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Algorithm for assessing the promptness of Earth space sensing information delivery

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Abstract. Remote sensing of the Earth is mainly carried out in the visible region of the spectrum, which corresponds to the current level of development of high-precision onboard instruments for Earth remote sensing. At the same time, methods and equipment for sensing in the radio- and infrared ranges of the electromagnetic spectrum are widely used and developed at a faster pace. The frequency of data acquisition ranges from once per month to once per minute, the spatial resolution ranges from kilometer to centimeter scales, and the electromagnetic spectrum covers wavebands ranging from visible light to microwave wavelengths. The efficiency of Earth remote sensing information delivery to consumers is considered under different variants of satellite-repeater network construction, taking into account the characteristics of existing and prospective high-speed radio lines of spacecrafts.

1 Introduction

Based on the analysis of needs in Earth remote sensing (ERS) data and the "Development Strategy of the State Corporation for Space Activities "Roscosmos" for the period up to 2025 and perspective up to 2030", by 2030 the spatial resolution indicators in the visible range of 0.2 m, in the radar range of 0.5 m, and in the infrared range of 30 m should be achieved, with a data update frequency of 8 times/day, which corresponds to 100% satisfaction of needs in ERS data [1-5].

Space communications, broadcasting and relaying are the most demanded, developed, profitable and commercially available part of space activities [6-15].

It is expected that the average annual growth rate of demand for the capacity of traditional fixed satellite communications satellites in the domestic market of Russia will amount to 15-25 %, the increase in demand for data retransmission capacity by 2030 is forecasted to be 5...7 times.

In terms of remote sensing of the Earth from space, the goal is to ensure round-the-clock and all-weather observation of the Russian territory, as well as to create a scientific and technical foundation for Russia's full-fledged representation in all segments of the world market of space services [16-25].

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2 Evaluation parameters

The efficiency of remote sensing information delivery to the receiving point is calculated for a grid, in the nodes of which the objects of observation are located. The position of the objects of observation is determined by the specified grid sizes and limited by the specified contour. The input parameters of the algorithm are divided into 3 groups: own parameters of the calculation, parameters of the technical characteristics of the remote sensing spacecraft and radio line, parameters of the data reception point and parameters of the simulation model [26-33].

Input parameters of the algorithm for calculating the efficiency of remote sensing information delivery to the reception point:

- $[\alpha_{\text{Smin}}, \alpha_{\text{Smax}}]$ - range of angles of admissible illumination of the filmed surface;
- $p_{\max}/L_{\max}$ - maximum linear projection of a pixel, m / maximum level of linear resolution on the terrain, m.

Input parameters of the remote sensing spacecraft and radio line used in the calculation of the efficiency of remote sensing information delivery to the data reception point:

- r - information flow, Gbit/sec;
- t_{ON}- shooting time of one object, sec;
- $\{V_{\text{VRL}}\}$ - list of information transmission speeds to the information receiving point, Gbit/sec;
- $\{V_{\text{GKAR}}\}$ - list of information transmission rates to the satellite retransmitter, Gbit/sec.

Input parameters of the information receiving point used in calculating the efficiency of remote sensing information delivery to the information receiving point:

- $\{V_{\text{APPC}}\}$ – list of data reception speeds, Gbit/sec;
- t_{d} - delay for entering the connection, sec.

Input parameters of the repeater satellite and radio link used in the calculation of the speed of remote sensing information delivery to the information reception point:

- $\{V_S\}$ - list of data reception rates from spacecraft, Gbit/sec.

Output parameters for calculating the efficiency of remote sensing information delivery to the receiving point:

- $G = \{t_a, t_{\min}, t_{\max}, t_p\}_{i,j}$ - set of calculated values of average, minimum, maximum, probabilistic efficiency of remote sensing information delivery to the receiving point at a point on the Earth surface, s. The coordinates of the point correspond to the indices i in latitude, j in longitude $t_{i,j} \in (0;\ t_N + 1]$, t_N - duration of the modeling interval, sec.;
- $y_i = F_j(t_{i,j})$ - graph of distribution of average, minimum, maximum, probabilistic efficiency of remote sensing information delivery to the point of information reception, averaged by longitude, by latitude;
- $T = \{t_a, t_{\min}, t_{\max}, t_p\}_{i,j}$ - table of average, minimum, maximum, probabilistic efficiency of remote sensing information delivery to the point of information reception;
- $I_a, I_{min}, I_{max}, I_p$ - integral index of average, minimum, maximum, probabilistic efficiency of remote sensing information delivery to the point of information reception;
- $\{C_t\}$ - isolines at a given level.

