A Unified Approach To Network Optimization of Satellite Communications Systems

Keiji Tasaki
Networks Division/Code 530
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
keiji.tasaki@gsfc.nasa.gov

Joseph Nickey
Stanford Telecommunications, Inc.
7501 Forbes Blvd., Suite 105
Seabrook, MD 20706
jnickey@stel.gsfc.nasa.gov

Robert J. Hollingshead
Stanford Telecommunications, Inc.
7501 Forbes Blvd., Suite 105
Seabrook, MD 20706
rhollingshead@stel.gsfc.nasa.gov

Abstract

This paper describes a networks optimization approach that is being investigated by the Networks Division in response to the need to efficiently handle the increasing demands of users of the Space Network (SN), Deep Space Network (DSN), and Ground Network (GN) resources (antennas, receivers, etc.), while reducing the operational and developmental cost of all communication systems.

Introduction

The Space Operations and Management Office (SOMO) of the National Aeronautics and Space Administration (NASA) is engaged in strategic planning and system engineering activities to promote and enhance the services offered to current and potential customers of NASA networks. In order to facilitate these activities, the Networks Division at NASA's Goddard Space Flight Center has been conducting research into the development of a unified approach for modeling satellite communications with the goal of generating and assessing future network architectures.

Objective

The primary objective of this project is to develop an integrated PC-based tool capable of generating solutions to problems of the following type:

Given:

1. *A set of network resource elements $\{E_1 ... E_n\}$ (representing SN, DSN, and GN antennas, receivers, etc.); and*

2. *A set of missions $\{M_1 ... M_i\}$*

Determine the optimum communication strategy for mission M_{i+1} when it is added to the mission set.

We will refer to the problem of determining whether a new mission can be supported adequately by a given set of network resources as a Type I problem as depicted in Figure 1.

In addition, this tool will find application as an aid in solving long term strategic planning problems where one is interested in examining how changes in network elements affect supportability of a given mission set and the companion problem of how best to configure a set of network elements for optimal support of a given mission set. We will refer to problems of this class as Type II problems as depicted in Figure 1.

In summary, the objective of the Network Optimization project is to develop a process by which:

1. A series of technically feasible space-to-ground and ground-to-space communications networks are rapidly assessed for any given mission (Type I problem), and

2. An optimum network solution can be identified for a given mission set based on cost, contact time, and other critical factors (Type II problem).

In the following we provide a overview of each step in the optimization process followed by a brief description of our progress to date in implementing each segment of the system.

