SAVOIR Communication Architecture

ESA/ESTEC Contract No.: 4000110966/13/NL/GLC/al

Final Presentation

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Summary

- Project Overview
- Programme of Work
  - Use Case
  - Services for Prototype
  - Flight Software Upgrades
- Main Study Results
  - FSW1.0 and FSW2.0 Comparison
  - SOIS and ECSS Standards Proposed Mapping
  - Lessons Learnt
  - Recommendations
- Conclusion

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Project Overview

Project

- ESA GSTP 5.1 project 3-13910/13/NL/GLC/al
- Apr 2014 – Nov 2015

Objectives

- Selecting services compliant with a satellite use case
- Identifying upgrades needed to implement SOIS services
- Defining the FSW architecture
- Designing/testing the new and adapted SW components
- Validating the overall FSW with SOIS implementation
- Assessing impacts of such implementation
- Providing feedback on SOIS standards

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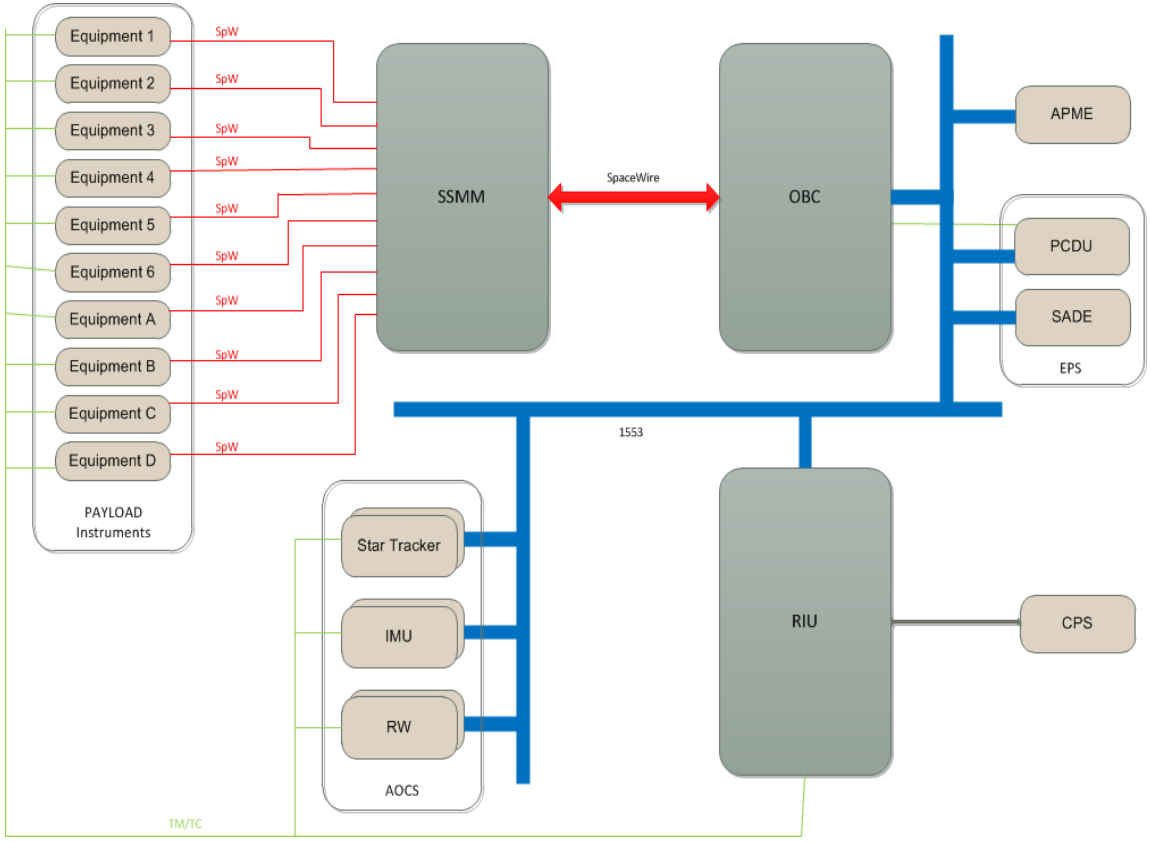
Mission Representative Use Case

Platform

- **1553B buses connecting OBC to**
  - AOCS sensors and actuators
  - RIU
  - PCDU…
- **Discrete I/O links**

Payload

- **SpaceWire links connecting OBC to 10 instruments through a SSMM acting as SpaceWire router**



