Review of the GNSS's Development and Its Civil Applications

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Abstract. This paper reviews the current development status of four main GNSS systems: GPS, GLONASS, GALILEO and BDS; the principle of GNSS; and the applications and challenges of GNSS. The results show that, as the application of GNSS has already significantly improved work efficiency in many civil areas, attaching importance to the development of GNSS would play a huge role in promoting a country's social economy and even the well-being of its people. Currently, the main challenges would be how to lower the cost of the receiver antenna for wide band frequency and how to strengthen the signal when transmitting indoors. As a promising field, the GNSS application industry has a wide range of features, including high-tech, high-investment, high-added-value, and high-growth. With the civil application of GNSS technology, it is extremely likely to be considered to become the third new growth point in the information economy. Thus, further development of GNSS will be crucial for each powerful nation.

Keywords: GNSS · Civil Application · GPS · GLONASS · Galileo · BDS

1 Introduction

The Global Navigation Satellite System (GNSS), as defined by the International Civil Aviation Organization (ICAO), is "a global position and time determination for the current system that includes one or more satellite constellations, aircraft receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation" [1]. The Global Navigation Satellite System (GNSS) is now widely used in both civil and military applications to identify the location of the receiver using a constellation of numerous artificial satellites [2].

As current research indicates, GNSS has been widely applied. According to Christopher and Eric's research [3], the GNSS significantly improves the efficiency and reliability of aviation. Yanbang and Caixia's research [4] indicates that GNSS has been sufficiently applied in traffic, agriculture, and mapping. While Dongju et al. [5] suggest that GNSS has great potential for detecting storm surges.

The article initially presents the current development of GNSS and the four main satellite navigation systems: GPS, GLONASS, Galileo, and BDS. Then the three particular applications of GNSS, including surveying and mapping, transportation, and precise agriculture, are discussed in detail. Then, the challenges, including the high cost of the
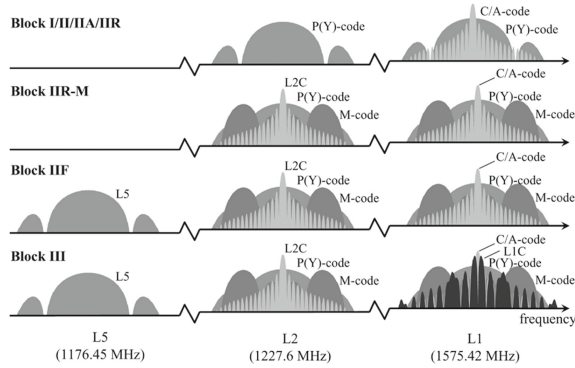
Fig. 1. Evolution of GPS signals [3]. Licensed by the author

wide-band frequency receiver antenna and the low strength of indoor transmission, are introduced and further reviewed.

Therefore, this paper will help researchers, developers, and users increase their understanding of the progress and application fields of GNSS. In addition, the research in this paper also enriches the research content of GNSS to a certain extent.

2 Constellations

This chapter discusses the GPS, GLONASS, GALILEO and BDS system, including their development, working orbit, and applications that have been implemented.

2.1 GPS

GPS (Global Positioning System), is a navigation system based on satellites implemented by the United States. The GPS program started in the early 1970s with 11 protype satellites, GPS Block I, launched and implemented in 1978 and 1985. Then, 41 satellites of the Block II series were launched before 2004. Currently, a total of 57 GPS satellites have been launched into the planned orbit, with 31 of them successfully operational.

