TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 10
Number 3
September 2016
DOI: 10.12716/1001.10.03.01

BeiDou and Galileo, Two Global Satellite Navigation Systems in Final Phase of the Construction, Visibility and Geometry

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ABSTRACT: Spatial segment is one of three segments of each satellite navigation systems (SNS). Nowadays two SNSs, GPS and GLONASS, are fully operational, two next SNSs, BeiDou in China and Galileo in Europe, are in final phase of the construction. In the case of China system this segment will consist of 35 satellites with three types of orbits – medium (MEO), geostationary (GEO) and inclined geosynchronous (IGSO). As GEO and IGSO satellites can be used in China and Asia-Pacific region only, BeiDou MEO constellation with 27 fully operational satellites will be taken into account in this paper. The orbital planes of the Galileo constellation will be divided in "slots" that contains at least one operational satellite. The Galileo reference constellation has 24 nominal orbital positions or operational slots in MEO homogeneously distributed in 3 orbital planes; i.e. 8 slots equally spaced per plane. As the error of user's position obtained from both systems depends on geometry factor DOP (Dilution Of Precision) among other things the knowledge of the number of satellites visible by the user above given masking elevation angle H_{min} and the distributions of DOP coefficient values, GDOP in particular, is very important. The lowest and the greatest number of satellites visible in open area by the observer at different latitudes for different H_{min}, the percentage of satellites visible above angle H, distributions (in per cent) of satellites azimuths and GDOP coefficient values for different H_{min} for BeiDou and Galileo systems at different latitudes are presented in the paper.

1 INTRODUCTION

In early 1980s, when the first satellite navigation system (SNS), Transit in USA and Cikada in Soviet Union were already operational, China began actively study the satellite systems in line with Chinas's conditions. This new system, called BeiDou (Big Dippler), earlier Compass, as all other SNSs, consists of three major components: the space constellation, the ground control segment and the user segment. In 2000, the BeiDou Navigation Satellite Demonstration System (BDS) was established. (Report...2013, www.insidegnss.com).

The functions and performance parameters at this step are as follows (Report…2013):

- position accuracy: better than 10 m (95%);
- velocity accuracy: better than 0.2 m/s;
- time accuracy: 50 ns;
- short message communications: 120 Chinese characters per message.

Global services BeiDou will provide by around 2019/2020 (Munich 2016, imo.org). The final space constellation of this system will consist of 35 satellites:

- 5 GEO (058.75° E, 080° E, 110.5° E, 140° E and 160° E), altitude 35,786 km;

– 27 MEO (altitude 21,500 km, inclination 55°, 3 evenly distributed orbital planes, on each 9 evenly distributed satellites). The phase is selected from the Walker 24/3/1 constellation, and the right ascension of ascending node of the satellites in the first orbital plane is 0°;
– 3 IGSO (altitude 36,000 km, inclination 55°, evenly distributed in 3 orbital planes). The tracks of sub-satellite points for those IGSO satellites are coincided while the longitude of the intersection point is 118° E, with a phase difference of 120°. The sub-satellite tracks for the current (August 2016) other two operational IGSO satellites are coincided while the longitude of the intersection point is at 095° E. These two satellites will not be in final constellation.

It means that the final number of operational satellites (35) will be the greatest among all currently operational (GPS – 32, GLONASS – 24) or under construction (Galileo – 30) SNSs. BeiDou constellation, as the only SNS, uses three mentioned above types of orbits, while all others use MEO orbits only (Januszewski J. 2010, Martin H. 2013).

The most important parameters of all BeiDou satellites are presented in the table 1.

Table 1. BeiDou system, parameters of GEO, IGSO and MEO satellites (www.isg.org)

Parameter	Satellite GEO	IGSO	MEO
Satellite bus	DFH–3B	DFH–3B	Navigation satellite bus
Launch vehicle	CZ–3C	CZ–3A	CZ–3B
Launch mass [kg]	4600	4200	800
Dry mass [kg]	1550	1900	no details
Body size [m]	1.8 x 2.2 x 2.5		
Solar array size [m]	3 x 2.2 x 1.7 (two pieces)		
Span width [m]	17.7	17.7	17.7
Cross section [m2]	27	27	27
Power output [kW]	6.8	6.2	1.5
Space design line [years]	8	8	5

The satellites are and will be launched from the XSLC (Xichang Satellite Launch Center) in the southwestern province Sichuan of China, using China's Long March 3 CZ launch vehicles (www.beidou.gov.cn).

