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Service Performance Enhancement Technologies for BeiDou Navigation Satellite System along the Belt and Road

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Abstract: To solve problems in the globalization of the BeiDou Navigation Satellite System (BDS), this paper analyzes the service performance and application status of the BDS based on the overall application and development trends in satellite navigation across the world. Major difficulties in the application and promotion of the BDS are analyzed from three perspectives: system service, characteristic service, and application industries. Further, promoting differentiated competitive advantages has proven to be effective in assisting the BDS to "go global." Based on the above analyses, preliminary technical approaches and schemes are designed to promote and apply satellite-based augmentation and short-message services (two characteristic services of the BDS) along the Belt and Road. By establishing over a dozen monitoring stations in countries along the Belt and Road, the demand for precise positioning in most of these countries can be satisfied. By developing an oversea short-message service system, a short-message communication service with better performance and usability can be provided for enormous numbers of BDS users along the Belt and Road. Promotion ideas for the BDS characteristic services and their applications are also presented. Additionally, several policy suggestions are proposed to accelerate the use of the BDS services in countries along the Belt and Road.

Keywords: satellite navigation; BeiDou navigation satellite system (BDS); the Belt and Road; application and promotion; demonstration application

1 Introduction

After more than 30 years of development, the BeiDou Navigation Satellite System (BDS) has become a vital space-time infrastructure in China and an important influence serving economic and social development and national defense construction. With the gradual completion of the BeiDou-3 satellite navigation system, the development focus on China's satellite navigation has been shifted to its application and promotion.

With the development of satellite navigation technology and related industries, global satellite navigation applications have gradually exhibited three major trends. First, high-precision applications are becoming the mainstream. By 2020, all of the world's four major satellite navigation systems will be operational, resulting in the coexistence of multiple satellite constellations and frequencies. The development of compatible and interoperable satellite navigation technology further simplifies the application of multi-system solutions, which lays a solid

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foundation for the diversified development of the terminal industry. With the advances in chip technology and the continuous performance improvement of low-cost devices, satellite navigation terminal applications are evolving towards low-cost and high-precision applications. Drive by the development of unmanned driving, the Internet of Things, intelligent wearables, and other emerging fields, high-precision services in the application market are becoming mainstream [1].

Second, positioning, navigation, and timing services (PNTs) are becoming ubiquitous, collaborative, and intelligent. With the rapid progress of technology, human beings have steadily realized space exploration, from deep space exploration at the macro scale to inner space exploration of organisms at the micro scale. The demand for space-time services has become ubiquitous. To provide a better service experience to users, the development and increasing maturity of various PNT devices and technologies has resulted in various PNT services (with satellite navigation at their core) becoming more collaborative and intelligent [2,3].

Third, "PNT+" will become an emerging application and research field. With the increase in space-based information system services, the integration of satellite navigation, communication, remote sensing, and other space-based service systems is inevitable in the quest for better system services, and the application of low-orbit satellite navigation and remote sensing fusion has entered the satellite test stage [4]. Low-orbit satellite navigation, underwater navigation, indoor navigation, and ground-based enhancement technologies are being integrated into satellite navigation PNT services, forming a new generation of integrated space and sky service systems offering seamless coverage with satellite navigation at the core. In the future, a number of "PNT+" type emerging technologies and application fields will appear, combining cloud computing, the Internet of Things, artificial intelligence, and other emerging disciplines.

2 Performance, status, and problems of the BDS application along the Belt and Road

2.1 Performance assessment of the BDS service

Compared with other satellite navigation systems, besides the basic navigation service, the BDS provides decimeter level satellite-based augmentation and a short-message service. Since its launch in 2017, the BDS decimeter level satellite-based augmentation service has improve the performance of the BDS' basic services, increasing the service mode of the satellite navigation system. The dual-frequency positioning performance comparison of the BDS and the Global Positioning System (GPS) from 2016 to 2018 is shown in Fig. 1.

