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VISIBILITY AND GEOMETRY OF GLOBAL SATELLITE NAVIGATION SYSTEMS CONSTELLATIONS

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ABSTRACT. Nowadays (November 2015) there are two global fully operational satellite navigation systems, American GPS and Russian GLONASS. Two next are under construction, Galileo in Europe and BeiDou in China. As the error of observer's position obtained from these systems depends on geometry factor DOP (Dilution Of Precision) among other things the knowledge of the number of satellites visible by this observer 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 (9 intervals, each 10^O wide), distributions (in per cent) of satellites azimuths (8 intervals, each 45^O wide) and GDOP coefficient values (8 intervals) for $H_{min} = 5^O$ for all these four systems at different observer's latitudes (9 intervals, each wide 10^O wide) are presented in the paper. Additionally the lowest elevation for which the number of satellites visible at different latitudes by the observer in open area above this angle is equal 4 or 3 and the distributions (in per cent) of GDOP coefficient values for different H_{min} at observer's latitudes $50{-}60^O$ for the same four systems are showed. All calculations were made for constellation of GPS 27 satellites, GLONASS 24, Galileo 30 and BeiDou 27 MEO satellites.

Keywords: GPS constellation, GLONASS constellation, Galileo constellation, BeiDou constellation, visibility, geometry

1. INTRODUCTION

The error M of the observer's position obtained from satellite navigation system depends on geometry factor DOP (Dilution of Precision) among other things. That's why the knowledge of the number of satellites visible at given moment by this observer above given masking elevation angle H_{min} and the distributions of DOP, GDOP in particular, coefficient value is very important (Hofmann−Wellenhof B. et al 2008), (Kaplan E.D., Hegarty C.J. 2006), (Langley R.B. 1999), (Specht C. 2007).

Nowadays (August 2015) there are two global fully operational satellite navigation systems (SNS), American GPS and Russian GLONASS (Martin III H.W. 2015), (Karutin S 2015), (www.glonass-ianc.rsa.ru), (www.gps.gov), (www.gpsworld.com), (navcen.uscg.gov). Two next SNS are under construction, Galileo in Europe and BeiDou in China (Chatre E, 2015), (China Satellite Navigation Summit, 2015), (www.esa.int).

Global services Galileo and BeiDou will both provide by around 2017/2018 or later (www.beidou.gov.cn), (www.insidegnss.com). The final BeiDou space constellation will consist of 35 satellites (27 MEO, 5 GEO, 3 IGSO) but as the signals transmitted by all GEO and IGSO satellites can be used in some regions of the Earth (China and adjacent areas) merely, the 27 MEO satellites were taken into account only (Munich 2015). In order to compare BeiDou MEO and GPS (MEO also) constellations it was assumed that the number American system satellites is equal 27 too even though since several years this number is incessantly at least 29 or 30 (www.gps.gov), (www.gpsworld.com). In the case of GLONASS and Galileo the number of satellites is equal 24 (actual nominal constellation) and 30 (final constellation with 3 planes and 9 operational satellites and one active spare per orbital plane), respectively (www.glonass-ianc.rsa.ru), (www.insidegnss.com). All 24 GLONASS, all 27 MEO BeiDou and all 27 operational Galileo satellites were evenly distributed on the orbits.

The parameters of the spatial segment and coverage surface area ensured by one satellite only of all four mentioned above SNSs are presented in Table 1 (Januszewski J, 2010), (www.gps.gov), (www.insidegnss.com). In calculations it was assumed the radius of the Earth 6,370 km and the Earth's surface 510,066,000 km^2. Because Galileo orbit altitude is the highest the coverage surface area is in the case of this system the greatest, near 40 % of the Earth.

Table 1. Spatial segment and coverage surface area of GPS, GLONASS, Galileo and BeiDou systems

System	Number of MEO orbits	Number of satellites		Orbit altitude [km]	Orbital period	Coverage surface area (one satellite only)	
		on one orbit	total			[km^2]	% of the Earth
GPS	6	4 ÷ 6	27	20,183	11 h 57 min 58.3 sec	193 705 518	38.0
GLONASS	3	8	24	19,100	11 h 15 min 44 sec	191 117 254	37.5
Galileo	3	10	30	23,222	14 h 4 min 45 sec	199 969 523	39.2
BeiDou	3	9	27	21,500	12 h 56 min 16.05 sec	196 773 430	38.6

2. TEST METHOD

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^O and 90^O was divided into 9 zones, each 10^O wide. In the observer's receiver masking elevation angle H_{min} was assumed to be 0^O (horizon), 5^O (the most frequently used value of H_{min}), 10^O, 15^O, 20^O and 25^O. The angle 25^O 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. As the GLONASS, Galileo and BeiDou satellites are evenly distributed amongst orbital planes and for all four SNSs appropriate time interval was taken into account in calculation the analyses concern both hemispheres.

For each system, for each zone of latitude and for each 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 min (10^O),
- longitude interval 0 −21600 min (360^O),
- time interval (in minutes): 0 – 1,435.94 (GPS, 2 orbital periods), 0 – 11,488.44 (GLONASS, 17 orbital periods), 0 − 14,360.75 (Galileo, 17 orbital periods), 0 – 10,091.48 (BeiDou, 13 orbital periods).

