# Commentary on
# “An Anytime Planning Approach for the Management of an Earth Watching Satellite”

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## 1. Introduction

In the paper "An Anytime Planning Approach for the Management of an Earth Watching satellite" the authors describe an earth watching mission and start to develop algorithms for the application. An autonomous on board approach to scheduling individual telescopes within a constellation of telescopes is described. The approach uses an anytime scheduling algorithm driven by a dynamic programming formulation of the problem. An experimental scenario is presented and used to evaluate the system. Finally future directions are outlined.

I offer the following commentary on the paper. First, I amplify the future directions by describing ways in which the experimental scenario could be improved. Second, I outline and analyze different approaches to distributing scheduling responsibility between the telescopes, and ground systems. Finally I offer brief but highly important advice on teaming with the science community.

## 2. Improving the experimental Scenario

The value of the experiments could be improved by increasing the fidelity of the experimental scenario. Two suggested areas for improvement are outlined below.

### 2.1 Sources of observations

In the application, observations come from requests triggered by the detection instrument, and requests uploaded from one of two ground mission centers. Requests triggered by the detection instrument have unknown arrival times and must execute a minute after detection. Requests uploaded from ground mission centers have known arrival times and have execution times distributed across the orbit. In contrast the dynamic component of the experimental scenario has 50 observations that have arrival and execution times distributed across the orbit. The experimental scenario should take into account the distribution of arrival and execution times from the application domain.

### 2.2 A Down load Bottleneck

From the experimental scenario 720 = 360 + 360 seconds are available each orbit for downloading. Given 11 seconds per down load yields a capacity of 65 downloads per orbit. The telescope can take much more data in an orbit. Assuming an average slew takes 5.75 = 11.5 / 2 the telescope could take ~166 = 5280/ (26 + 5.75) observations per orbit. Even if only half of these opportunities were used the telescope memory would fill up within a few orbits. Note that about 75 observations were scheduled per orbit in the experimental scenario. A multiple orbit scenario would force the scheduling system to address the download bottleneck.

## 3. Alternative Scheduling Approaches

Scheduling approaches for a constellation of satellites can be put into a continuum based on how much scheduling is done on board versus on the ground. After presenting the continuum, arguments are given describing situations where it may be beneficial to move towards placing responsibilities on the ground.

| | Ground Functionality | On-Board Functionality |
|---|---|---|
| Satellite | Provides a pool of observations to each telescope. | Iteratively builds plan from pool and triggered observations. |
| Intermediate | Provides a schedule and an over subscription pool to each telescope. | Executes schedule.<br>Repairs schedule in response to a triggered observation. |
| Ground | Provides a schedule of observations to each telescope. | Executes schedule unless preempted by a triggered observation. |

Table 1. A continuum of scheduling approaches.

Table 1 presents a continuum of scheduling approaches. In the satellite approach, as presented in the paper, the ground system distributes a pool of observations to each telescope. Each telescope independently schedules the pool and any triggered observations. On the other end of the spectrum, the ground approach uploads schedules produced on the ground to the telescopes. The telescopes execute the schedules unless an observation is triggered by the detection system. In this case the triggered observation preempts any planned observation that conflicts with the triggered observation. In the intermediate approach the ground system uploads both a schedule and a pool of over subscription observations. The telescope executes the schedule until a triggered observation occurs. In this case the telescope repairs the schedule using observations from the existing schedule and the over subscription pool.

### 3.1 Analysis

Cost is one motivation to move functionality to the ground. All things being equal it is more expensive to develop, test, and maintain software for space than it is for ground systems. We should only place functionality in space if it enables new science opportunities.

On board planning is motivated by the dynamic nature of observations triggered by the detection instrument. Any single observation triggered by the detection instrument can be scheduled in the current orbit. The offset between instruments gives a 1 minute delay between detection and the scheduling start for the observation instrument. This leaves plenty of time in the worst case where a 26 second observation has just started and a 11.5 second slew is required.

By definition triggered observations are critical to the mission. Given that there are few triggered observations the ground strategy works well as it gives preference to mission critical triggered observations and allows schedules to be created with no runtime pressure in the absence of triggered observations.

If there are many triggered observations then the preemption approach would impact on the uploaded long term science program. In this case the intermediate approach provides the ability to repair the schedule while allowing optimal ground based scheduling when there are no triggered observations.

In some cases a single telescope cannot handle multiple triggered observations in close proximity (e.g. two observations along the same detection swath). In this case the quickest way to handle the missed triggered observations is to schedule them on another telescope via the ground system. All of the approaches require a mechanism to select between competing triggered observations and to prevent the same triggered observation from being scheduled by different telescopes. One possibility would be to use the alarm mechanism to help in the coordination.

The size and stability of the long-term science program is another factor in evaluating the scheduling approaches. If the long-term science program is small compared to the triggered observations then we have a primarily reactive scheduler. As the size and importance of the long term program increases so does the benefit of centralized scheduling.

Having more centralized control on the ground may be useful when handling multiple telescopes. The proposed model may only be efficient if each telescope is provided with an over subscribed pool from which they can select observations. The experimental scenario gave the satellite 3.3 = 250 / 75 times as many observations as were scheduled. How would this pool be managed across multiple telescopes? Would there be enough observations to give each individual telescope sufficient over subscription to create efficient schedules? Considering the limited down load opportunities it is important that the same observation is not executed and downloaded more than once. Moving control to the ground system allows a global perspective on handling over subscription.

## 4. General Advice

Although I sincerely hope that this commentary provides useful analysis and suggestions, I strongly believe that the most important input on scheduling approaches come from the science stakeholders of the mission. By stakeholders I mean the science users, the operations staff, and the developers of other components of the ground system. Some issues that should be worked with the stakeholders include:

- Ensuring that the right objectives are optimized in the schedule.
- Ensuring that the scheduler integrates with the time allocation policies for the mission.
- Ensuring that the scheduler integrates with other components of the ground system.