Disposal Strategy of BDS Satellites Based on Long-term Collision Probability

14th Meeting of the International Committee on Global Navigation Satellite Systems

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Study Progress Related to the Issue of Orbital Debris

I. May 2019, 37th IADC Meeting

- In WG4 ESA has shown an analysis result and believed that the cumulated collision risk between BDS and GPS satellites is very low in the next 200 years.

II. June 2019, 22nd Meeting of the ICG Providers' Forum

- BDS has introduced the simulation result of the collision probability between BDS and GPS satellites, and suggested system providers to establish the GNSS/RNSS space debris guidelines together with IADC.

III. Sep 2019, ICG WG-S Intersessional Meeting

- In WG-S BDS has shown the simulation results of the collision risk between BDS and nearby constellations, and there was a discussion on the progress of the ICG-13 recommendation related to "IADC MEO/IGSO Study" .The BDS presentation was included in the WG-S report.

CONTENT

01

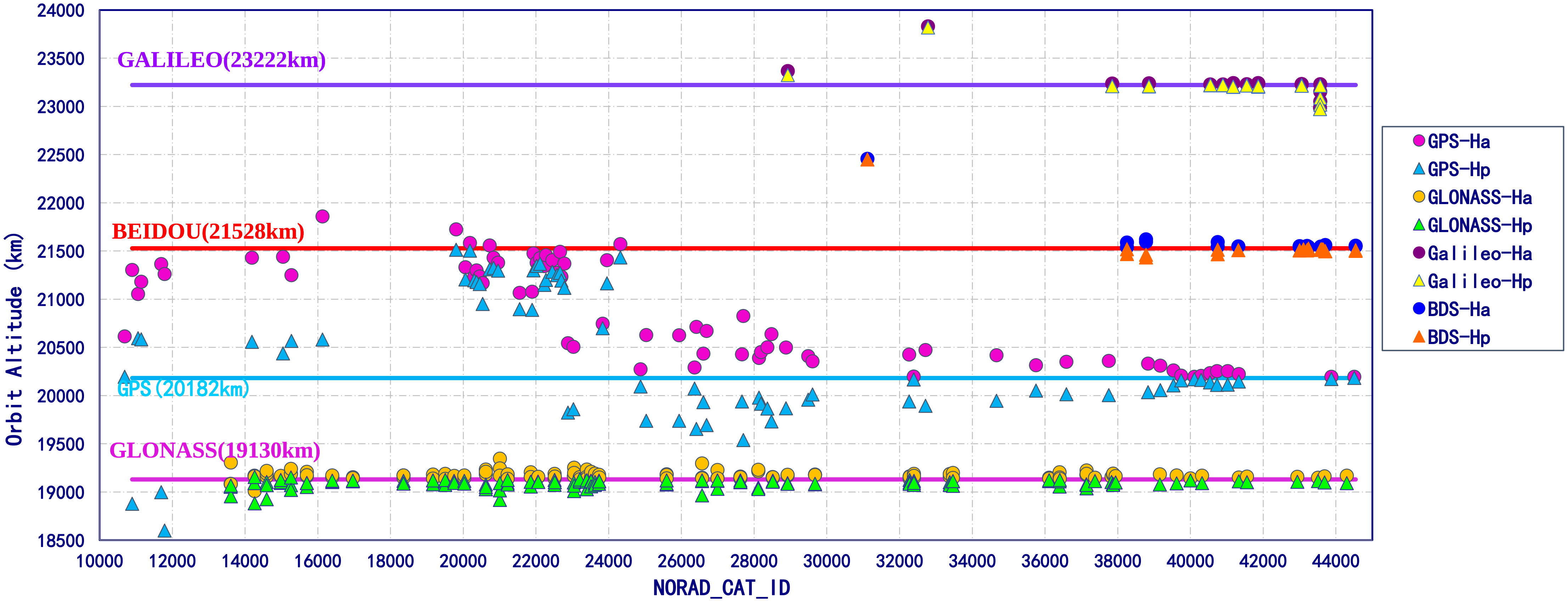
GNSS Space Debris Status Update and International Guidelines

