Investigation of the Possibility of Synchronizing Timestamps of Onboard Equipment and Determining the Location of a Spacecraft in Various Types of Orbits Using GLONASS/GPS Navigation Systems

Leonid Kurakhtenkov, Andrey Kuchumov
MTUCI
Moscow, Russia
lkurakht@gmail.com, kuchumov@gmail.com

Fedor Ivandikov
MTUCI
Moscow, Russia
Dr.Leprikon@yandex.ru

***Abstract*— Antenna complexes of satellite navigation systems are located in such a way that they cover the Earth with a reserve height of 1500-2000 km. Thus, it is possible to communicate with spacecraft located at different altitudes, including higher orbits than the navigation systems. The article provides estimates of the time intervals of communication with at least one navigation satellite to synchronize the timestamp and at least with four satellites to determine the coordinates of the spacecraft. Space vehicles in medium-altitude circular Earth orbits (MEO) in altitude from 2000 km to 44000 km, a geostationary orbit and a geosynchronous high-elliptical orbit (HEO) of the Molnia type with a perigee height of 1000 km are considered.**

I. Introduction

The task of time synchronization is a necessary requirement for the successful operation of any distributed system. Examples of tasks, requiring temporal synchronization may be: determining the position of an object, determining the velocity of an object, environmental observation, identification of radiation sources, separation of users of a communication network. The main problem is the inevitable deterioration of clock generators, which leads to a difference in timestamps of different nodes of a distributed system. To compensate for that various mechanisms of tuning the node's local clock relative to some reference clock are used. For onboard equipment of low altitude spacecraft such synchronization is possible, as the altitude of GLONASS/GPS orbits and the radiation patterns of the navigation systems' satellites allow for uninterrupted radio visibility of low altitude satellites. For medium-altitude spacecraft uninterrupted radio visibility is impossible to achieve. In the article the results of a simulation of spacecraft in circular, polar, geocentric and geosynchronous high-elliptical orbits are presented, estimates of mean duration of radio visibility of at least one GPS/GLONASS transmitter, the time of guaranteed timestamp synchronization and a guaranteed (longest) and mean time of spacecraft position determination using no less than four satellites are made.

II. Main part

GLONASS orbital grouping at the time of simulation consisted of 24 active spacecraft, operating at the altitude of 19 100 km. The aperture of the spacecraft antenna is 38º, so the range of radio visibility includes areas up to 2000 km above the surface of the Earth. GPS orbital grouping consists of 32 active spacecraft, operating at the altitude of 20 180 km. The aperture of the spacecraft antenna is 34º, which captures areas up to 1400 km above the surface of the Earth – Fig. 1.

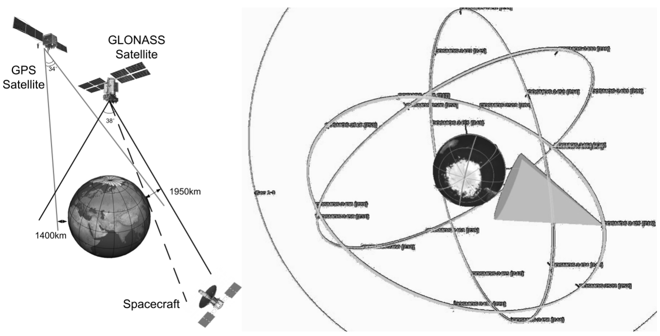

Fig. 1. Scheme of possible time synchronization using GLONASS/GPS radio signals.

Evaluation of the possibility of time synchronization with GLONASS/GPS spacecraft was conducted for three types of spacecraft: those placed in medium-altitude circular polar orbits at altitudes from 2000 km to 44000 km, those placed in a geostationary orbit and those in a high-elliptical geostationary orbit with perigee altitude of 1000 km. As a result of simulation of spacecraft operation in software package QSatStat, developed in MTUCI, the following parameters were calculated: average daily time window for synchronization (mean time spent in range of at least one transmitter of a navigation system), mean number of communication sessions in a day, mean duration of a communication session, mean time between sessions, maximum communication gap, maximum communication availability interval. The results of the calculations are presented in Table I.

TABLE I ESTIMATES OF CHARACTERISTICS OF POSSIBLE TIME SYNCHRONISATION USING GLONASS/GPS FOR SPACECRAFT IN MEDIUM-ALTITUDE, GEOSTATIONARY AND HIGH ELLIPTIC ORBITS.