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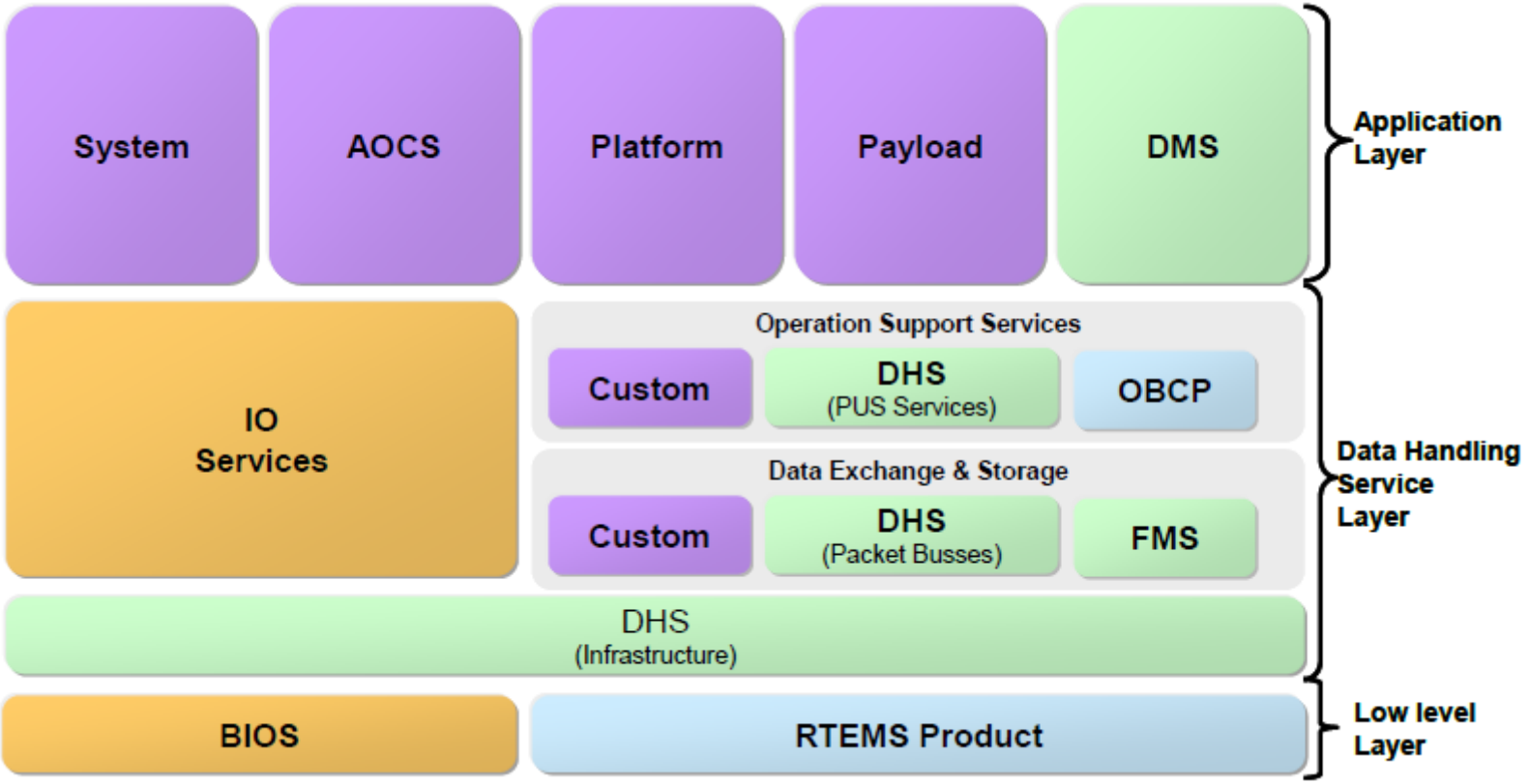
Initial Flight Software Architecture



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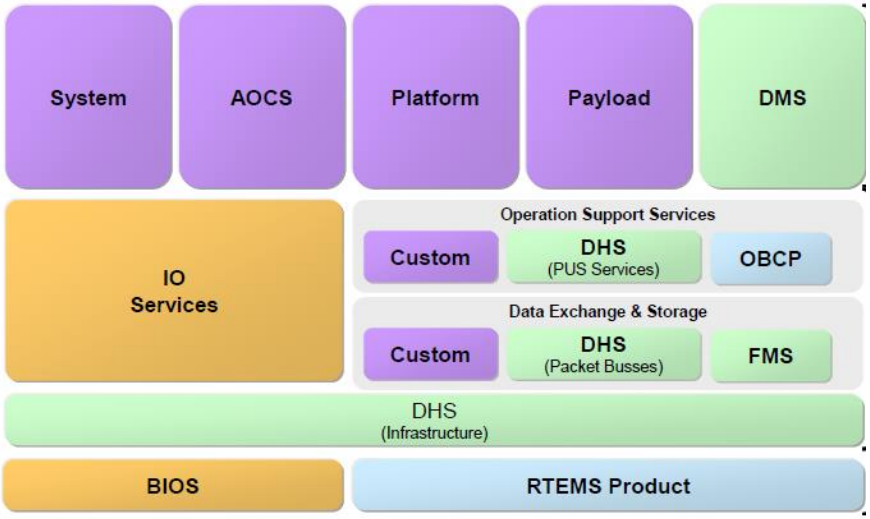
Flight Software Breakdown

Applications…

- **System**
  - Spacecraft management
  - System Level FDIR
  - SSMM management and control
- **AOCS**
  - AOCS modes and processing
  - Subsystems control
- **Platform**
  - Thermal control
  - Subsystems control
- **Payload**
  - Subsystems control
- **Data Management System**
  - TM/TC communication, PUS
  - Memory management
  - On-board Time management



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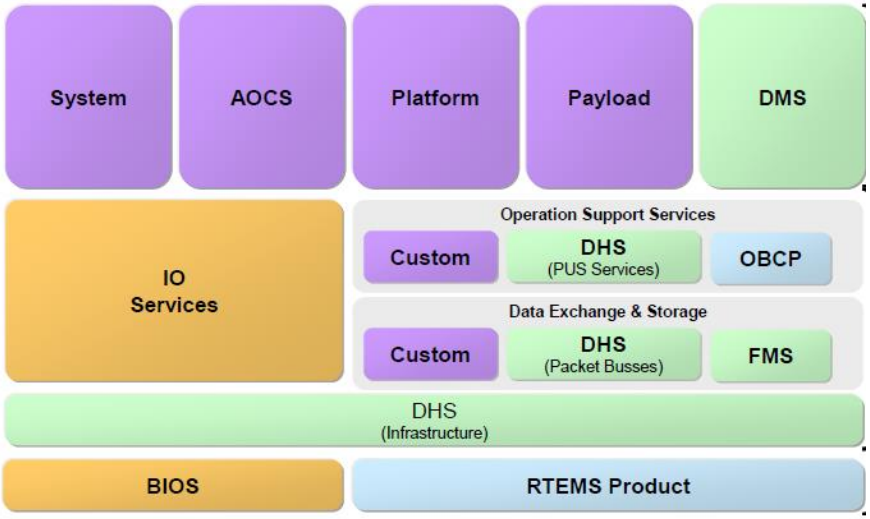
Flight Software Breakdown