The BeiDou navigation (NAV) messages are formatted in D1 and D2 based on their rate and structure in superframe, frame and subframe. The first format will be transmitted by all 35 satellites, the second is already by GEO satellites only. The rate of these messages is 50 bps and 500 bps respectively (www.beidou.gov.cn).

D1 NAV message contains basic, named sometimes fundamental also, information about broadcasting 27 MEO and 3 IGSO satellites, almanac information offsets from other global SNSs (GPS, GLONASS and Galileo).

D2 NAV message contains mentioned above basic NAV information of the broadcasting satellite and additionally augmentation service information – integrity and differential correction information, ionospheric grid information. In the case of this format the definition of basic NAV information is the same as that in format D1 except the page number (Pnum) and seconds of week (SOW), which are different from these in format D1 (BeiDou, Signal. 2013, BeiDou, Open. 2013).

In Europe the development of initial design concepts for a new own satellite navigation system began in the 1990s, with selection of an initial system design in 2002. In March 2002 the European Union and the European Space Agency agreed to fund the project, named Galileo, pending a review in 2003. The Galileo constellation design was originally planned based on a three-plane Walker constellation with a minimum of nine operational satellites in each plane and three active spares, one per orbital plane; total number of satellites – 30.

Over the course of time the planned Galileo constellation changed and in 2014 these changes became evident. The reference space segment has 24 operational satellites only in a Walker 24/3/1 design along with up to six operating spares – two in each plane. The eight satellites in each plane are equally spaced; locations of the spares will be determined. The MEO planes, altitude 23,222 km, have 120° separation with inclination 56°. Galileo satellites nominally have a mass of 700 kg, measuring 2.7 m x 1.1 m x 1.2 m, with deployed solar arrays spanning 18.7 m (Beitz J.W. 2016, www.gsc.europa.eu).

All Galileo satellites were launched, two satellites at once, from the Guiana Space Centre, French and European spaceport near Kourou in French Guiana, using carrier Soyuz-STB/Fregat-MT. Currently (August 2016) spatial segment consists of 9 satellites, one partially unavailable, four with status in commissioning (two last satellites launched May 24, 2016 will be operational soon). Next launch is scheduled for November 17, 2016 from Kourou also but using new carrier Ariane 5ES. This dispenser allows for a launch of four satellites at once. The subsequent eight satellites will be launched in 2017 and 2018, the last one in 2019.

2 BEIDOU AND GALILEO CONSTELLATIONS

The nominal values of geographical longitude of ascending node and argument of latitude of all 27 BeiDou MEO satellites and all 24 Galileo are showed in the table 2 and table 3, respectively.

Table 2. BeiDou system, geographical longitude of ascending node (An) and argument of latitude (Al) of all 27 MEO satellites

Orbit I, An = 0°		Orbit II, An = 120°		Orbit IIII, An = 240°	
No of satellite	Al [deg]	No of satellite	Al [deg]	No of satellite	Al [deg]
1	0	10	13	19	26
2	40	11	53	20	66
3	80	12	93	21	106
4	120	13	133	22	146
5	160	14	173	23	186
6	200	15	213	24	226
7	240	16	253	25	266
8	280	17	293	26	306
9	320	18	333	27	346

Table 3. Galileo system, geographical longitude of ascending node (An) and argument of latitude (Al) of all 24 satellites

Orbit I, An = 0°		Orbit II, An = 120°		Orbit IIII, An = 240°	
No of satellite	Al [deg]	No of satellite	Al [deg]	No of satellite	Al [deg]
1	0	9	15	17	30
2	45	10	60	18	75
3	90	11	105	19	120
4	135	12	150	20	165
5	180	13	195	21	210
6	225	14	240	22	255
7	270	15	285	23	300
8	315	16	330	24	345

3 TEST METHODS

All calculations based on reference ellipsoid WGS–84 were made on author's simulating program. The interval of the latitude of the observer between 0° and 90° was divided into 9 zones, each 10° wide. In the observer's receiver masking elevation angle H_{min} was assumed to be 0° (horizon), 5° (the most frequently used value of H_{min}), 10°, 15°, 20° and 25°. The angle 25° is representative for the positioning in restricted area where the visibility of satellites can be limited. This problem is very important in road transport (urban canyon) and in maritime transport in restricted area where the visibility of satellites is limited. The calculations were made for 27 BeiDou MEO and 24 Galileo satellites constellations.

