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## Performance Analysis of CCSDS Path Service

*Marjory J. Johnson*

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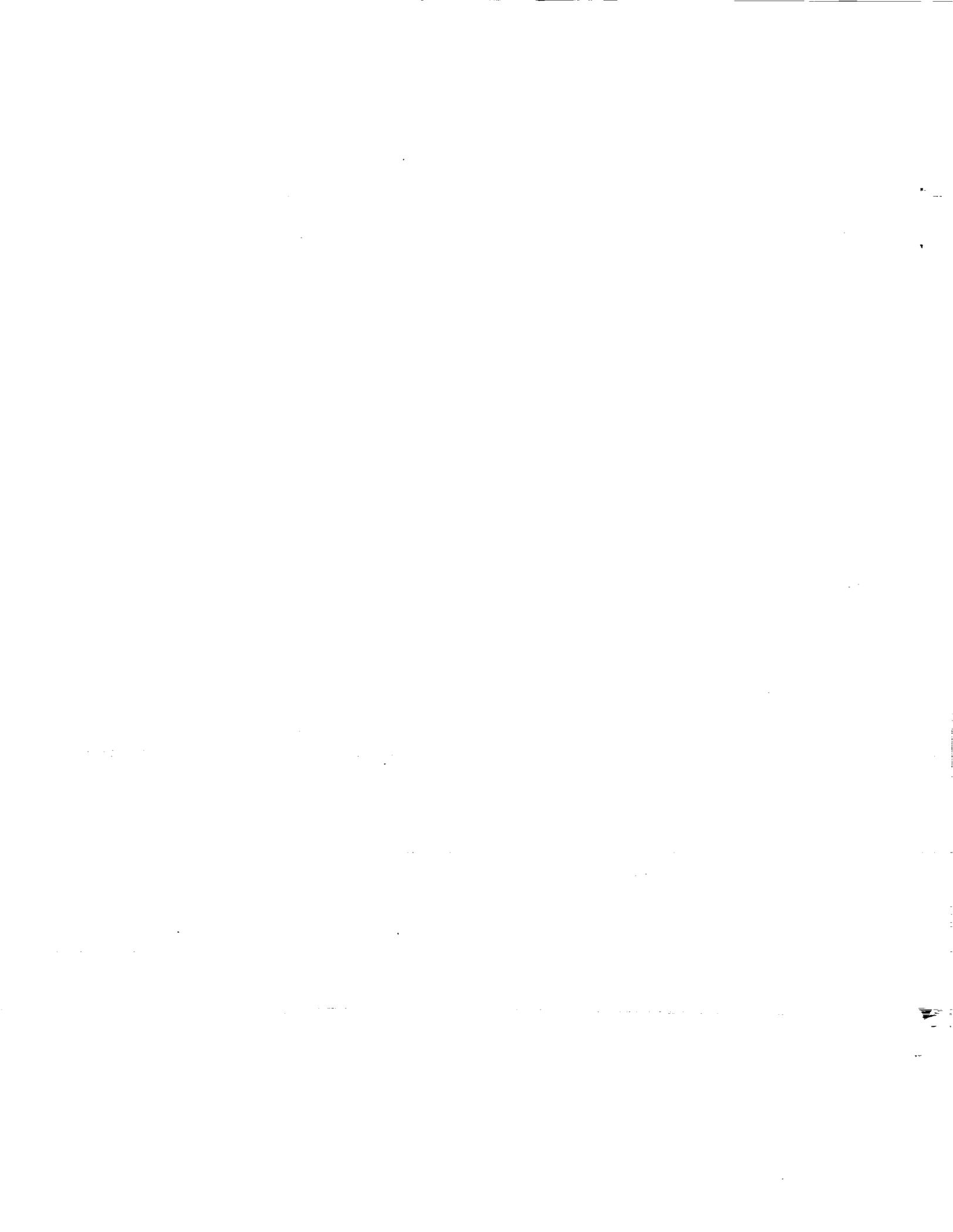
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A communications service, called Path Service, is currently being developed by the Consultative Committee for Space Data Systems (CCSDS) to provide a mechanism for the efficient transmission of telemetry data from space to ground for complex space missions of the future. This is an important service, due to the large volumes of telemetry data that will be generated during these missions. This paper presents a preliminary analysis of performance of Path Service, with respect to protocol-processing requirements and channel utilization.

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# Performance Analysis of CCSDS Path Service

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**Abstract.** A communications service, called Path Service, is currently being developed by the Consultative Committee for Space Data Systems (CCSDS) to provide a mechanism for the efficient transmission of telemetry data from space to ground for complex space missions of the future. This is an important service, due to the large volumes of telemetry data that will be generated during these missions. This paper presents a preliminary analysis of performance of Path Service, with respect to protocol-processing requirements and channel utilization.

