TELEMETRY PACKETIZATION FOR IMPROVED MISSION OPERATIONS

EDWARD P. GREENE
Goddard Space Flight Center
NASA

Summary. The requirements for mission operations data management will accelerate sharply when the Space Transportation System (i.e., Space Shuttle) becomes the primary vehicle for research from space. These demands can be satisfied most effectively by providing a higher level source encoding function within the spaceborne vehicle.

An Instrument Telemetry Packet (ITP) concept is described which represents an alternative to the conventional multiplexed telemetry frame approach for acquiring spaceborne instrument data. By providing excellent data integrity protection at the source and a variable instrument bandwidth capability, this ITP concept represents a significant improvement over our present data acquisition procedures. Realignments in the ground telemetry processing functions are described to take advantage of the ITP concept and to make the data management system more responsive to the scientific investigators.

Introduction. During the nearly two decades of scientific exploration from space, NASA has evolved data management systems for the acquisition, calibration, validation, analysis, and interpretation of space-acquired sensor data. As we look towards the future, we need to ask ourselves whether the basic structure of our present data management system is well-suited to cope with the requirements that will be levied as a consequence of the Space Transportation System. Some of the principal driving functions during the Shuttle Era will be:

1. Reduced pre-launch preparation time,
2. Greater number of missions,
3. Shorter mission support start-up time due to the necessity to provide operational support for Spacelab missions lasting on the order of one week,
4. Greater demand for near real-time experiment data processing from remotely located facilities,
5. Greater variety of recording media including post-flight recovered tapes and film,
6. Greater numbers and sophistication of spacecraft instruments, and
7. Higher composite data rates.

A key constraint which has influenced our data management systems in the past has been the requirement to keep the on-board telemetry and data handling subsystem as simple as possible. Size, weight, power, and reliability considerations all combined to dictate that strict attention to a minimal on-board subsystem be observed. These factors still remain important considerations but the technology that has emerged during the past twenty years has relaxed these constraints. Size, weight, and power consumption limitations have been significantly reduced due to a combination of improved digital logic technology and more capable launch vehicles. In addition, the speed and reliability of digital logic has improved immensely.

In analyzing our present data management system, it became apparent that many of the problems that we have experienced with our present data management structure could be eliminated or, at least, eased considerably by more intelligent telemetry control on-board the space vehicle. A key element in virtually every spacecraft telemetry system has been a multiplexer which, for a given mode, samples, encodes, and transmits various sensors signals in a predetermined sequence. In the earlier spacecrafts, only a single sampling mode and data rate were provided; now, multiple modes and data rates are usually available via ground-controlled commands.

As spaceborne instruments become more sophisticated they tend to become more selective regarding the phenomena being investigated. Instead of performing a continuous survey of some observable phenomena at a constant data rate, more recent instruments tend to search for specific transient phenomena that may only be within the instrument's field of view at sporadic intervals. When the phenomena is present, the instrument may be capable of collecting useful data at a very high rate; otherwise, no useful data is collected. This type of instrument is not well-suited for our present multiplexing system in that it is usually not possible to anticipate the occurrence of the phenomena and to select the optimum telemetry mode for its duration. The problem is further complicated by the competing demands by all the various instruments on-board a space mission and the requirement to transmit this data over a fixed bandwidth telemetry channel. The lack of adaptive on-board control makes it virtually inevitable that each instrument will be grossly oversampled when the applicable phenomena is not present and undersampled when it is present. It has been estimated that only about 1 percent of the telemetered scientific instrument data received from spacecrafts is ever subjected to detailed analysis.

The unit of data transmission from the spacecraft has traditionally been the multiplexed telemetry frame. The loss of a single telemetry frame results in gaps in all active instrument data sets. In some cases, where the data is very redundant, a simple smoothing operation can reconstruct the missing data points to a satisfactory accuracy; but, where the data is most interesting, it lacks this redundancy. Thus the loss of a single frame may have a serious adverse effect on the experimental analysis. Furthermore, it is usually necessary to extract instrument data from many consecutive multiplexed telemetry frames to form a set of observational data. The loss of a single frame creates a potential problem which may becloud the interpretation of the entire set. Thus, the fragmentation of the instrument data into numerous telemetry frames results in a multiple jeopardy situation which seriously impairs the inherent data integrity.

