- Second Generation:
  - Glonass-M (or Uragan-M or modernised/modified) is the second generation of satellites.
  - Developed from 1990, sent into orbit from 2001 on.
  - Glonass-M satellites have a longer design lifetime of seven years (improvements to the propulsion system and clock stability; caesium clocks): between the 2-3 years of first-gen. and below the 10-year of GPS.
  - Their mass is of about 1 480 kg, 2.4m in diameter and 3.7 high, with dual solar arrays of 7.2 m.
  - They also carry cornercube laser reectors for precise orbit determination and geodetic research.
  - A remarkable feature: the addition of a second civil signal on the G2 band (it allows civil users to cancel out ionospheric refraction).

Glonass Satellites (3/4)

- Third Generation:
  - These are the Glonass-K (or Uragan-K) satellites .
  - They have an increased lifetime design of 10-12 years and a reduced weight of 750 kg (allowing their launch in pairs on Soyuz-2-1a rockets).
  - They are also three-axis stabilised and nadir pointing with dual solar arrays.
  - They provide the new Code Division Multiple Access (CDMA) signal for civilian applications on the new G3 band, among the civil signals in the G1 and G2 bands using the Frequency Division Multiple Access (FDMA) technique, and a Search and Rescue (SAR) payload.
  - The first Glonass-K satellite was launched on 26 February 2011.

Glonass Satellites (4/4)

- Full Operational Capability (FOC): The Glonass constellation reached FOC on 8 December 2011, after the satellite launched on 4 November (into Slot 3) was declared operational at 11:42 Moscow Time.
- With 24 operating satellites, the Glonass constellation provides complete coverage of Earth's surface.

Galileo Satellites

- Galileo Satellites Experimental Phase:
  - Two experimental satellites were launched between 2005 and 2008: the Galileo In-Orbit Validation (GIOVE) satellites GIOVE-A and GIOVE-B.
  - Their mission served several purposes:
    - to secure the Galileo frequency filling with the International Telecommunications Union (ITU);
    - to validate technologies to be used in the Galileo operational constellation;
    - to monitor the environment at MEO; and to generate Galileo signals so that user equipment can be developed.
  - Both satellites were built in parallel to provide in-orbit redundancy and secure the mission objectives, and both provide complementary capabilities.

Galileo Satellites (2/4)

- GIOVE-A was built by Surrey Satellite Technology Ltd. (SSTL) and was launched on 28 Dec. 2005.
- It has a mass of about 600 kg and two redundant rubidium atomic clocks, with a stability of 10 ns/day.
- Its nominal lifetime of 27 months was extended prior to the launch of GIOVE-B and beyond.
- GIOVE-B was built by Astrium and Thales Alenia Space, and was launched on 27 April 2008.
- Its mass and estimated lifetime are similar to those of GIOVE-A, but it has a more advanced payload.
- There are four redundant clocks onboard, two small rubidium atomic clocks, with a stability of 10 ns per day, and two passive hydrogen maser clocks, with a higher stability (1 ns per day).

Galileo Satellites (3/4)

- Galileo IOV Phase:
  - This phase is aimed at qualifying the Galileo space, ground and user segments through extensive in-orbit/on-ground tests and operations.
  - During this phase, four operational satellites complement the two experimental satellites (GIOVE-A and GIOVE-B) already in orbit.
  - The first two operational Galileo satellites were launched on 21 October 2011, and placed in the first orbital plane. The next two satellites were launched on 12 October 2012 in the second orbital plane.
  - They are fully representative of the next ones.
  - Each satellite has a mass of about 700 kg and combines two rubidium and two passive hydrogen maser clocks with a powerful transmitter to broadcast precise navigation data.

