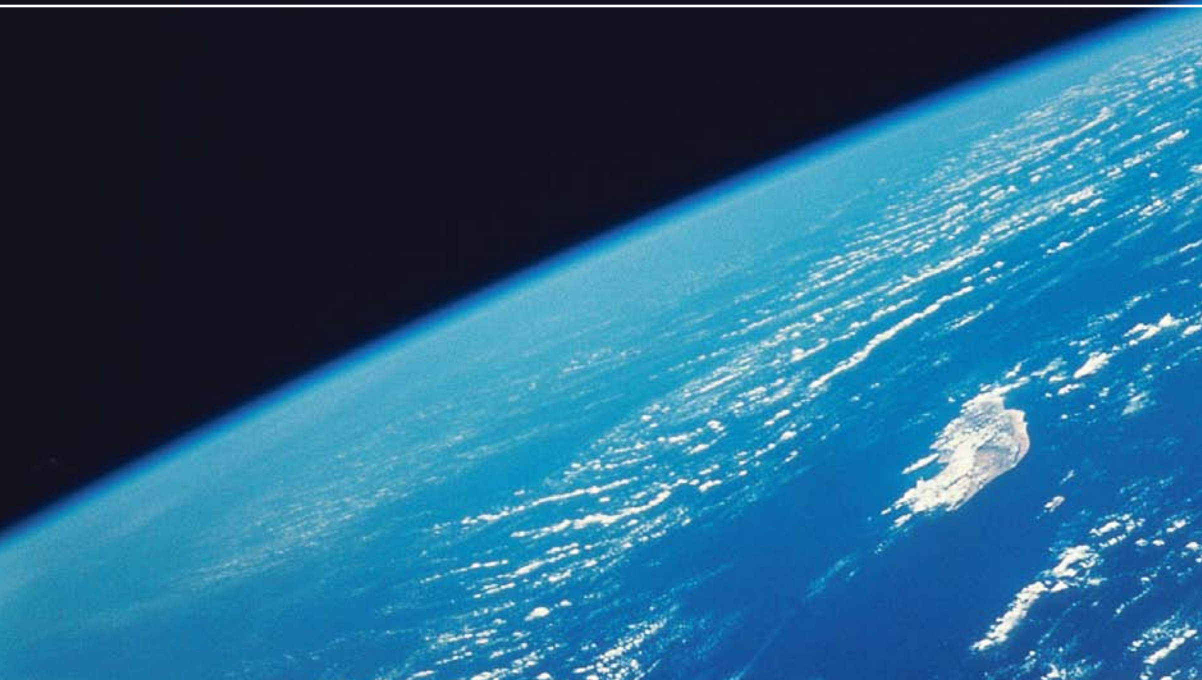
UNITED NATIONS
OFFICE FOR OUTER SPACE AFFAIRS

Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems

International Committee on Global Navigation Satellite Systems Provider's Forum



ICG International Committee on
Global Navigation Satellite Systems

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of the
International Committee on Global Navigation Satellite Systems Providers' Forum

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Preface

This report was produced by the Office for Outer Space Affairs of the United Nations, in its capacity as executive secretariat of the International Committee on Global Navigation Satellite Systems (ICG), on the basis of reports submitted by the members of the ICG Providers' Forum on their planned or existing systems and on the policies and procedures that govern the service they provide.

The purpose of this publication is to provide the user community and receiver-producing industry with a clear and consistent description of the global and regional systems that are currently operating and that will operate in the future. In order to reflect changes that will take place in the future, the publication will be updated as necessary. Readers should go to the website of ICG (www.icgsecretariat.org) for further information. The executive secretariat of ICG welcomes any suggestions on how to develop this document for the benefit of the global navigation satellite systems community.

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I. United States
The Global Positioning System and the Wide-Area Augmentation System

System description

Space segment

Global Positioning System constellation

The global positioning system (GPS) baseline constellation consists of 24 slots in six orbital planes, with four slots per plane. Three of the slots are expandable and can hold no more than two satellites. Satellites that are not occupying a defined slot in the GPS constellation occupy other locations in the six orbital planes. Constellation reference orbit parameters and slot assignments as of the defined epoch are described in the fourth edition of the GPS Standard Positioning Service Performance Specification, dated September 2008. As of that date, the GPS constellation had 30 operational satellites broadcasting healthy navigation signals: 11 in Block IIA, 12 in Block IIR and 7 in Block IIR-M.

Wide-Area Augmentation System

The Wide-Area Augmentation System (WAAS) currently relies on the service of two leased geostationary satellites positioned at 107° W latitude and 133° W longitude. On 3 April 2010, the telemetry tracking and control system on the Intelsat satellite (positioned at 133° W longitude) failed. Mitigation efforts are under way to ensure that dual coverage requirements are met over the long term. The objective of this System is to provide a user receiver with at least two geostationary satellites in view during localizer performance vertical operations.

Ground segment

Operational control segment of the Global Positioning System

The GPS operational control segment consists of four major subsystems: a master control station, an alternate master control station, a network of four ground antennas and a network of globally distributed monitor stations. The master control station is located at Schriever Air Force Base, in Colorado, United States, and is the central control node for the GPS constellation. Operations are maintained 24 hours a day, seven days a week. The master control station is responsible for all aspects of constellation command and control, including the following:

- Routine satellite bus and payload status monitoring
- Satellite maintenance and anomaly resolution
- Management of signal-in-space performance in support of the GPS standard positioning service and precise positioning service performance standards
- Navigation message data upload operations as required to sustain performance in accordance with accuracy and integrity performance standards
- Detecting and responding to GPS signal-in-space failures

In September 2007, the GPS operational control segment was modernized by transitioning from a 1970s-era mainframe computer-based system at the master control station, to a contemporary, distributed system known as the "architecture evolution plan". In addition to improving launch and early orbit, anomaly resolution and disposal operations, the plan has resulted in:

- Increased capacity for monitoring GPS signals, from 96.4 to 100 per cent worldwide coverage with double coverage over 99.8 per cent of the world
- Increased worldwide commanding capability, from 92.7 to 94.5 per cent while providing nearly double the back-up capability

Ground segment of the Wide-Area Augmentation System

There are 38 wide-area reference stations throughout North America (in Canada, Mexico and the United States, including Alaska and Hawaii) and Puerto Rico. The Federal

Aviation Administration of the United States plans to upgrade the wide-area reference stations with receivers capable of processing the new GPS L5 signal.

Local-Area Augmentation System

The Local-Area Augmentation System is a ground-based augmentation system that was developed to provide precision-approach capability for categories I, II and III approach procedures. It is designed to provide multiple runway coverage at an airport for three-dimensional required navigation performance procedures and navigation for parallel runways with little space between them and "super-density" operations. The first certified ground system has been completed at Memphis International Airport, and a final investment decision regarding category-III capability is expected by 2012.

Nationwide Differential Global Positioning System

The Nationwide Differential Global Positioning System is a national positioning, navigation and timing utility operated and managed by the United States Coast Guard. It consists of 50 maritime sites, 29 inland sites and 9 waterway sites. The System provides terrestrial services to 92 per cent of the continental United States with 65 per cent receiving dual coverage. The System is used in surface and maritime transportation, agriculture, environmental and natural resource management, weather forecasting and precise positioning applications.

National continuously operating reference stations

The network of national continuously operating reference stations, coordinated by the National Geodetic Survey and tied to the National Spatial Reference System, consists of more than 1,300 sites operated by over 200 public and private entities, including academic institutions. Each site provides GPS carrier phase and code range measurements in support of three-dimensional centimetre-level positioning activities throughout the United States and its territories.

Current and planned signals

The L1 frequency, transmitted by all GPS satellites, contains a coarse/acquisition (C/A) code ranging signal with a navigation data message that is available for peaceful civilian, commercial and scientific use, and a precision P(Y) code ranging signal with a navigation data message available to users with valid cryptographic keys. GPS satellites also transmit a second P(Y) code ranging signal with a navigation data message on the L2 frequency.

The central focus of the GPS modernization programme is the addition of new navigation signals to the GPS constellation. The new signals are being phased in as new GPS satellites are launched to replace older ones.

The second civil signal, known as "L2C", has been designed specifically to meet commercial needs. When combined with L1 C/A in a dual-frequency receiver, the L2C signal enables ionospheric correction, improving accuracy. For professional users with existing dual-frequency operations, L2C signals deliver faster signal acquisition, enhanced reliability and greater operating range for differential applications. The L2C modulation also results in a signal that is easier to receive under trees and even indoors. This also supports the further miniaturization of low-power GPS chipsets for mobile applications. The first GPS IIR-M satellite featuring L2C capabilities was launched in 2005. Every GPS satellite fielded since then has included an L2C transmitter. As at January 2010, there are seven GPS satellites broadcasting L2C signals. Interface specification information for the L2C signal can be found on the website of the Los Angeles Air Force Base.[1]

The third civil signal, known as "L5", is broadcast in a radio band reserved exclusively for aviation safety services and radio navigation satellite services. With a protected spectrum, higher power, greater bandwidth and other features, the L5 signal is designed to support safety-of-life transportation and other high-performance applications. Future aircraft will use L5 signals in combination with L1 C/A (also in a protected band) to improve accuracy via ionospheric correction and robustness via signal redundancy. The use of L5 signals will increase capacity, fuel efficiency and safety in United States airspace, railroads, waterways and highways. When used in combination with L1 C/A and L2C, L5 will provide a very robust service that may enable sub-meter accuracy without augmentations and very long-range operations with augmentations. The operational L5 signal will launch with the follow-on series of GPS satellites, Block IIF, beginning in 2010. Interface specification information on the L5 signal can be found on the website of the Los Angeles Air Force Base.[2]

[1] www.losangeles.af.mil/shared/media/document/AFD-081021-035.pdf.

[2] www.losangeles.af.mil/shared/media/document/AFD-081021-036.pdf.

