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Procedia Engineering 104 (2015) 147 – 156

Procedia Engineering

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Scientific and Technological Experiments on Automatic Space Vehicles and Small Satellites

The Technology of LEO Satellite Communication Systems Utilization for the Rapid Exchange of Data with the Low-Altitude Spacecraft: Scientific Technological Equipment "Kontakt-MKA" On the Small Spacecraft "AIST-2"

Igor Belokonov[a], Denis Avariaskin[a], Denis Davydov[a]

[a]Samara State Aerospace University, 34, Moskovskoye Shosse, Samara, Russia, 443086

Abstract

In this paper was analysed the possibility of communication sessions with the small spacecraft via the Globalstar system. The duration of communication sessions was estimated. It was made a stochastic analysis of the data transmission capabilities between the two spacecraft via the Globalstar system. The probability of data transmission between two spacecraft, depending on data volume and workload of the Globalstar system was estimated. The spaceexperiment on the small spacecraft "AIST-2" is planning to test the results.

Peer-review under responsibility of organizing committee of the Scientific and Technological Experiments on Automatic Space Vehicles and Small Satellites (SPEXP2014)

Keywords: nanosatellite; communication; LEO satellite communications systems.

* Corresponding author. Tel.: +7-846-267-44-44
*E-mail adress:*avaryaskind@gmail.com

1. Introduction

Nowadays it is actively developing and implementing the technologies of LEO satellite communications systems (LSCS) to enable communication between moving objects on the Earth. The problem of the use of such satellite communication systems for objects, moving on a low Earth orbit, becomes increasingly relevant. This is due to the fact that the carrying out of complex experiments or other operations with the use spacecraft (SC) constellations often requires a communication channel to provide receiving data from board of the SC and transmission commands

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doi:10.1016/j.proeng.2015.04.106

to SC in real time independently of their location within radio line of sight the Mission Control Center (MCC). Furthermore, there may be used effectively Internet, providing data transmission from the gateway to the user.

Traditional means of communication with SC require location of SC within radio line of sight of the MCC transceiver antenna, which is possible only in a certain range of latitudes. Using modern LSCS allows rapid and low-cost access to the processes occurring on the orbit by using advanced IT-technologies. In 2005 there was first carried out an experiment on the organization of data transmission via Globalstar LSCS on nanosatellite TNS-0 /1/ [1].

In this work was carried out the analysis of the possibility of communication sessions by using Globalstar LSCS, the duration of communication sessions and the possible volume of transmitting data were estimated.

2. Investigation of possible existing of communication links "SC-Globalstar - MCC"

For simulation of spacecraft motion and evolution of Globalstar satellites have been used the equations of motion of the center of mass of spacecraft in absolute geocentric coordinate system, which take into account the non-central gravitational field of the Earth and influence of atmosphere braking[2].

Simulation of the evolution of Globalstar satellites carried out without taking into account the influence of the atmosphere.

For transmission of data from SC to the mission control center (MCC) requires to transmit data on one of the Globalstar satellites, which transmits the data through a gateway. Further data from the SC available for user via the Internet (Figure 1).

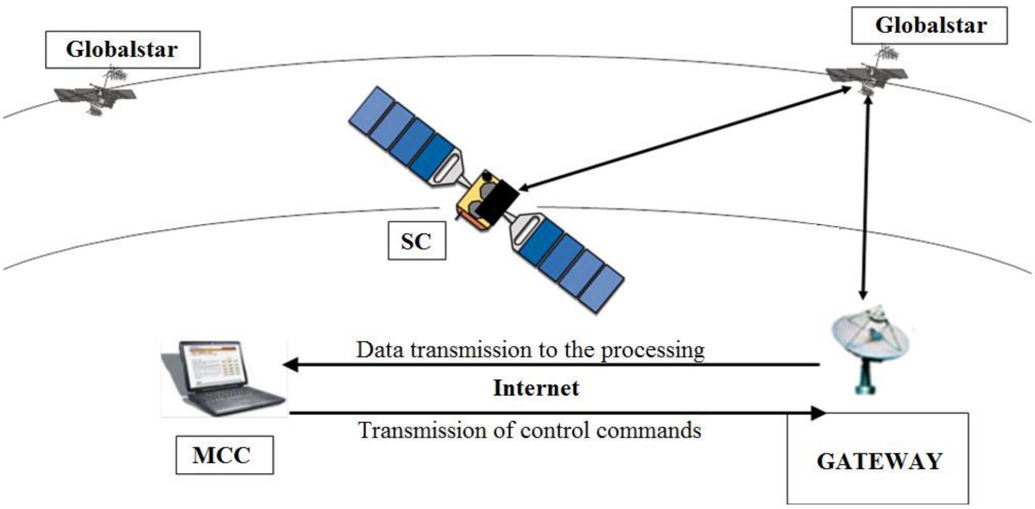

Fig. 1. Scheme of data transmission from the board of the spacecraft to MCC via LSCS Globalstar

