

Vorlesung Kommunikationssysteme, 4.5 Time-Sensitive Networks (TSN)

# Time-Sensitive Networking for Industrial Real-Time Communication

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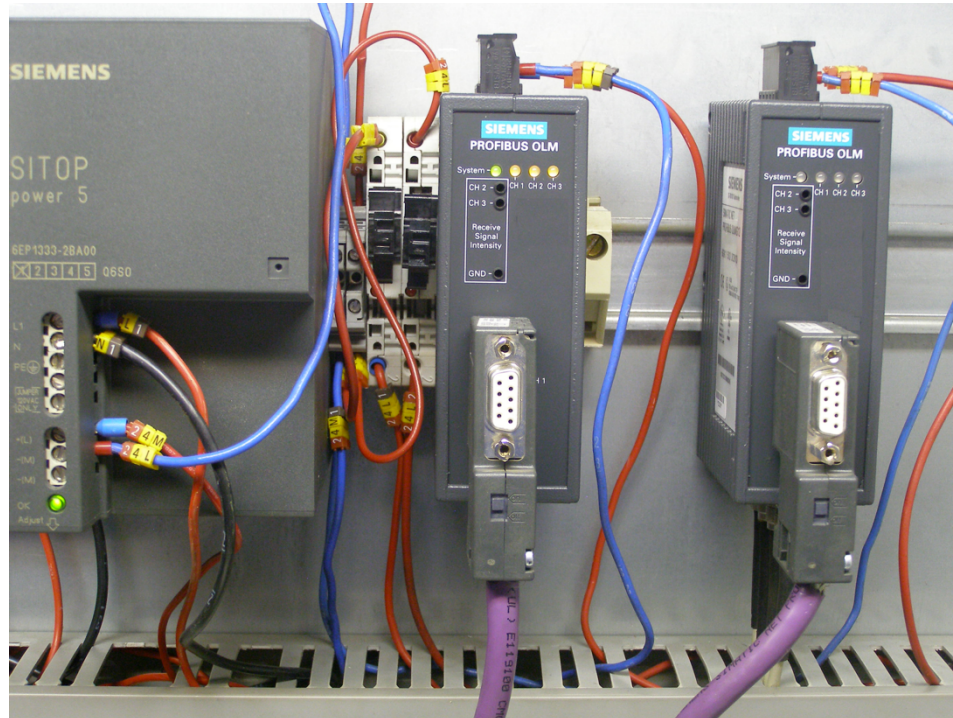
Forschungsgruppe Kommunikationssysteme

12.05.2020

[ma.boehm@ostfalia.de](mailto:ma.boehm@ostfalia.de)

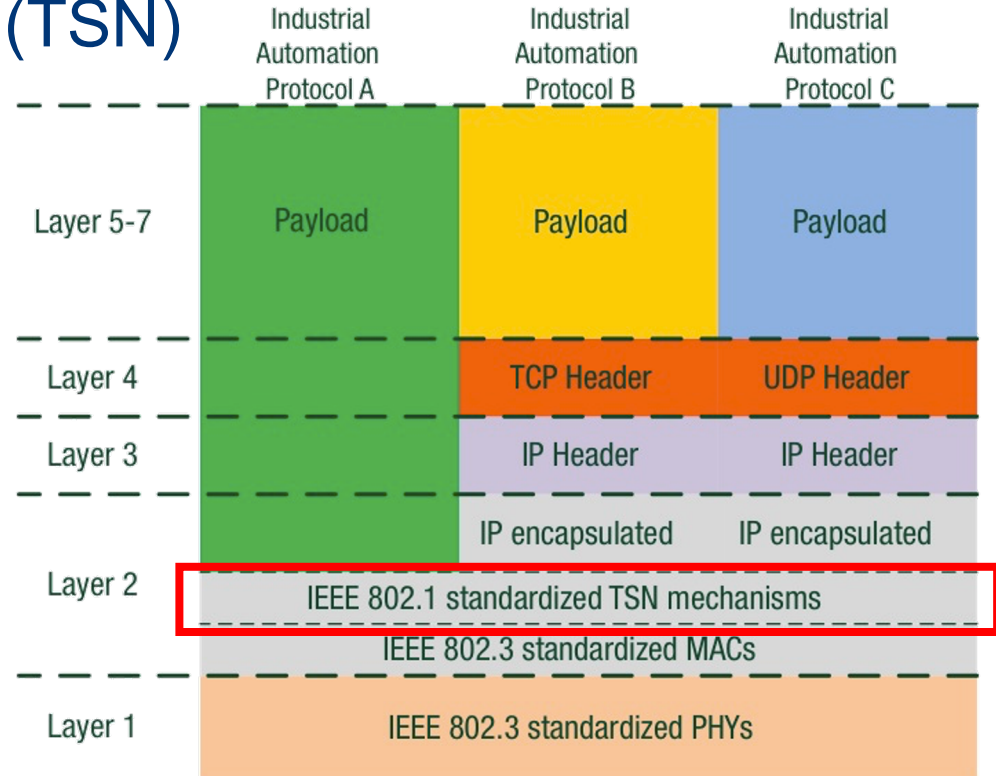
- Kia Sportage factory production line  
Source: <https://www.youtube.com/watch?v=sjAZGUcjrP8>

# Traditional Industrial Real-Time Communication

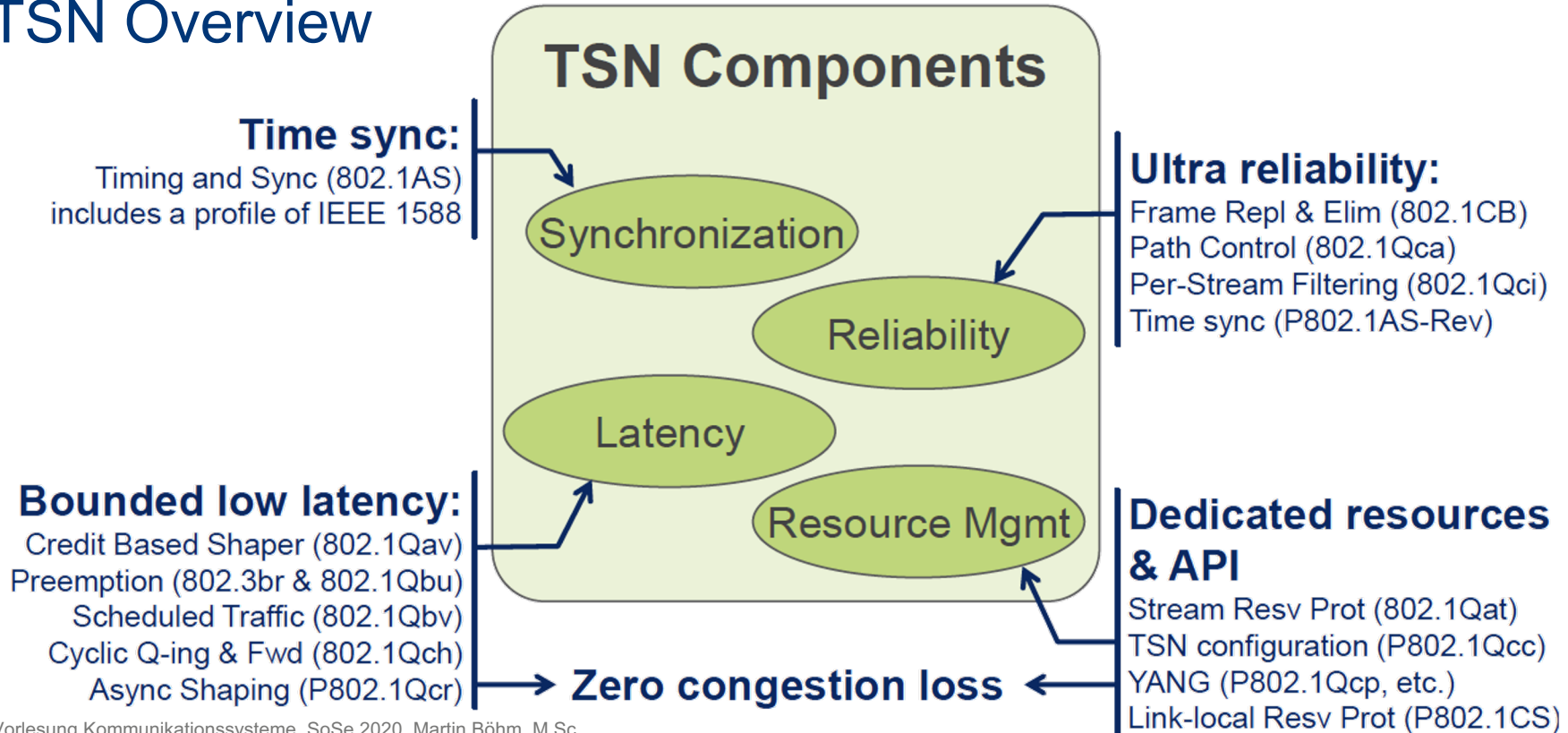


# Time-Sensitive Networking (TSN)

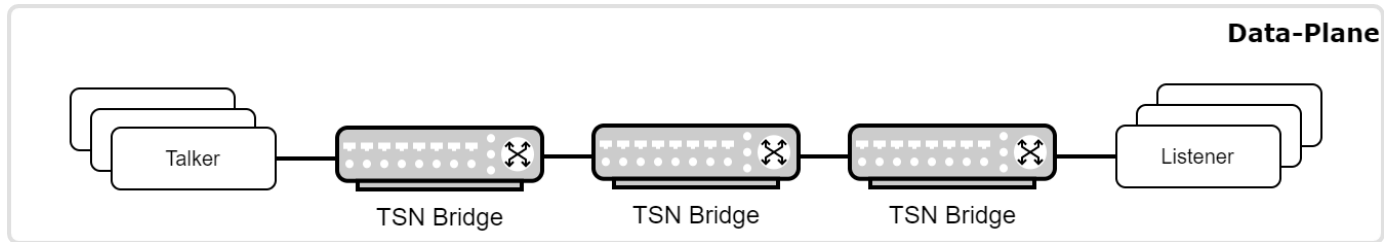
- Evolved from IEEE 802.1 Audio Video Bridging (AVB) in 2012
- Group of standards
  - IEEE 802.1 TSN Working Group
  - Open standards
  - Not proprietary
  - No vendor lock-in
- Based on Ethernet
- One enabler for Industry 4.0
- Key components
  - Scheduling and Traffic Shaping
  - Time-Synchronization



