NEW GNSS DEVELOPMENTS AND THEIR IMPACT ON PROVIDERS AND USERS OF SPATIAL INFORMATION

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ABSTRACT

Global Navigation Satellite Systems (GNSSs) involve satellites, ground stations and user equipment to determine positions around the world and are now used across many areas of society. Among currently used GNSSs, the Global Positioning System (GPS) from the US is the best known, and currently fully operational, GNSS. Russia also operates its own GNSS called GLONASS. Fuelling growth during the next decade will be next generation GNSSs that are currently being deployed and developed. Major components are the US's modernized GPS and planned GPS-III, the revitalised GLONASS, and Europe's planned Galileo system. Watershed advances in a major technology like GNSS only occur in 20 to 30 year cycles, therefore this is an opportune time to explore potential opportunities and issues for the geodetic, surveying and geospatial industry.

THE GLOBAL POSITIONING SYSTEM

The Current GPS

The most widely used current system is the Global Positioning System (GPS). The current constellation of 29 Block IIA/IIR satellites (US Coast Guard Navigation Center, 2006) operate without a hitch and civilian applications of GPS are now considered to be quite mature. The US has just launched one Block IIR-M satellite as part of its modernization program (see below). For a detailed description of the current GPS see UN Action Team on GNSS (2004). While it is beyond the scope of this paper to provide detailed review material, the following points are of relevance for later discussions:

- GPS broadcasts two signals in the so-called L1 and L2 frequency bands: L1 at 1575.42MHz and L2 at 1227.60MHz.

- GPS receivers can make *pseudorange* or *carrier phase* measurements, on the tracked L1 or L2 frequencies.

- Civilians using low-cost receivers currently only have direct access to the L1 signal, using the so-called Course Acquisition Code (*C/A-code*). This means that such receivers are unable to correct for delays to the signal as it passes through the ionosphere, which is now the dominant cause of error for users.

- Military receivers can access the ranging code (the Precise or *P-code*, now encrypted as the Y-code under the policy of *Anti-Spoofing*) on both the L1 and L2 frequencies, which enable them to correct for ionospheric errors.

- GPS provides two levels of service:

  - Civilian users have access to the *Standard Positioning Service* (SPS), whereby the C/A-code allows direct L1 measurements to be made. Specifying the accuracy of the SPS depends on many factors. Recent testing has shown that typically available accuracy from the SPS is often less than 10m. However, it should be noted that the officially stated standard for worst case horizontal positions using the SPS, and based only on the signals in space (ie ignoring local conditions), is less than or equal to 22m at the 95% confidence level. The equivalent value in height is less than or equal to 77m.

  - The *Precise Positioning Service* (PPS) enables enhanced accuracy and availability that is not available to civilian users by permitting the direct measurement of pseudorange on both the L1 and L2 signals using the Y-code. It is designed for the US and allied military, and for certain authorised US agencies.

For the geospatial industry, applications can be classified according to the achievable accuracy:

- *Single Point Positioning (SPP)* is the technique for which GPS was originally designed and delivers the SPS performance mentioned above.

- *Differential GPS (DGPS)* can overcome some of the limitations of GPS by applying corrections to the basic pseudorange measurements, based on a receiver making measurements at a known point (a reference station). The accuracy achievable from DGPS can range from a few metres down to few decimetres, depending on the quality of the receiver and the DGPS technique used.

- *GPS Geodesy / Surveying* also works differentially but can achieve centimetre (and under special circumstances even sub-centimetre) accuracy. A typical receiver, for both SPP and DGPS, measure the ranges to the satellites by timing how long the signal takes to come from the satellite (the *pseudorange*, referred to as such because this measurement is contaminated by the receiver clock error). However, receivers used in surveying and geodesy measure the phase of the underlying carrier wave signal (the so-called *carrier phase*). For baselines between points separated by more than (say) 20km, it is important that such receivers can also correct for the ionosphere, hence the need for dual-frequency receivers. For shorter baselines, dual-frequency receivers are necessary for rapid initialisation of cm-level positioning. Given that civilians users only have access to the SPS, surveying receivers employ sophisticated signal processing techniques to measure the phase of the L2 signal. This level of sophistication is a major reason why geodetic/surveying receivers are more expensive than receivers used for SPP and DGPS.

