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DEEP SPACE NETWORK RESOURCE SCHEDULING APPROACH AND APPLICATION

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ABSTRACT

Deep Space Network (DSN) resource scheduling is the process of distributing ground-based facilities to track multiple spacecraft. The Jet Propulsion Laboratory has carried out extensive research to find ways of automating this process in an effort to reduce time and manpower costs. This paper presents a resource-scheduling system entitled Plan-It with a description of its design philosophy. Plan-It's current on-line usage and limitations in scheduling the resources of the DSN are discussed, along with potential enhancements for DSN application.

INTRODUCTION

Scheduling is believed to be one of the most difficult issues artificial intelligence (AI) has attempted to resolve. This paper addresses the how and why of AI structures and techniques which were used in resolving the DSN Resource Allocation scheduling problem. Finally, the results, which caused a factor of six speed-up in the schedule generation process, will be discussed.

This paper encompasses three main topics. The first part of the paper describes the constraints and requirements of the DSN Resource Allocation scheduling problem, followed by a description of the design philosophy behind the AI scheduling system Plan-It, providing the conceptual background for this approach. The remaining portion of the paper will discuss Plan-It integration and application to DSN Resource Allocation scheduling, along with what has been learned from the task.

DSN RESOURCE ALLOCATION PROBLEM DESCRIPTION

The Deep Space Network is a worldwide system of tracking antennas, consisting of three ground stations spaced 120 degrees in longitude from each other. The stations are located in Canberra, Australia; Madrid, Spain; and Goldstone, California. As the earth rotates, this geographical arrangement of stations ensures that a spacecraft will be visible to at least one ground station at any time. Each station has a minimum of three antennas, two 34-meter dishes (one with receiver only, the other with a transmitter) and a 64-meter dish antenna.

Scheduling DSN support for tracking spacecraft is a very difficult problem, involving many dynamic factors that influence or even change a scheduler's strategy from month to month. The schedule is based on a set of constraints consisting of viewperiods, project requests, and DSN system requirements.

Viewperiods are time intervals in which radio dishes have line of sight to their targets. This line of sight is required to monitor the signal from a particular spacecraft or to uplink commands. When the DSN antenna is used for radar imagery of a planet, the planet must be viewable by the antenna. These time intervals may also be referred to as time windows.

Project demands upon the system fall into two major categories. The first consists of viewperiod-dependent requirements that a project levies upon the DSN. Flight projects usually submit a document containing these time-specific tracking requests for the spacecraft and the minimum antenna tracking requirements for the project. For instance, a project may require ten continuous hours of coverage in duration once a day on a 64-meter antenna. This request not only implies multiple usage of an antenna resource, but also implies viewperiod restrictions on where the activities may be placed in the schedule. Some non-spacecraft requests are also viewperiod dependent, if the project wishes to track a planet or a quasar.

The second category of project requests are known as non-viewperiod-dependent requests, and deal with non-time dependent observations, such as certain classes of radio astronomy. These may be in the same format as that of the first category, but contain no target-timing restriction. Both categories of requests have two types of requests: generic and specific. The generic request indicates multiple activities occurring in the schedule, with some time-dependence relationship between them. The specific request specfies a specific date, time, antenna, and duration which a project requires for antenna coverage.

The DSN also imposes many constraints on the system in the form of station maintenance requirements. Each antenna requires a certain amount of maintenance, usually eight hours a week. This maintenance activity is further constrained by not allowing personnel to cross workshift boundaries at the station. There are also times when the station is unmanned, so no requested activity may be scheduled during such time. Other DSN activities may be antenna upgrades, antenna calibration, and special activities.

In addition to the activities and constraints listed above, the scheduler must observe certain scheduling techniques which may further constrain the schedule. For example, no two antennas may simultaneously track the same spacecraft for more than 30 minutes, unless simultaneous tracking was specifically requested by the project. This limitation/restriction is used to maximize use of scarce antenna time.

Another potential problem the scheduler must address is viewperiod overlap among two spacecraft, causing a conflict in their tracking requests. This conflict forces the scheduler to work out some kind of compromise, such as juggling the projects' requests between other radio antennas or stations, or arranging some time-sharing schedule on an antenna between the two projects. These are just two of the many different strategies available to the scheduler in resolving this conflict.

The amount of constraints and the number of spacecraft requiring tracking yield an incredible number of solutions to a schedule for a particular situation. The scheduler's job is to find the solution which best optimizes antenna usage, meeting at least the minimum tracking requirements of each project.

