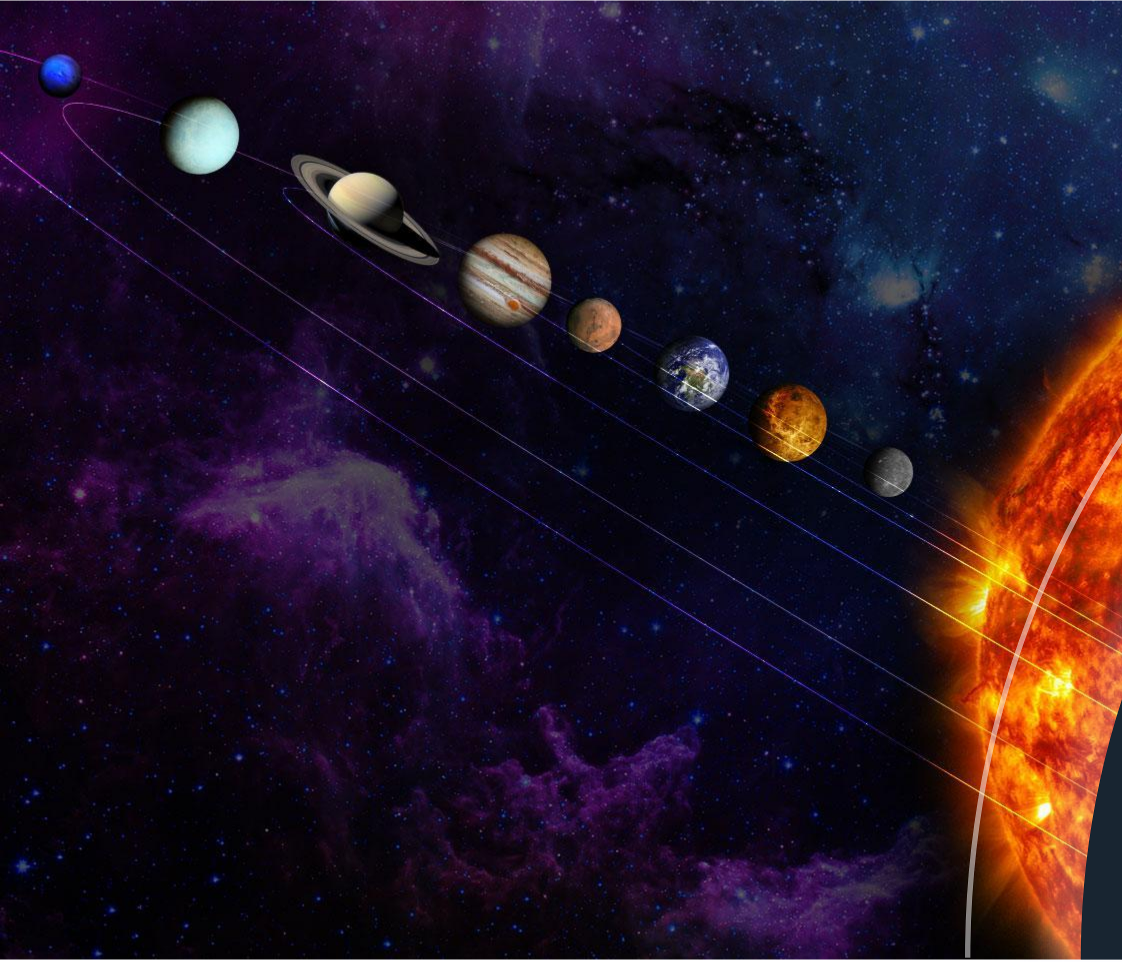


A New Network Paradigm for the On-board Reference Architecture (OSRA-NET)

