TELEMETRY FORMATS FOR THE SPACE STATION RF LINKS

Dr. Walter Marker
Tracking and Communications Division
Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

ABSTRACT

This paper discusses the formats that have been proposed for the manned Space Station space/ground RF link. In addition to discussing the specific RF formats, the paper seeks to discuss the requirements that have caused the proposed format to exist in its current form. The paper begins by briefly discussing the historical basis for telemetry formats within NASA, and then discusses the unique requirements that the Space Station imposes, compared to traditional space probes. The paper next treats the overall requirements that must be satisfied by the Space Station communications system. Finally the paper discusses the details of the RF format and its proposed operational usage.

INTRODUCTION

The telemetry formats for the Space Station RF links are driven by a variety of factors which are often in conflict. Perhaps the strongest driving factor is the goal of the NASA ground Receiving Stations to have a common RF format for all space missions. In the past, each space mission has tended to develop a telemetry format that was best suited to that mission's particular needs. This has usually resulted in telemetry formats that were unique for each space mission. This, in turn, has required extensive modifications of existing ground receiving facilities for each space mission. Clearly it would be advantageous for the ground systems, if all space missions used the same format. If this were the case, far fewer modifications of the ground receiving stations would be necessary. Furthermore, it makes cross support of various missions possible. For example, if there is equipment failure of one mission's ground station, if the formats are identical, it might be possible to use another mission's ground station temporarily. Similarly, it might be possible for the ground receiving stations of all the international partner agencies of the Space Station to cross-support one another.

On the other hand, there are several factors that tend to counterbalance the clear advantages of having a common format. To begin with, a common format has not been optimized for any particular mission. Hence, a format that is tailored for a particular mission will probably serve the needs of that mission better. Similarly, the requirements for space missions vary greatly. Very complicated missions such as the Space Station require far more elaborate communication services than a simple space probe. The problem is to adequately serve the requirements of the complicated missions without overburdening the hardware designs of the time, it must be flexible enough to meet the requirements of new space missions, as they occur.

The push for a common RF format for all space missions was pioneered by the Goddard Space Flight Center (GSFC) and by the Jet Propulsion Laboratory (JPL) through the Consultative Committee for Space Data Systems (CCSDS). CCSDS is an international committee of seven member space agencies (US, France, West Germany, European Space Agency, India, Brazil, and Japan) which develops recommendations for space systems. The original CCSDS work on RF format recommendations began several years ago and were directed toward unmanned space systems at low-to-moderate data rates (kilobits/sec). The original CCSDS format recommendations contained two data structures: a packetized data structure called a CCSDS Source Packet; an RF telemetry format called a CCSOS Transfer Frame. The general idea was that an experiment's output would bp formatted into variable length Source Packets. The transmission to the ground. The Transfer Frame also has a small header so that limited addressing is possible. A fixed Transfer Frame length was selected to allow the sync pattern to occur at fixed time increments. It was generally agreed that would allow the Transfer Frame boundaries to be determined more easily in the noisy RF environment. For the Space Station space/ground links a Transfer Frame length of 10,000 bits seems likely. The challenge facing the Space Station Program is how to adapt these standards (or some derivative of these standards) for a manned program with much higher data rates and a much more dynamic environment.

DIFFERENCES IN TRAFFIC FROM SPACE STATION VERSUS CLASSICAL SPACE MISSION

There are several main differences between the traffic that is envisioned for the manned Space Station and the traffic for which the CCSDS formats were originally conceived:

1. The Space Station traffic will have a much more dynamic component of traffic than traffic from most unmanned probes.
2. The Space Station traffic will involve human to human interaction via audio, video, and workstations.
3. The Space Station traffic will have a large number of users involved with computer to computer traffic.

4. The Space Station Program will have much higher data rates and will require a much broader geographic distribution of data in near real time.

Each of these items will be discussed in turn.

