Internetworking Asynchronous Transfer Mode With The Consultative Committee For Space Data Systems Advanced Orbiting Systems Protocols

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Abstract

Future space missions will require the integration of voice, video and data communications at increasing speeds and reduced costs. Both manned and un-manned missions may use the NASA/JPL Deep Space Network (DSN), which consists of two segments, the space segment and the ground segment. The space segment will use Consultative Committee for Space Data Systems (CCSDS) Advanced Orbiting Systems (AOS) protocols which end at the DSN ground stations. These protocols have been designed with the intended channel being a space segment. The ground based segments may use the emerging standard for broadband communications of integrated services called Asynchronous Transfer Mode (ATM). ATM has been designed with the intended channel being optical fibre. Thus the integration of the space segment with the ground network poses various implementation issues. The issues addressed here are the possible methods for integrating CCSDS AOS with ATM.

1 Introduction

Telepresence will play a role in future space missions. It is the use of communications to provide a remote projection of human presence, for instance this can be done with robotic rovers remotely piloted by earth based scientists. Robotic rovers require stereo vision using low rate compressed images. Therefore

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telepresence methods require transmission of integrated video and data. Future manned missions will require integrated voice, data, and video communications systems [7] [8]. Cost minimization requires the establishment of standardized communications techniques that may support these services. The deep space network (DSN) operated by the Jet Propulsion Laboratory (JPL) for NASA consists of an integrated network for communication between space craft and the earth. There are two main segments of this network, the space segment and the earth segment. The space segment will use the Consultative Committee for Space Data Systems (CCSDS) protocol [2] [3] [4]. As the CCSDS is intended for the space segment the characterstics of the channel are long propagation delay, low transmitter power available and random noise. The ground segment may use the emerging standard for broadband communications called Asynchronous Transfer Mode (ATM). ATM is designed for optic fibre high speed networks and so for ATM the channel would be not as long as the space segment and so retransmissions might be possible. Higher transmitter power is also possible. As both standards are designed for different channels there is a need to investigate the interworking of these protocols at the space/ground interface.

2 The CCSDS AOS Communications Protocols

2.1 CCSDS AOS Introduction

Between 1982 and 1986 the CCSDS developed a series of technical Recommendations for the standardization of conventional missions [9] [10]. These Recommendations form a basis for unmanned science and applications spacecraft communications. The Recommendations cover modulation, packet telemetry, telemetry channel coding, and telecommand formats. CCSDS Advanced Orbiting Systems (AOS) standards have emerged in order to meet future needs. The CCSDS AOS meets the needs of future manned missions.

The CCSDS AOS communications format standardizes communications and promotes interoperability. The CCSDS AOS standard integrates video, audio, telemetry, and scientific communications. Advantages of adopting the CCSDS AOS standard are that it: 1) integrates data, voice, and video transmission, 2) facilitates interoperability, and 3) provides flexibility in the allocation of communication bandwidth [5].

2.2 CCSDS AOS Services

The eight services provided by the CCSDS Principal Network (CPN) are: the internet, path, encapsulation, multiplexing service, bit stream service, virtual channel access, insert, and virtual channel data unit service. The internet and path services operate asynchronously across the entire CPN. The other services may be operated in either asynchronous or isochronous mode by the space link subnetwork (SLS). The internet service is asynchronous, non-sequence preserving with lifetime control and is meant for realtime interactive command and control operations. The internet service conforms with the ISO 8473 Connectionless Network Protocol Specification [4]. These services can be seen in Figure 1.