Described herein is a concept for more adaptive on-board telemetry control which will reduce some of the problems associated with multiplexed telemetry systems. While this concept has not yet been adopted for any NASA mission, its implementation is being considered as a partial solution to provide responsive data management capabilities in the Shuttle Era.

Instrument Telemetry Packet (ITP) Concept. The Instrument Telemetry Packet (ITP) concept is proposed as a replacement for the conventional multiplexed telemetry frame approach. The ITP concept basically requires that the telemetry data from a single spaceborne instrument or spacecraft subsystem be temporarily stored in a dedicated buffer memory and that a telemetry packet be assembled containing only the data from a single instrument along with any required ancillary data (spacecraft clock, reference voltages, spacecraft and instrument control states, parity check bits, etc.) necessary for the validation, calibration, and cross-linking of this data with other subsequently derived data sets. In the not too distant future it will be possible to generate and insert corrected time, position, and attitude directly into an ITP; however, this may be beyond the state-of-the-art at the time it would be desirable to implement the initial ITP concept. Except for these items, each ITP should be a standalone element containing all the data necessary for the validation, calibration, reduction, and interpretation of one or more experimental observations from a single instrument. Even a few years ago the ITP concept described herein would have been impractical due to the resulting complexity, cost, and power requirements. Now, with the emergence of powerful low-cost microprocessors and associated semiconductor memories, this concept is technologically feasible.

The need for such a technique is based on the principle that the integrity of the observational data can be best insured by encoding this data into a reliable transmission unit immediately at the source. Many of the problems and frustrations experienced within telemetry data processing operations originate because the basic integrity of the sensor data is compromised before it reaches the processing site, thus necessitating complex and usually only partially successful recovery procedures.

The ITP concept presented herein performs two extremely important functions:

1. It provides a high level source encoding function to improve the integrity of the resulting observational data, and

2. For the first time it frees the instrument designers from the shackles imposed by a synchronous telemetry system.

Both functions will have profound effects on mission data management. The subject of source encoding has traditionally involved the consideration of the statistical nature of the experimental waveform and the development of encoding techniques which would permit the transmission of a set of experimental observations using minimum bandwidth. The ITP concept extends this subject to include the capture of all feasible ancillary data required for the interpretation of the observation set. It also provides a more reliable transmission mechanism by eliminating the multiple jeopardy conditions that have heretofore plagued frame-multiplexed telemetry data processing. Implementing the ITP concept will not reduce the channel error rate but it will insure that a channel error will affect only a limited set of observations from a single instrument or subsystem.

Another important advantage of the ITP concept is that it eliminates arbitrary fixed instrument data bandwidth constraints and, within broad limits, permits the instrument designer to acquire experimental data at the rate appropriate for the process being observed. The ITP concept provides a means whereby the variable data bandwidth of an instrument can be accommodated for an indefinite period. Naturally, there are limits to this capability and the fixed-bandwidth real-time telemetry link would saturate if all instruments were to continually output data at the maximum data rate. However, it would be possible to implement an overflow provision such that sensor data in excess of the telemetry channel bandwidth are routed to an alternative output media (e.g., an on-board tape recorder). Nearly continuous data readout potential via the Tracking and Data Relay Satellite System (TDRSS) will be possible in the 1980's which will provide more flexibility in the data acquisition capability than is achievable in the present ground-station network.

The proposed Data Acquisition and Processing (DAP) subsystem implemented to take advantage of the ITP concept would consist of three functional units: 1) On-Board ITP Assembly, 2) Telemetry Data Reduction Facility, and 3) Instrument Analysis Centers. The processes performed by each of these units will be described in the following sections.

On-Board ITP Assembly. For each instrument or subsystem, sensor data will be collected, formatted, and stored in separate ITP processors which will contain buffer memory sufficient for storing two packets of the maximal size defined for that instrument. The ITP multiplexer will sequentially poll all ITP processors and any enqueued packets will be transmitted to the multiplexer buffer while the next packet is being assembled. This is shown diagrammatically in Figure 1. The ITP multiplexer unit will be responsible for servicing all active ITP processors and routing the encoded ITP to the proper digital output media.

