DETERMINISTIC6G

IEEE 802.1 Interim Meeting

Control Plane Extensions for Wireless-Aware Traffic Engineering with Corresponding YANG Data Models

Hamburg, Germany,
September 20, 2024

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DETERMINISTIC6G has received funding from the European Union's Horizon Europe programme under grant agreement No 101096504.

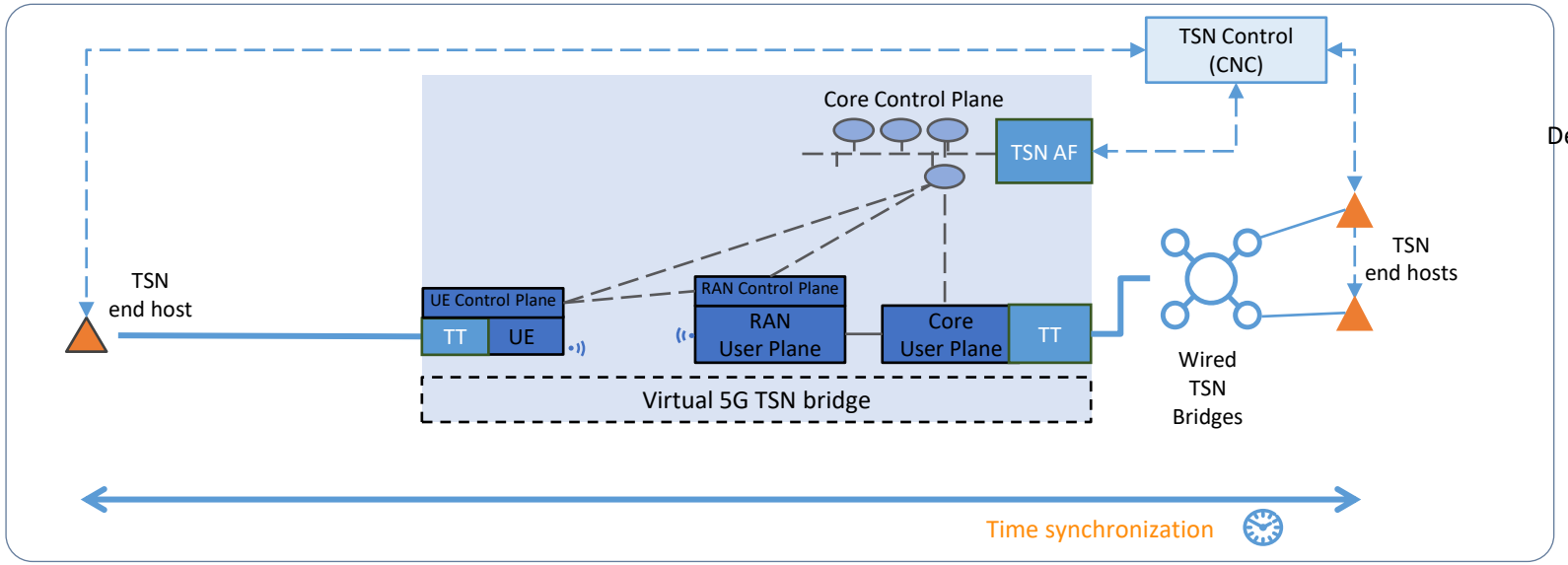
Agenda

- Virtual (wireless) TSN bridge
  - Characteristic port-to-port delay
- Wireless-friendly end-to-end scheduling
  - Requirements on port-to-port delay information
- Extended YANG Model for port-to-port delay
- NETCONF to retrieve port-to-port delay information

5G Standard Support for TSN

Standardized: 5G support for TSN (and for DetNet similarly)

- The 5G System represented as a **Virtual (Wireless) TSN bridge** in the end-to-end TSN view
  - External behavior (functionality) same for wired and wireless bridges
  - Including in particular gates and Gate-Control List (time table) for scheduled traffic (IEEE 802.1Qbv)
- Upper-bound latency via *ultra-reliable and low latency* (URLLC) communication

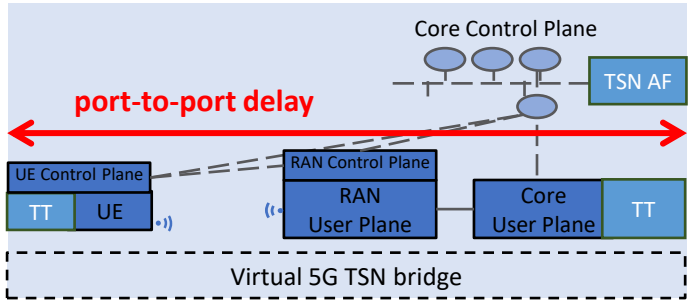


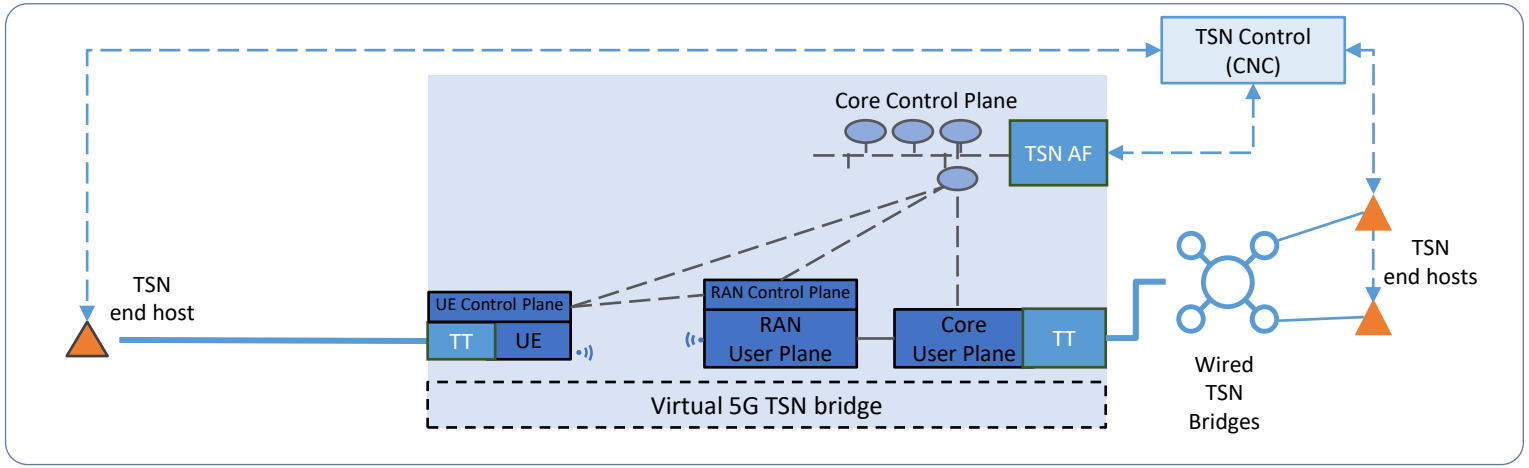
3GPP TS 23.501
5G-ACIA: 5G-TSN and 5G for IIoT Deliverables D1.4, D1.5, D5.1, D5.2, D5.3, D5.4, D5.5 and 5G-SMART Booklet [5G-SMART]