Thus, for data transmission it is required carrying out the condition of simultaneously visibility of SC with one of the satellites Globalstar LSCS, which should be in radio line of sight of one of the gateway (Figure 2). The equations (1) and (2) determine the moments of time of entering within radio line of sight and exit from it[3]:

$$\Phi_{CS-GW} = \bar{r}_{CS-GW}\bar{r}_{GW} - \bar{r}_{CS-GW} R_E \sin\gamma_{\min GW}, \quad (1)$$

$$\Phi_{CS-SC} = \bar{r}_{CS-SC}\bar{r}_{SC} - \bar{r}_{CS-SC} R_{SC} \sin\gamma_{\min SC}. \quad (2)$$

$\gamma_{\min GW}, \gamma_{\min SC}$ – minimum elevation angles;

$\bar{r}_{GW}$ – radius vector of the gateway; $\bar{r}_{CS-GW}$ – range vector from the gateway to the Globalstar satellite;

R_E – Earth radius;

$\bar{r}_{SC}$ – radius vector of the SC;

$\bar{r}_{CS-SC}$ – distance vector from the SC to the Globalstar satellite;

R_{SC} – radius of the orbit of SC.

If the function Φ takes a positive value, then there is a mutual radio line of sight of the SC, Globalstar satellite and gateway. If Φ<0, then there is no mutual radio line of sight. Changing the sign of the function Φ from negative to positive value corresponds to the rising of the Globalstar satellite above the horizon in relation to gateway or SC. Changing the function Φ from positive value to negative corresponds that the Globalstar satellite goes down the horizon in relation to gateway or SC.

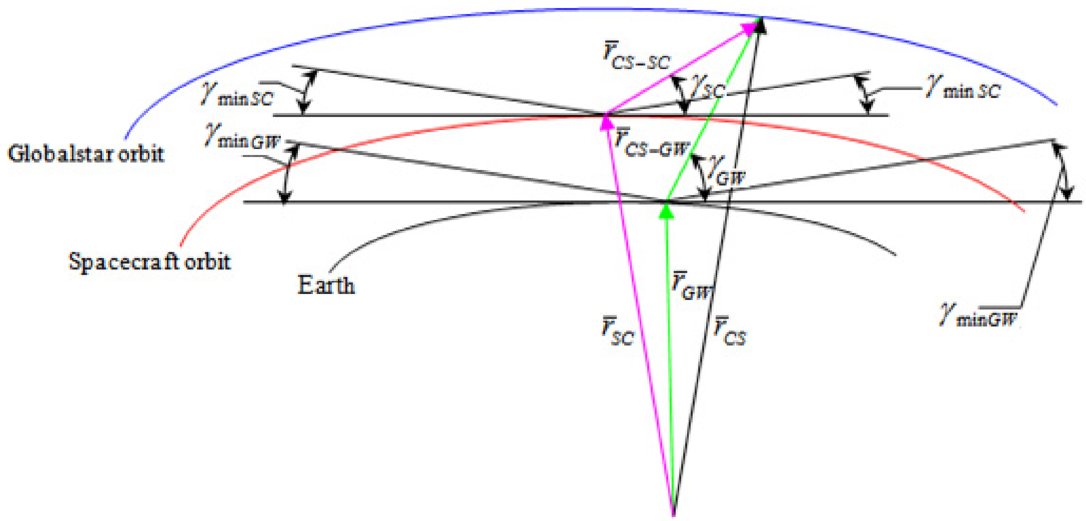

Fig.2. Determination of the mutual radio line of sight of the Globalstar satellite, gateway and SC.

Thus, to perform mutual radio line of sight "SC - Globalstar satellite - gateway" the condition should be satisfied:

$$\left.\begin{array}{l}\Phi_{CS-GW} \geq 0 \\ \Phi_{CS-SC} \geq 0\end{array}\right\} \quad (3)$$

This requirement is necessary due to the fact that the Globalstar satellites operate on the principle «Bent Pipe». This is means that they are not able to communicate with each other and they work as repeaters. In the case of using LSCS with inter-satellite communication satisfying of the simultaneous mutual radio line of sight LSCS satellites and gateway condition is not required.

