The Space Communications Protocol Standards Program

Alan Jeffries
Science Applications International Corporation
8301 Greensboro Drive
Mclean, VA 22102

Adrian J. Hooke
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109-8099

ABSTRACT

In the fall of 1992 NASA and the Department of Defense chartered a technical team to explore the possibility of developing a common set of space data communications standards for potential dual-use across the U.S. national space mission support infrastructure. The team focused on the data communications needs of those activities associated with on-line control of civil and military spacecraft. A two-pronged approach was adopted: a top-down survey of representative civil and military space data communications requirements was conducted; and a bottom-up analysis of available standard data communications protocols was performed.

A striking intersection of civil and military space mission requirements emerged, and an equally striking consensus on the approach towards joint civil and military space protocol development was reached. The team concluded that wide segments of the U.S. civil and military space communities have common needs for:

- An efficient file transfer protocol
- Various flavors of underlying data transport service
- An optional data protection mechanism to assure end-to-end security of message exchange
- An efficient internetworking protocol

These recommendations led to initiating a program to develop a suite of protocols based on these findings. This paper describes the current status of this program.

INTRODUCTION

The U.S. civil and military space programs are in a state of rapid and turbulent change. Both share the overarching need to more rapidly integrate and deploy space assets, while satisfying expanding mission requirements in an era of extreme cost constraints. Standardization and system interoperability are widely agreed to be the cornerstones towards achieving these goals. Recognizing that both communities share the same industrial contractor base the joint development of common standards and approaches may be expected to reap large benefits in terms of this nation's overall effectiveness in space.

For many years, space agencies have focused on solving the Physical (Layer 1) and Data Link (Layer 2) problems of data transfer through special purpose (noisy, bandwidth constrained, very long time delay) space channels that connect ground users with robotic or piloted space vehicles.

As space missions become more highly networked, requirements are emerging to provide capabilities at the Network layer (Layer 3) and above. Organizations such as the Consultative Committee for Space Data Systems (CCSDS) have begun to address these new needs. At Layer 3, CCSDS currently provides an "Internet

Service" which allows the option to run the full stack of commercially-supported ISO/OSI services (Transport, Session, Presentation and Application) between space and ground. The CCSDS Internet service is the same as the ISO 8473 Connectionless Network Protocol (CNLP). The Internet Service is paired with a special purpose "Path service" (using a low-overhead CCSDS Packet) which functions as a connection oriented network protocol.

There is mounting opinion that neither of these upper layer options can meet all future mission requirements. Concerns have been voiced about the communications overhead and onboard processing resource implications of operating the full ISO/OSI protocol stack in space, particularly with respect to the large amount of on-line protocol associated with the ISO CNLP, the time delay sensitivity of the early implementations of the ISO Class 4 Transport protocol, and the comprehensive but "heavyweight" nature of the ISO Layer 6/7 protocols. The CCSDS Path Service is very limited in terms of addressing capability, and presently has no support of needed upper layer functions such as flow control, end-to-end ARQ, and file transfer.

The strong need to provide a more robust and efficient set of end-to-end communications protocols prompted the initiation of the joint NASA/DoD Space Communications Protocol Standards Technical Working Group (SCPS-TWG) to develop more flexible upper layer protocol options for space missions.

The SCPS-TWG effort determined that many space missions share a common need for an efficient and reliable data delivery service to transfer individual messages, or files of messages, from their source end system to their destination end system error-free and with their sequence preserved. Many missions will also require that these transfers be secure.

Such a service should be standardized, easy to use and able to support a wide range of mission configurations. The protocols which implement the service must conserve onboard resources such as memory, processing power and (especially) communications capacity. They must be capable of supporting rapid, reliable on-line data exchange during brief contact sessions through unique space data channels with a wide range of significant propagation delays.

The development of these standard communication data protocols are being performed by the SCPS-TWG in three phases: Exploratory Analysis (FY93), Standards Development (FY94/95), and Validation (FY95/96). The Exploratory Analysis Phase has been completed and a report is available outlining the analysis efforts and their conclusions.

The remainder of this paper discusses the scope of the SCPS-TWG program, a overview of the Exploratory Phase activities and results, a review of efforts to date on the Development Phase activities and a summary.

SCPS-TWG SCOPE

The primary focus of the SCPS-TWG is to examine standardization of the data communications systems which support on-line spacecraft control. It therefore embraces the end-to-end aspects of the control center processes which are associated with commanding and monitoring the spacecraft and its payload, and returning mission results via a flow of telemetry, during periods when the end systems in space and on the ground are connected and are exchanging data.