## 1. Introduction

The Consultative Committee for Space Data Systems (CCSDS) is an international organization that develops recommendations for data-system standards to support space missions. Member agencies include the National Aeronautics and Space Administration (NASA)/USA, the European Space Agency (ESA)/Europe, and space agencies in the United Kingdom, Canada, France, West Germany, India, Brazil, and Japan. Although CCSDS recommendations are not considered binding on any of the member agencies, adherence to the recommendations will provide compatibility of data-handling systems among cooperating agencies. This will facilitate collaborative ventures such as Space Station Freedom.

Existing CCSDS recommendations apply to conventional space systems which serve a moderate number of users, at relatively low data rates. New CCSDS recommendations are being developed for advanced orbiting systems that are envisioned for the 1990's [3] (for example, manned and man-tended space stations, unmanned space platforms, and space transportation systems), to handle the high data rates (as high as 300 megabits/second for synthetic-aperture-radar data and 450 megabits/second for data from the High Resolution Imaging Spectrometer) and large numbers of users which will be typical of these systems. Two major types of traffic that will contend for communications resources in advanced orbiting systems are telemetry data and interactive traffic. Telemetry data will be transmitted using a light-weight communications service, called CCSDS Path Service. Interactive traffic will be transmitted using CCSDS Internet Service, which is based on the International Standards Organization (ISO) 8473 internet protocol [4].

The purpose of this paper is to analyze performance of CCSDS Path Service, with respect to protocol-processing requirements and channel utilization. The analysis is preliminary, because it is premature to quantify processing aspects of the service until further development occurs. In Sections 2 and 3 we give an overview of the types of applications that will be associated with advanced orbiting systems and the services, especially

Path Service, that are being developed by CCSDS to support them. In Section 4 we examine performance issues involved in each component of the Path Service process, from the instrument interface to processing at the ground terminus. In Section 5 we compare and contrast Path Service and Internet Service, with respect to functionality, performance bottlenecks, and appropriateness to support applications that are typified by the telemetry application.

## **2. Advanced Orbiting Systems Protocols and Applications**

In this section we present an overview of Path Service and Internet Service, the two packet-transmission services that the CCSDS has defined for advanced orbiting systems. There are substantial differences between the types of applications that the two services are expected to support.

### **2.1. Path Service**

Path Service is a special-purpose service developed by the CCSDS to provide an efficient, cost-effective means of transmitting large volumes of measurement data from earth-observing satellites to the end user on the ground. This type of data is called telemetry data. Data rates of current scientific instruments vary from less than 1 megabit per second to approximately 500 megabits per second. Instruments will be turned on for long periods of time, possibly several hours or even months, producing a steady stream of data packets that must be handled by the communications system, including both the onboard subnet and the space-to-ground subnet. Some data compression may be performed for the higher-rate instruments, but the volume of traffic to be transmitted to ground will still be enormous. Based on the rate at which the volume of data from earth-observing satellites has been increasing in recent years, NASA has projected that by 1995 the volume of telemetry data will be on the order of 3 gigabits per second [6]. Hence, efficient handling of telemetry data is essential. In fact, determining how to cope effectively with enormous amounts of scientific data is one of the most pressing problems faced by the agency today.

Besides the sheer volume of data involved, handling of telemetry data is further complicated by the fact that individual unmanned platforms (on which observational instruments are normally located) are typically scheduled for only a 10- to 20-minute space-to-ground communications window per 90-minute orbit. Accordingly, most of the data from the observational payloads must be stored onboard, by recording it on tape, for transmission during the next communications window. To protect against loss of data, some of the data generated during the spacecraft's period of contact is stored as well, causing an overlap between stored data and real-time data (i.e., data that has not been stored). Since rewinding the tapes before the data is played back for transmission would increase wear on the tapes, it is likely that recorded data will be transmitted to ground in reverse order. Because of these artifacts introduced by the space-networking environment, preliminary ground processing, called Level Zero Processing (LZP), is needed to restructure the data before it is delivered to the end user.

## **2.2. Internet Service**

The CCSDS recommendation for advanced orbiting systems [3] also provides a service, called Internet Service, to support more conventional interactive networking applications. This will be a new mode of operation for space-mission users, since onboard interactive local-area networking has not been provided in the past. Examples of applications that are expected to use Internet Service include interactive scientific experiments and interactive command and control of the spacecraft and resources located on it. CCSDS has selected the International Organization for Standardization (ISO) 8473 internet protocol [4] as the basis for Internet Service, in order to provide adequate flexibility to support applications of this type and to facilitate interoperability between networks provided by different organizations.

## **3. Path Service Overview**

### **3.1. Performance Objectives of Path Service**

Traditional performance measures of communications protocols are end-to-end delay and end-to-end throughput. Such end-to-end measures are somewhat inappropriate for Path Service, because of the delay incurred when data is recorded onboard.