As shown in Fig. 1, the accuracy of the basic services of the BDS system was greatly improved after the decimeter level satellite-based augmentation services were launched in 2017, which now has achieved the same accuracy as those of the GPS. The accuracy of the BDS decimeter level satellite-based augmentation service was significantly better than the GPS basic service accuracy; the GPS did not have the satellite-based augmentation function itself and needed to rely on the wide area augmentation system (WAAS) to realize such function.

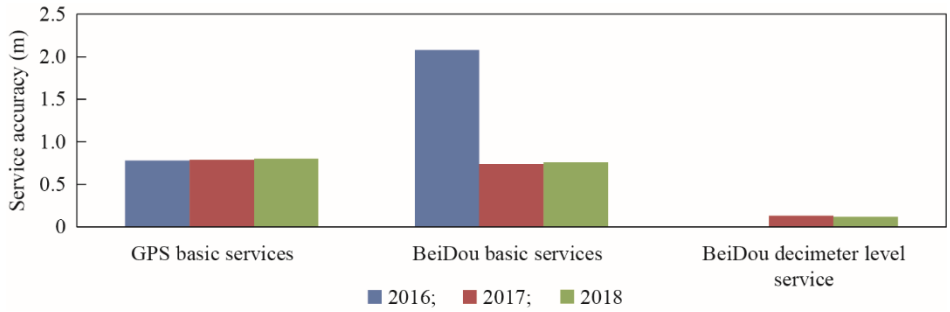

Fig. 1. Accuracy comparison of the GPS and BDS basic services, BDS decimeter level satellite-based augmentation service.

2.2 Application status of BDS along the Belt and Road

After years of application and promotion, the BDS has made some progress in its globalization. The industrial power based on BDS basic services had "sparked" a trend in countries and regions along the Belt and Road before the arrival of BDS featured services.

China has secured international cooperation agreements with countries including Laos, Pakistan, Thailand, Singapore, and Cambodia, with more than a dozen countries having signed a cooperation framework agreement, to implement the BDS application. In addition, China and Russia have established an exchange mechanism on major

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satellite navigation issues. China has also established a cooperation framework with Arab states, held the China–Arab BDS Cooperation Forum on a regular basis, and set up the first BDS overseas center (the China–Arab BDS center) in April 2018. In November 2018, China organized the 13th conference of the International Committee on Global Satellite Systems (ICG), and President Xi Jinping sent a congratulatory letter to the conference, demonstrating the global influence of the BDS.

Currently, in terms of industrial services, BDS applications have successively entered more than 30 countries and regions along the Belt and Road, with private enterprise product sales and applications in more than 10 countries. Some Chinese enterprises, such as CHC Navigation Technology Co., Ltd., ComNav Technology Co., Ltd., and Unistrong Science & Technology Co., Ltd., combined with partners and resources of countries along the Belt and Road, have applied BDS/Satellite navigation to bundle sales and have achieved some gratifying success in industrial application services.

2.3 Major problems in the application and promotion of BDS along the Belt and Road

2.3.1 System service

The results of a comparison between the international satellite navigation monitoring and evaluation systems in December 2018 (Fig. 2) show that [5] on a global scale, through the comparison of single-frequency positioning accuracy, it can be seen that the basic service performance of the BDS is similar to that of the GPS internationally (including the Belt and Road countries and regions). As the constellation of the European global navigation satellite system (GNSS), Galileo, is not yet complete, its availability and continuity remains to be further improved, although the overall service performance is similar to the BDS and the GPS. Russia's GNSS (GLONASS) has relatively poor service performance.

Although the service performance of the BDS is currently similar to that of the GPS, it is difficult for the BDS to replace the GPS in the basic service market. This is because the GPS enjoys the first-mover advantage in a very mature global industrial power system market, and has the greatest market share in the field of satellite navigation.

