GNSS: Resuscitated GLONASS, GPS Modernization, Galileo, and Beyond

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Abstract

With the fast developing pace, the Galileo system is entering the navigation stage with high profile. At the same time, U.S. is accelerating his GPS modernization schedule, and Russian also begins to resuscitate their GLONASS. Moreover, Chinese Beidou system has also joined the satellite navigation family with low profile already. And of course Japanese QZSS even moves forward. Along with the bitter competition in technology, finance, market and even military affairs, all these systems will firmly benefit each other and massively extend the role of civil satellite navigation industry in the future. The Global Navigation Satellite Systems (GNSS) would be almost certain to include above major satellite navigation systems. Thus how to utilize the navigation satellite resource for world peace and promote the progress of mankind should be the key issue of this century.

Keywords: GNSS, GPS, Galileo, GLONASS, Beidou, QZSS, Satellite Navigation

1. Introduction

The satellite positioning and navigation system has been widely used to provide precise navigation and positioning service for military and civilian users With the fast developing pace, the Galileo system, which controlled by the European Union (EU) and the European Space Agency (ESA), is entering the navigation stage with high profile. At the same time, U.S. is accelerating his GPS modernization schedule, and Russian also begins to resuscitate their GLONASS. Moreover, Chinese Beidou system has also joined the satellite navigation family with low profile already. And of course Japanese QZSS even moves forward.

2. Galileo, a High Profile of Well Designed and Fast Developing Satellite Navigation System

Europe decided to build up an independent satellite positioning system and started Galileo Project in March, 2003. Galileo, scheduled to be operationa1 by 2008, is designed to encircle the globe with 30 satellites in a Medium Earth Orbit. The 30 Galileo satellites will be distributed in 3 orbital planes inclined at 54° and at an altitude of around 23,000 km. A lot of sophisticated technology will go into Galileo, including highly advanced atomic clocks - giving greater accuracy and stability and being light weight with low power requirements. Sophisticated electronics and the latest high performance antennas will be incorporated into the satellite to generate Galileo space signal.

Galileo, the first satellite positioning and navigation system specifically designed for civil purposes, will offer its excellent services with outstanding performance in accuracy, continuity and availability. It will be more advanced, more efficient and more reliable than the current existing satellite navigation system.

The Galileo System is conceived as a core infrastructure upon which applications will be built. It will be the world's first global satellite positioning system totally open for civil use. The application may cover range transport and environment, timing, surveying and engineering, search and rescue, science and even recreation, etc. These in turn directly affect business areas such as oil, gas, banking, insurance, telecommunication, tourism and agriculture. Thus, the most important is that the Galileo will form part of today's greater technical infrastructure, including communications and broadcasting systems, on which we will all rely heavily. Initiated by the European Union and cooperated by many group and nations, Galileo system will provides users with rea1 time positioning accuracy within just one meter. As its utmost target of design, Galileo will directly benefits civil users, by satellite navigation services, such as all modes of transport including road, rail, sea and air traffic, telecommunication, agriculture and fisheries.

Some applications require the system to have special features. These features do not exist in the current positioning systems and will constitute added value for Galileo as a civil system. They may include service guarantee, authentication of the signal, integrity of the signal, liability of the service operator, traceability of past performance, operation transparency, availability of raw and processed data from the core system, certification and competitive service performance in terms of accuracy, continuity and availability. In addition to all these features, the Galileo Supervisory Authority and the Galileo Concessionaire will provide an institutional, regulatory and commercial framework to facilitate and regulate the exploitation of the downstream worldwide market. New applications are appearing every day in this huge market.

GALILEO is to be independent but interoperable with other systems, e.g. GPS and GLONASS, to provide greatly improved satellite coverage and availability, ensuring that sufficient satellites are always in view to obtain an optimal navigation solution. The clearest of these is the fact that satellite navigation will become a fully redundant service for civil users in the event of a number of satellites or system failure. The number of satellites in view will grow dramatically and become fully independent in the case of failure to either GPS or Galileo. This has been one of the major impediments of a sole GPS system and one stumbling block to the potential wider benefits that satellite navigation could offer civil market, but which it has not so far been able to be in the future.

