Design Trades for Mission/DSN Antenna Supportability Using TIGRAS

Yeou-Fang Wang, Chet Borden, and John M. Kehrbaum
Jet Propulsion Laboratory
California Institute of Technology / NASA

Abstract

With an increasing number of missions to be supported by NASA's Deep Space Network (DSN), it is becoming more challenging for space flight projects to forecast the support they can expect to receive from the DSN, and thereby, incorporate that information into their mission plans and spacecraft design. TIGRAS was developed to forecast DSN supportability based upon both the set of flight project ground antenna resource requirements over time and the project's viewperiods. The TIGRAS tool was originally developed for DSN analysts in order for them to more efficiently study antenna loading. TIGRAS has been extended to support the early mission and spacecraft design for flight projects. With the capabilities to perform coverage forecast and viewperiod analysis, flight projects may significantly reduce costly redesign late in the development process due to ground resource limitations.

1. Introduction

NASA's Deep Space Network (DSN) currently supports more than 30 space flight missions. This number is expected to increase in the near future. It has always been a challenge for space flight projects to consider DSN supportability early in their mission and spacecraft design activity. DSN supportability is the overall time that DSN can be used to support the uplink of commands and download of science and engineering data requested by flight projects. In general, such mission/DSN antenna supportability analysis is not explicitly considered early in the mission design life cycle. In fact, in only a few cases do early phase flight projects even try to anticipate conflicts with other missions. In these cases, simplified methods using only geometric calculations (i.e., trajectories and associated viewperiods) are used. While this is a start, we will show that this may result in an inaccurate expectation of DSN supportability. The consequences of this may imply a re-design of the mission or spacecraft, reduced data return during actual mission operations, or increased cost.

A tool has been developed to forecast DSN antenna supportability based on the set of ground antenna resource requirements over time and viewperiods from all projects. This tool is called TIGRAS. The tool was originally developed for DSN analysts to study antenna loads. It is now prototyped for projects to use to support early mission and spacecraft design.

In this paper, we describe the capability and usage of TIGRAS. To illustrate the usage of TIGRAS, a hypothetical "mission" called Jovian Moon Explorer (JME) was created. We discuss how DSN supportability affects mission and spacecraft design and how a project such as JME can use TIGRAS in an early design phase to design for better DSN coverage for its future operation.

2. Antenna Load Forecast

DSN antennas allow for communications between spacecraft and ground stations. The services provided by the ground system include primarily uplink, downlink, and ranging. Each flight project has its own resource requirements that are based on the mission events. For example, some resource requirements can be as simple as "two (2) 8-hour tracks per week at antenna DSS-XX". However, some other resource requirements can be significantly more complex such as arraying of multiple DSN antennas, simultaneous coverage of multiple spacecraft per antenna, coverage dependencies, or overlapping events. In addition to flight projects, DSN antennas also support maintenance, downtime, upgrade, and other activities. With this wide range of resource request, DSN arranges time and resources to satisfy those resource requirements with considerations of both DSN and project constraints. This job is very challenging since the DSN is oversubscribed much of the time. One common constraint is the spacecraft viewperiod. Viewperiod is the time interval that a spacecraft can be "seen" from a ground station (which in turn is a function of the "mask angles" used in generating the viewperiods). In a near term time frame, DSN needs to work out a schedule for all activities. This scheduling process is very complex and time consuming [1,2,3]. However, for long range planning, projects normally provide the DSN with high level info on their trajectory and tracking requirements (usually by mission phase). This is typically sufficient for DSN estimates of future loads.

We have developed a forecasting algorithm that can quickly estimate the antenna loading and project supportability based on the given viewperiod and resource requirements from all flight and non-flight projects. TIGRAS is a software tool that implements the algorithm. The tool can display forecast results interactively and can be used as a Decision Support System (DSS) for both antenna analysts and project designers to perform their specific analysis.

3. TIGRAS

Written in Microsoft C++ and MFC, TIGRAS is a rich graphical desk-top application (see Figure 1) which can be used to view antenna load analysis related data and perform load analysis. Since all analysis information is provided in the same analysis environment, we call this environment IAE (Integrated Analysis Environment). Users can perform analysis and view various data such as resource requirements, viewperiods, ground resources, forecast results, and schedule information all in one single environment. TIGRAS connects to a Microsoft SQL server database called MADB (Mission and Assets Database) for all requirement and viewperiod data.