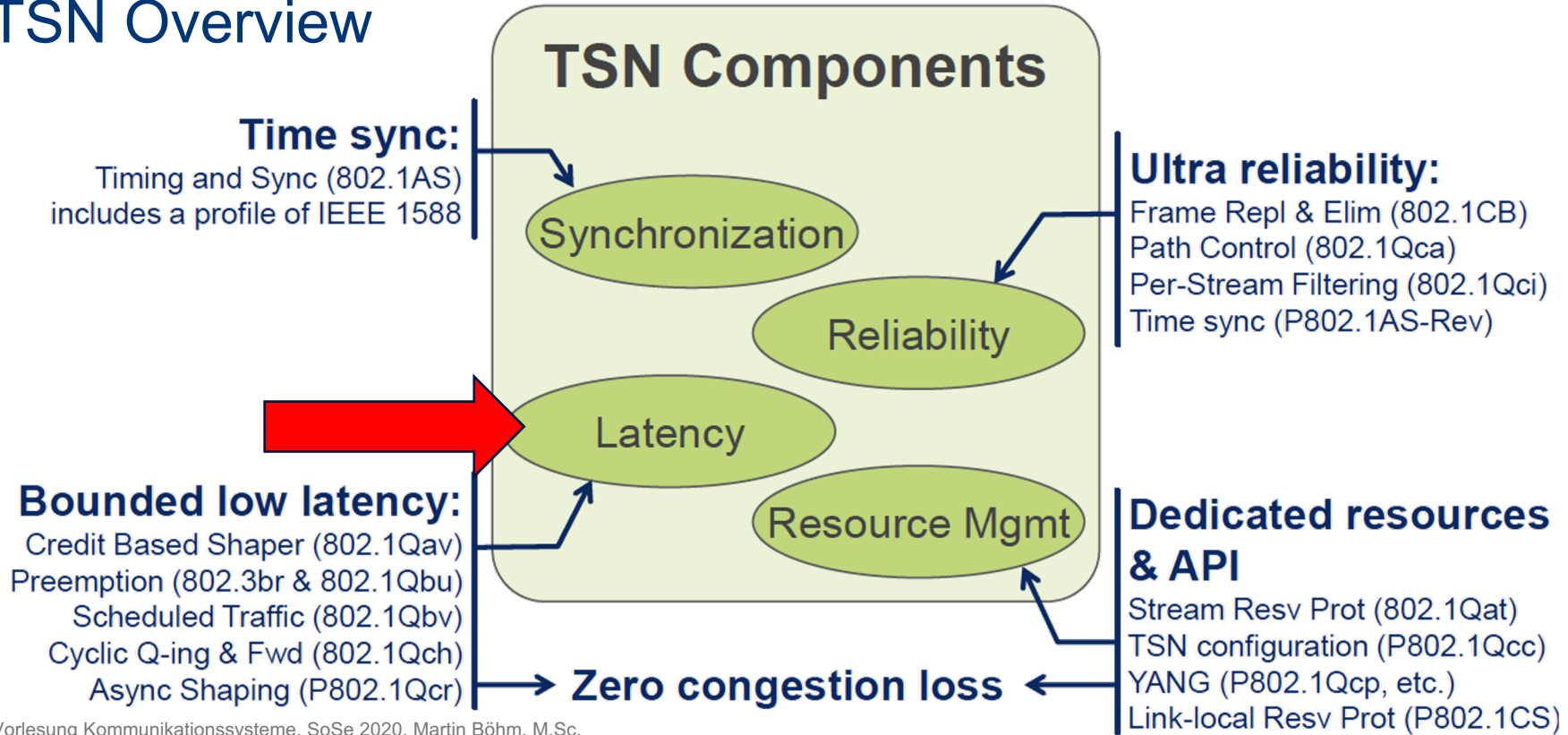
# TSN Overview



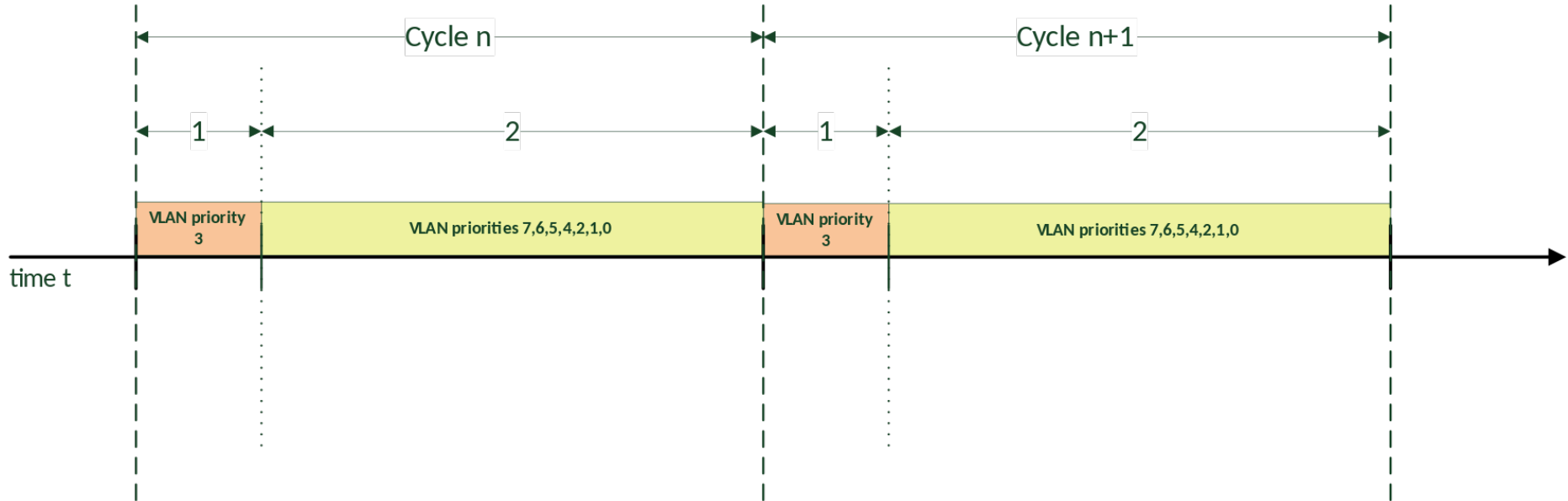
# Example TSN Architecture



# TSN Overview

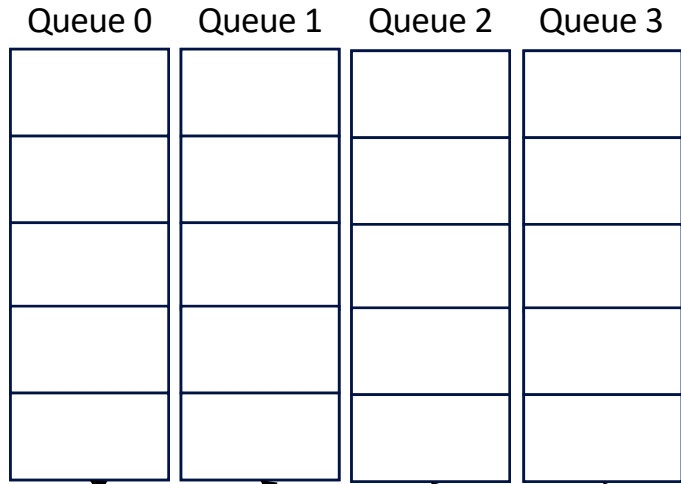


# IEEE 802.1Qbv - Enhancements for Scheduled Traffic





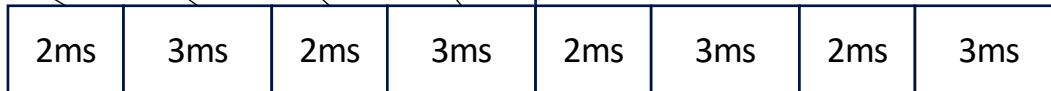
## Gate Control Lists (1 device)



