The Evolving GNSS Panorama: A Report to the European Space Agency

REPORT
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Annex 1 List of Acronyms
1. Introduction

So far the history of GNSS is largely that of the US Global Positioning System (GPS), which is now over 30 years old. During this time there have been other satellite navigation and positioning systems, including the Transit Doppler system, which preceded GPS itself, but is no longer operational. Others include the Russian global satellite navigation system (GLONASS), the regional Wide Area Augmentation Systems WAAS in the United States, EGNOS in Europe and MSAS in Japan. The European global satellite navigation system Galileo is still to be deployed and declared operational sometime between 2008 and 2010. In addition to the 3 global and 3 regional Space Based Augmentation Systems (SBAS), there have been several other initiatives leading to national or regional augmentation systems, some of which could conceivably develop into independent regional satellite navigation and positioning systems. Most notable among these is the Chinese Beidou, the Indian GAGAN and the Japanese QZSS, with other planned projects in Australia and Brazil. What is also clear is that all of these global, regional and national projects are not in a settled steady stage, but rather in a continuous phase of development, testing and exploration of cross-border collaboration plans. However, none is more active in all of these fields than GPS.

By contrast, the Galileo Project, which started with its early Conceptual stage in 1998, went quickly through its Definition and Design phases, and is now going through its Development and Deployment stages before the start of operations sometime after 2008, appears to have settled down. This is particularly apparent since the signing of the high level US-EU agreement in June 2004 on cooperation involving GPS and Galileo. Whereas before this agreement there seemed to be a significant amount of mutual discord, one would even say distrust, between the two governments, regarding their intentions concerning global satellite navigation, especially in relation to frequencies, military usage, and the much talked about Public Regulated Service (PRS). The agreement signed by the US Secretary of State Colin Powell and the Vice-President of the European Commission Loyola de Palacio created an atmosphere of co-existence and collaboration. GPS and Galileo are now going to operate together in a compatible and interoperable manner, for the benefit of users on both sides of the Atlantic. One senses that, as a result of this agreement, Europe can now relax and carry on with the Galileo Project as planned, with a strict regime of minimum necessary government expenditure, through the use of well publicised financial-economical tools such as the Public-Private-Partnership or PPP. The appointment of the Executive Director of the Galileo Supervisory Authority has just been announced and we are now waiting for the announcement of the Consortium of companies winning the Concession to run Galileo for the next 20 years. There is a general sense that all is now well and going Europe's way.

However, more perceptive observers could well suggest that this is not the case, and that the competition with others is just beginning, if not accelerating. This is particularly true in the case of GPS and the various national, intra-national and regional initiatives already
taken by the US government. One senses that the current GPS modernisation process, which will lead to GPS IIF and GPS III, will definitely prove to be a significant advance on the current GPS IIR, both in terms of performance and reliability. Similarly, the Russian Federation is going ahead with its development of GLONASS-K, and has signed recently an extensive technical collaboration agreement with India.

The Report surveys the changing global environment of GNSS, describing the various national programmes for the development of new systems and augmentations, new management structures that are highly relevant to the new GNSS environment, and intra-national collaboration agreements with clear global economic and political implications. The Report starts with an in-depth review of the 3 global systems, concentrating mainly on GPS and GLONASS which offer the main competition to Galileo. It then reviews the various regional, commercial and local augmentations, and related initiatives and test-beds in China, India, Japan, Australia and elsewhere. This is followed by a broad outlook on the international GNSS scene, in terms of intra-national cooperation agreements and other political initiatives. There is then a description of the new management structures which have been put in place to run GPS and Galileo. Although outside its immediate scope, the Report also briefly touches on the foreseen emerging services and applications. The Report is concluded with a summary of the current GNSS scene, tracing the roadmap from 2005 to 2015, and conclusions relevant to Europe if it is to remain an important player in the emerging and highly competitive international GNSS environment and market place.

2. Global Positioning System

The GPS system was developed by the US Department of Defense (DoD) who still remain responsible for sustaining, operating and providing overall management for the basic constellation through the GPS Joint Program Office (JPO). The JPO aims to ensure the system is continuously available, principally for the US and allied military users, although there are also increasing civilian demands for the continuous provision of position, navigation and timing services. Whereas primary management is provided by the DoD, the US Department of Transport (DOT) represents the civil interests in GPS and is responsible for civil augmentations to GPS. Furthermore, the US Department of Commerce is responsible for protecting the radio frequency spectrum used by GPS.

GPS consists of three major segments; namely a space segment, a control segment and a user segment. It is a dual-use system, providing military and civil users with position, navigation and time services. The GPS constellation also provides a platform for additional military sensor payloads that form part of the US Nuclear Detonation (NUDET) Detection System (NDS).
Despite the advancing age and unparalleled success of GPS, until recently the basic system has changed very little since its inception in the 1970’s, including the orbits and the signals.

However, there have been a series of notable improvements in service performance for the civil user community. In 1996, a US Presidential Decision Directive stated that the President would review the use of Selective Availability (SA), the intentional degradation of GPS for civil use. In 1998, the White House announced the addition of a second civil GPS signal to improve accuracy and reliability for civil users. This was followed in 2000 with the announcement that the degradation of the standard positioning service through Selective Availability was removed. Overnight the performance of GPS was dramatically improved to accuracy levels that proved to be acceptable for consumer applications, and the applications market mushroomed.

These decisions were the first steps in a comprehensive programme of modernisation for GPS. The GPS Modernisation programme, which is currently underway, aims to deliver significant improvements to military and civil user. The programme covers modernisation of the space segment and the control segment, including improved signals and monitoring, which together will deliver a significantly improved performance at the user end.

3. GPS Modernisation

The GPS constellation currently consists of several generations of GPS satellite, including 17 Block II/IIA satellites and 12 Block IIR satellites (Reaser, 2005). The constellation broadcasts the civil L1 C/A signal and the military L1 P(Y) and L2 P(Y) signals.

As part of the GPS Modernisation programme, 8 of the Block IIR satellites are currently on the ground, being upgraded by Lockheed-Martin and upgraded by adding more power and new signals. These satellites are referred to as Block IIR-M.

The latest generation satellites, Block IIF (follow-on) is under development and is being built by Boeing, who started work on them in 1990 and was awarded the contract in 1996. The Boeing built GPS Block IIF satellites will be in orbit and declared operational at about the same time as the European Galileo satellite system.

The modernised Block IIR-M and IIF satellites will incorporate an additional military signal (M-Code) on L1 and L2 and will add two new dedicated civil signals, L2C (Block IIR-M, IIF) and L5 (Block IIF only). The first Block IIR-M satellite will be launched in May 2005 (Reaser, 2005) and the first Block IIF satellite in 2007.
The new L2C signal will reduce the poor cross-correlation performance of the C/A code (which allows strong GPS signals to interfere with weak ones), and thus improve signal tracking performances.

The L5 signal which will be deployed on Block IIF satellites, will have two codes (civil and military). The civil code will contain a new data message and a pilot tone, but will have no data message for improving the acquisition and tracking properties of the signal. The military code signal is being introduced to support defence applications. The L5 frequency is located in the Aeronautical Radionavigation Service (ARNS) band of the spectrum, which is allocated under international rules, is designated for aviation services and offers protection from interference sources.

In addition to the space segment, the GPS ground segment is also subject to modernisation (Crews, 2004). As part of this process, the Legacy Accuracy Improvement Initiative (L-AII) was initiated in 2005. The aim of this initiative is to improve the signal-in-space accuracy of the GPS signal through the provision of enhanced information within the broadcast message. This information will be used to reduce degradation of the data quality over time, thus increasing accuracy in GPS satellite orbital position and clock data.

Orbital position & clock data is most accurate immediately after uplink to satellite, but becomes less applicable and less accurate over time. Improvements are achieved by better orbit determination and time synchronisation processes.

To do this, the GPS control segment is increasing its ground monitoring assets to include GPS satellite tracking data from reference stations controlled by the National Geospatial Intelligence Agency (NGA). This data will provide additional input for the satellite orbit determination and time synchronization process, which will deliver improved navigation performance at the user end.

Traditionally, there have been 5 GPS monitoring stations that supply data to the GPS control segment. This limited tracking network led to coverage gaps when a satellite could not be monitored. With the additional stations from the National Geospatial Intelligence Agency, these gaps will now be removed, and the resulting configuration will allow every satellite to be continuously observed from at least two ground monitoring stations.

The Block IIR and Block IIF satellites will also integrate a function termed AUTONAV. This function will provide both improved accuracy and long term validity of the navigation data message for up to several months without uplinks from the ground. This is achieved using inter-satellite range measurements. Within AUTONAV, the control segment produces and uploads a long term prediction of the satellite’s ephemeris. Each satellite will process the measured inter-satellite ranges with its ephemeris information to improve the long term prediction and estimate its onboard clock. The improved
ephemeris and clock estimates are then substituted into the navigation message and broadcast to users.

The effect of L-AII and AUTONAV will be significantly improved orbit and clock parameters that will result in an enhanced user positioning performance. It is estimated that for dual frequency civil users, the resulting performance could be as good as 1m.

4. GPS III Programme

The US Department of Defense is planning to incrementally upgrade and improve the GPS system. This process, which is known as GPS III, will address the future needs of military and civil users over the next 30 years. The technological drivers for GPS III include the provision of advanced anti-jam capabilities, improved system security, increased accuracy, system integrity, backward compatibility, survivability, compatibility and interoperability with Galileo, as well as interoperability with the Global Information Grid. A GPS III system consisting of 30 satellites, including spares and replenishments, is estimated to cost $14- to 15 billion (Avionics Magazine, 2004).

Two years ago the Air Force reduced funding for GPS III, but since then the DoD has restored funding to continue the work on GPS Modernisation.

For the procurement of GPS III, the Joint Program Office (JPO) is considering new approaches for both the space and control segments which will involve separating and procuring the segments separately. The systems integration task may also either be tendered or carried out within an integrated team (Gibbons, 2005).

4.1 Space Segment

The GPS III space segment development will be required to remain responsive and flexible to the growing needs for positioning, navigation and timing services, and will focus on incremental deliveries of GPS III capabilities, starting with the first delivery of Block IIIA satellites. The first Block IIIA will be launched in 2013.

The GPS III space segment acquisition will include the development of a new satellite bus to allow for the incremental growth and flexibility which are necessary to support full GPS III capability. In addition to the Block IIF capabilities, the GPS III satellites will also incorporate:

- additional civil and military signals
- reprogrammable payload and flexible power
- on-board signal integrity monitoring
- cross-links to support communications and inter-satellite ranging
GPS III will also add a new L1 civil (L1C) signal which will be interoperable with Galileo. The signal will provide increased M-Code signal power and/or highly directional M-Code spot beam. Lastly, GPS III will provide increased power and jam resistance which is necessary for military operations.

The L1C signal will provide superior performance over the existing C/A code, offering better correlation properties (longer codes) and additional power to provide improved performance indoors and in difficult environments and reception conditions.

Additionally, there have been proposals to provide improved message structures on L1C to support an improved navigation message containing a compact almanac to improve time-to-first-fix (TTFF) or to provide enhanced ephemeris data at greater precision. Proposals have also considered the possibility of broadcasting integrity messages and/or navigation related information (Hudnut and Titus, 2003).

There has been extensive consultation with industry, academia and users, and the current baseline for L1C specifies a signal with twice the minimum C/A signal power. The signal will have longer codes that will eliminate cross-satellite correlation interference. The navigation message improvements include higher resolution, error checking and more flexibility. A pilot carrier will be added to improve tracking threshold, which is better for high precision phase measurements. Finally, increased signal bandwidth will provide added interference protection and less code noise.