TIGRAS consists of 5 major windows for requirements, constraints, ground resources, forecast, and schedule. Each window consists of 5 panes for time navigation, display selection, graphical display, list display, and statistics/additional information. All windows

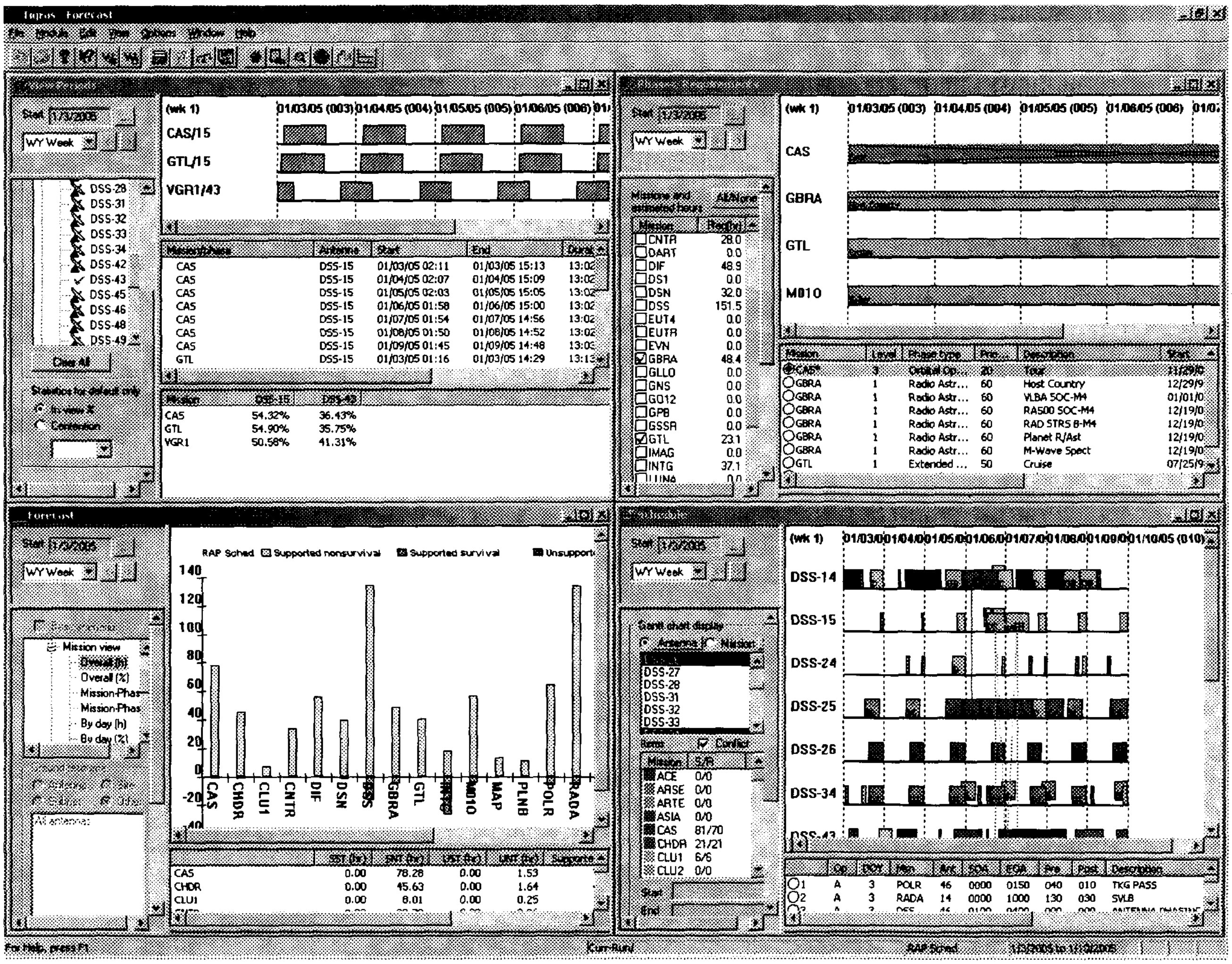

Figure 1. TIGRAS Integrated Analysis Environment (hypothetical data for illustration only)

