DETERMINISTIC6G

KuVS NetSoft

Simulating and Emulating the Characteristic Packet Delay of Logical 5G TSN Bridges

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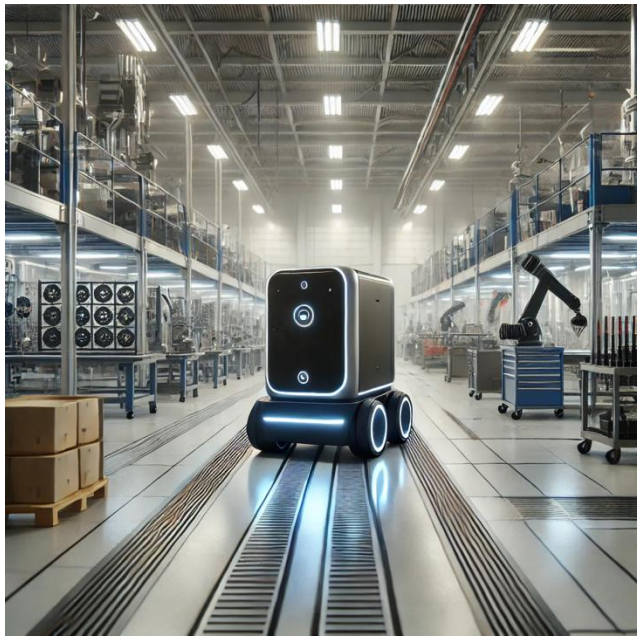
Converged 5G/TSN Networks



Images generated by DALL-E

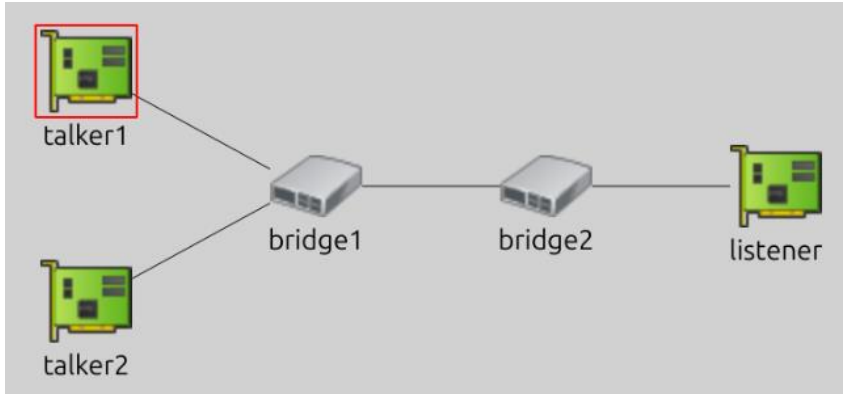
Agenda

- Introduction to Converged 5G/TSN networks
- Validation Framework Architecture
- 6GDetCom Simulator
- 6GDetCom Emulator
- Conclusion

Converged 5G/TSN Networks

Traditional TSN networks:

- Devices (endpoints and bridges) implement TSN features
- Ethernet-links:
  - Constant link speed
  - Low packet loss



