ARTIFICIAL SATELLITES, Vol. 44, No. 2 – 2009
DOI: 10.2478/v10018-009-0019-2

VISIBILITY AND GEOMETRY OF GLONASS CONSTELLATION

Jacek Januszewski
Gdynia Maritime University, Navigation Department
al. JanaPawla II 3, 81–345 Gdynia, Poland
e–mail:jacekjot@am.gdynia.pl

ABSTRACT. Nowadays there are two worldwide satellite navigation systems – American GPS, fully operational and Russian GLONASS, no fully operational. The number of GLONASS satellites is less than nominal 24; in June 2009 spatial segment consists of 20 satellites, 18 operational and 2 in maintenance. The number of GLONASS satellites visible in open and restricted area, the distributions (in per cent) of the Geometric Dilution of Precision (GDOP) coefficient values and No Fix (without 3D position) for different numbers of GLONASS satellites (interval [18, 24]), for different masking elevation angles (interval [0^O, 25^O]) at different observer's latitudes (9 zones, each 10^O wide), latitude of Poland (zone 50^O–60^O), in particular, are demonstrated in the paper. Additionally the detailed distributions of satellite azimuths (8 intervals, each 45^O wide) and the percentage of satellite visible in open area above given angle at different latitudes for different numbers of satellites are showed. The knowledge of all these distributions are very important, especially after the publication of the U.S. Government report in which we can read that in 2010 the overall GPS constellation will fall below the number of satellites required the actual level of GPS position fix accuracy.

Keywords: GLONASS system, satellite visibility, GDOP distribution

1. INTRODUCTION

The error M of the observer's poaition obtained from satellite navigation system depends on geometry factor DOP (Dilution of Precision) among other things. That's why the knowledge of the numbers of satellites visible by this observer above given masking elevation angle H_{min} and the distributions of DOP, GDOP in particular, is very important.

The problems concerning visibility and geometry of GLONASS and GPS for different numbers of operational satellites (24, 23, 22 and 21) were presented by the author in (Januszewski 1999, 2000). As at this time GLONASS spatial segment had decreased to 7 satellites operational only, the calculations were made for nominal (24 satellites) constellation. Since few years GLONASS system is being revamped and undergoing an extensive modernization effort. The calculations and the results of the measurements position accuracy based on the professional stationary receiver for the 13 satellites constellation were showed in (Januszewski, 2006). At the time of this writing (June 2009) the number of GLONASS satellites is less than nominal 24; spatial segment consists of 20 satellites (without satellites 1, 5, 12 and 16), 18 operational and 2 (4 and 23) in maintenance.

After the publication of the report abort the probable weakness of GPS system, the knowledge of the possibility of the position fix by means GLONASS system only is, even must be, very important for all users of satellite navigation systems all the more so because full operational capability (FOC) of two systems, actually under construction, Galileo and Compass, is predicted for 2013 or later. In the report of the U.S. Government Accountability Office (GAO) issued on May 7, 2009, we can read that there exists the very real possibility that in 2010, as old satellites begin to fail, the overall GPS constellation will fall below the number of satellites required to provide the level of GPS service that the U.S. government commits to (GPS Health in Question, 2009).

2. TEST METHOD

The GLONASS satellites positions were calculated by the author from the almanac for May 21, 2009 (Table 1) obtained from the website: www.glonass-ianc.rsa.ru.

Table 1. GLONASS almanac for May 21, 2009 [www.glonass-ianc.rsa.ru]

Satellite number	Plane	Orbital inclination [deg]	Number of frequency slug	Argument of latitude [deg]	LΩ [deg]	Status
1	II	–	–	–	–	–
2		64.7	1	36	74	OK
3		64.7	5	81	53	OK
4		64.0	6	116	35	M
5		–	–	–	–	–
6		64.0	1	212	350	OK
7		63.9	5	259	327	OK
8		64.7	6	305	298	OK
9	III	65.0	– 2	334	53	OK
10		65.4	– 7	18	202	OK
11		65.0	0	64	181	OK
12		–	–	–	–	–
13		65.0	– 2	155	138	OK
14		65.4	– 7	198	117	OK
15		65.4	0	244	95	OK
16		–	–	–	–	–
17	I	64.9	4	321	179	OK
18		64.8	– 3	6	328	OK
19		64.9	3	51	307	OK
20		64.9	2	96	286	OK
21		64.8	– 3	141	265	OK
22		64.8	4	186	244	OK
23		64.8	3	232	222	M
24		64.9	2	279	200	OK

LΩ – Geographical longitude of ascending node in according with ICD GLONASS, M − in maintenance

The latitude of observer 0^O–90^O was divided into 9 zones, each 10^O wide. For each number of satellites, for each zone of latitude and for each masking elevation angle (H_{min}) 1000 geographic-time coordinates of the observer were generated by random-number generator with uniform distribution:

- latitude interval 0 − 600 minutes (10^O),
- longitude interval 0 −21600 minutes (360^O),
- time interval 0 − 11487 minutes (7 days, 23 hours, 27 minutes)

For each geographic–time coordinates: the satellite elevation (H), the satellite azimuth (Az), the number of visible satellites (ls) and GDOP 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.