Ⅰ. GNSS/RNSS Satellites in Orbit

Constellation	Nation/Area	Number of SVs *			
		GEO	IGSO	MEO	Total
GPS	USA	0	0	72	72
GLONASS	Russia	0	0	134	133
Galileo	Europe	0	0	28	28
BDS	China	13	12	28	53
QZSS	Japan	1	3	0	4
NAVIC	India	3	6	0	9

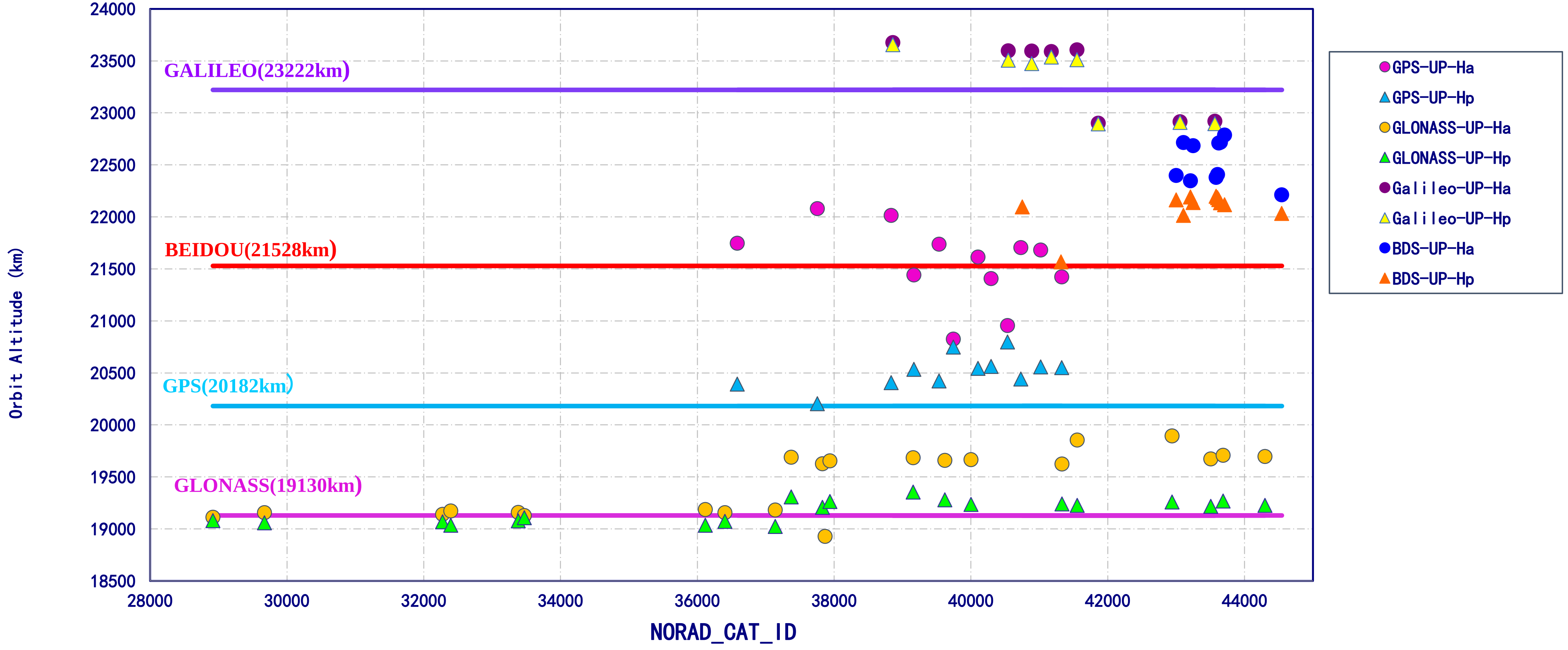
Data collected from www.space-track.org by the end of Oct 2019

Ⅱ. GNSS Satellites Orbit Altitude



Data collected from www.space-track.org by the end of Oct 2019

Ⅲ. GNSS Upper-stage Orbit Altitude



Data collected from www.space-track.org by the end of Oct 2019

Ⅳ. GNSS Spacecraft Disposal Orbit

Constellation	De-orbited Satellites		De-orbited Upper-stage	
	Number	△Ha (Increase in apogee altitude)/km	Number	△Ha (Increase in apogee altitude)/km
GPS	36	+350~+1700	12	+600~+1900
GLONASS	0*	0*	21	0~+700
Galileo	2	+120~+600	9	+350~+2900 -300
BDS	4(3GEO/1 MEO)	GEO:+140~+300 MEO:+900	11	+200~+6000
QZSS	—	—	—	—
NAVIC	—	—	—	—

*Glonass SVs at the end of life didn't have increase in orbit altitude yet.