GPS Modernization

The US has embarked on a program of *GPS Modernization* to provide better accuracy and more powerful and secure signals from future GPS satellites. Again, it is not within the scope of this document to describe this program in detail; see US Coast Guard Navigation Center (2006). While there are various improvements planned, the important issues to note for this paper revolve around extra signals to be broadcast by future GPS satellites:

- An improved code (instead of the current C/A-code) on the L2 frequency of GPS (the so-called *L2C*) is being implemented to enable civilian receivers to better account for ionospheric error, as well as to be more immune to RF interference and multipath. The first Block IIR-M satellite to broadcast L2C was launched 26 September 2005. The launch schedule to replace existing satellites is difficult to predict but full operational capability for L2C will not be until all 24 satellites (a combination of 8 Block IIR-M and 16 Block IIF satellites) in the constellation are broadcasting the new signal, and that is not expected to occur until 2013 or beyond.

- The Block IIR-M, and following constellations, also broadcast new military signals and codes (the so-called 'M-codes'), on slightly offset L1 and L2 frequencies. Civilian GPS receivers will not be able to track these signals.

- The radio spectrum for the L2 signal is not fully protected through the International Telecommunications Union, as it does not lie in the ITU's Aeronautical Radio Navigation Services band (the L1 frequency does). This means that L2C cannot be relied upon for so-called *safety of life* applications such as in civil aviation and emergency service operations. Therefore, a third civil frequency at 1176.45MHz (called *L5*) is planned for launch on the Block IIF satellites. The first Block IIF launch is scheduled for 2008, with full operational capability of L1-L2-L5 GPS satellites (ie 24 satellites, a combination of 16 Block IIF and 8 Block III satellites) unlikely until 2015 at the earliest.

- GPS-III, which will incorporate the extra L2 and L5 signals of the Block IIR-M and Block IIF satellites, as well as a new code on the L1 frequency (the so-called *L1C*), which will be compatible with Galileo's L1 signal. However, to preserve 'backward compatibility' with legacy user equipment, all current and planned Block II signals will also be broadcast. The 30 GPS-III satellites are planned for launch from about 2013 until 2017.

The implications for GPS receivers is low-cost receivers may not just be L1-only, as is currently the case, but they may be L2-only or L5-only, or even dual-frequency.

FROM GPS TO GNSS

Perhaps the single most important shortcoming of GPS is also its most obvious; there are some places where GPS simply does not work due to a lack of available satellites. Therefore while GPS Modernization will have a significant impact, a major influence in the future will be systems offering additional satellites/signals to those offered by GPS alone. We should therefore think in terms of an overall GNSS combining a number of *sub-systems*.

GLONASS from Russia

GLONASS was originally designed as the Soviet Union's answer to GPS. The design of GLONASS is very similar to GPS except that each satellite broadcasts its own particular frequency with the same codes (this is known as a FDMA, or Frequency Division Multiple Access, scheme), while GPS satellites broadcast the same frequencies and a receiver differentiates between satellites by recognising the unique code broadcast by a given satellite (this is known as a CDMA, or Code Division Multiple Access, scheme). GLONASS can also provide a different level of service to Military users compared to Civilian users. For a detailed description of GLONASS see UN Action Team on GNSS (2004). Current status information is available from the Russian Federation Ministry of Defense web site at GLONASS (2006).

Since the collapse of the USSR, the Russian Federation has struggled to find sufficient funds to maintain GLONASS and at the time of writing (May 2006) there are 15 satellites functioning (as opposed to the 24 necessary for full operational capability). However, the Russian Federation has commenced a program to *revitalise* GLONASS, with planned full operational capability as early as 2008. In addition:

- Current activity centres on launching GLONASS-M satellites with an improved 7-year design lifetime, which will broadcast in the L1 and L2 *bands* (though not on the same frequencies as GPS).

- From 2007 to 2008 it is planned to launch GLONASS-K satellites with improved performance, and which will also transmit a third civil signal in the Aeronautical Radio Navigation Services band near (but not identical) to GPS's L5 frequency.

