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VISIBILITY AND GEOMETRY OF GALILEO SATELLITES CONSTELLATION DURING INITIAL OPERATION CAPABILITY

ABSTRACT

The European Space Agency (ESA) confirmed that it plans to declare an Initial Operational Capability (IOC) once a constellation of 18 satellites is achieved in 2014 and after few Soyuz and Ariane launches Full Operational Capability (FOC) once a constellation of 26 satellites next year or later. In the paper are presented the distribution of the number of satellites visible by the observer and the distribution of GDOP coefficient values both for different masking elevation angles (H_{min}) at different observer's latitudes for three constellations, with 18, 22 and 26 satellites, the distribution of satellite azimuths in open area and the percentage of satellites visible above given angle. Additionally for latitude of Poland (zone 50–60°) No Fix (in per cent) and the detailed distribution of GDOP values for six angles H_{min} for all these constellations and the results of other calculations are showed. Finally the results concern the possibility of the positioning and its accuracy for different numbers of Galileo satellites at different observer's latitudes.

Keywords:

GNSS, Galileo.

INTRODUCTION

As the number of GPS and GLONASS satellites visible by the user is sometimes in restricted area not sufficient, and these systems cannot provide information about integrity, and there is one service only for civil users still, new satellite navigation system Galileo is under construction. Once envisioned to space segment consisting of 30 satellites Galileo has over time been reduced to a planned, though still not space-borne, four initial satellites IOV, plus 14 operational satellites for a total of 18. The European Space Agency (ESA) confirmed that it plans to declare an Initial Operational Capability (IOC) once a constellation of 18 satellites is achieved in the

2014 and after few Soyuz and Ariane launches Full Operational Capability (FOC) once a constellation of 26 satellites next year or later [Benedicto 2011, 2012].

The calculations concerning geometry of GPS system for 18 satellites constellation (3 satellites in each of six orbital planes), made among others by author, showed the Earth's areas where for the user during few minutes 4 satellites are visible only and GDOP coefficient value increases to several hundred and more [Januszewski 2001, 2002, 2006]. That's why the similar calculations for the same number of satellites (18) must be made for Galileo system, 6 satellites in each of three orbital planes. The FOC constellation will have 27 operational satellites and 3 active spares, all stationed on the three circular medium Earth orbits (MEO).

The knowledge of all these distributions and the possibility of the positioning will be very important for the users because according to ESA an initial constellation of 18 satellites and IOC must provide three early services: an initial Open Service (OS), an initial Public Regulated Service (PRS) and an initial Search and Rescue (SAR).

TEST METHOD

The calculations were performed for three Galileo constellations, A with 18, B with 22 and C with 26 operational satellites and additionally for nominal constellation (table 1) with 27 satellites (9 satellites on each orbit). The numbers of non-operational satellites for all possible 10 constellations with the number of satellites between 18 and 27 are given in the table 2. In constellation A it was assumed 6 satellites on each orbit. As at the time of this writing, April 2012, the numbers and positions (orbit and slot) of 18 satellites IOC constellation are unknown it was assumed that position of each satellite is its final position on orbit in nominal 27 satellites constellation.

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. Elevation H_{min} was assumed to be 0°, 5°, 10°, 15°, 20° and 25°. For each combination, 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 0–21 600 minutes (360°);
- time interval 0–1440 minutes (24 hours).

Table 1. Galileo System — nominal position of 27 operational satellites, β — longitude of the ascending node, u — argument of latitude [own study]

Orbit I			Orbit II			Orbit III		
Satellite	β [°]	u [°]	Satellite	β [°]	u [°]	Satellite	β [°]	u [°]
1	0	0	10	120	13	19	240	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 2. The numbers of non-operational satellites in different Galileo constellations [own study]

Constellation (total number of satellites)	Non operational satellites	Constellation (total number of satellites)	Non operational satellites
26	1	21	1, 2, 13, 14, 24, 25
25	1, 13	20	1, 2, 7, 13, 14, 24, 25
24	1, 13, 24	19	1, 2, 7, 13, 14, 17, 24, 25
23	1, 2, 13, 24	18	1, 2, 7, 13, 14, 17, 24, 25, 27
22	1, 2, 13, 14, 24		

