ANNUAL OF NAVIGATION 1/99

Jacek Januszewski
Maritime University
Gdynia

VISIBILITY AND GEOMETRY OF GPS AND GLONASS

ABSTRACT

Actually there are two world-wide satellite navigation systems - American GPS and Russian GLONASS. Distribution (%) of numbers of visible satellites and distribution (%) of GDOP (**G**eometric **D**ilution **O**f **P**recision) coefficient values for the observer at different latitude for different masking elevation angle for both systems are demonstrated in this paper.

INTRODUCTION

The ship's position can be obtained from many different methods. At present the most frequently used methods are the methods based on the propriety of radio waves, in particular terrestrial radionavigation system (Loran C) and satellite navigation systems (GPS, Differential GPS, GLONASS). The nineties of the twentieth century gave a rise to many important changes in the operational status and practical exploitation of these systems. Two global radionavigation systems - satellite system Transit and terrestrial system Omega were switched off in 1997. It's also remarkable that number of operational radiobeacons (RC) and the number of operational chains and working stations of Decca Navigator System have been decreased in last years too. At present (year 1999) we can expect that all of radiobeacons and Decca stations will be switch off within two-three consecutive years.

It means, that in the year 2000 and later the marine navigators will have a possibility to use the following systems: GPS, Differential GPS, GLONASS and Loran C. But two systems: GPS and GLONASS are the global systems only.

GPS is the first system that permits sea, land and airborne users to determine their three dimensional present position, velocity, and time, 24 hours a day in all weather conditions, anywhere in the world, with a high degree of accuracy and reliability. Receivers can automatically acquire the satellite signals and give us a redout of our position, in latitude and longitude coordinates. GPS is referenced to the World Geodetic System 1984 (WGS-84) Datum. GLONASS System, which became fully operational in January 1996, is similar to GPS and referenced to the Soviet Geocentric Coordinate System 1990 (SGS-90) Datum.

Fix position can be calculated from these satellites only, which elevation angle is at the moment of measurement higher than masking angle. The receiver needs to see at least four satellites to calculate latitude, longitude, time and altitude.

The geometry of the visible satellites is an important factor in achieving high quality results especially for point positioning and kinematic surveying. The geometry changes with time due to the relative motion of the satellites. A measure for the geometry is the Dilution of Precision (DOP) factor.

I. TEST METHOD

The final space segment configuration of GPS and GLONASS systems allows to know the distribition of numbers (ls) of satellites visible at H_{min} (masking elevation angle) or more above horizon for the obsever at different latitude and distribution of Geometric Dilution of Precision (GDOP) coefficient. GPS space configuration consists of 24 operational satellites. The real number of GLONASS operational satellites is less than 24 at present (year 1999), but for geometrical confrontation of these two systems it was considered in this paper, 24 GLONASS satellites being fully operational too.

The latitude of observer 0^O- 90^O was divided in to 6 zones, each 15^O wide. For more detailed calculations the latitude of observer 75^O-90^O was divided in to 3 zones, each 5^O wide. For each system, 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 - 900 minutes (15^O) or 0 - 300 minutes (5^O),
- longitude interval 0 - 21600 minutes (360^O),
- time interval 0 -1440 minutes (24 hours) for GPS System and time interval 0 - 11487 minutes (7 days, 23 hours, 27 minutes) for GLONASS System.

For each geographic-time coordinate the number of visible satellite (ls) and GDOP coefficient value were calculated. GDOP value (w) was divided in to 8 intervals: 1 for $w \le 2$, 2 for $2 < w \le 3$, 3 for $3 < w \le 4$, 4 for $4 < w \le 5$, 5 for $5 < w \le 6$, 6 for $6 < w \le 8$, 7 for $8 < w \le 20$ and 8 for $w > 20$.