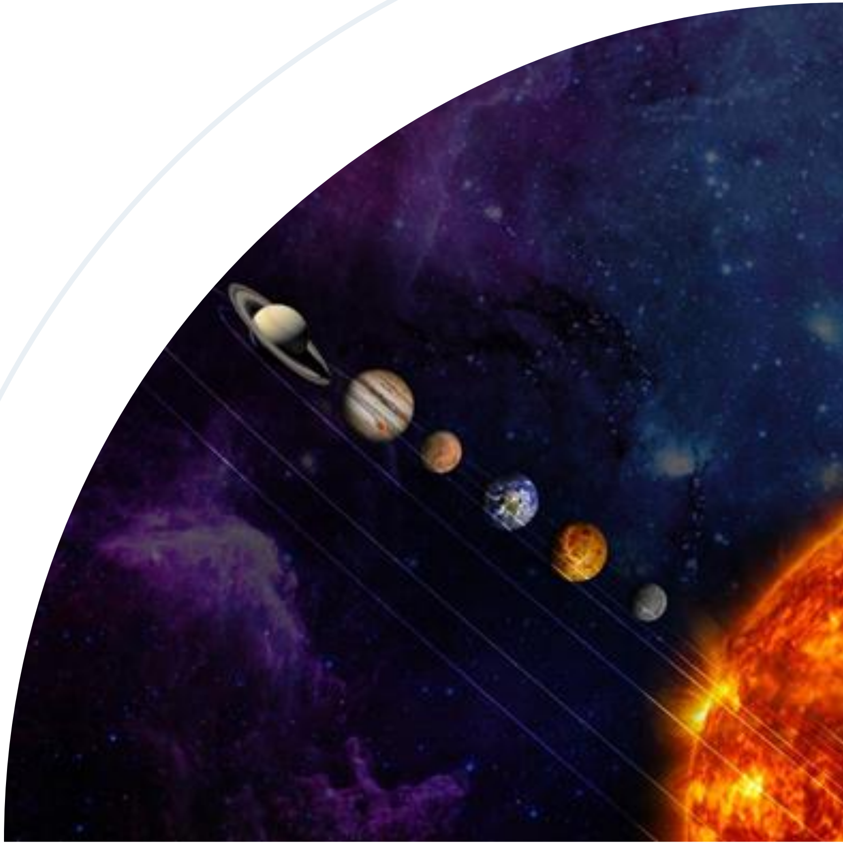
Marco Panunzio

Final Presentation Days – 09 May 2018 - ESA ESTEC

ThalesAlenia Space
a Thales / Leonardo company

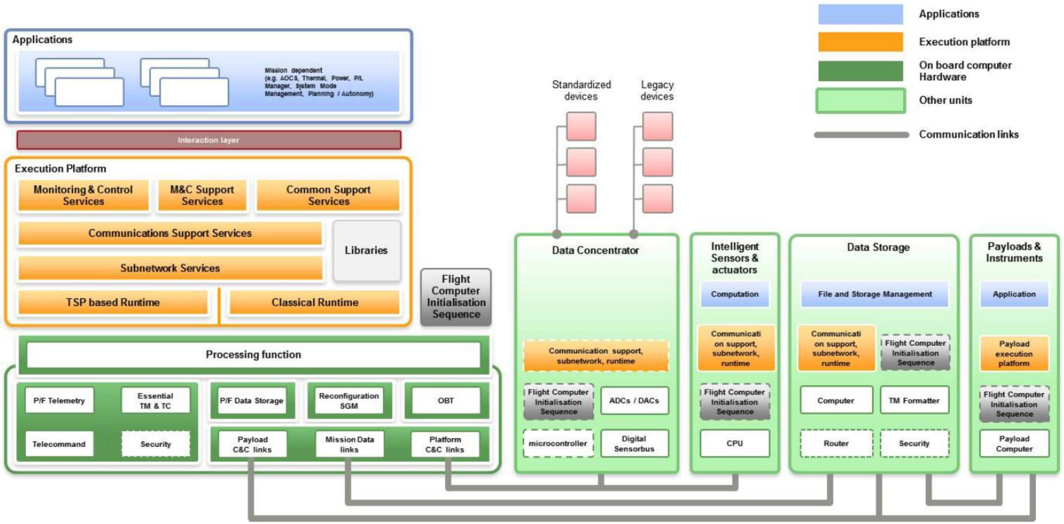
Outline

- SAVOIR and SAVOIR-FAIRE
- Goals of the OSRA-NET Study
- Study organisation
- Analysis phase
- The OSRA-NET Requirements Specification
- Demonstrator and Case Study
- Major results, lesson learnt and way forward



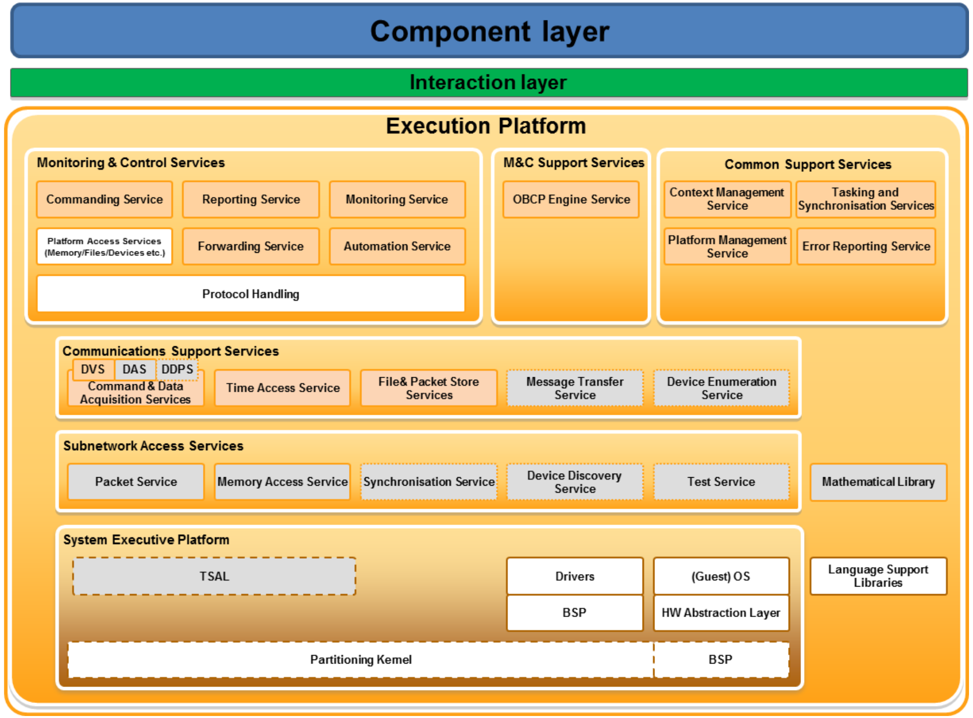
SAVOIR Avionics System Reference Architecture (ASRA)

