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Conception and Evolution of the China's Beidou (BDS) Navigation Satellite System: Its Implications for Space Users

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ABSTRACT
China has been reliant on the US government-owned Global Positioning System (GPS). Its idea of the Beidou navigation satellite system (BDS) was driven by the general security concerns due to the GPS's dominance. China's effort to develop and update the BeiDeou system aims at having a fully independent self-reliant global navigation satellite system (GNSS) as an alternative to the United States Space Force-maintained GPS, and to diminish its reliance on GPS. The BDS has evolved from the demonstration navigation satellite system (BDS-1) to the regional navigation satellite system (BDS-2). Now, with the effective launch of the 55th and last Geostationary Earth Orbit (GEO) satellite on 23rd June, 2020, to complete the Beidou-3 constellation, the BDS has become fully operational, providing global satellite navigation coverage in the network, after completing in-orbit tests and network access evaluations. With the development of the Beidou system, and the expansion of the "Belt and Road Initiative," China has established itself as a leading actor in the space game, positioned to have significant control on deciding how future actions in space will play out. China's development and promotion of BeiDou presents implications for space users in economic, security and diplomatic areas. Since China has achieved its goal of providing global satellite navigation coverage by 2020, and with the rising numbers of BeiDou-configured products now available, considering these implications will become ever more important. This study will be relevant to space-faring countries and commercial actors. In addition to promoting interoperability to ensure their firms remain competitive, space users can continue to monitor China's technological advancements closely to guarantee that security threats do not materialize.
Keywords: Beidou (BDS), Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), Inclined Geosynchronous Earth Orbit (IGSO)

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I. INTRODUCTION

China has been reliant on the US government-owned Global Positioning System (GPS), though Russia's GLONASS and the European Union's Galileo are other options. Following the general security concerns due to the GPS's dominance, China's effort to develop and update the BeiDeou navigation satellite system (BDS) aims at having a fully independent self-reliant global navigation satellite system (GNSS) as an alternative to the United States Space Force-maintained GPS (Goswami, 2020), and to diminish its reliance on GPS. China's BDS has evolved from the demonstration navigation satellite system (BDS-1) to the regional navigation satellite system (BDS-2). Now, with the effective launch of the 55th and last Geostationary Earth Orbit (GEO) satellite on 23rd June, 2020 (Howell, 2020), to complete the Beidou-3 constellation, the BDS has commenced operation in the network after completing in-orbit tests and network access evaluations (GPS daily, 2020). The design and functions of BDS-3 are quite different from those of BDS-1 and BDS-2 (Yang, Gao, Guo, Mao, & Yang, 2019). The core BDS-3 system began operations in 2018, but this latest launch will improve the signal strength and coverage for users around the world (Xiaoci, 2020).

China's development and promotion of Beidou presents implications for space users in security, economic, and diplomatic areas (Wilson, 2017). Since China has achieved its goal of providing global satellite navigation coverage by 2020 with the successful launch of the last Geostationary Earth Orbit (GEO) satellite, and with the rising numbers of BeiDou-configured products now available, considering these implications will become ever more important.

Today, the BeiDou system has played an important role in many fields. BeiDou's areas of application extend to key sectors such as transportation, deformation monitoring on large buildings, underground utilities and emergency situations, telecommunications, electric power, and survey/mapping, emergency communication and fishery (China Satellite Navigation Office (CSNO), 2019c). It can be effectively used to locate and communicate in the emergency rescue for rigorous Geological survey task where there is no network signal for the mobile phone (Ming et al., 2018). BeiDou has some unique features that GPS doesn't have. The most obvious one is messaging (Gong Zhe, 2020). Clients of the BeiDou-3 can send SMS-like text messages to each other with the satellites, which can be life-saving during ocean rescue.

Previous writers have discussed extensively on the BeiDou navigation satellite systems. While some have talked about the development of the system (CSNO, 2019b; Lu, Guo, & Su, 2020; Stuart, 2020; Yang, Gao, Guo, Mao, & Yang, 2019; Yang, Xu, Li, & Yang, 2018; Yang, Mao, & Sun, 2020), others have delved into the implications of the system's development for space users (Gong Zhe, 2020; Goswami, 2020; Ming, Jianlong, Ruiqing, Changrong, & Hong, 2018; Wilson, 2017). This report, though does not differ sharply from the earlier works, without claim for completeness, it does review the evolution of the BeiDou navigation satellite system, and its implications for space users in security, economic and diplomatic terms. This article is organized to include introduction, conception and development plan of the BeiDou system, evolution and the current status of the system, Beidou general services and signals, and the implications of BDS for space users.

