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TSN Experiments Using Commodity Off-The-Shelf Hardware and Open-Source Software: Lessons Learned

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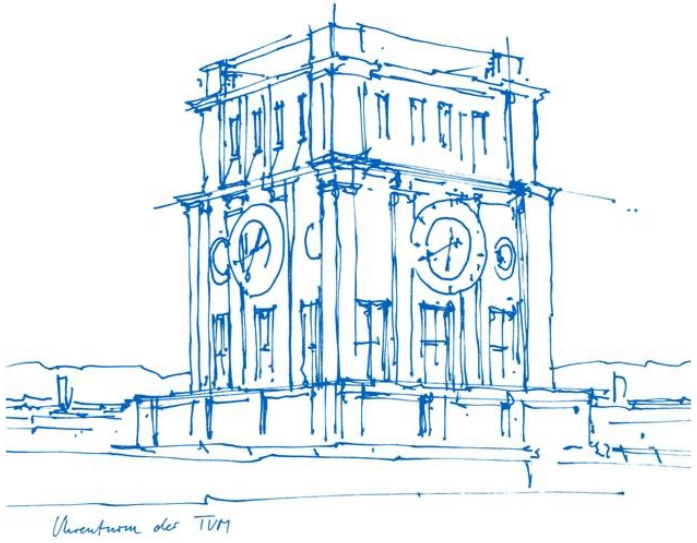
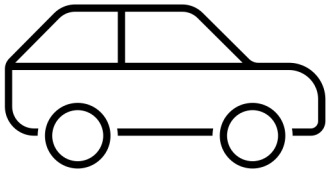
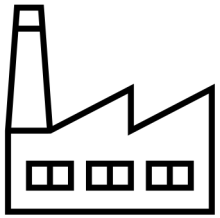


Introduction
Motivation

Intra-vehicular networks



Smart Manufacturing



Aerospace

High bandwidth, mixed traffic, lower cost → shift towards Ethernet

Time Sensitive Networking (TSN)

- Deterministic latency & bounded jitter
- Low packet loss
- Coexistence of high and low priority traffic

Introduction
Motivation

Structured approach to assessing the capabilities of networks with TSN

- In a **reproducible** manner
- Compare different **architectures** and their implications

EnGINE: Developing a Flexible Research Infrastructure for Reliable and Scalable Intra-Vehicular TSN Networks

Filip Rezabek[1], Marci … Bosk[1], Thomas Paul[1], Kilian Holzinger[1], Sebastian Gallenmüller[1], Angela Gonzalez[2], Abd… …esc Fons[2], Zhang Haigang[2], Georg Carle[1], and Jörg Ott[1]

[1]Departm… …ity of Munich, Germany

[1]{rezab… …any

[2]{angela.gonzale… …de

Abstract—Driver assistance, tems have two common imp network bandwidth and the n nodes. As a result, intra-vehi layout. They are built arou rest of the vehicle via Ethe a challenge, as it lacks su design. The solution is fo Networking (TSN) standa

Demo: Environment for Generic In-vehicular Network Experiments - EnGINE

Marcin Bosk*,1, Filip Rezabek*,1, Kilian Holzinger[1], Angela Gonzalez[2], Abdoul Kane[2], Francesc Fons[2], Zhang Haigang[2], Georg Carle[1], and Jörg Ott[1]

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Abstract—Self driving cars bring new challenges to intra-vehicular networks (IVNs), such as increased bandwidth and the need for more powerful computation. To solve these challenges, in recent years, the IVNs started shifting towards the use of Ethernet, which with IEEE Time-Sensitive Networking standards can support deterministic behavior required for these networks. To evaluate the application of Ethernet in IVNs, we introduce novel approach called *EnGINE* - an *En*vironment for *G*eneric *In*-vehicular *N*etworking *E*xperiments. The environment is based on commercial off-the-shelf components and open-source software. In this work we present *EnGINE* and showcase an exemplary use-case it can support.