The fourth civil signal, known as "L1C", has been designed to enhance interoperability between GPS and international satellite navigation systems. The United States and the European Union originally developed L1C as a common civil signal for GPS and the European Satellite Navigation System (Galileo). It features a multiplexed binary offset carrier (MBOC) waveform designed to improve mobile reception in cities and other challenging environments. Other satellite navigation systems, such as Japan's Quasi-Zenith Satellite System (QZSS) and China's Compass/BeiDou system, also plan to broadcast signals similar to L1C, enhancing interoperability with GPS. The United States will launch its first L1C signal with GPS III in 2014. L1C will broadcast at the same frequency as the original L1 C/A signal, which will be retained for backwards compatibility. Interface specification information for the L1C signal can be found on the website of the Los Angeles Air Force Base.[3]

System time and geodetic reference frame standards

The standard positioning service signal-in-space navigation message contains offset data for relating GPS time to Coordinated Universal Time (UTC) as maintained at the United States Naval Observatory. During normal operations, the accuracy of this offset data during the transmission interval is such that the UTC offset error in relating GPS time (as maintained by the control segment) to UTC (as maintained by the Naval Observatory) is within 40 nanoseconds 95 per cent (20 nanoseconds 1-sigma).[4]

The geodetic reference system used by un-augmented GPS is the World Geodetic System 1984 (WGS-84).[5] The most recent WGS-84 reference frame and the International Terrestrial Reference Frame are in agreement to better than 6 cm.

Performance standards versus actual performance

Since GPS initial operational capability in 1993, actual GPS performance has continuously met and exceeded minimum performance levels specified in the Standard Positioning

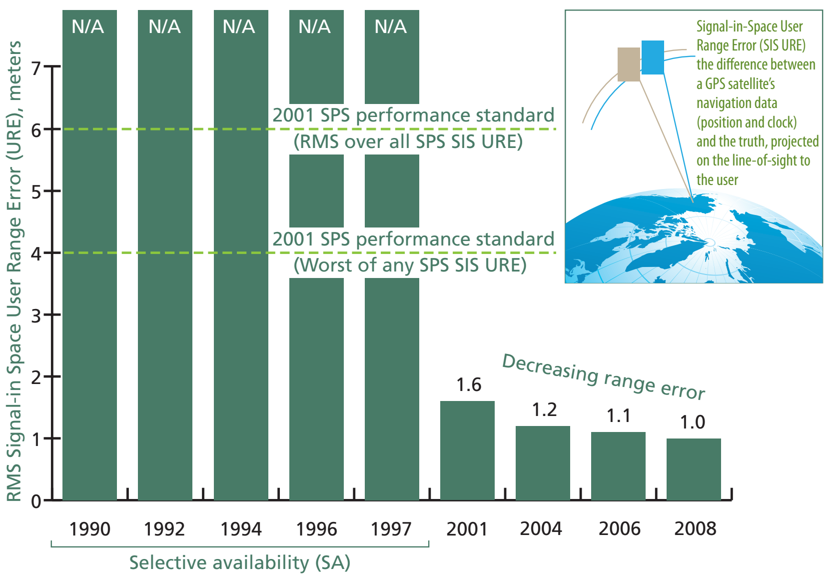
[3] www.losangeles.af.mil/shared/media/document/AFD-081021-034.pdf.

[4] www.losangeles.af.mil/shared/media/document/AFD-081021-035.pdf.

[5] United States of America, Department of Defense, *World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems*. Available from http://earth-info.nga.mil/GandG/publications/tr8350.2/wgs84fin.pdf.

Service Performance Standards. Users can generally expect to see improved performance over the minimum performance specifications. For example, with 2008 signal-in-space accuracy, well-designed GPS receivers were achieving horizontal accuracy of 3 m or better and vertical accuracy of 5 m or better, 95 per cent of the time. Improvements in signal-in-space user range error performance over time, compared with the published performance standard, are shown below (see figure I).

Figure I. **GPS signal-in-space accuracy exceeds the published performance standard**



Timetable for system deployment and operation

The schedule for GPS modernization is shown below:

"L2C" civil signal

- Available since 2005 without data message
- Phased roll-out of civil navigation message starting in 2009
- 24 satellites by 2016

"L5" civil signal	• First launch in 2009 • 24 satellites by 2018
"L1C" civil signal	• Launches with GPS III in 2014 • 24 satellites by 2021
Ground segment	• Ongoing upgrades synchronized with satellite modernization

Services provided and provision policies

GPS provides two levels of service: a standard positioning service, which uses the C/A code on the L1 frequency, and a precise positioning service, which uses the C/A code on the L1 frequency and the P(Y) code on both the L1 and L2 frequencies. Authorized access to the precise positioning service is restricted to the United States Armed Forces, federal agencies and selected allied armed forces and governments. The standard positioning service is available to all users worldwide on a continuous basis and without any direct user charge. The specific capabilities provided by the GPS open service are published in the GPS Standard Positioning Service Performance Standards. The United States Department of Defense, as the operator of GPS, will continue enabling codeless/semi-codeless GPS access until 31 December 2020, by which time the L2C and L5 signals will be available on at least 24 modernized GPS satellites.

United States space-based positioning, navigation and timing policy

The current United States space-based positioning, navigation and timing policy, signed by the President in December 2004, establishes the goal of ensuring that the United States maintains space-based positioning, navigation and timing services, as well as augmentation, back-up and service denial capabilities that do the following:

- Provide uninterrupted availability of positioning, navigation and timing services
- Meet growing national, homeland, economic security and civil requirements, and scientific and commercial demands
- Remain the pre-eminent military space-based positioning, navigation and timing service

- Continue to provide civil services that exceed or are competitive with foreign civil space-based positioning, navigation and timing services and augmentation systems

- Remain essential components of internationally accepted positioning, navigation and timing services

- Promote United States technological leadership in applications involving space-based positioning, navigation and timing services

The policy promotes the global use of GPS technology through the following key provisions:

- No direct user fees for civil GPS services

- Open and free access to the information necessary to develop and build equipment

- Performance improvements for United States space-based positioning, navigation and timing services

- Promotion of GPS standards

- International compatibility and interoperability for the benefit of end-users

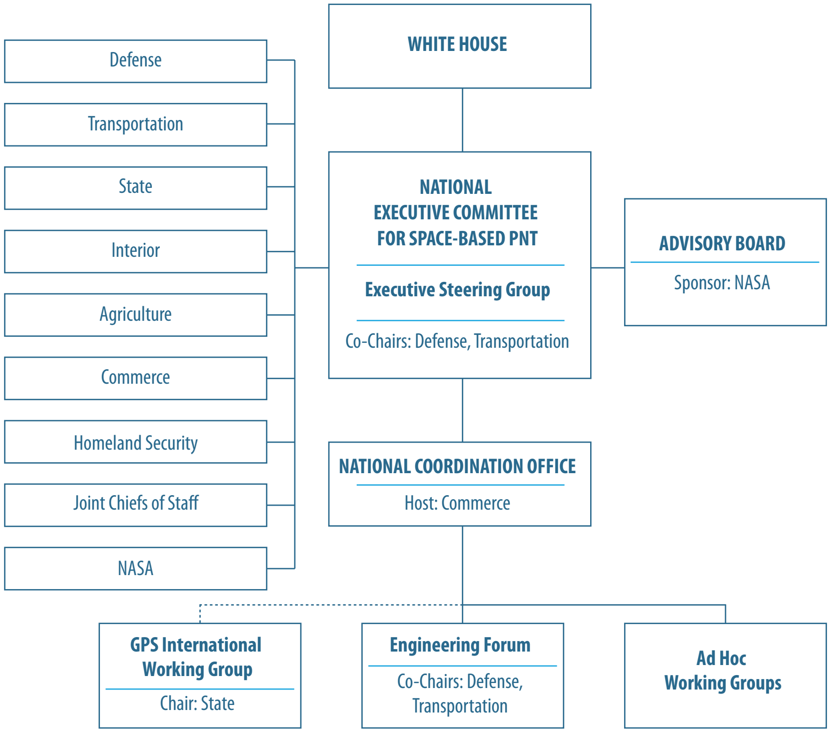
- Protection of the radio-navigation spectrum from disruption and interference

- Recognition of national and international security issues and protection against hostile use

- Civil agency responsibility to fund new, uniquely civil GPS capabilities

In addition, the National Executive Committee for Space-based Positioning, Navigation and Timing was established. The Committee is an inter-agency advisory body that is co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation. The United States national space-based positioning, navigation and timing management structure is shown in figure II.

Figure II. **United States national space-based positioning, navigation and timing management structure**



Perspective on compatibility and interoperability

Definition of compatibility and interoperability

The United States pursues compatibility and interoperability through bilateral and multilateral means. United States objectives in working with other GNSS service providers include:

- Ensuring compatibility, defined as the ability of United States and non-United States space-based positioning, navigation and timing services to be used separately or together without interfering with each individual service or signal, involving both radiofrequency compatibility and spectral separation between M-code and other signals

- Achieving interoperability, defined as the ability of civil United States and non-United States space-based positioning, navigation and timing services to be used together to provide the user with better capabilities than would be achieved by relying solely on one service or signal, with the primary focus on the common L1C and L5 signals

- Ensuring fair, market-driven competition in the global marketplace

International cooperation to ensure compatibility and pursue interoperability

In addition to participating in ICG, the Asia-Pacific Economic Cooperation forum and the International Telecommunication Union (ITU), as well as standard-setting bodies such as the International Civil Aviation Organization (ICAO) and the International Maritime Organization, the United States pursues its international GNSS objectives through bilateral cooperation with other system providers as follows:

- With the European Union: in 2004 an agreement was reached providing the foundation for cooperation; a first plenary meeting was held in October 2008

- With Japan: regular policy consultations and technical meetings on GPS cooperation began in 1996, leading to the 1998 Clinton-Obuchi joint statement; both countries have benefited from a close relationship; the QZSS and the Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) are designed to be compatible and interoperable with GPS

- With the Russian Federation: a joint statement issued in December 2004 and technical discussions have been ongoing through working groups on compatibility and interoperability, and on search and rescue

- With India: policy and technical consultations on GPS cooperation have been under way since 2005; a joint statement on GNSS cooperation was issued in February 2007 in Washington, D.C.

Global navigation satellite system spectrum protection activities

National-level Radio-Navigation Satellite Service (RNSS) spectrum regulation and management procedures

In order to minimize domestic service disruptions and prevent situations threatening the safe and efficient use of GPS, any transmission on the GPS frequencies is strictly regulated through federal provisions. Within the United States, two regulatory bodies oversee the use of the radiofrequency spectrum. The Federal Communications Commission is responsible for all non-federal use of the airwaves, while the National Telecommunications and Information Administration manages spectrum use for the federal Government. In that capacity, the National Telecommunications and Information Administration hosts the Interdepartment Radio Advisory Committee, a forum consisting of executive branch agencies that act as service providers and users of the Government spectrum, including safety-of-life bands. The broadcast nature of radio-navigation systems also provides a need for United States regulators, through the Department of State, to go beyond domestic boundaries and coordinate with other States through such forums as that provided by ITU.