For each geographic-time coordinates: the satellite elevation (H), the satellite azimuth (Az), the number of visible satellites (ls) and GDOP coefficient value were calculated. Elevation H was divided in 9 intervals, each 10° wide: 1st for $0^\circ < H \leq 10^\circ$, 2nd for $10^\circ < H \leq 20^\circ$, . . . , 9th for $80^\circ < H \leq 90^\circ$. Azimuth (Az) was divided in 8 intervals: 1st for $0^\circ < Az \leq 45^\circ$, 2nd for $45^\circ < Az \leq 90^\circ$, . . . , 8th for $315^\circ < Az \leq 360^\circ$. GDOP value (v) was divided in 8 intervals: 1st for $v \leq 2$, 2nd for $2 < v \leq 3$, 3rd for $3 < v \leq 4$, 4th for $4 < v \leq 5$, 5th for $5 < v \leq 6$, 6th for $6 < v \leq 8$, 7th for $8 < v \leq 20$ and 8th for $v > 20$.

For each mentioned geographic-time coordinates the mean number of satellites visible by the observer above given H_{min} was calculated additionally.

RESULTS

Minimal, maximal and weighed number of satellites visible above given H_{min} by the observer at different latitudes for three constellations (A — 18 satellites, B — 22 satellites, and C — 26 satellites) and additionally for nominal Galileo constellation N with 27 satellites are presented in the table 3. The angles $H_{min} = 5^\circ$ and $H_{min} = 25^\circ$ are selected because the first is the most frequently used in satellite navigation systems receivers and the second is representative of the positioning in restricted area. We can say that:

- for each constellation the number of satellites visible above $H_{min} = 5^\circ$ depends on observer's latitudes and changes between 1 and 12 for constellation A, 3 and 12 for constellation B, 5 and 12 for C and 6 and 12 for N. It means that for A constellation 3D position cannot be obtained in all zones, for B constellation it can be obtained in some zones only, while for C and N always in each zone;
- for nominal constellation and $H_{min} \leq 25^\circ$ the position 3D can be obtained in each zone always while for C constellation (one satellite less) in zone 80–90° only.

Distribution (in per cent) of No Fix (position 3D) and GDOP coefficient values v less than 3 for different masking elevation angle H_{min} for three constellations (A, B and C) at different observer's latitudes are showed in the table 4. We can recapitulate that:

- if the constellation consists of 22 satellites or less No Fix increases with H_{min} in each zone, but if the number of satellites is greater then this increasing is slower;
- for A constellation (18 satellites) 3D position can be obtained in zone 80–90° in open area ($H_{min} = 0^\circ$) only;
- for B constellation (22 satellites) 3D position can be obtained in all zones, but in open area ($H_{min} = 0^\circ$) only, if $H_{min} = 5^\circ$ it is possible in some zones, if $H_{min} = 15^\circ$ in zone 0–10° only;
- for C constellation (26 satellites) if $H_{min} \leq 15^\circ$ 3D position can be obtained in all zones, if $H_{min} = 25^\circ$ in zone 80–90°;
- as coefficient v increases with H_{min} and decreases with the number of operational satellites, for all constellations its value is greater than 3 if $H_{min} = 25^\circ$ in each zone, and if $H_{min} = 15^\circ$ at latitudes greater 60°;
- coefficient v depends on observer's latitude considerably, e.g. for constellation and $H_{min} = 5^\circ$ probability of GDOP value less than 3 is in zone 0–10° greater than 90% while in zone 60–70° less than 25%.