In contrast to existing system, Galileo will assure the quality of positioning accuracy by broadcasting integrity information. For some critical users, they will receive timely warnings in case of the system accuracy fails to meet its standards. The Galileo will transmit the warnings so timely enough that even the most demanding users' needs, e.g. aero and space navigation and landing will be satisfied.

The services provided by GALILEO may be categorized as two layers, free of charge and charged service. The former service is designed to meet the most ordinary requirements through basic satellite signals. The later services can be called improved services or value-added services which are designed to satisfy some special users through local operators. These services are as followings:

The Open Service (OS)   The Galileo Open Service provides signals for timing and positioning free of charge which is aimed for ordinary market applications. Any user can access the Open Service simply by a Galileo receiver. The Open Service may provide up to three separate frequencies, but single frequency receivers can only be used in situation of reduced accuracy. In addition, if Open Service applications use a combination of Galileo and GPS receiver, the service performance will get great improving.

The Open Service does not offer integrity information, and the determination of the quality of the signals will be left entirely to the users. There will be no service guarantee or liability from the Galileo Operating Company on the Open Service.

The Open Service will have global coverage with good accuracy of accuracy less than 10 meters at high masking angles over 25° and good availability more than 70%. It will be a mass market application for very low cost receivers such as single or dual frequency, in direct competition with GPS.

The Commercial Service (CS)   The Commercial Service will provided more higher timing and positioning performance, which by adding two signals to the open access signals on payment of a fee, than the Open Service. The Commercial Service includes data broadcasting and resolving ambiguities in differential applications.

The typical value-added Commercial Service include service guarantees; precise timing services; the provision of ionosphere delay models; local differential correction signals for extreme precision positioning; and other services based on the broadcast of system information data.

The Safety of Life Service (SoL)   The Safety of Life Service will provide the same accuracy in timing and positioning as the Open Service while has the worldwide high integrity level for safety critical applications, such as maritime, aviation, rail and road transport, where guaranteed accuracy is essential. Thus the Safety of Life Service will be mainly used for transport applications where lives could be endangered if the performance of the navigation system is degraded without real time notice.

The Safety of Life Service will have global coverage with very good accuracy less than 4 meters at low masking angles less than 5° and high availability more than 99.9 % for e.g. aviation. This will be a certified, controlled access service without direct user charges.

The Public Regulated Service (PRS)   The Public Regulated Service will be used only in Europe by public security parties such as the police, coastguard and customs and etc. Civil institutions will control access to the encrypted Public Regulated Service. The Public Regulated Service will be operational at all times and in all circumstances.

The Search and Rescue Service (SAR)   The Search and Rescue Service will greatly improve existing search and rescue system in efficiency and reliability. Compare with COSPAS SARSAT system, the Galileo Search and Rescue Service will receive distress messages from anywhere on Earth in almost real time (less than 1 minute) and precise location of alerts (less than 10 meters area) which can costs about an hour and area range about several kilometers in the COSPAS SARSAT system currently. The multiple satellite detection will overcome terrain blockage in severe conditions to increase chances for survival. Furthermore, Galileo will have communication of two way link function from the SAR operator to the distress beacon, thereby facilitating the rescue operations and helping to reduce the rate of false alerts. This service is being defined in cooperation with COSPAS- SARSAT, and its characteristics and operations are regulated under the auspices of the International Maritime Organization and the International Civil Aviation Organization.