II. CONCEPTION AND DEVELOPMENT PLAN OF THE BEIDOU NAVIGATION SATELLITE SYSTEM

The Beidou navigation satellite system is considered as a strategic system planned to reduce China's reliance on the U.S. Global Positioning System (GPS). Originally, support for Beidou was low because of the consideration that China was already benefiting from the free service provided by GPS, coupled with the initial financial impediments. Today, Beidou is regarded as a strategically important dual-use technology program intended to enable the Chinese military to conduct modern war and also known as supporting the development of a new commercial industry critical to China’s national infrastructure (Pollpeter, Besha, & Krolikowski, 2014).

Concepts for BeiDou were first realized in 1983 with a proposal by Chen Fangyun to develop a Twinsat regional navigation system using two geostationary satellites (Business reporting desk, 2019). The idea was verified in 1989 in a test using two in-orbit DFH-2/2A communications satellites, which showed that the Twinsat system compared favorably with the American Global Positioning System (GPS) (Pinggen, 2005). Furthermore, in 1996, during the third Taiwan Strait Crisis, when China fired three missiles to locations on the Taiwan Strait as a warning signal against Taiwan’s moves for independence and full internationally recognized statehood, and lost two, China asserts that the United States had cut off the GPS signal to the Pacific, on which China was dependent at that time for missile tracking (Chan, 2009). The People’s Liberation Army (PLA) saw the defenselessness of having such critical military space infrastructure in the hands of a foreign power. At this point, having learnt in a hard way, China decided, regardless of the cost, to develop its own global satellite navigation and positioning system. The program’s first launch came in October 2000, followed by a second launch in December of the same year (CSNO, 2019b). Those satellites remained in orbit for 10 years before being retired in December of 2011, marking the end of the experimental period. The project was to be completed within 25 years, to establish truly independent military command and control, and precision missile guidance and tracking (United States-China Economic and Security Review Commission, 2015; Goswami, 2020). China formulated a three-step development plan to actualize the construction of the BeiDou satellite navigation system (BDS). The various phases of BDS are referred to as BDS-1, BDS-2, and BDS-3 (CSNO, 2019b; Davies, 2020).

2.1. First phase-BeiDou-1

The project was started in 1994 as an experimental regional navigation system, and the system was completed and put into operation in 2000 with the launching of GEO satellites, providing GPS services for China (CSNO, 2018). The first satellite, BeiDou-1A, was launched on 30 October 2000, followed by BeiDou-1B on 20 December 2000 (Yang, 2010). The third satellite, a backup satellite, BeiDou-1C, was put into orbit on 25 May 2003 (Yang, Tang, & Montenbruck, 2017), leading to the establishment of the BeiDou-1 navigation system. Unlike the GPS, GLONASS, and Galileo systems, which use Medium Earth Orbit (MEO) satellites, BeiDou-1 uses satellites in GEO (Geostationary Earth Orbit) (CSNO, 2018). This means that the system does not require a large constellation of satellites, but it also limits the coverage to areas on Earth where the satellites are visible.

2.2. Second phase-BeiDou-2

The second step, the construction of BDS-2, commenced in 2004, and in 2007, the first BDS-2 satellite was launched. This permits preliminary positioning, navigation and timing (PNT) services in China and its surrounding areas (CGTN, 2020). On 27 December, 2012, the BDS-2 regional navigation satellite system, was launched with a constellation of 14 satellites; five geosynchronous earth orbit (GEO) satellites, five inclined geosynchronous orbit (IGSO) satellites, and four medium Earth orbit (MEO) satellites (Yang et al., 2014), to finish the space constellation deployment. Besides being compatible with BDS-1, BDS-2 also included a passive positioning scheme, and provided users in the Asia-Pacific region with positioning, velocity measurement, timing and short message communication services (CSNO, 2018). This phase launched an additional 35 assets to provide navigation, positioning and timing data for regions all over the Asia–Pacific region (Li et al., 2020).

2.3. Third phase-BeiDou-3

Subsequent upon the uninterrupted and stable regional service of BDS-2, a GNSS (BDS-3), to complete BDS and provide services around 2020 (Yang et al., 2019b, 2020), began to be developed. The construction of BDS-3 was preceded by the building of a demonstration system in 2015 (Yang, Xu, Li, & Yang, 2018). The core BDS-3 system began operations in 2018, with a total of 19 satellites launched to complete a primary system for providing improved signal strength and coverage for users around the world (Xiaoci, 2020). With the successful launch of the last Geostationary Earth Orbit (GEO) satellite on Tuesday, 23rd June, 2020 (Howell, 2020), BDS has completed the constellation. This is the third iteration of the BDS system and consists of 24 medium Earth orbit satellites, 3 inclined geostationary satellites and 3 geostationary satellites. Overall, 55 BDS satellites are currently launched into orbit, providing more continuous, stable, reliable, PNT services to world (Lu, Guo, & Su, 2020). A comprehensive and improved PNT system will be established before 2035, which will be more integrated and intelligent (CSNO, 2018).

