An Expert System for Scheduling Requests for Communications Links Between TDRSS and ERBS

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ABSTRACT

This paper describes the ERBS-TDRSS Contact Planning System (ERBS-TDRSS CPS) that has been built to help Earth Radiation Budget Satellite (ERBS) flight operations personnel generate requests for service from the Tracking and Data Relay Satellite System (TDRSS). The ERBS-TDRSS CPS is written in the C language and runs on an IBM PC-AT. It uses a graphics interface and the Transportable Inference Engine (TIE-1) developed for NASA-GSFC. First, ERBS-TDRSS Ground Track Orbit Prediction data are electronically transferred to the ERBS flight operations area where, in its batch mode, the ERBS-TDRSS CPS automatically generates requests for TDRSS service (usually for one week). In this process, a series of scheduling strategies is used to generate requested events while TIE-1 determines whether each requested event is consistent with ERBS scheduling constraints. As requested events are rejected, alternative context-sensitive strategies are used to generate new requested events until a schedule is completed. In the interactive scheduling mode the ERBS planner can edit a schedule that has been previously built or choose which alternative scheduling strategies the ERBS-TDRSS CPS should use to build a schedule. Finally, a report generator builds "Schedule Requests" for each separate ERBS-TDRSS contact.

1. INTRODUCTION

Generating weekly schedules of requests for communications links (contacts) between the Earth Radiation Budget Satellite (ERBS) and the Tracking and Data Relay Satellite System (TDRSS) has been a manual, labor-intensive task. In this activity, the ERBS flight operations planner first obtains large Ground Track Orbit Prediction data printouts from the Flight Dynamics Facility and performs a visual inspection to find desired ERBS-TDRSS contact times. In selecting good contact times, the planner must consider all of the ERBS scheduling constraints, make experienced judgements, and avoid errors. After a schedule of contacts has been determined, separate "Schedule Requests" for each separate ERBS-TDRSS contact have to be prepared and sent to the Network Control Center (NCC) via the Mission Planning Terminal. If particular requests for TDRSS service are rejected by the NCC, additional effort is required by the ERBS planner to generate alternative requests to satisfy ERBS requirements.

A system to automate this planning process has been built and is being tested by ERBS flight operations personnel. This system is called the ERBS-TDRSS Contact Planning System (ERBS-TDRSS CPS). The ERBS-TDRSS CPS is written entirely in the C language and operates on an IBM PC-AT. It features a user-friendly graphics interface and the Transportable Inference Engine (TIE-1) developed for NASA-GSFC/Code 514 by Bendix Field Engineering Corporation. The Transportable Inference Engine (TIE-1) was described at the 1986 Goddard AI Conference (McLean [1986]). A NASA-GSFC/Code 514 document describing the ERBS-TDRSS CPS and two describing the Interactive Experimenter Planning System Version 3.0 Prototype (on which the ERBS-TDRSS CPS is based) are listed in the reference section.

This paper will first describe how ERBS-TDRSS Ground Track Orbit Prediction data are transferred to the IBM PC-AT in the ERBS flight operations area and used in generating resource windows for the ERBS-TDRSS CPS scheduling process.

Next, the batch scheduling mode of the ERBS-TDRSS CPS will be described. In this mode a schedule of requests for TDRSS service (usually for a 1-week period) can be generated without any interaction with the ERBS flight operations planner. Here, the ERBS-TDRSS CPS uses a series of context-sensitive scheduling strategies (McLean and Littlefield [1987]) from a strategies knowledge base to generate requested events. The embedded inference engine TIE-1 determines whether each requested event is consistent with ERBS scheduling constraints contained in a constraint knowledge base. As requested events are rejected by TIE-1, alternative strategies generate new requested events until a schedule is completed. Examples will be given to show how this strategy and constraint information is represented in knowledge bases.

Following the description of the batch scheduling mode, this paper will describe the various scheduling and editing features of the ERBS-TDRSS CPS in its interactive scheduling mode. In this mode the ERBS flight operations planner can interact with the automated scheduling capabilities of the ERBS-TDRSS CPS to build a schedule or edit a schedule of events that has previously been built.

Finally, the report generator which is used to produce "Schedule Requests" for each separate ERBS-TDRSS contact will be described, and some general conclusions related to the ERBS-TDRSS CPS will be presented.

2. RESOURCE WINDOW GENERATION

ERBS-TDRSS Ground Track Orbit Prediction data are transferred from the Flight Dynamics Facility (FDF) at NASA-GSFC to an IBM 4341 mainframe in the Command Management Facility (CMF) area where a "filter" program is run to obtain a desired subset of the orbit data. The filtered orbit data are then transferred electronically to an IBM PC-AT located in the ERBS flight

operations area where the "ERBS to IEPS" (ETOI) program reformats the data, builds files containing data for one week or less (because of IBM PC-AT memory limitations), and generates resource windows for the ERBS-TDRSS CPS scheduling process.

