DYNAMIC POSITIONING CONFERENCE
November 15-16, 2005

Sensors I

The Impact of GPS Modernization and Galileo on the DGNSS Service Provider and User

Dr. David Russell

Subsea 7 (Aberdeen, UK)

Return to Session Directory

Biography

Dr David Russell is a Senior GNSS Technical Specialist with VERIPOS which is a business line within Subsea 7. He heads up the GNSS Technical Group within VERIPOS which has responsibility for the development, implementation and support of all VERIOS GNSS augmentation services, hardware/software and infrastructure. He received a Honours BSc degree in Topographic Science from the University of Glasgow in 1996 and a Ph.D. from the Institute of Engineering and Space Geodesy (IESSG) at the University of Nottingham in 2001. Previously he worked for Subsea Offshore as a hydrographic surveyor and prior to working with Subsea 7 he spent two years working for Thales GeoSolutions as Technical Analyst, principally involved with the research and development of Thales GeoSolutions GNSS initiatives.

Abstract

Navigating or positioning using GPS has been used in the marine industry for numerous years and is now accepted as a mature technology. Over the next decade, users will see significant changes in Global Navigation Satellite Systems (GNSS) with modernization of both the GPS and GLONASS constellations plus the addition of an entirely new satellite constellation named Galileo. These changes will impact both the user and service provider due to the increased number of satellites, new signals and potential new services.

This paper will investigate the impact of GPS and GLONASS modernization and the introduction of Galileo on future Differential GNSS (DGNSS) services. It will review the current status of DGNSS services including the requirements of the user. Existing proposals for GPS and GLONASS modernization, the development of Galileo and the evolution of GNSS augmentations will be examined that will allow the future performance of GNSS services to be estimated. Finally, the changes that would be required for DGNSS services to accommodate future GNSS constellations and new positioning techniques will be examined.

Introduction

When the engineers of the Global Positioning System began to design the system, they could never have predicted how the technology would proliferate into applications that were never envisaged would have any requirement for the use of satellite navigation. In the years since the development of GPS was initiated, significant advances in electronics, microprocessor technology and signal processing have seen satellite navigation grow into a mature technology that is now engrained in many application areas. Although the system was primarily designed as a military system, civilian users were quick to utilize the technology and help develop the system to bring improved positioning performance.

Applications for GPS and satellite navigation are vast and its use can be found in many areas ranging from surveying and geodetic applications to location based services. Markets are expanding from the traditional professional areas into mass markets such as mobile phones and road tolling. From market studies into the expansion of satellite navigation technology, it is envisaged that by 2020, the gross turnover for satellite navigation is predicted to be as high as $190 billion (€150 billion) [1] with location based services (e.g. mobile phones) accounting for a significant market share.

The fact that satellite navigation is now woven into the fabric of modern society for synchronizing timing networks and helping the emergency services locate people making emergency 911 calls from their mobile phone means that there is a reliance and dependence on the technology. Therefore, it is critical that satellite navigation systems are maintained and enhanced to meet the growing demand on the technology. This is the reason for the modernization of existing constellations and the introduction of a completely new and civil operated satellite constellation. These programs will ensure that positioning and navigation becomes more robust and accurate whilst allowing satellite navigation to serve existing markets and meet the needs of positioning, navigation and timing well into the 21st century.

This paper aims to provide information on the modernization programs for both GPS and the Russian equivalent system, GLONASS. It will also introduce the Galileo system which is currently in development and some of the new GNSS augmentations will also be examined. Finally, the impact on all these changes in satellite navigation on the DGNSS user and service provider will be examined

DGNSS Services in the Offshore Oil and Gas Industry

The offshore oil and gas industry have been using surface positioning systems for navigation and positioning since the 1960's. The first systems used were based on radio navigation from terrestrial based reference stations and included systems such as Syledis, Decca, Pulse-8 and HyperFix to name but a few.

