ADCSS 2019

An IPCORE for Deterministic Ethernet via Time Sensitive Networking (TSN) light implementation: challenges and opportunities

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gmv INNOVATING SOLUTIONS

INTRO

INTRO

- GETDEN Activity (GMV)
- MIURA 1 Mission (GMV)
- MIURA 1 Avionics Main Elements (GMV)
- TSN Development (7Sol)
- Summary and Conclusion (GMV)

GETDEN
Context

GETDEN

Goals:

- The goal of ITI "Gigabit Ethernet TSN DEtermnisitc Network (GETDEN)" activity is to provide a low-cost yet space-grade data bus solution based on open-source, already identified and implemented in other non-space domains.
- **Requirements** for adapting terrestrial TSN technology for space on-board avionics application based on COTS (focused on microlaunchers)
- **Traceability to SAVOIR** requirements
- **IP cores** for HW (HDL) implementation of Gigabit TSN protocol
- **Drivers** based on RTEMS
- **Testing** an on-board network, representative of microlauncher (Zynq SoC ARM processors)
- A **technology roadmap** for increase TRL and enable the adaption of Gigabit TSN solution as on-board data bus for microlauncher and other spacecraft

CONSORTIUM:

- esa → Innovation Triangle Initiative
- gmv → Developer (Prime)
- SENER Solutions → Inventor and Developer (Subcontractor)

towards

MIURA 1
Context and Mission

MIURA 1

MIURA1 Goals:

- Provide microgravity environment to a payload
- Flying Test bed for MIURA 5 technology

Launcher Main Characteristics:

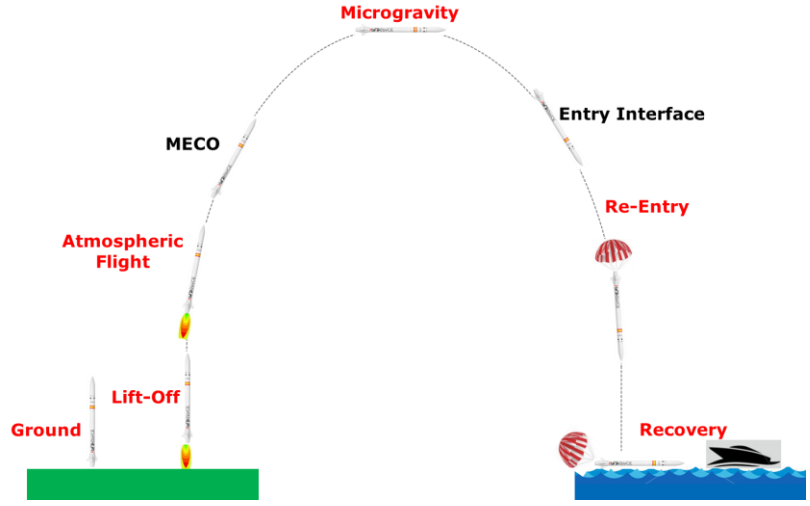
- 1 stage, 1 engine KeroLOX (30kN)
- 12 m height, 0.7m diameter
- Recoverable and reusable

Main Mission Figures:

- MECO Time: ~2 minutes
- Microgravity Time: ~3 minutes
- Payload: 100Kg
- Apogee Altitude: ~120Km
- Total Flight Time ~600 s
- Launch Site: "El Arenosillo" Southern Spain

CONSORTIUM:

- PLD SPACE → Launcher Prime
- esa flpp → Co-Financial partner
- gmv → **Avionics Prime**



towards

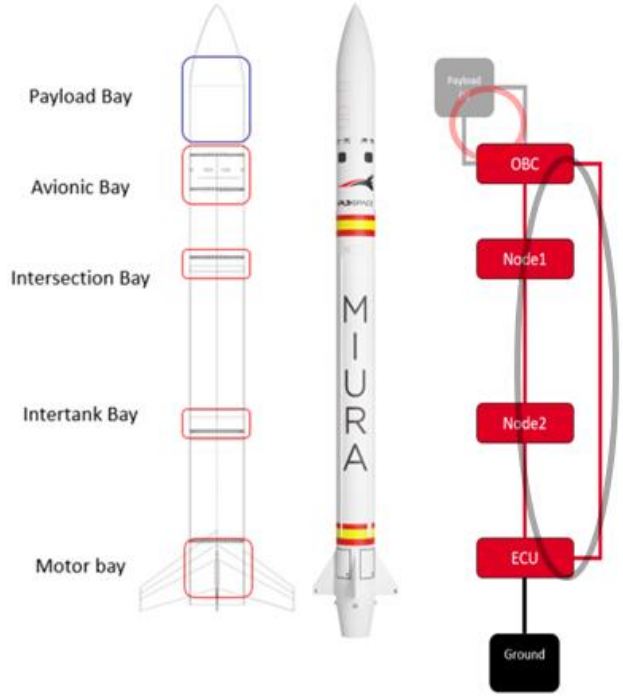
MIURA 1 **MIURA 5**

MIURA 1 Avionics Development & Qualification

Avionics Elements

- GMV is in charge of the development and qualification of complete avionics:
  - **Electrical Power Subsystem**, containing the storage, conditioning and distribution functions
  - **Data Handling**, for executing the mission and collect data from sensors, actuate valves and format telemetry
  - **Antenna systems**, for the different RF links
  - **Flight Termination System** for Safety
  - **GNC** subsystem, including GNC sensors and actuators
  - On-board Software (**OBSW**)
  - **Payload** management
  - **Harness**

- Avionics is **distributed** in nodes along the launcher, communicating via GEthernet bus with a Time Sensitive Network (**TSN**) light implementation:
  - OBC
  - ECU
  - Node1 & Node 2
  - Payload