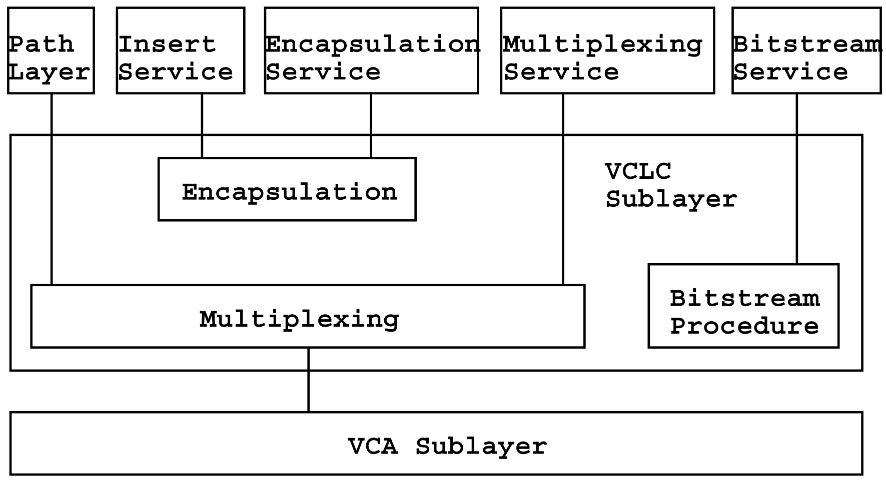

Figure 1: CCSDS Services

The internet service is intended for less fixed interconnections requiring flexibility. The CCSDS internet service can be used for engineering data and data communications. The internet service is intended primarily for intermittently transferring at relatively low data rates. This service can support realtime interactive control and command operations, file transfer, and interactive operations such as electronic mail and remote terminal access.

The path service is intended for high data rate users with relatively fixed interconnections. The path service has been developed to optimize the handling of telemetry data. The CCSDS path service can be used for both high and low data rate scientific instruments. Path service users do not require the functional capability provided by an OSI-like stack. The function of the path service is to route high volumes of packetized data. The path service transfers variable length application layer service data units across the network. The path service is asynchronous and non-sequence preserving. The path service is intended for transferring large volumes of data at moderate to very high rates between fairly static source and destination locations. This service is appropriate for transfer of telemetry from scientific instruments. With the path service pre-established associations known as CCSDS "Logical Data Paths", can be configured because of the known associations between the source and destination.

The encapsulation service transmits variable length data units not formatted as CCSDS packets across the SLS. Encapsulation can be used to accommodate non-CCSDS packets that have a variable length, such as TCP/IP. The transfer is asynchronous and sequence preserving. The multiplexed service sends variable length packets that conform to version-1 CCSDS packet format. The transfer is asynchronous and sequence preserving.

The bit stream service transmits serial strings of bits whose internal structure and boundaries are unknown to the CCSDS Principal Network. The transfer is sequence preserving and may be either asynchronous or isochronous. Isochronous service is provided with a specified maximum jitter. High rate video may be transferred using the bit stream service. In the bit stream service the stream of bit is broken into blocks that are mapped into fixed length data fields.

The virtual channel access service provide a project organization the ability to transfer private service data units that are matched to the size of a virtual channel data unit. The transfer is sequence preserving and may be asynchronous or isochronous.

The insert service allows private octet aligned service data units to be efficiently transferred isochronously over the SLS. The insert service may provide a quasi-isochronous service that can be used for voice transmission. The insert service establishes an insert zone in each virtual channel data unit. The insert data is inserted into this zone.

The virtual channel data unit service allows fixed length octet aligned virtual channel data units or coded virtual channel data units to be created by an independent SLS entity and to be transferred over the space link subnet (SLS).

2.3 CCSDS AOS Multiplexing

CCSDS AOS provides two levels of multiplexing. The virtual channel access sublayer provides virtual channels that allow several users to use the same physical channel simulateously. The vitual channel link control sublayer multiplexes packetized data allowing several users to utilize the same virtual circuit. The virtual channel access sublayer provides virtual channel service data units (VC_SDUs). These units are transmitted over the channel using VCDU (virtual channel data units). When error correction is used the transmitted units are called CVCDU (coded virtual channel data units).

2.4 CCSDS AOS Grades of Service

The virtual channel function accepts service data units from high layer functions and builds them into space link protocol data units (VCDU or CVCDU). VCDUs are virtual channel data units and CVCDUs are coded virtual channel data units. CVDUs may be used to insure a lower probability of the data units containing errors.

The CCSDS AOS Recommendations identify three classes of service. Grade-1 service operates with a space link ARQ procedure. The sequence of the data units is preserved with a high probability of no errors. Grade-2 service is Reed-Solomon block code protected. Grade-2 service is appropriate for compressed audio or video data. Grade-2 service is possibly incomplete but sequence is preserved with a high probability of no errors. Grade-3 service is intended for redundant data sources where bit errors are not critical. Grade-3 service data units are possibily incomplete with a moderate probability of containing errors. The sequence of the data units is preserved. Grade-3 might be used for redundant video or audio transmissions.

CCSDS AOS can provide video links. The CCSDS AOS recommendation provides for both video and audio capability. The CCSDS bit stream service should be used to transmit compressed video. Class-2 service should be provided. The CCSDS AOS recommendation class-2 type service provides Reed-Solomon forward error correction to correct transmission errors. Compressed video and voice signals require protection from error.