It will be necessary to implement a variable length packet format since no single length is well-suited for the diverse mixture of instrument requirements that are likely to be encountered. Even within a single instrument there may be needs for different sized packets depending upon the mode of operation. Table 1 depicts a possible packet format. This should be considered for illustrative purposes only. More careful analysis would be required to identify the control fields and their formats.

As illustrated, an ITP would contain three principal components:

1. A fixed length packet header containing a number of pre-defined fields common to all ITPs,
2. A variable length sensor data field (length defined within header), and
3. A fixed length parity check field.

Table 1
Possible ITP Format

		Field Length (Bits)
ITP Header		128 Bits
Frame Sentinel	32	
Sequence Number (Modulo 256)	8	
Packet Size (in 8-bit bytes)	8	
Instrument ID	8	
Spacecraft Control State	16	
Instrument Control State	16	
ITP Time Stamp	40	
Instrument Sensor Data		Variable
Error Control Coding		32 Bits
		160 + Variable Bits

The spacecraft time and control state fields would be supplied by the spacecraft control subsystem and distributed on a bus to all ITP processors. The ITP Time Stamp would represent a sample of the spacecraft clock at the time that the packet assembly was initiated. A 40-bit field is tentatively assigned which should permit the recording of time to the full resolution capability of the spacecraft clock. If necessary, the subsequent ground processing operation would derive a time correction value to convert this ITP Time Stamp to Universal Time. Where it is necessary to reconstruct the time sequence of observational data contained within an ITP to greater precision, it would be the responsibility of the instrument designer to generate and encode within the ITP whatever synchronization control is required to reconstruct the time-line relative to the ITP Time Stamp.

The ITP multiplexer will be responsible for controlling the distribution of all encoded ITPs from their respective ITP processors to the designated output media. It is envisioned that the ITP multiplexer would poll all active ITP processors in sequence and, if an enqueued ITP were ready, would set up a high speed Direct Memory Access (DMA) transfer between the ITP buffer and an internal buffer within the ITP multiplexer. The multiplexer will maintain routing tables (changeable via multiplexer commands) which will specify the desired output media for each instrument and the multiplexer will route the ITP to the appropriate device(s). The real-time telemetry system and the on-board tape recorders are expected to be the principal output devices. Other devices such as a digital film recorder or an on-board display system could be provided as the technology progresses.

Each ITP transfer represents a transaction for the ITP multiplexer and a short entry will be made in the transaction logger describing the transaction. Other events, which will be encoded as transactions, will be changes in the spacecraft control state, receipt and execution of stored or real-time commands, periodic time codes, and special error conditions (e.g., ITP buffer overrun). These transactions will be accumulated into an appropriate sized block and then encoded into and transmitted as a uniquely identifiable telemetry packet of the ITP format. This data set will then provide a complete summary of the on-board data management functions.

Provisions must be made to handle the fact that the desired instantaneous ITP data rate into the real-time telemetry system will not be identical to the fixed bandwidth capability of this system. When the instantaneous ITP data rate exceeds the channel rate, a certain amount of short-term buffering will be provided within the ITP multiplexer. If this buffer space is exhausted, then the ITP multiplexer will override the routing instruction and reroute the incoming ITP to one of two on-board tape recorders (or equivalent mass memories) for subsequent playback. Since the tape recorder bandwidth will presumably be much greater than the real-time telemetry bandwidth, permanent loss of observational data should never occur provided the on-board tape recorders are operating properly and that the telemetry channel has the capability of keeping up with the ITP data rate averaged over a long-term period (i.e., time required to fill up the on-board tape recorder). The two on-board tape recorders will be operated in a ping-pong mode. One will be recording the ITP multiplexer overflow while the second is being output to the telemetry transmitter during times when no real-time ITP is ready for transmission. When the telemetry channel bandwidth exceeds the composite (real-time and stored) ITP demand, the telemetry transmitter will be designed to transmit a continual sequence of “IDLE” patterns until an encoded ITP is ready for transmission. These “IDLE” patterns will be stripped out of the telemetry by the ground-receiving equipment.

