

Time Sensitive Networking (TSN) as reliable communication bus for micro-launchers

Introduction - What is TSN?

Time Sensitive Networking - TSN

Time Sensitive Networking (TSN) is a set of standards developed by the Time-Sensitive Networking task group of **the IEEE 802.1** working group. These standards define mechanisms for the time-sensitive transmission of data over **deterministic Ethernet** Networks.



Introduction - Advantages

- ✓ High performance
- ✓ Determinism
- ✓ Flexibility
- ✓ Enables Hard real time constraints
- ✓ Fault Tolerant
- ✓ Precise Time Synchronization (few nanoseconds)
- ✓ Extension of the widely used IEEE 802 Medium Access Control (MAC)
- ✓ Enables Mixed criticality data on a single harness
- ✓ Up to 100 m physical layer length at 100 Mbps
- ✓ Open standard - Compatibility – No vendor lock

Introduction - Data Classification in a Spacecraft Modular Avionic System

Critical Data – Priority 1

Real time needs
Up to Catastrophic consequences

HIGH PRIORITY

Essential Data – Priority 2

No Real time needs
Up to major consequences

ESSENTIAL

Best Effort Data – Priority 3

No real time needs
Minor or negligible consequences

BEST EFFORT

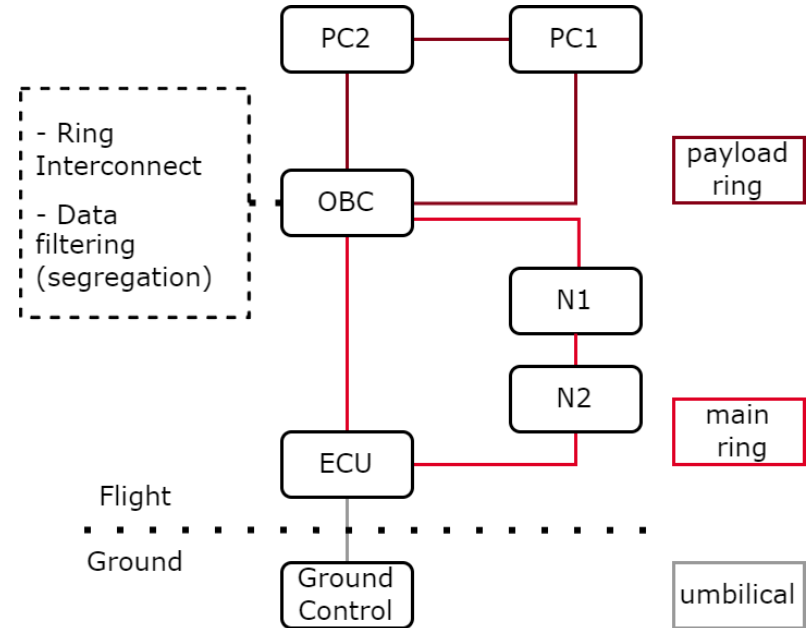
MIURA-1 Use Case

PLD Suborbital launch vehicle

- Single Stage
- Liquid oxygen and kerosene
- Thrust Vector control and ARCS

Avionic System

- Six processing nodes
- Two daisy chains
- Ground connection to **National Instruments** equipment
- Interfaces: TSN, CAN, Sensors, RS422, GPIOs, Ethernet



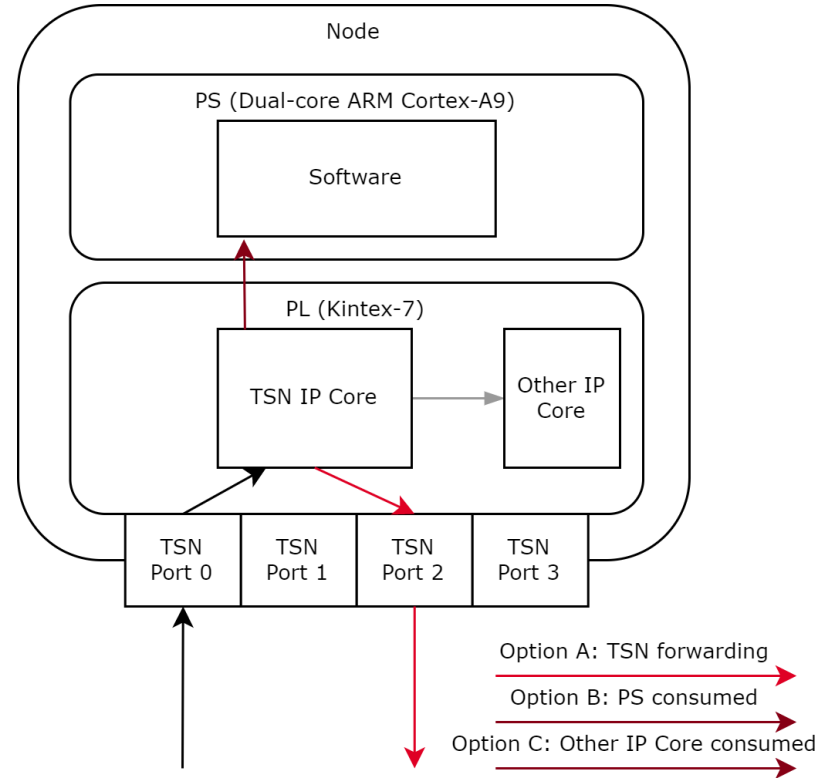
Standard Subset

Selected

- **IEEE 802.1AS** gPTP synchronization (including Best Master Clock selection BMC)
- **IEEE 802.1Qbv** Enhancements for Scheduled traffic – Time Aware Traffic Shaping
- **IEEE 802.1Qbu & IEEE 802.3br** Frame preemption and Interspersing Express Traffic