In addition to open civil signals, GPS III will also offer the opportunity for the US to provide additional navigation services with the GPS satellites. Current augmentation services to GPS are provided by a variety of Space Based and Ground Based Augmentation Systems (SBAS and GBAS). The advent of GPS III creates an opportunity to incorporate these civil services directly into the GPS mission. This could prove beneficial to international cooperation and allow other regions or states to maintain operational control over the provision of local, national or regional services (Aerospace Corp, 2002).

Another aim of the GPS III program is to ultimately incorporate a flexible navigation payload. This payload will offer the US the capability to modify code schemes, code rates, data rate and navigation messages on satellites in orbit giving them an ability to add new or to modify existing ranging signals in order to meet emerging needs. The increasing longevity of the GPS satellites has resulted in long delays in responding to new requirements for additional signals and the implementation of new services. A key element of GPS III will be the ability to reconfigure its architecture to changing requirements, enabling rapid implementation of additional military or civil signals onboard orbiting GPS satellites. To support this requirement, the future GPS III satellites will carry a flexible navigation payload.
GPS III will also offer a platform of opportunity to host additional operational and secondary experimental payloads in support of related missions (GPS JPO, 2001). Conceptually, the most attractive of these is the Global Multi-mission Support Platform (GMSP). The GMSP is a concept based on determining the most cost-effective method of fulfilling numerous critical communications requirements, using a sub-constellation of GPS.

The primary mission of GMSP is to provide military and civilian users global and continuous position, velocity, and time functions of GPS on a global basis. The DoD is also keen to explore solutions of providing protected navigation for friendly forces. There are recognised problems in defense communications within military operations, including imagery transfer, Blue Force Tracking, tracking equipment, and point-to-point and networked services. The purpose of GMSP is to provide a constellation of multi-mission satellites. These satellites will occupy some of the GPS satellite orbital slots and provide the navigation and nuclear detection services of GPS. The sub-constellation will also provide global narrow and wide-band communications services for US military and intelligence communities.

The goal of the GMSP is to generate cost savings in meeting future requirements of several missions by developing one new spacecraft. The program will take advantage of the synergy between traditionally independent mission areas such as navigation, satellite communications and other missions.

Another area of synergy under consideration in the GPS III programme is the use of a sub-constellation to provide Search And Rescue (SAR) services (GPS JPO, 2001). The US has identified that a cost-effective opportunity exists for implementing a near-instantaneous, global, high reliability space-based distress alerting and location system hosted by the GPS satellite constellation. The system would maintain compatibility with the current emergency beacons and provide a new tracking capability. Additionally, a future beacon could be used to implement a two-way digital communications service. This concept is called the Distress Alerting Satellite System (DASS) which could be used anytime, anywhere in the world to quickly identify, locate and rescue a person in need. The US considers DASS as the next generation global SAR service.

The NUDET Detection System, as a secondary payload, will remain largely unchanged within GPS III. The system is designed to support nuclear force management, integrated tactical warning and attack assessment, and test ban treaty monitoring. The system includes space based sensors and ground mission processing systems. The system detects, locates and reports nuclear detonations on a global basis.

4.2 Control Segment

To enhance the GPS III control segment and optimize its operation, several additional functions, which are traditionally control segment functions, are to be installed onboard the satellites.
For example, GPS III is investigating the concept of satellite-based autonomous integrity monitoring. GPS does not currently provide any integrity monitoring service. Integrity monitoring is normally achieved externally, using civil integrity monitoring algorithms, receivers and networks that track, process and analyse the GPS signals and determine their status. Satellite status messages are then typically broadcast to the user via a communications channel (satellite or terrestrial) with a resulting latency. The proposed GPS III concept is to provide an integrity monitoring service, by integrating detection and alert functions onboard the GPS satellites. In this scenario, as soon as a failure is detected in a particular satellite, an integrity message is incorporated in the navigation broadcast message to inform the user that the signal from that satellite is faulty. The aim of the service would be to provide greater integrity and notify users of failures within 1 second.

Another concept under consideration is the use of inter-satellite links to provide real-time integrity. Inter-satellite links can be used to provide rapid dissemination of alerts to GPS receivers and can be used to communicate health messages to and from the constellation to the control segment. In addition to providing communications, inter-satellite links are also being considered as a means of enhancing integrity through satellite-to-satellite ranging.

The same inter-satellite ranging observations can be used to improve the orbit determination process, as part of the AUTONAV function.

There is also evidence to suggest that the following onboard clock technology is being pursued for GPS III (Wu and Feess, 2000).

- Advanced Digital Rb Clock
- Optically Pumped Cs Beam Clock
- Space Linear Ion Trap System

The combination of inter-satellite links, AUTONAV and improved onboard clock technologies will facilitate an optimised control segment for GPS III and lead to improved performances for both military and civil users.

4.3 User Segment

At the user level the US DoD is migrating to a software radio approach to support next generation mobile communications with the acquisition of a Joint Tactical Radio System (JTRS). The JTRS will be a secure, multi-band, multi-mode, multi-channel software radio that supports a broad range of military communications requirements. Costing $14 billion, the system is set to enter service in 2010. It is foreseeable that GPS will be included as an application within the user terminal to account for enhanced services provided by GPS Modernisation. The main motivation for incorporating GPS
functionality is cost saving, as current Military GPS receivers are still rather expensive, compared to civil units because of encryption and a tamper resistant secure processor.

It is reported that the US DoD have commissioned work to build a Military Software GPS Receiver Test-Bed: The objective of this work is to build a prototype test-bed to support the development, test and evaluation of a GPS receiver suitable for use in the JTRS hand-held radios (JTRS JPO, 2004). The commercial potential for software GPS receivers is considerable. For example, the reconfigurable nature of a GPS software receiver enables it to be upgraded through firmware and software modifications to work with the next generation GPS and GNSS services and user applications. It is further conceivable that the reconfiguration keys and software can be broadcast by the satellites themselves to automatically reconfigure user receivers to extract the benefit of new services.

There are also initiatives within the US DoD to develop chip-scale atomic clocks (CSAC) technology for GPS receivers as well as for integrating low cost inertial micro-electro mechanical (MEMS) devices. The addition of these new technologies will improve the acquisition and tracking of the GPS signals, and could ultimately be used to provide continuous precision position, navigation and timing services in areas of extreme RF interference or GPS signal denial.

5. GLONASS

ROSKOMOS is the overall controller of the GLONASS system and its developments. However, there is also an Interagency Coordination Board, which coordinates the GLONASS program with several ministries, including the Ministry of Transport, Defence, Industry and Energy.

The latest launch of 3 satellites was successful in December 2004. This brought the total number of GLONASS satellites in orbit to 14. Eleven satellites are now operational, including the first GLONASS-M satellite.

The Russian Aerospace Agency has the approval of the Russian government to continue a long-term plan for the period 2002-2011, during which time it plans to deploy a GLONASS constellation of 24 satellites. Russia proposes to have 18 operational satellites by the end of 2008 and 24 operational satellites by the end of 2010.

The GLONASS-K satellite will be developed as part of a GLONASS Modernisation plan. The GLONASS-K satellites will be launched over the period 2008-2015 and operational until around 2025. These new satellites

- Will incorporate a third frequency in the L-band to improve reliability and accuracy of user navigation solutions
- Will have the satellite lifetime increased to 10 years
- The satellite mass will be reduced by half (to reduce launch costs)
- Additional payloads are planned, including Search and Rescue payload.
- Will include Integrity transmissions

There is also a Russian programme for the development of next generation GLONASS satellites, which are referred to as GLONASS-KM. The programme started in 2002 and is currently in early design phases. The first launch of a GLONASS-KM satellite is expected in 2015, in parallel to the GPSIII schedule.

India is to help Russia replenish its constellation of GLONASS satellites, including the launching of some satellites on Indian vehicles. Under an agreement signed by the Russian President Putin, and his Indian counterpart, the two countries will work together to bring the GLONASS system up to a minimum effective size of 18 operational satellites by 2007. Funding will be coming directly from the Russian Government, however there may be additional funding and in-kind contributions from the Indian government. As part of the agreement, the GLONASS ground infrastructure will be established to provide for joint satellite navigation activity.

At the same time as GLONASS undergoes extensive development and modernisation, the Russian Federation is embarking on the development of an augmentation service for GLONASS (Revnivykh, 2004). The architecture includes both a global and a regional component. The objective is to provide GNSS integrity monitoring, orbit and time correction determination and data broadcasting to users.

The basic service will be provided over the Russian Federation. The predicted accuracy of positioning in real time for mobile users applying global corrections to GNSS is around 1m, with the accuracy of positioning at the regional subsystem level is around 5cm in real time. There are currently several options available for delivery of the augmentation data, which are under investigation and include the following.

- New civil signal on GLONASS-K
- Geostationary satellite navigation transponder
- Internet, TV, FM, GSM

The proposed date of service entry is 2008-2010.
6. Galileo

The Galileo programme is Europe’s initiative to develop a civil global navigation satellite system that provides highly accurate and reliable positioning, navigation and timing services. Galileo will be compatible and interoperable with GPS and GLONASS, offering multiple civil frequencies. Galileo will also provide instantaneous positioning services at the metre level as a result of improved orbits, better clocks, dual frequency and enhanced navigation algorithms.

Galileo will also offer guarantees on service availability and will inform users within 6 seconds of a failure of any satellite. This will allow the system to be used in safety-critical, mission-critical and business-dependent applications. The combined use of Galileo, GPS and GLONASS systems will offer a very high level of performances for user communities and businesses.

The fully deployed Galileo system will consist of 30 satellites and the associated ground infrastructure. The System will offer the following services:

- Open Service (OS)
  - Free to air; Mass Market; Real-time Positioning, Navigation and Timing
- Safety of Life (SoL)
  - Unencrypted; Integrity; Authentication of signal
- Public Regulated Service (PRS)
  - Encrypted; Integrity; Continuous Availability
- Commercial Service (CS)
  - Encrypted; High Accuracy; Guaranteed Service
- Search & Rescue (SAR)
  - Near Real Time; Precise; Return Link Feasible

This is the baseline set for the global services for Galileo. However, Galileo has also developed additional concepts for integrating services at both regional and local scales.

The design of the Galileo system facilitates the introduction of data from 3rd party service providers using regional integrity services within Galileo. This provides the opportunity for establishing agreements with partnering countries/regions. A Galileo Regional Component is made up of an additional network of stations, to oversee the integrity of the signals, and a processing centre to provide this service.

For the most demanding applications, which require the highest level of performances, it will be necessary to integrate Galileo services with additional services at a local level. To achieve this aim, Galileo has developed the concept of Galileo Local Elements. Local Elements will provide additional positioning, communication and/or information services and will be tailored to suit the need of specific users, operations and environments.
example, Galileo Local Elements will be developed and adapted to meet specific requirements for positioning at airports, ports, railways, roads, urban areas and inside buildings, and provide seamless and reliable services. The Galileo Joint Undertaking, in partnership with Industry, is currently developing several application specific Galileo Local Elements, to demonstrate the expected performance and incremental benefits of combined GNSS services, as Galileo signals become available.

The Galileo programme is already underway. In December 2004, the European Space Agency and Galileo Industries signed a €150m contract, as a first stage of a contract covering the overall In-Orbit Validation (IOV) Phase. The overall IOV contract will be signed later in 2005, subject to additional funding.

The IOV Phase covers the detailed definition and subsequent manufacture of the various system components, namely satellites, ground components and user receivers. This phase will require the putting into orbit of prototype satellites and the development of a corresponding terrestrial infrastructure to support early operations. It will allow the necessary adjustments to be made to the ground segment with a view to its global deployment and the launching of operational satellites. During this phase it will also be possible to develop receivers and to verify the frequency allocations filed with the International Telecommunication Union (ITU).

