BeiDou Space Service Volume Parameters and its Performance

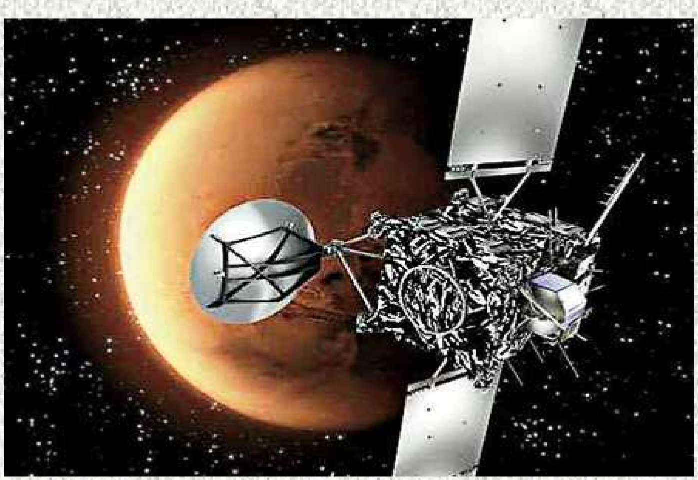
Prof. Xingqun ZHAN, Shuai JING
Shanghai Jiaotong University, China
Xiaoliang WANG
China Academy of Space Technology

International Committee on
Global Navigation Satellite Systems

Contents

Background and Motivation (1/2)

- Traditional orbit determination method of the human space explorations are based on an integration of Unified S-Band (USB) with Very Long Baseline Intervention (VLBI)
- Some key stages such as orbital transfer and maneuver are subject to the distribution of ground stations, thereby facing a tradeoff between optimized mission orbit and good visibility of ground stations on the earth.
- Acting as an alternative, GNSS service in medium and high orbital determination is necessary and feasible.



Yinghuo-1 Mars probe

Chang'e-3 lunar spacecraft

Background and Motivation (2/2)

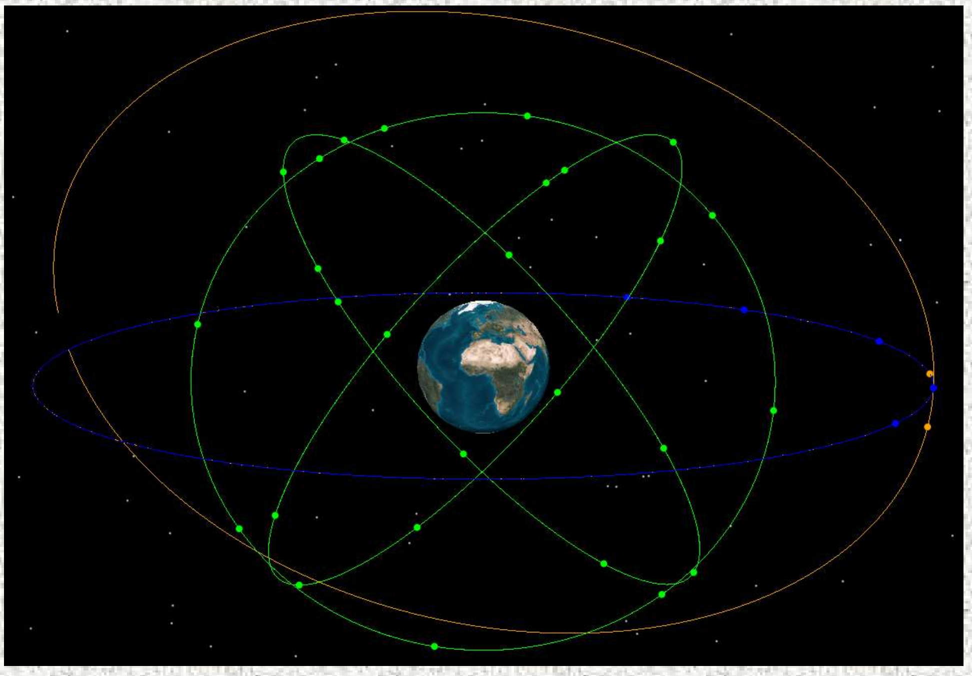
- To break the limitation of GNSS traditional signals on available beamwidth and to benefit the space applications all over the world, BDS is willing to participate in interoperable GNSS SSV.