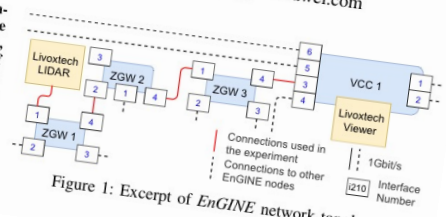

Figure 1: Excerpt of *EnGINE* network topology

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EnGINE: Flexible Research Infrastructure for Reliable and Scalable Time Sensitive Networks

…Bosk[1] · Thomas Paul[1] · Angela Gonzalez[2] · Al… …Carle[1] · Jörg Ott[1]

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METHODS

Methodology and Infrastructure for TSN-Based Reproducible Network Experiments

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PTP Security Measures and their Impact on Synchronization Accuracy

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Abstract—The Precision Time Protocol (PTP) synchronizes clocks in a network with high precision. The protocol finds use in many areas, such as smart manufacturing, intra-vehicular networks, and critical infrastructure. It becomes clear that striving for security is an important goal. If an attacker succeeds in disturbing the network synchronization, the impact can result in a cascading set of failures. Unfortunately, neither the previous two IEEE standards for PTP, nor the popular implementation `linuxptp`, feature or implement sufficient security options.
This work focuses on implementing the security extensions for PTP based on the latest PTP standard IEEE 1588-2019 to harm the synchronization stability. Successful attacks have the potential to cause catastrophic damages due to PTP being employed in critical infrastructure [4]. On top of that, the topic of security has not been a high priority in the past. The first two PTP standard versions only contain security advice of limited practicality, if any [7]–[9].

To implement security extensions, we use and analyze the popular PTP implementation `linuxptp`, which reveals only basic measures to secure the synchronization stability. As

What do we use for Experimentation?
COTS Hardware and Open-Source Software

Hardware

12 PCs

3 Servers

Intel I210

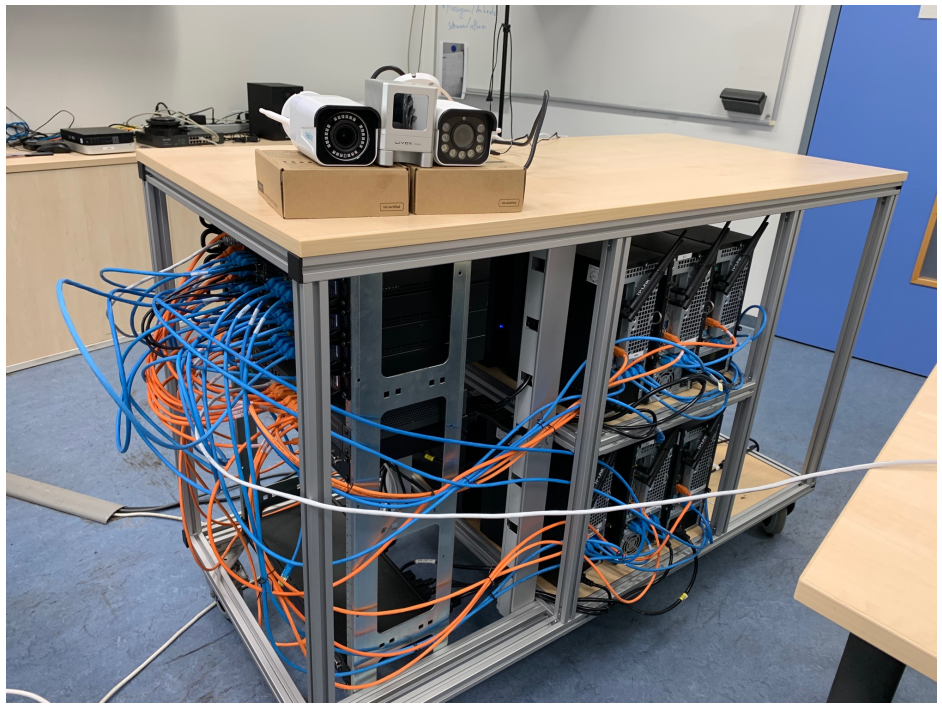
Intel I225

Intel I350

Intel X552

LIDAR
Livoxtech
Mid 40

Cameras
Reolink
Full HD



EnGINE Framework

Software

Linux OS

Linux TC
Qdiscs

Traffic
generation

Monitoring
&
Processing
tools

Focus on Time-Sensitive Networking

Supported TSN standards by *tc*

IEEE 802.1Qbv – Time Aware Priority (TAPRIO) shaper
IEEE 802.1AS – general Precision Time Protocol (gPTP)
} **Observation 1**

