Galileo - European Global Navigation Satellite System

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Abstract

Galileo is a new satellite navigation system being developed by the European Union. It will be a civil, internationally controlled and operated system that will secure the long-term availability of satellite-based navigation services for multi-modal purposes throughout the European region and beyond. This paper reports on the European efforts toward the development of Galileo. The current issues relating to the architecture and development programme of the Galileo system are also presented in the paper.

1 Introduction

Satellite positioning and navigation using the US Global Positioning System (GPS) and, to a limited extent, the Russian Global Navigation Satellite System (GLONASS), is now widespread within the international civilian community. Techniques have now been developed for using such systems in a wide variety of applications, beyond the original purpose of navigation. Examples of current areas of application include geomatics, multi-modal transport (land, air and sea) navigation, satellite altimetry, offshore seismic surveys, crustal deformation monitoring, time transfer, and climate studies.

Despite the convenience of using GPS and/or GLONASS for navigation, there are certain aspects of the systems which have continued to be of concern to the civilian community. These issues can generally be categorised into two classes.

a) **Institutional:** GPS and GLONASS are both military systems controlled by single nations. A system under civilian control is required if the required navigation performance (RNP) is to be guaranteed.
b) **Performance:** The current navigation performance of GPS and GLONASS, although adequate for many applications, cannot fully support all requirements for air, land and sea navigation.

A first step, aimed at addressing the concerns expressed above, has been through the initiation of the first-generation global navigation satellite system (GNSS1). GNSS1 has been defined by the ICAO/GNSS Panel to include existing systems GPS and GLONASS, and any augmentation systems required to enable RNP for all phases of flight. Because of the stringent RNP for aviation, GNSS1 will also meet the RNP for other modes of transport. In Europe, the European Tripartite Group (ETG), consisting of the Commission of European Union (CEU), Eurocontrol and the European Space Agency (ESA), are developing the European compliment to GNSS1, referred to as EGNOS (European Geostationary Navigation Overlay Service). EGNOS will enable land, sea and civil air (up to CAT I phase of flight) navigation within the ECAC (European Civil Aviation Conference) service volume [Loddo *et al*., 1996]. In the US, the Wide Area Augmentation System (WAAS) is under development [Fernow and Loh, 1994], while in Japan, the MSAS (MTSAT Satellite Augmentation System) is being developed [Fuller, 1998].

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GNSS1 will address mainly the performance constraints of the current systems. Institutional constraints will continue to be of concern even with GNSS1 operational. The second-generation global navigation satellite system (GNSS2) has been conceived as a natural evolution of GNSS1, aimed at addressing fully both the institutional and performance constraints of existing systems. The European contribution to GNSS2 is the *Galileo system*, which is currently under definition, with the aim of supporting multi-modal transport navigation requirements and many other applications requiring spatial and/or temporal information.

2 Development of GNSS, a European Approach

Over the last twenty years, the advantages of satellite navigation have been clearly demonstrated by GPS, and to some extent, by GLONASS. It is expected that, by the year 2005, the potential global market for GNSS will exceed 40 billion euros. However, both GPS and GLONASS are military systems controlled by single nations. Ultimately, these systems will be used to meet the interests of those individual countries. In the foreseeable future, transportation will be increasingly dependent on GNSS. If Europe is to place major reliance on any satellite navigation signal, it must have a say in the control of that signal. In order to participate in this business, there are three choices for Europe: joint development with all major players, EU development with one or more international partners, or independent development by the EU.

Europe’s real involvement in satellite navigation started in the early 90s, when it began to develop the EGNOS system. This is a complementary system to the existing satellite navigation systems to improve the system integrity and positioning accuracy. EGNOS consists of three main parts: a network of ground monitoring receivers, processing centres and geostationary satellites (GEOs). The ground network, mainly covering Europe, will monitor the performance of GPS/GLONASS satellites. The processing centres will generate the system integrity messages and WADGPS corrections. This information will then be transmitted to users through GEOs. The signal structures of GEOs are similar to those of GPS. Therefore, GEOs can provide extra range measurements to improve the availability of the existing satellite navigation services. EGNOS will start to be operational in 2003.

