A New Network Paradigm for the On-board Reference Architecture (OSRA-NET)

Brice Dellandrea

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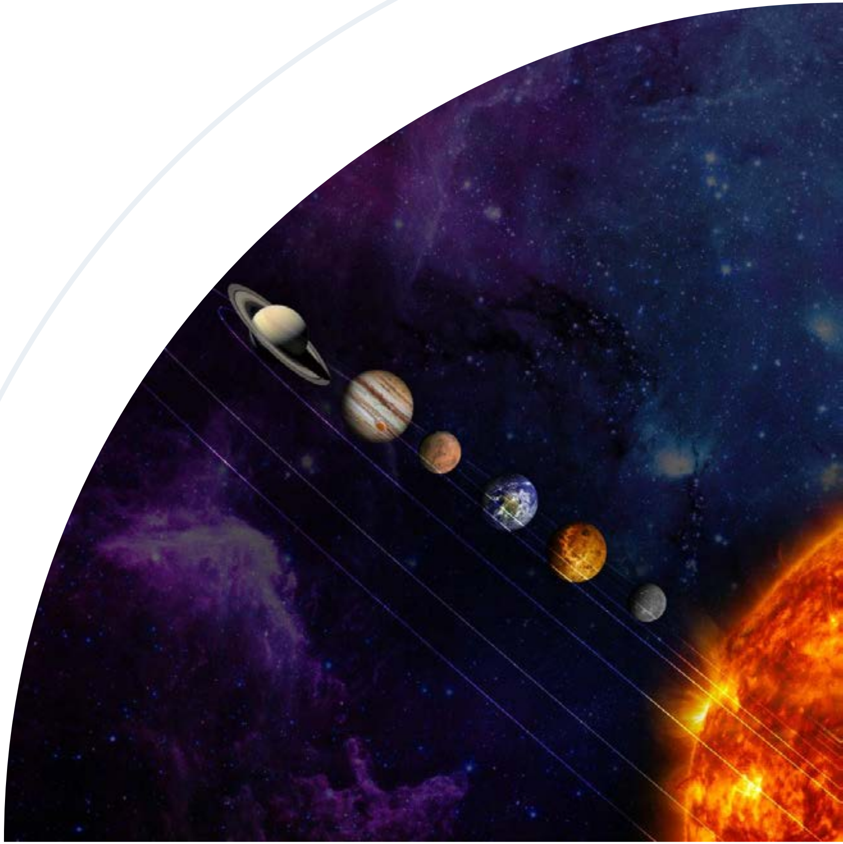
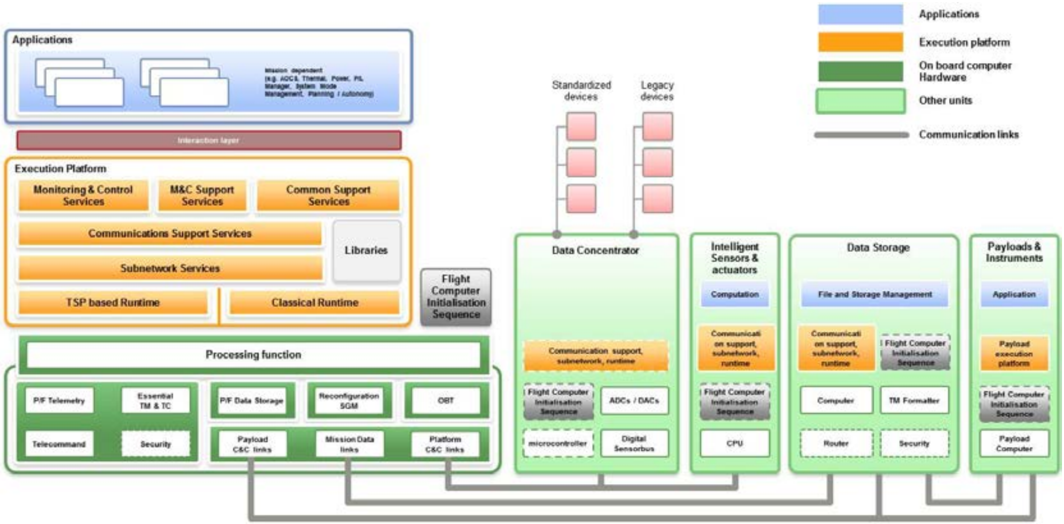
Outline