The preceding text has described but a few of the basic factors a scheduler must consider in establishing a basic DSN schedule. However, there are many other special requests and situations which may change this situation. For example, when a project has a planetary encounter, all of that project's requests become specific requests, which now provide for continuous spacecraft tracking for most of the encounter period. Two or more antennas may be used in tracking the spacecraft simultaneously for hours at a time. These types of constantly fluctuating constraints make the DSN scheduling problem a unique one for which the search for a better solution still continues.

A significant contributing factor to the problem with the DSN Resource allocation plan is that as spacecraft get farther and farther away from earth, a larger diameter antenna is required to pick up the signal from the spacecraft. And since there are few antennas capable of picking up deep space signals, there is a great deal of competition between the projects for the large antenna resources.

As the number of projects requiring support increased over the years, and more special events occurred closer together, each requiring more and more support, it became increasingly more difficult to produce a realistic schedule in a reasonable amount of time. To overcome this difficulty the DSN Resource Allocation Group was formed to develop an automated process to reduce preparation time and enhance reliability of the schedule. The proposed process is split into two parts. The first part consists of the Computer-Aided Resource Allocation and Planning system (CARPA), which provides an initial version of the schedule after all the constraints and requests have been entered into the system. This was a batch-mode scheduling system that uses a dynamic priority bin-packing technique. The second part consists of manually refining the plan to fit a particular situation.

Each part of the process, however, has its own special problems. A major problem in the refining process is that the conditions for which a schedule was produced may drastically change as the timeframe to implement the schedule approaches. This sometimes requires massive changes to a schedule, which must be made quickly and accurately. Excessive delays can cause further problems in the DSN schedule because the delays may impact a project's future inputs in planning communications with its respective spacecraft. Hence a need exists to further automate the process.

DSN RESOURCE ALLOCATION PLAN-IT OPERATION

Plan-It was developed to address the final refinement or tweaking portion of the scheduling process. The DSN scheduling problem was addressed by the resource-scheduling system Plan-It operating in several conceptual modes, from the most primitive to almost fully automatic. Another requirement Plan-It had to meet was the ability to interface with CARPA.

The figures on the following page show some of the capabilities a user can invoke in Plan-It on a typical DSN schedule. Figure 1 shows a menu of statistics, giving the user a quantitative measure of how the radio dishes are being used. Figure 2 shows the user mousing on a black conflict area to gather further information about that particular conflict. Menu interaction is the main user interface to the program. Every operation is mouse driven. The menus are accessed successively through a tree structure applicable to a particular task category, such as editing, data i/o, strategy implementation and modification, and graphical display control. The functions selected from the menus direct the tool to do different tasks. The major selectable functions are graphical manipulation, data i/o, schedule manipulation and verification.

The graphical display and user's ability to manipulate it maximize the bandwidth of information that passes between the person and the program. Each user has his own way of wanting to see how activities lay out in the schedule. To satisfy this need, Plan-It enables the user to dynamically reorder requests and resource lines on the screen. This further enhances the user-natural interface so a person can intuitively resolve conflict and opportunity patterns seen on the screen. Further capabilities the user possesses with Plan-It are redefining the relative sizes of the activity-plotting pane and the resource line pane. In order not to overwhelm the user with an abundance of scheduling data, the Plan-It screen consists of two major panes acting as small view windows on a much larger scratchpad of the schedule timeline. If the user wishes to concentrate only on a few resources but see more of the activity layout, he changes the relative proportions between the two windows. The final graphical manipulation tool the user has at his disposal is the ability to change the frequency that Plan-It updates its windows. By default, Plan-It will update its windows whenever any action occurs. If the user does not wish to see all of the intermediate action taking place during a task execution, he can change the

