Next Generation Launcher Communication System Based on Time Sensitive Networking Technology

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INTRODUCTION

Real-time communication services are a baseline requirement for launcher application.

The introduction of real-time services in industrial environments has led to the development of a variety of protocols providing deterministic behaviour: Token Bus, Token Ring, Profibus, SERCOS, CAN, MIL-STD 1553. In order to increase the bandwidth performance some verification without good result was take in consideration also the Ethernet.

Even if the large diffusion and higher speed ethernet is anyway used only for communication based on best-effort principle that it’s affected by communication non predictable delay if too many clients are trying to access to single path at the same time.

Since a few years, changes to the Ethernet standard have been proposed to provide real-time guarantees such as maximum transfer delay, jitter in the transmissions and available bandwidth. In this context, Time Sensitive Networking (TSN) standards offer a non-proprietary, viable, standardized solution which is being developed by the IEEE 802.1 working group.

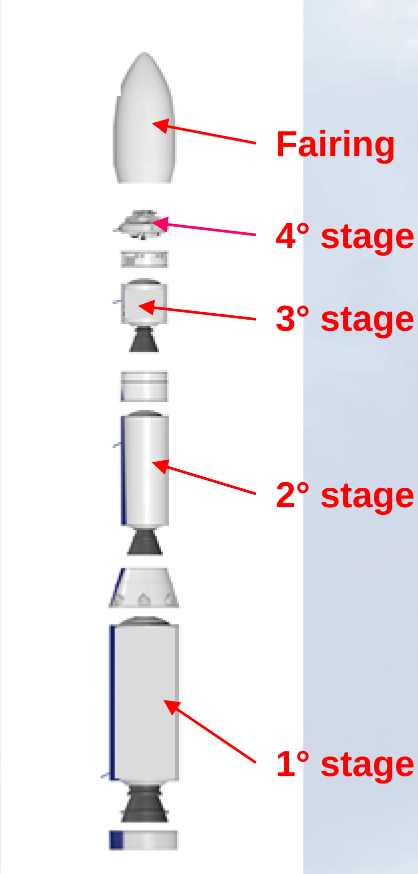
NEXT GENERATION LAUNCHER COMMUNICATION SYSTEM

Space Launcher operation phases:

- **The launch preparation**: hardwire connection to Ground Control (GC).
- **The actual flight**: no hardwire connection to GC. Communication based on TT&C subsystem.

In the avionic communication system, between each modules part of the avionic system, the main messages are grouped as follow types:

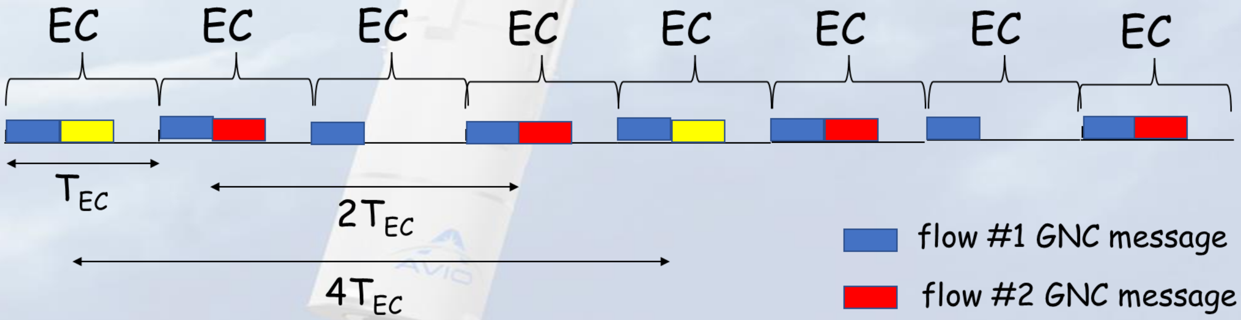
- **Guide Navigation and Control** (GNC) messages
- **Fault Detection, Isolation and Recovery** (FDIR) messages
- **Telemetry** messages
- **Sporadic** messages



NEXT GENERATION LAUNCHER COMMUNICATION SYSTEM

In most launchers, message transmission is organized in time intervals called Elementary Cycle (EC) of duration TEC. Below an example that comply with the requirements:

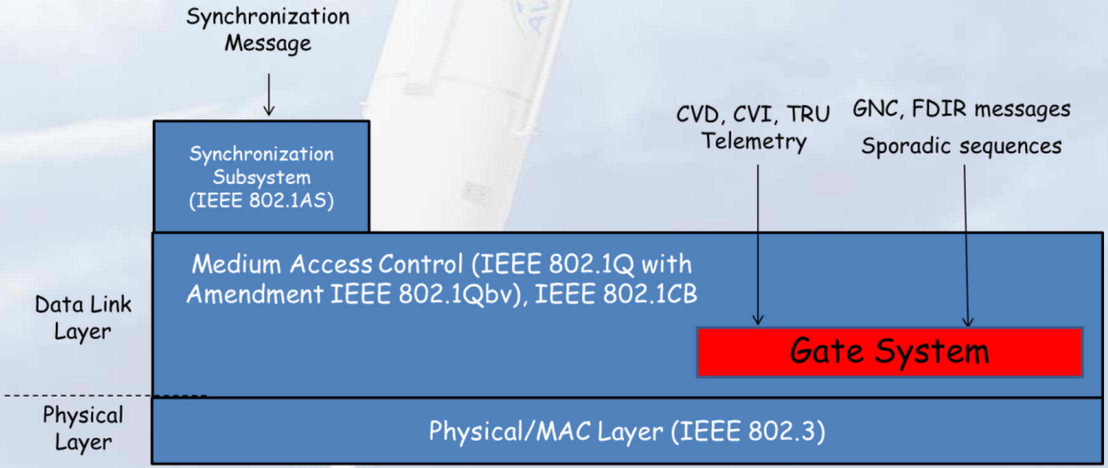
- Typical ECs duration: 5ms.
- GNC messages between a device couple (i.e. OBC and NAV).
- Synchronous transfer service with the same delay and negligible jitter need.