- SAVOIR and SAVOIR-FAIRE
- Goals of the OSRA-NET Study
- Study organisation & major outcomes
- Focus on the OSRA-NET Requirements Specification



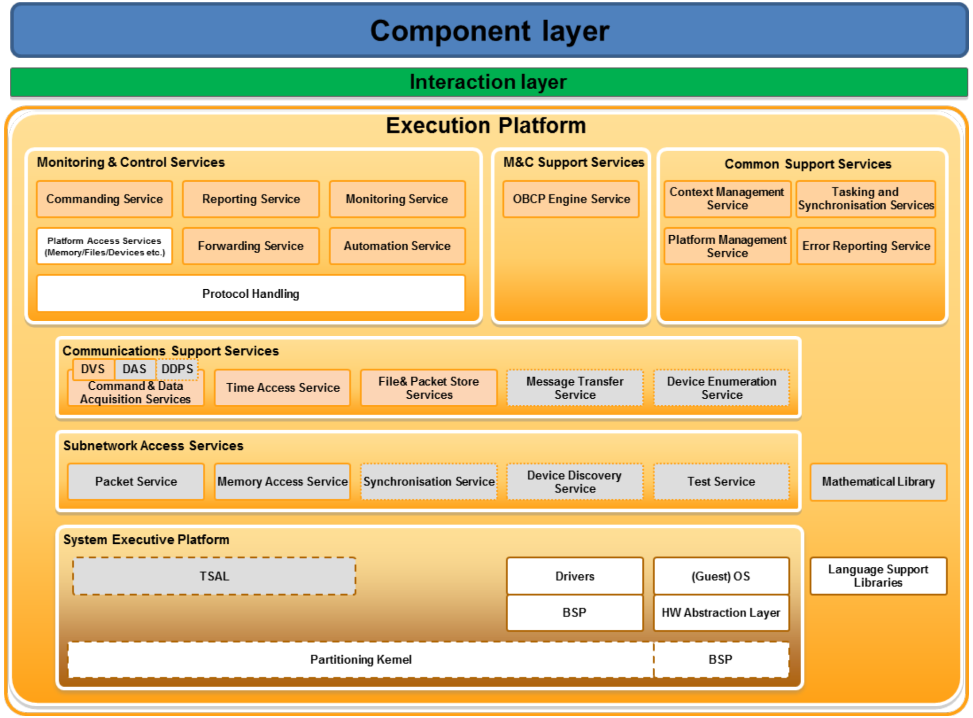
SAVOIR Avionics System Reference Architecture (ASRA)

- Reference avionics architecture (HW + SW vision)
  - Addressing the full platform avionics perimeter
  - Payload C/C, Data Storage, Telemetry, Routing and Security
- Stays as agnostic as possible w.r.t. technology and implementation choices
  - “Functional Reference Architecture”
  - Yet mapping to current reference implementation technologies are provided and discussed (e.g., 1553, SpW, CAN)



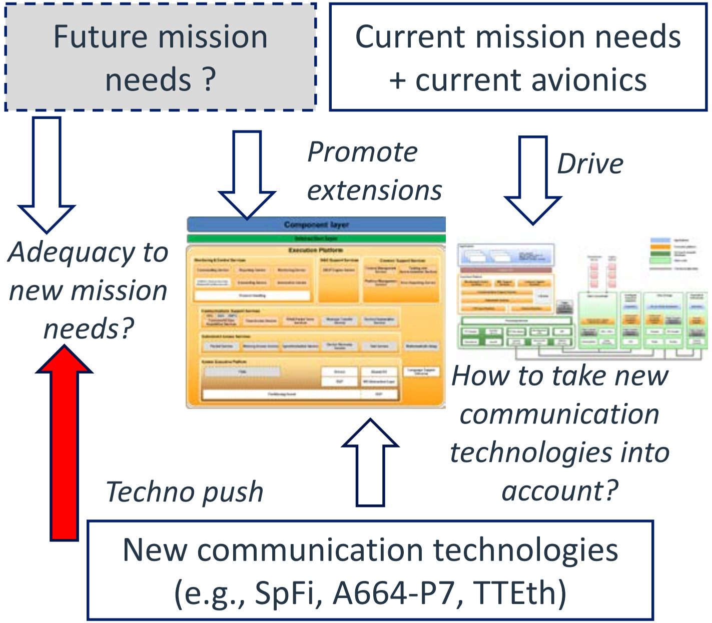
SAVOIR On-board Reference Architecture (OSRA)