Each ITP processor is envisioned to be a microcomputer containing a microprocessor, semiconductor memory (ROM for program execution and RAM for buffer storage), and I/O control. The firmware of each ITP processor would be developed to input sensor data from one specific instrument, input common reference data (i.e., spacecraft clock and control state), format this data into ITPs, buffer the enqueued ITPs, and output the ITPs to the ITP multiplexer when commanded to do so. The error control coding can be done most efficiently by the ITP multiplexer as the ITP is being transferred along a common bus into the multiplexer.

Telemetry Data Reduction Facility. As a consequence of the implementation of the ITP concept, the initial ground-based telemetry reduction operations can be greatly streamlined. The principal functions which would be performed by this facility are the following:

1. Receive, synchronize, and decode all incoming ITPs.
2. Sort ITPs into individual instrument and subsystem data sets.
3. Re-order ITPs into ascending time sequence and perform data completeness checks.
4. Compute the Universal Time associated with each ITP Time Stamp and merge this information with the received ITP into an Annotated Instrument Telemetry Packet (AITP) file.
5. Create an AITP file header containing a summary of each AITP file identifying:
   - The AITP count contained within file, the time period covered (and gaps if any), and other applicable quality control parameters, and
   - Extracted relevant transaction entries from Transaction Logger File.

- Transmit the AITP file to the applicable Instrument Analysis Center via telecommunications link.

In the proposed concept, the Telemetry Data Reduction Facility would not perform any of the following functions:

- Calibrate, analyze, or reformat the sensor data contained within an ITP.
- Perform time tagging of individual observations other than the conversion to Universal Time of the Time Stamp field within each ITP.
- Perform computation of position, attitude (or any other general reference parameter) except in response to a specific data request.
- Attempt to reconstruct data which may be lost or received with detected error(s).

The Telemetry Data Reduction Facility will copy the ITP into the AITP and will perform no inspection or processing of the instrument sensor data contained within an ITP other than to perform an error detection decoding operation and to set a quality control flag bit conditional on the result.

Instrument Analysis Center. Each mission instrument package will have an Instrument Analysis Center which is responsible for analyzing the instrument sensor data and performing whatever validation, calibration, conversion, correlations, transformations and/or media reformatting operations are required to generate data product(s) suitable for direct perusal and interpretation by the cognizant investigators. An Instrument Analysis Center may be co-located with the Telemetry Data Reduction Facility or it may be remotely located. However, even if the two facilities are co-located, it would be desirable to provide a clean separation of these two distinct functions in the interest of organizational cognizance and funding support. In the case of remotely located Instrument Analysis Centers, the AITP files will be transferred from the Telemetry Data Reduction Facility by telecommunications circuits.

Conclusion. Without discounting the potential problems associated with the ITP concept and the proposed DAP subsystem, it is believed that the advantages to be gained by such a change far outweigh the disadvantages. The adoption of the ITP concept as the future on-board processing system for NASA missions would have the salutory effects of:

- Increasing amount of useful data available to investigators,
- Reducing telemetry delivery time,
- Reducing overall processing cost per recovered data point, and
- Providing more responsive overall control of mission data operations.

While the ITP concept would have the effect of simplifying the ground-based telemetry processing operations, this is not the reason that it is proposed. For processing functions that can be performed with equal effectiveness either on-board the spacecraft or on the ground, it will still be more reliable and cost effective to perform the functions on the ground. However, the functions of insuring efficient instrument bandwidth utilizations and source data integrity can only be done at the location where the data is originally acquired. The entire purpose of intelligent bandwidth utilization is to allocate the fixed channel bandwidth resources among those instruments that have a current need for bandwidth. Obviously, it is too late to do this function after the data has been received on the ground. Unfortunately we don’t have an “untransmit” capability to recover the bandwidth lost when a data record, which later proves unnecessary, is transmitted to the ground! Insuring data integrity is a function that also must be performed at the source. If it is not done there, then the attempts to regain data integrity after the data has been transmitted over an imperfect communications channel can never be fully successful.

The proposed approach would distribute to the Instrument Analysis Centers a number of functions that are performed by the central Telemetry Data Reduction Facility under our present data management system. However, the transferred functions are those which could be performed most efficiently under the control of personnel having greater familiarity with the specific instruments. The general-purpose functions which are common to all instruments would continue to be performed centrally at the Telemetry Data Reduction Facility. As a consequence of freeing the Telemetry Data Reduction Facility from all instrument-unique processing responsibility, the delay introduced by the Telemetry Data Reduction Facility should be greatly shortened, thus making the overall data management system far more responsive to the needs of the investigators.

