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DEVELOPMENT OF SATELLITE OPERATION SCHEDULING MODULE FOR SPACE MISSION SIMULATION TOOL

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Abstract: *The implementation of satellite operations demands his ground based scheduling. This activity is decisive for stage of mission realization. The scheduling of satellite operations is very important at the stage of mission preparation, for analyzing of the feasibility of specific task and the entire mission too.*

The development of satellite operations scheduling module which work in the frames of space missions and experiments simulation tool is presented. The connection of this module with module for situation analysis is significant.

Some scheduling algorithms and auxiliary subroutine are developed. The work of scheduling algorithms is illustrated by solving of over-subscribed problem. A communication problem connected with data transfer toward/from Antarctic ground based stations is chosen as an example.

РАЗРАБОТКА НА МОДУЛ ЗА ПЛАНИРАНЕ НА СПЪТНИКОВИ ОПЕРАЦИИ КЪМ СИСТЕМА ЗА СИМУЛИРАНЕ НА СПЪТНИКОВИ ЕКСПЕРИМЕНТИ

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Резюме: *Извършването на спътникови операции изисква тяхното планиране във времето. Тази дейност е решаваща за етапа на протичането на мисията. Планирането на спътниковите операции може да се окаже от голямо значение още на етапа на подготовката на мисията за анализа на изпълнимостта на отделни задачи, както и за цялата програма.*

Представя се разработката на модул за планиране на спътникови операции работещ в рамките на програмна система за компютърно симулиране на космически мисии и експерименти. За работата на този модул е от изключително значение връзката му с модула за ситуационен анализ. Разработени са няколко алгоритъма за планиране и допълнителни подпрограми, подпомагащи тяхното изпълнение и графично онагледяване.

Работата на алгоритмите за планиране е илюстрирана с решаването на over-subscribed problem. За пример е избрана комуникационна задача свързана с пренос на данни до/от наземни изслдователски станции разположени на Антарктида.

Introduction

Planning and scheduling of satellite operations is vitally important at the stage of mission control. A preliminary preparation and simulation of planning and scheduling could drastically increase effectively and reduce the price of satellite missions. The purpose and significance of planning and scheduling in space mission analyzing and design is explained in detail in [1]. Different satellite tasks scheduling approaches are explained [2-7].

Space Missions Simulation Tool is under development at branch of Space Research and Technology Institute in Stara Zagora [8]. A development of satellite tasks scheduling module is presented in the paper. Satellite tasks model for definition of their parameters is presented. Some scheduling approaches are developed containing basic and auxiliary algorithms.

Formulation of scheduling problem

The satellite scheduling problem treats the process of ordering different activities or operations, which must be executed from instruments on the board of the satellite. Ground based resources (stations, instruments, peoples, apparatus etc.) could be involved also in satellite scheduling. The different activities are connected with fulfillment space based or joint space and ground based measurements and experiments. Satellite - ground based station communications are example about such joint activities.

Pemberton [3] proposes the following definitions:

- Task- activity and operation of satellite or combined satellite - ground based station necessary to be executed. One task could be compounded from some activities or operations.
- Resources- satellites with on board instruments, control stations with people, computers and memories, tools, etc., which are necessary to tasks execution.
- Events- specific conditions arise out of geometric or physic parameters (for example visibility, angle relation between vectors or physic parameters in specific interval etc.) in the frame of relatively short time interval, which allow tasks execution.
- Constrains- restrictions connected with resources or other tasks execution.

Every task request specifies duration of task and time window within which the task must be allocated.

Satellite operations scheduling model

According to our solving approach for automatic scheduling of satellite activities and operations the following model is applied in our development. It contains different attributes- some of them are used for definition of the operations, other indicate applying or not of priorities and repeatability in the frame of a given time interval. Some attributes contain mode of task execution and results (figure 1).

Every operation has private code**-** ID_code which distinguishes one operation from others. Every operation could be realized in time window of orbital event according previously solved situation problem denoted with SP_code. The time duration necessary for task execution is different for every task. In case of communication tasks time duration is depended on quantity of information and is requested from user. The parameter duration contains value required from user of the service.

A parameter priority is used for controlling the order of tasks execution. The tasks with higher priority are executed before tasks with lower one. The tasks with higher priority will be executed every time in the whole scheduling time horizon. Because of that other parameter is included- regularity. This parameter of the model allows additional possibilities for tasks execution control. Other variants about this parameter are possible to be realized in the future.