- Proposes a reference organisation of platform SW architecture in 3 layers
  - Component layer
    - for Mission-specific software
  - Execution platform
    - For Mission-independent software (e.g., generic services)
    - Oriented to re-use
  - Interaction layer
    - To guarantee independence of components from execution platform
    - Automatically generated
- Comes with an associated Model-Driven Engineering process
  - Semi-formal modeling of SW architecture design
    - Increased abstraction of design + precise SW / SW interface definition
  - Automated code generation
- Supports both "Classical" and Time and Space partitioning execution platform



Assessment of communication technologies

- Status today
  - Several technologies (UART / 1553 / CAN / SpW / Wizardlink / //LVDS) are available for flight
- Strong *techno push* of new communication technologies (e.g., SpaceFibre, TTEthernet, TSN)
  - They require possible extensions of standards, methodologies, development practices and reference architectures (at avionics and software level)
  - Albeit they promise interesting advantages, what are the needs these technologies respond to? How is their design driven?
- Those communication technologies are part of a system
  - How to ensure that new communication technology developments are driven so as to best respond to the right mission needs?
  - How to ensure that the SAVOIR reference architectures can take into account these new needs, possibly by leveraging on new communication technologies?



Goals of the OSRA-NET study

- To extend the concept of On-board Software Reference Architecture (OSRA) to new communication paradigms emerged in the past few years
  - Such as those promoted by SpaceFibre, ARINC 664 Part 7, TTEthernet, SpW-D, STP-ISS, TSN
- To enable the implementation of a multi-node On-Board Software Reference Architecture (OSRA-NET)
- To perform an impact analysis on all relevant SAVOIR and CCSDS documents
- Two major areas of work have been performed
  - The specification of the high-level communication system requirements for the OSRA
  - The definition of an extended OSRA methodology and process for the analysis of communication needs
    - So as to confirm the feasibility of an architecture design spread on multiple nodes
    - To possibly refine such architectural design into OSRA components
      - To perform automated code generation and implementation
- To prototype an implementation of the new OSRA-NET methodology and of a suitable communication stack on spaceborne hardware
  - Extension of reference OSRA Toolchain
  - Execution of a case study demonstration of the new approach

Overview of the OSRA-NET TRP Study

- The main R&D study (TRP) started in December 2015 and concluded in December 2017;
  - Analysis phase
    - Analysis of existing SAVOIR, ECSS, CCSDS standards
    - Methodology definition
    - Demonstrator technology selection
    - Case study preliminary definition
  - Specification phase
    - Specification of OSRA-NET communication requirements
    - Impact analysis on existing standards
    - Consolidated Case Study
  - Demonstrator implementation and case study execution
    - OSRA toolchain extension for OSRA-NET
    - Implementation of prototype OSRA-NET communication stack
    - Integration of communication stack into OSRA toolchain / TASTE
    - Case study modeling, implementation and execution
    - Extension of case study results to full-scale spacecraft
- 2018-2019: review process with SAVOIR and the SpW/SpFi Working Group and release of SAVOIR-GS-008: SAVOIR On-board Communication System Requirement Document