V. GNSS Disposal Orbit Interference

Operating Orbit	Disposal Satellites Intersected the Operating Orbit		Disposal Upper-stage Intersected the Operating Orbit	
	Number	Disposal Satellites	Number	Disposal Upper-stage
GPS 21200km	0	—	0	—
GLONASS 19100km	3	GPS	0	—
Galileo 23200km	0	—	0	—
BDS 21500km	>30	GPS	10	GPS

VI. MEO Disposal Requirements of IADC

Disposal Action	MEO Navigation Satellite Orbit
25-year decay	Not recommended due to large ΔV required
Disposal orbit	TBC: 1.Minimum long term perigee of 2000km,apogee below MEO 2.Perigee 500km above MEO or nearby operational region and e≤0.003;RAAN and argument of perigee selected for stability
Direct Reentry	Not recommended due to large ΔV required

Requirements from IADC-04-06'Support to the IADC Space Debris Guidelines' in May 2014

02

Proposed Disposal Strategy of BDS Satellites

02 Proposed Disposal Strategy of BDS Satellites

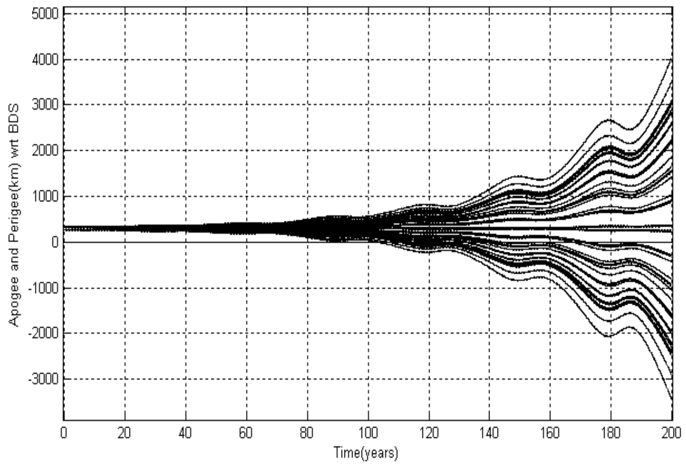
I. Disposal Safety Restrictions for BDS satellites

- Based on research of NASA and other organizations, disposal for BDS EOL satellites should ensure low collision risk with operational orbit and nearby constellations within 200 years.
- Considering propellant limitation and isolation from nearby satellite orbits, the increase in altitude of BDS EOL satellites should be more than 300km.
- The variation of altitude after disposal should be minimized over 200 years, or the disposal orbit should decay as early as possible.

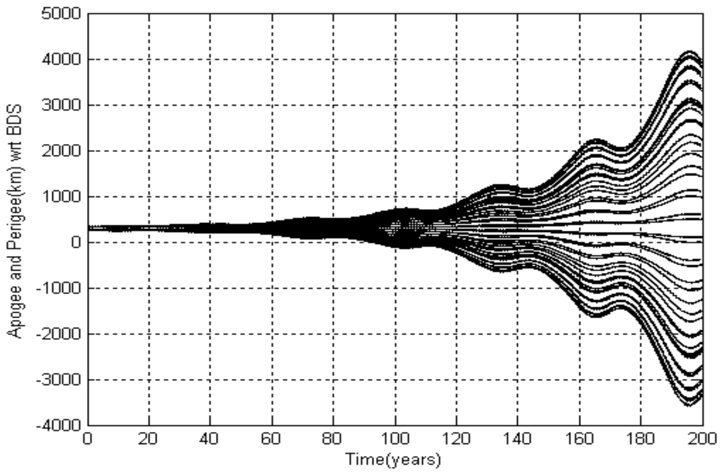
Proposed Disposal Strategy of BDS Satellites

