ADVANCED ORBITING SYSTEMS: A STANDARD ARCHITECTURE FOR SPACE DATA COMMUNICATIONS

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INTRODUCTION

The first thirty years of civilian space exploration were characterized by a series of individual missions, focussed towards specific goals and servicing small and close-knit user communities. Spacecraft (constrained by power, weight and volume considerations) were customized towards mission objectives. Their data handling and communications systems were primarily built for simplicity and robustness, and displayed little commonality from mission to mission.

All of the easy space missions have now been flown. As we move into the 1990s, requirements exist for complex missions involving Earth observation, exploration and a more permanent human presence in space. Internationalization of these missions is inevitable as a means to distribute and share costs, and to increase their political stability. Automation of their data handling systems is essential to support reliable, low cost operations.

Responding to this environment, the Consultative Committee for Space Data Systems (CCSDS) was formed in 1982 to develop and promote a full suite of internationally standardized space data communications protocols. The first set of recommended standards, covering the data handling requirements of conventional free-flying scientific spacecraft, was finalized in 1986.

Using the international space station “Freedom” program (a cooperative venture between the US, Europe, Canada and Japan) as a requirements model, the CCSDS has now extended its suite of recommended standards to cover “advanced orbiting systems” such as unmanned and man-tended Earth observation platforms, new space transportation systems, and manned laboratories. These systems, which operate as longterm orbiting facilities and therefore have changing user communities, produce prodigious rates and volumes of data including digitized video and audio. For the first time, the orbiting systems will use local area networks for internal data transfer. On the ground, they will interface with networks designed for worldwide Open Systems Interconnection (OSI).

This paper reviews the standard data handling service architecture which has been developed by CCSDS. It describes the communications protocols that are recommended for the networked transfer of space mission data, and focuses on the unique requirements of transmitting many different data types through weak signal, noisy space channels at rates which routinely may reach many hundreds of megabits per second.

STANDARDS FOR ADVANCED ORBITING SYSTEMS

The technical work of CCSDS is assigned to Panels, who establish Subpanels to address the development of specific standards. As needed, ad-hoc working groups are formed to identify how the standard techniques should evolve to meet new mission requirements, and to assist space Project organizations with their application.

The products of the CCSDS are known as Recommendations which, while they represent the full technical consensus and agreement of designated experts within the CCSDS agencies, are not standards in that they are not supported by any commitment of resources in terms of hardware, software, facilities and personnel. The job of creating standards is distributed among the agencies, each of whom is responsible for developing and enforcing local mechanisms for translating the CCSDS Recommendations into the required set of standard capabilities.

The original suite of CCSDS Recommendations, finalized in 1986, focussed on the needs of conventional, free flying scientific spacecraft. They introduced the concept of data packetization as a mechanism for standardization and for allowing data acquisition processes to be performed asynchronously with respect to their transmission through space data channels. Beginning in 1985, in cooperation with the space station Freedom program, the CCSDS began development of a standardized communication systems architecture for advanced orbiting systems of the 1990’s

(Reference [1]). These systems generate a very wide range of user data rates (a few bits per second to hundreds of megabits per second), they feature the integrated transmission of video, audio and computer data, and they service a large number of users who change across the lifetime of the Project and who conduct a diverse set of scientific, engineering and commercial investigations.

After analysis of user and mission requirements, CCSDS concluded that customized, high performance Link layer protocols, supporting the integrated ultra high rate transmission of many different types of data, are needed for use on the unique space/ground and space/space data channels. To service end-to-end user data transfer needs, a high performance technique is needed for the flow of large rates and volumes of telemetry data between relatively static end points; as an alternative user service, a conventional suite of OSI-compatible communications protocols is also required.

USER SERVICE MODEL

CCSDS has defined the logical concept of a “CCSDS Principal Network”, which consists of an “Onboard Network” in a space vehicle connected via a CCSDS “Space Link Subnetwork” either to a “Ground Network”, or to an Onboard Network in another space vehicle.

The Onboard Network provides low and medium rate intercommunication between users within the spacecraft. The Ground Network provides a similar capability for those users located on Earth. The Space Link Subnetwork interconnects the Onboard and Ground Networks. A key feature of the Space Link Subnet is the provision of “Virtual Channels” which allow one physical space channel to be shared among multiple traffic streams, each having different service requirements.