For each zone of latitude and for each masking elevation angle (H_{min}) one thousand (1000) geographic–time coordinates of the observer were generated by random–number generator with uniform distribution:

- latitude interval 0 – 600 minutes (10°),
- longitude interval 0 –21600 minutes (360°),
- time interval in minutes, Galileo: 0 – 14,360.75, (17 orbital periods, each 14 h 4 min 45 sec), BeiDou: 0 – 10,091.48 minutes (13 MEO satellite orbital periods, each 12 h, 56 min 16.05 sec).

For each geographic–time coordinates: the satellite elevation (H), the satellite azimuth (Az), the number of visible satellites (ls) and GDOP (Geometric Dilution of Precision) coefficient values were calculated. Elevation H was divided into 9 intervals, each 10° wide, azimuth (Az) was divided into 8 intervals, each 45° and GDOP value (w) into 8 intervals: w<2, 2≤w<3, 3≤w<4, 4≤w<5, 5≤w<6, 6≤w<8, 8≤w<20, w≥20.

4 VISIBILITY OF BEIDOU MEO SATELLITES AND GALILEO SATELLITES

The lowest (ls_{min}) and the greatest (ls_{max}) number ls of satellites visible by the observer in open area above different H_{min} in all 9 zones of latitudes for both systems are presented in the table 4. As for $H_{min} \leq 25°$ the number ls is in the case of BeiDou greater than 3 for all user's latitudes it means that 3D position can be obtained always and anywhere in the world. In the case of Galileo the number ls can be equal 3 in zone 0–10° and at latitudes 40–60°; it means 2D position only. We can say also that:

- for both systems the number ls depends on observer's latitude, independently of H_{min} value;
- for H_{min} = 0° the number ls_{min} is for BeiDou system the lowest (6) in zone 20–30° and the greatest (9) in zone 0–10° and at latitudes 60–90°, for Galileo system this number is the lowest (6 also) at latitudes 20–60° and the greatest (9 also) at latitudes 70–90°; the number ls_{max} (12 always) is for BeiDou in all 9 latitude zones, for Galileo at latitudes 10–40° and 60– 90°.

If the number ls is equal 4 the user must be very careful because the number of satellites which can be used in position determination can decrease at any moment and for any reason. That's why the additional calculations were made for both systems for different H_{min} in order to determine the greatest elevation H for which the number ls of satellites visible at different latitudes in open area above this angle is equal 4 (ls4) or 3 (ls3) (table 5).

Table 4. System BeiDou, the lowest and the greatest number of MEO satellites visible in open area above H_{min} at different observer's latitudes.

Latitude [°]		H_{min} 0°	5°	10°	15°	20°	25°
0–10	BeiDou	9–12	8–12	7–10	5–10	4–8	4–7
	Galileo	8–11	8–11	6–10	4–8	4–8	3–7
10–20	BeiDou	8–12	6–12	6–10	5–9	4–9	4–8
	Galileo	7–12	6–11	5–9	4–9	4–8	4–8
20–30	BeiDou	6–12	6–11	6–10	5–9	4–9	4–7
	Galileo	6–10	6–10	5–9	4–9	4–8	4–7
30–40	BeiDou	7–12	6–12	6–10	5–9	5–9	4–7
	Galileo	6–12	6–11	5–9	4–9	4–9	4–7
40–50	BeiDou	7–12	6–12	6–10	5–10	4–8	4–7
	Galileo	6–11	6–11	5–9	4–9	4–8	3–7
50–60	BeiDou	8–12	6–11	6–10	5–10	4–9	4–7
	Galileo	6–10	6–10	5–9	4–9	4–7	3–7
60–70	BeiDou	9–12	8–12	7–11	6–9	5–9	4–7
	Galileo	8–12	8–11	6–9	5–9	4–8	4–7
70–80	BeiDou	9–12	8–12	8–11	6–9	5–8	4–8
	Galileo	9–12	8–11	7–10	5–9	5–8	4–7
80–90	BeiDou	9–12	9–12	8–10	7–9	6–9	4–8
	Galileo	9–12	8–11	7–9	6–8	6–8	4–7

Table 5. BeiDou system (MEO satellites only) and Galileo system, the greatest elevation H [°] for which the number ls of satellites visible at different latitudes by the observer in open area above this angle is equal 4 or 3

Latitude [°]	Number ls of satellites 4		3	
	BeiDou	Galileo	BeiDou	Galileo
0 – 10	26	23	32	29
10 – 20	28	25	33	29
20 – 30	30	26	35	33
30 – 40	28	26	33	30
40 – 50	28	24	33	32
50 – 60	28	24	32	33
60 – 70	28	25	32	32
70 – 80	29	27	32	29
80 – 90	33	32	34	35

If the number ls is equal 4 the user must be very careful because the number of satellites which can be used in position determination can decrease at any moment and for any reason. That's why the additional calculations were made for both systems for different H_{min} in order to determine the greatest elevation H for which the number ls of satellites visible at different latitudes in open area above this angle is equal 4 (ls4) or 3 (ls3) (table 5).