UE : User Equipment
RAN: Radio Access Network
CNC: Centralized Network Configuration
TT: TSN Translator
AF: Application Function

End-to-End Scheduling of Scheduled Traffic (802.1Qbv)

- CNC configures schedules (time tables = gate control lists) for scheduled traffic (IEEE 802.1Qbv)
  - Schedule controls **queuing delay** (only)
- Algorithms for schedule calculation require information about delay:
  - Propagation delay between bridges
  - Transmission delay of frames (from line rate and frame size)
  - **Port-to-port delay of bridge (aka Bridge Delay)**





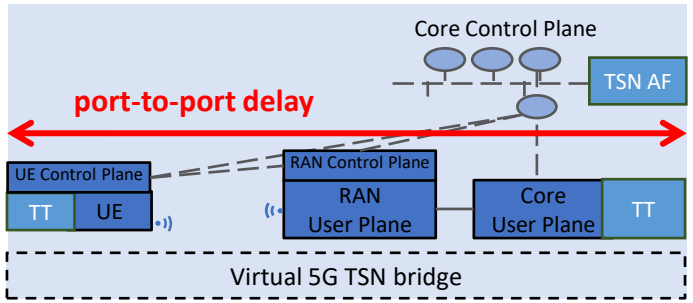
Port-to-Port Delay: Wired TSN Bridge vs. 5G Virtual TSN Bridge

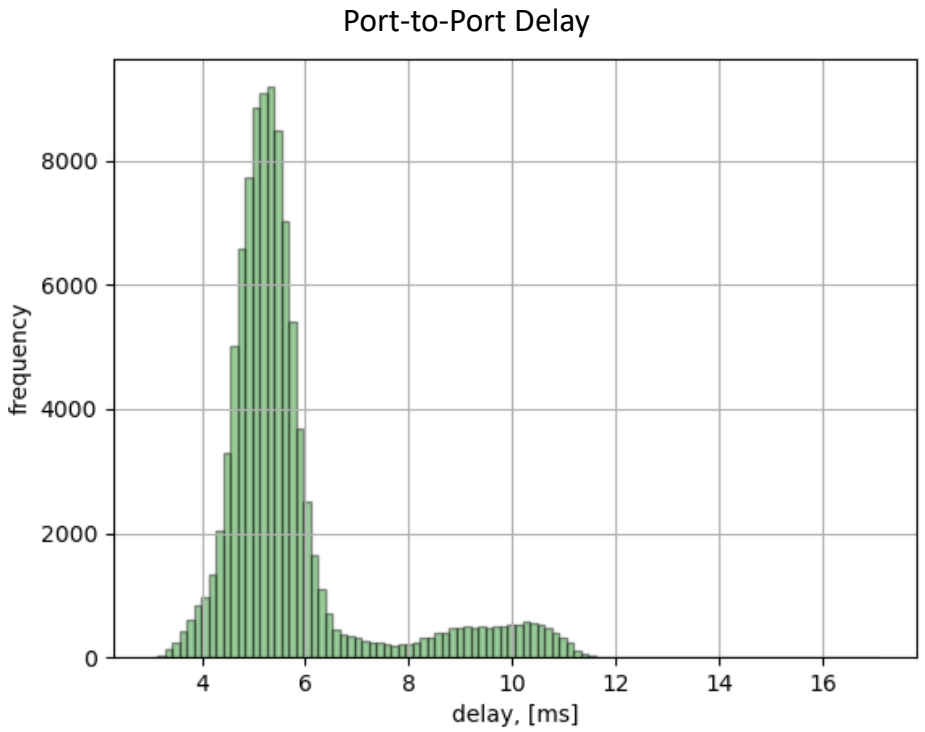
Port-to-Port Delay:

- Delay from ingress to egress port
- Without transmission selection
  - No queuing in egress queue (gates open)

Port-to-Port Delay Characteristics of Virtual Bridge:

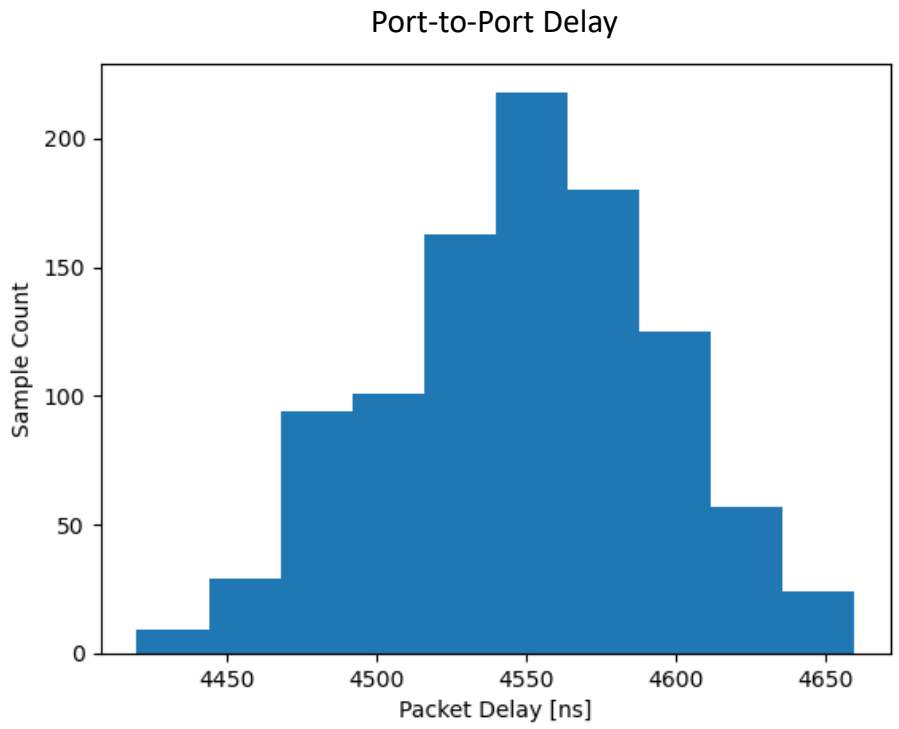
- Greater than for wired TSN bridges
  - But support for upper bound provided by URLLC
- Stochastic
  - Heavy-tailed



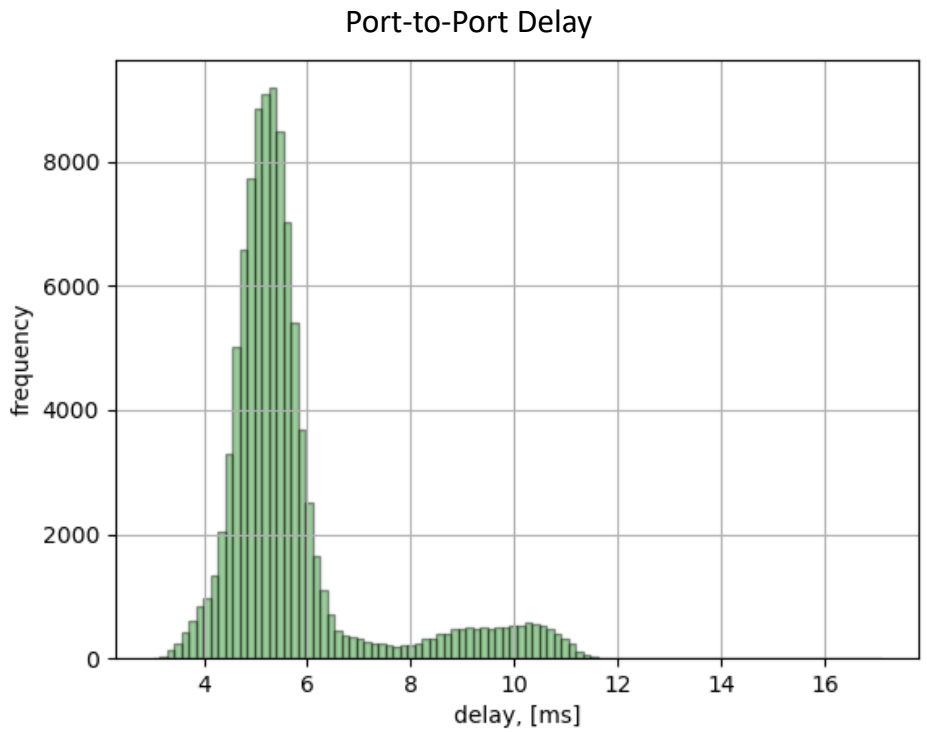


Port-to-Port Delay: Wired TSN Bridge vs. 5G Virtual TSN Bridge

Wired TSN Bridge



5G Virtual TSN Bridge



Delay data from measurements available here:
https://github.com/DETERMINISTIC6G/deterministic6g_data

Standard Support for Port-to-Port Delay Information (according to IEEE 802.1Q)

- "Each set of Bridge Delay attributes is accessed using three indices: **ingress Port**, **egress Port**, and **traffic class**."
- "The delays represent the **worst-case range per the design of the Bridge**, and are **not measured**."

Table 12-38—Bridge Delay attributes

Name	Data type	Operations supported[a]	Conformance[b]	References
independentDelayMin	unsigned integer	R	B	12.32.1.1
independentDelayMax	unsigned integer	R	B	12.32.1.1
dependentDelayMin	unsigned integer	R	B	12.32.1.2
dependentDelayMax	unsigned integer	R	B	12.32.1.2

[a] R = Read only access; RW = Read/Write access.
[b] B = Required for Bridge or Bridge component support of Stream reservation remote management; b = Optional for Bridge or Bridge component support of Stream reservation remote management.

[IEEE 802.1Q 2022]

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- **Wireless-friendly end-to-end scheduling**
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- Extended YANG Model for port-to-port Delay
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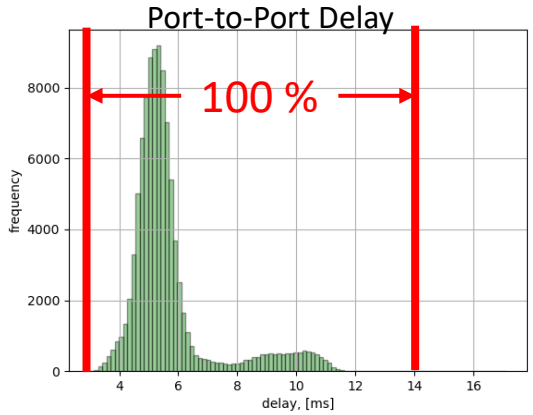
Wired vs. Wireless-friendly Scheduling for 802.1Qbv

