TT&C antenna at the Galileo Sensor and Uplink Station, Nouméa, New Caledonia
The Galileo ground segment

Sean Blair
Communication Department, ESTEC, Noordwijk, the Netherlands

The satellites in space are only the tip of the Galileo iceberg – a far-flung ground segment, unique in its complexity and scope, has taken shape all over the planet.

For the equivalent cost of expanding the European motorway network by less than 600 km, Galileo is Europe’s independent satellite navigation system, a wise and essential investment. And it will do more than just keep our continent’s traffic from snarling up during the century to come: Galileo is set to enable a host of future location-based businesses and services while supporting and expanding the estimated 6–7% of Europe’s economy – around €800 billion in value – already reliant on satellite navigation.

ESA and the European Commission are partners on the Galileo programme. The definition, development and In-Orbit Validation (IOV) phases of Galileo have been undertaken by ESA, co-funded by ESA and the EC. The follow-on Full Operational Capability (FOC) phase is being managed and fully funded by the European Commission, with ESA acting as design and procurement agent on behalf of the Commission.
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The first four Galileo IOV satellites – launched in 2011 and 2012 respectively – are already working in orbit, broadcasting navigation signals. Having served to validate the overall design of the Galileo system, they represent the operational nucleus of the full 30-satellite Galileo constellation to follow. Those follow-on FOC satellites are taking shape through a Europe-wide production and testing line that ends in Kourou, French Guiana, with the next tranche of launches.

But the satellites in space are only one element of the overall satellite navigation system – the tip of the Galileo iceberg. ESA has also been busy putting a global ground segment in place, extending to some of the world’s loneliest places. This work has been among the most complex developments ever undertaken by ESA, having to fulfil strict levels of performance, security and safety.

Galileo engineers were also working to a strict time schedule: the initial IOV ground segment infrastructure needed to be fully in place and online – linked by satellite to Galileo’s two control centres – before Galileo’s first position fix could be carried out, eventually carried out in March this year. A fast-track programme of station openings was implemented to make the deadline.

Like any standard ground station, each Galileo station has to be built on an area of flat ground – no easy task in some locations – away from inhabited areas or other potential sources of radio interference, with a steady power supply plus back-up generator and fuel supply as well as on-site spare parts.

Day to day, the stations operate autonomously, with technicians needed only for maintenance and anomaly investigation. The degree of attention likely to be required depends on the station type – on one hand, a Galileo Sensor Station is simply an automated 50 cm omnidirectional antenna while Uplink Stations incorporate steerable 3 m antennas and, at the top of the scale, Telemetry & Tracking Stations employ steerable 13 m diameter antennas. Each station is overseen by a local ‘hosting entity’, and is connected to the secure Galileo Data Dissemination Network via satellite link.

Because Galileo is an independent European programme, all the elements in its ground segment – while covering the world – have to be sited on European territory. This requirement saw ESA engineers despatched to some of the remotest European dependencies and colonies on the planet, a process that is continuing today. Just as the Galileo constellation is advancing from the IOV phase to the FOC phase, so the Galileo ground segment goes on growing to accommodate the many new satellites to come, and consolidate this truly global satnav system.

Why does ‘satnav’ need a ground segment?

Satellite navigation: wherever you go, there it is. As long as there’s a sufficiently open patch of sky above your head, from just about anywhere on Earth you can switch on your receiver to find out exactly where you are and in which direction you are heading.

The ubiquity of satnav is a major factor in why it has so swiftly transformed the way we live and work. Added to that is its apparent simplicity – from the user’s point of view, all that are needed are the navigation signals from the satellites in space and suitable equipment to receive them, whether handheld or embedded into a car or smartphone. At least that’s what most people think, but this misses a large part of the true picture.

If the orbiting satellites were left to operate alone – in the aftermath of a global catastrophe, for example – then the surviving population who consult their satnav receivers would find the accuracy begin to decline. Within a matter of days, their satnav systems might be unable to pinpoint which town they are in and, in a matter of weeks, which country.

