ON-BOARD PAYLOAD DATA PROCESSING SYSTEMS
ON-BOARD NETWORKS FOR FUTURE MISSIONS

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ABSTRACT

At the turn of this century, satellites which have demonstrated the feasibility of many space applications, enter in a new era. Today they have an additional mandate: they must provide a well-identified service to Users and/or to Customers. This is applicable not only to Telecommunication but also to Earth observation missions. Data products or derived information must be elaborated rapidly in order to either authorise a near real time direct dissemination of data to Users or to generate alarms (e.g. for forest fire detection).

Furthermore, the amount of data produced by instruments exceeds the downlink capability, leading to the need of implementing a selection or a compression mechanism on-board. On the same line, for observatory type of science missions, on board autonomy can bring significant advantages.

With respect to the points outlined here above, on-board Payload Data Processing Systems can provide a suitable solution and the necessary autonomy or intelligence. This paper focuses on Payload Data Processing Systems and in particular on their implementation based on On-board networks. Taking into account that space applications have specific requirements, no commercially available networking infrastructure could be directly used for on-board applications. Therefore, SpaceWire links, Networks and tools have been standardised and adapted to space use.

This paper presents their characteristics, related devices and tools developments and new opportunities offered by their intrinsic flexibility.

1. INTRODUCTION

Satellite payloads are becoming more and more complex and this trend induces increasing requirements in terms of on-board storage and processing capabilities.
Moreover, on-board intelligence and even some form of payload autonomy are envisaged for advanced satellites in the fields of earth observation, science missions and in more general terms in exploration missions. ESA has anticipated this evolution by developing a concept facilitating the implementation of such requirements. Assuming that a satellite can be decomposed essentially into a platform (providing power, attitude and orbit control functions, pointing capability and telemetry/command services) and a distinct module carrying the payload (e.g. instruments), it appears from the analysis of a large number of missions that this classical split leads to the implementation of dedicated control and processing
units for each sub-system. The analysis presented here focuses on **Payload Data Systems** for on-board data processing and on underlying technologies.

The driving prospects for the new concept can be outlined as follows:

- Short design phases, Risk reduction and Cost minimization by module re-use
- Asynchronous distributed architectures for real time Payload Data Systems and compatibility with UML/SDL modeling and mapping
- Requirement to reduce the on-board harness
- Progressive and de-centralized integration

This paper, on the basis of the review of the past and present situation, provides the rationale that has driven the selected architecture and the definition of development activities.

2. PAYLOAD DATA PROCESSING SYSTEMS ARCHITECTURES

2.1. Evolution of payload Data Processing systems

Classical On-board payload data systems [Fig 1] have basically three functions:

- Collecting/multiplexing data streams produced by sensors and instruments
- Temporary storage of the acquired data to bridge the gap between successive ground station visibility periods
- Formatting of the downlink data stream for ground transmission

The architecture of such a system is corresponding to a synchronous pipeline. In past missions (e.g. ERS 1-2), the mass memory function was provided by fragile tape recorders advantageously replaced today by solid-state mass memories.

Considering the ever increasing data rates produced by the new generation of instruments (high spatial, radiometric and spectral resolution) for earth observation and science missions, more functionality had to be introduced in payload data systems. Progresses performed at the level of downlink telemetry channels (somehow linear) are not commensurate to the quadratic or even higher degree increase of data rates produced by state of the art imagers.

The solution is to implement one part of the data processing on-board in order to decrease the data volume to be transmitted.