A user service model of a typical space mission data flow configuration is shown in Figure 1. This model, known as the “pipe diagram”, indicates that eight different user services are provided; each service access point is represented by one of the vertical pipes. For clarity, only the space half of the model is show: the ground half is conceptually a mirror image.

Two of the user services (“Internet” and “Path”)operate end-to-end across the entire CCSDS Principal Network. The remaining six services (“Encapsulation”, “Multiplexing”, “Bitstream”, “Virtual Channel Access”, “Virtual Channel Data Unit”, and “Insert”) are provided only within the Space Link Subnetwork for special applications such as audio, video, high rate payloads, tape playback, and the intermediate transfer of Path and Internet data. All of the user services, and their associated data communications protocols, operate bidirectionally (i.e., from space to ground, from ground to space, or from space to space).

Internet Service

The Internet service is used for intermittently transferring low rates and volumes of structured, delimited data between dynamically changing source and destination end points. The Internet service provides users with access to standard OSI upper layer services and allows them to communicate through space links with applications that are accessible through commercially supported OSI ground networks. It is the service most likely to be used to support interactive user operations.

Path Service

The Path service is used for continuously transferring, at moderate to very high data rates, large volumes of structured, delimited data units between fairly static source and destination end points. It is the service most likely to be used for the telemetering of measurement data from payload instruments and supporting systems.

Encapsulation Service

The Encapsulation service allows any variable length, octet aligned user data unit to be wrapped within a local CCSDS subnetwork protocol during its transfer through a space data link.

Multiplexing Service

The Multiplexing service uses a standard CCSDS subnetwork protocol that allows variable length, octet aligned data units from many users to be multiplexed together for efficient transfer through a space data link on the same Virtual Channel.

Bitstream Service

The Bitstream service allows a serial string of bits, whose internal structure and boundaries are unknown, to be transferred through a space data link on a dedicated Virtual Channel.

Virtual Channel Access Service

The Virtual Channel Access service allows a user to access one dedicated Virtual Channel to achieve point-to-point transfer through a space data link.

Virtual Channel Data Unit Service

The Virtual Channel Data Unit service allows trusted users to independently create their own Virtual Channel protocol data units for transfer through a space data link.

Insert Service

The Insert service allows fixed length, octet aligned service data units, (e.g., digitized audio) to be isochronously transferred through a space data link when the overall transmitted data rate is low.

SPACE LINK PROTOCOL

Within the Space Link Subnetwork, the Physical Channel layer provides the point-to-point transmission path through the space medium, to connect a spacecraft with its supporting ground system or with another spacecraft.

Data are transmitted through the weak signal, noisy Physical Channel as a serial symbol stream. Typically, the raw bit error rate of such a channel falls in the range of lxl0E-01 to 1x10E-05. Very poor channels may be improved by passing the symbol stream through a standard CCSDS Convolutional Code prior to transmission; however, this comes at the expense of a 50% coding overhead and for some channels may be unnecessary.

To facilitate frame synchronization on space links within the Virtual Channel layer, fixed length data structures are used: their boundaries are delimited using a standard CCSDS Synchronization Marker, which is a special pattern that is chosen to have good autocorrelation properties. The standard

CCSDS fixed length frame, which forms the basic protocol data unit of the Virtual Channel Access sublayer, is known as a “Virtual Channel Data Unit” or VCDU.

Each VCDU has limited error control which allow its use on a Physical Channel that provides a raw bit error rate of about lxl0E-05. However, since many space applications require a much lower error rate, a VCDU can have a powerful standard CCSDS outer code of error-correcting Reed-Solomon check symbols appended to it, in which case it is called a “Coded Virtual Channel Data Unit” or CVCDU. Relative to a VCDU, a CVCDU contains more error-control information and, hence, less user data: however, the Reed-Solomon code provides a virtually error-free transmission service. The format of the VCDU/CVCDU is shown in Figure 2.

The Virtual Channel Access service data units consist of long fixed length blocks of private user data that are directly inserted into the VCDU data unit zone, with no protocol applied, for point-to-point space link transfer. Encrypted user data blocks may use this service.

