ADVANCED ORBITING SYSTEMS TEST-BEDDING AND PROTOCOL VERIFICATION

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ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS) is developing a set of communications protocols for Advanced Orbiting Systems (AOS). The National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) are cooperating in an effort to extensively validate these AOS protocols. This paper describes the techniques and facilities being used to perform this validation.

Validation of the AOS protocols consists of (1) developing a formal specification of the protocols using a standard formal definition technique (FDT), (2) developing implementations of the protocols, and (3) remote testing of the implementations. From the FDT specifications, each agency is developing independent implementations which are consistent with the FDT specifications of the AOS protocols. Errors, omissions, or discrepancies detected during the development of the FDT specification and the implementation will be reported to the CCSDS and changes to the main specification will be suggested. The independent implementations will be extensively tested locally by the developing agency and then remotely tested through a cooperative test setup between the agencies. The implementations will interact to communicate between the agencies thus providing proof that the FDT specifications are sufficiently specific to be interpreted by everyone in the same way. Significant variations in the interpretations will result in feedback to the CCSDS and any needed changes to the main specification will be suggested.

The AOS protocols are divided into four categories: Path, Space Link ARQ Protocol (SLAP), Space Link (SL), and Management. Each agency has agreed to be either the leader or support agency for each of the categories. NASA has

agreed to be leader for the validation of the SLAP and SLS categories while ESA has agreed to lead in the validation of the Path and Management categories.

Testbeds at the European Space Research and Technology Centre (ESTEC) in Noordwijk, Holland and at the MITRE Corporation in McLean, Virginia have been constructed for the development of FDT specifications and AOS protocol implementations. Communications facilities are being obtained which will connect these testbeds. This paper describes these testbeds, the AOS FDT specifications, the protocol implementations being developed, and the results expected from the tests performed.

Keywords: Consultative Committee for Space Data Systems, CCSDS, protocol validation, test-bedding, LOTOS

INTRODUCTION

“Advanced Orbiting Systems” of the coming decades will require complex communications capabilities that far exceed the capabilities needed for “Conventional Systems”. Conventional space craft communications systems are characterized by relatively low volume, low data, low to medium data rates, and narrow band-width. In addition, their data requirements are usually met using a telemetry coded channel and accompanying audio/video channels, using time division multiplex (TDM) of frequency division multiplex (FDM) transmission schemes. Since their paths and routing are essentially static, a significant percentage of network path and routing chores can be handled by telephone exchanges and memorandums.

In contrast to conventional systems, AOS communications systems must handle high volume, high data rate communications, with an underlying wide bandwidth requirement. Such systems must provide continuous mission support and simultaneous access by many users with diverse needs. The CCSDS will meet these requirements using standard packet data structures for all users, communications services keyed for low rate, low volume to high rate, high volume users, and a data path and routing scheme based on virtual channel multiplexing techniques. The virtual channel techniques, combined with packet data routing schemes, will permit dynamic, packet routing and automated network reconfiguration capabilities to meet changing user needs over the extended lifetimes of AOS missions.

AOS missions will serve “complex international constellations of spacecraft, including manned and man-tended space stations, unmanned space platforms, free flying spacecraft, and advanced space transportation systems”. International partnership in space will require these advanced capabilities to be implemented with standard protocols that will allow the space agencies of the various countries to share communications facilities.

In response to these requirements, the Consultative Committee for Space Data Systems (CCSDS) began the development of a set of protocol recommendations for Advanced Orbiting Systems (AOS).

ADVANCED ORBITING SYSTEMS (AOS) PROTOCOLS AND SERVICES

Figure 1 illustrates the structure of the AOS protocols and the services they provide. The AOS protocols are divided into the Path and Space Link Layers which correspond roughly to the International Standards Organization (ISO) Network, and Link Layers respectively. While the Path Layer is divided into recommended procedures, the Space Link Layer is divided into sublayers which are subsequently divided into procedures. In addition to the Path and Space Link protocols, a Space Link Automatic Request Queuing Procedure (SLAP) is also included to provide retransmission services for the AOS Protocol Suite.

Eight types of service may be provided to the user by the AOS protocols. The Path Layer provides Octet String Service and Packet Service end-to-end. This means that a user can present and receive data to/from the Path Services Access Points (SAPs) in the form of octet strings or as preformed CCSDS Type 1 Path Packets.