- The full constellation is planned to be broadcasting three sets of civil signals by 2012.

Although the frequencies of GPS and GLONASS are different, a single antenna can track all the transmitted signals. The data modelling challenges for integrated GPS/GLONASS processing have already been addressed, and survey-grade receivers capable of tracking both GPS and GLONASS have been available for many years. These combined receivers have demonstrated a marked improvement in reliability and availability in areas where satellite signals can be obstructed, such as in urban areas, under tree canopies or in open-cut mines. All major manufacturers of survey-grade GPS receivers now can supply integrated GPS/GLONASS receivers. The International GNSS Service (IGS, 2006) has for many years tracked GLONASS satellites, and computed their orbits.

Galileo from the European Union

Perhaps the most exciting GNSS development is the decision by the European Union to launch its Galileo project. For a detailed description of Galileo see European Commission Directorate General Energy and Transport (2006) and UN Action Team on GNSS (2004). For the purposes of this paper, the following points are relevant:

- Galileo will be a constellation of 30 satellites in a similar orbital configuration to GPS, but at an increased altitude (approximately 3000km higher than GPS), which will enable better signal availability in high latitude areas.

- At the time of writing the exact signal structure for all signals has not been released (although a draft of the Open Service Interface Control Document is available from the GJU, 2006), but Galileo satellites will broadcast signals compatible with the L1 and L5 GPS/GLONASS frequency bands. Those Galileo signals are designated as L1, E5a and E5b. Galileo will also broadcast in a third frequency band at E6; which is not at the same frequency as L2/L2C GPS/GLONASS.

- Galileo will offer *five* levels of service, two of which are fee-based and one of which is restricted:

    - The *Open Service* uses the basic L1/L5 frequency band signals, free-to-air to the public with performance similar to single- or dual-frequency GPS and GLONASS.

  - The *Safety of Life* Service allows similar accuracy as the Open Service but with increased guarantees of the service, including improved integrity monitoring to warn users of any problems. This is a fee-based service.

  - The *Public Regulated Service* is aimed at EU public authorities providing civil protection and security (eg police, quasi-military), with encrypted access for users requiring a high level of performance and protection against interference or jamming.

  - The *Search and Rescue Service* is designed to enhance current space-based services (such as COSPAS/SARSAT) by improving the time taken to respond to alert messages from distress beacons.

  - The *Commercial Service* allows for tailored solutions for specific applications based on supplying better accuracy, improved service guarantees and higher data rates. This is a fee-based service.

- The Galileo ground segment has elements similar to the GPS or GLONASS global networks of tracking stations and master control stations.

- With GPS, under the firm control of the US Military, and GLONASS, under the control of the Russian Military, *augmentation systems* to improve accuracy or reliability are operated completely external to the GPS and GLONASS architectures. Such services are available from third parties such as FUGRO's Omnistar, NAVCOM's Starfire, or maritime DGPS beacons operated by national maritime safety authorities. Galileo, on the other hand, has a much more open architecture, whereby systems to improve service can be brought 'inside' the system through a provision for *regional elements* and *local elements*. The Galileo system architecture allows for regional *Up-Link Stations* to facilitate those improved services tailored to local applications in certain parts of the globe.

- Galileo is to be operated by a Civilian Agency and the business-operating model is more open than in the case of GPS/GLONASS. Galileo uses a Public Private Partnership (PPP) whereby the European Commission owns the physical system (satellites, ground stations, etc) as a public asset, but a *Concessionaire* will be responsible for the day-to-day operation. The business model is still a close kept secret, however the Concessionaire will probably seek to cover costs and generate profit through the Commercial Service and Safety of Life Service, while also delivering agreed service levels for the other services. At the time of writing (May 2006) the two consortia previously bidding for the Galileo concession have joined forces and have been negotiating with the European Commission since mid-2005.

- Galileo has moved out of its development phase and into the *In Orbit Validation* (IOV) phase. The first satellite (the Galileo IOV Experiment - GIOVE-A) was launched on 28 December 2005, and commenced broadcasting signals two weeks later. GIOVE-B will be launched in late 2006.

- The full constellation was planned to be launched 2007-2008, with full operational capability by 2009, however these dates will almost certainly slip two or more years.

