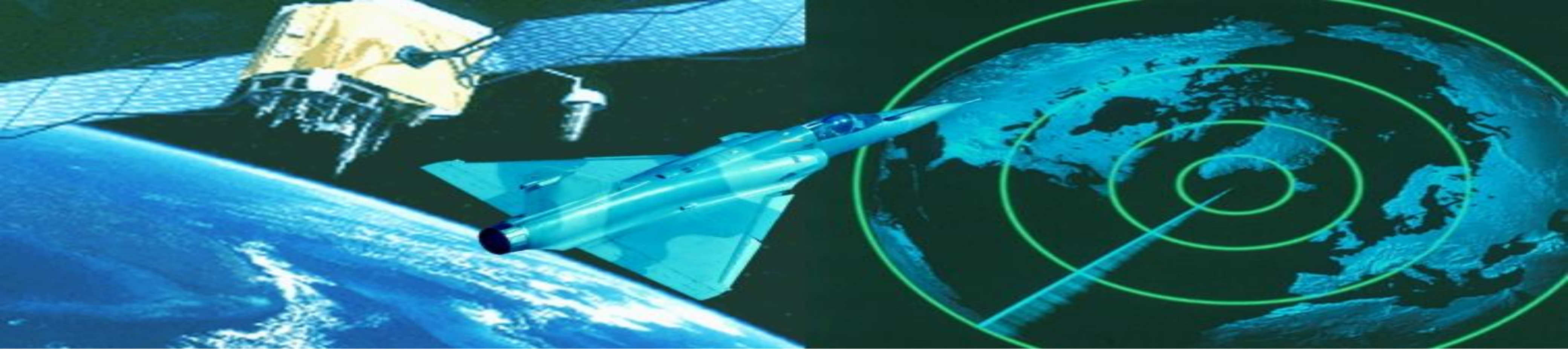

Deterministic Spacewire / SpaceFibre ?
The Challenge

ESA Contract No. 4000129566/19/NL/AS

SpaceWire Network Management Service suite definition and validation

- ESA contract No. 4000129566/19/NL/AS
- Kick–Off: March 2020, expected completion: December 2022
- Consortium
  - TELETEL prime
  - Thales Alenia Space – Cannes
  - Beyond Gravity – Sweden
  - AIRBUS Bremen
- Objectives
  - Define a deterministic layer for SpaceWire and SpaceFibre networks
  - Combine approaches from other domains (TTE, TSN) & previous work (SpW-D, N-Mass,etc.)
  - Simulate the proposed protocol in the MOST simulator
  - Prototype the proposed protocol in HW demonstrator
  - Execute validation scenarios in representative network topologies

Background on space on-board data networks 1/2

- The main objective of the activity is the development of a novel deterministic protocol layer for SpaceWire and SpaceFibre.
  - The protocol shall work primarily at network level (i.e. within routing switch devices),
  - It shall enable building fully deterministic networks with both protocol-aware and legacy SpaceWire/SpaceFibre nodes

- The protocol shall be compatible with the Space Avionics Open Interface Architecture (SAVOIR) concept by ESA.
  - The term ‘Deterministic / Determinism’ is clearly defined according to SAVOIR (function ensuring transmission within a certain time-window)

- The new protocol needs to include additional functions for FDIR, network management, quality of service, etc.

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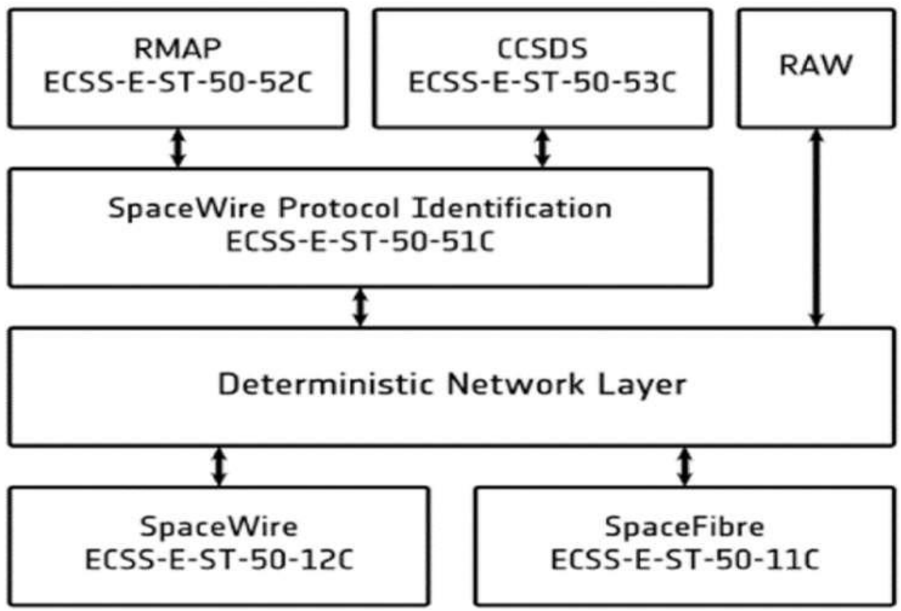
Background on space on-board data networks 2/2