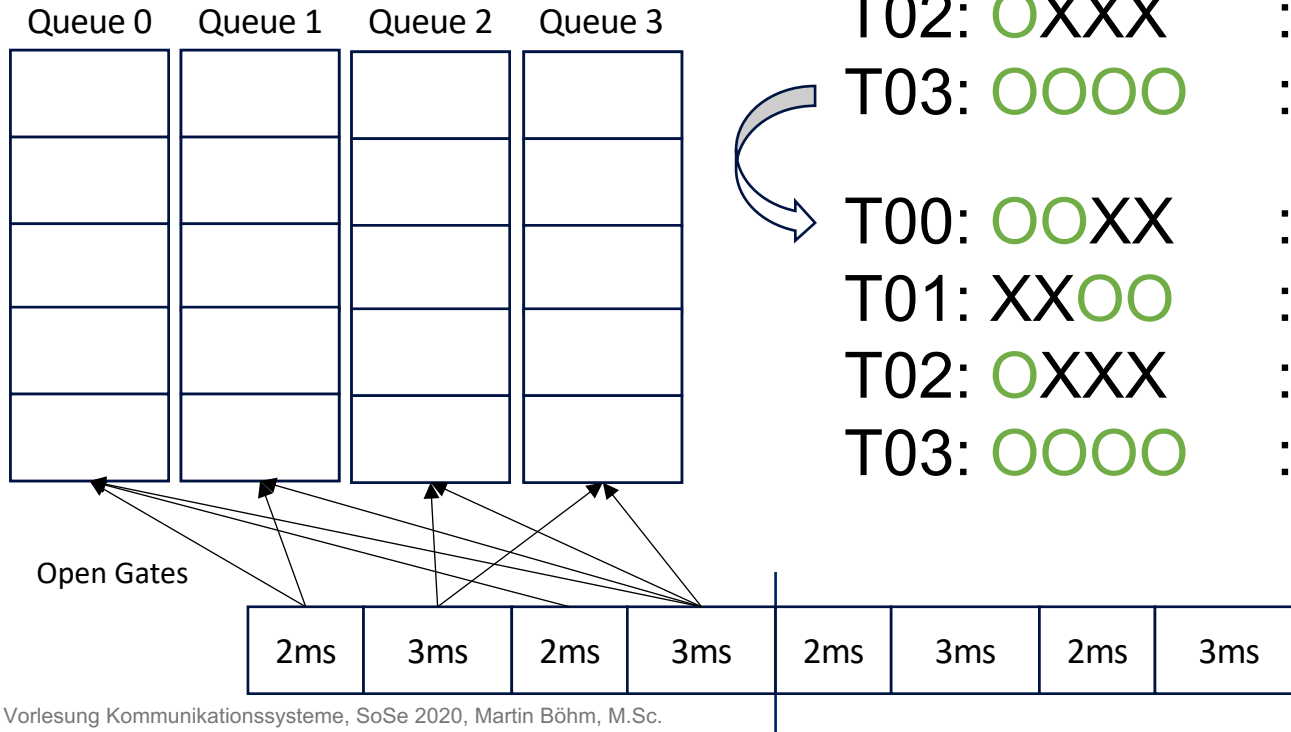
T00: OXXX	: 2ms
T01: XOXX	: 3ms
T02: XXOX	: 2ms
T03: XXXO	: 3ms
T00: OXXX	: 2ms
T01: XOXX	: 3ms
T02: XXOX	: 2ms
T03: XXXO	: 3ms

10 ms  
Cycle

Open Gates

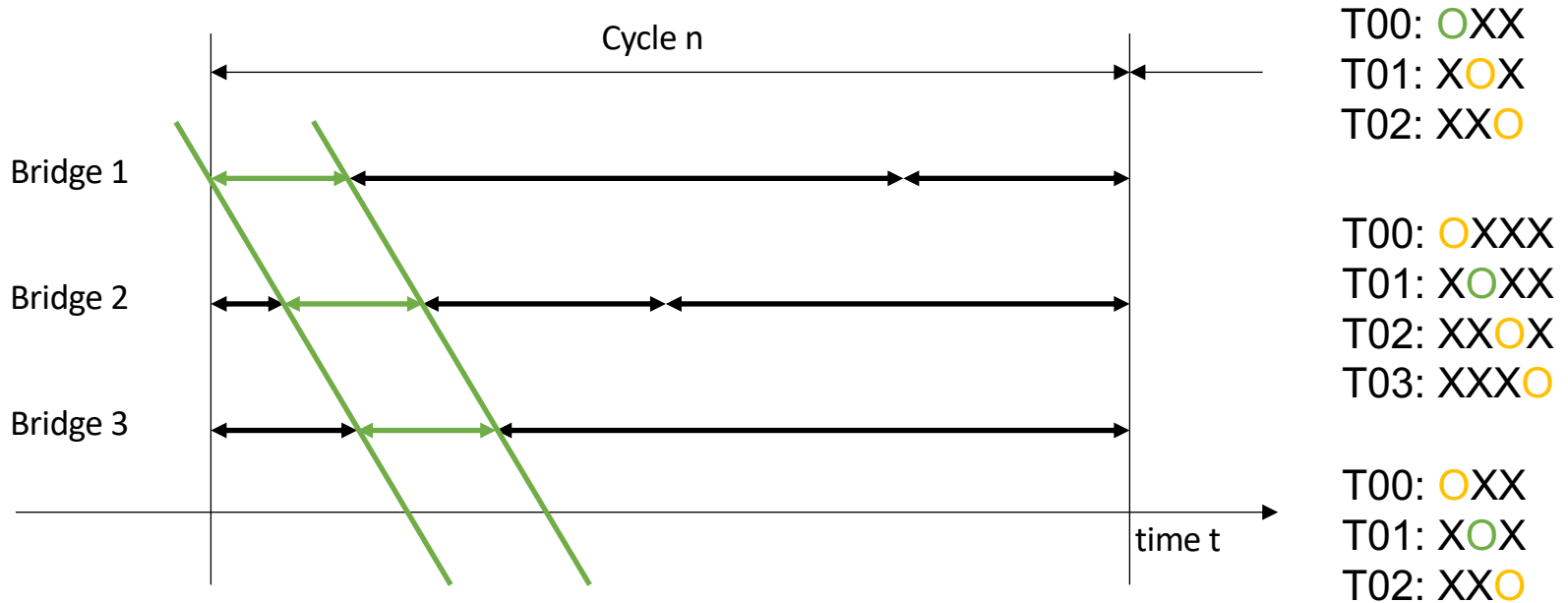


## Gate Control Lists (1 device)

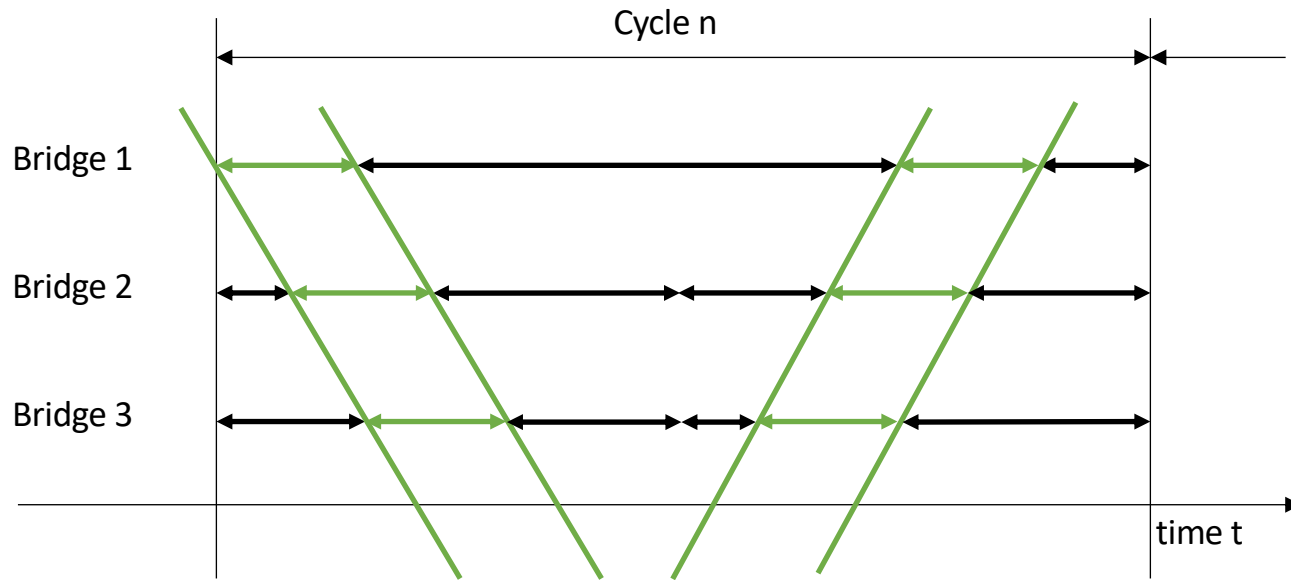


T00: ○○XX	: 2ms	} 10 ms Cycle
T01: XX○○	: 3ms	
T02: ○XXX	: 2ms	
T03: ○○○○	: 3ms	
T00: ○○XX	: 2ms	
T01: XX○○	: 3ms	
T02: ○XXX	: 2ms	
T03: ○○○○	: 3ms	

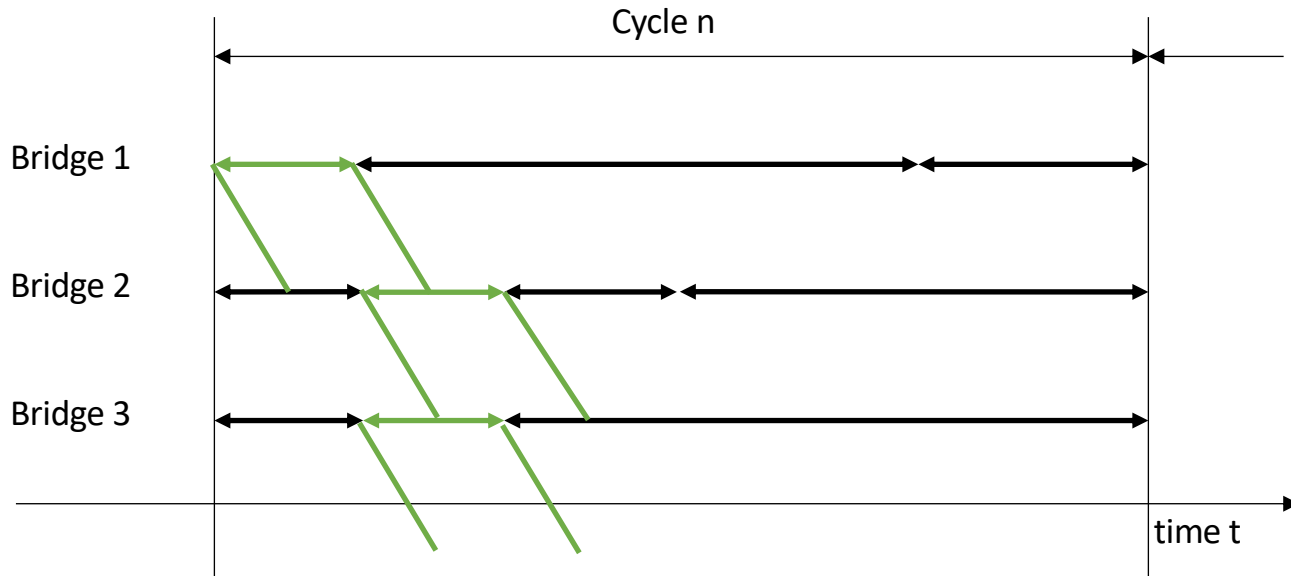
# Configuration of multiple Gate Control Lists (GCL)