In the GPS constellation, 24 orbital slots are maintained. These orbits are within circular orbits that are inclined at 55°. Each of the six orbital planes has four slots, each having an orbital radius of 26,559.7 km. The constellation design includes asymmetrical spacing in argument of latitude between satellites inside each plane, which was determined to provide robustness in performance against satellite failures. Excess satellites are frequently installed in spaces near satellites that will need to be replaced soon [3]. The progression of GPS transmissions from Block I to Block III satellites is depicted in Fig. 1. The normalized power spectral densities of the various GPS signals are shown in dB on the graph. The bandwidths spanned between the first spectral nulls of the P(Y) code and the L5 signals are each 20.46 MHz.
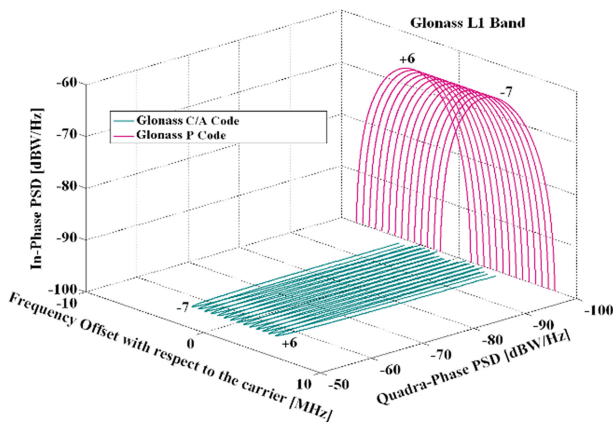
Fig. 2. GLONASS frequency band [6]. *Source* Gssc.esa.int. Licensed by Gssc.esa.int

2.2 GLONASS

GLANOSS is the satellite navigation system operated by the Russian Federation, with the first satellite launched in 1982. In the GLONASS constellation, it consists of 24 satellites which are arranged into three orbital planes, each with a 64.8° inclination angle and a height of 19,100 km [3].

As shown in Fig. 2, each of the channels was filtered to only broadcast the BPSK signal's main lobe, and the PSD was normalized to have unit power within the matching transmission bandwidth.

2.3 Galileo

Galileo is a satellite navigation system operated by the European Union that is specifically designed for multi-purpose tasks, including civil and commercial applications, with great feasibility compared to other navigation systems. In the Galileo constellation, a Walker 27/3/1 configuration is applied. It consists of a global constellation of 27 satellites in three medium Earth orbit (MEO) orbital planes inclined at 56° to the equator at around 23,000 km in height [3].

To meet the needs of the greatest variety of users, including professional users, scientists, mass-market users, safety of life, and public regulated sectors, four unique navigation services and one service to help search and rescue operations have been identified. For applications with more demanding needs and based on unique environmental features, Galileo navigation services can be upgraded on a local basis by combining them with local elements [3]. Figure 3 indicates that the spectra of the GPS and Galileo systems overlap. In fact, the actual E1 band of Galileo had received the name of L1 band in GPS for a certain period of time until 2008 [7].

2.4 BDS

The BDS navigation system is operated by China, which is able to provide two-dimensional location determination between user facilities and geostationary satellites
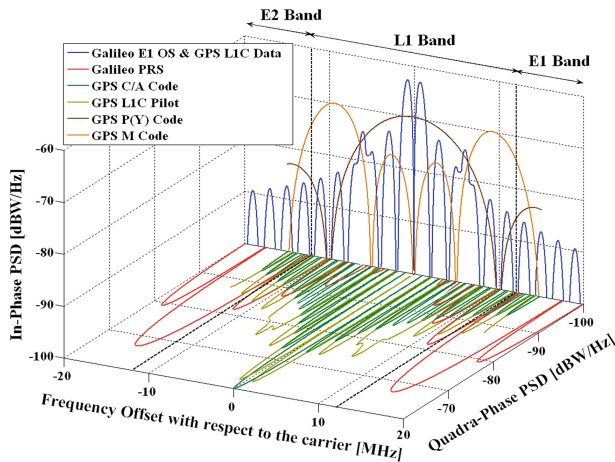
Fig. 3. Spectra of GPS and Galileo signals in L1 and E1 [7]. *Source* Gssc.esa.int. Licensed by Gssc.esa.int

on the order of 20–100 m [3]. The BDS-3 plan calls for a hybrid constellation of 30 satellites to provide multifunctional services, including 24 medium Earth orbit (MEO) satellites, three inclination geosynchronous orbit (IGSO) satellites, and three geostationary Earth orbit (GEO) satellites. Compatibility and interoperability have become the key aims of the BDS-3 plan in order to expand the regional open service (OS) to the global OS, and new signals with novel modulation techniques have been devised to suit such criteria [8].