Phase/Event	Description	Start	End
Launch Activity	Launch and Early Operations Phase	12/21/2004	1/20/2005
Cruise	Earth-Jupiter Cruise	1/20/2005	1/14/2008
Cruise	Jupiter Approach Tracking	1/14/2008	3/11/2008
Encounter Activity	JOI Tracking	3/11/2008	3/17/2008
Cruise	Jupiter Orbit Reduction	3/17/2008	2/12/2009
Cruise	Jupiter Moon Approach Tracking	2/12/2009	3/11/2009
Encounter Activity	JMOI Tracking	3/11/2009	3/17/2009
Prime Mission	JME Prime Mission	3/17/2009	4/16/2009
Extended Mission	JME Extended Mission	4/16/2009	6/15/2009
Cruise	JME Post-Extended Mission	6/15/2009	8/14/2009

Table 1. JME phases/events for Case 1

and panes can be manually arranged. TIGRAS provides copy-paste and printing capabilities as regular Windows applications. A context-sensitive help is also available for real-time assistance. TIGRAS is currently available for Windows 2000 and Windows XP operating systems. To install TIGRAS, one only needs the set up file. Run setup.exe to install all necessary files and database connections.

Since there are many different functions in TIGRAS and it is used by various users, TIGRAS provides a user access control scheme which permits the functionality of TIGRAS that can be executed by the login user. A second level data security then is controlled by the MADB database to control data access. Namely, a user needs to have access to both the function and the data to perform analysis. The reason for this is to separate the computation logic from the data to promote the encapsulation concept in an object-oriented environment. These two levels of access control are integrated using MADB authentication. With this control scheme, some users may be able to perform analysis on certain data but not the entire set. Or one may be able to see certain data but cannot perform certain analysis on the data. Currently, TIGRAS supports DSN long-range analysts, mid-range analysts, and DSN near-real time and real-time schedulers. Building on this prototype, will be able to support project designers, design trade analysts, project schedulers, and DSN operations.

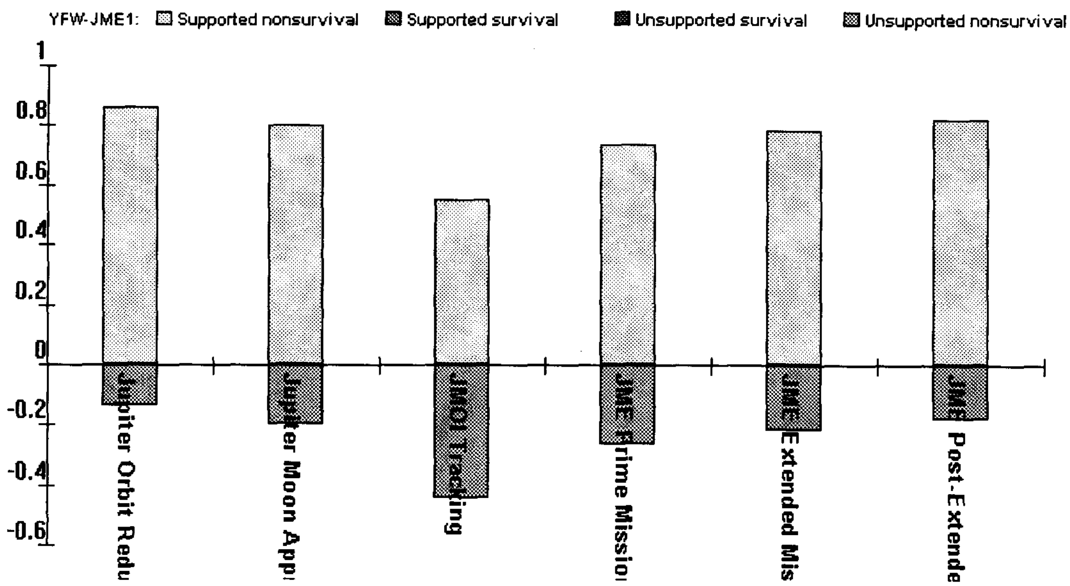

Figure 2. JME supportability for Case 1 (2/12/09 moon approach)

In addition to the forecast capability, TIGRAS also supports scheduling functions. TIGRAS can generate an initial conflict-aware schedule based on the given resource requirements and constraints. Various editing capabilities, including drag-and-drop, are provided. The users can use this capability to perform detailed conflict resolution studies for high contention area. TIGRAS also has internal algorithms to calculate tracking cost of each mission. This cost information allows DSN planners and project schedulers to estimate ground resource expenses.

