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APPLICATIONS OF CCSDS RECOMMENDATIONS TO INTEGRATED GROUND DATA SYSTEMS (IGDS)

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ABSTRACT

This paper describes an application of the CCSDS Principle Network (CPN) service model to communications network elements of a postulated Integrated Ground Data System (IGDS). Functions are drawn principally from COSMICS, an integrated space control infrastructure (Ref. 1), and the Earth Observing System Data and Information System (EOSDIS) Core System (ECS) (Ref. 2). From functional requirements, this paper derives a set of five communications network partitions which, taken together, support proposed space control infrastructures and data distribution systems. Our functional analysis indicates that the five network partitions derived in this paper should effectively interconnect the users, centers, processors, and other architectural elements of an IGDS. This paper illustrates a useful application of the CCSDS Recommendations to ground data system development.

Key Words: COSMICS, CCSDS, IGDS, EOSDIS, ECS, networks

1. BACKGROUND

In 1990, at the 2nd AIAA/NASA International Symposium on Space Information Systems, some of us proposed a unified information and control infrastructure for the coming space age. (Ref. 3) That paper described a system concept, referred to as the Cosmic Information and Control System (COSMICS), which integrates the necessary off line processing and support functions with the on line elements needed for aerospace craft control. The authors stated that a unified control facility might: (a) Minimize life cycle costs, (b) Provide for technological innovation and support evolutionary changes in social needs, (c) Evolve economically through cooperative and well placed additions of processors, communications, and control facilities, and (d) Make the latest technology available to the widest distribution of users in the most timely fashion.

The tasks required for control of spacecraft operations discussed in the COSMICS paper are similar to, and can be grouped into the same functional categories as, those identified for the Flight Operations Segment (FOS) of NASA's ECS. (Ref. 4) We distributed the combined functionality of COSMICS and the ECS segments across a network architecture comprised of the following architectural elements: 1) A user community which requires data services, 2) A mission operations element to control aerospace craft, 3) An element to accomplish information processing and distribution functions, 4) Governments, with both national and international relationships, and 5) Industry.

Space data systems are being designed to implement standardized and internationally agreed upon techniques of data handling, data classification, and data transmission. (Ref. 5) The Consultative Committee for Space Data Systems (CCSDS) has published recommendations in the following major areas:

1) Architectural specifications for the CCSDS Principle Network (CPN). These define a conceptual model for data handling networks to provide end-to-end data services in support of space missions. The CPN consists of an onboard network which resides on a spacecraft capable of orbit, a

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ground network which communicates with the spacecraft, and a space link subnetwork for connectivity. (Ref. 6)

2) Recommendations dealing with techniques for telecommand and telemetry (Ref. 7,8), and

3) Specifications for standardized data units, as well as for time code formats, radiometric and orbit data, radio frequency and modulation systems, ground networks, and other topics.

Recent work by the CCSDS has centered on developing recommendations to make possible cross-support services. (Ref. 9) As defined, this class of services will enable space agencies to bidirectionally transfer data from other space agencies between ground and space systems. (Ref. 10) It has the potential, through standardized implementations of data units and communications services to make possible apparently seamless network implementations, as seen from user perspectives. Work has concentrated on the services which will be provided at ground interfaces, referred to as Service Access Points (SAPs), where services would appear externally as functions and capabilities would be made available by a providing agency to a requesting agency. (Ref. 11)

2. ARCHITECTURAL ELEMENTS

In our view, the top level architectural elements needed for an IGDS parallel those described for EOSDIS. (Ref. 12) We include a government architectural element to those to implement a global infrastructure. The top level architectural elements, then, are as shown in Figure 1.

1) User Community. This would consist of a broad range of scientific and academic users in widely dispersed facilities. Government users would access the IGDS for general policy, planning, management and operation of the IGDS, and to exert operational direction. Commercial and industrial users would include developers of applications. Individual users and organized user groups would desire access to segments of the IGDS.

2) Mission Operations. Elements which correspond to those in COSMICS and the Flight Operations Segment of EOSDIS would be needed to implement an IGDS.