RNSS interference detection and mitigation plans and procedures

The United States Department of Homeland Security developed and published, in August 2007, the National Positioning, Navigation, and Timing Interference Detection and Mitigation Plan and, in January 2008, the National Interference Detection and Mitigation Plan Implementation Strategy to establish procedures and techniques to identify interferences and provide guidance for mitigating and resolving, in a timely manner, such events so that positioning, navigation and timing services could be restored quickly. These documents provide a framework and guidance from which to execute the responsibilities required to fulfil the directives of the United States space-based positioning, navigation and timing policy.

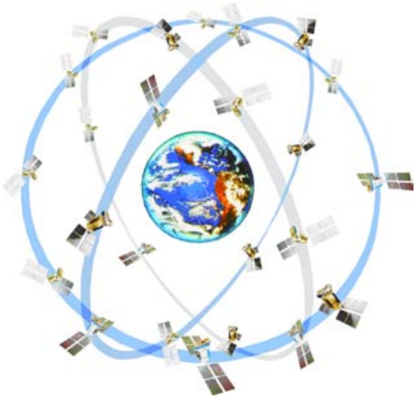
II. Russian Federation
The Global Navigation Satellite System

System description

Space segment

The nominal baseline constellation of the Russian Federation's Global Navigation Satellite System (GLONASS) comprises 24 Glonass-M satellites that are uniformly deployed in three roughly circular orbital planes at an inclination of 64.8° to the equator. The altitude of the orbit is 19,100 km. The orbit period of each satellite is 11 hours, 15 minutes, 45 seconds. The orbital planes are separated by 120° right ascension of the ascending node. Eight satellites are equally spaced in each plane with 45° argument of latitude. Moreover, the orbital planes have an argument of latitude displacement of 15° relative to each other (see figure III).

Figure III. **GLONASS orbital constellation**



This constellation configuration provides for continuous, global coverage of the Earth's surface and near-Earth space by the navigational field and for minimizing the effect of disturbances on deformation of orbital constellation.

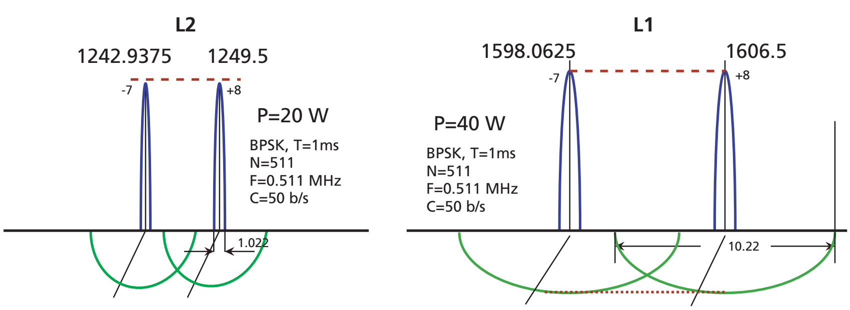
Ground segment

The GLONASS ground segment consists of a system control centre; a network of five telemetry, tracking and command centres; the central clock; three upload stations; two satellite laser ranging stations; and a network of four monitoring and measuring stations, distributed over the territory of the Russian Federation. Six additional monitoring and measurement stations are to start operating on the territory of the Russian Federation and the Commonwealth of Independent States in the near future.

Current and planned signals

Each GLONASS satellite transmits two types of navigation signals in two sub-bands of L-band: standard accuracy signal and high accuracy signal (see figure IV).

Figure IV. **GLONASS signals**



Existing signal characteristics are given below:

Signal polarization	Right-hand circular polarization
L1 carrier frequencies	1,598.06~1,604.40 MHz

L2 carrier frequencies	1,242.94~1,248.63 MHz
Superframe volume	7,500 bit
Superframe duration	2.5 minutes
Data rate	50 bps
Time marker iteration period	2 seconds

GLONASS uses the frequency division multiple access technique in both L1 and L2 sub-bands. The new code division multiple access (CDMA) signals will be introduced on the first "Glonass-K" satellite, whose launch is planned for 2010.

Performance standards versus actual performance

The document that defines requirements related to the interface between the space segment and the navigation user segment is the Interface Control Document (version 5.1, 2008). The main performance characteristics for GLONASS civil service are defined by the GLONASS Standard Positioning Service Performance Requirements. According to this document, for "Glonass-M" satellite constellation:

- The signal-in-space user range error value over any 24-hour interval for all healthy satellites should be less than or equal to 6.2 m, with a 0.95 probability when using open-service signals containing ephemeris and clock data transmitted by the operational constellation
- The position dilution of precision availability (the percentage of time over any 24-hour interval that position dilution of precision availability is less than or equal to 6 for the constellation of operational satellites) should be equal to or better than 98 per cent for the full 24-satellite constellation
- The corresponding real-time and absolute mode positioning accuracy in the state reference frame using signal-in-space only (neglecting user clock bias and errors due to propagation environment and receiver) and assuming position dilution of precision availability is equal to 2 should be 12.4 m over any 24-hour interval for any point within the service volume with 0.95 probability

According to the GLONASS performance monitoring conducted by the information and analysis centre for positioning, navigation and timing of the Central Scientific

Research Institute for Machine Building, which is a part of the Russian Federal Space Agency:

- Between 1 June and 25 October 2009, the signal-in-space user range error averaged 5.43 m for the constellation of operational and healthy satellites
- Position dilution of precision availability (position dilution of precision availability < 6, elevation mask angle > 5°) is 87 per cent for the 17-satellite constellation

Once the full 24-satellite constellation has been deployed, the GLONASS position dilution of precision availability (position dilution of precision availability < 6, elevation mask angle > 5°) is expected to reach 99.99 per cent.

Timetable for system deployment and operation

In accordance with the launch schedule, the baseline 24-satellite constellation will be deployed in 2010, after which time it will be maintained at that level by means of group- or single-profile launch events.

The next generation of "Glonass-K" spacecraft is expected to enter the flight demonstration phase at the end of 2010.

The ground control segment is expected to be extended and modernized by increasing the number of measuring and monitoring stations to 10.

The system will be deployed and operated in the framework of the federal GLONASS mission-oriented programme for the period 2002–2011. The programme is expected to be extended through 2020.

Services provided and provision policies

GLONASS satellites broadcast two types of navigation signals in L1 and L2 frequency bands: the standard positioning signal and the high accuracy positioning signal. The standard positioning signal is available to all users for free. The high accuracy positioning signal is modulated by special code and is used for special applications.

Perspective on compatibility and interoperability

Definition of compatibility and interoperability

Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference or other harm to an individual system or service.

- GNSS compatibility is mainly defined by radiofrequency compatibility of navigation signals
- ITU provides procedures for resolving radiofrequency signal incompatibility
- ICG recommends that new signals avoid spectral overlap between each system's authorized service signals and the signals of other systems
- Recognizing that spectral separation of authorized service signals and other systems' signals is not, in practice, always feasible and that such overlap exists now and might continue to do so in the future, stakeholders (providers concerned) should try to resolve those issues through consultations and negotiations

Interoperability refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together so as to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system.

- Interoperability of systems and augmentations and their services is provided by interoperability of signals, geodesy and time references
- Signal interoperability depends on the user market. Both common and separated central frequencies of navigation signals are essential:
    - Signals with common central frequencies minimize cost, mass, size and power consumption of the user equipment
    - Signals with separate central frequencies provide better reliability and robustness of the navigation service

- All GNSS geodesy reference systems should, to the greatest extent possible, be coordinated; the Parametri Zemli 1990 (PZ-90) used in GLONASS will continue to be improved in the future
- All national and system UTC realizations should, to the greatest extent possible, be coordinated with the international standard of UTC; GLONASS timescale will continue to be improved in the future
- Co-location of ground control segment monitoring stations of different GNSS is important to provide geodesy and time interoperability

International cooperation to ensure compatibility and pursue interoperability

The Russian Federation has cooperated with the following:

- The United States, on GLONASS-GPS compatibility
- The European Space Agency, on GLONASS-Galileo compatibility and interoperability
- ICG and its Providers' Forum

III. European Union
The European Satellite Navigation System and the European Geostationary Navigation Overlay Service

System description: the European Satellite Navigation System

Space segment

The space segment comprises the European Satellite Navigation System (Galileo) satellites, which function as "celestial" reference points, emitting precisely time-encoded navigation signals from space. The nominal Galileo constellation comprises a total of 27 satellites, which are evenly distributed among three orbital planes inclined at 56° relative to the equator. There are nine operational satellites per orbital plane, occupying evenly distributed orbital slots. Three additional spare satellites (one per orbital plane) complement the nominal constellation configuration. The Galileo satellites are placed in circular Earth orbits with a nominal semi-major axis of about 30,000 km and an approximate revolution period of 14 hours.

Ground segment

The Galileo ground segment controls the Galileo satellite constellation, monitoring the health status of the satellites, providing core functions of the navigation mission (satellite orbit determination, clock synchronization), determining the navigation messages and providing integrity information (warning alerts within time-to-alarm requirements) at the global level, and uploading those navigation data for subsequent broadcast to users.

The key elements of those data, clock synchronization and orbit ephemeris, will be calculated from measurements made by a worldwide network of reference sensor stations.

The current design of the system includes 30–40 sensor stations, five tracking and command centres and nine mission uplink stations.

Current and planned signals

Galileo will transmit radio-navigation signals in four different operating frequency bands: E1 (1559~1594 MHz), E6 (1260~1300 MHz), E5a (1164~1188 MHz) and E5b (1195~1219 MHz).

Galileo E1

The Galileo E1 band is centred at 1575.42 MHz. It comprises two signals that can be used alone or in combination with signals in other frequency bands, depending on the performance demanded by the application. The signals are provided for the open service and the public regulated service, both of which include a navigation message. Moreover, an integrity message for the safety-of-life service is included in the open service signal. The E1 carrier is modulated with a CBOC (6,1,1/11) (following the MBOC spectrum) code for the open source and a BOCcos (15,2,5) code for the public regulated service.

Galileo E6

The Galileo E6 signal is transmitted on a centre frequency of 1278.75 MHz and comprises commercial service and public regulated service signals, which are modulated with a binary phase shift keying (BPSK)(5) and BOCcos(10,5) code, respectively. Both signals include a navigation message and encrypted ranging codes.