TSN APPLIED TO NEXT GENERATION LAUNCHER COMMUNICATION SYSTEM

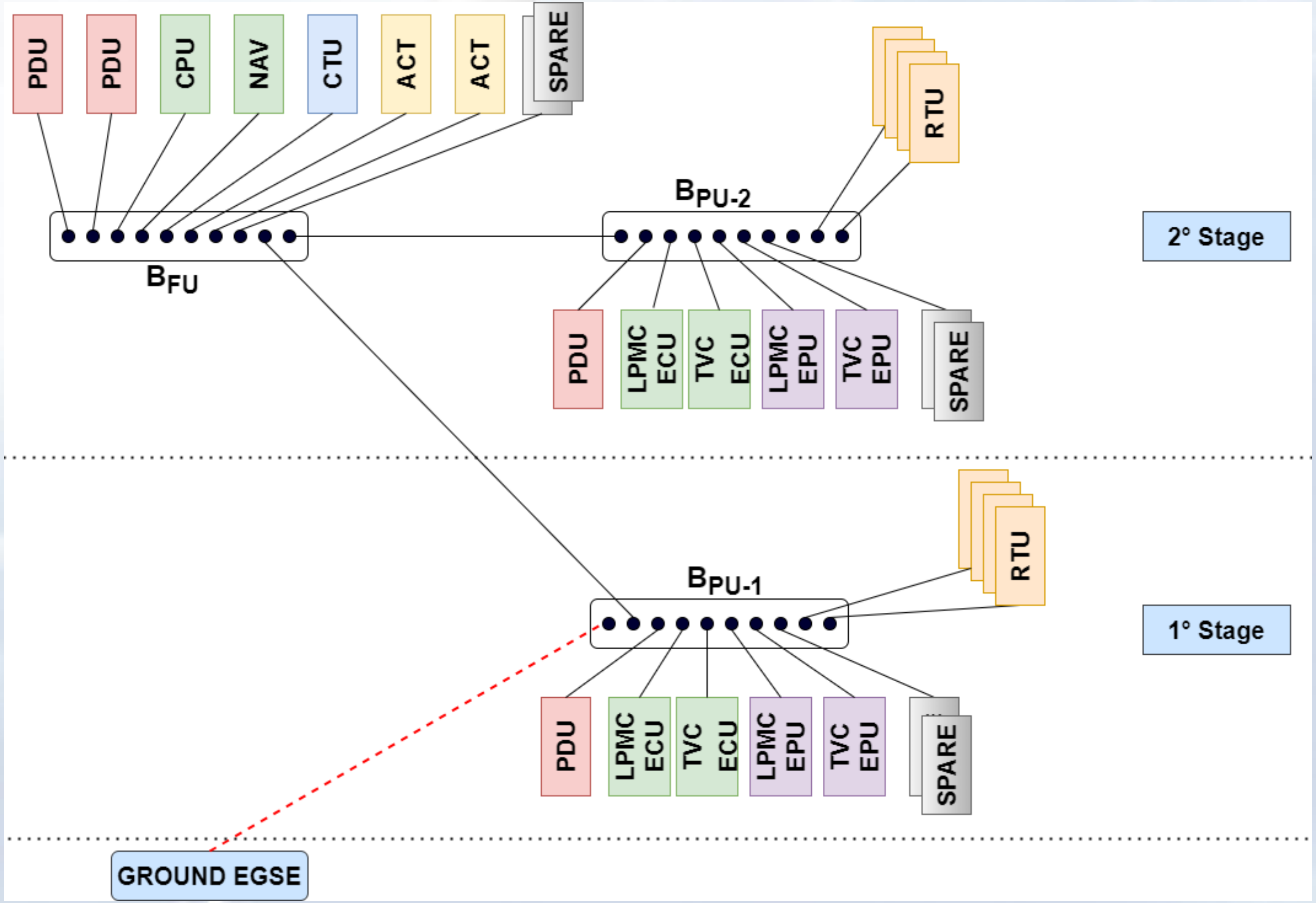
In the architecture of the TSN-based NGLCS is illustrated in figure below it is based on the following requirement choice:

- **IEEE 802.1Qcc standard:** centralized configuration
- **IEEE 802.1AS standard:** A time synchronization based on Generalized Precision Time Protocol.
- **IEEE 802.1CB standard:** Redundancy mechanism for fault tolerance.
- **IEEE 802.1Qbv standard:** Real time message scheduling based on the Time Aware Shaper.



NETWORK TOPOLOGY – STAR CONFIGURATION WITHOUT REDUNDANCY

The network topology shown is linear and it is equipped with three bridges B_{PU-2}, B_{FU} and B_{PU-1} located in the 1st and 2nd stage, respectively. All of the network links operate in full-duplex mode and support a 100 Mbps rate.