4. Antenna Load Forecast for Early Mission Design

Part of the flight project success is the ability to send comments from DSN ground stations to the spacecraft and to receive scientific and engineering data from the spacecraft. DSN antennas provide these communication services to spacecraft. Without sufficient DSN support, projects will not be able to achieve their science and mission goals. Therefore, DSN coverage plays an important (although currently implicit) role in mission and spacecraft design. Early consideration of ground support may impact mission and spacecraft design and reduce more costly re-work later. In this section, a hypothetical mission, Jovian Moon Explorer (JME), is

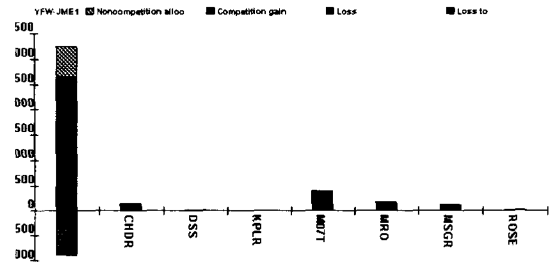

Figure 3. JME competition for Case 1

created to illustrate how mission designers can take advantage of the forecast results to design their spacecraft mission [4]. JME mission phases/events are listed in Table 1. All results in this section are produced by TIGRAS using data in MADB. All analysis products displayed in this paper are directly copied and pasted from TIGRAS tool with little or no edition.

The hypothetical JME mission was posited to launch from Earth toward Jupiter during the time frame from mid 2004 to early 2010. For this example, we will examine the critical events starting at the Jupiter Moon Approach through the end of the primary/extended mission. In the baseline case (Case 1), the Jupiter Moon Approach event starts on 02/12/2009 with the actual

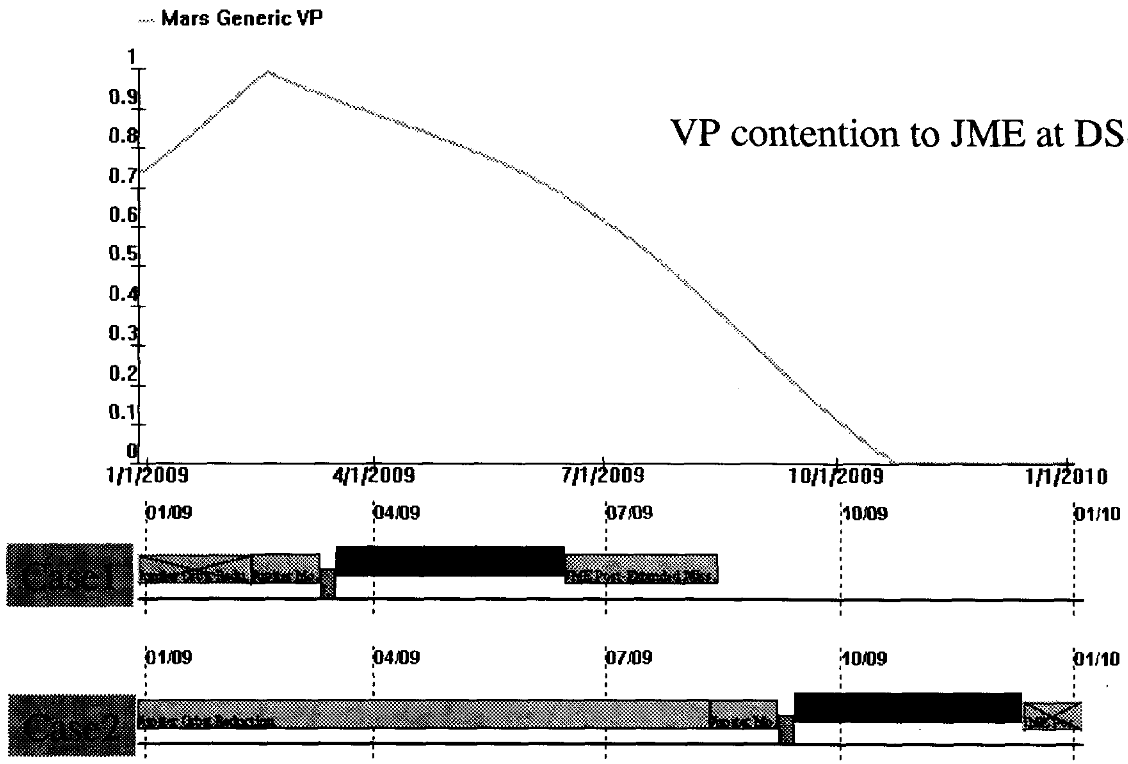

Figure 4. JME viewperiod competition

arrival at Jovian Moon scheduled to occur on 03/12/2009. With the given data in MADB that includes ground antenna resource requirements and viewperiods, JME encountered significant coverage competition in 2009 based on the forecast results. Figure 2 depicts the unsupportable tracking time of each JME event in 2009. As illustrated, JMOI Tracking event has more than 40% of the requested time that cannot be supported by the DSN due to conflicts with other mission requirements for coverage (i.e. it is unsupportable by the DSN). Now the question is: who is in competition with JME for the tracking time? TIGRAS provides a display that can show the contention information. Figure 3 depicts the contention results generated from TIGRAS. It shows two Mars missions (M07T and MRO), Messenger and Chandra missions are the major competitors to JME.