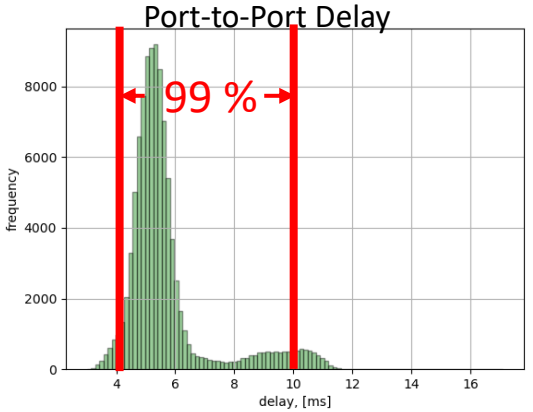
Wired TSN schedules

- **Reliability**(*1)**:** 100 % (**deterministic**)
  - Worst-case port-to-port delay



(Our) Wireless-friendly TSN schedules

- **Reliability:** a parameter (**dependable**)
  - Time window from delay distribution



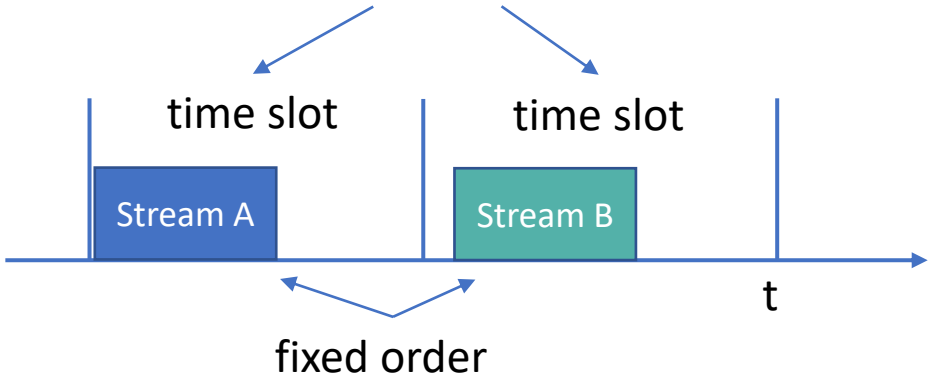
(*1) deliver frame within deadline

Wired vs. Wireless-friendly Scheduling for 802.1Qbv

Wired TSN schedules

- **No interleaving time slots**
  - Exclusive time slots per stream

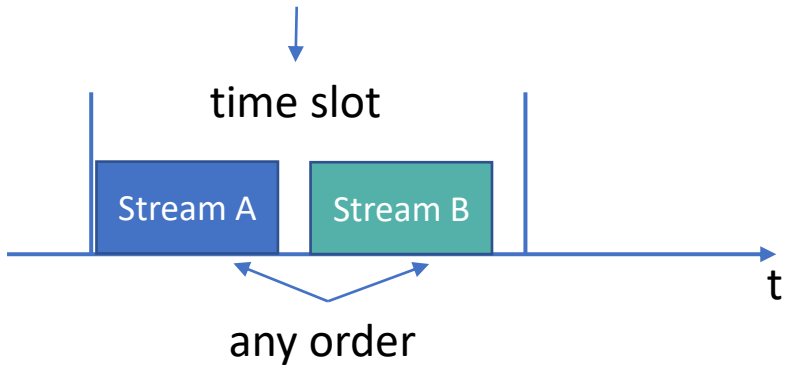
Time slots and stream assignment as defined by the calculated schedule



(Our) Wireless-friendly TSN schedules

- **Interleaving time slots**
  - Frames from multiple streams per time-slot

Time slots and stream assignment as defined by the calculated schedule



Wired vs. Wireless-friendly Scheduling: Performance

Evaluation Setup

- Real 5G PD histograms
- 100 Mbps Ethernet links
- Frames per 20 ms hypercycle:
  - 60 wireless + 50 wired
- Simulation: 100k hypercycles

type	$f.size$	$f.period$	$f.latency$	$f.jitter$
wireless	100	20 ms	20 ms	5 ms
wired	100	4 ms	500 µs	0

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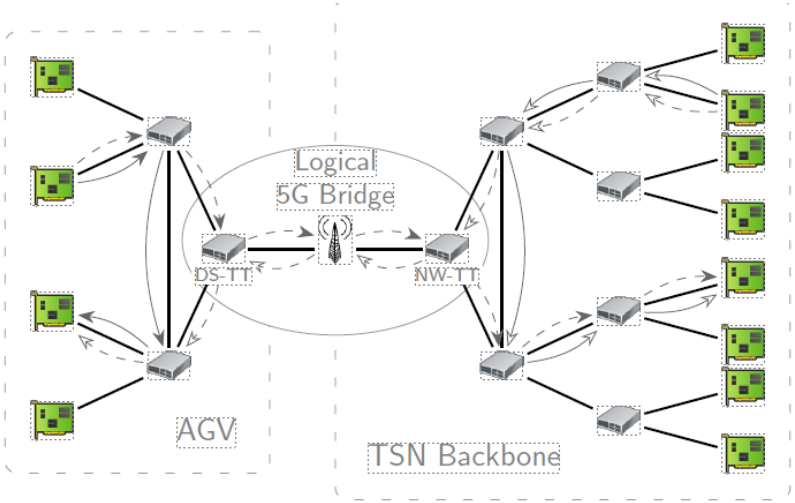
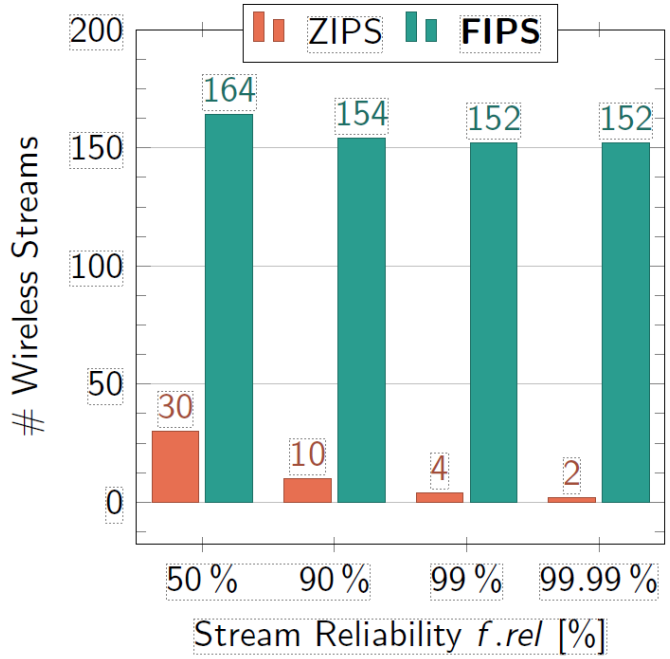