China has been expressing great interests in Galileo Project and looking for cooperation with ESA actively for a long time. On Sept.18 2003, Ministry of Science and Technology of China drew up a cooperation agreement with the European Union Directorate-General Energy and Transport. Under the agreement China and 15 EU nations are equal participants in the project. China will cooperate with the EU in satellite navigation through joint work in researching and developing, manufacturing and many other kinds of technical aspects in the Galileo Project. China, Europe GNSS Technology Training and Cooperation Center (CENC) was founded by the Ministry of Science and Technology of the People's Republic of China, EU Commission and European Space Agency(ESA). The CENC aims to promote cooperation between China and Europe in the scopes of global satellite navigation. On Oct, 30 2003, China and the European Union signed a cooperative agreement on the Galileo Project at the Great Hall of the People in Beijing. The signing was witnessed by Italian Prime Minister Silvio Berlusconi, European Commission President Romano Prodi and Chinese Premier Wen Jiabao. As the non-EU nation participant in Galileo, China will contribute 200 million euros to the more than 3 billion euros project. The two sides have agreed that China puts 5 million euros as the initial financing first.

At present, participants from the Chinese side have been in position. The Joint Undertaking is an organization responsible for the Galileo Project in which the Chinese side will have members to play their roles and they will enjoy 20 percent of the rights in voting. Chinese technicians will go to work in Brussels as staff members of the Joint Undertaking. Besides, as corporate operation is the way for running the Galileo Project, preparation for the incorporation of a satellite navigation company is now underway in China.

In general, satellite navigation positioning and timing services are becoming an indispensable element in human activities. Managing and controlling the various modes of transport, and their related safety of life aspects, communications networks and many other utilities are expected to rely heavily on satellite navigation. Mass- market applications, including combined mobile communications and navigation systems, are growing rapidly, with their own needs. Galileo is designed to satisfy the requirements of such a wide range of applications.

3. GPS, Great Ambition for Modernization

Although GPS has been in leading position and gained great success in satellite navigation area, the system's weaknesses are also clear with the fast developing requirements of navigation application. Take typical navigation applications for example, civil stand navigation operations can only access to the C/A code on L1 frequency. And of course they cannot make a dual-frequency ionospheric delay correction. In addition, L1 and L2 signals are not afforded total spectrum protection and they are relatively so weak that actually be buried in background noise. They cannot readily penetrate into concrete and steel buildings or underground and are susceptible to interference and jamming. Furthermore, the reflected signals or multi-path effect can cause position errors.

Therefore, it is inevitable that to modernize GPS system in order to meet the military and civil demand. The GPS modernization includes,

1. for the military user: add new signals with spectral separation and increased signal power to improve protection, prevention and preservation capacity.
2. for the civil user: add new signals to improve system accuracy, availability and signal redundancy. The civil benefits would include a second civil frequency for ionospheric correction and redundancy and a third civil signal for "safety of life" applications in protected spectrum and also providing high accuracy and benefits to real-time applications.

In 1996, a Presidential Decision Directive stated the president would review the issue of Selective Availability in 2000 with the objective of discontinuing SA no later than 2006. In addition, both the L1 and L2 GPS signals would be made available to civil users and a new civil 10.23 MHz signal would be authorized. To satisfy the needs of aviation, the third civil frequency, known as L5, would be centered at 1176.45 MHz, in the Aeronautical Radio Navigation Services (ARNS) band.

A variety of other enhancements were under consideration, including increased power, the addition of a new military code at the L1 and L2 frequencies, additional ground stations, more frequent uploads, and an increase in the number of satellites. These policy initiatives were driven by the dual needs of maintaining national security while supporting the growing dependence on GPS by commercial industry. This dual need is also reflected by the fact that GPS is controlled or influenced by many organizations. In addition, to the US Department of Defense, serving as executive agent of GPS, the Interagency GPS Executive Board (IGEB) has members representing Transportation, Commerce, Interior, State, Agriculture, and Justice, as well as a number of federal agencies.

A White House press release on March 30, 1998, announced officially that a civil signal would be added to the GPS L2 frequency. Instead of replicating the C/A code, as many expected, a truly modernized L2 civil (L2C) signal was designed.

The first step of GPS modernization was however done on May 2, 2000 with the removal of Selective Availability.

3.1 GPS Satellite Modernization

New generation GPS satellites include GPS II-R, GPS II-F and GPS III.

