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THE ESA STANDARD FOR TELEMETRY & TELECOMMAND PACKET UTILISATION P.U.S.

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ABSTRACT

ESA has developed standards for packet telemetry (Ref.2) and telecommand (Ref.3), which are derived from the recommendations of the Inter-Agency Consultative Committee for Space Data Systems (CCSDS). These standards are now mandatory for future ESA programmes as well as for many programmes currently under development. However, whilst these packet standards address the end-to-end transfer of telemetry and telecommand data between applications on the ground and ***Application Processes*** on-board, they leave open the internal structure or content of the packets.

This paper presents the ESA ***Packet Utilisation Standard (PUS)*** (Ref.1) which addresses this very subject and, as such, serves to extend and complement the ESA packet standards. The goal of the PUS is to be applicable to future ESA missions in all application areas (Telecommunications, Science, Earth Resources, microgravity etc.). The production of the PUS falls under the responsibility of the ESA Committee for Operations and EGSE Standards (COES).

Keywords: Packet Utilisation, Packet Structure, COES.

1. INTRODUCTION

In the past, the monitoring and control of satellites was largely achieved at the "hardware" level. Telemetry parameters consisted of digitised read-outs of analogue channels and status information sampled from registers or relays. These parameters were sampled according to a regular pattern and appeared at fixed positions in a telemetry format.

Similarly, control was performed using fixed-length telecommand frames which contained basic instructions for loading on-board registers or for enabling/disabling switches.

Moreover, the associated space-ground communications techniques guaranteed neither a reliable nor a complete transmission of telemetry and telecommand data.

Through the 1980s, there was a progressive increase in the use of on-board software to implement functions which should logically be performed on-board the satellite rather than on the ground e.g. control loops with short response times, data compression prior to downlink etc. However, this software had to be remotely monitored and controlled using the traditional hardware-oriented techniques.

This imposed significant constraints on the on-board software implementation, limiting its flexibility and consequently hampering the trend towards more on-board intelligence and autonomy.

In order to overcome these problems, the CCSDS recommended the use of telemetry and telecommand packets (Refs. 4 & 5) which provide a high quality space-ground communication technique enabling a flexible exchange of data between an on-board ***Application Process*** and a ground system. An Application Process is a logical on-board entity capable of generating telemetry packets and receiving telecommand packets for the purposes of monitoring and control. It is uniquely identified by an Application ID, which is used to establish an end-to-end connection between the Application Process and the Ground. Many different mappings can be envisaged between Application Processes and on-board hardware. At one extreme, each platform subsystem or payload (or part of thereof) could contain its own Application Process. In a more modest design, a single Application Process, say within the OBDH, could serve many, or even all the on-board subsystems and payloads.

The door was now open to implement a "message-type" interface between ground and space-based applications and thus to move towards the realisation of "process control" techniques.

In 1987 ESA set up the Committee for Operation and EGSE Standards (COES). The primary objective of this group was to define those functions which are common between a satellite checkout system (EGSE) and a satellite control system. Even though these systems are used for different objectives and in different project phases, the logical interface to the satellite is identical and many of the functions are similar. Therefore, a ***common system*** could be used for the pre-launch checkout and post-launch mission operations both within a given project and also across different projects (see Fig.1).

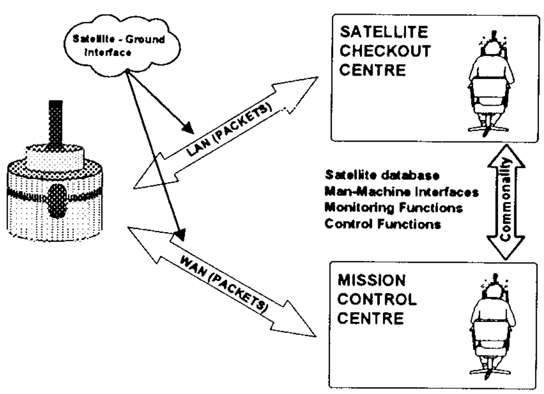

Fig.1 Check-out / Operations Commonality

COES decided to define such a common system for missions using the newly defined ESA Telemetry and Telecommand packets. However, the flexibility introduced by the use of packets leads to the possibility of implementing a given control function in many different ways. It soon became clear to COES that its task was only feasible if a clear satellite-ground interface existed, based on the use of packets.

