HAW HAMBURG

Migration from SERCOS III to TSN - Simulation based Comparison of TDMA and CBS Transportation

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CoRE

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Introduction

Challenges in modern Industrial- and Vehicle-Networks

- Communication infrastructure in various fields, such as industrial plants or vehicles must provide ever more bandwidth.

→ Demand for higher bandwidth can be met using Ethernet technology.

- Real-time aspect: strict timing requirements for the transmission of critical data.
  - Best-effort cross-traffic competes with time-critical data for bandwidth.

→ Real-time Ethernet protocols allow real-time communication over Ethernet.

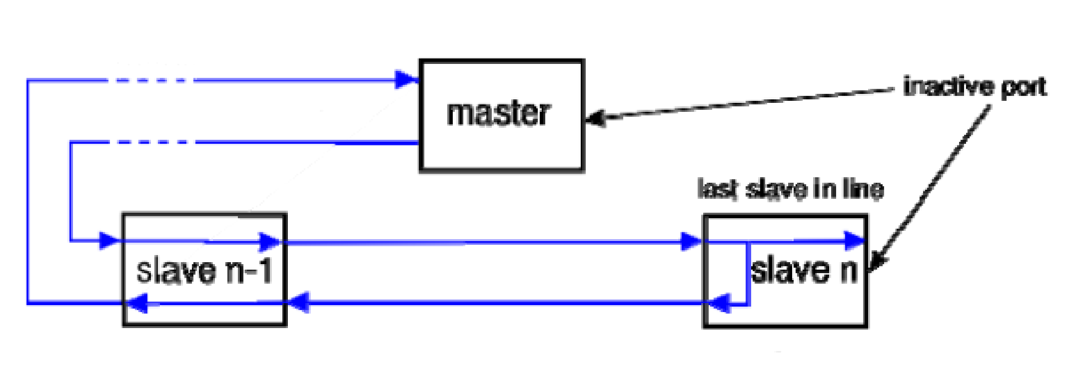
Introduction
SERCOS III

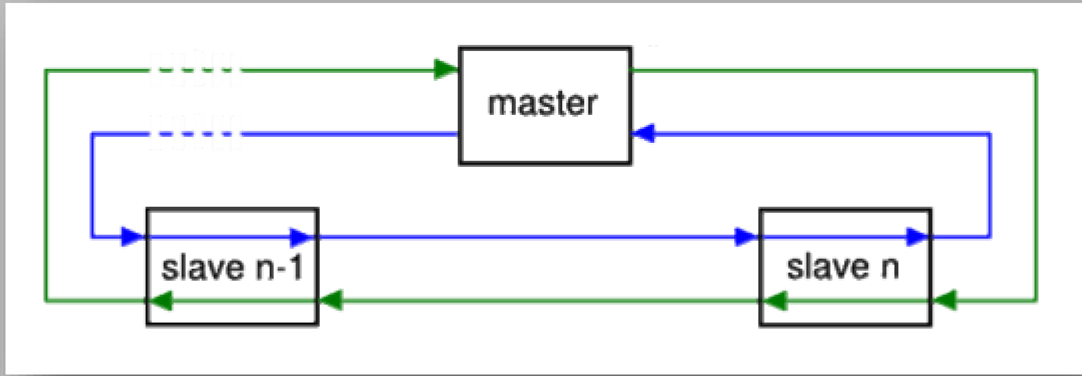
- **SERCOS III** (**Se**rial **R**eal-time **Co**mmunication **S**ystem) is an established Real-time Ethernet protocol, particularly used in the field of industrial plants.

Introduction

SERCOS III

- SERCOS III comes with certain limitations:
  - Network topology: only physical line or ring topology
  - Network must consist of SERCOS III devices only (no switches etc.)





Introduction

Time-Sensitive Networking (TSN)

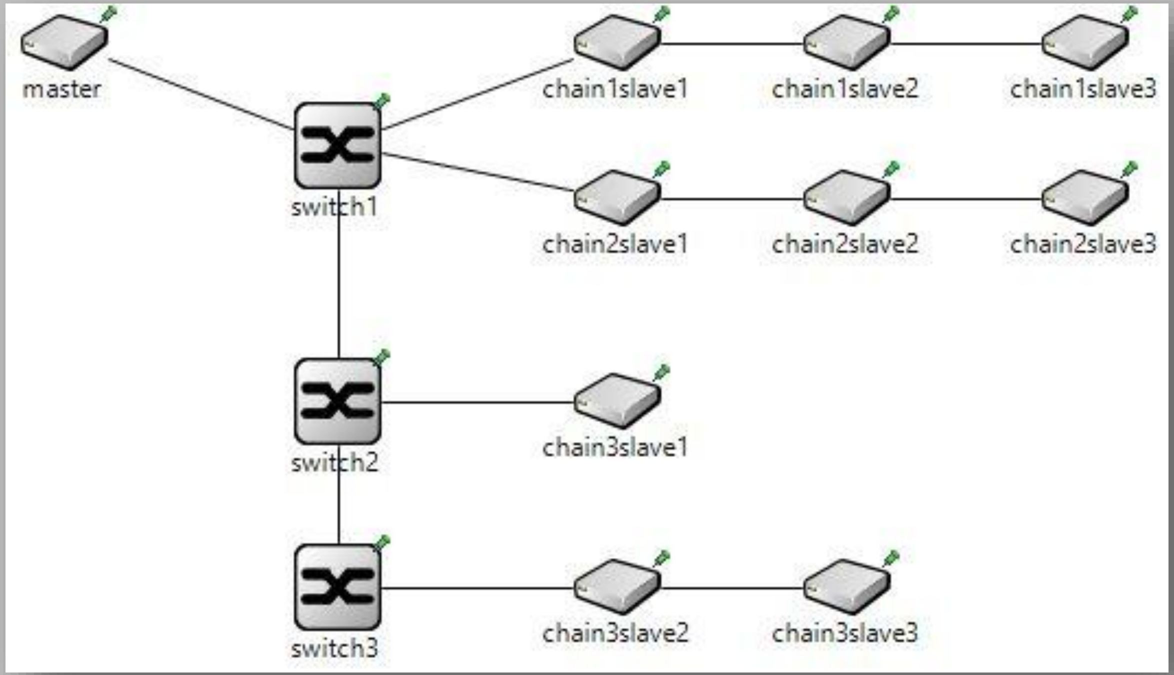
Time-Sensitive Networking (**TSN**)