As demonstrated by Fig. 4, the progression of the BDS open signals from BDS I to BDS III is described. The BDS III MEO and IGSO satellites will send the two new navigation signals, B1C and B2a/B2b, while all BDS III satellites will continue to transmit the historical B1I and B3I signals. Within the dashed lines on the right side of Fig. 4, the relevant signals of the radio determination satellite service (RDSS), which are exclusively transmitted by GEO satellites, are shown.

3   Principle and Operation of GNSS

The space segment, the user segment, and the control segment are the three major components of GNSS systems [3]. The space segment is made up of satellites in three orbital altitudes: low earth orbit (under 2000 km), medium earth orbit (5000–12,000 km), and geostationary earth orbit (fixed at 35,786 km), all of which are equipped with instruments for receiving, storing, and processing navigation data [6]. The control segment is composed of three parts, monitoring stations, which are primarily responsible for data collection (including carrier wave and pseudo wave) as well as transmission to the control centre; the control centre, whose primary function is to process monitoring station data in order to calculate satellite location, generate positioning data, and ensure satellite position; and tracking stations, which are generally used for tracking satellites [9].

For GNSS positioning, the trilateration method is utilized, which is an algorithm that can calculate a receiver's position by acquiring corresponding distances from a
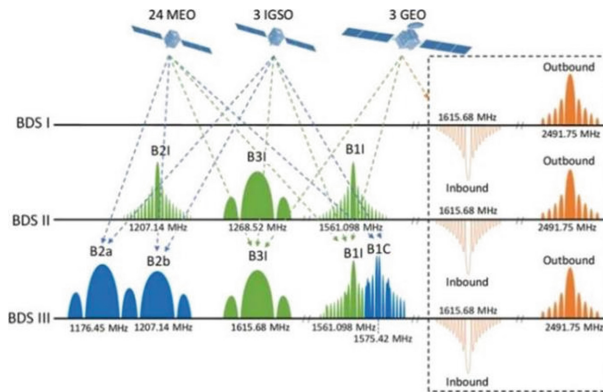
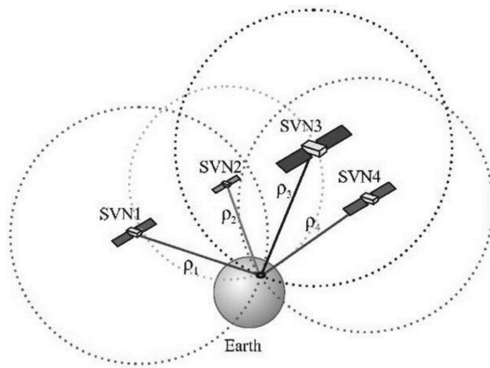**Fig. 4.** BDS frequency band [8]. Licensed by the author

Fig. 5. Basic principle of GNSS positioning [12]. *Source* What-when-how.com. Licensed by What-when-how.com

predetermined number of known places [10]. A point could be located by its three-dimensional coordinates in ideal conditions, hence at least three satellites are necessary to locate an item. Because signals travel at light speed, distances between satellites and receivers may be computed as long as transmission durations are available, as shown in Fig. 5. In practice, however, the distances acquired are referred to as "pseudorange" because, as a satellite signal travels through the atmosphere and reaches the receiver, the ionosphere and troposphere delay the signal, and the ground reflects it as well. As a result, the receiver uses the correction formula sent by the satellites to balance these mistakes and get as close to the precise range as possible [11]. Another aspect that contributes to the pseudo range is the temporal bias of the receiver clock [7]. To counteract the receiver clock issue, an extra satellite is utilized in practice for time synchronization. To position the receiver, at least four satellites must be above it at the same time [6].

As the GPS device obtained its distance from satellites, it could use geometry to ascertain its exact position in three dimensions.

4   Applications

4.1   Surveying and Mapping

GNSS is widely utilized in cadastral and engineering surveys, deformation detection of DAMS and large buildings, crustal movement observation, high-precision geodesy and control surveys, underwater topographic surveys, road and line lofting, and other applications. The most essential factor is that it may save a lot of people, material resources, financial resources, and time when compared to traditional approaches [4]. In road surveys, differential dynamic GPS is mostly utilized for data capture of digital ground models, control point encryption, center line lofting, longitudinal surveys, and airborne GPS aerial surveys without external control points. GPS readings provide three-dimensional data that can be used to create digital ground models, build center lines, and conduct longitudinal surveys. The vertical section can be obtained by lofting the Central Line's plane location. The data from the reference station should be transferred in real time to the mobile station over the data chain when lofting the Central Line, in order to provide the mobile station's real-time position. Because GPS instruments are not directional like theodolites, they must be used in conjunction with CAD systems to display the difference between the present position and the designed coordinates on a computer screen.

