SEVEN Solutions
When every nanosecond counts

Time-Sensitive Networking-Based Solution for Aerospace Micro Launchers

New Space Applications

Time-Sensitive Networking (TSN) is a set of standards under development by the TSN task group, part of the IEEE 802.1 working group. The standards define mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks. Most of the projects define extensions to the IEEE 802.1Q (bridges or bridged networks). These extensions address very low transmission latency and high availability.




User Challenges

- Ethernet standard for hard-real time space avionics.
- Deterministic latency, ultra-reliability, Ethernet best-effort QoS and flexibility over one infrastructure.
- Tight synchronization.
- Full integration with user software and logic applications on the same SoC FPGA.

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Context

Small satellites and CubeSats deliver a wide range of affordable space services and applications, suitable for both commercial and scientific institutions. So far, they are launched as secondary payloads or piggy backs on heavy rockets such as Vega, Ariane 6, or Soyuz. Some key features as the orbit, the launch date and the responsiveness depend entirely upon the main customer requirements. **Micro launchers** represent a valid and competitive response for this growing demand, by combining reusability and interoperability, to deliver adapted and cost-efficient solution for small satellite operators.

Under this approach, micro launcher avionics communication should provide additional features to the high-level determinism and reliability provided by classical aerospace fieldbuses, such as **MIL-BUS-1553**. Modern alternatives, such as SpaceWire, SpaceFibre, TTEthernet or EtherCAT provide flexible topology and high-bandwidth support. However, as they are vendor lock-in, they rely on high-cost implementation and lack of interoperability.

Seven Solutions has developed a user-oriented, affordable solution based on COTS and Gigabit Ethernet copper (1000-Base-T). In addition to the high bandwidth and interoperability features provided by the open and popular IEEE 802 Ethernet, determinism and reliability is achieved thanks to the implementation of a subset of IEEE 802.1 and IEEE 802.3 standards, conforming a **Light Time-Sensitive Networking** for time and safety critical applications requiring minimal system resources utilization. The solution has been successfully delivered to GMV and currently being deployed on the PLD Space Miura-1 micro launcher.

Besides, Seven Solutions has developed the SoC FPGA based platform, suitable for hosting the different mixed critical subsystems developed by GMV for the rocket avionics, as well as the logic submodules supporting four 1000-Base-T TSN interfaces. The avionics has been deployed along a double ring topology for resiliency and it has been tested under harsh environmental conditions including EMC, temperature and vibration tests.

The developed **TSN solution** supports seamless redundancy, reconfiguration and resize of ring topologies, as well as generalized Precision Time Protocol (PTP) supported by hardware timestamping. Besides, the light TSN is tightly coupled to the customer solution, as it provides direct TSN interface to the logic and synchronization for time-sensitive software. The aerospace segment widely uses the **real-time ESA qualified OS RTEMS v5** adopted on this solution. All the TSN drivers and required firmware comply with this environment and stringent aerospace requirements providing one of the first PTP implementations for the space domain.

The Solution

Seven Solutions has developed a light implementation of the Time Sensitive Networking on a Zynq-7030 based platform. To support real time capability both in software and programmable logic, the

ARMv9-based processing system hosts the real-time operating system widely used in aerospace, RTEMS 5.0. Configuration, monitoring and access to the different TSN features are provided by means of C99 drivers, POSIX API and firmware, according to the ESA software engineering standards. Since more than 40% of the FPGA resources and almost all CPU capabilities are available for on-platform user critical applications, it is possible to supply **deterministic latency**, **ultra-reliability**, and **full synchronization**.

The solution yields to a configurable N-port TSN bridge (**Figure 1**) supporting ring-like redundancy for the sensible data and offering full OS synchronization. Direct TSN connectivity to user IP-cores is also provided as an entry point of generic best-effort traffic to the dependable network.