For users seeking high accuracy and availability it is likely that they will want GNSS receivers that can track all satellites, and as many of the signals as is possible. However, it is inevitable that there will be many tradeoffs made, and that there will be many receiver options available.

The Quasi-Zenith Satellite System from Japan

The Quasi-Zenith Satellite System (QZSS) is a multi-satellite *augmentation* system proposed to the Japanese government by a private sector consortium. The plan is to launch at least three satellites broadcasting GPS-like (and perhaps Galileo- and GLONASS-like) signals in an orbital configuration that increases the number of satellites available at high elevation angles over Japan (hence the term "quasi-zenith"). This would benefit modified GNSS receivers operating in areas with significant signal obstructions such as urban canyons. It is expected that a demonstration QZSS satellite will be launched in 2008. For a detailed description of QZSS see UN Action Team on GNSS (2004). The orbital configuration of the QZSS constellation is such that the satellites will also pass over South East Asia and Australia (the satellites must be launched into a geostationary altitude). That will effectively increase the number of satellites available to suitably equipped GNSS users in this region. It is certain that other satellite augmentation systems will be developed over the next decade, eg Japan's MSAS, China's Bediou and India's GAGAN, but it is unclear whether they will be of benefit to high accuracy users. The reason is that unlike QZSS, these space-based augmentation systems are designed to serve aviation users. Hence only signals on the L1 frequency (initially) and the L5 frequency (much later) will be broadcast.

THE BENEFITS OF MORE SATELLITES

GPS and GLONASS combined have already demonstrated the benefits of extra satellites, and Galileo brings all that and more. The benefits of the expected extra satellites and their signals outlined above can be categorised in terms of continuity, accuracy, efficiency, availability and reliability.

Extra satellites improve *continuity*:

- GPS, QZSS and Galileo being independent GNSS means major system problems, unlikely as they are, are a very remote possibility of occurring simultaneously.

Extra satellites and signals can improve *accuracy*:

- More satellites to observe means a given level of accuracy can be achieved sooner.
- More signals means more measurements can be processed by the receiver's positioning algorithm.
- Position accuracy is less susceptible to the influence of satellite geometry.
- The effects of multipath and interference/jamming are mitigated, meaning the measurement quality is higher.
- Galileo also has the ability to deliver decimetre-level DGNSS accuracy directly, in the receiver via the RF frontend, courtesy of the Commercial Service.

Extra satellites and signals can improve *efficiency*:

- For carrier phase-based positioning, to centimetre accuracy, the extra satellite signals will significantly reduce the time required to resolve ambiguities.

- The density of GNSS reference stations to support differential positioning using triple-frequency techniques may also be reduced significantly.

Extra satellites and signals can improve *availability* (of satellites at a particular location):

- Improved ability to work in areas where satellite signals can be obscured or attenuated, such as in urban canyons, under tree canopies, open-cut mines, etc.

- A 'hot' research topic is *indoor GNSS*. Some receivers are now capable of measuring GPS signals inside buildings, and an increase in the number of available satellites, as well as better designed codes, will make indoor positioning more robust.

Extra satellites and signals can improve *reliability*:

- With extra measurements the data redundancy is increased, which helps identify any measurement outliers. The new measurements will be more independent than the current L1 and L2 measurements, because code-correlation techniques (based on a knowledge of the PRN modulating range codes) will be used, rather than the 'codeless/cross-correlation' techniques employed in today's dual-frequency GPS receivers. (GLONASS dual-frequency measurements do not have this problem.)

- The current L2 GPS measurements by survey-grade receivers are noisier and less continuous than those expected to be made on either of the new signals L2C or L5, hence reliable dual-frequency operation will be enhanced. (Current GLONASS L2 measurements do not have this problem.)

- More signals means that service is not as easily denied due to interference or jamming of one frequency, that may prevent the making of critical pseudorange and/or carrier phase measurements. However, there will be an impact on efficiency (in terms of time-to-ambiguity resolution) if not all frequencies/codes can be tracked.

It should also be emphasised that newer systems, with improved electronics and antennas in the satellites and user receivers, will deliver overall improvements in data quality.