The parameters t_begin and t_final contain current scheduling result. Parameters counter and total_time contain the number of task execution and total scheduled time, respectively. The parameter color is used for visualization in the course of scheduling process.

```
  type      Task_model
  integer   ID_code   ! current identification number of the Task
  integer   SP_code   ! SP(sit.prob.) which determine the time window (time slot) for the Task
  real      duration  ! time duration necessary for Task execution
  integer   regularity ! 0: one time only (date1-date2)
                       ! 1: one time dally; 2- one tine per week; 3- one time per month
                       !-1: every time when the situation allow
  real*8    interval(2) ! interval(1)- initial moment; interval(2)- final moment (regularity=0)
                        !        (1)- release moment & due/deadline
  integer   priority  ! (0-10)
  logical   fulfiled  ! .true. when the task is fulfilled and .false. while is not
  logical   mark      ! there are windows for scheduling- .true.; not- .false
  real*8    t_begin   ! scheduled begin time
  real*8    t_final   ! scheduled final time
  integer   counter   ! haw many times is satisfied
  integer   unsched   ! counter for no scheduling event
  real*8    total_time ! total time for task for entire period
  integer   color
 end type Task_model
```

Fig. 1. Structure containing different model parameters

Developed satellite tasks scheduling algorithms

Some approaches were developed for scheduling module of Space Missions Simulation Tool [8]. These approaches are based on well-known greedy algorithm [9]. When more tasks are ordered than available resources allow to be executed, then the scheduling problem is named over subscribed tasks (OSTs) scheduling problem [5]. Data transfer between one satellite and several ground-based stations, when the stations are located at short distances, rise to over-subscribed tasks. The satellite passes simultaneously through radio-zone of several stations. The situation analysis finds some mutually overlapped time windows in such cases. A group of such overlapped time windows as part of all series of situation solutions is named fragment. The entire series of situation solution is composed of fragments and single time windows.

A result from situation analysis represents a series of time intervals when different tasks could be fulfilled. Every task is assigned to only one situation problem. An auxiliary procedure for determination and separation of mutually overlapped time windows (fragments) with different duration of every one is developed. Developed scheduling algorithms are applicable toward such time windows fragments.

Tree scheduling approaches/ algorithms were developed:

- Ordinary greedy algorithm (**OG**a). Versions "*first begun – first scheduled*" and "*first finished -first scheduled*" are developed.

- Greedy algorithm with priorities (PGa). Modified greedy algorithm (**MG**a) is applied repeatedly according decreasing of priority toward connected fragment of overlapped time intervals, at which orbital events existed.

- Constrains based combined greedy algorithm (**CG**a). This approach applies tasks' prioritizing and different execution modes- how many times in the frame of simulation time horizon one task must be executed.

A check is made about execution possibilities for every serial task (from task list) in respective time interval. If execution is possible, this task is scheduled. Then all other intervals which are overlapped with the current one are shorten depending on beginning time and final time of scheduled task. This operation could exclude some other tasks from scheduling process.

Other auxiliary subroutines are developed too. One of them sorts time windows of current fragment under analysis according to their beginning time. Other subroutines are engaged with current scheduling visualization.

Example of scheduling algorithms application

Developed algorithms are applied to scheduling communication tasks between satellite and ground based stations located at Antarctica continent for transferring scientific, medical and other types of information. Situation analysis is preliminary executed for establishing time intervals when satellite fall in radio-visibility zone for each of 72 Antarctica stations [10]. This analysis is done by space missions and simulation tool which is under development [11].

Produced results are written in file. Each record contains starting and final times of time intervals when the particular satellite come in and come out from radio-visibility zone. Time intervals are naturally ordered by final times of intervals. Very important feature is connected with overlapping of time intervals for different stations (Fig. 2).