3 Asynchronous Transfer Mode

3.1 ATM Introduction

Asynchronous Transfer Mode (ATM) is the CCITT standard for broadband ISDN. It supports integrated voice, data, and video communications both for services available and for future services not yet defined [12] [6]. In ATM the information to be transmitted in divided into short 53 byte packets or cells, which have a 5 byte header. The reason for such a short cell length is that ATM must deliver real time service at low bit rates and thus it minimizes packetization delay. ATM networks are connection oriented with virtual channels and virtual paths. The virtual channel carries one connection while a virtual path may carry a group of virtual channels. This ensures that cell sequence is maintained throughout the network. The virtual channel is identified by the Virtual Channel Identifier, (VCI), and the virtual path is identified by the Virtual Path Identifier, (VPI). Both the VCI and VPI may change within the network and they are stored in the header of the cell. There is a Payload Type, (PT), field in the header which indicated whether the cell is user data or connection management information and also to indicate congestion in the network. There is also a Cell Loss Priority, (CLP), bit which is set high to indicate that the cell is low priority and set low to indicate high priority. There is a Generic Flow Control, (GFC), field which is for further study, but is essentially used for controlling the source to network connection. The whole header is protected an eight bit CRC contained in the Header Error Control, (HEC), field. The typical header therefore looks like that shown in Figure 2 for the user to network interface as specified by the ATM Forum [1].

As ATM will be a broadband service the network will be a high speed one. To lessen the effect of the relatively slow processors within the network only a subset of functions will be carried out in

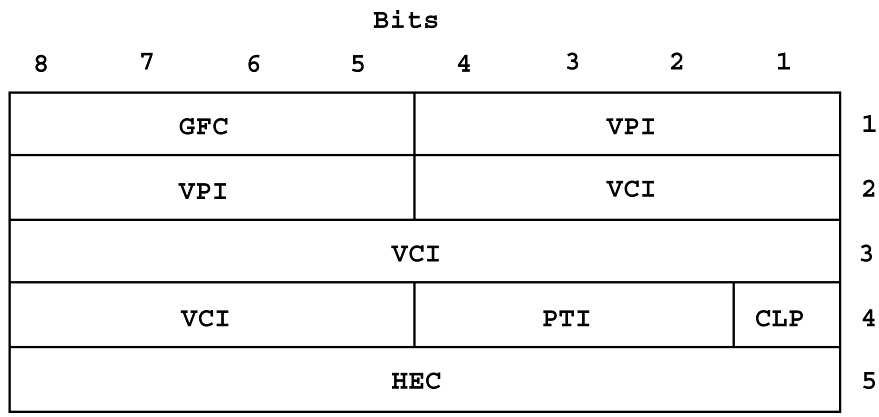

Figure 2: The ATM Cell Header Structure

the network. Error detection, correction, and flow control are done at the network edge rather than within the network. At the start of a call to set up a connection in terms of a virtual channel, there is negotiation between the user and the network on the parameters. Once admission is achieved the call is then monitored to ensure that it is compliant with the call setup paprameters. The network may drop low priority cells if congestion is about to or has occured. High priority cells may only be dropped when there are no lower priority cells left to drop. Services not sensitive to cell loss may have some low priority cells and these cells may be dropped. Because of this it is possible to get much higher utilisation than with previous networks.

3.2 ATM Adaptation Layer (AAL)

The ATM Adaption Layer, (AAL), makes the ATM layer services more adaptable to specific services. The specific services may include user services, control services and management services. The AAL is the layer above the ATM layer and it is responsible for converting the information from the higher layers into 48 byte lengths so that the ATM layer can add the 5 byte header to make the 53 byte cell. The two main functions of this AAL are to provide functions needed to support applications and to break up information into units that will fit into cells. The AAL layer is thus divided into two sublayers: the convergence sublayer (CS) and segmentation and reassembly sublayer (SAR). The convergence sublayer provides the functions needed to support specific applications, such as handling the cell delay variation and keeping a track of the clock. Each application accesses the AAL at a service access point (SAP), which is the address of the application. The SAR sublayer packs the information from the CS into cells and unpacks the information at the destination. The SAR maps SAR headers plus CS information into 48 byte cells.

The AAL accommodates all services and in particular adapts both packet switched and circuit switched services. The CCITT service classification is based upon the timing relation, bit rate, and connection mode. Figure 3 depicts the CCITT service classification according to these parameters. There are five AAL types that correspond approximately to the CCITT service classes as shown in Figure 3.