Table 3. Number of Galileo satellites visible above masking elevation angle H_{min} by the observer at different latitudes for different constellations [own study]

φ [$^{\circ}$]	H_{min} [$^{\circ}$]	Constellation											
		A — 18 satellites			B — 22 satellites			C — 26 satellites			N — 27 satellites		
		l_{min}	l_{max}	l_m	l_{min}	l_{max}	l_m	l_{min}	l_{max}	l_m	l_{min}	l_{max}	l_m
0–10	0	3	10	7.31	6	11	8.98	8	12	10.67	9	12	11.05
	5	3	10	6.67	6	11	8.14	7	12	9.68	9	12	10.00
	15	1	8	5.16	4	9	6.32	5	10	8.65	6	10	7.81
	25	1	7	3.58	2	8	4.40	3	8	5.27	4	8	5.47
10–20	0	3	11	7.15	6	12	8.77	8	12	10.45	9	12	10.84
	5	1	10	6.35	4	11	7.80	5	12	9.31	6	12	9.65
	15	1	9	4.80	3	9	5.91	5	10	6.75	5	10	7.35
	25	1	8	3.60	2	8	4.45	3	8	5.35	4	8	5.55
20–30	0	2	11	6.67	4	12	8.23	6	12	9.83	6	12	10.21
	5	1	10	5.91	3	11	7.28	5	12	8.50	6	12	9.05
	15	1	9	4.60	3	9	5.69	5	9	6.86	6	9	7.11
	25	1	8	3.56	2	8	4.43	3	8	5.34	4	8	5.54
30–40	0	1	11	6.50	4	12	7.99	6	12	9.58	7	12	9.95
	5	1	11	5.57	4	12	7.06	5	12	8.50	6	12	8.82
	15	1	9	4.49	3	9	5.59	5	9	6.75	6	9	7.00
	25	1	7	3.49	2	7	4.35	3	8	5.27	4	8	5.46
40–50	0	1	12	6.66	4	12	8.18	6	12	9.85	7	12	10.25
	5	1	11	5.78	3	12	7.16	5	12	8.63	6	12	8.97
	15	1	10	4.48	3	10	5.57	5	10	6.73	6	10	6.98
	25	1	7	3.44	2	7	4.30	3	8	5.21	4	8	5.40
50–60	0	3	11	6.97	5	12	8.63	7	12	10.42	8	12	10.84
	5	2	10	6.28	3	11	7.74	5	12	9.29	6	12	9.68
	15	2	8	4.65	3	9	5.70	5	10	6.87	6	10	7.14
	25	1	6	3.51	2	7	4.34	3	7	5.18	4	7	5.41
60–70	0	2	12	7.11	4	12	8.81	8	12	10.64	9	12	11.08
	5	2	12	6.38	4	12	8.00	7	12	9.66	8	12	10.06
	15	1	10	5.04	3	10	6.33	5	10	7.65	6	10	7.96
	25	1	7	3.53	2	7	4.43	3	7	5.35	4	8	5.56
70–80	0	3	12	7.19	4	12	8.91	8	12	10.74	9	12	11.20
	5	2	12	6.53	4	12	8.19	8	12	9.86	9	12	10.27
	15	1	10	5.30	3	10	6.69	6	10	8.08	7	10	8.41
	25	1	8	4.02	2	8	5.06	3	8	6.08	4	8	6.33
80–90	0	4	12	7.22	5	12	8.98	9	12	10.81	10	12	11.28
	5	2	12	6.59	4	12	8.28	8	12	9.95	9	12	10.38
	15	2	9	5.41	3	9	6.79	6	9	8.17	7	9	8.52
	25	1	8	4.19	2	8	5.31	5	8	5.27	5	8	6.67

l_{min} — minimal number, l_{max} — maximal number, l_m — weighed number.

Table 4. Distribution (in per cent) of No Fix and GDOP coefficient values ν less than 3 for different masking elevation angles (H_{min}) for three Galileo constellations at different observer's latitudes (φ) [own study]