3) Information Processing and Distribution element. A system similar to the backbone network element in EOSDIS would be needed in an IGDS. We combined components of the EOSDIS Science Data Processing Segment (SDPS) and Communications and System Management Segment (CSMS).

4) Government. Governments can be expected to interface at the space agency level to provide for national goals and to establish the basis for cooperation. (Ref. 13) Organizations such as INMARSAT and INTELSAT might provide suitable models.

5) Industry. A suitable system of interfaces between industry and IGDS system management would be needed to provide for development of a wide range of services. Governments might guarantee delivery of data products to vendors at network interface points, for example.

3. IGDS FUNCTIONALITY

In order to derive communications subnetwork partitions to support a functional IGDS, we partitioned the IGDS functions into independent sets which might be accomplished in cooperation. Our analysis indicates the functional partition at Table 1 to be adequate. Our methodology paralleled Walford's architectural development framework. (Ref. 14)

We imposed the structure described by Witworth (Ref. 15) to govern the relationship between the ground systems, space segments, and data users in typical space missions. We included the major ECS functions in our analysis (Ref. 16). A discussion of each of our functional categories follows.

1) Data User Services. These functions control design and implementation of those aspects of the network which directly interact with the end user. (Ref. 17) These functions ensure that users need not know details about the IGDS to effectively use it. We formed two functional groups from these: (1) Data operations, to process and distribute bulk data, and (2) User support, to provide user interfaces.

2) Mission Operations. We based this set of functions closely on the ECS Flight Operations Segment (FOS). We formed four functional categories: (1) Aerospace craft operations performed by worldwide communications and tracking facilities, (2) Mission planning and scheduling, (3) Person-

nel training, and (4) Engineering support conducted by science investigators and national centers primarily to solve technical problems which occur during missions.

3) IGDS Management and Operations. These functional categories provide for international participation by government and industry. They extend functions assigned to international partners in the ECS.

4) Network Services. We organized these functions according to the principles explained by Walford for communications network overlays. (Ref. 18) This functional grouping reflects an overlay structure wherein the IGDS communications network is to be realized as mutually exclusive subnetworks having characteristics determined by attributes required at appropriate levels of abstraction.

Our analysis of communications network services yields the following functional categories: (1) Network Management, which includes planning, operation, and administration of the communications network, (2) and (3) The Space and Ground Segments of the communications network, (4) Process support, which provides the services and functions needed by communications networks. We included applications development functions, which consist of the tools and techniques for developing and maintaining the applications provided by the IGDS to its users, in process support. It became apparent that, from the users' perspective, data processing applications services could best be supported by the network if treated in much the same fashion as other process support services.

4. NETWORK ORGANIZATION

We partitioned the IGDS into subnetworks using the following procedure:

1) We correlated the architectural elements discussed in Part 2 of this paper with the IGDS network functions discussed in Part 3 above. Our correlation produced an assignment of each function to one or more of the elements. We distinguished between the following four levels of involvement for each assignment: (a) Primary responsibility for accomplishment, (b) Collateral responsibilities, (c) Participatory, and (d) Nonparticipatory.

2) Next, we grouped the functional assignments into subnetwork overlays. We prioritized each overlay with regard to the criticality of the functions it contained. Criteria included timeliness and security.

3) We then grouped the subnetwork overlays into network partitions which could be implemented and controlled independently to make the IGDS fully functional.

Our analysis indicates that communications network partitions to support an IGDS could be implemented as five independent network partitions. These are shown in Table 2 and described below.

1) An Operations high speed, highly critical top priority network, which connects the Aerospace Operations and the Information Processing and Distribution architectural elements. This network supports the core operations mission functions. Connectivity is extended to elements of the User Community element on a case-by-case basis to enable payload command functions.

2) A less critical Engineering Support network which connects the same architectural elements as the Operations network. It is an entirely offline support environment.

3) A Data Processing network partition, confined to the Information Processing and Distribution architectural element, supports the high volume bulk data services which are at the heart of the IGDS. It connects the largest, most powerful data processors and archive facilities worldwide in support of the other IGDS functions.