Resource limitations are a major concern for space networking. Stringent constraints on power, weight, and volume limit onboard resources significantly. In addition, space-to-ground bandwidth is a scarce resource, because the channel must be shared not only by multiple spacecraft, but also by multiple space missions. Efficient use of both onboard resources and the space-to-ground channel is essential. Accordingly, the primary performance objectives of Path Service are to minimize onboard protocol processing and to optimize use of the space-to-ground channel. Optimization of the handling of telemetry data, which is expected to account for 85 to 90% of all space-mission data, will have a significant impact on overall system requirements.

### **3.2. Functionality of Path Service**

Path Service is designed to exploit the characteristics of the telemetry application. The nature of observational payloads and telemetry data are well understood. Once a payload has been configured, the communications requirements, including source-destination pairings, data rate, and data format, are static for long periods of time. Hence, it is possible to establish a communications infrastructure that will provide precisely the resources that are required for support of a particular instrument.

Path Service is based on the establishment of such an infrastructure. Network management preconfigures Logical Data Paths for telemetry data, completely specifying source-to-destination routing. At the same time attributes, such as data rate and data format, are associated with these Logical Data Paths. After configuration is completed, data can be routed across onboard subnets and the space-to-ground subnet by specifying only the Logical Data Path to be followed, rather than full source and destination addresses. No handshaking between the sender and the receiver during data transmission is necessary, because the preconfiguration process (along with careful scheduling of the various activities that will be sharing the communications resources) guarantees that each Path Service entity along the Logical Data Path can provide the services required of it before turning on the instrument. In this way Path Service creates a trunk for efficient

transmission of large volumes of data from space to ground.\*

### 3.3. Architecture of Path Service

CCSDS Path Service does not map directly into the structure of the Open Systems Interconnection (OSI) network model, since users of Path Service don't require all the functionality provided by the OSI protocol stack. CCSDS Path Service serves primarily as a routing service, so the Path Service layer serves as a network layer. However, no transport, session, or presentation services are required, so the Path Service layer interfaces directly to the application above. The Path Service layer interfaces to the logical-link-control layer below.

## 4. Performance Issues

The transmission of telemetry data from the space-based instrument to the ground-based end user consists of the following sequence of events. Scientific instruments located on-board a spacecraft (probably unmanned) generate sensor data at a given rate. The instrument interface is a simple processor that formats instrument data into CCSDS Packets, the basic unit of transmission for Path Service data. CCSDS Packets are transmitted over an onboard subnet to a location where they are formatted for transmission over the space-to-ground link. At this point data will probably be recorded for later transmission, since an unmanned space vehicle is likely to have limited contact with the ground. This recorded data will be transmitted to ground during the next communications window associated with that spacecraft. Once it reaches the ground, the telemetry data will be forwarded to a finite number of locations, where network-induced artifacts will be removed by Level Zero Processing. From there the reconstructed data will be forwarded to the end user via either public or private ground networks.

Based on this description, an analysis of the performance of CCSDS Path Service must address delay within the instrument interface, transmission over the onboard subnet, formatting for transmission to ground, transmission over the space-to-ground link, and Level Zero Processing on the ground. Another important element of Path Service is the role of network management in preconfiguring the communications infrastructure for telemetry transmission and in scheduling the use of limited onboard resources. We examine each of these components of the Path Service end-to-end process.

### 4.1. Onboard Processing

Components of onboard processing include the delay within the instrument interface and transmission over the onboard subnet.

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\*Path Service will be used to support other applications typified by the telemetry application, i.e., applications which have static communications requirements for long periods of time. These will likely include some space-to-space and ground-to-space applications. Since telemetry data accounts for the largest volume of Path Service data, by far, it is the only application we address in this paper.

#### 4.1.1. CCSDS Packet Format

The basic unit of transmission for Path Service is the CCSDS Packet, which has a header that is only 6 octets long. Figure 1 illustrates the structure of the CCSDS Packet; Table 1 explains the meaning of each of the fields of the primary header.

It is reasonable to assume that all the fields of the primary header, except the Packet Sequence Control Field, will be fixed for a particular instrument. Use of such a simple packet structure minimizes the amount of protocol processing required both at the instrument interface and at Path Service entities along the Logical Data Path which need to parse the header to determine how to forward the packet, e.g., at gateways between subnets.

#### 4.1.2. Instrument Interface

The instrument interface formats data into CCSDS Packets. Because most of the fields have a constant value for a given instrument, the packetization process is trivial. NASA engineers who are designing this instrument interface estimate that less than twenty medium-scale integrated circuits will be required. This design can be implemented on one integrated circuit board, using off-the-shelf technology. Implementing this instrument interface on a single chip, using VLSI technology, is a future possibility.