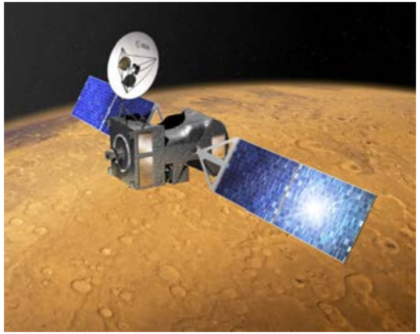
Study Organisation

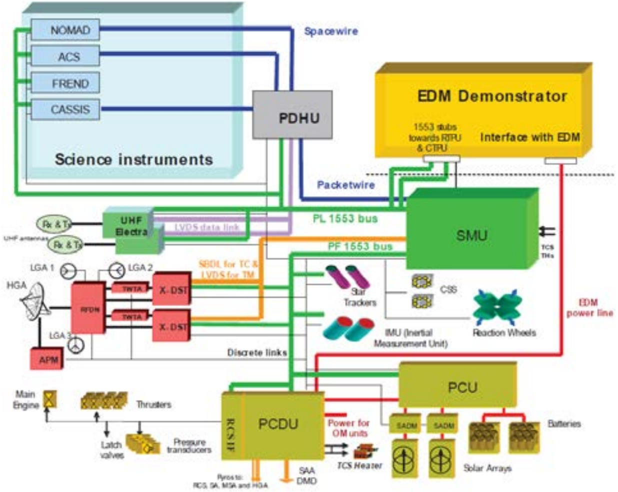
- ESA
  - Technical Officer: Christophe Honvault – TEC-SWE
- Thales Alenia Space in France (Study Prime)
  - Analysis Phase – *Leader*
  - Process and Methodology Definition
  - Case Study Definition – *Leader*
  - OSRA-NET Communication Requirements Specification
  - Impact Analysis – *Leader*
  - Demonstrator and case study - *Support*
    - Extensions of the OSRA Component model (SCM)
    - Extension of case study results to full-scale spacecraft avionics
- GMV
  - Analysis Phase – *Support*
  - Case study definition – *Support*
  - Impact Analysis – *Support* for OSRA-related standards
  - Demonstrator and case study – *Leader*
    - Extension of OSRA Component model editor and SCM to TASTE transformation
    - Integrated communication and middleware architecture (with TASTE)
    - Case study execution
- Teletel
  - Technology selection – *Support*
  - Implementation of prototype OSRA-NET communication stack
- Bright Ascension
  - Analysis phase and Impact Analysis – *Support* for SOIS, MOS, CCSDS recommended practices

Analysis of communication needs for current and future avionics

- Goal: to analyse the communication needs for current and future Command / Control and Science on-board communications
  - Understand the real "application" needs
  - Understand what needs have been "artificially" modified because of the adopted technologies
    - (e.g., traffic on 1553 forced on a given time schedule)

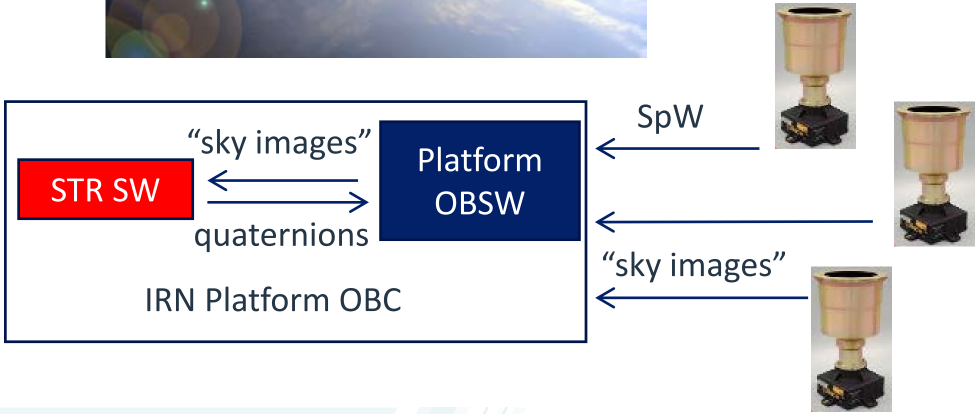
- Exomars TGO used as example of current operational avionics





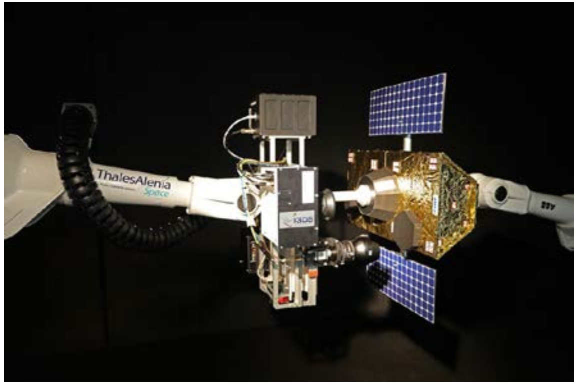
Analysis of communication needs for current and future avionics