The Space Link Layer provides six additional services (Multiplexing, Encapsulation, Bitstream, Virtual Channel UNITDATA, Virtual Channel Data Unit, and Insert) over a link. Users of Multiplexing Service present and receive data to/from the Space Link SAPs in the form of CCSDS Path Packets. Encapsulation Service allows the user to present and receive delimited data units that are not in the form of CCSDS Packets. These data units are “encapsulated” in CCSDS Packets before multiplexing. Bitstream Service allows for the transmission of pure bitstreams. Virtual Channel UNITDATA Service allows the user to send and receive data units preformed and sized to fit the information area (Data

Unit Zone) of Virtual Channel Data Units (VCDUs). Virtual Channel Data Unit Service provides the user with the ability to send and receive fully formed VCDUs. Insert Service provides for the isochronous transfer of octets over low bandwidth physical links. Space for the “Insert” octets is reserved in all VCDUs transmitted over a physical channel.

The format of Path Packets and Virtual Channel Data Units can be found in Advanced Orbiting Systems, Networks and Data Links: Architectural Specification (CCSDS 701.0).

THE AOS VALIDATION PROGRAM

As the specification of the AOS protocols proceeded, it became apparent that a comprehensive validation would be required before the AOS protocol recommendations could be finalized. At the October 1988 CCSDS Panel 1 meeting in Darmstadt, West Germany, representatives of the ESTEC proposed a validation program for the AOS protocols. At the April 1989 CCSDS Panel 1 meeting in San Francisco, California, a plan for the validation program was presented and accepted. Figure 2 illustrates the major activities contained in the plan. A complete set of LOTOS specifications for Path, Space Link, and the SLAP were scheduled for completion by the end of July, 1989.

THE AOS FORMAL DEFINITION

The first activity defined for the validation program consists of the development of formal definitions of the AOS protocols. It was generally agreed that the English definitions of the protocols that were contained in CCSDS 701.0 should serve as the basis for the validation work, but that the English in CCSDS 701.0 was not specific enough to be validated. It was therefore agreed that formal specifications, derived from CCSDS 701.0, would be developed and then used as the specifications to be validated. These specifications will be published as the Advanced Orbiting Systems, Networks and Data Links: Formal Specification (CCSDS 705.0).

Four sets of specifications were identified: the SLAP; the Space Link; the Path; and Management and Signalling. NASA agreed to provide the formal specifications for the SLAP and the Space Link while ESA agreed to provide the specifications for the Path and Management and Signalling. Because CCSDS 701.0 did not contain a fully developed recommendation for Management and Signalling, it was decided to delay the development of their formal specification until general agreement has been reached on the Management and Signalling recommendations.

A formal definition technique (FDT) was selected for the specifications. The Language for Temporal Ordering Specifications (LOTOS) and the Extended State Transition Language (Estelle) were evaluated. Due to a strong preference by European Space Agency (ESA) representatives and based on a survey of formal definition techniques conducted by Mark Gamble, of Logica Space and Defense Systems, LOTOS was chosen as the FDT for the validation effort. LOTOS is defined in the ISO Draft International Standard 8807: LOTOS - A Formal Description Technique Based on the Temporal Ordering of Observational Behavior.

In conjunction with the choice of LOTOS, the Software Environment for Design of Open Distributed Systems (SEDOS) LOTUS Toolset was also chosen. The SEDOS LOTOS Toolset consists of a LOTOS syntax checker, a LOTOS static semantics checker, a LOTOS pretty-printer and a LOTOS symbolic simulator. By using the SEDOS LOTOS Toolset, the specification writers can produce specifications that are syntactically, semantically, and logically sound. Lockouts and other error conditions were discovered and corrected in every specification due to the use of this toolset.

CONFIGURATION CONTROL

The CCSDS AOS formal specifications are being validated by this effort. It is therefore important to ensure that the formal specifications are under strict configuration control. The version of the specifications that are distributed for peer review at the end of July will be considered version 0 of the Advanced Orbiting Systems, Networks and Data Links: Formal Specification (CCSDS 705). Suggested changes to the specifications or changes necessitated by detected errors or omissions will be submitted to the CCSDS 705 editor. The CCSDS 705 editor and the LOTOS authors will constitute a review board and periodically review and disposition each change request. Change requests will be numbered as they are received by the CCSDS 705 editor and tracked until CCSDS 705 is finalized. Periodically new versions of CCSDS 705 will be issued that reflect the disposition of change requests.

