Traditionally, telemetry transmitted from spacecraft was formatted with a time-division multiplexing (TDM) scheme, where data items were multiplexed into a continuous stream of fixed-length frames based on a predefined multiplexing rule. To design and implement a data system for spacecraft, each mission was forced to develop a unique system because of the lack of established standards in this field.

In the early 1980s, the CCSDS developed an international standard for a packet telemetry protocol capable of sending processed telemetry efficiently using a variable-length data unit called the "source packet." Source packets generated by various instruments and subsystems on a spacecraft are transmitted from space to the ground in a stream of continuous, fixed-length "transfer frames." This standard has been used by many space missions, enabling them to share onboard and ground data-processing equipment.

Shortly after packet telemetry, another international standard on telecommand (TC) was developed by the CCSDS based on a similar concept for sending commands to a spacecraft with a data unit known as the TC packet. TC packets destined for various instruments and subsystems on a spacecraft are transmitted from the ground to space in a stream of sporadic, variable-length transfer frames.

In the late 1980s, the CCSDS extended the earlier standards to meet the requirements of the advanced orbiting systems (AOSs), such as the International Space Station, and came up with a third international standard. The AOS standard added to the packet telemetry standard services for transmitting various types of online data (such as audio and video data). It can be used for both space-to-ground and ground-to-space links. This standard uses the same packet structure as the packet telemetry standard, but the frame format is slightly different.

These three standards (packet telemetry, telecommand, and AOS) were later reorganized by the CCSDS in order to define the protocols in a more-structured and unified way; the following standards replaced the original standards:

- Space Packet Protocol;[2]
- TM, TC, and AOS Space Data Link Protocols;[3–5] and
- TM and TC Synchronization and Channel Coding.[6,7]

As an international standard for the radio frequency (RF) signal between a spacecraft and a ground station, the CCSDS developed a standard called Radio Frequency and Modulation Systems.[8] This standard specifies the characteristics of the RF signal used to carry packets and frames.

In the 1990s, CCSDS developed another set of protocols collectively known as Space Communications Protocol Specifications (SCPS), which includes the SCPS Network Protocol (SCPS-NP),[9] SCPS Security Protocol (SCPS-SP),[10] SCPS Transport Protocol (SCPS-TP),[11] and SCPS File Protocol (SCPS-FP).[12] The SCPS protocols are generally based on Internet protocols, but modifications and extensions are incorporated in the design of the SCPS protocols to meet the specific needs of space missions.

In response to the needs of space missions to transfer files to and from an onboard mass memory, the CCSDS has developed a protocol called the CCSDS File Delivery Protocol (CFDP).[13] This protocol provides the capability to transfer files reliably and efficiently over an unreliable protocol (for example, the Space Packet Protocol).

In the area of data compression, the CCSDS has developed a Lossless Data Compression standard,[14] an Image Data Compression standard,[15] and a Lossless Multispectral & Hyperspectral Image Compression[16] standard to either increase the science return or reduce the requirement for onboard memory, station contact time, and data archival volume. The lossless compression standards guarantee full reconstruction of the original data without incurring any distortion in the process, whereas the Image Data Compression standard may be unable to reproduce the original dataset without some distortion due to quantization or other approximations used in the compression process.

The CCSDS has recently developed a protocol called Proximity-1 Space Link Protocol[17–19] to be used over proximity space links. Proximity space links are defined as short-range, bidirectional, fixed or mobile radio links that are generally used to communicate among fixed probes, landers, rovers, orbiting constellations, and orbiting relays. This protocol defines a data link protocol,[19] coding and synchronization methods,[18] and RF and modulation characteristics.[19]

Security is of great concern to many space missions. The CCSDS has published a report[20] to provide guidance for missions that wish to use the CCSDS space communications protocols for spacecraft control and data handling but also require a level of security or data protection.

## 5.2 Telemetry System Concept

In the CCSDS space data link protocols, the system design technique “layering” is a useful tool for transforming the telemetry-system concept into sets of operational and formatting procedures. The layering approach is patterned after the ISO’s Open Systems Interconnection layered network model, which is a seven-layer architecture that groups functions logically and provides conventions for connecting functions at each layer. Layering allows a complex procedure, such as delivering the telemetry of spacecraft data to users, to be decomposed into sets of peer functions residing in common architectural strata.

Within each layer, the functions exchange data according to the established protocols. Each layer draws upon a well-defined set of services provided by the layer below and provides a similarly well-defined set of services to the layer above. As long as these service interfaces are preserved, the internal operations within a layer are unconstrained and transparent to other layers. Therefore, an entire layer within a system may be removed and replaced by a user or technological requirements without destroying the integrity of the rest of the system. Furthermore, as long as the appropriate interface protocol is satisfied, the user can interact with the system/service at any of the component layers. Layering is therefore a powerful tool for designing structured systems that change due to the evolution of requirements or technology.