Constellation characteristics - right ascension of ascending nodes and arguments of latitude for all 24 GPS satellites (1÷4 - numbers of satellites of orbit I, 5÷8 - orbit II, 9÷12 - orbit III, etc.) and for all 24 GLONASS satellites (1÷8 - numbers of satellites of orbit I, 9÷16 - orbit II, 17÷24 - orbit III) at the referred time were known. Masking elevation angle H_{min} was equal 0^O, 5^O, 10^O and 15^O. Satellite selection criteria (combination of 4 satellites) are founded on the minimalization of GDOP. All calculations, based upon a reference ellipsoid WGS-84, were made with use of autor's simulating program.

2. VISIBILITY OF SATELLITES

Distribution (%) of numbers (ls) of visible GPS and GLONASS satellites for the observer at latitude 0-90^{O} (6 zones, each 15^{O} wide) for different angle H_{min} and mean number of visible satellites (l_m) in each case is demonstrated in tables 1a and 1b.

Table 1a. Distribution (%) of numbers of visible satellites (ls) at different latitude n of observer (0 - 45^{O}) for different angle (H_{min}), l_m - mean number of visible satellites

n [^{O}]	H_{min} [^{O}]	System	Number of visible satellites - ls										l_m
			3	4	5	6	7	8	9	10	11	12	
0-15	0	GPS					<10	<10	30-40	40-50	10-20	<10	9,55
		GLO				<10	<10	10-20	40-50	20-30	<10	<10	8,92
	5	GPS					<10	30-40	40-50	10-20	<10		8,65
		GLO			<10	10-20	20-30	30-40	20-30	<10			7,82
	10	GPS			<10	<10	30-40	30-40	10-20	<10			7,62
		GLO		<10	<10	20-30	20-30	30-40	10-20	<10			7,22
	15	GPS		<10	<10	30-40	30-40	10-20	<10				6,60
		GLO		<10	30-40	30-40	10-20	<10					5,97
15-30	0	GPS					<10	20-30	40-50	20-30	<10		8,93
		GLO				<10	10-20	10-20	30-40	20-30	<10	<10	8,55
	5	GPS				<10	30-40	40-50	10-20	<10	<10		7,88
		GLO			<10	20-30	10-20	20-30	30-40	<10			7,62
	10	GPS			<10	20-30	50-60	20-30	<10	<10			6,99
		GLO		<10	10-20	30-40	20-30	10-20	<10	<10			6,72
	15	GPS		<10	10-20	40-50	20-30	<10	<10				6,18
		GLO		<10	20-30	30-40	20-30	<10	<10				5,93
30-45	0	GPS				<10	<10	40-50	30-40	10-20	<10		8,53
		GLO				<10	10-20	10-20	30-40	20-30	<10		8,81
	5	GPS			<10	<10	30-40	40-50	<10	<10	<10		7,58
		GLO			<10	20-30	10-20	30-40	20-30	<10			7,78
	10	GPS			<10	30-40	40-50	10-20	<10				6,76
		GLO		<10	<10	30-40	10-20	20-30	<10	<10			6,91
	15	GPS		<10	20-30	40-50	20-30	<10					6,00
		GLO		<10	20-30	30-40	20-30	10-20	<10				6,12

< 10 10-20 20-30 30-40 40-50 50-60 >60

Table 1b Distribution (%) of numbers of visible satellites (ls) at different latitude n of observer (45 - 90^O) for different angle (H_{min}), l_m - mean number of visible satellites

n [^{O}]	H_{min} [^{O}]	Sys-tem	Number of visible satellites - ls										l_m
			3	4	5	6	7	8	9	10	11	12	
45-60	0	GPS											9,10
		GLO											9,52
	5	GPS											7,99
		GLO											8,60
	10	GPS											6,98
		GLO											7,60
	15	GPS											6,04
		GLO											6,61
60-75	0	GPS											9,62
		GLO											9,78
	5	GPS											8,70
		GLO											8,95
	10	GPS											7,78
		GLO											8,18
	15	GPS											6,73
		GLO											7,37
75-90	0	GPS											9,72
		GLO											9,86
	5	GPS											8,84
		GLO											9,09
	10	GPS											8,05
		GLO											8,40
	15	GPS											7,22
		GLO											7,65