SOME ISSUES FOR USERS

However, there are also some GNSS issues that will complicate matters. Specialised, including high accuracy, applications will require the availability of multiple GNSS frequencies for improved performance, as well as associated correction data (ie for ALL tracked GNSS signals) from reference station networks. They also require as many satellites as possible delivering the improved capability at any time and in any location. In that context it is important to note that there will not be uniform compatibility across all the GNSS sub-systems in terms of the signals broadcast, and the timing of when new capabilities become available. In relation to signal compatibility, there will only be subsets of the possible 80 satellites broadcasting signals at the same frequency. The combinations for multiple signals are:

- GPS, QZSS – L1, L2, L5
- GPS, GLONASS, QZSS – L1, L2
- Galileo – L1, E5, E6
- GPS, QZSS, Galileo – L1, L5/E5

Considering the timing of when new capabilities will become available, it is important to note that the currently stated time frames for GPS Modernization, GPS-III deployment, GLONASS replenishment, and QZSS and Galileo deployment are not synchronised. Another uncertainty is whether receivers will be able to track the L1, E5 and E6 signals transmitted by the Galileo satellites without subscribing to the Commercial Service.

Current state-of-the-art techniques in *GPS Surveying* squeeze centimetre accuracy from the least possible amount of data from the reference and user receivers in real-time, using all satellites in view and observations of pseudorange and carrier phase on the two L-band frequencies (L1 and L2). Therefore, GPS (including combinations with current GLONASS signals in the L1 and L2 frequency bands, referred to here as GPS+GLONASS) is already a very good tool for high accuracy applications. In fact to date GPS surveying techniques have concentrated on achieving the best possible accuracy. The advantages from the coming developments to GNSS sub-systems outlined above is that the spotlight will be on improved *availability*, *efficiency* and *reliability*.

The future of high accuracy GNSS must recognise the following issues:

- Experience with real-time GPS(+GLONASS) surveying shows that performance improves when more satellites are available.
- Extra signals are not only useful for ionospheric correction; they also increase the number of observations available for ambiguity resolution, which delivers high accuracy sooner and with greater reliability. Therefore, dual-frequency measurements have proved very essential for high productivity GPS(+GLONASS) surveying, hence being able to use three frequencies will increase performance even more.
- Any extra signals carrying a civilian code can be accessed by less complicated receivers than is currently the case. This *should* lead to a new generation of less expensive receivers capable of delivering high accuracy. The measurement quality will also improve.
- The techniques employed in real-time GPS(+GLONASS) surveying are already addressing other applications, including the field of *machine guidance* servicing construction, mining and agriculture. These industries have high marginal costs and therefore require high levels of reliability and very robust solutions.

On the other hand, for operators of permanent GNSS receivers, both the IGS and service providers for RTK correction data, the timing of upgrades to current generations of GPS(+GLONASS) receivers is uncertain. Should all reference stations be upgraded at the same time? Will there be any ‘biases’ between old and new antenna installations? Will the same multi-frequency GNSS receiver be offered to the commercial surveying market as to the scientific geodesy users? Is there an optimal number of signals that need to be tracked to provide satisfactory performance? The IGS Governing Board (at their May 2006 meeting) launched an initiative to draft a set of specifications for future GNSS receivers for use on the global IGS network. These specifications will be provided to GNSS receiver manufacturers for comment in late 2006 or early 2007.

CONCLUDING REMARKS

The geodetic, surveying and geospatial communities has been revolutionised by the use of Global Navigation Satellite Systems. The Global Positioning System is the only currently fully operational GNSS, although Russia also operates its own GNSS. Fuelling growth in the coming decade will be next generation GNSS, and space augmentations of these, that are currently being developed. The USA is modernizing GPS, Russia is revitalising GLONASS, and Europe is moving ahead with its own Galileo system. Extra satellites will make possible improved performance for all application. In its various modes, modernized GNSS will also deliver higher accuracy and improved speed-to-first-fix for carrier phase-based positioning. However, there are many issues and unanswered questions concerning the interoperability of multiple GNSSs and augmentation systems that must be addressed if we are to enjoy the full benefits of next generation GNSS.

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