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



© GMV Property - 05/10/2023 - All rights reserved

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

Essential Data – Priority 2

No Real time needs Up to major consequences

Best Effort Data – Priority 3

No real time needs Minor or negligible consequences

HIGH PRIORITY

ESSENTIAL

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

				ECSS-E-ST-70-41C Packet			
Destination Address 6 bytes	Source Address 6 bytes	VLAN Tag 4 bytes	Lenght / Type 2 bytes	Data variable - bytes	FCS 4 bytes		
IEEE 802.1Q Frame							

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)

	v-netflix-problems-2011-07-06.pcap				- 0	>
ile	Edit View Go Capture Analyz	e Statistics Telepho	ny Wirele	ss Tools Help		
	🗉 🖉 😣 📙 🔚 🔀 😂 l 🔍 👄	🗢 🕾 🗿 🛓 📃	≣ @, ∈	(C, 🎹		
A	pply a display filter <ctrl-></ctrl->				Expression	
o.	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_2.1&v=1	. 5&r
	345 65.230738 174.129.249.228	192.168.0.21	TCP	66 80 → 40555 [ACK] Seq=1 Ack=188 Win=6864 Len=0 TSval=551811850 TSecr=4915193	47
	346 65.240742 174.129.249.228	192.168.0.21	HTTP	828 HTTP/1.1 302	Moved Temporarily	
	347 65.241592 192.168.0.21	174.129.249.228	TCP	66 40555 → 80 [ACK] Seq=188 Ack=763 Win=7424 Len=0 TSval=491519446 TSecr=55181	185
	348 65.242532 192.168.0.21	192.168.0.1	DNS	77 Standard que	ry 0x2188 A cdn-0.nflximg.com	
	349 65.276870 192.168.0.1	192.168.0.21	DNS	489 Standard que	ry response 0x2188 A cdn-0.nflximg.com CNAME images.netflix.com	.ed
	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=491519482	[Se
	351 65.297757 63.80.242.48	192.168.0.21	TCP	74 80 → 37063 [SYN, ACK] Seq=0 Ack=1 Win=5792 Len=0 MSS=1460 SACK_PERM=1 TSval	-32
	352 65.298396 192.168.0.21	63.80.242.48	TCP	66 37063 → 80 [ACK] Seq=1 Ack=1 Win=5888 Len=0 TSval=491519502 TSecr=329553413	3
	353 65.298687 192.168.0.21	63.80.242.48	HTTP	153 GET /us/nrd/	clients/flash/814540.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=4915195	93
	355 65.321733 63.80.242.48	192.168.0.21	TCP	1514 [TCP segment	of a reassembled PDU]	
E	thernet II, Src: Globalsc_00:3 nternet Protocol Version 4, Sr	912 Dits), 489 Dyt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds	es captur 3b:0a), D t: 192.16	ed (3912 bits) st: Vizio_14:8a:e1 (8.0.21	00:19:9d:14:8a:e1)	
E I U D	thernet II, Src: Globalsc_00:3 thernet Protocol Version 4, Sr ser Datagram Protocol, Src Por omain Name System (response)	912 Bits), 489 Byt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Vizio_14:8a:e1 (8.0.21 (34036)	90:19:9d:14:8a:el)	
E I U D	thernet II, Src: Globalsc_00:3 thernet Protocol Version 4, Src ser Datagram Protocol, Src Por- omain Name System (response) [Request In: 348]	912 bits), 489 byt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Vizio_14:8a:e1 (8.0.21 (34036)	00:19:9d:14:8a:el)	
	ame 345, 405 dytes of wire (s) thernet II, Src: Globalsc 00:31 nternet Protocol Version 4, Sr ser Datagram Protocol, Src Por- omain Name System (response) [Request In: 348] [Time: 0.034338000 seconds]	912 bits), 489 byt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: vizio_14:8a:e1 (8.0.21 (34036)	30:19:9d:14:Sa:el)	
F E I U D	Tans 39, 403 bytes of mile (S hternet IT, Src: Globalisc_00:3) thernet Protocol Version 4, Sr ser Datagram Protocol, Src Por main Name System (response) [Request In: 348] [Time: 0.043338000 seconds] Transaction ID: 0x2188	912 bits), 489 byt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Vizio_14:8a:e1 (8.0.21 (34036)	10:19:9d:14:8a:el)	