CCITT Service Class	Class A	Class B	Class C	Class D
Timing relation between source and destination	Required		Not Required	
Bit rate	Constant	Variable Bit Rate		
Connection Orientated	Yes			No
ATM AAL Layer	AAL 1	AAL 2	AAL 3/4 AAL 5	AAL 3/4 AAL 5

Figure 3: CCITT Service Classification

Class A is a constant bit rate connection with a timing relationship between source and destination and is often called circuit emulation. This could be used to carry voice of 64 kb/s or constant bit rate video. This could also be used for intelligent multiplexing equipment that needs what is essentially a circuit. The adaption layer that deals with this type of traffic is called AAL 1. AAL 1 operates by placing a 1 byte header on 47 bytes of user data and then transferring the 48 bytes to the ATM layer. The SAR of the AAL 1 will be notified of the extistance of the CS sublayer by the CS indicator, (CSI). A sequence number, (SN), is passed from the CS sublayer to the SAR and this SN can be used to detect lost of missing SAR loads. Finally the header of the SAR is protected by a sequence number protection, (SNP), field which can inform the CS sublayer of bit errors. The layout of the SAR is shown in Figure 4.

Class A is most appropriate for voice transmission that does not incorporate time assignment speech interpolation (TASI). In TASI speech is only transmitted when the speaker is active. To incorporate efficiencies that can be achieved with coding and compression techniques on real time services there is a second class called Class B. Class B is used for services similar to Class A but which are not constant bit rate. Examples of these would be variable bit rate audio and video. AAL 2 is the AAL layer responsible for providing these type of services from the ATM layer to the higher layers. AAL 2 is not yet fully specified but there is some indication as to the format of the protocol. As the intended use is for compressed voice and video there will likely be strict bounds on the bit error rate. To help the system

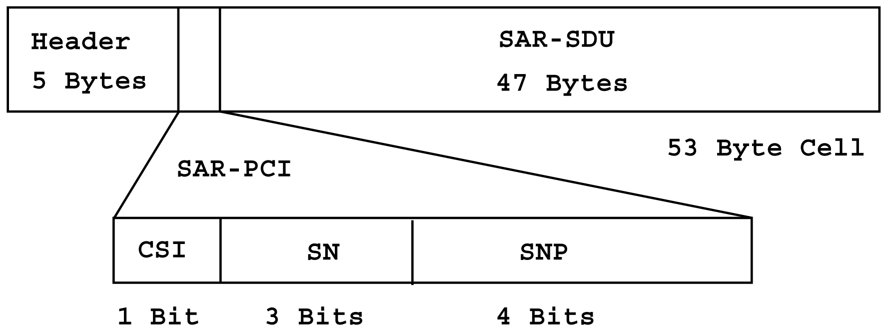

Figure 4: AAL 1 Cell Format

there is likely to be a CRC in the SAR to protect all the data being sent. As the user field may not be full it is likely that the user amount of information will be variable length and this will be indicated by the length indicator, (LI).

The remaining CCITT classes of service and AAL's are used for services which have no relationship of timing between source and destination. These services are esentially variable bit rate data services and can be differentiated by whether they are connection oriented or not. Class C is connection oriented data transfer while Class D is connectionless. The distinction between the conectionless and connection orientated AAL's has been lessened to such an extent that they now share the same AAL called AAL 3/4. Initially AAL 3 was for Class C and AAL 4 was for Class B services. The AAL 3/4 takes information from the higher layer and after the CS sublayer operates on it the SAR breaks the data up into 44 byte sizes and adds 4 bytes of header fields to make a 48 byte information load for the ATM layer cell. The four bytes of header are made up of a 10 bit CRC, a LI of 6 bits and an SN of 4 bits. There is also a 10 bit field reserved for either multiplexing or else are reserved for future use. There is also a field called the segment type, (ST), which indicated whether the SAR is the start, middle or end of a message. The CS sublayer also adds a header and trailer to the data coming from the higher layers. As yet that is not fully defined. Because of the high overhead of the AAL 3/4, 4 bytes for every 48 bytes of ATM user information, and because of the complexity of the protocol there has been a simplified AAL proposed called AAL 5 for data transfer. The AAL 5 basically puts the headers and trailers onto the CS-PDU rather than the SAR-PDU. This has a large number of advantages like improved efficiency and better error correction and detection [11]. The format of the AAL 5 is shown in Figure 5.

There is also the possibility of designing an AAL specific to a particular application service if there is a need. Even if a new AAL is designed to work with an application the overall system still adheres to ATM standards.