A companion standardization technique that is conceptually simple yet very robust is the encapsulation of data within an envelope. The header contains the identifying information needed of the layer to provide service while maintaining the integrity of the envelope contents.

### 5.2.1 Packetization layer

Within packet telemetry, spacecraft-generated application data is formatted into end-to-end transportable data units called telemetry source packets. This data is encapsulated with a primary header that contains identification, sequence control and packet length information, and an optional trailing-error control field. A telemetry source packet is the basic data unit acquired by the spacecraft that generally contains a meaningful quantity of related measurements from a particular source.

### 5.2.2 Transfer frame layer

The telemetry transfer frame is used to reliably transport source packets through the telemetry channel to the receiving telecommunications network. As the heart of the CCSDS telemetry system, the telemetry transfer frame protocols offer a range of delivery service options. An example of such a service option is the multiplexing of telemetry transfer frames into "virtual channels" (VCs).

The telementry transfer frame is a fixed-length unit that was chosen to improve the ability to synchronize the frame with weak signals such as those found in space–ground links, and for compatibility with certain block-oriented channel coding schemes. The primary header contains frame identification, channel frame-count information, and frame datafield status information. The telementry transfer frame begins with an attached frame synchronization marker and is followed by a primary header.

The transfer-frame datafield may be followed by an optional trailer containing an operational control field and/or a frame error-control field. The first of these fields provides a standard mechanism for incorporating a small number of real-time functions, such as TC verification or spacecraft clock calibration. The error control field provides the capability for detecting errors that may have been introduced into the frame during the data handling process.

The delivery of transfer frames requires the services provided by the lower layers (e.g., carrier, modulation/detection, and coding/decoding) to accomplish its role.

### 5.2.3 Channel coding layer

Because error-free delivery is a basic system requirement of the telementry transfer frames, telemetry channel coding is used to protect the transfer frames against telemetry-channel noise-induced errors. The CCSDS standard for telemetry channel coding is described in CCSDS 131.0-B-2.[6] This standard includes specification of a convolutional code, a Reed–Solomon block-oriented code, a concatenated coding system consisting of a convolutional inner code and a Reed–Solomon outer code, and of turbo codes. The basic data units of the CCSDS telemetry channel coding that interface with the layer below are the channel symbols output by the convolutional encoder; these are the information bits representing one or more transfer frames as parity-protected channel symbols.

The RF channel physically modulates the channel symbols into RF signal patterns interpretable as bit representations. Within the error-detecting and correcting capability of the channel code chosen, errors that occur as a result of the physical transmission process may be detected and corrected by the receiving entity.

The full potential of all CCSDS Telemetry System services could be realized if a mission complied with all CCSDS standards. Alternatively, missions can interface with any layer of the telemetry system as long as they meet the interface requirements specified in the standards.[2–7]

## 5.3 Space Packet Concept

Space packetization represents an evolutionary step from the traditional TDM method of transmitting scientific applications and engineering data from spacecraft sources to users located in space or on Earth. The space packet process conceptually involves:

1. Encapsulating observational data (to which ancillary data may be added to subsequently interpret the observational data) at the source, thus forming an autonomous packet of information in real time on the spacecraft.
2. Providing a standardized mechanism whereby autonomous packets from multiple data sources on the spacecraft can be inserted into a common "frame" structure for transfer to another space vehicle or to Earth through

noisy data channels, and delivered to facilities where the packets may be extracted for delivery to the user.

The space packet process has the conceptual attributes of:

1. Facilitating the acquisition and transmission of instrument data at a rate appropriate for the phenomenon being observed.
2. Defining a logical interface and protocol between an instrument and its associated ground support equipment that remains constant throughout the lifecycle of the instrument (bench test, integration, flight, and possible reuse).
3. Simplifying the overall system design by allowing microprocessor-based symmetric design of the instrument control and data paths ("TC packets in, telemetry packets out") compatible with commercially available components and interconnection protocol standards.
4. Eliminating the need for mission-dependent hardware and/or software at intermediate points within the distribution networks through which space data flows; in particular, enabling the multimission components of these networks to be designed and operated in highly automated fashion, with consequent cost and performance advantages.
5. Facilitating interoperability of spacecraft whose telemetry interfaces conform to CCSDS guidelines, i.e., allowing very simple cross-strapping of spacecraft and network capabilities between space agencies.
6. Enabling the delivery of high-quality data products to the user community in a mode that is faster and less expensive than would be possible with conventional telemetry.