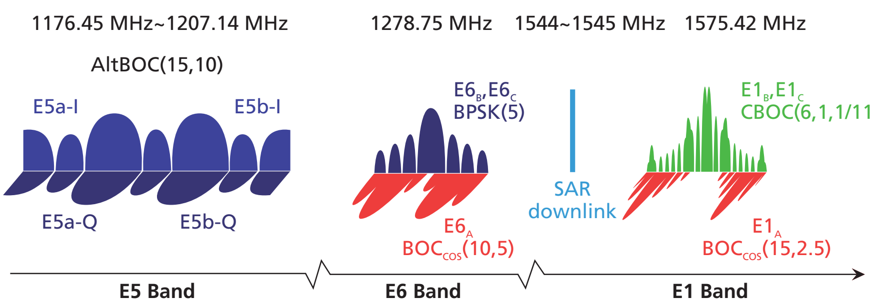
Galileo E5

The wideband Galileo E5 signal is centred on a frequency of 1191.795 MHz and is generated with an AltBOC modulation of side-band sub-carrier rate of 15.345 MHz. This scheme provides two side lobes. The lower side lobe of E5 is called the Galileo E5a signal, which is centred on a frequency of 1176.45 MHz and provides a second signal (dual frequency reception) for the open service and safety-of-life services, both of which include navigation data messages. The upper side lobe of E5 is called the Galileo E5b signal, which is centred on a frequency of 1207.14 MHz and provides a safety-of-life service, including a navigation message with an integrity information message.

Search and rescue

The search-and-rescue downlink signal is transmitted by the Galileo satellites in the frequency range of between 1544 and 1545 MHz. Figure V shows the frequency ranges of the Galileo signals.[6]

Figure V. **Frequency ranges of the Galileo signals**



Performance standards versus actual performance

Galileo open service

The Galileo open service aims at making positioning, navigation and timing services widely available, free of charge.

The target Galileo open-service positioning, navigation and timing accuracy performances are specified as the ninety-fifth percentile of the positioning, navigation and timing error

[6] A description of Galileo signals is available from www.gsa.europa.eu/go/galileo/os-sis-icd/galileo-open-service-signal-in-space-interface-control-document.

distribution for different user types and take into account any type of error, including those not under the responsibility of the Galileo system. Hence, the target positioning, navigation and timing performance specifications are subject to several assumptions on the user terminal and local environment: clear sky visibility, absence of radiofrequency interference, reduced multipath environment, mild local ionospheric conditions, absence of scintillations and fault-free user receiver.

Table 1 provides an overview of the Galileo open-service target positioning, navigation and timing performance specifications.

Table 1. **Galileo open-service target positioning, navigation and timing performance specifications**

Performance specification	*Single frequency open service user (E1)*	*Dual frequency open service user (E1-E5b)*
Horizontal accuracy (95 per cent)	15 m	4 m
Vertical accuracy (95 per cent)	35 m	8 m
Timing accuracy (95 per cent)	..	30 ns (wrt UTC)
Galileo open-service availability (averaged over the lifetime of the system)	99.5 per cent	99.5 per cent

Galileo safety-of-life service

The Galileo safety-of-life service complements the dual frequency (E1-E5b) Galileo open service by providing a global integrity service for critical safety applications that is compliant with the ICAO LPV200[7] definition. The target positioning, navigation and timing performance of the Galileo safety-of-life service is summarized in table 2.

[7] Precision approach with vertical guidance with 200-foot decision height.

Table 2. **Galileo safety-of-life integrity service-level specification**

Horizontal alarm limit	40 m
Vertical alarm limit	35 m
Integrity risk	2×10^{-7} in any 150 seconds
Continuity risk	8×10^{-6} per 15-second period
Time to alarm	6 seconds

Galileo search-and-rescue service

The Galileo search-and-rescue service complements the current International Satellite System for Search and Rescue (COSPAS-SARSAT) service by performing detection and localization of COSPAS-SARSAT distress beacons and by providing a return link capability for distress beacons fitted with Galileo open-service receivers. The Galileo search-and-rescue service will be provided free of charge.

The localization accuracy performance of the Galileo search-and-rescue service is expected to be better than 100 m (95 per cent) for COSPAS-SARSAT beacons fitted with Galileo receivers and better than 5 km (95 per cent) for legacy COSPAS-SARSAT beacons.

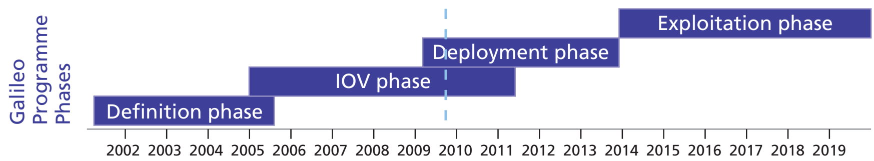
Galileo standalone provides Galileo search-and-rescue service coverage in the European territories and associated search-and-rescue areas of responsibility of all of the European Union and European Space Agency member countries.

Timetable for system deployment and operation

The deployment phase of the Galileo system includes the “in-orbit validation phase” and the “fully operational capability deployment phase”. It is expected that the in-orbit validation phase will be completed in 2011 and that it will comprise four satellites and an appropriate in-orbit validation ground segment. The procurement of the fully operational capability of Galileo is under way and commercial entities have been requested to participate in a bid on the basis of a target schedule for fully operational capability completion by 2014 (27 operational and three spare in-orbit) satellites and a full-ground segment. A phased approach to the introduction of services will be adopted, as the Galileo space and ground segments are deployed. Details of the contracted schedule and associated deployment details will be provided by the European Union as soon as the industrial contracts have been signed.

Two pre-operational Galileo satellites (GIOVE-A and GIOVE-B) are already transmitting signals in all three frequency bands (E1, E5 and E6). More information is available from www.giove.esa.int.

Figure VI. **Galileo global infrastructure and services**



System description: European Geostationary Navigation Overlay Service

The European Geostationary Navigation Overlay Service (EGNOS) provides an augmentation signal to the GPS standard positioning service. The EGNOS signal is transmitted on the same signal frequency band and modulation as the GPS L1 (1575.42 MHz) C/A civilian signal function. While the GPS consists of positioning and timing signals generated from spacecraft orbiting the Earth, thus providing a global service, EGNOS provides correction and integrity information intended to improve positioning navigation services over Europe.

Space segment

The EGNOS space segment consists of three navigation transponders onboard three geostationary satellites and broadcasting corrections and integrity information for GPS satellites in the L1 frequency band (1575.42 MHz). At the date of issue of this publication, the following three geostationary satellites were being used by EGNOS:

Name of geostationary satellite	*PRN number*	*Orbital slot*
INMARSAT AOR-E	PRN 120	15.5 W
INMARSAT IOR-W (F5)	PRN 126	25.0 E
ARTEMIS	PRN 124	21.5 E

Ground segment

The EGNOS ground segment is mainly composed of a network of ranging integrity monitoring stations, four mission control centres, six navigation land Earth stations and the EGNOS wide-area network, which provides the communication network for all the components of the ground segment. Two additional facilities, the performance assessment and system checkout facility and the application specific qualification facility, are also deployed as part of the ground segment to support system operations and service provision.

Current and planned signals

The EGNOS signal-in-space format complies with ICAO standards and recommended practices for satellite-based augmentation systems.

Performance standards versus actual performance

EGNOS open service

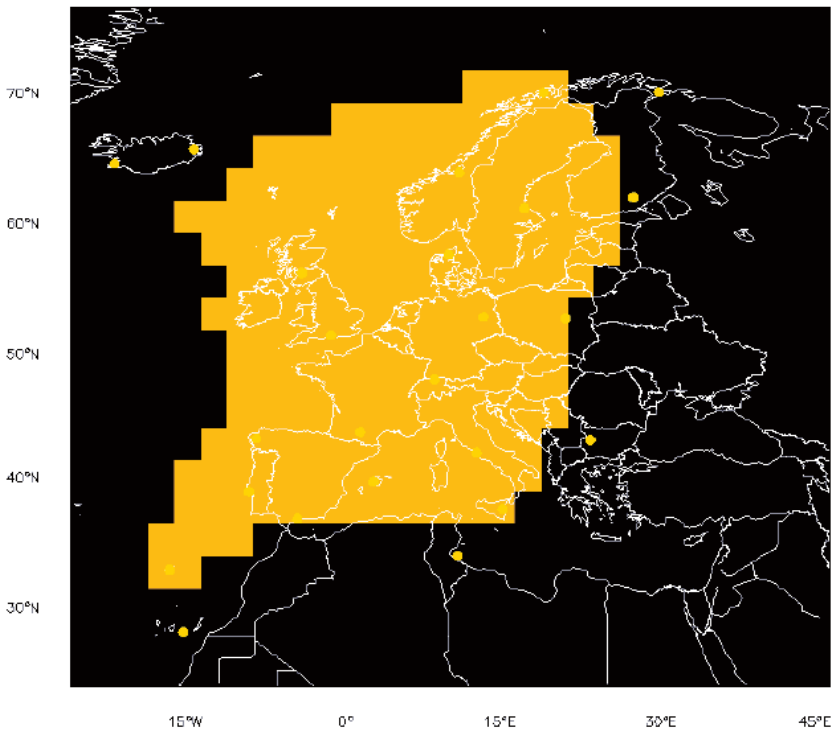
The main objective of the EGNOS open service is to improve the achievable positioning accuracy by correcting several sources of errors affecting GPS signals.

The accuracy achievable with the EGNOS open service is specified as the ninety-fifth percentile of the error distribution. The performance specifications, which are indicated below, assume a user terminal compliant with RTCA MOPS DO229 Class 3 specifications and clear-sky visibility of 5° above the local horizontal plane:

Horizontal accuracy (95 per cent)	3 m
Vertical accuracy (95 per cent)	4 m

The EGNOS open service area is defined as the region where the EGNOS open service positioning performance as defined above is available at least 99 per cent of the time. The EGNOS open service area is shown in figure VII below:

Figure VII. **EGNOS open service area**



The typical measured positioning accuracy in the middle of the EGNOS open service area is significantly better than the specification provided above (around 1 m (95 per cent) vertical accuracy).

EGNOS safety-of-life service

The main objective of the EGNOS safety-of-life service is to support civil aviation applications up to localizer-performance-with-vertical-guidance operations.

EGNOS safety-of-life service provides two different levels of integrity service compliant with the ICAO definitions for non-precision approach and vertical guidance approach. Figures VIII and IX show the qualified EGNOS safety-of-life service areas for several levels of availability.