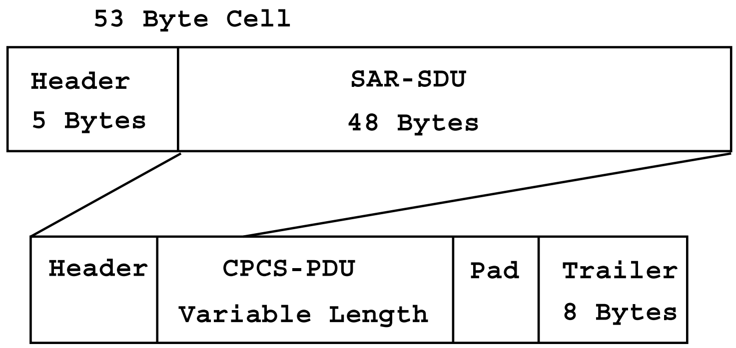

Figure 5: AAL 5 Cell Format

3.3 ATM Quality of Service

A number of parameters are used to define the QOS. These include the Cell Error Ratio, Cell Loss Ratio, Cell Misinsertion Rate, Cell Transfer Delay, Mean Cell Transfer Delay, Cell Delay Variation and the Severely Errored Cell Block Ratio. A number of classes of QOS are supported by the network and fall into either a Specified QOS or an Unspecified QOS class. Among all the classes of QOS the network must only support the Specified QOS class 1 which is the circuit emulation service and constant bit rate video. A specified QOS may have two cell loss objectives, for the high and low priority traffic. The unspecified QOS has no specified objectives given to the user but may have internal parameters for the network but these may change during a call. Even though there are no QOS the call may have specified traffic parameters, in fact that would be desirable for the network. This type of traffic could be the so called best-effort traffic. This allows the network to respond to time variable resources. The unspecified QOS is optional for the network to support.

Degradation of QOS may arise for many different reasons and one of these is the ATM switch. The buffer capacity could be a complex multiple queue system with an algorithmicaly defined service rule that could be based on priorities. The switch may thus introduce loss under heavy load. Of particular interest to JPL is that the buffering strategies for wide area low speed networks may be more complex than for high speed local area networks due to the detection of the PDU by a higher level. For compliant connections the QOS will be supported for at least the number of conforming cells as specified in the conformance definition. For non-compliant connections the network does not need to support and QOS. The QOS of a VPC will be the combination of the strictest set of QOS's of the underlying VCC's.

4 Mapping CCSDS AOS to ATM

4.1 Introduction

A key requirement in interconnecting networks is to minimize the impact on both networks. A proposal to interconnect networks should not require changes to the two networks. Two machines using incompatible protocols are to communicate. The basic question is how to interconnect two separate networks. Two possible alternative are identified.

The first alternative is not to interconnect two separate networks but to provide a direct user to user CCSDS AOS interface. In this case space craft operations may be connect to the earth stations through a leased line. In this case data is transported back to JPL by treating CCSDS AOS packets merely as a bit stream. This is currently the case for non-manned missions using the CCSDS version for unmanned missions. However, unmanned missions use only a fraction of the bandwidth necessary for manned missions. The cost of the leased lines that connect space craft operations with the earth stations is a major economic factor in considering other alternatives.

In the second alternative ATM is considered in order to interoperate with other scientific users not centrally located at space craft operations. ATM also yields bandwidth efficiency in the use of the leased circuits that connect the earth stations with space craft operations.

In CCSDS AOS and ATM both the sending and receiving network supports virtual circuit service packets. Since the ATM network resolves congestion problems by discarding packets the communications processors at the earth stations and space craft operations need to be prepared to do their own end to end error checking. This requires buffering at both space craft operations and the earth stations. ATM packets are very small. When we wish to send a large packet through a small packet size network fragmentation of the packets is necessary. Packet loss in the ATM network due to congestion may then be a problem.

Address translation is also an issue between the two protocols. In ATM virtual path identifiers can be used to set up a group routing of the individual ATM virtual circuits to the centralized location (JPL) where the individual virtual circuits are routed.

ATM and CCSDS AOS are communications protocols that both provide integrated digital services and thus there are many similarities in the protocols [7] [8]. However, while the physical layer in ATM is primarily optical cable with a low probability of bit error the physical medium of CCSDS AOS, the space channel, has a higher probability of bit errors. The physical layer of CCSDS AOS is made into a low bit error rate through the virtual channel data unit (CVCDUs). Both protocols are capable of providing integrated digital services they operate over vastely different physical channels. Both protocols adhere to the layering principles of the OSI model as is shown in Figure 6, which compares the layers of

CCSDS AOS and ATM.