## 5.4 Space Packet Structures

A space packet is a variable-length, delimited, octet-aligned data unit that encapsulates a block of observational data that may include ancillary data and may be directly interpreted by the receiving-end-application process. A space packet consists of 7–65542 octets (bytes). Detailed discussion of the format specification for the telemetry source packet is specified in CCSDS 133.0-B-1.[2]

As shown in Fig. 5.1, a space packet encompasses the two major fields positioned contiguously in the following sequence:

1. Packet primary header (fixed at 6 octets, mandatory), and
2. Packet datafield (variable from 1 to 65536 octets, mandatory). This field contains a mandatory user datafield and an optional packet secondary header.

The maximum packet length allowed by a particular spacecraft or ground implementation can be less than the maximum value (65536 octets).

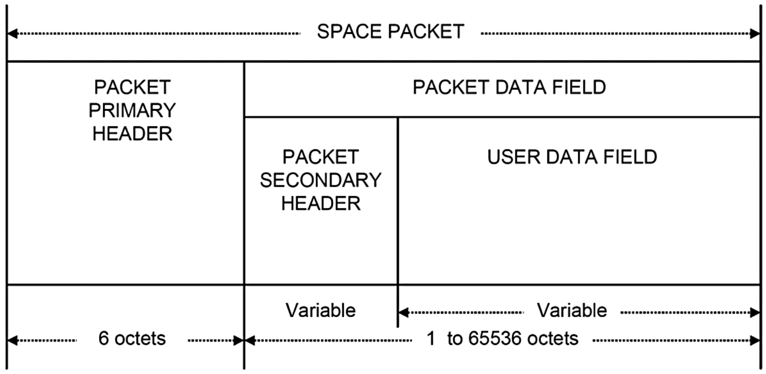


**Figure 5.1** Space packet structural components (image courtesy of CCSDS).

### 5.4.1 Packet primary header

The packet primary header is mandatory in the CCSDS standard and consists of four fields positioned contiguously in the following sequence:

1. Packet version number (3 bits),
2. Packet identification field (13 bits),
3. Packet sequence control field (16 bits), and
4. Packet data length (16 bits).

The format of the packet primary header is shown in Fig. 5.2.

#### 5.4.1.1 Packet version number

The packet version number indicates the version of the formatted packet (its length of three bits allows eight different versions to be identified). The number is used to reserve the possibility of introducing other packet structures. The Space Packet Protocol standard[2] defines a version-1 CCSDS packet whose binary encoded version number is '000.'

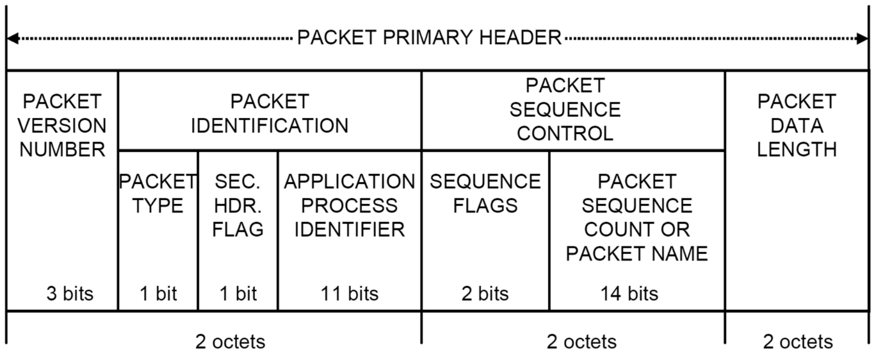


**Figure 5.2** Space packet primary header (image courtesy of CCSDS).

#### 5.4.1.2 Packet identification field

The packet identification field contains three subfields: the packet type (1 bit), the secondary header flag (1 bit), and the application process identifier (11 bits). The packet type is used to distinguish packets used for telemetry or for TC. For a telemetry packet, this bit is set to '0;' for a TC packet, this bit is set to '1.'

The secondary header flag indicates the presence or absence of the packet secondary header within this space packet. It is set to '1' if a packet secondary header is present; otherwise, it is set to '0' if a packet secondary header is not present.

The application process identifier provides the naming mechanism for the logical data path, which is the path from the source user application to the destination user applications through the subnetworks. This subfield can uniquely identify the individual sending or receiving an application process within a particular space vehicle. A space packet that contains idle data in its packet datafield is referred to as an idle packet. For idle packets, this subfield is set to "all ones," i.e., '11111111111.'

#### 5.4.1.3 Packet sequence control field

The packet sequence control field contains two subfields: sequence flags (2 bits) and packet sequence count or packet name (14 bits). Sequence flags indicate that the user data contained within the space packet is a segment of a larger set of application data. These flags identify whether the packet datafield contains the first, continuing, or last segment of a packet, or whether it contains no segment (meaning it contains a complete set of user data). The sequence flags are set to the following values:

- '00' if the space packet contains a continuation segment of user data,
- '01' if the space packet contains the first segment of user data,
- '10' if the space packet contains the last segment of user data, or
- '11' if the space packet contains unsegmented user data.