These systems served permitted the exploration and development of oil and gas fields all over the globe but technological developments and the introduction of satellite based navigation systems have seen positioning become more accessible to the wider community. The oil and gas industry was one of the early adopters of satellite navigation through the use of GPS and nowadays, satellite based radio navigation using GPS is used almost exclusively for positioning in the offshore oil and gas industry. The technology can now be considered a mature and accepted technology.

Several service providers provide differential corrections that enable users to improve their GPS position providing a higher level of accuracy and repeatability. There are two distinct user groups within the offshore oil and gas industry. The first is navigation and positioning for survey applications which includes seismic survey, hydrographic survey, construction and pipe-lay support. These applications tend to require sophisticated quality control processes and software, high levels of accuracy and redundancy to ensure high-quality data. The second group utilises navigation and positioning for vessel station-keeping such as dynamic positioning and mooring monitoring. This group requires simple to operate plus robust and stable positioning because it is critical to vessel operation. Typically, other reference systems such as acoustics or taut-wire are used to provide greater redundancy and minimise the reliance on one positioning system. However, the trend of developments into deeper water means that the reliance on GNSS systems becomes greater due to the restrictions on other positioning reference systems.

In addition to these two distinct user groups, the positioning requirements of user can be further divided into users who require seamless global coverage and others who only require regional coverage. Secondly, there is an accuracy requirement with certain users requiring high positional accuracy compared against users who do not require the same level of accuracy but demand high repeatability. Finally, there are users who wish to have a 'black-box' solution compared against those who wish to have more visibility and control of the positioning process.

In order to meet the demands of the market there are various products and services on offer that meet the diverse requirements of the offshore navigation and positioning. At present global suppliers of offshore positioning include VERIPOS, C&C Technologies and Fugro which includes Thales GeoSolutions which was bought by Fugro at the end of 2003.

GPS Modernization

Since the first launch of a GPS satellite in 1978, the GPS constellation has become an important tool for navigation and positioning. To ensure that this continues the constellation is in a program of modernization to protect the service for US and Allied military use but more importantly to preserve and enhance the system to benefit civilian users worldwide. This includes new civil signals, additional frequency, and upgrade of the ground control segment plus the introduction of the next generation of block III GPS satellites. The first step in the modernization program for GPS was the termination of selective availability in May 2000 as highlighted in Figure 1.

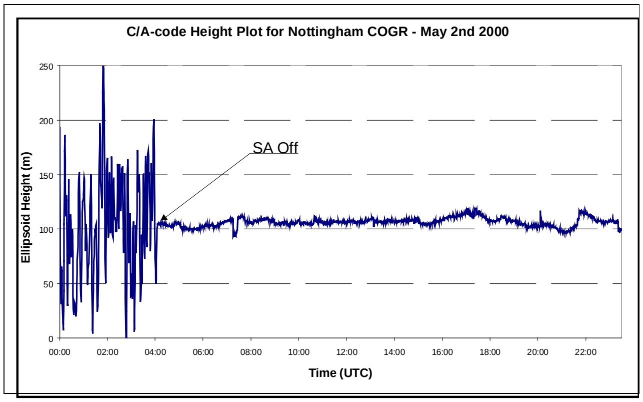

Figure 1 - Effect on Standalone Height After SA Termination

GPS L2C

The next step in the modernization program that will benefit civilian users is the inclusion of a new civilian code (L2C) on the L2 carrier signal. This will provide an improvement in the overall accuracy of the system and more importantly provide a redundant signal for safety-critical uses. The first launch with this capability was scheduled to occur with a Block IIR-M satellite in 2004 and will be available on all subsequent GPS satellites. At the time of writing (18 August 05) the launch of the first Block IIR-M has yet to occur due to several delays and is still awaiting a launch slot.