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^{O} wide, azimuth (Az) was divided into 8 intervals, each 45^{O} and GDOP value (w) into 8 intervals: $w<2$, $2\le w<3$, $3\le w<4$, $4\le w<5$, $5\le w<6$, $6\le w<8$, $8\le w<20$ and $w\ge 20$.

Table 2. The lowest and the greatest number of satellites visible for different masking elevation angle (H_{min}) for GPS, GLONASS, Galileo and BeiDou systems at different observer's latitudes (φ)

Latitude [^{O}]	System	H_{min}					
		0^{O}	5^{O}	10^{O}	15^{O}	20^{O}	25^{O}
0 – 10	GPS	9 – 13	7 – 13	6 – 12	5 – 10	4 – 9	3 – 8
	GLONASS	7 – 12	5 – 11	5 – 8	4 – 8	3 – 7	2 – 6
	Galileo	11 – 14	10 – 13	8 – 12	6 – 11	4 – 10	4 – 9
	BeiDou	9 – 12	8 – 12	7 – 10	5 – 10	4 – 8	4 – 7
10 – 20	GPS	8 – 13	6 – 12	5 – 11	4 – 10	3 – 9	3 – 8
	GLONASS	6 – 11	5 – 10	4 – 9	4 – 8	3 – 7	2 – 7
	Galileo	10 – 13	8 – 13	7 – 12	6 – 12	4 – 11	4 – 9
	BeiDou	8 – 12	6 – 12	6 – 10	5 – 9	4 – 9	4 – 8
20 – 30	GPS	7 – 13	6 – 12	5 – 11	4 – 10	3 – 9	3 – 8
	GLONASS	6 – 12	5 – 10	4 – 10	4 – 9	3 – 8	3 – 7
	Galileo	8 – 14	8 – 12	6 – 12	6 – 11	4 – 11	4 – 9
	BeiDou	6 – 12	6 – 11	6 – 10	5 – 9	4 – 9	4 – 7
30 – 40	GPS	7 – 13	6 – 13	5 – 10	4 – 9	3 – 9	3 – 7
	GLONASS	6 – 12	6 – 11	4 – 10	4 – 9	4 – 8	3 – 7
	Galileo	8 – 13	8 – 12	6 – 12	6 – 10	5 – 11	4 – 9
	BeiDou	7 – 12	6 – 12	6 – 10	5 – 9	5 – 9	4 – 7
40 – 50	GPS	7 – 13	6 – 12	5 – 11	4 – 9	3 – 9	3 – 8
	GLONASS	7 – 11	5 – 11	4 – 10	4 – 9	4 – 8	4 – 7
	Galileo	8 – 14	8 – 12	6 – 12	6 – 11	4 – 11	4 – 9
	BeiDou	7 – 12	6 – 12	6 – 10	5 – 10	4 – 8	4 – 7
50 – 60	GPS	8 – 13	6 – 12	5 – 11	4 – 10	3 – 9	3 – 8
	GLONASS	8 – 12	7 – 11	5 – 10	4 – 9	4 – 8	4 – 7
	Galileo	9 – 14	8 – 13	6 – 12	6 – 11	4 – 11	4 – 9
	BeiDou	8 – 12	6 – 11	6 – 10	5 – 10	4 – 9	4 – 7
60 – 70	GPS	8 – 14	6 – 13	5 – 12	4 – 11	3 – 9	3 – 8
	GLONASS	8 – 12	7 – 11	6 – 10	5 – 9	5 – 9	4 – 8
	Galileo	11 – 14	9 – 12	7 – 12	6 – 10	5 – 10	4 – 9
	BeiDou	9 – 12	8 – 12	7 – 11	6 – 9	5 – 9	4 – 7
70 – 80	GPS	8 – 14	6 – 13	6 – 12	5 – 11	4 – 10	3 – 9
	GLONASS	8 – 12	7 – 11	6 – 10	6 – 9	5 – 9	4 – 8
	Galileo	11 – 14	9 – 12	9 – 12	8 – 11	5 – 11	4 – 9
	BeiDou	9 – 12	8 – 12	8 – 11	6 – 9	5 – 8	4 – 8
80 – 90	GPS	8 – 14	8 – 12	7 – 12	6 – 11	4 – 10	4 – 9
	GLONASS	9 – 12	8 – 11	6 – 10	6 – 9	6 – 9	4 – 8
	Galileo	12 – 14	10 – 12	9 – 12	8 – 11	6 – 10	6 – 9
	BeiDou	9 – 12	9 – 12	8 – 10	7 – 9	6 – 9	4 8

3. VISIBILITY OF SATELLITES

The lowest (ls_{min}) and the greatest (ls_{max}) number ls of GPS, GLONASS, Galileo and BeiDou MEO satellites visible by the observer in open area above different H_{min} in all 9 zones of latitudes are presented in Table 2. The numbers ls_{min} and ls_{max} depend on the SNS, angle H_{min} and zone of latitudes. Additionally we can say that:

- for H_{min} = 0^O the greatest number of ls_{max} is equal 14, Galileo in zone $0÷10^O$ and at latitudes $40÷90^O$ and GPS at latitudes $60÷90^O$; the lowest number of ls_{min} is equal 6, GLONASS at latitudes $10÷40^O$;
- if $H_{min} \le 15^O$ the position 3D ($ls_{min} \ge 4$) can be obtained by all four SNSs in all 9 zones, if $H_{min} = 20^O$ or 25^O by Galileo and BeiDou only;
- if $H_{min} \le 20^O$ the position 2D ($ls_{min} \ge 3$) can be obtained by all four SNSs in all 9 zones, if $H_{min} = 25^O$ also but except for GLONASS at latitudes $0÷20^O$ ($ls_{min} = 2$);
- at given H_{min} in most of cases the numbers ls_{min} and ls_{max} are at low latitudes ($0÷20^O$) lower than at high latitudes ($70÷90^O$) for all 4 SNSs;
- total number of satellites for GPS and BeiDou taken into account in calculations is the same (27), but for $H_{min} \le 10^O$ in most of cases ls_{min} is for GPS equal or less than for BeiDou while ls_{max} is for GPS greater or equal than for BeiDou. For $H_{min} \ge 20^O$ ls_{min} is for GPS greater than 3 in zone $80÷90^O$ only while in the case of BeiDou which orbit is 1317 km higher than for GPS orbit (tab.1) in all 9 zones;
- the ls_{min} (12) and ls_{max} (14) are the greatest in the case of Galileo both for $H_{min} = 0^O$ (zone $80–90^O$) however for $H_{min} = 0^O$ and at latitudes $60–90^O$ the ls_{max} is for Galileo and GPS the same (14). It is possible even though the total number of GPS satellite (27) is less than the total number of Galileo satellites (30) but American satellites are not evenly distributed on the orbits;
- the differences of ls_{max} and ls_{min} for $H_{min} = 0^O$ and $H_{min} = 25^O$ are in most of cases for all four SNSs equal both 4, 5 or 6. The greatest difference (7) is for Galileo in zone $0–20^O$;
- the biggest difference (5) of ls_{min} in one zone is for $H_{min} = 5^O$ at latitude 0 10^O (Galileo 10, GLONASS 5);
- at latitudes $40–80^O$ for $H_{min} \ge 20^O$ the ls_{min} is the same for GLONASS and Galileo (5 or 4) despite Galileo spatial segment consists of 30 satellites while GLONASS of 24 only.

If the number ls is equal 4 the user must be very careful because the number of satellites which can be used in 3D position determination can decrease at any moment and for any reason. That's why the additional calculations were made for each SNS for different H_{min} in order to determine the greatest elevation H_{max4} and H_{max3} for which the number ls of satellites visible at different latitudes in open area above this angle is equal 4 (minimum for position 3D) or 3 (minimum for position 2D), respectively (Table 3). We can remark that:

- the elevation H_{max4} is lower considerably than H_{max3} always in all 9 zones for all 4 SNSs;
- the difference between H_{max4} and H_{max3} depends on the latitude zone and SNS (the total number of satellites and theirs distribution, orbit altitude and its inclination, in particular), the greatest (10) and the lowest (1) values of this difference are for GLONASS in zone $20–30^O$ and for BeiDou and for Galileo in zone $80–90^O$, respectively;
- comparing the results for different SNSs the elevation H_{max4} is in each zone the greatest for Galileo, in the case of H_{max3} also except the zone $80–90^O$ where maximum is for GLONASS (its orbit inclination is nearly 10^O higher than for Galileo);
- at low latitudes $0–20^O$ elevations H_{max4} and H_{max3} are for GLONASS lower or equal elevations for GPS, but at latitudes $40–90^O$ both elevations are for GLONASS greater than for GPS. It is the result of higher orbit inclination of Russian system in spite of lower orbit altitude and lower number of satellites;
- the greatest difference of H_{max4} and H_{max3} in one zone is equal 11 at latitude $20–30^O$ (BeiDou – 29, GLONASS – 18) and 10 at latitude 80 – 90^O (GLONASS – 40, GPS – 30), respectively.

Table 3. The GPS, GLONASS, Galileo and BeiDou systems, the greatest elevation H [^{O}], H_{max4} and H_{max3}, 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, respectively

Latitude [^{O}]	System	Number ls of satellites	
		4	3
0 – 10	GPS	20	25
	GLONASS	15	22
	Galileo	27	33
	BeiDou	25	32
10 – 20	GPS	19	25
	GLONASS	19	24
	Galileo	29	34
	BeiDou	27	33
20 – 30	GPS	19	26
	GLONASS	18	28
	Galileo	30	35
	BeiDou	29	35
30 – 40	GPS	18	27
	GLONASS	23	27
	Galileo	29	34
	BeiDou	28	33
40 – 50	GPS	19	27
	GLONASS	25	28
	Galileo	29	34
	BeiDou	28	33
50 – 60	GPS	18	26
	GLONASS	25	33
	Galileo	27	34
	BeiDou	25	32
60 – 70	GPS	18	27
	GLONASS	27	30
	Galileo	28	35
	BeiDou	26	32
70 – 80	GPS	22	27
	GLONASS	30	32
	Galileo	31	35
	BeiDou	30	32
80 – 90	GPS	26	30
	GLONASS	32	40
	Galileo	35	36
	BeiDou	33	34

4. SATELLITE ELEVATION AND AZIMUTH

Percentage of MEO satellites visible by the observer in open area above elevation angle H in all 9 latitude zones for all four SNSs is showed in Figure 1. Additionally the weighted mean number of satellites ls_m visible above horizon (H = 0^{O}) for each SNS in each zone was calculated. We can say that:

- the number ls_m is in all 9 zones the greatest and the lowest in the case of Galileo and GLONASS respectively;
- the percentage of satellites visible decreases with angle H in each zone for all SNSs, if this angle is equal 20^{O} this percentage decreases to about 60% or more, if it is 40^{O} to about 30% or more;
- for three SNSs, GPS, Galileo and BeiDou, the percentage of satellites visible is for each H in all zones almost the same. In the case of GLONASS this percentage differs, in zone $0–10^{O}$ and at latitudes $50–90^{O}$, in particular;
- because of orbit inclination value (55^{O} or 56^{O}) and geometrical figure of the Earth the GPS, Galileo and BeiDou MEO satellites in the zones $70–80^{O}$ and $80–90^{O}$ cannot be visible above 70^{O} and approximately 57^{O} respectively. In the case of GLONASS because of its orbit inclination (64.8^{O}) the satellites can be visible in zone $70–80^{O}$ above 80^{O} and in zone $80–90^{O}$ above 60^{O};
- for each SNS elevation angle H can be equal 90^{O} (satellite in zenith) but only at latitudes lower than given SNS inclination (GPS and BeiDou 55^{O}, Galileo 56^{O}, GLONASS 64.8^{O}). That's why in Poland, north part in particular (e.g. latitude of Gdynia 54^{O} 30') the GPS satellites are visible in zenith very rarely.

As the satellite azimuth depends on the user's latitude and angle H_{min} the calculations for all four SNSs were made for all 9 zones of latitudes and for different masking elevation angle.