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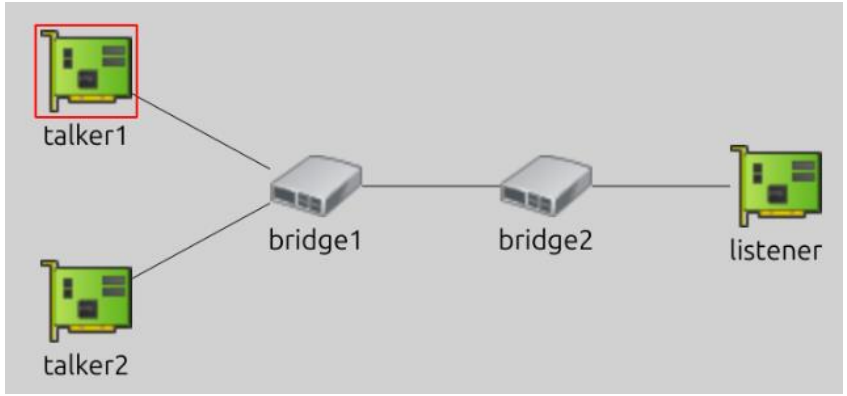
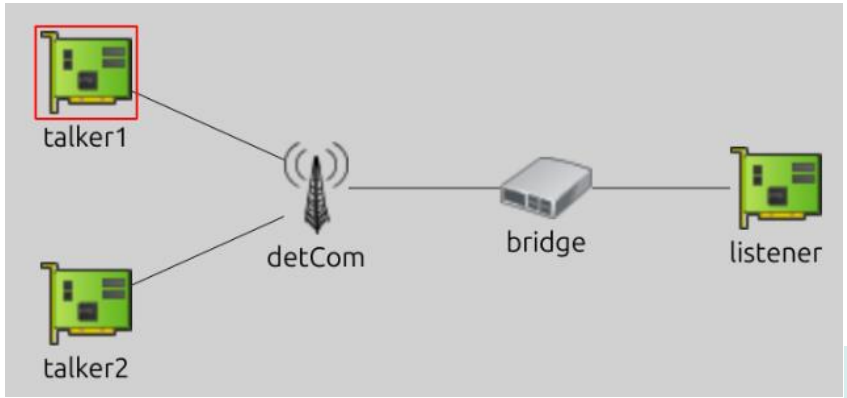
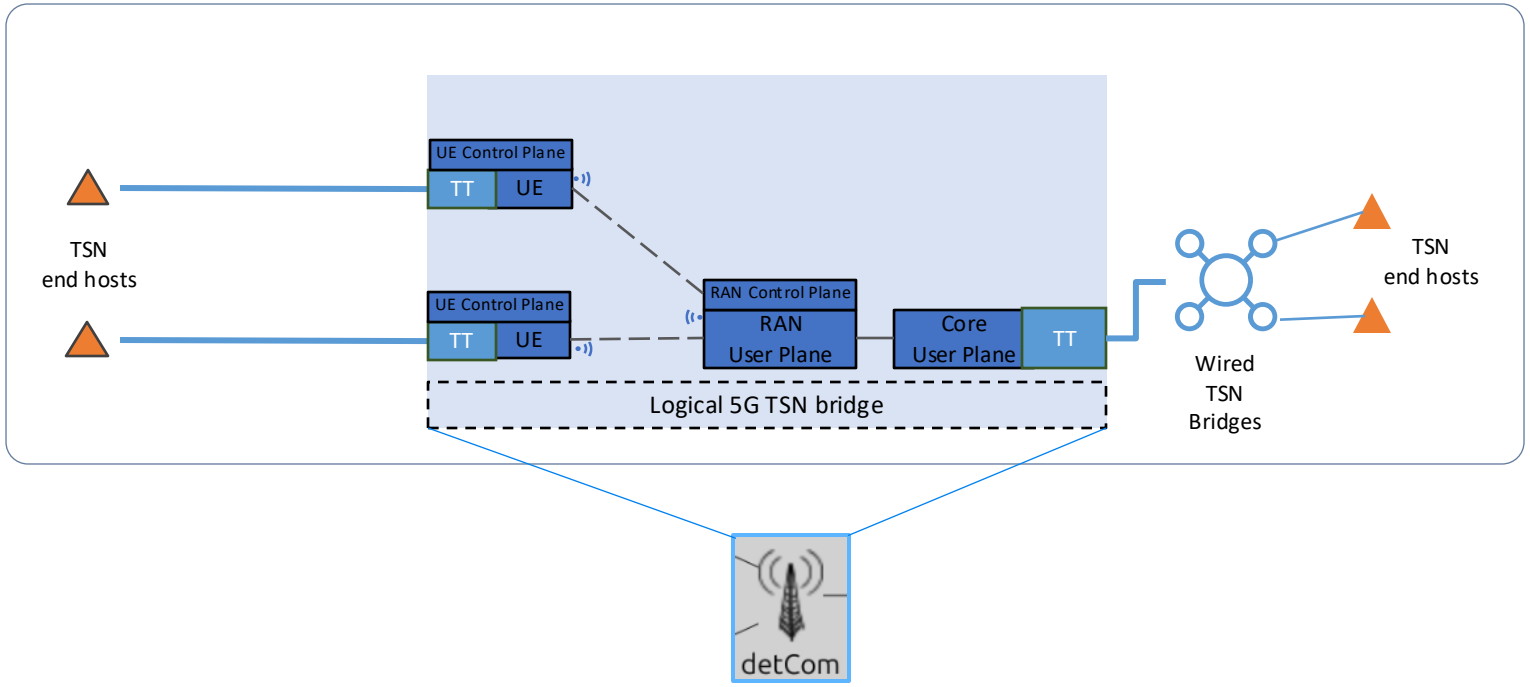