INDEPENDENT IMPLEMENTATIONS OF THE AOS PROTOCOLS

In order to validate that the formal LOTOS specifications of the AOS protocols were complete and unambiguous, it was decided that NASA and ESA would independently implement complete suites of AOS protocols from the LOTOS specifications. A comparison of the implementations would reveal the deficiencies in the LOTOS specifications that could lead to problems of interpretation. Changing the LOTOS specifications to remove these ambiguities would yield specifications upon which implementers could confidently base implementations.

A common configuration for development of the implementations was agreed upon by NASA and ESA. The platform for development was to be SUN workstations running the UNIX operating system. The C programming language was selected for the implementations.

At the April 1989 meeting of CCSDS Panel 1, NASA presented the CCSDS activities of the NASA/MITRE Network Services Testbed (NSTB) located at the MITRE Corporation facilities in McLean, Virginia USA. ESA presented the CCSDS work being conducted at the ESTEC in Noordwijk, Holland. The NSTB had developed and tested the Space Link and SLAP protocols based upon Issue-2 of CCSDS 701.0. The ESTEC had developed and tested a version of the Path Layer protocol, and had developed a graphical user interface to the Path Services. NASA and ESA agreed to have a full suite of AOS SLAP, Space Link, and Path protocols developed and tested in the facilities by the end of September 1989.

CROSS SUPPORT/INTEROPERABILITY TESTS

One of the primary motivations behind the development of the CCSDS AOS recommendations was the need for standard communications protocols that would allow the space agencies of the various countries to share communication facilities. In the case of the Space Station Freedom, the agencies will share common on-board, space to ground, and ground to ground networks. In future missions it is anticipated that the agencies may even share data relay satellite systems. One system may switch from one agency’s satellite system to another’s as it orbits the Earth. The testing of cross-support and interoperability between the agencies is, therefore, of prime concern to CCSDS.

An agency may use any of the AOS Services described above to transfer data across another agency’s networks. In addition, it is possible for an agency to provide another agency with asymmetric services. That is, an agency may submit data units from one service, such as Path packets at one end of a transfer and receive a data unit from another service, such as Virtual Channel Data Units, at the receiving end of the transfer. The availability of asymmetric services could result in many different types of service access points between the agencies. The use of asymmetric services would also result in a need for more coordination between the agencies.

The NSTB and ESTEC testbeds will be used to develop and test the cross-supportability and interoperability of the AOS protocols. Due to time and resource limitations for the validation program, the cross-support and interoperability testing will be limited initially to the three scenarios most likely to be implemented in real systems. The current choices for the services to be tested are Bitstream Service, Path Packet Service, and Virtual Channel Data Unit Service. These choices will be tested in a symmetric configuration, i.e., an agency may use the same CCSDS Service to transfer and to receive its data from a partner network.

Tests will be conducted between the NSTB and ESTEC testbeds via the Program Support Communications Network (PSCN). ESTEC and the NSTB are connected with 56k bps service utilizing CISCO routers. The Advanced Research Projects Agency (ARPA) protocols, TCP/IP, will be used between SUN computers in the two testbeds to provide underlying transfer of the CCSDS data units.

Cross-support/interoperability testing is scheduled to begin in September 1989. An informal test plan will be developed which will describe each test to be conducted and list the steps involved in conducting each test. Observations will be recorded which will document the success or failure of each test step. Failures will be traced to their subsequent resolutions. Change requests will be generated for any failure that results in a change to the AOS formal specifications.

In addition to the formal specifications, implementer’s agreements between the testbed developers will be documented. Implementer’s agreements are necessary because there are items, such as network management techniques, that are not part of the formal specifications but must be agreed upon by the implementers in order to get the two implementations to work together.

VALIDATION REPORTING

Upon completion of the Cross-support/interoperability testing a complete validation report will be issued to the CCSDS Panel 1 F/G. The report will contain a description of the tests conducted, the observations recorded during the tests, the corrective actions taken in response to any failures observed, and a description of the implementer's agreements that were established for the tests.

CONCLUSIONS

At the time of the writing of this paper, the CCSDS AOS Test-Bedding & Protocol Verification effort is not yet mature enough to yield conclusions as to the validity of the CCSDS AOS recommendations. It is the conclusion of members of the CCSDS community, however, that the testing program described above will yield a set of formal specifications of the CCSDS AOS protocols that can be used with confidence by space communications system designers and implementers, such as ESTEC (Europe), NASDA (Japan), and NASA (USA).

