Swarm of Satellites: Multi-agent Mission Scheduler for Constellation of Earth Remote Sensing Satellites

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Abstract. The paper describes the multi-agent system for scheduling of actions of a constellation of Earth remote sensing satellites. The functionality and architecture of the system are presented and the key scenarios of event processing are given, which demonstrate the advantages of multi-agent technology.

Keywords: Multi-agent technology · Constellation of satellites
Earth remote sensing · Planning and scheduling

1 Introduction

One of the new trends in Earth remote sensing is the shift from individual management of satellites – to managing swarms of satellites [1].

In swarm of satellites concept the new demands or any other events trigger adaptive re-scheduling of resources and new schedule is self-organized by negotiations of agents of orders, satellites, ground stations, on-board equipment, etc.

In this paper, we will briefly describe the functionality and architecture of the developed system and demonstrate key scenarios of events processing. It will demonstrate advantages of multi-agent technology for real-time resource allocation, scheduling and optimization, including better time-to-go, flexibility and high efficiency of resources.

2 Demonstration of Swarm of Satellites

2.1 Multi-agent Mission Scheduler

The Multi-agent Mission Scheduler is based on developed multi-agent technology for resource allocation, scheduling, optimization and controlling [2].

In the developed approach, agents of orders continuously negotiate with agents of satellites, ground stations and on-board equipment their allocations and pro-actively try

Y. Demazeau et al. (Eds.): PAAMS 2018, LNAI 10978, pp. 348–352, 2018.
https://doi.org/10.1007/978-3-319-94580-4_36

to improve their positions in schedules. Agents take into consideration a number of specific criteria, preferences and constraints – for example, each satellite has a memory limit, so a satellite cannot take images of all available areas and has to choose between image acquisition and downlinking.

Agents of orders take into consideration two criteria – time of getting images and resolution. These two criteria can certainly contradict one another, so the agent uses the convolution of criteria with specified weight coefficients. Agents of resources are trying to improve their load and to be fully utilized.

The resulting schedule is considered as unstable equilibrium achieved on virtual market, which can be easily re-balanced by events if required [3].

2.2 The Main Screens for Demonstration

Initial data, process of adaptive scheduling and its results are displayed on several screens and terminals for entering new events. The screens "Physical world" and "Create Mission" shows the space system configuration and locations of observation areas and ground stations. It can simulate their relative movements on 3D model (Fig. 1).

Fig. 1. Fragment of the screens "Physical world" and "Create Mission"

The screen "Mental world" illustrates the semantic links established between the agents in the process of schedule self-organization. All the agents are shown by circles gradually changing color from red to green until the agent fulfills its objective functions. Once the request is included in the schedule, links are built between the request circle and the selected satellite and ground station circles. If any of the resources have been removed, some of the orders scheduled earlier will no longer be possible. The links will disappear. Unscheduled orders will try to find an open vacant slot on the remaining resources. Finally, the schedule will be re-configured (Fig. 2).

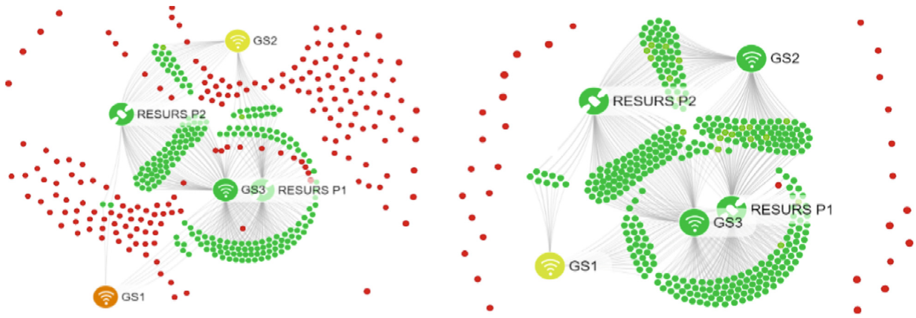

Fig. 2. Fragment of "Mental world" after excluding the satellite and repairing the schedule

The next screen represents a plan of actions of a selected satellite. Here, visibility zones of satellites are shown with all areas and ground stations as well as a plan of executing operations on image acquisition and data transmission (Fig. 3).