Figure VIII. **EGNOS safety-of-life service: non-precision approach service coverage (99.9 per cent availability)**

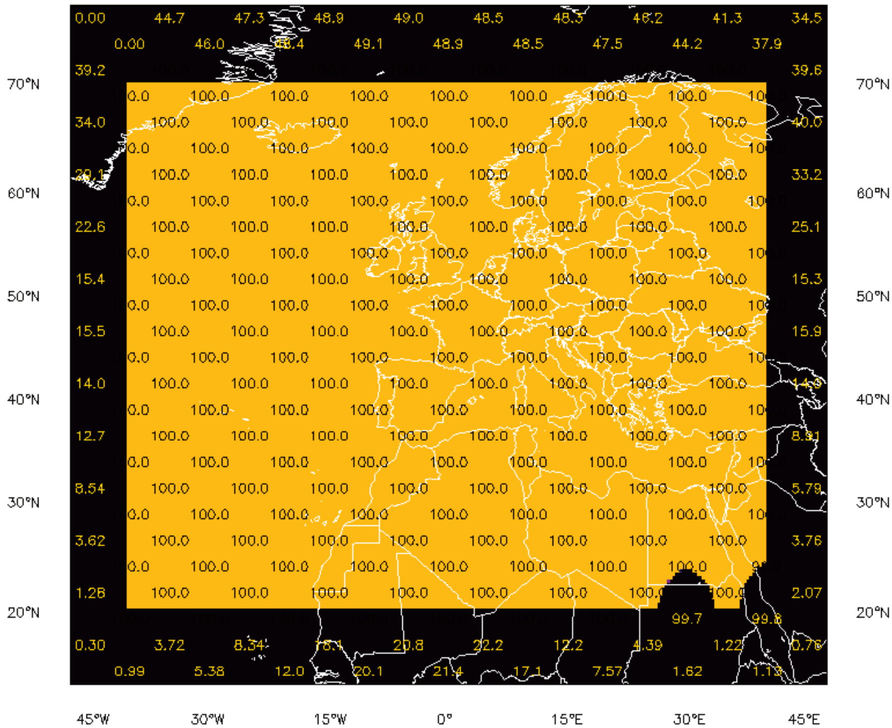
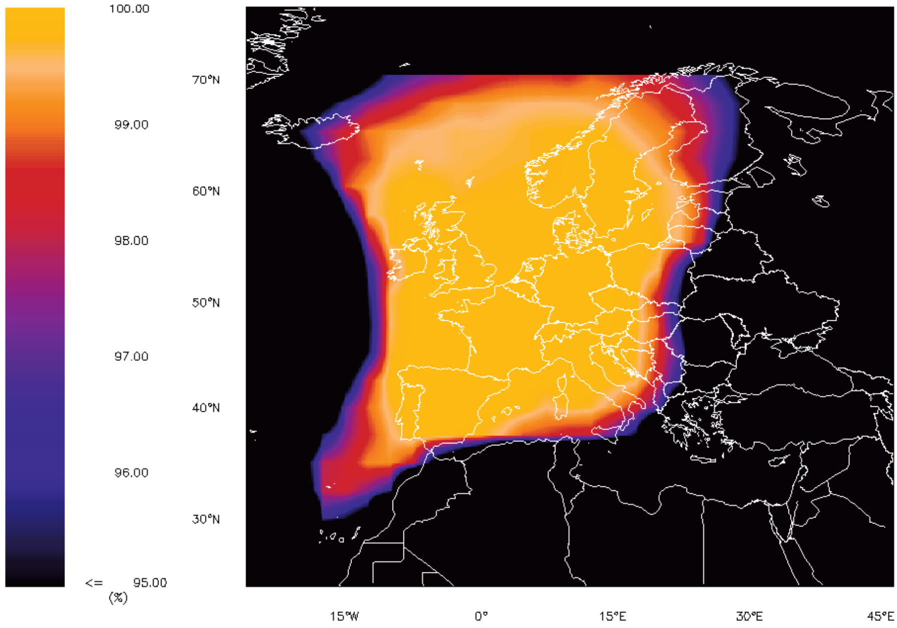


Figure IX. **EGNOS safety-of-life service: vertical guidance approach service coverage (95-100 per cent availability)**



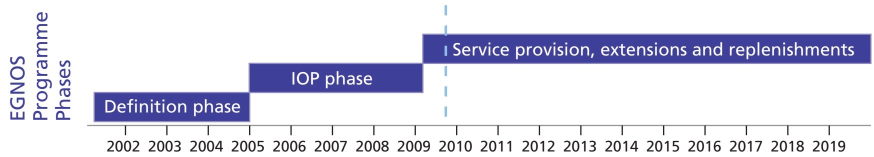
EGNOS timing service

In order to support timing applications, the EGNOS system transmits specific corrections that make it possible to trace "EGNOS Network Time" to the physical realization of UTC by the Observatoire de Paris.

Timetable for system deployment and operation

The EGNOS open service was declared operational on 1 October 2009 and it is planned that the EGNOS safety-of-life service will enter into service in mid-2010, following certification. It is also planned that testing of the EGNOS Data Access Service will be concluded in 2010. The timetable for EGNOS regional infrastructure and services is shown in figure X.

Figure X. **EGNOS regional infrastructure and services**



Services provided and provision policies

Galileo

The specific objectives of the Galileo programme are to ensure that the signals emitted by the satellites can be used to provide the following services:

- An *open service* that is available to all, free of charge, and that provides positioning and synchronization information. The accuracy in positioning achievable with monofrequency (open-service) receivers—without augmentation—will be better than 15 m in the horizontal dimension and better than 35 m in the vertical dimension. However, the accuracy in positioning achievable with dual-frequency receivers will be increased to better than 4 m (horizontal) and 8 m (vertical)
- A *safety-of-life service* aimed at users for whom safety is essential. This service also fulfils demanding requirements for service continuity, availability and accuracy and includes integrity data alerting users to any failure of the system
- A *commercial service*, including the availability of limited capacity data broadcasting on which a programme decision on the precise implementation is still to be taken
- A *publicly regulated service* for Government-approved use in sensitive applications that require a high level of robustness, especially where the delivery of other services is denied. The publicly regulated service uses encrypted signals
- A *search-and-rescue service*, provided in close connection and collaboration with COSPAS-SARSAT. This service will improve the detection of emergency signals emitted by beacons, relaying those messages to COSPAS-SARSAT ground infrastructure and broadcasting a response back to the beacon. The time needed to

transfer the return link message from the operational search-and-rescue ground segment to the user shall be less than 15 minutes

EGNOS

EGNOS delivers three services: an open service, a safety-of-life service and a commercial service.

Open service. In October 2009, EGNOS reached a milestone as the European Union declared the EGNOS open service to be ready, demonstrating the maturity of the development and qualification of EGNOS. For several months now, the EGNOS signal, of excellent quality, has been transmitted over Europe, allowing the augmentation of GPS by EGNOS to reach accuracies of between 1 m and 2 m, with an availability greater than 99 per cent. The declaration made in October 2009 marks an opportunity for the European Union to advertise the availability, at no cost, of such a well-performing service, one that it is here to stay for the long term. The EGNOS open service is accessible to any user equipped with a receiver that is compatible with GPS satellite-based augmentation systems within the EGNOS open service area in Europe. No authorization or receiver-specific certification is required to access and use the EGNOS open service, which opens the doors for GNSS receiver manufacturers and GNSS application developers to fully tailor the use of the EGNOS signal according to their needs and to benefit from the performance improvements provided by EGNOS at no additional cost.

Safety-of-life service. The second milestone is to be achieved in 2010, once the EGNOS service provider has been certified and once the European Union has declared the safety-of-life service to be ready. The certification procedure is being organized, in compliance with the Single European Sky initiative, by the French national supervisory authority, on behalf of the European Union. Only after certification will the EGNOS safety-of-life service be available for use in civil aviation applications, in particular for "en route to non-precision approach" and "vertical guidance approach" operations. The European Union intends to keep improving EGNOS performance and extending the geographic coverage of EGNOS services for all modes of transport, including maritime and land-based vehicles that might require more stringent augmentation requirements.

Commercial service. The EGNOS Commercial Data Distribution Service provides authorized customers (e.g. added-value application providers) of the following EGNOS products for their commercial distribution: *(a)* all EGNOS augmentation messages in real time (including satellite clocks and ephemeris corrections, propagation corrections and integrity information in the format of satellite-based augmentation systems); and *(b)* raw data from the network of ranging integrity monitoring stations in real time (including high-precision satellite pseudorange measurements). Those products are accessible via the EGNOS Data Access Service.[8] The EGNOS Commercial Data Distribution Service makes it possible to generate EGNOS post-processed products (to be provided through specific service providers connected to the EGNOS data server) in real time (including high-rate propagation corrections, EGNOS availability warnings, internal monitoring data, performance information, etc.)

Perspective on compatibility and interoperability

Definition of compatibility and interoperability

Compatibility is the ability of space-based positioning, navigation and timing services to be used separately or together without interfering with each individual service or signal, and without adversely affecting national security.

- ITU provides a framework for radiofrequency compatibility
- Respect of national security implies spectral separation between publicly regulated services and all other signals

Interoperability is the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together so as to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system with minimal additional receiver cost or complexity.

In order to achieve interoperability:

- Common centre frequency, common modulation and common maximum power levels, based on the same link budget assumptions, are necessary
- Highest minimum power level is desirable

[8] More details on the EGNOS Data Access Service are available from http://egnos-edas.gsa.europa.eu/edashd/php/.

- The availability of information on open signals characteristics (such as a public signal-in-space interface control document) is necessary
- Geodetic reference frames and system time references steered to international standards are necessary
- Performance standards and system architecture descriptions must be published

Efforts to ensure radiofrequency compatibility through bilateral and multilateral avenues

Galileo coordinates with other space-based positioning, navigation and timing systems to ensure compatibility. Achieving compatibility is essential when coordinating and it involves both radiofrequency compatibility and national security compatibility. So far, Galileo and EGNOS have completed coordination with GPS and WAAS, and the first satellite of QZSS.

Efforts to pursue interoperability through bilateral and multilateral avenues

Through bilateral and multilateral avenues, and when desirable for the benefit of end users, Galileo encourages interoperability between Galileo open signals (open services, safety-of-life services and commercial services) and other positioning, navigation and timing systems' signals. The focus is on E1 CBOC (MBOC spectrum), AltBOC E5 (which includes E5a and E5b signals) and E6 CS signals. So far, Galileo open signals have been interoperable with GPS and QZSS open signals.

GNSS spectrum protection activities

National-level RNSS spectrum regulation and management procedures

Within the European Union, each member State is responsible for its own spectrum activities, although European bodies such as the European Conference of Postal and

Telecommunications Administrations (CEPT), the European Telecommunications Standards Institute and the European Union ensure a good degree of spectrum harmonization, standardization and cooperation. The RNSS spectrum is managed by the relevant national authority of each country and there is coordinated, but no common, management of the RNSS spectrum at the European level.