- Since BDS III constellation and transmitting antenna gain pattern are not identical to that of other GNSS, the standalone BDS III SSV performance would be quite different from that of other GNSS.
  - First and foremost, we will introduce the distribution of BDS III satellites in consideration of its particular hybrid constellation structure.
  - As the transmitting antenna gain pattern has become a driver for the SSV specification, so secondly, we depict suggested BDS III transmitting gain pattern on B1/B2/B3 bands, and further provide BDS III SSV requirements.
  - The expected performance and advantages of BDS in interoperable GNSS SSV are presented in the end.

BDS III Constellation Parameters (1/3)

BDS III constellation arrangement

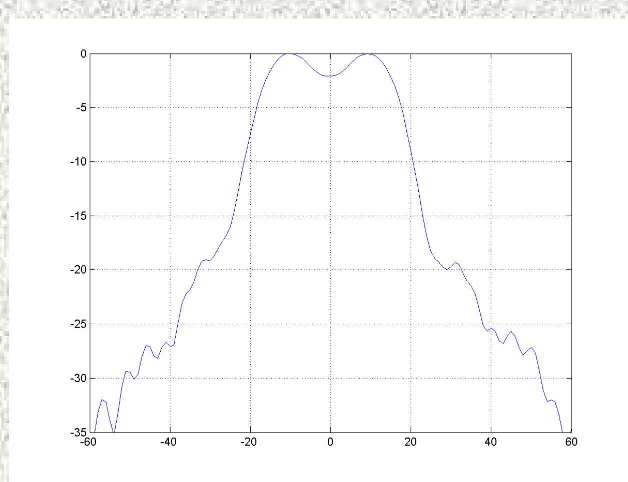
Orbit Type	MEO	GEO	IGSO
Num. of Sat.	27	5	3
Num. of Planes	3	1	3
Altitude (km)	21528	35786	35786
Inclination(°)	55	0	55
Eccentricity	0	0	0



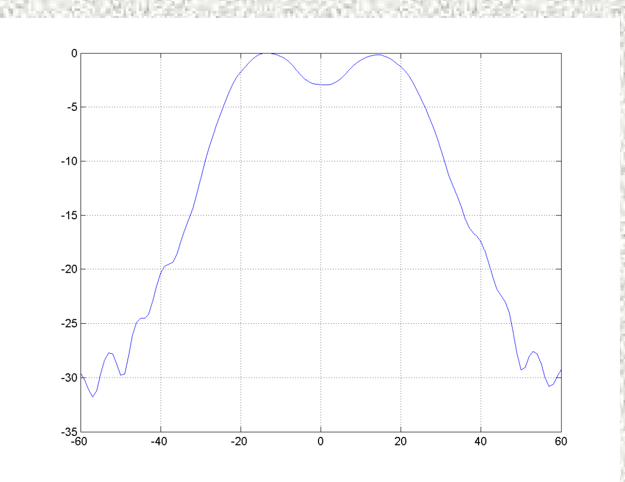
- BDS III is to be in full operation in 2020. The constellation of BDS III consists of **27 MEO** satellites, **5 GEO** satellites and **3 IGSO** ones, which makes it distinctive from other GNSSs.
  - The equatorial projections of the 5 **GEO** satellites are at 58.75ºE, 80ºE, 110.5ºE, 140ºE and 160ºE
  - The crossing longitudes of the 3 **IGSO** satellites locate at 118ºE
  - 24 out of 27 **MEO** satellites shape up into Walker 24/3/1, and the remaining 3 ones are separately taken as spare satellites in each orbit plane

BDS III Constellation Parameters (2/3)

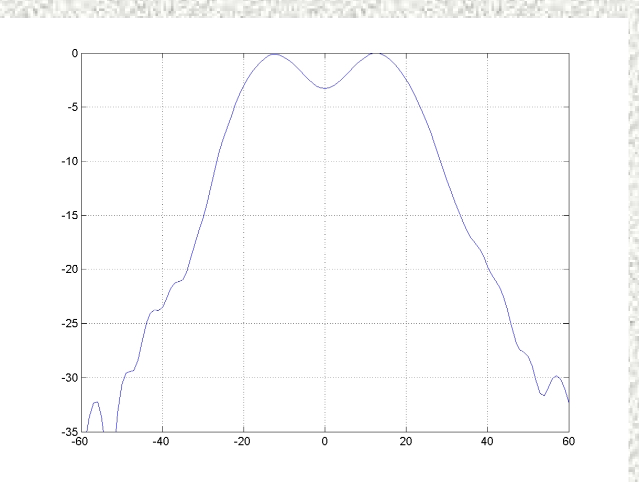
Suggested downlink broadcast pattern of BDS III transmitting antenna



B1 (1575.420MHZ)



B2 (1191.795MHz)



B3 (1268.520MHz)