III. EVOLUTION AND THE CURRENT STATUS OF THE BEIDOU SYSTEM

The BDS evolution follows a pattern of developing regional service capacities; it is being developed in an incremental way, gradually extending the services globally. From the experimental satellite system to the regional navigation satellite system, BeiDou navigation system has attained Full Operational Capability (FOC), with the successful launch of the last Beidou, (BDS-3) in June 2020 (Stuart, 2020).

China's BDS implements a cross constellation composed of satellites in three orbits - geostationary Earth orbit (GEO), medium Earth orbit (MEO), and inclined geosynchronous orbit (IGSO), and each BDS phase has supported these mix of satellites (CSNO, 2019b). This arrangement increases the number of visible satellites and provides better service globally (Golf, 2019). As with other global navigation satellite systems, Beidou also has requisite space segment, ground segment, as well as the user segments. The space constellation of BDS consists of 3 GEO satellites, 3 IGSO satellites, and 24 MEO satellites (Ruan et al., 2020). The spare satellites may be deployed in orbit. The GEO satellites operate in orbit at an altitude of 35,786 kilometers, while the IGSO satellites operate in orbit at an altitude of 35,786 kilometers, at an inclination of the orbital planes of 55° with reference to the equatorial plane. The MEO satellites operate in orbit at an altitude of 21,528 kilometers and an inclination of the orbital planes of 55° with reference to the equatorial plane (CSNO, 2017).

The deployment of the system started with the regional services (covering China and its neighboring regions) and Full Operational Capability (FOC) is attained in 2020. The space segment has accomplished worldwide networking. At present, the BDS-1 is already retired, and 15 satellites of the BDS-2 are in continuous and stable operation. Before formal deployment of the BDS-3 constellation, 5 BDS-3 test satellites had been launched, to carry out in-orbit test and verification. The two new satellites (18th and 19th) for the nation's Beidou Navigation Satellite system, launched on July 25, 2015, were used to test the new BeiDou Phase III navigation signal and inter-satellite links (Inside GNSS, 2015). China launched the 20th BeiDou satellite, with a series of tests related to the clock and a new Phase III navigation signal (India Tv, 2015). On September 30, 2015, this satellite started broadcasting a signal similar to the future GPS L1C signal with time-division BOC (1, 1) and BOC (6, 1) signals (Cameron, 2015). On February 1, and March 29, 2016, China launched the

21st and 22nd Beidou satellites respectively, as part of the Beidou Phase III (GPS World, 2016). The 23rd Beidou satellite was launched on June 12, 2016 (Inside GNSS, 2016).

For two years, starting November 2017, there were 18 consecutive launches. 28 BDS-3 satellites and BDS-2 backup satellites were effectively added the last launch on March 9, 2020. The nominal BDS-3 constellation has inter satellite links and provides also a Precise Point Positioning (PPP) service (Li et al., 2020; Ruan et al., 2020; Viet et al., 2020). With this successful launch (of BeiDou-3 M17 and M18), the basic BDS constellation deployment is now complete. The 55th and last satellite of the BeiDou Navigation Satellite System (BDS) commenced operation in the network after completing in-orbit tests and network access evaluations (GPS daily, 2020). Now, the BDS services are available worldwide, including countries and regions participating in the “Belt and Road Initiative (BRI).” Within the BRI, BDS is a part of China’s Space Silk Road, a concept which was introduced in 2014 by the International Alliance of Satellite Application Services (ASAS) (Sebastian, 2018). Currently, the global coverage capacity of the BDS has been further improved, and all the availability of space signals has also reached a world-class level due to the subsistence of high-orbit satellites (GEO and IGSO satellites). The number of visible satellites in the Asia–pacific region is between 7 and 15, and the average amount is about 11 (CSNO, 2019b, c; Yang et al., 2018, 2020).