Launch time feature – Earliest TxTime First (ETF)
} **Observation 2**

IEEE 802.1Qav – Credit-Based Shaper (CBS) algorithm
} **Observation 3**

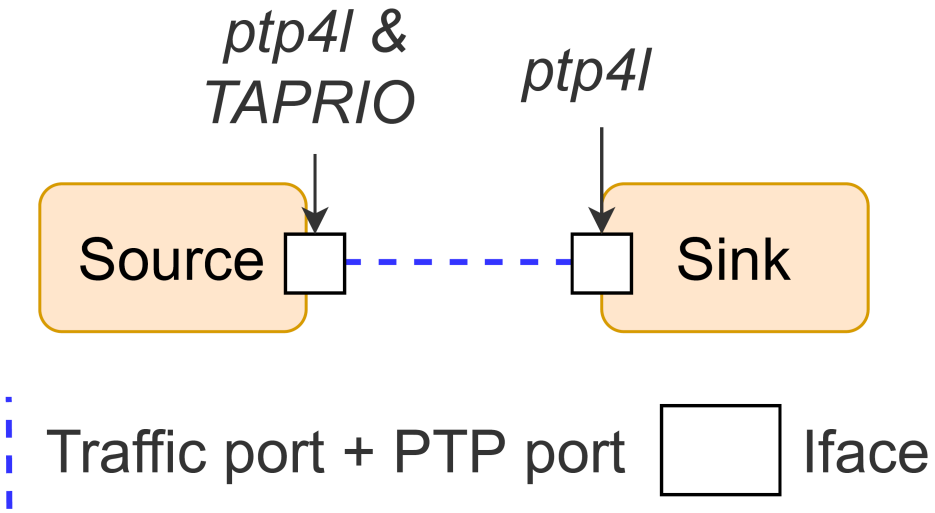
Observation 1
Coexistence challenge of TAPRIO and PTP

TAPRIO

Works as time division multiplexing

Uses gate opening and closing for traffic policing

Assigns traffic classes to respective transmission windows



PTP

Allows network clock synchronization with high accuracy

- Can achieve nanosecond accuracy if HW supports hardware timestamping

Organizes the clocks in master-slave hierarchy in a tree form

Grand master clock serves as a ground truth

Observation 1
Coexistence challenge of TAPRIO and PTP

Without proper synchronization, challenges for synchronous TSN standards

→ PTP does not synchronize when TAPRIO used on same interfaces

Possible to map PTP to higher priority classes

- Limited number of HW queues
- Introduces additional overhead for other high priority traffic