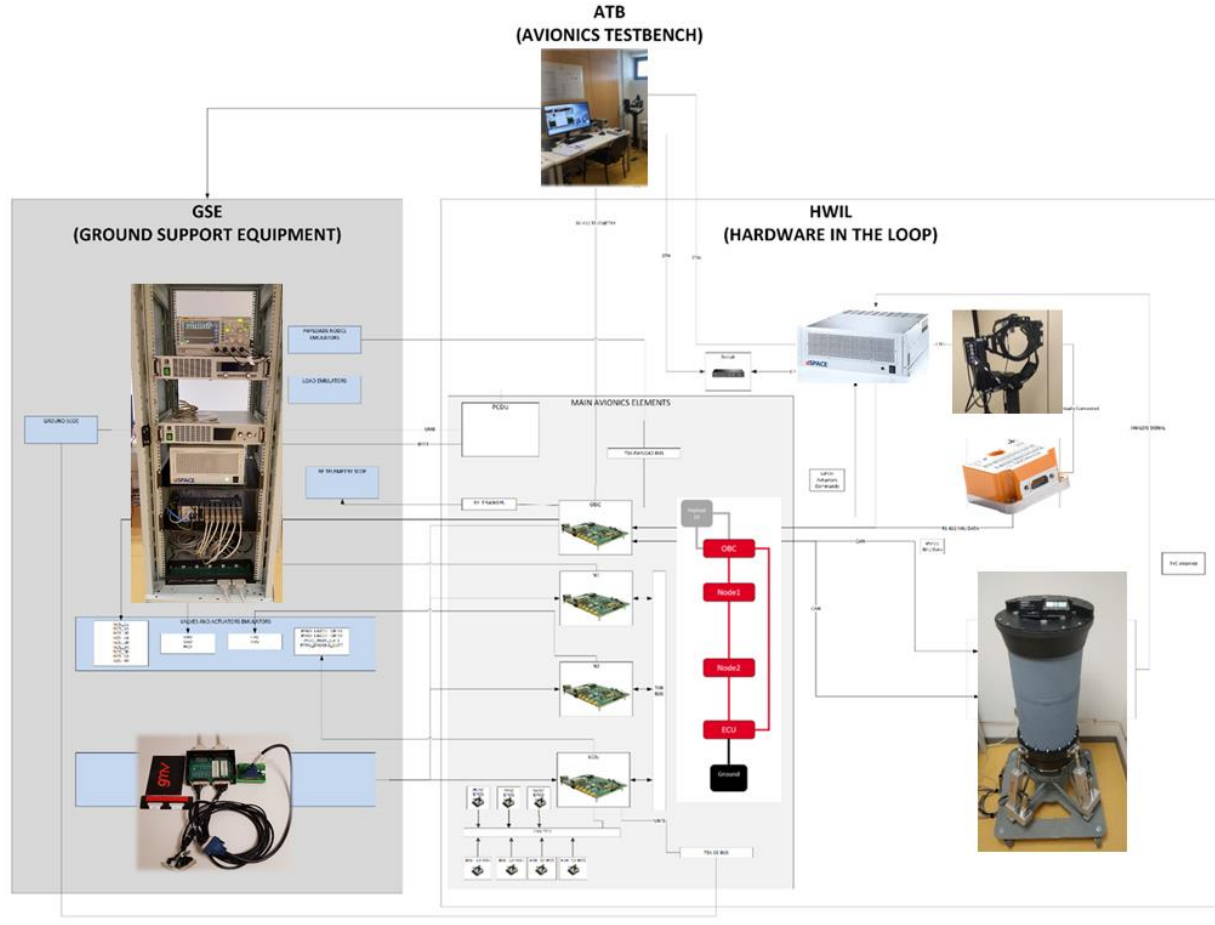
Avionics Development

- Functional and performance validation of avionics elements (SW/HW) at GMV premises:

FES
(Functional Engineering Simulator)

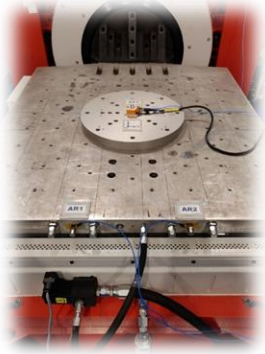
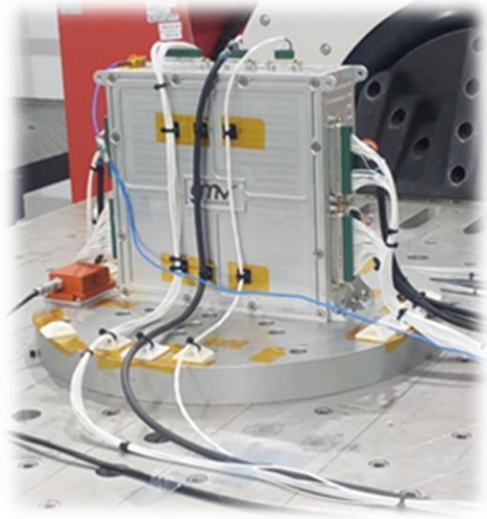
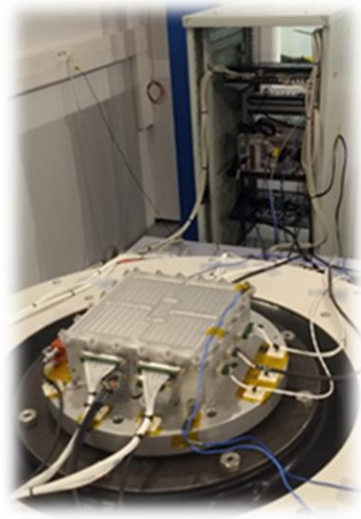
SVF
(Software Validation Facility)

ATB
(Avionics Test Bench)



Avionics Qualification

- Environmental tests have been considered for qualification:
  - **Random Vibrations Tests**:
    - IMU → √ Passed
    - OBC and ECU nodes → √ Passed
  - **Thermal Cycling Tests**:
    - OBC node → √ Passed
  - **Thermal-Vacuum Tests**:
    - ECU node → √ Passed


SEVEN Solutions

GETDEN

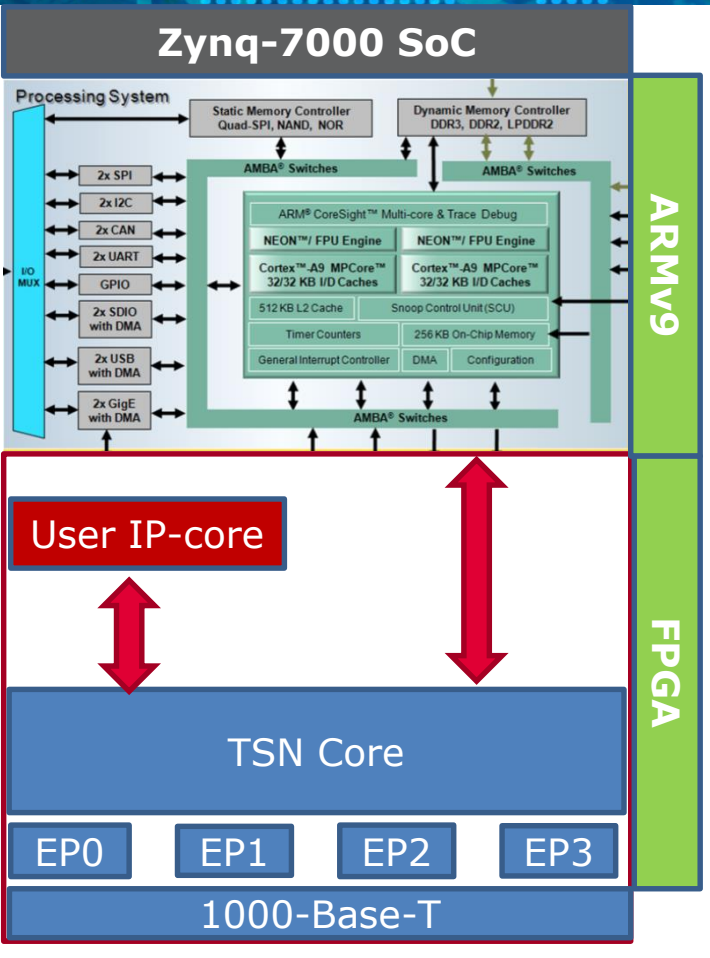
Gigabit Ethernet TSN DEterminstic Network

A light TSN implementation for avionics

www.sevensols.com

gmv

GETDEN: Light TSN for Avionics



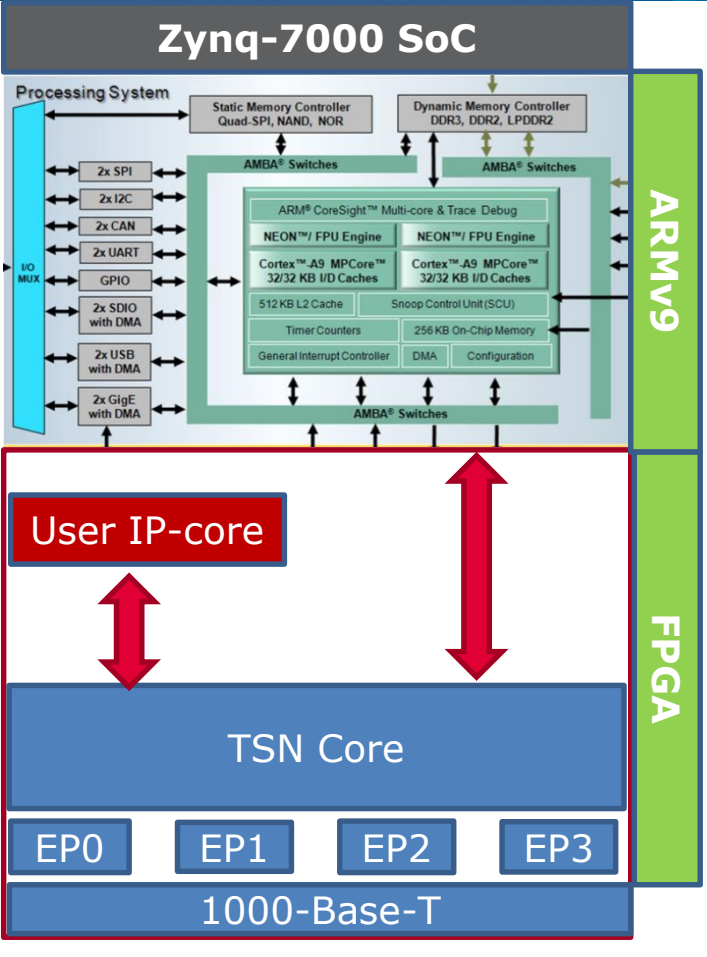
Oriented to space avionics:

- RTEMS 5.0
- C99 TSN drivers, API and firmware

Light implementation:

- Only the most relevant TSN standards:
  - Synchronization, Queueing, traffic shaping and frame preemption
- More than **40% FPGA** resources & **almost all CPU time** available for on-platform user critical applications:
  - Real Time
  - Deterministic latency
  - Full synchronization

GETDEN: Light TSN for Avionics



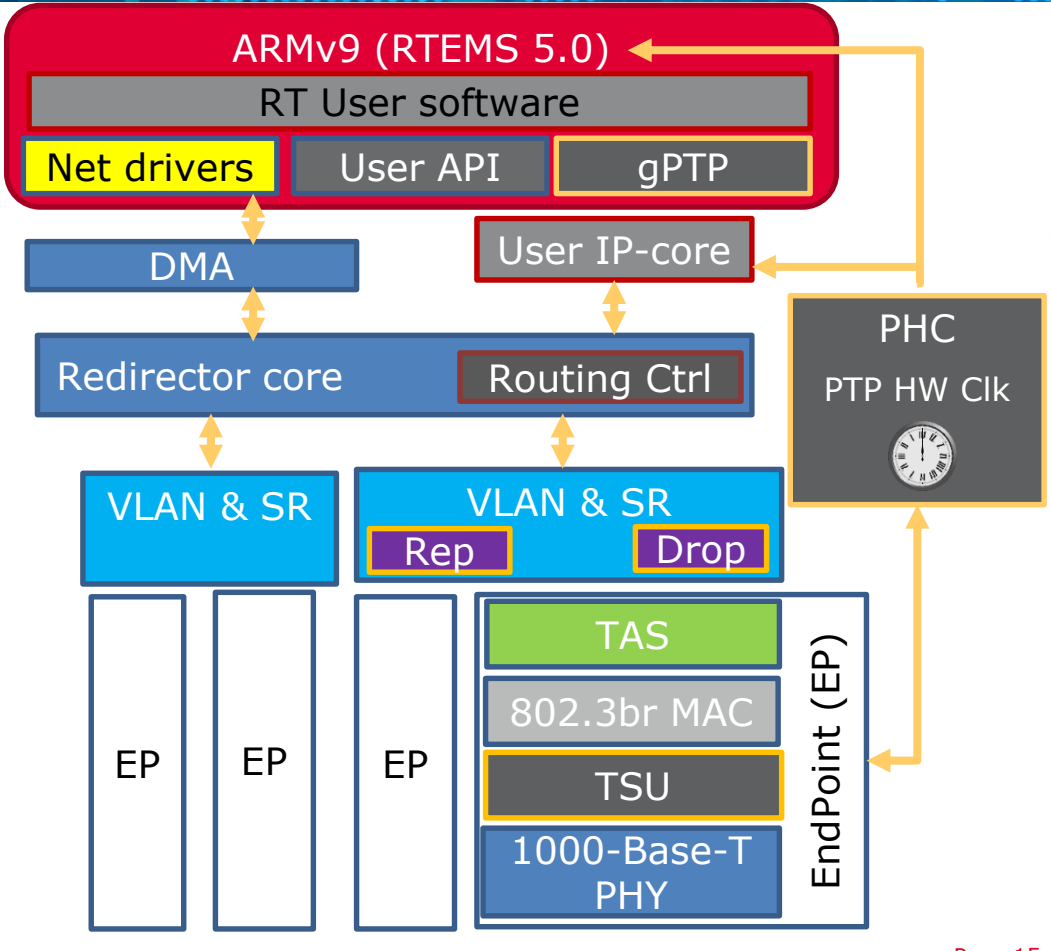
FPGA Resources: 4 Ethernet ports

	VLAN + Redundancy	Dropper	TAS + Preemption	Redirector	Common Infrastructure (DMA, MAC switching, TSU,...)	Z-7030 Resources
Slice Registers	4550	2090	3170	1490	12840	39%
Slice LUT	4160	1120	1820	1800	10440	57%
BRAM	3,5	0	20	9	12	53%
DSP	8	34	0	0	0	13%
MMCM + PLL	0	0	0	0	1	40%

Essential TSN standards

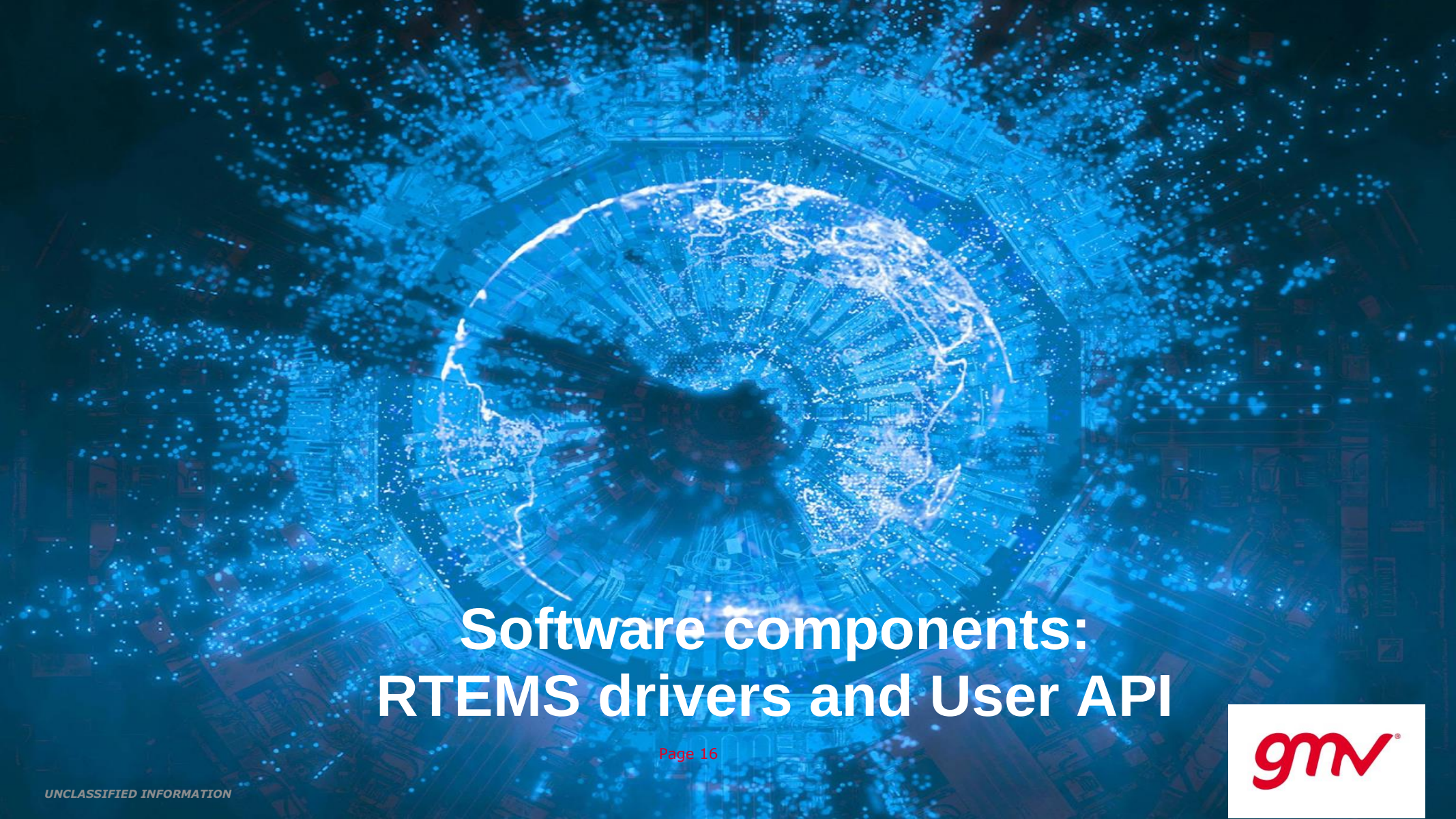
Standard	Area	Title
IEEE 802.1AS	Timing & Synchronization	*Enhancements and Performance Improvements*
IEEE 802.1Qbv	Forwarding and Queuing	*Enhancements for Scheduled Traffic – Time-Aware Traffic Shaping*
IEEE 802.1Qbu & IEEE 802.3br	Forwarding and Queuing	*Frame preemption and Interspersing Express Traffic*
IEEE 802.1Qca	Path Control and Reservation	*Path Control and Reservation*
IEEE 802.1Qcc	Stream Reservation (SRP)	*Enhancements and Performance Improvements*
IEEE 802.1Qci	Time Based Ingress Policing	*Per-Stream Filtering and Policing*
IEEE 802.1CB	Seamless Redundancy	*Frame Replication & elimination for Reliability*

GETDEN Architecture overview



- Configurable N-Port TSN bridge implementation.
- Support for TSN redundant streams.
- Direct TSN connectivity to user IP-cores.
- Keep RTEMS user executives synchronized to the network.