II. Evolution of BDS MEO Satellites

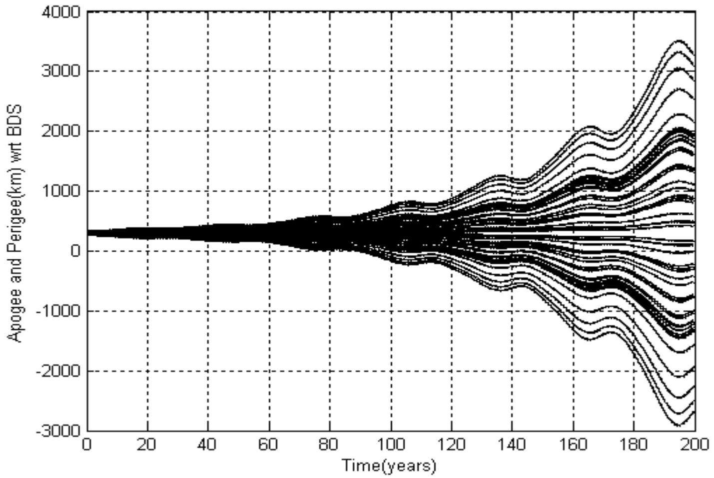
- **Minimum eccentricity growth strategy**: ω_0=190/320/240 deg, the disposal orbit is very **stable** (perigee remains above BDS constellation within 200 years)
- **High eccentricity growth strategy**: ω_0=290/70/350 deg, the disposal orbit eccentricity **grows significantly** (perigee crosses the BDS constellation but does not reach GEO within 200 years)



Ω_0=30°, e_0=0.001, ω_0=0~360



Ω=150°, e=0.001, ω=0~360°

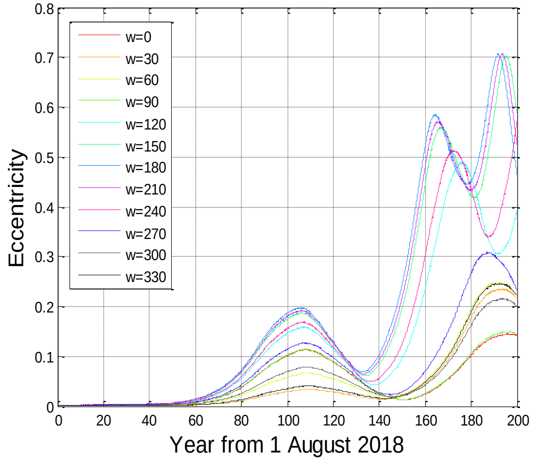


Ω=270°, e=0.001, ω=0~360°

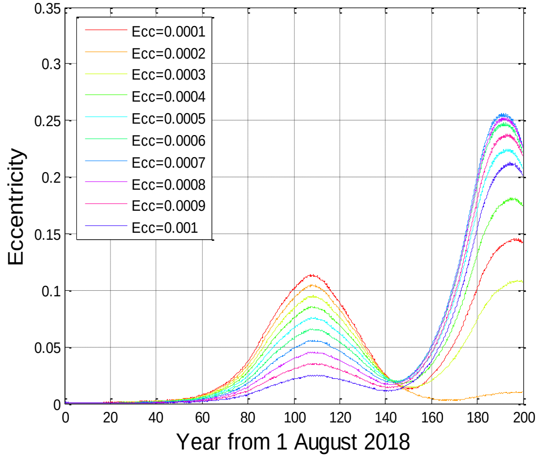
Proposed Disposal Strategy of BDS Satellites

III. Evolution of BDS IGSO Satellites

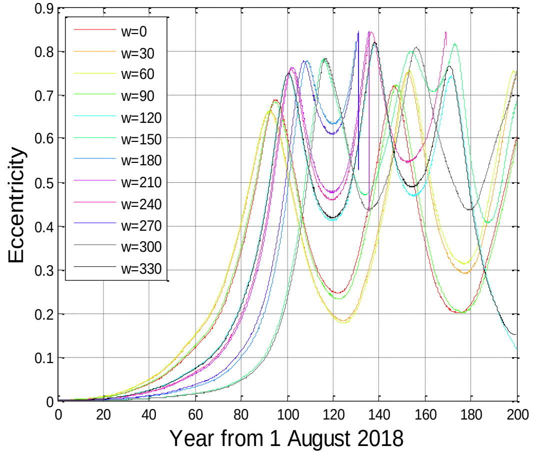
- **Minimum eccentricity growth strategy**: ω_0=0/0/120deg, the disposal orbit is very **stable** (perigee reaches GEO or MEO within 200 years)
- **High eccentricity growth strategy**: ω_0=180/270/270deg, the disposal orbit eccentricity **grows significantly** (perigee reaches MEO or has a reentry within 200 years)