In running the ETOI program, the ERBS flight operations planner must specify: (1) whether ERBS is flying "forward" or "backward" along its orbital track (the ERBS flight orientation is periodically switched and this affects antenna obstruction angles) and (2) the azimuth and altitude obstruction angles to be used for the S-band Single Access-2 (SSA2) TDRS antenna and the Multiple Access (MA) TDRS antenna. Presently there is only one TDRS in the TDRS System for the ERBS-TDRSS CPS to consider. From the orbit data the ETOI program reads: (1) ERBS daylight period information, (2) ERBS orbit number information, and (3) TDRS antenna angle information. As output, the ETOI program specifies:

a. Start and stop dates and times for ERBS orbital daylight periods.

b ERBS orbit numbers with start and stop dates and times

c. TDRS MA antenna viewing periods for ERBS

d. TDRS SSA2 antenna viewing periods for ERBS

3. THE BATCH SCHEDULING MODE

In the batch scheduling mode the ERBS-TDRSS CPS builds a schedule of ERBS-TDRSS contacts for two different types of spacecraft activities: (1) tape recorder dumps and (2) Stratospheric Aerosol and Gas Experiment (SAGE) monitor events. Tape recorder dumps are for sending tape recorded data from ERBS to TDRSS. SAGE monitor events are for sending real-time data obtained by the ERBS SAGE-II instrument (see ERBE Program document listed in the references) during selected sunrise or sunset periods.

In building a schedule of ERBS-TDRSS contacts, either the MA TDRS antenna or the SSA2 TDRS antenna can be requested. Tape recorder dump events (TRU dumps) are planned every other orbit (if possible) and require an event duration of either (1) 30 minutes via the MA TDRS antenna or (2) 20 minutes via the SSA2 TDRS antenna. A 30-minute TRU dump via the MA TDRS antenna is requested first (by the "START" strategy). If the MA TDRS viewing period is not available, the ERBS-TDRSS CPS next requests a 20-minute TRU dump during a SSA2 TDRS viewing period (using the "EVENT" strategy). If neither the original MA TDRS viewing period nor the SSA2 TDRS viewing period is available, the ERBS-TDRSS CPS requests (as a third choice) a 30-minute TRU dump via MA in the next orbit (using the NEXT strategy). The way this strategy information is represented in the strategies knowledge is illustrated in the example below.

```
TRU Dump via MA

;event to be scheduled every 2 orbits
     2
;duration of event:
     0:30
;strategies:
     START MA TDRS viewing periods
     EVENT TRU Dump via SSA2
     NEXT
.

TRU Dump via SSA2

;event to be scheduled every 2 orbits
     2
;duration of event:
     0:20
;strategies:
     START SSA2 TDRS viewing periods
.
```

One sunrise SAGE monitor event and one sunset SAGE monitor event are requested every 16 orbits. These events must each have a duration of 13 minutes for either the MA TDRS antenna or the SSA2 TDRS antenna and must take place while ERBS is in an appropriate sunrise or sunset window. Sunrise SAGE events must start 10 minutes before ERBS daylight while sunset SAGE events must start 10 minutes before ERBS night. A 13-minute MA TDRS antenna contact is requested first. If the MA TDRS viewing period is unavailable, a 13-minute SSA2 TDRS antenna contact is requested. If neither the MA TDRS nor the SSA2 TDRS antenna contact is available, a forward-backward search algorithm (NEXT-PRIOR strategy) is initiated to look for the MA TDRS antenna viewing period that is as close as possible to the initial requested event. If a previously scheduled TRU dump event is encountered, the ERBS-TDRS CPS tries to "shift" the TRU dump event within its resource window in order to make room for the SAGE monitor event.

An example of the way these primary and alternative strategies for sunrise SAGE events are represented in the strategies knowledge base is shown below and on the next page.

```
Sunrise SAGE via MA

;event to be scheduled every 16 orbits
     16
;duration of event:
     0:13
;bias
     -0:10
;shift
     TRUE
;strategies:
     START Daylight
     EVENT Sunrise SAGE via SSA2
     NEXT
     PRIOR
```

```
NEXT 2
PRIOR 2
NEXT 3
PRIOR 3
NEXT 4
PRIOR 4
NEXT 5
PRIOR 5
NEXT 6
PRIOR 6
NEXT 7
PRIOR 7
```