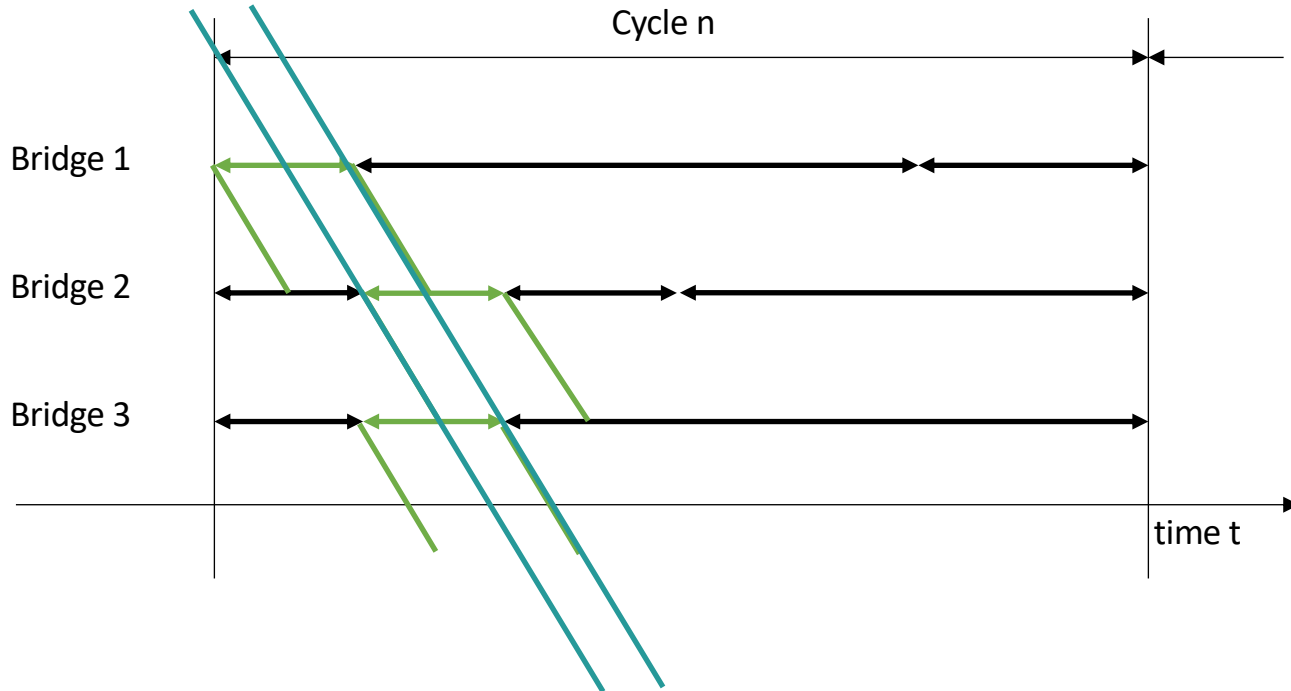
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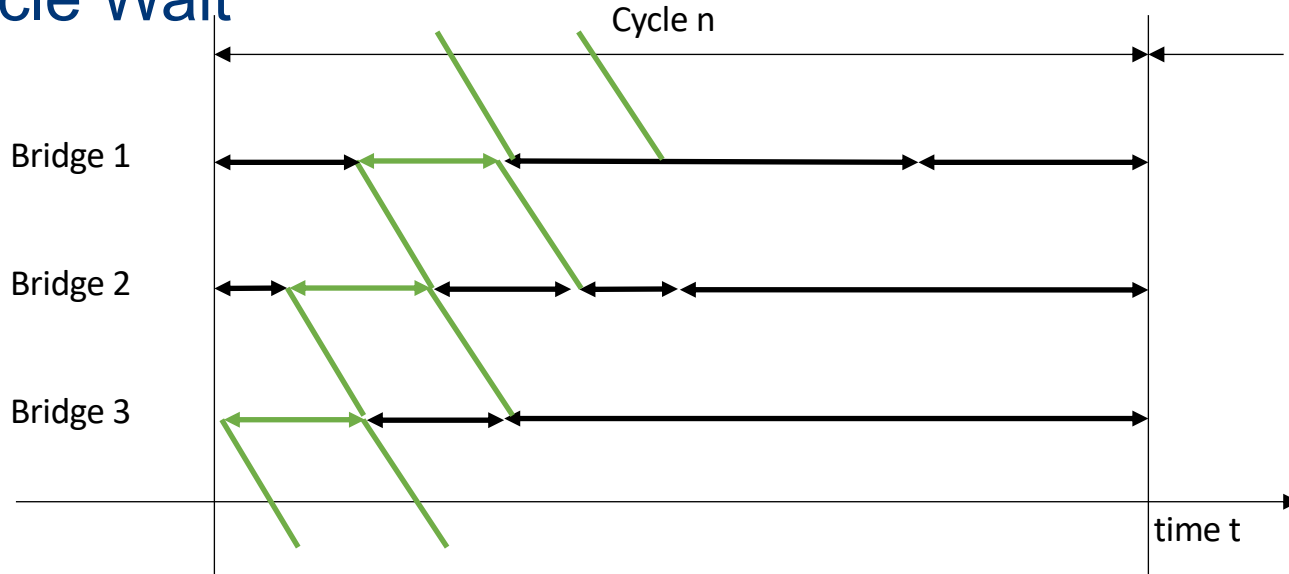
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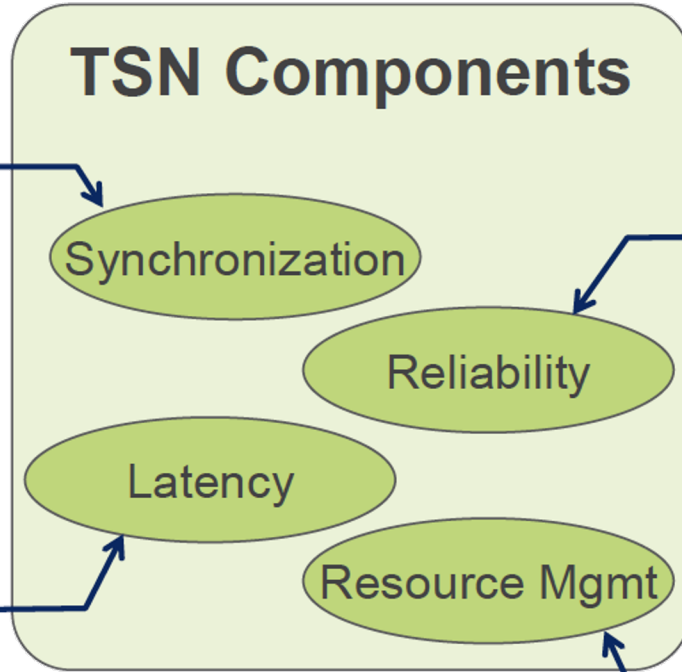
# Configuration of multiple Gate Control Lists (GCL)



# Worst-Case Configuration of multiple Gate Control Lists (GCL) Full Cycle Wait



# TSN Overview



## Time sync:

Timing and Sync (802.1AS)  
includes a profile of IEEE 1588

## Ultra reliability:

Frame Repl & Elim (802.1CB)  
Path Control (802.1Qca)  
Per-Stream Filtering (802.1Qci)  
Time sync (P802.1AS-Rev)

## Bounded low latency:

Credit Based Shaper (802.1Qav)  
Preemption (802.3br & 802.1Qbu)  
Scheduled Traffic (802.1Qbv)  
Cyclic Q-ing & Fwd (802.1Qch)  
Async Shaping (P802.1Qcr)

## Dedicated resources & API

Stream Resv Prot (802.1Qat)  
TSN configuration (P802.1Qcc)  
YANG (P802.1Qcp, etc.)  
Link-local Resv Prot (P802.1CS)