Consequently, the first task of the COES was to produce a standard which defined precisely ***how*** telemetry and telecommand packets should be used.

2. SCOPE OF THE PUS

The term "Utilisation" is used in the title of the standard, since the intention is that the PUS should address all aspects relating to the use of packets i.e. the circumstances under which they are generated and the rules for their exchange, as well as their structure, format and content.

The PUS can therefore be seen as an interface document defining the relationship between space and ground.

The PUS contains the following elements:

⇨ operational requirements relating to satellite monitoring and control functions and to testability;

⇨ standards for the secondary data header of telemetry and telecommand packets;

⇨ the definition of a set of PUS Services which respond to the operational requirements. A Service specification includes the corresponding on-board Service model and a full definition of all the Service Data Units (SDUs) supported by the Service i.e. the telemetry and telecommand packets;

⇨ standards for the data structures and parameter encoding types allowable within packets.

The Operational Requirements cover all aspects of Nominal and Contingency Operations for the full spectrum of mission types and classes. They include generic requirements for:

⇨ the different classes of telemetry data to be transmitted to the ground and the circumstances under which the data shall be generated;

⇨ the provision of different levels of telecommand access to the satellite to ensure the maximum degree of controllability;

⇨ telecommand verification;

⇨ the control of on-board software;

⇨ the loading and dumping of on-board

memories.

In addition, requirements are identified for a number of "advanced" on-board functionalities, which may only be required for particular classes of mission:

- ⇨ on-board scheduling of commands for later automatic release;
- ⇨ on-board parameter monitoring;
- ⇨ on-board storage and retrieval of data;
- ⇨ transfer of large data units (e.g. files) between space and ground and vice-versa.

The requirements for Contingency operations cover the setting up of a "diagnostic" mode, wherein the ground can oversample selected telemetry parameters for ground evaluation purposes. Also, it should be possible to by-pass on-board functions by ground command and to operate a function in an off-line mode in order to isolate hardware faults.

The Packet Data Field Header (PDFH) is left undefined within the ESA packet standards. However, the PUS identifies a fixed structure for this header for both telemetry telecommand packets, which is shown in Figure 2 below

Version Number	Checksum Type	Ack	Service Type	Service Sub-type
3 bits	1 bit	4 bits	8 bits	8 bits

Telecommand Packet Data Header

Version Number	Checksum Type	Spare	Service Type	Service Sub-type	Time
3 bits	1 bit	4 bits	8 bits	8 bits	Variable

Telemetry Packet Data Header ⇤ Mission Optional ⇥

Fig. 2 : Packet Data Field Headers

The PDFH for telemetry and telecommand packets is identical, with the exception that a telemetry packet may (optionally) contain a time field for datation purposes.

The version number allows for future versions of the data field header and possibly of other aspects defined by the PUS. For example, a new version could be defined for packets containing multiple Service Data Units, as proposed by NASA/JPL for deep-space missions.

The two most important fields in the PDFH identify the ***Service Type*** and the ***Service Subtype*** to which the packet relates. The specification of the "standard" Services provided by the PUS constitutes the bulk of the standard and these Services are covered in more detail in the next section.

In principle, 256 Services and, for each Service, 256 Service Subtypes can be defined. The range from 0 to 127 is reserved for the PUS, in both cases, whilst the range from 128 to 255 is denoted as "mission-specific". The PUS thus has considerable growth capability for the later introduction of new Services or new Service Subtypes within an existing Service.