- is a set of Ethernet standards meeting strict timing requirements.
- supports Time Division Multiple Access (**TDMA**) communication
- supports Credit-based Shaping (**CBS**) communication.
- supports flexible network topologies.

Introduction

SERCOS III Migration to TSN

- With migration from SERCOS III to TSN network limitations could be overcome.
  - → So what?

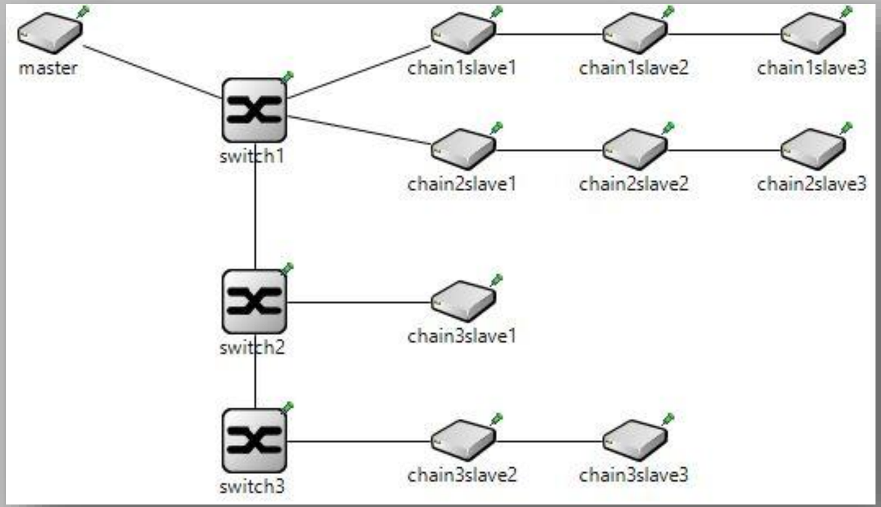


Introduction
SERCOS III Migration to TSN

- With migration from SERCOS III to TSN network limitations could be overcome.
  - → So what?

- SERCOS III could now be used in a wider range of networks (e.g. future vessel-networks?)

- In case of industrial plants: SERCOS III can directly be integrated into modern plant network with e.g. smart manufacturing applications…