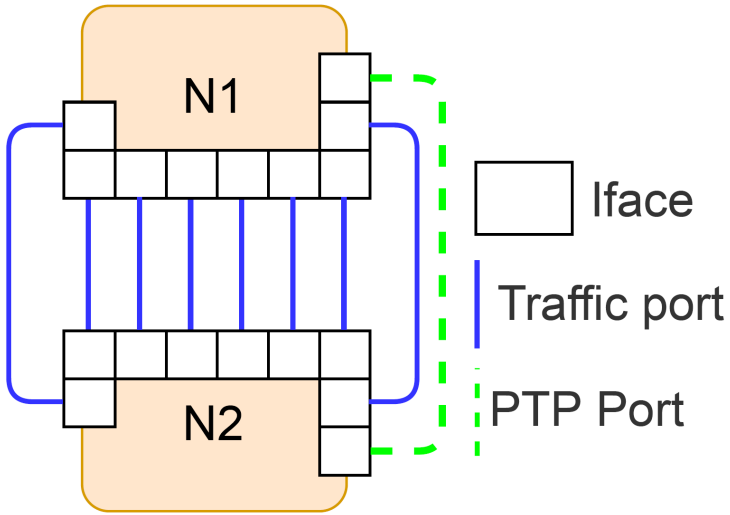
Defined several requirements

- PTP Precision
- Number of connections
- Processing overhead

Observation 1
Coexistence challenge of TAPRIO and PTP

Comparison of different solutions

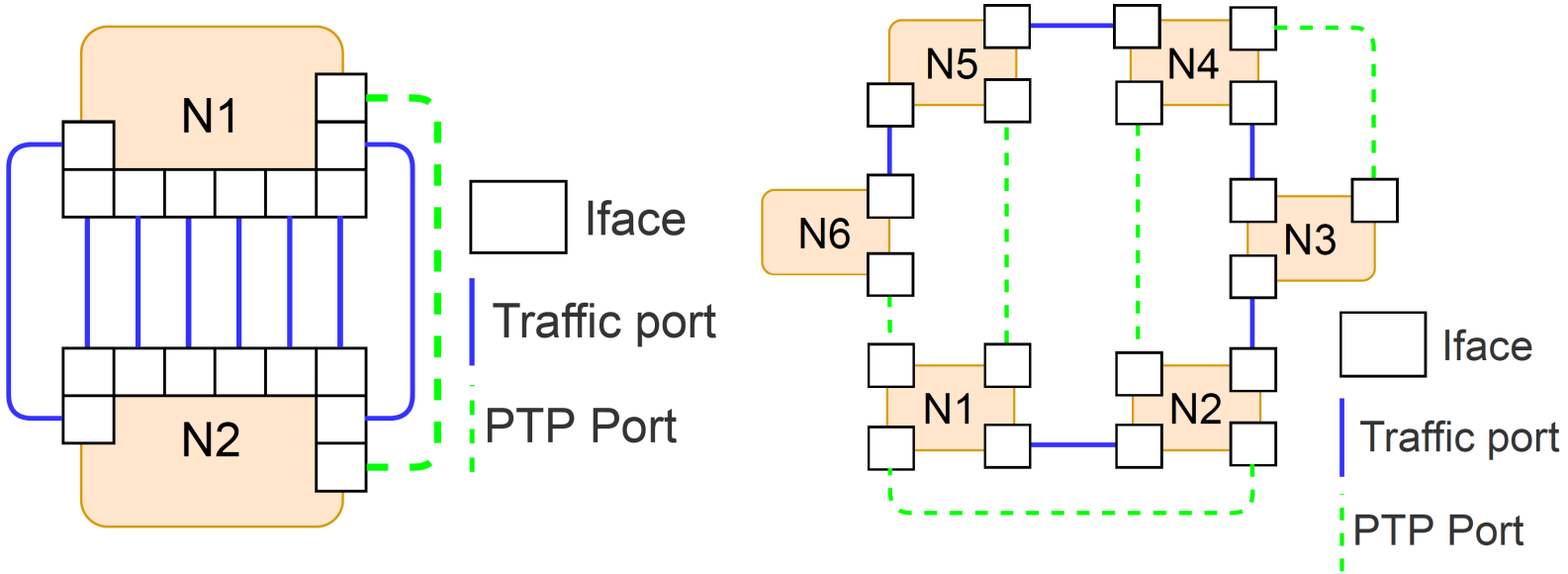
Solution	PTP Precision	Number of Connections	Processing overhead
I	✓	✓	○



Observation 1
Coexistence challenge of TAPRIO and PTP

Comparison of different solutions

Solution	PTP Precision	Number of Connections	Processing overhead
I	✓	✓	○
II	○	○	✓