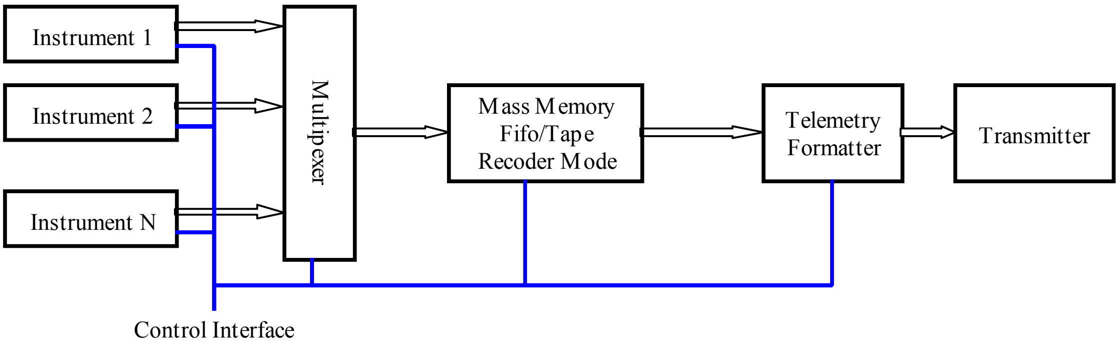

Figure 1: Classical synchronous pipeline architecture

In this case, on-board processing consists in performing:

- Data **Filtering**, when the processing inherently reduces the amount of data (e.g. by Fourier or de-correlation transforms)
- Data **Compression,** when the data correlation can be decreased to a lower entropy level
- Data **Selection,** when parameters, derived on-board, allow to select/discard data for ground transmission.

If on-board processing is needed, the usual approach is to dedicate specific Digital Processing Units to Instruments, leading to the configuration presented in [Fig 2].

Most of the earth observation satellites currently launched, integrated or under development are corresponding to such a scheme (ENVISAT, METOP, CRYOSAT, SMOS).

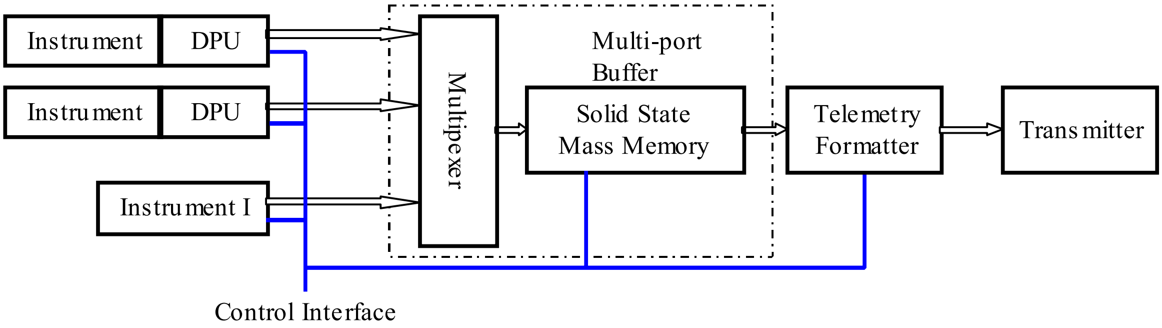

Figure 2: Pipeline Architecture with local embedded digital processing Units

Although more powerful than the simple synchronous pipeline, such a payload data system still suffers from a lack of flexibility and failure recovery capability. If a Digital Processing Unit (DPU) of a specific instrument fails, it cannot be replaced by a DPU of another instrument. This situation imposes in many instances a full duplication (cold redundancy) of all functions at DPU level.

Therefore, a natural evolution of the previous architecture, as shown in figure 3, consists in coupling a processor to the mass memory. In this case, the Payload Data Processor allows off-line processing of data acquired previously and before ground transmission. Such a scheme corresponds very well to deep space missions (e.g. ROSETTA) or to in-orbit observatories. As far as the second type of mission is concerned, it is no surprise to have such a concept selected as the baseline for NGST (Next Generation Space Telescope). An additional advantage of such a scheme is related to the possibility of mapping easily a file system on the mass memory.