In the case of BeiDou system and ls4 the elevation H is the lowest (26) in zone 0–10°, the greatest (33) in zone 80–90°. In the case of ls3 the lowest elevation H (32) is in zone 0–10° and at latitudes 50–80°, the greatest (34) in zone 20–30°. In the case of Galileo and ls4 the H is the lowest (23) in zone 0–10°, the greatest (32) in zone 80–90°, and for ls3 the lowest (29) at latitudes 0–20° and in zone 70–80°, the greatest (35) in zone 80–90°.

The weighted mean number ls_m of BeiDou MEO satellites and Galileo satellites visible above horizon and the percentage of satellites visible by the observer in open area above given angle H in all 9 latitude zones for both systems are showed in the table 6. Supplementary calculations were made for H = 5°, 15° and 25° in all these zones. Because of greater number of satellites (BeiDou – 27, Galileo − 24) the ls_m is for China system greater than for European system irrespective of latitude.

Additionally we can say that for both systems:
- the percentage of satellites visible decreases with angle H in each zone, if this angle is equal 20° this percentage decreases to about 60% or more, if it is 40° to about 30% or more;
- at latitudes equal or greater than 70° the percentage of satellites visible above H ≤ 20° is greater than in all other latitudes;
- at latitudes less than 70° the percentage of satellites visible above 20° ≤ H ≤ 50° is the greatest in zone 30–40°;
- because of altitude and orbit inclination values of both systems and geometrical figure of the Earth in zone 70−80° any BeiDou and Galileo satellite cannot be visible by the observer above 70° and 80° respectively, in zone 80–90° any satellite of both systems above 60°.

Distribution (in per cent) of satellites azimuths in open area for H_{min} = 5° and 25° in all 9 latitudes zones of hemisphere north for both systems is presented in the table 7. We can resume that for both systems:
- for each H_{min} and each zone both distributions are almost the same;
- distribution of satellites azimuths depends on observer's latitude and angle H_{min};
- at latitudes 0−20° the percentage of satellites with azimuths from intervals 045−135° and 225−315° is for H_{min} = 5° less than in all other intervals;
- at latitudes 30−50° the percentage of satellites in interval 45–90° and interval 270−315° is for both H_{min} values greater than in all other intervals considerably;
- at latitudes 50–70° in all 6 intervals of azimuths 45–315° the percentage of satellites increases with H_{min} whereas in two other intervals (azimuth 315−045°) decreases significantly;
- at latitudes 40–70° the percentage of satellites
- in intervals 45–90° and 270–315° is for H_{min} = 25° several dozen times greater than in interval 315−045°,
- at latitudes 80−90° the percentage of satellites in all intervals is for both H_{min} almost the same.
- the percentage of satellites is almost the same in all 9 zones however for Galileo system for each H≤60° it is greater than for BeiDou system;
- at latitudes 70−80° the number of satellites is in all intervals almost the same, but for H_{min} = 5° only.

The percentage of satellites azimuths in different intervals depends on observer's latitude. The greatest diversifications are at latitudes 30−70° for both systems. That's why the knowledge of these distributions are very important for the users, in road transport in urban canyon in particular.

Table 6. Percentage of BeiDou MEO satellites and Galileo satellites visible in open area above angle (H) at different observer's latitudes (φ), ls_m – weighted mean number of satellites visible above horizon (H = 0°)