The L2C signal contains two codes of different length, one of which provides a data message structured like that planned for L5. However, options are available in case the L5-like message cannot be supported in early satellites. The following definitions are used [2]:

- CM – the L2C moderate length code contains 10,230 chips, repeats every 20 milliseconds, and is modulated with message data
- CL – the L2C long code contains 767,250 chips, repeats every 1.5 second, is synchronized with the 1.5 second Z-count, and has no data modulation
- NAV – the legacy navigation message provided by the current L1 C/A signal
- CNAV – a navigation message structure like that adopted for L5

Initially, the L2C signal will only be exploited by professional dual frequency equipment but the single frequency market will grow once there are a significant number of signals available to the user. Signal choice is likely to trigger a new era of expanding GPS applications due to increased accuracy and robustness.

The principal advantage is the fact that L2C is superior to L1 in terms of cross-correlation, threshold tracking, and data recovery performance. The fact that L2C has a lower code clock rate means that it will be better than L5 for many consumer applications, where the low-power and miniaturization is a significant requirement. For dual-frequency users, the inclusion of L2C will permit users to directly account for the error caused by the ionosphere.

GPS L5

An entirely new civilian carrier signal (L5) is scheduled to occur with the first launch of a Block IIF satellite 2006/7. The L5 signal will be broadcast at a frequency of 1176.45MHz and has improved signal structure for enhanced performance. The signal will have higher power than the L1 and L2 plus a wider bandwidth (24MHz). The L5 signal has a higher chipping rate than the C/A code or L2C which will improve the noise performance of GPS receivers using L5. It will also help the receiver resolve the L5 signal and will help mitigate the effects of multipath.

The increase in bandwidth and increase in power will mean that the L5 signal will be significantly less vulnerable to radio frequency interference. The inclusion of the L5 signal should result in a more robust GPS service, as there is unlikely to be simultaneous unintentional interference affecting all three carrier signals. Benefits will also be seen in kinematic GPS navigation and positioning as TCAR (Three Carrier Ambiguity Resolution) processing (L1-L5, L1-L2, L2-L5) will be available to help resolve integer ambiguities.

GPS L1C

In addition to the new civil codes on the L2 and L5 signals, there are also feasibility studies into including a new civil code onto the existing L1 signal. It has to be remembered that the C/A-code was designed in the 1970’s and the understanding of radio navigation techniques has advanced with experience of using GPS. The initial feasibility study [3] determined that it was possible to add the L1C to the L1 signal will maintaining existing the C/A code, P(Y) code and M code. The study also looked at whether users wanted the L1C code and the survey result was a unanimous consensus that L1C is desired, even at the expense of a slight reduction in the C/A signal power. The study also concluded that the preferred signal characteristics were a BOC (1,1) and data rate of 25bps for the L1C signal.

The detailed signal specification for L1C has yet to start but the recommendation from the study was to retain C/A indefinitely, but implement L1C such that C/A can be discontinued in the distant future without a negative impact on L1C users [3]. The L1C signal will be included on the GPS Block III scheduled for launch in 2012.

Ground Segment

Whilst the space segment of GPS will undergo significant modernization changes, the ground segment is also undergoing a modernization program in order to make it compatible with the changes in the space segment. A new fully mission capable Alternate Master Control Station will be built at Vandenberg tracking station to provide additional redundancy.

In addition, the five core US Air Force tracking stations are being augmented by the inclusion of eleven monitor stations from the NGA (National Geospatial-Intelligence Agency) to provide better tracking of the GPS satellites and better determination of the satellite orbit and clock information. The objective is to reduce the 'User Range Error' (URE) which is a function of the error in the orbital position and clock data transmitted to users.

GPSIII

GPS III will be the next generation of GPS satellites designed to replace the Block II satellites. The goal GPS III program is to deliver best-value acquisition and architectural solutions that will satisfy the currently defined yet evolving military and civilian needs for a space-based navigation and timing system through to the year 2030. It is anticipated that the first operational satellite will be launched in 2012.

Features of the GPS III satellites will be increased anti-jam power, increased security and increased accuracy. The system will also have assured availability and better integrity plus greater system survivability.

The timetable for the implementation for each of the modernization programmes is shown in Figure 2.