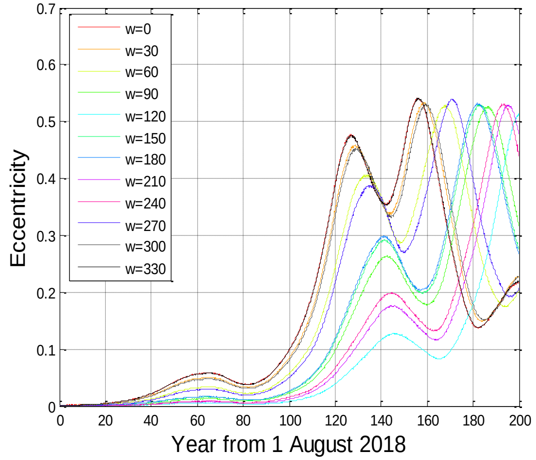
Ω_0=70°, e_0=0.001, ω_0=0~360



Ω_0=70°, ω_0=0, e_0=0.0001~0.001



Ω=190°, e=0.001, ω=0~360°



Ω=310°, e=0.001, ω=0~360°

IV. Recommendations for BDS Disposal Orbit Elements

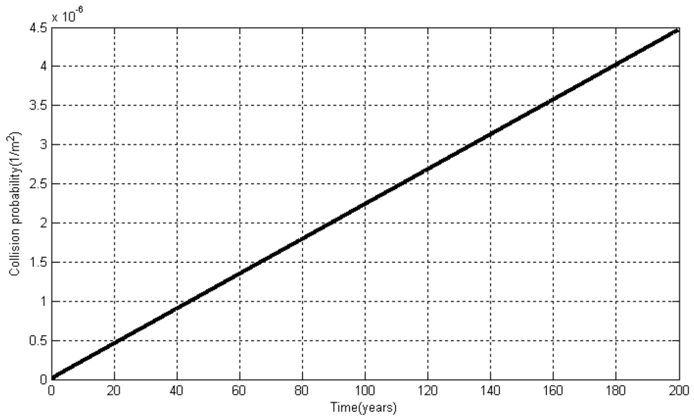
ORBIT	RAAN	Increase in orbit altitude/km	Eccentricity	Minimum Eccentricity Growth		High Eccentricity Growth	
				ω_0 / deg	Max Eccentricity in 200 years	ω_0 / deg	Max Eccentricity in 200 years
MEO	30	300	0.001	190	0.002	290	0.16
	150	300	0.001	320	0.006	70	0.14
	270	300	0.001	240	0.004	350	0.11
IGSO	70	300	0.0002	0	0.01	180	0.71
	190	300	0.001	0	0.72	270	0.82(decay in 130 years)
	310	300	0.001	120	0.52	270	0.55

03

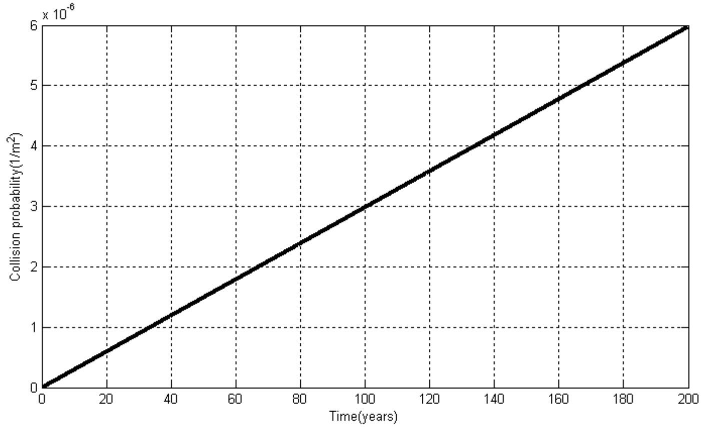
Collision Probability Posed to BDS and Nearby Constellations