As the number of GLONASS satellites will increase from actual 18 to nominal 24 certainly (Revnivykh 2007, 2009), the calculations were made for each number of satellites from interval [18, 24], i.e. for all 7 constellations. It was considered that in satellites constellation satellite number 4 was not taken into account, in 22 satellites constellation there were satellites numbers 4 and 23, in 21 constellation satellites 1, 4, and 23, in 20 satellites 1, 4, 5 and 23, in 19 satellites 1, 4, 5, 12 and 23, and in 18 satellites 1, 4, 5, 12, 16 and 23. All calculations, based on reference ellipsoid WGS–84, were made by using author's simulating program.

As the possibility of fix position and the accuracy of this position depend on the satellite elevation H and receiver's masking elevation angle H_{min}, the calculations were made for restricted area also, e.g. in the area where some satellites above horizon cannot be visible by the observer. These satellites can be named as Satellites Non Operational (SNO). This situation concerns maritime navigation along the high coast and land navigation in urban area. As in urban area the width of the streets (L) and the height of the buildings (B) have the tens of meters or more, the number of SNO can be greater than during the coastal and harbour navigation. The results of the calculations for GPS and Galileo systems in restricted area were presented by the author in (Januszewski, 2003). For GLONASS system the calculations were made in urban area for the observer situated in the middle of the street (width L = 70 m, building height B = 15 m). As the accuracy of the position depends on the observer's latitude and the satellite azimuths, these calculations were made in 3 different latitude zones (0–10^O, 30–40^O and 70–80^O) and for different directions of the street. The angle between North and the axis of the street (α) was assumed to be 0^O, 45^O, 90^O and 135^O.

3. RESULTS

The minimum value (l_{min}), maximum value (l_{max}) and the weighted value (l_m) of the number of GLONASS satellites visible in open area for $H_{min} = 5^O$ and $H_{min} = 25^O$ for 18 and 24 operational satellites in all 9 latitudes zones are presented in the table 2. The angles 5^O and 25^O are representative for the measurements in open and restricted area, respectively. Additionally in satellite navigation systems receivers masking elevation angle 5^O is the most frequently used. We can say that:

- all values l_{min}, l_{max} and l_{min} depend on observer's latitude for each H_{min} and for each number of satellites,
- for nominal GLONASS constellation (NS =24) the value l_{min} changes between 5 and 8 for $H_{min} = 5^O$ and between 2 and 5 for $H_{min} = 25^O$. It means that for $H_{min} = 5^O$ 3D position can be obtained in each cases,

- for H_{min} = 5^{O} the l_m is the lowest and the greatest at latitudes 10–30^{O} at latitudes 70–90^{O} respectively, for both numbers NS,
- for H_{min} = 25^{O} the l_m increases with the observer's latitudes, from 3 and 3.8 to 4.9 and 6.2 for NS = 18 and 24 respectively.

Table 2. Number of GLONASS satellites visible in open area for different masking elevation angles (H_{min}) for different numbers of satellites (NS) at different observer's latitudes (φ)

φ [^{O}]	**H_{min} [^{O}]**	**NS**	**Number of visible satellites**			**φ [^{O}]**	**H_{min} [^{O}]**	**NS**	**Number of visible satellites**		
			l_{min}	**l_{max}**	**l_m**				**l_{min}**	**l_{max}**	**l_m**
0 – 10	5	18 24	3 5	9 11	6.2 7.9	50 – 60	5	18 24	5 7	9 11	6.9 8.7
	25	18 24	1 2	5 5	3.0 3.8		25	18 24	1 4	6 7	4.0 5.0
10 – 20	5	18 24	3 5	9 10	6.0 7.6	60 – 70	5	18 24	5 7	9 11	7.1 8.9
	25	18 24	1 2	6 7	3.3 4.2		25	18 24	1 4	8 8	4.4 5.6
20 – 30	5	18 24	3 5	9 10	6.0 7.6	70 – 80	5	18 24	5 7	10 11	7.2 9.0
	25	18 24	1 3	6 7	3.6 4.3		25	18 24	2 5	8 8	4.8 6.0
30 – 40	5	18 24	3 6	9 11	6.1 7.7	80 – 90	5	18 24	5 8	9 11	7.2 9.1
	25	18 24	2 3	7 7	3.7 4.7		25	18 24	2 5	7 8	4.9 6.2
40 – 50	5	18 24	3 5	9 11	6.5 8.2	Number of visible satellites: l_{min} – minimum value l_{max} – maximum value l_m – weighed value					
	25	18 24	2 4	7 7	3.8 4.8						

