UDC 629.783:681.3

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Concept and modeling of the global aerospace system

A concept of an aerospace system is proposed, which includes three interacting components: 1) a basic network of satellites intended for the transmission, storage and processing of data; 2) clusters of Earth remote sensing satellites; 3) aviation facilities. A simulation model of the system for investigation of load flows has been developed.

The future of mankind is closely connected with the use of the capabilities of aviation and cosmonautics. In the joint use of aviation and spacecraft, a significant development potential. In this paper, the concept of an aerospace system providing a comprehensive solution to the problems of transportation, communications and remote Earth observation is presented. For the presented conceptual solution of the system, the aspect of transmission, processing and storage of information is considered.

Let us describe the space segment of the system. The basis of the system is a network of spacecrafts (the basic network of space vehicles) connected by software-controlled communication lines (optical lines or phased array antenna beams) [1-4]. Spacecraft are deployed in several high-altitude orbital groups (we will call them the different-altitude segments of the core network). Each spacecraft uses communication devices that allow one of six types of communication. The devices of the first and second type are intended for communication with space vehicles above and below the plane of the local horizon. The devices of the third and fourth types implement communication with space vehicles to the left and right of the orbital plane along the satellite's motion. Devices of the fifth and sixth types are used for communication with space vehicles that are in the same nominal orbital plane with the spacecraft implementing communication. In general, a spacecraft can establish several communication lines of each type. Communication in the network is implemented on the basis of the packet switching technology.

A simplified representation of the concept of the functioning of the core network is as follows. The spacecraft keeps and updates onboard full information about the network [3]. For this, it receives service data packets of two types: 1) service packets with the specified ephemeris value; 2) service packets with information about the load of each node of the network with transmitted information, which is waiting for its sending to the next node in the desired outgoing direction or an exit to the end user. On the basis of the received information, the spacecraft calculates the motion of the other spacecraft of the network, that is, the topology of the network. Using the software-defined topology and current information about the load of network nodes, the spacecraft solves the problem of decentralized routing based on the choice of the least cost path (in the particular case, the task of choosing the shortest path in order to minimize the time of delivery of information). To do this, it maintains and updates information about routing tables in each of the nodes of the network.

The communication lines created by the transmitting devices of the spacecraft are constantly maintained ready for transmission (even in the absence of information, the communication line is pointed at the spacecraft with which communication is implemented when necessary; from time to time, the service signals are transmitted via this line). Thus, we can talk about a virtually existing network structure (similar to a wired network), which constantly changes its form and, at discrete instants of time, its structure.

To determine the load condition of a network node, it is proposed to break up network buffers into fill levels. The node state is the number of filled levels of the data buffer. The packet about the change in the load of the node is generated by the node itself and must be delivered to all nodes. A packet about the value of ephemeris is generated into the network by ground stations of observation and control (it is also possible to update information by spacecraft relative to the orbital parameters of those spacecraft with which they directly communicate). To prevent network from loading with service information packets, it is proposed to use the uppermost segment of the network to broadcast service packets [3]. The broadcast segment is included in the network based on the packet switching technique. The multicast service packets are sent to the nodes of this segment. For all other nodes information from this segment comes not via the satellite network lines, but over the radio links by the principle of data broadcasting in navigation systems.

The switching over of communication lines between space vehicles is due to the following. For space vehicles in orbital planes of different altitudes, they are caused by the departure of spacecraft from the ranges of communication with each other due to their different angular velocities along the orbits (due to difference in altitude) and different precession velocities (due to the difference in the values of inclination and altitude). With sufficient filling of segments of the network by spacecraft, instead of corrections for such departures, they can be taken into account by sotware-controlled switching of communication lines. Switching also occurs for the devices of lateral connections in one segment of the network (when the two communicating space vehicles cross the intersection of their orbital planes, the spacecraft with which communication is realized appears not on the right, but on the left, or vice versa).

In the described network it is possible to allocate segments (most likely, in medium or high orbits), which are intended for information storage. This is, firstly, the segment of storing the service information necessary for the operation of the network. In particular, information on the location of aviation subscribers in the state of flight (including current information about the zone of their current location). Secondly, such a segment (or segments) of the network can be used to store the service and accumulated useful information of remote sensing systems of the earth or aviation services. Thirdly, there may be a segment (segments) intended for storing information of various terrestrial subscribers.

Such a global network can also include a segment (segments) that provide computing services for processing data coming from Earth remote sensing satellites. To provide an opportunity to comprehensively process information from mobile means of aviation and from aviation services [4].

In addition to the described basic satellite network, which is generally used for transporting, storing and processing data, the Earth's remote sensing satellites should also be considered as a part of the space segment of the global aerospace system. The current trend in the development of remote sensing systems of the Earth is such that it involves the use of clusters of space vehicles linked together by a common task shared between them. At the same time, clusters with communication between space vehicles are promising.

Two types of cluster groupings are needed. The orbital constellation of clusters of the first type presupposes a sufficiently close arrangement of the spacecraft in it (at a distance of hundreds of meters) and maintaining a fairly stable configuration [5]. In such clusters, non-directional communication is used. The second type of cluster grouping is a relatively compact group within a certain "traffic tube", but spacecraft can be separated by tens of kilometers. Stability of the grouping can be maintained within the specified limits [6]. If the trajectories of a certain set of satellites at orbits of different altitudes are supported within a certain tube, correcting the accumulation of the misalignment in the longitude of the ascending node, then a sufficient number of spacecraft can obtain clusters of a rolling composition (spacecraft in lower orbits move from one cluster to another faster, while satellites in higher orbits make this slower). In such clusters, it is reasonable to use directed links, according to the principle described for the core network.

Cluster networks can also be rationally implemented on the basis of packet switching technology. The cluster network is designed to coordinate the conduct of observations, to obtain information from ground-based sensors or aircraft objects. In addition, the cluster's satellites can perform calculations for the distributed processing of the information they receive. It is necessary to distinguish five types of information packets transmitted in the network: 1) network control information; 2) information on the coordination of the management of space vehicles; 3) management information for joint observations; 4) data exchange of distributed computing; 5) current results of observations.

Cluster networks can be connected through one or more spacecraft. Cluster networks can communicate through a core network. The objects of aviation for establish a temporary connection with clusters of space vehicles and be used to solve complex problems. Aviation facilities can interact with clusters of spacecraft through the core network.

Aviation objects, as well as terrestrial users, can communicate with each other through the core network (operational interaction with relatively close objects is implemented through one or a pair of satellites in lower orbits). When some delay in transmission of information is acceptable, communication can be implemented via a core network between sufficiently remote aircraft objects. The core network assumes several segments that are adapted to interact with users of a particular class (for example, low-power terrestrial users or aviation users). The types of traffic transmitted in the core network are divided by priority levels. In relation to the load of other users, the highest priority is given to the load of aviation subscribers.

A simulation model of the described system was designed for analysis of information flows in the network and development of approaches to managing this load. In the report, a number of calculations based on this model are presented.

Conclusions

Creation of a global aerospace system, which is proposed in the report, will enable solving a complex of diverse communication tasks, receiving and processing information based on the use of thousands of spacecraft. However, incorporation of a complex of tasks in one system will lead to a general decrease in space vehicles, necessary for an independent solution of these problems on the basis of individual systems. The developed simulation model of the network will enable investigation of the load not only for the given global version of the system, but also for its components (including separately for cluster groupings or for a satellite packet switching network implemented on a grouping of satellites with orbits of the same altitude).

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