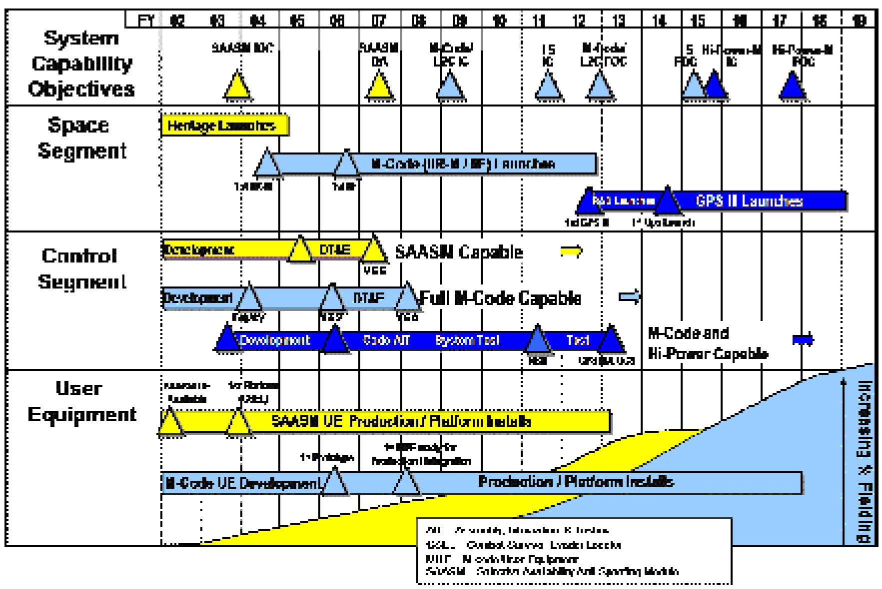

Figure 2 - GPS Modernization Timetable [4]

GLONASS Modernization

In the early 1970's, the former Soviet Ministry of Defence conceived the Global'naya Navigatsionnaya Sputnikova Sistema or the Global Navigation Satellite System (GLONASS). This like GPS is a space based radio navigation system offering two positioning services. The major features of both GPS and GLONASS are tabulated in Table 1.

		GPS	GLONASS
SATELLITES			
Number of satellites		21 + 3 spare	21 + 3 spare
Number of orbital planes		6	3
Orbital plane inclination (degrees)		55	64.8
Orbital radius (km)		26,560	25.510
Orbital period		11h 58m	11h 15m
SIGNALS			
Fundamental clock frequency		10.23 MHz	5.0 MHz
Signal separation technique		CDMA	FDMA
Carrier frequencies (MHz)	L1	1575.42	1602.0 - 1615.5
	L2	1227.60	1246.0 – 1256.5
Code clock rate (MHz)	C/A	1.023	0.511
	P	10.23	5.11
Code length (chips)	C/A	1023	511
	P	6.187104*1012	5.11*106
C/A-CODE NAVIGATION MESSAGE			
Duration (minutes)		12.5	2.5
Capacity (bits)		37,500	7,500
Word duration (seconds)		0.6	2.0
Word Capacity (bits)		30	100
Number of words within a frame		50	15
Techniques for specifying satellite ephemeris		Keplerian orbital	Geocentric Cartesian
Time reference		UTC (USNO)	UTC (SU)
Position reference (geodetic datum)		WGS84	PZ-90

Table 1 - Comparison of GPS and GLONASS Characteristics (adapted from [5] and [6])

The economic situation of the former Soviet Union has had an adverse effect on the GLONASS system over recent years. The constellation reached full design specification of twenty-four satellites in January 1996 but has since experienced a steady decline. This is the main reason why there have been no commercial GLONASS-only receivers available and very few GPS/GLONASS receivers have been manufactured in comparison to the number of GPS receivers. It is apparent that the potential benefits of using GLONASS are as an augmentation to GPS, providing redundancy and integrity

Although the GLONASS system has been plagued by lack of funding, over the past 2 years there has been significant investment in GLONASS to help restore the constellation. At present (18 August 05) the constellation currently has fifteen satellites in orbit of which thirteen are currently usable with the next launch of three M-type satellites due in December 2005. Although the GLONASS system does not have a fully operational satellite constellation the principal advantage is the availability of additional satellites which allows GLONASS to augment GPS providing more robust and reliable positioning.