	ame Java, was bytes on mile (J) htternet IT, Src: Globalisc_@0:31 hternet Protocol Version 4, Sr ser Datagram Protocol, Src Por main Name System (response) [Request In: 346] [Time: 0.034338000 seconds] Transaction ID: 0x2188 Flags: 0x8180 Standard query Montheres	912 Dits), 489 Dyt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:e1 (8.0.21 (34036)	30:19:9d:14:8a:el)	
	<pre>same_asy_mod_bjts_on_arte_c_ htermet II, scr: Globalsc_00:31 htermet Protocol Version 4, 5r. Ser Datagram Protocol, 5r. Por omain Name System (response) [Request In: 345] [Time: 0.034338000 seconds] Transaction ID: 0x2188 Flags: 0x81880 Standard query Questions: 1 frames Pice 6</pre>	912 Dits), 489 Dyt b:0a (f0:ad:4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:e1 (8.0.21 (34036)	00:19:9d:14:8a:el)	
	<pre>ame _prot Got Nate Co thermet II, Src: Globales @0:31 tternet Protocol Version 4, Src Por Datagram Protocol, Src Por main Name System (response) [Request In: 348] [Time: 0.034338000 seconds] Transaction 10: 0x2188 Flags: 0x8180 Standard query Questions: 4 Answer RRs: 4 Authority Der. 0</pre>	912 D15), 499 dyt bl@ (f0:40:40:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:e1 (8.0.21 (34036)	00:19:9d:14:8a:el)	
	amount of the second se	912 DITS), 499 Byt 1080 (f0:44:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: virio_14:8a:el (8.0.21 (34036)	10:19:9d:14:8a:el)	
	and say, may bytes of hint (), herner II, Sriv Globals (08) at hernet Protocol, Src Pour main Name System (response) [Request In: 345] [Time: 0.034330800 seconds] Transaction 10: 0x2188 Flags: 0x8180 Standard query Questions: 1 Authority R8: 9 Additional R8: 9 (Authority R8: 9	912 DITS), 499 Byt 1080 (föradis4e:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:el (8.0.21 (34036)	00:19:9d:14:8a:el)	
	and set of the Official set of the set of th	912 DITS), 499 Byt 1980 (f0:44:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:el (8.0.21 (34036)	00:19:9d:14:8a:el)	
	ame say, mus opted within (), herner II, Sriv Globalz (093) st hernet Protocol, Src Four main Name System (response) [Request In: 343] [Time: 0.03338000 seconds] Transaction 10: 002188 Flags: 008180 Standard query Questions: 1 Authority R&: 9 Additional R&: 9 Queries: 1) cdn-0.nflxing.com: type A, Ansuers	912 DITS), 499 Byt 1080 (f0:44:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro , class IN	es captur 3b:0a), D t: 192.16 t: 34036	ed (3912 bits) st: Virio_14:8a:el (8.0.21 (34036)	00:19:9d:14:8a:el)	
	the set is by a construction of the set of t	912 DITS), 499 Byt cola (féadiae:00: c: 192.168.0.1, Ds t: 53 (53), Dst Po response, No erro , class IN	es captur 3b:0a), D t: 192.16 rt: 34036	ed (3912 bits) st: Virio_14:8a:el (8.0.21 (34036)	00:19:9d:14:8a:el)	
	ame say, now opted within (), herner II, Sriv Globalz (2013) htternet Protocol, Src Pour maain Name System (response) [Request In: 343] [Time: 0.03338000 seconds] Transaction 10: 0x0180 Flags: 0x0180 Standard query Questions: 1 Authority R8: 9 Additional R8: 9 Cuerles > def-o.fflking.com: type A, Answers Authoritative nameservers	912 D125), 480 DJ2 1080 (f8:ad:4e:08: c: 192.168.0.1, D5 t: 53 (53), Dst Po response, No erro , class IN	es captur 3b:00), D t: 192.16 nt: 34036	ed (3912 bits) st: Virio_14:8a:el (8.0.21 (34036)	30:19:9d:14:8a:e1)	
	the set is 50 classified and the set of the	<pre>bil Dit2 ; Ass Dit2 bil (Dit3) Ass Dit2 c: 132.168.0.1, Ds t: 53 (53), Dst Po response, No erro , class IN 37 [2] 00 81.80 000</pre>	es captur 3b:0a), D t: 192.16 rt: 34036	ed (312) bit) st Vilo(14:8a:el (8.0.21 (34036)	00:19:9d:14:8a:el)	