Observation 1
Coexistence challenge of TAPRIO and PTP

Comparison of different solutions

Solution	PTP Precision	Number of Connections	Processing overhead
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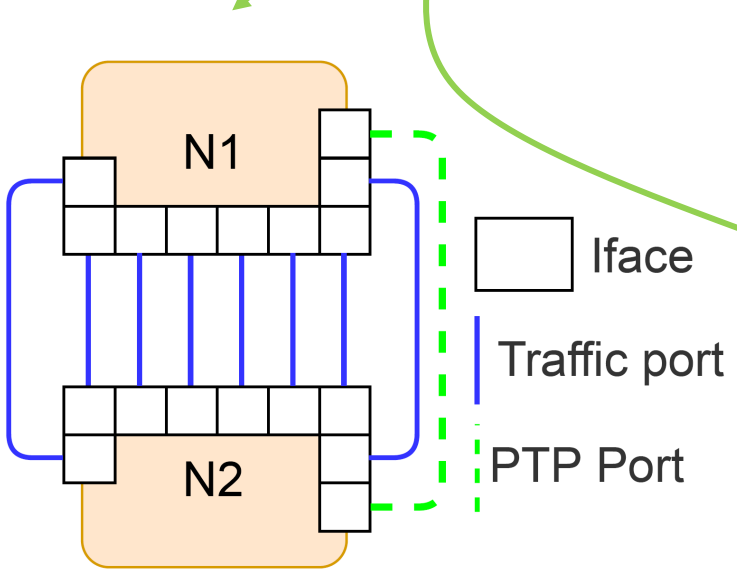
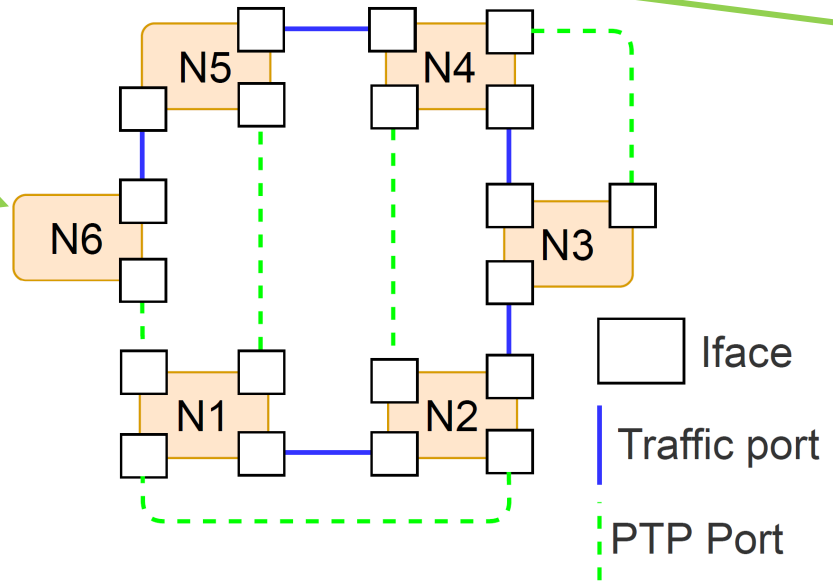
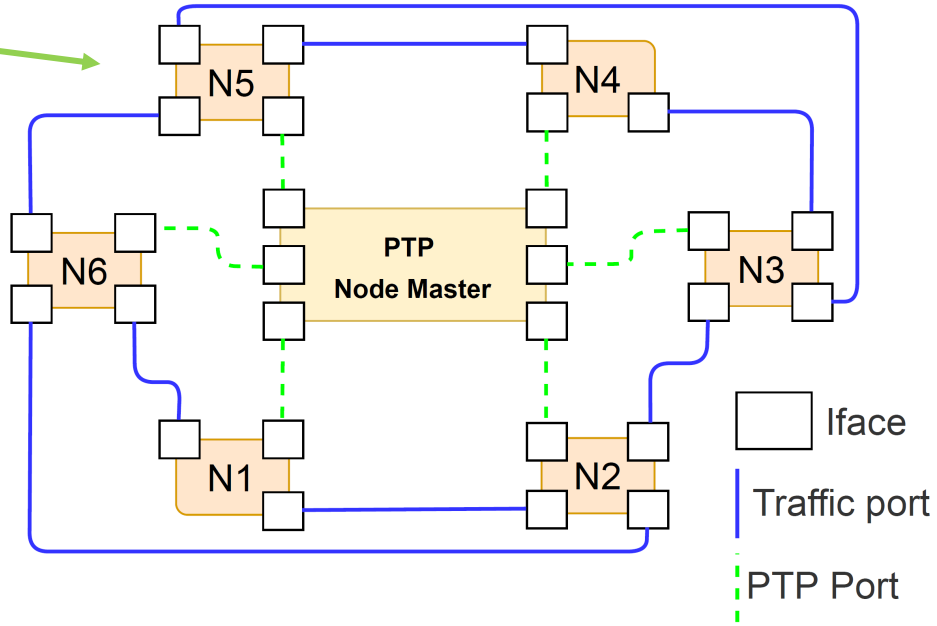
II	○	○	✓
III	✓	○	✓







Observation 2
ETF in offload mode

Earliest TxTime First (ETF) dequeues packets at a TxTime

TxTime is specified in the socket buffer (*skb*) of a given packet

Used NICs (Intel I210, I225), support ETF offload feature

→ Configuration parameter **delta** accounts for a delay in networking stack
→ **delta** is highly system dependent!

Observation 2
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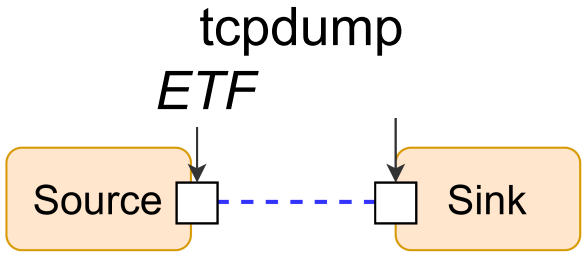