2.2. New architectural Concept

The previously described architecture suffers from many drawbacks. First of all, it induces long and costly development and manufacturing phases, as a re-use strategy was not considered initially. Second, each time a new architecture was defined and units designed from scratch, leading to long integration, testing and verification phases. Therefore they evolved through time from a full custom and not reusable design to a slightly more flexible one. Such an implementation scheme. Additionally, taking into account that different parts of the processing system were developed by different industrial partners, a high level of effort was dedicated to developing new units with somehow artificial interface points. Consequently in some cases, it generated a certain level of duplication in activities and functions and excessive mass and power budgets.

In order to circumvent the drawbacks outlined here above and considering the revolutionary advances provided for instance by simulation, modelling, fast prototyping tools, etc, a new approach for Payload Data Systems and a suitable architecture had to be defined.

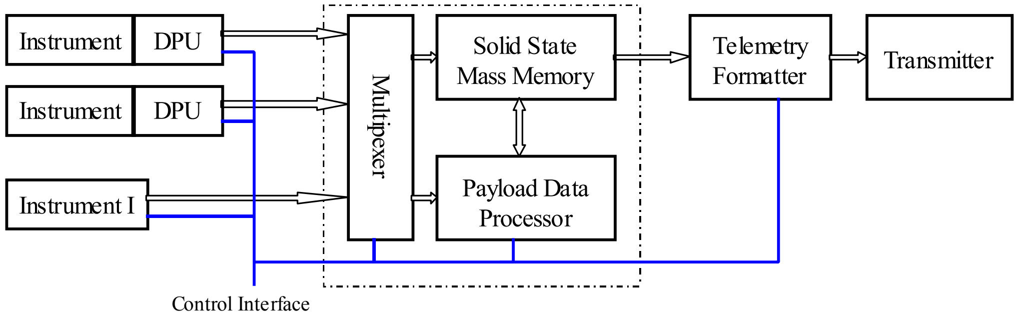

Figure 3: Payload Data system with intelligent mass memory

2.3. Advanced Payload Data Systems

Clearly, payload data system design is at a crossroad. The traditional pattern of highly specialized, customized satellites, designed and built one per mission at a time, is changing. Therefore ESA has initiated in the 90s an ambitious programme focusing on the definition of an advanced architecture for payload data systems.

Major requirements were flexibility, programmability, modularity and module re-use. The last point was judged as very important. Of course, implementing systems of such a complexity was only feasible/affordable if basic elements (H/W and S/W) could be reused.

A reference architecture was defined in cooperation with Industry. The objective was to decompose the global payload data processing system in nodes interconnected by high speed serial links.