4 and 5) We divided the remaining IGDS functions between two separate network partitions. Each are broadly connected to all of the IGDS architectural elements. The Communications Support network is the more critical of the two and provides the communications services. The other, the User Support and Administration network partition, provides those functions which manage the IGDS and determine the interface between the IGDS and its user community.

Our analysis indicates that an IGDS might be developed as independent but complementary implementations of the above five network partitions. As mentioned in the first section of this paper, the CCSDS recommendations describe a wide variety of communications protocol standards which are being developed or adopted for use on space missions during the coming decades. The architecture features extensive onboard and ground computer networking within the worldwide OSI framework integrating digital transmission of video, audio, telemetry, and computer data. (Ref. 19) The CCSDS architecture supports end-to-end data communication across networks connected to the CPN via gateways using cross-support services. (Ref. 20) In the next section we review the status of efforts to develop cross-support data services.

5. DATA SERVICES

CCSDS Panel 3: System & Cross-Support has been working to develop the services needed to transfer data across networks from different agencies participating in the CPN. It has concentrated on the services which will be exchanged at the ground interface, referred to as Service Access Points (SAPs), between the networks for space operations. (Ref. 21)

The Panel defines a service as "the external appearance of functions and capabilities made available by a providing agency to a requesting agency". It developed the following four classes of 24 major services: (1) Conventional Telemetry and Telecommand, which consists of data services for these functions; (2) Advanced Orbiting Systems (AOS), which extends the packetized AOS services previously defined on the CPN across the SAPs thereby making them accessible to agencies; (3) Nontelematic Spacecraft Monitor and Control facilities; and (4) New Services, which include facilities for reliable transport, file transfer, message service, and other services specialized to established space link services.

The scheme described by one of the Panel 3 members, A. Hooke, appears to efficiently map space link services into IGDS services in a way which can provide projects with a consistent view of services while controlling user access to the most critical of those services. Online mission control and data acquisition would, under this scheme, be provided by two independent service domains: 1) A Space Operations Data Services (SODS) segment, and 2) A Flight Operations Services (FOS) segment. SODS would provide the virtual and physical channel communications services between ground elements and aerospace craft which require little or no mission-unique setup. FOS would provide customized services for particular projects. FOS would provide operations support and end system services, such as flight dynamics, flight monitor and control, and flight planning. A third independent service domain, the Space Applications Service Infrastructure (SPSI), would provide user data analysis and distribution services to the IGDS User Community. This structure is shown in Figure 2, which is adapted from the Panel 3 report.

6. CONCLUSION

From a functional analysis of proposed aerospace control and information systems, this paper concludes that an IGDS might be effectively supported by five independent communications networks interfaced to CCSDS cross-support service domains. Each network partition would be tailored to one of the following functional areas: (a) Operations, (b) Data Processing, (c) Engineering Support, (d) Communications Support, and (e) User Support. It proposes that the interfaces between these network partitions and aerospace craft conform to CCSDS cross-support recommendations in order to provide an integrated information and control infrastructure.

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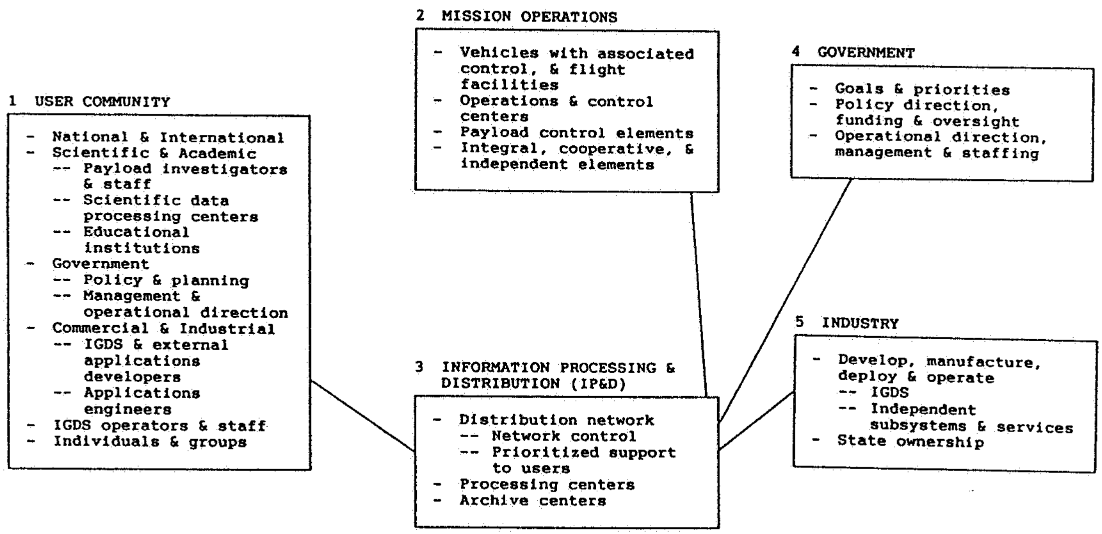

