Galileo is Europe's initiative for a global navigation satellite system, providing an accurate and guaranteed positioning service under civilian control. It will be interoperable with GPS and GLONASS, the two existing military systems, neither of which support safety-critical applications. Galileo will deliver positioning accuracy down to metre range, guarantee availability of service and inform users within seconds of any satellite failure, suiting it for safety-critical applications including maritime navigation. An overview is given of intended Galileo services and performance in this last context. GPS performance after modernisation (2013 and beyond) is considered, as is combined use of Galileo and GPS.

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Galileo Global Navigation System

Maritime aspects of future European satellite navigation

Galileo will be the first civil satellite navigation system designed and operated under public control. Guarantees will be offered for safety-of-life and commercial navigation services, an important differentiating feature with respect to current global navigation satellite systems.

GPS and Galileo

Both systems consist of three parts: the space segment, the user segment and the control segment. The GPS space segment actually consists of thirty satellites; the Galileo space segment will also consist of thirty. Each satellite will broadcast precise time signals, together with clock synchronisation, orbit ephemeris and other data. The user segment consists of receivers detecting, decoding and processing GPS and/or Galileo satellite signals. In both systems, position and time determination is based on measuring time that elapses as radio signals travel from at least four satellites to the receiver. The control segment consists in both systems of monitoring stations located around the world. At these stations information is collected, processed and broadcast to the satellites. GPS will be

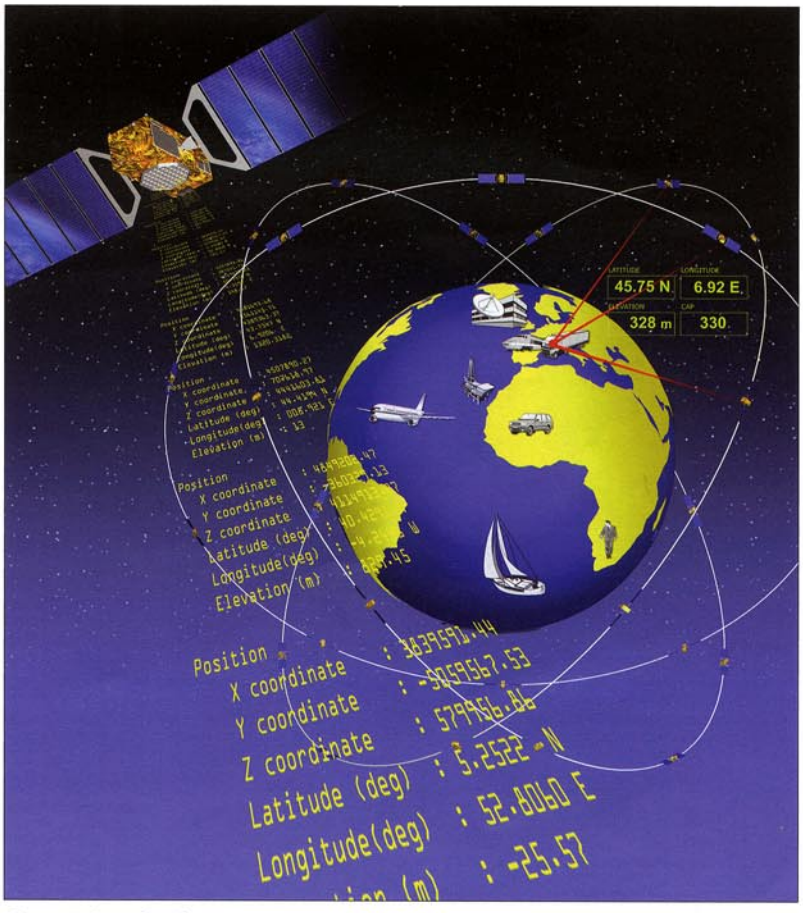

Figure 1: Signal authentication system.

	Open Service (OS)	Safety of Life Service (SoL)	Commercial Service (CS)		Public Regulated Service (PRS)	
Coverage	Global	Global	Global	Local	Global	Local
Accuracy	Horizontal 4m vertical 8m	4-6m	< 1m	< 10cm (locally augmented)	horizontal 6.5m vertical 12m	< 1m (locally augmented)
Availability	99.8%	99.8%	99.8%		99.999%	
Integrity	No	Yes	Value-added service		Yes	

Table 1: Performance for the four Galileo navigation services (dual-frequency services only are listed).

modernised over coming years, and by 2013 the accuracy will be 1-5m. In contrast to GPS, Galileo will offer the possibility of service guarantee.

Galileo Services

Four navigation services and one service in support of Search and Rescue operations will be provided worldwide.

- *Open Service (OS)* is based on a combination of open signals, free of user charge, and will provide positioning and timing of an accuracy competitive with other global navigation satellite systems
- *Safety of Life service (SoL)* improves Open Service performance through the provision of timely warning to user when it fails to meet certain margins of accuracy (integrity). The main difference with OS is the worldwide high-integrity level designed for safety-critical applications such as maritime, aviation and rail transport, where guaranteed availability of accuracy and integrity is essential
- *Commercial Service (CS)* provides access to two additional signals to allow for higher data-rate throughput and enable users to improve accuracy. This pair of signals is protected through commercial encryption, to be managed by service providers and the future Galileo Operating Company. On payment of a fee it will provide added-value services such as data broadcasting, precise timing services, and local differential correction signals for high-precision position determination
- *Public Regulated Service (PRS)* provides positioning and timing for specific users (governmental applications) requiring high continuity of service, with controlled access for civil institutions. PRS is required to be operational at all times and under all circumstances, notably during periods of crisis
- *Search and Rescue service (SAR)* broadcasts globally the alert messages received from distress-emitting beacons. It will improve the existing Search and Rescue system, including with near real-time reception of distress messages from anywhere on earth (less than 10 minutes in place of the current one-hour average), precise location of alerts (a few metres, in place of the currently specified 5km). It will also provide a return link from SAR operator to distress beacon, thereby helping to co-ordinate rescue operations and reject false alerts.