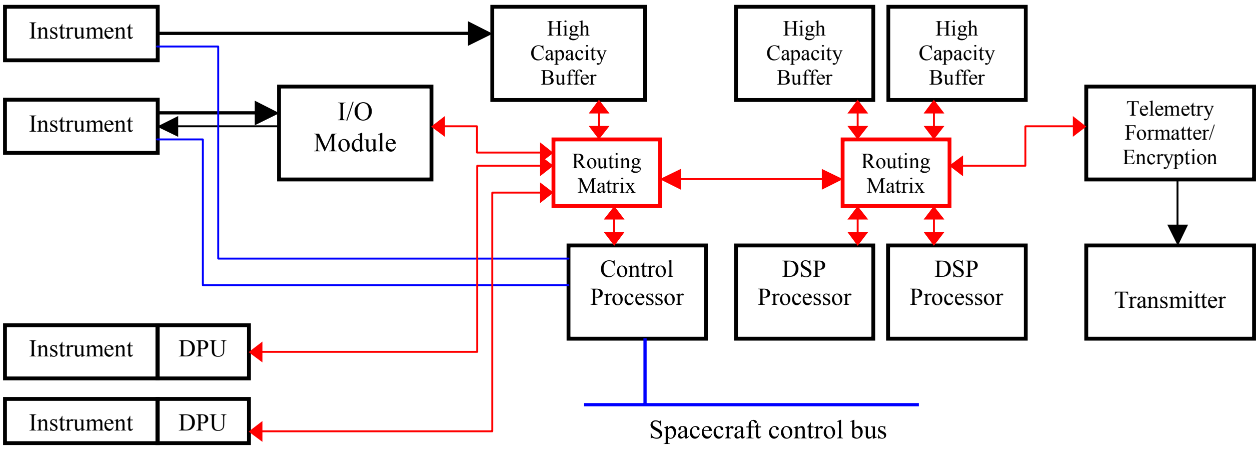

Figure 4: Scalable Architecture for a Payload Data System

A suitable granularity level had to be selected which led to allocating specific and balanced functions to modules. Typically, one module has a useful size (PCB area) of about 160 mm x 230 mm and has to comply as a minimum with the presence of IEEE1355/SpaceWire interfaces. More emphasis is placed nowadays on the use of common modules, standardised interfaces and the use of modelling tools to customize the payload to each new mission objectives. This produces a move towards new payload systems for which integration and testing can be highly automated. The extent and nature of testing is greatly reduced since prototyping and initial development is already accomplished. The essence of this new system design is represented by the Advanced Payload Data Processing sub-system presented in figure 4.

Basically, three types of modules are needed: ***processing modules, storage modules*** *and obviously* ***I/O modules***. This concept mimics the organisation of many ground based computer architectures. Consequently this organisation will benefit from a wide technical domain already mastered efficiently by the computer industry.

3. ON-BOARD NETWORKS

A paradigm like "The Network is the Computer ….", applies as well to on-board systems. Nodes in a system need to be interconnected. Taking into account the fact that back plane busses can be bottlenecks, networks of point to point links offer an attractive alternative. This trend is fully endorsed by ground computing infrastructures relying more and more on switch fabrics for data routing

The approach promoted by the Agency for Payload Data Processing Systems is relying deeply on SpaceWire links and Networks

Point-to-point links are used to interface modules and units (processors, mass memory) either directly or via SpaceWire packet routers. Key aspects of this technology are developed in the following paragraphs. More exhaustive information is provided by the corresponding ECSS standard Ref [1] and Ref [2] and associated links.

3.1. SpaceWire Nodes

SpaceWire nodes are the sources and destinations of packets in a SpaceWire network. A SpaceWire node comprises one or more SpaceWire link interfaces. A SpaceWire link interface consists of a transmitter, receiver and a state machine used to control the interface. In addition a pair of FIFO memories are usually added to provide the interface to the host electronic system, as illustrated on figure 5.

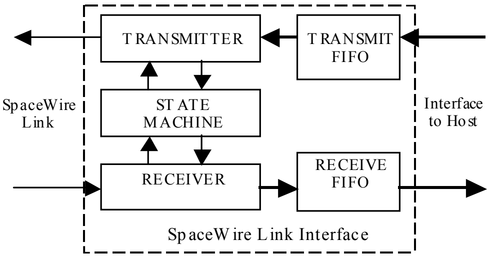

Figure 5: SpaceWire Link Interface

3.2. SpaceWire Routing switches

A SpaceWire routing switch connects together many nodes and provides a means of routing packets from one node to one of many other possible nodes. A SpaceWire routing switch comprises a number of SpaceWire link interfaces and a routing matrix. The routing matrix enables packets arriving at one link interface to be transferred to and sent out to another link interface on the routing switch. Each link interface may be considered as comprising an input port (the link interface receiver) and an output port (the link interface transmitter). An example of a 6-ports routing switch is given by figure 6.

A SpaceWire routing switch transfers packets from the input port of the switch where the packet arrives, to a particular output port determined by the packet destination address. A routing switch uses the leading data character of a packet (one of the destination identifier characters) to determine the output port of the routing switch to which the packet is to be routed. If there are two input ports wanting to use a particular output port at the same time then an arbitration mechanism in the output port decides which input port is to be served. There are two ways of addressing SpaceWire packets, path addressing or logical addressing:

- *Path Addressing:* Path addressing is used to specify the route through a network directly.
- *Logical Addressing*: Logical Addressing is used to specify the route through a network indirectly via routing tables held in the routing switches.