Topology

- **Flexible** packet management based on configurable rules
- No software intervention to forward packets to **reduce the CPU usage**
- **Redundancy** management based on CRC (Paired ports)



TSN Configuration

- **Flexible** configuration established at initialization time
- Data traffic **worst case analysis** needed to obtain the configuration

Best effort	no	no	yes
Essential	no	yes	yes
Critical	yes	yes	yes
	slot #1	slot #2	slot #3

0 ms

10 ms

TSN Configuration

Problem

- Configuration can be complex, i.e a dedicated VLAN needs to be defined per each destination ID and data priority.
- Every node need to know what to do with each VLAN.
- I.e, MIURA 1 TSN configuration file has around 1500 lines

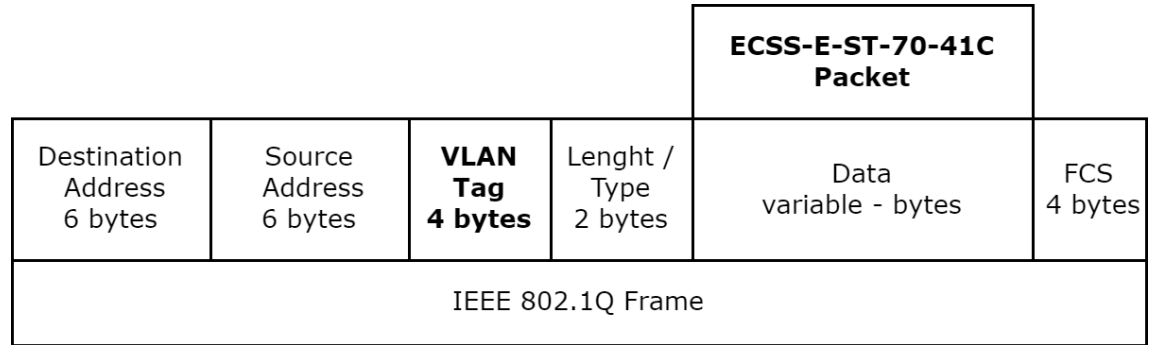
Solution - Tissen

- A dedicated tool has been created to support the TSN configuration.
- It automatically generates the configuration file based on the network topology and the data traffic definitions.



PUS over TSN

- Minimize overhead
- Reuse on-board and ground software
- Configurable translation from APID to address similar to IP routing tables



Testing and Qualification

Debug and troubleshooting

- Quick and efficient debug thanks to mature ethernet COTS tools
 - **Wireshark**
 - **Zero delay sniffers**
- Base ethernet protocol is well known by engineers (smooth learning curve)

No.	Time	Source	Destination	Protocol	Length	Info
343	65.142415	192.168.0.21	174.129.249.228	TCP	66	40555 → 80 [ACK] Seq=1 Ack=1 Win=5888 Len=0 TSval=491519346 TSecr=551811827
344	65.142715	192.168.0.21	174.129.249.228	HTTP	253	GET /clients/netflix/flash/application.swf?flash_version=flash_lite_2.18w=1.58...
345	65.230738	174.129.249.228	192.168.0.21	TCP	66	80 → 40555 [ACK] Seq=1 Ack=180 Win=6864 Len=0 TSval=551811850 TSecr=491519347
346	65.240742	174.129.249.228	192.168.0.21	HTTP	828	HTTP/1.1 302 Moved Temporarily
347	65.242592	192.168.0.21	174.129.249.228	TCP	66	40555 → 80 [ACK] Seq=188 Ack=763 Win=7424 Len=0 TSval=491519446 TSecr=551811852
348	65.242532	192.168.0.21	192.168.0.21	DNS	77	Standard query 0x2188 A cdn-0.netflix.com
349	65.276870	192.168.0.1	192.168.0.21	DNS	489	Standard query response 0x2188 A cdn-0.netflix.com CNAME images.netflix.com edge
350	65.277992	192.168.0.21	63.80.242.48	TCP	74	37063 → 80 [SYN] Seq=0 Win=5840 Len=0 MSS=1460 SACK_PERM=1 TSval=491519462 TSecr=
351	65.297757	63.80.242.48	192.168.0.21	TCP	74	80 → 37063 [SYN, ACK] Seq=0 Act=1 Win=5792 Len=0 MSS=1460 SACK_PERM=1 TSval=3295
352	65.298306	192.168.0.21	63.80.242.48	TCP	66	37063 → 80 [ACK] Seq=1 Ack=1 Win=5888 Len=0 TSval=491519502 TSecr=3295534130
353	65.298687	192.168.0.21	63.80.242.48	HTTP	153	GET /us/nrd/clients/flash/B14540.bun HTTP/1.1
354	65.318730	63.80.242.48	192.168.0.21	TCP	66	80 → 37063 [ACK] Seq=1 Ack=88 Win=5792 Len=0 TSval=3295534151 TSecr=491519503
355	65.321733	63.80.242.48	192.168.0.21	TCP	1514	[TCP segment of a reassembled PDU]