Like GPS, GLONASS has a planned program of modernization to ensure that the system remains operation and meets the future requirements of the Russian military and civilian user. The modernization program can be divided into the following phases that are expected to run from 2003 to 2011.

Phase 1

- Add on the current constellation with the launch of new GLONASS satellites;
- Maintaining the constellation at a useable level.

Phase2

- Upgrade constellation using GLONASS-M satellites;
- Flight tests of M-type satellite have been underway in 2003;
- M-type has increased lifecycle of 7 years;
- Introduction of a second civil frequency.

Phase 3

- Further system upgrade using GLONASS-K satellite;
- Upgrade of satellite active life to a minimum of 10 years;
- Reducing satellite mass to provide launches of 6 to 9 at one time;
- Upgrade of the ground control complex;
- Introducing a third frequency;
- Improving navigation signal characteristics for growing navigation requirements.

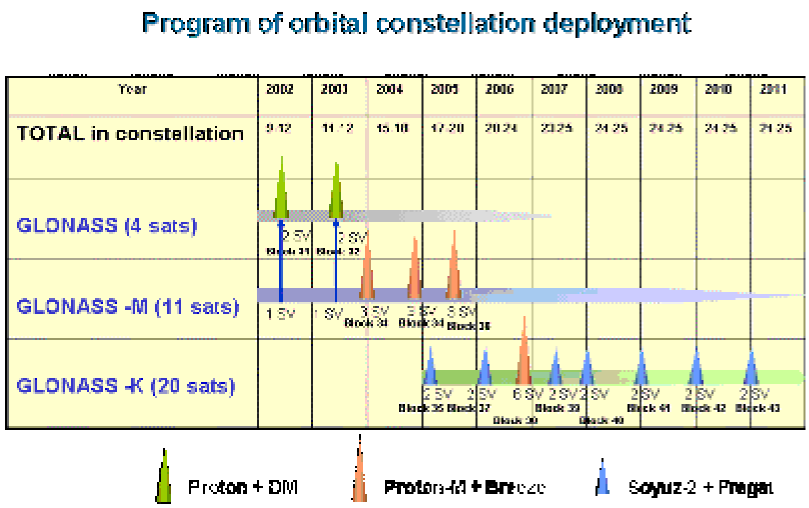

Figure 3 - GLONASS Satellite Deployment Program

Figure 3 presents the planned GLONASS deployment scheduled for the next 7-8 years but it remains to be seen whether this schedule will be maintained. If it is maintained then the GLONASS system will likely bring benefits to the user as an augmentation to GPS as this is the principal system used the world over.

Galileo

In response to the growing demand and need for satellite navigation, the European Community decided that it could no longer rely on using a military system which it has no control over. This is particularly important as satellite navigation is being used in various safety critical applications such as aviation. Additionally, as the market for satellite navigation is expanding, there clearly exists an opportunity for European industry to compete and provide an alternative choice in the satellite navigation market.

The European objective of full autonomy in satellite navigation will be achieved with the Galileo system, which is aimed at full operational capability by 2008 [1], although whether this timescale is meet is not clear due to problems that have been experienced during the development. Galileo will be the first civil satellite positioning and navigation system, designed and operated under public control and will be self financing through charging for access to certain signals. Galileo will be interoperable with other systems to facilitate their combined use. For safety of life and commercial applications, the navigation services will offer a guarantee, which is an important differentiator with respect to the current GNSS systems.