To provide better services, BDS is actively carrying out compatibility and interoperability work with other GNSS providers through international cooperation (Lu, Li, Yao, & Cui, 2019; United Nations Office for Outer Space Affairs (UNOOSA), 2020). Currently, BDS and GPS have reached a consensus on compatibility and interoperability of B1C/L1C signals, and that of B2a/L5 is being coordinated. BDS and GLONASS have completed Radio Frequency (RF) compatibility coordination; BDS and Galileo have actively engaged in cooperation and in-depth frequency coordination as well (Update on BeiDou Navigation Satellite System, 2019).

It is projected that, by the end of the year, 2020, BDS will have been widely used in many fields such as security, economy, and mass-market (CSNO, 2018). BDS has shown wide applications in conventional fields such as transportation, agriculture, forestry, marine fisheries, surveying, geographic information, power and energy, disaster monitoring, and telecommunications, and its achievements have been also further demonstrated (Betz et al., 2019). In emerging fields such as the industrial internet, Internet of Things, and the Internet of Vehicles, innovative applications such as autonomous driving, parking, and logistics are emerging in an endless stream. By 2035, the construction of a comprehensive spatial-temporal system will provide new supports for domestic and global users (Yang, 2016).

3.1. BeiDou General Services and signals

Unlike other satellite navigation systems such as GPS, the BeiDou satellite navigation system supports two different kind of general services: Radio Determination Satellite Service (RDSS) and Radio Navigation Satellite Service (RNSS). It broadcasts RDSS and RNSS signals simultaneously on its GEO satellites and provides related navigation services (Liu, Yuan, Ge, & Xu, 2019). The RNSS is very similar to that provided by GPS and Glonass.

The BDS-3 will provide a total of six satellite-based services (CSNO, 2016), including RNSS and featured services. BDS will highly integrate Regional Short Message Communication (RSMC), Global Short Message Communication (GSMC), PPP, and other featured services, with more intensive and efficient system functions (Yang et al., 2019, 2020). BDS service plan in harmony with Signal In Space Interface Control Document Open Service Signal is shown in table 3.1. BDS-3 satellites are fitted with high-performance three new navigation signals, namely B1C, B2a at the end of 2018, and B2b at the end of 2019. Among them, B1C and B2a are compatible and interoperable with the other existing global navigation satellite systems (Lu et al., 2019; Zhu et al., 2020). It also provides SBAS (Satellite-Based Augmentation System) and SAR (Search and Rescue) services. The BeiDou Satellite Based Augmentation System (BDSBAS) is an important part of BDS, and will provide the Single Frequency (SF) service through BDSBAS-B1C signal and the Dual-Frequency Multi-Constellation (DFMC) service through BDSBAS-B2a signal for users in China and surrounding areas, in accordance with the International Civil Aviation Organization (ICAO) standards (CSNO, 2020).

Table 3.1. The BDS Service Plan (CSNO, 2019a)

Service Types		Signal(s)/Band(s)	Broadcast Satellites
Worldwide	Positioning, Navigation and Timing (RNSS)	BII, B3I	3GEO+3IGSO+24MEO
		BIC, B2a, B2b	3IGSO+24MEO

	Global Short Message Communication (GSMC)	Uplink: L Downlink: C-B2bGSM	Uplink:14MEO Downlink: 3IGSO+24MEO
	International Search and Rescue (SAR)	Uplink: UHF Downlink: SAR-B2b	Uplink: 6MEO Downlink 3IGSO+24MEO
China and Surrounding Areas	Satellite-based Augmentation System (SBAS)	BDSBAS-B1C,BDSBAS-B2a	3GEO
	Ground Augmentation System (GAS)	2G, 3G, 4G, 5G	Mobile Communication Networks, Internet
	Precise Point Positioning (PPP)	PPP-B2b	3GEO
	Regional Short Message Communication (RSMC)	Uplink: L Downlink: S	3GEO

3.1.1. BeiDou Signals

The BeiDou signals, based on CDMA technology, are summarized in Table 3.2. Three levels of service will be provided (Hexagon, 2020):

- Public service for civilian use and free to users
- Licensed service, available only to users who have obtained a subscription
- Restricted military service, more accurate than the public service, also provides system status information and military communications capability.

Table 3.2. BeiDou Signal Characteristics

Designation	Frequency	Description
B1	1561.098 MHz	B1 provides both public service signals and restricted service signals.
B2	1207.140 MHz	B2 provides both public service signals and restricted service signals.
B3	1268.520 MHz	B3 provides restricted service signals only.