3. PUS SERVICES

At present, 17 PUS Services have been defined and these are listed in Table 1 below.

Type	Service Name
1	Telecommand Verification
2	Device Command Distribution
3	Housekeeping & Diagnostic Data Reporting
4	Statistical Data Reporting
5	Event Reporting
6	Memory Management
7	Task Management
8	Function Management
9	Time Management
10	Time Packet
11	On-Board Scheduling
12	On-board Monitoring
13	Large Data Transfer
14	Packet Transmission Control
15	On-Board Storage and Retrieval
16	On-Board Traffic Management
17	Test

Telecommand Verification Service

Whilst none of the PUS Services is mandatory, it is expected that all Application Processes would implement this particular Service. Depending on the operational requirements and the on-board capabilities, commands can be verified at all stages: acceptance, start of execution, intermediate stages of execution and completion of execution. The selection of verification stages and whether positive as well as negative acknowledgement packets shall be generated can be done at the level of each individual command which is uplinked.

Device Command Distribution Service

There are 3 sub-services for the distribution of hardware-level commands:

⇨ distribution at Telecommand Segment level; these commands require no software for their execution and would be used e.g. for unblocking or resetting the on-board Packet Assembly Controller (PAC);

⇨ distribution by the CPDU (Command Pulse DIstribution Unit) within the decoder. These are high priority on/off commands which are distributed directly (hardwired) to on-board devices;

⇨ distribution by other Application Processes to devices, for example over an internal bus. Such commands may be used for normal operations or in a contingency situation e.g. where the normal higher-level control of the device is not to be, or cannot be, used.

Housekeeping and Diagnostic Data Reporting Service

The ***housekeeping*** sub-service covers the reporting of engineering data to the ground for monitoring and evaluation purposes. In order to adapt to changing operational conditions, the capability exists to define new housekeeping packets (or to re-define the contents of existing packets). Also, instead of systematically transmitting the housekeeping data to the ground, an optional "event-driven" mode is available. Event-driven means that the housekeeping packet is only generated if the value of a parameter within it varies by more than a prescribed threshold.

The ***diagnostic*** sub-service is used to support ground-based troubleshooting, where high sampling rates may be required for selected parameters

Statistical Data Reporting Service

In addition to the direct reporting of engineering data to the ground, summary ***statistical*** data may also be provided, consisting of the reporting of maximum, minimum and mean values of specified parameters over a time interval.

Event Reporting Service

This Service covers reports of varying severity from "normal" reports (e.g. progress of operations) to the reporting of serious on-board anomalies. This provides the mechanism for on-board functions to report to the ground autonomous actions they have taken or events they have detected.

Memory Management Service

This covers all aspects of loading and dumping of on-board memory blocks, as well as performing checksums on specified memory areas on ground request.

Task Management Service

This Service allows the ground to exercise control (e.g. start, stop, suspend etc.) over on-board software tasks managed by an Application Process. For many missions, this level of control may only be exercised in contingencies.

Function Management Service

This Service provides the "normal" mechanism for control of the functions executed by an Application Process (e.g. activate, deactivate, pass parameters etc.)

Time Management Service

This service permits control over the on-board generation rate of the Time Packet. In the future, this may be extended to cover the use of GPS.

Time Packet Service

This service is constituted solely of the Time Packet which is defined at the higher level of the ESA Packet Telemetry Standard (Ref.2).

On-Board Scheduling Service

For many missions, it will be necessary to load telecommands from the ground in advance of execution, for release on-board at a later time. For example, LEO missions, where operations must be conducted whilst outside of the limited ground passes.

This Service provides the capability for loading, deleting, reporting and controlling the release-status of telecommands in an On-board Schedule. Telecommands may also be time-shifted, without the necessity of deleting and re-loading them with new times.