Following the IOV Phase, the Galileo programme will enter its Deployment Phase. The constellation deployment phase will consist of putting all the operational satellites into orbit and in ensuring the full deployment of the ground infrastructure, leading to an operational service. Deployment and commercial operation of Galileo will be awarded to a private Concessionaire. Two consortia have submitted proposals for this Concession, but no final decision has yet been taken (May 2005). The Concessionaire will be responsible for procuring the space infrastructure and operations, launch services and developing the business to ensure a commercial success of the venture. The public side of the Galileo programme will be managed by the European GNSS Supervisory Authority.

The Galileo programme closely resembles the GPS Block IIF programme, in terms of schedule, functionality and performances. Both constellations are under development, and due to be launched over the same period. Both constellations will broadcast multiple civil signals and offer metre level positioning performance. The challenge for Galileo is to enter a market dominated by GPS and to maintain its equity with the state-funded system through continued investment and improvement. One must remember that the Block IIF constellation is currently being procured and the GPS III programme is into its 5th year of architecture development. In this regard, it is important to note is that both GPS III contractors (Boeing and Lockheed Martin) are currently completing their $20m Phase A contracts with System Requirements Reviews (SRR) scheduled for later this year (Gibbons, 2005) which are expected to be followed by parallel Preliminary Design
and Risk Reduction contracts. The first launch of a GPS Block IIIA satellite is expected in 2013.

Design work for the next generation GLONASS-KM satellites has also begun.

7. Satellite Based Augmentation Systems (SBAS)

SBAS have been designed to provide the necessary levels of accuracy, integrity, availability and continuity from GPS (and GLONASS), to facilitate the migration towards a satellite based navigation infrastructure vision conceived by the International Civil Aviation Organisation (ICAO). This is achieved through the following SBAS navigation services.

- Provision of wide-area correction models for the satellite orbits, clocks and ionosphere.
- Provision of integrity messages on satellite health and performance status.
- Provision of additional ranging signals, enabling additional observations to be made

In recent years, there has been significant interest in the development of SBAS by an increasing number of regions in the world. The US, Europe and Japan were the first regions to commit to the SBAS development. More recently they have been joined by India and Australia (who has adapted the SBAS concept to its airspace). There are also SBAS testbeds and trials in Africa, Latin America and Asia. Russia has also announced recently its intention to develop an SBAS (Revnivykh, 2004). Although SBAS provides independent regional augmentation services, there is also a need to establish interoperability between neighbouring coverage areas to provide a seamless navigation service to users.

7.1 Wide Area Augmentation System (WAAS)

WAAS is a programme of the US Federal Aviation Administration (FAA) within the Department of Transport. The WAAS architecture is based on a wide area network of ground tracking stations across the US, which provides relayed messages via geostationary satellites all over the United States. WAAS enables Category 1 approaches for civil aviation (FAA, 2005a).

In 2003, WAAS was commissioned by the FAA over most of the continental United States, adjacent oceanic regions, and most of Alaska. WAAS is the only SBAS currently certified for instrument flight rules (IFR) operations in the world. There have been 700 approaches developed to date, allowing pilots to descend safely using vertical guidance provided by WAAS. In November 2004, the FAA and Raytheon agreed a $204m
restructuring contract to enhance and extend WAAS in terms of coverage and performance (Raytheon, 2005a).

This next phase of WAAS will cover the next 4 years. This phase will provide services over a greater area of the continental US and Alaska. During this period, the FAA plans to upgrade WAAS in the areas of coverage, continuity, and availability. To increase the coverage, additional WAAS reference stations will be installed in Alaska, Canada, and Mexico. The FAA plans to upgrade the system making it more efficient and yielding increased operational performance. The locations of the current geostationary satellites used in WAAS are not optimal for the WAAS coverage area and causes a potential single point failure for users on the East Coast of the US. To mitigate this shortfall, and to improve service availability, the FAA has awarded a contract to Lockheed Martin, to secure additional geostationary satellites in more favourable locations.

In 2004, the FAA approved a revised baseline for WAAS. This new baseline covers the development of WAAS that provides a GNSS Landing System (GLS) capability through the use of GPS L1 and L5 frequencies. The L5 signal is also be available on additional WAAS geostationary satellites. When both L1 and L5 are available on both GPS and WAAS, the airborne system will use a combination of signals to provide the best possible service. This may involve using the ionospheric correction model broadcast by WAAS or generating onboard dual frequency corrections depending on what is available and what is most accurate. WAAS will then broadcast ionospheric corrections and integrity data on both L1 and L5. The implementation of WAAS GLS will run in parallel with GPS Modernisation and is expected to take place within the 2015 timeframe.

As mentioned above, WAAS is being extended to cover neighbouring airspace. September 2004 witnessed a series of agreements between the US, Canada and Mexico to provide a seamless satellite navigation system, more direct aircraft routing procedures, and greater airspace capacity and flexibility. The agreements included initiatives to expand the use of the WAAS throughout North American airspace, which will involve the installation of WAAS reference stations in Canada and in Mexico with the aim of improving cross-border navigational capability as well as improving WAAS availability in Alaska. The three countries are working actively together to complete installations and testing, as well as to finalise architectures and implementation plans, and to conduct operational readiness activities.

In February 2005, it was reported that the FAA had spent $950m to date on WAAS (Avionics Magazine, 2005).

7.2 European Geostationary Navigation Overlay Service (EGNOS)

EGNOS provides a service similar to WAAS across the ECAC (European Civil Aviation Conference) airspace. EGNOS is a joint project of the European Space Agency (ESA), the European Commission (EC) and Eurocontrol, the European Organisation for the
Safety of Air Navigation. These three organisations were responsible for the development and initial testing of the system.

The first phase of the EGNOS project is nearing completion. The infrastructure has been deployed and the EGNOS subsystems have been qualified. The technical qualification of the system is currently ongoing and completion is imminent.

The EGNOS transponders on the geostationary satellites have been transmitting successfully since mid-2004. System qualification is currently ongoing and is to be completed in May 2005. The Operational Readiness Review (ORR) will also occur in May 2005.

After the ORR has been completed, the EGNOS system will be ready for service. The system technical operator contract is currently under negotiation with the European Satellite Service Provider (ESSP). ESSP will provide staff to man EGNOS facilities, validate and stabilise operating procedures and processes. The ESSP will also qualify operations at appropriate standard towards certification (Oosterlinck, 2005).

The EGNOS signal transmissions will continue and will be available for non-safety of life applications. This will lead to an expected announcement in late 2005, of the availability of the Open Service which will be provided and monitored against measured service continuity performance.

EGNOS open service is to remain open and free of charge for multi-modal applications. Further enhancements are expected to EGNOS, to provide a commercial service by the end of 2006, and the EGNOS safety-of-life service should be certified by the end of 2006, with the successful completion of the Operations Qualification Review. A financing structure to achieve these milestones is yet to be specified. It is also important to note that EGNOS is based on a MRD (Mission Requirements Document) which was developed in 1998. Since then, the GNSS environment has changed significantly, and therefore EGNOS needs to address the following developments, to keep pace with the evolving situation.

- Advent of the Galileo programme
- GPS Modernisation program underway (Block IIR-M, Block IIF, GPS III)
- New L1/L5 geostationary satellites
- Export opportunities for SBAS technology
- GPS/SBAS L5 standardisation work
- WAAS FOC program launched
- SARPS Updates (eg new message types)

Furthermore, the Council of the European Union declared that EGNOS is an integral part of the European satellite navigation policy and approved the integration of EGNOS into Galileo, proposing that EGNOS should.
• Become operational as soon as possible
• Allow for service availability in the long term
• Be used as a precursor to Galileo
• Enable Galileo to penetrate rapidly the market
• Meet the obligations of the international standards
• Be extended determinedly to other parts of the world

A two–stage process of EGNOS modernisation has been approved. The initial phase of the modernisation (2005-2006) will require significant manpower and financial resources which have not been secured. This is happening at a time when manpower resources are being deployed on Galileo and at a time when Galileo budgets are under constant review. Once the EGNOS modernization programme is allocated the necessary resources, the initial phase will involve the release of EGNOS v2.1 with the following new missions:

• Support to service expansion to the south and east of Europe
• Non geostationary satellite service for the provision of services to multi-modal platforms

An additional activity foreseen within the programme, is to provide support to the extension of EGNOS to other regions of the world. This was included in the European Commission Communication on “the integration of the EGNOS programme into the Galileo programme” (European Commission, 2003). The EU Council of Ministers agreed that “the extension of EGNOS to other parts of the world should be pursued determinedly by the Commission and Member States”. To this end, there are several ongoing initiatives to extend EGNOS services into other regions, most notably, the Mediterranean, Africa and Latin America.

The extension of EGNOS eastwards is a natural evolution to this process, including coverage across the new and potential future member states of Europe. There is also the possibility that EGNOS could extend into Russia and/or be used to offer support to the Russian SBAS developments.

To date, it appears that the financial means to carry out this programme of EGNOS modernisation do not exist.

7.3 **MTSAT Satellite-based Augmentation System (MSAS)**

The Japan Civil Aviation Bureau has invested considerably in the augmentation of GPS and is implementing its own SBAS known as MSAS. The MSAS (MTSAT Satellite Based Augmentation System) payload is on board the MTSAT satellite which has been launched by the Ministry of Transport in Japan. The MTSAT satellite is in geostationary orbit and will provide voice, data and meteorological services to aviation users, over Japan and neighbouring regions.
The MSAS ground segment has already been procured and installed by Raytheon. It is essentially the same system as used for WAAS and is based on the provision of augmentation services to the GPS signals.

Following the launch failure of MTSAT1, a replacement satellite, MTSAT-1R, was launched successfully on 26 February 2005 (JCAB, 2005) and was maneuvered into orbit in March. The in-orbit validation tests are ongoing. MTSAT-1R includes an aeronautical services and a meteorological payload and will provide meteorological and ATM services for users throughout the entire Asia-Pacific region. It is expected that the satellite will be declared operational at the end of May 2005.

MTSAT1R will be joined in orbit by MTSAT2 which will host a communications payload built by Alcatel.

7.4 GPS And Geo Aided Navigation system (GAGAN)

The Indian Space Research Organization (ISRO) is collaborating with the Airport Authority of India (AAI) to develop a programme for implementing a Satellite Based Augmentation System (SBAS) within the Indian sub-continent region, to provide seamless coverage over Indian airspace between EGNOS and MSAS services. In 2001, the two organisations signed a Memorandum of Understanding for jointly establishing the GAGAN system, with the objective of demonstrating the SBAS technology over the Indian region. There is a plan to have an operational system to provide a seamless navigation facility in the region, which is also interoperable with other SBAS.

The GAGAN space segment consists of a navigation payload onboard the Indian geostationary satellite GSAT-4. The indigenously designed and developed navigational transponder has the latest features inclusive of L1 and L5 operation (Panwar, 2005).

GSAT-4, the space platform for the augmentation system, is scheduled to be launched in 2006. GSAT-4 is primarily an experimental satellite for a Ka band communication payload. Following launch of GSAT-4, GAGAN will enter an experimental phase before it is declared operational. Once declared operational, GAGAN will bridge the gap between the European EGNOS and the Japanese MSAS systems.

The GAGAN ground segment will initially consist of 8 reference stations which will receive the signals from the GPS and GLONASS satellites. GAGAN will host one mission control centre and one uplink station will be based in Bangalore. In November 2004, it was announced that the ground infrastructure will be developed and installed by Raytheon, and this will be based on the technology that they supplied to the US for the WAAS system (Raytheon, 2005b). Future enhancements will include the addition of Galileo functionality.
Although primarily developed for civil aviation, GAGAN will also bring benefits to other user communities.