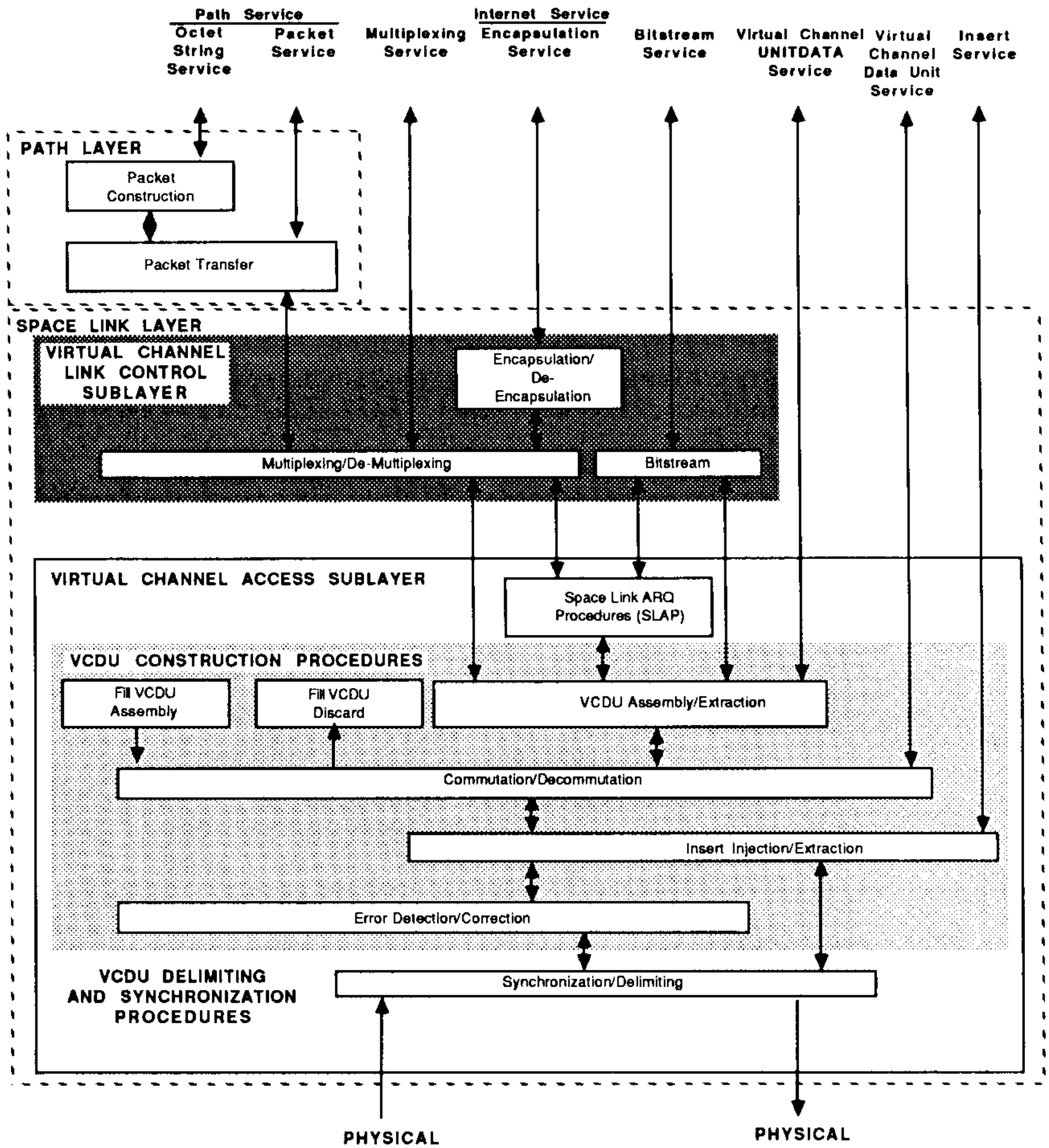
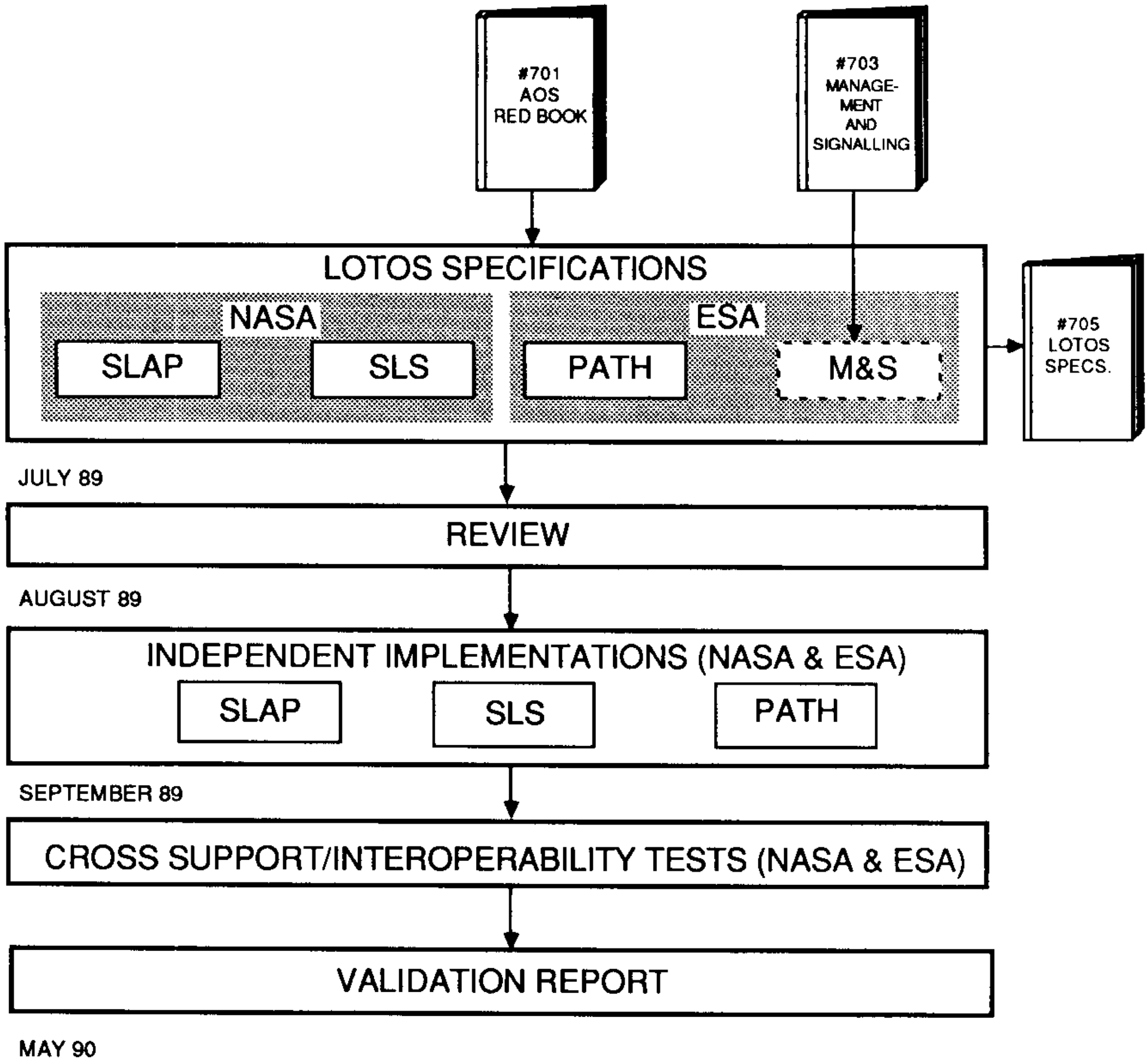