The quantities that are important for onboard equipment are power, weight, and volume. The instrument interface described above, whether implemented as a single board or as a VLSI chip, has minimal requirements with respect to these three measures.

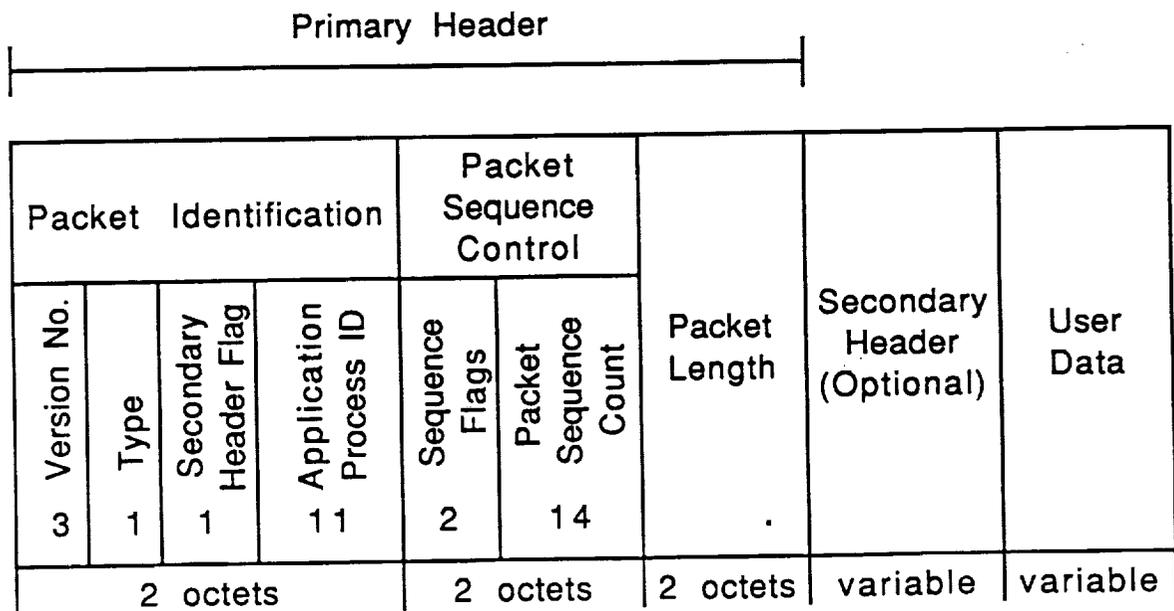


FIGURE 1. CCSDS PACKET STRUCTURE

TABLE 1. FIELDS OF CCSDS PRIMARY PACKET HEADER

Field	Length	Contents
<b>Packet Identification Field:</b>		
Version Number	3 bits	Version of CCSDS Packet.
Type	1 bit	Currently not used.
Secondary Header Flag*	1 bit	Indicates presence or absence of secondary header.
Application Process ID	11 bits	Identifies Logical Data Path.
<b>Packet Sequence Control Field:</b>		
Sequence Flags	2 bits	Indicates whether packet is a first, last, or intermediate component of larger user data structure.
Packet Sequence Count	14 bits	Sequential count of packets associated with this Logical Data Path.
Packet Length	2 octets	Length of packet.

#### 4.1.3. Onboard LAN Transmission

After the packet is constructed, it will be transmitted over an onboard subnet, which may be either a local area network (LAN) or a point-to-point direct connection. For Space Station Freedom low-rate instruments will be connected to a LAN, while high-rate instruments will be directly connected to an onboard location where data is formatted for transmission over the space-to-ground link. Placing the low-rate instruments on a LAN enables them to share the same Virtual Channel (discussed in Section 4.2.1) on the space-to-ground link.

We do not quantify channel efficiency on the onboard subnet in this paper, because it is dependent both on the type of subnet involved (i.e., whether the subnet is a local area network or a point-to-point connection) and on the selection of other network-layer protocols that might be used in conjunction with Path Service.

Processing at the onboard receiver, i.e., the location where data is formatted for transmission over the space-to-ground subnet, is minimal. Data arrives at a predetermined rate and in a predetermined format, based on the particular Logical Data Path, and the formatting procedure is a simple one (as indicated in Section 4.2). Since there are no connections in the sense of the OSI network model, there is no end-to-end handshaking. In particular, no mechanisms are provided for flow control or acknowledging receipt of data.

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\*Use of the Secondary Header is currently under consideration by the CCSDS. It will likely be used to specify ancillary data to help identify the user data.

## 4.2. Space-to-Ground Transmission

The space-to-ground subnet, the communications channel between space and ground, provides services that correspond to the data-link and physical layers of the OSI network model. Special protocols have been defined for its use, because of the uniqueness of the space-networking environment.