- MIL-STD-1553 protocol is used to provide determinism but has the following limitations:
  - Implements low data rate networks
  - Based on single master topology (does not support multi-master / switched network topologies)
- TTEthernet is baselined for Ariane 6 and European contributions to the Lunar Gateway and in use for the European Service Module for ORION.
  - TTE combines high-speed communication (up to 1Gbps) with determinism.
  - The effort for planning and configuring the network and the verification process is high
- SpaceWire / SpaceFibre (in the future) are widely used in modern on-board architectures
  - Provide a much higher data-rate
  - SpW is not natively deterministic / SpFi provides only QoS features
  - Extensions to the protocol have been proposed in the past but require additional protocol layers

Initial ESA requirements for a deterministic SpW/SpFi layer 1/2

- Determinism shall be implemented by adding an additional network layer low in the SpW/SpFi protocol stack



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Initial ESA requirements for a deterministic SpW/SpFi layer 2/2

- The design shall be able to handle new deterministic and older legacy nodes
  - The new layer shall be developed in a way that it is mainly managed by the routing switches to support legacy nodes
  - New deterministic nodes may manage the new protocol layer directly
  - Deterministic switches shall act as translator for legacy nodes (extending or stripping traffic according to the new protocol
- Determinism requires all devices in the network to operate in the same time-basis
  - A mechanism is required to provide robust and accurate time-code distribution
- The new protocol shall provide reliability features
  - Implement FDIR concepts (controllability of new protocol layer from user application / network, mechanisms to check the status of the network)

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Comparison between existing deterministic protocols 1/2

- There is no single universal deteminism solution
  - Solution for each protocol heavily relies on:
    - Specific Protocol Mechanisms
    - Traffic Profile / Needs
  - Specific concepts / features from other deterministic protocols could be considered

- AFDX protocol
  - Does not provide high level of determinism
  - Controls the data flow
  - Ensures a bandwidth for every emitter

- MIL-1553 protocol
  - Fully deterministic (defines every communication slot for every endpoint)
  - Cyclic traffic definition does not provide any flexibility

Comparison between existing deterministic protocols 2/2

- Time-Sensitive Networks / Time Triggered Ethernet
  - Fully deterministic
  - High level of flexibility (TSN)
  - Based on accurate synchronization of all equipment in the network
  - Combination of hard / soft determinism features:
    - TAS (Time Aware Shaper) for strict real-time transmission
    - CBS (Credit Based Shaper) for introducing flexibility for lower priority traffic

- Interesting way to develop deterministic for SpaceWire:
  - Use the advantages of different mechanisms
  - Avoid drawbacks that lead to monolithic solutions / add several contraints

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Methodology used to define final requirements

- Requirements were sourced from multiple sources
  - SpW Working Group Questionnaire (e.g compatibility with legacy SpW nodes, multiple masters/slaves topology, adjustable packet size, increasing SpW switch buffer size, store and forward inclusion debate etc.)
  - Requirements extraction from ESA SoW, SpW-NMaSS, SpW-D (e.g definition of determinism, quality of service features, legacy node support, common time basis, FDIR concepts etc.)
  - Requirements from ADS missions and use cases (bandwidth goals, low latency, data acknowledgement features, time tagging etc.)
  - Requirements from SAVOIR and TAS missions (guaranteed message transmission for certain message types, accurate time tagging, limited message delay, SpW time-codes priority / jitter / latency etc.)

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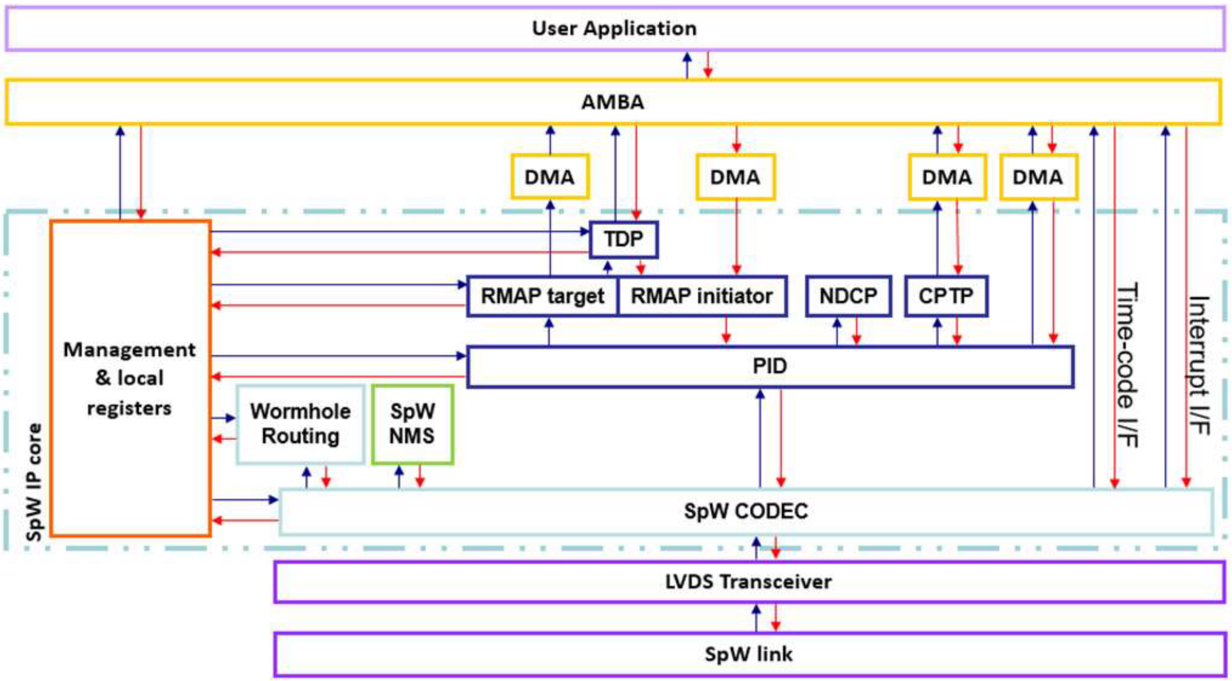
Basic Notions / Features Towards Final Requirements Definition

