GPS HRN
GLOBAL POSITIONING SYSTEM in Health Research Network

NEWS UPDATE

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An international collaboration to connect academics and health professionals interested in GPS technology

Note from the editor

Hello everyone,

Significant time has elapsed since the last GPS-HRN newsletter. Importantly, the continuity of this newsletter directly relies on proposals of content that you can send me, whenever you like.

In this new issue, Jean Maréchal from the French National Center for Space Studies (CNES) describes the characteristics of Galileo, the European GNNS and opportunities for research. Galileo should be fully operational by the end of 2020.

As you may know, the PALMS system was shutdown at the end of 2018. Dr Jasper Schipperijn introduces HABITUS, the new system for merging and processing accelerometer and GPS data.

Many thanks to both for their contribution to this newsletter!

Please remember to check that your member page is up to date on the website: www.gps-hrn.org

Thank you in advance!

All the best,

Alexis Le Faucheur

Contents

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Galileo is operational and accurate: use it!

Jean Maréchal
CNES GNSS Programme Manager
French Space Agency (CNES)
Jean.Marechal@cnes.fr

Galileo, the European global positioning system, has been providing early services since December 2016. Since this date, the constellation deployment has continued and the good performance is confirmed. But the Galileo story is just beginning for the worldwide users: better accuracy, new services, future augmentation by the European Geostationary Navigation Overlay Service (EGNOS), and plenty of renewed usages.

Galileo program status

Galileo is the European global navigation satellite system (GNSS), decided and developed by Europe to ensure its autonomy in the key domain of satellite navigation. Europe initiated the programme in the late 1990's and two test satellites called GIOVE were launched in 2005 and 2008.

The operational constellation deployment started with four "In Orbit Validation" satellites (IOV) launched in 2011 and 2012, followed since then by twenty-two other satellites. The last launch of four satellites by Ariane 5 from Kourou took place successfully in July 2018. The constellation is now almost complete with 26 satellites in orbit and 22 of them being fully operational. In parallel the ground control centres and stations have been deployed and are being finalised.

The next key milestones will be two Galileo service declarations. The first one, the "Enhanced Services" declaration, will improve the guaranteed service levels. It is expected in 2019. The full operational capability and the full Galileo services declaration are expected by end 2020.

Initiated by the European Space Agency (ESA), Galileo is financed by the European Union since the early 2000's and managed by the European Commission and the European GNSS Agency (GSA). ESA has been playing a key role in the system procurement, development and deployment since the beginning of the programme.

Since 2017, GSA is responsible for Galileo service provision and contracted with SpaceOpal to operate the system and the constellation.

Galileo principles

Galileo principles are largely inspired by the American global positioning system (GPS): a minimum of 24 satellites in medium earth orbit (23 200 km for Galileo), a worldwide network of stations to supervise the constellation and compute precise satellite orbits, and few uplink stations to feed the satellites with their ephemerids that will be transmitted to users by the constellation (**Figure 1**).

The Galileo satellites are transmitting navigation signals based on the following principles: a carrier – the sinusoidal signal that will be used for phase measurement – is modulated by a predefined code. The code identifies the satellite and allows the receiver tracking the signal, measuring the propagation delay from the satellite and computing the range between the receiver and each satellite. On top of the carrier and the code few data are sent to the user – the navigation message (from 120 bit/s to 244 bit/s for Galileo) – in order to synchronise all signals together and provide satellites ephemerids (satellite orbit and position on the orbit). Knowing where the satellites are, knowing also the distance with each satellite, the receiver is able to compute its position by trilateration.

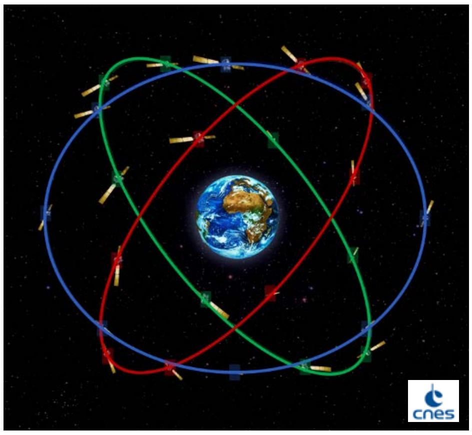
Four satellites at least are needed to obtain a position because four unknowns have to be determined: the receiver coordinates (three unknowns) and the time difference between the satellite atomic clocks and the receiver clock. Once the position is obtained, the receiver is fully synchronised with the system. Therefore, a GNSS receiver provides not only position and velocity but also an excellent synchronisation to UTC, with an accuracy better than 0.1 microsecond.