It was performed multiparametric research of the communication sessions duration with SC via LSCS Globalstar in depending on orbit altitude for different values of the orbit inclination i and orbital plane displacement ΔΩ of the SC orbit relative LSCS Globalstar constellation orbits for case of local (Figure 3) and global (Figure 4) roaming. The time interval of the simulation was selected from the condition–Globalstar satellites and SC make integer number of turns on their orbits.

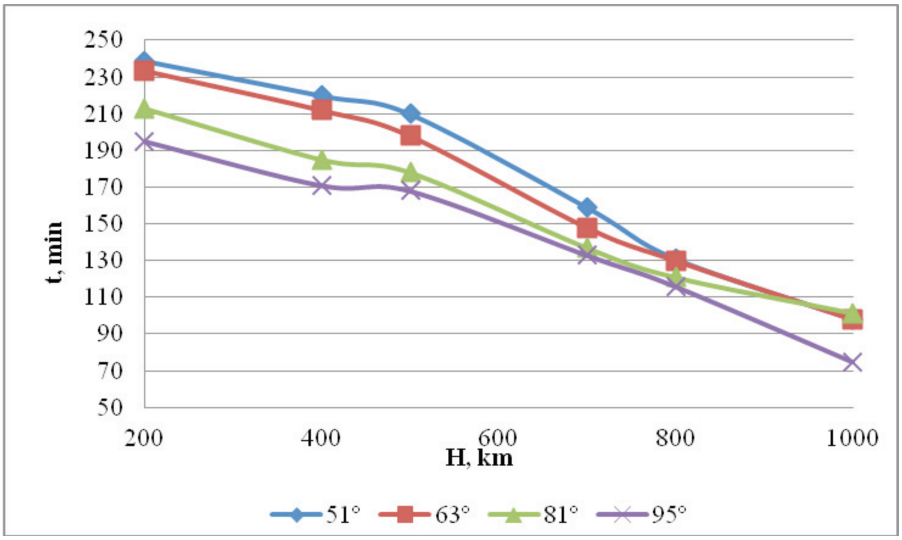

Fig. 3. The communication time via Globalstarfor localroaming (ΔΩ=0°)

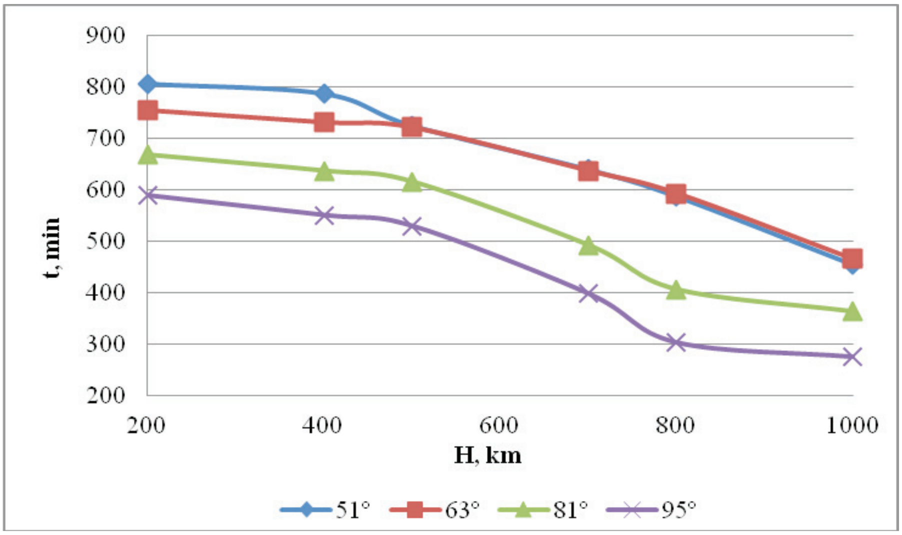

Fig. 4. The communication time via Globalstarfor global roaming (ΔΩ=0°)

The simulation results show that the communication time via the Globalstar system for the 19 hour flight can range from 80 to 300 minutes without the use of global roaming services, depending on the altitude of the orbit, its inclination and longitude of the ascending node. Using global roaming service allows you to increase the communication time is more than 3 times.

The estimation of the information amount that is possible to transmit using the system Globalstar, were made under the same conditions as the simulation to determine the duration of communication sessions.

The maximum amount of data transferred from the board of the spacecraft in orbit with an altitude 200 km, inclination i = 51 ° and longitude of the ascending node Ω = 45 ° at the gateways only in Russia (local roaming) is more than 20 MB for 19 hours.

