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AN OPEN SPECIFICATION FOR A SPACE PROJECT MISSION OPERATIONS CONTROL ARCHITECTURE

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O OVERVIEW

The Space Project Mission Operations Control Architecture ("SuperMOCA") project has been initiated across the US space community with the goal of developing an open international standard specification for the activities associated with the monitor and control of spacecraft and their supporting ground systems. SuperMOCA addresses the mechanisms required to conduct a telecommunicated process control dialog between a human (or machine) user and remote, distributed end systems, some of which are located in space. One example of such a dialog is the exchange of telecommand and telemetry messages between a ground operations center and a remote space vehicle in order to control its activities; another is the configuration and operation of a ground terminal which is acting as the ground entry point for spacecraft data flow. The SuperMOCA, which will soon be proposed as a new work item to the Consultative Committee for Space Data Systems (CCSDS), will thus promote standardization and widespread commercial support of control languages, reasoning engines, space messaging protocols, and space mission information architectures. Customers of the new standard capability are expected to include:

- o The civil space community (e.g., CCSDS Agencies).
- o The military space community.
- o The commercial space community (e.g., mobile satellite service providers).

1 INTRODUCTION

As national budgets shrink, space agencies face a pressing need to significantly reduce mission operations costs without sacrificing either mission flexibility and capability. Driven by the profit motive, the emerging commercial space community seeks low-cost "off the shelf" command and control systems that reduce the need for capital and operating investment.

Standardization is well recognized as a key tool in resolving the conflict between space mission complexity and increasingly limited budgets. For well over a decade, CCSDS has been laying the foundation for increased standardization of the dialog between spacecraft and their ground support systems. More recently, the US Space Communications Protocol Standards (SCPS) project has been extending the CCSDS Recommendations "up the stack" towards the Application layer in the form of extensions to commercial data handling protocols which, from a user viewpoint, give spacecraft the apparent functionality of an "Internet node in the sky". The SCPS protocols[1] (which are currently being introduced to the CCSDS) will provide a variety of robust and reliable file and message transfer services that will encourage more widespread standardization of the applications which are conducted in support of a mission.

[1] 'The Next Generation of Space Telemetry and Telecommand Standards', Adrian J. Hooke, paper # RAL,GS.101 at this conference

The command and control of spacecraft and their supporting ground networks is an application that appears ready for standardization. Currently lacking standards or guidance (and the corresponding availability of cheap commercial products), space mission command and control has been significantly re-invented for each mission; this drives up cost because a constant cycle of system redesign results in customized, non-automated operations that are highly labor intensive. New standard user services would allow many different types of spacecraft (as well as their supporting ground networks) to appear basically harmonious from the perspective of ground controllers, allowing automation to be deployed and operations and maintenance budgets to be contained.

Building upon work performed early in the Space Station Freedom program, a small "Spacecraft Control Working Group" convened within the American Aeronautics and Astronautics (AIAA) has been studying the feasibility of developing a full open standard for space mission control. This group is now advocating the development of the SuperMOCA as a loose partnership between government, industry, academia and the international community.

2 ELEMENTS OF THE SuperMOCA

To control a remote spacecraft the user formulates command directives, initiates their transmission, monitors their execution and takes corrective action in case of anomalous behavior. The spacecraft executes the command directives using various levels of onboard autonomy. The control center and the spacecraft exchange information via a space data communications system that includes both ground and space/ground networks. Users in the operations center perform a similar set of actions. to configure, monitor and control the remote ground data acquisition stations and launch systems which are supporting the spacecraft. The SuperMOCA considers all of these distributed activities to be instances of space mission process control.

The SuperMOCA conceptually exists as an execution-phase capability. It provides a mission control service interface to the planning phase systems which are used to construct the broad profile of desired mission activities and it draws upon communications services provided by various stack of underlying standard space and ground protocols. In the terminology of Open Systems Interconnection (0S1), the SuperMOCA therefore resides within the Application layer.

