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Analysis of Space Network Loading

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Abstract

The NASA Space Network (SN) consists of several geosynchronous communications satellites, in addition to ground support facilities. Space Network management must predict years in advance what network resources are necessary to adequately satisfy all SN users. Similarly, users of the Space Network must know throughout all stages of mission planning and operations to what extent their communication support requirements can be met. NASA, at the Goddard Space Flight Center, performs Space Network and Mission Modeling using The Network Planning and Analysis System (NPAS), to determine the answers to these questions.

Introduction

The Network Planning and Analysis System (NPAS) is a deterministic modeling tool that accepts either generically or specifically stated communication support requirements. Using its own scheduling and orbital determination software, the NPAS produces an operationally valid schedule. Analysis software can then generate a variety of reports such as the percentage of satisfaction for users, or the total utilization of the SN. Analysts can view schedules graphically allowing them to identify conflicts easily.

Detailed in its approach, the NPAS can model such difficult problems as antenna blockage and support requirements based on the physical position of a user satellite. The tool can also model such factors as the effect of solar

radiation on the spacecraft and the radio-frequency interference between users. Also, the NPAS is not limited to the NASA Space Network alone. Given the necessary information, it can model other space based communication networks, as well as ground-based networks, both foreign and domestic.

NASA has used the various versions of NPAS successfully over the past 15 years as a tool in analyzing Space Network loading. The NPAS has also changed with the times. It has recently been ported to a Unix-based workstation and has a new X-window graphical user interface. Currently, efforts are in place to develop a neural network application for the NPAS. This application could be used to obtain an instant response to many questions that arise during the planning of communication support for new space missions.

Overview of the Space Network

Modeling with the NPAS at GSFC is applied to NASA's Space Network (SN). The space-based portion of the SN is referred to as the Tracking and Data Relay Satellite System (TDRSS). The TDRSS consists of five geosynchronous Tracking and Data Relay Satellites (TDRS), two of which are currently operational at 41° W and 174° W. Two others are held in reserve and the fifth, the oldest and least capable satellite in the network, is dedicated to support of the Compton Gamma Ray Observatory.

Only low earth orbiting spacecraft can make use

of the SN. These users can communicate with a TDRS at K-band using one of two Single Access (SA) antennas or at S-band using SA or Multiple Access (MA) Ground-station limitations restrict the number of MAR users to to about five per TDRS. Even though each TDRS has only one MAF, the SA resource, due to its heavy use, is by far the most constrained TDRSS resource.

It is the job of the NPAS to determine how this network will perform in the future under changing conditions.

Modeling SN Loading

Modeling different aspects of SN loading with the NPAS proceeds along two lines, *Space Network Modeling* and *Mission Modeling*. In theory, SN Modeling methods hold user requirements constant and vary network resources. This is contrasted by Mission Modeling techniques which hold network resources constant and vary user requirements.

Analysts perform SN Modeling by determining what combination of TDRSS resources and mission priorities result in the best overall performance of the SN on a yearly basis. They make recommendations to NASA management, who then decide what course to adopt. These formally approved NPAS models are called *baseline models* and used as starting points for further studies. Using such approved baseline models, analysts perform Mission Modeling. Usually the requests come from management of new or prospective mission projects, or from management of existing mission projects that are contemplating changes to communications support requirements. During the course of mission modeling analysts produce *variant models* that reflect some change, or a collection of changes, to a baseline model. End products of Mission Modeling are termed *standard models* to differentiate them from true baseline models.

Regardless of the modeling method selected, analysts interact with the NPAS software in the same way, defining network resources, mission requirements, and evaluating resulting schedules.

Obtaining Model Parameters

The model parameters used by the NPAS can be divided into two parts, scheduling and coverage. Scheduling parameters include information about mission support requirements. Examples include minutes of support needed per orbit and the minimum separation between contacts. Coverage parameters deal with the geometry between user spacecrafts and network resources. Locations of the TDRS, the orbital elements of the user spacecraft, and information relating to the blockage of the user antenna are examples of such parameters.

