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Research Project Colloquium

Investigating the performance and interoperability of hardware and software interfaces for TSN-capable Linux Devices

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Agenda

- **Motivation**

- **Brief look at TSN and the IEEE/IEC 60802**
 - **Focus on the End Station Requirements (ESR)**

- **Creating success scenarios and test setups**

- **Exemplary implementation with TSN-components**

- **Results of the investigation**

- **Conclusion and outlook**

Motivation

- **Creating an IEEE/IEC 60802 conform end station device**
 - **Commonly found hardware**
 - **Open-source software based on Linux**

- **Investigate the requirements**
 - **Focus on the End Station Requirements (ESR)**
 - **Are they complete and reasonable?**

Brief look at TSN

- **IEEE Working group for Time Sensitive Networking (TSN)**
 - Part of the IEEE 802.1
 - Intended to make Ethernet communication real-time capable by standard

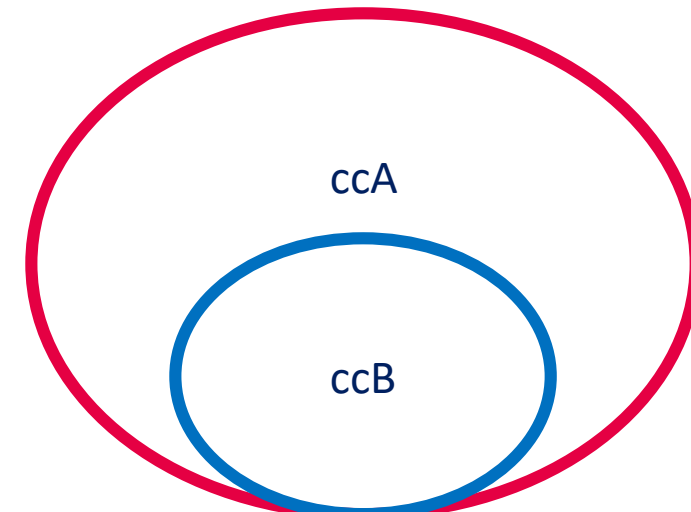
- **Important IEEE 802.1 Standards:**
 - IEEE 802.1AS synchronisation for Time-Sensitive Applications (gPTP*)
 - IEEE 802.1Qbv Enhancement for scheduled traffic (TAS+)
 - IEEE 802.1Qbu Frame Preemption

- **IEEE/IEC 60802 TSN Profile for Industrial Automation available**

[1]

Brief look at the IEEE/IEC 60802 ESR

- **Draft version d1-3 of the profile**
- **Profile provides requirements and options for the industrial network**
 - **Bridges**
 - **End Station Devices**
- **Differentiation between two Conformance Classes:**
 - **ccA: Uses a lot of TSN features e.g., resource rich devices**
 - **ccB: Resource constrained, e.g., an embedded device**



[2]

Difference in the conformity classes

Common ESR (ccB)				
PHYMAC1	TopDis1	Sync1	Sync7	C-VID1
	TopDis2	Sync2	Sync8	C-VID2
Sync3a/b		Sync9		
PHYMAC2	TopDis3	Sync4a/b	Sync10	C-VID3
		Sync5	Sync11	
	TopDis4	Sync6	Sync12	C-VID4

ccB

Extended ESR (ccA)		
TAS1	FP1	IET1
TAS2	FP2	
TAS3	FP3	IET2
TAS4	FP4	IET3
TAS5	FP5	

ccA

Creating success criteria and test setups

- **Derived from the requirement**
- **Follows the previous introduced name convention**
- **Detailed description on how they are fulfilled in the thesis**
- **Differentiation between theoretical and practical success criteria**

Creating success criteria and test setups

- **Success criteria with literature research/ code extraction**
 - Theoretical approach
- **Usage of different literature**
 - Datasheet
 - So called *man pages* (manual pages)
 - Source code (if available)