E I U D D D D D D D D D D D D D D D D D D	ame say, now opted within (); herner II, Srci Gobalaz (003) hernet Protocol, Src Pour mann Name System (response) [Request In: 443] [Time: 0.03338000 seconds] Transaction 10: Woll88 Flags: 0x8108 Standard query Questions: 1 Authority RRs: 9 Additional RRs: 9 Queries > def-o.nflxing.com: type A, Answers Authoritative nameservers 0 00 15 00 35 44 60 17 63 04 68 00 00 00 56 55 46 46 00 75 80 55 46 40 00 75 46 80 80 90 80 80 55 46 40 00 75 46 80 80 90 80 80 55 46 40 00 75 46 80 80 80 80 80 80 80 80 80 80 80 80 80	Did Dit2), 440 0jt did (fitad:44:00: c: 132.168.0.1, 05 response, No erro class IN 37 03.05 81 82 60 80 62 41 30 07 64 65	es captur 3b:0a), D t: 192.16 rt: 34036 rt: 34036	ed (312 bit) st Vilo(14:8+el (8.0.21 (34036) 5	30:19:9d:14:8a:e1)	
E I U D > > > > > > > > > > > > > > > > > >	the set in 20/2 cloud line of 2 there set in 20/2 cloud line of 2 here the Protocol Jession 4, 5 set Datagrams Protocol, 5 sc Por- main Name System (response) [Anyunes In: 44] Transaction 1D: 0x2188 Flags: 0x2180 Standard query Questions: 1 Ansuer BRs: 4 Authority RRs: 9 Additional RRs: 9 Cueries) cdn-0. riking.com: type A, Asuboritative nameservers 1 00 15 00 35 84 f4 01 c7 83 00 84 00 09 00 95 85 84	<pre>bil 0121 / add 0j; bil 0121 / add 46:00; c: 192.168.0.1, 05 response, No error class IN >f 01 00 61 80 60 66 20 40 07 65 65 66 40 46 16 7 65</pre>	es captur 3b:0a), D t: 192.16 nt: 34036 nt: 34036	ed (311) bits) st Vilo_14:8*el (0.0.21 (34095) 5	00:19:9d:14:8a:el)	
E I U D O	ame say, now offeed within (); herner IT, Srci Gobalat, Ce 3); hternet Protocol, Src Four main Name System (response) [Request In: 443] [Time: 0.43433600 seconds] Transaction 10: 80:188 Flags: 0.84380 Standard query Questions: 1 Authority RBs: 9 Additional RBs: 9 Additional RBs: 9 Additional RBs: 9 Additional RBs: 9 Additional RBs: 9 0 ed: 0.67 Additional RBs: 9 0 ed: 0.67 Add	<pre>bil Dit2 ; Ass Dit2 bil Dit2; Ass Dit2 bil (Bil Ad-e:00: class IN association of the second class IN association of the second class IN association of the second class IN association of</pre>	es captur bica), D t: 192.16 t: 34036 t: 34056 t: 3405656 t: 340565656 t: 34056565656565656565656565656565656565656	ed (312)bit) st: Vilo_14:8+el (8.0.21 (34036) 5	90:19:9d:14:8a:e1)	
E I U D O	thermer II, 50:03 Shahala, 64:3 thermer IP roticed. Version 4, 5:5 thermer IP roticed. Version 4, 5:5 sam Datagram Protocol, 5:5: 5:0 sam Name System (response) [Arguments In: 443] Transaction 10: 0x288 Flags: 0x288 Standard query Questions: 1 Assumer R8: 4 Authority R8: 9 Additional R8: 9 Queries > dm 0: 15 0x 35 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 7:05 5: 4: 4:0 7 6:00 4:0 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 5:00 7:00 0:5 7:00 7:00	<pre>bil Dit2 ; AsU 0; AsU 0;</pre>	01 6c 67 67 60 esu	ed (311) bits) sti Viio_14:8*ei (0.0.21 (34095) 5;10 (34095) 5;10 (34095) 5;10;10;10;10;10;10;10;10;10;10;10	00:19:9d:14:8a:el)	

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



Commnication 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



OBC_TSN_ADJUSTMENT

Portability

Software driver available for:





Easy porting to other RTOS / Hypervisor



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



FPGA

Go% 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.



Carlos Domínguez cdsanchez@gmv.com



© GMV Property - 05/10/2023 - All rights reserved