GLONASS/GPS availability characteristic	Medium-altitude circular orbit, 10 000 km altitude	Geostationary orbit	High-elliptic orbit
Average daily synchronization time	21h 55m/ 19h 21m	10h 20m/ 9h 48m	15h 49m/ 12h 31m
Average number of communication sessions per day	18.3/ 34.6	36.5/ 22.2	25.4/ 22.1
Average communication session duration	1h 11m/ 33m	34m/ 26m	37m/ 34m
Average time between communication sessions	7m/ 8m	45m/ 38m	19m/ 31m
Maximum time between communication sessions	19m/ 31m	1h 33m/ 1h 47m	1h 26m/ 58m
Maximum duration of communication session	6h 11m/ 2h 36m	2h 7m/ 1h 28m	4h 9m/ 2h 14m

For medium-altitude orbital groupings of significance are plots of maximum delay between communication sessions (guaranteed synchronization duration) and average daily time window for synchronization against spacecraft latitude, they are presented in Fig. 2, and Fig. 3. The analysis was conducted for spacecraft in orbit at altitudes from 2000 km (uninterrupted communication with GLONASS satellites) to 20 000 km (guaranteed synchronization duration of 56 minutes, average daily communication duration of 15 hours 49 minutes).

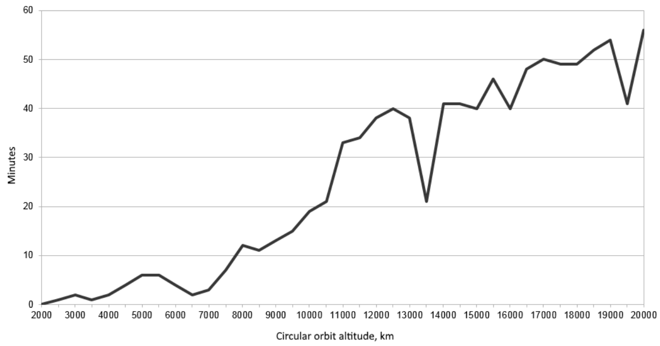

Fig. 2. Plot of guaranteed synchronization time with GLONASS against spacecraft orbit altitude

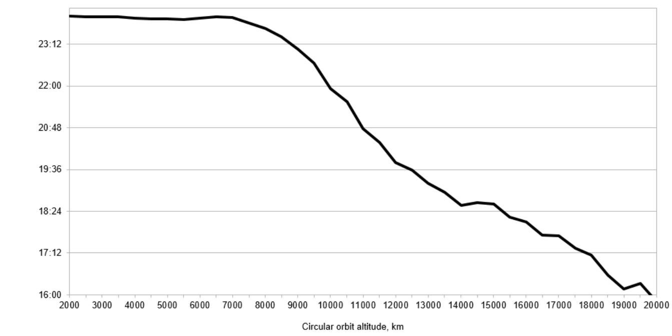

Fig. 3. Plot of average daily synchronization time using GLONASS against spacecraft orbit altitude

In the simulation communication was deemed possible, if the spacecraft is inside the antenna aperture of at least one GLONASS/GPS satellite, and the communication line doesn't come closer than 20 km to the surface of the Earth.

It is worth mentioning, that the maximum distance between spacecraft in a high-elliptical orbit and a navigation satellite is three times the distance from a navigation spacecraft to a receiver on Earth. Nevertheless, the radio link will have enough power for time synchronization, due to the absence of atmosphere dampening, the use of a directional receiver antenna is also possible.

Similar simulations were performed in order to determine the position of the spacecraft, i.e. the time characteristics of communication capabilities with at least 4 navigation satellites simultaneously. Estimates of guaranteed (maximum) and mean positioning time were made. The results are presented in Table II.

TABLE II ESTIMATES OF CHARACTERISTICS OF POSSIBLE SPACECRAFT POSITIONING FOR DIFFERENT ORBIT TYPES AND ALTITUDES.

Orbit altitude, km/type	Guaranteed (maximum) time between positioning sessions via GPS	Mean time between positioning sessions via GPS	Guaranteed (maximum) time between positioning sessions via GLONASS	Mean time between positioning sessions via GLONASS
2000	12 m	3 m	3 m	2 m
4000	54 m	9 m	38 m	9 m
6000	1 h 59 m	19 m	1 h 31 m	19 m
8000	2 h 26 m	38 m	2 h 2 m	29 m
10000	5 h 22 m	52 m	7 h 33 m	1 h 1 m
12000	6 h 44 m	1 h 36 m	9 h 33 m	2 h 2 m
14000	15 h 48 m	2 h 58 m	12 h 14 m	2 h 29 m
16000	30 h 39 m	8 h 49 m	13 h 39 m	2 h 51 m
18000	71 h 42 m	26 h 37 m	10 h 11 m	3 h 46 m
20000	88 h 20 m	29 h 10 m	19 h 17 m	4 h 33 m
22000	105 h 32 m	34 h 14 m	24 h 53 m	5 h 31 m
24000	147 h 30 m	47 h 58 m	22 h 9 m	5 h 55 m
26000	175 h 44 m	79 h 58 m	25 h 48 m	9 h 55 m
28000	214 h 28 m	79 h 59 m	27 h 46 m	10 h 18 m
30000	Impossible	Impossible	46 h 24 m	12 h 30 m
32000	Impossible	Impossible	31 h 54 m	11 h 54 m
34000	Impossible	Impossible	55 h 14 m	17 h 3 m
36000	Impossible	Impossible	44 h 32 m	14 h 56 m
38000	Impossible	Impossible	53 h 57 m	14 h 1 m
40000	Impossible	Impossible	39 h 35 m	15 h 56 m
42000	Impossible	Impossible	73 h 15 m	26 h 37 m
44000	Impossible	Impossible	74 h 17 m	19 h 57 m
GEO	Impossible	Impossible	Impossible	Impossible
HEO	10 h 21 m	2 h 6 m	11 h 2 m	2 h 27 m

Plots of guaranteed and mean positioning time against height of the polar orbit are presented in Fig. 4 and Fig. 5.