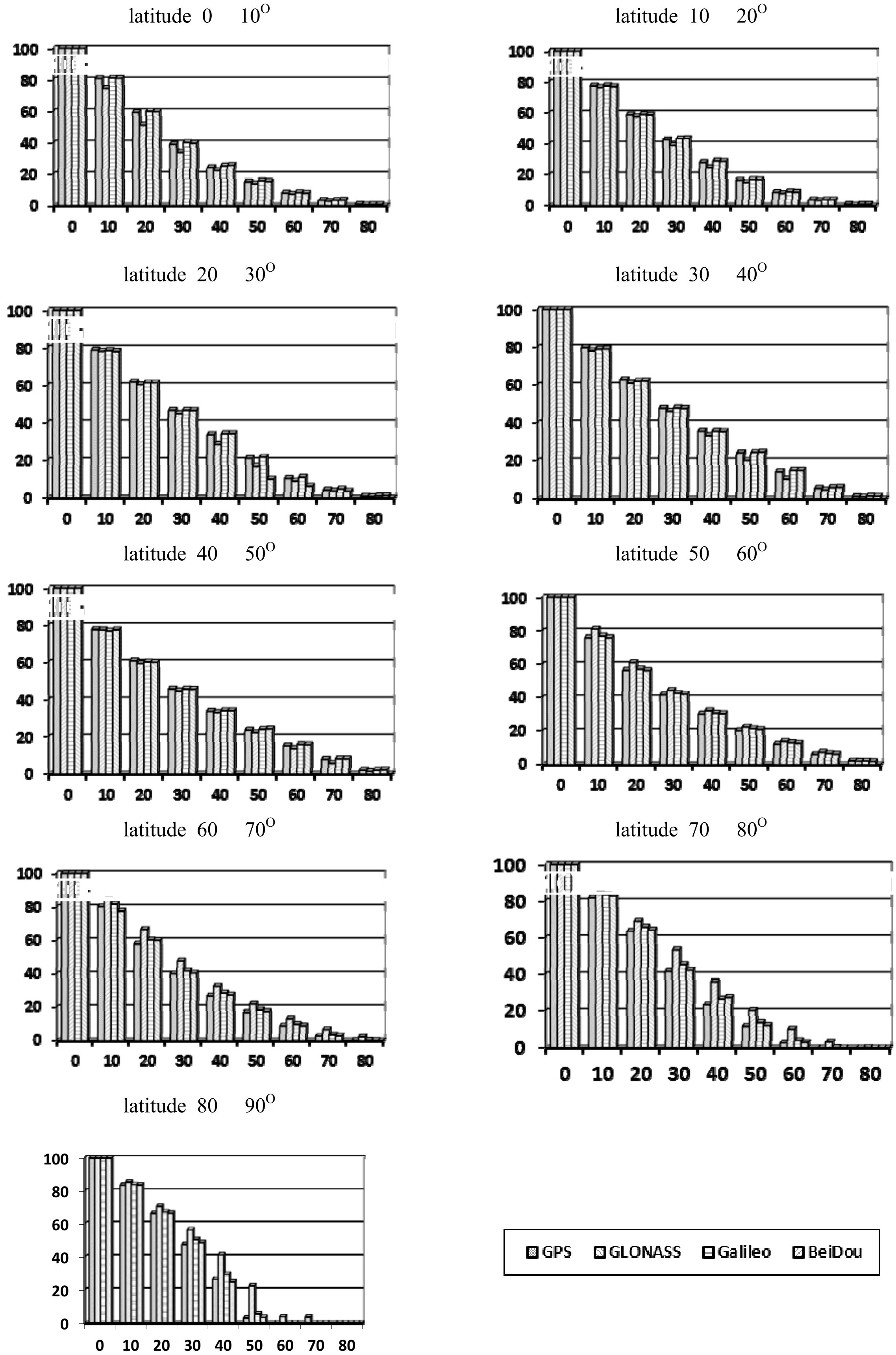
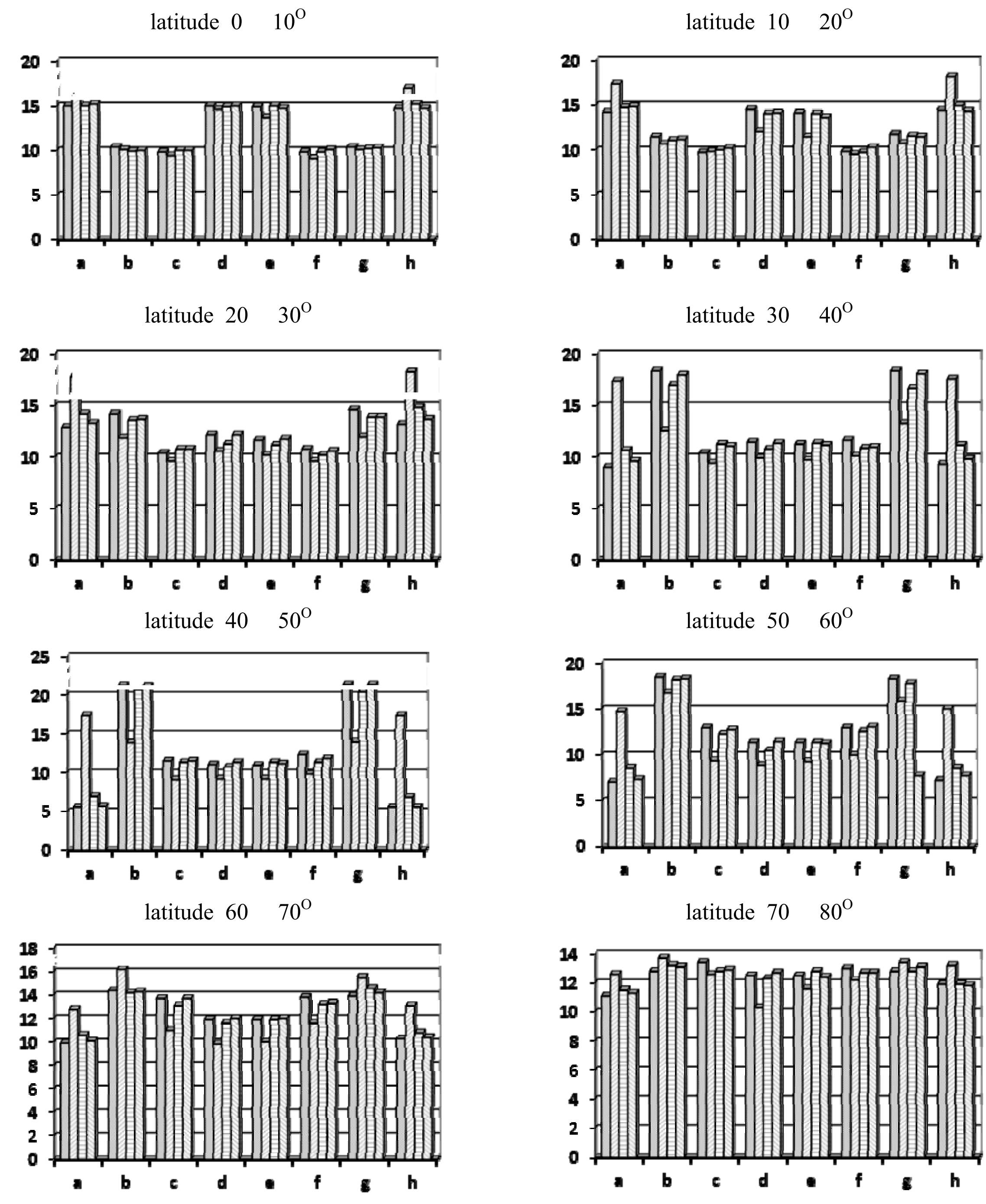
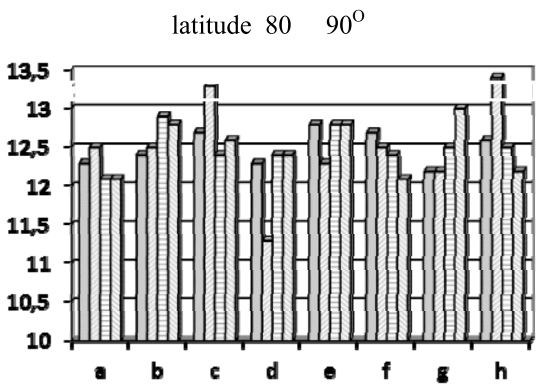


Fig. 1. Percentage of GPS, GLONASS, Galileo and BeiDou MEO satellites visible in open area above angle (H) at different observer's latitudes (φ)





Satellite azimuth [^{O}]			
a	0 – 45	E	180 – 225
b	45 – 90	F	225 – 270
c	90 – 135	G	270 – 315
d	135– 180	H	315 – 360

