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MULTI-AGENT SCHEDULING OF COMMUNICATION SESSIONS BETWEEN MICROSATELLITES AND GROUND STATIONS NETWORK

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Abstract

The problem of constructing an effective mechanism for rapid transmission of data between microsatellites and network of ground stations in the dynamically changing environment is considered. The main target of the developed system is to ensure the efficient data transfer from group of microsatellites to the ground stations with a minimum time delay and considering current limitations on reception by stations. The system must adaptively adjust plans for every station according to new events coming. Multi-agent approach to solving this class of problems is proposed. It is shown that the schedule is constructed as a dynamic balance of interests between stations agents and orders agents. Both types of agents negotiate their position in the schedule and plan their work shifting basic schedule due to the tolerance between actual and preferred start time. The ontology, agents, interaction protocols and key benefits of proposed system are discussed.

Keywords: *microsatellite, ground station, multi-agent system, communication session, ontology, data-stream scheduling, agent.*

Introduction

Recent achievements in the microelectronics and microelectromechanics area allowed reducing the weight of spacecrafts keeping their target characteristics. As the result, a new class of spacecrafts called small-scaled spacecrafts (SSC) has appeared. A stable SSC classification has formed abroad by their weight characteristics: pico-satellites under 1 kg, nano-satellites from 1 to 10 kg, microsatellites from 10 to 100 kg, mini-satellites from 100 to 500 kg and small SC from 500 to 1000 kg. Cost and time reduction needed for development and manufacture of SSC allows the creation of the whole satellite systems, capable of continuous earth surface monitoring, resolve navigation and telecommunication issues. SSC groups creation can dramatically change the set opinion about space systems part and place and considerably expand customer services spot comparing to the ones that are implemented today [1]. On the other hand, SSC number increase in the orbit group results in management systems overload and the necessity of processing big amounts of target information. Under these circumstances, a problem of scheduling the timely data transfer from spacecrafts to the ground stations becomes the most urgent.

A problem description of communicational environment design for data transfer from microsatellites system to the ground geographically distributed infrastructure of data receipt and processing is given in the suggested paper and its solution based on the multi-agent technologies is suggested.

1 Problem statement

Let there be given a set of microsatellites that belong to different types of users (e.g. several universities, ERS operators, etc.) and is focused on getting the information from microsatellites and on data transceiving to the ground stations. Microsatellites number can change in time (some of them break down, the new ones are launched, etc.). Each microsatellite can have constraints of technical, organizational, financial or of any other character on the data transmission to the ground stations that belong to different developers. Therefore there is a group of available stations for data “dump” and the group of constantly (or temporary) unavailable stations.

Moreover, some of the ground stations have an ability to transmit the received information to another station or use Internet resources for interested consumers to access this information. Data dump task is to transmit the specified data amount from one particular microsatellite in a given time period. Data transmission to the ground station should be preceded by a procedure of communication sessions schedule coordination. It is necessary for the implementation of some preliminary work on the station, including the computation of target destinations for complex antenna aiming to a certain spacecraft, preparation of engineering software tools for processing of incoming information.

The main point of the suggested development is to design a mechanism providing a possibility for microsatellites to transmit data to ground stations system with constraints, including the unexpected ones. Duration of communication sessions between microsatellites and ground stations is one of the key factors that affect monitoring performance and data delivery efficiency. Therefore, data delivery to the ground stations program optimization directly influences system efficiency as a whole.

System’s purpose is to provide the efficient data dump from microsatellites group in a way for it to happen at the required time with the minimum delay from the moment of on-board data receipt and with regard of current receipt constraints. At the same time, system should adaptively correct the built schedule for each station, considering the arising events: shooting schedule changes on microsatellite board, its failure, station equipment failure, another user request on data receipt form one of the microsatellites, etc. If unexpected events have occurred on one of the ground stations, its tasks should be redistributed between other stations of the network.