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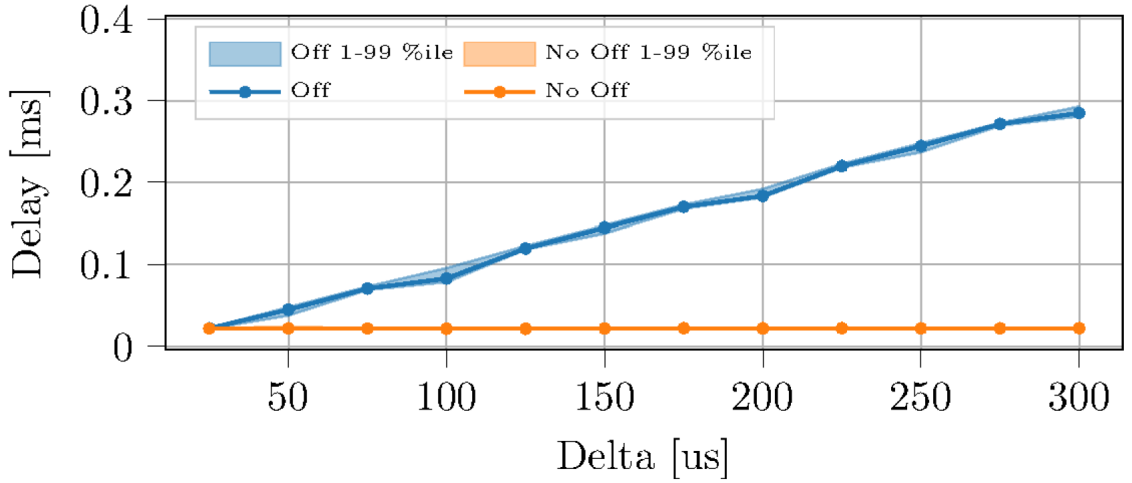
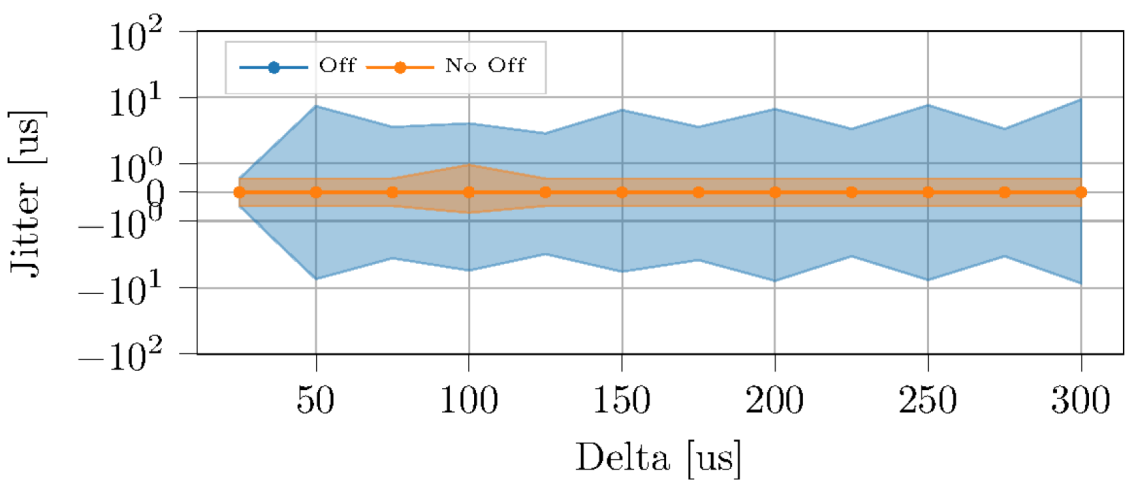




