Satellite Navigation

Over the last twenty years Global Positioning System (GPS) receivers have revolutionised navigation. Integrated devices are capable of providing time, position, height, direction, heave and attitude, to accuracy of a few nanoseconds time, 1cm position or 0.01-degree heading. This article explores the future development and implications of Satellite Positioning. Satellite Positioning dominates navigation at sea, in the air and on land and is now available in our cell phones and wristwatches. How it currently works was explored in the October 2006 issue of Hydro international in an article titled â€˜Satellite Positioningâ€™ (pp 35-39). But how will it work in the future Will the receivers of today be usable in ten years time Will augmentation still be required for accurate positioning Will legislation force new receiver technology to be installed GPS is evolving; the Russian equivalent Glonass is in resurgence, the European Galileo system progressing and other GNSS (Global Navigation Satellite Systems) are under development by Japan, India and China. In addition, there are increasing numbers of GNSS Augmentation Systems. For GNSS manufacturers and users the next decade will see rapid technological change, more choice and greater performance.
ce.

GNSS Overview

The expected GNSS operational characteristics are summarised in Table 1. Items in red text are expected to become available in the future, according to the most recent statements by their respective owners/planners. Table 2 shows the expected codes and signals available for GPS, Glonass and Galileo. Compass is still at the definition stage and there is as yet no Interface Control Document publicly available. The timeline for the number of GNSS satellites expected to be operating at the different frequencies is shown in Figure 1.

USA GPS and WAAS

Thirty-one satellites currently provide two frequencies, L1 and L2, with the civilian Coarse Acquisition Code (C/A) on L1 and the Military P Code encrypted to Y Code available on both L1 and L2. The first three GPS IIR-M satellites with the new L2C codes have been launched and the next launch is scheduled for spring 2007. The first of the next-generation IIF satellites has been postponed to at least March 2008; this will feature the new L5 frequency and codes, plus an anti-jam flex power capability for the military. The L1C code, compatible with the Galileo L1C, is due for launch in 2013 on the first of the GPS IIIA satellites. This is later than originally anticipated because of the outstanding longevity of the satellites and recent budgetary restraints.

Broadcast orbit and clock accuracy have reportedly improved by as much as 15-20% since 7th September 2005 when the number of tracking stations was increased from six to twelve, providing increased coverage at high latitudes. Five more tracking stations are due to be added within the next two years.
Dual-frequency L2C capable receivers will be capable of accessing the L2 signal with a 10 to 20dB greater signal strength than the currently used cross-correlation techniques, resulting in more reliable dual-frequency performance in areas of poor signal. The full benefits of L2C will not be available until the majority of the current satellite constellation has been replaced by L2C-capable satellites; then we may see low-power, consumer-grade, dual-frequency GPS receivers. Unlike L1 and L5, L2 has never had International Telecommunications Union (ITU) protection for Aeronautical Radio Navigation Service (ARNS).
The future L5 will feature a higher power signal, higher bandwidth and enhanced signal structure for superior performance. Higher power will help overcome Distance Measuring Equipment (DME), which shares the ARNS band that includes L5. Receiver manufacturers will need to blank these relatively high-power DME signals where they become noticeable near airports.

The introduction of L1C will be in addition to the existing C/A code, ensuring that legacy GPS equipment continues to work. L1C is currently being designed to be compatible with Galileo. Future tri-frequency GPS receivers will be better able to determine ionospheric and tropospheric delay, leading to greater confidence in determined position, especially height. In addition there will be three possible signal pairs, and this will improve reliability and robustness of integer selection for Real Time Kinematic (RTK) precise positioning and the range at which integers can be successfully resolved from a single RTK base station.

WAAS is now fully operational, covering USA, Alaska, Hawaii and Puerto Rico. The performance level set by the Federal Aviation Authority for L1 receivers equipped with WAAS will be 7m horizontal and vertical. Consumer handheld-GPS manufacturers have been advertising a performance of less than 3m. WAAS performance for a static dual-frequency receiver on the USA west coast in September 2006 shows an accuracy over 24 hours of 0.3m horizontal and 0.4m vertical (1 sigma).
New WAAS tracking stations are to be added in Canada and Mexico to extend the applicable area footprint. Two new satellites, PanAmSat Galaxy 15 and Telesat Anik F1R at Longitudes 133W and 107W respectively, are the first satellites to transmit on L5 with WAAS corrections also on L1. The third WAAS satellite, AOR-W, has been moved to Longitude 142W. The WAAS data includes timing signals to permit ranges to be calculated and can be used in addition to normal GNSS satellite ranges.
The FAA has called for a move to Automatic Dependent Surveillance Broadcast (ADS-B), the aerial equivalent of marine Automatic Identification System (AIS), to be implemented by 2013. Tests in Alaska have shown that ADS-B can improve safety by 49% and UPS has been using it for more efficient fleet management and fuel cost savings.