The amount of information transmitted at the interval 19 hours without the use of global roaming services at altitudes of flight spacecraft up to 500 km ranges from 10 to 20 MB. For flight altitudes from 500 to 1000 km the amount of transmitted information is twice less.

The maximum amount of data transferred from the board of the spacecraft in orbit with a height of 200 km, inclination i = 51 ° and longitude of the ascending node Ω = 27 ° for all gateways of the Globalstar system, is more than 60 MB for 19 hours.

The dependence of the volume of information transmitted from the altitude and inclination of the spacecraft orbit had been identified for the case is the same either for local and global roaming.

3. Investigation of possible existing of communication links "SC - Globalstar - SC"

Performed a numerical research of principal possibility of transmission data between two SC via Globalstar LSCS resources (Figure 5) and specially designed experimental equipment "Kontakt-MKA" within the project of small spacecraft "AIST-2" (Figure 16, 17). Creating of a communication channel between two SC is possible if it is satisfied the conditions of mutual radio line of sight, at those times when the satellites Globalstar LSCS are within radio line of sight of ground gateway and two SC. The condition mutual radio line of sight, under which data can be transmitted between two spacecraft is:

$$\left.\begin{array}{l}\Phi_{CS-GW} \geq 0 \\ \Phi_{CS-SC_1} \geq 0 \\ \Phi_{CS-SC_2} \geq 0\end{array}\right\} \quad (4)$$

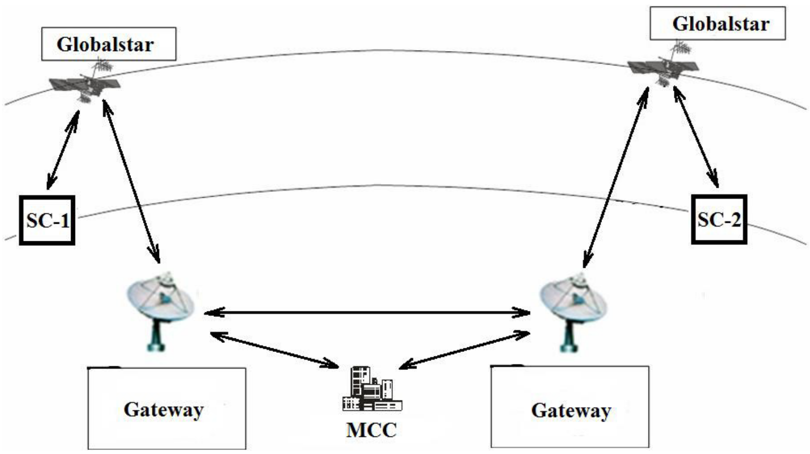

Fig. 5. The scheme of the organization of communication between two SC via LSCS Globalstar

It was performed the modeling for the cases of absence and the presence of global roaming. Modeling was performed for two SC moving in orbits with the same parameters - height of 510 km and an inclination of 97,3° on the range of multiplicity of mutual initial position. In the result of the modeling it was defined that for different values of the relative displacement ΔΩ of the two SC orbital planes relative to each other and the angular distance between two SC Δθ, not exceeding 25 °, it is possible to carry out from 8 to 12 communication sessions duration from 5 minutes in the absence of a global roaming, as well as from 22 to 37 communication sessions duration of more than 5 minutes in the presence of global roaming on the same interval repeatability of relative configuration. At the same time, with increasing values of the ΔΩ and Δθ number of short sessions increases and the number of long sessions decreases (Figure 6 -15).

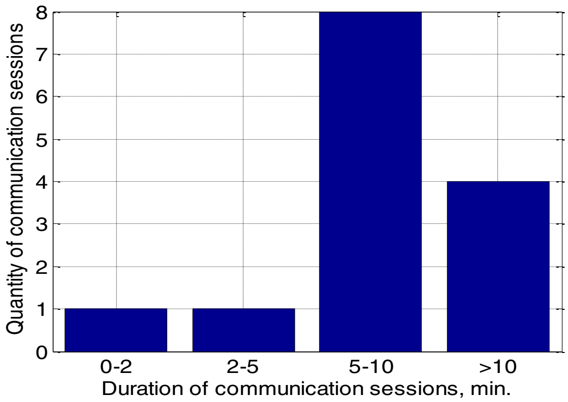

Fig. 6. The quantity of communication sessions between two SC when Δθ=5° and ΔΩ=0° (Local roaming)