Since 1998, development towards GNSS-2 has been intensified in Europe. In March 1998, the council of transport ministers of the EU requested 1) recommendations on the future approach to GNSS, 2) the intensification of contacts with the US and Russia, and 3) the acceleration of work to examine the options of a European satellite navigation system. In July 1998, a high level GNSS-2 Forum was established. A number of research projects have been carried out to investigate problems associated with GNSS-2, including legal and institutional issues, technical and financial issues, defence and security considerations, and user and service requirements. In June 1999, the Galileo Resolution was announced by the EU transport Council. Meanwhile, the European Space Agency approved the GalileoSat programme to support this initiative. In May 2000, the Galileo Office was established to co-ordinate Galileo development activities across Europe.

Figure 1 shows the overall schedule for the realisation of the Galileo system [Basker, 1999].

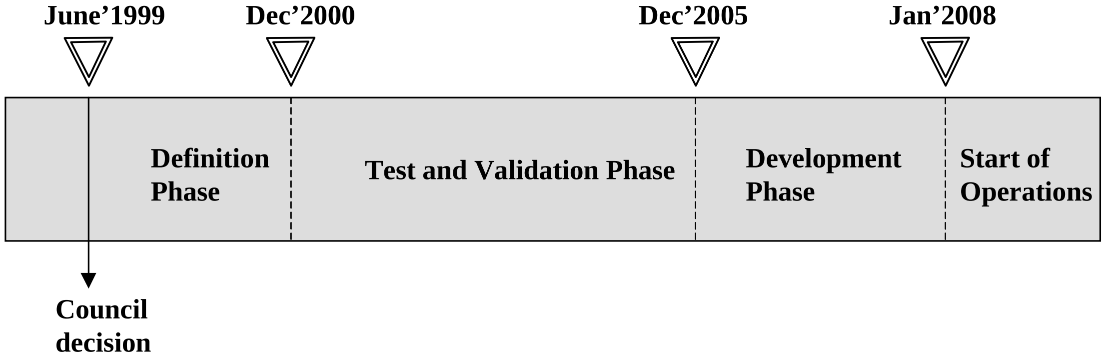

Figure 1: Overall development schedule for the Galileo system

The definition phase, to be completed by the end of the year 2000, was initiated in June 1999 by a European Union resolution to carry out studies with the objectives of establishing the feasibility and viability of the Galileo system. The activities include investigating the possibilities for international co-operation, including negotiating with the United States, the Russian Federation and other third countries, the performance of a cost benefit analysis involving the development of scenarios for revenue streams, proposing a framework for Public Private Partnership (PPP), and finally securing funding for the project. The output of the definition studies will be used by the Council in December 2000 to decide on whether to go ahead with the project. If approved, detailed system design, testing and validation will be carried out during the period 2001 to 2005, followed by the development of the functional and physical components, and qualification of the system during the period 2005 to 2008. The system is expected to be operational during the year 2008. The estimated cost of the establishment of the Galileo system (1999-2008) is in the range of 1.6-2.2 billion euros, dependent on the selection of system constellations. Recurring costs from 2008 are estimated to be in the range of 140-205 million euros per year.

3 The Galileo System High Level Architecture

The Galileo system currently under definition is the European contribution to the second-generation global navigation satellite systems (GNSS 2). The system has been proposed as a global, European-controlled satellite-based navigation system, and will support *multi-modal* transport navigation requirements and many other applications requiring spatial and/or temporal information (plus derivatives) to users equipped with suitable Galileo receivers. It has also been proposed to be compatible with GPS/GLONASS, and interoperable with the space-based augmentation systems (SBAS) and ground-based augmentation systems (GBAS) currently under development. It should be noted, however, that the issues of compatibility and interoperability, and their impact on the Galileo system, are still to be studied and consolidated. The system is expected to achieve *full operational capability* (FOC) by the year 2008 (± 2 years). A brief note on the status of each of the key aspects of the definition studies, including user requirements and system definition, is given below.

3.1 User requirements

As with any development aimed at providing services of this kind, a detailed analysis of the potential user needs is required. These needs are then translated into system requirements which form the basis for design, development, testing and eventual implementation. Part of the Galileo definition studies is devoted to the identification and quantification of the user requirements within the domains of navigation and navigation-related communications. This process is currently underway, with preliminary results already published (Ochieng *et al*., 2001a; 2001b). The parameters used to define the performance requirements for the different user needs have been identified to include the usual required navigation performance (RNP) parameters (Ashkenazi *et al*., 1995).