< 10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | >60

Mean number (l_m) of GPS and GLONASS satellites for different latitude of observer for two extremal values of H_{min}: 0^O and 15^O is illustrated in figure 1. On the base of tables 1a, 1b and figure 1, we can say that:

- the number ls of satellites visible above horizon (H_{min} = 0^O) changes between 6 and 12 for both systems. Probability of extremal values is small. That's why GPS receivers have up to 12 channels (option "all in view"). The number ls has maximum in zone 75-90^O for both systems and minimum in zone 30-45^O for GPS and in zone 15-30^O for GLONASS,

- at latitude of observer less than 30^O the mean number l_m is for GPS greater than for GLONASS, at latitude greater than 30^O this number for GPS is less irrespective of H_{min} value,
- the mean number l_m decreases with angle H_{min} in all 6 zones for both systems. In each zone the number l_m is for $H_{min} = 15^O$ about 2,2-3,1 less than for $H_{min} = 0^O$. In major zones this decrease is for GPS greater than for GLONASS. The least decrease of the number l_m is in zone 75-90^O for both systems. The greatest decrease of this number is in zone 45-60^O for GPS and in zone 0-15^O for GLONASS,
- the number of visible satellites ls for $H_{min} = 0^O$ and $H_{min} = 5^O$ is greater than 4 in all zones for both systems. For $H_{min} = 10^O$ the number ls is equal 4 for GLONASS for the observer at latitude less than 60^O but for GPS in zone 60-75^O only. For $H_{min} = 15^O$ the number ls is greater than 4 for GPS in zone 75-90^O only, for GLONASS for the observer at latitude greater than 60^O only. The number ls decreases to 3 (position of observer in option "3D" cannot be obtained) for GPS in zone 45-60^O only.

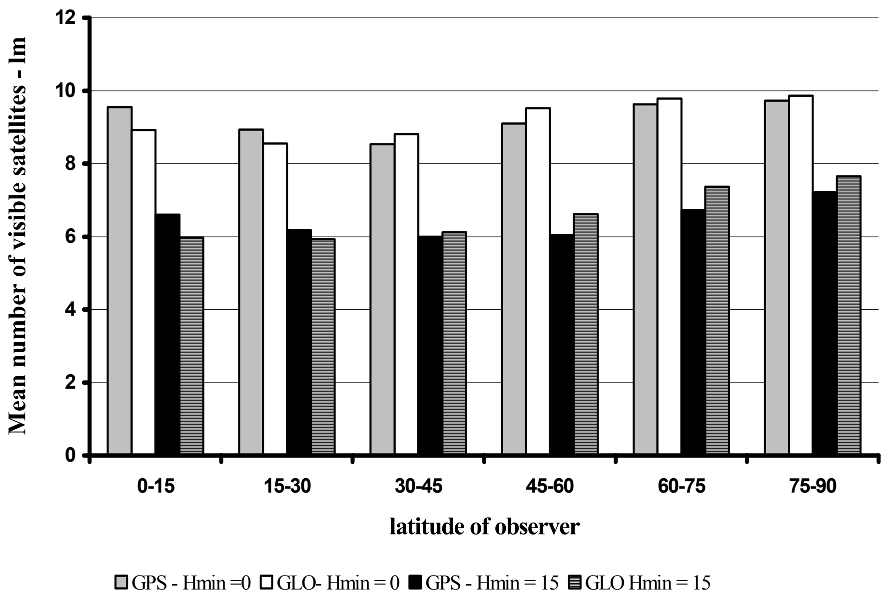

Fig.1 Mean number (l_m) of visible GPS and GLONASS satellites for different latitude of observer for $H_{min}=0^O$ and $H_{min}=15^O$