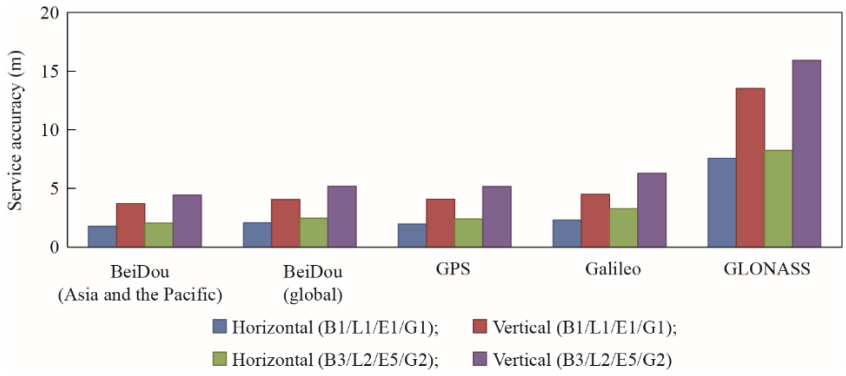

Fig. 2. Comparison of positioning accuracy of the major GNSS.

2.3.2 Characteristic service

In addition to the basic service, the BDS' main characteristics are its decimeter level satellite-based augmentation and short-message services features.

In 2017, the BDS completed the decimeter level satellite-based augmentation system (SBAS), which was based on the world-leading quadruple difference parameter superposition system and high-precision differential parameter broadcasting system. BDS realized decimeter level satellite-based augmentation high-precision services covering China and surrounding areas. Compared with the ground-based augmentation service, there was no need to build a large infrastructure on the ground, and the high-precision service capability could meet most economic and social development needs, which was an important way to promote the high-precision service. Currently, four major navigation satellite systems have been completed or have carried out the construction of SBAS. For example, Europe is promoting its free satellite-based augmentation service, and Japan is promoting centimeter-level satellite-based augmentation service. In addition, commercial companies are rapidly entering the market for satellite-based augmentation services. Limited by the service coverage area, the promotion of satellite-based augmentation services has not been realized in most areas along the Belt and Road at present, which presents an opportunity.

To promote the application of the BDS along the Belt and Road more effectively, it is necessary to strengthen the construction of the BDS system services, provide the necessary system open service platform for the BDS, and

enable the BDS featured services to “go abroad” and enter the countries along the Belt and Road as soon as possible.

2.3.3 Application industries

The influence of the satellite navigation system is mainly exemplified at the application level. Compared with the application of satellite navigation abroad, China’s industrial development started late, and the satellite navigation industry (upstream and downstream) is typically small scale, dispersed, and uncompetitive, even though overall development is rapid. According to the European Union *GNSS Market Report* published in 2017 [6], the Chinese market accounts for just 11% of the global market, showing a significant gap compared to the United States, the European Union, and Japan (Fig. 3).

In the United States, for example, the development of the GPS and various GPS augmentation methods provides unique conditions for the overall development of the satellite navigation industry. It has created companies such as Qualcomm, Broadcom, Trimble, and Apple that provide the world’s leading GPS chips, baseband products, user devices, and services, giving birth to a satellite navigation application industry centered on GPS applications. It has formed a complete industry supply chain of satellite navigation applications and attained a world-leading position [7]. The leadership position of the United States is reflected in its leading technology and products, the scale of their products, the complete satellite navigation application service system, and their powerful influence on the global satellite navigation application field.

By contrast, although the BDS services and terminal products have been promoted and applied in various forms in China, which has promoted the rapid development of related industries and enterprises, the components, high-end devices, and products still lag behind the rest of the world. On the premise that the basic service capacities are equivalent, if the BDS application wants to achieve competitive advantage over the GPS in its promotion and application along the Belt and Road, it needs to enhance its differentiated competitiveness based on the BDS featured services and create a new market entry point and growth point.