φ [°]	Constellation	Masking elevation angle H_{min} [°]							
		0		5		15		25	
		No Fix [%]	$\nu < 3$ [%]	No Fix [%]	$\nu < 3$ [%]	No Fix [%]	$\nu < 3$ [%]	No Fix [%]	$\nu < 3$ [%]
0–10	18	0.2	67.9	0.8	50.9	10.5	8.1	47.8	0
	22	0	89.0	0	73.9	0	17.4	17.6	0
	26	0	97.6	0	90.6	0	38.8	1.5	0
10–20	18	0.2	64.2	2.5	41.1	18.4	4.6	46.7	0
	22	0	88.0	0	63.5	1.1	10.8	18.7	0
	26	0	98.4	0	84.6	0	23.6	1.4	0
20–30	18	2.3	52.5	6.3	30.2	21.1	2.6	47.0	0
	22	0	79.3	0.2	55.4	1.8	7.1	18.9	0
	26	0	94.2	0	78.2	0	12.7	1.9	0
30–40	18	3.5	51.1	6.1	29.3	21.6	2.5	51.0	0
	22	0	81.4	0	62.9	2.0	9.4	20.1	0
	26	0	97.8	0	91.0	0	20.4	0.6	0
40–50	18	2.9	51.1	6.5	28.0	23.5	1.7	54.1	0
	22	0	82.8	0.3	57.5	3.0	4.9	24.3	0
	26	0	97.1	0	77.0	0	9.2	1.9	0
50–60	18	2.0	42.7	6.1	21.8	23.7	1.2	53.3	0
	22	0	73.7	0.3	46.5	2.6	3.1	26.3	0
	26	0	89.5	0	64.8	0	5.4	1.7	0
60–70	18	1.0	15.6	4.1	4.9	16.2	0	53.2	0
	22	0	33.6	0	14.3	1.8	0	24.0	0
	26	0	51.4	0	24.4	0	0	0.3	0
70–80	18	0.2	0.4	1.6	0.1	10.7	0	38.2	0
	22	0	0.7	0	0.1	1.4	0	18.3	0
	26	0	1.9	0	0.1	0	0	0.2	0
80–90	18	0	0	0.2	0	9.1	0	35.9	0
	22	0	0	0	0	1.6	0	15.3	0
	26	0	0	0	0	0	0	0	0

Additional calculations were made for zone 50–60° (latitude of Poland), i.e. for $H_{min} = 0^\circ, 5^\circ, 10^\circ, 15^\circ, 20^\circ$ and 25° , No Fix (in per cent) and the detailed distribution

of GDOP coefficient values both for three constellations, A, B and C, (table 5) and for the same H_{min} values minimal, maximal and weighed number of visible satellites for all 10 constellations with the number of satellites between 18 and 27 (table 6). We can say that in this zone:

- in open area 2D position can be obtained with each constellation 18 satellites or more, 3D position with 19 satellites or more;
- for $H_{min} = 5^\circ$ and $H_{min} \leq 20^\circ$ 3D position can be obtained if the constellation consists of 24 satellites or more and 27 satellites respectively;
- for C constellation (26 satellites) probability of GDOP less than 3 is greater than 2, but less than 6 always.

Table 5. No Fix (in percent) and GDOP coefficient values for different masking elevation angles (H_{min}) at latitudes 50–60° for different Galileo constellations [own study]

φ [°]	Constellation	No Fix [°]	GDOP coefficient — ν [%]							
			$\nu \leq 2$	$2 < \nu \leq 3$	$3 < \nu \leq 4$	$4 < \nu \leq 5$	$5 < \nu \leq 6$	$6 < \nu \leq 8$	$8 < \nu \leq 20$	$\nu > 20$
0	18	2.0	0	42.7	41.7	5.3	5.1	1.8	0.9	0.5
	22	0	0	69.9	27.2	1.7	1.2	0	0	0
	26	0	0	89.5	10.5	0	0	0	0	0
5	18	6.1	0	21.8	47.4	9.6	9.8	3.8	0.7	0.8
	22	0.5	0	43.8	46.9	5.5	1.9	0.8	0.6	0
	26	0	0	64.8	34.5	0.6	0.1	0	0	0
10	18	12.0	0	7.3	36.9	14.7	17.7	8.8	1.8	0.8
	22	1.7	0	19.8	47.0	16.0	8.6	4.1	2.3	0.5
	26	0	0	32.3	53.2	12.5	1.8	0.2	0	0
15	18	16.2	0	1.2	19.2	14.7	22.1	11.1	4.7	3.3
	22	4.9	0	2.7	37.4	23.2	15.7	7.2	6.3	2.6
	26	0	0	5.4	54.8	31.4	6.9	1.4	0.1	0
20	18	37.8	0	0	8.8	12.8	22.8	9.4	4.9	3.5
	22	12.5	0	0	19.7	26.0	21.8	6.8	9.1	4.1
	26	1.1	0	0.1	32.1	44.3	17.6	1.9	1.7	2.2
25	18	53.3	0	0	2.0	9.7	18.2	6.8	5.6	4.4
	22	25.8	0	0	5.4	21.4	22.4	5.9	11.3	7.8
	26	1.7	0	0	10.0	41.4	25.7	2.5	9.9	8.8