- Convergence of common features from all sources
  - Guaranteed bandwidth
  - Guaranteed delays
  - Priority management
  - High resolution time synchronisation service
  - Acknowledgement on data transfer
  - Definition of a deterministic traffic class that guarantees the delivery within a defined time slot
- Other interesting features
  - Session management (health check & FDIR)
  - Compatibility with HW or SW-based end-users
  - Bandwidth efficiency
  - Multi-initiators
  - Centralised management
  - Protection against failure

Proposed protocol architecture

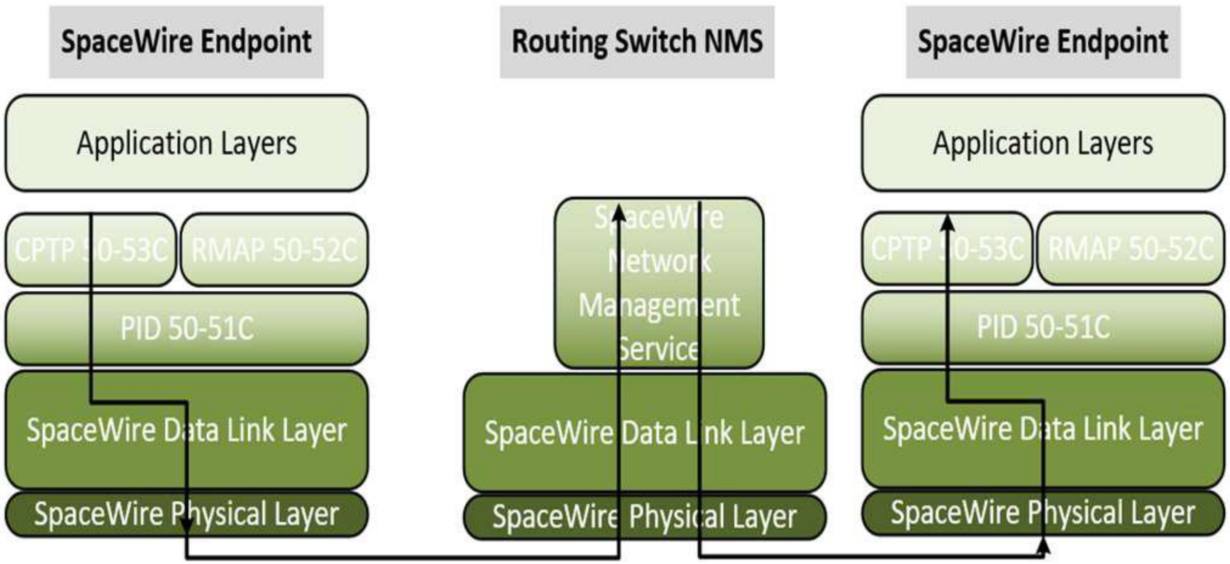
- Summary of SpW overall layers used in different networks



- Proposed SpW NMS block can replace traditional Wormhole routing implementing a Store and Forward approach with ingress policing, packet filtering and traffic shaping

Proposed protocol architecture (SpW Switch)