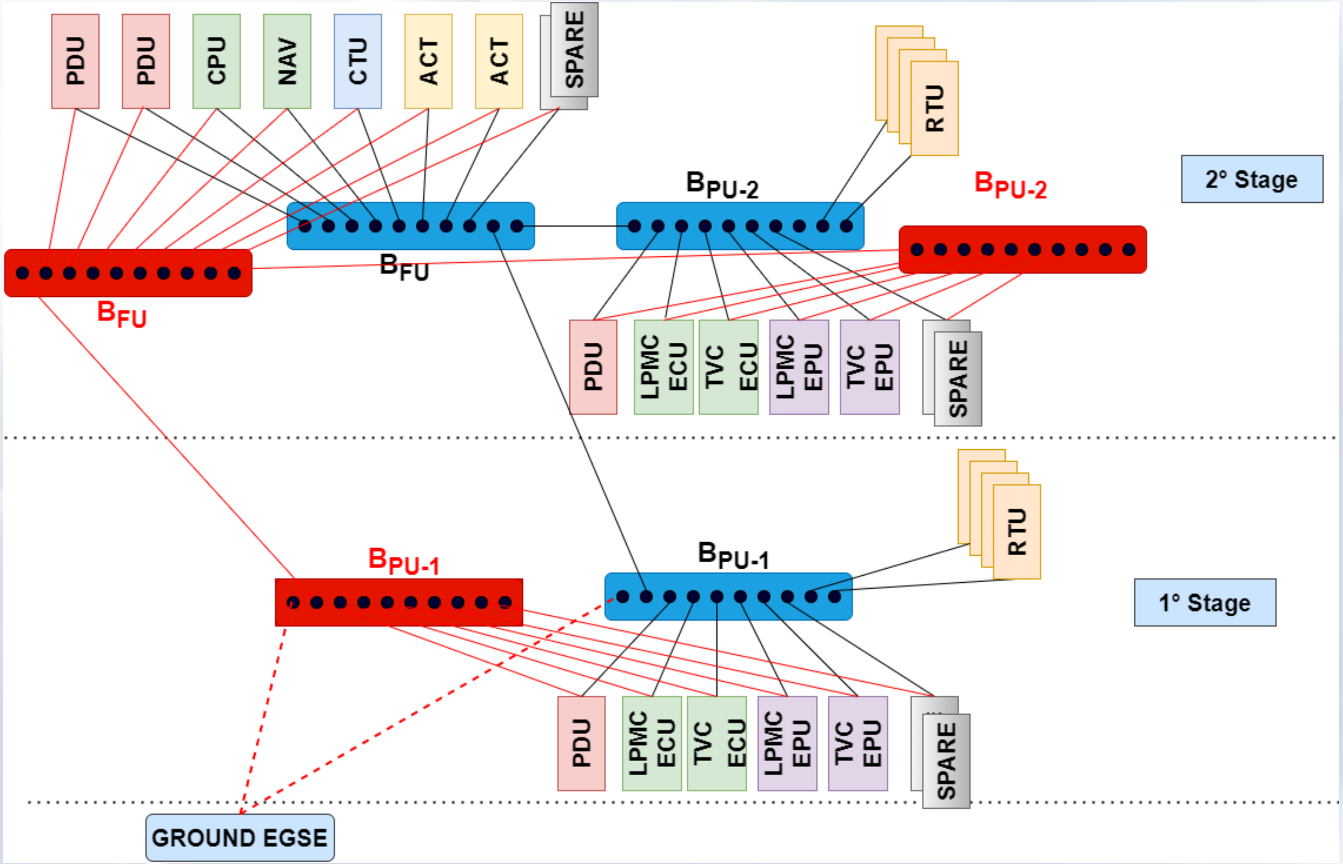


<u>This star topology doesn't guarantee resiliency to the failure of either one network link</u>

NETWORK TOPOLOGY - STAR CONFIGURATION WITH REDUNDANCY

The figure shows the redundant solution, that as what proposed in TTEthernet networks guarantees resiliency to the failure of either one link or one bridge.

- Critical end system protected
- Number of bridges duplicated
- Not critical end system connected with one only network interface