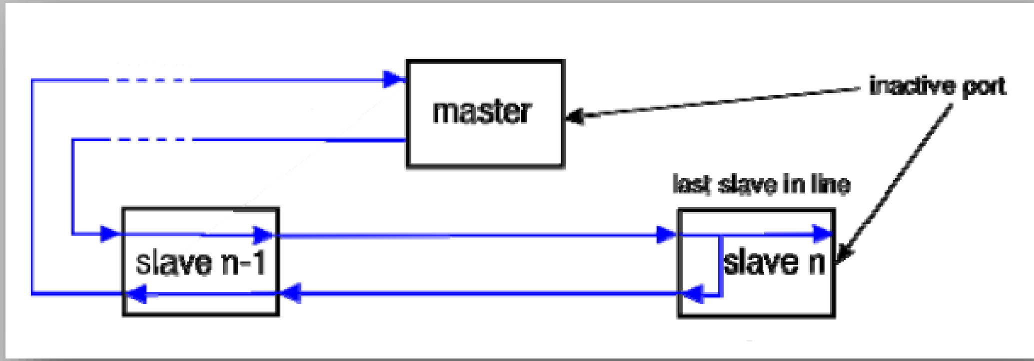


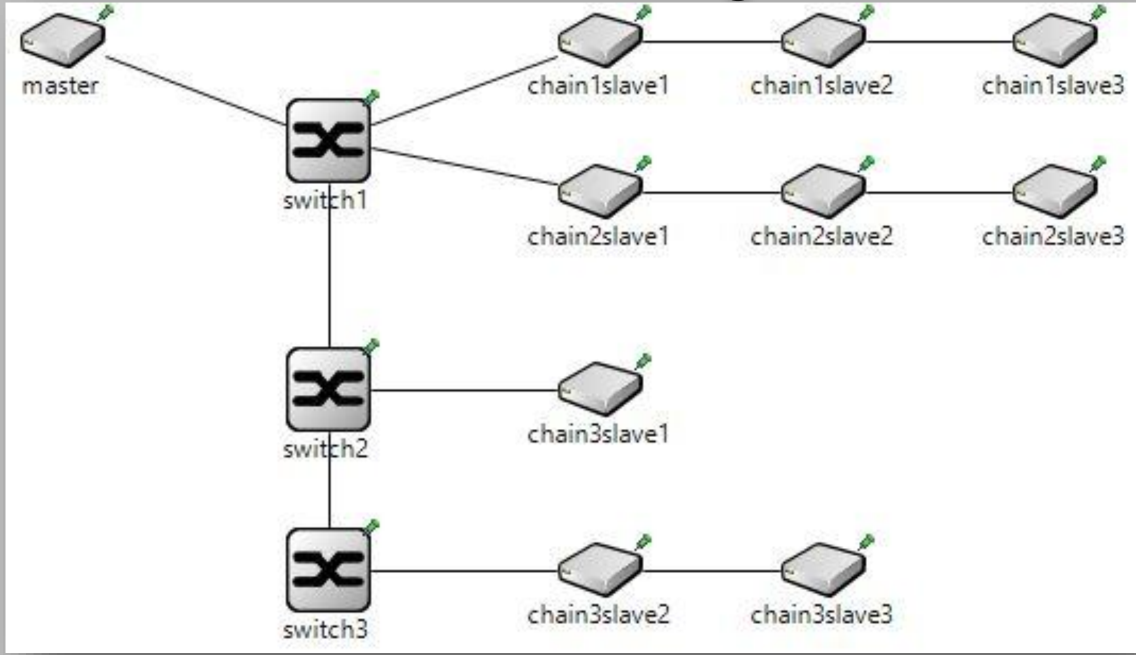
Introduction

SERCOS III Migration to TSN

- *Round-trip time* (**RTT**): time it takes for a frame transmitted by the master to traverse the line/ring and reach the master again).

- RTT can be reduced: parallel (shorter) lines instead of one line or ring (as in the work of Nsaibi et al.).





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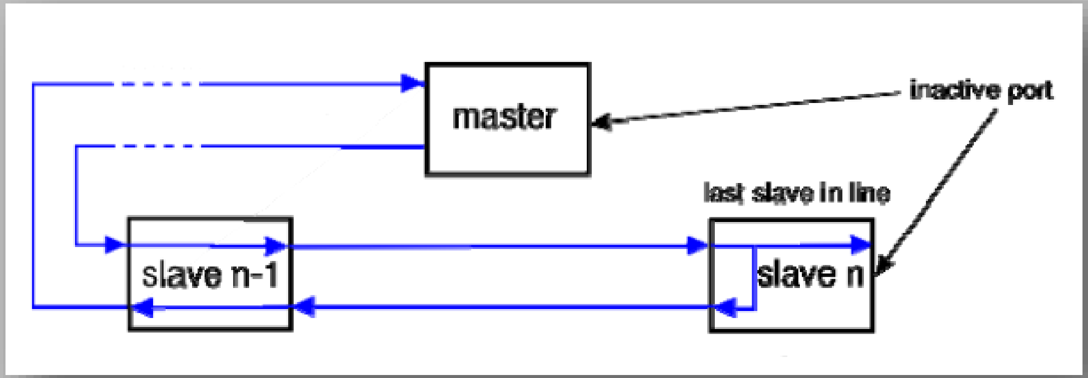
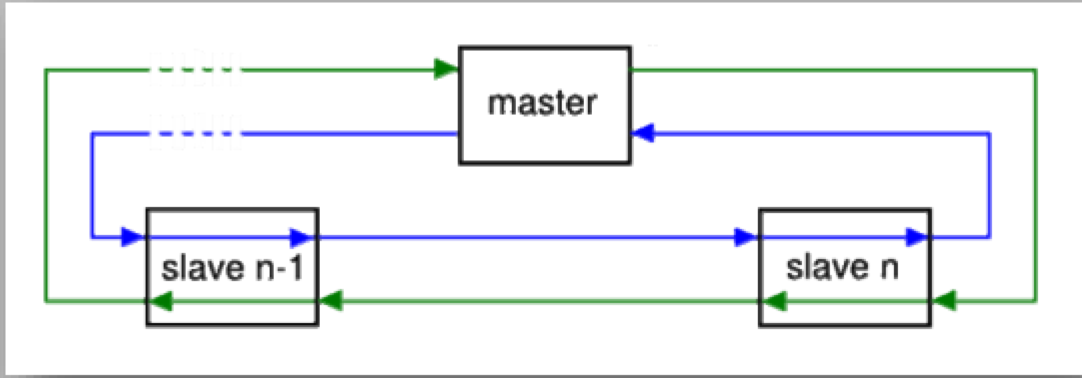
SERCOS III Protocol Overview

Network Topology

SERCOS III

- is a master-slave protocol with exactly one master.
- only supports a physical line or ring (for redundancy) topology and no switches.
- the master creates the frames (with ring topology: two copies of each frame are created).