### 4.2.1. Channel Structure and Bandwidth Limitations

Space-to-ground bandwidth is an extremely scarce resource, since it is so expensive to provide the channel. The protocol that the CCSDS has developed for the Space Link Subnet is patterned after time-division multiplexing, which is generally considered to provide the highest channel utilization in a heavily loaded network. Fixed-length data blocks from different Virtual Channels are interleaved on a single physical space channel; consecutive data blocks are separated by synchronization markers. There is a single data-block length for all Virtual Channels that share the same physical space channel. Fill data is transmitted if necessary, so that data is transmitted over the physical space channel as a synchronous symbol stream, with synchronization markers appearing at constant intervals. This transmission pattern facilitates simple, robust synchronization processes at the ground terminus.

NASA currently has three Tracking and Data Relay Satellite System (TDRSS) satellites in orbit, which constitute the space-to-ground subnet. Each provides two channels which can transmit approximately 300 megabits per second from space to ground. Because TDRSS will be shared by all U.S. space missions, not only the various spacecraft within the Space Station Freedom constellation, efficient use of this scarce resource is absolutely essential.

### 4.2.2. Format of Coded Virtual Channel Data Units

The basic data structure for transmission of telemetry data over the Space Link Subnet is the Coded Virtual Channel Data Unit (CVCDU), i.e., a Virtual Channel Data Unit (VCDU) with Reed-Solomon Check Symbols appended to provide forward error detection and correction. CVCDUs must have the same, constant length for a given physical space channel. Faster channels will be able to support longer CVCDUs. CCSDS Packets are multiplexed together to form a Multiplexing Protocol Data Unit (M-PDU), which then becomes the user data field of the CVCDU. The CCSDS Packet is the only packet type that is recognized by this multiplexing function; CCSDS recommends that a packet of any other type, including an Internet Packet, be encapsulated within a CCSDS Packet before transmission over the space-to-ground link.

Many of the attributes of Virtual Channels are static, such as the length of the CVCDU, data-handling requirements at the ground terminus, maximum data rate, etc. The static nature of these attributes means that network management can preconfigure the structure of the various Virtual Channels, thus reducing the amount of information that needs to be specified in the CVCDU header. This results in a simple structure for the CVCDU. There are several possible formats for a CVCDU, depending on the type of data contained in the user-data field. Figure 2 illustrates a CVCDU format which is reasonable to use for the transmission of telemetry data. The meaning of each of the fields presented in Figure 2 is given in Table 2. Note that the CVCDU header, including the M-PDU header, is only 8 octets long. Because of its simple format, minimal processing

is required to construct the CVCDU.

### 4.2.3. Channel Efficiency for Space-to-Ground Link

We compute channel efficiency, i.e., the ratio of the number of octets of user data to the total number of octets transmitted, for a Virtual Channel that transmits only telemetry data. We use the CVCDU configuration given in Figure 2 and Table 2, and we assume that all CVCDUs contain useful measurement data, i.e., there is no fill data. Since the length of the user data field of the CVCDU illustrated in Figure 2 is the largest possible value supported by the CCSDS recommendation, this configuration gives maximum channel efficiency.