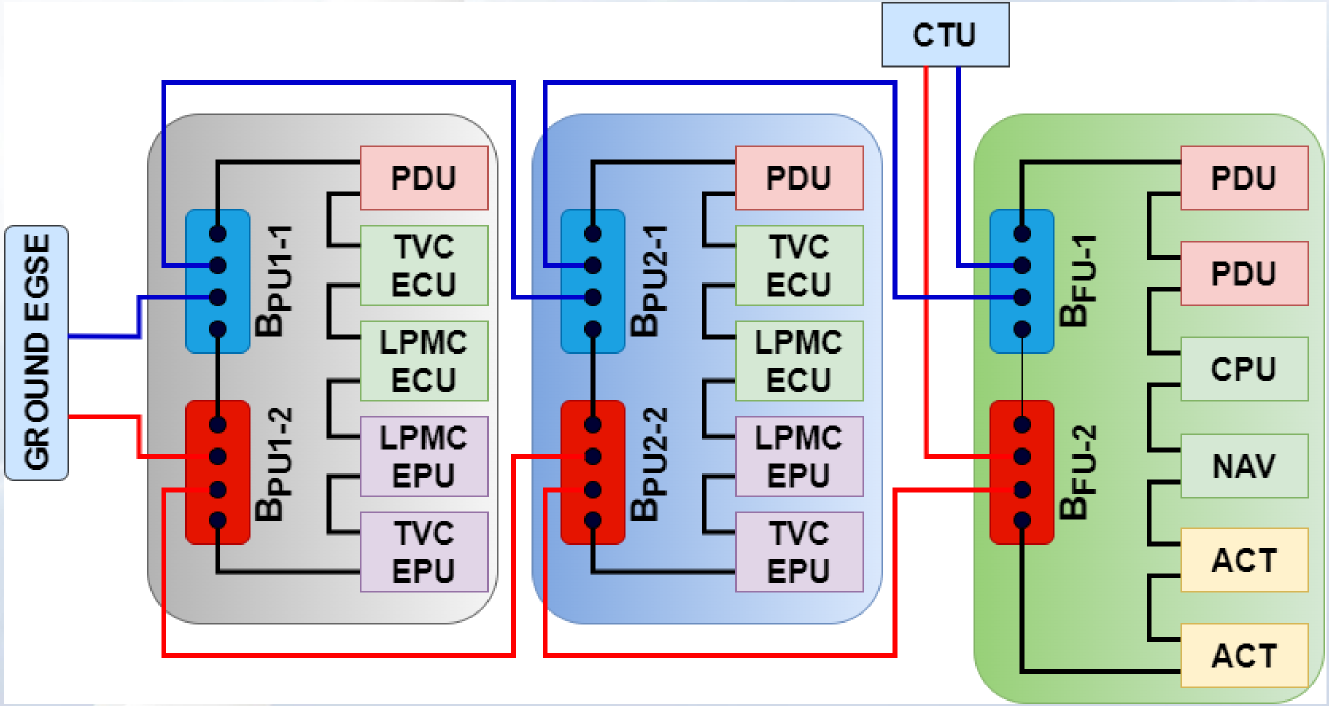


NETWORK TOPOLOGY – STAR RING CHAIN NETWORK CONFIGURATION

Two ring loops implementing a daisy chain with redundancy.

Main highlights:

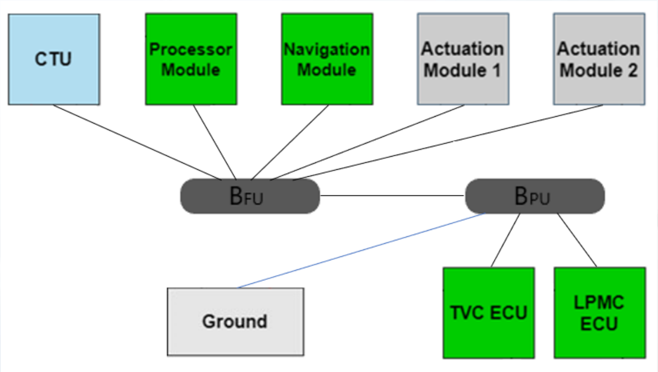
- Implementation with lower size bridges
- resiliency to the failure of either one link or one bridge.
- Critical end system with two network interface.
- Each ring has two bridges.
- Two copies of the frame in the ring up to the erasing.



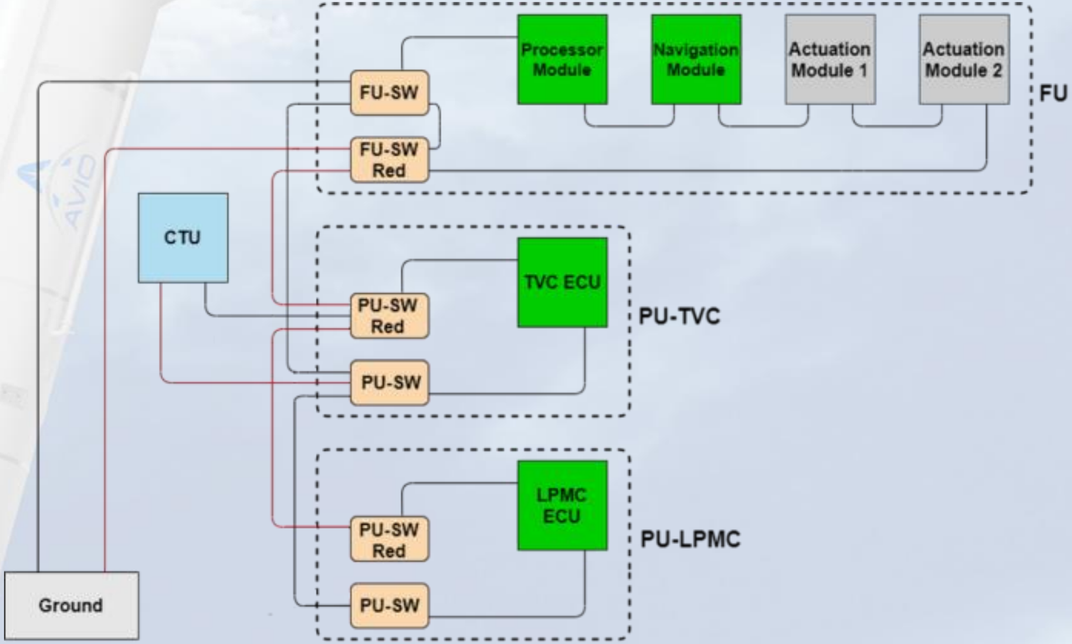
NUMERICAL RESULTS

In order to evaluate the performance of the network topologies, an analysis has been put in place considering a set of standard messages originating from a real launcher traffic scenario.