Task of data transmission scheduling between many microsatellites and ground stations can be formulated in the following way. There must be provided data flow Φ maximization in the microsatellites system N on the time horizon T for M stations:

$$\Phi = \sum_{j=1}^{M}\sum_{i=1}^{N}\int_{0}^{T} rate_{ij}(t)\cdot link_{ij}(t)\cdot schedule_{ij}(t)dt,$$

where $rate_{ij}(t)$ is a speed of data transfer from microsatellite i to ground station j, $link_{ij}(t)$ is a mutual data transfer efficiency from microsatellite to ground station, $schedule_{ij}(t)$ – data transfer schedule, built considering mutual visibility of stations and microsatellites.

Therefore, a solution of the given problem requires coordinated scheduling of works in the stations and microsatellites network.

2 Description of multi-agent approach to problem solving

Multi-agent technologies that allow to solve complex problems by means of self-organization of competing and cooperating agents, can be used as a basis for the given task solution [2, 3].

When scheduling communication sessions, a concept of demand-resource networks (DRN) is applied, where each schedule is designed as a flexible (rebuilt by the events) network of demand (problem) and resource agents connections. It is based on the principle of the joint interest of all the participants in the solutions profitable for each of them and for the system as a whole. At the same time, worsening of one participant's position can be compensated at other participants' expense in the interest of the group if it leads to the group benefit in general.

Basic principles of suggested multi-agent approach to adaptive scheduling can be formulated as follows:

- Dataflow from every microsatellite for transfer to the ground can be represented as a problem with a certain starting time, limited ending time, volume and priority.
- Each task and ground station gets their own program agents that have individual schedules.
- Task agent defines the requirements and constraints for scheduling, according to its capacity and preferable execution time.
- If at the attempt to schedule an appropriate ground station is occupied by another task, then a conflict is stated and negotiations start to resolve it by tasks shifts in time or their reallocation to other stations.
- The key rule of schedule changes confirmation is the condition that the sum of the improvements is bigger than sum of deteriorations, caused by a new event in the interests of the system as a whole for works execution.
- Even after solving the problem, agent does not stop and keeps trying to improve its position (while he has the time to solve the problem).

Therefore, the final schedule is built as a dynamic balance of interests of tasks and stations agents that negotiate for their position in the network schedule and plan their work by shifting, based on acceptable deviations of tasks implementation starting time from the desired time.

3 Multi-agent scheduling system development

To consider the domain area specifics and problem specifics of scheduling data flow between the set of microsatellites and ground stations there have been developed an ontology structure and its fragment is shown in the Figure 1. According to this structure, each ground station has an individual schedule where planned communication sessions with microsatellites and station operation schedule are displayed. Each communication session is characterized by priority, duration, performance status and time period when it need to be executed. Communication sessions can be possible only in certain time intervals, during which a direct visibility between a microsatellite and a station is maintained.

Each ground station is associated with a resource agent. Resource agent's purpose is the thickest jobs scheduling with the preference of scheduling tasks of "its own" microsatellites and providing minimum downtime of the equipment. Each communication session is associated with a problem agent. Problem agent purpose is to allocate to the best for him ground station, which parameters satisfy problem constraints. Problem agent can react to the events, addition/removal of ground stations and other problems allocation cancellations. A special scene agent that is responsible for the interaction with the system user performs problems registration and cancellation.

To consider the cost component, agents' virtual market is introduced, where all process characteristics are expressed in virtual money equivalents. Each agent has an objective and penalty function. Objective function represents satisfaction of the agent depending on the achievement of the set goal. Penalty function sets a bonus or a fine for one or another objective function value. At the same time, it allows to set the acceptable values intervals for scheduling where it is necessary by setting an intentionally unacceptable fine amount in the unacceptable values area.

Each agent tries to maximize its satisfaction and increases the profit that he can spend like "energy" for shifting other agents in the case of a conflict, which he tries to resolve in the interests of the system as a whole. Scheduling problem is solved iteratively by the gradual increase (local improvement) of the objective functions values of each agent.