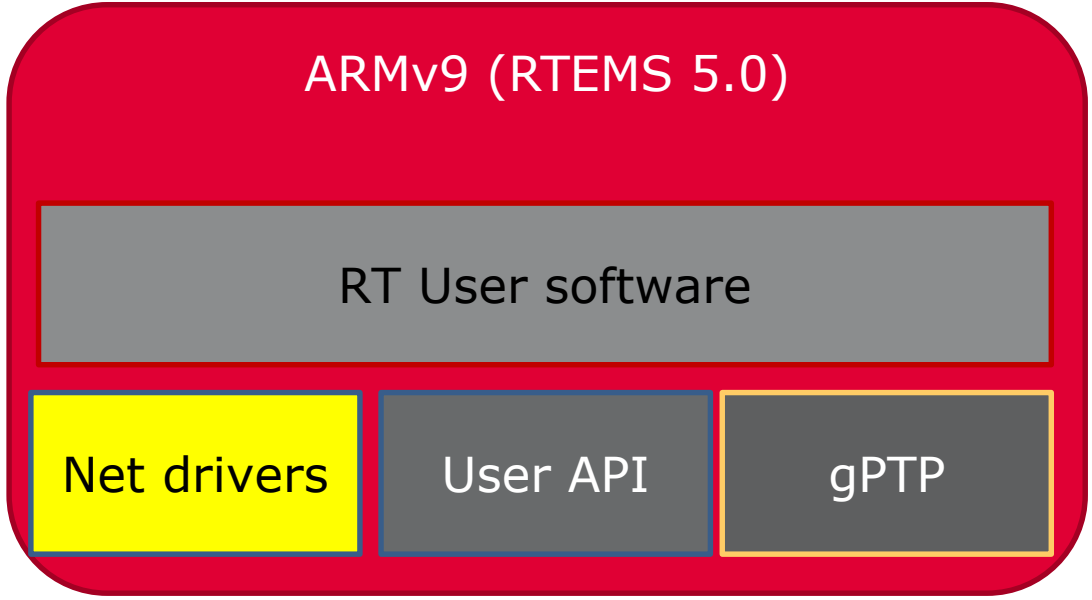
802.1AS	▪ Timing and synchronization (deterministic latency)
802.1Q	▪ Bridges and bridged networks. ➢ Differentiation and prioritization: TSN streams ➢ 802.1Qbv -- Time Aware traffic Shaper ➢ 802.1Qbu -- Frame Preemption
802.1CB	▪ Frame Elimination and Replication for Reliability
802.3br	▪ Express traffic interspresing



Software components: RTEMS drivers and User API

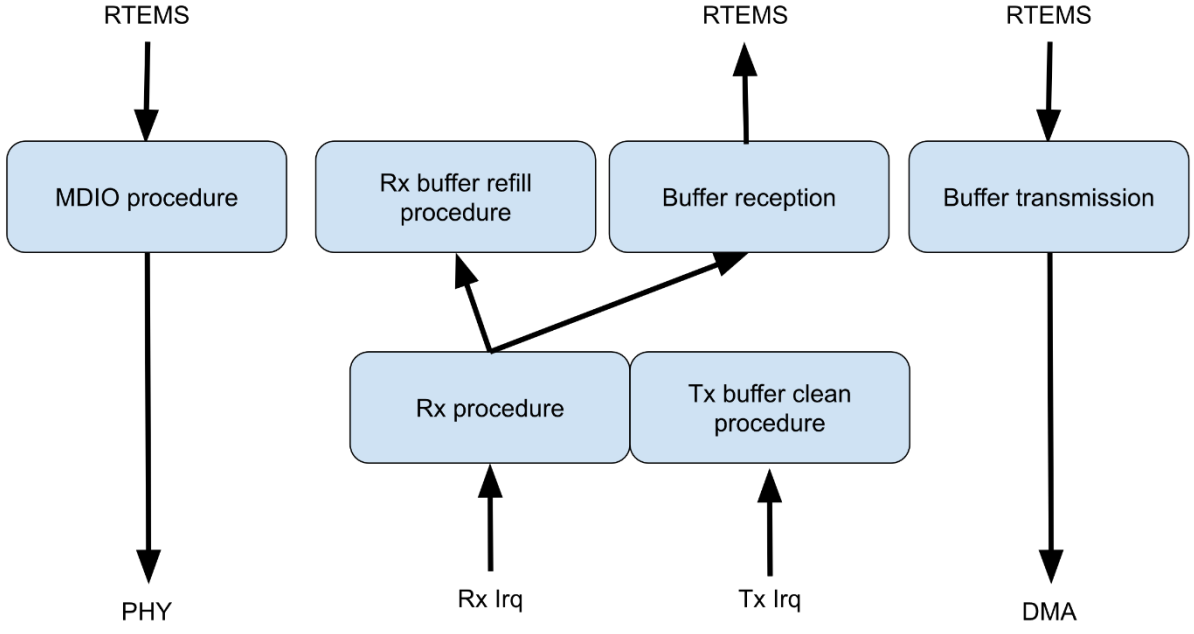
GETDEN Software components

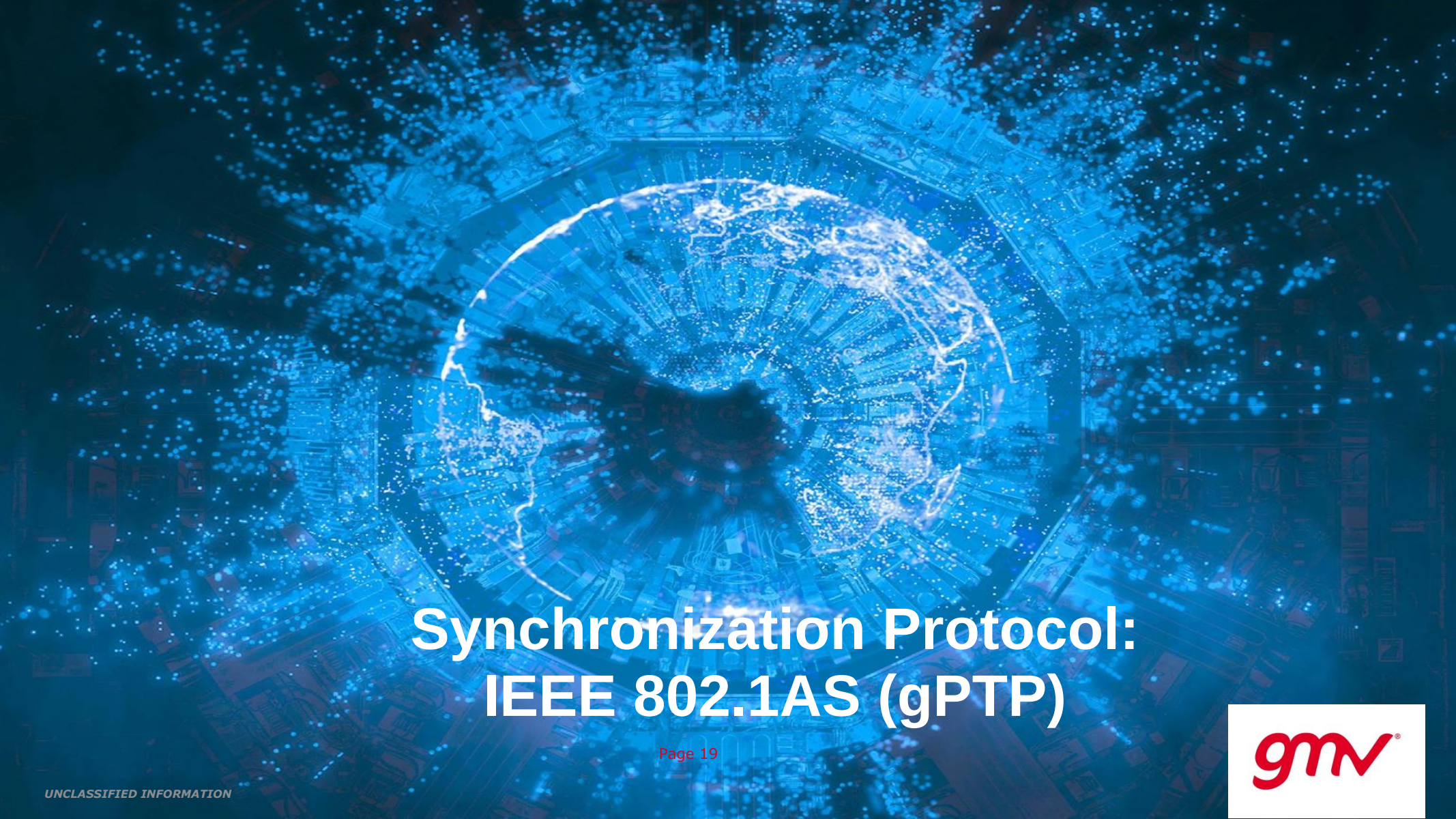
- User API: Configuration of the TSN modules
  - VLAN: Traffic identification & tagging
  - TAS: Time-aware traffic shaping schedule
  - Seamless redundancy configuration
- gPTP cyclic executive
- Network drivers