Table 6. Minimal l_{min} , maximal l_{max} and weighed number l_m of Galileo satellites visible above masking elevation angle H_{min} by the observer at latitudes 50–60° for different constellations [own study]

Constellation — number of satellites	Number of satellites visible	Masking elevation angle H_{min} [°]					
		0	5	10	15	20	25
18	l_{min}	3	2	2	2	1	1
	l_{max}	11	10	9	8	7	6
	l_m	7.06	6.28	5.45	4.65	4.06	3.51
19	l_{min}	4	3	3	3	2	2
	l_{max}	11	10	9	8	7	6
	l_m	7.49	6.66	5.77	4.93	4.31	3.73
20	l_{min}	4	3	3	3	2	2
	l_{max}	11	11	10	9	8	7
	l_m	7.90	7.04	6.09	5.21	4.54	3.94
21	l_{min}	5	3	3	3	2	2
	l_{max}	11	11	10	9	8	7
	l_m	8.28	7.69	6.38	5.46	4.76	4.12
22	l_{min}	5	3	3	3	2	2
	l_{max}	12	11	10	9	8	7
	l_m	8.63	7.69	6.65	5.68	4.95	4.29
23	l_{min}	5	3	3	3	3	2
	l_{max}	12	11	10	9	8	7
	l_m	9.08	8.10	7.00	5.99	5.22	4.52
24	l_{min}	6	4	4	4	3	3
	l_{max}	12	11	10	9	9	7
	l_m	9.54	8.50	7.34	6.28	5.47	4.74
25	l_{min}	6	4	4	4	3	3
	l_{max}	12	11	10	10	9	7
	l_m	10.0	8.93	7.71	6.60	5.74	4.97
26	l_{min}	7	5	5	4	3	3
	l_{max}	12	11	10	10	9	7
	l_m	10.64	9.29	8.01	6.87	5.98	5.18
27	l_{min}	8	6	6	6	4	4
	l_{max}	12	12	10	10	9	7
	l_m	10.85	9.68	8.35	7.14	6.22	5.41

The percentage of satellites visible above given angle H for three constellations (A, B and C) at different observer's latitudes is presented in the table 7. We can recapitulate that:

- the percentage of visible satellites decreases with the angle H in each zone; this diminution is practically the same for all constellations;

- if masking elevation angle H_{min} is equal 0° it means that 100% of satellites can be used for positioning, if this angle is equal 5° the percentage of these satellites decreases to about 90%, if $H_{min} = 25^\circ$ this percentage is about 50% only;
- the percentage of satellites visible above 50° is very little, in zone $70-80^\circ$ it is about 18%, in zone $80-90^\circ$ about 5% only.

Table 7. Percentage of satellites visible above angle (H) for Galileo system at different observer's latitudes (φ), L_m — weighed mean number of satellites visible above horizon ($H = 0^\circ$) [own study]