We considered two topology scenarios: star and ring-chain, both utilizing the same set of message flows, as detailed below.



Star test-bed topology



Multi-Ring test-bed topology

NUMERICAL RESULTS

The simulated message set is drawn from the communication patterns within a light launch vehicle.

The EC duration is 5 ms. The behaviour of flows is assumed to be deterministic and periodic, and message scheduling adheres to a Hyper-Cycle (HC) with a duration equivalent to the least common multiple of flow time periods.

The periodicities of the message flows are equal to 5 ms, 20 ms and 40 ms that leads to a HC duration equal to 40 ms. In the next slide table represents the following information:

i. An identifier (Flow ID).
ii. The sender and the receiver.
iii. Message flow length expressed in byte.
iv. The periodicity and the starting EC expressed in terms of number of ECs.

Numerical results

Characteristics of the Message Flows					
Flow ID	***Sender***	***Receiver***	***Length***	***Periodicity***	***Starting EC***
1	TVC	PM	24	8	3
2	TVC	PM	24	8	3
3	TVC	PM	22	8	4
4	TVC	PM	22	8	4
5	PM	TVC	8	8	3
6	PM	TVC	8	8	3
7	LPMC	PM	24	8	3
8	LPMC	PM	24	8	3
9	LPMC	PM	22	8	4
10	LPMC	PM	22	8	4
11	PM	LPMC	8	8	3
12	PM	LPMC	8	8	3
13	NM	PM	18	8	0
14	NM	PM	14	8	0
15	NM	PM	44	8	0
16	PM	NM	6	8	2
17	NM	PM	14	8	2
18	PM	AM1	476	1	0
19	AM1	PM	110	1	0
20	PM	AM2	476	1	0
21	AM2	PM	110	1	0

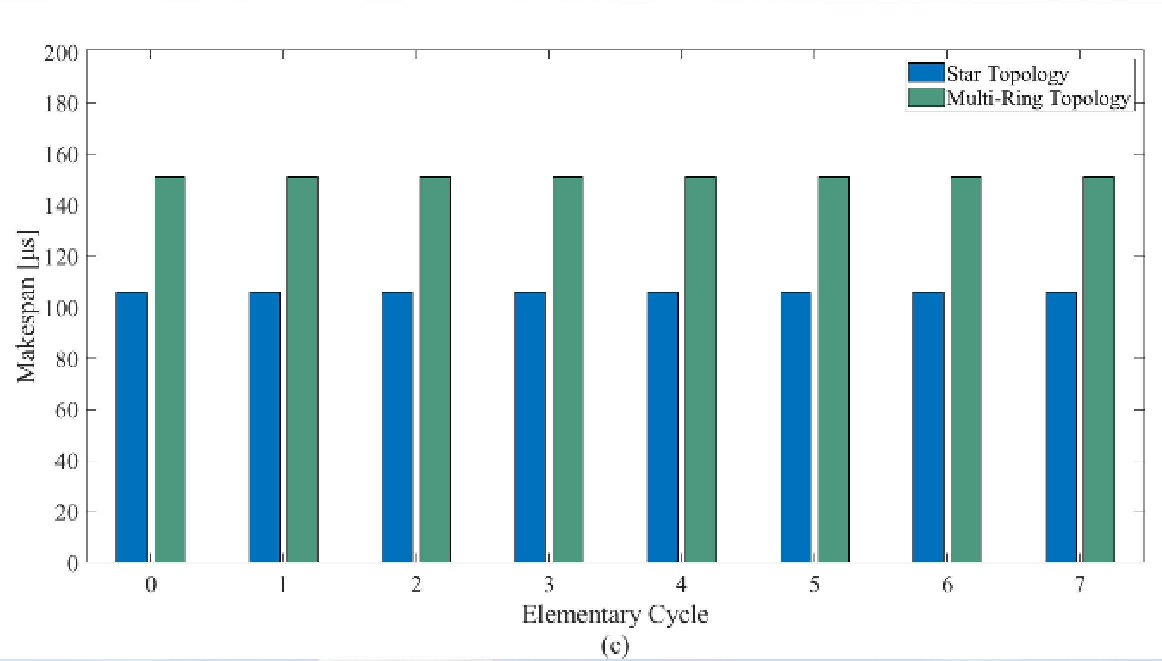
Makespan, defined as the time elapsed from the beginning of the EC to the time in which last scheduled message in the EC is delivered to the destination on any link.

Considering TEC as the duration of an **EC**, **THC** the duration of the **HC**, we define NHC = **THC/TEC** as the count of **ECs** within a hyper-cycle **HC**.

In this specific case, NHC is equal to 8 cycles, each with a duration of 5 ms.

The ***Makespan*** was assessed for each of these 8 **EC**, as shown in next slide in the two considered topologies.