The constraint knowledge base contains the ERBS scheduling constraints used by the inference engine (TIE-1) to determine whether requested events from the strategies knowledge base can be scheduled. For TRU dumps via the SSA2 TDRS antenna, the constraint knowledge base requires: (1) that the start and stop times requested be within the appropriate antenna availability window, (2) that no other events be scheduled during the interval requested, and (3) that the event be of the proper duration. If a constraint is violated a diagnostic message from the constraint knowledge base is written to a log file. In the interactive mode this diagnostic message is displayed on the screen. The manner in which this information is represented in the constraint knowledge base is shown below and on the next page.

```
TRU Dump via SSA2

event name                  eq      TRU Dump via SSA2

in SSA2 TDRS window         eq      true

     "The SSA2 TRU Dump you are trying to schedule must
      be within a SSA2 TDRS window."
```

event duration eq 20

"The duration of the SSA2 TRU Dump you are trying to schedule is not 20 minutes. A PE-S02 event requires 20 minutes."

conflicting event ne TRU Dump via MA

"The SSA2 TRU Dump you are trying to schedule conflicts with a previously scheduled TRU Dump via MA."

conflicting event ne Sunrise Sage via MA

"The SSA2 TRU Dump you are trying to schedule conflicts with a previously scheduled Sunrise SAGE event via MA."

conflicting event ne Sunrise Sage via SSA2

"The SSA2 TRU Dump you are trying to schedule conflicts with a previously scheduled Sunrise SAGE event via SSA2."

conflicting event ne Sunset Sage via MA

"The SSA2 TRU Dump you are trying to schedule conflicts with a previously scheduled Sunset SAGE event via MA."

conflicting event ne Sunset Sage via SSA2

"The SSA2 TRU Dump you are trying to schedule conflicts with a previously scheduled Sunset SAGE event via SSA2."

For sunrise SAGE events via the MA TDRS antenna, the constraint knowledge base requires: (1) that the start and stop times requested be within the appropriate antenna availability window, (2) that the start and stop times requested be within the appropriate sunrise window, (3) that no other event is scheduled during the interval requested, and (4) that the event is of the proper duration. If a constraint is violated, a message is written to a log file. In the interactive mode, this diagnostic message is displayed on the screen. The way in which this information is represented in the constraint knowledge base is shown below and on the next page.

Sunrise SAGE via MA

event name eq Sunrise SAGE via MA

in SAGE morning interval eq true

"The sunrise MA SAGE event you are trying to schedule does not start 10 minutes before onset of orbit daylight. Respecify the event times."

in MA TDRS window eq true

"The Sunrise MA SAGE event you are trying to schedule must be within an MA TDRS window."

event duration eq 13

"The duration of the MA SAGE event you are trying to schedule is not equal to 13 minutes. A PE-M02 event requires 13 minutes."

conflicting event ne TRU Dump via SSA2

"The MA SAGE event you are trying to schedule conflicts with a previously scheduled TRU Dump via SSA2."

conflicting event ne TRU Dump via MA

"The MA SAGE event you are trying to schedule conflicts with a previously scheduled TRU Dump via MA."

conflicting event ne Sunrise Sage via SSA2

"The MA SAGE event you are trying to schedule conflicts with a previously scheduled sunrise SAGE event via SSA2."

conflicting event ne Sunset Sage via MA

"The MA SAGE event you are trying to schedule conflicts with a previously scheduled sunset SAGE event via MA."

conflicting event ne Sunset Sage via SSA2

"The MA SAGE event you are trying to schedule conflicts with a previously scheduled sunset SAGE event via SSA2."

4. INTERACTIVE SCHEDULING MODE

The ERBS flight operations planner begins an interactive scheduling session by calling up a schedule (either a blank schedule or a schedule that has been previously built) and selecting the types of items to be displayed in the schedule-building window. These items are initially displayed on 24-hour timelines where the start and stop times of each event are

shown graphically. From the main menu located just below the schedule-building window, the planner may select one of eight options by (1) using cursor positioning or (2) using the key representing the first letter of the menu option, and then pushing the ENTER key. The eight options that can be selected from the main menu are:

HELP: Pushing the "h" key at any time provides help messages concerning the operation of the scheduling system.

ITEMS: Pushing the "i" key allows the planner to select a different group of timeline items to be displayed in the schedule-building window.

DAY: Pushing the "d" key allows the planner to select the day for which 24-hour timelines are shown in the schedule-building window.

EDIT: Pushing the "e" key provides the planner with several options for editing schedules (described in more detail below and on the next page).

LIST: Pushing the "l" key provides numerical listings of the start and stop times for the items shown graphically in the schedule-building window.

ZOOM: Pushing the "z" key allows timelines shown in the schedule-building window to be zoomed from 24 hours to as few as 8 minutes.

SCROLL: Pushing the "s" key allows the planner to scroll to new items or to new time values.

QUIT: Pushing the "q" key provides several options for saving files and exiting from the interactive scheduling mode.