- Proposed implementation of a Deterministic SpW switch

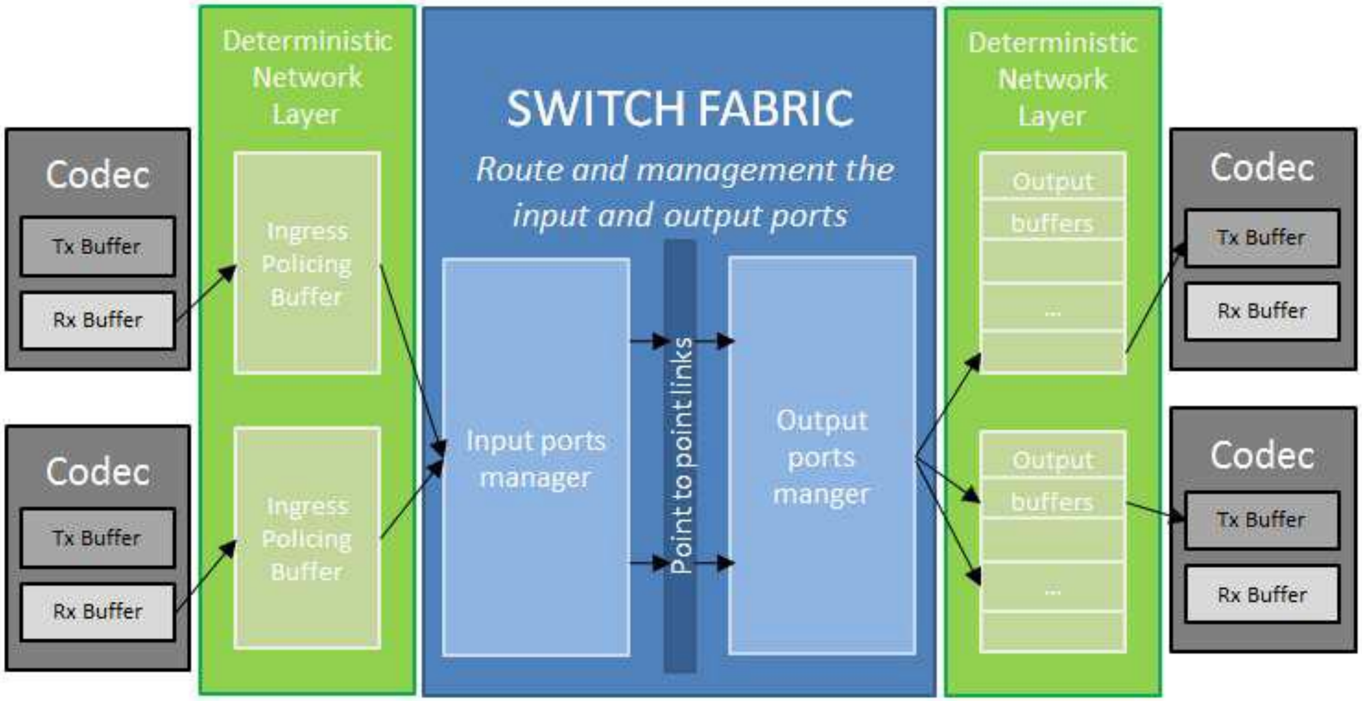


- Analysis on the new protocol determines that the SpW node shall not be modified in order to retain compatibility with all existing SpW units. All new functions will be implemented in the SpW Switch level.

Proposed protocol architecture (New Features Overview)

- The new features to be implemented in the SpW switch in order to enable deterministic traffic are the following:
  - Stream Identification and Priority Assignment
  - Packet Size Control
  - Store and Forward Routing
  - Priority Queues at Output Ports
  - Traffic shapers

Proposed protocol architecture (Switch Architecture) 1/2



- SpW Codecs (unmodified)
- Switch Fabric (unmodified)
- Deterministic Network Layer (new development implementing determinism functionality)

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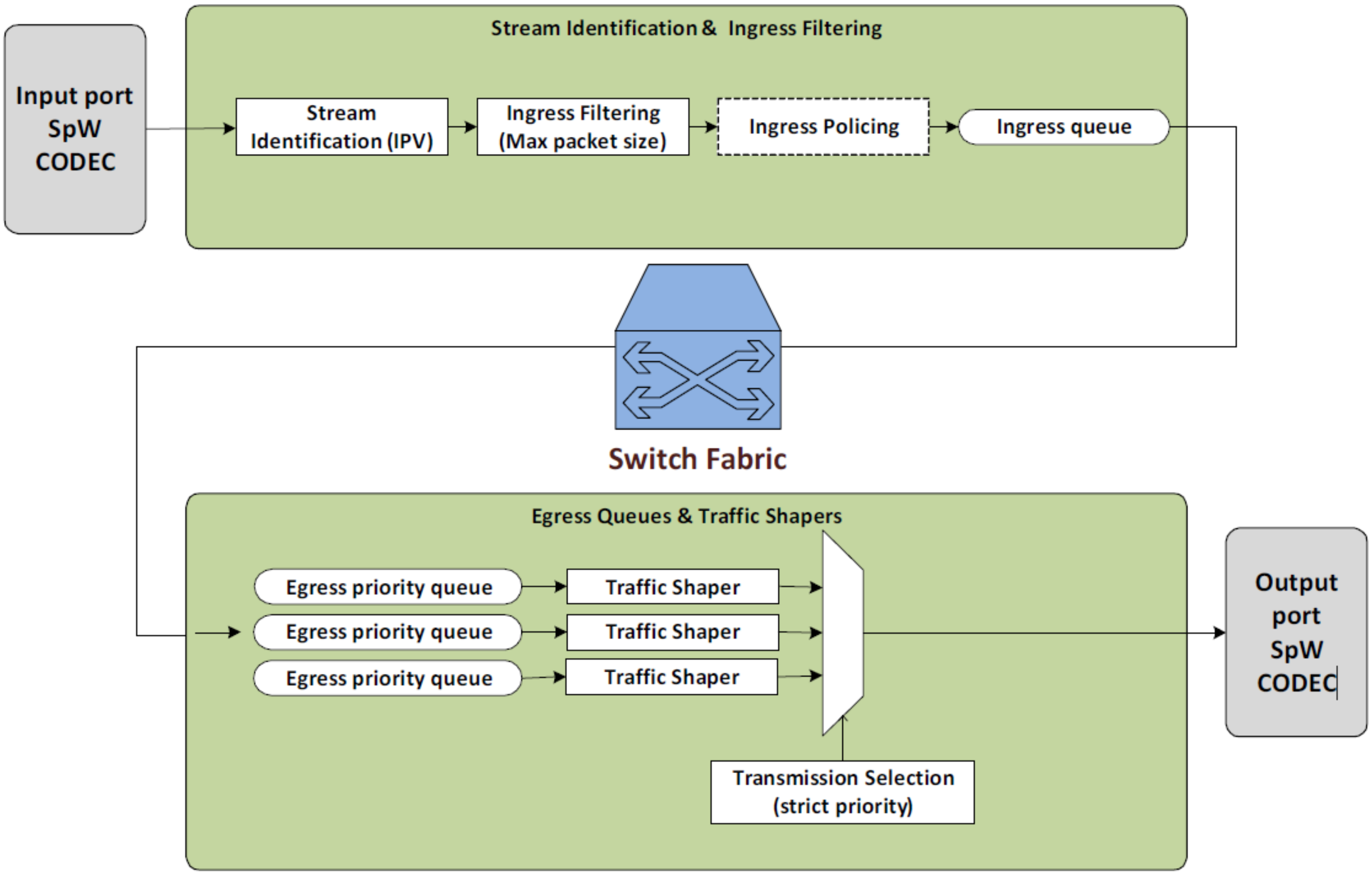
Proposed protocol architecture (Switch Architecture) 2/2