…built by assembling standardized objects

- **Set of processing**
- **Equipment unit Managers**
  - Interfaces and telecommands to manage units
  - Unit states and implements the processing of the data from/to the HW unit
- **Equipment unit Hardware Abstraction layer**
  - Handles the communication with a real HW equipment unit



…and supported by I/O handling managers

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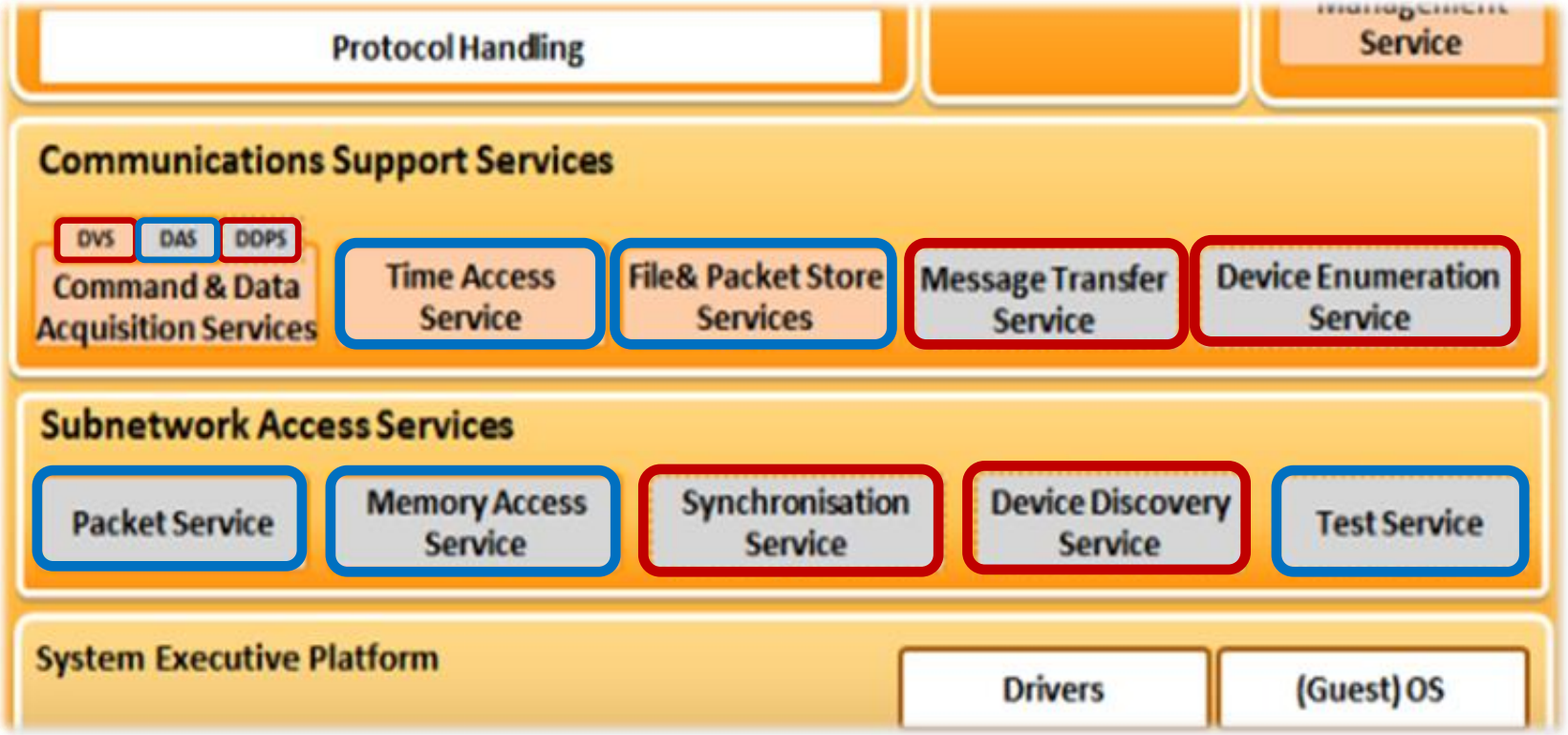
Services for Prototype



: *Selected Service*

: *Unselected Service*

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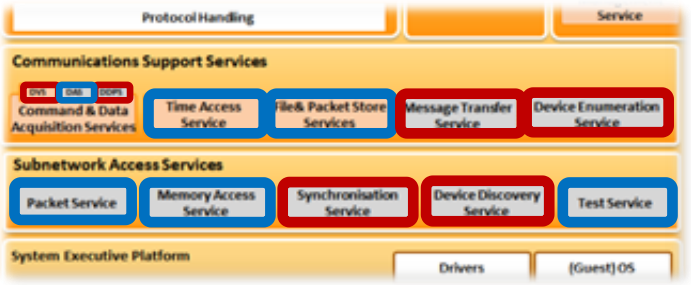
Services for Prototype



: *Selected Service*

: *Unselected Service*

Selected services for prototype

- **Device Access Service (DAS)**
  - Well adapted to interact with equipment managers
  - DAS interacts with PS or MAS services to communicate with remote devices
- **Time Access Service (TAS)**
  - Provides a standard access to the spacecraft On-Board Time (OBT)
- **File and Packet Store Services (FPSS)**
  - Provides a standard interface to handle the files and the packet stores
- **Memory Access Service (MAS)**
  - Used to read or write data on a remote device at a specified address
- **Packet Service (PS)**
  - Used to exchange TM/TC packets over a subnetwork
- **Test Service (TS)**
  - Used to check the connectivity of a remote device on a subnetwork