3.1.1. 1. BeiDou-2 Signal Plan

The BeiDou System (BDS) provides triple-frequency (B1, B2 and B3) measurements (Chu & Yang, 2018; Editorial Team, 2017); the Beidou-2 signal characteristics are shown in table 3.3. The communication access scheme of the Beidou signals is Code Division Multiple Access (CDMA) (Gao et al., 2008). The frequency of the B1I signal is centered at 1561.098 MHz. The B1I signal is Right-Hand Circularly Polarized (RHCP). The bandwidth of the B1I signal is 4.092MHz (centered at carrier frequency of the B1I signal) (CSNO, 2019a).

Table 3.3. BeiDou-2 signal characteristics:

Signal	Carrier frequency (MHz)	Bandwidth (MHz)	PRN code chip rate (Mcps)	Signal modulation
B1	1561.098	4.092	2.046	QPSK
B1-2	1589.742	4.092	2.046	QPSK
B2	1207.14	24	10.23	QPSK
B3	1268.52	24	10.23	QPSK
B1-BOC	1575.42	16.368	1.023	MBOC (6,1,1/11)
B2-BOC	1207.14	30.69	5.115	BOC (10,5)
B3-BOC	1268.52	35.805	2.5575	BOC (15, 2.5)
L5	1176.45	24	10.23	QPSK

As with GPS, GLONASS, and Galileo, the Beidou-2 system is planned to provide two navigation services: an open service for (commercial) customers and an “authorized” positioning, velocity, and timing communications service (Grelier, Ghion, Delatour, Dantepal, & Ries, 2007), this is shown in table 3.4. The open service is free to the global user community, while the authorized service on a commercial basis will be more reliable Positioning, Velocity, Timing (PVT) information and communications services as well as integrity information.

Table 3.4. Signals provided in the two service categories

Open Service	Authorized service
B1, I (In-phase component)	B1, Q (Quadrature component)
B1-BOC (Binary Offset Carrier)	B1-2
B2 I	B2 Q
B2-BOC	B3
L5	B3-BOC

3.1.1.2. BeiDou-3 Signal Plan

BDS-3 defines three open service signals (Hunter-Spirent, 2018; CSNO, 2017); (i) B1C: 1575.42 MHz with a bandwidth of 32.736 MHz (ii) B2a: 1176.45 MHz with a bandwidth of 20.46 MHz and (iii) B3I: 1268.52 MHz with a bandwidth of 20.46 MHz. The BeiDou system (BDS-3) introduces new signal frequencies B2a/B2b (1191.795 MHz), and Bs test frequency (2492.028 MHz) (Ma, 2018). BDS-3 satellites also include SBAS (B1C, B2a, B1A) and SAR capabilities (CSNO, 2020).

In addition to the legacy B1I and B3I signals, new open service signals, B1C and B2a/B2b, as well as some new authorized service signals, will be broadcast by BDS-3 satellites. Among them, B1C and B2a are compatible and interoperable with GPS and Galileo (Lu, Li, Yao, & Cui, 2019). Interoperable with GPS and Galileo, the carrier frequency of B1C, 1575.42 MHz, is the same as the carrier frequency of GPS L1 C/A and L1C, and the Galileo E1 OS signal. The QMBOC (6, 1, 4/33) modulation (Lu et al., 2019; Lu, 2019) is applied to B1C. The Beidou B1C components; frequencies and modulations, are shown in table 3.5a.

Table 3.5a. Beidou B1C components: frequencies and modulations

Signal	Signal component	Carrier frequency (MHz)	Modulation	Symbol rate (sps)
B1C	Data component B1C_data	1575.42	BOC(1,1)	100
	Pilot component B1C_pilot		QMBOC(6, 1, 4/33)	0

BeiDou B2a Band describes the signal characteristics corresponding to the B2a signal contained within the 20.46 MHz bandwidth with a center frequency of 1176.45 MHz. B2a signal is interoperable with GPS L5 and Galileo E5a. Table 3.5b indicates the Beidou B2a components; frequencies and modulations (CSNO, 2017; Li, Shivaramaiah, & Akos, 2019; Lu, 2018).

Table 3.5b. Beidou B2a components: frequencies and modulations

Signal	Signal component	Carrier frequency (MHz)	Modulation	Symbol rate (sps)
B2a	Data component B2a_data	1176.45	BPSK(10)	200
	Pilot component B2a_pilot			0

The B3I open service B3I signal is transmitted by the BDS-2 and BDS-3 satellites. The frequency of the B3I signal is centered at 1268.520MHz. The B3I signal is Right-Hand Circularly Polarized (RHCP).The signal multiplexing mode is Code Division Multiple Access (CDMA). The bandwidth of the B3I signal is 20.46 MHz (centered at carrier frequency of the B3I signal). The Binary Phase Shift Keying (BPSK) modulation is applied to B3I (CSNO, 2018).