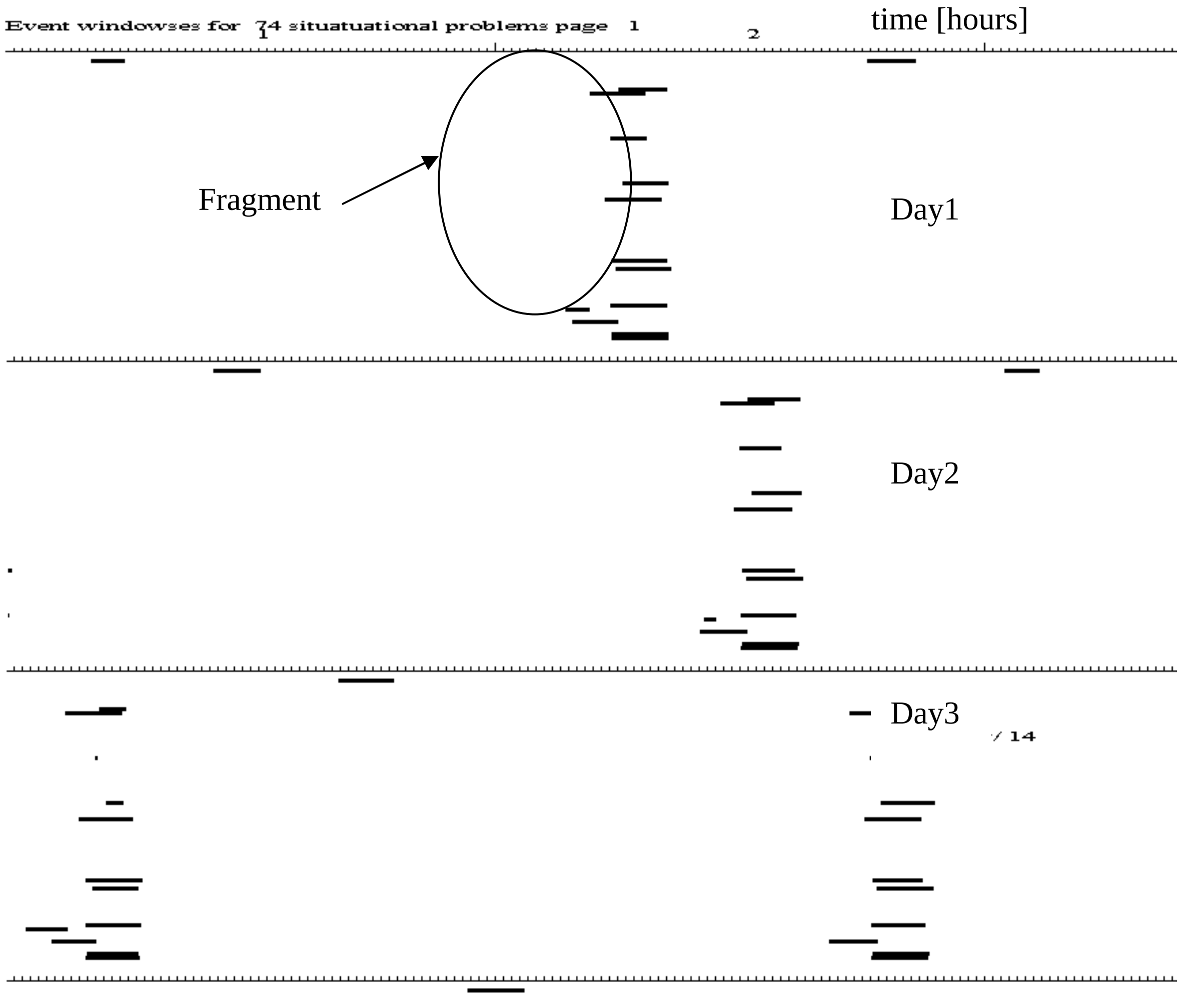
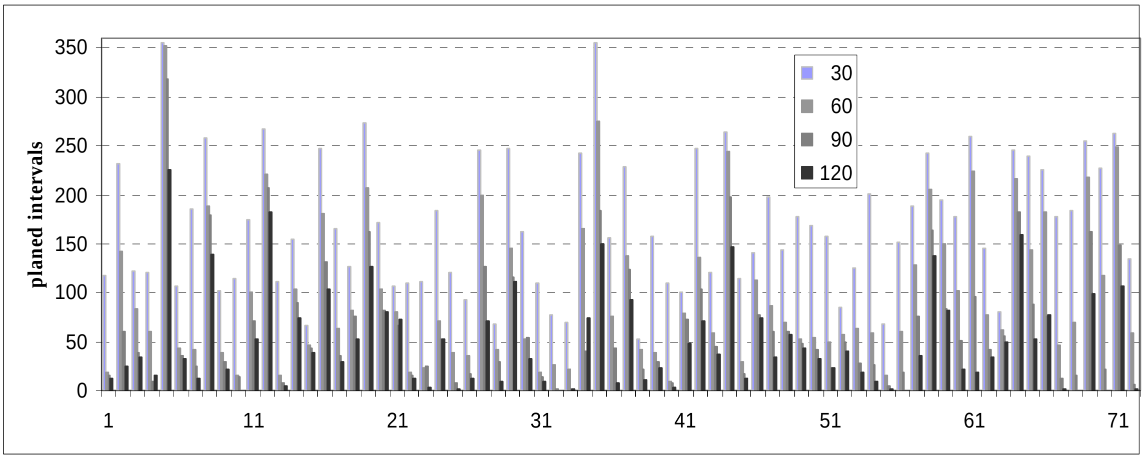