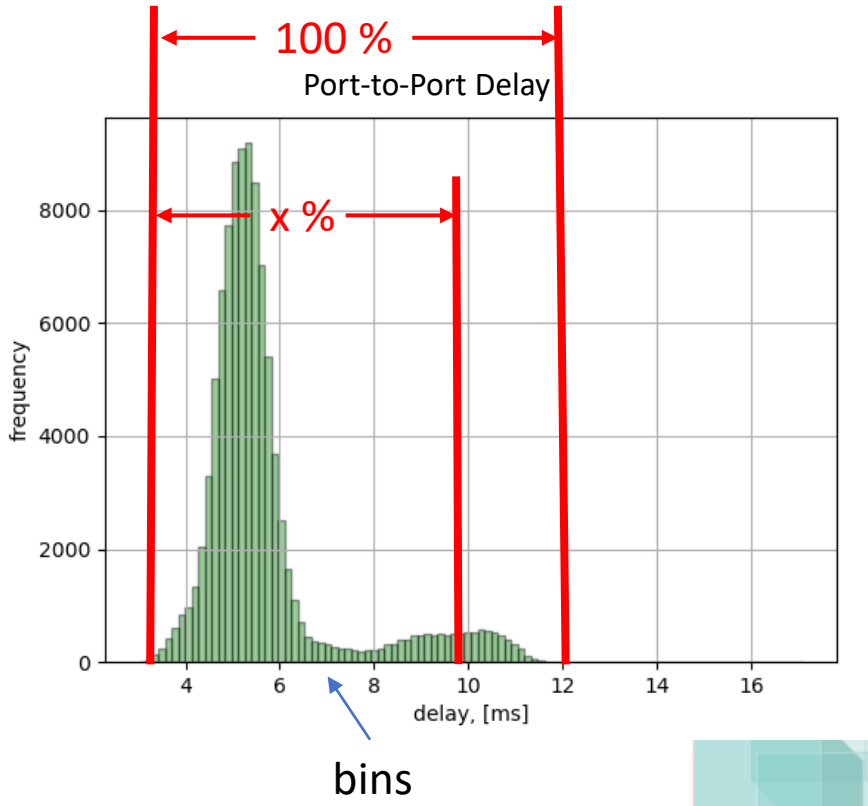
Efficiency: number of schedulable streams

- ZIPS: zero-interleaving (wired algorithm)
- FIPS: fully interleaving (wireless-friendly)



Requirement to Implement Wireless-friendly Scheduling: Extended Port-to-Port Delay Model

- Wireless-friendly scheduling needs information about **probabilistic port-to-port delay distribution**
- Our approach: **Histograms**
  - Binning of **online** (!) **delay measurements** by bridge
- Histograms are versatile including:
  - the standard worst-case bound model
    - 100 % between min and max delay (single bin)
    - **backward compatible** to standard min/max model
  - Quantiles
    - x % between min and max delay (single bin)
    - Difficult to specify the “best” quantile in a standard
  - Approximation of probability distribution functions
- Reasonably **simple to implement** on bridge