Request In: 345
[Time: 0.034330000 seconds]
Transaction ID: 0x2188
Flags: 0x8100 Standard query response, no error
Questions: 1
Answer RRs: 4
Authority RRs: 9
Additional RRs: 9
Queries
> cdn-0.netflix.com: type A, class IN
> Answers
> Authoritative nameservers

0020	00	15	00	35	84	f4	01	c7	83	3f	11	30	01	80	00	01	...	...	7f	...	
0030	00	04	00	09	00	09	05	63	64	6e	2d	30	07	6e	6d	6c	...	...	c	dn-0.nf1	
0040	78	69	6d	67	03	63	6f	6d	00	00	01	00	01	c0	0c	00	...	...	xing.com	.....
0050	05	00	01	00	00	05	29	00	22	06	69	6d	61	67	65	73	...	...	.	images	.....
0060	07	6e	65	74	66	6c	69	78	03	63	6f	6d	69	65	64	67	...	...	.	netflix.com	edge
0070	65	73	75	69	74	65	03	6e	65	74	00	c0	2f	00	05	00	...	...	.	esuite.n	et.../...

Testing and Qualification

Integration Test – Development and EM boards

- Software ECCS Criticality B

Validation Tests – Avionic Qualification model

- **Environmental**
 - Vibration and shock
 - Thermal
 - Vacuum
 - EMC
- **Avionic Test Bench (ATB)**
 - Full Mission
 - Mission scenarios
 - Contingencies

System Tests – Avionic Integrated in the Micro-launcher

Testing and Qualification



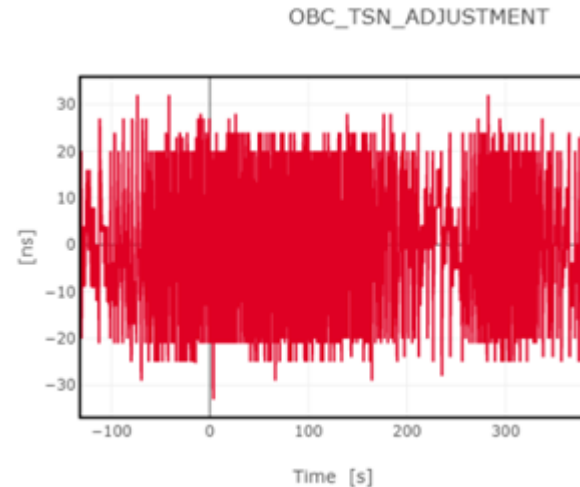
Communication architecture performances

Data rates MIURA1 use case

- 0.5 Mbps of critical data
- 2 Mbps of essential data
- 1 Mbps of best effort data

Results – Including avionic qualification, flight model tests and launch attempts.

- No packet lost
- No synchronization lost
- No real time constraint violated
- Clock adjustment under 60 ns
- Link delay under 500 ns



Portability

Software driver available for:

RTEMS 5.0

Bare Metal

AIR Hypervisor



Easy porting to other
RTOS / Hypervisor

air

REAL-TIME HYPervisor
COMPLIANT WITH ARINC 653 and IMA-SP

Resources

FPGA

- ❑ **<60% LUTs, <40% Slice registers, <55% BRAMs, <15% DSPs – 4 port** implementation in a **Xilinx Zynq 7030**

FPGA RESOURCES NEEDED FOR THE TSN IMPLEMENTATION.

TSN Conf.	LUTs	Slice Reg.	Multiplexers	BRAMs	DSPs
4 TSN Ports	46408	62587	566	136.5	50
2 TSN Ports	34649	48643	313	88.5	42

Processor

- ❑ Around **10%** in a single core ARM Cortex A-9

MIURA 1 Status

At the moment of preparing this presentation ...

- ❑ System qualification completed including hot tests
- ❑ Two launch attempts:
 - ❑ **31/05/2023** Abort due to altitude winds
 - ❑ **17/06/2023** Abort due to anomaly detected in the umbilical release
- ❑ Next attempt foreseen in autumn 2023



Conclusion

- ❑ A novel **communication architecture** for modular spacecraft avionic system has been design, implemented, and **qualified** for flight within the MIURA 1 micro-launcher.
- ❑ The results indicate the communication architecture can exceedingly fulfill the needs of a launcher.
- ❑ The communication architecture is very **flexible** and can be instantiated in reduced boards.
- ❑ The communication architecture is **portable**, software driver available for RTEMS, AIR hypervisor and bare-metal.

Thank you

Carlos Domínguez
cgsanchez@gmv.com