Figure 3: The 1st Galileo satelite Giove - A undergoing prerations at the ESA-ESTEC test facilities in Noordwijk-The Netherlands. Photo taken by Jacques van Oene.

The service is being defined in co-operation with the international COSPAS-SARSAT Search and Rescue system. Its characteristics and operations are regulated under the auspices of IMO (International Maritime Organisation) and ICAO (International Civil Aviation Organisation). SAR fulfils the requirements and regulations of the IMO (detection via Emergency Position Indicating Radio Beacons of the Global Maritime Distress Security Services). Table 1 shows the performance of the four Galileo navigation services. Table 2 shows the Galileo SoL service performance for open-sea navigation in the maritime domain.

Service Guarantees

It is envisaged that a guarantee will be offered on all applications for which disruption of service would have significant safety-of-life or economic impacts. The Galileo Operating Company (GOC) will guarantee the quality of the Signal In Space (SIS). An agreement or contract will be concluded between operator and user or, in certain cases, with third-party service provider. Should the SIS fail to meet certain margins of accuracy, the GOC will provide timely warnings (integrity messages) to users. An authentication signature will be built into the signal to overcome any 'spoofing'
(intentional malicious provision of non-authorised faulty signal) and will result in a higher safety and service guarantee. Figure 1 shows how the signal authentication system will work. It will use public as well as private-key cryptography. The public key will be included in the navigation message of all satellites. The deciphering process would authenticate the satellite message and reject all but true Galileo satellite signals. The certification process, mainly focusing on the signals and services delivered by Galileo, will not overlap or replace traditional certification schemes used by different user communities to certify specific applications. The aviation or maritime communities will be able to apply their own safety specifications.

Local Elements

Positioning accuracy can be improved locally by providing users with differ-

Type of Receiver	Number of carriers	3 frequencies
	Computes Integrity	Yes
Integrity	Alarm Limit	556m
	Time-to-Alarm	10 seconds
	Integrity risk	10^{-7}/hour
Continuity Risk		10^{-4}/hour – 10^{-8}/hour
Certification		Yes
Availability of integrity		99.5%
Availability of accuracy		99.8%

Table 2: Service performance for the Galileo Safety of Life service in the maritime domain.

ential corrections. A differential reference station comprises a fixed Galileo receiver that measures pseudo-range to the Galileo satellites. Since the location of such a ground-station is precisely known, the differential correction can be calculated, enabling removal of most of the error component common to all users in the coverage area. Enhanced integrity information can also be provided on a local basis through utilisation of Local Integrity Monitors (LIMs). These can deliver enhancements with respect to all aspects of integrity provision, namely Time to Alarm, Alarm Limits and Risk of Missed Detections. Moreover, LIMs can be used to ensure that the differential reference stations do not broadcast any hazardous misleading information. Some applications might be port-approach and precision harbourdocking, precise positioning for the offshore industry, and precise positioning for surveying. The Galileo Operating Company may also offer Galileo local-element service guarantees on a domain basis (road, rail, aviation, maritime etc).

Galileo Advantages

The major concern for current satellite navigation users is the reliability and vulnerability of the navigation signal. Galileo will contribute significantly to reducing these shortcomings by independently providing additional navigation signals broadcast in different bands. It is intended to provide a guarantee for the SoL and CS services. The Galileo Operating Company will guarantee the minimum quality of the Signal In Space. The SoL service will increase safety globally through the provision of integrity information and is especially significant in areas where no traditional ground infrastructure is available. The Commercial Service will provide added-value services such as data broadcasting, precise timing services and local differential correction signals for high-precision position determination.

Development Plan

The Galileo infrastructure is being implemented in three phases: development and in-orbit validation (2001-2005), deployment (2006-2007), and commercial operations (from 2008).

Combined Services

Galileo will use a geodetic reference frame identical to GPS. Galileo time will be referenced to International Atomic Time. Allowing Galileo and GPS to be efficiently combined will result in improved availability (the number of operational satellites will be doubled to about sixty), and redundancy. By combining services from separate and fully independent systems, full redundancy can be achieved, particularly important for Safety of Life applications.

Further Reading

For more information on Galileo, visit the website: http://europa.eu.int/comm/dgs/energy_transport/galileo

Biographies

Henri Kannemans completed his studies at the Technical University Delft in 1976 and is currently working as senior scientist at the Flight Test department of the National Aerospace Laboratory, NLR. He has experience in GNSS verification flight-testing and is involved in preparing tests for the Galileo user segment.
After serving seven years as a deck officer at The Netherlands merchant marine Sam Storm van leeuwen studied physics at the University of Amsterdam. After graduating in experimental physics he joined the National Aerospace Laboratory NLR of The Netherlands in 1980 as a flight test instrumentation engineer.
He headed instrumentation projects such as the prototype instrumentation of the Fokker100 test aircraft. In 1990 Sam headed the development of a GPS/ inertial /Kalman filter Position Velocity Time reference system for flight test purposes. Currently Sam serves as GNSS and airworthiness specialist at NLR. ■

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