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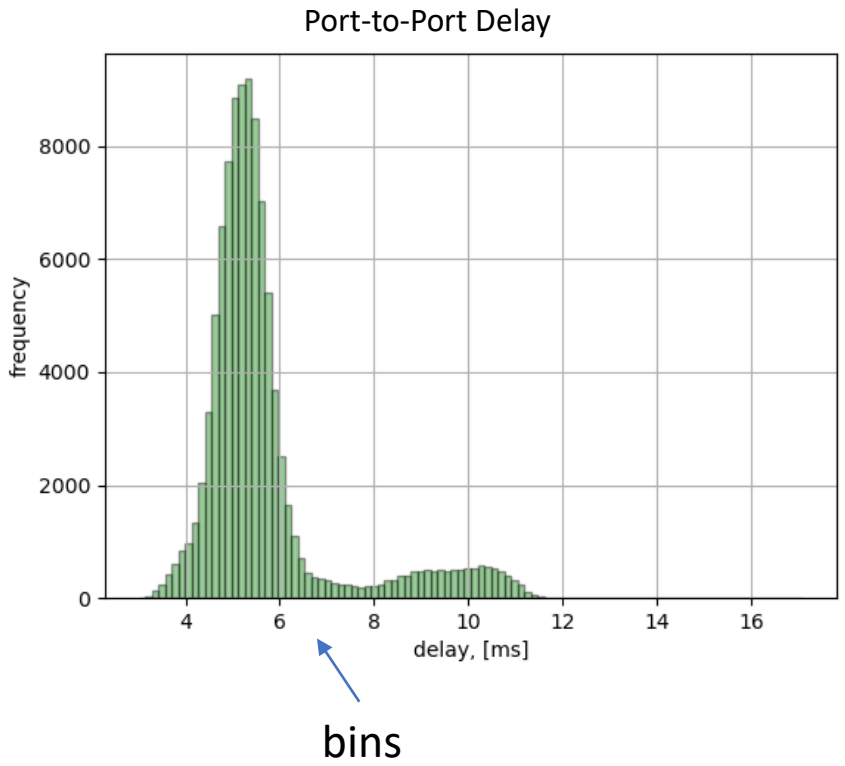
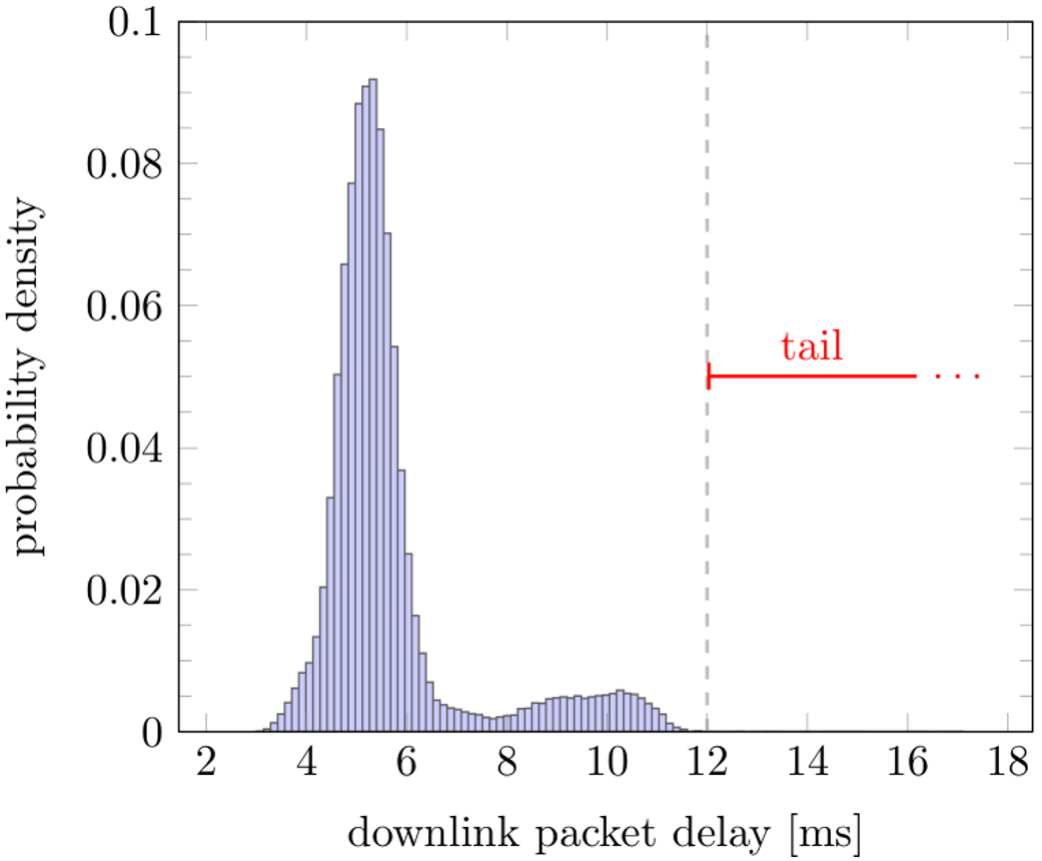
YANG Model for Port-to-Port Delay Histograms: Bins

```
grouping delay-histogram {
    description "Delay histogram";
    leaf start {
        type uint64;
        description
            "The start value of the first bin in nano-seconds.
            If not specified, the first bin starts at 0.";
    }
    leaf bin-count {
        type uint32;
        mandatory true;
        description "Number of bins.";
    }
    list bin {
        description "Bins of histogram.";
        key index;
        leaf index {
            type uint32;
            mandatory true;
            description "The index of this bin.";
        }
        leaf width {
            type uint64;
            mandatory true;
            description "The width of this bin in nano-seconds.";
        }
        leaf count {
            type uint32;
            mandatory true;
            description "Count of values in this bin.";
        }
    }
```



YANG Model for Port-to-Port Delay Histograms: Support for unbound delay distributions

```
grouping delay-histogram {
    …
    leaf tail {
        type uint32;
        description
            "Count of values in the
             tail of the histogram
             after the upper bound of
             last bin until infinity.
             Can be used to define an
             unbounded distribution.";
    }
```



YANG Model for Port-to-Port Delay Histograms: Added Below Bridge Component

- Added to **bridge component** (as for standard model; IEC/IEEE 60802)
- Per **port-pair** histograms (as for standard model)
  - Multiple histograms possible, e.g., for different frame sizes, channel conditions, etc.

```
augment "/dot1q-bridge:bridges/dot1q-bridge:bridge/dot1q-bridge:component" {
    container port-to-port-delays {
        config false;
        list port-to-port-delay {
        key "ingress-port egress-port traffic-class index";
        leaf ingress-port {
            type dot1qtypes:port-number-type;
            config false;
            mandatory true;
            description "Unique number of ingress port.";
        }
        leaf egress-port {
            type dot1qtypes:port-number-type;
            config false;
            mandatory true;
            description "Unique number of egress port.";
        }
```