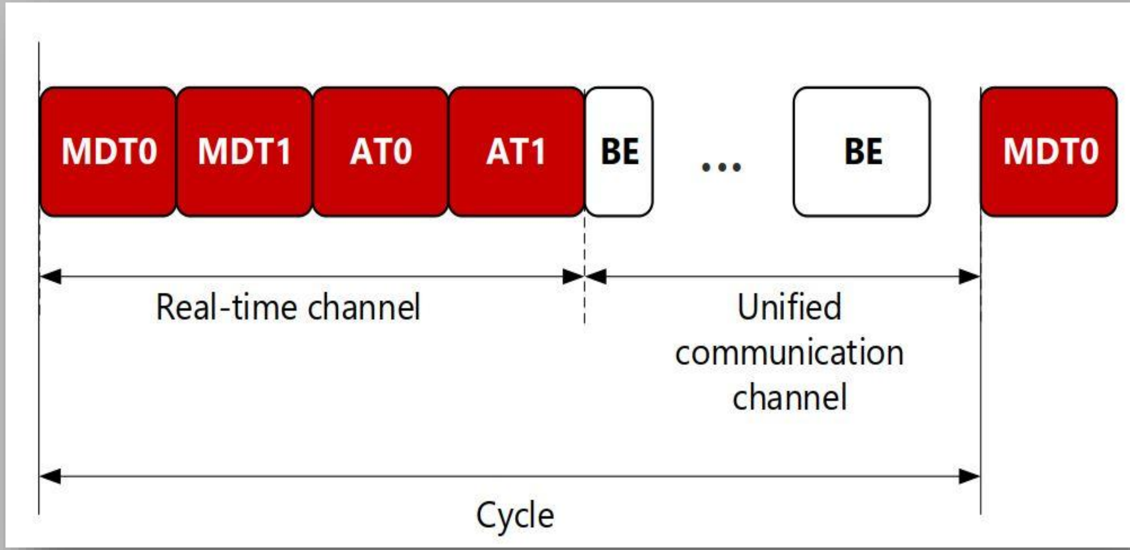




SERCOS III Protocol Overview
Communication Cycle

- SERCOS III is TDMA-based.

- Communication cycle is divided into 2 channels:
  - RTC for real-time data
  - UCC for standard Ethernet communication

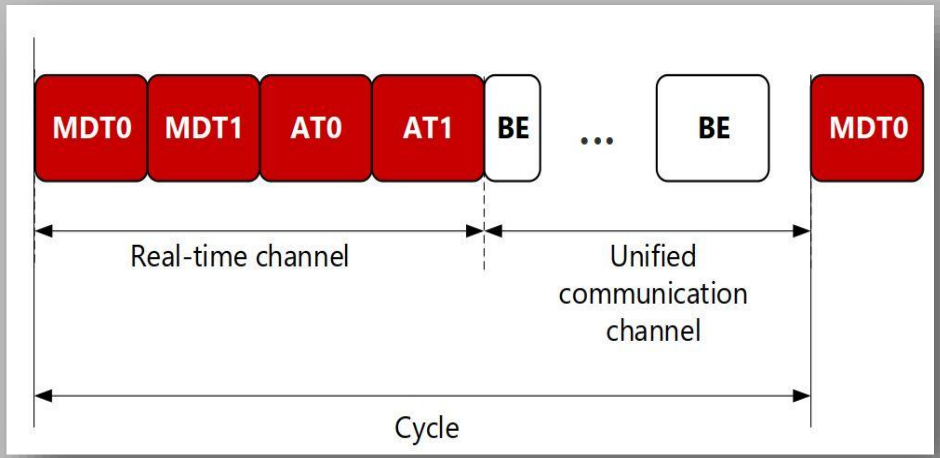


- RTC: fixed number of
  - Master-Data Telegrams (MDTs)
  - Acknowledgement Telegrams (ATs)
  - SERCOS III telegrams are standard Ethernet frames.

SERCOS III Protocol Overview

Clock Synchronization

- SERCOS III comes with own clock synchronization mechanism.
- Master distributes time (current time + offset) to slaves via MDT0.
- MDT0 has to arrive on predefined time for synchronization to work correctly.
  - → with minimum jitter!



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The Simulation Model

SERCOS III Migration to TSN

- Migration from SERCOS III to TSN includes 3 sub-tasks:

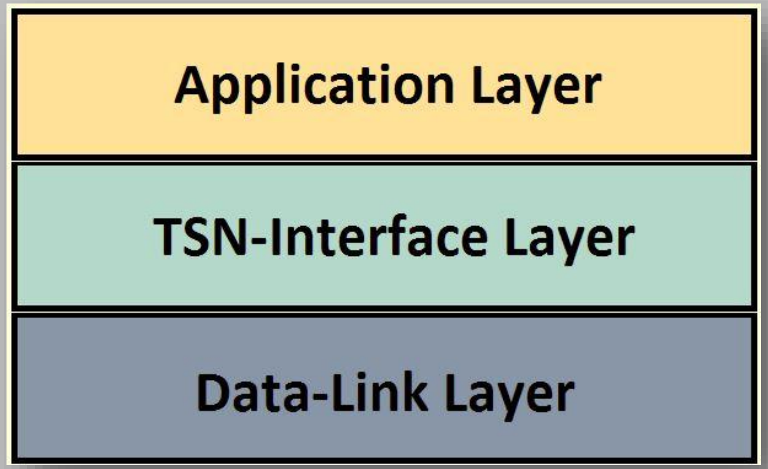
1. *Clock synchronization:*
   Instead of synchronization via MDT0: IEEE 802.1AS protocol defined in TSN
   → clock synchronization decoupled from timing of MDT0 frame

2. *Support of legacy systems:*
   SERCOS III transports application data via several standard Ethernet frames and migration must not change that.