Glonass and SDCM SBAS

As of 3rd December 2006 there were twelve operational satellites, plus four satellites switched off. The next launch of three satellites will be on 25th December 2006. Glonass availability is expected to reach 24 by 2009, for full operational capability. The technical performance in September 2006, as reported by the Russian Federal Space Agency Roskosmos, shows Glonass user-range error to be typically 2-8m compared to 0.5-2m for GPS. The Russians are aiming at the target of 2011 to achieve performance as good as the current GPS accuracy of 0.5-2m. A lack of tracking stations outside Russia severely limits system integrity-monitoring capability. The frame of reference for

Glonass will be brought into line with the International Terrestrial Reference Frame (ITRF) in 2006 and will be called PZ-90.02 to distinguish it from the original Parametri Zemli 1990 (PZ-90).

From 2008 a third frequency and code L3 will be added to Glonass, overlapping Galileo E5B at fractional frequencies 94/125 of Glonass L1.
Earlier plans showed Russia transmitting GNSS augmentation signals from its Glonass-K satellites. In May 2006 it was announced that this had yet to be confirmed. There will now also be the System for Differential Correction and Monitoring (SDCM), planned to be operational by 2011, which will transmit corrections for both Glonass and GPS within Russia from geo-stationary satellite(s). This will use eight tracking stations within Russia, plus yet to be decided foreign tracking stations, and will provide a WAAS-like capability over Russian airspace. In an announcement made on 13th November by the Defence Minister of Russia, restrictions on Glonass accuracy will be removed on 1 January 2007.

Galileo and EGNOS

Galileo is a public/private partnership, the public providing one third of deployment costs and the private consortium to be given a twenty-year management concession. Current projections show a deployment cost of _7B (US$8.67B) versus revenues of _8.5B (US$10.5B) for the duration of the initial concession.
The first prototype satellite, Giove-A (Giove: Italian for â€˜Jupiterâ€™), was launched aboard a Soyuz from Baikonur spaceport on 28th December 2005. This has successfully transmitted signals and codes according to an earlier draft of the Galileo Interface Control Document, thereby securing the frequencies allocated by ITU before the deadline of July 2006. A public ICD was made available on 28th May 2006 with the codes copyrighted and the document labelled â€˜draftâ€™. The ICD specifically forbids commercial exploitation of the copyrighted information without a licence from the copyright holder, and further adds, â€˜The present document is subject to evolution, and the information contained in it may changeâ€™.
A second prototype satellite was scheduled for launch towards the end of 2006, but an onboard computer fault has further delayed this until early 2007. The main purpose of the second prototype is to test the desired orbit and critical satellite components. Principal amongst these is the Hydrogen Maser atomic clock, and the question is whether this can outperform the â€“Rubidium and Cesium-based technology aboard GPS. Four IOV satellites are scheduled for deployment before 2008, with two satellites launched per Soyuz vehicle. These will permit the first Galileo-only positioning tests using space signals. Until then it will be possible to test Galileo receivers using simulators or the GATE facility in Germany, which consists of six ground-based Galileo pseudolites. The full constellation of 27+ three operational satellites is officially to be deployed before the end of the decade. The orbit has been chosen to optimise the average elevation to 25 degrees for better performance in urban canyons and northerly latitudes, as opposed to the original GPS orbit that was optimised for a 10-degree elevation for military purposes.

Galileo will provide four frequency bands and four principal codes: Open Service (OS), Safety of Life (SoL), Commercial Service (CS) and Public Regulated Service (PRS). CS and PRS will be encrypted and accessible only to authorised users. CS is intended for commercial operations demanding guaranteed high performance and reliability, whilst PRS is for use by approved government agencies. Three different navigation messages will be provided: F/NAV (Free) on E5A OS, I/NAV (Integrity) on E5B and E1B SoL and C/NAV (Commercial) on E6B CS. Data will be Viterbi Forward Error Corrected (FEC) using two symbols per bit, making it more expensive in bandwidth but providing a more robust signal.