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

•IonSAT

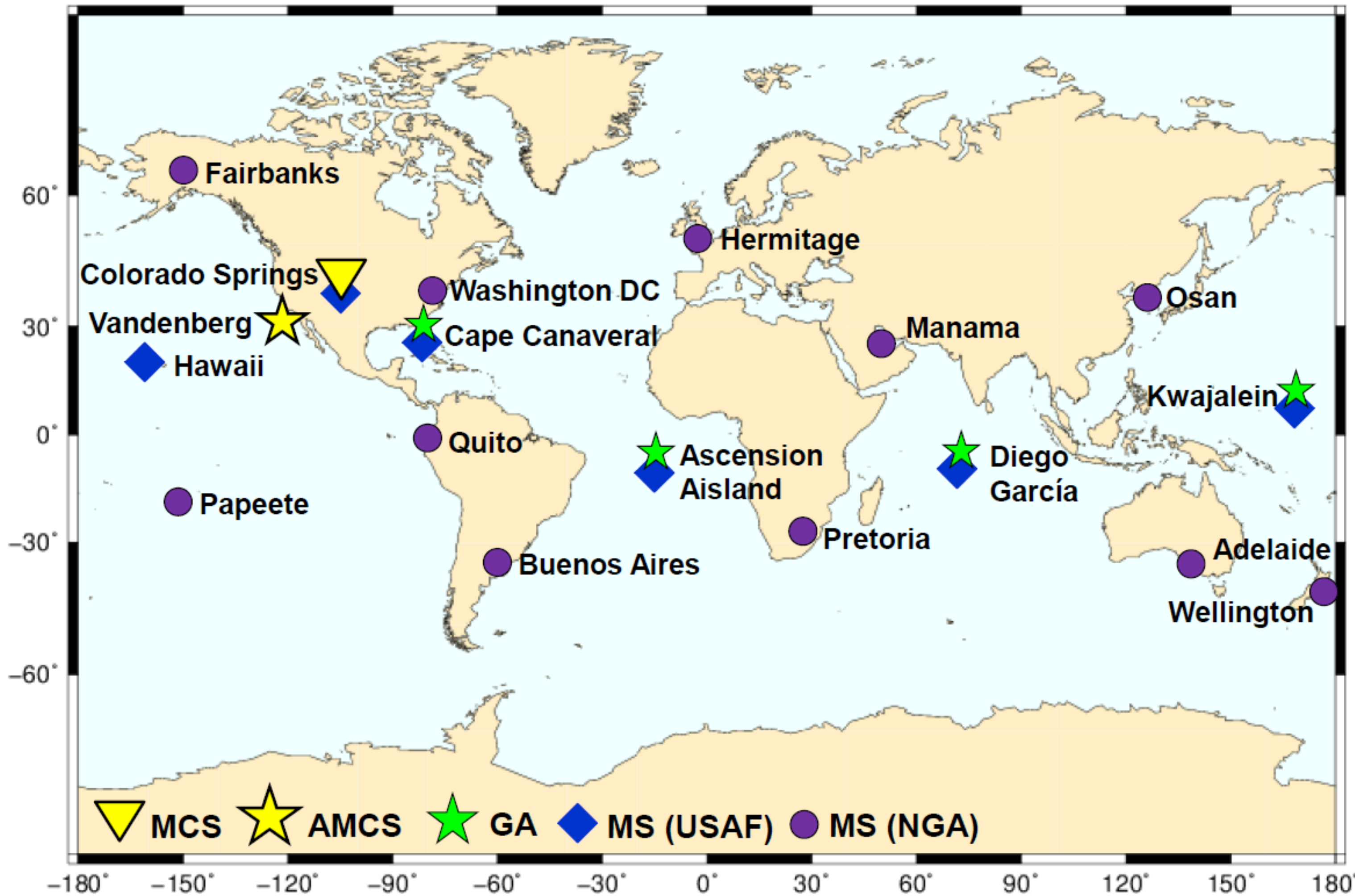
Galileo Satellites (4/4)

- <u>Galileo FOC Phase:</u>
  - By 2014-2016, the constellation is expected to have grown to 18 satellites, including the 4 satellites from the IOV phase, and it is hoped that FOC will be reached by 2019-2020, with a constellation of 27 operational satellites, plus 3 spares.