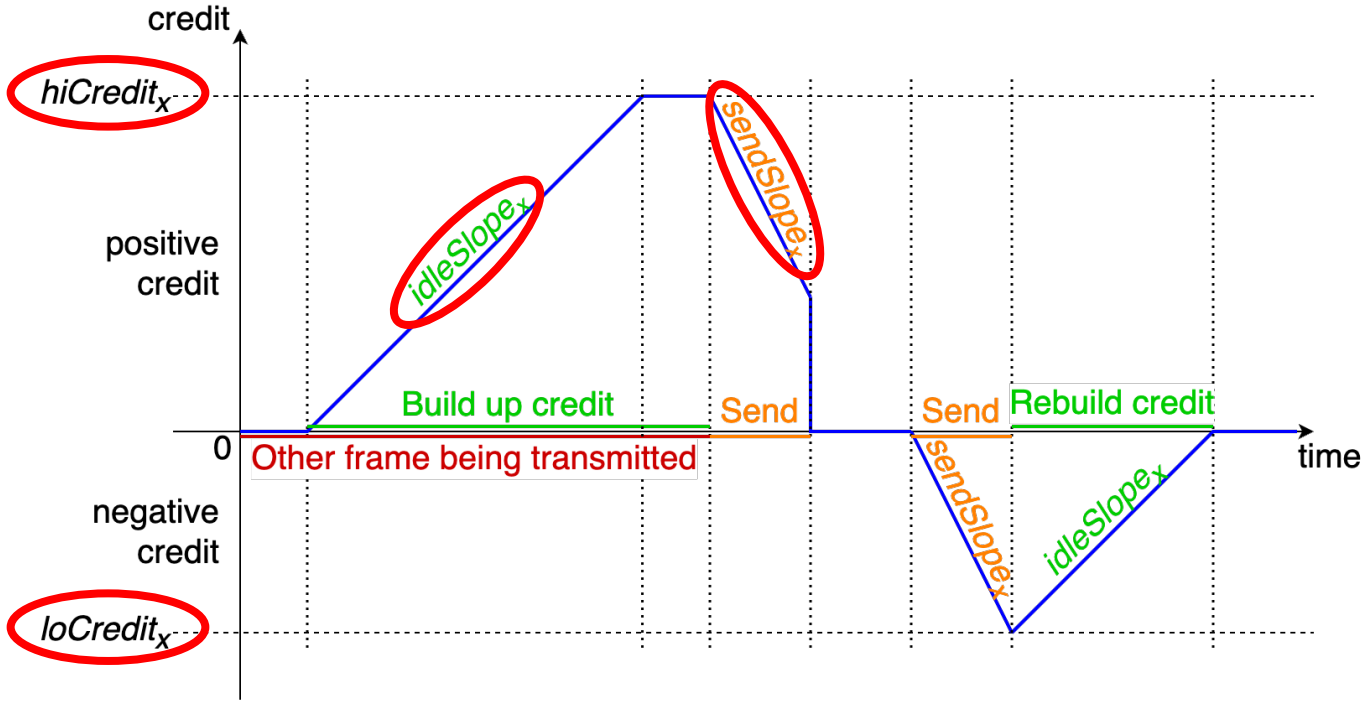
Observation 3
CBS dependency on the NICs

Credit-Based Shaper

Bandwidth allocation for traffic classes

Enforcement using a credit mechanism

Provides soft delay and jitter guarantees for time-sensitive systems

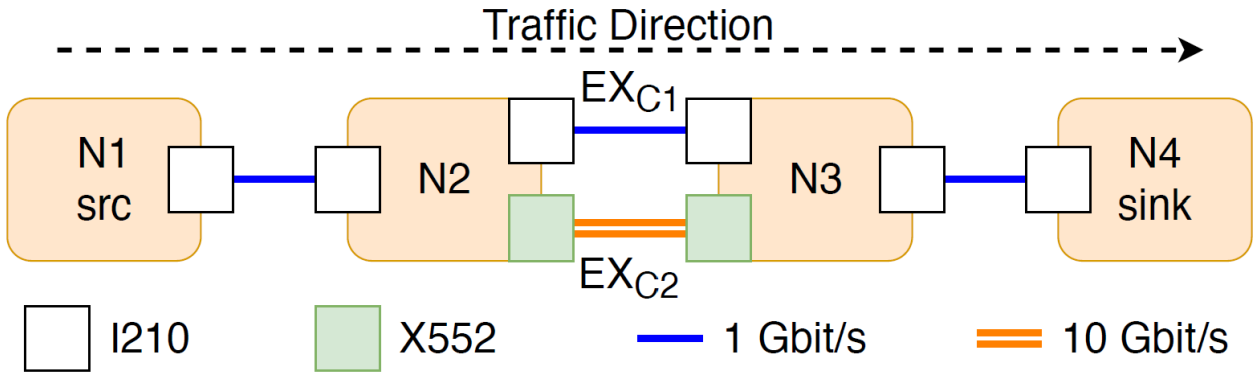


Challenges for TSN applications

→ Settings depend on the NIC parameters

→ Settings need to match expected traffic

How do we find those settings?