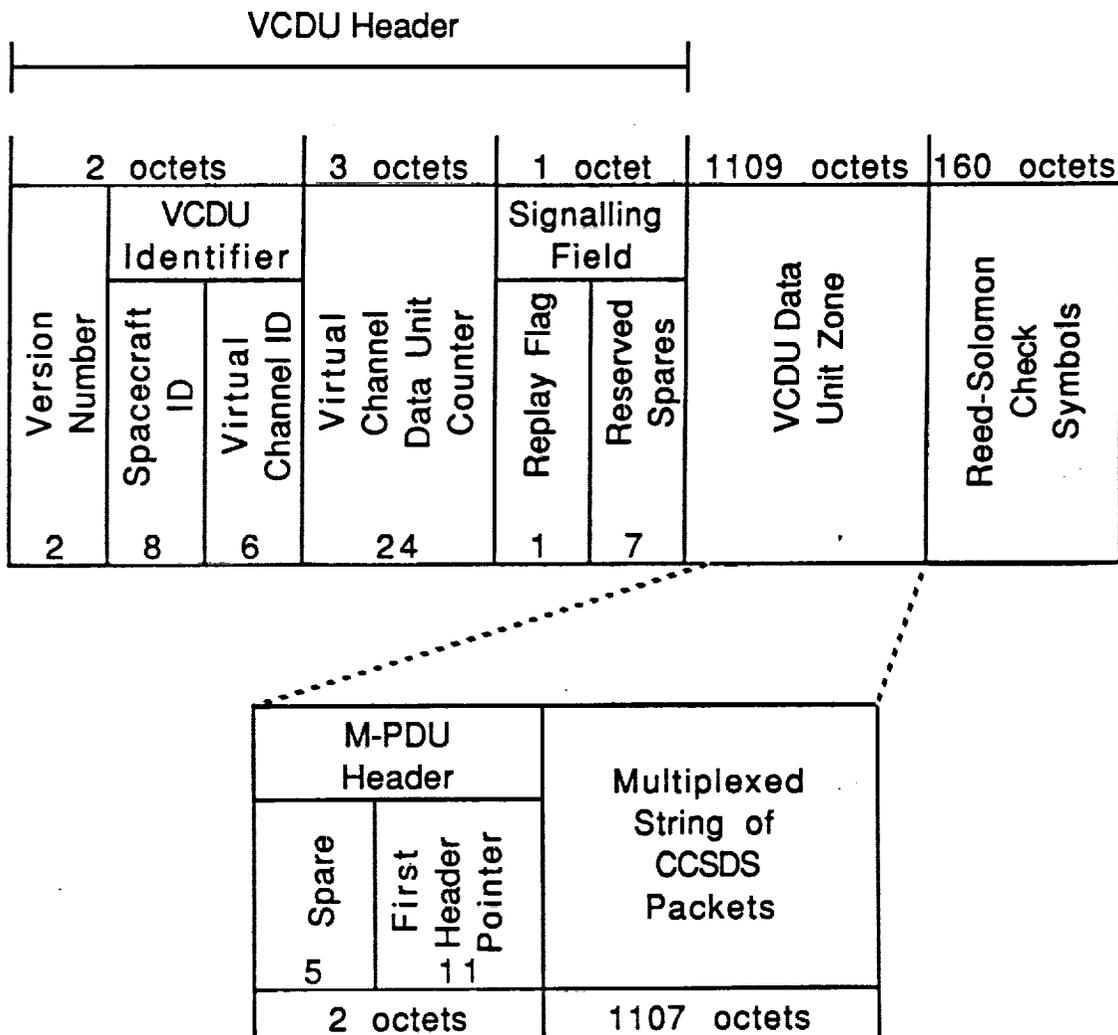


FIGURE 2. CODED VIRTUAL CHANNEL DATA UNIT STRUCTURE

TABLE 2. FIELDS OF CODED VIRTUAL CHANNEL DATA UNIT

Field	Length	Contents
Version Number	2 bits	Version of the Virtual Channel Data Unit structure.
VCDU Identifier (VCDU-ID): Spacecraft Identifier	8 bits	Uniquely identifies flight vehicle.
Virtual Channel ID	6 bits	Uniquely identifies Virtual Channel.
Virtual Channel Data Unit Counter	3 octets	Provides running count of VCDUs which have been transmitted on this Virtual Channel.
Signalling Field: Replay Flag	1 octet 1 bit	Indicates whether or not data has been recorded.
Reserved Spares	7 bits	Reserved for future signalling applications.
Data Unit Zone: M-PDU Header: Spare First Header Pointer	1109 octets 2 octets 5 bits 11 bits	Currently undefined. Points to first CCSDS Packet header.
User Data Reed-Solomon Check Symbols	1107 octets 160 octets	Provide error detection/correction for the entire VCDU.

Part of the overhead associated with the CVCDU structure is fixed and part is variable. CVCDUs are separated by synchronization markers that are 4 octets long. A CVCDU together with its preceding synchronization marker is called a Channel Access Data Unit (CADU). Thus, the total length of a CADU for our configuration is 1279 octets. The fixed overhead is 172 octets per CADU, including the synchronization marker, the VCDU header, the M-PDU header, and the Reed-Solomon Check Symbols. Hence, fixed overhead is  $172/1279 = 13.4\%$ .

The user data field of a CVCDU consists of a multiplexed string of CCSDS Packets. Headers of these packets constitute variable overhead, because the number of packets contained in the user data field is variable. The size of a packet containing telemetry data varies from approximately 500 octets to 2000 octets, depending on the type of instrument. The average size is approximately 1000 octets. Engineering packets which

contain information for diagnosing the instruments will be shorter, approximately 100 octets in length.

By combining fixed overhead with variable overhead, channel efficiency can be computed over a range of packets per CVCDU. The resulting figures are more meaningful if channel efficiency is also computed when the CCSDS Packet structure in the CVCDU is replaced by a general-purpose packet structure. To obtain such a comparison, suppose that the packetizing structure for the VCDU data unit zone were the Internet Service Packet rather than the Path Service Packet, i.e., suppose that the VCDU data unit zone were a multiplexed string of ISO 8473 packets rather than CCSDS Packets. Because the ISO 8473 packet header is considerably larger than the CCSDS Packet header, this would substantially increase the variable part of the overhead associated with the CVCDU structure.\*