Latitude [°]	System	ls_m	Elevation angle H [°] 0	10	20	30	40	50	60	70	80
0 – 10	BeiDou	10.9	100	81.0	59.7	39.7	25.8	15.5	8.2	3.7	0.9
	Galileo	9.8	100	80.8	59.4	39.7	25.8	15.7	8.0	3.4	0.9
10 – 20	BeiDou	10.7	100	77.0	58.7	43.7	29.0	16.9	9.0	4.0	1.0
	Galileo	9.6	100	76.9	58.4	43.4	29.5	17.0	8.9	3.9	1.0
20 – 30	BeiDou	10.0	100	78.1	61.5	46.9	34.4	21.6	11.4	3.7	1.3
	Galileo	9.1	100	78.3	61.2	46.9	34.3	21.7	11.1	4.9	1.2
30 – 40	BeiDou	9.7	100	79.1	62.3	48.0	35.6	25.0	15.2	6.2	1.5
	Galileo	8.8	100	79.5	63.1	48.3	35.4	25.0	15.1	6.3	1.6
40 – 50	BeiDou	9.9	100	77.7	60.1	45.9	34.2	24.5	15.7	8.2	2.3
	Galileo	9.0	100	77.4	60.7	46.5	34.3	24.0	15.9	8.7	2.1
50 – 60	BeiDou	10.6	100	75.9	56.4	42.3	30.7	21.2	13.1	6.7	2.0
	Galileo	9.6	100	76.6	56.9	43.3	30.7	21.2	13.4	7.2	2.6
60 – 70	BeiDou	10.9	100	77.6	60.0	40.5	27.6	17.6	9.2	3.0	0.2
	Galileo	9.8	100	81.6	57.4	42.0	28.7	18.4	9.7	3.9	0.4
70 – 80	BeiDou	11.0	100	82.9	64.5	42.5	27.7	12.4	3,1	0	0
	Galileo	10.0	100	83.2	66.0	45.3	26.7	13.6	4.3	0.2	0
80 – 90	BeiDou	11.0	100	83.5	66.6	48.6	25.1	3.4	0	0	0
	Galileo	10.0	100	83.7	67.6	50.4	29.2	5.6	0	0	0

Table 7. Distribution (in per cent) of BeiDou MEO satellites and Galileo satellites azimuths in open area for different masking elevation angles (H_{min}) at different observer's latitudes (φ), ls_m – weighted mean number of satellites visible above H_{min}

φ N [°]	System	H_{min} [°]	l_m	Azimuth [°] 0 – 45	45 – 90	90 – 135	135 – 180	180 – 225	225 – 270	270 – 315	315 – 360
0–10	BeiDou	5	9.9	15.2	10.0	10.0	15.0	14.7	10.1	10.3	14.7
		25	5.4	17.3	10.1	10.4	12.7	11.7	10.0	10.5	17.3
	Galileo	5	8.9	14.5	10.3	9.8	15.1	15.3	9.8	10.3	14.9
		25	4.8	16.5	11.0	10.0	12.3	12.2	9.7	10.8	17.5
10–20	BeiDou	5	9.5	14.8	11.2	10.2	14.1	13.6	10.3	11.5	14.3
		25	5.5	18.7	10.5	10.5	10.7	10.4	9.9	11.0	18.3
	Galileo	5	8.6	14.6	11.3	9.8	14.0	14.0	9.9	11.4	15.0
		25	4.9	18.2	10.9	9.9	10.5	10.5	11.7	11.7	18.6
20–30	BeiDou	5	8.9	13.3	13.7	10.8	12.2	11.8	10.6	13.9	13.7
		25	5.4	16.9	12.7	10.5	9.8	10.2	10.0	13.3	16.6
	Galileo	5	8.0	14.1	13.2	10.6	11.8	11.8	10.6	13.8	14.1
		25	4.9	17.0	12.3	10.2	10.2	10.3	10.0	13.2	16.8
30–40	BeiDou	5	8.7	9.6	18.0	11.1	11.4	11.2	11.0	18.1	9.8
		25	5.3	10.4	18.2	11.0	10.0	10.6	10.6	18.7	10.5
	Galileo	5	7.8	10.6	17.2	10.9	11.1	11.4	10.9	16.8	11.1
		25	4.9	11.5	17.4	10.9	9.7	10.5	10.6	17.3	12.1
40–50	BeiDou	5	8.7	5.7	21.2	11.6	11.4	11.2	11.9	21.4	5.6
		25	5.2	2.9	23.5	11.9	11.6	10.7	12.8	23.7	2.9
	Galileo	5	7.9	6.6	20.8	11.4	10.9	11.3	11.6	20.4	7.0
		25	4.8	3.8	23.5	11.8	10.5	11.0	12.3	23.0	4.1
50–60	BeiDou	5	9.3	7.4	18.3	12.8	11.5	11.3	13.1	17.8	7.8
		25	5.1	0.3	21.4	14.9	13.3	12.6	16.3	20.8	0.4
	Galileo	5	8.5	8.7	18.3	12.3	10.8	11.2	12.3	17.8	8.6
		25	4.8	0.8	22.3	14.1	12.0	12.7	15.4	21.7	1.0
60–70	BeiDou	5	9.8	10.1	14.3	13.7	12.0	12.0	13.3	14.2	10.4
		25	5.3	1.5	16.0	17.5	15.0	14.8	17.7	16.1	1.4
	Galileo	5	9.0	10.8	14.6	12.8	11.8	12.2	12.8	14.3	10.7
		25	4.9	2.0	16.8	16.1	14.6	15.1	16.4	16.6	2.4
70–80	BeiDou	5	10.0	11.3	13.1	12.9	12.7	12.4	12.7	13.1	11.8
		25	6.0	7.7	13.2	14.6	14.4	14.4	14.3	13.5	7.9
	Galileo	5	9.1	11.8	13.1	12.7	12.2	12.7	12.5	13.1	11.9
		25	5.6	8.9	13.5	14.2	13.3	14.0	14.0	13.3	8.8
80–90	BeiDou	5	10.1	12.1	12.8	12.6	12.4	12.8	12.1	13.0	12.2
		25	6.4	11.4	12.6	12.9	13.0	13.4	12.2	13.0	11.5
	Galileo	5	9.2	12.3	12.5	12.5	12.4	13.0	12.4	12.5	12.4
		25	5.9	12.5	11.8	13.3	12.8	13.0	13.1	11.8	11.7