Creating success criteria and test setups

- **Success criteria with test setups**
 - **Practical approach**

- **Measurement and observation for certain requirements**
 - **Transmission Interval Period**
 - **Time slots of the TAS**
 - **Synchronisation of the device**

Exemplary implementation with TSN-components

- **Hardware:**
 - Intel i210 network interface card (NIC)
 - Intel i3 processor
- **Linux Distribution and Kernel Version**
 - Debian 11
 - 5.15lts rt17 PREEMPT_RT Kernel
- **Open-source Software:**
 - Linux PTP project (ptp4l, ts2phc, phc2sys)
 - taprio qdisc*
 - etf qdisc*
 - ethtool

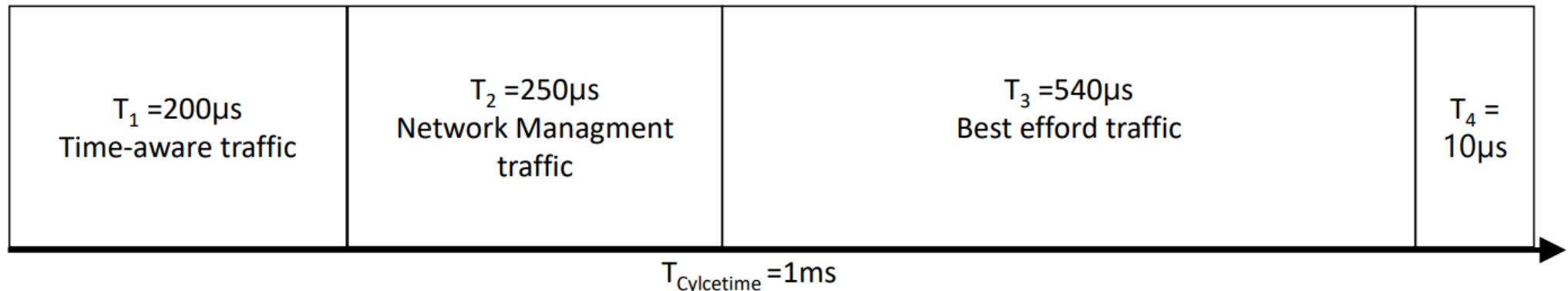


Intel i210 NIC

*qdisc: queueing disciplin; used for network traffic scheduling

Exemplary implementation with TSN-components

- **Configuration files for the software**
 - Configure the gPTP frame(s) send intervals etc.
- **Shell scripts**
 - Synchronisation according to the profile
 - Setup of the custom VLAN IDs
 - Time aware shaper (TAS) network scheduling