The Insert service data units consist of short fixed length blocks of private isochronous data that are directly inserted into the Insert zone of every VCDU that is transmitted on a particular Physical Channel. The Insert Zone shares the VCDU with the data unit zone supporting other types of service, and provides a synchronous time division multiplexed sampling interval which is needed by data types such as digitized audio and teleoperations control. This service is only activated at low transmitted data rates (below about 10Mb/s).

Some trusted users may be allowed to create their own VCDUs which, as Virtual Channel Data Unit service data units, are interleaved into the continuous stream of VCDUs that are transmitted on the Physical Channel.

Bitstream service data units are formatted into a Bitstream protocol data unit that occupies the entire fixed length VCDU data unit zone, and which provides delimiting if fill data are inserted. High rate video, or playback data from onboard storage devices, may use this service.

Multiplexing service data units conform to a standard “CCSDS Packet” structure that is recognized by all CCSDS Agencies: the CCSDS Packets are concatenated together into a

Multiplexing protocol data unit that occupies the entire fixed length VCDU data unit zone, and which delimits the boundaries of the individual Packets.

Encapsulation service data units are first wrapped within individual CCSDS Packets before being submitted to the Multiplexing service.

Internal to the VCDU, an option exists to add extra protocol to support a bidirectional retransmission control procedure known as a “Space Link ARQ Procedure”, or SLAP. This is achieved by attaching a “Link ARQ Control Word” to either a Multiplexing, Bitstream or Virtual Channel Access data unit. Three different “Grades of Service” are provided by the Space Link Subnetwork, according to the selected combination of error detection, error correction and retransmission control techniques. Each Virtual Channel supports a single Grade of Service.

Grade-3 Service

This service provides the lowest quality of service. The VCDUs are transmitted through the Physical Channel without the protection of Reed-Solomon encoding. Data transmitted using Grade-3 service may be incomplete and there is a moderate probability that errors induced by the space link are present. Grade-3 service is not used for transmission of packetized data, because it provides insufficient protection for the control information contained in the packet headers.

Grade-2 Service

In Grade-2 service the VCDU is protected by a block of Reed-Solomon check symbols, which provides extremely powerful error correction capabilities. Data transmitted using Grade-2 service may be incomplete, but there is a very high probability that they do not contain space link errors.

Grade-1 Service

Grade-1 service is the highest quality of service available: data are delivered through the space link complete, in sequence, without duplication and with a very high probability of containing no errors. It is provided by using two paired Reed-Solomon encoded Virtual Channels, in opposite directions, each of which implements the SLAP ARQ retransmission scheme.

END-TO-END PROTOCOLS

The two end-to-end services provided across a CCSDS Principal Network are Path and Internet. Both services correspond to the OSI Network layer. The Path service, however, interfaces directly to the user application, since it is an enhanced performance service that needs no transport, session, or presentation services. The Internet service, on the other hand, maps directly into the OSI protocol stack, interfacing to the Data Link layer below and the Transport layer above.

The Path service uses a special purpose protocol, developed by the CCSDS, which is optimized to handle the space mission telemetry data. Path service provides very high performance and efficiency, at the expense of some flexibility. The CCSDS Packet is the protocol data unit of the Path service: since the same CCSDS Packet is used both in the Path service and in the Multiplexing service of the Space Link Subnetwork, Path data may be directly and efficiently multiplexed onto the space links. The structure of CCSDS Packet is shown in Figure 3.

The Path service relies heavily on network management to configure the necessary network routing. Since the service supports high volume flows of data whose endpoints are fairly static, pre-configured “Logical Data Paths” (LDPs) are set-up by management. The Application Process ID field in the CCSDS Packet provides a “Path ID” tag to identify with which LDP a Packet is associated. At some relay points between subnetworks, this Path ID may be examined to determine subsequent routing, in which case the Packet supports a limited internetworking capability. In other cases, local subnetwork addresses may be reserved for particular LDPs, thus the Packet header need not be examined.

The Internet service is a complementary user facility that provides maximum flexibility for interactive applications, at the expense of speed and efficiency. CCSDS has selected the commercially-supported ISO 8473 Connectionless Network Protocol Specification for use within the Internet service, thus allowing space missions to exploit the rich communications service infrastructure of Open Systems Interconnection. The ISO 8473 packet provides full endpoint addressing and is compatible with standard OSI subnetwork routing techniques. During transfer through the space data links, each ISO 8473 packet is encapsulated within a unique CCSDS Packet so that it may be efficiently multiplexed into the fixed length Virtual Channels.