As the number of GLONASS satellites fully operational will increase gradually, the minimum value (l_{min}), maximum value (l_{max}) and the weighted value (l_m) of the number of satellites visible in open area for H_{min} = 0^{O}, 5^{O}, 10^{O}, 15^{O}, 20^{O} and 25^{O} for each number of satellites from interval [18, 24] in latitude zone 50−60^{O} (latitude of Poland) are showed in the table 3. We can recapitulate:

- all values l_{min}, l_{max} and l_{min} increase with the number NS,
- the value l_m is for H_{min} = 25^{O} less than for H_{min} = 0^{O} considerably, around 50 %,
- for 18 satellites constellation $l_{min} \leq 3$ for $H_{min} \geq 10^{O}$, for H_{min} = 25^{O} l_{min} = 4 for nominal constellation (NS = 24) only.

Table 3. Number of GLONASS satellites visible in open area for different masking elevation angles (H_{min}) for different numbers of satellites (NS) at observer's latitudes 50−60^O; l_{min} – minimum value, l_{max} – maximum value, l_m – weighted value

H_{min} [^{O}]	NS	Number of satellites			H_{min} [^{O}]	NS	Number of satellites		
		l_{min}	l_{max}	l_m			l_{min}	l_{max}	l_m
0	18	5	10	7.1	15	18	2	8	5.2
	19	5	10	7.6		19	2	8	5.4
	20	5	10	7.9		20	3	8	5.7
	21	6	11	8.3		21	3	8	5.9
	22	6	11	8.7		22	3	9	6.2
	23	7	11	9.1		23	3	9	6.5
	24	8	12	9.5		24	4	9	6.8
5	18	4	9	6.5	20	18	2	7	4.4
	19	4	10	6.9		19	2	7	4.6
	20	5	10	7.3		20	2	7	4.8
	21	6	10	7.6		21	3	7	5.1
	22	6	10	8.0		22	3	8	5.3
	23	6	10	8.3		23	3	8	5.6
	24	7	11	8.7		24	4	8	5.8
10	18	3	9	5.9	25	18	1	6	3.8
	19	3	9	6.2		19	1	6	4.0
	20	3	9	6.5		20	2	6	4.2
	21	4	9	6.8		21	3	6	4.4
	22	4	10	7.1		22	3	7	4.6
	23	5	10	7.5		23	3	7	4.8
	24	6	10	7.8		24	4	7	5.0

Number NF of fix without 3D position and the distribution of GDOP coefficient value for all 9 latitude zones for H_{min} = 5^O and H_{min} = 25^O for 18 and 24 satellites are presented in the Table 4. We can say that:

- GDOP coefficient increases with H_{min},
- the probability of GDOP value less than 3 is at latitude 20–40^O less than at latitude 0–20^O and 40–60^O,
- at latitude 60–90^O GDOP coefficient increases with latitude considerably,
- NF is for NS = 24 and for H_{min} = 5^O equal 0 at latitudes 0–90^O,
- for H_{min} = 5^O the probability of GDOP value less than 3 is the greatest at low latitude, zone 0–10^O in particular, for both NS,
- NF is for H_{min} = 5^O and NS =18 greater than 0 at latitudes 0–50^O only,
- NF for H_{min} = 25^O is for NS = 18 and NS = 24 greater than 0 at latitudes 0–90^O and at latitudes 0–40^O only, respectively.