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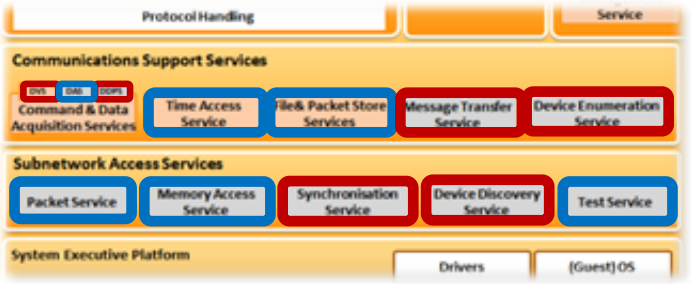
Services for Prototype



: *Selected Service*

: *Unselected Service*

Unselected services for prototype

- **Device Virtualisation Service (DVS)**
  - Not applicable due to nominal/redundant equipment differentiation in this use case
  - Redundancy aspects not treated
- **Device Data Pooling Service (DDPS)**
  - Too dimensioned compared to the needs
  - Substantial development effort compared to the slight added value
- **Device Enumeration Service (DES) / Device Discovery Service (DDS)**
  - Effort to implement DDS too high (impacts on bus link traffic, feasibility on test bench)
  - Effort to implement "bottom-up" mechanisms too high (asynchronous indication mechanisms with messages, queues…) with respect to added value
  - Too low added value of "top-down" mechanisms
- **Message Transfer Service (MTS)**
  - Inter-application communication done via PUS services
  - MTS too dimensioned and high development effort (better-managed using DAS+PS)
  - High complexity brought by CCSDS Asynchronous Message Service (AMS)
- **Synchronisation Service (SS)**
  - Not applicable to the selected use case, since OBC is time master

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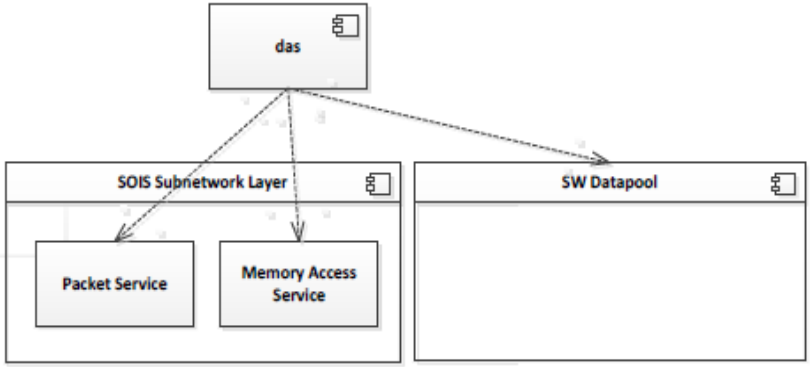
Flight Software upgrades

Device Access Service (DAS)



- **Interfaced with equipment unit managers**
- **HAL functionalities deported within the DAS**
  - sending a data from an application to the equipment
  - acquiring a data and providing it to the application
  - some specific operation has been kept within the HAL
- **Provides a standard access to the Subnetwork Layer**
  - depending on the physical device and value identifier parameters, the DAS maps the requests onto underlying services (PS and MAS).
- **Mandatory Acquire From and optional Command functions implemented**
- **Transaction Identifier parameter not used**
  - API directly return operations result
- **MIB used to map Device and Value Identifiers onto individual DAPs and parameters of underlying services**

Flight Software upgrades

Memory Access Service (MAS)

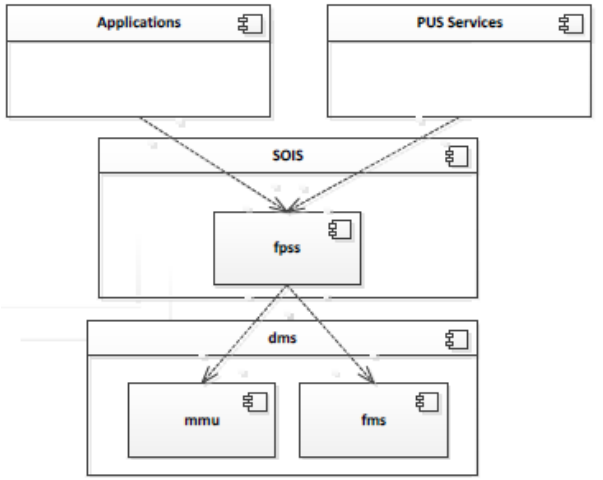
- **Interfaced with DAS and 1553B manager**
- **Used to write/read a value in/from a Remote Terminal unit**
- **Provides parameters such as**
  - destination address
  - memory address to the 1553 manager (corresponding to the number of the RT)
  - sub-address number,…
- **Mandatory Read and optional Write functions implemented**
- **Parameters not used**
  - MASAP Address
  - Transaction Identifier
  - Priority
  - Channel
- **MIB used to map Destination Address and Memory ID parameters onto functions to Get/Set data on a remote device**

Flight Software upgrades

Packet Service (PS)

- **Applicable to the STR for MIL-STD-1553B**
  - Interfaced with DAS and 1553B manager
  - Connected to STR HAL for equipment specific communication protocol
    - Data Block protocol
- **Applicable to the SSMM for SpaceWire**
  - Interfaced with DAS and SpaceWire manager
  - Connected to SSMM HAL for equipment specific communication protocol
    - CPTP protocol
- **Mandatory functions implemented**
- **Parameters not used or supported**
  - Priority
  - Channel
  - QoS
- **MIB used to map Packet Destination SAP Address onto packet handling API**

Flight Software upgrades



File and Packet Store Services (FPSS)

- **Interfaced with File Management System and Mass Memory manager**
- **Functions subset implemented**
  - OPEN_FILE / CLOSE_FILE
  - READ_FROM_FILE / WRITE_TO_FILE
  - LIST_DIR
  - COPY_FILE
  - CREATE_FILE / DELETE_FILE
  - GET_PACKET_STORES_INFO
  - CLEAR_PACKET_STORE
  - WRITE_PACKETS
- **No MIB used for the FPSS**

Time Access Service (TAS)