The four GNSS, Navstar GPS (USA), Galileo (EU), GLONASS (Russia), and BEIDOU (China, regional service is operational, global system is under deployment) are built on these same principles and are all interoperable for what concerns the open service.

Galileo services

Regarding broadcast signals, Galileo took advantage of the existing GPS to create new signals in order to improve the final services. With four civil signals, Galileo provides three civil services. Galileo also provides one regulated service and contributes to the international search and

Figure 1 - Galileo nominal constellation: 24 satellites distributed on 3 orbital plans (Source: CNES).



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rescue service COSPAS-SARSAT.

The three civil services are the following:

- The Open Service (OS)
  - Supported by three frequencies: E1 (named L1 in GPS), E5A (L5 in GPS) and E5B.
  - This is the main civil service, fully interoperable with the existing "GPS" on L1. The open service can be monofrequency (E1, or also E5A or E5B) or bi-frequency (main standard should be E1-E5A, similar to the GPS L1-L5).
  - This service is available since December 2016.
- The High Accuracy Service (HAS)
  - Supported by one frequency for data dissemination (E6, 448 bit/s) and the open service frequencies.
  - This is a new global precise positioning service (PPP) which accuracy will be at least 20cm. It will be free of charge.
  - This service should be available end 2020 and will require a specific receiver (compatible with E6, phase measurements and PPP user algorithms). Currently most recent high-end receivers are compatible with the E6 frequency and several chipsets are announced in the coming months. The PPP user algorithms are expected to be available in 2020.
- The authentication service, split in two sub-services:
  - The OS Navigation Message Authentication (NMA), free of charge, will allow authenticating the satellite ephemerids and synchronisation data.
  - The Commercial Authentication Service will be a paying service. Based on a strong encryption of the code, it will guarantee that the signal is not spoofed (protection against pirated signal).

As a matter of comparison, GPS is only providing one civil service, the Open Service, based on L1, L2 and L5 signals. The L5 frequency is currently available only on the 12 GPS-IIF satellites (half of the constellation).

Galileo Open Service performance

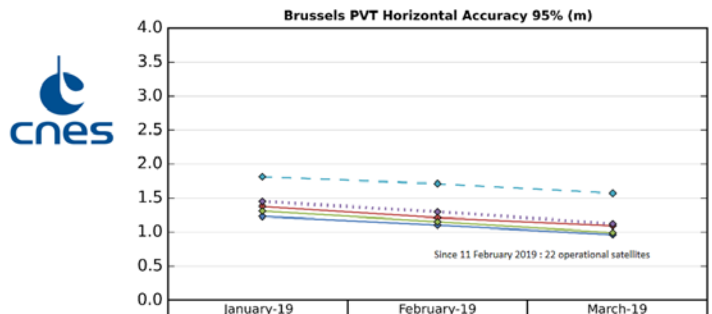
Whereas the first political target of Galileo is reaching navigation independence from GPS, the first technical target of Galileo is to provide better services than the existing GPS, which means also that these services will be at least as good as the modernized GPS (expected in 2024).

Today Galileo performance measured with the partially deployed constellation demonstrate that the target is achieved: the accuracy of Galileo ephemerids is about 25 cm (95% of the time) when GPS ephemerids accuracy is 80 cm. When these ephemerids are used to get a Galileo position, the user accuracy will be about 1 m (95% of the time) when GPS position is about 1,5 m to 2 m. Currently the Galileo user accuracy is almost optimal because the constellation is missing only two satellites (see **Figures 2 et 3**, 1.5 m measured in Brussels, Belgium).

Consequently, a receiver that is compatible with both GPS and Galileo and that combines the two, is providing today a better accuracy than a "GPS only" receiver. When the Galileo constellation will be completed in 2020, it would be possible to use a "Galileo only" receiver anytime and anywhere, but such receivers would very likely not have much success because combining GPS and Galileo will offer several benefits such as a better service availability in constrained environments (twice as many satellites in view), a very good redundancy (two fully independent systems) and the ability to get now bi-frequency measurements (E1-E5A). In fact, you will certainly get in your next smartphone not only a Galileo/GPS chipset but more likely a Galileo/GPS/Glonass/Beidou chipset: the future will definitively be "multi-constellation" and "multi-frequency" for more accurate services with better availability.