Table 4. Distribution (in per cent) of GDOP coefficient values and number of fix without 3D position for different masking elevation angles (H_{min}) for different numbers of GLONASS satellites (NS) at different observer's latitudes (φ)

φ [^{o}]	H_{min} [^{o}]	NS	Without fix [%]	GDOP coefficient – v [%]						
				v≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤20	v>20
0–10	5	18	2.0	55.8	24.4	7.9	1.0	3.5	3.6	1.8
		24	–	86.6	13.1	0.3	–	–	–	–
	25	18	75.8	–	5.4	2.9	1.5	3.3	6.3	4.8
		24	29.1	–	12.2	9.4	5.6	9.4	19.4	14.9
10–20	5	18	4.4	38.0	31.1	15.5	1.9	2.5	2.0	4.6
		24	–	67.4	31.3	1.3	–	–	–	–
	25	18	68.4	–	2.8	4.9	3.5	3.9	7.7	8.8
		24	10.7	0.2	7.0	14.2	9.5	13.6	25.8	19.0
20–30	5	18	3.5	26.9	40.4	19.8	1.9	1.8	1.6	4.1
		24	–	49.0	49.8	1.1	–	–	0.1	–
	25	18	56.6	–	1.1	7.6	4.0	5.6	8.7	16.4
		24	6.4	0.2	6.0	20.6	7.8	12.8	23.0	23.2
30–40	5	18	2.8	22.3	41.7	26.6	2.4	1.3	0.9	2.1
		24	–	41.1	52.2	6.7	–	–	–	–
	25	18	51.6	–	4.7	7.7	4.2	3.9	6.4	21.5
		24	0.4	0.1	13.3	19.6	5.4	6.1	10.8	44.4
40–50	5	18	1.1	33.7	36.9	22.0	3.1	1.4	1.2	0.6
		24	–	70.8	23.6	5.6	–	–	–	–
	25	18	47.1	–	5.6	16.1	4.9	3.2	4.9	18.2
		24	–	–	12.6	28.9	6.3	2.1	3.2	46.9
50–60	5	18	–	24.4	49.4	18.5	3.0	2.1	2.5	0.1
		24	–	61.3	38.7	–	–	–	–	–
	25	18	39.0	–	0.9	18.5	10.1	6.9	10.3	14.3
		24	–	–	4.4	47.5	15.4	4.4	6.2	22.1
60–70	5	18	–	8.5	53.6	23.6	7.6	3.6	2.8	0.3
		24	–	21.8	75.5	2.7	–	–	–	–
	25	18	27.3	–	1.3	9.6	15.5	16.1	21.6	8.6
		24	–	–	5.2	26.3	24.4	20.5	19.2	4.4
70–80	5	18	–	–	17.2	38.1	29.5	11.7	3.0	0.5
		24	–	–	32.9	49.9	16.6	0.6	–	–
	25	18	16.9	–	–	4.8	7.5	19.0	41.9	9.9
		24	–	–	0.1	13.6	17.2	33.2	35.9	–
80–90	5	18	–	–	–	0.1	4.8	24.2	43.4	27.5
		24	–	–	–	0.3	10.8	26.2	39.0	23.7
	25	18	13.6	–	–	–	–	2.8	39.9	43.7
		24	–	–	–	–	–	8.6	59.1	32.3

Table 5. Distribution (in per cent) of GDOP coefficient values and number of fix without 3D position for different masking elevation angles (H_{min}) for different numbers of GLONASS satellites (NS) at observer's latitudes 50−60^{O}