- **Interfaced with the On-Board Time manager**
- **Used to provide the interface to the local time source**
- **Mandatory Time function implemented**
- **TASAP Address and Transaction Identifier parameters not used**
  - API directly return the OBT
- **No MIB used for the TAS**

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Flight Software upgrades

Test Service (TS)

- **On MIL-STD-1553B**
  - Equivalent to Data-Wrap Around function
  - Interfaced with1553B manager
- **On SpaceWire**
  - Interfaced with PUS Service 17 Connection Test
- **Used to perform verification of the connectivity of a remote device on a subnetwork**
- **Mandatory Test function implemented**
- **MIB used to**
  - Map TEST Address parameter onto SAPs of underlying services
  - Map TSAP Address onto application SAPs to distribute test indications
  - Define timeout duration for each equipment

Unit, Integration and Validation

A large set of tests has been reused and adapted from the initial FSW and tests have been specifically developed for new SW components (i.e. for SOIS SW components)

Test Means

- **Unit software validation facility**
  - Check the correctness of the implementation (code) with respect to the SW design
  - Performed per component or set of components on the SW Units produced

- **Numerical software validation facility**
  - SOIS integration with underlying components and with Applicative SW components
  - Validation against requirements on a simulated computer, representative of the HW, and with the equipments and environment models

All requirements have been covered by at least one test

All test cases have been successfully performed

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Performance Assessment

Memory Budget

- **Impact of SOIS implementation**
  - Increasing of 2.42% of the EEPROM memory budget
  - RAM memory budget only increased by 0.12%

CPU Utilisation

- **Measurement mean**
  - Tasks statistics
  - FSW instrumented with user traces

- **Computed from validation tests**
  - Worst Case average CPU utilisation
    - difference between FSW1.0 and FSW2.0 increasing by 1.1544%
    - representing a relative increase of 7.77%
  - Worst Case peak cyclic CPU utilisation
    - difference between FSW1.0 and FSW2.0 increasing by 2.967%
    - representing a relative increase of 14.58%

Performance Assessment

CPU Utilisation

- **Schedulability Analysis**
  - Worst-case operational scenario defined
  - Worst-case computational time for each event determined
  - CPU utilisation analysis performed

- **Computed from WCET and frequencies**
  - FSW1.0 CPU utilisation is 59.11%
  - FSW2.0 CPU utilisation is 59.40%
  - difference of 0.29% representing a relative increase of 0.5%

Performance Assessment

Access Time

- **SOIS overhead measured comparing the CPU consumption of SOIS functions with direct calls to the corresponding IO functions from the initial FSW**

	ΔSOIS/non-SOIS (µs)
Test request	+30
Test answer	+64
STR: transmission of TC	+56
STR: reception of TM	+3
SSMM: transmission of TC	+55
File open	+6
File close	+6
File write (64 bytes)	+7
Write packet list (1 TM - 78 bytes)	+8
1553 write (access to IO function)	+67
1553 acquisition (access to IO function)	+40

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Implementation Assessment Synthesis

Implementation of SOIS Services within a FSW Architecture

- **Substantial impact on the current FSW architecture**
- **Substantial effort to implement and test SOIS services**
- **Performance overhead introduced by SOIS layer**
  - Increasing of CPU load
  - Increasing of the execution time for operation
    - 50% increasing for a STR TC transmission
    - 20% increasing for a SSMM TC transmission
    - 20% increasing for a test request/answer
    - 5% increasing for File operations
- **No SW architecture simplification**
- **No SW memory budget reduction**

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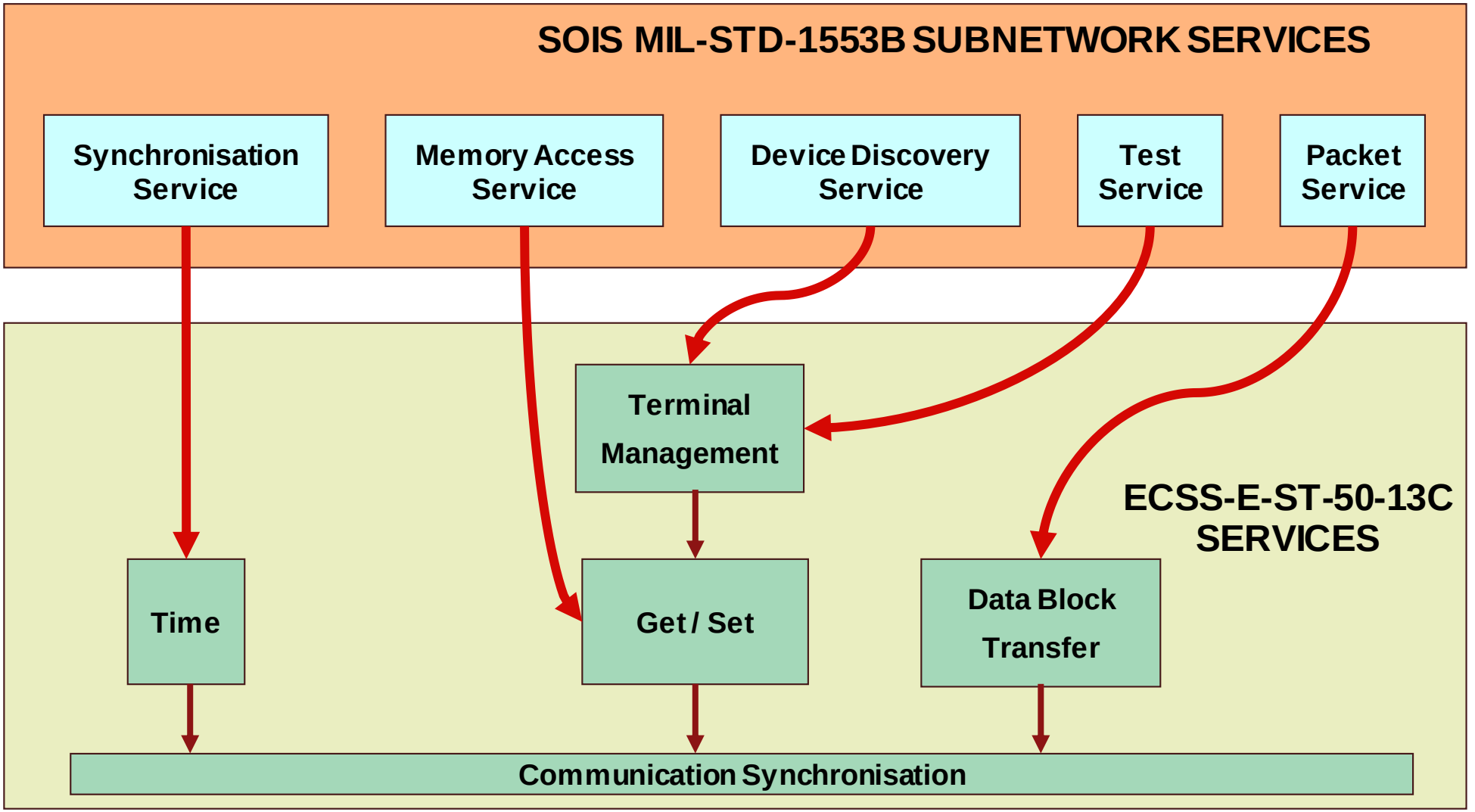
SOIS 1553 Subnetwork & ECSS-1553 Proposed Mapping