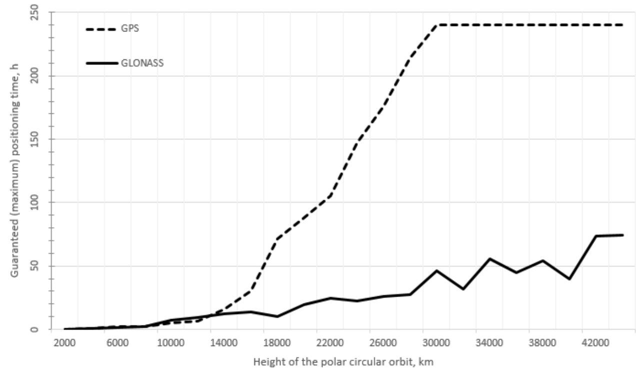

Fig. 4. Plot of garanteed (maximum) positioning time against circular polar orbit altitude.

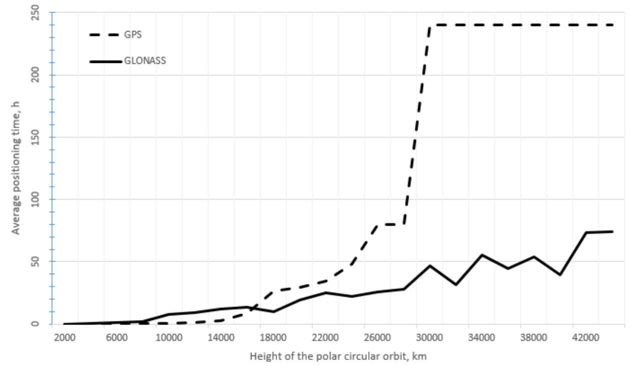

Fig. 5. Plot of average positioning time against circular polar orbit altitude.

III. CONCLUSION

GLONASS/GPS timestamps can be used to synchronize time in distributed radio engineering systems, whose nodes are placed onboard spacecraft. Guaranteed synchronization time for spacecraft in a high-elliptic and geostationary orbit communicating with GLONASS satellites is one and a half days. For spacecraft in a circular orbit with an altitude of no more than 10 000 km guaranteed synchronization time is less than 20 minutes. For synchronization with GPS said parameters differ negligibly. The same cannot be said for positioning times: while GLONASS and GPS have comparable positioning capabilities concerning spacecraft in low-altitude orbits, for nearly polar orbits at altitudes of up to 44 000 km positioning is possible using GLONASS with positioning times of under a day, meanwhile positioning using GPS becomes impossible in similar orbits at altitudes over 30 000 km. At the altitudes of 18 000 – 20 000 km positioning time (both mean and guaranteed) is up to 7 times longer when using GPS, than when using GLONASS.

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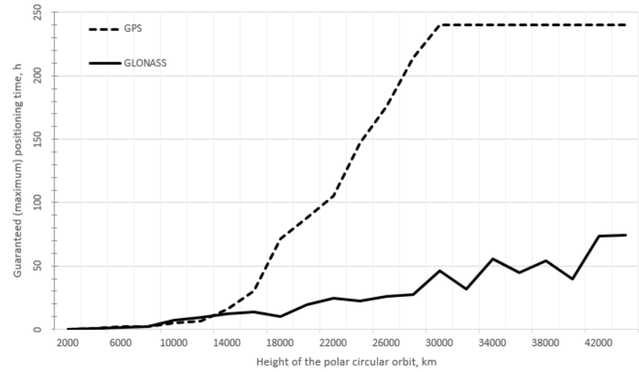

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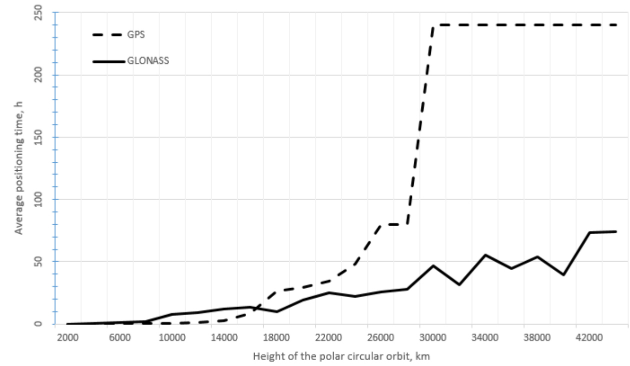

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