In the cases of Galileo and EGNOS, the European Union, as programme manager, has been given the authority to negotiate frequency matters, as well as compatibility and interoperability agreements with relevant international partners. The European Union is supported in this by the national administrations in Europe.

Views on ITU RNSS spectrum issues or items on the agenda of the World Radiocommunication Conference

CEPT (whose membership includes 48 European countries) is the forum where European views on all spectrum-related matters are discussed. Those views are then submitted as common proposals at relevant ITU meetings. CEPT members also work through the Conference Preparatory Group to put forward individual positions on the agenda of the World Radiocommunication Conference that are debated and ultimately forged by consensus into a common European position.

In preparation for the World Radiocommunication Conference meeting to be held in 2012, Galileo is supporting proposals for a new global allocation at 2.5 GHz for use by RNSS systems. This additional spectrum would offer useful synergies with mobile services that are planned for operation in the bands above 2500 MHz. Also Galileo is seeking to ensure that RNSS bands at 5 GHz remain available for ubiquitous deployment of mobile RNSS receivers in the future. WRC is also expected to decide whether a new aviation service could share the bands. Both of these Galileo positions have provisional support from CEPT.

RNSS interference detection and mitigation plans and procedures

Due to the usually localized nature of interference to RNSS, automatic detection of interference is not currently practical, although there are European studies looking into this. Interference is usually reported by professional users. In most European countries, it is usually the national regulatory authority for spectrum matters that deals with resolving interference issues and that has procedures and resources for detecting the source of the interference and for enforcing compliance if needed. CEPT also has a common satellite monitoring facility in Leeheim, Germany, that can be used to check for space-based sources of interference.

In parallel to detection activities, electrical equipment sold within the European Union is subject to certification. The standards that must be reached to get certification often define maximum levels of unwanted emissions, which reduces the risk of unintentional interfering emissions occurring.

Participation in ICG

Discussion on the involvement of service providers in the working groups and the workplan of ICG

The European Union, the European Space Agency and European experts are actively involved in all the working groups and task forces connected to the workplan of ICG.

Views on future areas of focus and activities of ICG

The Government of Italy will be organizing, in coordination with the European Union, the fifth meeting of ICG, to be held in October 2010.

IV. China
The Compass/BeiDou Navigation Satellite System

System description

Space segment

The Compass/BeiDou Navigation Satellite System consists of five geostationary satellites and 30 non-geostationary satellites. The geostationary satellites are located at 58.75° E, 80° E, 110.5° E, 140° E and 160° E.

The orbit parameters of non-geostationary satellites (in medium-Earth orbit (MEO) and inclined geosynchronous orbit) are given in table 3. The inclined geosynchronous orbit intersect node is 118° E.

Table 3. The orbit parameters of non-geostationary satellites

	Medium-Earth orbit	*Inclined geosynchronous orbit*
Number of satellites	27	3
Number of orbit planes	3	3
Orbit altitude (km)	21 500	36 000
Orbit inclination (degree)	55	55

Ground segment

The ground segment of the Compass/BeiDou Navigation Satellite System consists of one master control station, upload stations and monitor stations.

Current and planned signals

The frequency bands of the Compass/BeiDou Navigation Satellite System include:

B1: 1559.052~1591.788 MHz

B2: 1166.22~1217.37 MHz

B3: 1250.618~1286.423 MHz

The basic parameters of Compass/BeiDou signals are shown in table 4.

Table 4. The basic parameters of Compass/BeiDou signals

Component	*Carrier frequency (MHz)*	*Chip rate (MHz)*	*Data/Symbol rate (bps/sps)*	*Modulation type*	*Service type*
B1-C_D	1,575.42	1.023	50/100	MBOC (6, 1, 1/11)	Open
B1-C_P			No		
B1		2.046	50/100	BOC (14, 2)	Authorized
			No		
B2a_D	1,191.795	10.23	25/50	ALTBOC (15, 10)	Open
B2a_P			No		
B2b_D			50/100		
B2b_P			No		
B3	1,268.52	10.23	500 bps	QPSK (10)	Authorized
B3-A_D		2.5575	50/100	BOC (15, 2.5)	
B3-A_P			No		

4. Performance standards versus actual performance

The basic information on performance standards is shown in table 5.

Table 5. **Performance standards**

Coverage area	Global
Positioning accuracy	10 m (95 per cent)
Velocity accuracy	0.2 m/sec
Timing accuracy	20 nsec

Timetable for system deployment and operation

Compass/BeiDou navigation demonstration system

The Compass/BeiDou navigation demonstration system has been built. After the first satellite (located at 140° E) was launched on 31 October 2000, a second satellite (located at 80° E) and a third satellite (located at 110.5° E) were launched on 21 December 2000 and 25 May 2003, respectively. The demonstration system can provide positioning, timing and short-message communication services to users in China and nearby areas. Besides, a GPS augmentation function is included. The system has been applied to many fields including geodesy and surveying, communication, fishing, mineral prospecting, forest fire prevention, national security etc. The system played a significant role in rescue and relief efforts during the ice-snow disaster that took place in southern China and in the Wenchuan earthquake that struck Sichuan province in 2008.

Compass/BeiDou Navigation Satellite System

On 14 April 2007, the first MEO satellite, named Compass-M1, was launched. On 15 April 2009, the first geostationary satellite, named Compass-G2, was launched. According to the construction schedule, the Compass/BeiDou Navigation Satellite System will, as a first step, cover China and the nearby area, by around 2011, but the full deployment of the System will be completed between 2015 and 2020. At present, the System is being developed as planned.

Services provided and provision policies

The Compass/BeiDou Navigation Satellite System can provide two types of service at the global level: open service and authorized service. Through its open service, it provides free positioning, velocity and timing services. Through its authorized service, it provides safer positioning, velocity and timing services, as well as system integrality information, for authorized users.

The Compass/BeiDou Navigation Satellite System can provide two kinds of authorized services, including a wide-area differential service (with a positioning accuracy of 1 m) and a short-message communication service in China and nearby areas.

Perspective on compatibility and interoperability

Definition of compatibility and interoperability

Compatibility refers to the ability of multiple satellite navigation systems to be used separately or together, without interfering with the navigation performance of each system.

Interoperability refers to the ability of the open services of multiple satellite navigation systems to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service, without significantly increasing the complexity of receivers.

Efforts to ensure radiofrequency compatibility through bilateral and multilateral venues

The Compass/BeiDou Navigation Satellite System will achieve frequency compatibility with other satellite navigation systems under the ITU framework through bilateral or multilateral coordination. Presently, the COMPASS/BeiDou Navigation Satellite System has facilitated coordination meetings with GPS, Galileo, GLONASS and QZSS.

3. Efforts to pursue interoperability through bilateral and multilateral venues

The Compass/BeiDou Navigation Satellite System will achieve interoperability with other satellite navigation systems by coordinating through bilateral or multilateral platforms, including ICG. So far, the System has facilitated coordination meetings with GPS and Galileo concerning interoperability.

GNSS spectrum protection activities

National-level RNSS spectrum regulation and management procedures

The Radio Regulatory Bureau of the Ministry of Industry and Information Technology of China is responsible for managing radiofrequency resources in China.

Views on ITU RNSS spectrum issues or agenda items of the World Radiocommunication Conference

From 2003 to 2007, China actively participated in the ITU Radiocommunication Sector Working Party 8D, on all mobile-satellite services and the radiodetermination-satellite service, to carry out research on technical characteristics of RNSS receivers and associated protection requirements. In that context, China made many contributions and conducted research on interference evaluation of non-RNSS services on RNSS services and on interference among RNSS systems. Throughout the period 2007-2011, China will continue to actively participate in the ITU Radiocommunication Sector through Working Party 4C, on efficient orbit/spectrum utilization for mobile-satellite services and the radiodetermination-satellite service.

As its global navigation satellite system is still under construction, China has attended the second to sixth consultation meeting on World Radiocommunication Conference resolution 609 and participated in RNSS system Aepfd calculation in 1,164~1,215 MHz frequency band. The fifth consultation meeting was held in Xi'an, China, in May 2008.

RNSS interference detection and mitigation plans and procedures

Research on techniques and regulations for RNSS interference detection and mitigation is being carried out.

Participation in ICG

With the participation of States Members of the United Nations, intergovernmental bodies and non-governmental organizations, ICG has already become an important platform for communication and cooperation in the field of global satellite navigation. Presently, the main satellite navigation service providers (countries and organizations) attach importance to the communication and cooperation that happens through ICG. As a country with an independent navigation satellite system, China wishes to exchange information and cooperate with all the other navigation satellite systems via ICG.

V. Japan
The Multi-functional Transport Satellite Satellite-based Augmentation System and the Quasi-Zenith Satellite System

Description of the Multi-functional Transport Satellite Satellite-based Augmentation System

The Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) provides GPS augmentation information for the civil aircraft onboard satellite navigation system under the FUKUOKA Flight Information Region; it is one of the satellite-based augmentation systems that complies with ICAO standards and recommended practices.

Space segment

MSAS provides navigation services for all aircraft within Japanese airspace via two geostationary satellites: MTSAT-1R, which is at 1400E, and MTSAT-2, which is at 1450E.

Ground segment

MSAS consists of two geostationary satellites and a ground network made up of two master control stations (one at Kobe and one at Hitachioota), two monitoring and ranging stations (one in Australia and one in Hawaii), and four ground-monitoring stations (at Sapporo, Tokyo, Fukuoka and Naha).

The master control stations generate augmentation information based on the GPS and MTSAT signals received at the ground-monitoring stations and the monitoring and ranging stations. The ground-monitoring stations monitor GPS satellite signals and transfer the information to the monitoring and ranging stations.

Monitoring and ranging stations monitor the MTSAT orbits. They also have the GMS function and transfer the information to the monitoring and ranging stations.

Current and planned signals

MSAS navigation signals transmit from the L1 C/A satellites at a centre frequency of 1575.42 MHz.

The signal is modulated by a BPSK technique with pseudo-random noise (PRN) spreading codes having a clock rate of 1.023 MHz, which is contained in the 250 bps/500 sps binary navigation data stream. The parameters of the MSAS signal are summarized in table 6.

Table 6. **MSAS transmission parameters**

Parameter (units)	L1 C/A
Carrier frequency (MHz)	1575.42
PRN code chip rate (Mcps)	1.023
Navigation data bit/symbol rates (bps/sps)	250/500
Signal modulation method	BPSK(1)
Polarization	RHCP
Minimum received power level at input of antenna (dBW)	–161.0
Frequency bandwidth (MHz)	2.2

MSAS is planning to expand bandwidths for L1 and L5. (This implementation is under study, in accordance with the improvement schedule for the Wide-area Augmentation System of the United States.)