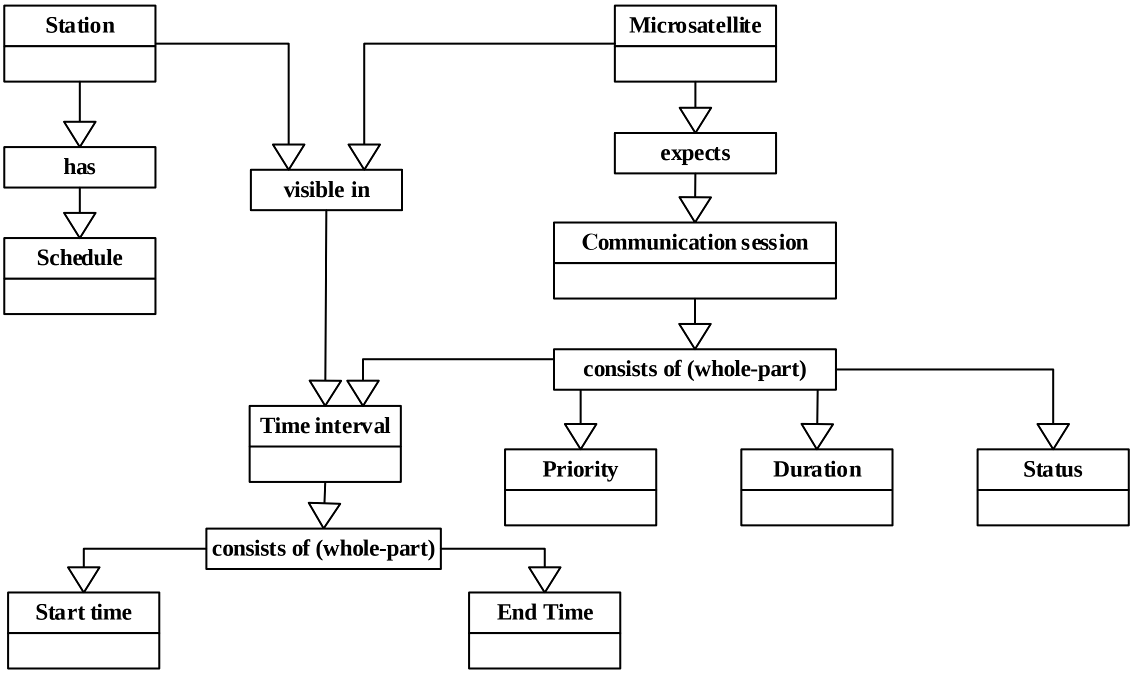

Figure 1 – Ontology fragment of the multi-agent system for communication sessions scheduling

When the problem is initialized it is given the initial sum of virtual money according to its priority. This money can be used as a payment for allocation on the chosen resource and for the compensation of the expenses of the tasks shifted during the allocation. Objective and penalty functions are built considering time constraints on the deadlines for the problem agent and considering the loading on the certain scheduling interval fort the resource agent (Figure 2).

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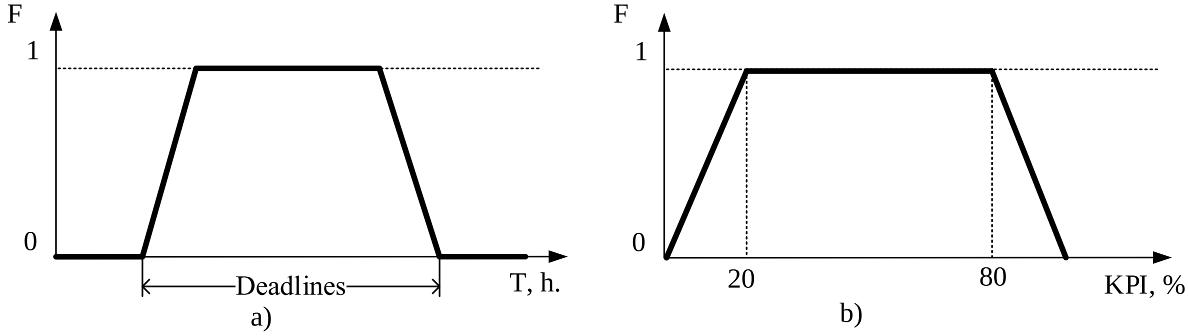

Figure 2 - An example of the problem (on the left) and resource (on the right) objective function

Scheduling process includes two stages:

1) Primal initialization of problems allocation to the resources considering preferences and time constraints;

2) Profit proactive improvement from the tasks by rescheduling.