To understand why this happens, the viewperiod contention and the associated requirement/events are examined (see Figure 4). As shown, in the beginning of 2009, JME has significant viewperiod overlap with Mars missions. Therefore, one mission design option is to time-shift the JME trajectory to reduce the overlap with Mars missions, and potentially result in higher DSN supportability of JME requirements. The delay of the arrival date can be achieved by using a smaller engine burn to get captured into the Jupiter system. This results in a larger (longer duration) first orbit around Jupiter. By changing the arrival date, JME starts its Jupiter Moon Approach on 8/11/09 (Case 2 in Figure 4). With a new TIGRAS run, Figure 5 shows the supportability results from TIGRAS for Case 2. It is clear that JME now can get almost full requirements coverage from the DSN. JME contention with other projects is shown in Figure 6. It is obvious that competition with Mars missions is now reduced to almost zero and is a significant contributor to this greater support available from the DSN.

Antenna load forecasting is the combination of

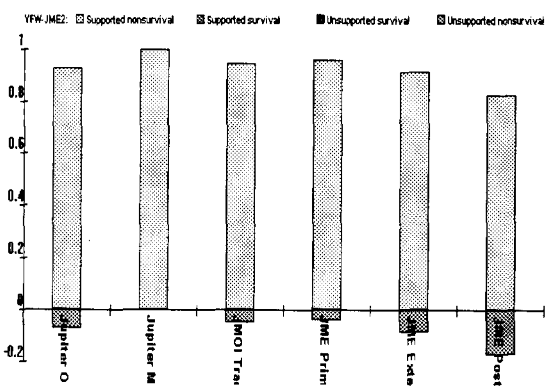

Figure 5. JME supportability for Case 2.

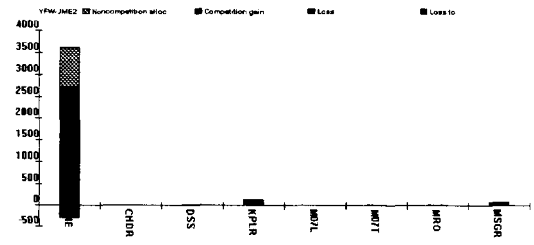

Figure 6. JME mission contention for Case 2

resource requirements and constraints such as viewperiods. Therefore, though viewperiods are important, they are not the only factor that needs to be considered. Figure 7 shows a case that JME has high viewperiod contention with Mars missions. However, there is little impact to JME coverage due to only limited overall requirements on those resources during that time frame. Therefore JME can still get the coverage it wants even within a high viewperiod contention. This illustrates the condition under which examining merely the geometric information (viewperiods) would lead to an inferior assessment of the availability of the DSN to support the mission.

In addition to forecast capability, TIGRAS can also perform scheduling activities. For example, an analyst can generate a schedule for a particular week if he/she needs to learn more about the details of the supportability and mission contention.

5. Future development

TIGRAS is currently a desk-top application. From a data access point of view, TIGRAS is a client of the MADB database in a client-server environment. While we are expanding the capability of TIGRAS, we are also re-designing the architecture to move to a multi-tier environment. In this architecture, TIGRAS is the client application. All computation and algorithms will eventually move to the middle-tier and all data access will be moved to a data access layer. With the multi-tier environment, we can design in a more object-oriented manner. Encapsulation allows developers to change objects implementation without affecting rest of the system. In the mean time, we can design various kinds of user interfaces such as Excel and Web pages without re-implementing the core functions. The current design for the middle-tier is called DRAGON. It utilizes agent concepts on top of a distributed object-oriented system. The current prototype implementation is using Microsoft .NET framework. Web services are used to wrap the calling methods/functions of the agents. TIGRAS as a client then connects to the DRAGON server using XML/SOAP through Web services for the necessary data and perform certain computation activities.