5 GEOMETRY OF BEIDOU MEO SATELLITES AND GALILEO SATELLITES

Distribution (in per cent) of GDOP coefficient values in open area for H_{min} = 5° and 25° in all 9 latitudes zones for both systems is presented in the table 8. Additional calculations were made in zone 50–60° (latitude of Poland) for four other H_{min} values (0°, 10°, 15° and 20°). We can say that GDOP coefficient value:

- depends on angle H_{min} and observer's latitudes and its distributions are almost the same for both systems;
- increases with H_{min} in all 9 zones for both systems, but the greatest values and growths are at high latitudes;
- can be less than 2 for BeiDou system and H_{min} = 5° at latitudes 0–20° only;
- for H_{min} = 5° is always less than 4 for BeiDou in zone 0–10° and for Galileo in zone 20–40°;
- for H_{min} = 5° for both systems is always greater than 3 in zone 70–80° and greater than 4 in zone 80–90°;
- for H_{min} = 25° can be less than 3 for Galileo in zone 10–20° only and for BeiDou in zone 60–70° only;
- for H_{min} = 25° can be equal or greater than 20 in all 9 zones for both systems;
- for H_{min} = 25° and for both systems is equal at least 4 or greater in zone 70–80° and equal 6 or greater in zone 80–90°.

As was showed in the table 4 in the case of Galileo in three latitude zones, 0–10°, 40–50° and 50–60°, if H_{min} = 25° 3D position cannot be obtained always. When the number of satellites visible by the observer decreases to three the number of fix without position (No fix) is greater than zero.

Distribution (in per cent) of GDOP coefficient values for the observer at latitudes 50–60°, if the number of visible satellites ls is known, for H_{min} = 25° and 5°, for both systems is presented respectively in the table 9 and the table 10. We can showed that:

- for BeiDou system if H_{min} = 5° GDOP value is less than 3 if ls = 11 and can be less than 3 if ls = 8, 9 or 10. If ls = 6 this coefficient is equal or greater than 3 and less than 5;
- for Galileo system if H_{min} = 5° GDOP value is less than 3 if ls = 10, can be less than 3 if ls = 7, 8 or 9. If ls = 6 this coefficient is equal or greater than 3 and less than 4;

– for BeiDou system if H_{min} = 25^{O} GDOP value is less than 4 if ls = 7 and can be less than 4 if ls = 6 or 5. If ls = 4 this coefficient is equal at least 8;
– for Galileo system if H_{min} = 25^{O} ls can be equal 3 (0.3 %) and then the position 3D cannot be obtained. GDOP value is less than 4 if ls =7 and can be less than 4 if ls = 5 or 6. If ls = 4 this coefficient is equal at least 5.
– there is not a direct relation between a number ls of satellites visible above H_{min} and GDOP coefficient value, but in the case of both systems we can realize "when ls is greater, GDOP can be less" and vice versa "when ls is less, GDOP can be greater".