Results of the theoretical analysis

- **Majority of requirements are fulfilled**

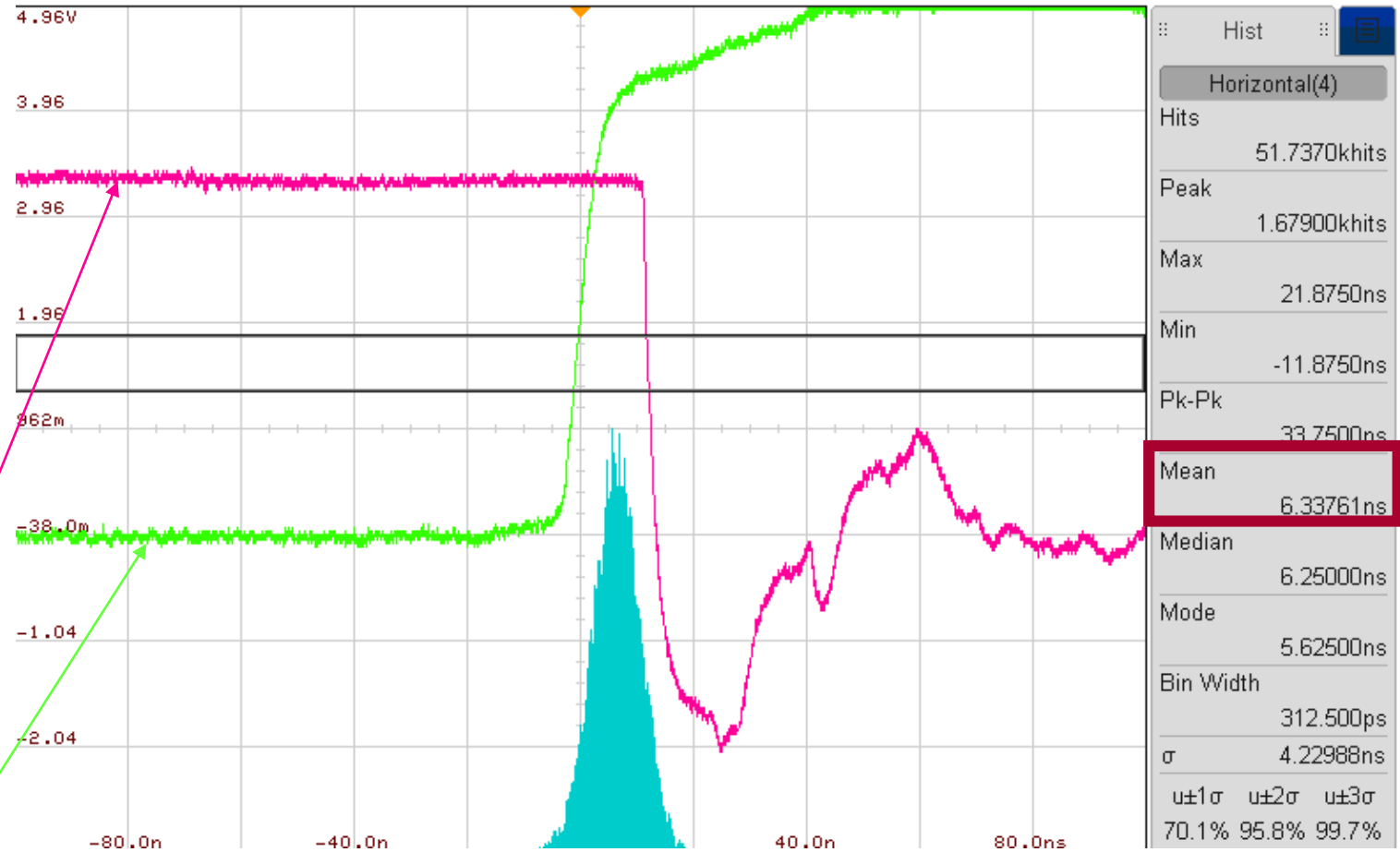
- **Certain requirements are not found**
 - **Synchronisation requirements (e.g. Fractional Frequency Offset)**
 - **TAS Requirements such as the On-the wire timing point**

- **Topology discovery Requirements are not tested/checked because of the missing TLVs* in the Profile**
 - **May have to be revisited and checked when TLVs are available**
 - **LLDP and SNMP daemons are available**

*TLV: Type, Length, Value. A way to store information of a device.

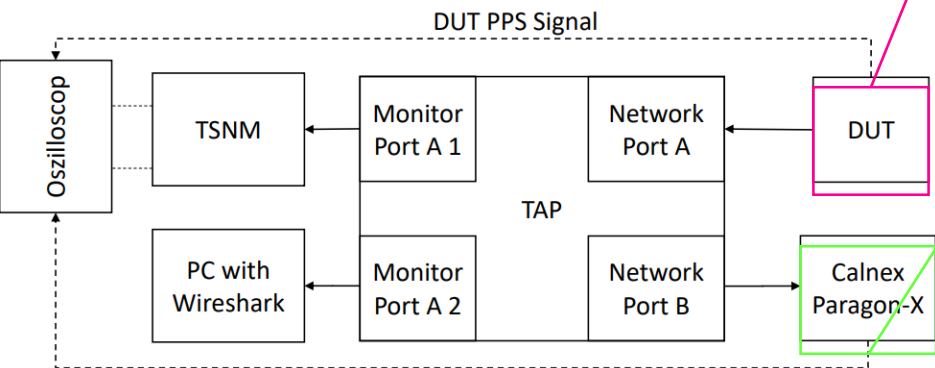
Results of the test setups: Synchronisation