Converged 5G/TSN networks:

- DetCom node needs to provide TSN features
- Wireless Links:
  - Variable packet delay
  - Higher packet loss



Converged 6G/TSN Networks



UE : User Equipment
RAN: Radio Access Network
TT: TSN Translator

DETERMINISTIC6G Simulation and Emulation Frameworks

Existing frameworks:

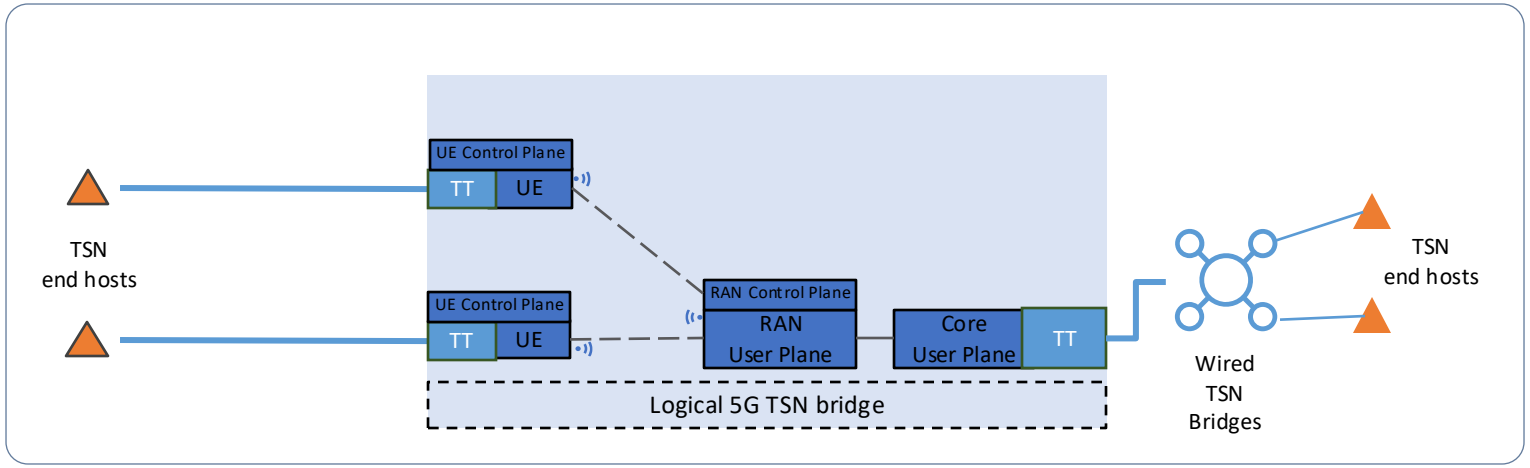
- Wired TSN networks:
  - ➔ No 5G features

- Wireless 5G networks
  - ➔ No deterministic communication mechanisms

Problem: There is no existing simulation/emulation framework to evaluate converged 5G/TSN networks.