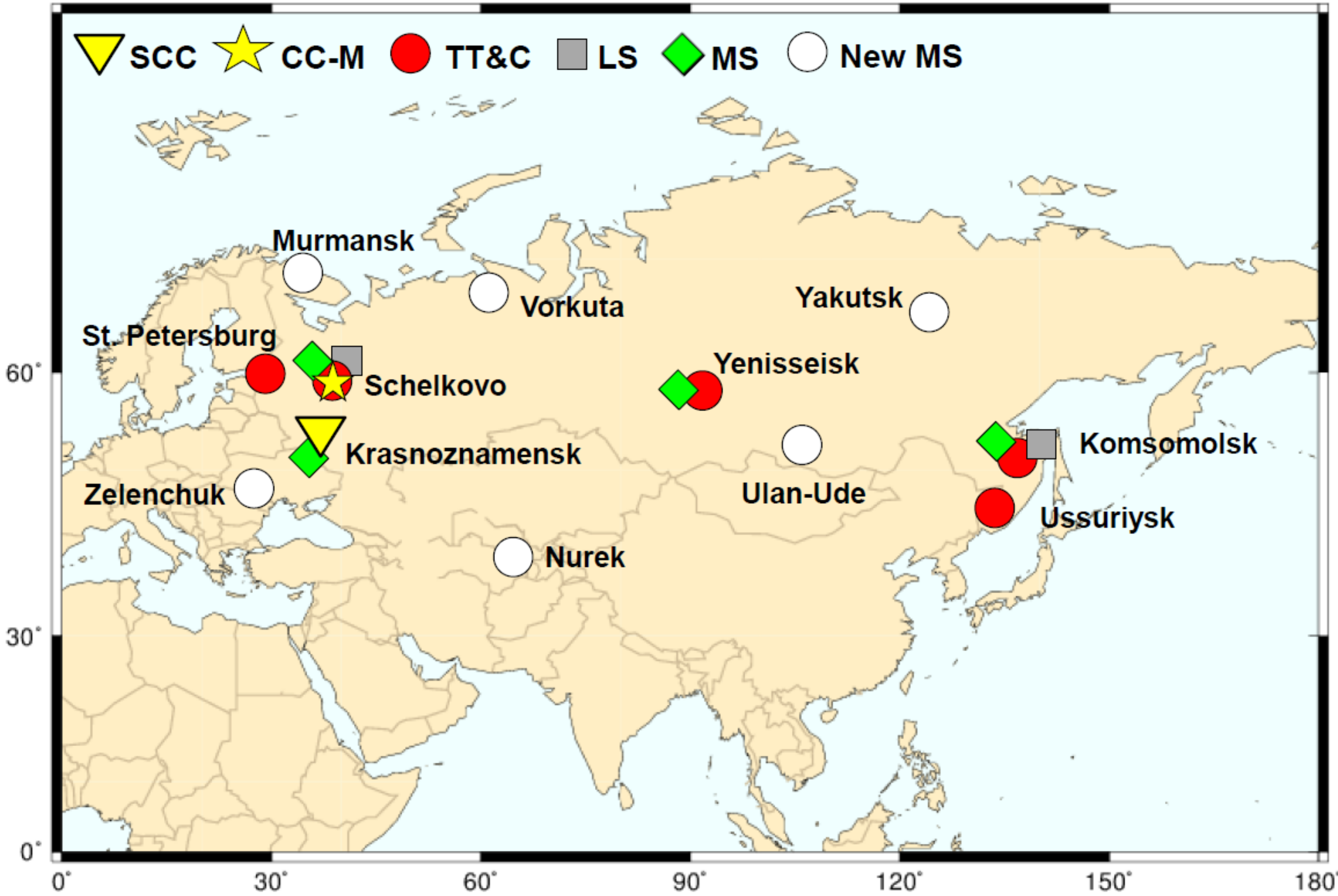
Beidou Satellites

- There are 3 variants: the geostationary Beidou-G, the geosynchronous Beidou-IGSO and the MEO Beidou-M.
- They have a design lifetime of eight years.
- The first Beidou Phase II satellite in orbit was the experimental Beidou-M satellite, launched on 14 April 2007 (local time) to test the onboard payload.
- By late December 2011 China had put four Beidou-G and five Beidou-IGSO satellites into orbit.
- On 27 December 2011, with 10 orbiting satellites, the Beidou system started an initial Phase II operating service to China and its surrounding area.
- By the end of 2012, there are five GEO, four MEO and five IGSO navigation satellites in orbit.
- Completion of the 35-satellite constellation (5 GEO, 27 MEO and 3 IGSO) is scheduled for 2020 (Phase III, global service) [BeiDou-SIS-ICD, 2012].