H_{min} [^{O}]	NS	Without fix [%]	GDOP coefficient – v [%]						
			v≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤20	v>20
0	18	–	52.6	33.6	10.4	1.5	1.5	0.4	–
	19	–	60.2	32.7	5.3	0.6	0.9	0.3	–
	20	–	65.4	30.7	3.0	0.1	0.6	0.2	–
	21	–	72.7	25.3	1.6	0.1	0.5	–	–
	22	–	77.3	21.4	1.3	–	–	–	–
	23	–	83.1	16.2	0.7	–	–	–	–
	24	–	88.0	12.0	–	–	–	–	–
5	18	–	24.4	49.4	18.5	3.0	2.1	2.5	0.1
	19	–	30.4	52.6	13.1	1.0	1.3	1.6	–
	20	–	34.4	55.3	8.4	0.5	0.6	–	–
	21	–	43.6	49.8	5.4	0.5	0.7	–	–
	22	–	48.2	47.5	4.1	0.1	0.1	–	–
	23	–	54.0	44.3	1.7	–	–	–	–
	24	–	61.3	38.7	–	–	–	–	–
10	18	0.3	7.5	45.7	28.9	7.5	4.1	4.7	1.3
	19	–	10.4	52.1	26.6	4.3	2.3	3.4	0.8
	20	–	12.1	57.3	24.1	3.4	1.5	1.0	0.5
	21	–	17.3	59.9	17.9	3.1	1.5	–	–
	22	–	19.6	62.7	14.7	2.3	0.7	–	–
	23	–	22.3	66.7	9.7	1.3	–	–	–
	24	–	27.7	67.3	4.9	0.1	–	–	–
15	18	5.8	1.3	25.2	36.4	14.7	6.2	7.2	3.2
	19	4.0	1.9	31.4	38.1	11.7	4.8	5.5	2.6
	20	2.3	2.2	35.2	40.8	10.5	3.9	2.7	2.4
	21	0.4	3.5	41.4	37.4	9.3	4.2	2.4	1.4
	22	0.2	3.8	47.1	34.2	9.2	2.8	1.5	1.2
	23	0.2	5.1	52.4	32.4	7.3	1.0	0.5	1.1
	24	–	6.8	58.5	29.7	3.9	0.3	–	0.8
20	18	20.2	–	7.6	30.5	14.0	9.2	10.4	8.1
	19	13.8	0.1	9.9	36.1	13.3	8.8	9.3	7.7
	20	8.2	0.1	11.1	42.3	13.9	8.1	6.9	9.4
	21	3.2	0.1	14.7	44.6	14.5	8.0	6.2	8.7
	22	1.9	0.1	19.3	45.0	15.0	6.5	4.3	7.9
	23	1.0	0.1	21.8	50.2	14.4	3.6	2.3	6.5
	24	–	0.2	25.1	53.8	11.6	1.4	0.8	7.1
25	18	39.0	–	0.9	18.5	10.1	6.9	10.3	14.3
	19	29.7	–	1.4	22.9	10.4	7.3	11.0	17.3
	20	21.2	–	1.4	27.3	11.3	6.9	11.7	20.2
	21	13.1	–	1.8	31.1	14.0	9.0	10.6	20.4
	22	9.4	–	3.2	35.2	15.8	7.1	9.0	20.3
	23	3.9	–	4.0	40.9	16.7	5.8	7.7	21.0
	24	–	–	4.4	47.5	15.4	4.4	6.2	22.1

Additionally the detailed distribution of NF and the GDOP coefficient value for H_{min} from interval 0, 25^O with step 5^O for each number NS from interval [18,24] at observer's latitudes $50–60^O$ are showed in the Table 5. We can recapitulate:

- for $H_{min} \geq 15^O$ NF is greater than 0 for NS ≤ 23, for $H_{min} = 10^O$ NF is greater than 0 for NS = 18 only,
- GDOP coefficient decreases with the number NS for each H_{min},
- GDOP coefficient value less than 2 can be for $H_{min} = 0^O$ and for NS = 24 only,
- For $H_{min} \geq 15^O$ GDOP coefficient increases considerably, for $H_{min} = 25^O$ its value is greater than 3 always.

The percentage of GLONASS satellites visible in open area above given angle H for 18 and 24 operational satellites at different observer's latitudes (φ) is presented in the Table 6. The detailed distribution at $50–60^O$ for H from interval [0^O, 25^O] with step 5^O are showed in the Table 7. We can say that:

Table 6. Percentage of GLONASS satellites visible in open area above angle (H) at different observer's latitudes (φ) for different numbers of satellites (NS), l_m – weighted mean number of satellites visible above horizon ($H = 0^O$)

φ [^{O}]	**NS**	**l_m**	**Elevation angle H [^{O}]**								
			0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**
0 – 10	18 24	6.8 9.0	100 100	74.7 74.6	50.1 51.3	34.0 34.1	22.3 22.5	13.8 14.0	7.5 7.6	3.1 3.0	0.7 0.7
10 – 20	18 24	6.5 8.7	100 100	76.0 76.5	56.9 57.6	38.4 38.9	24.6 24.8	15.0 15.1	8.1 8.2	3.4 3.5	0.6 0.6
20 – 30	18 24	6.4 8.5	100 100	77.7 78.2	59.8 60.4	44.8 45.2	28.9 28.8	16.9 16.9	9.1 9.1	3.7 3.8	0.9 0.8
30 – 40	18 24	6.5 8.7	100 100	78.1 78.2	61.5 61.2	46.6 46.5	33.9 33.5	20.5 20.3	10.5 10.6	4.7 4.8	1.0 1.1
40 – 50	18 24	6.9 9.2	100 100	77.4 77.6	59.9 59.4	45.3 45.0	33.4 33.2	22.7 22.4	14.1 13.6	5.9 5.8	1.4 1.4
50 – 60	18 24	7.2 9.6	100 100	81.3 81.2	61.3 61.1	44.8 44.7	32.4 32.5	22.7 22.7	14.4 14.3	7.9 7.9	2.3 2.2
60 – 70	18 24	7.3 9.7	100 100	84.2 84.1	67.0 66.8	48.4 48.0	33.3 32.7	22.5 22.1	13.6 13.4	7.2 7.0	2.5 2.4
70 – 80	18 24	7.4 9.9	100 100	83.7 83.9	69.6 69.3	54.1 53.6	36.3 36.0	20.8 20.5	10.4 10.3	3.4 3.3	0.1 0.1
80 – 90	18 24	7.4 9.9	100 100	85.4 85.2	71.1 70.5	57.0 56.4	41.6 41.2	22.7 22.5	3.8 3.8	0.0 0.0	0.0 0.0