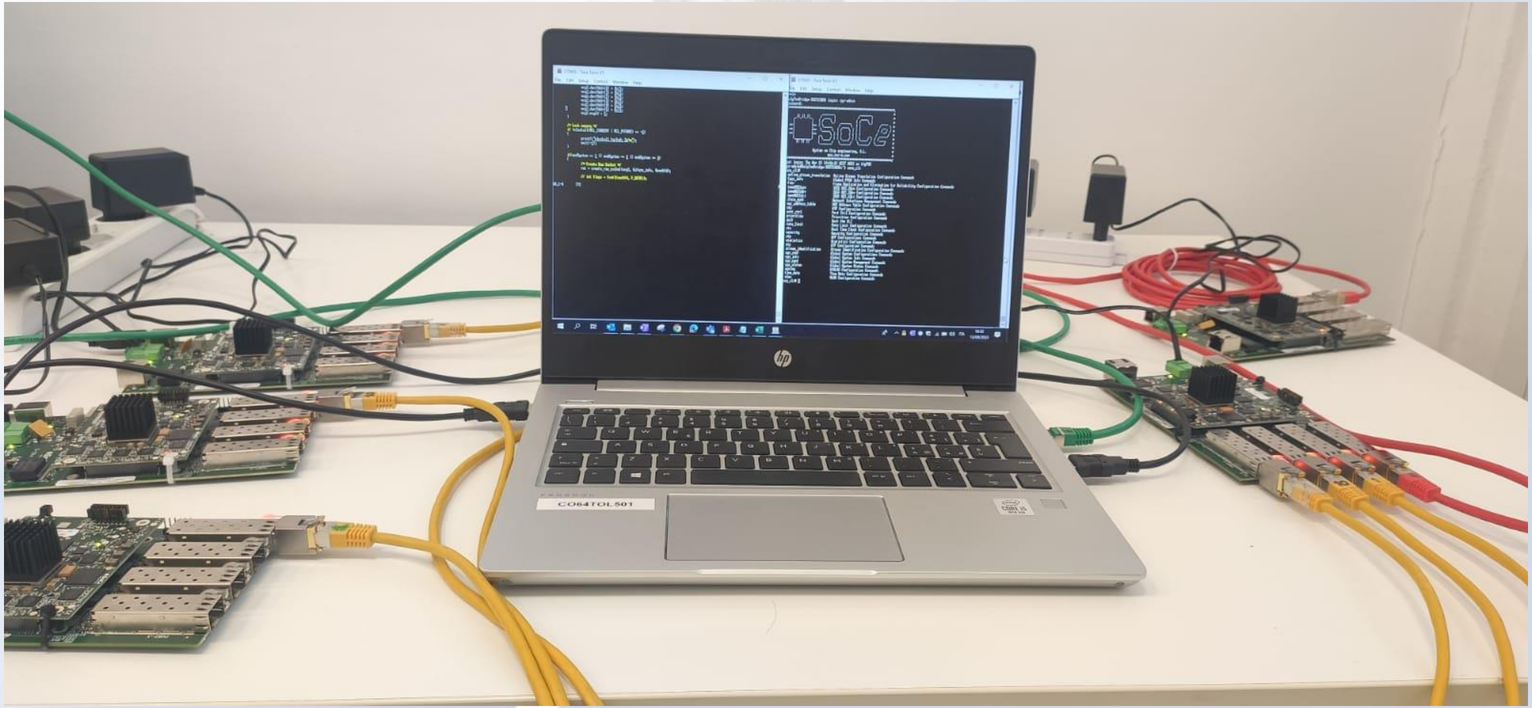
NUMERICAL RESULTS



- Maximum ***makespan*** values of ***106 µs*** and ***151 µs***, respectively, in the Star and Multi-Ring topologies.
- The Star topology outperforms the Multi-Ring topology, delivering lower **makespan** values and, consequently, higher bandwidth efficiency. Specifically, we observe a substantial **45.4%** performance difference between these two topologies.

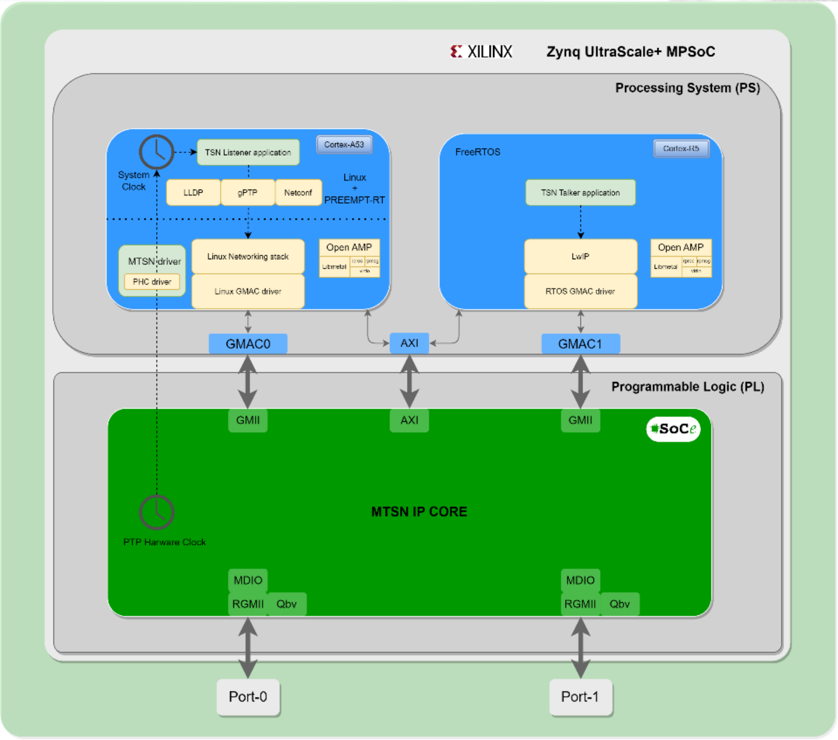
Test setup by means of SOC-E Development boards with MTSN ip core