φ [$^\circ$]	Constellation	L_m	Elevation angle H [$^\circ$]											
			0	5	10	15	20	25	30	40	50	60	70	80
0-10	18	7.31	100	91.2	81.0	70.6	60.1	48.9	39.9	24.9	15.2	8.2	3.5	0.9
	22	8.98	100	90.6	80.9	70.4	59.9	49.0	39.8	24.9	15.2	8.1	3.4	0.9
	26	10.67	100	90.7	81.1	70.7	60.0	49.4	40.1	25.4	15.7	8.5	3.5	0.9
10-20	18	7.15	100	88.8	77.3	67.2	58.3	50.3	43.2	28.2	16.5	9.2	4.0	1.0
	22	8.77	100	88.8	77.6	67.4	58.7	50.7	43.4	28.5	16.6	9.1	4.0	1.0
	26	10.45	100	89.0	77.7	67.8	59.1	49.7	43.8	29.2	17.1	9.3	4.0	1.0
20-30	18	6.67	100	88.0	78.0	68.5	60.6	53.0	45.6	33.8	21.2	10.9	4.6	1.2
	22	8.23	100	87.8	78.2	69.1	61.1	53.6	46.3	33.8	21.4	11.1	4.8	1.2
	26	9.83	100	88.7	78.6	69.7	61.6	54.2	46.8	34.1	21.7	11.1	4.8	1.1
30-40	18	6.50	100	87.9	78.2	69.1	61.3	53.7	47.2	35.4	24.6	14.5	5.7	1.5
	22	7.99	100	88.3	78.6	69.8	61.6	54.3	47.6	35.6	24.8	15.1	6.0	1.6
	26	9.58	100	88.6	79.1	70.2	62.4	54.9	48.3	35.7	24.9	15.2	5.1	1.6
40-50	18	6.66	100	86.7	76.5	67.4	59.4	51.7	45.3	33.9	24.0	15.6	7.8	1.9
	22	8.18	100	87.8	76.9	68.1	59.7	52.5	45.9	34.3	24.5	15.9	8.2	2.0
	26	9.85	100	87.6	77.1	68.1	60.1	52.7	46.1	34.1	24.2	15.8	8.3	2.1
50-60	18	6.97	100	88.6	77.1	65.3	57.6	49.2	45.5	33.8	24.5	13.5	7.0	2.2
	22	8.63	100	89.2	76.9	65.8	57.7	49.7	42.9	31.4	22.0	13.7	7.1	2.2
	26	10.42	100	89.2	76.9	66.0	57.4	49.8	42.8	31.0	21.7	13.5	7.1	2.3
60-70	18	7.11	100	89.7	81.7	70.9	60.4	49.6	42.0	28.9	18.3	10.0	3.6	0.3
	22	8.81	100	90.8	81.9	71.8	60.5	50.2	41.9	29.1	18.7	10.2	3.6	0.3
	26	10.64	100	90.8	81.9	71.9	60.4	50.2	41.8	28.7	18.5	10.1	3.6	0.3
70-80	18	7.19	100	90.8	82.9	73.7	65.3	56.0	45.8	26.8	14.0	4.2	0.1	0
	22	8.91	100	91.2	83.6	74.9	65.9	56.6	45.9	27.1	14.3	4.3	0.1	0
	26	10.74	100	91.8	83.6	75.1	66.1	56.6	45.8	27.0	14.2	4.2	0.1	0
80-90	18	7.22	100	91.2	83.9	74.9	67.1	58.0	50.3	29.2	5.4	0	0	0
	22	8.98	100	92.2	84.0	75.8	67.3	59.2	50.7	29.4	5.5	0	0	0
	26	10.81	100	92.1	83.9	75.7	67.4	59.2	50.9	29.6	5.4	0	0	0

Distribution (in per cent) of satellite azimuths (8 mentioned above intervals) for $H_{min} = 0^\circ$ (open area without any obstacles) for three Galileo constellations (18, 22 and 26 satellites) at different observer's latitudes are shown in the table 8.

Table 8. Distribution (in per cent) of satellite azimuths for masking elevation angle $H_{min} = 0^\circ$ in open area for different Galileo constellations at different observer's latitudes (φ), l_m — weighed mean number of satellites visible by the observer [own study]