Table 7. Percentage of GLONASS satellites visible in open area above angle (H) at observer's latitudes 50−60^{O} for different numbers of satellites (NS), l_m – weighted mean number of satellites visible above horizon (H = 0^{O})

NS	l_m	Elevation angle H [^{O}]					
		0	5	10	15	20	25
18 24	7.2 9.6	100 100	90.5 90.5	81.3 81.2	72.2 70.8	61.3 61.1	54.2 53.3

- the percentage of satellites visible decreases with angle H in each zone. The diminution is practically the same for both numbers of satellites,
- for H≤40^{O} the percentage of satellite visible increases with latitude φ; e.g. for H = 20^{O} this percentage is at latitude 60–70^{O} 30% greater than at equator and for H = 40^{O} at latitude 80–90^{O} almost twice greater than at latitude 0–10^{O},
- if in the receiver the masking angle H_{min} is equal 0^{O} we can say that 100% of GLONASS satellites visible can be used for the position fix, if this angle is equal 20^{O} the percentage of these satellites decreases to 60% or less, if H_{min} = 40^{O} this percentage is about 30% only,
- for H = 25^{O} the percentage of satellite visible is equal about 53% only for both NS.

As the possibility of position fix depends on masking elevation angle the calculations were made in order to find the maximum value of this angle (H_{max}) for which the observer's position in mode 3D (l_m ≥4) and in mode 2D (l_m ≥3) can be obtained. These calculations were made for nominal GLONASS constellation (NS = 24) in all 9 latitude zones (Table 8). The H_{max} value increases with latitude for both modes, at latitude 80–90^{O} is almost twice higher than at equator.

Table 8. Maximum values of masking elevation angle (H_{max}) for position fix (No FIX = 0) in open area in mode 3D (l_m ≥4) and in mode 2D (l_m ≥3) for 24 GLONASS satellites, at different observer's latitudes (φ)

φ [^{O}]	H_{max} [^{O}]		φ [^{O}]	H_{max} [^{O}]	
	l_m ≥4	l_m≥3		l_m ≥4	l_m≥3
0 – 10	16	23	50 – 60	27	33
10 – 20	18	24	60 – 70	27	32
20 – 30	20	27	70 – 80	31	33
30 – 40	23	28	80 – 90	33	40
40 – 50	27	29	l_m – weighted mean number of satellites visible above H_{max}		

Distributions (in per cent) of satellite azimuths for H_{min} = 5^{O} and H_{min} = 25^{O} for NS = 18 and NS = 24 at different observer's latitudes are shown in the Table 9. We can recapitulate that:

Table 9. Distribution (in per cent) of satellite azimuths in open area for different masking elevation angles (H_{min}) for different numbers of GLONASS satellites (NS) at different observer's latitudes (φ), l_m – weighted mean number of satellites visible above H_{min}