Figure 1 shows the SuperMOCA operating within an operations center and using both conventional ground data communications and the SCPS/CCSDS protocols to control a remote spacecraft, a ground terminal, a launch complex and launch vehicle. As currently envisaged, the SuperMOCA contains four elements. Three of these elements (the Control Interface, the Decision Support Logic and the Space Messaging System) form the heart of the actual process control system; the Information Architecture supplies the framework within which the other elements operate.

o Control Interface

The Control Interface allows a flight controller to specify and monitor the desired sequence of operations to be conducted in a remote system.

o Space Messaging System

The Space Messaging System translates machine-readable command calls from the user's Control Interface into standard-syntax messages that invoke the desired actions in the remote end system and return the response information to the sender.

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0 **Decision Support Logic**

The Decision Support Logic allows rules for command execution to be programmed into a distributed inference engine (which may be located wholly on the ground, wholly in space, or partitioned in varying degrees between the two). Commands may only be issued to end effecters in remote systems when they conform to the conditions that are programmed into the engine. Responses from end effecters will be compared against rule-based expectations and the Decision Support Logic may take further preprogrammed command actions based on the observed performance,

0 **information Architecture**

The information Architecture provides the mechanism whereby the precise characteristics of a concrete spacecraft system can be captured and described in abstract terms. it allows specific spacecraft devices to be described in standardized ways and for this information to be compiled into data dictionaries and encyclopedias. These data descriptions can be gathered starting at the earliest point in the project design lifecycle, thus supporting the progressive and seamiess capture, refinement, extension and translation of information.

3 SuperMOCA TECHNOLOGY BASE

In recent years several commercial products have emerged which support many of the SuperMOCA functions. All of them assume a generally non-standardized space mission environment and all of them provide useful capability in largely proprietary ways. The goal of SuperMOCA is to provide and overall open framework in which diverse commercial products may evolve across the common marketplace of civil, military and commercial space. The basic SuperMOCA approach is to assimilate as many off the shelf technologies as possible and to integrate them into high-performance space process control systems.

The Control interface is currently being modeled around the User interface Language (UIL) that was developed for the early Space Station Freedom program. The UIL is a fourth generation space operations language which provides a very English-iike mechanism for expressing control directives. The UIL is the culmination of a systems engineering effort which examined a number of operations languages, programming languages and operating system shells including:

- the Ground Operations and Aerospace Language (GOAL);
- the Space Station Operational Language (SSOL - based on GOAL);
- the Systems Test and Operations Language (STOL);
- the Customer Data and Operations Language (CDOL - based on STOL);
- the Transportable Applications Executive (TAE) Command language (TCL);
- the ESA Test and Operations Language (ETOL);
- ATLAS language used in avionics testing;
- programming languages including ADA and Smalltalk;
- operating system command languages including ANSI OSCRL, MS DOS, VAX DCL and UNIX shells.

in the era of Graphical User interfaces (GUIs) as a primary bridge between humans and the machine, there is still a need for a natural command language to simplify the training and expertise required to operate a spacecraft. Complex sequences of activities may preplanned, scripted and reviewed by human operators without sophisticated support tools. As voice recognition systems become more commonplace, operation of telerobotic devices using a programming language or an operating system command language would be extremely difficult and complex; imagine an astronaut speaking UNIX, DOS, Ada or a combination of these languages during the assembly of the space station in orbit.

The UIL is based on an object model paradigm anti provides for the manipulation of objects and their attributes using English-like statements. For example,

> Turn ON PUMP2
> Perform PUMP2 TEST With TEST DURATION Of 14 MINUTES 30 SECS
> Verify PUMP2 is ON and FLUSH VALVE is not OPEN
> Turn OFF PUMP2

The objects in this example are: PUMP2, FLUSH VAl VE and TEST. The actions taken are: Turn ON, Perform, Verify and Turn OFF. An attribute of TEST is DURATION which is set to 14 MINUTES 30 SECS.