Table 8. BeiDou MEO satellites and Galileo satellites distribution (in per cent) of GDOP coefficient values and No Fix (without position) for different masking elevation angles (H_{min}) at different observer's latitudes (φ)

Latitude [^{O}]	System	H_{min} [^{O}]	No Fix	GDOP coefficient value – w w<2	2≤w<3	3≤w<4	4≤w<5	5≤w<6	6≤w<8	8≤w<20	w≥20
0–10	BeiDou	5	–	0.6	91.3	8.1	–	–	–	–	–
		25	–	–	–	25.8	37.7	15.0	7.0	9.4	5.1
	Galileo	5	–	–	93.5	5.2	1.3	–	–	–	–
		25	0.9	–	–	17.6	27.5	5.6	10.1	25.5	12.8
10–20	BeiDou	5	–	0.4	86.3	12.4	0.9	–	–	–	–
		25	–	–	–	16.0	41.3	14.7	8.3	16.9	2.8
	Galileo	5	–	–	89.7	9.9	0.4	–	–	–	–
		25	–	–	0.7	8.5	32.7	8.2	11.6	27.5	10.8
20–30	BeiDou	5	–	–	76.1	17.4	6.5	–	–	–	–
		25	–	–	–	18.7	34.4	16.8	8.2	13.5	8.4
	Galileo	5	–	–	69.2	30.8	–	–	–	–	–
		25	–	–	–	2.2	47.0	7.5	11.2	24.7	7.4
30–40	BeiDou	5	–	–	95.8	2.7	1.5	–	–	–	–
		25	–	–	–	11.2	44.7	36.7	1.6	5.6	0.2
	Galileo	5	–	–	54.7	45.3	–	–	–	–	–
		25	–	–	–	10.8	46.1	2.2	5.7	17.5	17.7
40–50	BeiDou	5	–	–	86.4	7.8	5.8	–	–	–	–
		25	–	–	–	24.5	27.2	28.5	–	14.9	4.9
	Galileo	5	–	–	51.5	47.3	1.2	–	–	–	–
		25	0.1	–	–	27.5	18.4	1.6	4.7	18.4	29.3
50–60	BeiDou	5	–	–	70.4	27.8	1.8	–	–	–	–
		25	–	–	–	13.6	39.0	22.4	0.1	14.7	10.2
	Galileo	5	–	–	69.6	30.1	0.3	–	–	–	–
		25	0.3	–	–	17.7	45.0	0.3	2.8	11.1	22.8
60–70	BeiDou	5	–	–	28.1	69.3	2.6	–	–	–	–
		25	–	–	0.1	1.8	29.9	49.2	5.7	8.4	4.9
	Galileo	5	–	–	19.2	79.5	1.3	–	–	–	–
		25	–	–	–	1.9	37.7	15.9	13.5	15.5	15.5
70–80	BeiDou	5	–	–	–	35.7	49.1	14.4	0.8	–	–
		25	–	–	–	–	8.8	27.1	27.0	35.5	1.6
	Galileo	5	–	–	–	31.1	54.4	14.2	0.3	–	–
		25	–	–	–	–	9.4	23.1	24.6	41.5	1.4
80–90	BeiDou	5	–	–	–	–	0.8	13.1	27.2	37.1	21.8
		25	–	–	–	–	–	–	10.8	60.6	28.6
	Galileo	5	–	–	–	–	0.6	11.5	26.6	39.0	22.3
		25	–	–	–	–	–	–	7.2	61.8	31.0

Table 9. BeiDou MEO satellites and Galileo satellites, distribution (in per cent) of GDOP coefficient values at observer's latitudes 50–60^{O}, if the number of visible satellites ls is known, H_{min} = 25^{O}, No fix – the percentage of fix without position

System and satellites ls	System	%	GDOP coefficient value – w 3≤w<4	4≤w<5	5≤w<6	6≤w<8	8≤w<20	w ≥20
ls<4	BeiDou	–	–	–	–	–	–	–
No Fix	Galileo	0.3	–	–	–	–	–	–
4	BeiDou	24.7	–	–	–	–	14.6	10.1
	Galileo	36.1	–	–	0.2	2.1	11.0	22.8
5	BeiDou	39.3	0.1	16.5	22.4	0.1	0.1	0.1
	Galileo	47.9	3.0	44.0	0.1	0.7	0.1	–
6	BeiDou	32.7	10.2	22.5	–	–	–	–
	Galileo	13.7	12.7	1.0	–	–	–	–
7	BeiDou	3.3	3.3	–	–	–	–	–
	Galileo	2.0	2.0	–	–	–	–	–
	BeiDou	100	13.6	39.0	22.4	0.1	14.7	10.2
	Galileo	100	17.7	45.0	0.3	2.8	11.7	22.8