Figure 1. Architectural elements comprising an IGDS.

SERVICE	FUNCTIONS
Data User Services	1.1 Data Operations 1.1.1 Processing 1.1.2 Archive: Receive, store, and retrieve 1.1.3 Distribution 1.1.4 Auditing 1.1.5 Management: Planning, operations, & administration 1.2 User Support 1.2.1 Information and catalogs 1.2.2 Data and processing 1.2.3 Algorithm development, integration, test, and distribution
Mission Operations	2.1 Aerospace Craft Operations 2.1.1 Mission Control 2.1.2 Mission Operations 2.1.3 Payload commanding 2.1.4 Vehicle Commanding 2.2 Mission Planning 2.3 Personnel Training 2.4 Engineering Support 2.4.1 Engineering Analysis 2.4.2 Payload Health & Safety 2.4.3 Vehicle Health & Safety
IGDS Management & Operations	3.1 Government 3.2 Industry
Network Services	4.1 Network Management 4.1.1 User interactions 4.1.2 Maintenance 4.1.3 Network control 4.1.3.1 System performance, fault, and security management 4.1.3.2 Configuration control 4.1.3.3 Production schedule assignment 4.1.3.4 Conflict resolution 4.1.4 Accounting & billing 4.2 Space Segment 4.3 Ground Segment 4.4 Process Support: Services and functions on the network. 4.4.1 Data Processors 4.4.2 System Software 4.4.3 Communications Processors 4.4.3.1 Among Distributed Active Archive Centers (DAACs) 4.4.3.2 Interface with external networks 4.4.3.3 Network communications and processing 4.4.4 Applications Development

Table 1. Functions performed by Integrated Ground Data System (IGDS).

NETWORK PARTITION AND PRIORITY	FUNCTIONS	ARCHITECTURAL ELEMENTS
OPERATIONS PRIORITY 1	2.1.1 CONTROL 2.1.2 OPERATIONS 2.1.3 PAYLOAD COMMANDS 2.1.4 VEHICLE COMMANDS 4.1.3 NETWORK CONTROL 4.1.3.1 PERFORMANCE 4.1.3.2 CONFIGURATION 4.1.3.3 PRODUCTION SCHEDULE 4.1.3.4 CONFLICT RESOLUTION 4.2 SPACE SEGMENT	1 USER COMMUNITY 2 AEROSPACE OPERATIONS 5 INFORMATION PROCESSING & DISTRIBUTION (IP&D)
DATA PROCESSING PRIORITY 2	1.1.1 PROCESS 1.1.2 ARCHIVE 1.1.3 DISTRIBUTE 1.1.4 AUDIT 1.1.5 MANAGE	5 IP&D
ENGINEERING SUPPORT PRIORITY 2	2.4.1 ENGINEERING ANALYSIS 2.4.2 PAYLOAD HEALTH & SAFETY 2.4.3 VEHICLE HEALTH & SAFETY	1 USER COMMUNITY 2 AEROSPACE OPERATIONS 5 IP&D
COMMUNICATIONS SUPPORT PRIORITY 3	4.3 GROUND SEGMENT 4.1.2 MAINTENANCE 4.1.4 ACCOUNTING & BILLING 4.4.1 DATA PROCESSORS 4.4.2 SYSTEM SOFTWARE 4.4.3 COMMUNICATIONS PROCESSORS 4.4.3.1 ARCHIVE CENTERS 4.4.3.2 EXTERNAL NETWORK 4.4.3.3 INTERNAL NETWORK	1 USER COMMUNITY 2 AEROSPACE OPERATIONS 3 GOVERNMENT 4 INDUSTRY 5 IP&D
USER SUPPORT & ADMINISTRATION PRIORITY 4	1.2.1 INFORMATION & CATALOGS 1.2.2 DATA & PROCESSING 1.2.3 ALGORITHM DEVELOPMENT 3.1 GOVERNMENT 3.2 INDUSTRY 4.1.1 USER INTERACTIONS 2.2 PLANNING & SCHEDULING 2.3 PERSONNEL TRAINING 4.4.4 APPLICATIONS DEVELOPMENT	1 USER COMMUNITY 2 AEROSPACE OPERATIONS 3 GOVERNMENT 4 INDUSTRY 5 IP&D