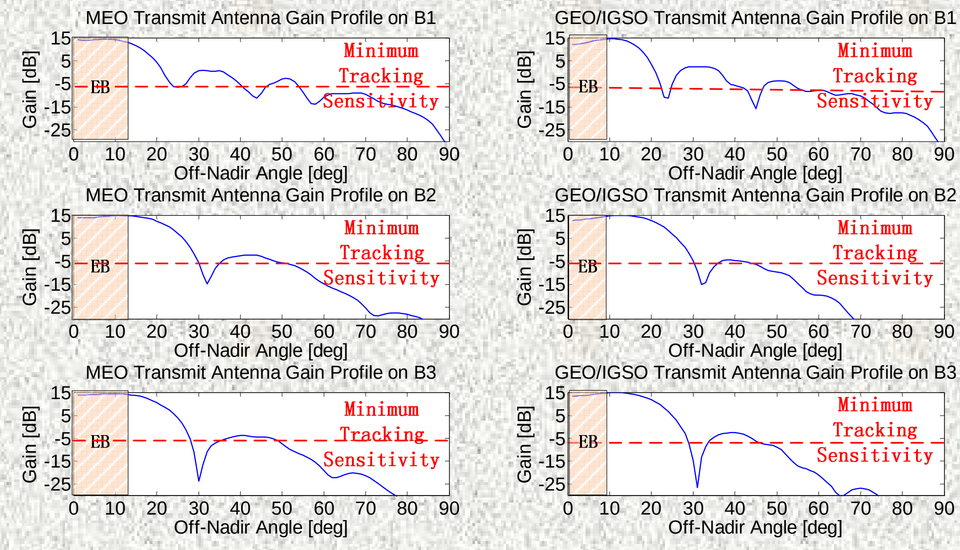
- At present, BDS antenna doesn’t consider the utilization of signal emissions originated from the side lobes
- BDS III is possible to make dedicated design to improve PNT service for SSV users in future!

BDS III Constellation Parameters (3/3)

- The lower bound of off-nadir angle is called Earth Blocked Angle (EBA). By calculating the space geometry, the minimum EBA that enables BDS MEO signals to be free of Earth obstruction is 13.212º, while the EBA for BDS GEO/IGSO signals is 8.691º.
- Excluding the signals blocked by Earth, only a few signals from main lobe can be utilized by SSV users. Just taking the gain pattern on B1 as an example, the MEO main lobe cut-off angle is about 22º, while the GEO/IGSO main lobe cut-off angle is about 21º on the condition that the required transmitting gain is -5dB at least subject to minimum tracking sensitivity.

$$EBA_{MEO} = \arcsin(\frac{r_E}{R_{MEO}}) = \arcsin(\frac{6371}{27871}) = 13.212°$$

$$EBA_{GEO/IGSO} = \arcsin(\frac{r_E}{R_{Geo/IGSO}}) = \arcsin(\frac{6371}{42157}) = 8.691°$$



BDS III transmitting gain vs. off-nadir angle

BDS III SSV Characteristics (1/2)

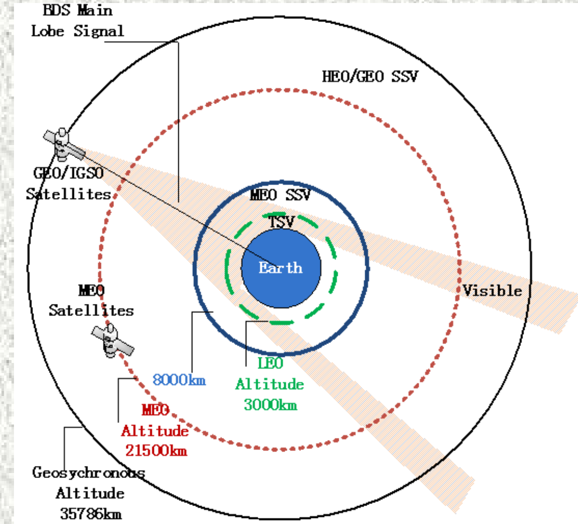
Minimum Received power for BDS III

Orbit Type	MEO			GEO/IGSO		
Signal Type	B1	B2	B3	B1	B2	B3
Carrier Frequency (GHz)	1.575	1.192	1.269	1.575	1.192	1.269
Output of Power Amplifier (dBW)	16.50	15.20	13.96	18.04	16.49	15.13
Worst Transmitting Antenna Gain (dBil)	-5	-5	-5	-5	-5	-5
EIRP (dBW)	11.50	10.20	8.96	13.04	11.49	10.13
Maximum Distance (km)	68806	68806	68806	83346	83346	83346
Maximum Free Space Loss (dB)	193.1	190.7	191.3	194.8	192.4	192.9
Atmospheric Loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5
Receiving Antenna Gain (dBil)	3	3	3	3	3	3
Polarization Mismatch (dB)	4	4	4	4	4	4
Minimum Received Power (dBW)	-183.1	-182.0	-183.8	-183.3	-182.4	-184.3