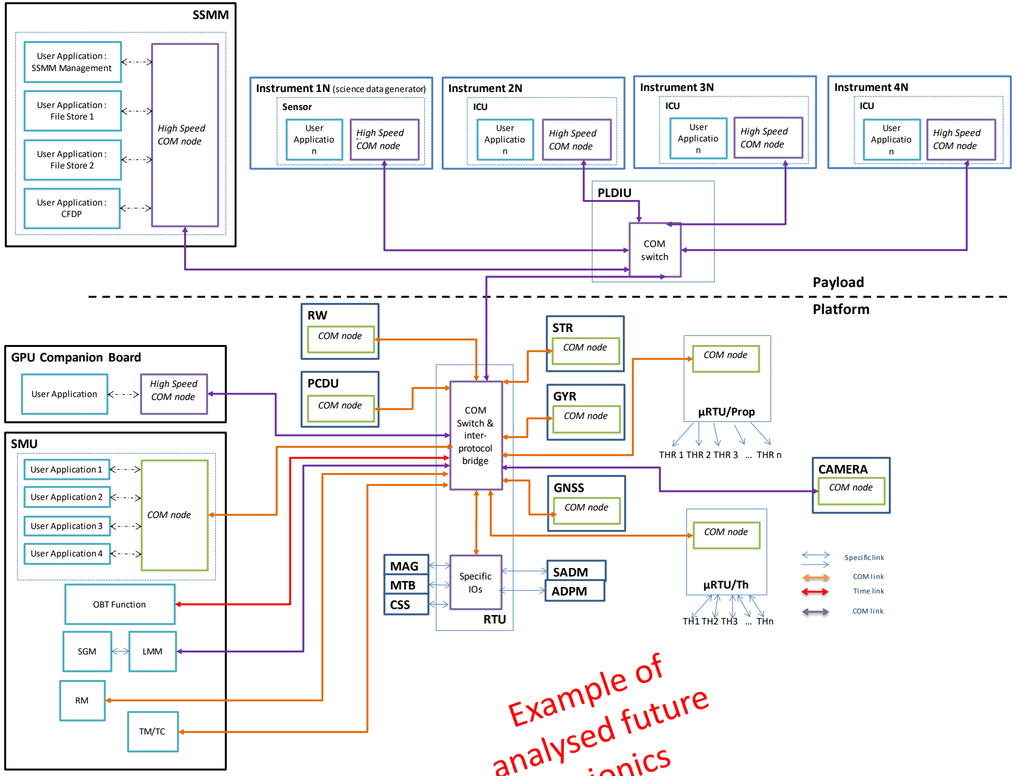
- Star Tracker SW processing on Platform On-Board Computer taken into account in the analysis
  - By using Iridium Next as example of operational avionics
  - Each Leonardo STR Optical Head transmits “sky images” over Spacewire point-to-point links to the Platform On-Board Computer



Analysis of communication needs for current and future avionics

- Analysis extended with needs for future missions for command/control & data transfer in real-time for:
  - Science
  - Earth Observation
  - Exploration missions
  - Servicing missions

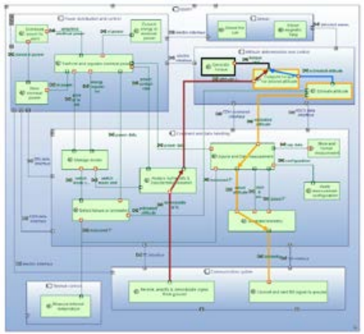




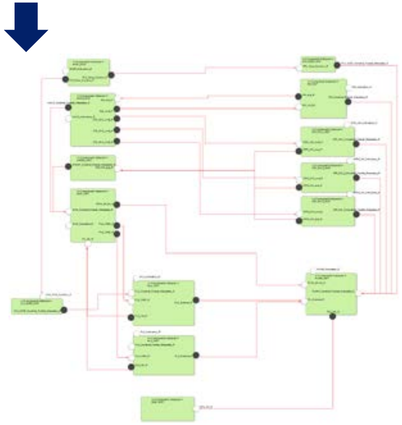
Example of analysed future avionics

OSRA-NET methodology

System / Avionics modeling



OBSW modeling



- System / Avionics modeling
  - Modeling languages such as Capella or SysML
  - Goal: Enable ***Coarse-grained*** communication analysis
    - Oriented to
      - Preliminary communication sizing
      - Avionics system feasibility
- OBSW modeling
  - Leveraging on e.g., the OSRA component model
  - Goal: Enable ***Fine-grained*** communication analysis
  - Capitalise on avionics modeling effort => coherent model transformation is required
  - Refinement of communications with knowledge of
    - Communication patterns used at OBSW level
      - E.g., send, request / response, etc…
    - Overhead due to full communication protocol stack
      - Hardware Comm Protocol + SW comm protocols + software real-time architecture