Between the spacecraft and the information receiving point, the following characteristics of the communication channel are taken into account when calculating the speed of the radio line:

- width of antenna system radiation patterns;

- frequency range;
- radiated energy;
- and other parameters of the transmitting and receiving systems.

The time delays associated with the orientation of the antenna systems of the radio link to the receiving point are taken into account in the parameter of the time of entry into communication.

The time delays associated with the orientation of the antenna systems of the radio communication line from the repeater satellite and the provision of retransmission to the information receiving point are not taken into account because of their low significance and influence on the calculation of the efficiency of remote sensing information delivery.

The illumination of objects of observation is determined by the correspondence of the Sun elevation angle in the topocentric coordinate system to the range of angles of permissible illumination $[\alpha_{\text{Smin}}, \alpha_{\text{Smax}}]$.

The condition for observing an object is that the object falls within the remote sensing spacecraft's field of view, calculated taking into account the specified maximum pixel projection size $p_{\max}$ or the maximum level of linear resolution on the ground $L_{\max}$.

3 Evaluation algorithm

Operational efficiency of remote sensing information delivery to the receiving point is the time between the moment at which imaging of objects of observation is performed and the moment at which remote sensing information delivery to the receiving point ends.

Delivery of remote sensing information to the receiving point is possible when the spacecraft is within the radio visibility zone of the receiving point. Delivery is also possible when retransmitting remote sensing information via a satellite transponder. Communication between the spacecraft and the repeater satellite is possible when installing a communication line with an altitude exceeding 10 km.

Among the list of information transmission rates $\{V_{\text{VRL}}\}$ of the spacecraft radio line and the list of information reception rates $\{V_{\text{APPC}}\}$ of the information reception point the same maximum frame transmission and reception rate $\{V_\kappa\}$ is searched. If there are no identical velocities in the lists, it is impossible to transmit remote sensing information from the spacecraft to the receiving point.

When retransmitting to a repeater satellite, the compatibility of the range of the radio line of the repeater satellite and the radio line of the remote sensing spacecraft is taken into account. Similarly, for the radio line of the repeater satellite and the radio line of the remote sensing spacecraft, the same maximum rate of transmission and reception of the $\{V_{\kappa GKAR}\}$ frame is sought.

Verification of entry into the zone of radio visibility of the information reception point is performed for the time moments of discrete modeling (calculation points).

Therefore, if at the calculation point with time t_i the spacecraft entered the radio visibility zone of the data reception point, and at the calculation point with time $t_j (j > l)$ the spacecraft left the radio visibility zone, the radio visibility interval is equal to:

$$[t_l - dt/2,\ \ t_j - dt/2] \tag{1}$$

where dt - is the modeling step.

After the beginning of radio visibility the spacecraft enters into communication with the receiving point during the time t_{d} set in the parameters of the information receiving point. After the expiration of this time starts counting down the frame transmission time. Checking the installation of communication between the spacecraft and the satellite repeater is performed for the time moments of discrete modeling (calculation points).

Consequently, if at the calculation point with time t_{m} spacecraft established radio communication with the repeater satellite, and at the calculation point with time $t_{\mathrm{n}}(n > m)$ spacecraft ceased communication with the repeater satellite, then the session of communication between the spacecraft and the repeater satellite is equal to:

$$[t_m - dt/2, t_n - dt/2] \tag{2}$$

The volume of a frame transmitted to a receiving point or satellite repeater is calculated using the following formula:

$$I_s = r * t_{ON} \tag{3}$$

The time required to transmit a frame to the receiving station is calculated using the following formula:

$$t_s = I_s/V_s \tag{4}$$

The time required to transmit a frame to the satellite repeater is calculated using the following formula:

$$t_{sGKAR} = I_s/V_{sGKAR} \tag{5}$$

The generalized algorithm for calculating the efficiency of delivery by one spacecraft of remote sensing information from one object of observation to a data reception point, including the use of a repeater satellite, consists of the following steps.

Step 1. All time moments of discrete modeling (calculation points) are enumerated.

Step 2. For the current calculation point, for each spacecraft, a field of view is constructed in accordance with the specified requirements for the conditions of imaging of the object of observation. For the object of observation, the possibility of imaging by the spacecraft is calculated.