The Internet service provides the key “hook” that allows the full stack of OSI protocols to be operated throughout a space data system. Since the ISO 8473 packet may carry commercial protocols associated with the Transport, Session, Presentation and Application layers, a user on the ground may conduct a full OSI dialogue with a user located in space, and vice versa. other than the inevitable large propagation delay, the special purpose intervening Space Link Subnetwork is conceptually transparent.

CONCLUSION

The CCSDS Recommendation for Advanced Orbiting Systems is scheduled for finalization in the Fall of 1989. Some specialized topics (e.g., the space link retransmission procedure, the network management and signalling system, and audio/video data handling) will be finalized later. It is hoped that the basic architecture will be adopted by the space station Freedom program as well as several major new NASA ground data handling activities. With such an architecture in place, the stage will be set for applying standard data communications techniques to a wide variety of high data rate mission applications in coming decades, such as the proposed Mission to Planet Earth and future manned and unmanned exploration of the solar system. These standards will offer many attractive opportunities to reduce space mission costs via automation and international cooperation, and to improve the overall reliability and user responsiveness of space data exchange.

ACKNOWLEDGMENT

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REFERENCE.

[1] CCSDS 701.00-R-3 “Recommendation for Space Data System Standards. Advanced Orbiting Systems, Networks and Data Links: Architectural Specification”, June 1989 or later issue.