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Proposed protocol architecture (New Features Analysis)

- **Ingress Block**

  - **Stream Identification:** Assign an IPV to the packet based on input port or based on packet fields.
  - **Ingress Filtering:** Drop or Truncate with EEP the packets with size larger than the max length allowed for this input port or for this IPV.
  - **Ingress Policing:** Ensure ingress flows meet their specifications, mark frames that are out-of-spec and drop, count for diagnostics, etc. (future extension).
  - **Ingress Queue:**
    - One ingress queue at each input port
    - Temporarily store input packet pending reception (EoP) or input packet(s) pending switching
    - Capacity at least one packet of maximum size with any additional space to compensate technological delays

Proposed protocol architecture (New Features Analysis)

- **Switch Fabric**

  - Decide set of egress queues based on packet's destination address and IPV
  - Transfer the packet from the ingress queue to the destination egress queue if not full
  - If egress queue is full and GAR is used, select an alternative egress queue
  - If egress queue is full drop the packet or pause the reception from the input port
  - If more than one ingress queues have a packet to be transferred at the same egress queue select the packet based on a first-in-first-out arbitration or based on round-robin arbitration

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Proposed protocol architecture (New Features Analysis)

- **<u>Egress Block</u>**
  - **Egress Priority Queues:**
    - At least three queues at each output port
    - One queue per used priority IPV
    - Temporarily store packets pending transmission
    - Required capacity depends on scenario and has a dependency on shapers configuration and traffic profiles
  - **Traffic Shaper:**
    - Allow or deny transmission of packets from this egress queue based on bandwidth and timing criteria
    - Two shapers are proposed CBS or Bandwidth Allocation Table (BAT)
    - Other shapers can be defined / used in future
- **Transmission Selection:**
    - Select the packet for transmission at this output port from the egress queues based on strict priority criteria

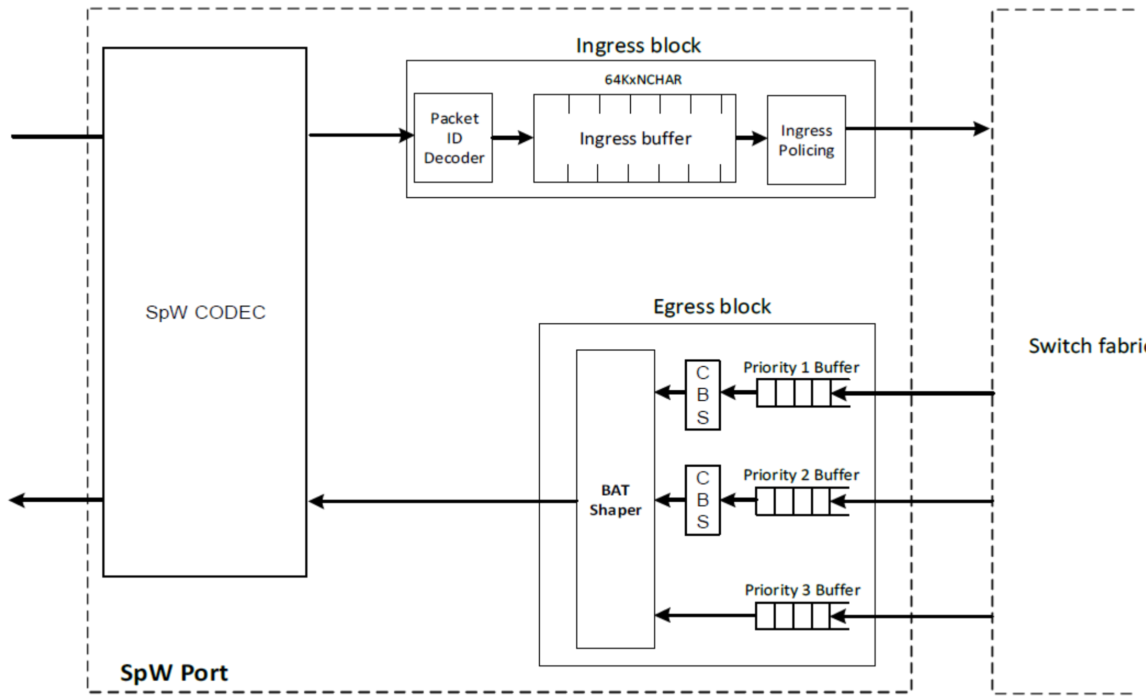
Prototype Implementation (Main Features)

- In the scope of the SpW NMS project TELETEL developed/implemented the proposed deterministic SpW Switch

- SpW Switch characteristics:
  - 8x SpW Ports
  - Store and Forward Routing / Cut-through routing implementation
  - Per port / per packet priority assignment
  - Ingress Block max packet size up to 64K (independently settable)
  - Three priority queues per egress block
  - BAT and CBS shapers on the egress block (with ability to be used simulataneously)
  - High performance SpW switch fabric

Prototype Implementation (Block diagram 1/2)