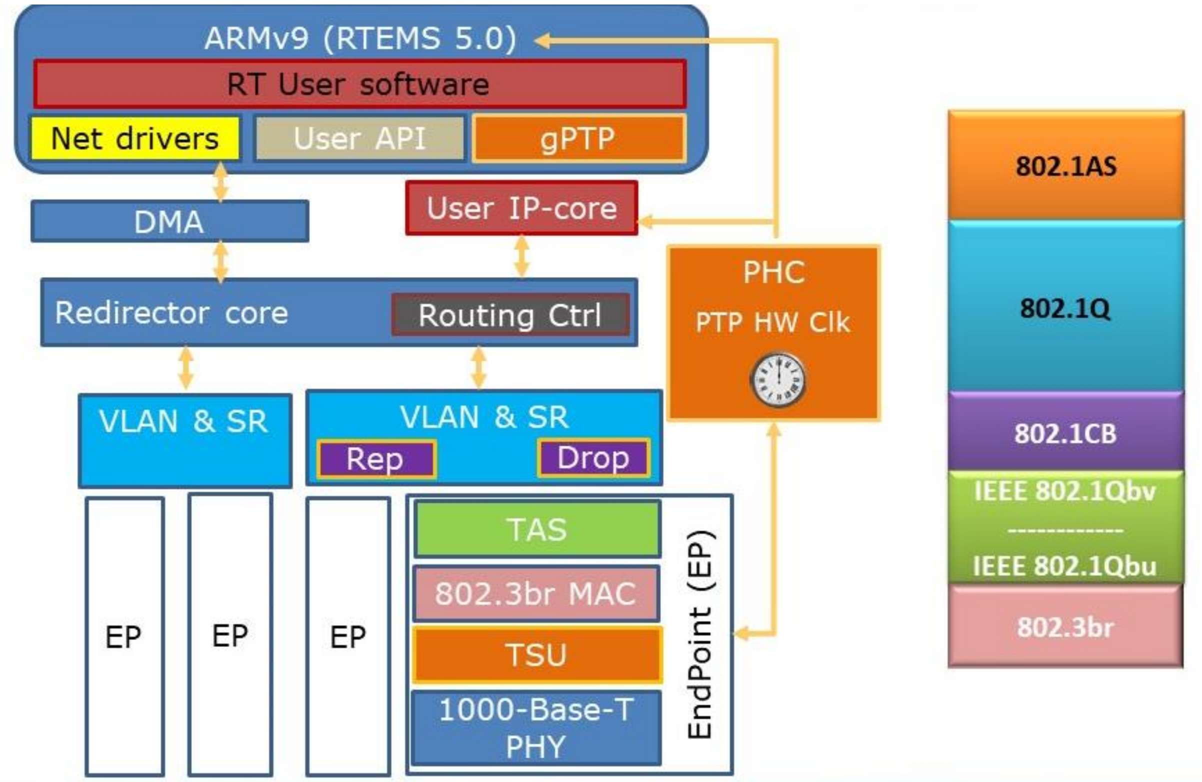

Figure 1. Architecture of the Giga Ethernet Light TSN Bridge

The solution implements the most relevant **TSN standards** over Gigabit Ethernet copper (**Table 1**), focusing on synchronization, determinism, reliability, and the concurrent transmission of the mixed criticality traffics existing on aerospace communications over on a single infrastructure.

In particular, the **TSN bridge** yields seamless redundancy and sub microsecond latency deviation for safety and time-critical telecommands, bandwidth guarantee for payload data and high bandwidth guarantee for ultra-HD video streaming (120 Mbps). The stringent quality of service, as well as end-to-end real time control and monitoring is supported by the generalized Precision Time Protocol (accuracy better than 50 ns).

Standard	Area	Rationale
IEEE 802.1AS	Timing & Synchronization	PTP Specific Profile for TSN
IEEE 802.1Qbv	Queuing & Forwarding	Scheduled Traffic; Time-Aware Traffic Shaper
IEEE 802.1Qbu IEEE 802.3br	Queuing & Forwarding	Frame Preemption and Interspersing Express Traffic
IEEE 802.1CB	Seamless Redundancy	Frame Replication & Elimination for Reliability (FRER)

Table 1. TSN Standards used on the Light TSN Solution

The solution supports reliable and **fault-tolerant network** topologies, requiring minimum time to recover from unplanned (physical connection) or planned (stage separation) network reconfigurations. On one hand, frame replication and elimination for reliability is provided for safety critical traffic. On other hand, the Best Master Clock Algorithm (BMCA) provides automated recovery from network time reference (Grand Master) failures and supports redundant synchronization information.

The light TSN bridge is hosted on a small Zynq-7030 SoC platform specifically designed for the micro launcher application, keeping almost all the CPU resources and half of the Programmable Logic to additional user software and IP-cores. To this end, the CPU hosts the *de facto* real-time OS for aerospace applications, RTEMS v5, along with the required firmware and API to control and access to the TSN bridge functionality. The CPU is fully synchronized with the network time to execute mixed-critically user software tasks. The user IP-modules have direct access to the logic storing the network time and the TSN. This way, the light TSN supports the different functionalities required on the avionic bus: The Engine Control Unit (ECU), the On-Board Computer (OBC) and the required nodes to drive sensors, actuators, and cameras. The four 10/100/1000-Base-T TSN interfaces enable routing capability and ring redundant topologies.