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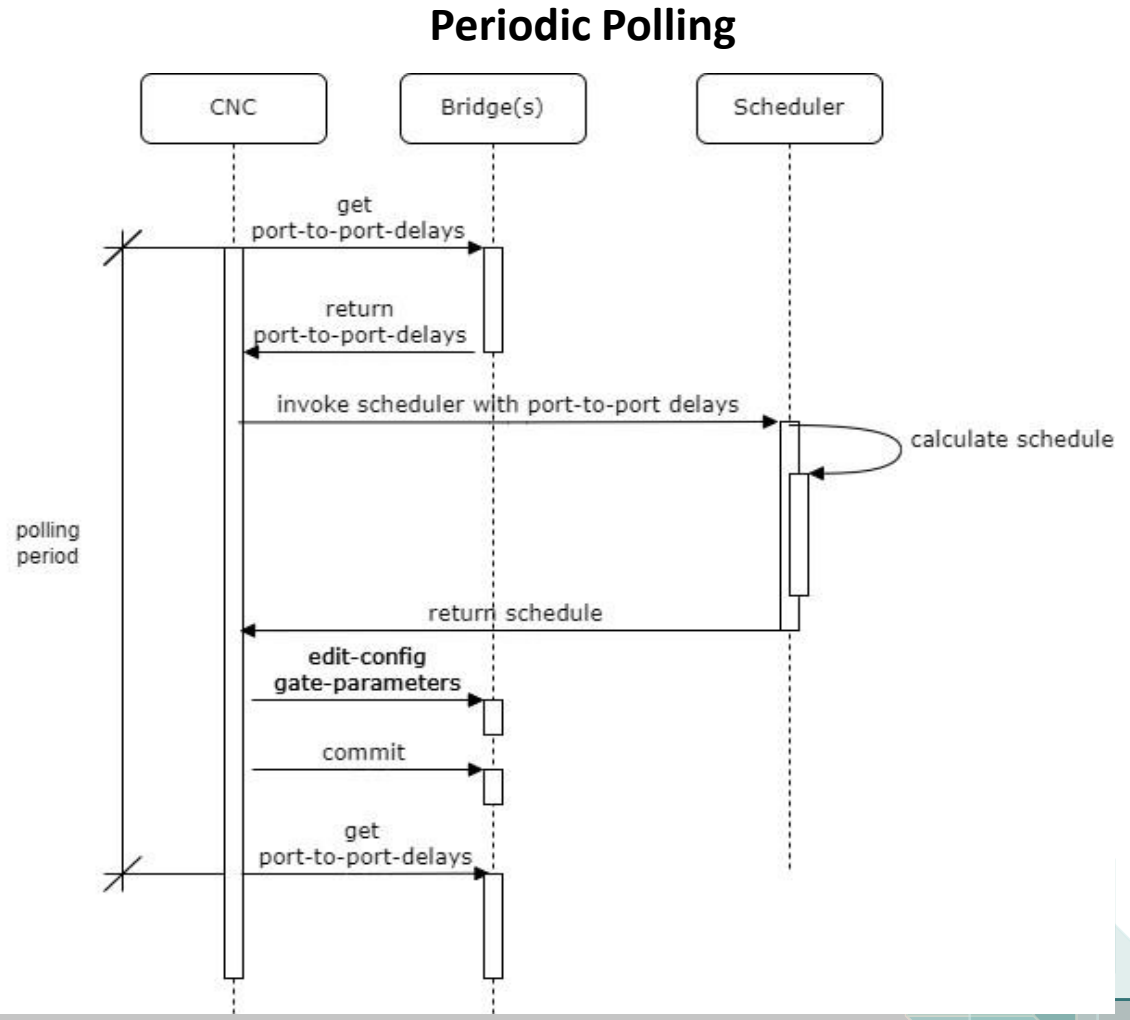
NETCONF for Retrieving Port-to-Port Delay

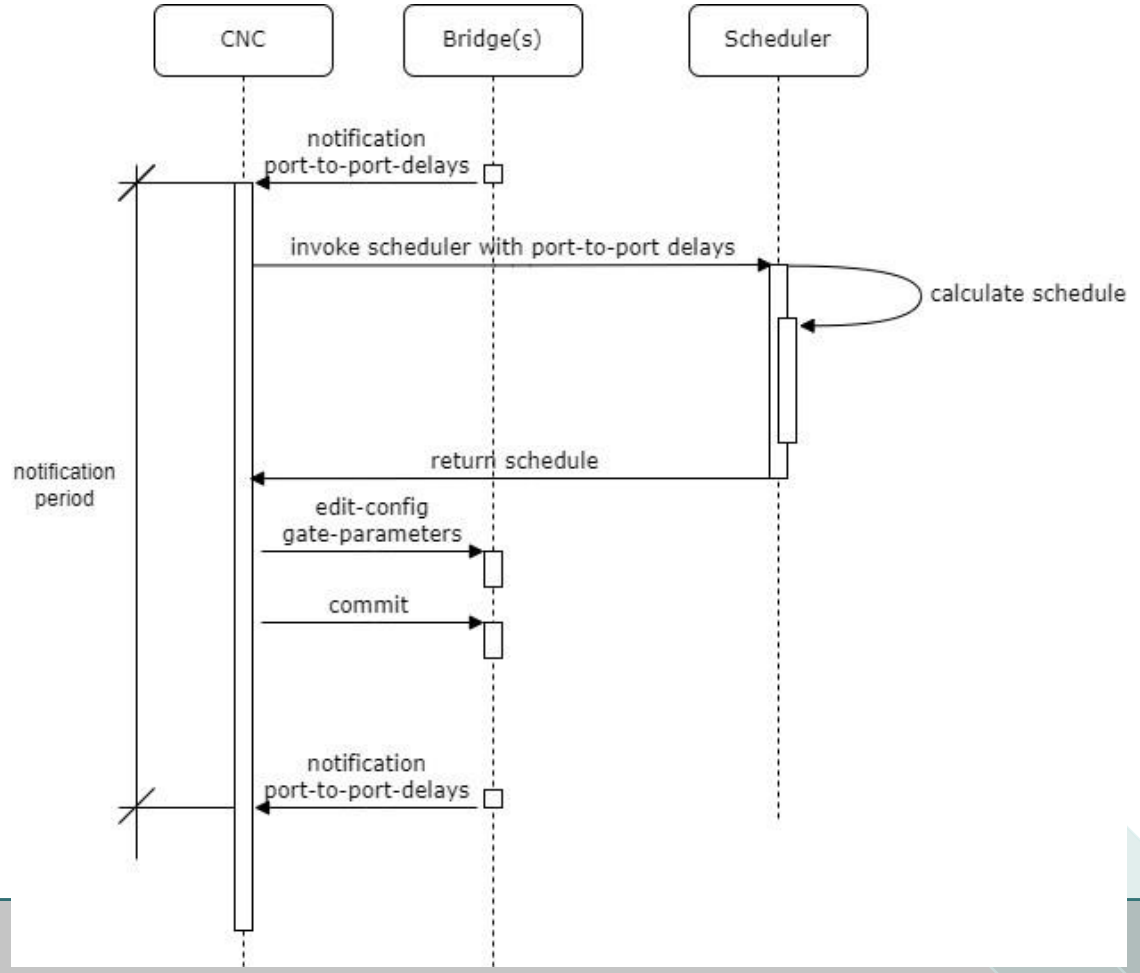
- Port-to-port delay might be non-stationary
- Different **NETCONF**-based schemes to retrieve current information by CNC:
- **Periodic polling** and **periodic subscriptions**
  - Difficult to define polling period