- 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)

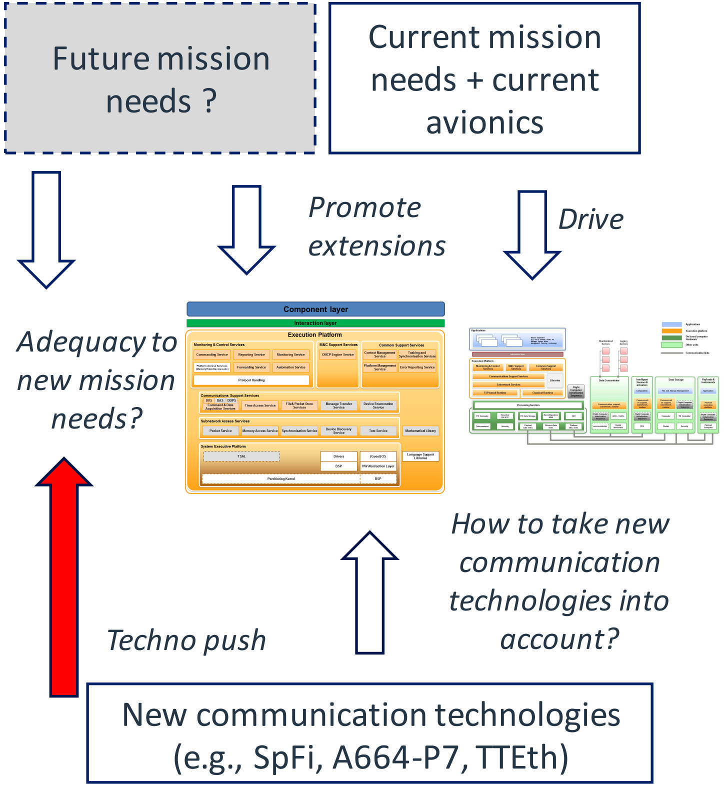
- Proposes a reference organisation of platform SW architecture in 3 layers
  - Component layer
    - for Mission-specific software
  - Execution platform
    - For Mission-independent software (e.g., generic services)
    - Oriented to re-use
  - Interaction layer
    - To guarantee independence of 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 (2016)

- ASRA + OSRA could adequately describe existing avionics and on-board software
- Technology references in the technical notes is mostly related to currently flying technology
  - e.g., 1553, SpaceWire, CAN in the OBC generic specification
- Strong ***techno push*** of new communication technologies (e.g., SpaceFibre, ARINC 664 P7, TTEthernet)
  - 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?

- 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 or TTEthernet
- To enable the implementation of a multi-node On-Board Software Reference Architecture (OSRA-NET)
- To perform an impact analysis on all relevant SAVOIR, ECSS and CCSDS documents
- Two major areas of work
  - 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

- 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

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

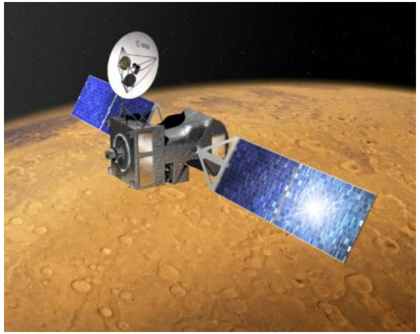
Analysis of communication needs for current and future avionics

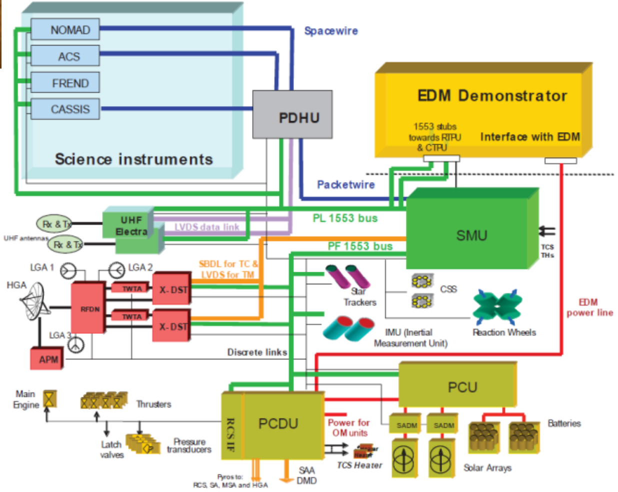
- A first paramount activity established reference terms and definitions
  - Why? : A lot of variability in use and semantics of terms was observed
    - It mostly derives from the fact that on-board communication is an area in which overlap between several disciplines occurs (e.g., control / GNC, avionics, data handling, electronics, software)
  - It can cause several misunderstandings and confusion in discussions
- Definitions for the following concepts were established and used coherently during the study
  - Time Critical / Non Time Critical (communication)
  - Determinsm / Predictability (deterministic / predictable communication, respectively)
  - Control domain
    - Delay
      - Sensor Acquisition Delay, Actuator Commanding Delay
    - Jitter
      - Sensor Acquisition Delay, Actuator Commanding Delay
  - Networking / Communication domain
    - Propagation Delay
    - Message Transmission Latency
    - Message End-To-End Latency