Figure 3 compares channel efficiency using CCSDS Packets for the VCDU data unit zone to channel efficiency using ISO 8473 packets instead, over a range of 1 to 8 packets per CVCDU. This is a reasonable range, based on the above packet sizes for telemetry data. Since the CCSDS Packet header is so short, efficiency decreases only slightly as packet size decreases. In contrast, if ISO 8473 Packets are used instead of CCSDS Packets, packet-header overhead rapidly becomes significant as the number of packets per CVCDU increases. This figure illustrates the relative efficiency of using CCSDS Packets. The advantage of using CCSDS Packets becomes more significant as the number of packets per CVCDU increases. For example, if there are 8 packets per CVCDU, channel efficiency when using CCSDS Packets is approximately 42% higher than when using ISO 8473 Packets. This is an impressive figure, especially since the space-to-ground channel is such a precious resource.

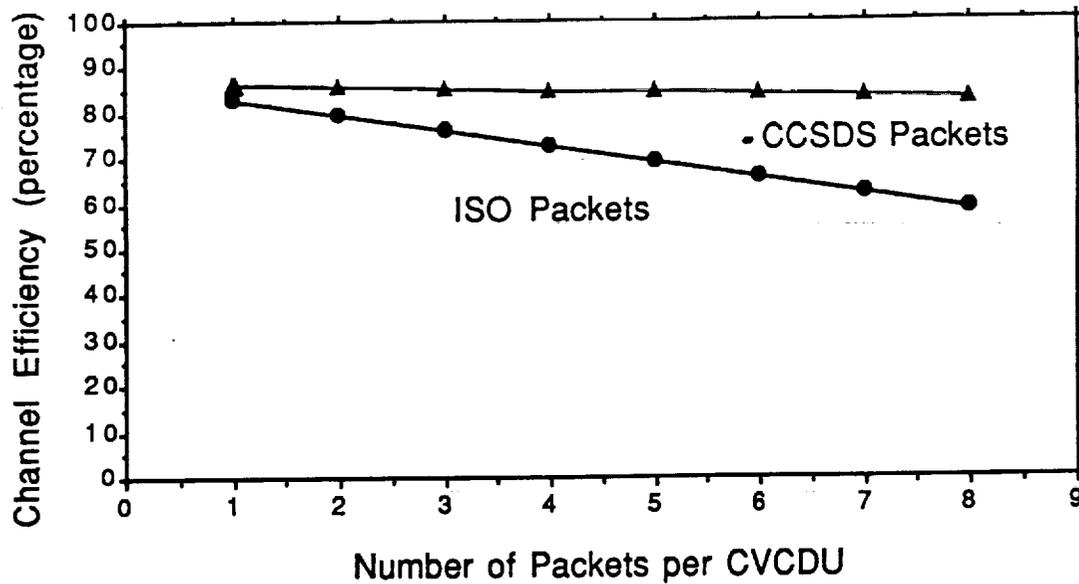
#### 4.3. Ground Processing of Path Service Data

Path Service data must be processed when it reaches the ground to remove the artifacts introduced by onboard recording. The nature of this processing, called Level Zero Processing, will differ from agency to agency. When Level Zero Processing is centralized, as NASA plans to do it, data can be completely reconstructed before it is forwarded to the end user. This includes reversing the data, removing overlaps between stored data and real-time data, and resequencing the packets. If Level Zero Processing is distributed, some of these functions may be performed by the end user.

Level Zero Processing enables system complexity to be shifted from space to ground. This is highly desirable, because resource constraints are less stringent on the ground than in space. Also, it is more cost-effective and more reliable to provide processing power on the ground than in space.

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\*The length of the ISO 8473 header is variable. For our computation we assumed a header length of 45 octets. If upper layer protocols (e.g., a transport-layer protocol) are used in conjunction with ISO 8473, the length of the header would have to be appropriately increased.



*FIGURE 3. COMPARISON OF SPACE-TO-GROUND CHANNEL EFFICIENCY, USING CCSDS PACKETS VS. USING ISO PACKETS*

#### 4.4. Role of Management

The reason Path Service is able to provide such efficient communications services to handle telemetry data is that a supportive communications infrastructure is preconfigured by network management prior to transmission of any data. This infrastructure includes Logical Data Paths and Virtual Channels, along with specifications of pertinent attributes, such as maximum data rate and length of time an instrument will be turned on. The amount of overhead involved in this configuration process cannot be quantified at this time, because development of the management portion of the CCSDS recommendation has just begun.

After management has configured the communications infrastructure to support each of the instrument payloads, a schedule can be developed that specifies when various instruments should be turned on. Such a schedule will ensure the availability of adequate resources to handle the communications load.

#### 5. Path Service Versus Internet Service

Path Service is a special-purpose, high-performance service that was developed to support high-rate, high-volume applications, such as telemetry, which have static communications requirements over long periods of time. Internet Service supports interactive applications which have more traditional networking requirements. In this section we contrast the functionality of the two services, identify performance bottlenecks of each, and argue that general-purpose OSI protocols are inappropriate for Path Service applications.