Table 10. BeiDou MEO satellites, Galileo satellites, distribution (in per cent) of GDOP coefficient values at observer's latitudes 50 – 60°, H_{min} = 5°, if the number of visible satellites ls is known

System	Visible satellites l_s	%	GDOP coefficient value – w 2≤w<3	3≤w<4	4≤w<5
BeiDou	6	2.1	–	0.3	1.8
Galileo		2.0	–	2.0	–
BeiDou	7	3.5	–	3.5	–
Galileo		7.7	1.0	6.4	0.3
BeiDou	8	14.9	3.3	11.6	–
Galileo		36.2	15.1	21.1	–
BeiDou	9	28.1	16.8	11.3	–
Galileo		44.5	43.8	0.7	–
BeiDou	10	45.0	43.9	1.1	–
Galileo		9.6	9.6	–	–
BeiDou	11	6.4	6.4	–	–
Galileo		–	–	–	–
		100	70.4	27.8	1.8
		100	69.6	30.1	0.3

As the longitudes of two extreme BeiDou GEO satellites are 058.75° E and 160° E, the trucks of sub-satellite points for 3 IGSO satellites are coincided and the longitude of the intersection points is 118° E, this system currently provides positioning data between longitude 055° E to 180° E and from latitude 55° S to 55° N. This area includes China territory entirely.

6 BEIDOU AND GALILEO STATUS

Currently (August 2016) there are 20 BeiDou satellites in orbit and healthy and one with status in commissioning and 9 Galileo operational satellites, 4 with status in commissioning and one partially unavailable. By 2020 or earlier BeiDou would reach full operational capability (FOC) with 35 satellites. In the case of Galileo 12 next satellites are planned to be launched in the years 2016–2018, the last in 2019. FOC of this system is planned in 2020 (European GNSS Service Centre, www.gpsworld.com, www.gsc.europa.eu).

7 CONCLUSIONS

- Full Operational Capability (FOC) of BeiDou system will made China the third nation in possession of independent, global navigation system following the United States and Russia. FOC of Galileo will made the first in history international institution (European Union) in possession of global system.
- BeiDou MEO constellation with 27 fully operational satellites will provide global coverage and the possibility of user's 3D position determination at any moment and any point on the Earth as well as in the case when the satellites are visible by the user below 25° only. In the case of Galileo 24 satellites constellation this possibility will be the same except for zone 0–10° and latitudes 40–60°.
- The percentage of satellites visible in open area above given angle and the distributions of satellites azimuths for different elevation angle are at different latitudes almost the same.
- The number of BeiDou MEO satellites (27) is greater than the number of Galileo satellites of nominal constellation (24) but orbit altitude of European system (23,222 km) is greater than in China system (21,500 km). That's why the distributions of GDOP coefficient values is for both systems at different latitudes almost the same.
- BeiDou system will meet the demands of China's national security, economic development. One of the most important aims of Galileo is to provide an indigenous alternative high precision positioning system upon which European nations can rely. Galileo is intended to provide horizontal and vertical position measurements within one-metre precision (95%). Both these new SNSs will be committed to providing stable, reliable and quality satellite navigation services for global users.
- Whereas the constellation of 27 BeiDou MEO satellites will provide global coverage at any moment, the constellation of 3 IGSO and 5 GEO satellites will can be used in limited area only. It means that the advantages of D2 NAV message, integrity information in particular will be accessible to users in China and the Asia–Pacific region only.

REFERENCES

BeiDou Navigation Satellite System, Signal in Space Interface Control Document Open Service Signal (Version 2.0), China Satellite Navigation Office, December 2013

BeiDou Navigation Satellite System, Open service, Performance Standard (Version 1.0), China Satellite Navigation Office, December 2013

Beitz J. W. 2016. Engineering Satellite-Based Navigation and Timing Global Navigation Satellite Systems, Signals, and Receivers. John Wiley & Sons, Inc., Hoboken, New Jersey

European GNSS Service Centre, Constellation Information, 2016

Januszewski J. 2010. Systemy satelitarne GSP, Galileo i inne. Warszawa: PWN, (in polish)

Martin H. 2013. U.S. Space-Based Positioning, Navigation and Timing policy and Program Update. 8th International Committee on GNSS, Dubai

Munich Satellite Navigation Summit, Munich, 2016

Report on the Development of BeiDou Navigation Satellite System (version 2.2) 2013. China Satellite Navigation Office

www.beidou.gov.cn

www.directory.eoportal.org

www.gpsworld.com

www.gsc.europa.eu

www.imo.org

www.insidegnss.com

www.isg.org