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)

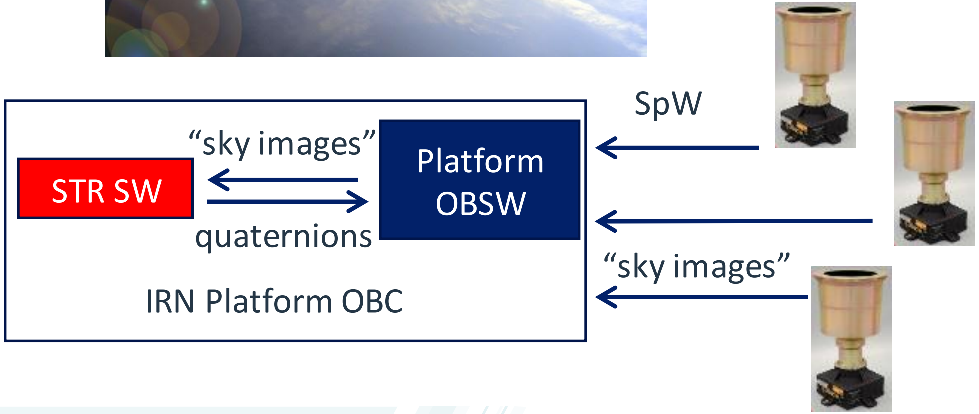
- Exomars TGO used as example of current operational avionics





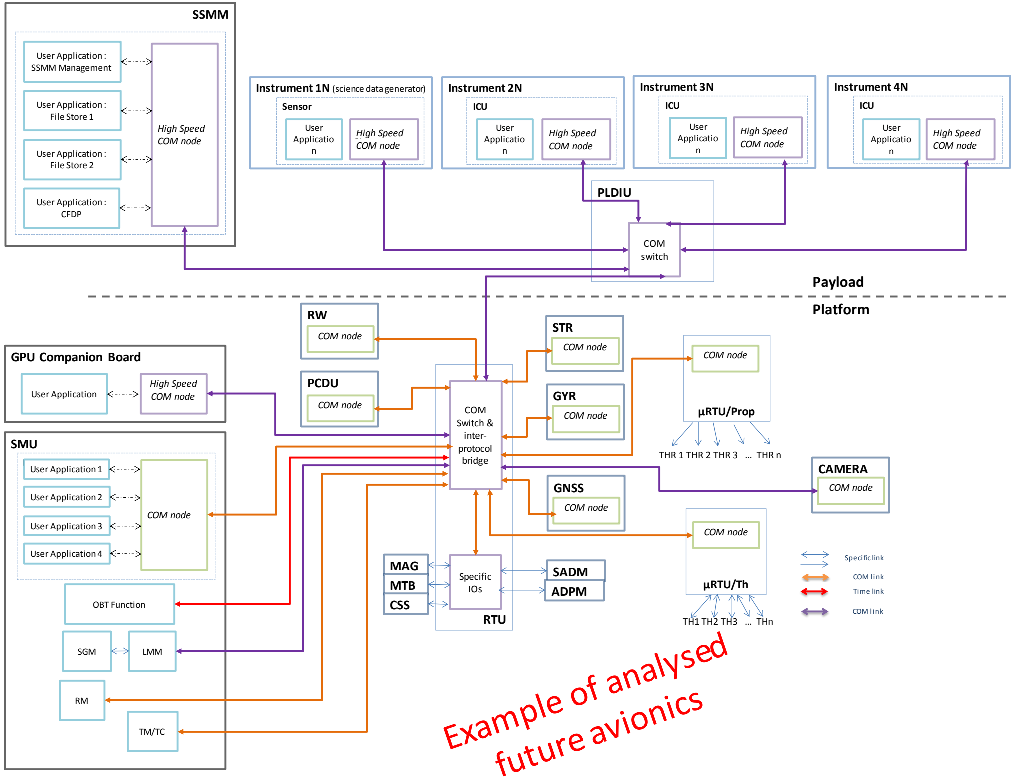
Analysis of communication needs for current and future avionics

- 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
  - Science
  - Earth Observation
  - Exploration missions



Analysis of communication needs for current and future avionics

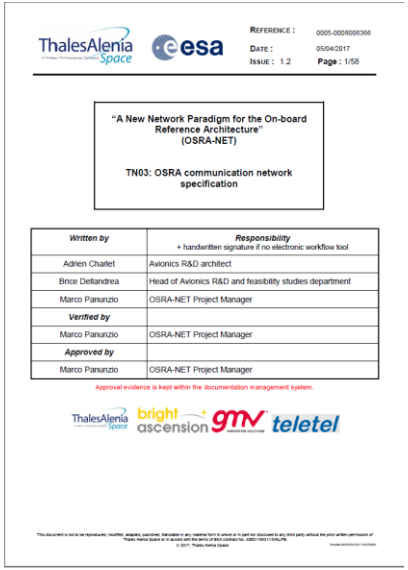
- The analysis permitted to extract expected communication needs for devices of future avionics architectures
  - Expected min-max message size
  - Frequency
  - Max Jitter / Latency
  - Need for timestamp