For the Space Messaging System, SuperMOCA proposes to adopt and adapt commercial techniques for use in the unique space environment. In addition to emerging capabilities such as CORBA, the Manufacturing Message Specification (MMS) which, used extensively in automated factories and the FieldBus standard (SP50) which is gaining widespread use for critical industrial process control applications can form a mature basis for the command and control of distributed space systems, Both MMS and SP50 emphasize the concept of "Intelligent Device Controllers" which isolate the low-level internal functions and intricacy of a device from its external control system. Using an object oriented approach, the intelligent controllers provide a well-defined standard interface to the outside world which allows virtually any unique device to be controlled using high level instructions. Another paper[2] elaborates further on the significance of this technology. Large numbers of commercial components are now becoming available to the industrial automation community which permit fully 'open" (i.e., vendor-independent) factories to be designed and operated using standard computer communications protocols. These components are virtually self-integrating and thus allow very rapid reconfiguration and re-tooling to occur. It is now time to extend this environment into space. Robotic factories are not conceptually dissimilar from robotic spacecraft or automated ground terminals, and critical industrial process control loops are not dissimilar from critical onboard spacecraft control systems. By adopting and adapting the commercial techniques, spacecraft may soon look like "factories in the sky" and may thus exploit the robust commercial base of industrial products and techniques in order to achieve significant economies.

The Decision Support Logic provides for the execution of mission objectives and routine operation of the spacecraft. The concepts employed in software inferencing engines will form the basis of the SuperMOCA specification. Inference engines have been incorporated in commercial products such as the Spacecraft Command Language (SCL) by Interface and Control Systems and RTworks by Talarian Corporation. In practice, the decision support logic will operate on the abstract objects defined in the information architecture and instantiated in the onboard system; actions and reactions are based on operational constraints and conditional rules, also defined as objects.

The information Architecture, which is at the core of the SuperMOCA, must provide the mechanisms to define, describe and manage the information resources associated with a space mission. The object paradigm has been adopted as its foundation: using this paradigm, the spacecraft and the real devices used to construct the spacecraft are described as abstract objects. The externally visible

[2] 'The Adaptation of Industrial Protocols for a Space Massaging Service", W. Randy Heuser, paper #RAL.GS. 102 at this conference

characteristics and behavior of the real devices are attributes of their abstract object models. Associations between real devices are described as relationships between object models. The SuperMOCA Information Architecture will build on the concepts proposed for the Space Station Encyclopedia, which was based on two established standards: the Information Resource Dictionary (IRDS) and Directory Services (X.500). The IRDS is a ANSI standard for data dictionaries. It provides a set of services designed to define, describe and manage data dictionaries in terms of entities (or objects), their attributes and relationships. This approach parallels the object paradigm. The IRDS is organized into four layers shown in Figure 2: the definition of the concepts used to construct the data dictionary are stored in layer 1; the definition of dictionary object types are, stored at layer 2; the definition of "real world" object type are contained in layer 3; and the "real world" objects are contained in layer 4. The IRDS was designed as a central repository for an information systems and made no provisions for distributed operations. However, many space missions are often collaborative ventures with development and operational facilities distributed geographically. To support distributed operations, the Space Station Encyclopedia adapted the X.500 standard to support the management of IRDS objects across networks: Directory Services was developed by the CCITT to support electronic telephone directories. It provides services to define and manage objects and attributes in a way similar to IRDS. Directory Services also provides directory agents and services to search for objects in distributed object repositories (see Figure 3). The Space Station Encyclopedia proposed adapting the services of X.500 to support distributed IRDS operations (see Figure 4). The marriage of IRDS with X.500 is expected to provide the services necessary to support the SuperMOCA distributed information architecture.