7.5 Ground-based Regional Augmentation System (GRAS)

Airservices Australia has developed an augmentation service that combines elements of space and ground-based augmentation systems, to enhance GPS in supporting navigation services across the Australian airspace. This approach, called the Ground-based Regional Augmentation System (GRAS), is SBAS-like in using a wide area network of reference stations for monitoring GPS, and a central processing facility for computing GPS integrity and differential correction information. However, instead of transmitting this information to users via geostationary satellites, GRAS delivers its SBAS message data to a network of terrestrial stations, which format and emit a VHF data broadcast, compatible with existing standards. Suitably equipped airspace users can obtain augmentation data to support GPS for en-route and terminal area operations.

Importantly, GRAS also allows for state control of navigation services, using terrestrial infrastructure, while still providing corrections and integrity in a recognized standard format. ICAO has recently adopted GRAS as another augmentation system in conjunction with SBAS and GBAS.

Australia is currently developing a roadmap for the implementation of GRAS in Australia and in 35 neighbouring countries (McPherson, 2005)

8. Commercial Augmentation Services

In addition to regional implementations for aviation, there are several commercial augmentation services that provide regional and global coverage. The following examples on offer, demonstrate the current state of the art, and are global leaders in delivering high accuracy global/regional augmentation services. There are also other commercial services offering similar or lesser performance.

8.1 Starfire

The Starfire Network is a global commercial service capable of providing real-time decimetre level accuracy. Starfire computes each of the GPS satellite signal error sources independently. GPS satellite orbit and clock corrections are calculated from a global tracking network of dual frequency GPS receivers, and the correction models are transmitted to users via a geostationary satellite to Starfire receivers. Starfire receivers use a dual frequency GPS receiver, that measures the ionospheric delay for each satellite. Tropospheric zenith delays are calculated from a multi-state time and position model, aided by redundant satellite observables. The resulting service provides decimeter
accuracy which has found commercial outlets in offshore positioning, surveying and the precision farming markets.

8.2 **Omnistar**

Omnistar provides global coverage GPS enhancement data via a geostationary satellite. The enhancement data is computed from 70 reference stations around the world. Omnistar offers two levels of Differential GPS service.

- A sub-meter level of service
- A high precision service offering decimetre accuracy

Both services are based on the use of improved modeling of error sources and the optimal use of signals and observations. These concepts have not been considered to date in SBAS systems.

9. **Local Augmentation Services**

There is a great variety of civil and commercial services based on DGPS. The best known local augmentation services are those used at present by the aviation, maritime and surveying communities.

9.1 **Local Area Augmentation System (LAAS)**

LAAS is a US FAA programme and represents the US implementation of ICAO’s Ground Based Augmentation (GBAS) concept. LAAS is a ground based GPS augmentation system that provides differential corrections to airspace users. LAAS will be based at major US airports and will ultimately provide Category 1, 2 and 3 approaches. LAAS will augment GPS to provide an all-weather approach, landing, and surface navigation capability. LAAS is a local service and broadcasts its correction message via VHF from a terrestrial transmitter located at the airport.

Standards and Recommended Practices (SARPs) for the Ground-Based Augmentation System (GBAS) for Category 1 have been approved by the ICAO Air Navigation Commission in 2001.

In 2003 the FAA awarded Honeywell a contract for the Category 1 Local Area Augmentation System (LAAS). The contract is for 10 separate LAAS systems to be delivered and installed starting in 2006. Four of the systems will be used for testing and evaluation purposes, and the remaining six will be installed at major commercial airports. Airspace users will use these systems to assess the resulting operational benefits during daily operations. The first system is scheduled to become operational in late 2006.
Work has also started on various schemes for integrating WAAS functionality into LAAS (Enge, 2005).

9.2 Maritime DGNSS Radio beacon Services

The maritime community has been using Differential GPS services for over 20 years. A large number of states have implemented national services to improve the safety of navigation in coastal, port and inland waters. The performance standards have been developed by the International Association of Aids to Navigation and Lighthouse Authorities (IALA) and the format and protocol have been developed by RTCM. Differential services can be based on GPS, GLONASS or on both systems. The differential correction messages are typically broadcast on maritime radiobeacons.

Many states have implemented the IALA DGNSS services to provide safe navigation services in coastal waters.

Several countries have densified the IALA DGNSS networks to provide seamless coverage over land regions. This is in part to provide services for inland waterway navigation, but also to support terrestrial applications. For example, the US as part of the National DGPS service has extended the coverage of its Differential GPS service across the US land mass. This will facilitate road and rail applications based on DGPS services.

On a technical level there are also several development projects to broadcast DGNSS corrections using other communications channels. These include AIS (Automatic Identification Systems) and Loran-C. The aim of this research is to extend the coverage of the DGNSS services and, with Loran-C, to provide an additional back-up terrestrial navigation service to GNSS.

9.3 Continuous Operating Reference Station (CORS) Networks

CORS networks provide a continuous service for receiving GNSS data from a large number of reference stations located throughout a country or region. The data can be used for surveying, geodesy, geodynamics and meteorology as well as for other engineering and scientific applications. The data is typically assimilated at a server which is accessed via the internet. The data is then downloaded to the user’s system, where it is processed to obtain results. Additionally, an increasing number of CORS networks have started to provide online services using GSM/GPRS communications to broadcast the collected data into the field for real-time use.

10. Other Initiatives and Testbeds

In addition to GPS, GLONASS and Galileo, there are other existing and planned GNSS initiatives underway in China and Japan. Furthermore, WAAS and EGNOS have been
active in the promotion of GNSS services and the development of regional testbeds for SBAS.

10.1 **Beidou (China)**

China is pursuing the development of its own satellite navigation and positioning system, Beidou. Beidou was officially launched in the early 1990s, and is being developed by the Chinese Academy of Space Technology (CAST).

The first two experimental navigation and positioning satellites, Beidou-1A and 1B were launched in 2000. The Beidou satellite navigation and positioning system consists of two geostationary satellites. The final Beidou constellation is believed to include 4 geostationary satellites, made up of two operational and two backup satellites. The Beidou system will provide horizontal navigation and positioning signals covering the East Asia region but cannot provide vertical positioning.

Beidou is the first generation of indigenous autonomous satellite navigation and positioning capability for China. CTC (China Top Communication Company) is the first civilian service provider of the Beidou Navigation System within China. The company was co-founded by CTTC (China Traffic Telecommunication Center, within the Ministry Of Communications) and the Shenzhen Jiexin Science and Technology Development Company. CTC provides civilian services of the Chinese Beidou Navigation System, which includes positioning & navigation, short message services and value added services.

10.2 **ETS-VIII (Japan)**

ETS-VIII (Experimental Test Satellite VIII) is Japan’s first venture in developing an indigenous satellite navigation capability. ETS-VIII differs from MSAS in that MSAS uses a L-Band transponder payload to provide signals and broadcast augmentation services, whereas ETS-VIII will have an onboard regenerative L-band payload. Furthermore, the MSAS ground network was procured from the US, whereas the ETS-VIII ground segment will be developed by Japanese industry. It is understood that the onboard clocks will still be US procured items (DTI, 2005).

10.3 **QZSS (Japan)**

The Quasi-Zenith Satellite System (QZSS) is currently under development in Japan. It is a future multi-mission communications, broadcast and navigation system, intended to provide multimedia entertainment and telematics services to a wide range of mobile users (excluding aviation). The QZSS system has been designed to overcome the satellite visibility restrictions experienced with rugged terrains and high rise cities by using an inclined geosynchronous orbit. The projected service area is restricted to Japan, and
although the satellites cross over Korea and Australia, neither country has been included in the system development to date.

QZSS is a joint public/private sector venture. The private sector part is being led by ASBC (Advanced Space Business Corporation), which consists of a large number of private stakeholders, including Mitsubishi Electric Corporation, Hitachi, Itochu Corporation, NEC Toshiba Space Systems, Mitsubishi Corporation and Toyota Motor Corporation. ASBC has responsibility for the overall system, the mobile communications payload, the broadcasting payload and the ground segment. Responsibility for the navigation payload is with the government as it is regarded as an experimental technology. The navigation payload is a GPS augmentation service, including ranging signals compatible with civil GPS L1, L2 and L5 and integrity messaging using S-Band. Additional frequencies may also be available for coordination with Galileo.

The public sector contributes to the cost of the system through technology programmes for the satellite platform, launch cost support, compensation for the mass and power demands of the navigation payload and for the provision of necessary ground infrastructure such as GPS monitoring stations. The total system cost is estimated at 1.2B€ for three spacecraft including launches. It is understood that no long term funding has been guaranteed (DTI, 2005).

10.4 Brazil

The US FAA has been examining the potential of GPS and augmentations to meet air navigation requirements within Brazilian airspace. There are now formal agreements in place between the two countries. To this end, the FAA has provided technical assistance to Brazil for the development, procurement and installation of the Brazilian testbed which has been used to collect GPS data/SBAS data at 5 locations in Brazil (FAA, 2005b).

10.5 Caribbean and South America (CAR/SAM)

The CAR/SAM Satellite Test Bed (CSTB) consists of a wide-area test bed based on Wide Area Augmentation System (WAAS) prototype technology. CSTB Reference Stations are being installed throughout the CAR/SAM region, to form a wide area monitoring network for GPS, which will derive corresponding SBAS data messages (FAA, 2005b).

The FAA has contributed 5 reference stations to the project, which are installed in Argentina, Bolivia, Peru, Colombia, and Honduras. In addition, a further 3 reference stations and a Master Station have been installed by the FAA in Chile.

Brazil has also contributed to the project by providing 5 reference stations and one Master Station. Brazil also plans to provide an aircraft for testing and geostationary
satellite communications to broadcast the CSTB correction signal throughout the entire CAR/SAM region.

To complete the CSTB architecture, the FAA will also provide a reference station in Panama and several other stations in Mexico.

The final component of this project will be the addition of a prototype Local Area Augmentation System to be installed within the CAR/SAM region to examine terminal area operations, including Category 1, 2 and 3 precision approaches.

The WAAS extension initiatives are supported by both the FAA and the US Trade and Development Agency, and include WAAS and LAAS development, integration and demonstration activities with flight trials and training.

10.6 Asia Pacific (APEC)

In December 2004, the US Trade and Development Agency published a Request for Proposals (closing date February 2005) to provide support to the implementation and operation of a wide area testbed capability and advanced test and evaluation of a seamless satellite navigation system in Southeast Asia.

The APEC Global Navigation Satellite System (GNSS) testbed will support the research, development, acquisition and implementation of a GNSS-based air navigation system throughout the APEC region (USTDA, 2005). The testbed will used to demonstrate how GNSS technology could function across Asia's flight information regions. The testbed will allow for an incremental integration of system components and evolving capabilities, and will support the participating counties in their implementation of GNSS services. The testbed will also provide a “menu” for the APEC countries to guide their decisions in what testbed components are needed and at what cost and schedule.

The Aeronautical Radio of Thailand Limited will act as customer on behalf of the other participants, including Indonesia, Malaysia, the Philippines and Vietnam. The selected US company is to be paid $675,000 by the US Trade and Development Agency (Pringvanich, 2005).

10.6 Nigeria

In December 2003, Nigeria announced its intention to develop its own satellite L-band navigation payload for SBAS, on the proposed Nigeria communication Satellite, to cover the African Continent (Rufai, 2003). The initiative came as result of increased awareness on GNSS from regional workshops. The intention is to provide seamless navigation services over Africa. Furthermore, Nigeria have declared their openness and willingness for strategic partnerships with services providers (particularly the Galileo and GPS).
In April 2005, it was announced that China has been awarded a contract to develop and launch a dedicated communication satellite for Nigeria in 2007. The contractor is understood to be the China Aerospace Science and Technology Corporation and the Chinese Academy of Space Technology (CAST).