		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
Sensors	Coarse Sun Sensors	AOCS	96	8	125,00	770 bits/s	Low	10	1 cycle	10	1 cycle	order of msg		No	2
Sensors	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	
Sensors	Gyro (fine-grained)	AOCS	576	32	31,25	18 kbits/s	1 cycle	2	< 1 Cycle	2	< 1 Cycle			Yes	8
Sensors	Gyro (future)	AOCS	576	32	31,25	18 kbits/s	1 cycle	2	< 1 Cycle	1	< 1 Cycle			TBD	8
Sensors	Star-Tracker (Smart)	AOCS	8194 - 32777	8	125,00	65 to 262 kbits/s	1 cycle	1	< 1 Cycle	10	1 cycle			Yes	2
Sensors	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
Sensors	Star-Tracker	AOCS - Agility	8194 - 32777	30	33,33	245 to 983 kbits/s	<< 1 Cycle	0	<< 1 Cycle	1	<< 1 Cycle			Yes	5
Sensors	Camera - High Res.	AOCS - Rendez-vous	41943040	8	125,00	335 Mbits/s	1 cycle	10	< 1 Cycle	100	1 cycle			Yes	6
Sensors	Camera	AOCS - Nav. Cam	10485760	8	125,00	84 Mbits/s	> 1 cycle	100	> 1 cycle	100	> 1 cycle			Yes	4
Sensors	Camera	AOCS - Multi stage (1kHz)	1000000	1000	1,00	1000 Mbits/s	> 1 cycle	100		100				Yes	6
Sensors	IR Spectrum Camera	AOCS	2457600	1	1000,00	2,5 Mbits/s	> 1 cycle	100		100				Yes	6
Sensors	Payload sensors	Various - closed loop	Mission dependant	100	10,00	Mission dependant	<< 1 Cycle	Mission dependant	<< 1 Cycle	Mission dependant	<< 1 Cycle			TBD	5
Sensors	Tachometer	AOCS	30720	8	125,00	245 kbits/s	> 1 cycle	10	> 1 cycle	100	> 1 cycle			No	3
Sensors	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
Sensors	GNSS	AOCS	10000	1	1000,00	10 kbits/s	1 cycle	10	1 Cycle	10	1 Cycle			Yes	1
Sensors		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
Actuators	Thrusters (x28)	ACOS	2800	8	125,00	22 kbits/s	<1 cycle	Mission dependant		Mission dependant			1 or 2	No	3
Actuators	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
Actuators	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
Actuators	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
Actuators	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
Payload	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
Payload	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

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
- Already getting attention in the community!
  - e.g., mapping to SpaceFibre performed by ESA / University of Pisa, ADCSS 2017
- Currently being transformed in a SAVOIR document



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DATE : 05/04/2017
ISSUE : 1.2 Page : 1/58

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

TN03: OSRA communication network specification

Written by	Responsibility + handwritten signature if no electronic workflow tool
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Marco Panunzio	OSRA-NET Project Manager
Approved by	
Marco Panunzio	OSRA-NET Project Manager

Approval evidence is kept within the documentation management system.

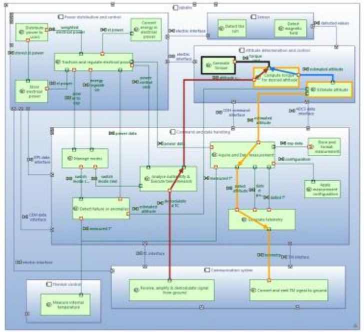
A major output of the activity!

Communication Classes

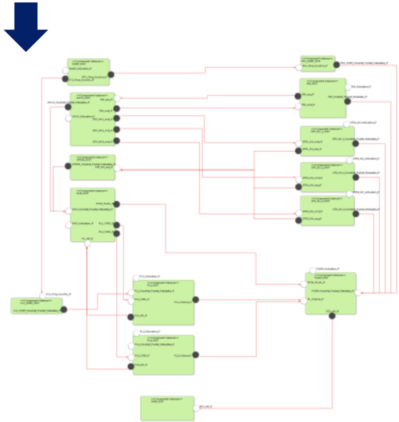
- Class 1: Low frequency, small / medium data size, non time critical
  - E.g., low-rate AOCS sensors, thermal, payload HK
- Class 2: Medium frequency, Medium data size, time critical, medium QoS
  - E.g., STR, GNSS, occasional data losses can be tolerated
- Class 3: Medium frequency, Medium data size, 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 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

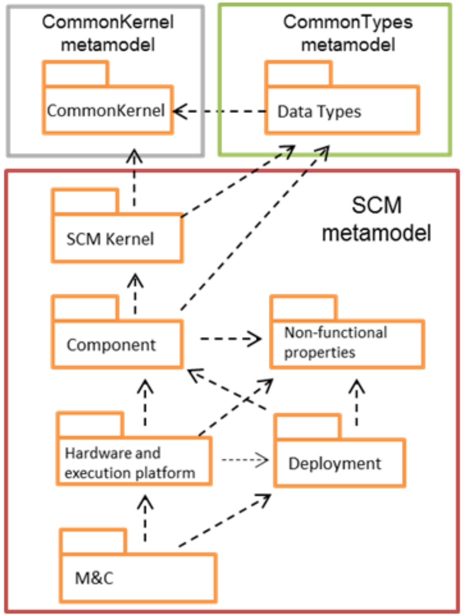
- OBSW modeling
  - Leveraging on e.g., the OSRA component model
  - Goal: Enable ***Fine-grained*** communication analysis
  - Capitalise on avionics modeling effort => coherent model transformation is required
  - Refinement of communications with knowledge of
    - Communication patterns used at OBSW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