The new generation GPS satellites include GPS II-R and GPS II-F. the current GPS constellation are consist of 29 Block II satellites, include GPS II, GPS II-A and GPS II-R. On September 25, 2005, a new GPS II-R-M1 satellite was launched into space. This marked the GPS modernization pace from IIR to IIR-Ms to speed up the availability of the military M code on L1 and L2 and the civil code on L2 into a new era.

Since the first launch of a Block IIR-M satellite, the new GPS signal is in operational. Initial Operational Capability (IOC) which are 18 properly placed satellites is anticipated in 2008, Full Operational Capability (FOC) which are 24 satellites is about in 2010.

The modernized GPS signal will enhance L1 by increasing P(Y) and C/A code power and military code. As well as enhance L2 by increasing P(Y) and L2C code power and military code.

Owing to the L2C code for the correction of ionospheric group delay, the accuracy of the civil stand-alone positioning will be improved to 5 to 10 meters.

GPS II-F satellite will mainly enhance military application and continue to carry the L2C signal on L2, the M code on the L1 and L2 frequencies. At the same time, for the safety of life service it will carry a new civil code at the L5 frequency. The GPS II-F satellite will have the following characteristics,

1) adding a new long military M code which segregated from civil L5 signal,
2) M code encryption makes military satellite signal safer and easier to access,
3) keeping broadcast bandwidth 20 MHz (minimum), and
4) better anti-interfere characteristic with existing ground-based navigational aids.

First Launch of the Block IIF is foreseen in 2005. IOC is anticipated in 2012, FOC in 2015.

The GPS III program aims to fulfill the future navigation and even more demanding request in military, as well a s the integrity need from civilian aviation. GPS III will deliver the best navigation value and solutions that will satisfy the military and civilian needs for a space-based positioning, navigation and timing. The GPS III will have better anti-jam capability by increasing output power of M code signals in L1 and L2 channels for military users. Furthermore, it will add two other channels to provide navigational signal of local, regional and national safety-of-life service for civilian users.

GPS III may has the following changes,

1) introduce totally new constellation quite different with currently,
2) provide communication function,
3) adopt M code to provided better anti-interference ability,
4) transmit narrow spot beam, and
5) increase precision of satellite clock.

The first GPS III satellite is expected to be launched in 2010. IOC is expected in 2016 and FOC in 2018.

3.2 Ground Station Modernization

The GPS Control Segment has been modernizing since 2000. The main upgrades aims to reduce operator workload and operational costs. The modernization includes that,

1) upgrade monitor stations and ground antennas with new digital receivers and computers,
2) replace existing master control station mainframe computed,
3) add Accuracy Improvement Initiative, Air Force Satellite Control Network,
4) build full mission capable Alternate Master Control Station (AMCS) at Vandenberg Tracking Station, and
5) add IIF command and control functionality.

3.3 Precision Improvement from the Modernization

The precision of the stand-alone positioning has been greatly improving as figure listed below in recent years.

1) 50 ~ 100 m, by C/A code with SA on, before 1st May 2000,
2) 10 ~ 30 m, by C/A code with SA off, after 1st May 2000 till now,
3) 5 ~ 10 m, by C/A code and L2C code on L2, by 2009,
4) 1 ~ 5 m, by C/A code, L2C code on L2 and additional civil code on L5, by 2013,

Stimulated by fast developing GNSS markets, and demanding application from users, the performance of Global Positioning System is undergoing amazing changes. These stunning improvements will enhance firstly military and then civil capabilities for the seek of the system construction target. As we discussed here above, the main changes focus on signal modernization including adding a new M code for military application and a new L5 frequency for civilian service. In accordance with this modernization, the whole system has to be subject to a series of changes. After even during these changing, the positioning and timing performances are continuously improving. As GPS users, we are the biggest beneficiaries of course.