03 Collision Probability Posed to BDS and nearby constellations

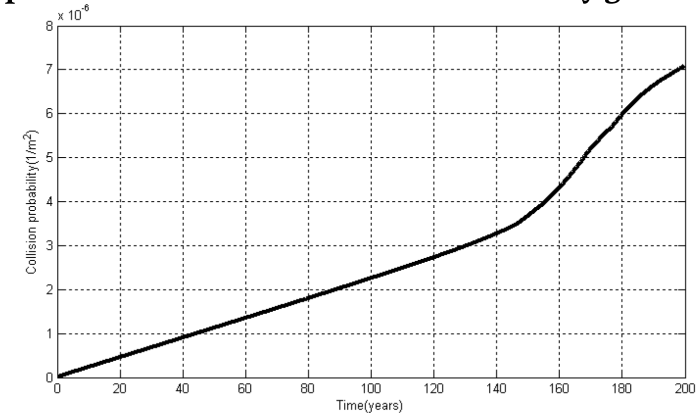
I. Collision Probability posed to GPS and Galileo Nominal Constellations



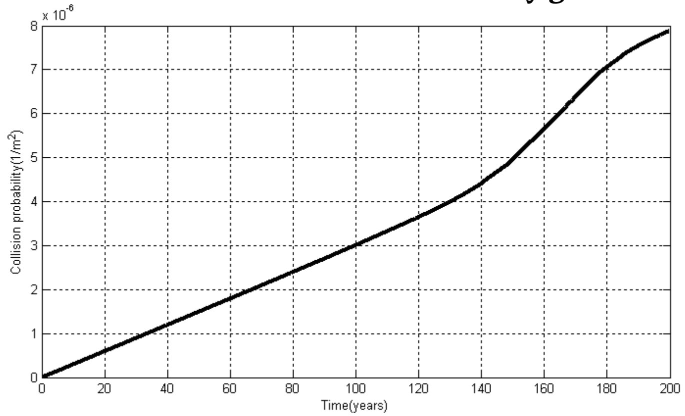
Collision probability posed to GPS constellation by BDS disposal satellites with minimum eccentricity growth strategy



Collision probability posed to Galileo constellation by BDS disposal satellites with minimum eccentricity growth strategy



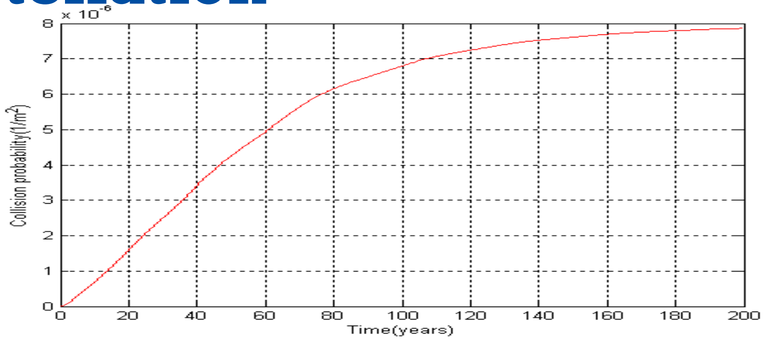
Collision probability posed to GPS constellation by BDS disposal satellites with high eccentricity growth strategy



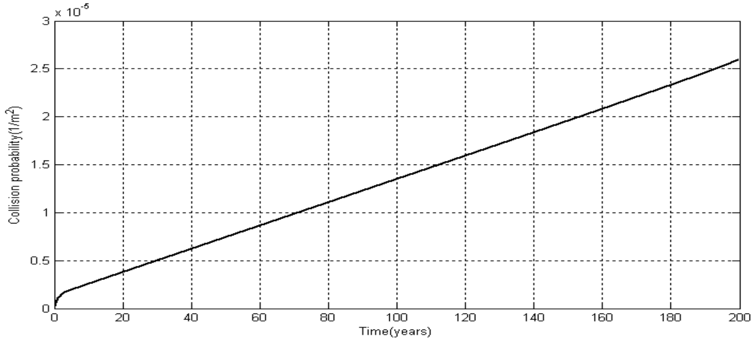
Collision probability posed to Galileo constellation by BDS disposal satellites with high eccentricity growth strategy