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SOIS SN Packet Service & ECSS-1553 Proposed Mapping

Packet Service (PS)

SOIS Service	Primitives	ECSS-1553 Service	SOIS Parameters	ECSS mapping
Packet Service	PACKET_SEND.request	Direct use of Data Block Distribution service; dataDist_submit(), dataDist_status()	PSSAP Address	Not used by ECSS
			PDSAP Address	DestinationAddress
			Service Class (Best Effort and Guaranteed)	QualityOfService
			Priority	Not used directly
			Channel	Not used directly
			Data	UserData
			Not addressed	UserDataLength
			Not addressed	Distribution Transfer Confirmation feature
	PACKET_RECEIVE.indication	Direct use of Data Block Acquisition service; dataAcq_msg()	PSSAP Address	Not used by ECSS
			PDSAP Address	BC address defined in the Acquisition Transfer Request
			Service Class (Best Effort and Guaranteed)	The QoS at ECSS-1553 service layer depends on the RT request, not user's request
			Channel	Not used directly
			Data	UserData
			Not addressed	NbNoResponse
			Not addressed	Acquisition Transfer Confirmation feature

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SOIS SN Memory Access & ECSS-1553 Proposed Mapping

Memory Access Service (MAS)

SOIS Service	Primitives	ECSS-1553 Service	SOIS Parameters	ECSS mapping
Memory Access Service	READ function	use of Set/Get Data type2: setDataT2_submit(), getDataT2_submit() - 1 Set Data, i.e. BC->RT to specify memory Id , start address and size. - A suite of Get Data, i.e. BC<-RT SA x-y to transfer the data	MASAP Address	Not used by ECSS
			Destination Address	Destination (RT number)
			TransactionID	GetData Id
			Memory ID	Destination (SA number)
			Start Memory Address	Not addressed directly, define by the first set operation
			Size	Not addressed directly, define by the first set operation
			Priority	Not used directly
			Channel	Not used directly
			Data	Data
			ResultMetadata	ReceiveData.Deliver
	WRITE function	use of Set Data type2: setDataT2_submit() - Set Data, i.e. BC->RT to specify memory Id , start address and size. - a suite of Set Data, i.e. BC->RT SA x-y to transfer the data	MASAP Address	Not used by ECSS
			Destination Address	Destination (RT number)
			TransactionID	SetData Id
			Memory ID	Destination (SA number)
			Start Memory Address	Not addressed directly, define by the first set operation
			Size	Not addressed directly, define by the first set operation
			Priority	Not used directly
			Channel	Not used directly
			Data	Data

SOIS SN other services & ECSS-1553 Proposed Mapping

Synchronisation Service (SS)

SOIS Service	Primitives	ECSS-1553 Service	SOIS Parameters	ECSS mapping
Synchronisation Service	SS function	use of TimeData_submit()	SYNCSAP Address	Not used because as BC node is considered as Time Master, the time is directly gotten from on-board timer, not from ECSS-1553 service. RTs are slaves and don't request the time
			Time	Time

Device Discovery Service (DDS)

SOIS Service	Primitives	ECSS-1553 Service	SOIS Parameters	ECSS mapping
Device Discovery Service	DDS function	use of termMgt_RTHM()	DDSAP Address	Not used by ECSS, using of get operation
			Device address	RT number (and SA1)
			Device Metadata	RT_Health & Monitoring data

Test Service (TS)

SOIS Service	Primitives	ECSS-1553 Service	SOIS Parameters	ECSS mapping
Test Service	TS function	use of termMgt_DWAD()	TSAP Address	Not used by ECSS, using of get operation
			Test address	RT number and (SA30)
			Test Status	32 data words at SA30

SOIS SN & ECSS-E-ST-50-12C/5x Proposed Mapping (1/4)

Packet Service (PS)

- **No standardised SpaceWire packet transfer protocol**

SOIS Service	Primitives	SpaceWire	SOIS Parameters	ECSS mapping
Packet Service	PACKET_SEND.request	CCSDS Packet Transfer Protocol (CPTP) defined by the ECSS-E-ST-50-53C: CCSDS_PACKET_SEND.request	PSSAP Address	Not used by ECSS
			PDSAP Address	Target SpaceWire and Logical Addresses
			Service Class	Not supported
			Priority	Not supported
			Channel	Not used
			Data	User Application Value
			Not addressed	Packet Length
			Not addressed	CCSDS Packet
	PACKET_RECEIVE.indication	CCSDS Packet Transfer Protocol (CPTP) defined by the ECSS-E-ST-50-53C: CCSDS_PACKET_RECEIVED.indication	PSSAP Address	Not used by ECSS
			PDSAP Address	Not used by ECSS
			Service Class	Not supported
			Channel	Not used
			Data	User Application Value
			Not addressed	Status