Packet sequence count is used to order each packet with other packets generated by the same user application, even though their order may be disturbed during transport from the sending user to the receiving user. For a telemetry packet (i.e., the packet type set to '0'), this field contains the packet sequence count. For a TC packet (i.e., the packet type set to '1'), this field contains either the packet sequence count or packet name.

The packet sequence count provides the sequential binary count of each space packet generated by the user application identified by the application process identifier. The packet sequence count is continuous modulo-16384. The packet sequence count can be used in conjunction with a time code to provide unambiguous ordering; it is therefore essential that the resolution of the time code is sufficient for this code to increase at least once between successive recyclings of the packet sequence count. The packet name allows a particular packet to be identified with respect to others occurring within the same communications session. There are no restrictions on binary encoding of the packet name. That is, the packet name can be any 14-bit binary pattern.

#### 5.4.1.4 Packet data length

The last field of the primary header delimits the boundaries of the space packet. It is a count of the number of octets in the packet datafield beginning with the first octet after the 6-octet (48-bit) primary header and ending with the last octet of the packet. This 2-octet (16-bit) field allows packet lengths up to 65,536 octets (not counting the 48-bit primary header). This packet limit was a compromise between the majority of users (who produce medium-size packets) and the few users who may produce exceptionally long packets. Placing a reasonable limit on packet size helps avoid the flow control problems associated with very large packets and eliminates the overhead penalty of a larger length field for the majority of packet producers.

### 5.4.2 Packet datafield

As indicated in Fig. 5.1, the packet datafield consists of at least one of the following two fields, positioned contiguously, in the following sequence: packet secondary header (variable length) followed by user datafield (variable length). The packet datafield contains at least one octet and a maximum of 65536 octets.

#### 5.4.2.1 Packet secondary header

The format of the packet secondary header is shown in Fig. 5.3. The purpose of the packet secondary header is to allow a CCSDS-defined means for consistently placing ancillary data (time, internal datafield format, spacecraft position/attitude, etc.) in the same location within a space packet. The packet secondary header is optional and is mandatory only if the user datafield is empty. The presence or absence of a packet secondary header is signaled by the secondary header flag within the packet identification field in the packet primary header.

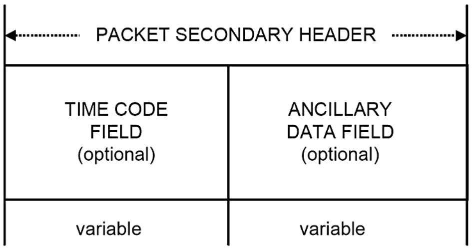


**Figure 5.3** Space-packet secondary header (image courtesy of CCSDS).

The contents of the packet secondary header are specified by the source end user for each path ID and reported to the destination end users by management. If present, the packet secondary header consists of an integral number of octets of a time code field (variable length) only, an ancillary datafield (variable length) only, or a time code field followed by an ancillary datafield.

The time code field consists of one of the CCSDS segmented binary or unsegmented binary time codes specified in CCSDS 301.0-B-3.[21] The time codes defined therein consist of an optional preamble field, which identifies the time code and its characteristics, and a mandatory time field. Examples of time codes are the CCSDS unsegmented time code and the CCSDS day-segmented time code. Examples of characteristics include ambiguity period, epoch, length, and resolution.

The ancillary datafield may contain any ancillary information necessary for the interpretation of the information contained within the user datafield of the space packet.

#### 5.4.2.2 User datafield

The user datafield follows either the packet secondary header (if a packet secondary header is present) or the packet primary header (if a packet secondary header is not present). The user datafield contains application data supplied by the sending user. It is mandatory if a packet secondary header is not present, otherwise it is optional.

## 5.5 Telemetry Transfer Frame

The space packet data structures described in Section 5.4 are unsuitable for transmission directly through the space communication links that connect the spacecraft and data capture element in space or on Earth. They must be embedded within a data transfer structure that provides reliable, error-controlled transfer through the media. The CCSDS has developed such a data structure, referred to as “transfer frame,” which has a fixed length for a given mission or spacecraft. This section describes the transfer and the attributes of the transfer frame. Figure 5.4 illustrates the telementry transfer frame format.

A telemetry transfer frame encompasses five of the major fields positioned contiguously in the following sequence:

1. Transfer frame primary header (6 octets, mandatory),
2. Transfer frame secondary header (up to 64 octets, optional),
3. Transfer frame datafield (integral number of octets, mandatory),
4. Operational control field (4 octets, optional), and
5. Frame error control field (2 octets, optional).