Analysis of communication needs for current and future avionics

- The analysis permitted to extract expected communication needs for devices of future avionics architectures
  - Expected min-max message size
  - Frequency
  - Max Jitter / Latency
  - Need for timestamp
  - FDIR/network monitoring requirements

		Traffic description													
	Equipment	Datatype	Max Cargo size (bits)	Frequency (Hz)	Period (ms)	bit rate	AOCS sensitivity	Jitter requirement		Latency (ms)		Other requirements	QoS level	Time stamp (8 octets)	Proposed Class of Comm
								Value (ms)	ROM	Value (ms)	ROM				
Sensors	Magnetometers	AOCS	12	8	125	100 bits/s	> 1 cycle	1000	1 cycle	1000	1 cycle	order of msg		No	2
	Coarse Sun Sensors	AOCS	96	8	125,00	770 bits/s	Low	10	1 cycle	10	1 cycle	order of msg		No	2
	Gyro (Coarse/safe mode)	AOCS	576	8	125,00	4,6 kbits/s	1 cycle	2	1 cycle	2	1 cycle	order of msg		No	
	Gyro (fine-grained)	AOCS	576	32	31,25	18 kbits/s	1 cycle	2	< 1 Cycle	2	< 1 Cycle			Yes	8
	Gyro (future)	AOCS	576	32	31,25	18 kbits/s	1 cycle	2	< 1 Cycle	1	< 1 Cycle			TBD	8
	Star-Tracker (Smart)	AOCS	8194 - 32777	8	125,00	65 to 262 kbits/s	1 cycle	1	< 1 Cycle	10	1 cycle			Yes	2
	Star-Tracker (Smart)	AOCS - Geo	8194 - 32777	8	125,00	65 to 262 kbits/s	> 1 cycle	2	1 cycle	10	> 1 cycle			TBD	2
	Star-Tracker	AOCS - Agility	8194 - 32777	30	33,33	245 to 983 kbits/s	<< 1 Cycle	0	<< 1 Cycle	1	<< 1 Cycle			Yes	5
	Camera - High Res.	AOCS - Rendez-vous	41943040	8	125,00	335 Mbits/s	1 cycle	10	< 1 Cycle	100	1 cycle			Yes	6
	Camera	AOCS - Nav. Cam	10485760	8	125,00	84 Mbits/s	> 1 cycle	100	> 1 cycle	100	> 1 cycle			Yes	4
	Camera	AOCS - Multi stage (1kHz)	1000000	1000	1,00	1000 Mbits/s	> 1 cycle	100		100				Yes	6
	IR Spectrum Camera	AOCS	2457600	1	1000,00	2,5 Mbits/s	> 1 cycle	100		100				Yes	6
	Payload sensors	Various - closed loop	Mission dependant	100	10,00	Mission dependant	<< 1 Cycle	Mission dependant	<< 1 Cycle	Mission dependant	<< 1 Cycle			TBD	5
	Tachometer	AOCS	30720	8	125,00	245 kbits/s	> 1 cycle	10	> 1 cycle	100	> 1 cycle			No	3
	Tachometer	AOCS - Agility Multi stage	Time stamp could be greater than actual value	100	10,00	TBD	1 cycle	1	< 1 Cycle		< 1 Cycle		1	Yes	5
	GNSS	AOCS	10000	1	1000,00	10 kbits/s	1 cycle	10	1 Cycle	10	1 Cycle			Yes	1
		AOCS	14	1	1000,00	10 kbits/s	1 cycle	0,001	<< 1 Cycle	0,001	<< 1 Cycle			Yes	1
Actuators	Magneto-Torquer Bars	AOCS	12	0,125	8000,00	neglectable	1 cycle	500	< 1 Cycle	8000	1 cycle		1 or 2	No	1
	Thrusters (x28)	ACOS	2800	8	125,00	22 kbits/s	< 1 cycle	Mission dependant		Mission dependant			1 or 2	No	3
	Thrusters - chemical	ACOS	2800	256	3,91	720 kbits/s	< 1 cycle	0,1	< 1 Cycle	0,1	< 1 Cycle	no loss	2	TBD	5
	Thrusters - electrical	ACOS	No hard constraints due to propulsion cycles: several minutes and the imapct on trajectory is not immediate										1 or 2	TBD	1
	Reaction Wheels	AOCS	30720	8	125,00	250 kbits/s	1 cycle	10,00	< 1 Cycle	10,00	1 cycle		1 or 2	Yes for some	2
	Reaction Wheels (high speed)	AOCS-Agility	30720	100	10,00	3 Mbits/s	1 cycle	0,50	< 1 Cycle	1,00	< 1 Cycle	No Loss of msg End of process in same cycle	2	TBD	5
Payload	Spectrometer	Science	2,00E+08	10	100,00	2000 Mbits/s	N/A	N/A	N/A	N/A	N/A		0 or 1	No	4
	Ultra HD Camera (4K)	Science	9,95E+07	10	100,00	1000 Mbits/s	N/A	N/A	N/A	N/A	N/A		0 or 1	No	4
	X Ray detector	Science	1,80E+10	0,0303	33003,30	545 Mbits/s	N/A	N/A	N/A	N/A	N/A		0 or 1	No	4