Four navigation services and one service to support Search and Rescue operations have been identified to cover the widest range of users needs, including professional users, scientists, mass-market users, safety of life and public regulated domains. The following Galileo Satellite-only services will be provided worldwide and independently from other systems by combining the Galileo’s Signals in Space:

- The **Open Service (OS)** results from a combination of open signals, free of user charge, and provides position and timing performances competitive with other GNSS systems (e.g. GPS).
- The **Safety of Life Service (SoL)** improves the open service performances through the provision of timely warnings to the user when it fails to meet certain margins of accuracy (integrity). It is envisaged that a service guarantee will be provided for this service.
- The **Commercial Service (CS)** provides access to two additional signals, to allow for a higher data rate throughput and to enable users to improve accuracy. It is envisaged that a service guarantee will be provided for this service.
- The **Public Regulated Service (PRS)** provides position and timing to specific users requiring a high continuity of service, with controlled access. Two PRS navigation signals with encrypted ranging codes and data will be available.
- The **Search and Rescue Service (SAR)** broadcast globally the alert messages received from distress emitting beacons. It will contribute to enhance the performances of the international COSPAS-SARSAT Search and Rescue system.

The Galileo satellite-only services will be enhanced on a local basis through combination with local elements such as DGNSS for applications with more demanding requirements.

Signal Structure

The proposed signals for Galileo and the modernized GPS constellation are presented in Figure 4. From the diagram it can be seen that only two common signals that share the same frequency. These are the GPS L1 and Galileo L1 plus the GPS L5 and Galileo E5A.

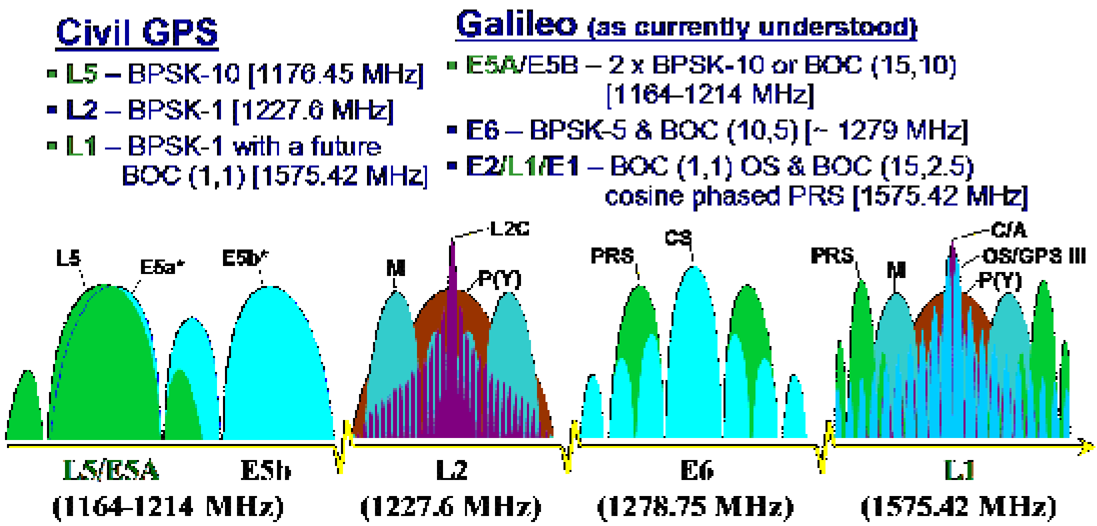

Figure 4 - GPS and Galileo Signal Structures

The fact that there are only two common frequencies has implications for interoperability between GPS and Galileo. By having common frequencies and similar signal structures, it is possible to enable common civil receiver designs which should obtain better user navigation performance. Receiver manufacturers are likely to prefer common frequency signals because it simplifies both the receiver and antenna design keeping costs lower. However, signals which are spectrally different will provide more robust positioning as it is unlikely that radio frequency interference will simultaneously affect all signals.

For some mass markets, manufacturers may adopt dual frequency designs to improve accuracy but single frequency, narrow bandwidth designs will probably still dominate the mobile phone and related markets where low price and power consumption are key requirements.