The aforementioned US$8.5B revenue may come from licensing of code copyright, access to the CS and PRS codes, decryption chips, receiver levies, navigation fees or any combination thereof. The exact revenue mechanism is pending on negotiations currently underway between the Galileo Joint Undertaking (GJU) and the Concession Consortium, which includes such companies as Alcatel Alenia, Thales and EADS Astrium. The current expectâ€“ation is that these negotiations will be completed at the end of 2006 at which point the GJU ceases to be and transfers oversight to the Galileo Supervisory Authority (GSA).
Standalone service performance targets are 4m Horizontal, 8m Vertical for dual-frequency receivers for the SoL, OS and CS codes with 15m H and 35m V for single-frequency receivers. Availability aims at 99.5%. There will be no integrity on the OS and CS services, but SoL will have an alert limit of 12m H and 20m V, with a time to alert of six seconds. Of specific interest to mariners is the Galileo Search and Rescue (SAR) capability. Each satellite has a SAR beacon receiver in the frequency range 406.0-406.1MHz and an L-Band downlink 1,544-1,545MHz to communicate back to the control centre. SAR data will be encoded in real time in the Galileo OS datastream transmitted on the E2-L1-E1 frequency for confirmation and co-ordination of SAR teams.

The EGNOS System Test Bed (ESTB), which provides corrections for the GPS satellites, has reported an accuracy of 0.7m Horizontal and 0.9m Vertical with the current EGNOS SBAS test signals. Testing with a static NavCom dual-frequency GPS receiver in Germany in July 2006 showed an accuracy of 0.5m Horizontal and 0.7m Vertical (1 sigma). As of the end of June 2006 the ESTB was closed and control of EGNOS transferred to the European Satellite Services Provider (ESSP). It is expected that EGNOS be qualified by the end of April 2007, and then declared operational. Corrections are transmitted from three satellites and are also available via a real-time Internet Protocol datastream for use via cellular and internet-enabled Personal Digital Assistants and portable computers.
QZSS and MSAS
The Quasi Zenith Satellite System was a government/private-sector co-operative programme that included three GPS-compatible and interoperâ€“able satellites in an elliptical figure-of-eight High Earth Orbit (HEO) above Japan and Australia, such that one satellite was always above Japan at an elevation look-angle above 70 degrees. The main purpose was to enhance zenithal GNSS satellite availability above Japanâ€™s urban canyons and provide increased accuracy. Simulations had shown positioning availability improvement within city centres of from 60% availability for GPS alone to above 90% for GPS+3 QZSS. QZSS satellites were to transmit on L1, L2 and L5 with GPS-compatible signals. A joint US-Japan working group developed the draft GPS IS-ICD-800 specification for the L1C signal to be used by GPS III and QZSS. A fourth frequency, L6, the same as Galileoâ€™s E6, was to include an experimental signal designated LEX.

The commercial viability of this system was insufficient to win private-company participation. The government has made a commitment to fund the first satellite that the Japan Aerospace Exploration Agency (JAXA) is committed to with Mitsubishi, for launch in 2008. The second and third satellites were planned for launch in 2009. Technology for QZSS includes development of a satellite Hydrogen Maser clock, a new signal, L1-SAIF (L1 with sub-meter augmentation with integrity function), plus development of centimetre and decimetre-class GPS augmentation technologies with Network RTK. There are tentative plans for four tracking stations in Japan plus six international sites at Bangalore, Singapore, Perth, Cairns, Guam and Hawaii. QZSS satellite user-range accuracy is expected to be 30cm (1 sigma), which may be sufficient to identify the exact lane taken by a car.

Japan has two satellites, MTSAT-1R and MTSAT-2, in orbit and under test for MSAS SBAS GNSS augmentation data transmissions.

Although these will be received throughout a large area of the Western Pacific, the corrections will be valid only for the immediate vicinity of Japan. This is expected to be declared operational in 2007.

Beidou, Compass, SNAS

The Beidou (Big Dipper) three-satellite constellation launched on 31st October 2000, 21st December 2000 and 25th May 2003 was declared operational in 2004. The three Beidou geo-stationary satellites were launched to Longitudes 80, 140 and 110.5 degrees east, respectively, and are capable of communication and horizontal positioning for Chinaâ€™s military within their region. There are three main tracking stations for orbit determination, at Jamushi, Kashi and Zhanjiang. The satellites transmit at 2491.75+/-4.08MHz and the ground receiver can transmit back to the satellite on 1615.68MHz. The Beidou reference-frame is the Beijing 1954 Coordinate System, with time referenced to China UTC as determined in Beijing.

China was one of the few non-EU countries involved in Galileo, but the inability of China to participate as a part of the GSA and have access to the PRS signal has led to China announcing plans for an upgraded Beidou, called Compass. It is notâ€“able that China has contracted the Swiss company TEMEX for eighteen to twenty Rubidium clocks for a satellite constellation. TEMEX are also supplying clocks for the European Galileo programme. New frequencies that may be used by Compass are 1,207, 1,268, 1,561 and 1,575MHz. China has registered with ITU for Compass geo-stationary satellites at Longitudes 58.75E, 80E, 110.5E, 140E, 160E, plus types H, M and MG, which are multiple satellites in geo-synchronous medium earth orbit. The same registration refers to 27 H/M/MG satellites in three planes at altitude 21,500kms and inclination 55 degrees: this would appear to take some characteristics from both GPS and Galileo. The China Daily reported on 2nd November 2006 that there would be an Open Service providing 10m posâ€“ition, 0.2m/s velocity and <50ns timing accuracy, plus an Authorised Service which would offer â€˜saferâ€™ positioning and greater accuracy for Authorised Users. The report went on to say that China was open to working with other countries on their GNSS. It is expected that the first two Compass satellites will be launched in 2007, presumably to complement the three existing regional Beidou geo-stationary satellites by occupying the open slots at Longitudes 58.75 and 160 degrees East.