## Zero congestion loss

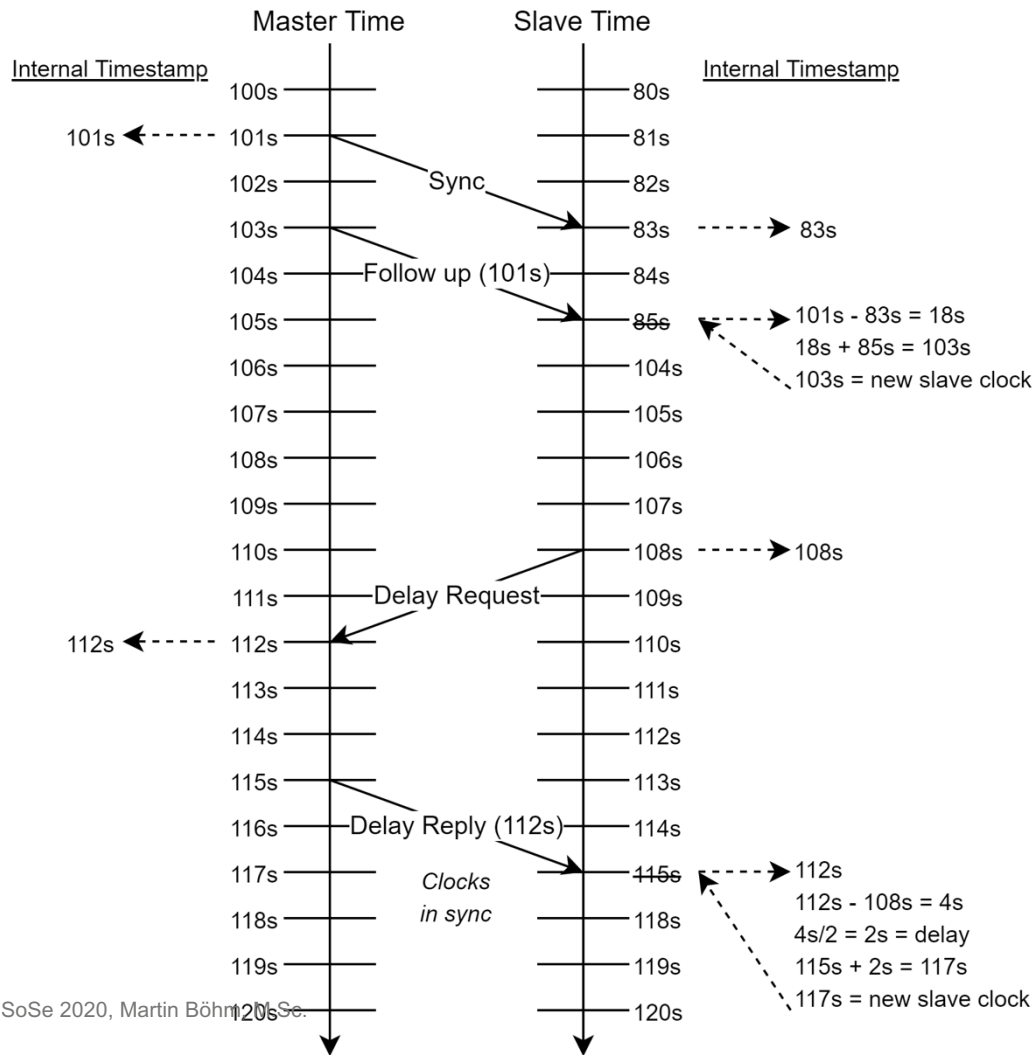


# Time-Synchronization

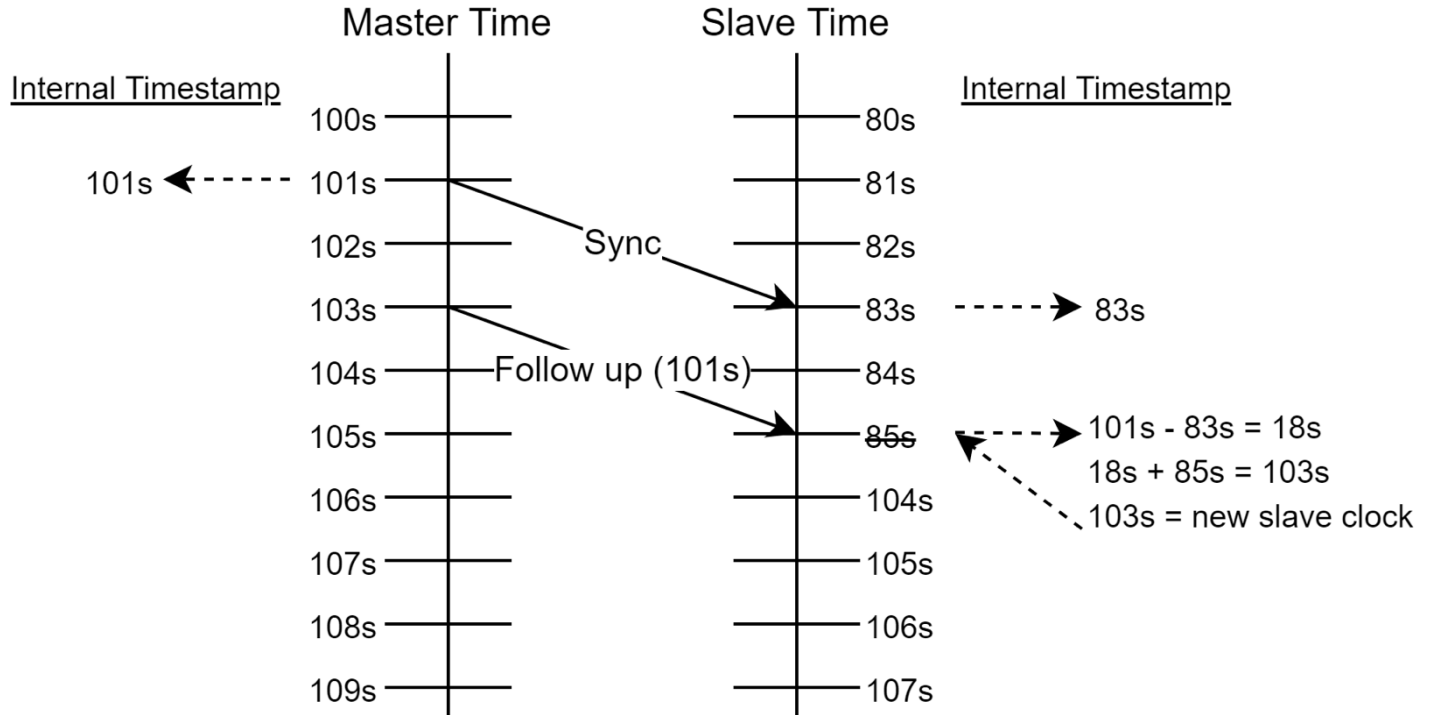
- Precision Time Protocol (PTP)
  - IEEE 802.1 AS-Rev - Timing and Synchronization for Time-Sensitive Applications
- Master/Slave architecture
- Accuracy in nanoseconds



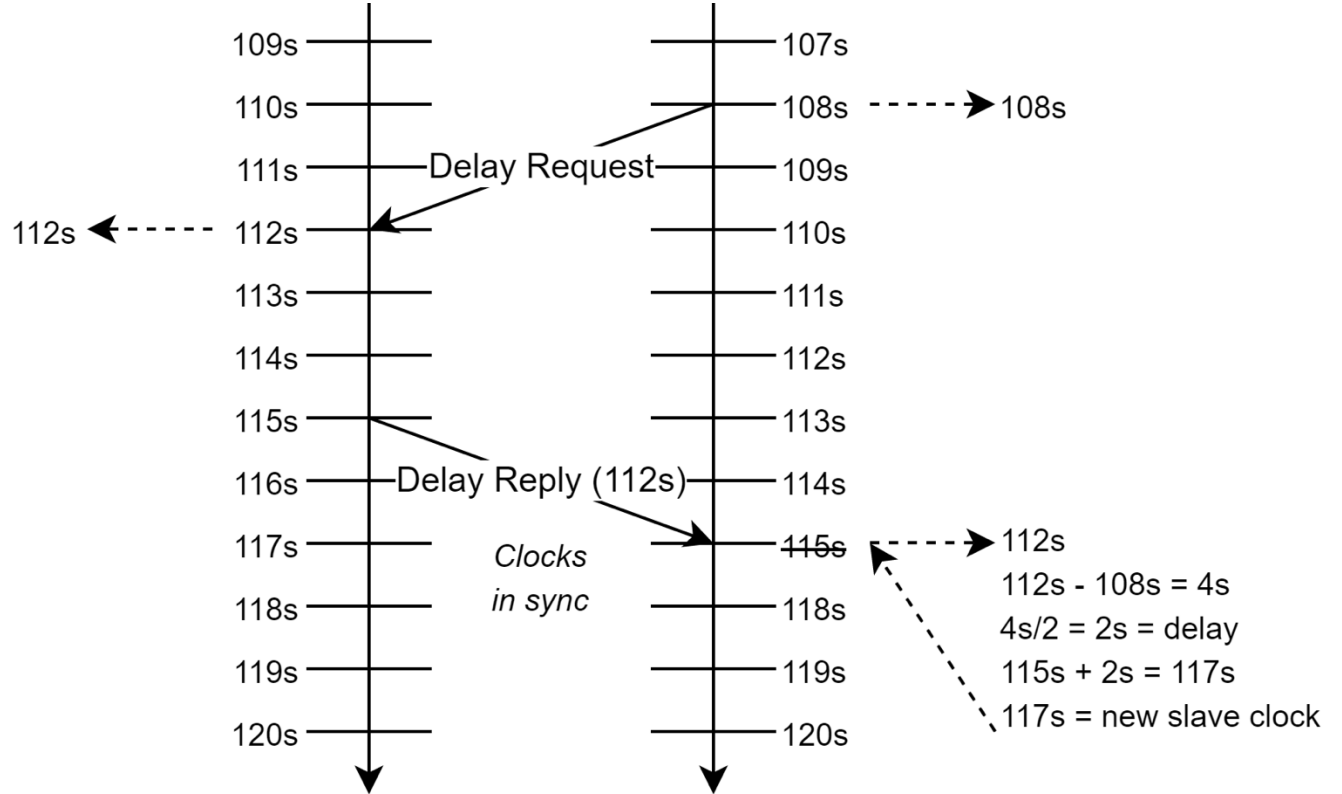
# Precision Time Protocol (PTP)