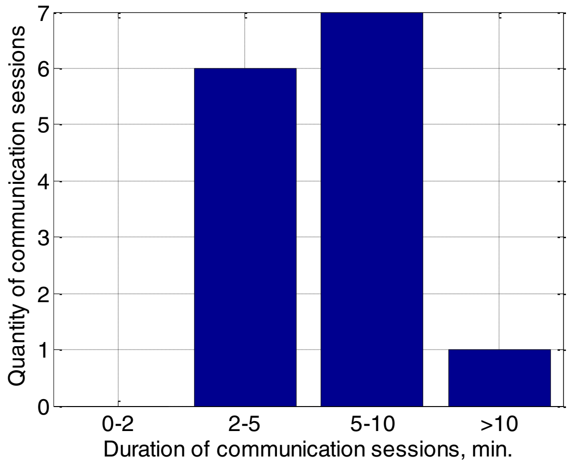

Fig. 7 The quantity of communication sessions between two SC when Δθ=25° and ΔΩ=0° (Local roaming)

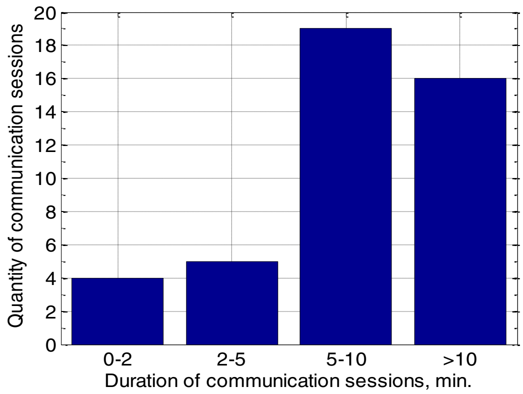

Fig. 8. The quantity of communication sessions between two SCwhen Δθ=5° and ΔΩ=0° (Global roaming)

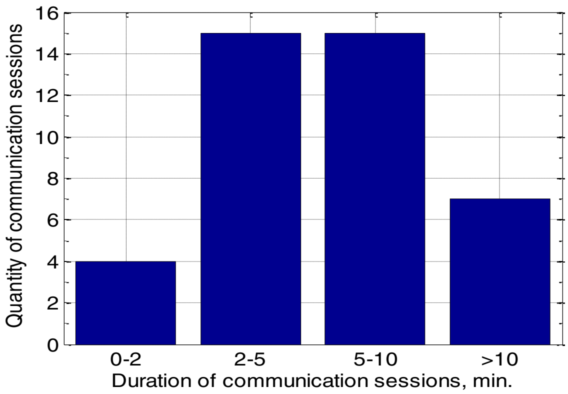

Fig. 9. The quantity of communication sessions between two SC when Δθ=25° and ΔΩ=0° (Global roaming)

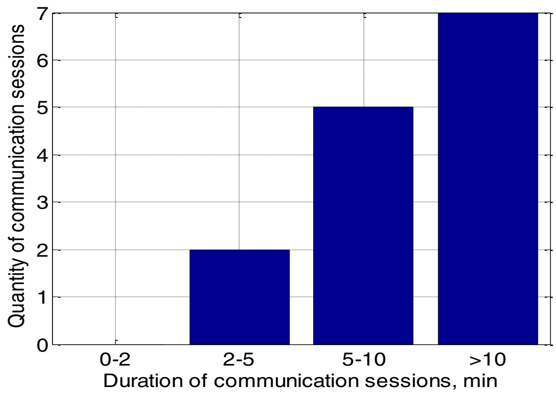

Fig. 10. The quantity of communication sessions between two SC when ΔΩ=5°and Δθ=0° (Local roaming)

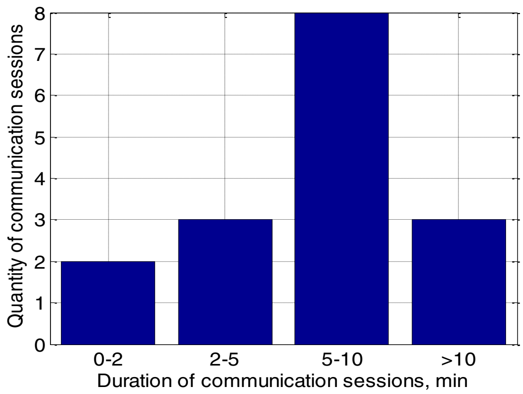

Fig. 11. The quantity of communication sessions between two SC when ΔΩ = 25 ° and Δθ = 0° (Local roaming)