RTEMS Network driver

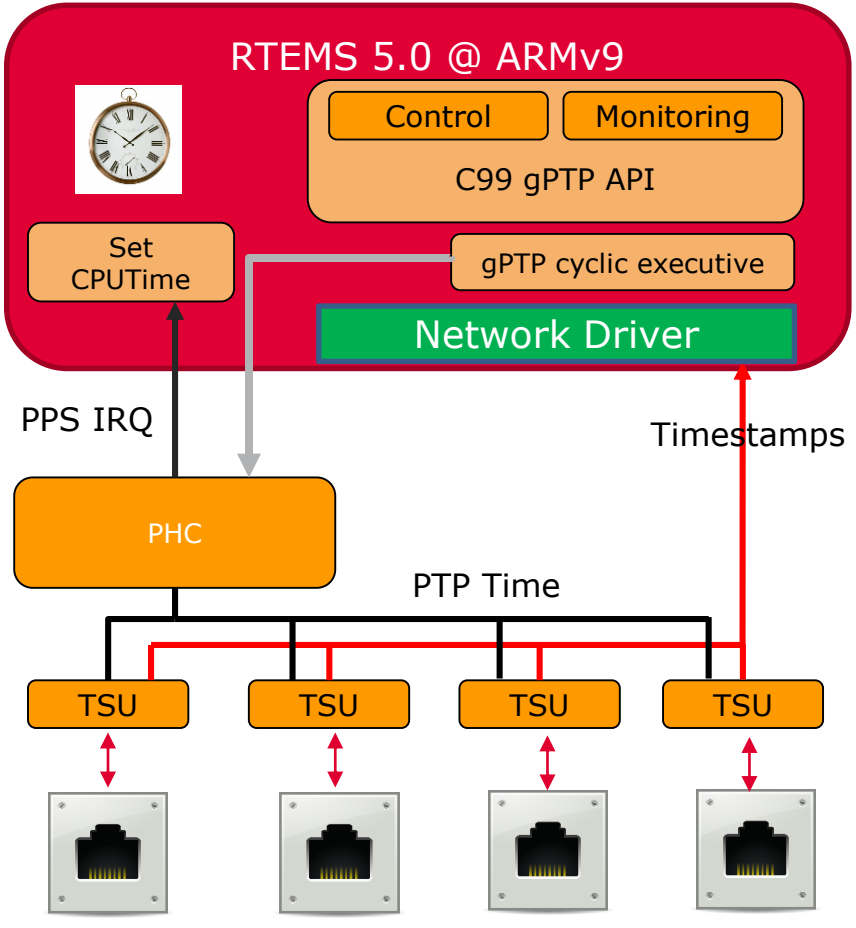
- Custom Ethernet driver with TSN support
- Based on FreeBSD Network API
- Scatter-gather DMA support
- HW Timestamping Support
- MDIO support for external PHY device





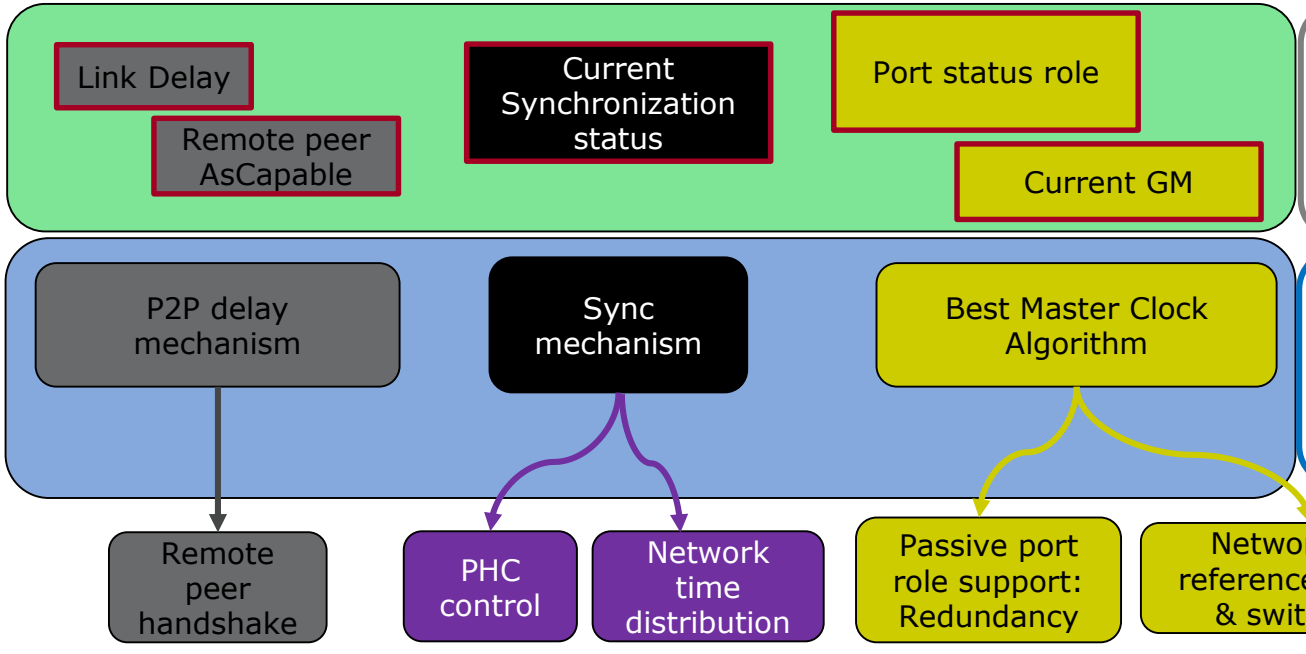
Synchronization Protocol: IEEE 802.1AS (gPTP)

IEEE 802.1AS: gPTP (I)