The reason for this is that a world-spanning ground segment is needed to maintain contact with all satellites in the satnav constellation and to keep their performance from straying off track. Recall that satnav is ultimately...
based on the highly precise measurement of time: the signal from each satellite contains a time code from its onboard atomic clock, so the length of time it has taken from the signal to reach the receiver can be deduced.

Multiply that value by the constant speed of light to derive your distance from the satellite – you now know you are somewhere within a fixed sphere around the satellite (to sharpen accuracy further, your receiver contains details of all the satellites’ orbits – their ‘ephemerides’). Do the same with other satellite signals simultaneously – from a minimum of four satellites, in practical terms – and your receiver calculates a set of overlapping spheres, with you placed within their point of shared overlap. This method is called ‘trilateralisation’, the three-dimensional equivalent of triangulation.

However, individual atomic clocks might be prone to drift – and an error of just a billionth of a second corresponds to a 30 cm increase in ranging error. A clock error of an entire second would put users 300 000 km off target, or most of the way to the Moon. So a network of ground stations continuously checks each satellite’s clock against the system time generated by a much more accurate collection of ground-based atomic clocks (the Galileo System Time, in the case of Galileo).

Satellite orbits can drift too, nudged by the gravitational tug from Earth’s equatorial bulge, and by the Moon and Sun. Even the slight but continuous pressure of sunlight itself can influence satellites over time. So for satnav to work well, their present positions in three-dimensional space need to be certain to sub-metre accuracy. Three or more adjacent ground stations viewing the same satellite at once perform trilateralisation up to space, to quantify any drift (laser-ranging can also be employed for even better accuracy).

Ground stations around the globe also need to identify any signal delay or disturbance because of perturbations in the ionosphere – the electrically active outer layer of the atmosphere, which can be influenced by solar activity. Ionospheric delay can be largely subtracted by employing dual-frequency satnav receivers, but to date the majority of receivers remain single frequency, so these effects need to be accounted for.

Finally, all these data gathered at widely dispersed ground stations need to be collected together at the control centre of the ground segment so that a list of corrections can be made then uplinked to the satellites for rebroadcast within the navigation signal for user receivers to take account of when determining position. This correction process takes place as often as needed, typically on a daily basis. In essence, the satellite constellation with its ground segment forms an enormous self-correcting closed-loop system.

In addition, Galileo’s ground segment is even more complex than the other global navigation satellite systems that have come before, because it is designed not only to deliver worldwide positioning services, but also their associated integrity information – with an estimate on the current trustworthiness of the signals plus prompt error messages in the event of failure. This is essential for the ‘Safety of Life’ applications, such as managing air traffic, highways, railway networks and shipping.
Outposts on the edge

→ FROZEN FRINGE OF EUROPE

Location: Kiruna, northern Sweden
Host: Swedish Space Corporation

One of two telemetry, tracking and command (TT&C) stations for Galileo’s IOV phase – the other is based at Kourou, French Guiana. Kiruna’s extreme northerly attitude, 200 km north of the Arctic Circle in the forests of Swedish Lapland, gives it good visibility for Galileo satellites at the top of their three orbital planes, while its remote location avoids any signal interference from built-up areas. The station is hosted at the Esrange Space Center of the Swedish Space Corporation, one of the oldest space sites in Europe, first established by ESA’s predecessor ESRO in the mid-1960s as a rocket range as well as satellite ground station.

→ BOTTOM OF THE WORLD

Location: Troll research base, Antarctica
Host: Kongsberg Satellite Services

The most southerly Galileo site to date is Troll base in Antarctica. Hosting a combination of Galileo Sensor Station and Uplink Station, this Norwegian facility is located some 235 km inland in the thin air 1270 km above sea level. The stations are sited on the solid foundation of a mountain peak rising through surrounding glaciers. This is also home to the TrollSat satellite ground station, staffed year round, with supplies coming in via an adjacent glacier-based airfield and supplemented by overland convoys during the round-the-clock sunlight of the brief Antarctic summer.
→ POLAR OPPOSITE

Location: Spitsbergen Island, Svalbard archipelago, Arctic Ocean
Host: Kongsberg Satellite Services

The site of an Uplink Station and Sensor Station, Svalbard is the most northerly node in the Galileo ground segment, positioned at more than 78°N, less than 1000 km from the North Pole. The Svalbard Satellite Station, SvalSat for short, also serves as a ground station to numerous polar-orbiting Earth observation missions. But it remains one of the remotest Galileo sites. The road to Spitsbergen’s main settlement of Longyearbyen is regularly blocked by severe weather – a helicopter pad provides back-up access for the 23-strong engineering team operating SvalSat around the clock. There are more polar bears on the island than people.