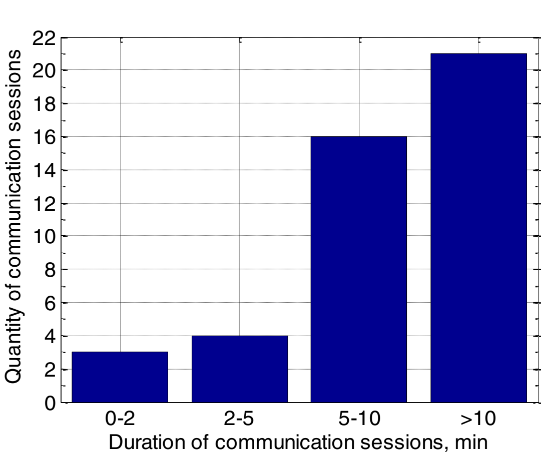

Fig. 12. The quantity of communication sessions between two SC when ΔΩ=5° and Δθ=0° (Global roaming)

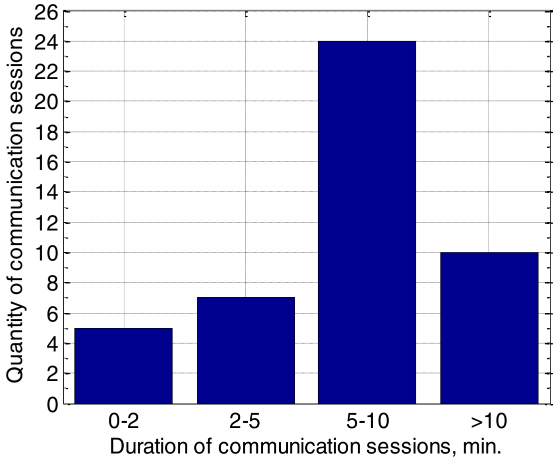

Fig. 13. The quantity of communication sessions between two SC when ΔΩ=25° and Δθ=0° (Global roaming)

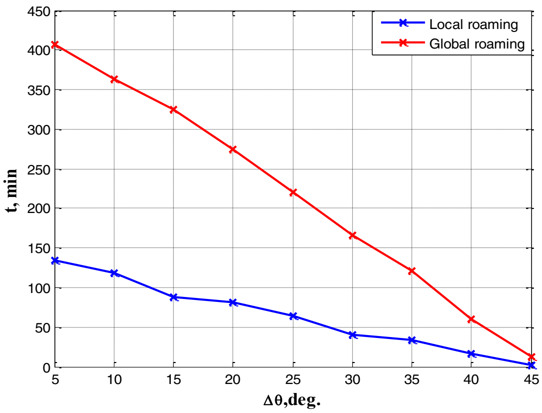

Fig. 14. The total communication time via Globalstar in depending on the angular distance between the spacecraft when ΔΩ=0°

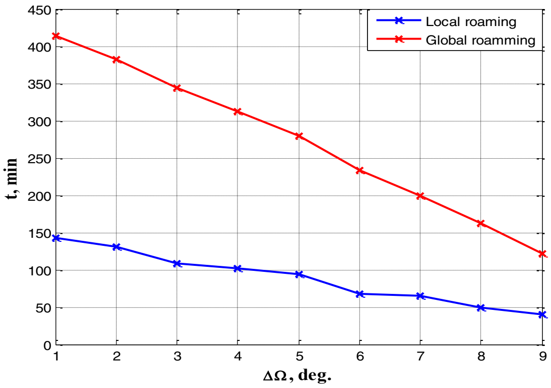

Fig. 15. The total communication time via Globalstar in depending on the spacecraft orbital planes displacement when Δθ=0°

4. Stochastic analysis of communication link "SC - Globalstar - SC"

Based on the presented earlier communication sessions simulation results it was made the stochastic analysis of the data transmission possibility between the two spacecraft via LSCS Globalstar. For this was assumed probabilistic model of the data transmission (figure 16).