The process of collecting user parameters is conducted in advance of actual modeling. This serves to reduce the needed during modeling to acquire needed information.

Capabilities of the NPAS

Once the modeling requirements have been gathered, the analyst can prepare to input the parameters into the NPAS. The number of steps required in this process is dependent upon the type of study being performed and similarities between the new requirements and existing baseline, variant, or standard models. Often times, minor modifications can be made to an existing model to analyze the new requirements.

Usually, the first step taken by an analyst is to define the support network. The support network can consist of SN or ground-based stations, and is referred to as the "network model."

Then, missions that would be users of the defined network for the year being studied are modeled. The combination of orbital and coverage parameters of the spacecraft with the scheduling requirements of the mission is referred to as the "mission model" for the particular mission.

Once the network and all appropriate mission models are created for the year being studied, coverage data is generated for each mission at each station. From this coverage data, and subject to any constraints defined in the

network and mission models, a schedule for each mission and each station can be generated.

This schedule can then be analyzed using a number of applications included in the NPAS package. Various mission and station report analyses can be requested, and a facility exists that allows an analyst to examine graphically the schedule and certain coverage events.

Modeling the Network

A network model in the NPAS can consist of stations, physical antennas, services, and crews. Hardware limitations, such as TDRS interface channels, may also be modeled.

SN and ground-network stations can have their locations specified in a number of ways. In particular, SN TDRS locations can be specified as either fixed or moving. In the former case, only the longitude and the height of the TDRS need to be given. In the latter, orbital elements for the TDRS are specified by the analyst.

When creating the network model, the analyst has the ability to define constraints, such as service availability times and fixed down times. Other special-purpose constraints, such as allowing scheduling to occur on no more than six out of eight SA antennas simultaneously, also may be modeled. Events such as planned maintenance also are easily modeled.

These features allow the analyst to define real-world support network situations. Some examples might include TDRS' that are damaged or are otherwise not fully-functional. In the course of analyzing SN loading using baseline models, the number of single-access (SA) antennas available at each TDRS is modified often, and the NPAS Modeling Tool interface was designed to ease this process.

Defining Coverage Parameters

Embedded within the NPAS is a complete orbit and coverage generation system which uses a modified GTDS to generate station visibility data with accuracy to the nearest second. Additionally, a facility exists to accept externally-generated orbit data.

An NPAS analyst defines the basic orbital parameters of a spacecraft using Keplerian orbital elements. Other options exist that allow more complex orbit models to be created from this point. An example of such a model may be one that uses impulsive orbital maneuvering, thrust, or transfer orbits. Further modifications to the spacecraft orbit can include gravitational, solar and drag forces.

A number of mission-specific coverage events may also be calculated. Some of these mission-specific events include mission apogee and perigee points, ascending and descending nodes, spacecraft or subpoint sun events, land, water, and user boundaries. These events may be calculated in the coverage event generation, and would normally be used for scheduling options in the schedule parameters portion of the mission model.

Many missions in the loading studies performed using NPAS include mission-specific events to direct the mission scheduling. One of these missions is Landsat, which specifies a number of user and earth boundaries over which to schedule. Also, this and other spacecraft may only want to schedule when the spacecraft or the Earth sub-point is in sunlight, and this may be modeled using the mission-specific events.

As another coverage parameter, the analyst also can apply an antenna mask to the spacecraft, and define the spacecraft attitude and antenna orientation. Spacecraft masks are defined for a small number of missions in the most recent set of baseline models. The effects of masking on individual spacecraft has been extensively analyzed in variant and standard models for some missions, including EOS and the Space Station. For the latter mission, a number of masks reflective of the various "build" stages were modeled.

Options exist to determine separation angle events between a spacecraft and the sun or another spacecraft. Here, the angle apex may be located at either the spacecraft or the station, and the station may be either SN or ground-based. Separation angle events have been used in the past in variant models in which mutual interference between spacecraft was analyzed.