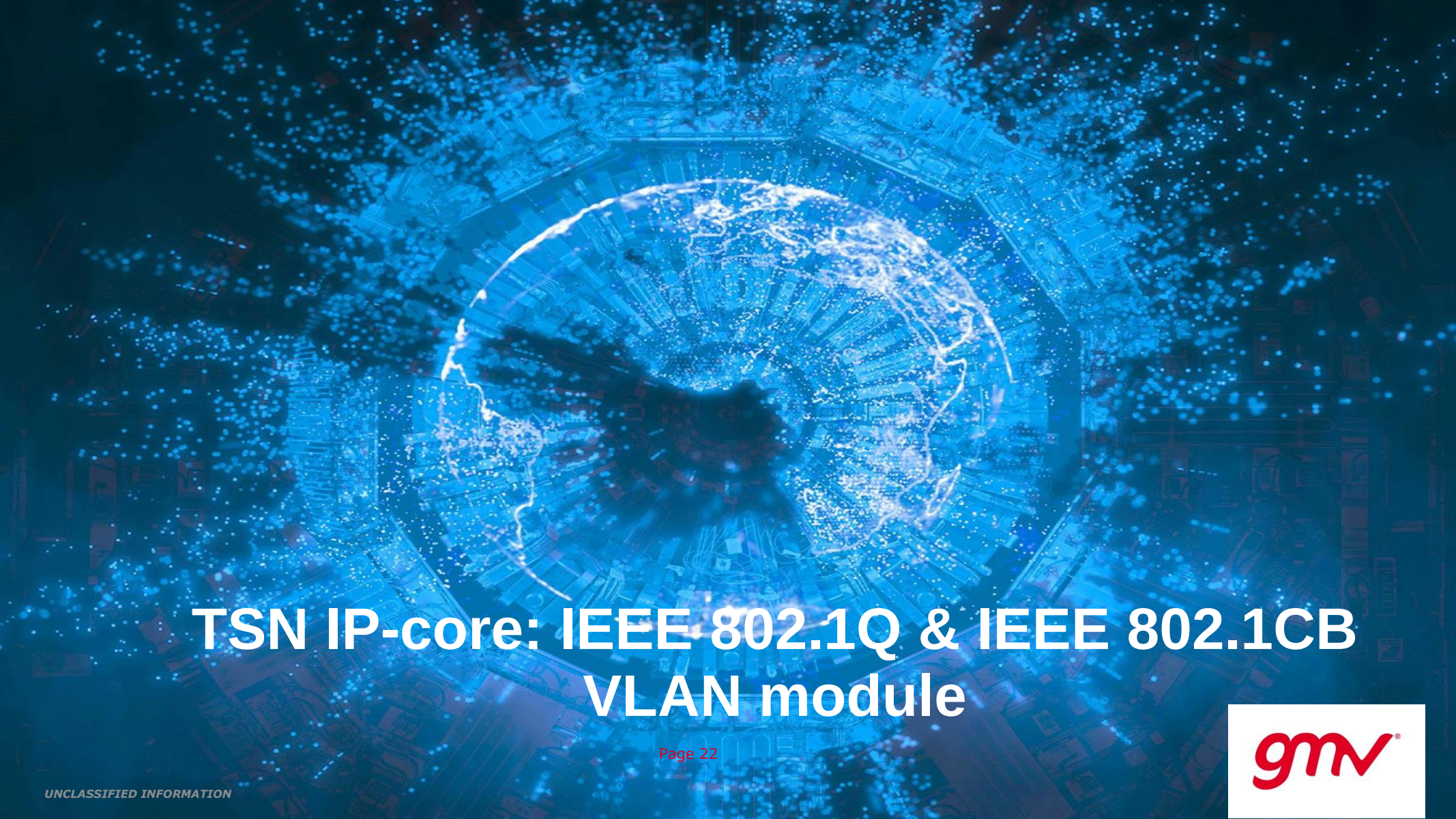
- Synchronization accuracy < +/- 50 ns span, supported by
  - PTP Hardware Clock: Local time reference storage and distribution
  - Hardware TimeStamp Unit
- Common time knowledge for coordinated execution on distributed networks.
- Synchronization guaranteed for RTEMS executives and IP-cores.
- Network driver to manage TSU and remote peer connectivity.
- Decoupled, C99 & 802.1AS compliant User API
- gPTP cyclic executive:
  - Best Master Clock
  - Peer to Peer delay mechanism
  - Time distribution
  - Local time (PHC) management
  - Low CPU time consumption (<5%)

IEEE 802.1AS: gPTP (II)



- gPTP User API: Runtime control & monitoring
  - AS Standard monitors
  - Decoupled from cyclic executive.

- gPTP cyclic executive
  - Protocol state machines
  - Low CPU time consumption < 5%



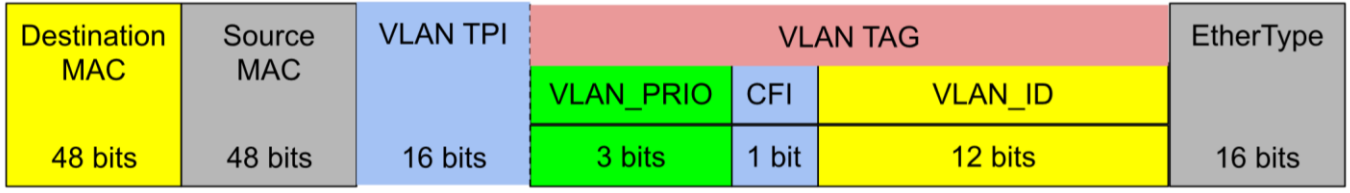
TSN IP-core: IEEE 802.1Q & IEEE 802.1CB VLAN module

VLAN & Seamless Redundancy Module

IEEE 802.1Q: Traffic differentiation and prioritization

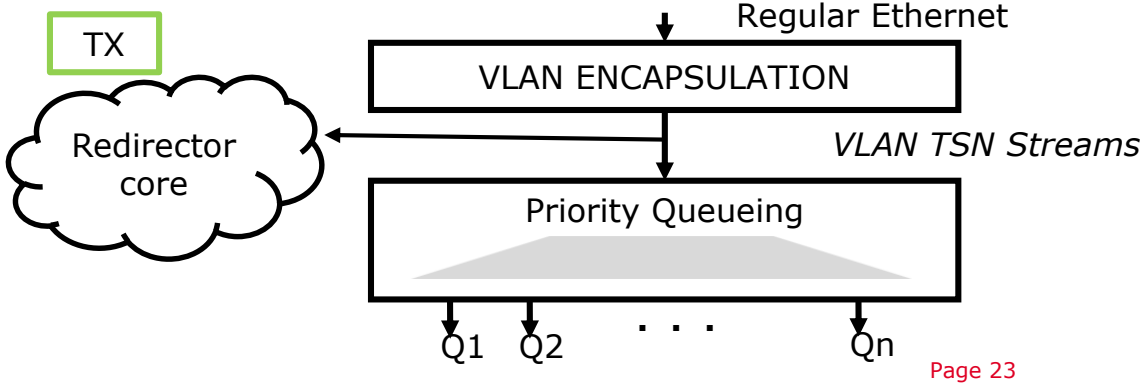
VLAN translation

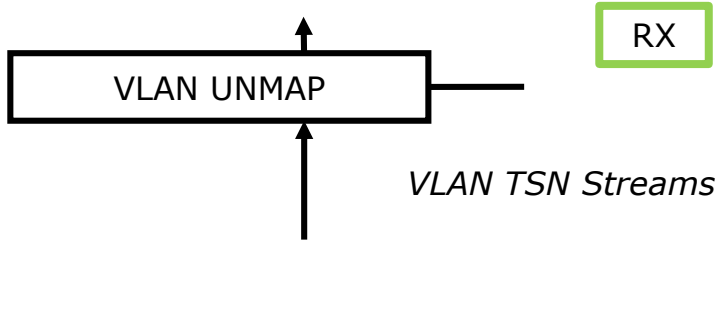
- Time Sensitive Regular Ethernet traffics are translated into TSN streams. (**Up to 16 rules**)
- TSN Stream: VLAN_ID + VLAN_PRIO + MAC (dst/broadcast).