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SOIS SN & ECSS-E-ST-50-12C/5x Proposed Mapping (2/4)

Memory Access Service (MAS)

READ.request

RMAP Parameters	SOIS Equivalent
Target SpaceWire Address, Target Logical Address	Destination Address
Read Command Options, Key	
Reply Address, Initiator Logical Address,	SSNSAP
Transaction Identifier	SSNSAP, Destination Address, Memory ID, Start Memory Address, Size
Extended Address, Memory Address	Memory ID, Start Memory Address
Data Length	Size

READ.confirmation

RMAP Parameters	SOIS Equivalent
Transaction Identifier	SSNSAP, Destination Address, Memory ID, Start Memory Address, Size
Status	Failure Metadata
Data Length	Size
Data	Data

WRITE.request

RMAP Parameters	SOIS Equivalent
Target SpaceWire Address, Target Logical Address	Destination Address
Write Command Options, Key	
Reply Address, Initiator Logical Address,	SSNSAP
Transaction Identifier	SSNSAP, Destination Address, Memory ID, Start Memory Address, Size
Extended Address, Memory Address	Memory ID, Start Memory Address
Data Length	Size
Data	Data

WRITE.confirmation

RMAP Parameters	SOIS Equivalent
Transaction Identifier	SSNSAP, Destination Address, Memory ID, Start Memory Address, Size
Status	Failure Metadata

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SOIS SN & ECSS-E-ST-50-12C/5x Proposed Mapping (3/4)

Synchronisation Service (SS)

- **Time distribution function only, event not supported**
- **No standardised SpaceWire time distribution protocol**
  - Using of SpaceWire packets and time-codes

SOIS Service	Primitives	SpaceWire	SOIS Parameters	ECSS mapping
Synchronisation Service	SS function	No existing standardised SpaceWire time distribution protocol. To map the SpaceWire Synchronisation Service onto SpaceWire, a using of SpaceWire time-codes and SpaceWire packets can be done to implement the time distribution function.	SYNCSAP Address	Not used
			Time	Time

SOIS SN & ECSS-E-ST-50-12C/5x Proposed Mapping (4/4)

Device Discovery Service (DDS)

- **No standardised SpaceWire device discovery protocol**

SOIS Service	Primitives	SpaceWire	SOIS Parameters	ECSS mapping
Device Discovery Service	DDS function	No standardised SpaceWire device discovery protocol exists. To implement the SpaceWire Device Discovery Service onto SpaceWire, RMAP protocol defined by the ECSS-E-ST-50-52C can be used.	DDSAP Address	Not used
			Device address	Target SpaceWire and Logical Addresses
			Device Metadata	Device identification registers data of a 10X switch

Test Service (TS)

- **No standardised SpaceWire test protocol**

SOIS Service	Primitives	SpaceWire	SOIS Parameters	ECSS mapping
Test Service	TS function	No standardised SpaceWire test protocol exists. To implement the SpaceWire Test Service onto SpaceWire, RMAP protocol defined by the ECSS-E-ST-50-52C can be used.	TSAP Address	Not used
			Test address	Target SpaceWire and Logical Addresses
			Test Status	Status registers data of a 10X switch

Lessons Learnt and Recommandations

Request/Indication (DAS+PS/MAS) impact on performances

- **Initially, applications don't send request to equipments to acquire data**
  - Data directly extracted from the datapool
  - Synchronization of applications, data handling layer and I/O components
- **Mapping between DAS and PS/MAS overloads the software architecture by adding an unnecessary additional layer**
  - Useless since DAS indirectly knows details about the subnetworks and protocols
    - Device ID and Value ID from DAS mapped to access-type-specific primitives like Destination Address, Transaction ID, Memory ID, StartMemoryAddress, size, etc (in case of the MAS)
- **SOIS recommended practices do not discuss about the real-time impact of the exchanges between DAS and subnetwork layer (i.e. MAS and PS)**

⇒ **Performance degradation**

- Increasing in terms of access time, blocking time, WCET

Lessons Learnt and Recommandations

Synchronisation, Real-Time and Dynamic Behaviour

- **Static architecture of services, with primitive interfaces, not considering**
  - Dynamic architecture
  - Performance
  - Synchronisation between the dynamic behavior of different layers
- **A lot of things can vary the dynamic behavior of each service such as**
  - synchronisation mechanisms,
  - time access or concurrent access by application
- **SOIS concept takes into account all that can be mapped to it but not their associated dynamics, which causes blocking mechanisms and latencies**

Configuration by MIB

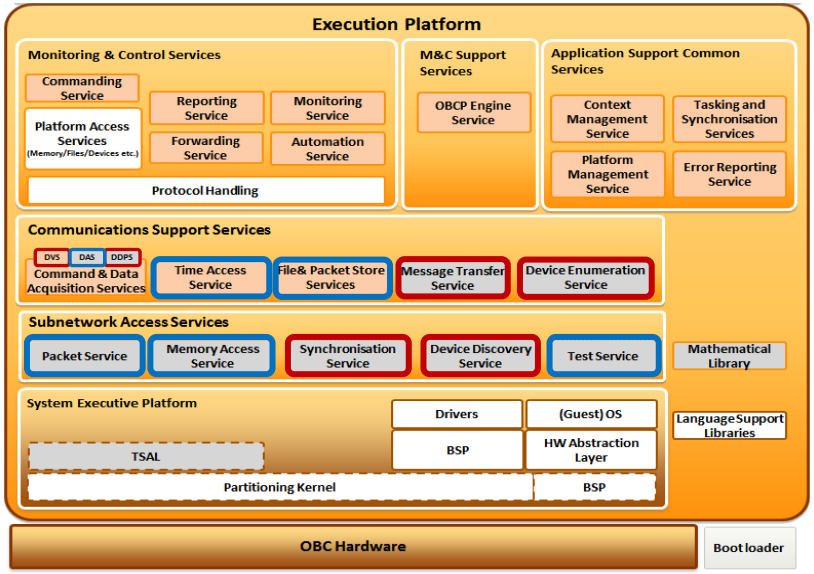
- **Configuration aspects of services not approached in SOIS standards**
- **Since MIBs are not standardised, MIB access and use not optimized**