BeiDou-3S transmit legacy B1 signals similar to the BeiDou-2 satellites as well as modernized signals in the L1, E5, and B3 band. To provide better services, BDS is actively carrying out compatibility and interoperability work with other GNSS providers. Currently, BDS and GPS have reached a consensus on compatibility and interoperability of B1C/L1C signals, and that of B2a/L5 is being coordinated. BDS and GLONASS have completed Radio Frequency (RF) compatibility coordination; BDS and Galileo have actively engaged in cooperation and in-depth frequency coordination as well (Peng, 2019).

3.2. Ground control segment

The BeiDou Ground Control is based on a standard centralized system including the various ground stations, master control stations, time synchronization and uplink stations, and monitoring stations. The BDS III Control Segment will be developed based on the BDS II control segment. Currently, it consists of 1 master control station, 7 Class-A monitor stations, 22 Class-B monitor stations, and 2 time synchronization/upload stations. The Inter-Satellite Links, one of the most important highlights of BDS III, will become a part of the Control Segment to improve the system's performance (Lu, 2018).

The ground segment has fulfilled upgrade and improvement. 12 new ground operation and control stations (including one uplink station and 11 class-II monitoring stations) have been built, to complete the satellite-ground joint debug and integration tests, and the overall operation of the system is stable. The BDS-3 has established high-precision time and space reference, added operation and management facilities of inter-satellite links, realized measurement and processing of satellite orbits and clock offsets, based on joint observation of satellite-ground and inter-satellite links. Basic global navigation services capabilities have been achieved, including positioning, velocity measurement, timing, et cetera. By the end of October 2019, 34 BDS satellites are operating in orbit to provide services to global users, including 15 BDS-2 satellites and 19 BDS-3 satellites (CSNO, 2018; Yang, 2019). User segment refers to receivers and processors that allow a system or device to make use of the signals transmitted by satellites.

IV. IMPLICATIONS OF BDS FOR SPACE USERS

Chapman (2019) recognizes that many countries and commercial firms now participate in human spaceflight, satellite construction, space exploration, and space launches due to the decreasing costs and technological barriers to space operations. Today, there are potential consequences from countries such as China developing capabilities. China's potentials impact on the ability of other countries and companies to benefit from space, as huge parts of the global economy and society are increasingly reliant on space applications.

In order to appreciate the spirit behind Beidou's growth, it is reasonable to understand the current American GPS constellation and how it blends with American military operations as well as economic and social development. Presently, the GPS constellation fits into American military actions at a superior height than any point before (Santarelli, 2020). Its development and modernization also enables productivity, quality, and economic benefits that would not otherwise be (O'Connor et al. 2019). Having seen the benefits of space-enabled operations, more space-faring countries and commercial actors are getting involved in space, utilizing their developing launch capabilities to build similar systems of their own design, leading to, not only a rapid expansion in the number of GNSS constellations and additional modernism and benefits worldwide, but also more overcrowding and rivalry in space (Weeden & Samson, 2020). While these improvements are creating ground-breaking prospects, new-fangled threats, well beyond the military are imminent, as larger parts of the global economy and society are ever more reliant on space applications (Defense Intelligence Agency, 2019). China's development and promotion of BeiDou presents challenges for space users in economic, security and diplomatic areas.

4.1. Economic implications of BDS

In the coming years, Beijing sees BeiDou services as a major business enterprise, particularly for countries partnering with China in the Belt and Road Initiative (BRI). Within the BRI, BDS is a part of China's Space Silk Road, a digital corridor of China's Belt and Road Initiative (BRI) (Siddiqui, 2020), a concept which aims at creating an entire range of space capabilities including satellites, launch services, ground infrastructure, and supporting related industries and service providers going global (Dotson, 2020). Many Belt and Road countries (table 4.1), including Nigeria, Pakistan, Saudi Arabia, Myanmar and Indonesia, et cetera, have signed agreements to establish BDS domestically (Sebastian, 2018). Some authorize China to build ground stations, which improves BDS's accuracy and reliability.

This growing user base for BeiDou outside of China adds to its geopolitical and economic rise. This would naturally amplify Beijing's global outreach and increase its presence in all major technological and infrastructure projects using navigational and positional services. To corroborate this, some countries, mostly in the Middle East, Africa, and Asia (table 4.1), already have been using BeiDou services. Though the BRI looks to increase the territorial presence of Chinese civil and military undertakings across the globe, BeiDou is China's space-controlling interface (Halappanavar, 2020).