Dynamic Component of Traffic

In addition to classical telemetry, the Space Station will have a type of user who will cause much more dynamic changes in traffic. The Space Station will have a very large number of ground controllers and ground based experimenters who will interact with both experiments onboard and with core Space Station functions. This will be much more like a Local Area Network at a university, than a classical space mission. Like any other computer networks, this will involve large numbers of users interacting with the computers onboard the Space Station. Users will be logging on, issuing commands, checking system status, interacting with astronauts, etc., in addition to dumping data. This is very different from a classical space probe mission in which a fixed number of instruments produce data at a fixed rate. The classical space mission could use standard Time Division Multiplexing to interleave the data from its fixed number of instruments. The Space Station must employ modern data communication techniques of buffers and statistical multiplexing.

Human Interaction Via Audio and Video

Human interaction also imposed unique requirements on the Space Station Program. The telephone companies long ago discovered that humans are very sensitive to time delays in communications. For example, if someone asks a question, ("Do you agree?"), if the reply does not occur relatively rapidly the question tends to be repeated. In communication systems with long internal delay times, the reply can be processed by the system, while the question is being repeated. This tends to cause the two ends of the communication system to "talk over" each other. This greatly increases effective system response time and tends to cause confusion since the question is often changed when it is repeated. The long distance telephone companies have found that this "talk over phenomenon" tends to occur when the round trip delays exceeds 1/2 sec. Similar phenomena occur with human interaction via video and workstations. Unfortunately, the RF speed of light transmission delays for Space Station traffic relayed from the TDRS satellites are approaching this figure. Thus the Space Station communication system can only add minimal processing delays of its own to the communication process.

Computer-to-Computer Traffic

As described in (1) and (2), interaction of users with the Space Station will be much more like interaction with a computer system than like classical telemetry. The Space Station is simply too complicated to be run manually by flipping switches. Instead, large numbers of computers are required to monitor system status, configure equipment, etc. Communications with these computers will be implemented using standard data communication techniques. The Data Management System (DMS), which connects all U. S. computers onboard the Space Station, and also provides gateways to the international partner's modules, is planning to implement a full International Standards Organization (ISO) Open Systems Interconnection (OSI) 7 layer protocol stack. These computer-to-computer protocols are generally intolerant of bit transmission errors and effectively have to be delivered error free. This is a much more stringent error criterion than has been applied to data from most space mission in the past. An exception to this statement is the loop back of commands that is used on the current Space Shuttle. In this system, commands issued by the ground are echoed back by the Orbiter. The ground then does a bit by bit comparison, to determine if any bits were corrupted during transmission. This technique works, but it is very slow and inefficient in bandwidth utilization. It is not practical for the large volume of data anticipated for Space Station.

High Data Rates and Widespread Geographic Distribution of Data

The Space Station Program has baselined a Space-to-Ground data rate of 300 megabits/sec. This is a tremendous amount of data. It makes data storage of all data at a single facility impractical. This corresponds nicely with the desires of most scientists to see their data as quickly as possible. Thus, it is planned to distribute most Space Station data fairly quickly to the experimenters facility. For small amounts of data (status, summary, command loops, etc.), this usually involves transmitting the data over data networks on the ground. Thus, considerable internetworking will be required. This is very different from classical space missions where data was recorded onto tape at the ground station to be processed and finally mailed to the experimenters weeks or even months after it was received.

FUNDAMENTALS OF SPACE STATION ARCHITECTURE AND TRAFFIC

The details of the Space Station communication systems architecture are given in other papers in this session. However, the key point for the current paper is that all onboard systems are interfaced with the ground via the signal processors, which are part of the Communications and Tracking System. In terms of the OSI model , this signal processor is a low level relay node in the overall Space Station Information System (SSIS). The signal processor has very limited data communication functionality. Its job is to transform the onboard Space Station communications to the RF link format. The preliminary Space Station design calls for a 300 Megabits/sec space to ground downlink and a 12 or 25 megabits/sec ground to space uplink. These are the current operational limits of the TDRS satellite that will be used to relay Space Station traffic to/from the ground. The vastly different data capacities on the up and down links are reasonable because the Space Station is envisioned to be somewhat of a research facility in the sky. Tremendous quantities of data will be broadcast from the Space Station to the ground. Relatively little data will flow to the Space Station. The same format is planned to be used on both the uplink and downlink.

This signal processor interfaces to:

1. The Data Management System Local Area Networks (LAN's);
2. Individual Fiber optic links from high rate payloads;
3. The audio system
4. The video system

Each of these traffic sources will be discussed in turn.