4. GLONASS, Scrupulous Resuscitation as Part of GNSS

GLONASS system started almost the same era of cold war in the last century. The system is controlled by Russian Federation now. System full configuration, which consists of 24 satellites distributed in 3 orbits planes of height about 19,800 km, has already been finished in 1996. In general, GLONASS adopts the similar navigation theory and technique as GPS. There are nominally about 5 ~ 11 observable satellites at any position on the earth. However with the disaggregation of former Soviet Union, Russian encounters finance dilemma. GLONASS system began to deteriorate due to lack funding. The worst situation was only 6 satellites available in orbits. Thus, in fact, GLONASS has very limited operational ability. Many efforts were made to finance and keep the system from deteriorating further, ensuring a full compliment of satellites for GLONASS were available. The purpose of GLONASS as stated by the Russian Federation Declarative of 1999 is to provide and promote “strengthening confidence and openness in international affairs, upkeep international stability and widen scientific and technical relations between states”.

At the beginning of this century, Russian Federation seeks a variety of corporation with international community and gets great achievement to improve GLONASS system functionality. With several launch efforts in recent years, GLONASS constellation has improved its distribution by. pushing the existing number of satellites in orbit to 16 (operational 15), but it is still short of the scheduled 24. The detailed constellation is as Table 1.

Operating with a limited number of satellites, the GLONASS can only provided reduced navigation ability. Despite of this, the GLONASS constellation is still of great interest to GNSS users who need a high grade of precise measurement, and to high-end users working in high elevation mask areas with a bi-system receiver.

Under the Indo-Russian agreements some of the current Russian GLONASS-M satellites would be launched from the Indian soil with the help of Indian launch vehicles. According to latest information, Russia Defense Minister Sergei Ivanov revealed that as the important defense and economic infrastructure, GLONASS system will be improved its competitiveness of navigational service and fully deployed by 2010. And the new generation GLONASS-K satellite will function compatibly with the American GPS.

Table 1 GLONASS constellation status for 02.09.06 under the analysis of the almanac accepted in IANC

Plane	Slot	Freq Chl	GLONASS No	Cosmos No	Launch date	Input date	Outage date	Life months	Notes
I	1	7	796	2411	26.12.04	06.02.05		18.2	
	2	1	794	2402	10.12.03	02.02.04		30.7	
	3	12	789	2381	01.12.01	04.01.02		53.8	
	4	6	795	2403	10.12.03	29.01.04		31.0	
	5	7	711	2382	01.12.01	13.02.03	09.07.06	36.1	off
	6	1	701	2404	10.12.03	08.12.04		16.5	
	7	4	712	2413	26.12.04	07.10.05		9.3	
	8	6	797	2412	26.12.04	06.02.05		18.0	
II									
III	17	5	787	2375	13.10.00	04.11.00		68.4	
	18	10	783	2374	13.10.00	05.01.01		61.0	
	19	3	798	2417	25.12.05	22.01.06		7.2	
	20	11	793	2396	25.12.02	31.01.03		41.0	
	21	5	792	2395	25.12.02	31.01.03		42.8	
	22	10	791	2394	25.12.02	21.01.03		42.5	
	23	3	714	2419	25.12.05	31.08.06		0.1	
	24	2	713	2418	25.12.05	31.08.06		0.1	

5. Beidou, Low Profile of Chinese Regional Satellite Navigation System

On October 31, 2000, China launched the first Beidou navigation satellite on a Long March-3A. On December 21, 2000, China launched the second Beidou navigation satellite. With these first generation satellites, Beidou system started its experimental operation until officially declared in full operational condition June 1st, 2003.

Beidou satellites system，as a regional navigation system, can provide satellite navigation information in all weather round-the-clock． The system mainly provides navigation including positioning and timing service for military, security, communication，as well as road, rail, aviation, and maritime transportation. The system can provide the service with an accuracy of 20 meters over China and surrounding areas. Beidou is an active positioning system that requires transmissions between satellite and the user, slowing the time it takes a user to receive a corrected position. The active part of Beidou also enables communication between system and users.