NETCONF for Retrieving Port-to-Port Delay

- Port-to-port delay might be non-stationary
- Different **NETCONF**-based schemes to retrieve current information by CNC:
- **Periodic polling** and **periodic subscriptions**
  - Difficult to define polling period
- **Event-based**
  - on-change subscriptions in YANG Push
- Proactively if delay prediction is available
  - Avoids invalid schedule due to slow schedule calculation

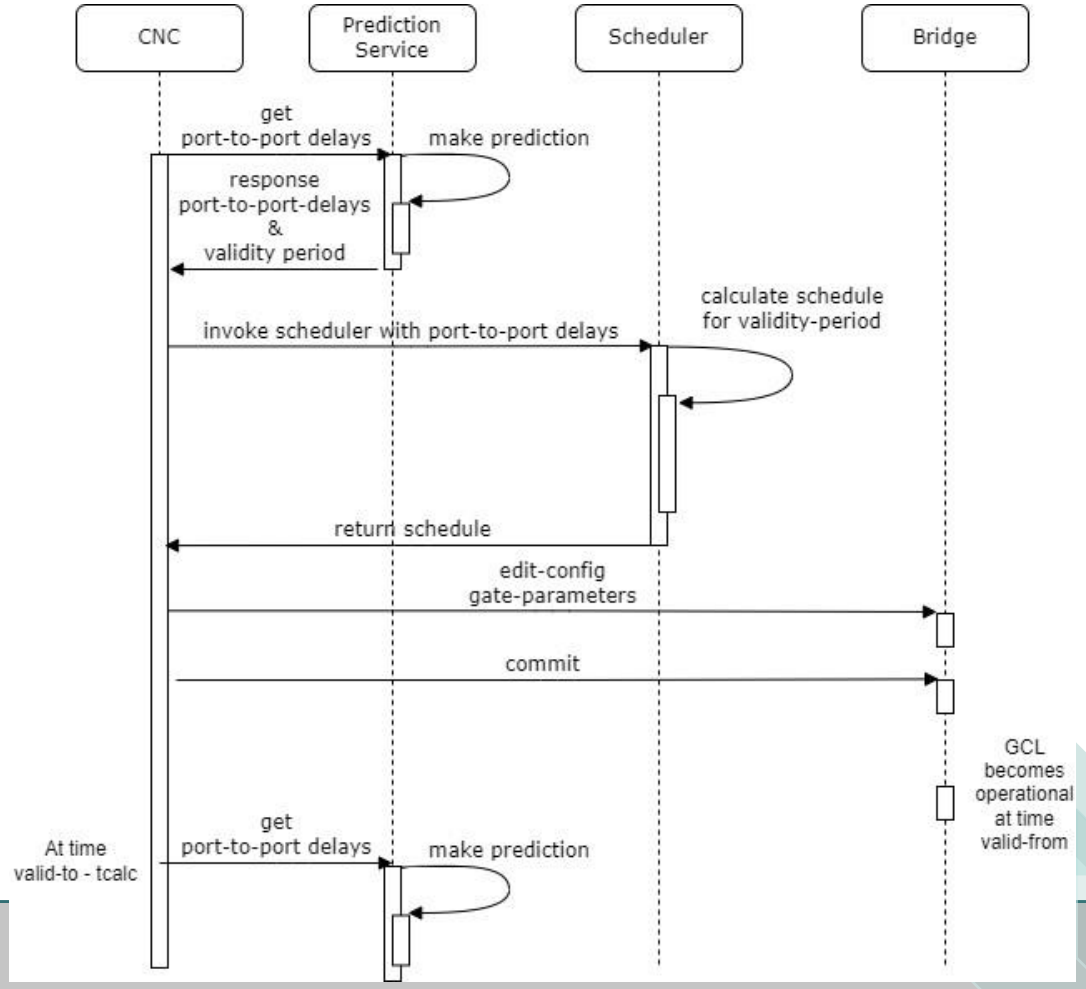
Event Notifications



NETCONF for Retrieving Port-to-Port Delay

- Port-to-port delay might be non-stationary
- Different **NETCONF**-based schemes to retrieve current information by CNC:
- **Periodic polling** and **periodic subscriptions**
  - Difficult to define polling period
- **Event-based**
  - on-change subscriptions in YANG Push
- **Proactively** if delay **prediction** is available
  - Avoids invalid schedule due to slow schedule calculation when reacting to out-dated distribution

Proactive



Conclusion

- **Virtual (wireless) bridge** has **characteristic port-to-port delay**
  - Greater magnitude, probabilistic, heavy-tailed
- **Wireless-friendly scheduling** can significantly improve efficiency of scheduled traffic
  - Interleaving of streams
  - Reliability as parameter of dependable schedule
- **Extended YANG models** to define histograms of port-to-port delay
- **NETCONF** to retrieve port-to-port delay information
  - Pull & event-based
  - Proactively with delay prediction

References / Contact

- Delay measurements of virtual TSN bridge (documentation and data):
  - D4.2: Latency measurement framework https://deterministic6g.eu/images/deliverables/DETERMINISTIC6G-D4.2_v1.0.pdf
  - Github: https://github.com/DETERMINISTIC6G/deterministic6g_data
- Wireless-friendly scheduling
  - D3.4: Report on Optimized Deterministic End-to-End Schedules for Dynamic Systems, https://deterministic6g.eu/images/deliverables/DETERMINISTIC6G-D3.4-v1.0.pdf
  - Contact authors for more information (pre-print): simon.egger@ipvs.uni-stuttgart.de
- YANG models, NETCONF integration (files and documentation)
  - D3.4: Report on Optimized Deterministic End-to-End Schedules for Dynamic Systems, https://deterministic6g.eu/images/deliverables/DETERMINISTIC6G-D3.4-v1.0.pdf
  - Github: https://github.com/DETERMINISTIC6G/deterministic6g_yang_models

… or directly contact: frank.duerr@ipvs.uni-stuttgart.de

DETERMINISTIC6G Grant Agreement No. 101096504

The DETERMINISTIC6G project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101096504.

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