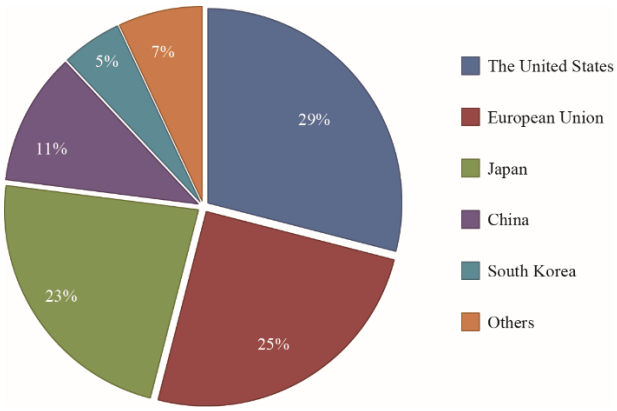

Fig. 3. Market share distribution of satellite navigation industry.

3 Service performance augmentation methods of the BDS application along the Belt and Road

3.1 Satellite-based augmentation

Foreign satellite navigation systems themselves can currently only provide positioning services with the highest accuracy at a meter level. For more accurate wide-area positioning services, additional SBAS must be established, such as WAAS in the United States, the European Geostationary Navigation Overlay Service (EGNOS), and the System of Differential Correction and Monitoring (SDCM) in Russian. Correction parameters transmitted by the above system-level GPS/GLONASS augmentation system include orbit, satellite clock error correction (number E), and integrity parameters.

The BDS decimeter level SBAS synchronously calculates the basic navigation message parameters and satellite-based augmentation parameters through the original quadruple difference system, and realizes the integration and synchronous broadcasting of the two types of parameters. As shown in Fig. 4, the BDS quadruple difference parameter further corrects the spatial environment error based on the usual orbital and satellite clock differences and corrections, adding the parameters of ionospheric grid correction and zone comprehensive correction. In addition, the spare fields of the BDS broadcast message protocol are used for parameter incremental arrangement and are

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broadcast to all users via the geosynchronous orbit (GEO) satellite.

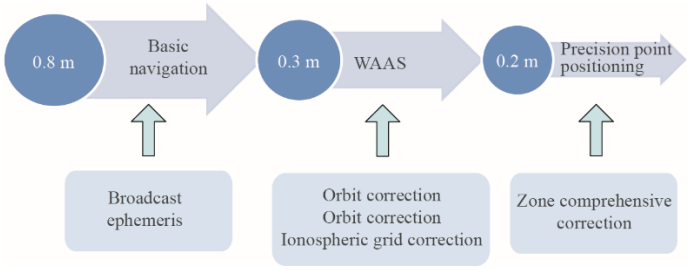

Fig. 4. The current coverage of the BDS' decimeter level SBAS.

Ground infrastructure needs to be built on a priority basis. The BDS can only achieve 3–5 m positioning accuracy along the Belt and Road. A small number of ground monitoring stations should be built in the Belt and Road countries and regions in order to achieve the coverage of location services at a decimeter level. According to the service capacity of the current decimeter level service system, each ground monitoring station can realize decimeter level satellite-based augmentation services covering an area with a radius of about 1000 km.

Currently, the BDS navigation system space signal accuracy reaches 0.8 m, the WAAS accuracy is 0.3 m, and the precision point positioning is 0.2 m. Among them, the decimeter level satellite-based augmentation coverage area is shown in Fig. 5. As can be seen, the light purple areas covered by the BDS system's decimeter level services are mainly concentrated in China and its surrounding areas.

In the Belt and Road promotion and application, by expanding ground observation networks and satellite broadcast resources, the BDS high-precision satellite-based augmentation services can be extended to the countries and regions of the Belt and Road.