3.3. Tools and parallel developments

Support tools have not been forgotten and activities are being launched to develop and have commercialised EGSE interface boards and network monitoring tools (from break-out boxes to protocol analysers). Two other initiatives have been undertaken. The former regroups under the "TopNet" initiative a concept allowing easy and powerful decentralised system integration via heterogeneous networks, i.e. SpaceWire, Intranets and Internet. The latter is aiming at developing intelligent systems for on-board usage based on smart sensors, data fusion and a configurable S/W approach called "TaskWare". Special emphasis shall be given to Fault Detection and Recovery management schemes and automatic code generation related to design patterns. It is worth mentioning here that the presence of a routing switch enables to introduce efficient reconfiguration mechanisms on which elaborated FDIR mechanisms can be built.

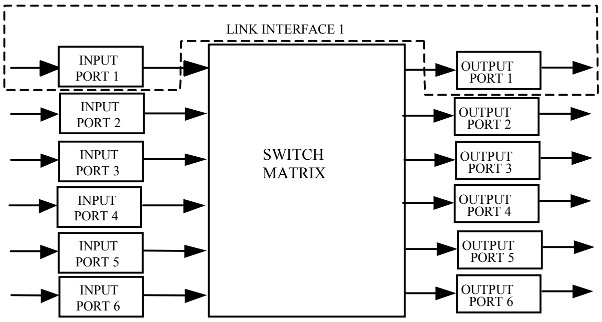

Figure 6: SpaceWire Routing Matrix

4. APPLICATIONS AND CONCLUSIONS

On-board Payload Data Processing systems have evolved from purely synchronous pipelines to more flexible architectures. SpaceWire networks being inherently asynchronous, they are perfectly suited for handling variable data rates. This feature is useful for data compression and essential for lossless schemes. Additionally, on-board operations can be more efficient and flexible as required for instance by the intended NGST instruments operations that shall be based on an event-driven operating paradigm, normally free of absolute-time-tagged commanding. Finally, SpaceWire based on-board networks can support "Faster than Real Time" services allowing a better handling of design margins which rather than being lost during most of the operational phases, can be used for additional products elaboration.

Taking into account that the network structure can remain stable (thanks to standardisation), most of the effort in the coming years can be focused on improving the performance of modules that can benefit of technology improvements. Existing modules have already produced off-springs for many currently developed missions. The existence of on-board networks connecting processing, storage and I/O modules, provides the flexibility required by the large diversity of instruments. Thanks to significant efforts, Europe has a leading role in the field of Payload Data Processing Systems, at conceptual level and implementation wise.

5. ACKNOWLEDGMENTS

As stated in the introduction, many developments have been necessary in order to reach the status outlined in this paper. As it would not be practical to list here the names of all the contributors, the authors would like instead to acknowledge the role of the SpaceWire Working Group, represented by its chairman Dr. Steve Parkes (UoD, UK), in particular for his contribution to the third chapter of this paper.

6. REFERENCES

[1] ECSS:European Cooperation for Space Standardisation: http://www.estec.esa.nl/ecss
[2] ECSS-E-50-12 SpaceWire links, routers and networks, For more information about SpaceWire products: www.estec.esa.int/tech/spacewire
[3] CCSDS Panel 1K (SOIF) ftp://ftp.estec.esa.nl/pub/ws/wsd/ccsds/ccsdsoif/index.htm
[4] “On-Board Payload Data Processing Systems” Workshop ESTEC 19-20 Sep 2001 Proceedings Available at: http://www.estec.esa.nl/conferences/01C25
[5] "SpaceWire Networks", S. Parkes and C. McClements, DASIA 2002