TSN Stream mapping

- Routing
- FRER replication and dropping.
- Assignment to Egress queues according to the VLAN_PRIO field

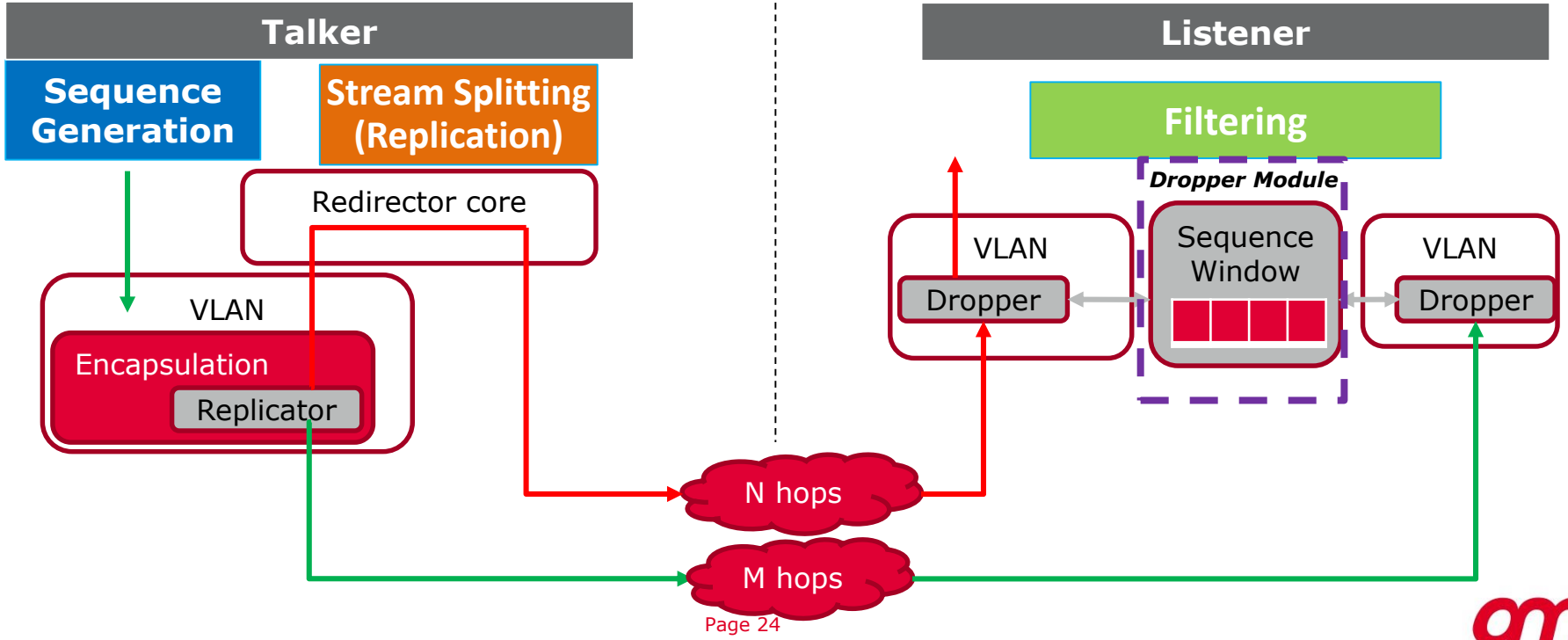




VLAN & Seamless Redundancy Module

IEEE 802.1CB: Frame Elimination and Replication for Reability (FRER)

- Seamless redundancy oriented to TSN streams
  - Zero-time switchover for most critical traffics
- GETDEN implements End-to-End FRER.



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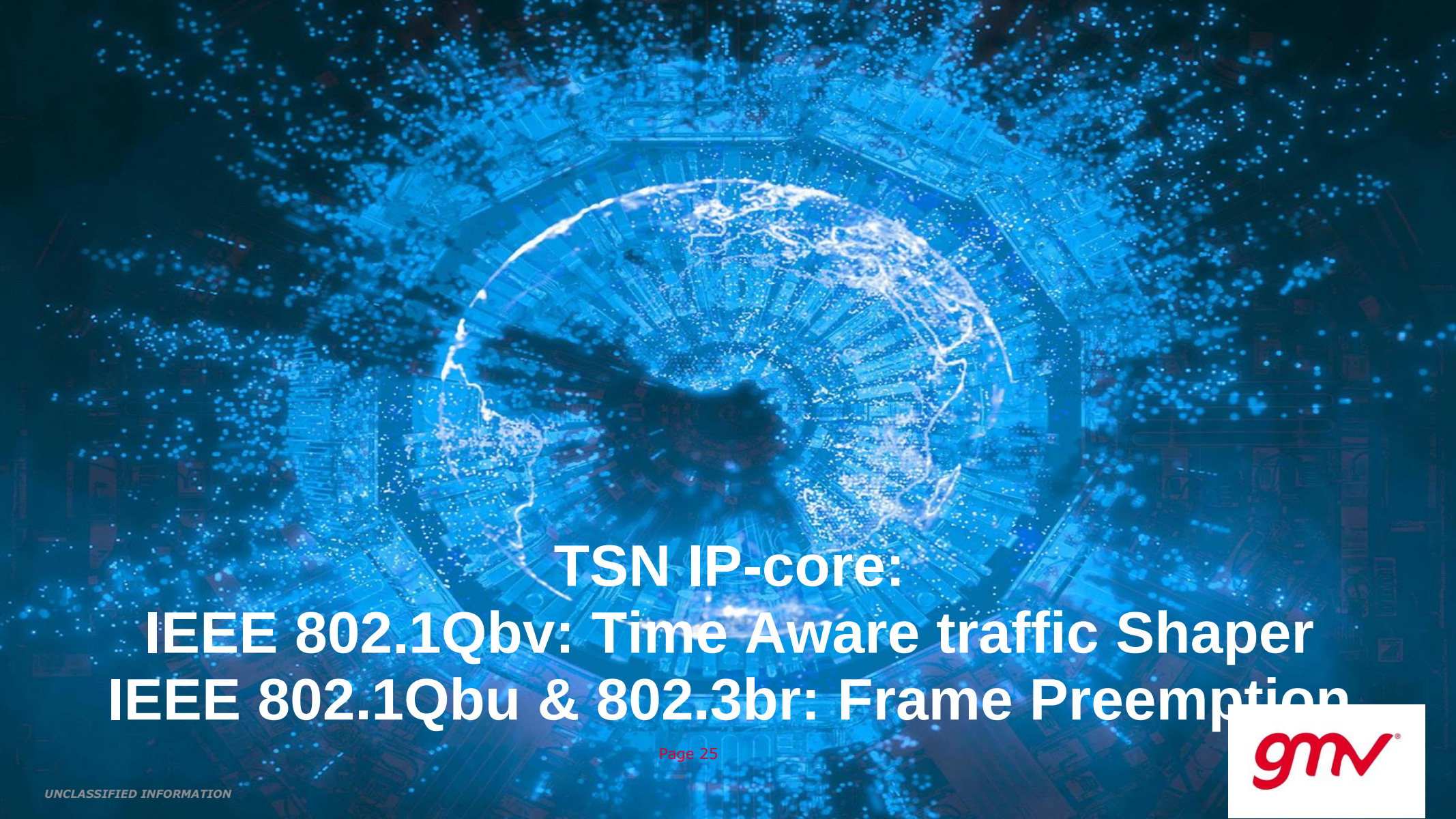
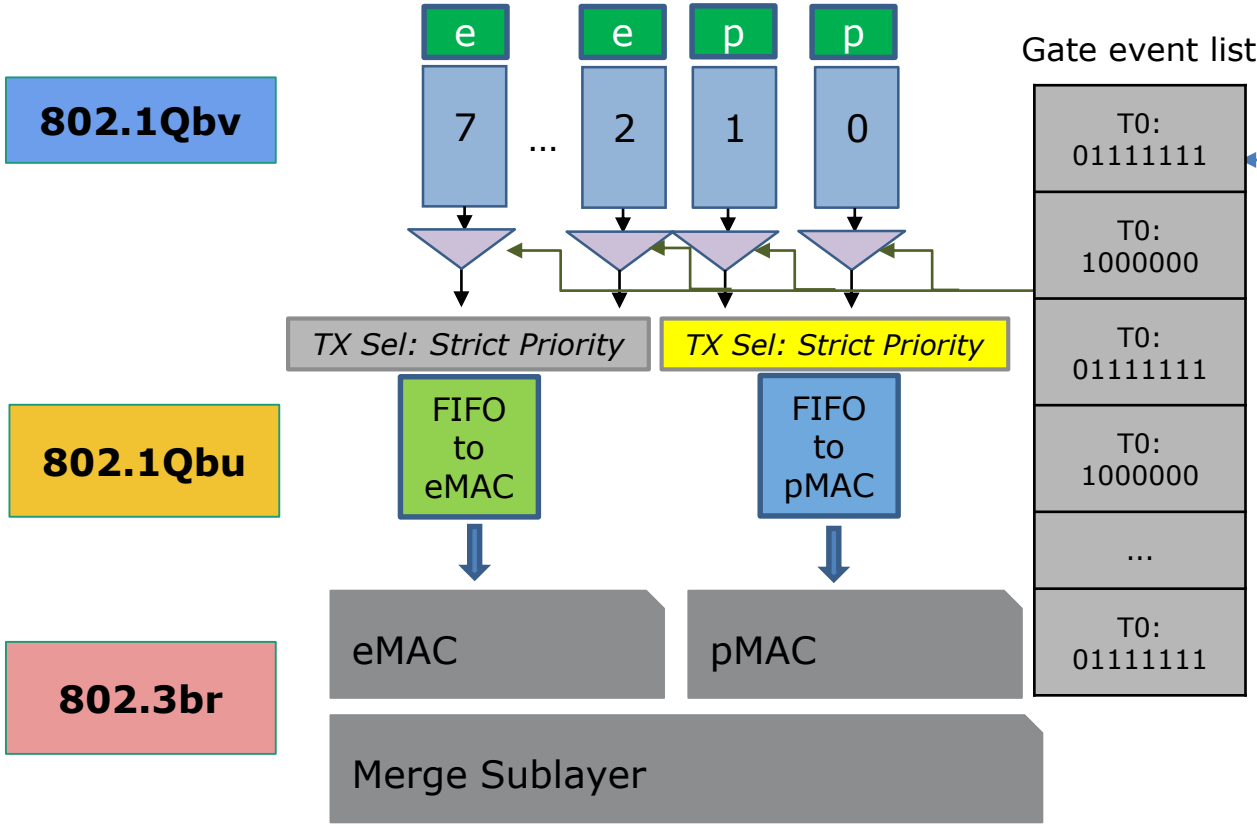