- Synchronisation tests
- Used Software:
 - Linux PTP project
 - ptp4l
 - phc2sys
 - ts2phc



Histogram of the DUT's PPS* Signal

*PPS: Pulse per second



Paragon-X PPS Signal
Synchronisation test setup

Results of the test setups: TAS

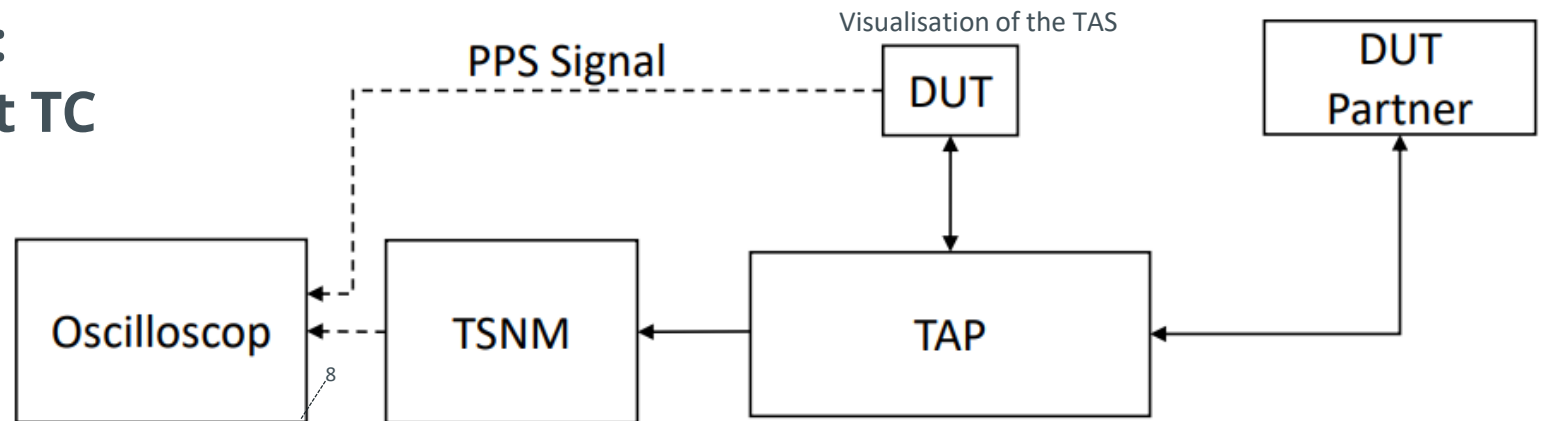
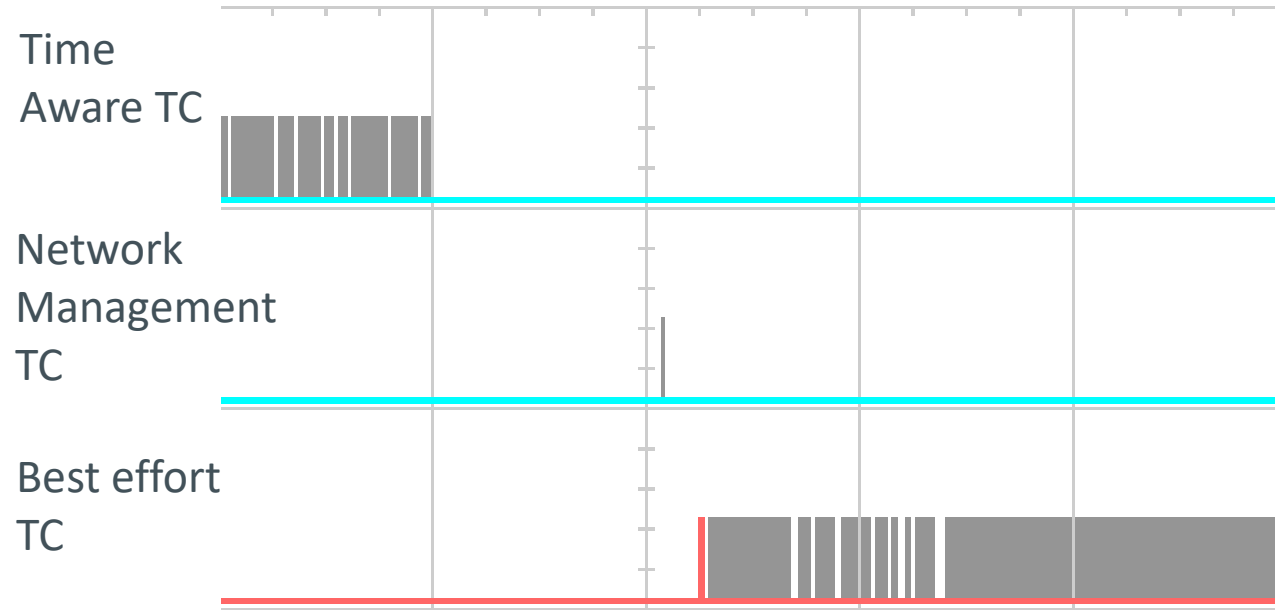
■ TAS test setup