φ [^{O}]	H_{min} [^{O}]	NS	l_m	Satellite azimuth [^{O}]							
				0 – 45	45 – 90	90– 135	135 – 180	180 – 225	225 – 270	270 – 315	315 – 360
0 – 10	5	18 24	5.9 7.9	16.1 16.0	10.0 10.1	9.3 9.4	15.0 14.6	13.8 13.7	9.1 9.1	9.8 10.1	16.9 17.0
	25	18 24	2.8 3.8	13.9 13.5	12.1 11.9	10.6 10.8	13.1 12.8	12.3 12.5	10.1 10.6	12.1 12.2	15.8 15.7
10 – 20	5	18 24	5.7 7.6	17.8 17.4	10.4 10.7	9.7 9.8	12.5 12.1	11.5 11.5	9.4 9.5	10.4 10.8	18.3 18.2
	25	18 24	3.1 4.2	17.5 17.1	10.9 11.3	10.1 10.3	10.5 10.3	10.1 10.2	10.1 10.2	10.8 11.2	20.0 19.4
20 – 30	5	18 24	5.7 7.6	18.5 17.8	11.7 11.9	9.2 9.6	10.8 10.6	10.0 10.2	9.5 9.6	11.7 12.0	18.6 18.3
	25	18 24	3.3 4.5	20.0 19.4	11.1 11.3	8.9 9.3	9.1 8.9	8.8 9.2	9.3 9.5	11.9 12.1	20.9 20.3
30 – 40	5	18 24	5.8 7.7	17.8 17.4	12.8 12.6	9.2 9.4	9.9 9.9	9.6 9.7	9.9 10.1	13.1 13.3	17.7 17.6
	25	18 24	3.5 4.7	18.9 18.6	12.3 12.2	9.2 9.3	9.1 9.0	9.0 9.2	9.7 9.8	13.0 13.1	18.8 18.8
40 – 50	5	18 24	6.1 8.1	17.6 17.4	14.2 13.9	9.0 9.1	9.2 9.2	8.9 9.2	9.6 9.8	13.7 14.0	17.8 17.4
	25	18 24	3.6 4.8	16.3 16.2	15.2 14.9	9.5 9.6	9.2 9.2	8.6 8.8	9.9 10.2	15.1 15.3	16.2 15.8
50 – 60	5	18 24	6.5 8.7	14.7 14.7	17.2 16.8	9.4 9.4	8.9 8.9	9.1 9.3	9.8 10.0	15.7 15.9	15.2 15.0
	25	18 24	3.8 5.0	8.8 8.9	21.1 20.6	10.2 10.4	9.6 9.6	9.8 9.8	10.8 11.1	19.8 20.0	9.9 9.6
60 – 70	5	18 24	6.7 8.9	13.0 12.8	16.6 16.2	10.9 11.0	9.8 9.8	9.8 10.0	11.5 11.6	15.5 15.5	12.9 13.1
	25	18 24	4.2 5.6	8.5 8.7	19.3 18.6	11.9 12.0	9.7 9.8	10.3 10.6	13.0 12.8	18.7 18.5	8.6 9.0
70 – 80	5	18 24	6.8 9.1	12.9 12.6	13.9 13.7	12.5 12.6	10.8 10.3	11.8 11.6	11.8 12.2	13.3 13.4	13.0 13.2
	25	18 24	4.6 6.1	11.8 11.8	14.1 13.7	12.9 13.2	10.9 10.8	12.3 12.0	12.4 12.7	14.3 14.1	11.3 11.7
80 – 90	5	18 24	6.9 9.2	12.9 12.5	12.3 12.5	13.5 13.3	11.3 11.3	12.6 12.3	12.2 12.5	11.9 12.2	13.3 13.4
	25	18 24	4.7 6.2	12.4 12.2	12.4 12.4	13.8 13.5	11.5 11.5	12.9 12.6	12.5 12.7	11.9 12.1	12.6 13.0

- distributions of satellite azimuths are practically the same for both NS independently of observer's latitude and masking angle,
- distribution of satellite azimuths depends on latitude φ; e.g. for $H_{min} = 25^O$ the number of satellites with azimuths from intervals 315–045^O is at latitudes 0–10^O the greatest and at latitudes 60–70^O the lowest,
- in zone 80–90^O the number of satellites in all intervals is for each H_{min} and for both NS practically the same,
- the relationship between the number of satellites and azimuth interval is for $H_{min} = 25^O$ greater than for $H_{min} = 5^O$,
- at latitudes 50–60^O and for $H_{min} = 25^O$ the number of satellites with azimuth from intervals 315–045^O is less than from adjacent intervals (45–90^O and 270–315^O) twice or three times and more.

Mean number of GLONASS satellites l_{ms} visible above H_{min} and the obstacles by the observer situated in the middle of the street (width L = 70 m, height B = 15 m) for different angles H_{min} for different angles between the North and street axis (α) at different observer's latitudes φ is presented in the Table 10. We can say that:

- the number l_{ms} depends on angle α, at latitude 0–10^O in particular. This relationship is for $H_{min} = 0^O$ greater than for $H_{min} = 20^O$,
- in each latitude zone for both NS the number l_{ms} decreases with H_{min}, but simultaneously the quotient l_{ms}/l_m increases with this angle,
- in restricted area masking elevation angle of the receiver must be low, no more than 5^O.