The test setup has been implemented by means n. 6 equipment as below:



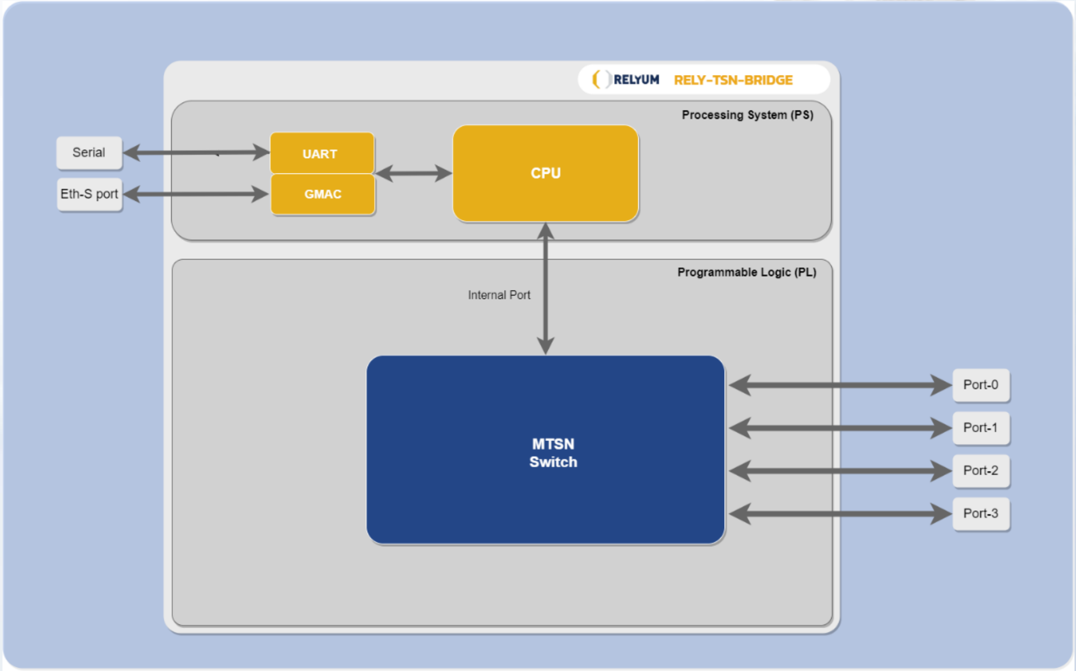
TEST SETUP BY MEANS OF SOC-E DEVELOPMENT BOARDS WITH MTSN IP CORE

End System (firmware) architecture:



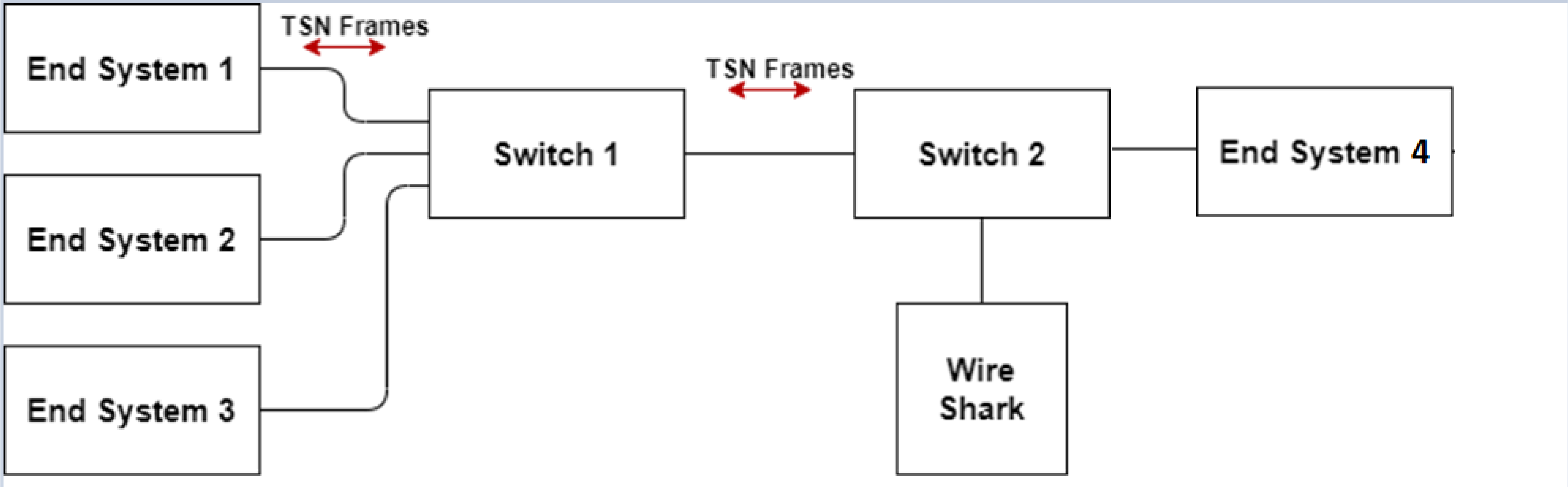
Test setup by means of SoC-e Development boards with MTSN IP core