- The block diagram of the deterministic SpW switch. Each SpW port consists of the following:
  - TELETEL SpW CODEC
  - Ingress block implementing:
    - ID Decoder
    - Ingress Buffer
    - Ingress policing (packet drop or truncate)
  - Egress block implementing:
    - Egress Buffers
    - BAT traffic shaper
    - CBS traffic shaper



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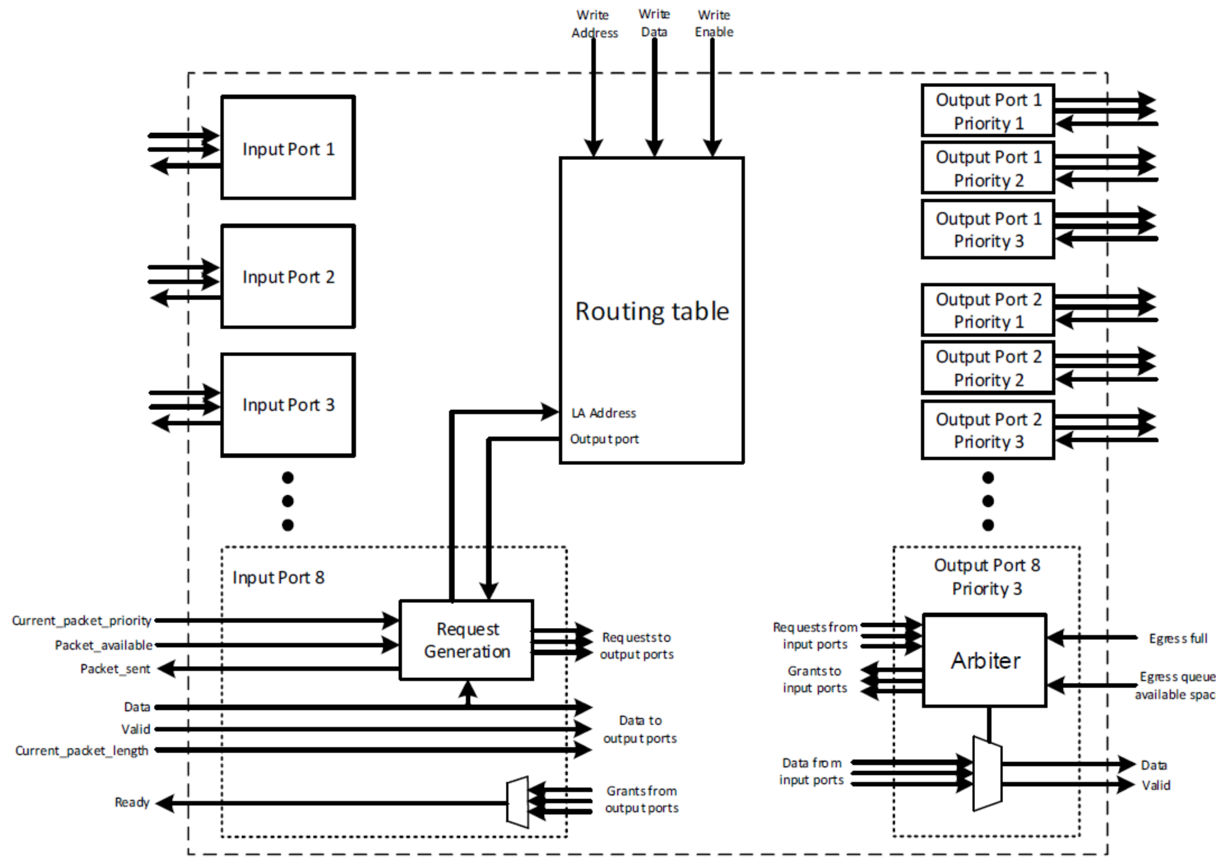
Prototype Implementation (Block diagram 2/2)

- SpW Switch Fabric Block diagram:
  - Input Port Block (interface with Ingress Block, request generation logic)
  - Configurable Routing Table
  - Output Port Block (interface with Egress Block, Arbiter logic, Egress queues fill level monitor logic)



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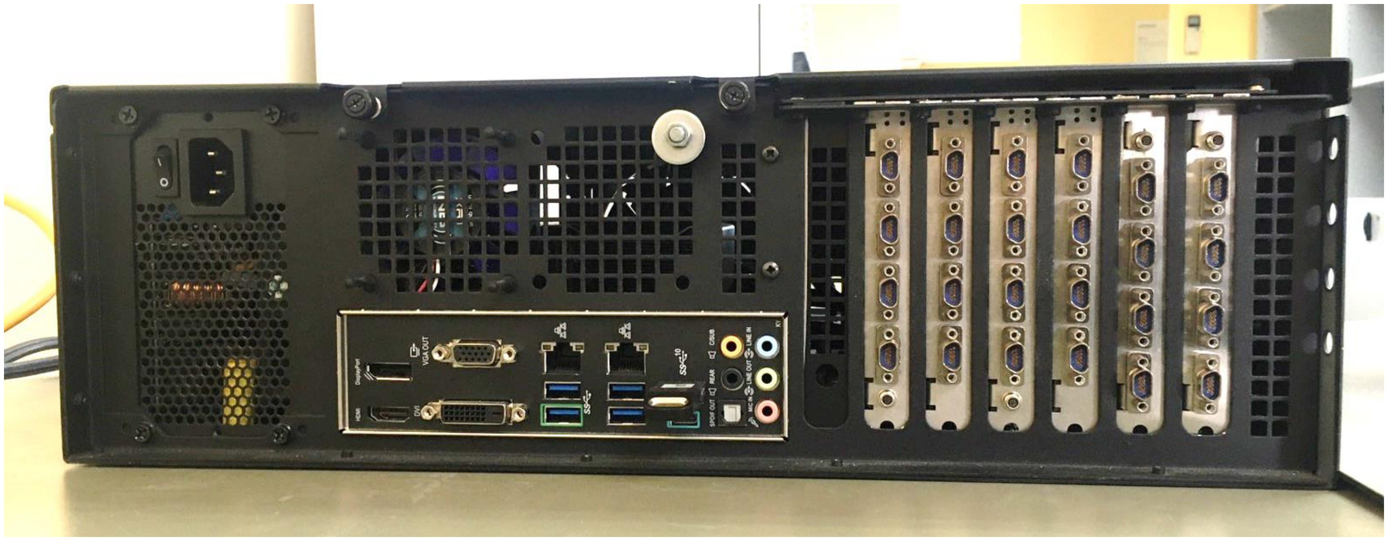
Prototype Implementation (Demonstrator Integration 1/2)