Table 2. Five network partitions support the functions needed to implement the proposed Integrated Ground Data System (IGDS). Each network has the priority indicated in the first column. The remaining two columns list the functions, keyed to Table 1, performed by each network partition and the architectural elements, keyed to Figure 1, served by each partition.

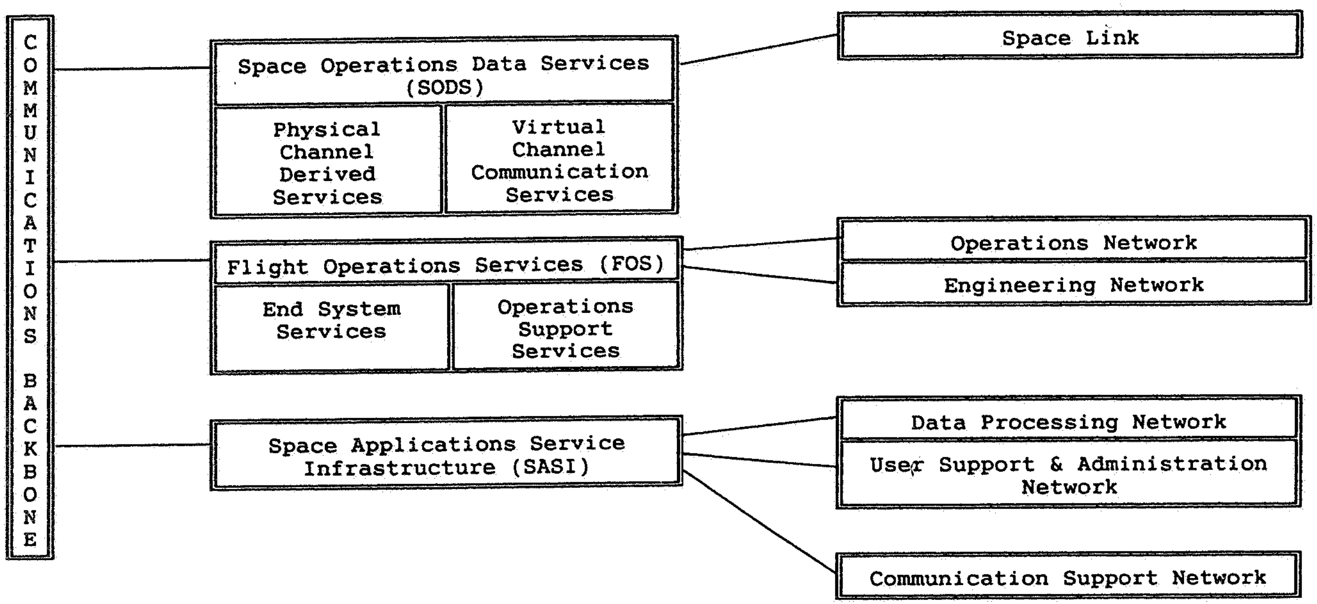

Figure 2. IGDS Infrastructure