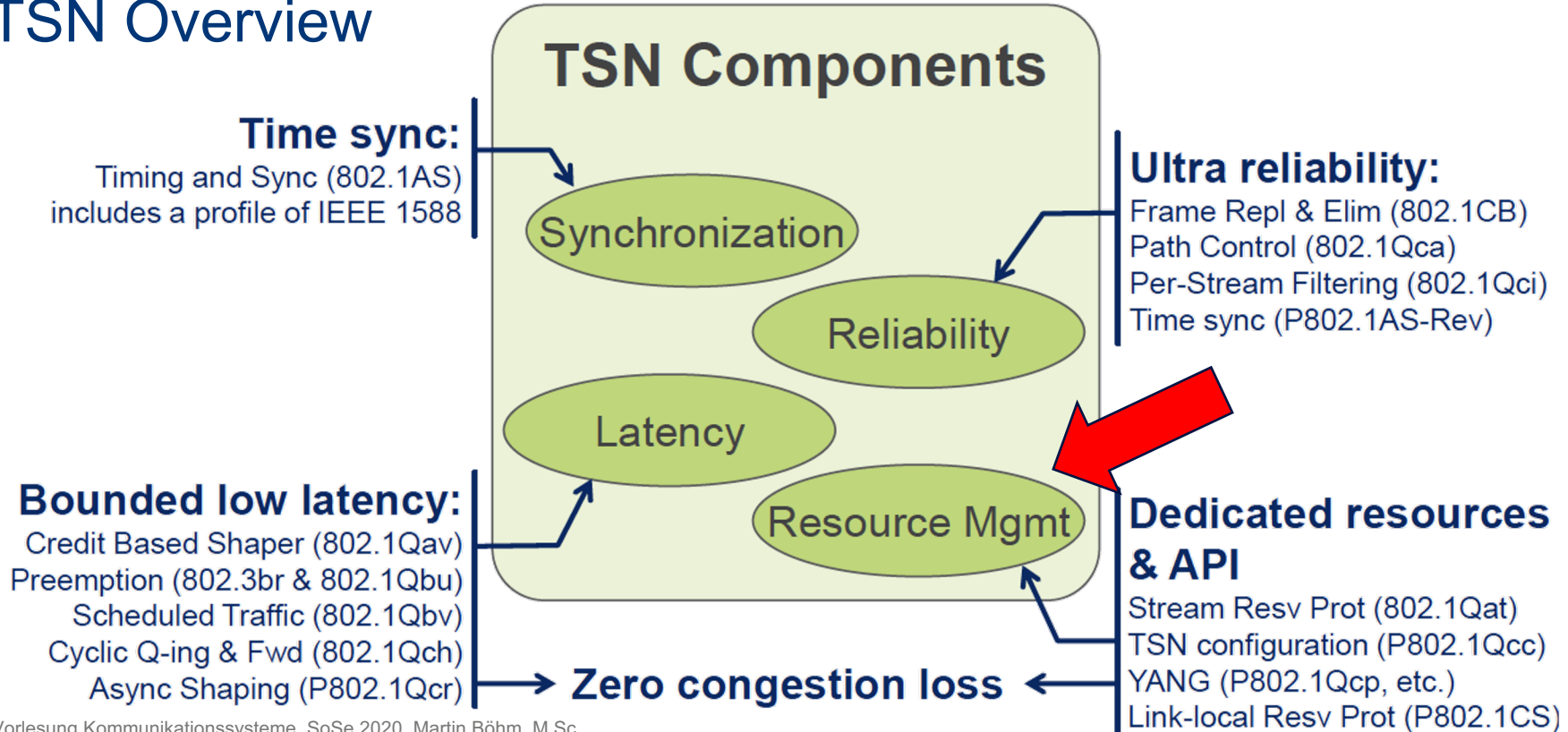
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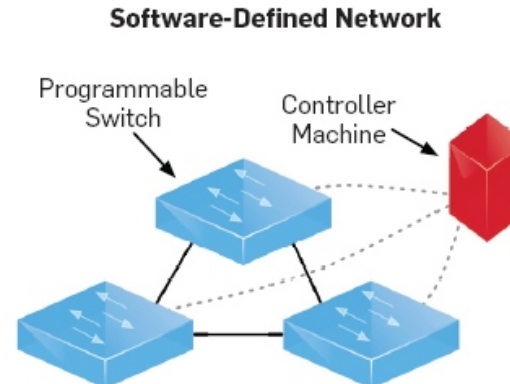
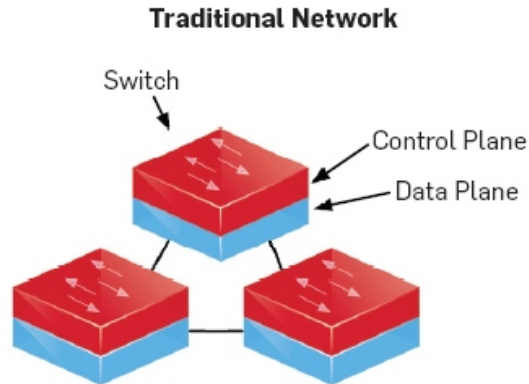


# TSN Overview



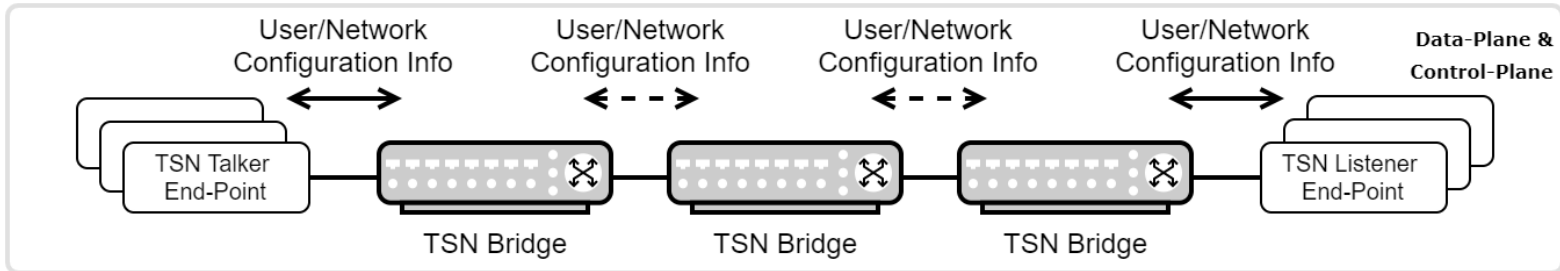
# Data-Plane & Control-Plane

- Data-Plane
  - Forwards packets
- Control-Plane
  - Defines what to do with incoming packets



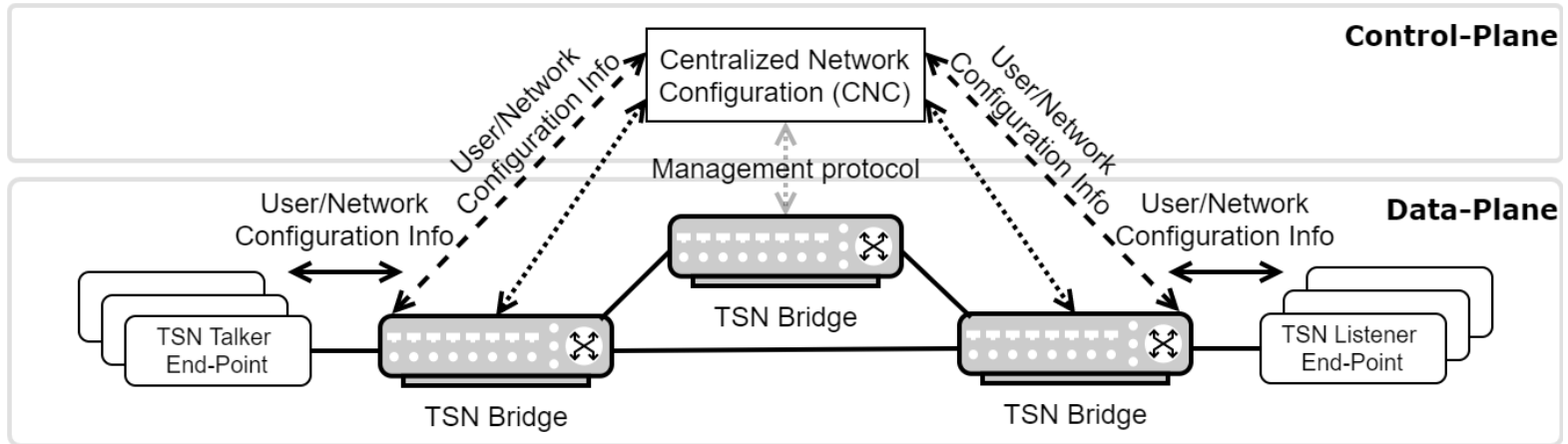
# Auto Configuration

- IEEE 802.1Qcc - Stream Reservation Protocol (SRP) Enhancements and Performance Improvements
- Standard describes 3 different auto configuration mechanisms
- Fully distributed model



# Auto Configuration

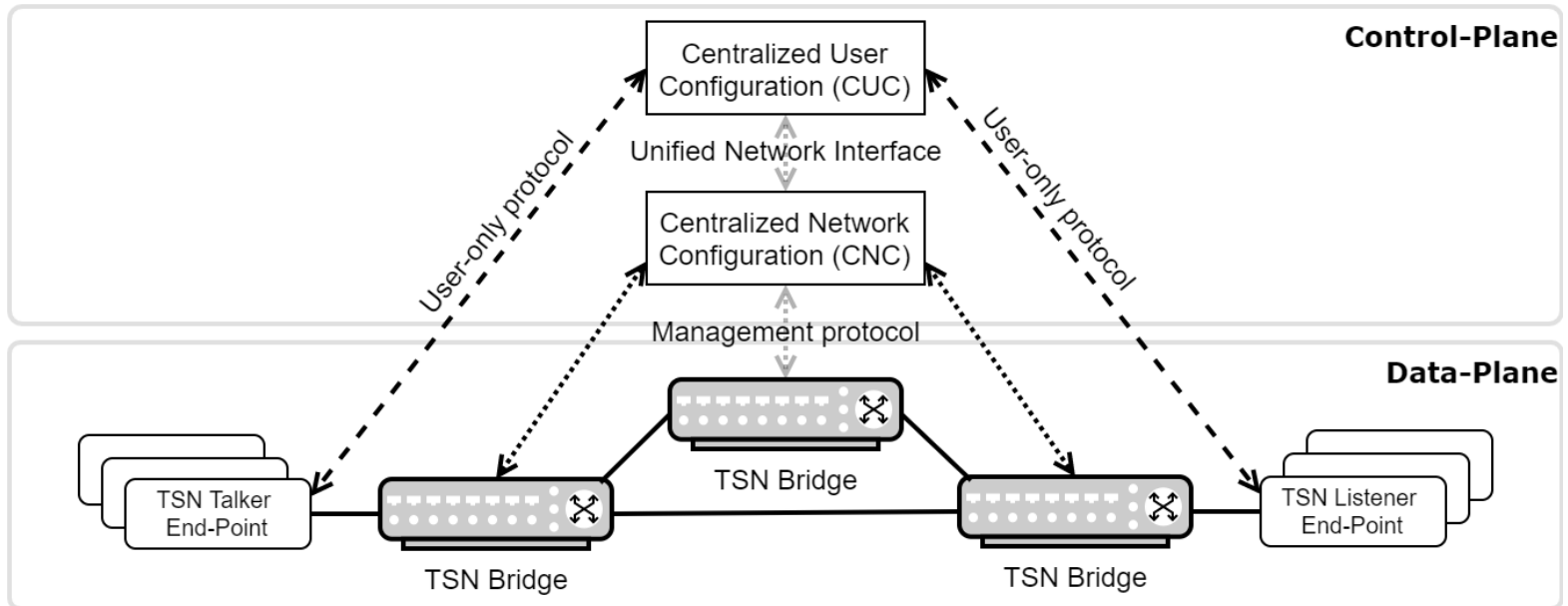
- Centralized network / distributed user model