Goal: Evaluation platform for analysis of end-to-end deterministic communication in converged 5G/TSN networks.

Simulation and Emulation Frameworks: Architecture



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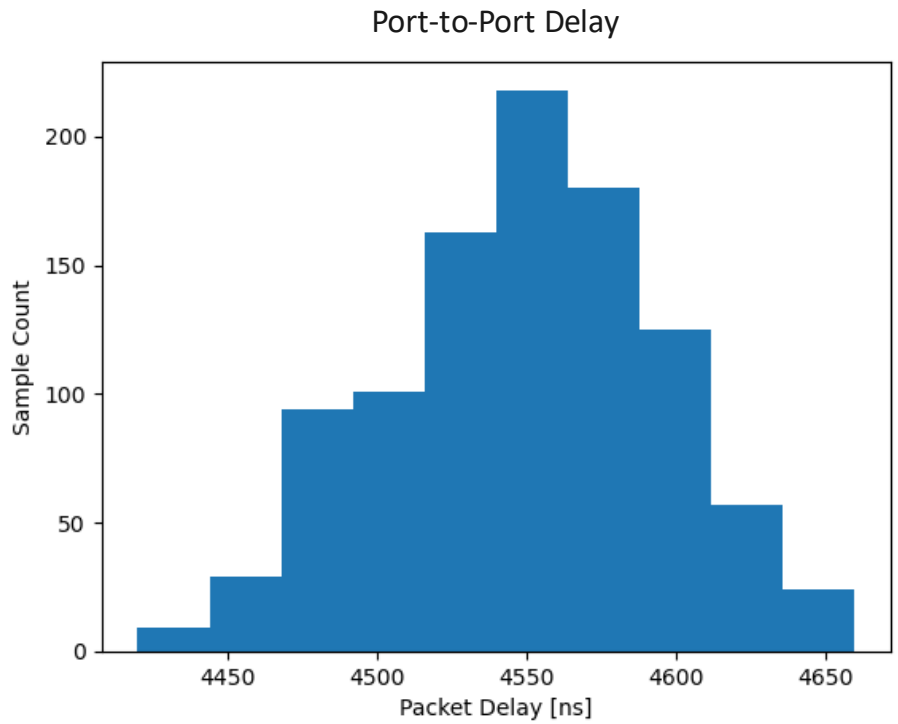
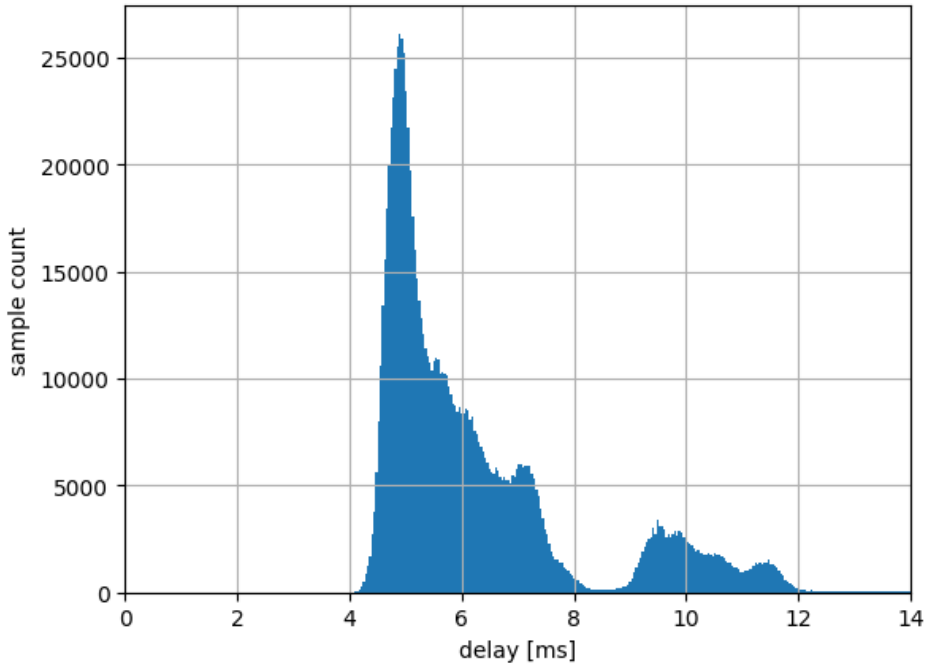
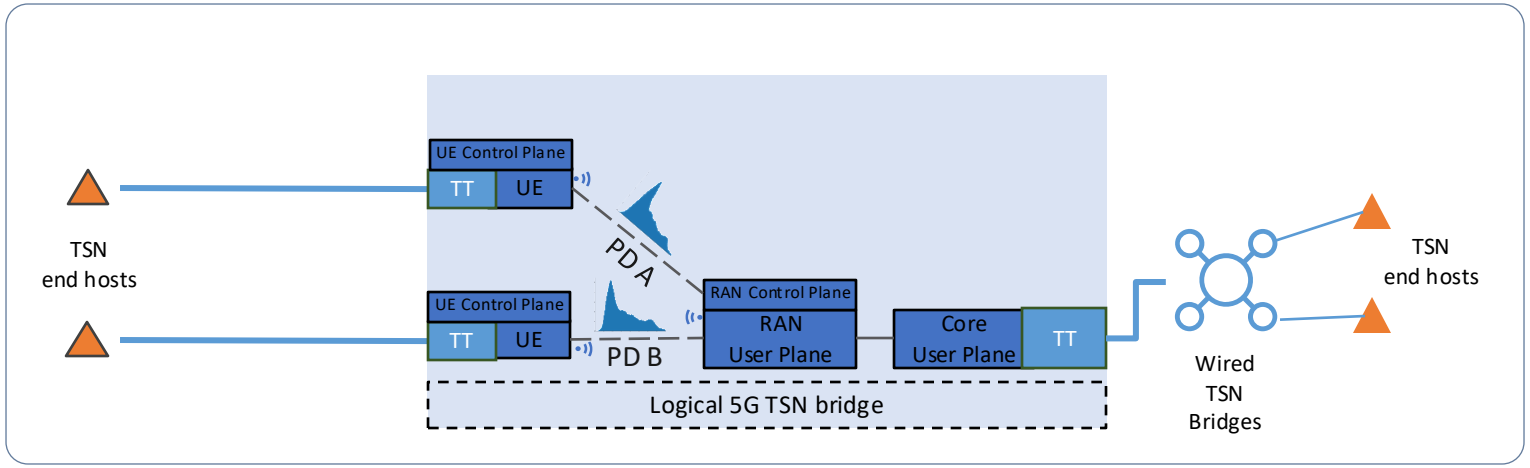