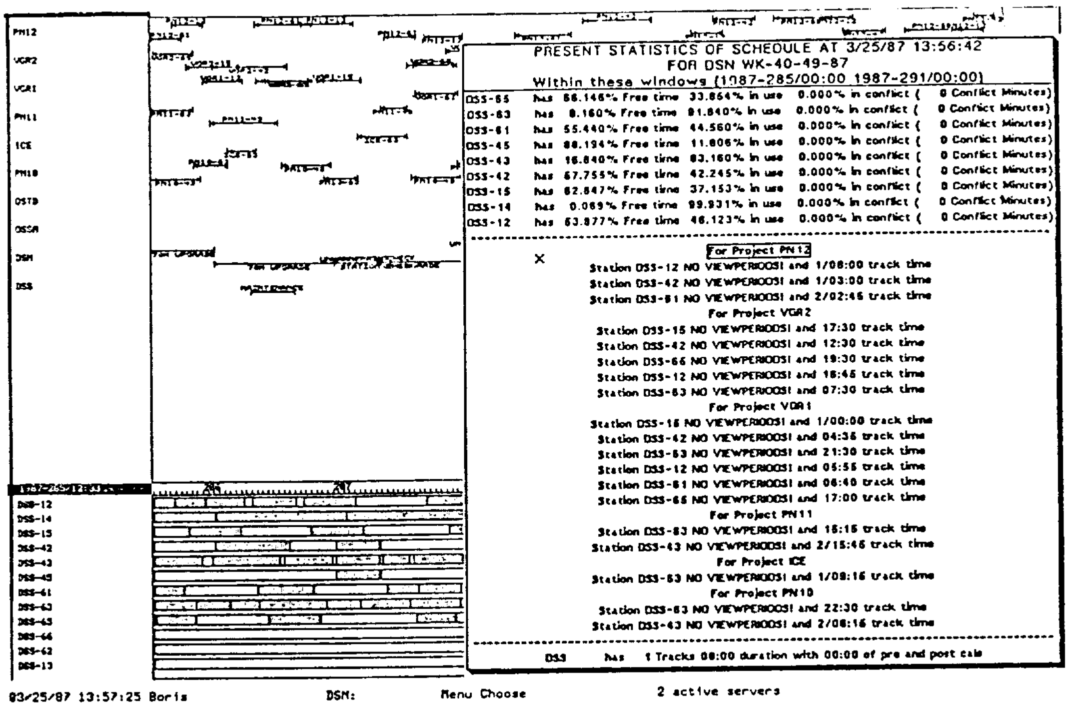

Figure 1. DSN Plan-IT Display with Statistics Menu

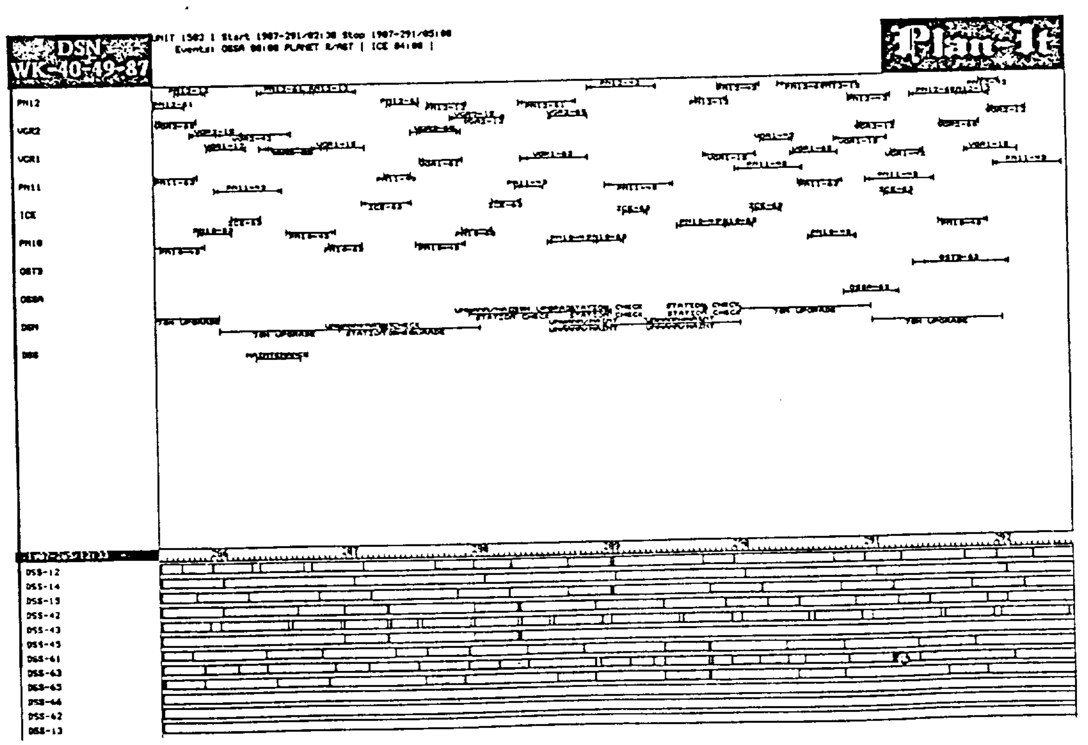

Figure 2. DSN Plan-It Display. Top pane shows information on the conflict area the user had moused on.

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frequency of update to occur at whatever time interval he desires.

Via the menu interface, the user loads in the scheduling problem and data files. There are several different types of files Plan-It would accept for DSN scheduling, ranging from Plan-It's initialization files, viewperiod or targetting files, and the schedule file output from CARPA. The user's task is to iterate on the input requests or partially generated schedule and to finalize the schedule. During any point of the operation of Plan-It, the user can request via a menu to either save the present state of the schedule or view statistics of the resource usage. The statistics gives the user another quantitative means of measuring his progress toward completion of the schedule, rather than the graphical view that is always present in Plan-It. The saved schedule file can be later loaded in to resume scheduling from that point.