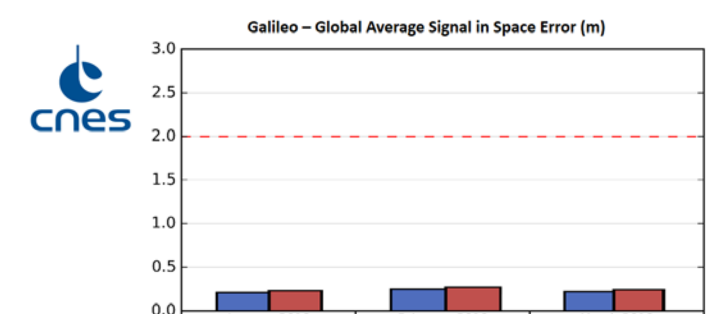
At the time of going to press, the list of Galileo enabled devices numbered around 750 million. A number of models of Garmin devices use this system. Check the lists here to see if your devices are using the system: www.usegalileo.eu

Figure 2. Horizontal accuracy (95% of values), receiver located in Brussels, 2017 Q4 Galileo, GPS, and combined Galileo/GPS solutions (mono and dual-frequency) – Source CNES.



	January-19	February-19	March-19
GAL E1, E5a	1.23	1.10	0.96
GAL E1, E5b	1.38	1.21	1.09
GAL E1	1.31	1.15	0.99
GAL L1 + GPS E1	1.45	1.30	1.12
GPS L1	1.81	1.71	1.57

Figure 3. Galileo signal in space accuracy (ephemerids and clocks), 2017 Q4 – Source CNES.



	January 2019	February 2019	March 2019
GAL E1, E5b (95%)	0.21	0.25	0.22
GAL E5a (95%)	0.23	0.27	0.24

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European GNSS: Galileo and EGNOS

The European GNSS Programme consists in two programmes, Galileo presented above, and EGNOS, the GPS augmentation for Safety-of-Life users (civil aviation) and Open Service users expecting a better and more stable accuracy (e.g., agriculture).

EGNOS is operational since 2009. It is based on GPS corrections and integrity data that the EGNOS user applies on his GPS range measurements to improve the accuracy (about 80cm 95% of the time) and to compute a protection volume which guarantees the maximum positioning error with a risk of 10^{-7}. The continuity of service is also specified. The levels of protection and continuity are defined firstly for civil aviation users using dedicated receivers in open sky conditions. The better accuracy is available to any user in good receiving conditions with an EGNOS compatible receiver.

EGNOS next generation (called also EGNOS V3) is now under development: it will offer the legacy service (GPS augmentation on L1) but will turn also to a multi-constellation and multi-frequency service, augmenting Galileo and GPS on two frequencies (E1-E5A). This new service is expected in 2024.

Galileo second generation is also under preparation: new signal to improve the acquisition and tracking in difficult conditions, improved availability, stability and reliability of the system are the main objectives, which is a challenge considering the already excellent performance of the system.

Galileo and GNSS usages

Galileo, together with the other GNSS, has of course plenty of usages in our societies.

For example, when studying movement and displacements, the availability in urban environment is most of the time an issue. Using a 4-GNSS receiver will multiply the number of satellites in view by 3 to 4 and obviously improve the service availability very significantly. The accuracy of the resulting service will still depend on the buildings or hills masking the satellites to the user: even all satellites are visible in the same small part of the sky, because of geometry, you cannot get the same accuracy than in open sky conditions (dilution of precision). Another typical degradation in constrained environment is the multipath, when satellite signals are reflected by buildings or other constructions, impairing the range measurement with the satellites. However, Galileo E5 signals have been specifically designed to detect and exclude such unexpected multipath and can be used by receiver manufacturers to improve the accuracy of the positioning.

The dynamic accuracy will be improved the same way as the positioning accuracy. In case the dynamic information (typically the speed of displacement) is of high importance for the user, specific receivers should be selected. There are different ways of computing the speed in a GNSS receiver and the basic “derivative of the position” is most of the time not providing the better performance. Dynamic performance can also be improved, in particular the continuity of the measure in case of masking, with hybridization of GNSS with inertial sensors: integrated modules are proposed by manufacturers.