Agent interaction protocol in the primal initialization of problem allocation is shown in the Figure 3. This protocol is a Contract Net Interaction Protocol implementation, specified by the FIPA standard [4]. Arrived task agent defines a list of available and appropriate agents for the ground stations allocation and then it sends a message-request CFP (Call for Proposal) to each of them, which contains satellite name and time interval, during which a communication session should be scheduled.

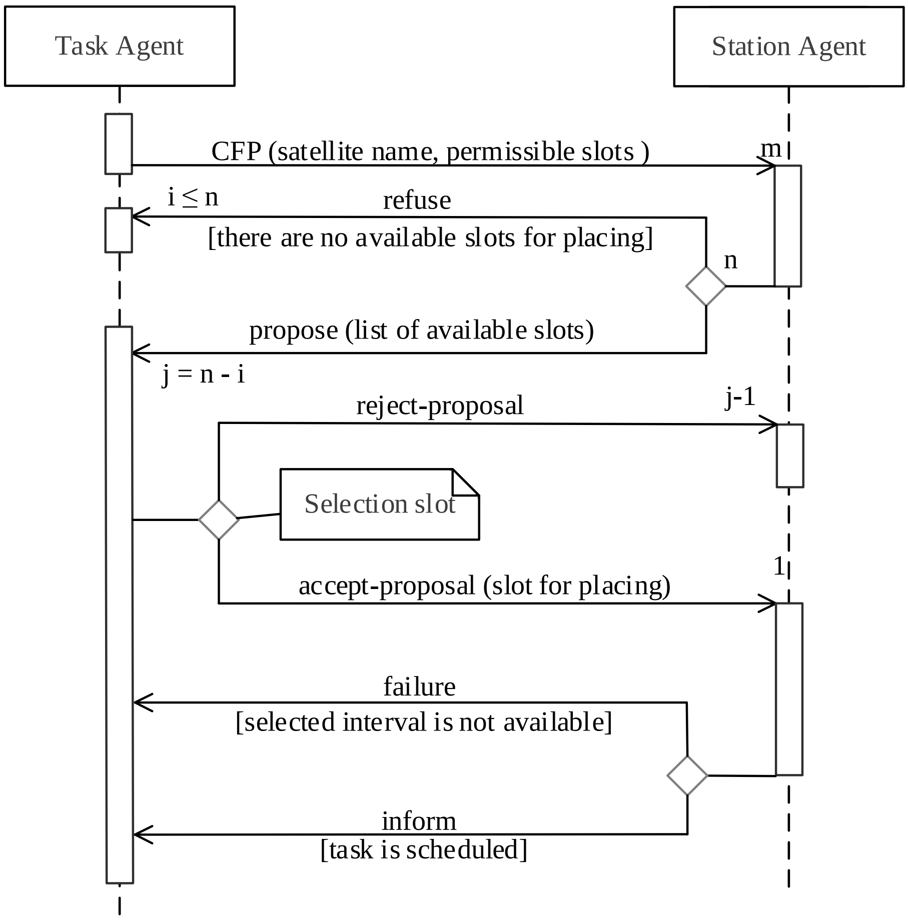

Figure 3 - Agent interaction protocol in case of a new task arrival

Each ground station agent that received this message, performs a visibility intervals analysis of the specified microsatellite in the specified time slot. The calculations are only performed on request, because visibility intervals calculation between microsatellite and a station is a resourceful operation. Then from the obtained list of the possible task allocation intervals those time slots are excluded during which station is busy executing other tasks according to its schedule. If there are no time slots available for allocation, station agent sends a response *refuse*, otherwise – message *propose* that contains a list of the available intervals.