Table 2. Distribution (%) of numbers of visible satellites (ls) at latitude of observer greater than 75^O and for different angle (H_{min}), l_m - mean number of visible satellites

n [^{O}]	H_{min} [^{O}]	System	Number of visible satellites - ls 5	6	7	8	9	10	11	12	l_m
75-80	0	GPS	-	-	-	5,8	27,7	52,3	14,1	0,1	9,75
		GLO	-	-	-	-	36,2	41,9	19,1	2,8	9,88
	5	GPS	-	0,1	5,6	24,9	51,9	16,5	1,0	-	8,82
		GLO	-	-	0,7	8,1	74,2	15,9	1,1	-	9,08
	10	GPS	-	3,5	23,9	44,6	27,1	0,9	-	-	7,98
		GLO	-	1,2	13,4	36,6	47,8	1,0	-	-	8,34
	15	GPS	3,1	21,2	38,1	31,9	5,7	-	-	-	7,16
		GLO	-	9,9	36,2	39,7	14,2	-	-	-	7,58
80-85	0	GPS	-	-	-	4,7	31,4	50,1	13,8	-	9,73
		GLO	-	-	-	-	32,9	47,3	19,0	0,8	9,88
	5	GPS	-	0,1	4,0	21.0	59,7	14,0	1,2	-	8,87
		GLO	-	-	0,1	7,2	74,5	17,8	0,4	-	9,11
	10	GPS	-	4,5	19,3	43,5	31,6	1,1	-	-	8,05
		GLO	-	0,2	13,2	36,9	49,2	0,5	-	-	8,37
	15	GPS	0,3	18,6	43,1	32,0	6,0	-	-	-	7,25
		GLO	-	4,4	43,0	34,5	18,1	-	-	-	7,66
85-90	0	GPS	-	-	-	5,6	34,8	41,2	18,4	-	9,72
		GLO	-	-	-	-	24,9	63,2	11,8	0,1	9,87
	5	GPS	-	-	3,7	21,0	61,1	13,8	0,4	-	8,86
		GLO	-	-	-	6,5	73,5	19,6	0,4	-	9,14
	10	GPS	-	5,2	19,4	35,2	39,1	1,1	-	-	8,12
		GLO	-	-	6,1	49,1	44,0	0,8	-	-	8,40
	15	GPS	-	20,6	38,2	31,8	9,4	-	-	-	7,30
		GLO	-	0,9	36,3	54,7	8,1	-	-	-	7,70

Distribution (%) of numbers (ls) of visible GPS and GLONASS satellites for the observer at latitude 75-90^O (3 zones, each 5^O wide), where mean number l_m is greatest for both systems, is demonstrated in table 2. In zone 85-90^O the number of visible satellites ls for $H_{min} = 15^O$ is greater than 5 for both systems. For $H_{min} = 0^O$ the number ls is equal to 12 for GPS in zone 75-80^O and for GLONASS in each of these three zones.

Table 3a. Distribution (%) of GDOP values at different latitude n of observer ($0\text{-}45^O$) for different masking elevation angle H_{min}