Observation 3
CBS dependency on the NICs

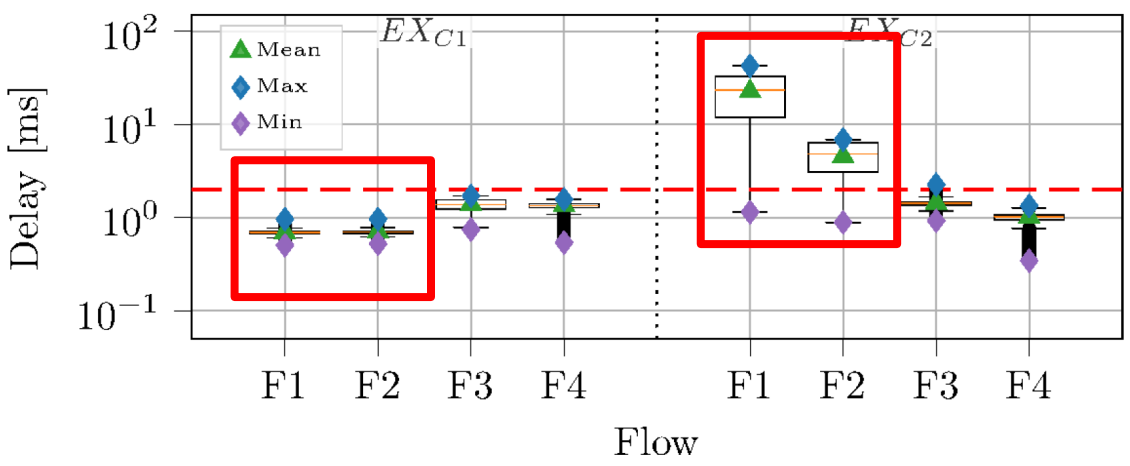
Comparing configurations for different NICs – 1Gbps (Intel I210) and 10Gbps (Intel X552)

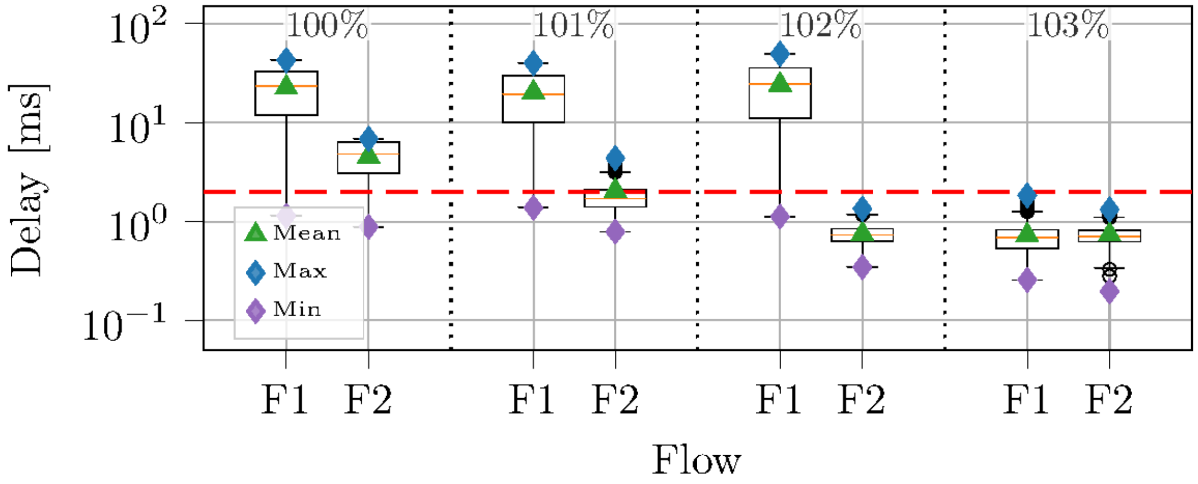
→ F1 and F2 Include CBS policed traffic on highest and second-highest priority

Discrepancy between expected and actual end-to-end delay distribution for 10 Gbps NIC

→ Indicates some misconfiguration

→ Needs in-depth understanding of the NIC





Summary
Open Challenges

1. Open-source implementations of PTP and TAPRIO do not work well together
2. ETF parameters depend on hardware and need to be defined for each system
3. CBS parameters heavily depend on used hardware and require good understanding of the NIC

→ Available tools, but needs to be verified carefully
→ Initial phases of adoption – limited available COTS HW and less documentation for SW

Open challenges:

- Multiple flows in one class for CBS and TAPRIO
- Creation of TAPRIO schedule
- Combination of various qdiscs
- Quantification and validation of system artifacts
- Missing/Partial artifact collection
- High throughput networking – 10Gbps and above

Experience with Simulation and hardware deployments?

Thank You!

EnGINE Framework

Are those issues because the area is too new?

Would be better with Commercial deployments?

Common challenges in other areas?

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