a) *Accuracy:* defined as the degree of conformance of an estimated or measured position at a given time, to the *truth.*
b) *Integrity:* relates to the trust which can be placed in the correctness of the information supplied by the navigation system. It includes the ability of the navigation system to provide timely warnings to users when the system must not be used for navigation/positioning. Specifically, a navigation system is required to deliver a warning (*i.e. an alarm*) of any malfunction (as a result of a set *alarm limit* being exceeded) to users within a given period of time (*i.e. time-to-alarm*) and with a given probability (*i.e. integrity risk*).
c) *Continuity:* defined as the ability of the total system to perform its function without interruption during an intended period of operation. Continuity risk is the probability that the system will be interrupted and not provide guidance information for the intended period of operation. This risk is a measure of system unreliability.

d) *Availability:* defined as the percentage of time during which the service is available for use, taking into account all the outages, whatever their origins. The service is available if the accuracy, integrity and continuity requirements are satisfied.

The other parameters include the *time-to-first fix* (TTFF), which is the receiver warm-up time (i.e. the period between the start of signal acquisition and the availability of an acceptable navigation solution), the *navigation solution* rate (which is the frequency of update of navigation solution based on new data), *timing accuracy*, *velocity accuracy* and *maximum outage time* (the maximum acceptable level of outage without impacting on availability). Environmental constraints identified to impact on performance include *service coverage area*, *satellite masking angle* and *level of multipath induced errors*.

Several mass market applications have been identified to benefit from Galileo services either directly (supported by the Galileo system) or indirectly (supported through the combined use of the Galileo system with other sensors (e.g. inertial navigation systems) and systems (e.g. GPS). Mass market areas of application include (but are not limited to) *land-based transport, leisure, surveying/geodesy*, *meteorological forecasting*, *oil & gas exploration*, *GIS & mapping*, *asset management*, *construction & civil engineering*, *precision agriculture*, *fisheries*, *environment*, *mining and geodynamics*. Other key areas of application cover safety-of-life requirements within *aviation*, *rail*, *maritime* and *land-based* applications.

3.2 Proposed Galileo service types

The system is proposed to support the user navigation requirements through five different access modes or service types:

a) *Open Access Service (OAS)* - for mass-market applications.
b) *Controlled Access Service 1 (CAS 1)* - for professional market applications.
c) *Safety-of-life Access Service (SAS)* - for safety of life applications.
d) *Government Access Service (GAS)* - for government (secure) applications.
e) *Time Transfer Service (TTS)* - for timing requirements.

3.3 High level system description

The user requirements have been translated into a high-level Galileo system decomposition into three basic components (Ochieng *et al*., 2001):

f) *Global* **-** includes a space segment that provides a navigation signal-in-space (SIS) worldwide. A network of tracking stations referred to as the Orbitography and Synchronisation Stations (OSS) continually track the Galileo satellites and transmit the data to the Orbitography and Synchronisation Processing Facility (OSPF). The OSPF uses the tracking data to determine the satellite navigation parameters, including ephemerides, clock parameters and the corresponding quality indicators referred to as the signal-in-space accuracy (SISA). This information is then sent to the Uplink Station (ULS) via the Global Uplink Interface (GUI) for uplink to the Galileo satellites. The possibility of providing integrity at two levels, through receiver autonomous integrity monitoring (RAIM) and based on an independent network of monitoring stations via a dedicated Galileo Integrity Channel (GIC), is to be considered for the global component.
g) *Regional* **-** provides specific services regionally, such as integrity monitoring using the space segment of Galileo, plus a regional integrity monitoring network. The regional integrity monitoring network uses a network of Receiver Integrity Monitoring Stations (RIMS) to track the Galileo satellites and to verify the SISA data for each satellite from the global network. A failure in the verification process results in the generation of an integrity flag which must be transmitted to the user within the time-to-alarm budget.
h) *Local* **-** provides specific local services, for example enhanced navigation solution using a local differential navigation capability.

The Galileo space segment consists of a constellation of Medium Earth Orbit Satellites (MEO) and Geostationary Satellites (GEO). Two primary versions have been proposed: either 21 MEO plus 3 GEO or 36 MEO plus 9 GEO. The configuration of the constellation is given below.

- 21-36 MEOs + 3-9 GEOs
- MEOs are in 3 orbital planes
- 57 degree orbital inclination to celestial equator
- Altitude of 23000 km

Figure 2 shows the overall system structure of Galileo. It consists of a satellite constellation of MEOs and GEOs, satellite control centres and Galileo Wide Area Network which will provide high integrity and accuracy improvement.

