BENEFITS FROM THE PACKET UTILIZATION STANDARD IN TELEMATICS APPLICATION FOR SPACE MISSION CONTROL

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Abstract: The application-level Packet Utilization Standard (PUS) is supporting European space missions in providing adequate degree of spacecraft operability to on-ground based mission control.
This paper presents an introductory description of the PUS services concept, the steps required for their implementation, the evaluation of the past and present experience and a summary of the benefits so far gained. *Copyright © 2001 IFAC*

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1. INTRODUCTION

Earlier spacecraft missions made use of frame-based transfer protocol for supporting the communication needs between a flying spacecraft and a ground-based mission control system. The evolution, in terms of complexity, of the spacecraft architecture, of the increased amount of transmitted parameters and of the level of specialization of payloads put in evidence the limits of the static frame-based protocol.

The use of packet telemetry and packet telecommand to *transport* data between user applications on the ground and Applications Processes on-board was introduced in the '80 and regulated by appropriate Consultative Committee for Space Standardization (CCSDS) standards and derived European Space Agency (ESA) standards.

Later, in the early 1990s ESA has promoted the standardisation of the *application* level interface between space and ground to satisfy upcoming operational requirements arising from the satellite check-out operations and the flight operations domains.

2. THE PUS STANDARD

2.1 The concept of application service

The PUS addresses the utilization of telecommand packets and telemetry source packets for the purposes of remote monitoring and control of spacecraft subsystems and payloads, during both on-ground testing and in-flight operations.

The standard is devoted to define the services between onboard application processes and cooperating applications on the ground, and their associated telemetry and telecommand packet structure.

The *PUS service*, also called *Type*, is conceived as a set of onboard functions that can be controlled and monitored by a service user, such as a ground system, through a well-defined set of service requests and reports.

An onboard *application process* is defined as the source of telemetry packets and the sink for telecommand packets. Example of applications processes is a subsystem, a unit within a platform or a payload. Each application process has a unique identifier called Application Process ID (APID).

The PUS services cover spacecraft operational requirements for nominal operations, contingency operations and troubleshooting, throughout all operational phases, such as Launch and Early Orbit Phase (LEOP), Commissioning phase, Routine phase, Disposal. The standard is applicable to a variety of unmanned missions, like earth observation, science research, planetary exploration, advanced technology, and also to manned missions.

2.2 The PUS application services for space missions

The identification, selection and standardisation of PUS services were based on the past ESA experience in operating satellites. It was a long process that culminated in the definition of 17 services. They cover the most frequent needs in the field of space mission operability.

In May 1994 the PUS was issued as an ESA PSS standard. Since then a number of missions made use of the PUS, selecting those services most suitable to satisfy specific mission needs in term of operability. The spirit of the standard , in fact, is to offer a sort of "*menu of services*" among which each mission selects and customizes those services suitable to the specific needs – new services can also be envisaged to satisfy peculiar mission requirements.

Each service is made of several sub-services called *sub-type*, which can be service requests, service reports or capabilities. For each service the sub-types are grouped into two sets:

- The minimum capability set
- The additional capability set.

The first set is mandatory once the service is considered suitable for the specific mission. The second one is optional and the correspondent sub-types can be selected as needed.

2.3 Evolution of the PUS toward a European standard

After gaining practical experience in implementing or flying missions supported by the PUS it was decided to review the standard to introduce improvement and extensions derived from the learnt lessons and, at the same time, to make the PUS part of the ECSS standards (Parkes, *et al.*, 1998).

The PUS was aligned with the evolution of the CCSDS Recommendations on packet telemetry, resulting in the deletion of the telemetry segmentation concept.

The PUS presentation was improved clarifying:

- the operational concepts on which the PUS is premised;
- the concept of tailoring of the PUS to suit the needs of a particular mission, possible both at mission level, at application process level and at service implementation level;
- the individual service specifications.

Table 1: Standard PUS Services

Type	PUS Service Name
1	Telecommand Verification Service
2	Device Command Distribution Service
3	Housekeeping and Diagnostic Data Reporting Service
4	Parameter Statistic Reporting Service
5	Event Reporting Service
6	Memory Management Service
7	Task Management Service
8	Function Management Service
9	Time Management Service
10	*Not used*
11	Onboard Operations Scheduling
12	Onboard Monitoring Service
13	Large Data Transfer Service
14	Packet Transmission Control Service
15	Onboard Storage and Retrieval Service
16	Onboard Traffic Management Service
17	Test Service
18	Onboard Operations Procedure Service
19	Event/Action Service

The scope of the standard was also extended:

- to allow the unique identification of a missing telemetry source packet, not only at Type but also at Subtype service level;
- to allow an unambiguous end-to-end identification of the intended routing of a given packet where necessary, such as the case of multiple ground control centres;
- to support two new services, respectively the Onboard Procedure service and the Event/Action service.

The new set of standard PUS services is reported on Table 1. The updated standard - thoroughly tested using object-oriented analysis techniques (Merri, *et al.*, 1996) - is now undergoing public review at ECSS level and will be published afterwards.

3. IMPLEMENTATION OF THE PUS

3.1 The services selection process

Every new mission needs to be defined in terms of overall objectives, operational orbit, ground visibility, payload selection and spacecraft preliminary architectural design. After that the selection process for the adequate PUS services will identify, based on a well defined Operational Concept, covering all phases of the missions and the associated operational requirements, the optimal set of services required to support the mission.