Our present telemetry data processing operations are analogous to an attempt to unscramble an egg. As applied to the expected future workload, these procedures are likely to result in a slow and inefficient operation. The time to start to develop viable plans for responsible data management in the mid 80’s is now.

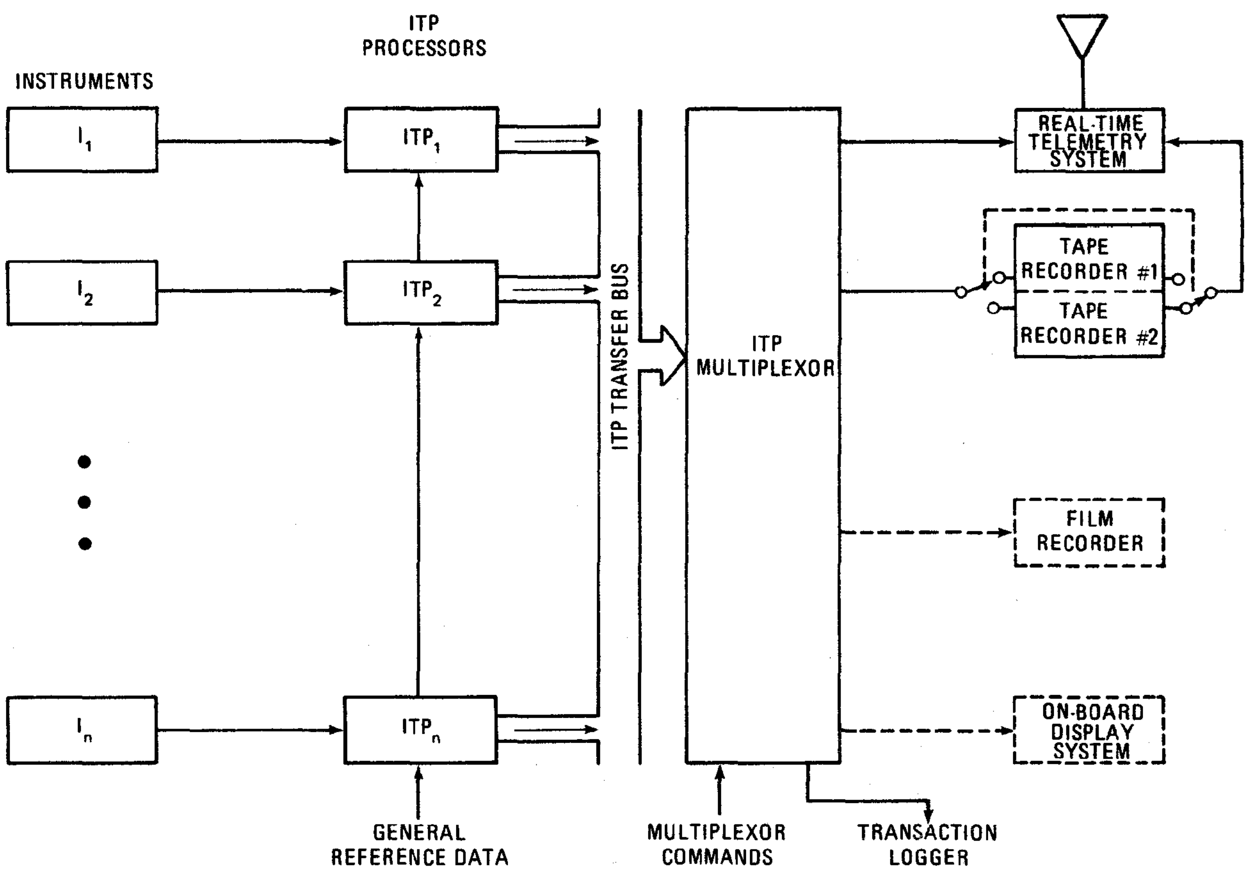

Figure 1. On-Board ITP Distribution System