Assessment of impact on other standards

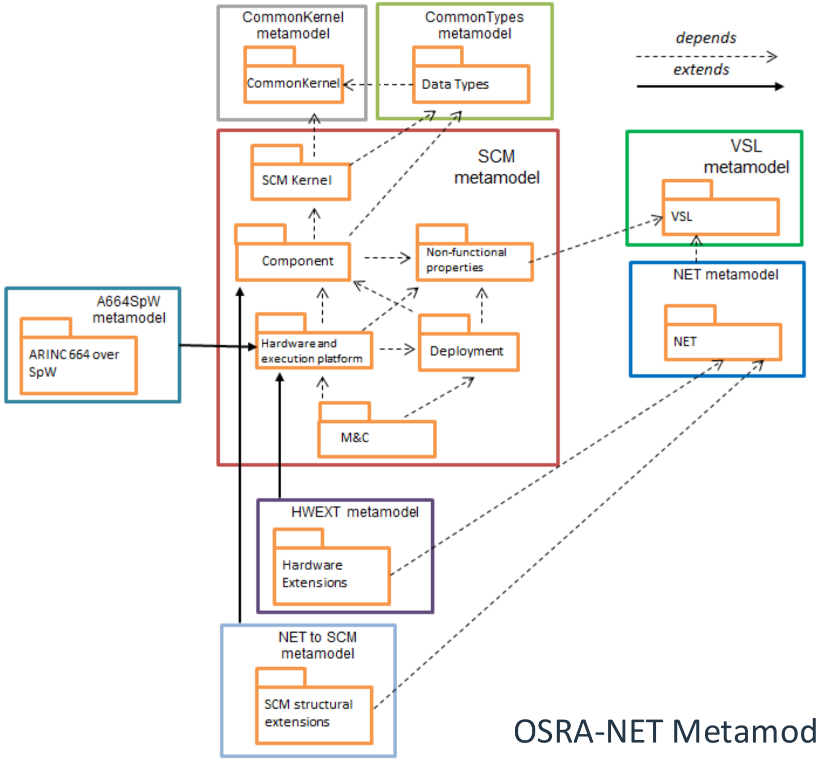
- The study produced also an impact analysis of the adoption of OSRA-NET on other SAVOIR documents, notably
  - SAVOIR Avionics Reference Architecture ASRA
  - SAVOIR-FAIRE On-board Software Reference Architecture (OSRA)
  - SAVOIR OBC Specification
  - SAVOIR MASAIS

- No major impact was detected in most documents
  - A few recommendations to improve some parts of the ASRA (regarding separation between functional / logical / physical architecture)
  - A few recommendations on the OBC specification regarding redundancy policy or some mentions of specific technologies for given links (e.g., C/C link)
  - An analysis was performed also on the execution platform of OSRA
    - But at the beginning of the study, OSRA was still heavily based on CCSDS SOIS, which is not necessarily the case today

OSRA(-NET) Component model



OSRA Metamodels (COrDeT-3)