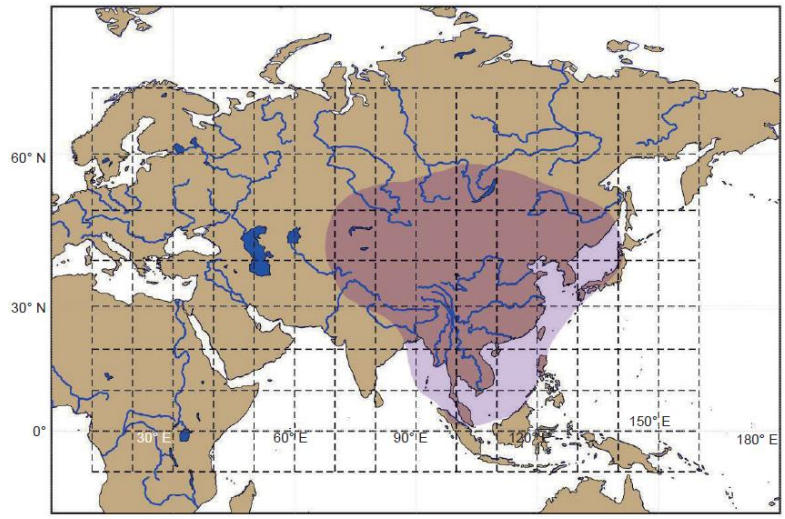

Fig. 5. The current coverage of the BDS' decimeter level SBAS.

According to the design principle of the current the BDS decimeter level SBAS, a service within a radius of approximately 1000 km can be realized based on the observation data of each ground monitoring station. About 18 new continuous observation stations were constructed based on observations along the Belt and Road, as shown in Fig. 6. The pale purple area in Fig. 6 is the coverage area of the BDS decimeter level service based on the data of existing and newly added continuous stations. Table 1 shows the positioning service performance of the BDS decimeter level augmentation system's coverage area along the Belt and Road. By constructing a small number of BDS continuous observation stations in this area, the service performance of the user's 3D positioning accuracy can be improved to better than 0.25 m. In addition, the BDS can be integrated with other navigation system which can further improve service performance.

The quadruple difference parameters of the BDS are broadcast to users by five GEO satellites distributed on the equator. Along the Belt and Road in the European area, the GEO cannot fully cover the region. In order to realize

the availability of the decimeter level satellite-based augmentation service in the region, the BDS system backup or retired GEO satellites can be considered for supplementation. According to the existing message protocol and the existing service frequency band, the satellite-based augmentation message information is broadcast to the currently difficult coverage areas.

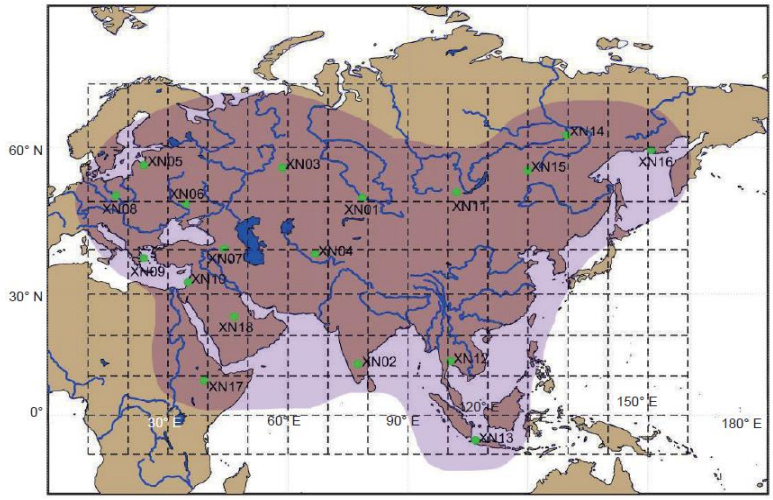

Fig. 6. Distribution and coverage of the decimeter level SBAS monitoring stations along the Belt and Road.

Table 1. Experimental results of decimeter items in each region of the Belt and Road.