Fig. 2. Distribution (in per cent) of GPS, GLONASS, Galileo and BeiDou MEO satellites azimuths in open area at different observer's latitudes (φ), $H_{min} = 5^O$

The distributions of satellite azimuths for open area for the most frequently used angle $H_{min} = 5^O$ are presented in Figure 2. In the case of three SNSs, GPS, Galileo and BeiDou, we can resume that:

– as the orbit inclination of these systems is almost the same (55^O or 56^O) the distribution of satellites azimuths is for each system almost the same also;
– at latitudes 70 90^O the number of satellites in all 8 azimuths intervals is almost the same;
– at latitudes 30 60^O the number of satellites in azimuth interval 045−90^O and 270−315^O is greater than in all 6 other intervals considerably;
– at latitudes 40 60^O the number of satellites with azimuth 315 045^O is less than in all other intervals, adjacent intervals in particular.

In the case of GLONASS system we can say that:

– the distribution, except for zone 80−90^O, differs from the distribution of all three other SNS, in some zone considerably;
– at latitudes 0−20^O the number of satellites with azimuths from intervals 045−135^O and 225−315^O is for $H_{min} = 5^O$ less than in all other intervals;
– at latitudes 40−60^O the greatest number of satellites is interval 315−045^O while in this interval the number of GPS, Galileo and BeiDou satellites is the lowest.

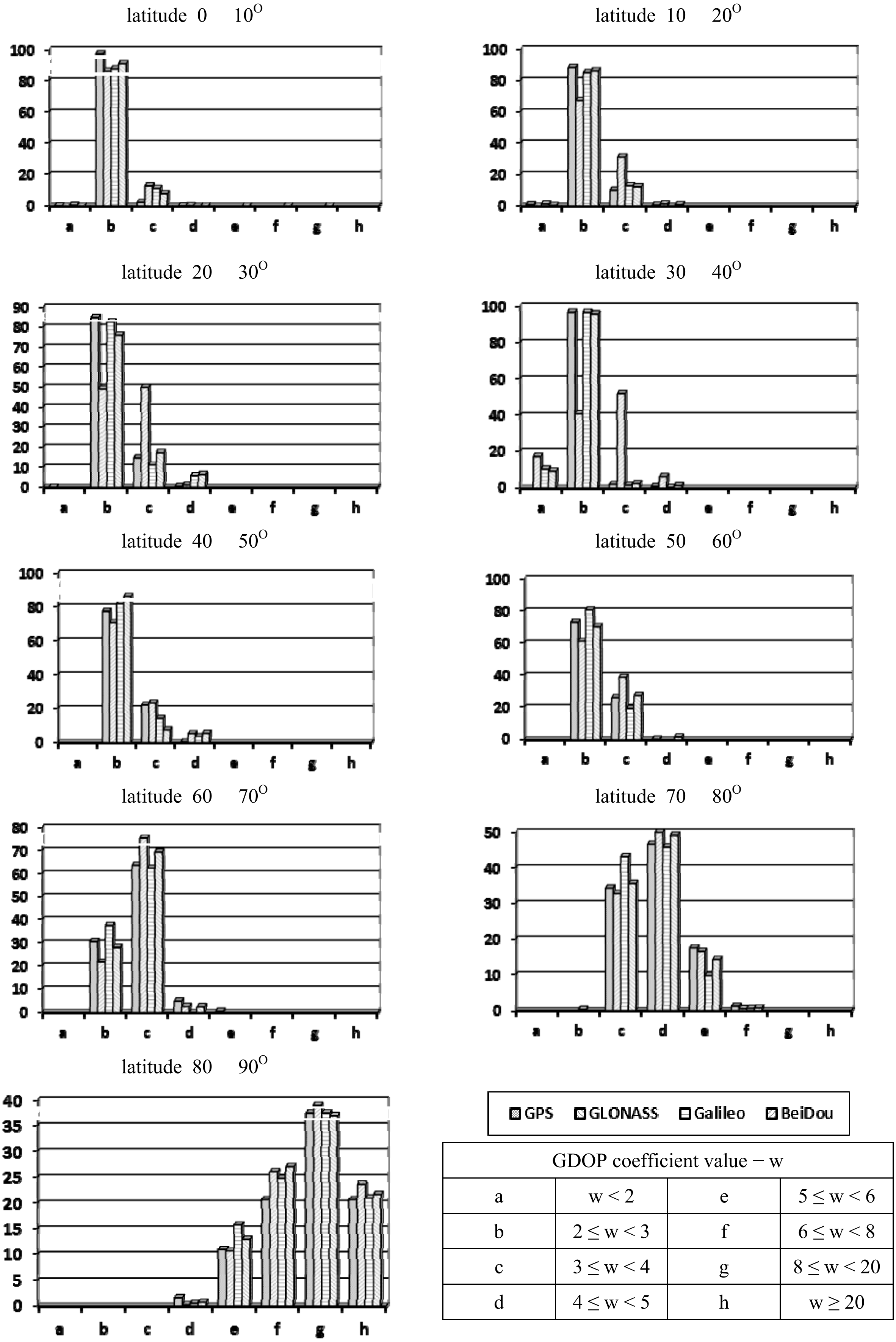
5. GDOP COEFFICIENT VALUE

Distribution (in per cent) of GDOP coefficient values in open area for all 4 SNSs for $H_{min} = 5^O$ in all 9 latitudes zones is presented in Figure 3. We can say that:

– for each SNS distribution of GDOP values depends on observer's latitude and angle H_{min};
– for all SNSs GDOP value is at latitudes 70−90^O greater than at latitudes 0−70^O, in zone 80−90^O in particular;
– distribution for GLONASS system differs from the distributions for other 3 SNSs, at latitudes 20−40^O in particular;
– in zone 80−90^O GDOP value is for all SNSs equal at least 4, in approximately 20% it is greater than 20;
– GDOP value can be less than 2 but in the case of GPS, Galileo and BeiDou at latitudes 0−20^O only;
– at latitudes 0−60^O for all SNSs GDOP value is in most cases less than 3 except for GLONASS system at latitudes 20−40^O;
– at latitudes 0−70^O for all SNSs GDOP value is less than 5, except for GPS system in zone 60−70^O.

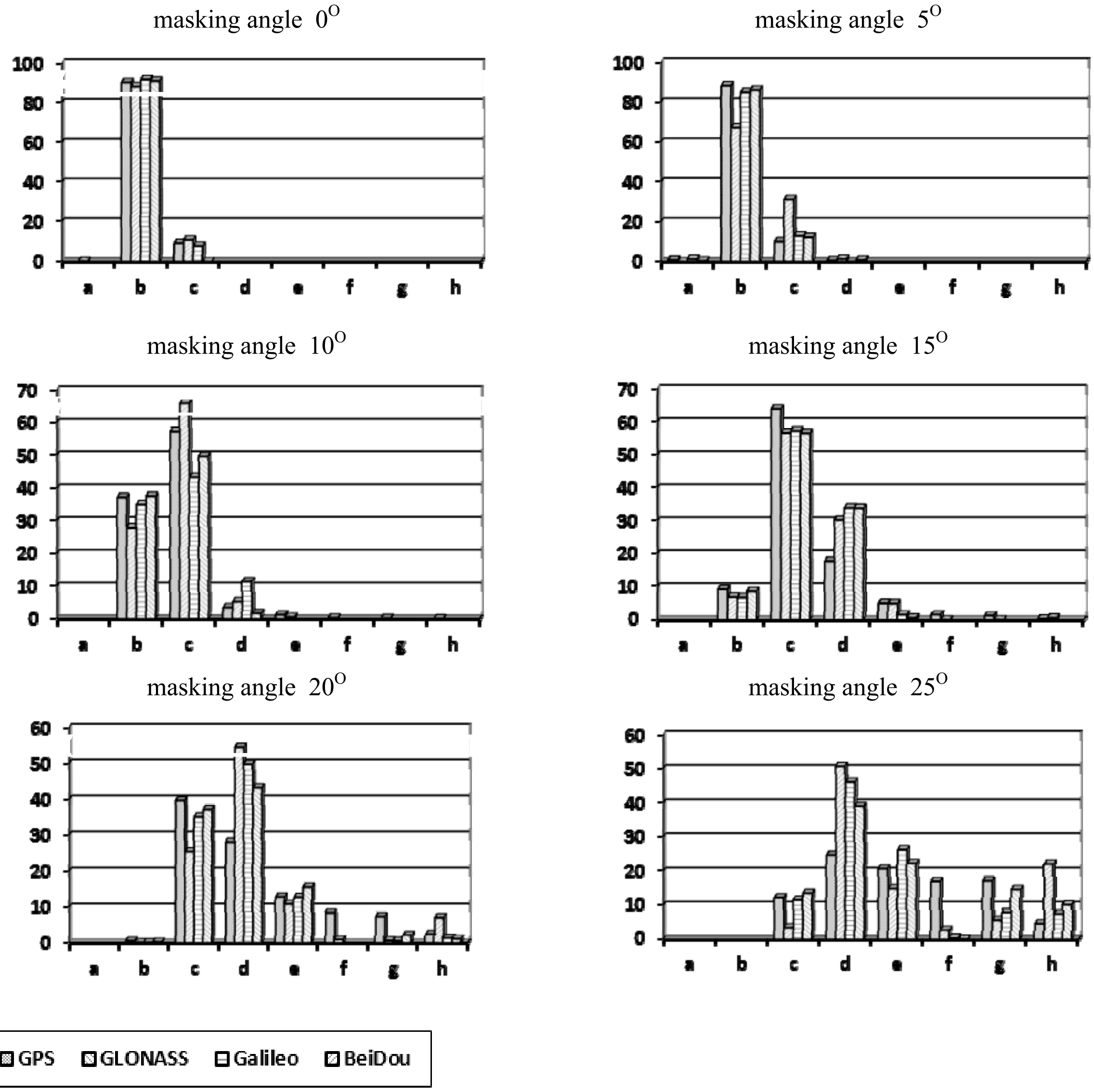
The additional calculations were made in zone 50−60^O for the same SNSs for other H_{min} values (0^O, 10^O, 15^O, 20 and 25^O). The results are showed in Figure 4. We can state that:

– for all four SNSs GDOP value increases with H_{min}, the greatest increase is between 10^O and 15^O;
– if $H_{min} \leq 20^O$ the distributions of GDOP values is for all four SNSs almost the same however if $10^O \leq H_{min} \leq 15^O$ the greatest values of GDOP for Galileo and BeiDou systems are less than for GPS and GLONASS systems;
– if $H_{min} = 25^O$ GDOP values for GLONASS systems are greater than for other 3 SNSs considerably;
– if $H_{min} \leq 5^O$ GDOP value is for GLONASS and Galileo systems less than 4 and for GPS and BeiDou systems less than 5. If $H_{min} = 25^O$ this value is for all SNSs greater than 3.