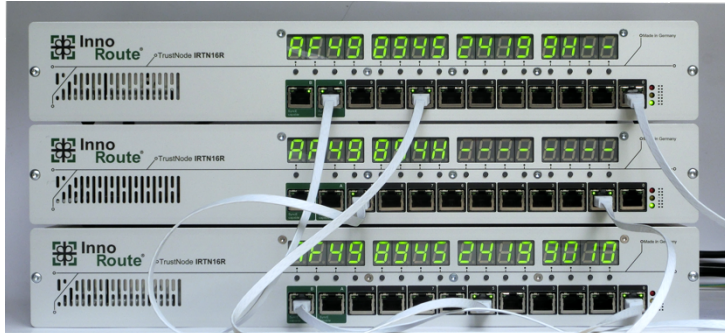
# Auto Configuration

- Fully centralized model



# Configuration of a TSN Bridge TrustNode (Research Equipment Coms Lab)

- > TNtsnctl Change\_entry -i0 -S0x01 -I5000000000 -a2 -P0
- > TNtsnctl Change\_entry -i1 -S0xff -I5000000000 -a2 -P0
- > TNtsnctl apply -C1000000000 -b0 -P0



Add timeslot to GCL

-i0 → ID

-S0x01 → Open Gate 1

-S0xff → Open All Gates

-I5000000000 → in ns (0,5s)

-a2 → Entries in GCL

-P0 → Switch Port 0

Apply Configuration

-C100.. → Total cycle period

-b0 → Basetime/Start of cycle

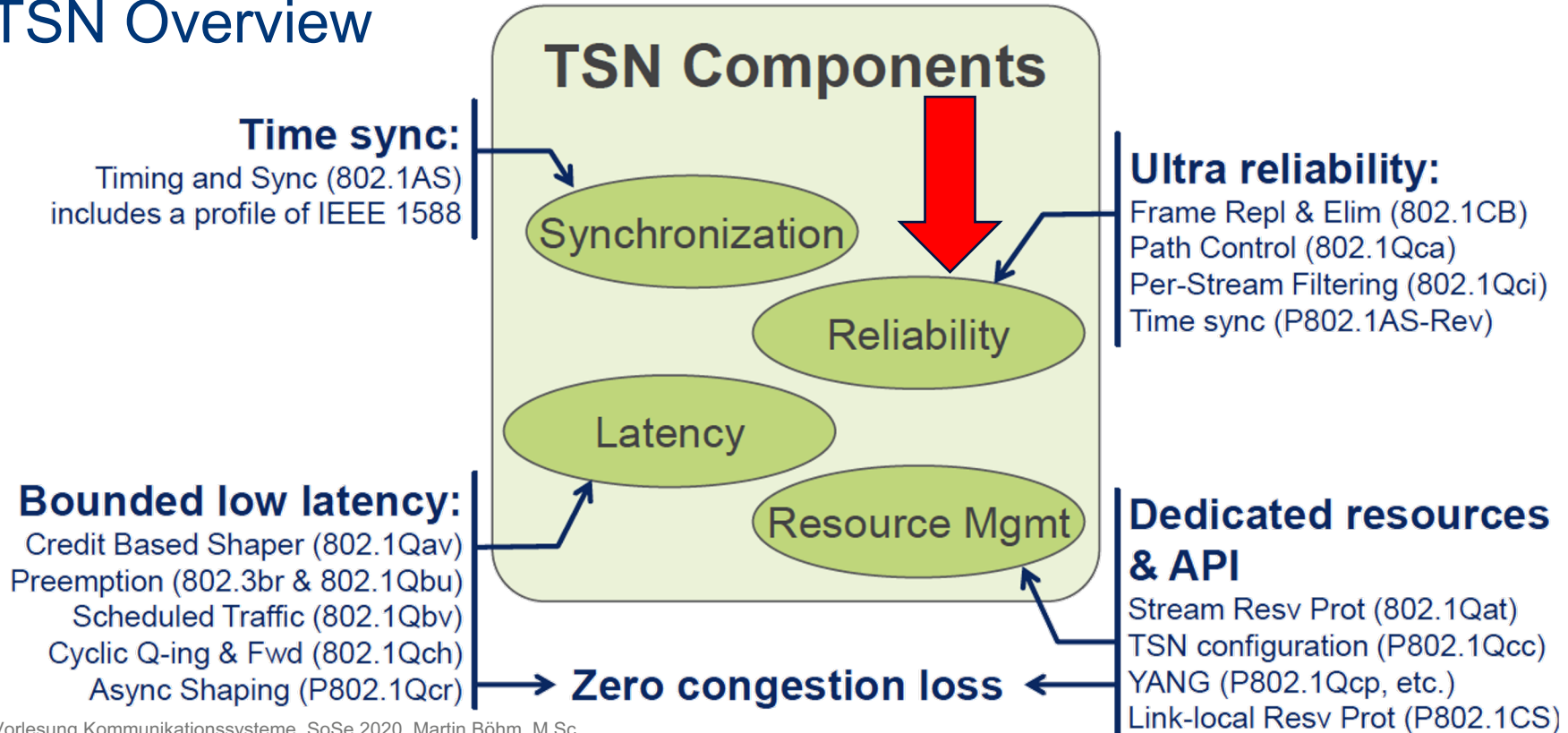
-P0 → Switch Port 0

# Device Configuration

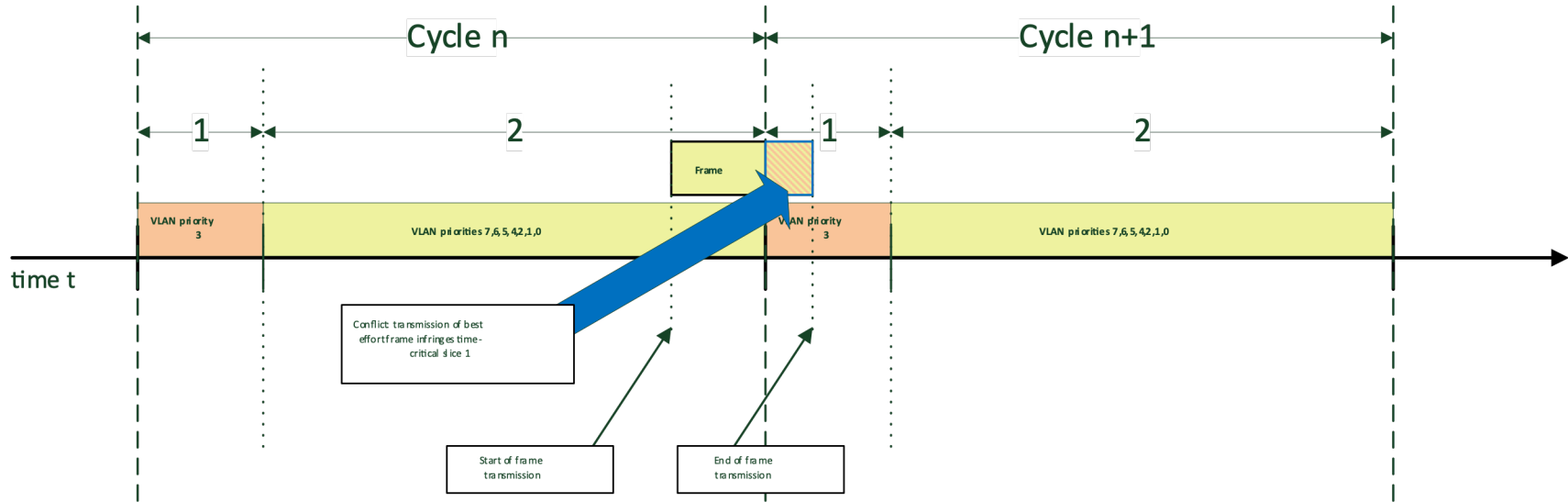
- Manual configuration
  - Local
  - Remote
- YANG Data Model (IEEE 802.1Qcp)
  - Device representation in XML/JSON
  - Configure schedules, flows, ...

```
<TNtas xmlns="urn:sysrepo:TrustNode:TNsysrepo">
  <ports>
    <id>0</id>
    <GCL>
      <id>0</id>
      <timeperiod>500000000</timeperiod>
      <gatestates>1</gatestates>
    </GCL>
    <GCL>
      <id>1</id>
      <timeperiod>500000000</timeperiod>
      <gatestates>2</gatestates>
    </GCL>
    <admin_base_time>0</admin_base_time>
    <admin_cycle_time_ext>0</admin_cycle_time_ext>
    <gate_enable>true</gate_enable>
  </ports>
</TNtas>
```