On 27 June 2005, the Galileo Joint Undertaking (GJU) accepted the joint bid by the two remaining consortia, Eurely and iNavSat, to run the Galileo system. Negotiations have started on the concession contract based on the joint proposal and this process should be completed before the end of 2005.

Also, the first of two Galileo satellites have been delivered to ESA for testing prior to launch later in 2005. The satellite will carry a payload that will transmit a Galileo experimental signal which will make up the first phase of in the 'in-orbit validation' of the Galileo system. The primary mission of the first Galileo satellites is to secure the Galileo frequency filings, validate new technologies for operational use, characterize the radiation environment of the medium earth orbits that the operational satellites will occupy and enable experimentation with live Galileo signals.

Augmentation Systems

In addition to the modernization of existing satellite navigation constellations and introduction of a new constellation, there are also various augmentation services which have been deployed or are in development. These include WAAS, EGNOS, MSAS, BEIDOU and GAGAN and are designed to be freely accessible to users and cover specific areas of the globe.

The augmentation services provide users with corrections and integrity information for the GPS and GLONASS satellites but the service is restricted to regional areas of the world, for example WAAS covers North America and EGNOS covers North West Europe. These services provide positional accuracies at the 3-5m level.

Impact on DGNSS User

What does this all mean for the average GNSS and DGNSS user? Basically the user within the next decade will have the ability to use more signals which should lead to more robust and accurate positioning with greater integrity, continuity and availability of signals. It will mean that new hardware and firmware will be required by the user to take full advantage of these new signals and also the augmentation services offered by DGNSS service providers.

It is questionable whether the user will want to use all the signals because of restrictions such as receiver power and size. Furthermore, the user may be restricted to using certain signals as dictated by the receivers designed and built by the GNSS manufacturers. Receiver manufacturers will favour using common GPS and Galileo signals because of the fact that it simplifies the design. While using two satellite constellations brings the user more satellites which will give greater accuracy, it does not necessarily guarantee signal robustness as radio frequency interference in the same part of the spectrum could theoretically deny the availability of both signals.

Which combination of signals and GNSS receiver to use will be very much dependant on the requirements of the market and also what augmentation services are available to the user. It is clear that different types of user will use different combinations of signals and services to meet their requirements.

With the introduction of new signals and new augmentations to those signals, new positioning techniques will be developed that will improve accuracy and continuity of positioning for the DGNSS user. Augmentation services will undoubtedly provide the user with higher accuracy at the decimetre level but there is a question about how all the data will be sent to the user and processed. Factors such as data compression and correction update rates will be key in the new augmentation services.

A key feature for the user using both GPS and Galileo (and even GLONASS) will be compatibility and interoperability between the various constellations. Each constellation has it own reference frame, time system and signal structure and it has to been ensured that if the user wishes to use GPS and Galileo they must be interoperable. The systems must also be compatible in order that none of the GNSS system interferes or degrades another GNSS.

Over the next decade the user will have more choice and flexibility when using GNSS and DGNSS in the future. This means that the user can expect greater accuracy, more system integrity and signal availability.

Impact of DGNSS Service Provider

For the DGNSS service provider, the impact of the modernised and new satellite constellations means significant changes to the service network. Additional signals will have an impact on data collection, data transfer from the network, data processing, message generation and transfer of service to the user. New techniques for data compression and positioning will be developed to efficiently and reliably provide services to the user delivering increased accuracy and robustness of service.

However, will the market want corrections for all signals? This will depend on the actual requirements of the market but the service provider will be targeting users requiring high accuracy positioning as freely available services (e.g. EGNOS) or even standalone positioning will meet the position requirements of certain users. For example, there may be a point at which a dual frequency solution with no differential input is more accurate than a single frequency DGPS position. In the future there may be no requirement for DGPS services to support single frequency users but that will depend on the requirements and availability of a suitable market.