GDOP coefficient value – w			
a	$w < 2$	e	$5 \leq w < 6$
b	$2 \leq w < 3$	f	$6 \leq w < 8$
c	$3 \leq w < 4$	g	$8 \leq w < 20$
d	$4 \leq w < 5$	h	$w \geq 20$

Fig. 3. GPS, GLONASS, Galileo and BeiDou systems, distribution (in per cent) of GDOP coefficient values for masking elevation angle $H_{min} = 5^{O}$ at different observer's latitudes (φ)



GDOP coefficient value − w			
a	w < 2	e	5 ≤ w < 6
b	2 ≤ w < 3	f	6 ≤ w < 8
c	3 ≤ w < 4	g	8 ≤ w < 20
d	4 ≤ w < 5	h	w ≥ 20

Fig. 4. GPS, GLONASS, Galileo and BeiDou systems, distribution (in per cent) of GDOP coefficient values for different masking elevation angles at observer's latitudes 50 − 60^O

Distribution (in per cent) of GDOP coefficient values for the observer at latitudes 50 – 60^O, if the number of visible satellites l_s is known, for H_{min} = 5^O is presented in Table 4. We can notice that there is not a direct relation between a number ls of satellites visible above H_{min} and GDOP coefficient value, but we can realize "when ls is greater, GDOP can be less" and vice versa "when ls is less, GDOP can be greater". We can observe also that GDOP coefficient value for:

– all four SNSs is from interval [2, 4] if ls is equal 8, 9 or 10;
– GPS and BeiDou systems is from interval [3, 5] if ls is equal 6;
– GPS, GLONASS and BeiDou systems is from interval [3, 4] if ls is equal 7;
– GPS system is less than 3 if ls is equal 11 or 12.

Table 4. Distribution (in per cent) of GDOP coefficient values at observer's latitudes 50 –60^{O} H_{min} = 5^{O}, if the number of visible satellites l_s is known

Visible satellites			**GDOP coefficient value − w**		
l_s	**System**	**%**	**2≤w<3**	**3≤w<4**	**4≤w<5**
6	GPS	0.6		0.2	0.4
	GLONASS				
	Galileo	–	–	–	–
	BeiDou	2.1	–	0.3	1.8
7	GPS	3.8		3.8	
	GLONASS	1.0		1.0	
	Galileo	–	–	–	–
	BeiDou	3.5	–	3.5	–
8	GPS	14.5	3.6	10.9	
	GLONASS	38.5	9.2	29.3	
	Galileo	6.6	0.5	6.1	–
	BeiDou	14.9	3.3	11.6	–
9	GPS	27.8	17.0	10.8	
	GLONASS	51.2	42.8	8.4	
	Galileo	8.5	5.6	2.9	–
	BeiDou	28.1	16.8	11.3	–
10	GPS	46.0	45.2	0.8	
	GLONASS	9.2	8.8	0.4	
	Galileo	35.1	35.1	10.0	–
	BeiDou	45.0	43.9	1.1	–
11	GPS	7.1	7.1		
	GLONASS				
	Galileo	38.2	36.9	0.3	–
	BeiDou	6.4	6.4	–	–
12	GPS	0.2	0.2		
	GLONASS				
	Galileo	11.3	11.3	–	–
	BeiDou	–	–	–	–
13	GPS				
	GLONASS				
	Galileo	0.3	0.3	–	–
	BeiDou	–	–	–	–
	GPS	100	73.1	26.5	0.4
	GLONASS	100	61.3	38.7	
	Galileo	100	80.7	19.3	–
	BeiDou	100	70.4	27.8	1.8

6. CONCLUSIONS

- as in the case of GPS, Galileo and BeiDou orbit inclination and its altitude are almost the same and therefore the percentage of satellites visible above given angle and the distributions of satellite azimuths are almost the same also the most important for many users is the number of operational satellites. When this number is greater, DOP coefficients values can be less;
- GLONASS system with the lowest number of satellites (24 only) is and can be in the future thanks to orbit inclination (64.8^{O}) useful especially for the users of area transport at high latitudes;
- the results of comparison between 27 BeiDou constellation (final number of MEO satellites) and GPS constellation with the same number of satellites showed that the visibility parameters and geometry are for both systems almost the same. It means explicitly that at the moment of FOC of BeiDou the users will have at least three SNSs (GPS, GLONASS and BeiDou) to choose from. The best system for all users will be certainly GPS system with the biggest number of satellites. BeiDou system can be back up system only;
- Full Operational Capability (FOC) of BeiDou system (2017 or later) will made China the third nation in possession of independent, global navigation system following the United States and Russia, however the interest in this system among satellite navigation systems users in the world will be little. D2 navigation message transmitted via 5 BeiDou GEO satellites will provide augmentation service information to the users but in China and Asia-Pacific region only. It means that integrity information will be not accessible to users in Europe, in Poland also.

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