Stations Services	
T046	2) SS-R
T171	5) SS-F
T041	
T174	

Mission: 36 - TRMM
 SUPIDEN: [REDACTED]
 Priority: 2141 Series: [REDACTED]
 Conflict Analysis Group: N/A

Service Mask: Select Mask Select List
 10) User Spacecraft Mask

Prototype Event Code: SA02

Schedule Periods are defined by orbits. Each orbit is 91.32 minutes.
 The length of each Schedule Period will be [REDACTED] orbit(s).
 Add [REDACTED] 0 Seconds to the start and end of each Schedule Period.

Delay scheduling this request [REDACTED] 0 Seconds from the START of the run.

For each Schedule Period, attempt to schedule at least [REDACTED] and at most [REDACTED] prime service event(s).

Each prime service should be at least [REDACTED] 14.0 and at most [REDACTED] 20.0 minutes in duration.

Provide at least 0 and at most 9999 minutes between services.

Status: ACTIVE

Record Functions	Schedule Satisfaction	Separation Requirement	Station Options	PC/Database SSE Code
Save Cancel Next	Schedule Windows	Mission Only Service	Schedule Options	Included/Excluded

Figure 1- Sample Schedule Request

Defining Schedule Parameters

Tasks to be performed by each mission are modeled as schedule requests in the NPAS. A schedule request is simply a request for a service, or set of related services, of some time duration, to be scheduled over a set of stations. Each request is subject to a number of constraints that can be imposed by the network model, the given request, and other schedule requests. Additionally, some constraints, like mission pre-pass and post-pass times at various relay stations, can be applied to all the requests of a single mission.

Each schedule request is given a priority number by the analyst and is subsequently scheduled in "highest priority first" order. Requests for different missions may be intermixed to allow scheduling of all missions' critical requirements before any other requirements, if this is desired. The current practice, however, is to schedule all requests for any individual mission together, and place the missions into priority order.

Most schedule parameter modeling in the NPAS is accomplished using generic schedule requests. A generic request does not specify an exact time at which the defined service or set of related services is to be scheduled. Additionally, the request is typically repeatable over periods that extend across the schedule span.

Furthermore, using a generic request, an analyst can specify a variable length service contact time, in which shorter contact times, down to a minimum, can be accepted if the maximum length contact cannot be scheduled.

One mission that is modeled in NPAS using generic requests is TRMM. The primary request is one 20-to-14 minute S-band forward service, with concurrent S-band return service, event per orbit. Only one generic request would be required in the NPAS to model this requirement.

In the above example (Figure 1), the TRMM requirement was for two concurrent services, repeatable over the schedule span. Whenever

two or more services need to be related in some manner and scheduled repeatedly over the span, a Prototype Event (PE) structure is defined in the generic request. A PE is best viewed as a "template" for defining a variety of complex relationships between desired services.

There are a number of options and constraints that an analyst can model in each schedule request in order to accurately represent the request in NPAS and to emulate real-world situations. One of these options is the mission antenna masking toggle. This allows the schedule request to use, or not use, the mission antenna mask specified in the coverage parameters for the mission. This toggle is useful in determining the net effects of blockage on the spacecraft visibility.

A multi-mission shared resources option allows a number of selected spacecraft to communicate simultaneously over one physical antenna. This option could be used to model situations in which the Space Shuttle and its payload can communicate simultaneously on the same TDRS link.

Many other options exist as well, including dynamic rescheduling, in which selected higher-priority requests can be removed from the schedule if the invoking request did not attain a given satisfaction. Once the other requests are removed from the schedule, the invoking request is rescheduled, and the requests which had been removed are scheduled following.

Other special scheduling options include station and station antenna schedule preferences, forced-handover and hybrid support, and maximum elevation priority scheduling.

Some constraints might include a minimum or maximum separation between services, or scheduling windows, which define repeatable periods in which to schedule. Scheduling can also be directed around mission-specific events, such as when the spacecraft is in sunlight or when passing over a desired land mass, for example. The request can be directed to schedule when these events occur, or they can be directed to avoid scheduling at these times. Other mission-specific events include any that

were defined in the coverage parameters for the mission.

Schedule Algorithm Summary

Three of the more commonly used schedule algorithms in the NPAS are the standard PE, standard non-PE, and geometric optimization algorithms.