It is not known whether the SBAS payload programme is continuing as part of the communications satellite programme, although the satellite will host L-Band transponders. Nevertheless, it is important to identify that there is interest within the African continent to explore the development of SBAS technologies and services.

10.7 EGNOS Extension to MEDA

The Fifth Euro-Mediterranean Ministerial Conference in 2002 adopted an action plan for the development of the Euro-Mediterranean partnership together with a regional strategy. GNSS technology and applications were identified as a key component of the strategy. As a result, a dedicated GNSS project for the MEDA region has been launched, consisting of infrastructure development, demonstration and training based on the use of EGNOS.

Further activities are planned, and a GNSS Cooperation Office has been established to provide a reference point for the promotion of GNSS applications and services in the region.

10.8 EGNOS Extension to ACAC region (Arab Civil Aviation Commission)

Europe has been collaborating with MEDA and Middle East partners to define a plan for the replacement of traditional ground-based navigation aids to GNSS. More recently, the ACAC has expressed an interest to take the collaboration further and to assess the implementation of EGNOS services in their region, on the basis that it will provide a cost effective solution to release the benefits of GNSS services in the short term (GJU, 2005).

The ACAC region is ideally suited for EGNOS. It receives coverage from all three EGNOS geostationary satellite signals and can benefit from the existing EGNOS ground infrastructure within the European service area. It is estimated that, with the addition of 10 to 14 reference stations, the ACAC region can be fully covered and will meet the requirements of the ACAC countries. The architecture, operational structure and financing mechanism remain to be determined.

10.9 EGNOS Extension to Africa

The ICAO Africa and Indian Ocean (AFI) Regional Implementation Plan includes a GNSS strategy plan which has been adopted by AFI States and is based on the following.
• An initial phase (2002-2005) for the implementation of an AFI GNSS test bed as an extension of the EGNOS test bed
• The conditional deployment of an operational system relying upon EGNOS components, in order to meet initial capabilities before 2008
• The long term development of GNSS-based enhanced capabilities relying on the availability of a second satellite constellation

The cooperation between Europe and Africa on GNSS is a specific objective in the transport policy strategy of the EU-ACP Partnership Agreement (Cotonou Agreement). In support of this agreement several studies have been financed by EC to assess the benefits of developing GNSS-based services in Africa. The EC and ESA are supporting the development and implementation of an AFI GNSS test bed and are currently assessing various options to finance a pre-operational Inter-regional SBAS over AFI (GJU, 2004a).

10.10 EGNOS Activities in Latin America

In 2004, the EU-Latin America summit agreed to assess the potential for collaboration in the field of GNSS. As a first step, GNSS Information days have been carried out in Mexico and Brazil and, as a follow up measure, the GJU is investigating the establishment of a GNSS regional plan and a regional centre, to support further cooperation.

This initiative also builds on previous collaborative work between EU and Latin America on GNSS. This work included carrying out some EGNOS trials and hosting a seminar in the region. The trials included the deployment of 3 reference stations in the region which were connected to the EGNOS System Testbed. An EGNOS test signal was broadcast by the Inmarsat AOR-E geostationary satellite to enable a series of static and dynamic tests to be carried out. The results confirmed the potential of EGNOS (with limited ground infrastructure) to provide air navigation services to Latin America (GJU, 2004b).

11. International Developments

With the growing interest in GNSS, as demonstrated by the development of new systems and augmentations, the US government, the Russian Federation and the European Union are very active in international discussions to promote the use of their systems and to guarantee interoperability between GPS, Galileo, GLONASS, WAAS and EGNOS and the services provided by other regions and states.

11.1 United States - European Union

The most notable and high profile political development in GNSS, occurred in 2004 when the US and EU signed a GPS/Galileo agreement on June 26, 2004 (White House,
2004a). The agreement was signed by the US Secretary of State Colin Powell and European Commission's Vice-President Loyola de Palacio.

The agreement followed several years of bilateral talks on cooperation and interoperability of GPS and Galileo. The agreement is significant in its scope and will run for an initial 10-year term, addressing the following key issues:

- Common signal structure for future open services
- Suitable signal structure for the encrypted Galileo Public Regulated Service (PRS)
- Trade, technology export, and national security compatibility
- Process that allows improvements, either jointly or individually, in the baseline signal structures to further improve the performance of the systems
- Confirmation of interoperable time and geodetic standards to facilitate the joint use of GPS and Galileo

The agreement calls for the establishment of 4 working groups to address GNSS issues, namely

- Compatibility and interoperability for civil navigation and timing services
- Trade and civil applications
- Cooperation on the design and development of the next generation of civil satellite-based navigation and timing systems
- Security issues

The agreement is expected to benefit to both sides, and is in the common interest of all users.

At the same time, the US Defense Science Board initiated a study of GPS's future in the context of the emerging Galileo system (see Section 12.1).

11.2 United States - Russian Federation

The US and the Russian Federation met in December 2004 to continue discussions on matters concerning GPS and GLONASS cooperation. Both sides confirmed their commitment to cooperation and reaffirmed their intention to provide the GPS and GLONASS civil signals on a continuous, global basis, free of direct user fees for commercial, scientific and safety of life use (White House, 2004b).

The US and the Russian Federation agreed to cooperate on matters related to civil satellite-based navigation and timing signals and systems, value-added services, and global navigation and timing goods in relevant international organizations and fora. In particular, it is agreed to maintain radio frequency compatibility in spectrum use between each other's satellite-based navigation and timing signals. They will also work together
to maintain compatibility and promote interoperability of GPS and GLONASS for civil user benefits worldwide.

To this end, both sides intend to establish working groups on matters of development and the use of GLONASS and GPS and their respective augmentations. Both sides will begin preliminary discussions on an agreement for GPS and GLONASS cooperation.

11.3 United States - Japan

In 1998, the US and Japan released a joint statement on the cooperation and use of GPS. The document states that Japan intends to work closely with the US to promote broad and effective use of the GPS as a worldwide positioning, navigation, and timing standard and that the cooperation will

- Promote compatibility of operating standards for GPS technologies, equipment, and services
- Help develop effective approaches toward providing adequate radio frequency allocations for GPS and other radionavigation systems
- Identify potential barriers to the growth of commercial applications of GPS and appropriate preventative measures;
- Encourage trade and investment in GPS equipment and services as a means of enhancing the information infrastructure of the Asia-Pacific region
- Facilitate exchange of information on GPS-related matters of interest to both countries, such as enhancement of global positioning, navigation, and timing technologies and capabilities

The US and Japan have also agreed to work together on GPS-related issues that arise in the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Telecommunication Union (ITU). The two governments have established a mechanism for cooperation which involves an annual plenary meeting to review and discuss matters of importance regarding the use of the GPS. Working groups will also be set up under the plenary meeting to discuss issues of mutual interest.

The most recent meeting between US and Japan took place in November 2004 to review and discuss cooperation in the civil use of the GPS. During the meeting, representatives of both sides reviewed the ongoing work of the US-Japan working group on GPS-related technical issues related to satellite navigation on the international scene.

The Government of Japan intends to work cooperatively with the US to ensure that a free and open Global Navigation Satellite System (GNSS) benefits all civil users of GPS. Both Governments believe that a free and open GNSS will assist in the further peaceful development of the Asia-Pacific region, strengthen cooperative relations between the US and Japan, and promote global economic growth.
The Japanese delegation briefed the US on the progress on MSAS and outlined Japan’s plans to construct a regional satellite positioning system, known as the Quasi-Zenith Satellite System (QZSS), which will be supplementary to and interoperable with GPS. Japan offered to work cooperatively with the US to ensure that QZSS benefits all civil GPS users.

The US expressed its strong support for Japan’s plans to develop the Quasi-Zenith Satellite System, which will provide significantly improved regional services to positioning, navigation and timing users in Japan and the neighbouring region. QZSS will strengthen cooperative relations between the US and Japan, foster Japan’s capability in space technology, provide new economic and public transportation safety benefits to Japan and its neighbours, and contribute to the peaceful development of the Asia-Pacific region.

11.4 US–Africa

The Common Market for Eastern and Southern Africa (COMESA) have expressed an interest in developing a GPS based navigation service that could be modeled on the US Wide Area Augmentation System (WAAS). The COMESA countries are also working on a proposal for a high-altitude airspace management service, using GPS signals which would provide en-route coverage of the African airspace (Avionics Magazine, 2000). The status of both initiatives is unclear.

However, as part of a US-African partnership to make air travel on the African continent safer and more secure, an agreement was signed in 2003 between the US and the East African Community (EAC) that will assist member states in upgrading their navigational systems. The agreement provided funding from the US Trade and Development Agency for technical assistance consultancy from the US to support the implementation of GNSS in Kenya, Tanzania, and Uganda (USTDA, 2005b).

The work is believed to include an assessment of the current state of 10 airports in the EAC region and the development of an operational roadmap to guide the region as it transitions from a ground-based to a satellite-based air navigation system.

In addition to the East African Community, the FAA in partnership with the International Air Transport Association (IATA) has developed GNSS procedures for 26 airports in 14 states in the Southern African Development Community. The project consisted of three tasks. In the initial task, geodetic surveys were carried out at each airport. The second task involved the development of GNSS procedures for all airports. The final task was to inspect and certify the new procedures to ensure that they meet International Civil Aviation Organization requirements. These GNSS procedures will ultimately enable aircraft to approach and land at the South African Development Community airports using GNSS technology.
11.5 European Union

The European Union has also been very active in engaging into dialogue with international partners, regarding their interest and potential participation in the Galileo programme. To date, discussions have taken place with China, Israel, India, Ukraine, South Korea, Morocco, Brazil, Mexico, Chile, Argentina, Australia and Malaysia (Europa, 2005). The level of interest has been significant and has so far resulted in signed agreements with China and Israel.

11.6 EU-China

The Sixth EU-China Summit was held in Beijing on 30 October 2003, during which the European Union and Chinese officials signed a cooperation agreement on Galileo.

The agreement covers cooperative activities on GNSS in a variety of sectors, including science and technology, industrial manufacturing, market development, standardisation, frequency and certification. China has since committed to investing 200m€ in the programme through a stakeholding in the Galileo Joint Undertaking and in the development activities managed by the European Space Agency. The Technical Agreement between the Galileo Joint Undertaking and the National Remote Sensing Centre of China was signed in October 2004.

The Chinese government has identified four state-owned space technology companies to oversee research and development as part of China's participation in Galileo. The announcement in March 2005, referenced the creation of China Galileo Industries Ltd, which is a consortium consisting of China Aerospace Science and Industry Corporation, China Electronics Technology Group Corporation, China Satcom and the Chinese Academy of Space Technology. The consortium has been nominated as providing the Chinese industrial effort into Galileo, and is tasked with commercialising the civilian use of the Galileo system in China. It is believed that these companies are different to those engaged in the Chinese Beidou system.

11.7 EU-Israel

Israel expressed its interest in participating in the Galileo programme and its willingness to support the European position on standardisation and frequencies allocation in June 2003. This expression was followed up with discussions and negotiations which culminated in July 2004, when the EU and Israel reached an agreement on the participation of Israel in the Galileo programme.

The agreement covers cooperation on technical, operational, institutional and commercial issues. Israel is participating in the Galileo programme financially, through a stake holding in the Galileo Joint Undertaking.
Several government ministries and participating aerospace companies will contribute to the programme. The government departments include the Ministry of Industry, Trade and Labor, and the Ministries of Defense, Finance, and Science & Technology. Israeli industry is represented by Israel Aircraft Industries, Israel Armament Development Authority., Orbit/FR, BAE Systems Rokar International, and AccuBeat.