Data Management System LAN's

It has been proposed that the Data Management System will consist of two 100 Megabits/sec LAN's. One LAN will connect all core Space Station computers. The other LAN will interface all experiments with data rates below approximately 10 megabits/sec. Traffic from the core DMS system will be typical computer-to-computer traffic. It will be very bursty as various users require various actions from the computers and will require very low bit error rates. The full ISO protocol stack has been proposed. The DMS traffic on the low rate payload LAN will consist of actual user data, which has been encapsulated by whatever of the OSI protocol suite is required to support the services requested by the user. The DMS will interface to the RF link via an interface to the C&T signal processor.

Preliminary analysis of Space Station traffic has indicated that Space Station users fall into two distinct classes from a data communication standpoint:

- Transaction oriented users, who require the full suite of ISO data communication protocols.
- Stream oriented users, who desire only stripped down telemetry service with a minimum of protocol overhead.

In fact, a given user probably falls into both categories at different times during their interaction with Space Station. For example, when a scientist interacts with their payload, they will probably engage in a computer-to-computer dialogue, which requires the full suite of ISO protocols. However, when the payload is in the data transmission phase, only classical telemetry services are required. Since the Space Station communication system is being designed using a layered communication architecture, the type of data being carried is largely transparent to the RF format.

High Rate Payload Links

Some payloads that are planned for Space Station have data rates that exceed the throughput capacity of the DMS/C&T interface. Hence, they cannot be adequately served by the DMS LAN's. Instead it is proposed that these payloads be attached directly to the C&T signal processor via optical fibers. The high rate payload data will be inserted directly into the RF format. Little if any data communication services will be performed for this data.

Audio System

The Space Station will have an internal audio network which extends throughout all the pressurized modules. There will be numerous internal taps throughout the Space Station that will enable the crew to plug into the audio system and obtain most of the audio services that are available from a modern telephone. While the exact audio format has not been baselined by the Space Station Program (as of the writing of this article), the ISDN format is currently favored. Regardless of the format selected for the onboard audio system, when transmission to the ground is required, the audio channel must be extracted from the onboard audio network and integrated into RF space ground link.

Clearly, it is not acceptable to place audio into its own channel by accumulating enough audio samples to fill a 10,000 bit/frame. The standard digital audio sampling channel is 64 kilobits/sec. Thus to accumulate 10,000 bits will take approximately 1/6 of a second. This is a large fraction of the total available time budget. Audio compression that has been contemplated will only aggravate the problem. A more time efficient method must be used to handle audio. The number of audio channels that must be transported to the ground will vary considerably as a function of the mission profile. However, the number will never be very large. The Space Station is currently baselined to have an initial crew size of 10. It is unlikely that all the crew will want to talk to the ground at the same time. Hence, only 3 or 4 simultaneous audio channels are anticipated. With a maximum of 64 kilobits/sec per audio channel, it is clear that audio will only use a small portion of the space/ground bandwidth.

Video System

The video system has a network that extends both throughout the pressurized modules as well as on to the Space Station external truss and boom structure. Numerous attachment points are provided for both video cameras and monitors. Again the precise format that will be used for video has not yet been baselined by the program (as of the writing of this article). However, there is a strong push for the use of international standards. CCITT standards are currently being investigated for possible use. Regardless of the format selected for the onboard video system, when transmission to the ground is required, the video channel must be extracted from the onboard video network and integrated into RF space ground link. Preliminary analysis suggests that the video signal can easily be compressed to approximately 22 megabits/sec for full motion, full color video. Further compression is possible if full motion is not required. However, the large number of video channels that will probably be utilized means that video will contribute significantly to the utilization of the space/ground link.

OVERVIEW OF THE REVISED CCSDS TRANSFER FRAME FORMAT

The details of the CCSDS Transfer Frame format are undergoing rapid evolution. It is planned to finalize the format late in 1987. The evolution of the Transfer Frame format is caused by the need to update the original CCSDS Transfer Frame format so that it is suitable for use on advanced space missions like the Space Station. Thus, the previously published CCSDS documents which discuss the Transfer Frame format are useful references for design philosophy and approach. However, slight changes in the bits of the header should be anticipated.