n $[^O]$	H_{min} $[^O]$	System	GDOP coefficient – w							
			w≤2	2<w≤3	3<w≤4	4<w≤5	5<w≤6	6<w≤8	8<w≤20	w>20
0-15	0	GPS	4,5	94,6	0,9	-	-	-	-	-
		GLO	5,2	89,4	5,3	0,1	-	-	-	-
	5	GPS	-	93,4	6,3	0,3	-	-	-	-
		GLO	-	79,8	19,4	0,8	-	-	-	-
	10	GPS	-	68,9	26,9	3,3	0,7	-	0,2	-
		GLO	-	21,8	54,7	17,9	3,8	0,8	0,8	0,2
	15	GPS	-	34,4	45,2	14,4	3,4	1,5	0,9	0,2
		GLO	-	19,1	59,2	8,8	3,5	3,2	3,0	3,2
15-30	0	GPS	4,3	90,8	4,8	0,1	-	-	-	-
		GLO	2,6	77,6	19,7	0,4	-	-	-	-
	5	GPS	0,4	77,0	20,9	1,6	0,1	-	-	-
		GLO	-	55,3	42,7	2,0	-	-	-	-
	10	GPS	-	47,0	44,2	7,1	1,5	0,1	0,1	-
		GLO	-	27,5	57,6	11,0	-	0,6	2,0	1,3
	15	GPS	-	17,0	52,4	17,6	7,0	3,7	1,9	0,4
		GLO	-	10,5	51,7	21,1	1,3	2,9	8,1	4,4
30-45	0	GPS	1,5	89,1	9,4	-	-	-	-	-
		GLO	-	80,8	18,4	-	-	-	-	-
	5	GPS	-	70,6	28,4	0,7	0,1	0,2	-	-
		GLO	-	47,8	44,8	7,4	-	-	-	-
	10	GPS	-	39,5	52,9	6,0	0,9	0,6	0,1	-
		GLO	-	16,0	58,2	23,0	1,3	0,4	0,4	0,7
	15	GPS	-	11,9	59,2	17,0	6,0	4,1	1,5	0,3
		GLO	-	1,7	51,3	31,3	4,2	2,0	3,6	5,9

If ls is equal to 4 and the signal from one of these four visible satellites is, for any reason, absent, the position of observer (option "3d") cannot be obtained.

When in the publications (for instance in [Spilker, 1996] the number ls of visible GPS satellites is equal to 13, it means, that 24 operational satellites and three active spares also must be taken into consideration.

Table 3b. Distribution (%) of GDOP values at different latitude n of observer (45- 90^O) for different masking elevation angle H_{min}

n [^{O}]	H_{min} [^{O}]	System	GDOP coefficient – w							
			w≤2	2<w≤3	3<w≤4	4<w≤5	5<w≤6	6<w≤8	8<w≤20	w>20
45-60	0	GPS GLO	-- -	87,6 89,8	12,1 10,2	0,3 -	- -	- -	- -	- -
	5	GPS GLO	- -	63,1 65,6	35,5 33,9	1,2 0,5	0,2 -	- -	- -	- -
	10	GPS GLO	- -	32,9 28,9	60,5 59,9	4,7 10,4	1,6 0,5	0,3 -	- -	- 0,3
	15	GPS GLO	- -	9,7 5,4	59,5 53,8	17,0 33,8	6,7 3,6	3,8 -	2,2 0,1	0,9 3,3
60-75	0	GPS GLO	- -	32,5 29,2	60,2 65,0	6,7 5,8	0,6 -	- -	- -	- -
	5	GPS GLO	- -	17,3 13,9	60,1 69,6	19,3 16,4	3,0 0,1	0,3 -	- -	- -
	10	GPS GLO	- -	4,6 3,9	51,2 61,7	31,5 30,9	8,8 2,6	3,3 0,3	0,3 0,6	0,3 -
	15	GPS GLO	- -	0,7 0,2	31,6 38,5	38,2 46,7	15,9 7,2	8,3 5,5	4,2 1,9	1,1 -
75-90	0	GPS GLO	- -	- -	6,7 6,1	22,1 25,1	16,3 13,8	17,3 16,1	24,3 25,0	13,3 13,9
	5	GPS GLO	- -	- -	2,3 2,4	17,5 19,9	18,2 17,8	21,5 17,6	26,3 27,3	14,2 15,0
	10	GPS GLO	- -	- -	0,3 1,0	11,3 13,2	19,4 20,2	24,0 18,9	29,5 30,4	15,5 16,3
	15	GPS GLO	- -	- -	- -	5,4 7,3	15,9 18,6	25,6 22,0	36,1 34,7	17,0 17,4

3. GEOMETRY OF SATELLITES

Distribution (%) of GDOP values for both systems for the observer at latitude 0-90^O (zones, each 15^o wide) for different angle H_{min} is demonstrated in tables 3a and 3b. Probability of GDOP values less than 3 in each zone for H_{min} = 0^O and H_{min} = 15^O for both systems is illustrated in figure 2.