Compare with other satellite navigation system, Beidou system has the following features,

1) Only provided regional coverage within China and surrounding areas,
2) Satellites are geosynchronous obit with 60°apart in angle,
3) Bi-way communication between user and system control center, active solution,
4) User capacity is not unlimited because communication has to be set up during positioning, and
5) Real-time navigation capacity is limited by its design

principle, not suitable for carriers of fast moving navigation.

On June 25, 2003, China successfully put the third Beidou navigation satellite to orbit, which is considered as the experimental one or norm of second generation satellite. It is said that the next generation system, which is planning to include 4 geosynchronous satellites, 12 medium orbit satellites and 9 high orbit satellites, is going to start its plan next year. After complete configuration, Beidou will also be a globe coverage, high accurate navigation system.

China also uses the GPS and GLONASS navigation satellite systems, and has invested in the European Union's Galileo navigation system program. As the third country who owned the self-independent satellite navigation system, China is accelerating satellite navigation construction and as an active participant in GNSS families.

According to ITU, new Beidou satellite will also use L band frequency like GPS. In this way, the compatibility with GPS signal should be considered. As to Galileo system, the compatibility should as well be one of Beidou's aims since good cooperation has already been established between EU and China.

The latest information shows the parameters of new Beidou system,

Satellites

1) medium satellites net: 22000 km orbit, 12 satellites,

2) high satellites net: 36000 km orbit, 9 satellites,

3) position of 4 geosynchronous satellites net: 58.75E, 80E,110.5E,140E.

Frequency band

1) down, 1164 ~ 1215MHz,

2) down, 1260 ~ 1300MHz, and

3) up, 1300 ~ 1050.

6. QZSS, Active Planning of Japanese Regional Satellite Navigation System

Japanese Quasi-Zenith Satellite System (QZSS) project argumentation started in November 2002 and is planning to provide integrated multi-services covering Japanese, East Asia and Oceania region for mobile applications based on communications, video, audio, data broadcasts, timing and positioning probably no later than 2010.

QZSS is designing to consist of a constellation of several satellites in different inclined orbital planes of 36,000 km height. Each QZSS satellite is so allocated on the orbit as to pass over the same ground track at constant intervals. Consideration of Japanese geographic topography and physiognomy and well citified urban area, the orbit eccentricity and inclination are planed that in service area the minimum elevation angle is to be larger than 70 degrees all the time. While the first experimental QZSS satellite is intending to be launched to orbit of eccentricity about 0.1 and inclination about 45 degrees. QZSS will transmit navigation signals on L1, L2 and L5 frequency band which are the same band with modernized GPS system. Also the signal have the same frequency features, PRN code family and message structure with GPS.

The constellation design of the QZSS will enhance GPS coverage effectively; improve GPS performance in Japan where there are many mountainous and narrow roads within close buildings in urban areas. In these circumstances, the satellite with high elevation angle is highly important for land mobile users.

Japan and US established GPS-QZSS Technical Working Group (TWG) in the 2nd US-Japan GPS plenary meeting in 2002. Interoperability, compatibility and others issues relating to GPS and QZSS have been discussed. They agreed to establish joint interface specification document in order to maximize interoperability between GPS and QZSS. Japanese is making great effort to study and experiment QZSS and GPS bi-system performance in different cities. QZSS users will finish precise navigation calculation combining GPS signals with little modification of existing GPS receiver in the future.

7. Conclusion

Now, satellite navigation system is a system that could incarnates science, technology, culture, economic, and political of a nation massively. In the next 10 years, it is easy to anticipate that the performance of GNSS, such as availability, accuracy, reliability, integrity and vulnerability will be greatly improved. Along with the bitter competition in technology, finance, market and even military affairs, all the existing and developing satellite navigation systems will firmly benefit each other and massively extend the role of civil satellite navigation industry. Just like other electronic navigation system we are familiar with, such as Omega, Decca, Loran and etc., the development of each single satellite navigation system will go together and serve the globe peace and progress finally. Now the development of satellite navigation system has already triggered and will still trigger this century's revolutionary changes in every aspect of our life.

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