GPS control segment

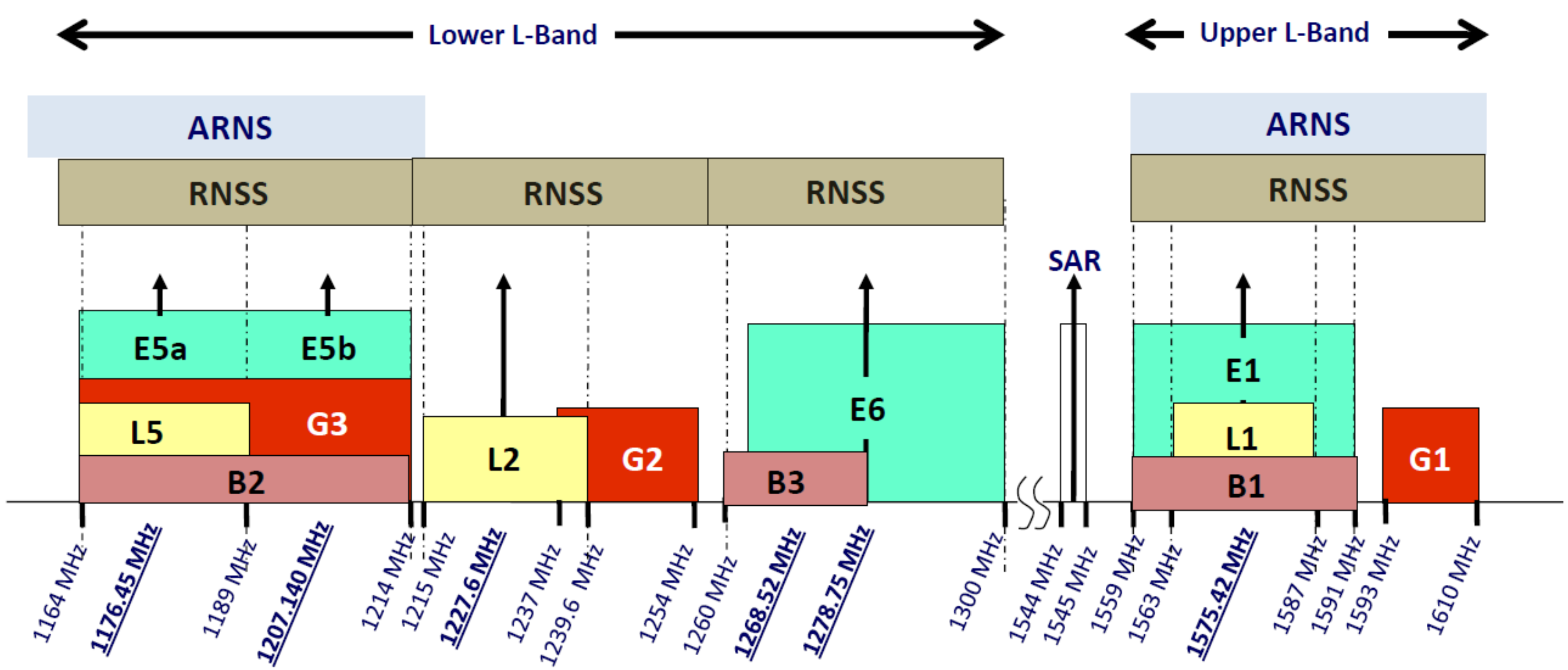


Glonass control segment



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Navigation frequency bands of GNSSs



L GPS Bands G Glonass Bands E Galileo Bands B Beidou Bands **SAR:** Galileo Search and Rescue Downlink

ARNS: Aeronautical Radio Navigation Service **RNSS**: Radio Navigation Satellite Service