For both systems GDOP coefficient decreases with masking elevation angle H_{min} and with latitude of observer. For GPS constellation GDOP values are less than for GLONASS constellation for the observer at latitude 0-45^{O,} irrespective of H_{min} value. At latitude greater than 45^{O} distribution of GDOP is almost the same for both systems. For GPS system GDOP coefficient can be greater than 20 at latitude 0-75^{O} for H_{min} = 15^{O}, in zone 75-90^{O} irrespective of H_{min} value. For GLONASS system GDOP coefficient can be greater

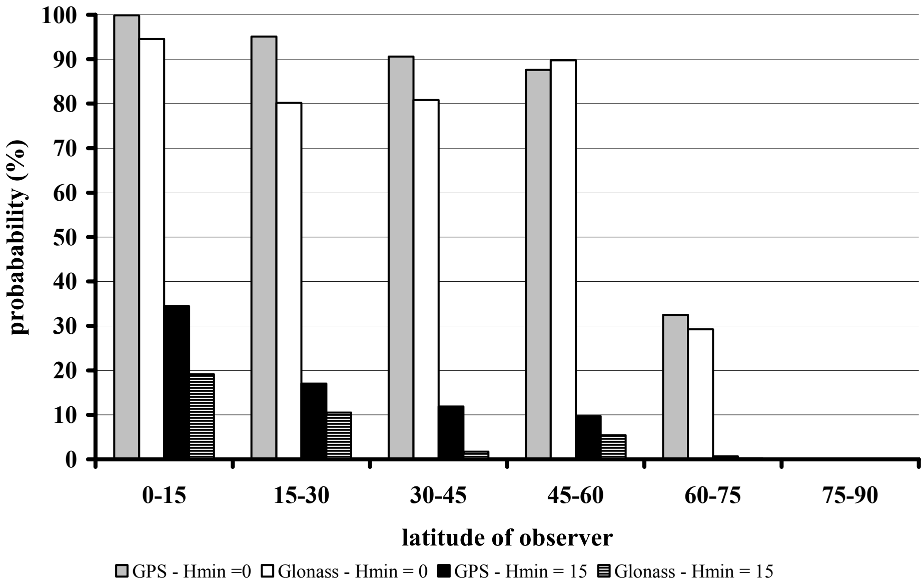

Fig. 2. Probability of GDOP<3 at different latitude of observer for GPS and GLONASS systems for H_{min} = 0^{O} and H_{min} = 15^{O} than 20 at latitude 0-60^{O} for H_{min} =10^{O} and in zone 75-90^{O} irrespective of H_{min} value

Distribution (%) of GDOP values for the observer at latitude greater than 75^{O} and for different masking elevation angle is demonstrated in table 4. For H_{min} = 0^{O} GDOP value is less than 4 in zone 75-80^{O} and greater than 6 in zone 85-90^{O}. For H_{min} = 15^{O} GDOP value is less than 5 in zone 75-80^{O} and greater than 8 in zone 85-90^{O}, for both systems.

Distribution of GDOP value for the observer at latitude 45-60^{O} and for H_{min}=5^{O}, if the number of visible GPS satellites and GLONASS satellites (ls), is known is demonstrated in table 5.