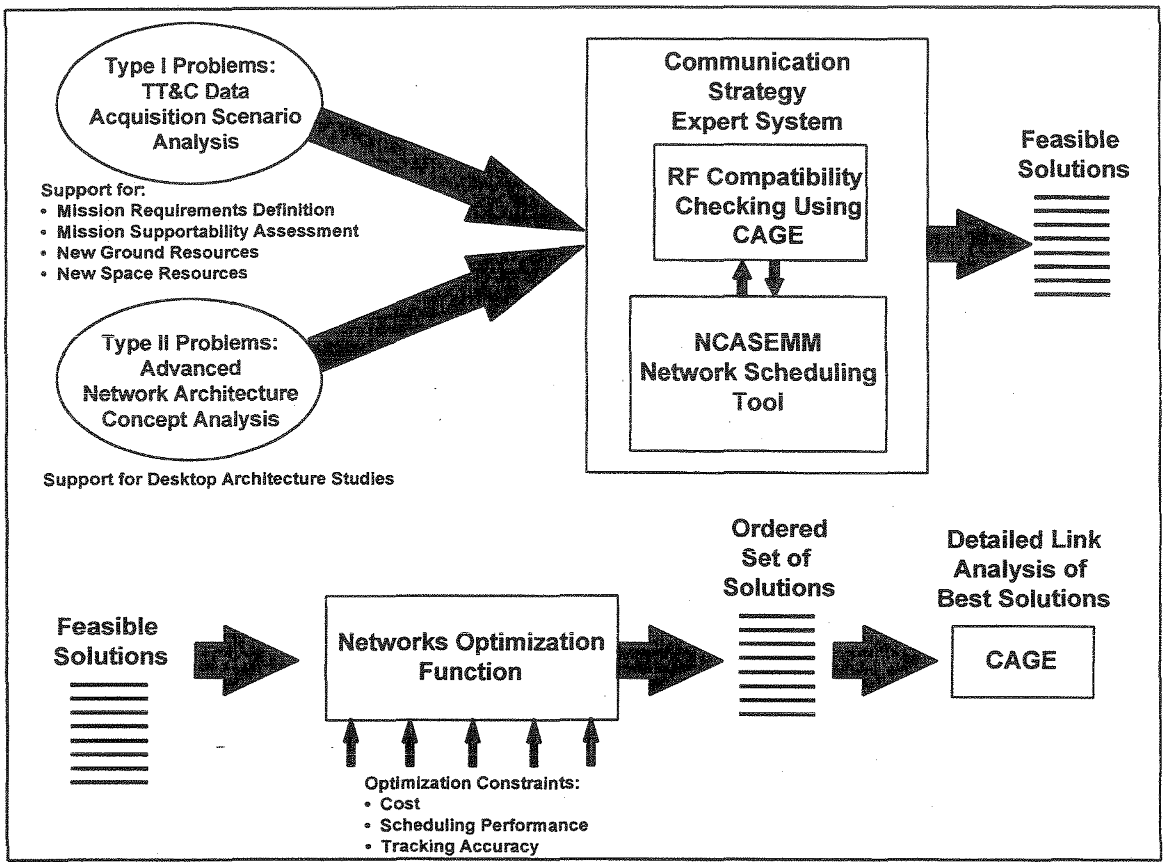

Figure 1. Network Optimization Applications.

A Five Step Approach to Optimization

Figure 2 depicts the system-level optimization process. As shown, the first step in the process is to develop an expert system front end to automate the task of converting mission requirements into a communication strategy in support of specific communication network service requests. The expert system will interrogate the user for mission communication requirements such as:

1. Orbital Information
    - Keplerian orbital elements
2. Downlink Requirements
    - Data volume per day (science)
    - Data volume per day (housekeeping)
    - Onboard storage capability (drives contact duration and data rate required)
    - Required notification of celestial events
3. Uplink Requirements
    - Data volume per day (commanding)
    - Stored command capability
4. Spacecraft Antenna Characteristics
    - Operating frequencies
    - Transmitter and Receiver characteristics
5. Control Center Location Information
    - Mission Operations location
    - Science Operations location

The expert system will then generate a set of preliminary communication alternatives that satisfy the requirements set forth by the user. A typical contact requirement for an Earth-observing mission with a 100-minute, polar orbit would be two 10-minute contacts per orbit at X-band (5.2 - 10.9 GHz) for science data downlink and three 5-minute contacts every two orbits for spacecraft housekeeping at S-band (1.5 - 5.2 GHz).

It is important to note that at this stage in the process the communication scenarios are only constrained by the mission requirements and the known *existence* of a particular communication service (e.g., TDRSS S-Band Single Access (SSA)). The actual *availability* of the service to a given mission at a specific instant is not a constraint at this stage. It is therefore likely that many of the communication scenarios that are generated at this stage are not going to be suitable final solutions because they may depend on the availability of finite resources that are in fact not available at the requested time due to preemption by other missions. The problem of assigning communication services among competing users in a nearly optimal fashion will be the subject of the next step in the optimization process where we consider the global optimization problem of allocating finite communication resources among competing missions.