The light TSN solution has been applied on five different nodes conforming the Miura-1 micro launcher avionics bus and it is suitable for scaling up according to future system updates.

Results

The Light TSN bridge features have been validated over realistic benchmarks. **Figure 2** shows three **TSN bridges** of four 1000-Base-T interfaces deployed over a ring, and two Light TSN end stations (ZEN 12 and ZEN 20) sourcing and receiving traffic flows over the network. The ZEN12 generates telecommand traffic (PRIO2 tagged), object of deterministic latency QoS. The data path is shared with a best-effort HQ Video stream to show the lack of interference over the deterministic traffic. The PRIO2 traffic is replicated over the ring to show the seamless redundancy featured delivered by FRER. The PRIO1 traffic, generated between Board 48 and ZEN20 tests the concurrent transmission between two different interfaces.

The different functionalities (**determinism**, **accuracy**, **interoperability**) have been measured on a realistic set up.

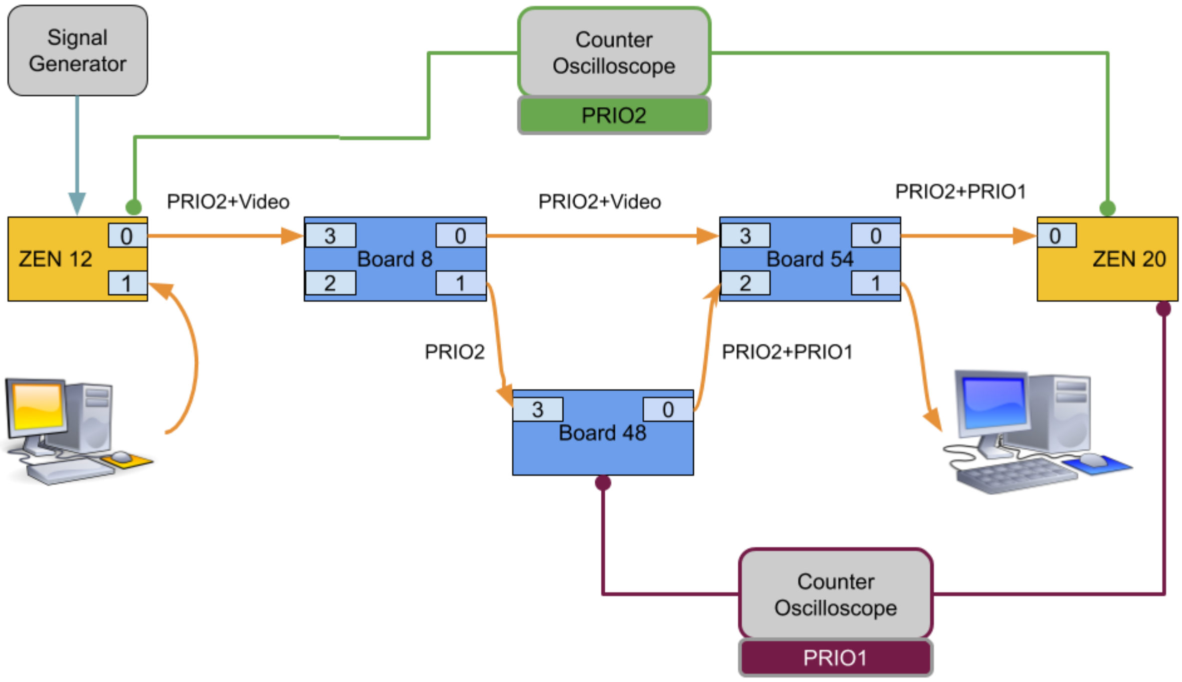

Figure 2. Light TSN Bridge Benchmark

The **determinism** has been measured over prioritized packets of 400 bytes sent at a rate of 10 packets per second. The network is also shared by rate constrained traffic (PRIO1) and full-HD video streaming.