11.8 EU-India

EU officials are also hopeful of reaching an agreement with India to join the Galileo programme. There has been extensive discussions and mention of a 300m€ stake in the programme. An EU-India draft cooperation agreement on Galileo exists, but no firm decision has been reported.

11.9 EU-Australia

At a recent meeting of the Australian GNSS Coordination Committee (AGCC) in December 2004, it was reported that Australian Department of Transport and Regional Services is considering an Australian Government position on possible involvement in the Galileo project, and is to establish an inter-departmental committee on Galileo.

The AGCC is the national advisory body to Minister for Transport and Regional Services on issues relevant to GNSS. The Committee consults with Australian GNSS stakeholder communities, and is informed by linkages with international GNSS providers and authorities.

At the last meeting of AGCC in February 2005, the official position of Australia on Galileo was discussed. It is clear from the statement made by the committee’s Chairman, that Australia sees benefits in Galileo and will provide a response to the EC’s offer of entering into a Memorandum of Understanding (AGCC, 2005). The response will aim at opening up the opportunity for further discussions between Australia and the EC. It is anticipated that officials will invite the GJU to Australia in 2005.

Australia have also noted that Galileo commercial services will require wide area networks, similar to that being implemented in GRAS. This may provide an opportunity for engaging interest.

11.10 EU-Argentina

The EU and Argentina have expressed a wish to pursue negotiations leading to an agreement on Galileo. Preliminary talks identified possible co-operation in the areas of market development, industrial applications, ground segments, and possibly also satellite elements, training, regional and local augmentation systems.
11.11 EU-Ukraine

Ukraine is an important player within the global space community which possesses significant technological background in space programmes. Ukrainian companies are also active in both applications and in the service development sector. GNSS technology is used for a variety of civilian applications such as transportation, environment, agriculture, engineering, personal outdoor recreation and safety of life systems.

In September 2004, the European Commission started negotiations on a cooperation agreement with Ukraine on the development of a Civil Global Navigation Satellite system (GNSS). The cooperation will include multilateral and industrial cooperation, research and scientific activities, especially on standardisation issues, regional integrity monitoring and financial investment in Galileo.

11.12 EU-South Korea

South Korea has expressed an interest in participating in the Galileo project. In February 2005, the government of Korea decided to join the European Galileo project and plan to formalise an agreement in 2005. Korea will be required to contribute at least 5m€ to be a part of the Galileo programme. Korea intends to continue to use GPS as a primary platform while maintaining Galileo as a backup. In addition to ensuring an alternative satellite navigation system to GPS, Korea has an industrial incentive aimed at boosting sales of GPS enabled cell phones.

Korean made cell phones currently account for about 30 percent of the world market, and therefore involvement of Korea in Galileo is essential to ensure their continued pre-eminence in mobile phone technology using both GPS and Galileo signals. Furthermore, it has been reported that in 2004, 35 million GSM phones were exported to the EU market by Korean companies (Lee, 2005).

11.13 EU-Malaysia

Malaysia has set a strategic objective to have full coverage of GNSS services throughout the country which will be achieved through the following mechanisms

- GNSS Core Service
- Regional Augmentation System
- Infrastructure for Marine Sector
- Infrastructure for Land Sector
- Infrastructure for Aviation Sector
- Infrastructure for Precise Time Scale

Of particular interest to Europe is the participation in a GNSS Core service. Malaysia has publicly declared its intention to become part of the Galileo programme and discussions
with the European Commission have begun. Malaysia has also expressed an interest in a small scale participation in the Galileo test-bed campaign and are seeking to participate in the development of MSAS and GAGAN with the intention to extend the services to cover its airspace (Subari, 2004).

11.14 India – Russian Agreement

Outside of the US and EU, there has been a significant development between India and the Russian Federation on GNSS. In 2004, the Indian Cabinet ratified an agreement with Russia on long-term cooperation in the joint development, operation and utilisation of the Russian Global Navigation Satellite System (GLONASS) for peaceful purposes.

The agreement covers an Indian contribution to Russian augmentation to GLONASS through

- The joint development of onboard equipment for geostationary satellites
- The establishment of an associated ground infrastructure
- The development of a combined receiver operating on signals from GLONASS and the overlay

More recently in May 2005, the press has reported that as part of the cooperation agreement, Indian booster rockets will be used to launch GLONASS satellites.

12 GNSS Policy & Management

The principal development in GNSS policy occurred in 2004 with the release of new political structures for GPS and Galileo by the US and European Union respectively. The two structures are somewhat similar in nature, but different in terms of motivation. The US has dramatically restructured the coordination of GPS and GNSS with the establishment of a new Executive Committee. Meanwhile in Europe, the Council of Transport Ministers has established a European GNSS Supervisory Authority, which will replace the Galileo Joint Undertaking and provide the public authority responsible for EGNOS and Galileo. There is also news that the Russian Federation has developed the concept of the “National Navigation and Time Provision” approved by President Putin in 2004 which has GLONASS as a key element (Revnivykh, 2005). However no detailed information is available on this policy.

In addition to the higher profile events in 2004 regarding GNSS policy and management, the US DoD established a Task Force to examine the future of GPS.

12.1 Defense Science Board Task Force on Future of the Global Positioning System

The mission of the Defense Science Board is to advise the Secretary of Defense and the Under Secretary of Defense for Acquisition, Technology & Logistics on scientific and
technical matters as they affect the perceived needs of the Department of Defense. In April 2004, the Acting Under Secretary of Defense (Acquisition, Technology and Logistics) requested the Defense Science Board to establish a Task Force on Future of the Global Positioning System (GPS). The Task Force addressed a range of concerns related to GPS, Galileo and radionavigation in general, including

- Provision of capabilities and services within GPS to ensure its viability in commercial markets, including moving the management and development of GPS to another government agency
- The impact on frequency spectrum use, signal waveforms and power management
- Access and denial issues throughout the spectrum of conflict
- Possible alternatives to a global radio navigation system, including the development of small compact timing devices and/or navigation units, including an assessment of the costs of integrating these technologies into DoD assets
- Vulnerabilities and upgrade strategies for all global radio navigation satellite systems

The Task Force also identified areas in which DoD should seek partnerships and relationships outside DoD, both within government and industry (Pentagon, 2004).

12.2 US Space Based Positioning, Navigation and Timing Policy

In December 2004, President Bush called for the formation of an Executive Committee on Position, Navigation and Timing (PNT) to be co-chaired by deputy secretaries from the United States DoD and the DoT. Members of the Executive Committee will include representatives from the Department of State, Department of Commerce, Department of Homeland Security, the Joint Chiefs of Staff, NASA and other agencies as needed. The Executive Committee will make recommendations to agency officials and to the President and provide advice and coordination for policies, architectures, needs and resources.

This policy document represents a significant development in the management of GPS, augmentations, backup systems and international affairs. It sets the scene for the future policy management and organizational structure of GNSS and demonstrates the criticality of GPS to the US government.

The objectives of this new policy are explicit and include the following.

- Provision of uninterrupted access to US space-based PNT services for US and allies (without being dependent on foreign systems)
- Provision of a continuous, worldwide basis civil space-based PNT services free of direct user fees
- Improved capabilities to deny hostile use of space-based PNT services, without unduly disrupting civil and commercial access
• Improved the performance of space-based PNT services
• Maintainance of GPS as a component of US critical infrastructure
• Encouragement of foreign development of PNT services based on GPS
• Promotion of the use of US space-based PNT services and capabilities

The policy also sets out the new roles and responsibilities within government departments regarding PNT services.

The policy reaffirms the free, open use of current and future GPS civil signals and unrestricted access to the specifications needed to manufacture equipment.

The DoD will still have the primary responsibility “for providing resources for development, acquisition, operation, sustainment, and modernisation” of GPS.

The DoT is given responsibility for identifying, specifying, and funding new civil capabilities beyond the C/A-code and planned L2C and L5 signals. The DOT will also be responsible for Civil Monitoring and Augmentations of GPS.

The CIA and secretaries of Defense and Homeland Security will be responsible for identifying and mitigating possible threats to GPS and prevent its hostile use by adversaries. The Department of Homeland Security (DHS) will lead the development of “contingency responses to ensure continuity of operations” in the event that access to GPS “is disrupted or denied” within the United States. Furthermore, the DoD and DHS have responsibility for developing “backup” PNT capabilities that can support critical infrastructure applications within the US if required. This could include the use of Loran-C.

In addition to allocating specific responsibilities, a five-year strategic plan for space-based PNT will be developed to analyse options for sharing the costs of GPS operation, modernisation, augmentations and new capabilities.

The PNT executive committee will establish a National Space-Based Positioning, Navigation, and Timing Coordination Office and a Space-Based Positioning, Navigation, and Timing Advisory Board to be comprised of experts from outside the US government. The Advisory Board will provide expert support (White House, 2004c).

12.3 European GNSS Supervisory Authority (GSA)

In Europe, the European GNSS Supervisory Authority (GSA) has been established to manage the public interests relating to European GNSS programmes. This also includes acting as the GNSS regulatory authority. A High Level Administrative Board has also been established to oversee the work of the GSA. This board is composed of representatives from Member States and the Commission. The main task of the Board is to approve the annual work programme of the GSA and has a responsibility for
establishing advisory committees to support the work of the GSA. The GSA reports directly to the Administrative Board.

The duties of the GSA are far reaching and include the following.

- Regulatory Agency
- Ownership of EGNOS and Galileo assets
- Conclude and manage the contract with Concessionaire
- Specification of operating procedures
- System safety, security and reliability
- Management of frequencies
- Modernisation
- Certification

GSA will also be responsible for managing all aspects relating to the system's safety and security including the following.

- Develop and manage a consultation procedure/process
- Manage the use of and access to classified information
- Security standards and specifications
- Cryptography
- Approvals and accreditations
- PRS receivers and management/distribution rules
- Enforce and verify compliance by the concession holder with international rules
- Identify measures to be taken in the event of hostile mis-use or threat to security
- Advice on security policy issues

To assist the GSA, the Administrative Board will establish a System Safety and Security Committee composed of acknowledged security experts from the Member States and the Commission. A Centre for Security and Safety will also be established to carry out expert assignments linked to the safety and reliability of the systems. The Centre may also be given responsibility for taking measures required in a crisis.

On a technical front, the European Space Agency (ESA) shall provide the GSA with technical and scientific support. Additionally, the Administrative Board has the option to establish a Scientific and Technical Committee composed of acknowledged experts. The exact role of the Committee is yet to be determined. However, such a committee could be a valuable asset in providing independent opinion and analysis on technical questions or advice on proposals involving major changes in the design of the European GNSS system including recommendations on the modernisation of the Galileo and EGNOS systems and services.
The GSA has a legal personality, responsibilities and a budget. It is managed by its recently appointed Executive Director, who has complete control and independence in the exercise of his duties (*European Council, 2004*).

### 13. Future Services

Within the next 10 years, GPS and Galileo will co-exist and provide independent systems which are fully compatible and interoperable in the provision of position, navigation and timing services to a global marketplace. During this period, a combined Galileo and GPS constellation will offer system redundancy for operations that require the most demanding levels of continuity. In the event that one system fails, missions and operations can continue based on the remaining global system. This feature is essential for mission critical, financial and safety critical activities. Furthermore, additional SBAS and GBAS services will be available around the globe to provide further augmentation to one or both systems.

The orbits of the Galileo and future GPS constellation are being optimised to offer increased performance. However, the greatest advantage comes through the use of a GNSS receiver capable of receiving signals from both GPS and Galileo. This dramatically increases the number of satellite signals and improves the availability of positioning in built up areas and other difficult environments. GPS and Galileo will provide 24 hour, global, all weather, open access positioning services. Additional satellite signals, together with optimized navigation messages and advanced user receiver algorithms will ensure that when Galileo signals are combined with GPS observations in a dual-constellation, dual frequency GNSS receiver, the user will obtain metre level accuracy globally.