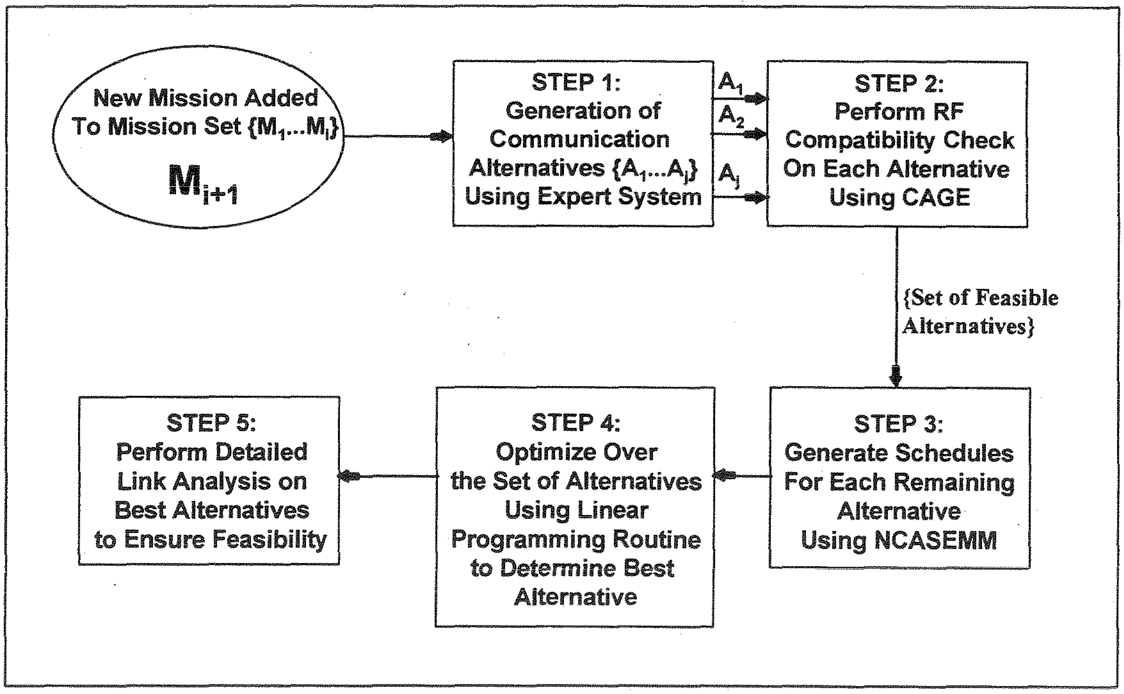

Figure 2. Network Optimization Process Flow.

The Second Step in the Optimization Process: RF Compatibility

The second step in the optimization process is to perform RF compatibility checking on the user specified contact and RF requirements to guard against attempting to schedule across incompatible or non-existent resources. We have identified a COTS product called the Configurable Analysis Graphical Environment for Space Systems (CAGE) that runs on a PC platform and can be adapted for this purpose. In addition to other useful features, CAGE allows easy modeling of link performance, interference and frequency assignments and it contains numerous libraries that model transmitters, receivers, antennas and other communication components. We are currently in the process of investigating the feasibility of interfacing it with the scheduling tool that we have selected which is discussed in the next section.

The Third Step in the Optimization Process: Generate Feasible Solutions

The third step in the optimization process is the generation of a set of feasible communication solutions that satisfy the requirements for a new mission (Type I problem) or a new network configuration (Type II problem). A feasible solution is defined as a complete network/mission set pair that is capable of supporting the requirements of a given mission set. A scheduling simulation tool will be used to determine supportability. This process is repeated a number of times with different network architecture or mission set scenarios to generate a series of alternatives each of which satisfies all communication requirements. Each alternative represents a complete communications network consisting of elements of tracking stations, transportable tracking terminals, tracking and data relay satellites, and/or commercial services.

The NASA Computer Aided System Engineering and Management Model (NCASEMM) was developed by Veda, Inc. as a PC-based scheduling support tool that generates network communication schedules for non-operational mission planning purposes. NCASEMM accepts as inputs the mission orbital characteristics, desired mission communication contact requirements in terms of event duration and frequency, and the communication resources that are available for scheduling such as ground based or space based (TDRSS) tracking stations. It then performs a scheduling function that attempts to best accommodate all requirements for all missions.

Figure 3 depicts the results of a typical NCASEMM run. Note the imperfect scheduling that results from finite availability of resources and other inherent limitations characteristic of the scheduling algorithm.