TSN IP-core:
IEEE 802.1Qbv: Time Aware traffic Shaper
IEEE 802.1Qbu & 802.3br: Frame Preemption

GETDEN: Time Aware traffic Shaper



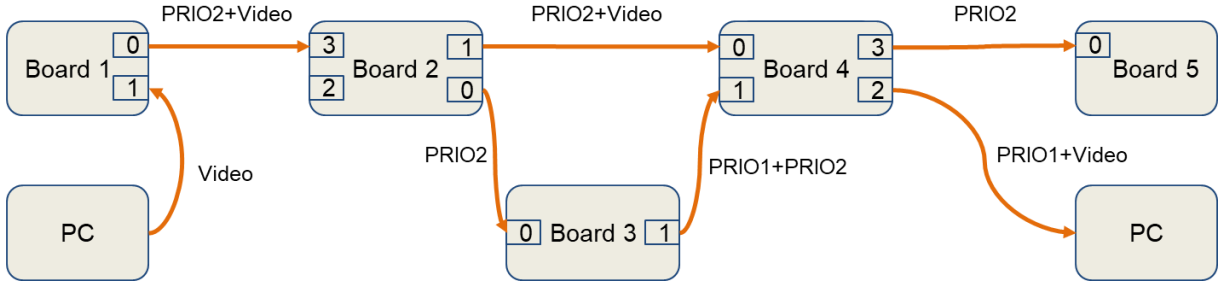
Customizable Parameters

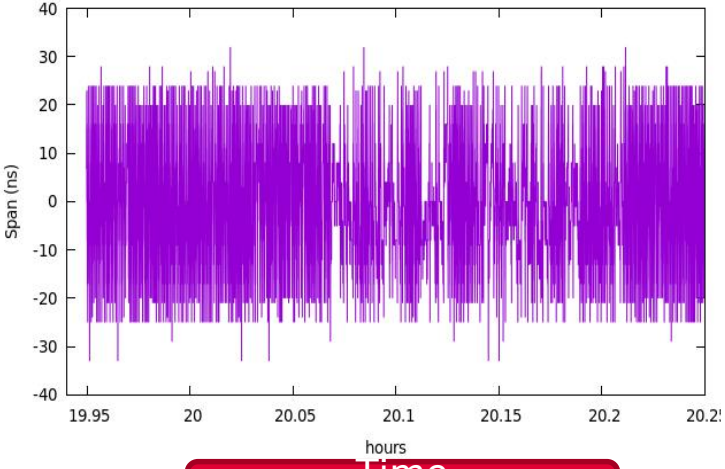
- Number of FIFOs
- FIFO Width and depth
- AXI Slave data width
- Gate control list width
- Gate control maximum table rows

Performance measurements

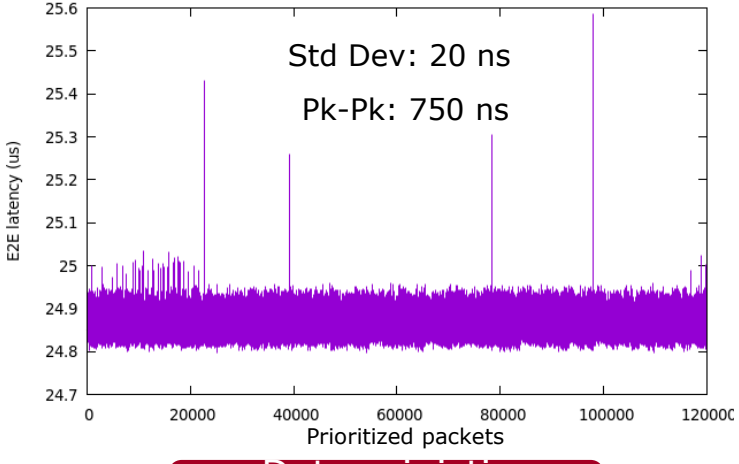
GETDEN: Performance & Setup

- Prioritized & Best effort traffic
  - Prioritized: 10 pk/ms, 400 bytes/pk
  - Best effort: 20 Mbps
- Deterministic latency < 1us
- Time synchronization < ± 50ns
- Three hops
- Four different traffic priorities





Time synchronization



Deterministic latency

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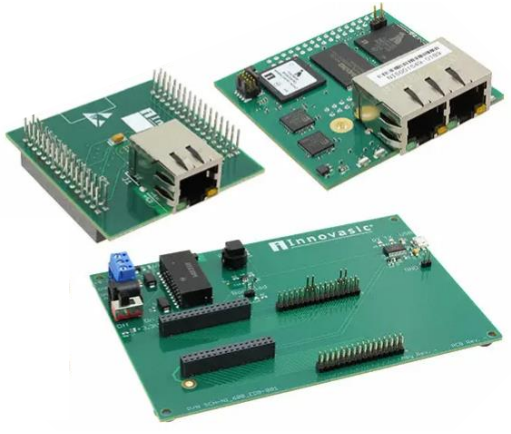
GETDEN: Interoperability

- Tests with 3rd party gPTP & TSN stations



- IEEE 802.1Q & Qbu: TSN stream communication.
- IEEE 802.1AS: Master & Slave configuration.
- IEEE 802.3br: Frame preemption

Innovasic – Analog Devices
TSN development kit

Arista Switch

National Instruments
IC-3173

Summary and Conclusion

Summary and Conclusion

- GMV is in charge of the development and qualification of complete MIURA1 avionics
- MIURA 1 avionics will be up-scaled to MIURA 5 Microlauncher
- COTS have been used to reduce costs of avionics development
- Functional and performance tests have been performed at FES, SVF and ATB level at GMV premises
- Environmental tests have been successfully passed for qualification

Challenges and Oportunities

- Once again, ‘common’ understanding of requirements has proved to be an important step in a new development (in particular when actors are coming from different background)
- Identification of the key aspects of TSN Standards suite to implement a ‘light’ version
- Adaptation to RTEMS drivers
- Verification and Validation thru proper test cases identification and usage of representative traffic (interesting demo just after launch break! **Room NC321 in Erasmus, 15:00**)
- Co-engineering of teams with different backgrounds improving results taking advantages of differences
- Technological demonstration that such a solution can be a good candidate for future communications bus in space applications

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THANK YOU

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