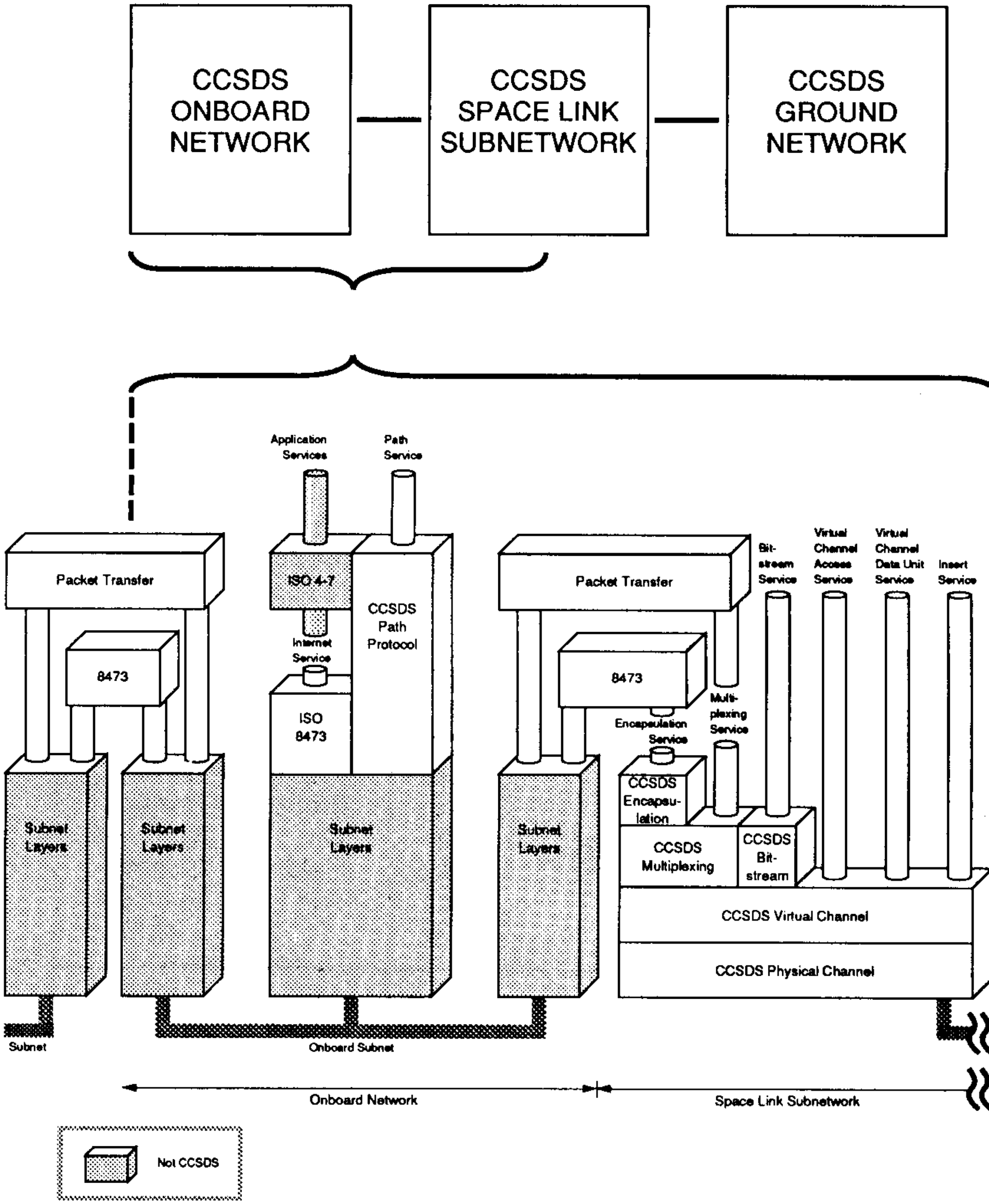

Figure 1: CCSDS Service Model

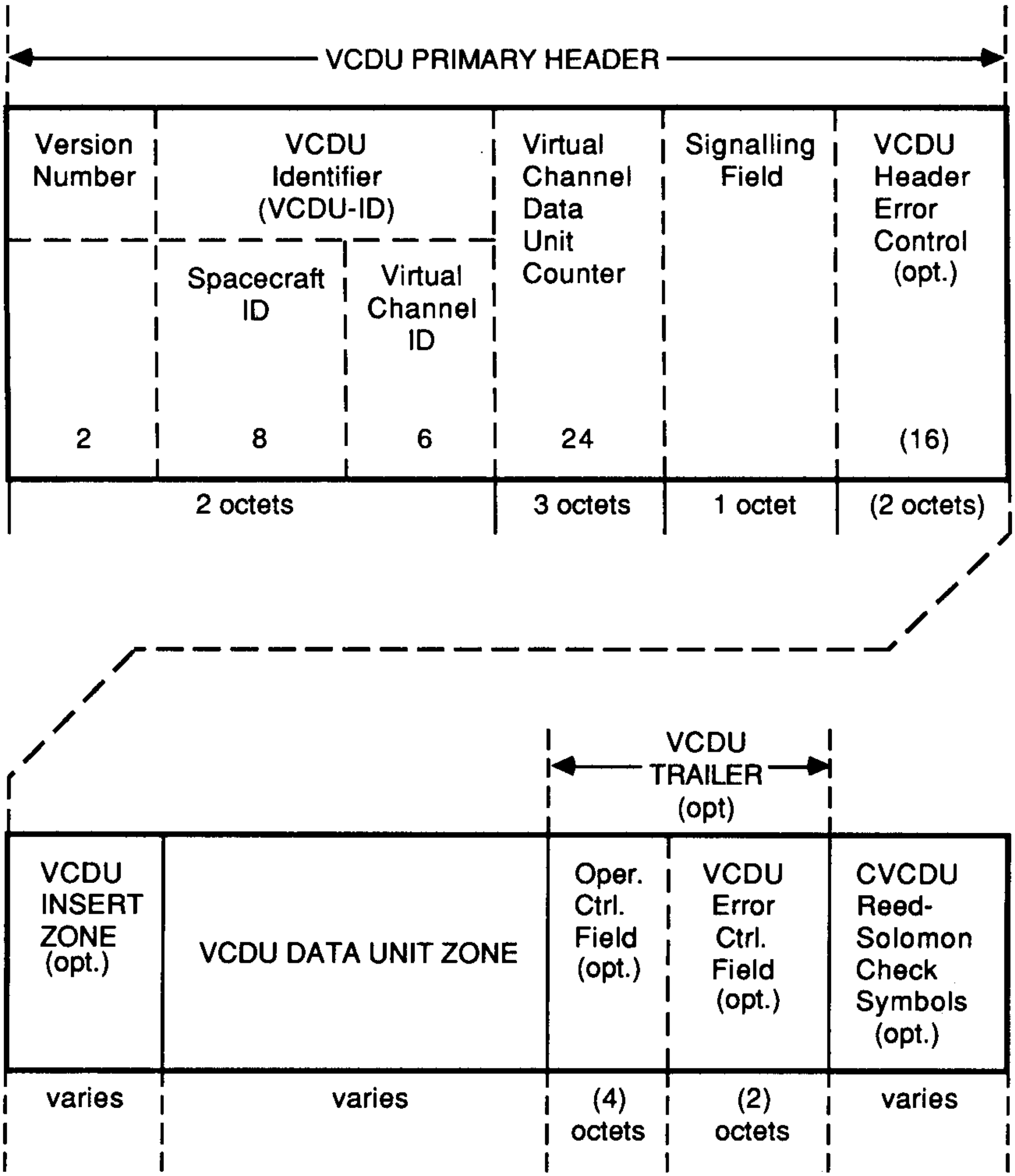