Current Airbus Execution Platform Architecture

Our existing Execution Platform

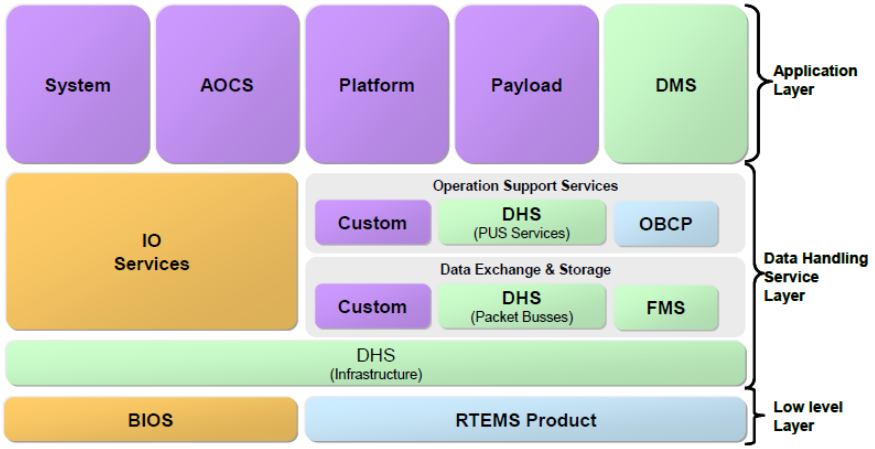
- **Application Support Layer: PUS Services**
  - Wide range of functionality
  - Reusable and customizable
  - But strongly integrated to the Exec PF

  ⇒ Key element of industrial efficiency



SAVOIR Execution Platform Architecture

- **Subnetwork Layer: similar mechanisms already used and satisfying in terms of**
  - Cost
  - Performance
  - Portability
  - Interoperability



Current Airbus Execution Platform Architecture

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Interoperability Needs and SOIS Positioning 1/2

1. **Application development (above the Execution Platform) by various providers : partially covered by SOIS**
   - Execution Platform level need, PUS Services already provide standardization
   - A lot of different applications from various missions can already be plugged on a single Execution Platform

   ⇒ Execution Platform holders should make available their interfaces/user manuals, as done by Airbus Defence and Space for the PIM SW in the frame of MetOp-SG
2. **SW adaptability to the variability of HW interfaces for smart sensors/actuators and payloads : not covered by SOIS**
   - "Device Virtualization" and "Plug-and-Play" promoted in SOIS don't fulfill this need
   - Protocol aspects to be deepened, necessitate a low effort

   ⇒ SAVOIR-SAFI initiative should be restarted and extended to treat sensors/actuators and payload functional aspects and could be supported through EDS

   ⇒ Payload interfaces standardization could also be treated as a supplementation of the hosted payloads standardization

   ⇒ It could be extended to semi-functional sensors/actuators such as RIU and PCDU. The priority should be the SAVOIR RTU Operability Requirements document completion

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Interoperability Needs and SOIS Positioning 2/2

3. SW adaptability to the variability of the On-Board Computer HW : partially covered by SOIS

- SOIS shouldn't be considered as a standardization solution of Low-Level SW interfaces for On-Board Computer HW providers
- As shown by prototyping, it is not a good solution to guarantee satisfying performances

⇒ This variability should be treated in the SAVOIR generic OBC specification

⇒ Anyway, on current on-board computer, this point is mainly an industrial efficiency matter for our Execution Platform

4. SW adaptability to the variability of communication links : covered by SOIS and the study

- SOIS relies on a unique and simple model (messages, memory accesses, packets)
- But no standardized mapping between SOIS and ECSS communication standards

⇒ *If a new bus is used or if an equipment on a specific link is changed for one on another link, adaptations have to be performed thus SOIS doesn't provide any added value*

⇒ *Airbus Defence and Space use standardized avionic architectures and Execution Platforms already integrate adaptations w.r.t. type of links (1553, SpW, CAN, UART)*

⇒ As for the On-Board Computer HW variability, on current set of communication links, this is mainly an industrial efficiency matter for our Execution Platform

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Roadmap

As Prime, since conditions are not met to deploy SOIS Services (i.e. no technological break), it is preferable to streamline the current need and thus deeper investigate

- **Intelligent I/O Controller**
- **On-Board Computer with more powerful CPU**
- **Next generation of Communication Network**
  - More bandwidth, Network Management, Quality of Service, etc.
- **Standardization of external communication interface and protocol with equipments up to the functional level**
  - SAVOIR-SAFI initiative restarting
  - SAVOIR RTU Operability Requirements document completion

Outcomes from all initiatives will potentially be merged in an Execution Platform New Generation, which will go hand in hand with the redefinition of the standard avionic architecture and the adoption of a communication network next generation.

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Conclusion

Our current Execution Platform is already efficiently covering interoperability needs despite important variability factors (Applications development, OBC, Communication Bus, Equipment).

The study has shown that implementing and integrating SOIS Services in our existing Execution Platform would require a very significant effort with limited added value on avionics interoperability needs.

The integration of SOIS layers in future OBSW can only be considered with next generation of avionics architecture including:

- **On-Board Computer with more powerful CPU & Intelligent I/O controller**
- **New generation of data communication network**
- **Functional interfaces standardization of all equipment of the avionic platform & payload interfaces**

Thank you for your attention !

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