φ [$^\circ$]	Constellation	l_m	Satellite azimuth [$^\circ$]							
			0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360
0-10	18	7.31	14.2	10.1	10.4	15.3	15.7	10.2	10.0	14.1
	22	8.98	14.4	9.8	10.3	15.3	15.5	10.0	10.2	14.5
	26	10.67	14.6	10.1	10.2	15.1	15.0	10.0	10.3	14.7
10-20	18	7.15	13.4	11.2	10.4	14.9	15.1	10.1	11.2	13.7
	22	8.77	13.7	10.8	10.3	14.8	15.2	9.7	11.3	14.2
	26	10.45	13.9	11.1	10.2	14.7	14.7	9.7	11.5	14.2
20-30	18	6.67	12.9	13.0	10.9	13.3	13.0	10.6	13.2	13.1
	22	8.23	13.1	12.8	10.8	12.9	13.1	10.5	13.2	13.6
	26	9.83	13.2	13.0	10.9	12.8	12.9	10.4	13.2	13.6
30-40	18	6.50	11.1	16.7	11.1	11.6	11.5	11.2	15.9	10.9
	22	7.99	11.1	16.3	11.1	11.3	11.8	11.0	16.2	11.2
	26	9.58	11.0	16.4	11.1	11.4	11.6	11.0	16.1	11.4
40-50	18	6.66	8.6	19.9	11.3	10.7	11.1	11.3	18.5	8.6
	22	8.18	8.7	19.6	11.0	10.6	11.3	11.0	19.3	8.5
	26	9.85	8.6	19.6	11.1	10.6	11.2	11.0	19.2	8.7
50-60	18	6.97	10.0	17.8	12.2	10.3	11.1	12.3	16.6	9.7
	22	8.63	10.1	17.6	11.9	10.2	11.1	12.1	17.2	9.8
	26	10.42	9.9	17.4	12.1	10.4	11.1	12.0	17.1	10.0
60-70	18	7.11	10.9	14.8	13.3	11.2	11.9	13.2	13.9	10.7
	22	8.81	11.2	14.3	13.0	11.0	12.0	13.2	14.3	11.0
	26	10.64	10.9	14.3	12.9	11.5	12.0	13.0	14.2	11.2
70-80	18	7.19	11.6	13.6	13.1	11.8	13.0	12.3	13.0	11.6
	22	8.91	11.9	13.2	12.7	11.8	12.8	12.7	13.1	11.8
	26	10.74	11.7	13.1	12.6	12.1	12.6	12.8	13.0	12.0
80-90	18	7.22	12.2	13.3	12.6	12.3	13.0	11.8	12.6	12.2
	22	8.98	12.3	12.9	12.1	12.3	13.0	12.2	12.8	12.4
	26	10.81	12.0	12.9	12.2	12.4	12.9	12.3	12.7	12.6

We can say that:

- distributions of satellite azimuths are practically the same for all three constellations, independently of observer's latitudes;

- in zone 80–90° the number of satellites in all intervals is for all constellations practically the same, while in all other 8 zones this distribution depends on observer's latitude;
- at latitudes 0–20° the numbers of satellites with azimuth from intervals (135–225° and 315–045°) are greater than from the rest intervals (045–135 and 225–315°) considerably;
- at latitudes 30–70° the numbers of satellites with azimuth from two intervals, 045–090° and 270–315°, are greater than from all the rest intervals, at latitudes 40–50°, in particular.

CONCLUSIONS

1. The possibility of positioning by means of Galileo system before Full Operational Capability (FOC) will depend on the constellation, the number of active satellites, in particular, user's latitude and masking elevation angle.
2. For 18 satellites constellation 3D position can be obtained in open area ($H_{min} = 0^\circ$) in zone 80–90° only.
3. For 22 satellites constellation if $H_{min} = 0^\circ$ 3D position can be obtained in each zone, if $H_{min} = 5^\circ$ in some zones only, but 2D position in each zone.
4. For 26 satellites constellation if $H_{min} \leq 15^\circ$ 3D position can be obtained in all zones but if $H_{min} = 25^\circ$ in zone 80–90° only.
5. At latitude of Poland (zone 50–60°) if $H_{min} \leq 15^\circ$ 3D position can be obtained if the constellation consists of 24 satellites at least. Nominal constellation permits positioning in restricted area ($H_{min} \leq 25^\circ$) also.
6. Distribution of satellite azimuths depends on the observer's latitudes, but it is practically the same for all three constellations, independently of the number of satellites.
7. The percentage of satellites visible above masking elevation angle is for all constellations practically the same. It means that the possibility of position fix in restricted area depends first of all on the total number of satellites in current constellation.

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Received May 2012

Reviewed August 2012