4.2   Traffic

The use of GNSS reception equipment in ocean navigation and harbor diversion can be accomplished with the use of GNSS in water transportation. GNSS technology is used in land transportation, car rental services, logistics and distribution, taxis, and other industries for vehicle tracking and scheduling management, which can not only respond to users' driving or delivery requests quickly but also reduce energy consumption and transportation costs. In the future, the city will develop a digital traffic radio station to broadcast real-time traffic information. Vehicle equipment will use GNSS to perform exact positioning, automatically match the best course by merging an electronic map with real-time traffic conditions, and enable autonomous vehicle navigation. It can also be applied in air transportation. It not only allows pilots to correctly align with the runway landing, but it also allows for a more compact aircraft arrangement, increasing the airport's utilization rate and guiding aircraft safely into and out of the airport.

4.3   Precision Agriculture

Agricultural machinery control, precise disease and pest control and irrigation, and farmland resource survey and planning are among the applications of satellite navigation and positioning technology in precision agriculture [13]. For application in machinery control, the GNSS technology can navigate the working machines, enabling their automatic operation when seeding, harvesting, and ploughing to maximize their working efficiency. For precise disease and pest control and irrigation, by connecting a GNSS system to a camera system, shooting and analyzing images. It is possible to collect original data, monitor field crops, and determine the distribution position of pests in the field, as well

as confirm the migration route, population number, and damage degree of pests, as well as the development direction and epidemic trend of pests. Additionally, a GNSS land parameter sampler could be used to collect plant growth environmental parameters such as soil moisture and ground temperature, and a GNSS central control base station is used to analyze plants using an expert system, which can regulate the plant growth environment and accurately regulate water-saving irrigation systems. Technicians can use a GNSS handheld to determine the geographic location of cropland. It can determine the operating area and other parameters quickly, efficiently, and correctly using satellite location measuring technology.

5 Challenges and Future Development

In terms of technical obstacles, receiver design is currently facing difficulties, and the satellite navigation system is in the midst of an explosion, with new types of navigation systems appearing all the time. As a result, receiver designers should concentrate on overcoming the challenges from one end of the receiver's antenna to an interface that offers users precise positions [14]. The design of an antenna must be capable of receiving across the entire bandwidth at each GNSS frequency, which is thought to be a very difficult undertaking. According to studies, balancing the cost and adaption of patch antennas for commercial receivers is nearly impossible [15]. Thus, the development of a low-cost multifrequency antenna may still be a long way off.

Another issue that arises when GNSS receivers are used indoors is substantial signal deterioration. This is a huge issue, especially when you consider that almost four-fifths of all cellphone calls begin or conclude within buildings. This could be due to signal deterioration as it travels through the building's components, such as the roof, floors, walls, and other internal obstacles. The transferred signal's intensity would be harmed by reflection, refraction, and absorption. As a result, improving the indoor signal strength for GNSS is critical.

6 Conclusion

Apart from the four main GNSS discussed, more emerging navigation systems, including Japanese QZSS, and Indian IRNSS, will become operational. The accuracy, consistency, availability, and robustness of GNSS will be considerably improved by these additional range sources.

As a booming and promising emerging technology, GNSS would be able to offer tremendous benefits to civil applications worldwide, including improving the precision of surveying and mapping in the construction field, providing extra support and safeguard mechanisms to the transportation industry, and prompting agriculture to be more efficient and high quality. The future challenge includes balancing the cost and frequency bands that the antenna may receive and increasing the signal strength of GNSS for indoor transmission. Despite the fact that the papers and articles reviewed and the material researched were published a few years ago, and with the consideration that GNSS technology develops rapidly and significantly, this article may not cover all of the latest progress in the field of GNSS application. Thus, the next area of research

is to update the emerging applications of GNSS and evaluate the benefits they might contribute.

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