4 NEXT STEPS

During the Spring of 1995, a study of standards needed to support low cost mission operations standards (performed by the CCSDS Agencies) ranked the SuperMOCA high in development priority. Activities are now underway to begin the definition of the new standard: partial funding for the activity has been allocated by NASA Headquarters and a small system engineering team has been assembled at the Jet Propulsion Laboratory. Initial activities are focusing on the Control Interface and the Space Messaging System. The University of Colorado is working on updating the UIL requirements and implementing a prototype interface system within an operations center testbed. MMS software is being procured and readied for rapid prototype testing with a developmental deep space ground station and with the JPL flight system testbed. Preparations are being made to propose the adoption of the SuperMOCA as an item of new work to the CCSDS Management Council. The participation of interested organizations across the international community is warmly invited.

ACKNOWLEDGMENTS

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[3] 'A Next-Generation Language for Space Mission Operations', R.L. Davis, paper # RAL.GS.43 at this conference

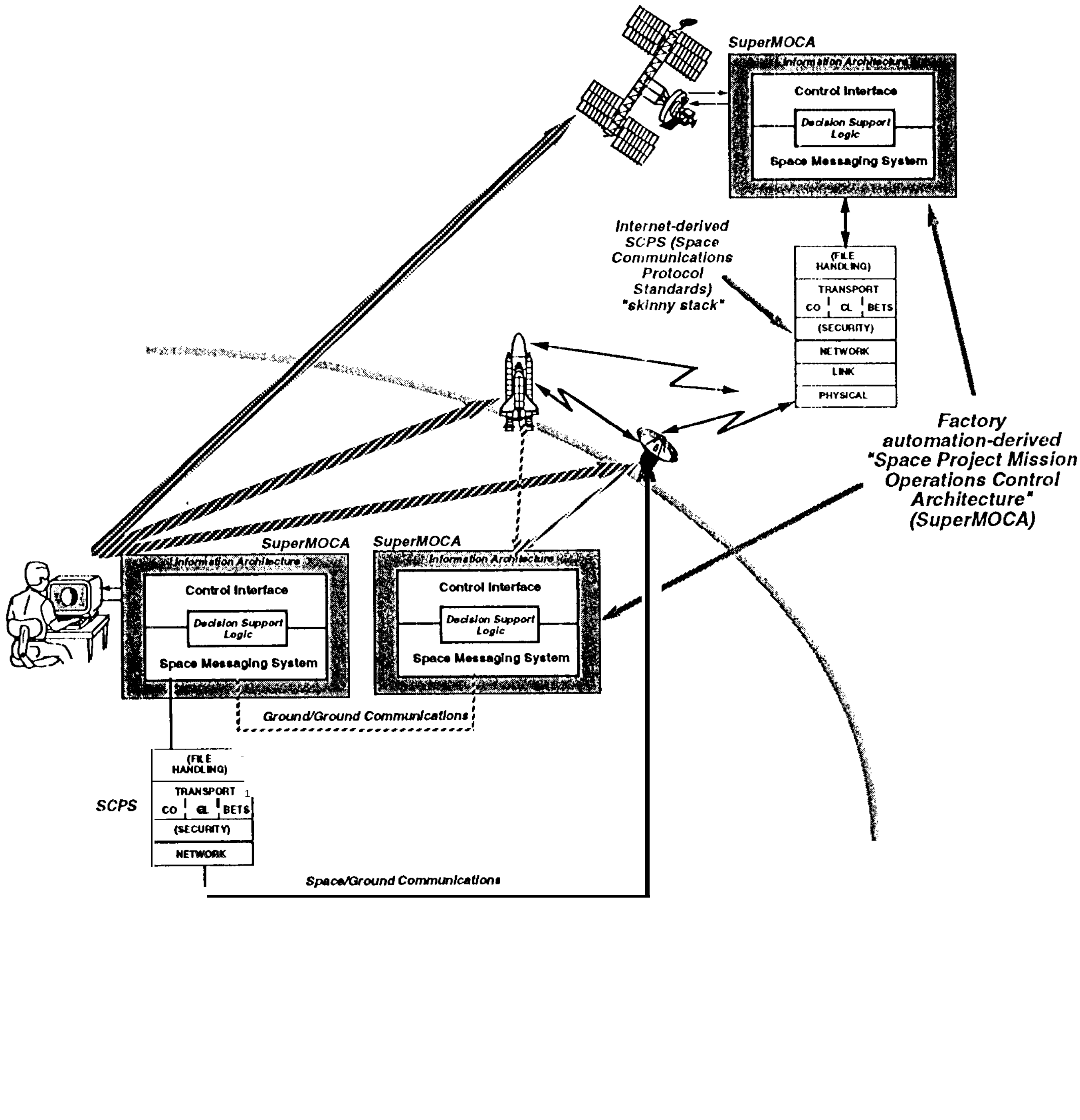

FIGURE 1: SuperMOCA Context

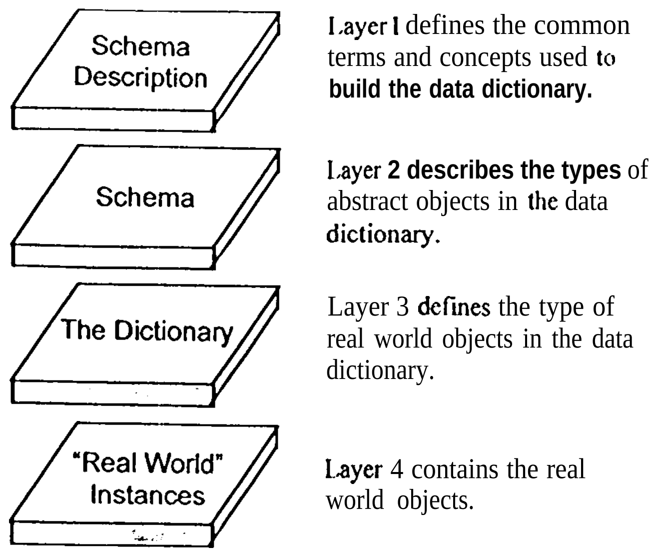

FIGURE 2 IRDS provides a four layer approach to construction of a data dictionary [From: A Technical Overview of the Information Resource Dictionary System, NBSIR 88-3700].

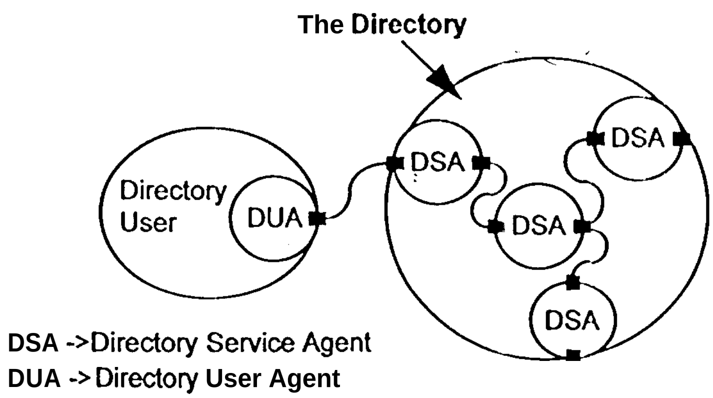

FIGURE 3 Directory Services provides services for User to access and retrieve objects in a distributed directory system.

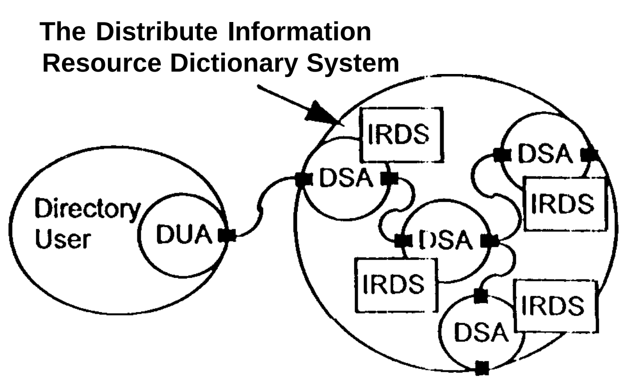

FIGURE 4 Directory Services could be used to link distributed IRDS systems into a distributed data dictionary.