Of course, each application is specific and therefore requires specific performances, in given conditions, and within specific budget constrains when selecting a receiver. For instance, the GNSS chipset in a smartphone costs just few euros and the antenna is of low quality, whereas the receiver in a bus or a tramway will be more expensive, have a larger antenna and offer better performances. Each user should analyse its needs and its operating conditions to identify the better product and the reachable performance.

Finally, the limitations inherent to GNSS are not solved by Galileo: for instance, the indoor tracking (inside buildings) requires other specific systems.

Precise positioning

Finally, a few words about the precise positioning which is the new ere of GNSS. Adding real time corrections to the code and phase measurements, the user can get a centimetre level accuracy in certain conditions. Two main technics exist, RTK and PPP, and combinations of both technics are also proposed by high-accuracy service providers (PPP-RTK).

RTK is based on corrections that are applicable to a user close to specific reference stations. A dense network of stations and a significant amount of data is required to offer the service in given area.

PPP is based on regional or global corrections that are usable whatever the position of the user with respect to reference stations. A network of 50 to 80 stations worldwide is needed by a system to compute such corrections. The PPP technic has currently one main drawback, namely a slower convergence (5 to 10 minutes), but providers are continuously innovating to reduce this convergence delay, in particular making use of precise atmospheric corrections and more than two frequencies.

Both technics require that the user receives in real time the corrections by a specific data link (e.g., GSM network, GEO satellite, etc.) or a specific dataflow in the navigation signal itself (e.g. the Galileo E6 signal, providing the high accuracy service HAS).

To conclude, keep in mind that Galileo is there and is free of charge. Please try it out!

Note

Picture of Jean Marechal by LECARPENTIER Lydie for CNES (2018).
Galileo performance results and analysis from Bernard Bonhoure and Cédric Rouch, CNES.

Find more information at:
https://galileo-mission.cnes.fr/fr
http://www.esa.int/Our_Activities/Navigation/Galileo/What_is_Galileo

@GPS-HRN

PALMS becomes HABITUS - Human Activity Behavior Identification Tool and data Unification System

Jasper Schipperijn
Associate Professor
University of Southern Denmark | jschipperijn@health.sdu.dk

The PALMS system for merging and processing accelerometer and GPS data was developed by the Center for Wireless and Population Health Systems at the University of California, San Diego and has been serving many GPS researchers from around the world since 2009. Funding for development and maintenance of PALMS ran out in 2012 and despite the abundant support letters from many of you, efforts in the last few years to attract new funding have not been successful. At the end of 2018, the PALMS system was therefore shutdown.

Building on the PALMS experiences and algorithms, we have developed a new system, HABITUS, which is hosted by the University of Southern Denmark.

HABITUS consists of three separate elements: 1) secure data storage, 2) user interface with processing algorithms, and 3) data processing on the ABACUS 2.0 High Performance Computer (HPC).
Researchers can upload their data to a personal virtual hard disk which is fully compliant with all GDPR regulations for sensitive personal data. Processing choices are made in a Shiny (Rstudio) user interface. Once the processing decisions are made, the system temporally loads the data onto the HPC where it is processed. The original data, as well as a processed dataset are returned to the secure data storage. If a researcher allows their data to be used for meta-analysis, the system can run a federated analysis across multiple virtual hard disks without revealing the original data to the analyst.

The original PALMS processing algorithms are included in HABITUS, securing backwards compatibility, but also new functionality is added (e.g., in the form of raw accelerometer data processing using the GGIR accelerometer data processing package by Vincent van Hees).

We have not fully committed to a business model, but expect a model similar to many commercial cloud systems where a user pays for storage capacity and processing time separately. If all goes according to plan, our service will be fully available in fall 2019. Feel free to contact me for more information.

Furthermore, we also plan to make all data processing algorithms freely available (in R) so that researchers that have their own secure data-storage and sufficient data management skills, and don't need high speed data processing, can process their own data independent of our system.

In a similar way, we hope to collaborate even more with other research groups in the future to be able to incorporate their processing algorithms in our system.

We are looking forward to working with many of you again in the future.

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Publisher: ENS Rennes. Campus de Ker Lann - Avenue Robert Schuman - 35170 Bruz - FRANCE
Phone: +33 (0)2 9905 9419
Email: alexis.lefaucheur@ens-rennes.fr

www.gps-hrn.org