→ BLACK BEACH

Location: Jan Mayen Island, Arctic Ocean
Host: Kongsberg Satellite Services

Famed for having some of the worst weather in the world, this remote volcanic island is linked to the outside world by Norwegian military flights to an unpaved airfield, operating only a few times per year, with access strictly controlled to protect its pristine Arctic environment. Jan Mayen hosts a Galileo Sensor Station set up on a beach of volcanic black sand, littered with bleached timber washed up from the distant Russian mainland – the only flat plain available on the island.
‘HMS ASCENSION’

Location: Ascension Island, South Atlantic Ocean
Host: C&W

This isolated tip of an underwater volcano enjoys a mild tropical climate, although much of its land is made up of lava flows and cinder cones. The greenest place on the island is actually its rain-prone highlands, planted with trees and plants introduced by amateur gardeners during the last two centuries. Britain’s Royal Navy officially assigned Ascension Island as a vessel or ‘stone frigate’ – HMS Ascension – after taking possession of it in 1815. It was thereafter used as military base, cable station and, latterly, satellite ground station. A Galileo Sensor Station came online this year. Uniquely, Ascension Island also hosts a GPS ground antenna and monitor station, located at a US Air Force base on the island.

MELANESIAN OUTPOST

Location: Nouméa, New Caledonia, Pacific Ocean
Host: TDF

Already home to a Galileo Sensor Station and Uplink Station with a TT&C station due to come online soon, this French-administered group of tropical islands is far from a hardship posting. But at the start of July, the engineers manning the site found themselves marooned by a flash flood. Nouméa is built on a flat plain surrounded by bowl-like hills that normally help to screen out unwanted radio signals, but in this case funnelled water down to the site in the heaviest rains on New Caledonia since 1951. As a nearby stream burst its banks, the waters washed away the access road to the site. The engineers sat tight for 40 hours, the time it took for rescuers to repair the road. The station remained operational throughout, helped by high foundations and an onsite generator.
→ DESOLATION ISLE

Location: Grande Terre, Kerguelen Islands, Indian Ocean
Host: Terres australes et antarctiques françaises (TAAF)

There is no airport on this sub-Antarctic French territory — also known as the Desolation Islands — and a boat calls only four times a year. The main island of Grande Terre, much of it covered by glaciers, is home to seabirds, feral cats and about 100 polar scientists. This is the site of a Galileo Sensor Station that had to be constructed during a hectic stay by Galileo engineers at the end of 2011, who saved time in this case by reusing a surplus protective facility to host the station rather than starting with an empty field.

→ STATIONS FOR SEARCH AND RESCUE

Locations: Maspalomas, Canary Islands / Spitsbergen, Svalbard

Not all Galileo ground stations are devoted to navigation. ESA has prepared a trio of sites for satellite search and rescue, part of the international Cospas–Sarsat programme. Founded by Canada, France, Russia and the US, Cospas–Sarsat has assisted in the rescue of tens of thousands of people in its three decades of service. Distress signals from across the globe are detected by participating satellites, then swiftly relayed to the nearest search and rescue (SAR) authorities.

Now the programme is introducing a new Medium-Earth Orbit Search and Rescue (MEOSAR) system to provide enhanced coverage and response times. Just a trio of MEO Local User Terminals (MEOLUTs) are required to cover all of European territory: ESA has already completed the sites at Maspalomas in the Canary Islands and Spitsbergen in Svalbard, with Larnaca in Cyprus currently approaching completion. These three sites are monitored and controlled from the SAR Ground Segment Data Service Provider site, based at Toulouse in France.