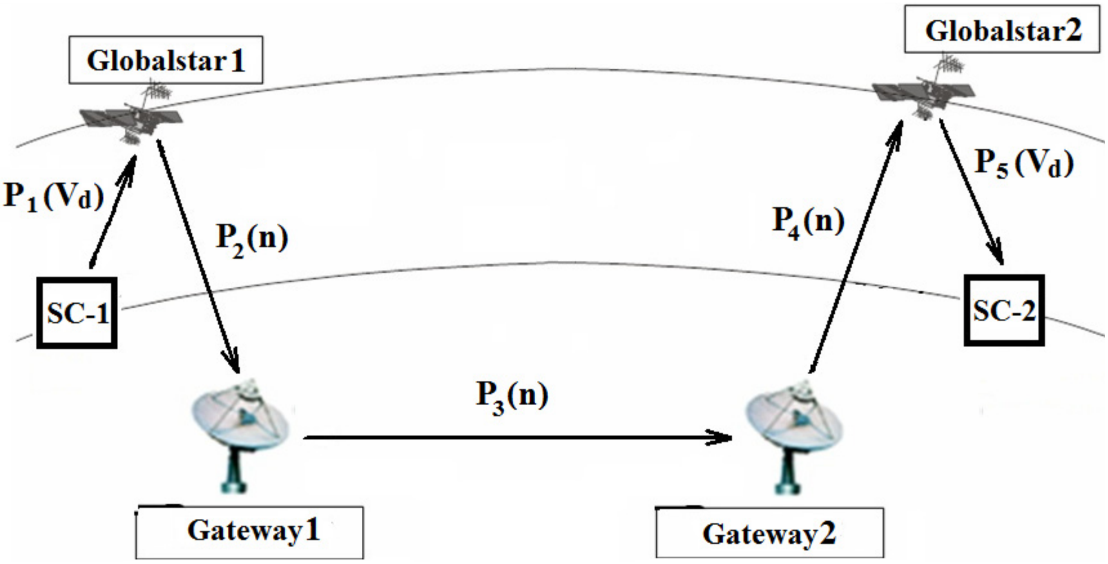

Fig. 16. Probabilistic model of the data transmission

To determine the probability of data transmission between the each spacecraft and Globalstar satellites (P_1 and P_5) it was used the normal law distribution of the data rate V_d inside the Globalstar (Figure 17). I.e. to transmit a required data volume for a predetermined communication time interval it is requires a certain minimum data rate. The occurrence probability of the data rates which is equal to (or higher) the minimum has normal law distribution. The estimation of the communication time intervals depending on both spacecraft orbital parameters presented earlier.

The Globalstar system was assumed as queuing system. The probability determination of the data transfer inside the Globalstar system (P_2, P_3, P_4) is performed using a Poisson law distribution depending on the quantity of simultaneous requests n (Figure 18). I.e. the more simultaneous requests are received for processing in Globalstar the lower the probability of successful transmission. It was assumed that one Globalstar satellite is able to process not more than 2000requestssimultaneously.

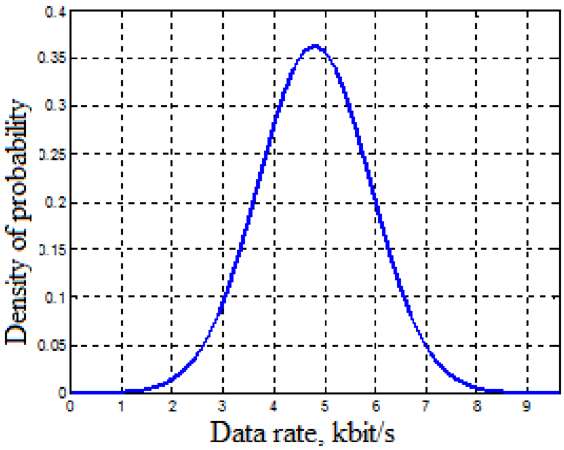

Fig. 17. Normal law distribution of the data rate

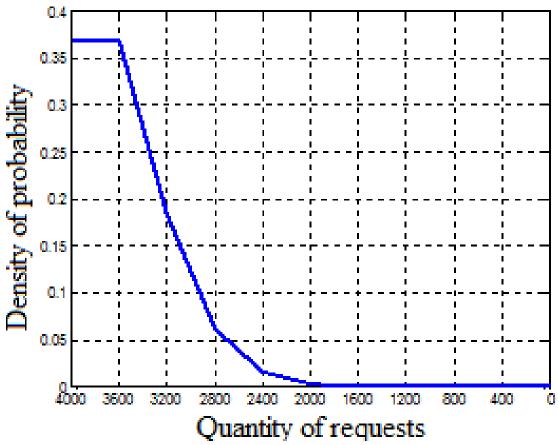

Fig. 18. Poisson law distribution of the simultaneous requests

During the probability of transmitting data estimation via Globalstar system the probability of data transmission without packet loss was also taken into account (P_f=10^{-6}).

Thus, the overall probability of the required amount of data transferring via the Globalstar system for a given time interval is calculated by the formula:

$$P = P_1(V_d)\ P_2(n)\ P_3(n)\ P_4(n)\ P_5(V_d)\ P_f \quad (5)$$

The results of calculating the successful transmission of data probability depending on various values of the amount of data I, the quantity of simultaneous requests presented in Figures 19-21. The results are presented for the total communication time of 150, 300 and 400 minutes.