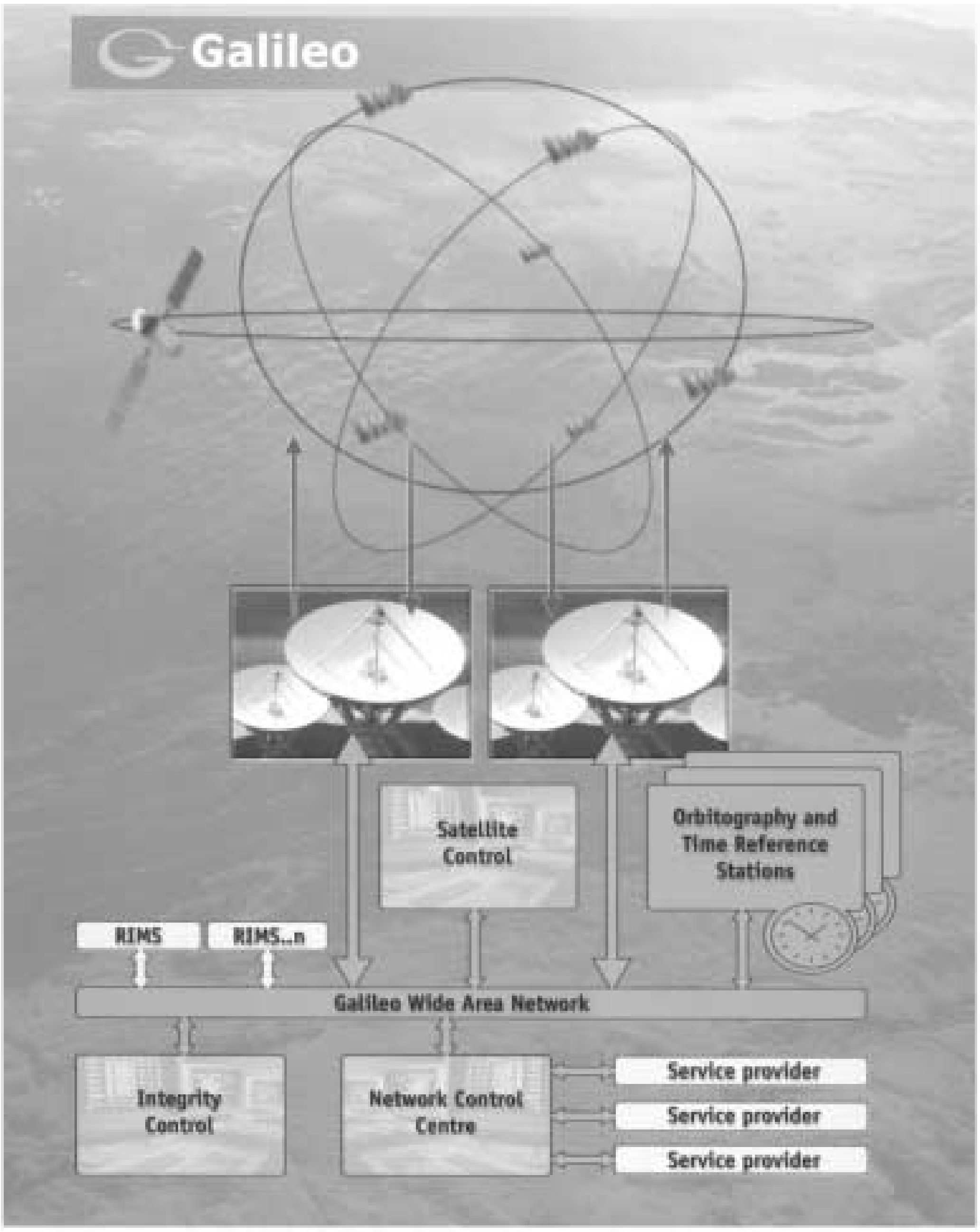

Figure 2 Overall Structure of the Galileo System (Courtesy from the ESA GNSS brochure)

4 Conclusions

This paper has presented a high-level description of the Galileo architecture and reviewed the programmatic issues involved in the development of the Galileo system. It is widely expected that the European Council, when it meets in December, will give the go-ahead for the realisation of the system. A key question then is how Galileo will relate to the other systems either already in operation (GPS and GLONASS) or those currently under development (GNSS1). Some of these issues have been addressed in some of the papers listed in the reference section.

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