Switch (firmware) architecture:



TEST SETUP CONFIGURATION

The above setup is configured as below:



TEST SETUP TALKER CONFIGURATION AND SYNCHRONIZATION

The talker send packet each 40ms with different priorities:

- ES1 → PCP=7
- ES2 → PCP=4
- ES3 → PCP=0

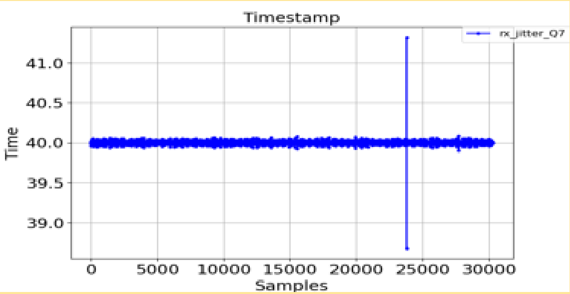
All the devices in the network have been synchronized to each other and the PTP master has been assigned to the **Switch-1**.
All the devices have their **own system clock synchronized to each own current** time.

Each talker has been programmed to sent 10 000 frames, filled only with data useful for timing post-processing function, and starts to send packet after 500s from the power on.

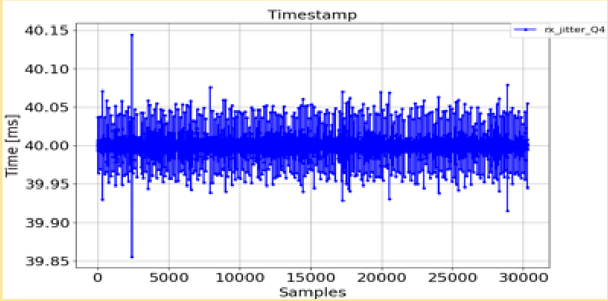
TEST SETUP JITTER

The jitter seen for each queue is here below reported:

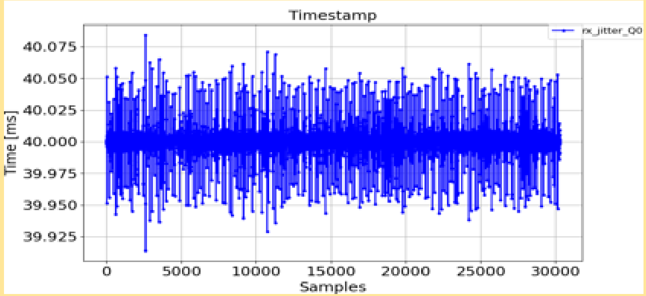
Talker, measured by the listener based on non-RT OS timestamping is **150us**.



Q7



Q4



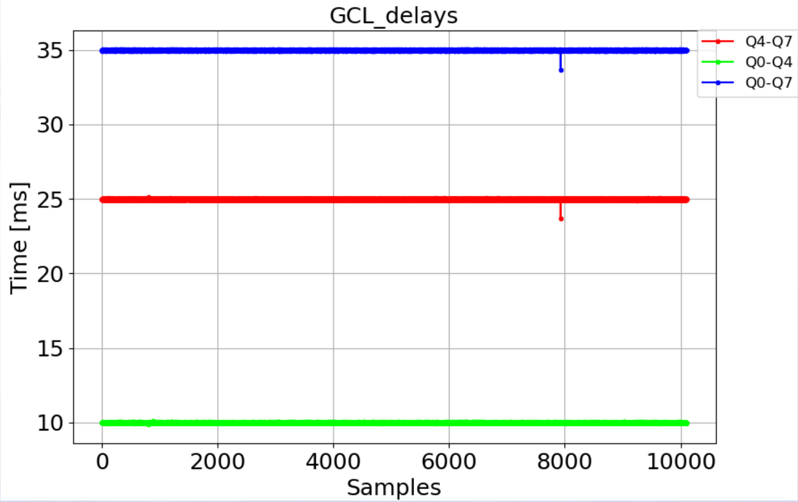
Q0

The average of the **<u>40ms</u>** are respected with exception of some spikes linked to the non-deterministic behaviour of the OS.

The function send and receive called by the Talker/Listener application are served non in a deterministic way from the OS.

TEST SETUP GCL COHERENCE

GCL coherence is showed by the following picture:



This plot shows that the relative timing distance between frame of the different queues is deterministic, with exception of some spikes that correlated with the one seen in the previous slide.

This plot confirms also the capability of the talker to send packet in coherence with the ‘’Slot 0” of the Time Aware Shaper.

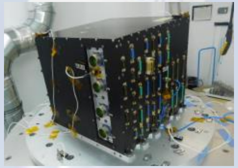
CONCLUSION AND NEXT STEPS

The test results provide above confirm the suitability of this communication bus solution w.r.t launcher vehicle application. Main requirements highlighted in the above slides have been verified:

- Time determinism of packet transmission → TSN standards, RTOS, Ethernet bandwidth
- Communication bus bandwidth → Ethernet based bus
- Flexibility for network change (stage sep.) → Electrical isolation of the bus ethernet
- Time synchronization → gPTP

The next step in this project will be:

- Verification of impact of simulated failure
- Frame elimination and replication (FRER) verification
- Communication bus waveform robustness w.r.t LV environment
- RTOS introduction (PikeOS is the selected one)
- LV full avionic network validation test.



SoCe System-on-Chip engineering

THANK YOU

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