3. *Transportation of critical data according to given QoS requirements:*
   TDMA or CBS in arbitrary topology of end nodes and switches.

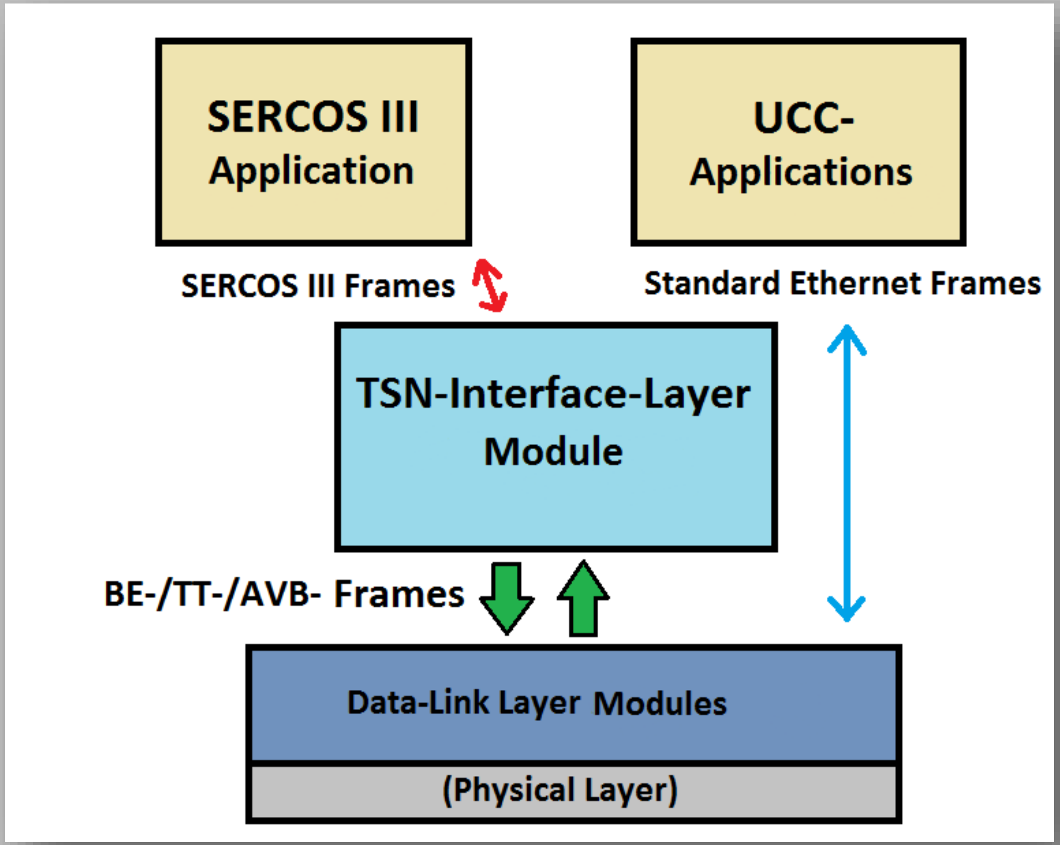
The Simulation Model
Frameworks and Layers

- OMNeT++ simulation model based on CoRE4INET and INET frameworks.
- CoRE4INET implements different Ethernet transportation mechanisms (TDMA, CBS).
- The model consists of 3 layers:



The Simulation Model
Modules

- The model provides the following modules:
  - SERCOS III device compound module
  - SERCOS III application modules
    - Master application
    - Slave application
  - TSN-Interface modules
    - TDMA
    - CBS
  - Module for generating best-effort cross-traffic
- The data link- und physical layer modules are provided by the CoRE4INET and INET frameworks.