Figure 2: Virtual Channel Data Unit

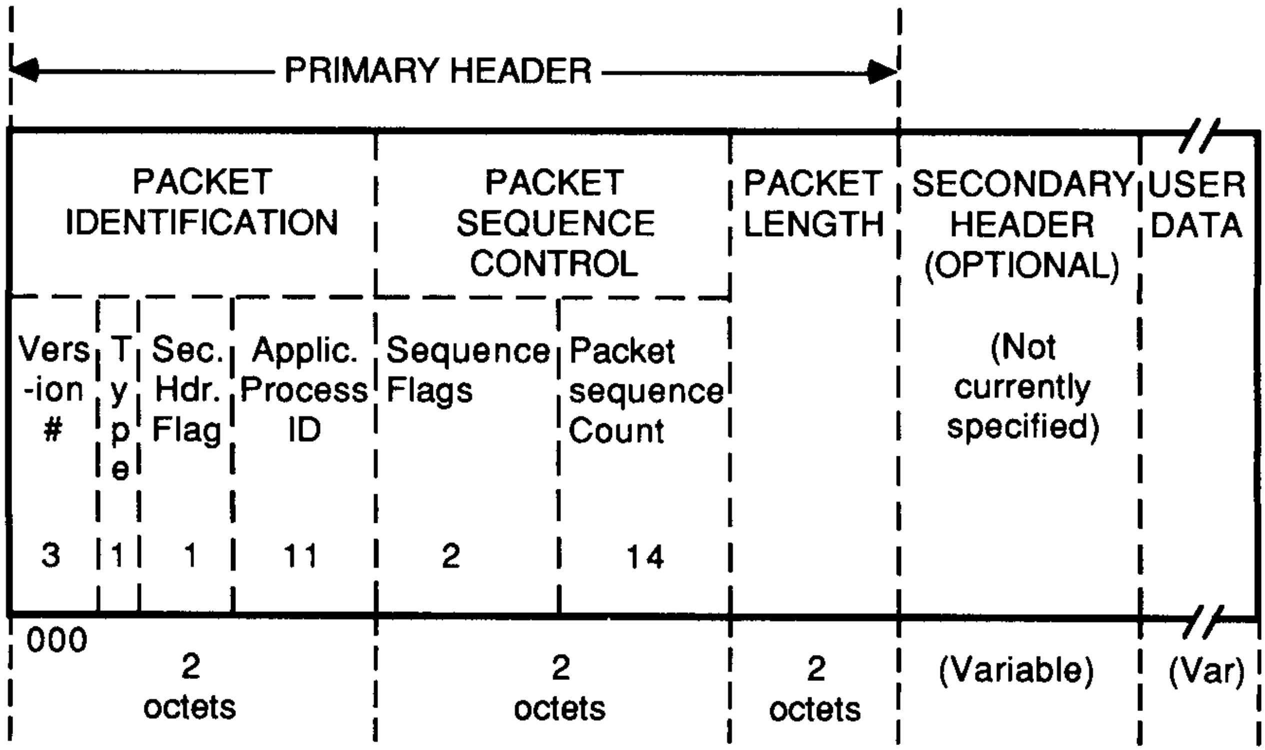

Figure 3: CCSDS Packet Structure