- Demonstrator based on TELETEL iSAFT SpW Front-End



  - Two iSAFT quad SpW cards Simulating the SpW Nodes
  - Two iSAFT octal SpW cards (configured as SpW deterministic switches)

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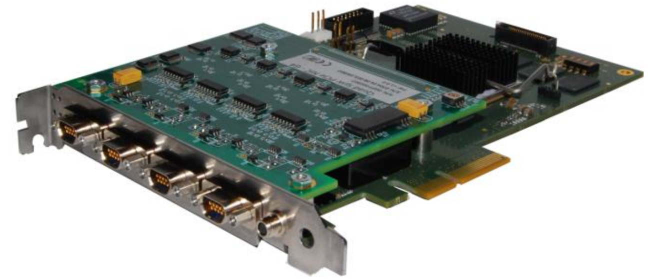
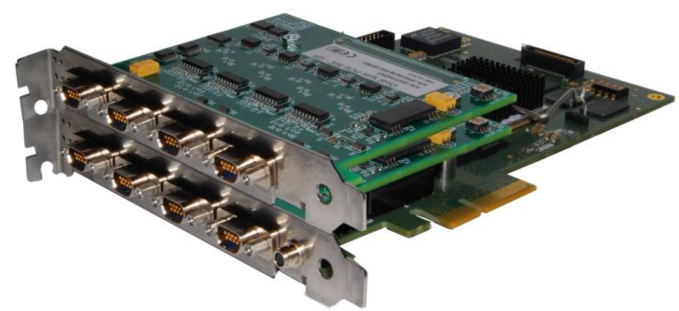
Prototype Implementation (Demonstrator Integration 2/2)



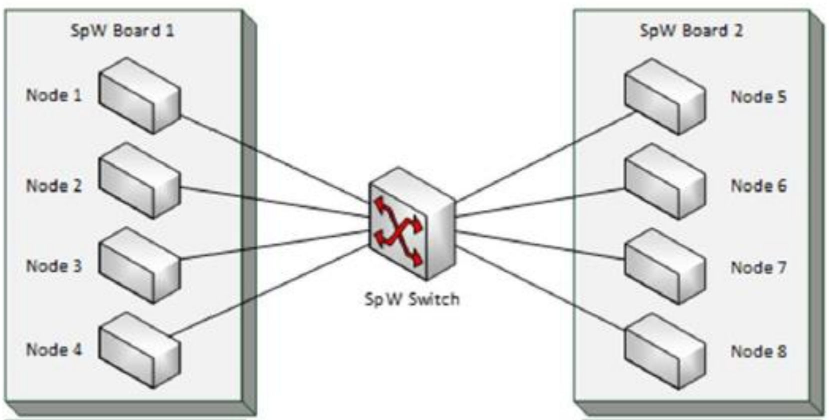
- TELETEL iSAFT system characteristics:
  - Ability to host different interface types in a single software platform / system
  - Ability to reconfigure Interface Cards with desired functionality (SpW Simulation, SpW router)
  - SpW Simulation environment for test definition and execution (scenario / traffic generation, error injection, protocol / results analysis, common timestamping across all interfaces for accurate timing results)

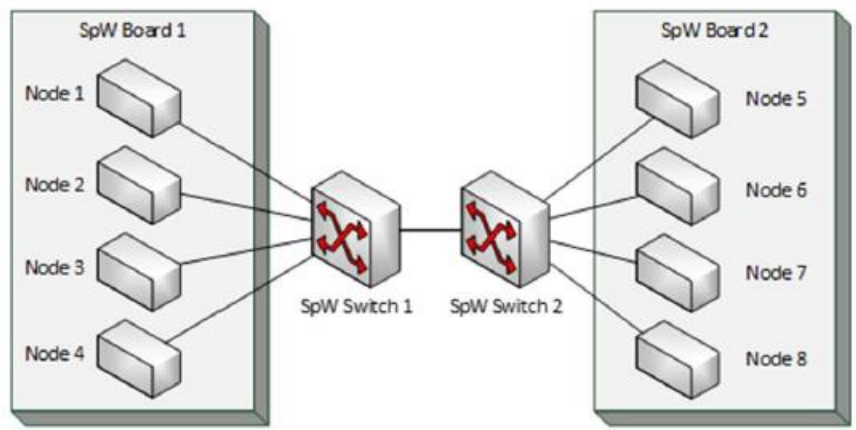


Demonstration scenarios (Demonstration Setup)