Each MEOLUT is equipped with four antennas to track four satellites. The stations are networked to share raw data from participating satellites (Glonass as well as Galileo, with GPS Block III satellites also participating later in this decade), effectively acting as a single huge 12-antenna MEOLUT, delivering unprecedented detection time and localisation accuracy.
Galileo’s double heart

At the centre of Galileo’s worldwide ground segment is not a single control centre but two. This built-in redundancy provides reliability and robustness to the overall Galileo system. During the IOV phase, each centre runs a different half of the ground segment, but in future the two centres will host equivalent facilities, working together as ‘hot’ back-ups with real-time data synchronisation. In the event of loss of one centre, the other will be able to pick up operations seamlessly.

The Fucino control centre in central Italy is the home of the Galileo Mission Segment (GMS), which oversees the running of all navigation services provided by Galileo. It ensures highly accurate mission performance on an ongoing basis by processing data from the worldwide network of ground stations, then embeds any necessary corrections into the navigation message being uplinked to the satellites. The GMS includes two million lines of software code, 500 internal functions, 400 messages and 600 signals circulating through 14 different elements.

Fucino is the site of one of the largest satellite communication stations in the world. The location is ideal because it has plenty of broad flat ground, screened from terrestrial electromagnetic signals by surrounding hills. This distinctive geography is the result of one of the ancient world’s greatest feats of engineering: the Romans dug a tunnel to drain much of the lake that originally covered the Fucino basin. This pioneering work of Emperor Claudius was finally completed in 1875, when the rest of the lake was drained using the very same tunnel. The rich soil left behind is today used for farming.

The Oberfaffenhofen control centre near Munich in southern Germany is the home of the Ground Control Segment, which monitors and controls the Galileo satellite platforms across the whole of their 12-year operating lives. Each satellite sends at least 20 000 signals about its
status to Earth – data being continuously analysed in the control centre. Satellite performance has to be checked daily, to ensure that important parameters remain within defined ranges, including power availability and attitude control. Each satellite’s orbit is being monitored down to an accuracy of less than 50 cm. Of course, managing this task will grow progressively more challenging as the Galileo constellation grows.

Oberpfaffenhofen is one of the largest sites of the German Aerospace Center, DLR, home to the German Space Operations Center, which has been overseeing Germany’s space missions since the 1970s. Oberpfaffenhofen, like Fucino, hosts a Galileo Precise Timing Facility, an ensemble of atomic clocks on site to generate Galileo System Time (GST) on an averaged basis, employed to synchronise all system clocks and signals in the Galileo system. The difference between GST and GPS time – known as the ‘offset’ – is then broadcast in the Galileo navigation message, helping to enable ongoing interoperability of Galileo and GPS.

Operational management of the two control centres is undertaken by Spaceopal, a joint venture between the Fucino owner and operator Telespazio with DLR GfR, a company set up by the German Aerospace Center.
→ GALILEO GROUND SEGMENT OVERVIEW

KEY
- GCC: Ground Control Centre
- GSS: Ground Sensor Station
- ULS: Uplink Station
- TTFC: Telemetry, tracking and Command
- SAR MEOLUT: Search and Rescue Medium Earth Orbit Local User Terminal
- GSNC: Galileo Security Monitoring Centre
- TGVF: Timing and Geodetic Validation Facility
- IDT: In Orbit Test Centre
- LEOPCC: Launch & Early Operations Phase Control Centre

Status: March 2013
→ Definitions

Telemetry, Tracking and Command (TT&C) Stations – the space/ground interface for telemetry acquisition and telecommand uplink to the satellite platforms, as well as two-way ranging

Uplink Stations – a network of stations to uplink the corrections and integrity data to the satellites for rebroadcast to users as part of the navigation message

Galileo Sensor Stations – spaced across the globe to receive navigation signals from the constellation for rebroadcast to the control centres, enabling continuous clock synchronisation, signal quality and satellite ranging measurements

MEOLUTs – Medium-Earth Orbit Local User Terminals, not part of Galileo’s navigation infrastructure but instead used to relay search and rescue messages to local authorities as part of the international Cospas–Sarsat programme