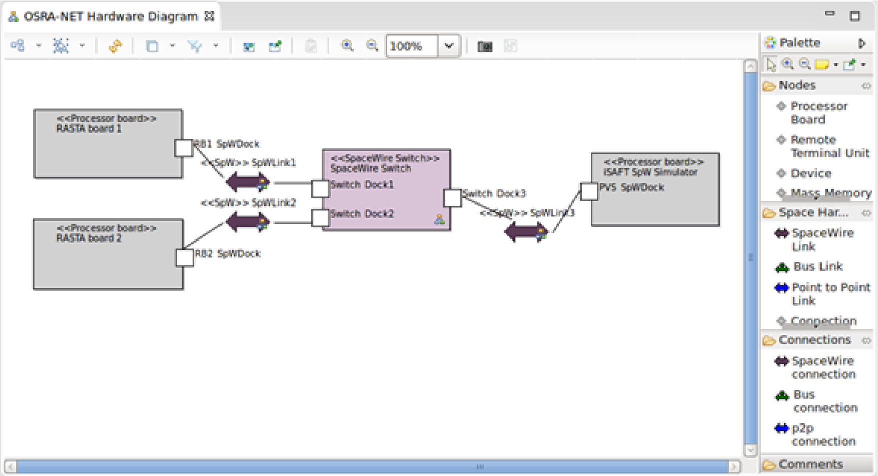
OSRA-NET Metamodels

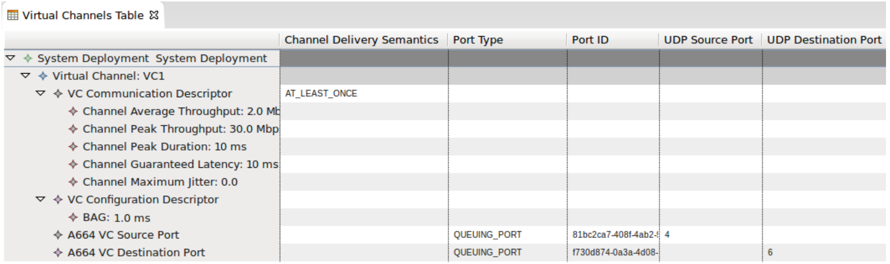
OSRA(-NET) Component model

- Improvement of OSRA metamodels architecture
  - Value Specification Language spinned out as independent metamodel
- Extensions to existing metamodels
  - Improvements for component deployment
  - Added new generic concepts such as “hardware switch” and “virtual channel”
- Added technology-specific extension
  - Spacewire hardware
  - ARINC664 Part 7 over Spacewire protocol
- Added OSRA-NET metamodel
  - Communication properties for coarse-grain and fine grained analysis
  - Not coupled to OSRA SCM
  - Can be reused independently of SCM
    - It is sufficient to add a new EMF metamodel adapter, as for e.g., Capella

OSRA(-NET) Graphical Model Editor

- Extended to reflect the new metamodels and permit modeling of new concepts
  - Virtual Channels, Communication Properties, new Hardware entities, deployment, etc…

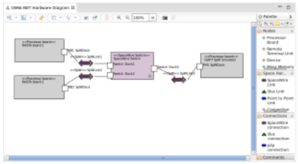



Virtual Channels Table

	Channel Delivery Semantics	Port Type	Port ID	UDP Source Port	UDP Destination Port
System Deployment System Deployment					
Virtual Channel: VC1					
VC Communication Descriptor	AT_LEAST_ONCE				
Channel Average Throughput: 2.0 Mb					
Channel Peak Throughput: 30.0 Mbp					
Channel Peak Duration: 10 ms					
Channel Guaranteed Latency: 10 ms					
Channel Maximum Jitter: 0.0					
VC Configuration Descriptor					
BAG: 1.0 ms					
A664 VC Source Port		QUEUING_PORT	81bc2ca7-408f-4ab2-	4	
A664 VC Destination Port		QUEUING_PORT	f730d874-0a3a-4d08-		6

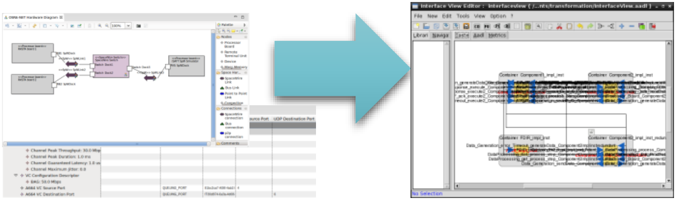
Demonstrator infrastructure development

- Development of an ARINC 664 P7 SW stack for spaceborne technology
  - ARINC 664 P7 over SpW physical medium
  - For RASTA LEON2 (with RTEMS) and iSAFT PVS (SpW EGSE)

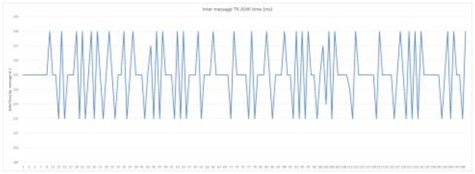


- Tranformation bridge between OSRA-NET metamodels and TASTE implemented

- Extension of the TASTE toolchain
  - To support the same new modeling concepts of OSRA-NET
  - To integrate the ARINC 664 P7 Communication Stack

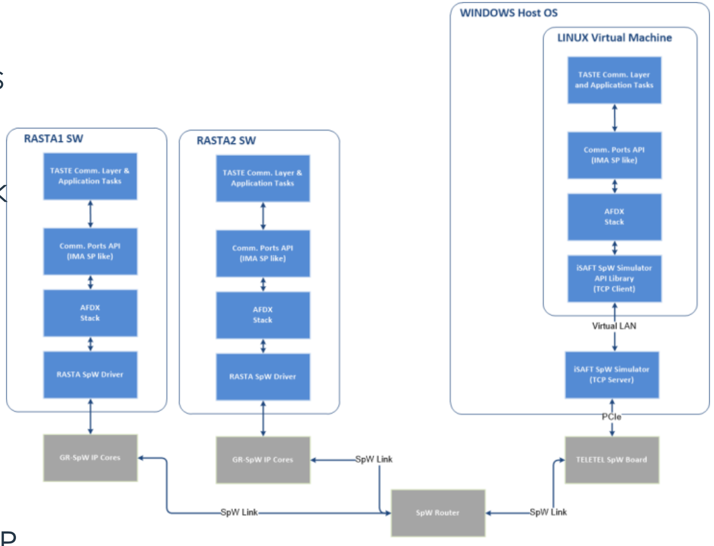


- Verification tests and Integration Tests (Communication Timing)