Step 3. The event at this step is compared with event A and the moment with events B and C is searched for. Between event B and C the event that occurred earlier is searched for, it determines the efficiency of remote sensing information delivery:

- A. At the current design point, the spacecraft has the capability of imaging the object of observation, while at the previous design point it did not.
- B. At the calculation point (after the current one), the remote sensing information is delivered to the receiving point from the spacecraft. The delivery occurs at the earliest moment of time after the event A, before which the spacecraft had the possibility of radio communication with the same data reception point during the time of entering into communication t_d and the time of frame transmission t_k. The condition of successful remote sensing information delivery must be fulfilled;

$$\left(t_j - dt/2\right) - (t_l - dt/2) - t_d \geq t_k \tag{6}$$

- C. At the calculation point (after the current one), the remote sensing information is delivered to the reception point using the retransmitter satellite. Delivery takes place at the earliest moment of time after the event A, before which the spacecraft was able to communicate with the repeater satellite during the frame transmission time t_{kGKAR}.

The condition of successful remote sensing information delivery must be fulfilled:

$$(t_n - dt/2) - (t_m - dt/2) \geq t_{kGKAR} \tag{7}$$

The found delivery intervals form a list of remote sensing information delivery operability times, from which the average, minimum, maximum and probabilistic remote sensing information delivery operability (t_{aD}, t_{minD}, t_{maxD}, t_{pD}) are distinguished.

Figure 1 shows a block diagram of the generalized algorithm for calculating the efficiency of remote sensing information delivery to the information reception point, including the use of a repeater satellite.

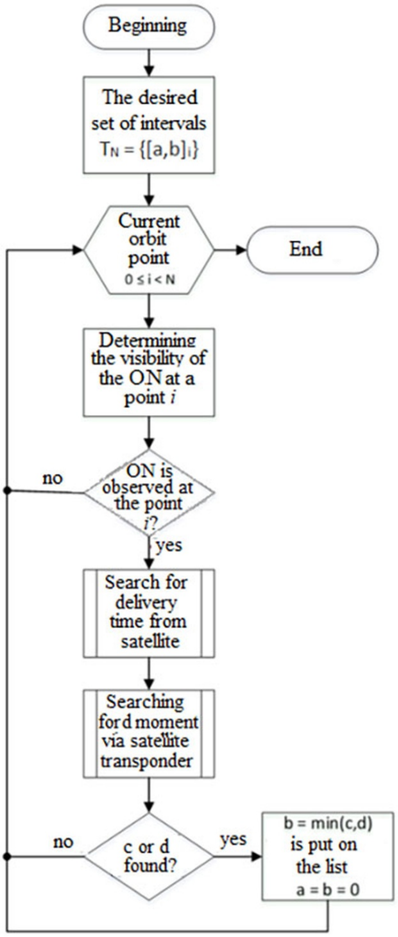

Fig. 1. Block diagram of the algorithm for calculating the intervals of remote sensing data delivery to the receiving point using a repeater satellite.

The block diagram depicts the algorithm for calculating the intervals of remote sensing data delivery to the receiving point, including the use of a repeater satellite.

From the data set of intervals for all spacecraft in the orbital constellation, maximum and minimum values are selected for each observation point (in modeling - Earth points within the selected grid frame) and average values are calculated. The array of selected values characterizes the operability of remote sensing information delivery in different Earth surface currents.

The algorithm of modeling of RS spacecraft information delivery efficiency at different variants of building a network of relay satellites uses the ground object field - 1 or several information reception points and a grid of observation objects to obtain the distribution of delivery efficiency values over the entire Earth surface.

The parameters of the observation object location grid (number of grid points in latitude, number of grid points in longitude, grid step in latitude, grid step in longitude) are set as calculation parameters. These parameters determine the discreteness of the distribution of the calculation distribution of information delivery efficiency on the Earth's surface.

4 Conclusion

The result of the calculation is a display of the values of the delivery efficiency statistics at points on the Earth's surface. The gradient values correspond to the palette of the distribution of delivery efficiency time, which may vary for different variants of the orbital constellation construction depending on the maximum values of delivery efficiency.

The time intervals between the following pairs of events are calculated to obtain the information delivery operability:

First event. At the current calculation point at least one satellite from the constellation is visible from the current point of the Earth's surface, and at the previous calculation point no satellite from the constellation is visible from the current point of the Earth's surface.

Second event. At the current calculation point, the satellite that was visible in event number 1 establishes radio contact with the receiving site or has direct line-of-sight with the repeater satellite.

If event 1 occurs more than once for the same spacecraft and the same point on Earth before event 2 occurs, each event 1 shall be counted.

Radio visibility with a data reception point is established if the slant range between the spacecraft and the data reception point is less than or equal to the specified maximum slant range of the data reception point, the angle of elevation of the spacecraft above the data reception point is greater than or equal to the specified minimum elevation angle of the data reception point, and the radio visibility session time is greater than or equal to the minimum communication time of the data reception point.

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