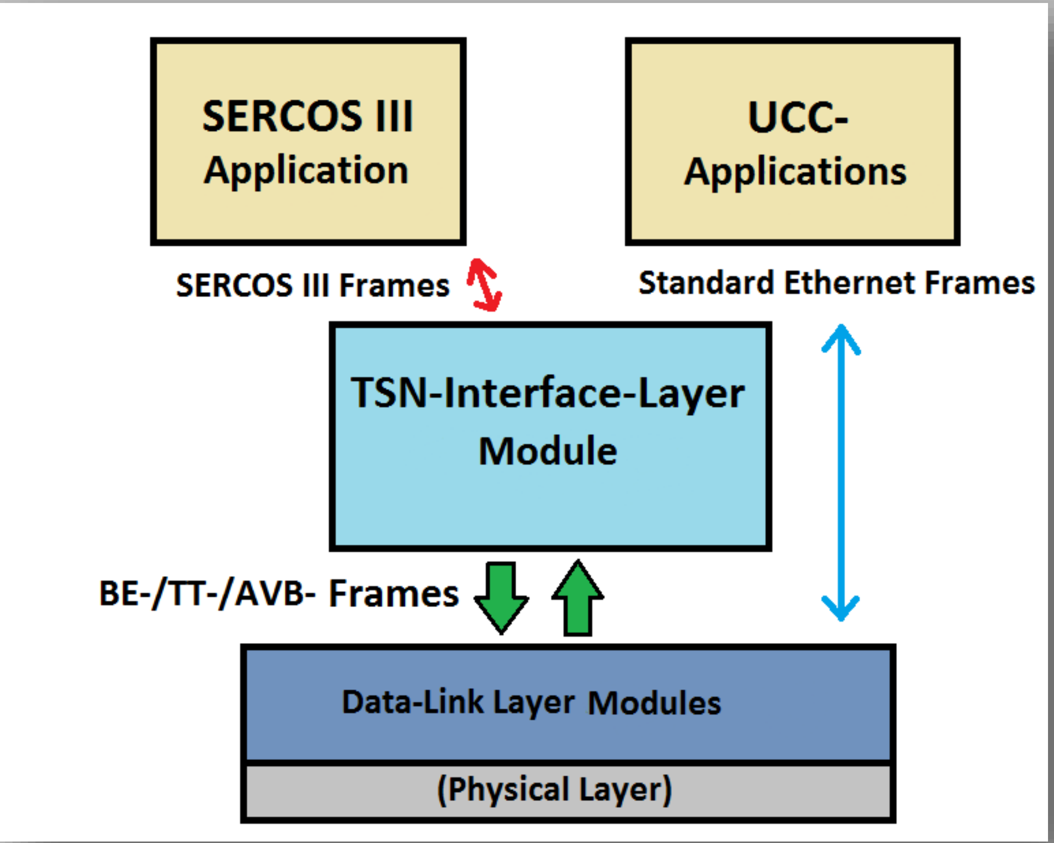


The Simulation Model

SERCOS III via TSN

- SERCOS III applications generate and process SERCOS III payload.

- TSN-Interface layer modules
  - encapsulate SERCOS III payload from the applications in standard Ethernet-frames.
  - Standard Ethernet-frames are encapsulated in real-time Ethernet-frames, e.g. TT-frames.



- TSN-Interface layer modules (TDMA, CBS) can be used interchangeably.

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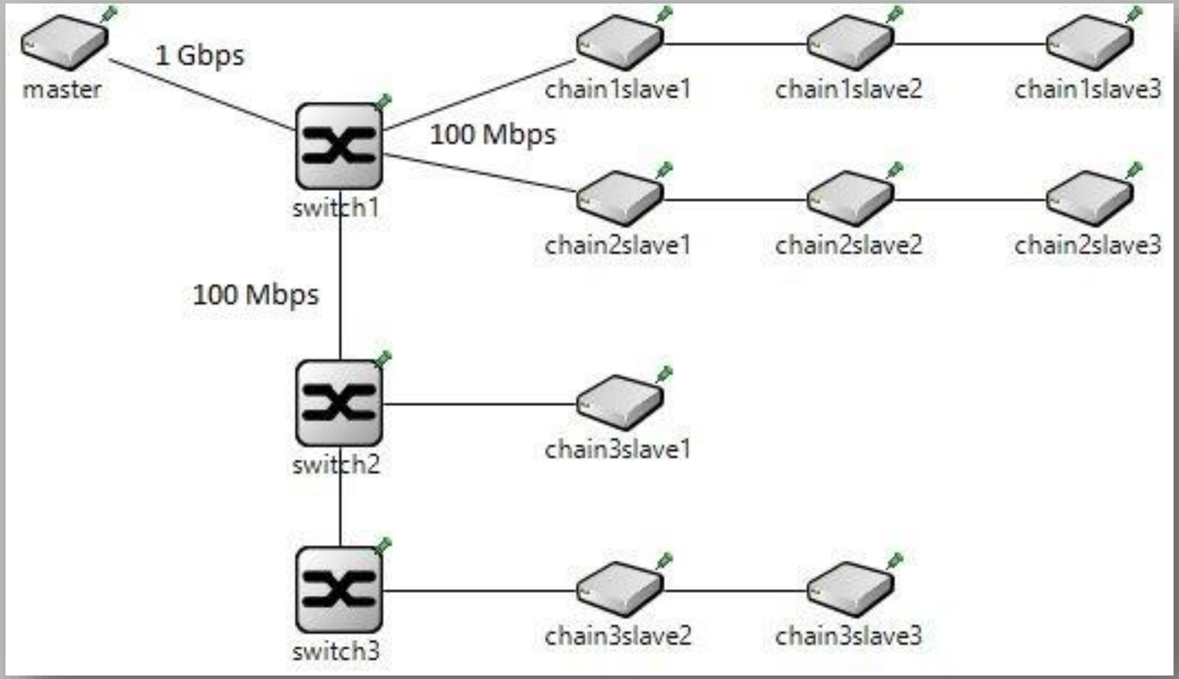
Case Study

- Case study to analyze migration from SERCOS III to TSN using simulation model:
  - SERCOS III transportation via TDMA
  - SERCOS III transportation via CBS