- SSV pseudorange accuracy may be conceived as User Range Accuracy (URA) since the latter represents the official requirement. There are 4 bits in almanac to indicate URA Index (URAI), which has a definite conversation relationship with URA. Generally, BDS satellites URAI is 0, which means the real-time URA is exactly 2.0m.

$$URA = \begin{cases} 2^{\frac{URAI}{2}+1}, 0 < URAI < 6 \\ 2^{URAI-2}, 6 < URAI < 15 \\ N/A, URAI = 15 \end{cases}$$

BDS III SSV Characteristics (2/2)

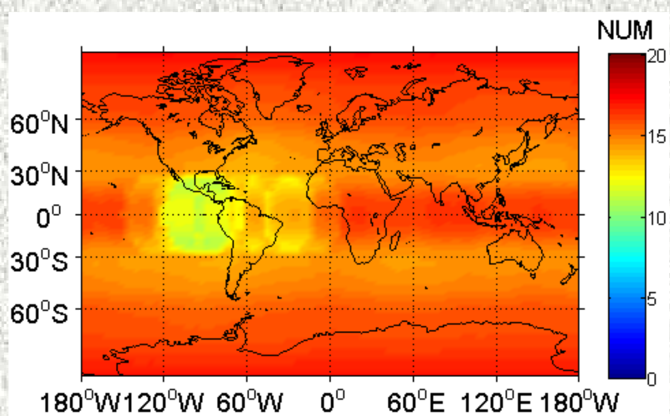


SSV visibility without side lobe signals

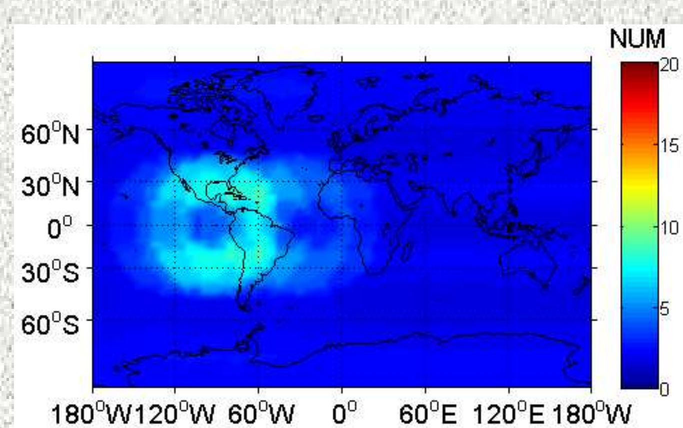
Availability of BDS III in SSV

Signal Type	MEO SSV		HEO/GEO SSV	
	At least 1 signal	4 or more signals	At least 1 signal	4 or more signals
B1	100%	99%	⩾82%	⩾4.5%
B2,B3	100%	100%	⩾95%	⩾13.1%

Compared with other areas, the different visibility over Central America can be interpreted that signal beams from GEO and IGSO satellites overlap each other above Central America at the altitude of 36000km, but they are all invisible when the height drop down to 8000km.



Visibility projection for 8000km height sphere



Visibility projection for 36000km height sphere

Interoperable SSV Performance (1/2)

BDS III Space Service Volume: Characteristics

Parameters	Value	
User Range Error	2.0 meters	
Minimum Received Civilian Signal Power	0 dBi RCP antenna at GEO	Reference Off-Boresite Angle
B1(MEO)	-183.1 dBW	22 deg
B1(GEO/IGSO)	-183.3 dBW	21 deg
B2(MEO)	-182.0 dBW	28 deg
B2(GEO/IGSO)	-182.4 dBW	29 deg
B3(MEO)	-183.8 dBW	27 deg
B3(GEO/IGSO)	-184.3 dBW	27 deg
Signal Availability		
Lower Space Service Volume (MEO)	**At least 1 signal**	**4 or more signals**
B1	100%	> 99%
B2, B3	100%	100%
Upper Space Service Volume (HEO/GEO)	**At least 1 signal**	**4 or more signals**
B1	≥ 82%	≥ 4.5%
B2, B3	≥ 95%	≥ 13.1 %