CONCLUSIONS

- nowadays the system GLONASS is the second after GPS a satellite navigation system, whose the importance from several already years incessantly grows up,
- with actual 18 satellites constellation and $H_{min} = 5^O$ 3D user's position can be obtained always at latitudes greater than 50^O only, at latitude of Poland number of fix without position 3D is greater than zero for $H_{min} \geq 10^O$,
- if the number of fully operational satellites increases, GDOP coefficient value decreases, that's why each user waits anxiously on the enlargement of GLONASS satellite constellation,
- maximum value of masking elevation angle (H_{max}) for position fix depends on observer's latitude, e.g. at equator H_{max} for 3D must be less than 17^O. It means that the possibility of position fix is for GLONASS system in restricted area less than in open area considerably,
- as in all 9 zones about half of satellites is visible below 30^O, masking elevation angle H_{min} in user's receiver must be possibly least, e.g. if $H_{min} = 5^O$ 90% satellite visible above horizon can be used for fix position,
- as the distribution of satellites azimuths depends on observer's latitude the position accuracy in restricted area, in urban canyon in particular, depends on its geographic location.

Table 10. Mean number of GLONASS satellites l_{ms} visible above H_{min} and the obstacles by the observer situated in the middle of the street (width L = 70 m, height B = 15 m) for different angles H_{min} for different angles between the North and street axis (α) at different observer's latitudes φ, l_m – weighted mean number of satellites visible above H_{min}

φ [^{O}]	H_{min} [^{O}]	NS	l_m	Angle α [^{O}]							
				0		45		90		135	
				l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]
0 – 10	0	18 24	6.8 9.0	4.7 6.2	69.1 68.9	4.2 5.7	61.8 63.3	3.9 5.2	57.4 57.8	4.3 5.7	63.2 63.3
	5	18 24	5.9 7.9	4.6 6.2	78.0 78.5	4.2 5.6	71.2 70.9	3.9 5.2	66.1 65.8	4.2 5.6	71.2 70.9
	10	18 24	5.1 6.7	4.4 5.8	86.3 86.6	4.0 5.4	78.4 80.6	3.8 5.0	74.5 74.6	4.1 5.4	80.4 80.6
	15	18 24	4.2 5.6	3.9 5.2	92.9 92.9	3.8 5.4	90.5 89.3	3.6 4.8	85.7 85.7	3.8 5.1	90.5 91.1
	20	18 24	3.5 4.6	3.4 4.6	97.1 99.9	3.4 4.5	97.1 97.9	3.3 4.4	94.3 95.7	3.4 4.5	97.1 97.8
30 – 40	0	18 24	6.5 8.7	4.5 6.0	69.2 69.0	4.6 6.1	70.8 70.1	4.6 6.1	70.8 70.1	4.6 6.1	70.8 70.1
	5	18 24	5.8 7.7	4.5 5.9	77.6 76.6	4.5 6.0	77.6 77.9	4.5 6.0	77.6 77.9	4.6 6.1	79.3 79.2
	10	18 24	5.1 6.8	4.4 5.8	86.3 85.3	4.4 5.8	86.3 85.3	4.4 5.9	86.3 86.8	4.4 5.9	86.3 86.8
	15	18 24	4.5 6.1	4.2 5.6	93.3 91.8	4.2 5.5	93.3 90.2	4.2 5.6	93.3 91.8	4.2 5.6	93.3 91.8
	20	18 24	4.0 5.3	3.9 5.2	97.5 98.1	3.9 5.2	97.5 98.1	4.0 5.2	99.9 98.1	3.9 5.2	97.5 98.1
60 – 70	0	18 24	7.3 9.7	5.6 7.5	76.7 77.3	5.5 7.4	75.3 76.3	5.3 7.1	72.6 73.2	5.5 7.3	75.3 75.3
	5	18 24	6.7 8.9	5.6 7.4	83.6 83.1	5.5 7.3	82.1 82.0	5.3 7.1	79.1 79.8	5.5 7.3	82.1 82.0
	10	18 24	6.1 8.2	5.5 7.2	90.2 87.8	5.4 7.1	88.5 86.6	5.2 6.9	85.2 84.1	5.3 7.1	86.9 86.6
	15	18 24	5.5 7.4	5.2 6.9	94.5 93.2	5.2 6.9	94.5 93.2	5.0 6.7	90.9 90.5	5.1 6.8	92.7 91.9
	20	18 24	4.9 6.5	4.8 6.4	97.9 98.5	4.8 6.4	97.9 98.5	4.7 6.3	95.9 96.9	4.8 6.4	97.9 98.5

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Received: 2009-07-31,
Reviewed: 2009-10-07, by Z. Rzepecka,
Accepted: 2009-10-14.