The ground infrastructure for the Sino Navigation Augmentation System (SNAS) SBAS has been established. This will eventually offer WAAS-like capability for the China region.

IRNSS and GAGAN

In July 2006 the Indian Space Research Organisation (ISRO) announced its intention to create the India Regional Navigation Satellite System (IRNSS), with eight satellites for development over the next five to six years. The latest information as of December 2006 shows three geo-stationary satellites. There are also four geo-synchronous satellites in figure of eight orbits over India. This system will incorporate the Geostationary Earth Orbit Augmented Navigation (GAGAN) SBAS recently successfully tested by Raytheon to provide WAAS-like capability for ISRO and the Aviation Authority of India. GAGAN will be transmitted on L1 and L5 transponders aboard the Indian communication satellite GSAT-4, which will be launched by Indiaâ€™s Geosynchronous Satellite Launch Vehicle (GSLV) in mid-2007. India and Russia have signed a GNSS co-operation agreement ratified by the Russian Duma on 30th October 2006. This provides Russia with Indian-based launch facilities for Glonass, using the GSLV, and provides India with access to Russian Glonass military signals.

Added Augmentation

In addition to the aforementioned regional SBAS initiatives, Inmarsat, Turkey and Nigeria have also filed with the ITU for GNSS L5 transmissions. Current ground-based GNSS augmentation systems consist predominantly of coastal-based Beacon DGPS, the USA National DGPS (NDGPS) Beacon network, regional and national government RTK networks and regional, national and global commercial augmentation networks. The vast majority of these networks are based upon GPS L1 or L1+L2 technology. As the GNSS systems evolve there will need to be upgrading of these ground-based networks in terms of GNSS receiver technology and communication medium, as this will require increased bandwidth to accommodate correction data for all the new satellites, their frequencies and codes.

Concluding Remarks

GNSS receiver technology will require more complex antennae, additional radio-frequency circuits and more powerful processors, all of which will initially increase the cost of receivers. For some applications the core technology may move to software-based radio architecture. Figure 1 illustrates how L1 and L5 frequencies will provide the greatest number of satellites; future dual-frequency receivers may be L1/L5-based instead of the current L1/L2. The inclusion of Chinaâ€™s Compass GNSS to Figure 1 would potentially provide 87 satellites at L1, and 81 satellites at L3/E5B.

An increased number of satellites (Glonass and Galileo) that provide SAR functionality will aid mariners. The planned Galileo system of providing a SAR confirmation message and co-ordination of SAR efforts would appear extremely beneficial. More satellites will improve signal availability in difficult environments, such as close proximity to offshore platforms as per Figure 2, which shows a typical GNSS installation on a barge cleaning up hurricane damage in the Gulf of Mexico. Additional satellite ranges will improve integrity monitoring and permit positions to be determined by each GNSS and compared in real time. The use of additional frequencies will improve ionospheric correction, and this will benefit navigation near the geo-magnetic equator and during the next solar-cycle peak, expected in 2011.

Multiple code ranges from different satellites may permit more accurate positioning and remove the need for some augmentation methods. The most precise positioning (<20cm) is still expected to require an augmentation signal, whether global, regional or local. Ground-based augmentation networks should be upgraded prior to availability of new satellites, so that the user can benefit as soon as satellites are switched on. However, given that some GNSS specifications exist only in draft form or are still under feasibility study, many government-funded ground-network owners will be reluctant to incur the cost of new GNSS receivers and communication systems until they can confirm all future GNSS system specifications. Users requiring high-level accuracy positioning using all available satellites will need to replace their receivers and have to rely more heavily upon commercial augmentation providers. Current GNSS receivers using L1 C/A alone or in combination with L2 should continue to work but will not offer the full benefits from future GNSS.

Lastly, with so many different GNSS becoming available in the future there may be a tendency to rely too much upon satellite positioning. All the planned GNSS use similar methods and frequencies; space weather and electromagnetic effects will affect each similarly. Having an alternative non-GNSS positioning system, for example Loran, would seem prudent in terms of safety.

E-mail: kdixon@navcomtech.com