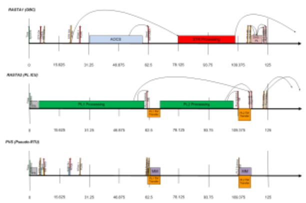


Communication stack implementation

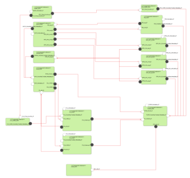
- Development of an ARINC 664 P7 SW stack for spaceborne technology
  - ARINC 664 P7 over SpW physical medium
  - For RASTA LEON2 (with RTEMS) and iSAFT PVS (SpW EGSE)
- Uses an open source (BSD style license) IP protocol stack, lwIP as a base for UDP/IP/ETH and packet buffers implementation
  - Modifications and adaptations of ETH layers w.r.t. ARINC664P7, integration with VL scheduler and SpW network interfaces
- ARINC 664: Implemented Integrity Checking, VL Scheduler (BAG regulator), FCS, Tx VL queues, etc.
- SpaceWire network interface and drivers
  - Low level SpW layer (addressing, handling of PID fields) for tunneling ETH/AFDX frames, link speed is set to 100Mbps (80Mbps user data rate)
- Implementation of protocol stack statistics (per Comm. Ports, UDP, IP, ETH, PHY Link (SpW), Memory Pools usage)



Overall case study process flow



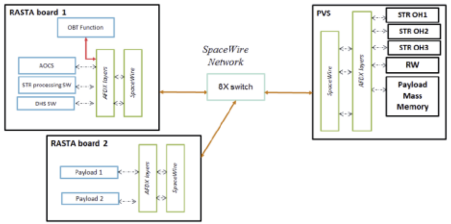
- Definition of a small-scale yet representative case study
  - Not representative of functionality but of communication traffic
  - Star Tracker with processing on OBC, Reaction Wheels, Payload Science TM, PF HK, PL HK



+ taste

- Case study modeling with the OSRA(-NET) Component model + code generation with TASTE

- Deployment of case study on final demonstrator configuration
  - 1 RASTA board as PF, 1 RASTA board as PL, 1 iSAFT PVS as pseudo-RTU



- Case study execution and verification report

- Extension of results via analysis to full-scale spacecraft avionics

Case study implementation and lessons learnt (I)

- A number of iterations to refine the notional case study scenario were necessary
  - To match the notional scenario with ARINC 664 P7 over SpW mechanisms
  - To cope with features of the execution platform / middleware stack that were missing in TASTE at the moment in which the demonstrator was implemented
- Major areas of work
  - Message segmentation ought to be implemented at application level. Impact on all messages >=1471 bytes
  - TCP not implemented in the communication stack (and is anyhow optional in ARINC 664 which uses UDP as default) => not possible to use or demonstrate ACK / NACK at transport layer
  - "Time synchronisation messages" were split in 2 separate messages, 1 per destination (RASTA2 and PVS). The second message is sent with a known static offset
  - FCS (ARINC 664 CRC32 integrity check) had to be deactivated, due to severe performance penalty on the RASTA LEON2 (80 MhZ)
    - ~585 microseconds to calculate the FCS of a packet of maximum size
    - This function should be ideally offloaded to dedicated hardware / FPGA
  - Running the VL scheduler in the ARINC 664 Stack with a 500 us period adds a considerable overhead for a LEON2 processor with RTEMS

Case study implementation and lessons learnt (II)

- Major Areas of Work (cont'd)
  - Allocation of transmission to ARINC 664 Virtual Links: ARINC 664 BAG (Bandwith Allocation Gap) is a power of 2. Therefore messages had to be allocated to VLs with possible periods of 1, 2, 4, etc…milliseconds. This implied oversampling for some messages.
  - Most Command and Control traffic could be easily accomodated on ARINC 664 with timing guarantees
    - However accomodating plenty of communications with messages >=1471 bytes and demanding timing guarantees requires a lot of iterations
      - due to the specific ARINC 664 mechanisms for bandwidth enforcement (communication split in several messages on the same VL with BAG minimum separation) => relevant e.g., for STR with SW processing in OBC
  - Relaxing of some timing constraints of the communication schedule was necessary due to eccessive jitter introduced by use of a Virtual Machine with TASTE on the iSAFT PVS

  - Lesson learnt were used to extrapolate trends for a full spacecraft (LEO Earth Observation)
    - Execution times and protocol overhead
    - Number of virtual channels for platform avionics and payload
    - Accomodation of message schedule in future avionics

Overall study results

- Major results
  - An analysis phase to gather communication needs of current and future avionics
  - Impact analysis on ASRA, OSRA, generic OBC specification, SAVOIR MASAIS, etc…
  - OSRA-NET communication requirements specification
  - OSRA-NET methodology
  - Extension of OSRA metamodels, and toolchain
  - Implementation of ARINC 664 P7 over SpW network
    - On RASTA LEON2 + iSAFT PVS
  - Prototype demonstrator with small-scale yet representative case study

Lessons Learnt and Future Work

- 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 (or have dedicated HW controllers)
  - Benefit from HW / SW algorithm co-design!
- Implementation / bridge to communication analysis engines
  - And relationship with avionics and OBSW modeling process
- Detailed communication protocol information for fine-grained protocol overhead
- Recommendations for improvement of TASTE middleware real-time architecture
- Avionics modeling to SW modeling transformation bridges (e.g., Capella to OSRA SCM)

End of Presentation

Thank you for your attention

Questions?