Another factor that needs to be considered by the service provider is the GNSS receivers that will be required for use on their reference station network. Like the GNSS user, it is unclear whether there will be receivers capable of tracking all available signals and processing the data in order that the service provider can generate corrections. Additionally, a lower number reference stations will be required to provide the necessary coverage and accuracy.

Other issues that the service provider has to consider are how the transition from the current operating environment to future operations is managed in terms of the differential service and user equipment. Also the service provider will need to determine how often corrections have to be broadcast especially with improved clock stability for the Galileo satellites (and possibly GPS III) which will improve the overall accuracy and stability of the position, requiring less frequent correction information.

Other significant issues that the service provider must consider are the interoperability between the different satellite constellations. Will the service provider be responsible for computing and broadcasting the offset between the GPS and Galileo time systems or will the DGNSS user solve the offset as an additional unknown in the position solution. The difference between the Galileo Terrestrial Reference Frame and GPS reference frame will also need to be known so that the user can determine a combined position solution.

The new signals clearly present an opportunity for the service provider to offer enhanced and more accurate positioning solutions to the user. As yet the actual services that will be offered to the various markets is unclear but over the next couple of years this will become more apparent as user requirements are better defined and use the new signals is experienced.

Conclusions

The impact of GPS modernization and Galileo will mean that the DGNSS users will see an increase in the position accuracy, increased integrity, availability and continuity of position. If the user has the availability of three constellations, then there will be potentially up to 80 satellites orbiting the earth providing navigation signals to users. Typical accuracies expected from a combined Galileo OS and GPS C/A code position is 2.15m horizontal and 4.26m vertical [7]. The provision of augmentation services will provide the user with position accuracies at the decimeter or even the centimeter level.

In the future GNSS will be useable in more locations (including inside buildings!), provide greater accuracy, provide greater integrity, be more cost effective and provide more confidence in GNSS as there will be multiple constellations providing redundancy and no reliance on one nation.

Some questions that will need to be answered are which signals and combination of signals will be used by the DGNSS user and also offered by the service provider. That will depend on user/market requirements, GNSS manufacturers providing suitable hardware and interoperability between the different satellite constellations. For the service provider additional signals will have a significant impact on their network and on data collection, data transfer, data processing and message generation. However, the new signals present an opportunity for both the user and service provider and for the further integration of satellite navigation into our society.

It is clear that significant changes are expected within satellite navigation over the next ten to twenty years. Exactly the impact that these changes will have can only be guessed at. One thing is clear, when the original pioneers of GPS first started work on the GPS system they could have no comprehension how rapidly satellite navigation technology and applications would have developed. Perhaps in twenty years when users look back on the impact of GPS and GLONASS modernization plus the introduction of Galileo, they will wonder if anyone had ever thought of the applications that satellite navigation would be use for.

Acknowledgements

The author would like to acknowledge the support of various people who helped provide the reference material for this paper. This paper includes the personal opinions of the author and does not necessarily represent the opinions of VERIPOS or Subsea 7.

References

[1] Galileo Joint Undertaking, 2003. Business in Satellite Navigation: An Overview of Market Developments and Emerging Applications. 5 March 2003.

[2] Fontana, R.D., Cheung, W. and Stansell, T., 2001. The Modernized L2 Civil Signal. GPS World, September 2001

[3] Hudnut, K.W. and Titus, B., 2004, GPS L1 Civil Signal Modernization (L1C), THE INTERAGENCY GPS EXECUTIVE BOARD STEWARDSHIP PROJECT #204, JULY 30, 2004

[4] Swider, R., 2003. GPS Modernization. Presentation at the 2003 RTCM Annual Assembly Meeting. St Pete Beach, Florida.

[5] Leick, A., 1995. GPS Satellite Surveying. 2nd Edition, Wiley and Sons, New York.

[6] Langley, R.B., 1997. GLONASS: Review and Update. GPS World, July 1997, pp 46.

[7] Rodrguez, J.A.A, et al., 2004. Combine Galileo/GPS Frequency and Signal Performance Analysis. Proceedings of ION 2004 – 21-24 September 2004, Long Beach, California