03 Collision Probability Posed to BDS and nearby Constellations

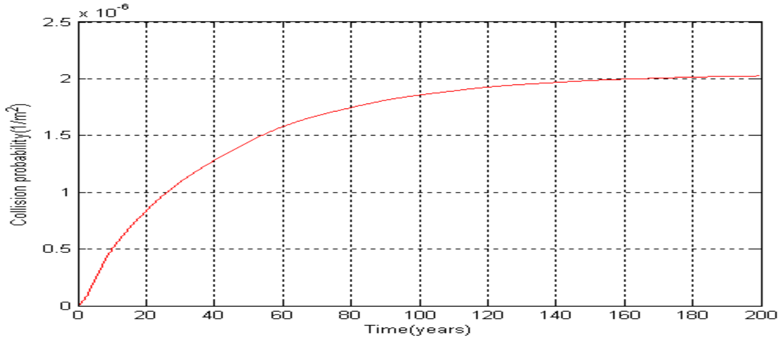
II. Collision Probability posed to the Graveyard Orbit and BDS Operational Constellation



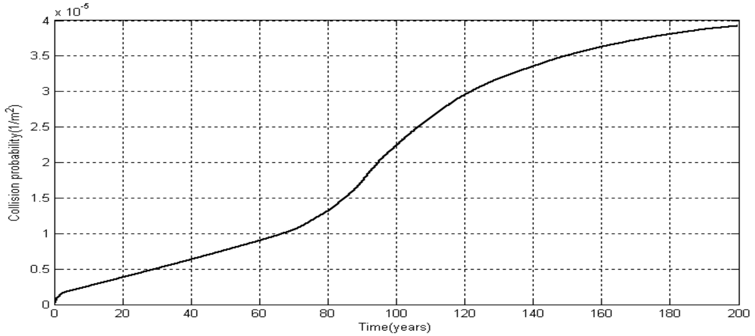
Collision probability posed to the graveyard orbit by BDS disposal satellites with minimum eccentricity growth strategy



Collision probability posed to the nominal BDS constellation by BDS disposal satellites with minimum eccentricity growth strategy



Collision probability posed to the graveyard orbit BDS disposal satellite with high eccentricity growth strategy



Collision probability posed to the nominal BDS constellation by BDS disposal satellites with high eccentricity growth strategy

03 Collision Probability Posed to BDS and nearby Constellations

III. Comparison of the Collision Probability

	Cumulative Collision Probability after 200 years	
	Minimum eccentricity growth strategy	High eccentricity growth strategy
Posed to GPS nominal constellation by BDS disposal Satellites	4.5×10^{-6}	8×10^{-6}
Posed to Galileo nominal constellation by BDS disposal Satellites	6.0×10^{-6}	8.0×10^{-6}
Posed to BDS nominal constellation by BDS disposal satellites	2.6×10^{-5}	3.9×10^{-5}
Posed to graveyard orbit by BDS disposal satellite	7.9×10^{-6}	2.0×10^{-6}

IV. Comparison of the Collision Probability

- The collision probability posed to operational orbit or graveyard orbit is of a 10^{-5} ~10^{-6} order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.
- The high eccentricity growth strategy results in a lower collision probability to the BDS graveyard orbit than the minimum eccentricity growth strategy.
- The minimum eccentricity growth strategy results in a lower collision probability to the nominal constellations of BDS, GPS and Galileo than the high eccentricity growth strategy.
- As for BDS MEO EOL satellites, the minimum eccentricity growth strategy would be proposed.
- The study on collision probability of BDS IGSO disposal satellites posed to nearby GEO satellites is in progress.

Conclusions

- There are no final guidelines for GNSS MEO satellites post-mission disposal from international organizations (IADC), while post-mission disposal strategy and safety restrictions of GNSS EOL satellites are not exactly the same.
- The analysis showed that the collision probability posed to operational orbit or graveyard orbit by BDS MEO disposal satellites within 200 yeas is of a 10^{-5} ~10^{-6} order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.
- Although the collision probability among MEO space debris is less than 0.001, the collision risk will increase as there will be more GNSS/RNSS satellites deployed in the future. As a result, ICG members should continue to pay more attention to the safety of MEO and IGSO space debris.
- System providers should try to establish the GNSS/RNSS space debris guidelines together with IADC and continue to exchange information on their GNSS/RNSS satellites post-mission disposal plans and implements in WG-S.