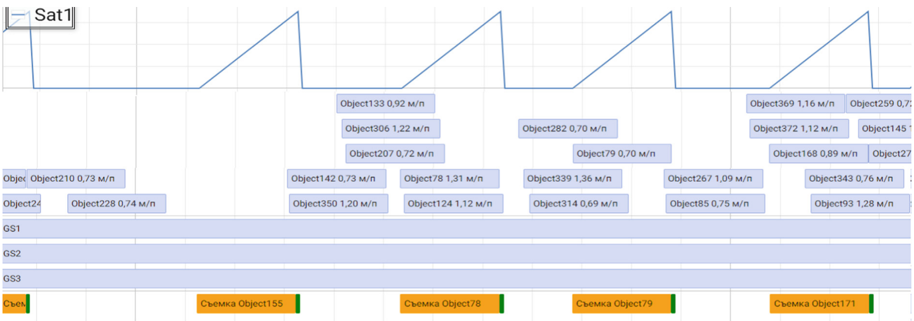

Fig. 3. Fragment of satellite's plan of actions

The diagrams in the next screens show the evolution of the schedule quality in the course of schedule self-organization. The agents create the schedule by iterations. At the initial time point, nothing is scheduled anywhere: no links between agents, full chaos. However, gradually, the order agents negotiate the placements with satellite and ground station agents.

First, agents of orders occupy open slots and then improve positions by making coordinated swaps and shifts in the schedule. When the system is reaching balance of agents interests (consensus) which cannot be improved further in any trials, the system stops and presents the final schedule to the user (Fig. 4).

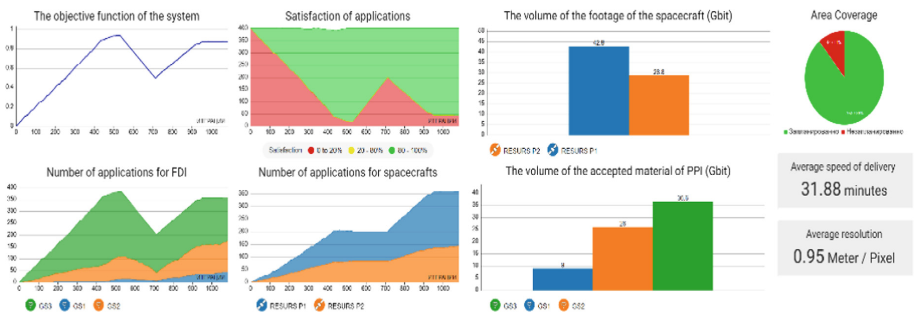

Fig. 4. Screens with results of scheduling

The system recognizes a new order, satellite failure or ground station outage as an external event. Multiple events change the schedule repeatedly, pushing down the agents' objective functions (Fig. 5). However, the agents are able to effectively deal with the changes by adaptive re-scheduling of the resources.

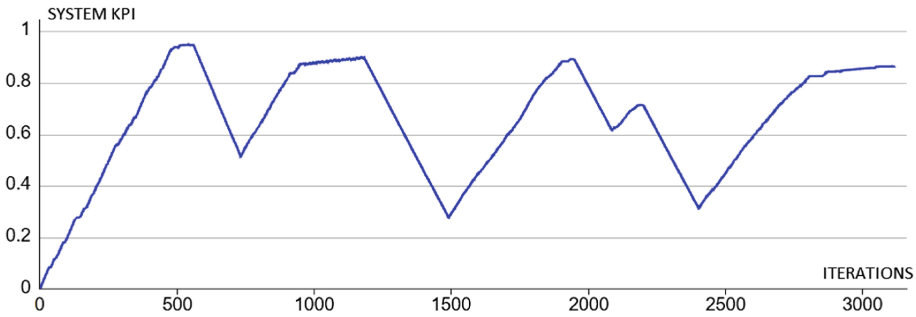

Fig. 5. System KPI during the planning process

As it is shown in Fig. 5, some of the events significantly decrease the system KPIs but then it adaptively re-schedules the resources and improves the situation.

The demo is available on https://youtu.be/JOjhaIRBVdI (short version) and https://www.youtube.com/watch?v=r7vKK9XnTCE (full version).

3 Conclusions

In this paper, we demonstrate the multi-agent system for solving the Earth sensing satellites scheduling problem in dynamic environment. In these circumstances, the system vividly demonstrates its unique adaptability to quickly restore the damaged schedule and to re-schedule the given resources of satellites in real time.

Acknowledgment. This paper was prepared with the financial support of the Ministry of Education and Science of the Russian Federation – contract №14.578.21.0230, project unique ID is RFMEFI57817X0230.

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