Dialog between control centers and remote spacecraft requires frequent (and often two-way) interchange of digital command and response messages through space data links. Such interchange must routinely cope with a data transmission environment that has unique characteristics that are not

encountered in commercial data networking.

The current efforts embrace data communications functions at the Network, Transport and File Transfer (3,4,7) layers. Services of existing (and usually different) underlying civil and military physical and data links layers were assumed.

EXPLORATORY PHASE

The SCPS-TWG Exploratory Phase was performed during the period of October 1992 through December 1993 and culminated in a report on activities and recommendations for initiating the development program. The purpose of this phase was to assess whether there was a common need for data communications protocols between the civil and military space communities, and if there was, what were the common functional requirements. Additionally the Exploratory Phase was to assess the feasibility of adapting existing data communications protocols to meet these common requirements and to define a recommended program of development.

The SCPS-TWG employed an approach of simultaneous top-down and bottom-up analysis. The top-down activity involved a surveying representative, civil and military missions to gather a broad set of functional and performance requirements, and to pinpoint technical constraints intrinsic to space based communications which must be factored into the development of standards. The captured requirements and constraints were allocated to specific protocol layers and fed into the bottom-up activity.

The bottom-up analysis activity involved evaluating the capability of existing off-the-shelf data communications protocols to perform needed space mission functions at each of the layers. As a matter of policy, ISO protocols were the first choice for evaluation to maintain as much conformance as possible with GOSIP and to ensure a high degree of interoperability with ground-based systems. The selection of commercially supported protocols allows the space community to leverage the years of effort that went into engineering their development, and to avoid expensive and duplicative re-invention of capabilities.

The missions surveyed during the Exploratory Phase were as follows:

DoD
- BMD/Brilliant Eyes
- Global Positioning System
- Defense Met Sat Program

NASA
- Space Station
- Earth Observing System (EOS)
- Solar Anomalous and Magneto-sphere Particle Explorer (SAMPEX)
- Tropical Rainfall Measurement Mission (TRMM)
- X-ray Timing Explorer (XTE)
- Advanced Composition Explorer (ACE)
- Discovery Series

The mission survey documented specific functional services by protocol layer (based on the ISO/OSI layered model) which were common between the civil and military projects. These services form the functional data communication requirements that are being supported in the SCPS-TWG protocol stack development, and are listed below in Table 1.

Table 1: Functional Requirements for SCPS Protocols by ISO/OSI Layer

File Transfer (10)	*Transport (9)*
Operations on entire files	Full reliability
Operations on file records	Best effort reliability
Two party file transfer	Minimal reliability
Three party file transfer	Multicasting
User initiated interrupt, resumption and abort	Operation over spacelink bandwidth, outages and delays
Automatic progress monitoring	Segmentation
Automatic interrupt detection	Precedence handling
Automatic resumption after interrupt	Graceful closing of connections
Integrity over operations on entire files	Response to congestion and corruption
Integrity over operations on file records	
	Networking (6)
Data Protection - Optional (5)	Support for multicasting
Access control	Support for multiple routing options
Source authentication	Packet lifetime support with auto discard
Command authentication	Reporting of congestion and corruption
Integrity	Support for precedence handling
Confidentiality	Differentiation between real and exercise data

The bottom-up review of candidate off-the-shelf protocols evaluated potential protocols by asking the following questions:

- Is the functionality provided by the protocol necessary for space use, and if not can the protocol be easily trimmed down?
- Does the selected functionality provide complete support for space use (i.e., is the protocol sufficient in its off-the-shelf state or are additional capabilities required)?
- Does the selected functionality operate efficiently and within the constraints of the space environment, or are modifications needed?
- Can the selected space functionality be achieved with minor change (i.e., is the protocol still commercially supportable after modification) or does it have to be discarded?

If the initial ISO protocol was not able to meet the space application needs, then other commercially available and broadly implemented protocols were assessed (such as those used within the Internet community). Only once all reasonable, off-the-shelf options were discarded, was a solution unique to space use considered. Results of this review are as follows:

File Transfer - OSI FTAM was determined to be too large and couldn't be slimmed down through tailoring. The Development Phase activity is doing a detailed analysis comparing the Internet FTP and Space Station File Transfer protocols to determine which will form the basis for the SCPS-TWG file transfer protocol

Transport - Initially the OSI TP4 protocol was selected, but it too is larger than its Internet counterpart and is expensive to procure. Subsequently a combination of the Internet UDP and TCP protocols are being used to develop the SCPS-TWG transport protocol.

Data Security - the SP3 protocol, based on the OSI NLSP protocol, is being adopted as one option to use with existing or soon to be completed systems. A skinny version of SP3

(called SP3-prime) is being developed to reduce the bit overhead associated with SP3 as an option for future missions.