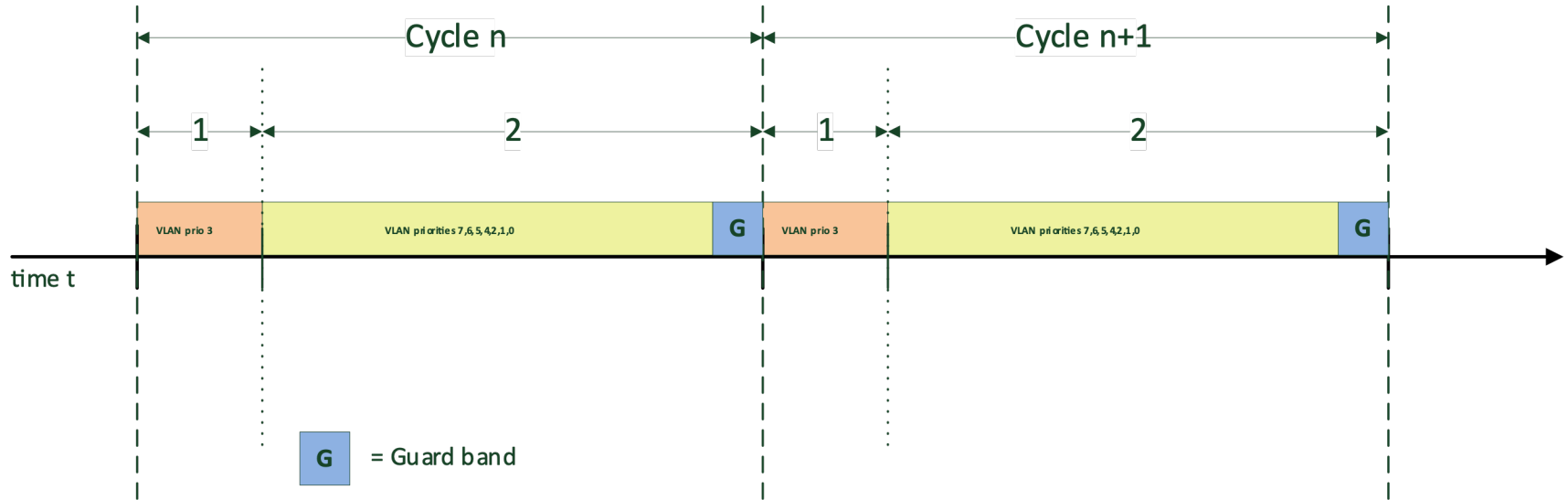
# TSN Overview



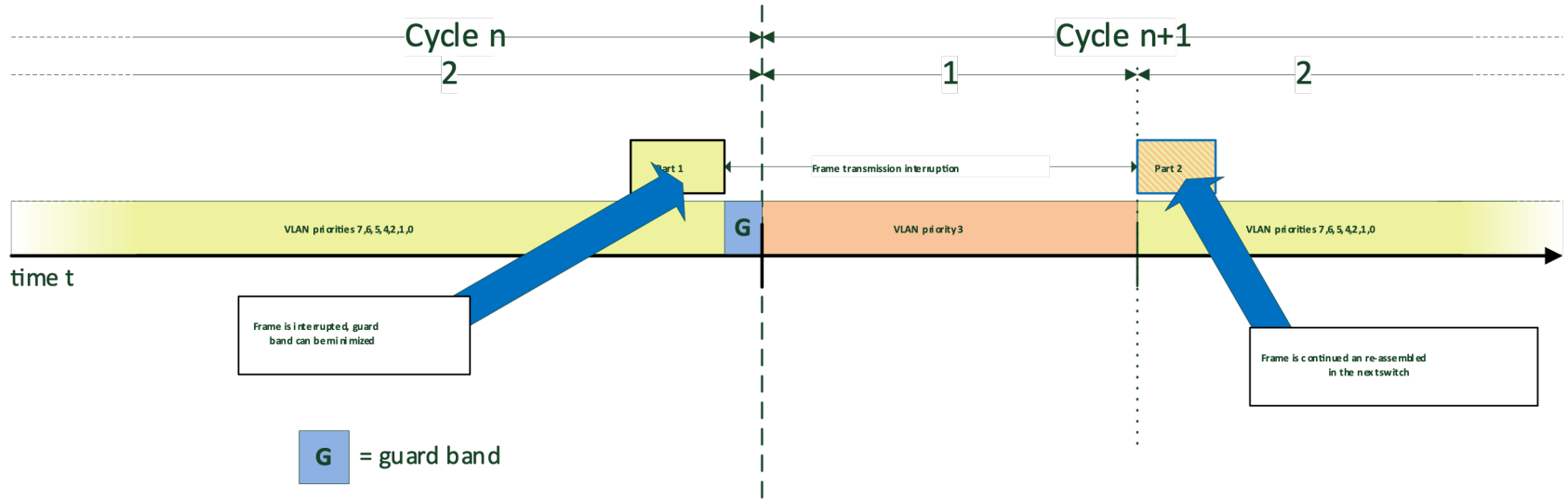
# Guard Bands



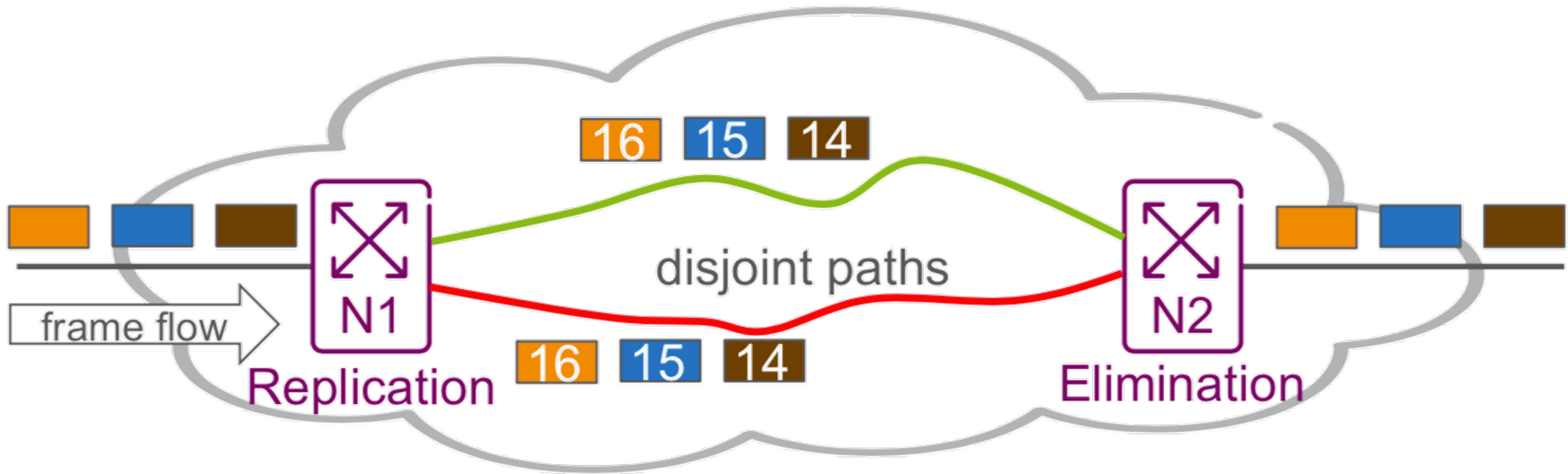
# Guard Bands



# Frame Preemption (IEEE 802.1Qbu - Frame Preemption)



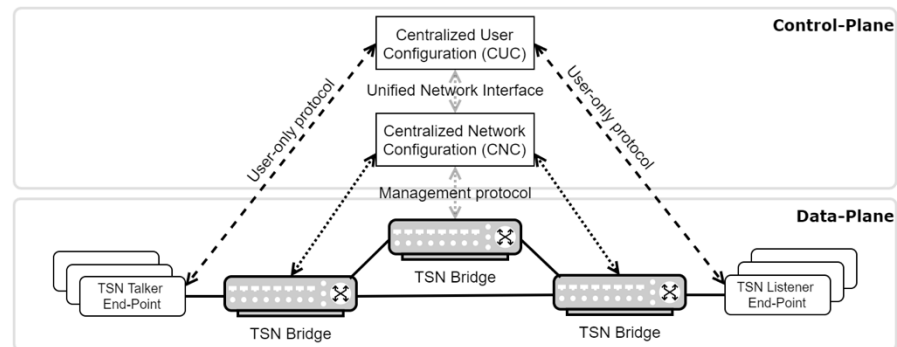
# Frame Replication and Elimination for Reliability (IEEE 802.1CB)





## TSN Standards

- Time synchronization (IEEE 802.1AS-rev)
- Request a connection (IEEE 802.1Qcc)
- Find path (IEEE 802.1Qca)
- Calculate schedule (IEEE 802.1Qch)
- Filter traffic (IEEE 802.1Qci)
- Device configuration (IEEE 802.1Qcp)
- Scheduled traffic (IEEE 802.1Qbv)
- Frame replication (IEEE 802.1CB)
- Frame preemption (IEEE 802.1Qbu)
- ...



# Store-and-Forward vs. Cut-Through Forwarding

- Store-and-Forward
  - Wait for full frame to arrive before forwarding
  - Error handling
  - Apply security policies
- Cut-Through
  - Examine frame header and forward immediately before whole frame has been received
  - No error handling
  - Reduce latency

## Current Research - Ostfalia

- SecuRIIn - Security Referenzmodell Industrie 4.0
  - <https://securin.de>



- MONAT - Modellbasierte und bedarfsgerechte Netzwerkkonfiguration für Netzwerke der Automatisierung und Telekommunikation
  - <http://www.forschungsprojekt-monat.de/>



- GrowIn 4.0 – Growing into Industry 4.0
  - <https://northsearegion.eu/growin4/>



- Spin-Off:
  - <https://2kai.eu/>