GPS III Space Service Volume: Characteristics (NASA--'Enabling a Fully Interoperable GNSS Space Service Volume' on 2012 ICG WG-B Interim Meeting held in Vienna)

Parameters	Value	
User Range Error	0.8 meters	
Minimum Received Civilian Signal Power	0 dBi RCP antenna at GEO	Reference Off-Boresite Angle
L1 C/A	-184.0 dBW	23.5 deg
L1C	-182.5 dBW	23.5 deg
L2 (L2C or C/A)	-183.0 dBW	26 deg
L5 (I5 or Q5)	-182.0 dBW	26 deg
Signal Availability[1]		
Lower Space Service Volume (MEO)	**At least 1 signal**	**4 or more signals**
L1	100%	> 97%
L2, L5	100%	100%
Upper Space Service Volume (HEO/GEO)	**At least 1 signal**	**4 or more signals**
L1	≥ 80%[2]	≥ 1%
L2, L5	≥ 92%[3]	≥ 6.5 %

Interoperable SSV Performance (2/2)

Statistic signal availability in different scenarios

Scenario	GNSS	Signal Type	MEO SSV			HEO/GEO SSV		
			At least 1 signal	4 or more signals	Outage Time [Min]	At least 1 signal	4 or more signals	Outage Time [Min]
1	GPS	**X1**	100%	97%	0	80%	1%	108
		X2	100%	100%	0	92%	6.5%	84
2	BDS	**X1**	100%	99%	0	82.0%	4.5%	99.9
		X2	100%	100%	0	95.0%	13.1%	56.5
3	BDS+GPS	**X1**	100%	100%	0	97.0%	47.8%	31.9
		X2	100%	100%	0	99.1%	51.5%	19.3
4	BDS+GPS +Galileo	**X1**	100%	100%	0	99.4%	72.7%	13.7
		X2	100%	100%	0	99.7%	75.3%	10.1
5	BDS+Glonass GPS+Galileo	**X1**	100%	100%	0	99.7%	89.7%	7.4
		X2	100%	100%	0	99.8%	91.9%	5.3

X1 here involves B1, L1 and E1 which have a smaller half beamwidth,
while X2 includes E5a, E5b and E6 besides B2, B3, L2 and L5 which have a larger half beamwidth.

Conclusions (1/2)

- The simulation results indicate that BDS signal availability for GEO SSV users is inferior to that for MEO SSV users, which is consistent with the expectation, but the visibility for users above Central America are quite different.
  - For users located 8000km height, those above Central America have less visible satellites compared with others, because most of the signals transmitted by GEO and IGSO satellites from the other side of the Earth are blocked by the planet, but the number of visible satellites here is enough to get position solutions.
  - For users in the orbit of 36000km height, those above Central America can receive more signals from GEO and IGSO satellites over the limb of the Earth compared with other locations.
  - The hybrid constellation of BDS III can satisfy the signal availability requirement in the MEO SSV and win a better performance than GPS especially for GEO spacecraft over Central America regions, which makes BDS III more distinguished in the SSV compared with other GNSSs.

Conclusions (2/2)

- The overall SSV performance for BDS III is similar to the current GPS's. And it is obviously inadequate to achieve the timing goal that at least 1 satellite shall always be in view in the HEO/GEO SSV for a standalone GNSS. Therefore, robust navigation performance within this volume calls for an interoperable GNSS SSV.
- Compared with MEO users or TSV users, HEO/GEO navigation users will benefit the most from interoperable GNSS SSV as this is the only way to overcome the limited satellite visibility provided by single constellation on an individual basis.
- Interoperable GNSS SSV is primarily responsible for improving the performance of signal availability, so it would make sense to promote the cooperation on GNSS interoperability in the SSV as soon as possible.
- It is recommended to make "Space Service Capability" or "Space Service Performance Template" as a substitution of "Space Service Volume" to express a clearer meaning.

Breakthrough Points in Future (1/1)

- Interoperable GNSS SSV is primarily responsible for improving the performance of signal availability, but there are other GNSS constraints in the SSV:
  - Multipath interference on high dynamic platforms
  - High doppler & doppler rates
  - Wide variation range of received signal power
  - Poor navigation accuracy with occultation signals

- SSV need to be settled gradually through succeeding work, and extra parameters are likely to replenish the original 3 ones. Future work will be focused on some related technical issues:
  - Multi-GNSS receiver with high-sensitivity (threshold down to 20dB-Hz)
  - GNSS signals acquisition and tracking technology in high dynamic circumstances
  - Enhanced ranging accuracy of weak signals
  - It is recommended that GNSS service providers carry out interoperable SSV space experiments jointly.

Thank you for your attention!