Network - No existing protocol provided the functionality required with the minimal bit overhead required to optimize use of the spacelink resources. Therefore a custom protocol with elements derived from OSI 8473 and IP is being developed for space applications.

The final suite of protocol services is depicted in Figure 1. As illustrated the SCPS protocol suite can be run over the existing CCSDS protocols used by NASA or the DoD SGLS protocols which achieves the expected interoperability.

DEVELOPMENT PHASE

The SCPS-TWG Development Phase was officially begun in January, 1994 and is planned to run for 33 - 36 months. The first 18 months of this phase are focused on developing protocol specifications for broad community review (equivalent to CCSDS redbooks). The remaining 15-18 months involve two or three rounds of distribution and comment by the US space community culminating in final protocol specifications ready for NASA and DoD adoption.

During the first 18 months the development teams for each of the protocol layers are working in conjunction with a systems engineering group to develop, analyze, and validate the protocol specifications.

The basic approach to this phase is illustrated in Figure 2. Each development team will employ a three pronged development effort consisting of protocol specification development, prototype development, and simulation analysis. The purpose of this approach is to ensure that the specifications developed during this phase have been properly assessed under the broad range of mission architectures represented by DoD and NASA missions.

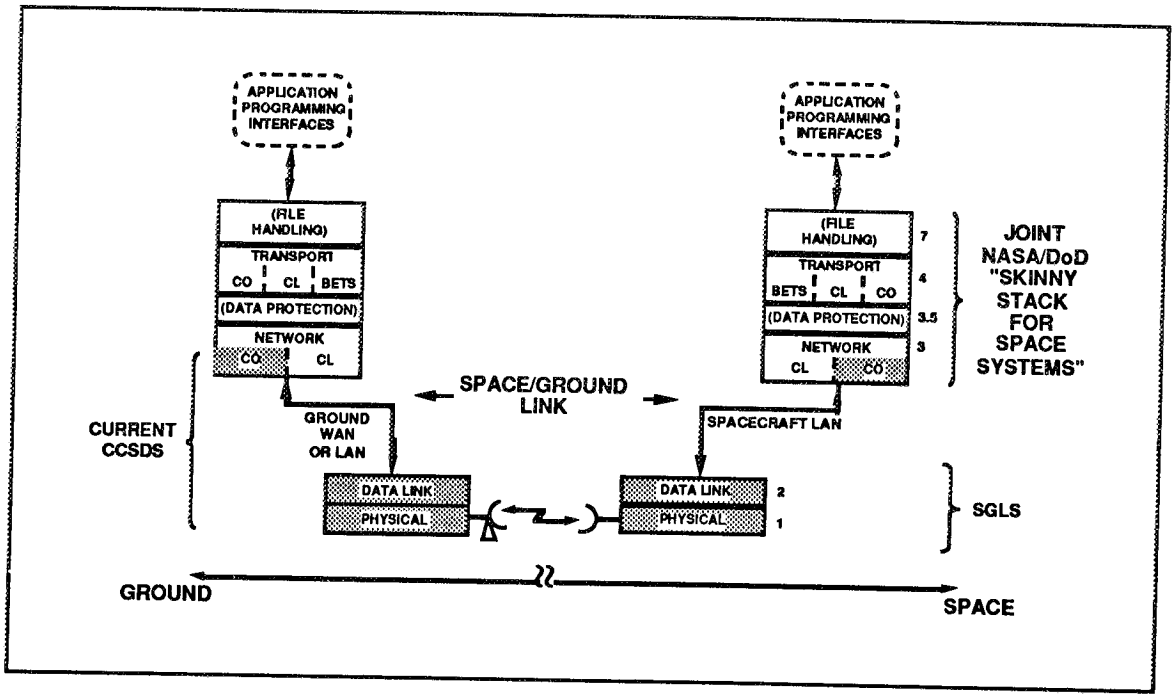

Figure 1: SCPS-TWG Exploratory Phase Recommended Suite of Protocol Services

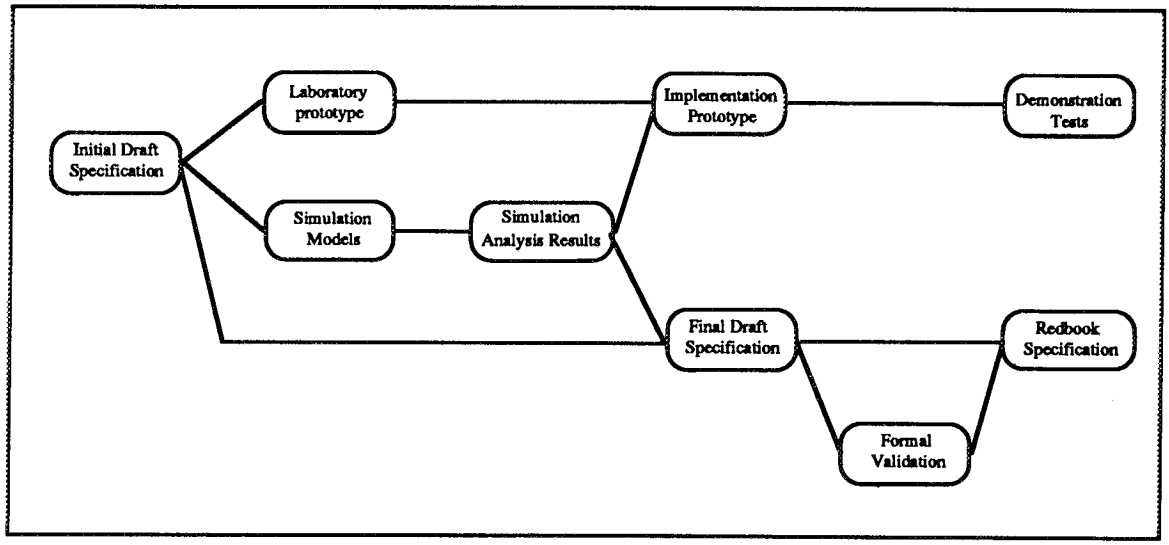

Figure 2: SCPS-TWG Protocol Development Approach

Most of the analysis will be performed via simulation using the MIT NETSIM modeling tool. Each of the protocols will be modeled using NETSIM and then assessed under at least five mission architectures and various scenarios:

- Single earth orbiting satellite communicating through relay satellites
- Single earth orbiting satellite communicating through ground stations
- Single deep space satellite communicating through ground stations
- Multiple deep space satellites communicating through relay satellites
- Multiple earth orbiting satellites communicating through ground stations

Operational prototypes of the protocols will initially be used to benchmark the simulation models to ensure the models accurately represent actual implementations. Once analysis and design of the protocols is complete, the prototypes will be modified to represent the recommended protocols defined in the final specifications. they will then be used in a series of proof-of-concept demonstration tests. These demonstrations are planned to include the use of flight equivalent testbeds such as the GSFC AOS Testbed, "bent-pipe" testing using DoD and NASA on-orbit platforms, and the hosting of the protocols on a spacecraft which has completed its mission phase and is available for the evaluation of new technology concepts.

The detailed schedule of activities which lead to the first set of protocol specifications available for broad community review in September of 1995 is presented in Figure 3. Note that at this time not only will draft specifications be available, but some level of functional prototypes and a sophisticated simulation capability will have also been developed.

In order to ensure community involvement in the protocol development efforts, the SCPS-TWG holds quarterly "Users Forums" identified in the schedule as SCPS-TWG -XX meetings. These meetings are designed to provide community insight into the protocol development and analysis activities. Participation from government, industry and commercial space ventures is welcomed.