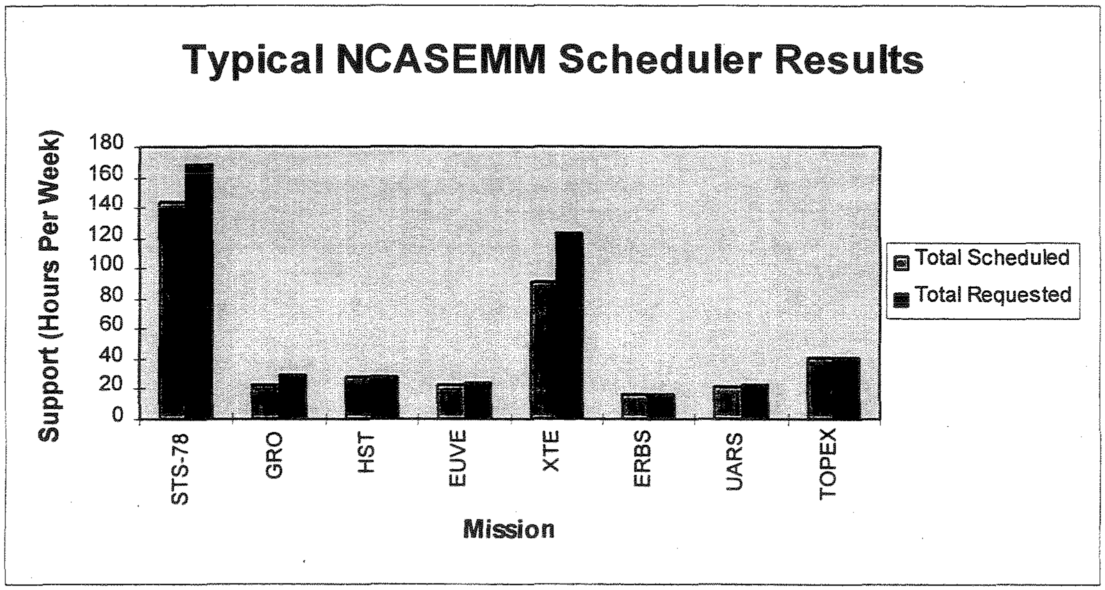

Figure 3. NCASEMM scheduler results for a NASA Space Network mission set.

We have performed an in-depth assessment of NCASEMM and found that the performance of the scheduler is strongly dependent on the manner in which the user specifies the contact requirements. We have concluded that with minor enhancements NCASEMM is capable of performing the scheduling function in our optimization plan.

The Fourth Step: Optimization of the Set of Feasible Solutions

At this stage in the process we have generated a set of technically feasible communication architecture solutions, all of which are capable of satisfying the requirements of the mission set under consideration. The fourth step in the optimization process is to optimize over the set of feasible solutions to identify the preferred solution. In order to perform this task, one must first identify relevant constraints that are to be considered. Our focus has been to minimize on the cost of communication.

The major factors contributing to cost include: service charge per minute for the use of the TDRSS, DSN, or GN; the fabrication and installation costs of transportable tracking terminals for dedicated use; the maintenance and operation of the terminals; service charges associated with the use of commercial providers; service charges associated with the use of tracking stations; and the cost of the onboard communications equipment (e.g., transmitters, receivers, transponders, antennas, etc.). These cost factors are added together to form an objective function for the cost minimization problem. The primary set of constraints, on the other hand, includes the total budget available for communications for the mission under study and the total service time available at each resource location. It is clear that when this minimization problem is kept at this level of complexity, it can be solved straightforwardly using a variety of methods including linear programming. However, when additional factors are taken into account, such as variable service pricing structures for priority users, operating hours of tracking facilities, and scheduling of hand-over from commercial services to a NASA-managed tracking station, the minimum cost problem becomes extremely complex. In addition, some of the constraint equations become non-linear. For these reasons, the current effort has concentrated on the simpler model, tabling the more challenging issues for the time being. This iterative process will produce an ordered set of communications alternatives which will be very useful for decision-makers who are responsible for planning the communications systems for future missions.

The Fifth Step: Detailed Link Analysis of Preferred Solutions

The fifth and final step in the optimization process is to perform a detailed link analysis on the preferred solution and any other highly optimal solutions obtained from step four. This will ensure that the optimal solutions are truly capable of performing as anticipated. We currently envision using CAGE to perform this function.

Summary

This Network Optimization project has been an on-going effort for the past twelve months. Resource allocation, linear programming, and decision theory are key to solving this complex problem of optimally developing and assigning limited and costly communications resources to satisfy the demands made by new missions. Although the project is still in the early stages, the scheduling scenarios that we have generated using the NCASEMM scheduling tool are promising. Upon completion of the Network Optimization project, it is anticipated that the outlined process will significantly aid in assessing and designing communications network architectures for future NASA missions.