Fig. 2. An Illustration of situation analysis results is shown – part of screen. The time in hours is presented in horizontal direction. Vertically are presented tree days. One fragment of overlapped time windows is shown too. Each bar represents time window when the satellite overpass in radio-zone of respective ground-based station

Radio-visibility zone for each station depends on satellite altitude, geographical position of the station and constrain the satellite to be at some angle over horizon. In our instance, the altitude of circular orbit is accepted to be 800km, inclination- 84 deg and angle of the satellite over the horizon bigger than 30deg.

Some scheduling examples when all ordered communication tasks are with equal durations 30, 60, 90 or 120 s are simulated. Figure 3a shows the number of scheduled communication time intervals when data transfer is possible. Figure 3b presents total time for each station depending on requested from control centre time intervals durations. All simulation scheduling experiments are made for a monthly time horizon.



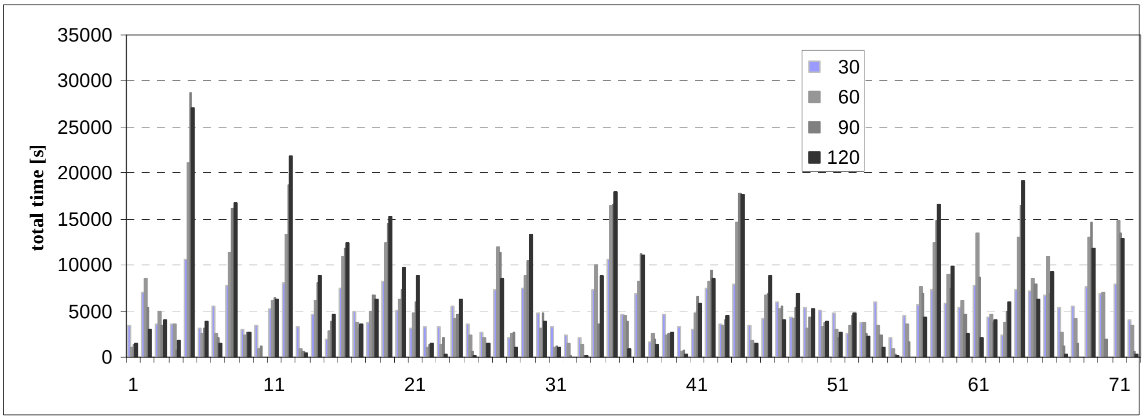


Fig. 3. The first panel shows the number of scheduling for each of tasks, related to respective ground station, according to equal tasks' duration of 30, 60, 90 and 120sek. The second panel shows communication total time for each station according tasks' duration

Applying of different requested tasks durations for each station don't change the general course of the results above. The geographic locations of the stations appear to be very significant. Some stations occupied available resource every time and don't leave any possibilities for tasks related to other stations to be scheduled. This is a problem when ordinary scheduling method is applied. The pointed problem could be mitigated with applying priorities to every task. The tasks which is impossible to be executed must receive highest priority. Except with priorities, other heuristics are applicable for mitigation the same problem. Some tasks could be executed only once in the frame of simulated time horizon which give them priority. Such tasks couldn't block execution of other tasks. After its execution they don't participate more in scheduling. A reducing required duration of communication tasks allows evenly execution of tasks for different Antarctic stations.

Conclusion and future work

A model for satellite operations definition is proposed. The model connects every satellite task with situation problem which determines the time window when the task execution is possible. Except task duration, other attributes as priorities and reiteration in the frame of time interval for scheduling are included. Algorithms which use some of model attributes are developed. An application of some other attributes of proposed model is under development. An example illustrating satellite transfer data communication tasks scheduling is presented.

A possibility for scheduling with accounting finite size of satellite memory for information saving and transferring toward/from satellite control centre and communication séances with this centre are under development.

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