Experimental value, Approximation

Communication Classes

- Class 1: Low frequency, small / medium data size, non time critical
  - E.g., low-rate AOCS sensors, thermal, payload HK
- Class 2: Medium frequency, Medium data size, time critical, medium QoS
  - E.g., STR, GNSS, occasional data losses can be tolerated
- Class 3: Medium frequency, Medium data size, time critical, high QoS
  - E.g., actuators, especially with spacecraft safety consequences
- Class 4: Low frequency, Big data size, non time critical
  - E.g., science TM
- Class 5: High frequency, Medium data size, time critical, medium QoS
  - E.g., future high-rate sensors / actuators (e.g., RW, CMG)
- Class 6: Medium frequency, Big data size, time critical, medium QoS
  - E.g., Navigation Cameras
- Class 7: Medium frequency, Small data size, time critical, low jitter
  - E.g., Application / Network Synchronisation

OSRA-NET Communication System Requirement Specification

- Provides generic requirements related to the communication needs for avionics systems currently under development and that could be foreseen in future missions
- It can therefore be considered as a common-core of requirements that is expected to be relevant to a sizeable range of future missions
- Addresses
  - Capability requirements (Communication needs requirements, QoS)
  - Communication infrastructure requirements
  - Error handling and FDIR
  - System-level communication requirements
- Reviewed at study level and separately by SAVOIR-UNION Working Group
- Getting the attention of the space community
  - e.g., mapping to SpaceFibre performed by ESA / University of Pisa, ADCSS 2017, 28th, 30th & 31st SpaceWire Working Group, DASIA 2018, …
- **Transformed in a SAVOIR document: GS-008**


esa
estec
DOCUMENT

SAVOIR On-board Communication System Requirement Document

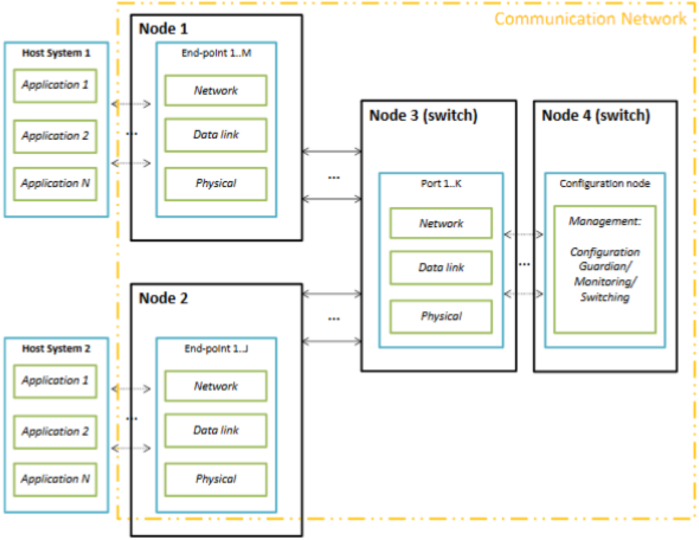
SAVOIR
space avionics open interface architecture

Prepared by	SAVOIR
Reference	SAVOIR-GS-008
Issue	1
Revision	0
Date of Issue	06/08/2019
Status	Released
Document Type	Generic Specification
Distribution	ESA Member States

European Space Agency
Agence spatiale européenne

OSRA-NET new content?