An added benefit of having an increased number of signals is the ability to perform outlier detection and exclusion at the user receiver. Whereas the Galileo integrity service provides assurance of system performance, additional techniques are available to the user to determine the confidence in the receiver’s ability to compute a position. Chief among these is Receiver Autonomous Integrity Monitoring (RAIM) which currently offers a complimentary function to the ground based integrity services which is enabled and enhanced through additional redundant satellite signals. Clearly the combined GPS and Galileo constellation offers additional signals and can improve the availability and performance of RAIM. Future satellites may also include the ability to monitor themselves and autonomously modify their broadcast signals and messages according to the status of their health, without the need for an extensive ground based integrity monitoring networks and control centres.

The current proposals for GPS and Galileo services include the provision of signals based on the use of pilot codes, with no data message modulated on to them. The use of pilot codes enables signals to be acquired and tracked at very low signal strengths. This will
support the future use of GNSS to provide continuous position under difficult conditions and in buildings.

Future GNSS services may include a very low speed communication channel which may be used to transmit information from service centres-to-users or from users-to-centres. The service and information content remain to be defined. The service could provide information and guidance to users of the location of incidents or activities. It could also be used for broadcast or tracking services.

Both GPS and Galileo will provide civil signals on 3 frequencies which can be used to providing very high accuracy and robust positioning services (Multiple Carrier and Trilaning). This service can be used for surveying and mapping, positioning, monitoring and geo-referencing applications which require centimetric and millimetric accuracy.

Future GNSS systems will also contribute to the international Search And Rescue (SAR) service, enhancing the world-wide performance of the current COSPAS-SARSAT system. The GPS DASS and the Galileo SAR service will drastically reduce the time to alert, and the position of the distress beacon will be determined to within a few metres.

The increase in signals and overall system accuracy and reliability will ensure improved services for all user communities.

14. Enabling New Applications

Looking further ahead, the availability of improved services from GPS III, an enhanced Galileo and potentially a GLONASS-KM constellation will allow global systems to gradually replace many regional and local services. Furthermore, the additional integrity provided by onboard monitoring and inter-satellite ranging will reduce the need for extensive ground based networks. Maritime administrations in particular will have to re-examine their services and identify the best combination of GNSS systems and augmentations to meet their requirements.

Ground networks will still be required for high accuracy applications, however the availability of three civil frequencies and improved orbit and clock products, from three constellations will allow centimetre level performances with a sparse ground monitoring infrastructure. New applications on a global scale requiring reliable, robust and high accuracy positioning will then become a reality.

Secondary payloads and services may also provide integrated services for applications requiring navigation and communication. Satellite communications and navigation are perfect partners, when dealing with tracking and tracing applications at regional and global scales. In future, these technologies will be increasingly and seamlessly integrated to enable instantaneous relaying of position data across continents. Both technologies are
able to provide global solutions for business and governments. Higher power positioning signals and greater integration with terrestrial systems and MEMS technologies will also provide total solutions for universal tracking in all environments (outdoor and indoor) and under all conditions.

Within the commercial markets, it can be envisaged that all items and objects that are moveable will be available for tracking. This will mean that individuals and businesses will be able to locate assets immediately, efficiently and reliably allowing for enhanced location based services. In the regulated markets, legislation will have entered into force for the tracking and charging of road freight vehicles, where taxation will be based on reliable and authenticated location and timing data from GNSS. This market has the potential to spread horizontally across all road vehicles, therefore charging the individual and business by the distance traveled rather than through fixed taxes. This market is also expected to expand into vertical business services related to insurance, congestion charging, access restrictions, theft, breakdown and emergency calls.

It is expected that legislation will be in place at the right time in the US, Europe, Japan and other regions to improve the response times to accidents. This will involve accurately positioning the location of emergency calls, so that emergency services can respond to the incident in an optimal manner. The location function within mobile telephones will be enabler for the future growth of information services for society, business and governments.

An increasing focus will be placed on the use of GNSS within governmental services to support regional, national, European and global policies and agreements. The potential is vast and will cover traditional markets and new applications in justice, borders, customs, trade and exports as well as agriculture, fisheries, food and healthcare. The security and law enforcement domain is also expected to mature over this same period. In particular, container tracking is an area of concern to international governments and legislation is increasingly becoming essential to improve customs and security. The US and EU are moving on this issue already, whereby every container traveling in and out of international ports will require tracking at a global scale. However, the widespread use of GNSS data as evidence in law enforcement applications will only materialise if and when the ethical and privacy concerns are resolved.

Lastly, GNSS safety services will have penetrated the transport sector and will be providing safe navigation services to the aviation, maritime and rail markets. GNSS based services will be part of driver assistance systems and will support cooperative vehicle highway systems. New applications will also be emerging that enable, disable and reconfigure the functionality and performance of an object, vehicle or service according to its location and context of operation. Location technology will be ubiquitous and pervasive. Location based services will have entered a new era.
15. Conclusions

The early conceptual discussions on Galileo took place in 1998. At that time, the project was not even known as Galileo, but only as a component of GNSS-2, implying that, as far as Europe was concerned, GPS plus the 3 regional wide area augmentation systems, including the European EGNOS, constituted GNSS-1. The US agreed partially to this by adopting the term GNSS, but without its two numerical suffices. Clearly, this was not merely divergence of views about nomenclature, but a much more serious conceptual-political discrepancy involving the future of global satellite navigation. The US was at a loss to understand why a global system of satellite navigation required more than one global satellite system, ie GPS, especially considering the security and military implications of a second independent global satellite system. Europe, on the other hand, considered that this was not just a security problem, but rather one with commercial, economic and political implications. How could a GNSS, with only GPS as its core global satellite system, offer full security and equal commercial, industrial and business opportunities to all the countries involved in GNSS? These mutual concerns were eventually resolved when the EU and the US signed the GPS and Galileo cooperation agreement in June 2004.

However, it is now becoming clear that this bilateral agreement, while ending the political discord between US and EU, has also created a new scenario where the battle lines are now drawn in terms of technical prowess, economic and commercial muscle, and political influence. This is well illustrated, firstly by the new technical developments in the current constellation of GPS IIR, the GPS IIF satellites that are currently being developed (with first launch planned for 2007 and full operational capability in 2013), and lastly the GPS III satellites which, at present, are in their early conceptual and definition phases (with first launch planned in 2013, and full operations starting in 2020 timeframe, with the full system expected to last until 2030). Already the current GPS IIR satellites have the AUTONAV capability, which allows these satellites to survive without any ground support and inputs for 60 days. Clearly, now that the Cold War is over, this is somewhat of an overkill. However, these inter-satellite communication links can also be used for other purposes, most notably to improve instantaneous orbital accuracies and integrity of the satellite messages. The GPS IIR satellites also possess NUDET, a nuclear blast detection function, as well as a limited amount of communications capability which is only available to military users.

Both GPS IIF and GPS III will have a range of well protected military signals, as well as 3 civil signals, namely L1, L2 and L5, which will allow much greater accuracies and better integrity. They will also enjoy a new clock technology, higher power, and better codes and signals. It is proposed that the early GPS III satellites will have fully reconfigurable payloads, which could offer several potential benefits to military and civil users. It is not too difficult to conclude that the final configuration and full specifications of GPS III will not be defined until 2008 or soon thereafter, when Galileo is expected to be fully deployed and declared operational. Only then will one be able to fully assess its
capabilities and the resulting commercial advantages from the users' point of view, including service providers, government, receiver manufacturers, safety critical transportation users, and ordinary citizens. By then one would also have a clearer idea on the uptake of its commercial services and PRS, its contribution to search-and-rescue operations, and especially its penetration of the mass-market commercial applications on a global basis. This is when the US will show its full hand, or most of it, and define GPS III.

In its present configuration, the Galileo design is comparable to GPS Block IIF which, in turn, was defined in 2000. Whereas the US is now considering GPS III, the EU does not yet appear to have plans beyond 2010 for Galileo. Leaving the technical issues aside, and considering the financial and funding aspects of GPS and Galileo, it is clear that GPS enjoys a distinct advantage over Galileo in terms of project funding. GPS is still fully funded by the Department of Defense, although its governance is now shared with the Department of Transportation. By contrast, Galileo is expected to be funded through the public-private-partnership (PPP) model, still to be defined and fully fleshed out. It is clear this is one of the main issues under discussion between the Galileo Joint Undertaking (GJU) and the two short listed consortia bidding for the Galileo concession. How much of the project will be funded from the government, and how much of the financial risk will be shouldered by the winning Concessionaire? Would the emerging funding model be a full PPP or somewhat loosened to become, say, a PFI (Private Finance Initiative), with all its public funding implications? These issues will need to be clarified very soon, but whatever the resulting outcome, financially speaking, GPS operations appear to be more secure simply because of their funding model, which is straightforward if apparently more costly, from the taxpayers point of view. The qualification "apparently" is justified in this case, because the US government has a clear vision of the direct costs of running GPS, compared with the enormous economic, industrial and commercial benefits that the country derives from it. Unlike Galileo, which is ultimately controlled by the Council of Ministers of Transport in Europe, and therefore largely considered a mere transportation utility comparable to, say, to a tunnel across the Alps, GPS will now be run by an Executive Committee on Positioning, Navigation and Timing (PNT), which includes representatives from the State Department, the Department of Commerce, the Department of Homeland Security, the Joint Chiefs of Staff, NASA and other government departments and agencies, as required. This has been instituted in December 2004, following a call by President Bush who decided that the PNT Executive Committee was to be co-chaired by the Deputy Secretaries of both the DoD and DoT, and include representatives of all the other government agencies which would be affected by PNT in the future. The Committee will make recommendations to agency officials and the President and provide advice and coordination for policies, architectures, needs and resources. In addition to the PNT Executive Committee, the US will also establish a space-based PNT Advisory Board, whose members will be experts “from outside the US government”. Clearly, this is somewhat different from the administrative and political arrangements so far put in place to administer Galileo.
The Evolving GNSS Panorama: A Report to the European Space Agency
Final Report, Version 1.0
May 2005

The US has also been very active on the international front in terms of promoting GPS and WAAS. In addition to the US-EU agreement signed in 2004, which will run for an initial term of 10 years, the US and the Russian Federation have agreed to cooperate on matters related to civil satellite-based navigation and timing signals and systems, and value added services. In 1998, the US and Japan signed a cooperation agreement on the use of GPS and its civilian applications, as well as in promoting the Japanese regional Quasi-Zenith Satellite System (QZSS) which will be interoperable with GPS, for the benefit of users in the Asia-Pacific region. The US has also been promoting either GPS and/or WAAS in other regions of the world, including Central and South America, the Caribbean and Africa.

The European Union has also been very active on the political and diplomatic front, in promoting Galileo. It has signed collaboration agreements with China and Israel, and engaged in dialogues with India, Ukraine, Brazil, Mexico, Chile, Argentina, Korea, Australia and Malaysia. It is also exploring ways to extend the EGNOS service into neighbouring regions.

The same is true of the Russian Federation in promoting GLONASS internationally, but doing this on a more selective basis. In particular, Russia has signed a close collaboration agreement with India for the joint further development, operation and utilisation of GLONASS for peaceful purposes.