Performance standards versus actual performance

MSAS provides horizontal guidance for navigation, which is used in non-precision approaches.

According to ICAO standards and recommended practices, in order to satisfy these requirements: horizontal accuracy is less than 220 m (with selective availability on), observed value is less than 2.2 m (95 per cent), integrity (probability of hazardous, misleading information) is less than 1×10^{-7}/hour, fault tree analysis leads 0.903×10^{-7}/hour, availability is more than 99.9 per cent, observed 99.97 per cent.

Timetable for system deployment and operation

MTSAT-1R was launched in February 2005 and entered orbit at 140° E. MTSAT-2 was launched in February 2006 and orbited into 145° E. MSAS has been operating since September 2007.

Services provided and provision policies

MSAS is used for aircraft navigation. MSAS offers three advanced functions. In the event of a GPS failure, the health status of GPS is transmitted via the integrity function of MSAS, while the differential correction function provides ranging error data. MSAS also employs a ranging function to generate GPS-like signals and enable aircraft to use MTSAT as an additional GPS satellite.

In order to ensure the reliability of this function, MSAS is monitoring MTSAT/GPS signals, ranging for determinate MTSAT satellite orbit and estimating ionospheric delay on a 24-hours-a-day, seven-days-a-week basis.

Perspective on compatibility and interoperability

MSAS is compatible and can interoperate with other satellite-based augmentation systems.

GNSS spectrum protection activities

MSAS has been coordinated under the rule of ITU. Especially L5 has been coordinated under Resolution 609 on WRC-2007.

Participation in ICG

MSAS has participated in the Interoperability Working Group and navigation system panel meeting at ICAO.

Description of QZSS

QZSS is a regional space-based, all-weather, continuous positioning, navigation and timing system that provides interoperable signals for GPS (L1, L2 and L5), a wide-area differential GPS augmentation signal called "L1-SAIF" and an experimental signal, "LEX", having a message that contains more data, at a shorter time of transmission. QZSS provides navigation services for East Asia, including Japan, and Oceania.

Space segment

The space segment comprises the QZSS satellites, which function as celestial reference points, emitting precisely time-encoded navigation signals from space. The operational constellation of three satellites operates in 24-hour orbits with an altitude of apogee of less than 39,581 km and a perigee of more than 31,911 km. Each of the three satellites is placed in its own separate orbital plane inclinedfrom 39° to 47° relative to the equator. The orbital planes are equally separated(i.e. phased 120° apart) and the satellites are phased so that there is always one satellite visible at a high elevation angle from Japan.

The satellite is a three-axis stabilized vehicle whose mass, without propellant, is of approximately 1.8 tons, including a 320 kg-navigation payload. The major elements of its principal navigation payload are the atomic frequency standard for accurate timing, the onboard navigation computer to store navigation data, generate the ranging code and stream navigation messages, and the 1.2/1.6 GHz band transmitting antenna whose shaped-beam gain pattern radiates near-uniform power of signals at the four 1.2/1.6 GHz band frequencies to users on or near the surface of the Earth.

Ground segment

The control segment performs the tracking, computation, updating and monitoring functions needed to control all of the satellites in the system on a daily basis. It consists of a master control station in Japan, where all data processing is performed, and some widely deployed monitor stations in the area that are visible from the space segment. Monitoring stations are located in Sarobetsu, Koganei, Ogasawara and Okinawa in Japan; in Hawaii, United States; Guam; Bangkok; Bangalore, India; and Canberra.

The monitoring stations passively track all satellites in view and measure ranging and Doppler data. These data are processed at the master control station so that the satellite's ephemerides, clock offsets, clock drifts and propagation delay can be calculated, and are then used to generate upload messages. This updated information is transmitted to the satellites via telemetry, tracking and command and navigation message uplink station at Okinawa for memory storage and subsequent transmission by the satellites as part of the navigation messages to the users.

Current and planned signals

The QZSS navigation signals transmitted from the satellites consist of five modulated carriers: two L1 carriers at centre frequency 1575.42 MHz ($154f_0$), L2 at centre frequency 1227.6 MHz ($120f_0$), L5 at centre frequency 1176.45 MHz ($115f_0$) and LEX at centre frequency 1278.75 MHz ($125f_0$) where f_0 = 10.23 MHz. f_0 is the output of the onboard frequency reference unit to which all signals generated are coherently related.

The L1 signal consists of four BPSK modulation signals. Two of them, the L1 C/A and the L1-SAIF, are modulated with two different pseudo-random noise spreading codes that are modulo-2 add sequences of the outputs of two 10-bit-linear-feedback-shift-registers (10-bit-LFSRs) having a clock rate of 1.023 MHz and a period of 1 ms. Each of them is modulo-2 added to a 50 bps/50 sps or 250 bps/500 sps binary navigation data stream prior to BPSK. The other two signals, L1Cp and L1Cd, are modulated with two different spreading codes having a clock rate of 1.023 MHz and with two same square waves having a clock rate of 0.5115 MHz. Data stream is modulo-2 added to L1Cd. Only L1-SAIF signal is transmitted through a separate horn antenna using different L1 carrier wave.

The L2 signal is BPSK with an L2C spreading code. The L2C code has a clock rate of 1.023 MHz with alternating spreading codes having a clock rate of 0.5115 MHz: L2CM with a period of 20 ms and L2CL with a period of 1.5 s. A 25 bps/50 sps data stream is modulo-2 added to the code prior to phase modulation.

The L5 signal consists of two BPSK signals (I and Q) multiplexed in quadrature. The signals in both I and Q channels are modulated with two different L5 spreading codes. Both of the L5 spreading codes have a clock rate of 10.23 MHz and a period of 1 ms. A 50 bps/100 sps binary navigation data stream is transmitted on the I channel and no data (i.e. a data-less "pilot" signal) on the Q channel.

The LEX signal is also BPSK. A set of small Kasami Code sequences is employed for the spreading code having a clock rate of 5.115 MHz.

The main characteristics of QZSS signals are summarized in table 7.

Table 7. **QZSS transmission parameters**

Parameter (units)	*L1 C/A*	*L1-SAIF*	*L1C*	*L2C*	*L5*	*LEX*
Carrier frequency (MHz)	1,575.42	1,575.42	1,575.42	1,227.6	1,176.45	1,278.75
PRN code chip rate (Mcps)	1.023	1.023	1.023	1.023	10.23	5.115
Navigation data bit/ symbol rates (bps/ sps)	50/50	250/500	25/50	25/50	50/100	2000/250

Parameter (units)	*L1 C/A*	*L1-SAIF*	*L1C*	*L2C*	*L5*	*LEX*
Signal modulation method	BPSK(1)	BPSK(1)	BOC(1,1)	BPSK(1)	BPSK(10)	BPSK(5)
Polarization	RHCP	RHCP	RHCP	RHCP	RHCP	RHCP
Minimum received power level at input of antenna (dBW)[a]	−158.5	−161	−163 (pilot), −158.25 (dataless)	−160 total	−154.9 total	−155.7 total
Frequency bandwidth (MHz)	24	24	24	24	25	42

[a] The QZSS minimum received power assumes the minimum receiver-antenna gain is at angles of 10° or more above the Earth's horizon viewed from the Earth's surface.

Performance standards versus actual performance

The specification of signal-in-space user range error is less than 1.6 m (95 per cent), including time and coordination offset error to GPS. While user positioning accuracy for QZSS is defined as positioning accuracy combined GPS L1_C/A and QZSS L1_C/A for single frequency user, L1-L2 for dual frequency user. The figures of specification are 21.9 m (95 per cent) and 7.5 m (95 per cent) respectively. These specifications have already been verified by simulation using actual system design and parameters measured in an engineering model test. Simulation result shown an signal-in-space user range error of 1.5 m (95 per cent), a positioning accuracy of 7.02 m (95 per cent) for a single-frequency user and of 6.11 m (95 per cent) for a dual-frequency user.

The L1-SAIF signal provides wide-area differential GPS correction data and its positioning accuracy is to be estimated 1 m (1 sigma rms) without large multipath error and ionospheric disturbance.

Timetable for system deployment and operation

The first satellite will be launched and the technical verification and application demonstration will be performed after launch, which is currently planned for mid-2010.

The development of the first satellite is progressing steadily. A critical design review for whole system was completed in August 2008. The manufacturing and testing for the proto-flight model of the navigation payload was completed in March 2009. The manufacturing of the satellite bus system and the system integration and assembly was completed in August 2009. The proto-flight test of the satellite system started in August 2009.

Services provided and provision policies

GPS interoperable signals like L1 C/A, L2C, L5 and L1C are to be provided free of charge to direct users. Regarding GPS performance enhancement signals, such as L1-SAIF and LEX, a charging policy is under examination. In order to support the design of a QZSS receiver by receiver manufacturers and its application by a positioning, navigation and timing service provider, interface specifications for QZSS users were released at an early stage of system development. The document describes not only radiofrequency properties, message structure and definition but also system characteristics, service performance properties and the concept of operation. Both Japanese and English versions of the document can be downloaded free of charge from the JAXA website.[9]

Perspective on compatibility and interoperability

GPS-QZSS

The GPS-QZSS Technical Working Group was established in 2002 to achieve compatibility and technical interoperability between QZSS and current and future configurations of GPS. QZSS signals were successfully designed as GPS common signals. Five of the six QZSS signals use the same signal structures, frequencies, spreading code families and

[9] http://qzss.jaxa.jp/is-qzss/index_e.html.

data message formats as GPS or satellite-based augmentation system signals. In the joint statement made by the United States and Japan on 27 January 2006, it was concluded that GPS and QZSS were designed to be fully interoperable and compatible.

Galileo-QZSS

JAXA and the European Union's Galileo signal task force have had six coordination meetings to secure radiofrequency compatibility between QZSS and Galileo. QZSS and Galileo have the same spectrum for L5-E5a OS and LEX-E6 CS, and have a similar spectrum for L1C-E1OS. The coordination has not yet completed. However, all discussions on overlapping frequency bands, except for L1, have been concluded.

Compass/BeiDou-QZSS

Radio frequency compatibility coordination has been achieved between QZSS and COMPASS since 30 July 2007. According to recent presentations about Compass/BeiDou, both systems share same frequency bands (L1 and L5). A couple of coordination meetings are to be requested.