Table 4.1. Countries that belong to the belt and road initiative (Sebastian, 2018)

Country	**Agreement Type**	**Application**
Algeria	MoU	BDS use according to China BRI policies
Brazil	Co-op Agreement	Space agency cooperation
Brunie		Application of BDS in smart city construction and tourism
Cambodia		BDS and satellite launch framework agreement, drone mapping
Egypt	Co-op Plan	BDS use
EU	Agreement	Interoperability agreement
Indonesia		Application of BDS in maritime positioning and navigation information, land confirmation
Kuwait		Building construction
Laos	BDS use	Precision agriculture, land rights
The Arab League	Agreement	Promote the use of BDS across the middle east
Malaysia	Co-op Plan	Apply BDS, BDS ASEAN Data and service center
Maldives		Offshore pilling applications
Morocco	Co-op Plan	BDS use
Myanmar	BDS plan	Land planning and channel supervision, agricultural data collection
Nigeria	Co-op Plan	Communication satellites
Pakistan		Application of BDS in transport and port administration, established regional BeiDou Navigation satellite system network
Russia	Agreement	Integrate GLONASS with BDS
Thailand		BDS continuously operating reference stations (CORS); plans for a China ASEAN (BDS) science and technology city, logistics and e-commerce
Tunisia		China Arab states BDS/GNSS center
Saudi Arabia	Co-op Plan	BDS use
Singapore		Construction and piling applications
Sri Lanka		BDS continuously operating reference stations (CORS);
UAE	Co-op Plan	BDS use
United State	Joint Statement	Civil signal compatibility and interoperability
Venezuela		Satellite imports

There are several economic implications of the completion of the Chinese BeiDou navigation system. BeiDou, as an alternative to GPS, would enable China to further consolidate its hold on global infrastructure and rulemaking to challenge the centrality of the United States to form partnerships and alliances and to control the standards for information technology, mobile devices, 5G, self-driving cars and drones, and the broader internet of things. Such information-based economic dependency on China, hinged on the global use of BDS, increases China's influence for coercion (Goswami, 2020). China, has implemented a number of domestic policies to promote the adoption of BeiDou-compatible receivers and expand its GNSS industry. This move will raise hopes for substantial economic growth brought on by BeiDou (Wilson, 2017).

4.2. Military and Security implications of BDS

Having launched "Information Silk Road," China has virtually upgraded the Belt and Road Initiative (BRI) network into a multi-dimensional super-project, which provides navigation to aircraft, submarines, missiles, as well as commercial services dependent on such navigation (Lele & Roy, 2019). While countries participating in China's global trade initiative are expected to enjoy unprecedented technological links, however, with this information and space corridor comprising a vast network of undersea cables, satellite networks and terrestrial links, China could monitor or divert data traffic, and even cut off links with entire countries if it wished. There could also be risks of cyber-interruption, particularly in underdeveloped countries, where such tampering cannot be monitored (Siddiqui, 2019). In view of the worldwide impact of managing satellites and deep-sea Internet cables, the "Digital Silk Road" could further complicate relations between the US and China. The US might consider it a long-term surveillance strategy and try to stop Beijing from getting more control over the global telecom infrastructure. Having similar reservations, other global powers would also wish to enhance the security of sensitive internet data from all over the world (Siddiqui, 2020).

China's pursuit of expansion of its security frontier along the Belt and Road routes has implications for the U.S. government. This development could make difficult, limit, or even deny the United States' ability to project power, protect the lines of communication through the global commons, exert influence, and shape future regional security developments, as well as the United States' ability to defend its allies and interests (United States Department of Defense, 2018).

Concerns have also been raised regarding inherent security vulnerabilities in Beidou-equipped receivers. While other global navigation satellite systems including GPS, GLONASS and Galileo mainly act as beacons, beaming out signals picked up by devices using them to determine their precise position on earth, BeiDou is a two-way communication system, allowing it to identify the locations of receivers. This means that once BeiDou technology is in wide use, it can become a portal for attacks, by allowing China's government to track users of the system via embedded malware in devices containing Chinese-manufactured satellite navigation chips) (Xie, 2020; Tien-pin, 2016; Cluley, 2016). Such a capability has raised serious security concerns. However, the opinion of technical experts on these claim differ; they maintained that they are not aware of ways to feasibly transmit malware through a navigation signal; and they are also of the view that receiver chip manufacturers would be unlikely to include the "texting service" due to cost factors (Wilson, 2017).