OSI	ATM	CCSDS AOS
Data Link Layer	ATM Adaption Layer	Virtual Channel Link Conrol Sublayer
	ATM Layer	Virtual Channel Access Sublayer
Physical Layer		Physical Channel Layer

Figure 6: CCSDS AOS and ATM Protocol Layers

4.2 Necessary Service Mappings

Use of ATM in the ground segment of the communications system requires mapping the services of CCSDS AOS to the services provided by ATM. The categories to be transmitted are: uncompressed voice, compressed voice, compressed video, engineering data (telemetry), real-time control, high resolution images, electronic mail, computer files, high speed data transfer. Figure 7 shows the suggested mapping of CCSDS AOS services to ATM Adaptation Layers.

Application	AAL Layer	CCSDS
Voice	AAL 1	Insert Service
Voice with TASI	AAL 2	Insert Service
H.261 Video	AAL 1	Bitstream Service
MPEG Video	AAL 2	Bitstream Service
Telemetry	AAL 3/4 AAL 5	Path Service
Electronic Mail	AAL 3/4 AAL 5	Encapsulation Service

Figure 7: ATM to CCSDS AOS Service Correspondences

4.3 Mapping Voice

In CCSDS constant bit rate voice may be transmitted using either the bit stream or the insert service. ATM can serve constant rate voice using AAL-1. In CCSDS the insert service is established by an "insert zone" in every virtual channel data unit that is transmiited on the physical channel. The insert service data units are placed in this insert zone. The CCSDS insert service data can use AAL-1. AAL-1 provides circuit emulation. CCSDS insert service data is buffered until enough data is received to fill a AAL-1 SAR-PDU payload.

4.4 Mapping Video

In the CCSDS AOS protocol the bitstream service may be used to transmit variable bit rate video. The protocol data unit structure for the CCSDS AOS bit stream service is shown in Figure 8.

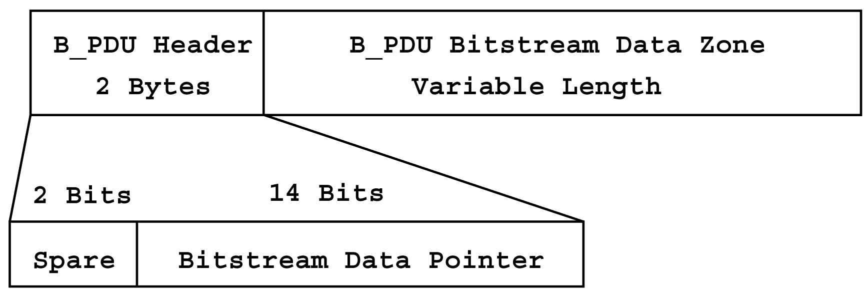

Figure 8: Bitstream Packet Format

The spare field is currently undefined and is set to 00. An insufficient number of bits may have been received before it is necessary to release a B_PDU. Therefore the bitstream data pointer is used to indicated the location of the last valid user data bit within the B_PDU bitstream data zone. The corresponding ATM service is provided by AAL-2. In AAL-2 the sequence number SN is used to detect lost or misinserted cells. The information type field (IT) is used to indicate that video is being transmitted. The LI field provides a length indicator. In addition a CRC field is provided.

4.5 Address Translation

Internetworking CCSDS AOS and ATM requires address tranlation between the two protocols. In CCSDS AOS the Application Process ID (APID) is used as the address of the communicating process. The CCSDS Version-1 packet allows up to 2048 APIDs. The APID may be combined with an 8-bit spacecraft ID to produce a unique address. In ATM the virtual circuit identifier combined with the virtual path identifier provide a unique address. Virtual path identifiers may be used to route many services as a group back to the Jet Propulsion Laboratory from the Deep Space Network earth stations. Virtual circuit identifiers may then be used to split the individual services apart.

5 Conclusions

CCSDS AOS can provide the communications services necessary for teleoperated rovers and distributed scientific instruments. The AOS protocols provide flexibility for changing mission requirements. Since the CCSDS protocols stop at he entrance into the ground network internetworking with ATM has been proposed. Incorporation of ATM into the ground segment of the DSN has been investigated in order to deal with the requirement of realtime voice and video. The background of establishing an appropriate internetworking scheme has been discussed.

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