IRNSS-QZSS

Bilateral coordination between the Indian Regional Navigation Satellite System (IRNSS) and QZSS is necessary in order to secure compatibility if IRNSS provides L5 band usage.

GLONASS-QZSS

There is no frequency overlapping with the current GLONASS system. Adopting additional GLONASS CDMA signals on L1 and L5 band would mean further bilateral coordination with QZSS in the future.

GNSS spectrum protection activities

National-level RNSS spectrum regulation and management procedures, RNSS interference detection and mitigation plans and procedures have been stipulated, as has a general radio station.

Deconfliction with geosynchronous orbit and re-orbit procedures

Each satellite orbit is slightly eccentric, keeping it at an appropriate distance from geosynchronous orbit. The vector of eccentricity will be maintained this appropriate separation more than 50 km during operation. After whole mission life, the satellite will be injected into "disposal orbit", which is defined as the orbit with a perigee altitude of more than 1,000 km from one of the geosynchronous orbits.

VI. India

The Indian Regional Navigation Satellite System and the Global Positioning System-aided GEO-Augmented Navigation System

System description

Space segment

Indian Regional Navigation Satellite System

The nominal baseline of the Indian Regional Navigation Satellite System (IRNSS) constellation comprises seven satellites, some of which are geostationary and some of which are not. Three satellites will be placed in geostationary orbit, at 34° E, 83° E and 131.5° E respectively, and two satellites will be placed in geosynchronous orbit with an equator crossing at 55° E and 111.5° E, respectively, with an inclination of 29°. The constellation provides continuous regional coverage for positioning, navigation and timing services.

GPS-aided GEO-Augmented Navigation System

As an operational system, it is planned that the space segment will consist of two geostationary satellites, located at 82° E and 55° E respectively, each of which will carry a bent pipe transponder. An additional on-orbit spare (located at 83° E) will also be added.

Ground segment

Indian Regional Navigation Satellite System

The ground segment is responsible for the maintenance and operation of the IRNSS constellation. This segment comprises nine IRNSS telemetry, tracking and command stations, two spacecraft control centres, two IRNSS navigation centres, 17 IRNSS range and integrity monitoring stations, two IRNSS timing centres, six CDMA ranging stations and two data communication links.

GPS-aided GEO-Augmented Navigation System

As a part of the ground segment, 15 Indian reference stations for monitoring and collecting the data, two master control centres and three uplink stations are planned. The communication links are planned to be established as dual communication links.

Current and planned signals

The IRNSS constellation transmits navigation signals in L5 and S bands. Standard position services and authorized/restricted services that use encryption technologies are the basic services offered by IRNSS. The IRNSS standard position and restricted services are transmitted on L5 (1164-1215 MHz) and S (2483.5-2500 MHz) bands. The IRNSS carrier frequencies and the bandwidths of transmission for the services are shown in table 8.

Table 8. **IRNSS carrier frequencies and bandwidths**

Signal	*Carrier frequency*	*Bandwidth*
SPS – L5	1,176.45 MHz	24 MHz
RS – L5	1,176.45 MHz	24 MHz
SPS – S	2,492.028 MHz	16.5 MHz
RS – S	2,492.028 MHz	16.5 MHz

The standard position service signal is BPSK(1) modulated on L5 and S bands. The navigation data is at a data rate of 25 bps and is modulo 2 added to a pseudo-random noise code chipped at 1.023 Mcps identified for the standard position service. The CDMA-modulated code modulates the L5 and S carriers at 1176.45MHz and 2492.028 MHz, respectively.

The restricted service is only for authorized users. The restricted service signal is transmitted on L5 and S bands using binary offset coding. It has two channels: a "data" channel and a "pilot", or "data-less", channel. The navigation data at 25 bps is modulo 2 added with designated PRN code chipped at 2.046 Mcps in the data channel. The CDMA bit stream modulates the L5 and S carriers using BOC (5,2). The pilot channel is transmitted using primary and secondary codes without data modulation. The primary codes are chipped at 2.046 Mcps. The pilot carrier is in phase quadrature with the data channel.

Table 9. **GPS-aided GEO-Augmented Navigation System centre frequency and bandwidth**

Description	*Signals*
Satellite-based augmentation system signal	L1 – 1,576.42 MHz L5 – 1,176.45 MHz

The GPS-aided GEO-Augmented Navigation System (GAGAN) signal-in-space format complies with ICAO standards and recommended practices for satellite-based augmentation systems.

Performance standards versus actual performance

Indian Regional Navigation Satellite System

It has been assumed that IRNSS would primarily provide services to the area covering India. IRNSS provides dual frequency users with a targeted position accuracy, in terms of the circular error probability, of less than 10 metres over India.

GPS-aided GEO-Augmented Navigation System

The intended performance is to achieve a required navigation performance of 0.1 and an approach with vertical guidance of 1.0/1.5 over India.

Timetable for system deployment and operation

Indian Regional Navigation Satellite System

The first IRNSS satellite is scheduled for launch in the third quarter of 2011. Then, the remaining satellites are planned to be launched every six months. The entire constellation is planned to be operational by 2014.

GPS-aided GEO-Augmented Navigation System

The technology demonstration system was completed in 2007 and a fully certified and operational system is under development. A certified satellite-based augmentation system (APV1.5) with coverage of the whole of India is planned by the end of 2013.

Services provided and provision policies

Indian Regional Navigation Satellite System

Standard position services and authorized service/restricted service are the basic services offered by IRNSS. The standard position service is free for all users. The restricted service is encrypted and, as such, available only to authorized users.

GPS-aided GEO-Augmented Navigation System

GAGAN will provide a safety-of-life service that meets all the requirements of accuracy, integrity, continuity and availability required by ICAO for the utilization by civil aviation for en-route, non-precision and precision approaches.

Perspective on compatibility and interoperability

IRNSS plans to achieve compatibility and interoperability with other GNSS operators and service providers through bilateral and multilateral meetings.

Definition of compatibility and interoperability

Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference or other harm to an individual system or service.

- ITU provides procedures to resolve radiofrequency compatibility of navigation signals
- Recognizing the fact that the spectral separation is not always possible between the various players and co-existence is inevitable, the parties concerned will have to resolve the issues through consultations

Interoperability refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together so as to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system.

Interoperability is achieved through common centre frequency, common modulation, compatible signal power levels, geodetic reference frames and system time referenced to international standards.

Efforts to ensure radiofrequency compatibility through bilateral and multilateral venues

IRNSS coordinates with other agencies to ensure compatibility, which it views as crucial.

Efforts to pursue interoperability through bilateral and multilateral venues

Interoperability is considered desirable but as something that still has to be worked out. IRNSS intends to achieve the goal of interoperability by interacting with other GNSS agencies through bilateral and multilateral talks.

GNSS spectrum protection activities

RNSS spectrum regulation and management procedures

The national level RNSS spectrum regulation management is done by the Wireless Planning Commission of the Government of India in close coordination with the Indian Space Research Organisation of the Department of Space.

Views on ITU RNSS spectrum issues or items of the agenda of the World Radiocommunication Conference, as appropriate or necessary

Recognizing that navigation signal frequency bands need protection everywhere, IRNSS is seeking to ensure such protection.

Participation in ICG

Discussion of the service providers involvement in the working groups and workplan activities of ICG

IRNSS intends to be involved, to the extent possible, in the working groups and workplan activities of ICG.

Annex

Technical parameters

	Nominal constellation	*Full operational capability*	*Number of operational satellites*	*Coverage*	*Civilian spectrum*
GPS	24	1995	30 (January 2010)	Global	Current 2009: L1 C/A, L2C Future: L1 C/A, L1C, L2C, L5
WAAS	3	IOC/2003 FOC/2008	2	Regional (North America)	Current: L1C/A, L5 Future: L1C/A, L5
GLONASS	24	1995 (GLONASS) 2010 (GLONASS-M)	24 (December 2010)	Global	Current 2007: L1PT, L2PT Future: L1PT, L2PT, L3PT,[a] L1CR,[a] L2CR,[a] L5R[b]
SDCM	2	2014 (expected)	2 geostationary satellites	Wide area (Russian Federation)	SBAS L1 C/A
GALILEO	30 medium-Earth orbit satellites	2014	2 medium-Earth orbit satellites	Global	E5 OS/SoL E6 CS/PRS E1 OS/SoL/PRS
EGNOS	3 geostationary satellites	2009 for open service 2010 for safety-of-life service	3 geostationary satellites	Regional	Current: L1C/A

	Nominal constellation	*Full operational capability*	*Number of operational satellites*	*Coverage*	*Civilian spectrum*
COMPASS/ BeiDou	5 geostationary satellites and 30 non-geostationary satellites	2020	6 (January 2010)	Global	1,559.052~1,591.788 MHz 1,166.22~1,217.37 MHz 1,250.618-1,286.423MHz
GAGAN/ IRNSS	3/7	2013/2014		Regional	GAGAN: L5, L1 IRNSS: S, L5 AND L1
MSAS	2 geostationary satellites		2 geostationary satellites (MTSATs)	Asia and the Pacific	L1
QZSS	1 (first phase) 3 (second phase)[c]		1 (FY 2010)	Regional (Asia and Oceania)	L1 C/A, L1C, L2C, L5, L1-SAIF (L1 – submeter-class augmentation with integrity function), LEX (L-Band Experimental Signal)

[a] Signal structure is under refinement.

[b] Pending final decision.

[c] The QZSS plan will basically proceed to the second phase of public-private cooperation after the evaluation of the results of technological verifications and demonstrations of the first phase.

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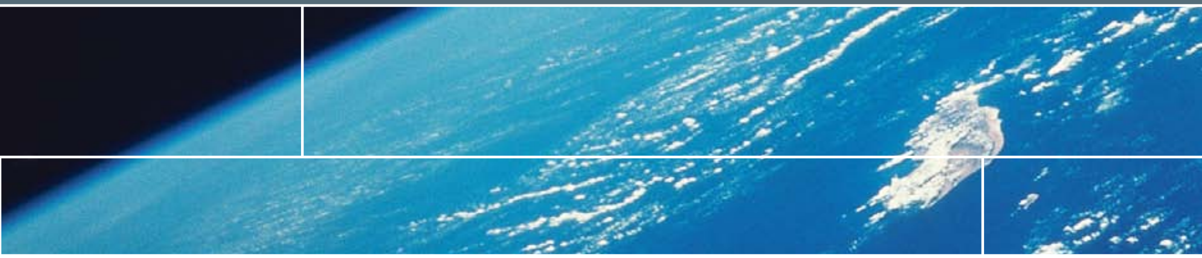

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