If the EDIT option is chosen, the planner can either (1) insert or delete individual events in a schedule or (2) choose which alternative scheduling strategies the ERBS-TDRS CPS should use to build a schedule of events. If the first EDIT option is chosen, a type of spacecraft activity to edit is first selected. Next, an event of the selected type is manually requested by (1) typing the desired start and stop times for the event or (2) using the cursor to graphically locate the desired start and stop times for the event on the graphics interface. After an event is requested, the inference engine (TIE-1) determines whether the requested event is consistent with the ERBS scheduling constraints in the constraint knowledge base. If the inference engine returns a status of "OK", the color of the bar that represents the requested event on the graphics interface changes to blue to indicate that the event has been successfully scheduled. However, if the inference engine returns a status of "NOT-OK", the system sends a diagnostic message to the planner indicating why the selected event cannot be scheduled.

While in the EDIT mode the planner can invoke the ZOOM, SCROLL, or LIST feature without going back to the main menu by pushing the "z", "s", or "l" key. In addition, three other editing features are available directly from the EDIT mode by key selection, including:

OVERRIDE: Pushing the "o" key allows the planner to enter a password to override the constraints in the constraint knowledge base to schedule an event.

EXPAND: Pushing the "e" key while the cursor is resting on a scheduled event provides an expanded listing of information concerning that particular event.

DELETE: Pushing the "d" key while the cursor is resting on a scheduled event deletes the event.

The second main EDIT option allows the ERBS flight operations planner to interact with the ERBS-TDRS CPS and choose which alternative scheduling strategies the ERBS-TDRS CPS should use to build a schedule. In this mode the planner has the option of: (1) utilizing only the primary scheduling strategies in the strategies knowledge base (ignoring alternative scheduling strategies) to build a schedule, (2) utilizing all of the context-sensitive scheduling strategies (primary and alternative) in the strategies knowledge base to build a schedule, or (3) specifying with the "y" (yes) key or the "n" (no) key which alternative scheduling strategies the ERBS-TDRSS CPS should use to build a schedule. With the third option, the ERBS-TDRSS CPS asks the planner whether each specific alternative strategy can be used, waits for the planner's yes or no response, and then either tries the strategy or not depending on the planner's response. If a particular scheduling strategy fails, the ERBS-TDRS CPS provides a diagnostic message to explain why the event cannot be scheduled. As events are successfully scheduled, they are displayed graphically on the appropriate timeline.

5. GENERATING SCHEDULE REQUESTS

After a schedule of contacts has been built and saved as an output file, a "report-generation" program is invoked to read information in the output schedule file, along with information from the activities section of the strategies knowledge base, to prepare "Schedule Requests" for each separate ERBS-TDRSS contact period. The ERBS flight operations planner controls the report generation program through a configuration file by specifying: the date to be printed on each form, the name of the output schedule file to be read, the name of the report file to be created, the name of the strategies knowledge base to be used, the form file to be used, and the map file to be used. The map file specifies where data from the output schedule file and the strategies knowledge base are placed on the completed "Schedule Request" forms.

The requests for TDRSS service are then sent (via the Mission Planning Terminal) to the Network Control Center which has the responsibility of determining the usage of the Tracking and Data Relay Satellite System by all NASA and non-NASA users. If particular requests for TDRSS service are rejected, the ERBS-TDRSS CPS can be used to select and generate alternative ERBS-TDRSS contact requests to try to satisfy ERBS mission requirements.

6. CONCLUSIONS

As this paper is being completed, the ERBS-TDRSS CPS has been delivered to ERBS flight operations personnel for use but has not been fully evaluated. Early indications are that the ERBS-TDRSS CPS will be very useful in automating several planning/scheduling activities performed by the ERBS flight operations planner, including:

a. Reading ERBS-TDRSS Ground Track Orbit Prediction data and generating resource windows.

b. Applying context-sensitive primary and alternative scheduling strategies to generate requested events. If desired, the ERBS flight operations planner may interact with the ERBS-TDRSS CPS to select which alternative scheduling strategies the ERBS-TDRS CPS uses to generate requested events.

c. Checking requested events for consistency with the ERBS scheduling constraints before adding them to a schedule of events. With the use of a special password, the ERBS flight operations planner may manually overide the constraints in the constraint knowledge base to schedule an event.

d. Preparing "Schedule Request" forms for each separate ERBS-TDRSS contact in the proper format.

A valuable feature of the ERBS-TDRSS CPS is that its strategies and constraint knowledge bases can be easily edited to reflect changing operational requirements for the system that may occasionally arise. In addition, since the source code for the entire ERBS-TDRSS CPS (including the embedded inference engine and the user-friendly graphics interface) was developed by the NASA-GSFC/Code 514 contractor, extensive modifications or enhancements to the system can be made.

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