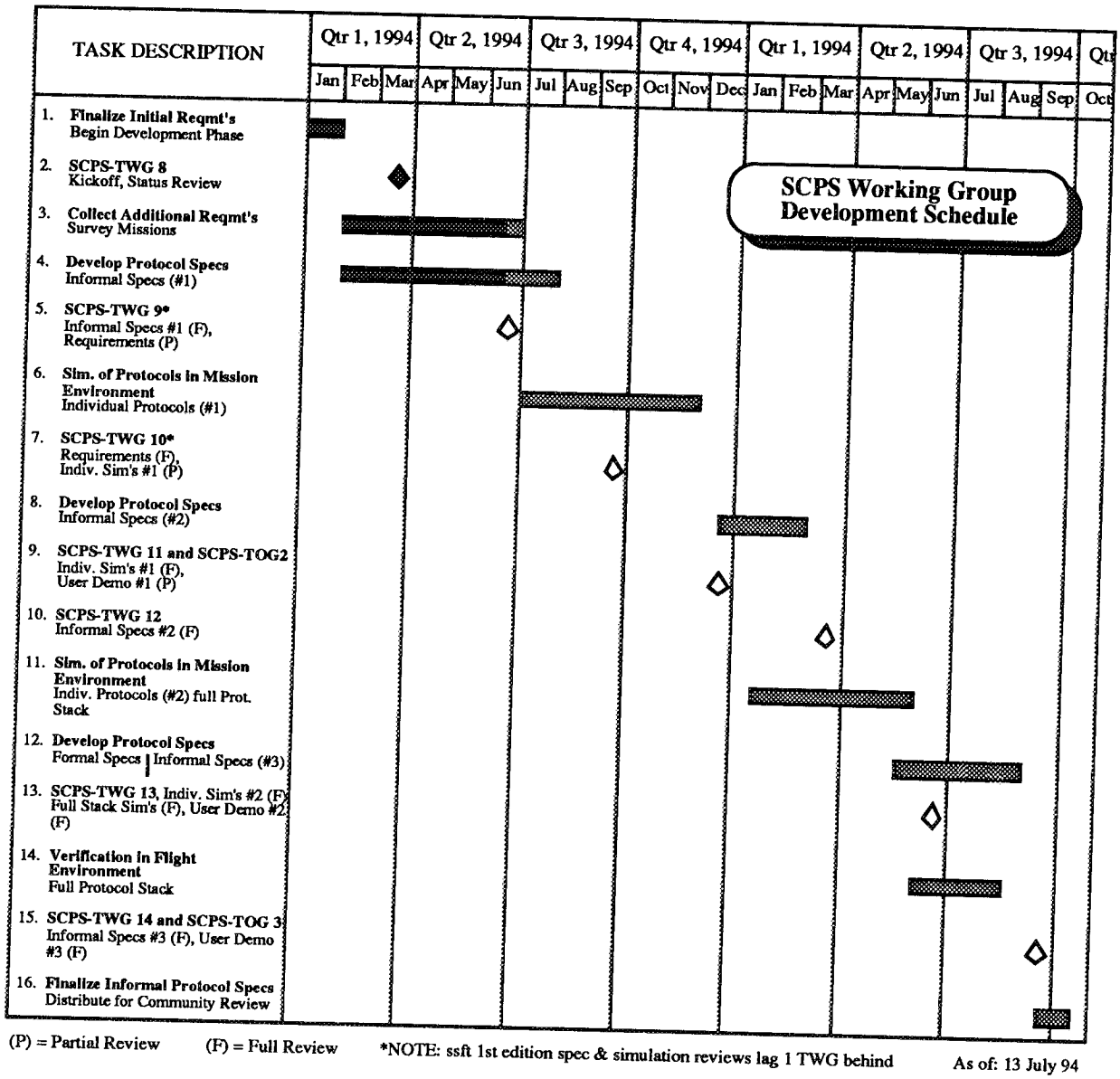

Figure 3: SCPS Working Group Schedule

To date initial draft specifications have been completed and circulated for review for the file transfer, transport and network layer protocols. These drafts are the first in a series of three SCPS-TWG internal drafts which will be developed prior to full community review in September of 1995. Work is proceeding on developing initial prototypes for these three layers with a prototype file transfer protocol based on FTP already completed. Additionally, efforts to develop models of the three current protocols are also in development as is the simulation environment which will model the various mission architectures and data communications scenarios.

SUMMARY

The SCPS-TWG efforts has been highly successful to date in identifying common data communications requirements across U.S. civil and military space missions and defining a program that consists primarily of adapting existing communication protocols to meet the rigors and unique characteristics of space communications.

As one indicator of its success the Defense Information Systems Agency (DISA) has designated the SCPS-TWG activity as its lead effort for developing "thin stack" data communications protocols applicable to a wide range of applications, including airborne, shipboard and in-field communications.

Another indicator is the recent interest in SCPS efforts shown by the commercial satellite venture called Teledesic, which plans to deploy a constellation of 840+ satellites to create a full data communications system equivalent to ground based systems on-orbit.

At the last SCPS-TWG Users Forum, held in June, 1994, DoD representatives working on an existing experimental communications satellite initiated discussions on how to perform "bent-pipe" testing of the SCPS protocol.

Recently, even representatives of the British and French national space complexes have begun discussions on how to become participating members of the SCPS-TWG User Forum. Additionally, the SCPS-TWG team has been coordinating its activities with CCSDS members to facilitate the acceptance of the final protocol by that international body which has shown great interest also.

The importance of this work in NASA can be illustrated by current efforts on the GSFC Mission Operations Control Architecture (MOCA) initiative which has stated that in order to achieve standardized and autonomous operations of GSFC spacecraft communications services of the type now being developed by the SCPS-TWG are paramount. Interest from the NASA missions surveyed in having these protocols was universal.

Continued success of this program is dependent on continued interaction and review by the space community at large. These inputs can have their most positive influence during the current initial 18 month activities of the SCPS Development Phase while preliminary design and analysis are being performed. Critical insights and lessons learned need to be provided by government and industry representatives who have years of space mission experience to share.