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ScienceDirect

Procedia Computer Science 103 (2017) 396 – 402

Procedia Computer Science

XIIth International Symposium «Intelligent Systems», INTELS'16, 5-7 October 2016, Moscow, Russia

Application of multi-agent technology in the scheduling system of swarm of Earth remote sensing satellites

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Abstract

The paper studies the problem of scheduling a group of Earth remote sensing satellites. The following idea is proved: development of Earth remote sensing systems needs changing of approach to planning of their application. Problem statement is described. As criteria of efficiency, information delivery time, resolution and cost of request execution are used. The schedule has to comply with the following constraints: visibility between satellites, observation areas and data receiving points, storage capacity of the memory unit as well as coordination of operations on shooting, storing, transmitting and receiving data. Review of ways of problem solution is provided. Implementation of the approach has been suggested, where the sought schedule is built as dynamic balancing of interests of satellites, data receiving points and observation area agents. Multi-agent planning system is developed. Architecture of the system is described as well as functions of the modules it includes. Dynamically occurring events are taken into account when planning, including introduction of a new task or change of task options, failure of a satellite or means of communication. The experimental assessment of time spent on recovery of the damaged schedule is given. In conclusion benefits of the multi-agent approach at management of swarm of Earth remote sensing satellites are provided.

Keywords: multi-agent technology; swarm of satellites; multisatellite; ground station; remote sensing; planning and scheduling; adaptability; multiobjective optimization

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1877-0509
doi:10.1016/j.procs.2017.01.127

1. Introduction

Modern space remote sensing tools represent complex technical systems distinguished by a great diversity of types of target equipment, its modes and application conditions as well as structure and functionality of ground infrastructure. Due to increase in the number of consumers of space information, now sensing systems are being created which consist of a swarm of heterogeneous satellites and a wide network of geographically distributed data receiving and processing stations. Managing such systems is closely connected with efficiency of their target application, planning of which has to take into account technical resources of satellites, external conditions, interests of operating organizations and consumers of target information as well as economic feasibility.

The scheduling process of a swarm of Earth remote sensing satellites is affected by the following factors:

1. Growth of a swarm dimension and the need to switch to solution of a new type of tasks on complex management of multi-satellite space systems.
2. Change of requirements to volume, quality and efficiency of acquisition of remote sensing information, specified by consumers. Updating of satellites' action plan becomes necessary as far as new observation requests and unforeseen events occur in real time.
3. Multicriteriality. Efficiency of target application of space sensing system can be assessed by various criteria, such as productivity, information capacity and efficiency of information delivery.

Nevertheless, most of developments in planning of Earth remote sensing are oriented to single satellite functioning in determined conditions[1]. As a final result, a static plan of using satellite is considered, which is updated no more than several times per 24 hours. At that, no mechanisms of plan recovery are presupposed when actual conditions deviate from the expected ones in the moment of plan building. In the result, the problem of finding rational methods providing acceptable locally optimal planning of actions of a swarm of satellites with an opportunity of adaptive plan changing depending on various events is becoming quite relevant.

2. Multi-satellite scheduling problem

2.1. Problem Statement

Let there be a lot of satellites, stations and observation requests assigned. Time of requests occurring is unpredictable, the number and characteristics of resources can also change in the process. Request processing is presented as a graph where nodes are separate operations (shooting, storing, transmitting and receiving information), and bonds are relations determining the sequence of operations.

For each satellite and ground station there is a list of operations, cost and conditions of their execution consistency. For example, each satellite is able to perform operations on shooting and data transmission without possibility of their intersection in time. Sequence of one-type operations is united in a mode, in the beginning of which preparatory section is arranged. There should be no inclusions of other modes between operations of one mode. The duration of pause between neighboring operations should not exceed the assigned value.

For each satellite orbit parameters are assigned as well as technical constraints for memory capacity, duration of modes and operations. For stations geographic coordinates are assigned.

There are models formed which allow for determining:

- time when a satellite passes over visibility zones with ground stations and areas;
- resolution of image in each area caught in the observation of a satellite;
- volume of information recorded in the on-board memory unit while shooting;
- duration of operation execution on image acquisition and information transmission.

Each request has the corresponding feature, for example, information delivery time, resolution in the assigned spectrum range, and cost of execution. For feature a range of acceptable values can be specified as well as optimal value. On the basis of separate features, components of efficiency of request distribution are formed, which are outlined in Figure 1. Efficiency of request distribution is determined via linear convolution of all components with the assigned weighting coefficients.