Before any request is processed by these algorithms, the set of available time on individual station and mission antennas is generated. This set, referred to in NPAS documentation as "freetimes," consists of the mission visibility at each station with any time scheduled by previously scheduled requests removed. Additionally, any station or station antenna or service downtimes, as well as mission-oriented station service suppressions, would be removed from this set.

The standard PE and non-PE algorithms select events to schedule from this set using the aforementioned priority scheme in which higher priority requests are scheduled before lower priority requests. Further event scheduling is performed on a longest-prime-service-length-first, first-come, first-served basis.

The geometric optimization (GO) algorithm is similar to the standard algorithms, but the major difference is that this algorithm determines a large number of suitable schedules for each request and chooses the one that maximizes the total scheduled time for the request. In GO, an initial greedy schedule is determined by selecting the local-optimal solutions from partitions of the schedule span. If the total scheduled time of this solution is less than the predicted maximum, then a backtracking process is invoked in which the schedule is reevaluated using local-sub-optimal solutions from one or more partitions.

Post-Schedule Analyses

There are a number of applications available in the NPAS that allow an analyst to prepare different types of reports from the schedule results. For example, it is possible to create reports of utilization of service types, antennas, and frequencies. Analysts can also generate

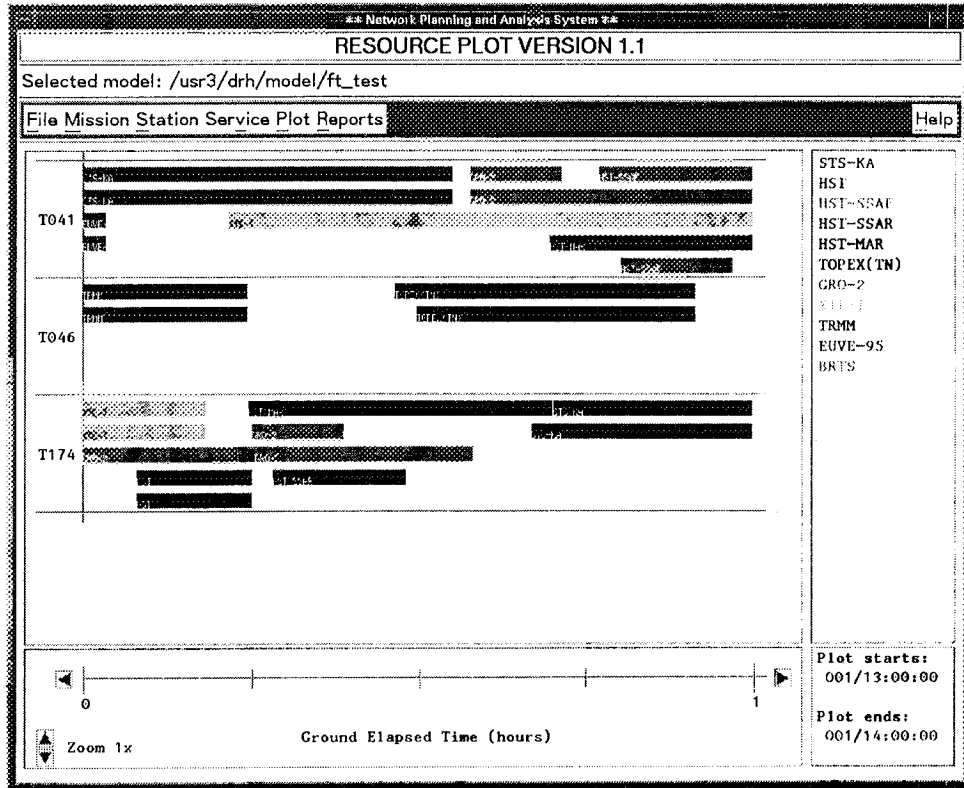


Figure 2 - Sample NPAS Schedule

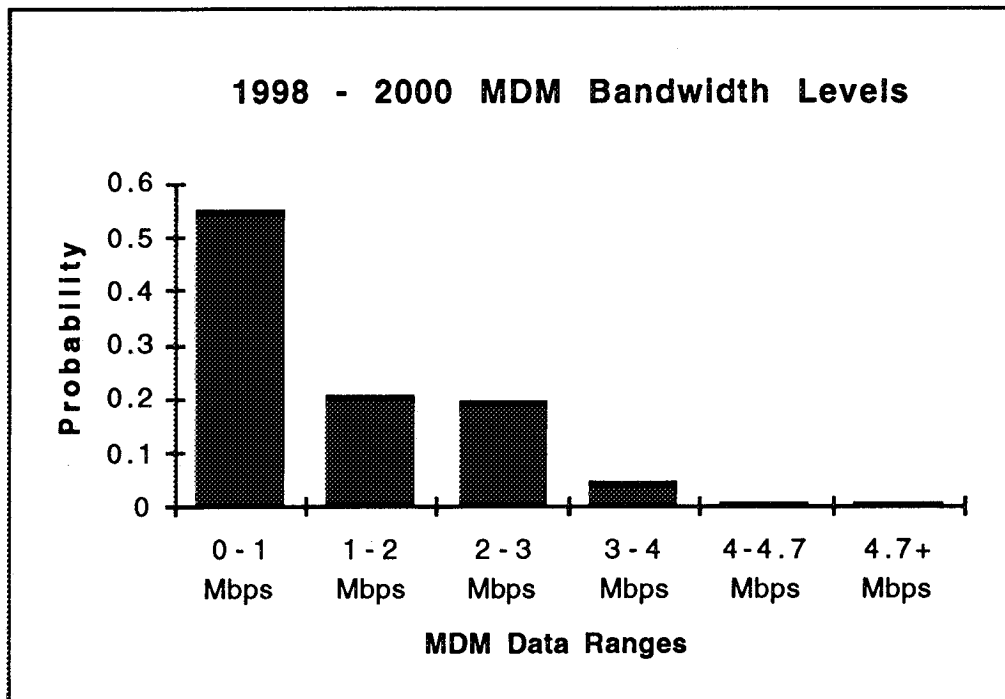


Figure 3 -Results from TRMM Study

reports of mutual interference between spacecraft. Communication channel loading can also be analyzed using an NPAS report application.