There are also clear military implications, as BeiDou is a force multiplier in the military context for China. For example (Wilson, 2017; Reinsch & Shea, 2015), for fixed military targets, China can now independently guide missiles and bombs onto targets without fear that the United States would turn off navigation services. In the case of mobile targets, once geolocated through satellites or other means, China can guide its missiles very close to the target. Furthermore, BeiDou enables independent military command and control by allowing precise knowledge of the location of one's own forces, and the ability to precisely target and provide navigation for military forces and strikes. This capability strengthens China's ability to coerce or compel others within its sphere of interest. It also limits U.S. counter intervention options, and raises the credibility of China's ability to impose costs should the United States or its allies seek to intervene. Fourth, an independent BDS coupled with 5G means real-time military command and control and devastatingly accurate automated weapons systems. BeiDou is also of enormous strategic value to China, with the ability to provide cyber espionage and tactical maneuvers essential for the Chinese intelligence and military establishments, and acts as a domestically controlled substitute for global systems, for the People's Liberation Army (PLA) of China (Halappanavar, 2020).

4.3. Diplomatic Implications

Beidou's achievement of global coverage could provide China with power to obtain more influence over PNT-related decisions in several international and regional organizations that deal with issues, such as the International Telecommunications Union, the International Committee on Global Navigation Satellite Systems, the Asia-Pacific Economic Cooperation forum, and the International Civil Aviation Organization (Reinsch & Shea, 2015). Beyond providing influence in international organizations, Beidou will likely contribute to China's broader foreign policy approach toward specific countries and regions in its early days as a global system.

China has used the BeiDou system as a selling point for building satellite communications infrastructure within the Belt and Road Initiative (BRI) participating countries to promote its foreign policy and strategic interest. China's plan to expand Beidou coverage to most of the countries covered in its "One Belt, One Road" initiative by 2018, is an indication that it recognizes the system as playing a role in its economic diplomacy efforts. For example, on the basis of Digital Silk Road, the increasing use of e-commerce and mobile payments has allowed greater partnership between e-commerce and traditional players (Hao, 2019). In addition, the Digital Silk Road allows China to hasten domestic digitalization, evade complexities connected with hard infrastructure, and develop both soft power (the national resources that can lead to a country's ability to affect others through co-optive means) and hard power (using military or economic coercion to get others to change their position) through the control of Information and communications technology (ICT) infrastructure (Magnus & Bretherton, 2020; Trunkos, 2013).

Beijing's January 2016 "Arab Policy Paper" specifically identifies plans to accelerate the application of Beidou services to Arab countries as contributing to Beijing's regional infrastructure development and space cooperation objectives (Information Office of the State Council, 2016). China has also sought to motivate countries in Southeast Asia and the Middle East to begin using Beidou, and seeks to build a network of ground stations throughout Asia to improve the system's accuracy. For example, Pakistan has had operational access since the rollout of ground stations, and their military opted to switch from GPS to BeiDou services as their main source of GNSS (Andrew, 2020).

V. CONCLUSION

The BDS has evolved from the demonstration navigation satellite system (BDS-1) to the regional navigation satellite system (BDS-2). Now, with the effective launch of the 55th and last Geostationary Earth Orbit (GEO) satellite in June 2020, to complete the Beidou-3 constellation, the BDS has become fully operational, providing global satellite navigation coverage in the network. The successful completion of the BeiDou satellite constellation is an ultimate milestone in China's stride toward the development of China's national defense aspirations, to meet its rightful security needs. The conception and evolution of the China's Beidou navigation satellite system has contributed to the momentous boost in China's overall national strength, sustained and stable economic development, and major enhancement in scientific and technological innovation capability. China has established itself as a leading actor in the space game, positioned to have significant control on deciding how future actions in space will play out.

In the understanding of the strategic insight that "whichever country dominates space infrastructure will dominate future geopolitics," China will continue to endorse the building and industrial advancement of satellite navigation systems, promote the use of new satellite navigation technologies, and continually expand application areas to meet the ever-growing diverse needs of people. Despite claims that China's ambitions in space are peaceful and economically driven, there is a clear military motivation behind their pursuit of an independent global satellite positioning system. Though, with the expansion of China's BRI, the BDS will certainly impact China's position politically and economically around the world, however, its development has implications for space users in security, economic, and diplomatic areas. The U.S. must be careful to not allow these promising accords to grow into full allied partnerships which go on to eat into the security grip it has around the world.

This study will be relevant to space-faring countries and commercial actors. In addition to promoting interoperability to ensure their firms remain competitive, space users can continue to monitor China's technological advancements closely to guarantee that security threats do not materialize.

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