■ Used Software:

- Taprio qdisc
- ETF qdisc
- Linux PTP project

■ Three Traffic classes (TC):

- Network management TC
- Time aware TC
- Best effort TC



Visualisation of the TAS

Common ESR (ccB) results

Requirement ID	Fulfilled?	Note
PHYMAC1	Yes	
PHYMAC2	Yes	
TopDis1	n.a.	TLVs necessary for the requirements are not published yet. There are however, SNMP and LLDP daemons available
TopDis2		
TopDis3		
TopDis4		
Sync1	Yes	Support of IEEE 802.1AS-2011
Sync2	Yes	
Sync3a/b	n.a.	Source code implies it is not known
Sync4a/b	n.a.	
Sync5	n.a.	Only one time domain possible. Also not found

Requirement ID	Fulfilled?	Note
Sync6	n.a.	Only one time domain possible. Also not found
Sync7	Yes	
Sync8	Yes	31,25 ms seems too high of an interval
Sync9	Yes	
Sync10	No	One port device-> no residence time possible to be measured
Sync11	Yes	
Sync12	Yes	
C-VID1	Yes	
C-VID2	Yes	
C-VID3	Yes	
C-VID4	Yes	

Extended ESR (ccA) results

Requirement ID	Fulfilled?	Note
TAS1	No	Tick Granularity of 32 ns
TAS2	Yes	
TAS3	n.a.	Not possible to be measured or find in datasheet
TAS4	Yes	
TAS5	n.a.	Not possible to be tested due to the uncertainty of the devices time slot

Requirement ID	Fulfilled?	Note
FP1	No	Since the Device does not provide a separated MAC Layer (IEEE 802.3br), the overlaying IEEE 802.1Qbu is not supported.
FP2		
FP3		
FP4		
FP5		
IET1	No	The device does not provide a MAC Layer which is capable of the IEEE 802.3br separation of the MAC
IET2		
IET3		

Conclusion and outlook

- **Research Project provided insight in TSN and TSN-adjacent standards**
- **Certain requirements are added to the profile**
- **Test setups are explained and executed with a prototype device**
- **Open-source software needs time to mature for the latest IEEE 802.1AS standard to become truly IEEE/IEC60802 ccB compliant**
- **Other device combinations are possible.**
 - **Xilinx/AMD TSN IP-Core**
 - **Intel i225 NIC**

Sources

- [1](2017, May) Time-Sensitive Networking Task Group. IEEE 802.1. [Online]. Available: <http://www.IEEE802.org/1/pages/tsn.html>
- [2] L. Winkel and J. Woods. (2021, February) Conformance Class IEC/IEEE 60802. IEC/IEEE.



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Thank you for listening
Are there any questions?