Case Study
Scenario

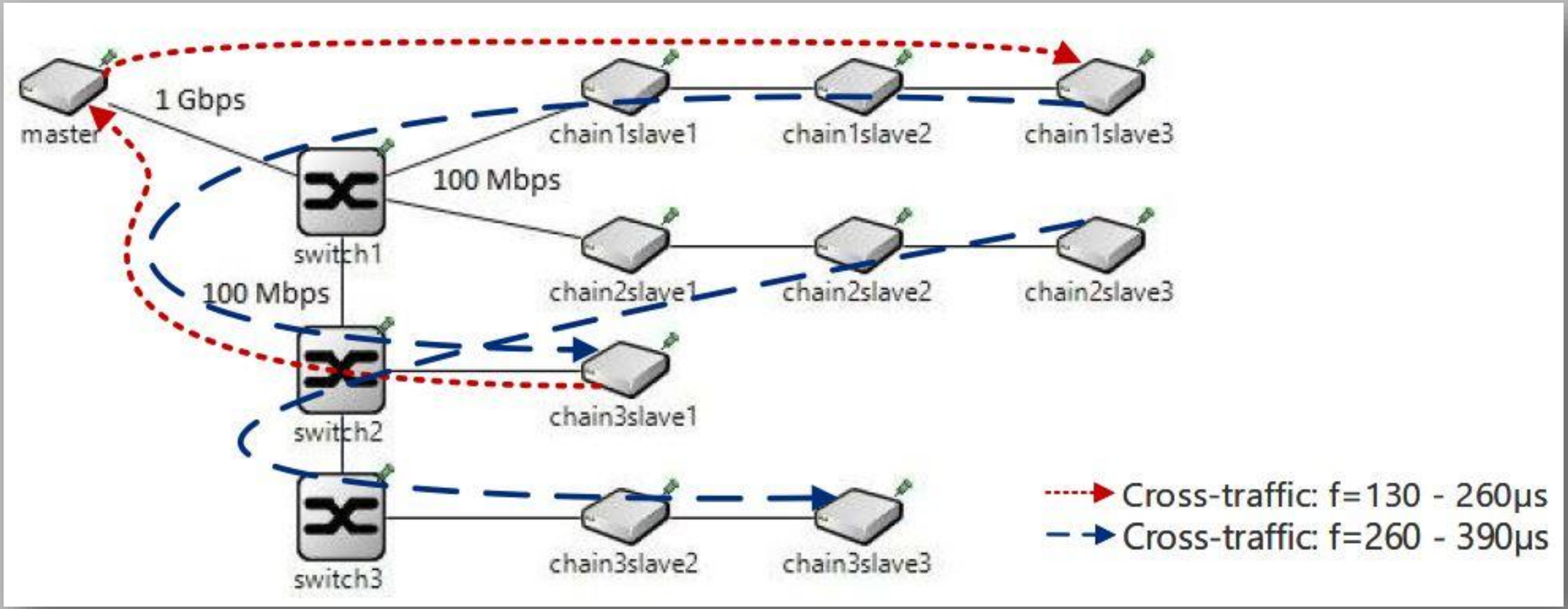
- Case study set-up:
  - Network with best-effort cross-traffic



Case Study

Scenario

- Cross-traffic: MTU and transmission interval uniformly distributed (800-1500 bytes, 130-390 µs).



Case Study

SERCOS III via TDMA

- SERCOS III is transported via TDMA traffic:
  - SERCOS III payload was set to 30 bytes resulting in 66 byte frames due to encapsulation.
  - Processing delay of TSN-switches and SERCOS III devices was set to 4.6 µs.
  - Maximum clock-jitter of all devices was 400 ns.
  - The TDMA schedule was configured to achieve best possible RTT: every frame is sent without additional delay.

Case Study

Results SERCOS III via TDMA

TDMA			
[µs]	RTT_{min}	RTT_{max}	jitter
Chain 1	71.7	72.06	0.36
Chain 2	74.95	75.31	0.36
Chain 3	140.61	140.97	0.36

- Expected round-trip times were achieved with TDMA.
- Constant jitter of 0.36 µs.

Case Study

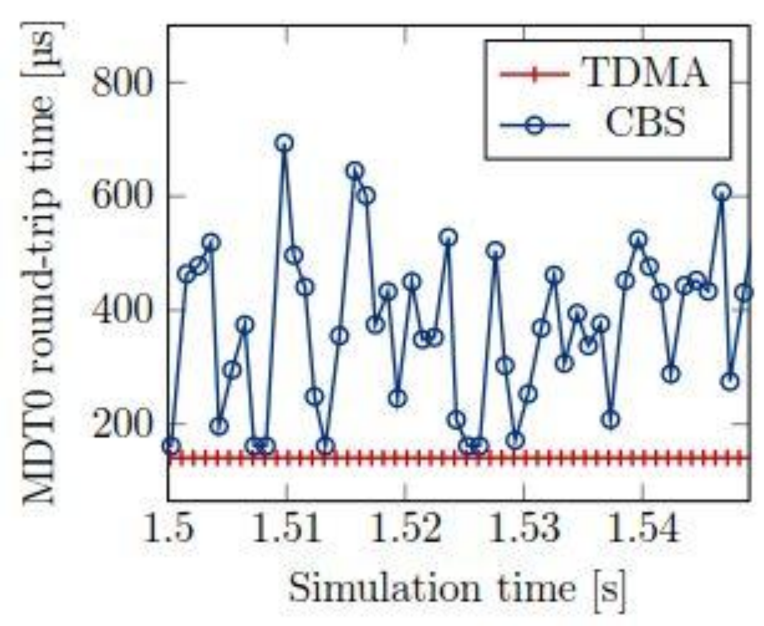
SERCOS III via CBS

- SERCOS III is transported via CBS:
  - The simulation parameters are the same as with TDMA.
  - Due to the header for CBS the size of the frames increases to 70 bytes (66 bytes for TDMA transportation).
  - Bandwidth reservation: ~23 Mbit/s per stream