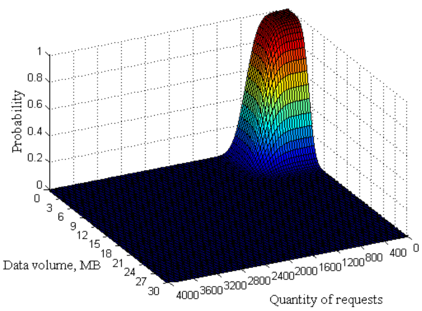

Fig. 19. The probability of data transmission for 150 minutes communication

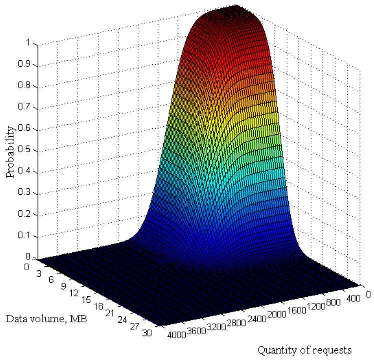

Fig. 20. The probability of data transmission for 300 minutes communication

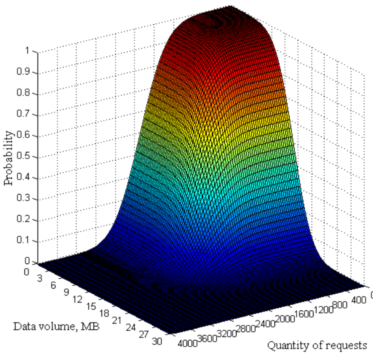

Fig. 21. The probability of data transmission for 400 minutes communication

5. Communicating experiment on SC "AIST 2"

The described data transmission technology via LSCS Globalstar will be tested during the small spacecraft "AIST-2" (Figure 22) flight. There will be the scientific technological equipment (STE) "Kontakt-MKA" (Figure 23) on its board. Its mass is about 1 kg and formfactor 180x164x57 mm.

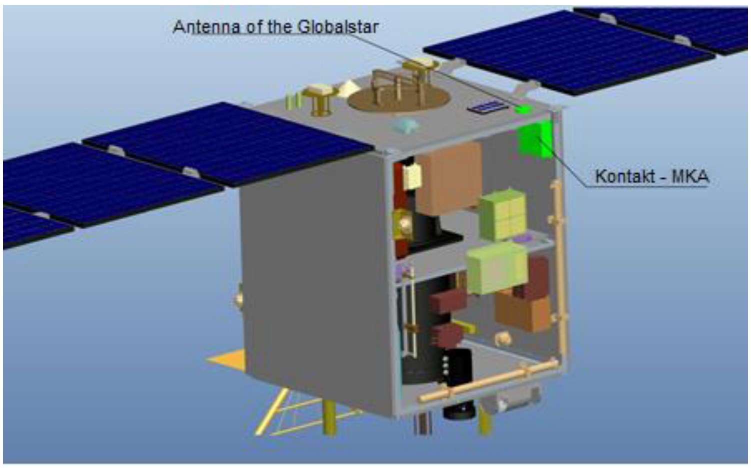

Fig. 22. Position of the Kontakt-MKA in «AIST-2»

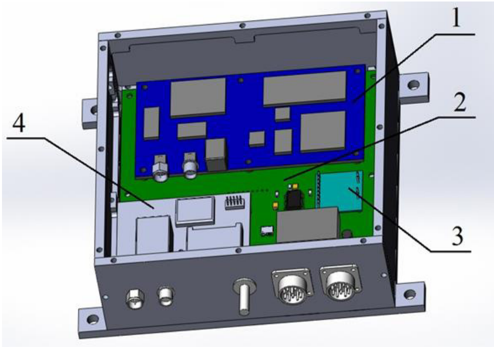

Fig. 23. The STE «Kontakt-MKA»

The STE «Kontakt-MKA» consists of:
1 – Modem GSP1720 LSCS Globalstar;
2 – Motherboard;
3 – Dynamic measurement unit (accelerometer, angular velocity sensor, magnetic field sensor);
4 – On-board computer.

The main function of this equipment is to transmit data from sensors on STE to MCC via LSCS Globalstar. The experiments with the STE are:

- access to board of spacecraft anytime (when works Globalstar communication link);
- autonomous monitoring of spacecraft motion;
- data transfer between two spacecraft.

The launch "AIST-2"is scheduled on 2015, for data transmission to MCC as well as on the scientific SC "Lomonosov", which will be launched at the same time.

Acknowledgements

This work was supported by the Ministry of Education and Science of the Russian Federation, in frame of project part of state task in scientific activity area (№ 9.1421.2014/K).

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