DSN RESOURCE ALLOCATION SCHEDULE GENERATION PROCESS

CARPA generates the initial schedule. After CARPA completes this phase of the scheduling process, the CARPA schedule file is transferred to Plan-It for further refinements. In many instances CARPA adequately resolves the initial schedule with some lower priority requests deleted. Once Plan-It receives the CARPA file, the deleted requests are brought back into the schedule. The resource lines representing the radio antennas utilized by the requests graphically depict the conflict areas. The user may mouse on the conflict area to obtain further information on the exact time frame and requests or activities contributing to the conflict. Seeing the conflicts and opportunities motivates the user to either edit or invoke specific heuristics to further resolve the schedule. This display representation can be seen in the figures under the menus. After many cycles of iteration between the user and Plan-It, the schedule will finally be completed.

This mode of operation shows that the Plan-It scheduling process is totally user-controlled. As the user edits the schedule, he supplies the intuition and motivation to apply and guide the supplied Plan-It heuristics, called strategies. The "user-natural" graphical interface of the program allows the user to see conflicts and opportunities as they arise from previous actions in Plan-It, whether initiated by him or the strategies. Upon viewing the results, the user can edit directly or invoke other strategies. This is the circular-action cycle that the user cooperating with the Plan-It employs to produce a schedule.

The most utilitized concept in the Plan-It system is the strategies. Strategies act as a library of simple DSN scheduling heuristics for use by the Resource Allocation Team. These strategies may be scoped by user-imposed constraints or modifications, specified by strategy-modification menus. For example, in DSN scheduling there is an activity-expansion strategy, the purpose of which is to expand any activity or request to its maximum allowable duration without causing conflicts. The fact that the user does not have to be precise on the amount of expansion or which activities to expand demonstrates the robustness of these strategies. Also, the strategy may be modified by the user to expand about the middle of the activity or expand forward or even backwards. The user may further scope the strategy to take action only on non-conflicting activities of a certain class of projects that only use specific radio dishes within particular intervals of time. This broad flexibility of modifying the strategy further enhances the user interaction in a more satisfying scheduling process.

WHAT'S BEEN LEARNED

One thing learned from watching the Resource Allocation Team schedule the DSN is that a scheduler tends to avoid resolving the schedule in a chronological order. This jumping about to different time frames on the schedule during the scheduling process is a result of changing perspective or focus level. People look for opportunities and quick fixes. Initially, during the early phases of schedule development, the user lays out the requests in the schedule at their preferred locations and applies global strategies. This defines the general layout of the schedule. This action may produce conflicts throughout the schedule, but the user usually is not concerned with them until later, unless by changing his focus level he can quickly resolve a conflict that may appear during that process. As the user goes through the Plan-It action cycle, the types or pattern of conflicts shown cause the user to localize his focus level to the particular conflict or opportunity at hand. At this point, he may edit the specific activity, causing the conflict or invoking a strategy on the conflict itself to resolve it. Both the Plan-It strategies and the user monitor their performance from the resource lines. Presently, only the user is knowledgeable enough to change focus level and choose the order of invoking the strategies.

The last and most important feature emphasized in Plan-It's creation is cooperation with people. Approaching a complicated scheduling problem in a top-down, time-ordered programmatic manner does not work. Knowledge of the problem domain must be gathered from seeing how people deal with it. In the DSN scheduling domain, resource contention and tracking opportunities play a major role in determining how a person allocates his time and effort in resolving the schedule. Presently, Plan-It views the scheduling problem solely from one basic perspective: the resource lines. This single viewpoint forces the Plan-It strategies to be more algorithmic rather than intuitive driven, thus limiting the scheduling-resolving capabilities of Plan-It. But because the person actually sees what Plan-It sees, he can supply the conflict pattern and opportunity recognition, changing perspective and focus control as needed to resolve a scheduling problem.

CONCLUSION

Originally the Resource Allocation Team generated schedules manually. This manual operation was reduced in part by CARPA. However, even with an initial computer-generated schedule, the Resource Allocation team was barely able to keep pace with the realtime generation of schedules, taking nearly a month to generate one month's schedule. The close interaction between Plan-It and the scheduler resulted in a rapid turnaround time for producing schedules. It is now possible to generate schedules for an entire year within two months. Plan-It's user-natural concept and graphical display increase the user's scheduling prowess by enabling him to readily see the results of the actions he performs in the schedule itself. But in spite of this improvement in scheduling performance, additional research is needed to address the issue of incorporating the user's intuitive abilities into Plan-It.

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