The figure below (**Figure 3**) shows the **time synchronization accuracy** measured on the network. The time synchronization is always below 50 ns span. The **deterministic latency** (**Figure 4**) has been measured between the source and destination of the prioritized data stream, yielding an end-to-end latency of 24.85 ms. The determinism measured in terms of latency standard deviation is of 50 ns. The peak-to-peak measured value is 750 ns as shown on some spike and it is due to some shared paths used to minimize logic. It can be improved by increasing resources utilization if required.

Besides, the TSN implementation **interoperability** has been tested with third party gPTP and TSN stations, such as an Arista DS-7150 switch and the National Instruments industrial controller IC-3173 showing full compatibility with the devices according the TSN standards.

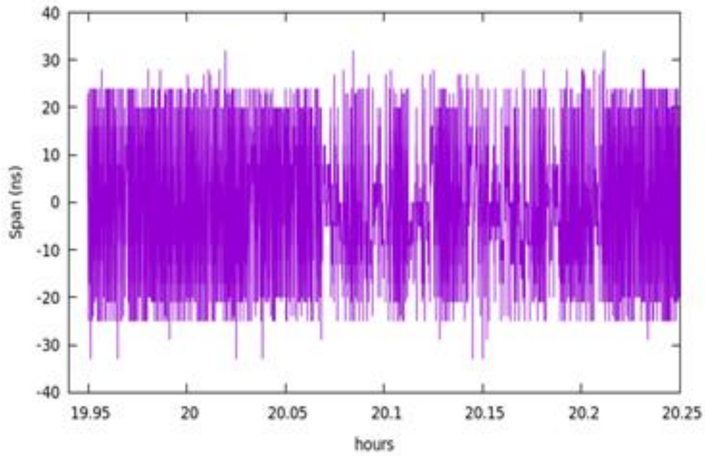

Figure 3. Time Synchronization Accuracy

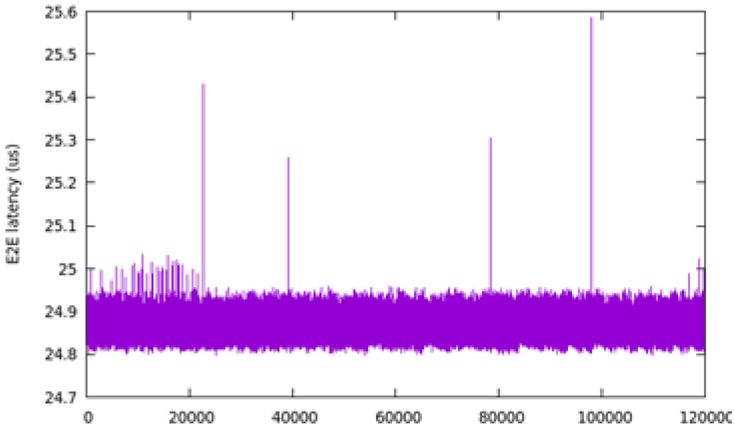

Figure 4. End to End Latency

Conclusions

The **Light Gigabit Ethernet Time Sensitive Networking** developed by Seven Solutions is an IEEE interoperable standard solution providing concurrent best effort and time-critical quality of service fully integrated with user time-critical IP-cores and software.

The solution provides VLAN tagging differentiation and prioritization of multiple and heterogeneous traffics, deterministic latency, bandwidth guarantee and high bandwidth capability on one network infrastructure, all available using a very low resources implementation.

The proposed solution supersedes the current state of the technique, based on fieldbuses, such SpaceWire or MIL-STD-1553B data bus, as bridged Gigabit Ethernet yields high bandwidth capability over an arbitrary topology. Moreover, it offers for the first time in the market the RTEM OS together with an accurate PTP timing implementation and TSN standards on a single device.

About Seven Solutions

Seven Solutions S.L. is a telecommunications company leader in accurate sub-nanosecond time transfer for reliable industrial and scientific applications. We have more than 15 years of expertise in embedded systems design and control (electronics, firmware and embedded software), with a remarkable track-record in cutting-edge projects at different sectors such as fintech, avionics, telecommunications, Smart-Grid, space, defence and scientific facilities as particle accelerators and distributed radio-telescopes.

We are leaders in ultra-accurate time transfer and synchronization in the Fintech and Science segments. We were born in the framework of Large Scientific Infrastructures (Industry for Science). In this segment we are continuously growing and consolidating creating break-through solutions for timing and also for advanced control systems and diagnosis in particle accelerators.

We are leaders in time and frequency distribution solutions based on White-Rabbit technology and derived standards (IEEE-1588-2019-HA). www.sevensols.com.

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