When task agent receives response messages, it finds the best allocation option according to its objective function and then it sends an *accept-proposal* message to the station agent that suggested this option. This message contains scheduling time slot, defined by the task, that depends on the starting time and communication session duration. The rest of the station agents receive a *reject-proposal* message

When station agent receives an *accept-proposal* message, it checks the specified scheduling time slot for occupation by other tasks. If the interval is free then a responding message *inform* is sent, resource agent gets a payment for the allocation and task information is recorded in the schedule. Otherwise, a *failure* message is sent and when task agent receives it, it tries to be allocated on the other resource.

Then an algorithm of proactive improvement of task agent satisfaction is initiated. Task agent with the smallest objective function value starts the improvement process first. Proactive task questions the appropriate resources, defining the allocation cost in the different schedule parts. Two closest tasks on the left and on the right sides from the middle of the interval for scheduled task are chosen, among the tasks that were scheduled in the considered time slot. Agents of these tasks receive a request on shift on the specified time. Recursive shifting of the tasks affected by the shift continues until one of the tasks can move to the new position without obstacles, the displacing task still have means to compensate the expenses or a counter that limits recursion depth equals zero. From the set of possible allocation positions those options are excluded, which confirmation will not let to improve the system objective function value, and the best option is chosen from the ones that are left.

The task that remains unscheduled is put in the list of tasks that wait for the scheduling. New attempt of scheduling these tasks will be made in case of arising events of adding new resources or schedule changes of the existing ones.

The designed system develops models, methods and algorithms that were earlier developed for the multi-agent SSC group management system [5], where the incoming ERS tasks adaptively distribute between SSC with different technical abilities.

Conclusion

The suggested approach to the communication sessions scheduling allows achieving high operability, flexibility and efficiency in microsatellites and stations network operation, especially with a priori uncertainty in demand and supply changes on microsatellites and ground stations services and high level of dynamics of unexpected events occurrence. Dynamic forming and support of the adequate schedule that was coordinated with all of the participants in negotiations of task and station agents will allow to consider the changing external conditions that are connected with data transfer conditions change, orbit parameters, microsatellites equipment failure, communication channels overload, etc. Moreover, microsatellites and stations operation will be transparent for all participants; it will allow reducing the scheduling workload and mistakes caused by human factor; it will increase the reliability of the designed technics.

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ПЛАНИРОВАНИЕ СЕАНСОВ СВЯЗИ МЕЖДУ МИКРОСПУТНИКАМИ И СЕТЬЮ НАЗЕМНЫХ СТАНЦИЙ С ИСПОЛЬЗОВАНИЕМ МУЛЬТИАГЕНТНЫХ ТЕХНОЛОГИЙ

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Аннотация

Рассматривается задача построения эффективного механизма быстрой передачи данных между микроспутниками и сетью наземных станций в динамично меняющейся среде. Цель разрабатываемой системы – обеспечить эффективную передачу данных с группировки микроспутников в требуемое время, с минимальной задержкой от момента получения информации на борту, с учетом текущих ограничений станции по приёму. При этом система должна адаптивно корректировать построенное для каждой станции расписание с учётом возникающих событий. Предлагается мультиагентный подход к решению данного класса задач. Показано, что расписание строится как динамическое равновесие интересов агентов задач и станций, которые ведут переговоры о своём положении в расписании сети и планируют свою работу за счёт сдвигов, исходя из допустимых отклонений моментов начала выполнения задач от предпочитаемого времени. Описываются онтологии, агенты, протоколы взаимодействия между агентами и основные преимущества предлагаемой системы.

Ключевые слова: *микроспутник, наземная станция, мультиагентная система, сеанс связи, онтология, планирование потока данных, агент.*

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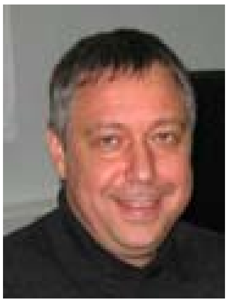
Сведения об авторах



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