Zone number	3D positioning error (m)	Zone number	3D positioning error (m)
XN01	0.21	XN10	0.12
XN02	0.19	XN11	0.10
XN03	0.13	XN12	0.18
XN04	0.15	XN13	0.17
XN05	0.15	XN14	0.12
XN06	0.14	XN15	0.14
XN07	0.09	XN16	0.22
XN08	0.15	XN17	0.20
XN09	0.16	XN18	0.19

3.2 Oversea short-message service system

To promote the short-message service in countries and regions along the Belt and Road, it is necessary to expand the BDS overseas service capacity and build a dedicated system platform for overseas services.

3.2.1 Oversea short-message service system

To provide popular services to the Belt and Road countries, it is possible to design a set of military-civilian integration signals for overseas services, to expand the operation and processing center of the new system signals and the overseas operation system and service platform, and to enhance the application capacity of the BDS overseas services. Tens of millions of service capacity resources per hour can be released, application chips developed, terminal costs and power greatly reduced, and personal intelligent terminals embedded, according to the scale of overseas applications.

3.2.2 Satellite system

Depending on the demand for short-message overseas service capacity, the service can be provided based on the existing GEO satellite in the early stages. When existing GEO satellites are unable to meet the service needs of future large-scale decimeter level users, additional augmentation GEO satellites can be considered for the Belt and Road service area. The initial longitude of the satellite has been designed to be in the 60° or 140° east longitude region, carrying a short-message and satellite radio navigation service system (RNSS) payload, which can enhance both the existing service area and expand it along the Belt and Road. At that time, a satellite with supplementary services will simultaneously provide an overseas short-message and decimeter level satellite-based augmentation service.

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3.3 Demonstration application

Since the launch of the BDS short-message and satellite-based augmentation services, a series of standard documents (such as user interface protocols and user application algorithms) have been formulated to promote the application of the system more effectively. Chip, board, and terminal manufacturers have also completed the corresponding protocol upgrades and the transformation of application software. For the Belt and Road application of the BDS, it is necessary to improve the framework for the relevant intellectual property rights, upgrade existing protocols and standards, and meet the service requirements of significantly more users, wider regions, and higher accuracy.

In the field of chip technology, the focus is to obtain a series of key technology breakthroughs in system-on-chip (SoC) navigation chips, develop multi-system-integrated navigation and positioning chips with independent intellectual property rights, and keep up with international mainstream chip technology, so as to further enhance the competitiveness of products. In the field of user terminals, the fusion applications of BDS short message service and satellite-based augmentation need to be strengthened, embedded software that is standardized and easy to transplant needs to be designed, and multi-frequency and general-type user terminals need to be developed, including the BDS single frequency, enhanced single-frequency, dual-frequency navigation, and multi-frequency precision point positioning terminals. In doing so, convenient application from chips to terminals can be realized, and high-precision end products for intelligent application need to be the focus of development.

In terms of the promotion of the Belt and Road, a strategy based on local conditions needs to be adopted. Based on an in-depth investigation of local needs, targeted Radio Determination Satellite Service (RDSS) featured service products and high-precision navigation products need to be developed, and marketable products and services need to be provided.

4 Policy suggestions

First, the opening up process of the BDS characteristic services needs to be accelerated. Characteristic services such as the BDS decimeter level SBAS and short-message services in countries along the Belt and Road need to be applied and promoted as soon as possible.

Second, overseas infrastructure construction needs to be pushed forward simultaneously. The overseas application of the BDS should be promoted through various channels, via international cooperation in various forms to promote the arrival of overseas infrastructure.

Finally, a characteristic service demonstration system needs to be actively explored. We should research and develop demonstration products targeted at key areas of the Belt and Road. Relying on domestic enterprises with rich overseas engineering experience, a promotion platform of the BDS characteristic service demonstration applications (such as traffic location and smart cities) can be built.

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