It is clear that Europe is very active in terms of promoting the Galileo system internationally, just like the US and the Russian Federation are promoting GPS and GLONASS. What appears to be lacking is a comparable effort in terms of the future development of the system beyond 2010, when Galileo will be fully deployed and operational. Consider the time lag between the conceptual definition phase of the project, which started in 1998, and the full operations phase which is due to begin sometime between 2008 and 2010. If one extrapolates this to the next generation of Galileo satellites which should become operational, say, around 2020, then one should start planning for their conceptual definition phase no later than, say, 2007 or 2008. Otherwise, the current configuration of Galileo will find it impossible to compete with GPS III, its GLONASS-KM counterpart, and quite possibly with other regional and even conceptually new global systems, designed by countries like China, India and Japan, potentially in collaboration with their neighbouring countries. This could affect Europe’s ability to compete with the rest of the world on the commercial and industrial front which, in turn, could have long term economic, security and political consequences.

Europe took a substantial first step on the international Positioning, Navigation and Timing (PNT) applications front when it went ahead with the Galileo Project. It must now make sure that this momentum is maintained, by devoting all the necessary technical, financial, administrative and political resources to the next phase of the Galileo Project, beyond 2010.
References

Aerospace Corp, 2002
AGCC, 2005
Avionics Magazine, 2000
Avionics Magazine, 2004
Avionics Magazine, 2005
Crews, 2004
DTI, 2005
Enge, 2005
Europa, 2005
European Commission, 2003
European Council, 2004
FAA, 2005a
FAA, 2005b
Gibbons, 2005
GJU, 2004a
GJU, 2004b
GJU, 2005
GPS JPO, 2001

www.aero.org/publications/crosslink/summer2002/07.html
http://www.aviationtoday.com/cgi/av/show_mag.cgi?pub=av&mon=0200&file=02avscan.htm
http://www.avionicsmagazine.com/cgi/av/show_mag.cgi?pub=av&mon=0204&file=0204scan.htm
http://www.avionicsmagazine.com/cgi/av/show_mag.cgi?pub=av&mon=0205&file=scan.htm
GPS Modernisation, CGSIC 44th Meeting, Long Beach, California, September 2004
Present and Future Satellite Navigation Infrastructure in Location Based Services: Understanding the Japanese Experience, DTI Globalwatch Publication, UK
Status of LAAS and WAAS: A Researcher’s Perspective, Munich Satellite Navigation Summit, March 2005
http://gps.faa.gov/Programs/WAAS/waas.htm
www.faa.gov/asd/international
GPS JPO Rethinks GPS III Strategy, pp 12, GPS World, April 2005
Africa GNSS Service Implementation Plan, Internal Document, 2004
Galileo cooperation project for Latin America, Statement of Work, 15 November 2004
ACAC Regional GNSS Service Implementation Plan, Internal Document, 2005
Global Positioning System (GPS) III, System Definition and Risk Reduction (SD/RR), State of Objectives (SOO), Draft Release #1 to Industry, 2001
<table>
<thead>
<tr>
<th>Hudnut and Titus, 2003</th>
<th><em>L1C Modernisation</em>, CGSIC 42nd Meeting, Portland, Oregon; September, 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>JCAB, 2005</td>
<td><em>MSAS Status</em>, ICAO GNSS Seminar &amp; NSP Working Group Meeting, Bangkok, Thailand, 10-18 May 2005</td>
</tr>
<tr>
<td>Raytheon, 2005a</td>
<td><em>FAA and Raytheon agree to a $204 million FAA contract modification to provide full LPV performance for the Wide Area Augmentation System</em>, Airspace Management and Homeland Security News, Volume 2, Number 1, 2005</td>
</tr>
<tr>
<td>Revnivykh, 2004</td>
<td><em>Developments of the GLONASS system and GLONASS Service</em>, UN/US GNSS International Meeting, Vienna, 13-17 December, 2004</td>
</tr>
<tr>
<td>Revnivykh, 2005a</td>
<td><em>GLONASS: Status and Perspectives</em>, Civil GPS Service Interface Committee, International Information Subcommittee, Prague, 14-15 March, 2005</td>
</tr>
<tr>
<td>Revnivykh, 2005a</td>
<td><em>Developments of the GLONASS system and GLONASS Service</em>, Munich Satellite Navigation Summit, March 2005</td>
</tr>
</tbody>
</table>
| Rufai, 2003          | *Nigerian initiative for the benefit of Africa: project to develop a navigation payload for SBAS on a proposed Nigeria communication satellite*, United Nations/United States of America
America International Workshop on the Use and Applications of Global Navigation Satellite Systems, Vienna, Austria, 8-12 December 2003

Shaw, 2005  

Subari, 2004  
The Applications of GNSS in Malaysia: Status Updates,

USTDA, 2005a  
http://www.ustda.gov/USTDA/USTDA%20By%20Region/Asia 2.htm

USTDA, 2005b  
http://www.tda.gov/region/sectoral/aviation.html

White House, 2004a  

White House, 2004b  

White House, 2004c  

Wu and Feess, 2000  
*Development and Evaluation of GPS Space Clocks for GPS III and Beyond*, The Aerospace Corporation, PTTI 2000
# Annex 1 List of Acronyms

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AAI</td>
<td>Airports of India Authority</td>
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<td>ACAC</td>
<td>Arab Civil Aviation Commission</td>
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<tr>
<td>AFI</td>
<td>Africa and Indian Ocean Region</td>
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<td>AGCC</td>
<td>Australian GNSS Coordination Committee</td>
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<tr>
<td>APEC</td>
<td>Asia Pacific Region</td>
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<tr>
<td>ARNS</td>
<td>Aeronautical Radionavigation Service frequency band</td>
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<td>ASBC</td>
<td>Japanese Advanced Space Business Corporation</td>
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<td>AUTONAV</td>
<td>Autonomous Navigation function</td>
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<td>Beidou</td>
<td>Chinese Regional Satellite Navigation System</td>
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<td>C/A</td>
<td>Coarse Acquisition</td>
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<td>CAR/SAM</td>
<td>Caribbean and South American Region</td>
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<td>CAST</td>
<td>Chinese Academy of Space Technology</td>
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<tr>
<td>CIA</td>
<td>US Criminal Intelligence Agency</td>
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<td>COMESA</td>
<td>Common Market for Eastern and Southern Africa</td>
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<td>CORS</td>
<td>Continuously Operating Reference Stations</td>
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<td>Cs</td>
<td>Caesium</td>
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<td>CS</td>
<td>Galileo Commercial Service</td>
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<td>CSTB</td>
<td>CAR/SAM GNSS testbed</td>
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<td>DASS</td>
<td>Distress Alerting Satellite System</td>
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<td>DGNSS</td>
<td>Differential GNSS</td>
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<td>DHS</td>
<td>US Department of Homeland Security</td>
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<td>DoD</td>
<td>US Department of Defense</td>
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<td>DoT</td>
<td>US Department of Transportation</td>
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<td>EAC</td>
<td>East African Community</td>
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<td>EC</td>
<td>European Commission</td>
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<td>ECAC</td>
<td>European Civil Aviation Conference</td>
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<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service</td>
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<td>EGSA</td>
<td>European GNSS Supervisory Authority</td>
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<td>ESA</td>
<td>European Space Agency</td>
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<td>ESSP</td>
<td>European Satellite Service Provider</td>
</tr>
<tr>
<td>ETS</td>
<td>Japanese Experimental Test Satellite</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAA</td>
<td>US Federal Aviation Administration</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
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</tr>
<tr>
<td>FM</td>
<td>Frequency Modulation (Radio)</td>
</tr>
<tr>
<td>GAGAN</td>
<td>GPS And Geo Aided Navigation System</td>
</tr>
<tr>
<td>Galileo</td>
<td>Europe's Global Navigation Satellite System</td>
</tr>
<tr>
<td>GBAS</td>
<td>Ground Based Augmentation System</td>
</tr>
<tr>
<td>GLONASS</td>
<td>Russian Global Navigation Satellite System</td>
</tr>
<tr>
<td>GLS</td>
<td>GNSS Landing System</td>
</tr>
<tr>
<td>GMSP</td>
<td>Global Multimission Support Programme</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>GPS</td>
<td>US Global Positioning System</td>
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<tr>
<td>GRAS</td>
<td>Ground-Based Regional Augmentation System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global Standard for Mobile (communications)</td>
</tr>
<tr>
<td>IALA</td>
<td>Inter'l Assoc of Aids to Navigation and Lighthouse Authorities</td>
</tr>
<tr>
<td>ICAO</td>
<td>International Civil Aviation Organisation</td>
</tr>
<tr>
<td>IFR</td>
<td>Instrument Flight Rules</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organisation</td>
</tr>
<tr>
<td>IOV</td>
<td>In-Orbit Validation</td>
</tr>
<tr>
<td>ISRO</td>
<td>Indian Space Research Organisation</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>JPO</td>
<td>GPS Joint Program Office</td>
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<tr>
<td>JTRS</td>
<td>Joint Tactical Radio System</td>
</tr>
<tr>
<td>L1C</td>
<td>Proposed GPS civil L1 signal</td>
</tr>
<tr>
<td>L2C</td>
<td>GPS civil L2 signal</td>
</tr>
<tr>
<td>LAAS</td>
<td>Local Area Augmentation System</td>
</tr>
<tr>
<td>L-AII</td>
<td>Legacy Accuracy Improvement Initiative</td>
</tr>
<tr>
<td>Loran-C</td>
<td>Long Range Navigation system</td>
</tr>
<tr>
<td>MEDA</td>
<td>Mediterranean Region</td>
</tr>
<tr>
<td>MEMS</td>
<td>Micro Electro Mechanical Systems</td>
</tr>
<tr>
<td>MRD</td>
<td>Mission Requirements Document</td>
</tr>
<tr>
<td>MSAS</td>
<td>MTSAT Satellite Augmentation System</td>
</tr>
<tr>
<td>MTSAT</td>
<td>Japanese Multifunctional Transport Satellite</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NDS</td>
<td>NUDET Detection System (additional payload onboard GPS)</td>
</tr>
<tr>
<td>NGA</td>
<td>National Geospatial Intelligence Agency</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>----------</td>
<td>---------------------------------------------------</td>
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<tr>
<td>NUDET</td>
<td>Nuclear Detonation</td>
</tr>
<tr>
<td>ORR</td>
<td>Operational Readiness Review</td>
</tr>
<tr>
<td>OS</td>
<td>Galileo Open Service</td>
</tr>
<tr>
<td>PFI</td>
<td>Private Finance Initiative</td>
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<tr>
<td>PPP</td>
<td>Public Private Partnership</td>
</tr>
<tr>
<td>PNT</td>
<td>Position, Navigation and Timing</td>
</tr>
<tr>
<td>PRS</td>
<td>Galileo Public Regulated Service</td>
</tr>
<tr>
<td>QZSS</td>
<td>Quasi-Zenith Satellite System</td>
</tr>
<tr>
<td>RAIM</td>
<td>Receiver Autonomous Integrity Monitoring</td>
</tr>
<tr>
<td>Rb</td>
<td>Rubidium</td>
</tr>
<tr>
<td>RTCM</td>
<td>Radio Technical Committee for Maritime</td>
</tr>
<tr>
<td>SA</td>
<td>Selective Availability</td>
</tr>
<tr>
<td>SAR</td>
<td>Search and Rescue</td>
</tr>
<tr>
<td>SARPS</td>
<td>ICAO Standards And Recommended Practices</td>
</tr>
<tr>
<td>SBAS</td>
<td>Satellite Based Augmentation System</td>
</tr>
<tr>
<td>SoL</td>
<td>Galileo Safety of Life Service</td>
</tr>
<tr>
<td>SRR</td>
<td>System Requirements Review</td>
</tr>
<tr>
<td>TTFF</td>
<td>Time To First Fix</td>
</tr>
<tr>
<td>TV</td>
<td>Television</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency (communications)</td>
</tr>
<tr>
<td>WAAS</td>
<td>Wide Area Augmentation System</td>
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