Path Service
Octet String Service
Packet Service
Multiplexing Service
Internet Service
Encapsulation Service
Bitstream Service
Virtual Channel UNITDATA Service
Virtual Channel Data Unit Service
Insert Service
PATH LAYER
Packet Construction
Packet Transfer
SPACE LINK LAYER
VIRTUAL CHANNEL LINK CONTROL SUBLAYER
Encapsulation/ De-Encapsulation
Multiplexing/De-Multiplexing
Bitstream
VIRTUAL CHANNEL ACCESS SUBLAYER
Space Link ARQ Procedures (SLAP)
VCDU CONSTRUCTION PROCEDURES
Fill VCDU Assembly
Fill VCDU Discard
VCDU Assembly/Extraction
Commutation/Decommutation
Insert Injection/Extraction
Error Detection/Correction
VCDU DELIMITING AND SYNCHRONIZATION PROCEDURES
Synchronization/Delimiting
PHYSICAL
PHYSICAL

FIGURE 1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JULY 89
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AUGUST 89
INDEPENDENT IMPLEMENTATIONS (NASA & ESA)
SLAP
SLS
PATH
SEPTEMBER 89
CROSS SUPPORT/INTEROPERABILITY TESTS (NASA & ESA)
VALIDATION REPORT
MAY 90

FIGURE 2