- Definitions for communication systems
  - Determinism, latency, jitter, class of communication, redundancy schemes, quality of service a FDIR
  - Terminology aligned with SpaceWire world!
- Clarifies the system dependancy of communication properties between the communication system and the host systems

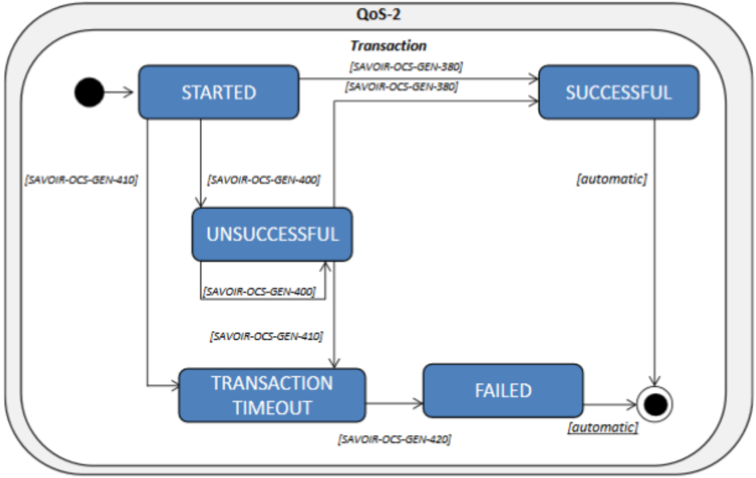


- Minor rework on the classes of communication with a synthetic table:

Class	Freq of data exchange scale (Hz)		QoS			Data Rate scale		Jitter	Latence	Level of determism			Timestamp
	Min	Max	0	1	2	Min	Max	ms	ms	None	guaranteed bounded latency	deterministic	Mandatory / Optional
1	0,1	1	X	X		100 bits/s	10 kbits/s	10	10		X		Optional
2-a	4	32		X	X		1 Mbits /s	5-10	10			X	Optional
2-b	4	32		X	X		1 Mbits /s	5-10	10		X		Mandatory
3	8	10			X		250 kbits /s	5	10			X	Optional
4	0,1	1	X	X		100 Mbits/s		up to 100	up to 100	X	X		Optional
5-a	10	1000		X	X		3 Mbits/s	0,5 -1	0,5			X	Optional
5-b	10	1000		X	X		3 Mbits/s	0,5 -1	0,5		X		Mandatory
6	1	10		X	X	100 Mbits/s		2	10			X	Mandatory
7	1	10	X	X		100 bits/s	1 kbits/s	1	2			X	Optional

GS-008: more than 100 RIDS processed

- All requirements come with a rationale
- Many requirements have been reworked to be agnostic of the technology (compatible with busses or networks)
  - Acknowledgement process *(ACK/NACK/Silence)*
  - Clarifications on the QoS section (classes)
- Clarification on the error reports for FDIR & network monitoring
  - Transactions verification in QoS 1 & 2
  - Bandwisdth usage, communication health status, node status
  - Repeated data link errors (number vs threshold)
  - Data integrity check
  - Missing packets detection, duplication filtering
- Integrated within the SAVOIR document tree
- Takes into account current & near-future satellites



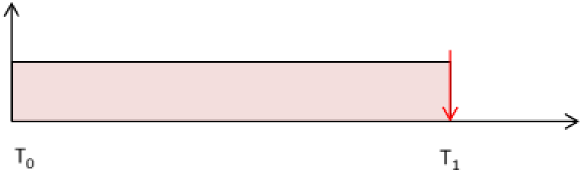


Figure 1: Transmission with guaranteed bounded latency property

Figure 2: Transmission with determinism property

Lessons Learnt

- Feasibility and performance of complex communication stack in SW
  - Take advantage of future heterogenous target such as the Compact Reconfigurable Avionics (multi-core LEON4 processor + reconfigurable FPGA) or DAHLIA (4 ARM R52 + reconfigurable FPGA) to offload CPU by using the FPGA
    - or have dedicated HW controllers
  - Benefit from HW / SW algorithm co-design!
- Implementation / bridge to communication analysis engines needs to be implemented
- Detailed communication protocol information for fine-grained protocol overhead (or protocol bridging) would be useful
- Recommendations for improvement of the ESA TASTE middleware real-time architecture were provided at the end of activity
- A relationship with avionics modeling process needs to be established
  - Including avionics modeling to SW modeling transformation bridges (e.g., Capella to OSRA SCM)

End of Presentation

Thank you for your attention

Questions?