The primary characteristics of the CCSDS Transfer Frame structure are:

1. Fixed length of approximately 10,000 bits for Space Station space/ground link.
2. A header of approximately 48 to 64 bits.
3. An error protection code of unspecified length (probably in the range of 24 to 48 bits) protecting the header. (This is a modification of the original Transfer Frame format.)
4. Within the header, having fields which indicate (among other things):

   - space craft identifier
   - Virtual Channel (VC) ID
   - VC sequence number
   - pointer to beginning of first packet header within the data portion of the Transfer Frame
   - flag to indicate existence of audio insert field (This is a modification of the original Transfer Frame format.)

5. Audio insert field immediately following the header error correction field. (This is a modification of the original Transfer Frame format.) The audio insert field is a variable length field which consists of:

- A one octet field that indicates the length of the audio insert field in octets.
- The indicated number of octets of audio data.

6. The option of protecting the entire Transfer Frame with Reed-Solomon encoding.

OPERATIONAL USE OF TRANSFER FRAME CONCEPT

While the operational plans for the usage of the CCSDS Transfer Frame for the Space Station are still evolving, a consensus is beginning to emerge within NASA. The header of all Transfer Frames will be protected by the header error protection code. It seems reasonable to use the VC ID number to segregate the various types of traffic on the RF link; video, high rate payload, etc. In other words, when the traffic initially arrived at the C&T signal processor, a specific VC ID would have already been selected for that traffic. In fact many things are assumed to be prearranged. A few VC's are assumed to be reserved as "order wires" to specify the type of service the data receives and to control the configuration of the network, particularly between the Space Station and the ground receiving stations Data Interface Facility (DIF). When the data arrives at the C&T signal processor everything has been preparranged. The data is placed in a buffer for that particular VC; either approximately 8,000 bits for Reed-Solomon coded VC's or 10,000 bits for uncoded VC'S. The data is placed into transfer frames and transmitted on the RF link, either when the buffer is full or when some prearranged timeout has been reached. In addition, it is assumed that there will be a small number of "Emergency" priority channels. Data in these channels will be placed in Transfer Frames as quickly as possible, when they arrive at the signal processor. However, it is envisioned that this will be handled by a sequential poling scheme in the signal processor which just samples the emergency VC often enough to satisfy any SSIS delay criterion.

This mapping of data to VC's is perhaps easiest to visualize if each type of traffic is discussed sequentially.

High Rate Payload Data

The manner in which high rate payload data is handled is clearly the easiest case to visualize. The traffic arrives at the C&T signal processor on a dedicated optical fiber. It is not multiplexed on the fiber with any other traffic. The C&T signal processor must take all data that appears on that fiber and place it in Transfer Frames with a prearranged VC ID number and Grade of Service. It is not assumed that there is any protocol information on the fiber which can be used to configure the treatment that the data receives. The data only requires stream service. The VC ID number that has been preallocated for this data has been communicated to both the C&T signal processor and the DIF. When the DIF receives this VC it switches it (based on VC ID number) to the next set of equipment which has been preallocated to perform whatever processing the data requires.

This type of service represents the classical telemetry service. It is assumed that the high rate payloads will generate vast quantities of data, but will require very little network services from SSIS. It is assumed that the data will either be processed at the ground station or put onto dedicated transmission lines to route it to its final destination. Hence, no elaborate networking protcols are required. The VC ID number alone will be sufficient.

Video

The case for video is very similar to the case of the high rate payload data, but is a little more complicated because many video channels are available on the video network. At the interface of the signal processor to the video network, the signal processor will be directed to select a specific video channel and place it in a preselected VC (i.e., place channel 4 in VC 49). The DIF will have been informed in advance of what to do with the selected VC. In most cases, the DIF will perform any required smoothing, buffering, etc, and then place the video onto a ground will be similar to what is done today for video distribution.