## 5.1. Functionality

Internet Service will interface above to the transport layer of the OSI network model. The combination of ISO 8473 and a transport-layer protocol, such as ISO TP-4 [5], provides rich functionality to ensure reliable end-to-end data transmission for general-purpose applications. Specific functions provided by these layers include routing, connection management, dynamic flow control, computation of checksums, handling of acknowledgements and retransmissions, resequencing of data at the receiver, and segmentation and reassembly.

As indicated in earlier sections, Path Service provides few of these functions. Since communications requirements of Path Service applications are static over long periods of time, network management can preconfigure a communications infrastructure to support the application. Routing and static flow control are provided through this infrastructure. Dynamic flow control is not necessary.\* Resequencing of data is done by Level Zero Processing after data reaches the ground. Path Service is a connectionless service; it does not guarantee end-to-end reliability, i.e., reliability from the space-borne instrument to the end user on the ground. Use of an acknowledgement and retransmission scheme for telemetry data over the lossy space-to-ground subnet is not anticipated, because of the associated cost. Hence, providing end-to-end reliability for Path Service over the onboard subnet would be wasteful of scarce resources.

## 5.2. Performance Bottlenecks

The primary bottleneck in general-purpose networks is processing at the network and transport layers of the OSI network model. For example, prototype network interface units (NIUs) that implement the ISO 8473 and ISO TP-4 protocols have been developed under NASA sponsorship for the Space Station Freedom Program. Throughput that was measured at 20 megabits per second at the data-link layer of one of these prototypes was reduced to less than 3 megabits per second at the transport layer [7]. Specific network/transport-layer performance bottlenecks that have been identified include buffer management, timer management, data copying, computation of checksums, processing within the receiver, segmentation within gateways, and operating system overhead [1,2,7,8].

Path Service is not subject to many of the above bottlenecks. For example, because Path Service does not provide end-to-end reliability, the traditional problems associated with timers to handle acknowledgements and retransmissions are avoided. Some of the other bottlenecks listed above can be avoided, or at least their effects can be lessened, if the communications infrastructure is appropriately configured. For example, buffer management can be optimized for Path Service, because packet length is likely to be fixed for a particular instrument. In general, it is much easier to optimize for special-purpose applications than to optimize for general-purpose applications.

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\*Some Virtual Channels will be data-driven, rather than schedule-driven, to provide the flexibility to respond to unpredictable physical phenomena, such as the occurrence of solar flares. Possible techniques for dynamic flow control, which will be necessary to manage these data-driven Virtual Channels, are currently under investigation.

The major source of overhead for Path Service is likely to be the preconfiguration of Logical Data Paths and Virtual Channels. However, this overhead is incurred only once. Because of the static nature of the communications requirements for Path Service applications, such preconfiguration will result in considerable savings in protocol processing and channel utilization.

### **5.3. Inappropriateness of OSI Protocols for Path Service Applications**

Traditional general-purpose OSI protocols are not well-suited for Path Service applications because they are not designed to cope with the anomalies of the space-networking environment. Communications requirements for Path Service applications can be provided more efficiently by using a special-purpose protocol.

General-purpose network/transport protocols that provide end-to-end reliability are unable to cope with the excessive delays introduced by the onboard recording of data. End-to-end connections, between the application onboard the spacecraft and the end user on the ground, would be difficult to manage. An end-to-end acknowledgement and retransmission scheme would needlessly congest the network, because timer thresholds that are reasonable to handle interactive applications would cause needless retransmission of packets that have been delayed because of onboard recording.

Internet Service will be used primarily for onboard applications or for interactive space-to-ground applications while the communications window is open. It is not intended for use with applications that will be subject to onboard recording.

As we showed in Section 4, Path Service provides a streamlined means of handling high-rate, high-volume data with static source-destination pairings. The flexibility provided by the OSI protocols is too wasteful of scarce space resources to be used for such structured applications.

## **6. Conclusions**

Path Service is a high-performance service, optimized for the transmission of telemetry data from space to ground. The primary performance objectives are to minimize onboard protocol processing and to optimize use of bandwidth on the space-to-ground channel. Since telemetry data will account for the largest percentage of data that is generated by space missions, efficient handling of this data significantly impacts overall system requirements. In this paper we have shown how Path Service provides both protocol-processing simplicity and channel efficiency, and we have argued that general-purpose protocols are inappropriate for Path Service applications.

This is a preliminary study of performance issues related to CCSDS Path Service. Though we have qualitatively shown how Path Service simplifies protocol processing for applications typified by the telemetry application, it is premature to quantify these benefits because implementation issues are just now being addressed.

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