Table 4. Distribution (%) of GDOP values at latitude of observer greater than 75^{O} and for different masking elevation angle (H_{min}),

n [^{O}]	H_{min} [^{O}]	System	GDOP coefficient - w					
			$3<w\leq 4$	$4<w\leq 5$	$5<w\leq 6$	$6<w\leq 8$	$8<w\leq 20$	$w>20$
75-80	0	GPS	19,7	62,6	17,0	0,7	-	-
		GLO	18,4	66,3	15,3	-	-	-
	5	GPS	7,0	50,8	35,9	6,2	0,1	-
		GLO	5,8	60,5	32,0	1,7	-	-
	10	GPS	1,1	34,3	45,3	18,5	0,8	-
		GLO	2,1	39,5	46,8	10,4	1,2	-
	15	GPS	-	16,8	40,4	35,5	7,2	0,1
		GLO	-	20,7	51,1	20,9	7,3	-
80-85	0	GPS	-	6,7	30,2	48,8	14,3	-
		GLO	-	5,8	28,0	49,1	17,1	-
	5	GPS	-	3,1	18,5	55,6	22,8	-
		GLO	-	1,5	19,0	52,9	26,6	-
	10	GPS	-	0,7	11,2	52,2	35,8	-
		GLO	-	-	11,3	50,5	38,2	-
	15	GPS	-	-	4,6	41,5	53,9	-
		GLO	-	-	4,7	46,4	48,9	-
85-90	0	GPS	-	-	-	0,9	58,9	40,2
		GLO	-	-	-	0,1	56,8	43,1
	5	GPS	-	-	-	0,4	57,7	41,9
		GLO	-	-	-	-	54,2	45,8
	10	GPS	-	-	-	-	54,6	45,4
		GLO	-	-	-	-	51,4	48,6
	15	GPS	-	-	-	-	50,2	49,8
		GLO	-	-	-	-	48,5	51,5

CONCLUSIONS

When all 24 GPS satellites and all 24 GLONASS satellites are fully operational, than GPS system is better for low latitude (0-45^{O}) and GLONASS system for the high latitude (45-90^{O}). There is not a direct correlation between the number ls of satellites visible angle defined by H_{min} or more above horizon and GDOP coefficient value, but we can say "when ls is greater, GDOP is less" and vice versa "when ls is less, GDOP is greater".

When the satellite is below 5^{O} above the horizon, the radio wave reflection and interference with delayed waves can cause erroneous positioning.

In most sophisticated receivers the user can improve the positioning accuracy by masking the elevation angle. However, the large mask value shortens the signal receiving time as more of satellite combinations are rejected.

Table 5. Distribution (%) of GDOP values at latitude 45-60^O and masking elevation angle 5^O, if the number ls of visible satellites is known.

System	ls	% of case	GDOP coefficient - w			
			2<w≤3	3<w≤4	4<w≤5	5<w≤6
GPS GLO	6	4,1 0,3	0,2 -	3,4 0,3	0,3 -	0,2 -
GPS GLO	7	27,0 6,9	10,5 1,8	15,8 4,7	0,7 0,4	- -
GPS GLO	8	39,7 36,0	28,5 13,3	11,1 22,6	0,1 0,1	- -
GPS GLO	9	24,1 47.0	18,8 40,7	5,2 6,3	0,1 -	- -
GPS GLO	10	5,0 9,8	5,0 9,8	- -	- -	- -
GPS GLO	11	0,1 -	0,1 -	- -	- -	- -
GPS **GLO**	•	**100** **100**	**63,1** **65,6**	**35,5** **33,9**	**1,2** **0,5**	**0,2** **-**

REFERENCES

1. Januszewski J. Radionavigation and Satellite Systems at Present and in the Future", XIVth IALA Conference, tome Radio Aids to Navigation", Hamburg, 1998.
2. Januszewski J. Geometry of GPS and GLONASS Systems, II European Symposium GNSS'98, tome II, Toulouse, 1998.
3. Januszewski J. Geometry of GPS and GLONASS Systems for different area in Poland" III Krajowa Konferencja Zastosowanie satelitarnych systemów lokalizacyjnych GPS, GLONASS, Poznań, 1998 (in Polish).
4. Spilker Jr. J.J. Satellite Constellation and Geometric Dilution of Precision, Global Positionning System: Theory and Applications vol. I, American Institute of Aeronautics and Astronauticus, Inc. Washington, 1996.