Case Study

Results SERCOS III via CBS and Comparison to TDMA

	TDMA			CBS		
[µs]	RTT_{min}	RTT_{max}	jitter	RTT_{min}	RTT_{max}	jitter
Chain 1	71.7	72.06	0.36	72.91	744.75	671.84
Chain 2	74.95	75.31	0.36	82.56	433.17	350.61
Chain 3	140.61	140.97	0.36	154.44	1029.15	874.71



- CBS with significantly higher jitter and maximum round-trip times (RTT) than TDMA.

Case Study

SERCOS III via CBS

SERCOS III is transported via CBS:

- Additional simulation run with normal CBS setup but with network consisting only of 1 Gbit/s links.

Case Study

Results SERCOS III via CBS and Comparison to TDMA

TDMA			
[µs]	RTT_{min}	RTT_{max}	jitter
Chain 1	71.7	72.06	0.36
Chain 2	74.95	75.31	0.36
Chain 3	140.61	140.97	0.36

CBS with 1 Gbit/s links		
RTT_{min}	RTT_{max}	jitter
41.81	95.91	54.1
51.46	93.11	41.65
92.23	153.78	61.55

- 1 Gbit/s links lower CBS maximum RTT to 134% of TDMA maximum RTT.

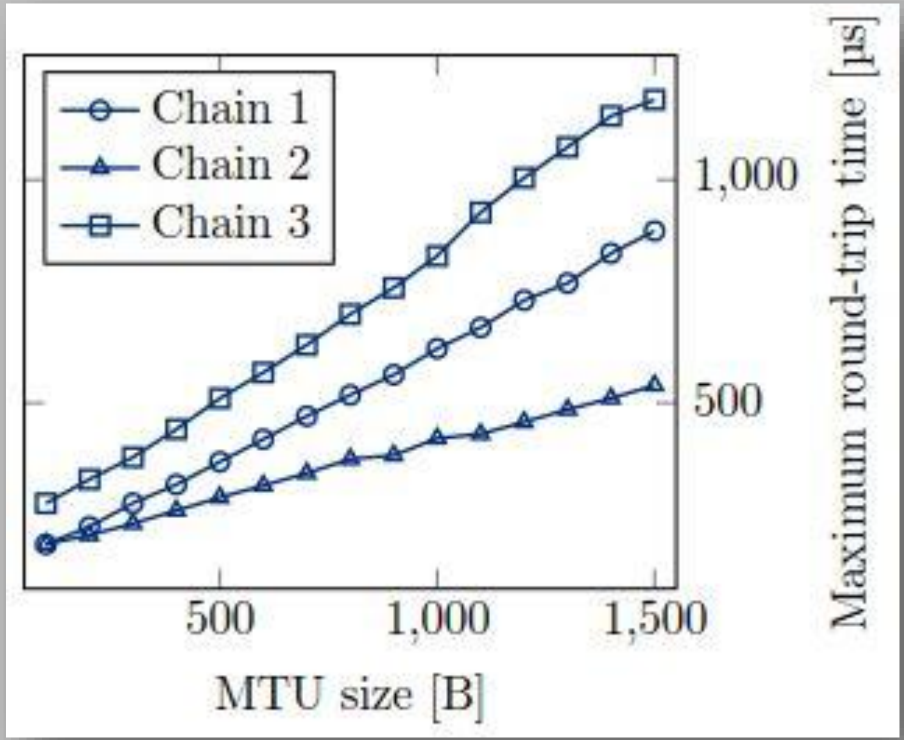
Case Study
SERCOS III via CBS

SERCOS III is transported via CBS:

- Additional simulation run to show the effect of limiting cross-traffic MTU on SERCOS III traffic:
  - MTU is increased by 100 bytes in a range from 100-1500 bytes.

Case Study

Results SERCOS III via CBS



- Limiting cross-traffic MTU significantly reduced CBS maximum RTT.

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Conclusion

- More flexible network design with TSN
  - Reduction of RTT with parallel lines
- Best performance (RTT and jitter) with SERCOS III via TDMA
- More flexibility with CBS than TDMA
  (no static off-line configuration of entire schedule)
  - CBS performance improved by higher link bandwidth or fragmentation of best-effort cross-traffic.
- If sufficient for timing requirements, CBS should be used due to flexibility.

Migration from SERCOS III to TSN - Simulation based Comparison of TDMA and CBS Transportation

- Thank you for your attention!
- Any questions?

References

- NSAIBI, Seifeddine; LEURS, Ludwig; SCHOTTEN, Hans D. Formal and simulation-based timing analysis of industrial-ethernet sercos III over TSN. In: *Proceedings of the 21st International Symposium on Distributed Simulation and Real Time Applications*. IEEE Press, 2017. S. 83-90.

Credit Based Shaping

- Frames are sent according to pre-reserved bandwidth (credit value).
- While credit value is negative or CBS buffer is not empty, credit value is increased.
- If credit value ≥ 0 and port is free, frame is transmitted.
- During transmission credit value decreases.