A telecommand may also be "interlocked" to another telecommand, released earlier in time from the Schedule. That is to say, the release of the telecommand will be dependent on the success (or, alternatively, the failure) of the earlier command.

On-Board Monitoring Service

This Service provides some of the basic telemetry monitoring functions which are normally implemented on the ground i.e. mode-dependent limit, trend and fixed-status checking. Out-of-limit conditions are automatically reported to the ground.

Large Data Transfer Service

For many mission, it is anticipated that the largest desirable packet size may be much bigger than the maximum allowed by the ESA standards. This Service provides for the reliable transfer of a large Service Data Unit of any Type (e.g. a file. a large memory load block or a large report) by means of a sequence of smaller packets. The Service may be invoked either for the uplink or the downlink of a large Service Data Unit.

Packet Transmission Control Service

This Service permits the enabling and disabling of the transmission of packets (of specified Type/Sub-type) from an Application Process.

On-Board Storage and Retrieval Service

This Service allows for the selective storage of packets for downlink at a later time under ground control.

In principle, a number of independent stores may exist, which may be used for different operational purposes. For example, for missions with intermittent ground coverage. packets of high operational significance (e.g. anomaly packets) could be stored in a dedicated packet store so that they may be retrieved first during the next period of coverage.

A "lost packet recovery" capability may also be achieved by systematically storing all event-driven packets on-board.

On-Board Traffic Management Service

This Service provides the capability to monitor the on-board packet bus (e.g. its load, the number of re-transmissions etc.) and to exercise ground control over on-board traffic and/or routing parameters or problems.

Test Service

This Service provides the capability to activate test functions on-board and to report the results of such tests in the telemetry. A standard Link Test ("Are you alive?") Sub-service is provided.

4. MISSION-TAILORING

An important aspect for the wider acceptance of the PUS is that it should be easily to tailor it to the specific requirements of a given mission.

This consideration has been at the forefront whilst developing the standard and is achieved by the following measures:

⇨ a mission may choose to implement only that sub-set of the PUS Services (and/or Sub-services) which it deems appropriate to its requirements;

⇨ the structures defined for the Service Data Units (the telecommand and telemetry packets) identify "mission-optional" fields. These correspond to the "optional" capabilities within a Service (the so-called ***Capability Sets***). If a capability set is not implemented for a particular Service, then the corresponding mission-optional fields may be omitted;

⇨ for the data type of each field of the Service Data Units, the PUS only specifies the ***encoding type*** (e.g. real or integer) with the ***encoding length*** being specified at mission-level;

Thus, a mission may remain fully compliant with the PUS whilst incurring no detrimental impact on its packet overhead as a consequence.

5. VALIDATION

Prior to approval of the PUS, and before implementing supporting infrastructures, it was necessary to ensure the correctness, practicability and operational usefulness of the standard. This was achieved by means of a prototyping exercise completed in 1992, which both validated the standard and, at the same time, provided some indicators for possible implementation techniques.

The packet communication techniques were not addressed in this prototype since these have already been independently demonstrated. Instead, the prototype concentrated on the end-to-end application-level aspects, emulating the on-board behaviour in response to the Ground control system.

This prototype (called PUSV) runs on one or two SPARC workstations and at the same time allows modelling of different on-board Application architectures. A reference satellite model (called PUSSAT) was implemented for validation and demonstration purposes.

6. FUTURE PERSPECTIVE

Following an exhaustive review at Agency level during the course of 1993, the PUS in its present version was approved by the ESA Inspector General and thus is now an Agency standard.

The PUS is expected to evolve in the future, in an incremental manner, as new monitoring and control Services become sufficiently mature to be generalised and thus standardised.

ESOC is currently undertaking a major mission control Infrastructure development, the so-called SCOS-II, which is a distributed system based on SUN workstations. SCOS-II will provide full application-level support to missions conforming with the PUS.

COES is also specifying the functional requirements for a generic system to be used for checkout and operation across different projects.

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