Audio

Audio traffic is handled somewhat differently from the two previous cases. The audio data will be inserted into the audio insert field of selected, prearranged, Virtual Channels. However, the final destination of the audio traffic need not be related to the final destination of the other data in the selected VC’s. The VC’s in which audio will be insert are planned to be selected on the basis of a high and regular data rate. In other words, the goal is to insert audio into transfer frames that will be transmitted as near as possible to synchronously with the audio sampling rate or some multiple of it. The goal of course is to minimize the buffering and time delays in accumulating the 8 bit audio samples. For example, if there was a data source onboard Space Station that transmitted a Transfer Frame every 125 micro seconds, then the audio sampling rate would be exactly matched and the 8 bits of audio could merely be inserted into every transfer frame. However, 10,000 bits every 125 micro seconds corresponds to 80 Megabits/sec. This is a very high data rate and will not usually be available. On the other hand, the Reed-Solomon encoding adds about 20% coding overhead, so an encoded channel only carries about 8000 bits of data. Thus, the real data rate required for a near-synchronous encoded channel is closer to 64 megabits/sec. This is still rather high. However, if 4 audio 8 bits samples were included in each transfer frame, the required data rate would drop to 16 megabits/sec, which is reasonable.

The audio insert field represents a flexible way of configuring the system to allow audio to be transmitted to the ground in a time efficient fashion. It is not anticipated that the length of the audio insert field will vary over a short time period; i.e., frame to frame on the selected VC’s. Over a long time period, as audio channels are added or subtracted from the link, the size of the audio insert field will change. Similarly, the size of the audio insert field will also change as the bit rate of the piggyback channel changes. For this reason, a relatively static relatively synchronous Virtual Channel is desired. Core Space Station housekeeping data seems to be a good candidate data stream on which to piggyback audio. The Core Station housekeeping data will always be present and its rate should be known apriori.

When the VC which contains the audio insert field reaches the DIF, the audio data is immediately copied from the transfer frame and sent to an audio processor which performs any necessary smoothing, buffering, etc., and then sends the data out over ordinary audio lines. If for example, the ISDN standard was both used on the Space Station and available on commercial telephone networks, a direct interface to the telephone network would be possible.

The significance of the word copied in the above description should not be overlooked. If the piggyback channel is a Reed-Solomon encoded channel, the audio insert field falls within the coded space. Thus these bits cannot be removed before the Transfer Frame is decoded. To avoid processing time delays, the alternatives are either to build very fast decoders or to copy the audio insert field. It was initially believed that copying the audio insert field would be cheaper to implement. However, this issue is still being studied.

DMS LAN Traffic

The DMS LAN traffic falls into two distinct types; transaction oriented and stream oriented. However, both service types are handled identically by the C&T signal processor, except for error protection. All DMS traffic is segregated at the interface of the C&T signal processor with DMS, into memory buffers on the basis of the VC in which the data is to be placed. The mapping of data sources to these VC have been coordinated between DMS and the DIF. In other words, the data is segregated according to the type of service it is to receive at the ground. For example, DMS has a Payload network as one of its LAN’s. Some data from this LAN is only destined for local processing at the ground station, just like the high rate payload data. Such data can be treated exactly like the high rate data was treated. It is placed “as is” into Transfer Frames and the initial routing on the ground is based on the VC ID number.

On the other hand, the DMS transaction oriented service involves data that has been encapsulated by layers of ISO protocols. These protocols are carried transparently by the

Transfer Frame in its data portion. As far as the Transfer Frame is concerned, this data looks like any other data. However, the error requirements for this type of data are far more stringent than classical telemetry. Effectively, no errors are tolerable. The only way error free, complete transmission can be provided is with a retransmission protocol. It is planned to save each Transfer Frame of transaction oriented service onboard the Space Station until it has been received and decoded on the ground. If uncorrectable errors are detected, retransmission of the frame will be requested.

CONCLUSION

This paper has discussed both the formats and the operational concepts of the format that have been proposed for the Space Station space/ground link. The requirements that are causing the evolution of NASA RF formats have been discussed. A similar set of delibrations are also underway for the Space Station space-to-space links. Again, there is discussion of using a format that is similar to CCSDS Transfer Frame. However, the variability of data rates and equipment sophistication that must be supported over the space-to-space links are much greater than over the space-to-ground link. This will be a major study area for near term work within the Space Station Program and the standards committees.

REFERENCES

1. Muratore, John F., “Trends in Space Station Telemetry Applications,” International Telemetry Conference Proceedings, 1987.
2. Whitelaw, Virginia, “Telemetry Handling on the Space Station Data Management System,” International Telemetry Conference Proceedings, 1987.