Each selected service will be then tailored, starting from the set of minimum capability sub-types and adding the optional functionality to satisfy the operational requirements.

3.2 The services implementation on-board and on-ground

The primary mechanism for telemetry bandwidth control is via the use of virtual channels. It also provides a valid means to differentiate and map onboard operational states.

The on board design architecture gives the input to identify the data sources and/or sinks for both telemetry and telecommand packets. The same process takes place for the ground segment, in particular, in case of multiple mission control centres, and therefore allowing the possibility of multiple sources/sinks for the same onboard application process.

Different APIDs shall be then assigned to different on board data sources or sinks and also within the same source or sink where there are packet streams that have different bandwidth characteristics and operational significance.

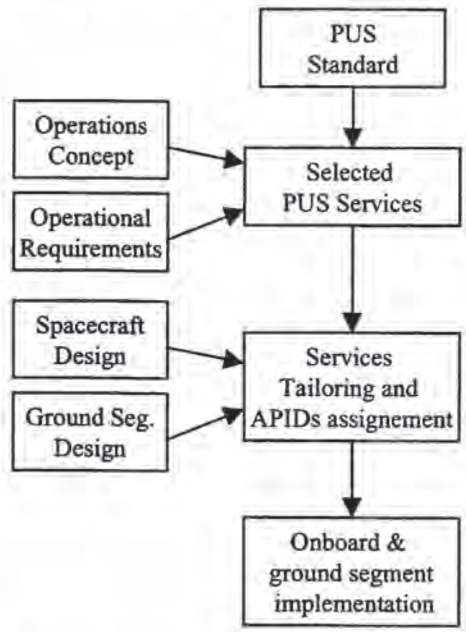

Figure 1: PUS Services Implementation

3.3 The PUS supporting tools

In order to facilitate the diffusion of the PUS standard and ease its implementation and adaptation for the specific mission a set of supporting tools has been envisaged.

The first objective is to translate the PUS into a set of formal Mission Information Base Data Requirements (MIBDR).

A second step consists in tailoring the PUS standard to suit the needs of the specific space mission and generate the "Packet Structure Definition" document. This process implies the selection of the PUS services and sub-services needed by the mission and, optionally, to create new mission-specific services/sub-services. The tailoring tool makes use of questionnaire as man-machine interface to capture the mission-specific needs.

As a final result the documentation tool generates the Mission-Specific PUS and the

Mission-Specific MIBDR compliant with the initial needs (Merri, *et al.*, 1999).

3.4 The European space missions using the PUS

Figure 2 reports the space missions in Europe using or implementing the PUS for supporting the in-flight operations.

Table 2 – Missions using the PUS

Mission	Type
XMM	Astronomy
Meteosat Second Generation	Weather
INTEGRAL	Astronomy
GOMOS (ENVISAT instr.)	Earth obs.
ATV	Transport.
ORSTED	Scientific
PROBA	Technology
ROSETTA	Deep Space
Mars Express	Deep Space
CRYOSAT	Earth Obs.
GOCE	Earth Obs.
FIRST/PLANK	Scientific

The experience so far acquired during the design process, the on-ground testing and the operational phase has allowed the operations engineers community to give an initial judgement on the impact of using packet-switching-based application level protocol and associated services in support of spacecraft operation, monitoring and control.

4. BENEFITS AND LESSONS LEARNT

4.1 The enhancement of spacecraft operability

With the availability of the PUS standard it has been demonstrated that it became easier to satisfy the spacecraft operability having already available a menu' of defined services, however still open for tailoring and fine-tuning.

The guide-lining standard represents a synthesis of operational experiences from different missions. It is therefore facilitating cross-fertilizations of approaches and practical solutions between projects in the implementation of adequate application level solutions to operability requisites.

4.2 Reuse of spacecraft design and of ground system infrastructure

The PUS standard also represents a common approach throughout European spacecraft manufacturing companies, particularly with those involved in the Onboard Data Handling (OBDH) subsystem design.
The OBDH is considered the heart of the spacecraft, where all incoming data, either from ground (telecommands) or from other onboard subsystems and payloads, are dispatched to the final destination.

A reuse of design and a consequent cost saving is leveraged by the implementation of PUS services, leaving, at the same time, an adequate degree of freedom for the specific mission tailoring.

Reuse of the mission control system compatible with the PUS is the benefit we get on the ground segment side. In this domain the implementation of the tailored subset of services is an easier job with respect to the new design for a new mission approach.

4.3 Increase Robustness of the Spacecraft Observability and Controllability

The experience and lessons learnt that have stimulated both the definition of the standard and its recent update are contributing to provide a more robust approach for guaranteeing the adequate observability and controllability of the spacecraft both during nominal and contingency operation.

This aspect will impact positively on the increased robustness of the operational activity, made of a mixture of hardware, software, procedures and human expertise. The use of PUS, in fact, provides a more reliable and performing application-level services and contributes to maximize the delivery, both in terms of quality and quantity, of space mission products/service. Which is considered the final goal of *flying a space mission*.

5. CONCLUSIONS

The Packet Utilisation Standard is now being applied in Europe to augment the operability of unmanned and manned space missions. Several missions, with different objectives, are now taking advantage of complementing their packet-switching communication approach with the application-level services defined in the PUS.

Among the benefits from this approach we can recall the enhancement of spacecraft operability, the reuse of space subsystems design and ground segment infrastructure and the increased robustness of the spacecraft observability and controllability.

6. REFERENCES

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