6. Conclusion

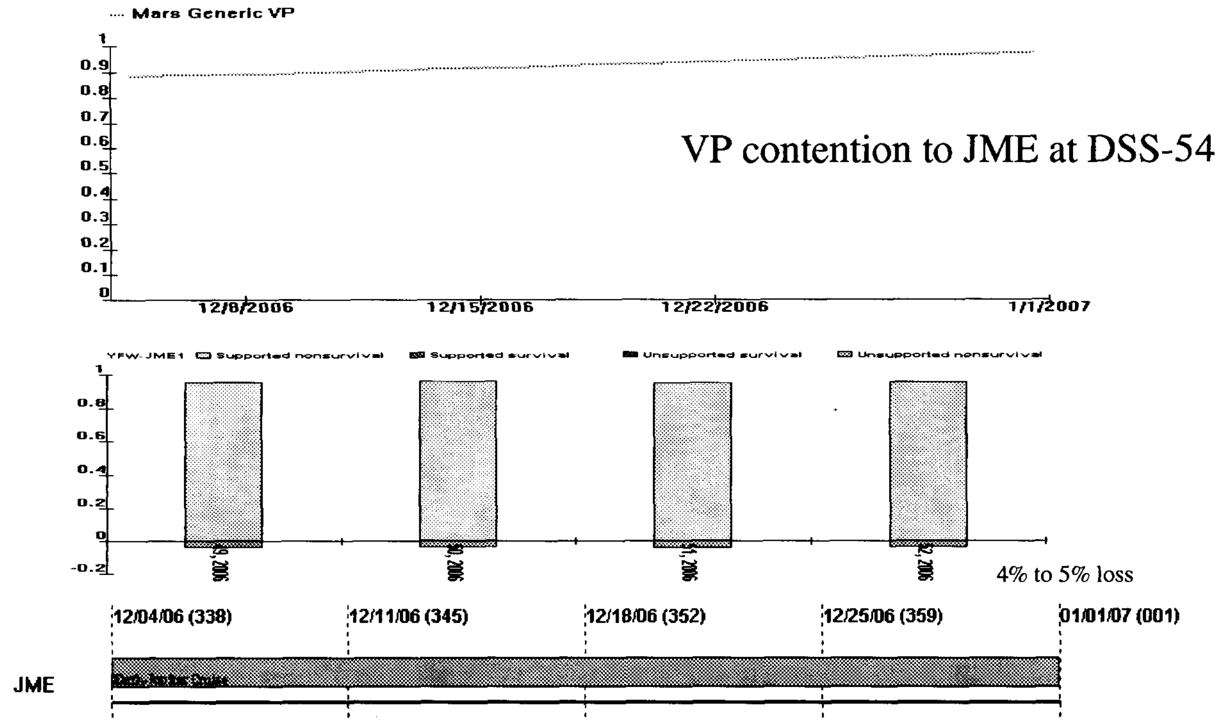

Figure 7. High availability even in a high contention environment.

In this paper we describe how antenna load forecasting can be computed and how the results can be used for early mission design. A hypothetical Jovian Moon Explorer (JME) mission is created for illustration. TIGRAS runs were conducted for this mission against other missions in the MADB database. By modifying the date of the actual Jovian Moon arrival by approximately six months, JME was able to achieve significantly more expected DSN coverage.

The forecast process is shown to be a combination of mission requirements, ground resource capability, and constraints/viewperiods. In addition, an example was shown where even with significant viewperiod contention, JME can still get most of the coverage it desires. By providing TIGRAS capabilities to mission and spacecraft designers, in addition to DSN analysts, we allow consideration of DSN coverage as a mission design variable and can be included as an element of mission design trades.

Acknowledgement

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

Reference

[1] Y.-F. Wang, Jose B. Cruz, Jr., J. H. Mulligan, Jr., "Adaptive Scheduling Utilizing a Neural Network Structure," *PROCEEDINGS ICNN 94*, VOL 6. 1994, pp.3806-3811.

[2] C. Borden, Y.-F Wang, G. Fox, "Planning and Scheduling User Services for NASA's Deep Space Network," *NASA Planning and Scheduling Workshop*, 1997.

[3] J. H. Smith, Y.-F. Wang, "E-Scheduling Deep Space Network," *IEEE Aerospace conference*, 2001.

[4] J. Kehrbaum, "Using Available DSN Tracking Coverage as a Design Parameter in Mission Proposals," *12th AAS/AIAA Space Flight Mechanics Meeting*, 2002.