- Demonstration setup includes:
  - 8x SpW Nodes for packet transmission / reception
  - 2x eight port SpW deterministc switches

- The following topologies will be tested





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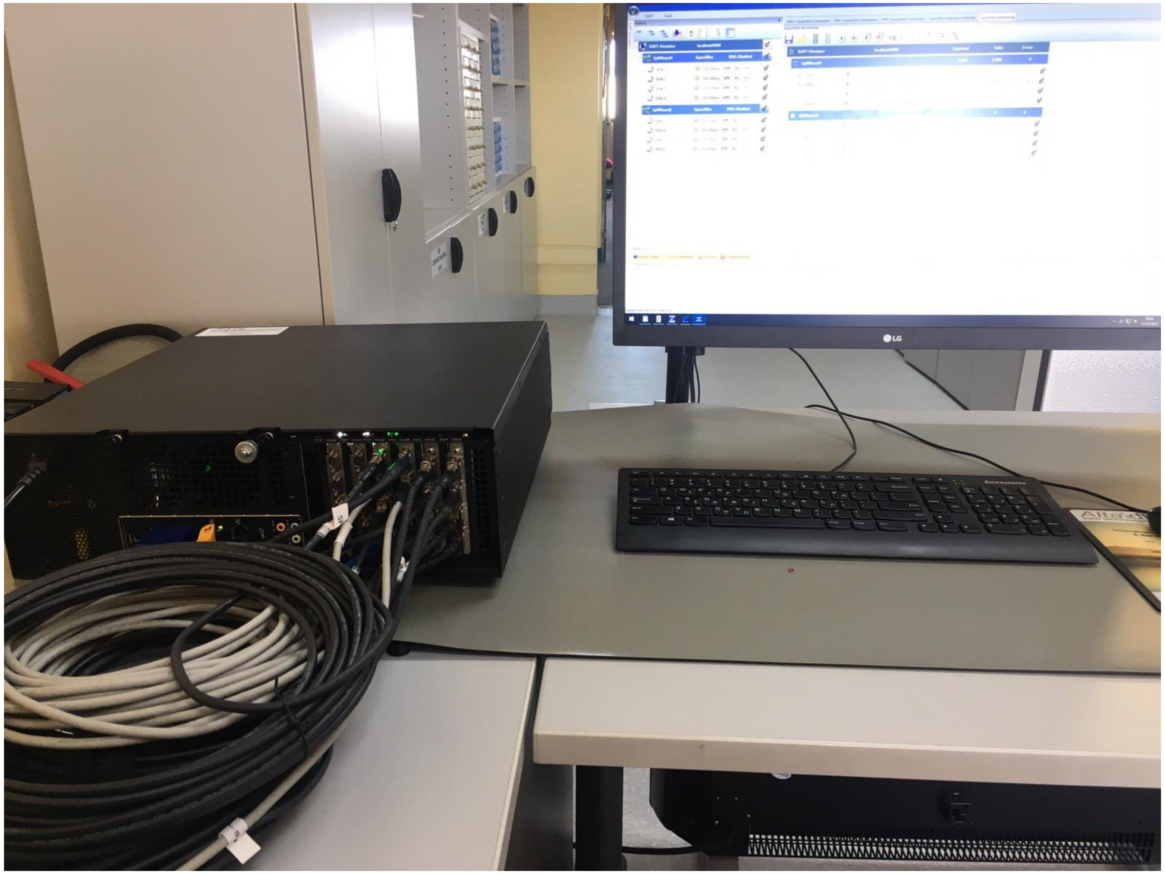
Demonstration scenarios (Validation Test Categories)

- A variety of tests will be executed to validate the protocol features and switch functionality:
  - Unit tests: Scenarios to verify the correct functionality of individual features / requirements of the SpW NMS router. Each test shall use a simple scenario to validate a single (or a few) functional features of the router
  - Network performance measurement tests: Scenarios used to quantify the performance of the NMS router in a network. The performance characteristics of the network shall be validated (switching latency, end to end latency, packet jitter, bandwidth etc.)
  - Legacy device support tests: Scenarios to validate the routers behaviour when legacy SpW devices are used
  - Error cases tests. Scenarios to validate the router's functionality in network error cases (babbling idiot, link congestion, disconnects etc)
  - Full demonstration scenarios. Scenarios to validate the router's functionality and performance in full demonstration scenarios as defined in the network simulation activity (in order to directly compare the results between the simulation and the real implementation)

Demonstration scenarios (Demonstrator setup)

- The demonstration tests are being executed in TELETEL since the beginning of October. The campaign shall be finalized by mid November.



Conclusions

- The activity started in March 2020 and is expected to be completed in December 2022.
- The proposed deterministic network layer has been already simulated with different scenarios in the MOST simulator by TAS. Prototype implementation in FPGA has been carried out by TELETEL and the resulting deterministic SpW router has been integrated in the target evaluation boards by TELETEL
- Several demo scenarios are being executed at an experimental testbed at TELETEL premises aiming at assessing the correctness of the approach. The results of the study will be available to the SpaceWire/SpaceFibre community in December 2022
- The main limitation of the implementation of the deterministic router in a FPGA board is the buffer size(multiple ingress and egress buffers are required for each of the 8 ports). This does not affect the functional aspects of the protocol but is not indicative of a real application implementation
- Several additions to the protocol are being considered for further study (full timecode support, timecode synced BAT shaper, solutions to further improve jitter etc.)

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