One of the more frequently used analysis tools is the NPAS Resource Plotter (RPLLOT). RPLLOT allows an analyst to view a mission's or station's schedule graphically in an X-Windows display. A wide range of options exists for examining mission- or station-related data, where different types of objects to be plotted appear in different colors. Mission-related data includes raw station antenna visibility and mission-specific events, such as apogee or a spacecraft-in-sun condition. Station-related data includes station antenna and service schedules. An example of an RPLLOT display appears below in Figure 2.

Recent Work

As examples of our work, we have two recent mission studies performed for the Tropical Rainfall Measuring Mission (TRMM) and the Earth Observing System (EOS) projects.

The TRMM project will be launched in 1997 and will downlink data at 2 Mbps in real-time during its 20 minute SA events. Since ground terminal equipment (known as the MDM) limit the total downlink bandwidth to 6 Mbps, there was a concern whether or not the TRMM would experience data loss. Analysis using the NPAS took into account the downlink rates of all 1997 SN users, and showed that there is little to no probability that such data loss would occur. It also showed that loads on the terminal equipment follows an exponential distribution. Results are shown in Figure 3. We have also recently provided the EOS project with a projected schedule of the their EOS-AM1 spacecraft as modeled in 1998. This information will assist them as they size the needed on-board solid-state memory.

Future Directions

We are currently exploring aspects of artificial intelligence to help speed parts of SN Modeling. SN modeling can be a time consuming process. We are now developing a neural network application that, once properly

trained, could be used to achieve instant responses to specific loading and user satisfaction questions. The application would be trained by automating numerous database modifications, generating schedules, and then collating and preparing the data.

NPAS is a changing modeling system that has adapted itself to the environment that it is designed to model. It has served NASA well over the years and will continue to play an important role in the analysis of Space Network loading.