Wired TSN bridge



5G Logical Bridge

Simulation and Emulation Frameworks: Architecture



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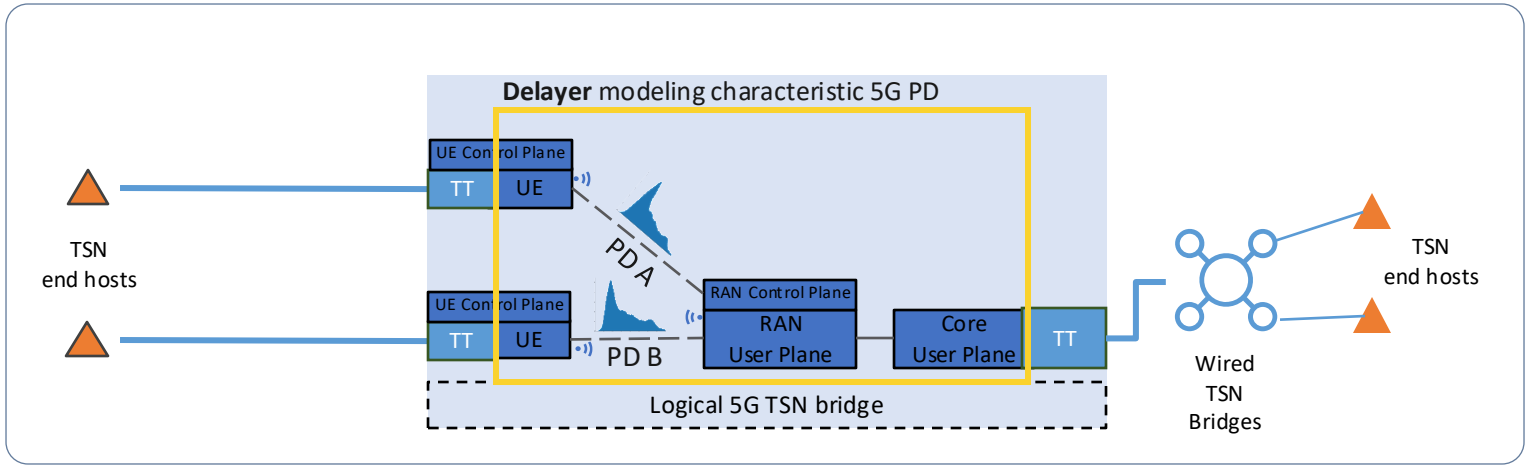

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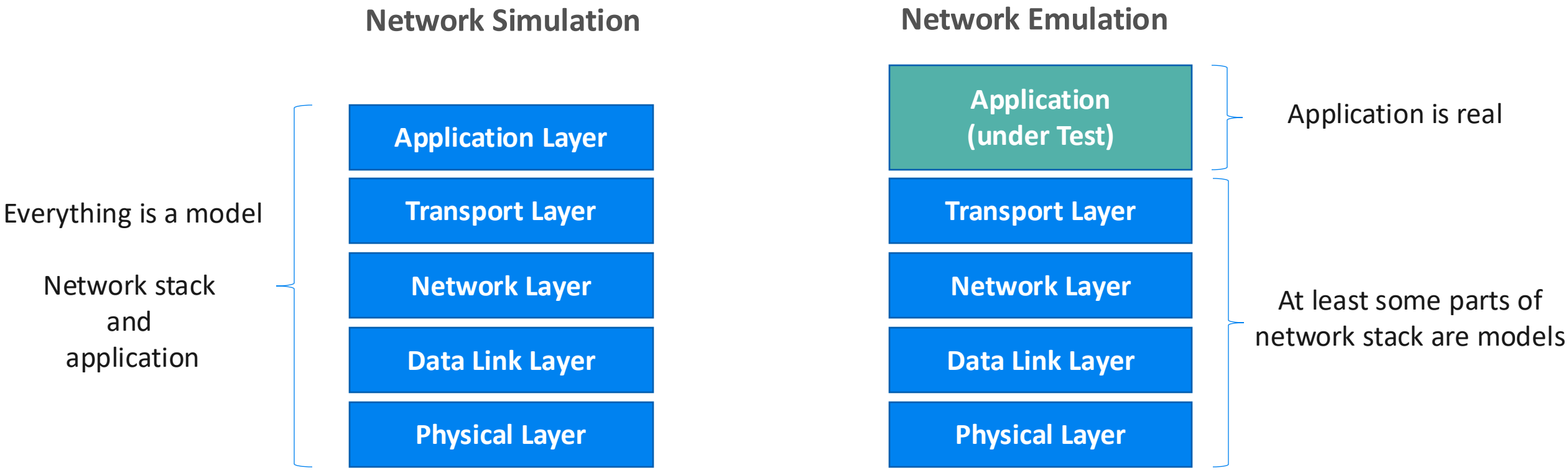
Simulation and Emulation Frameworks: Data-Driven Approach

- Novel **data-driven** simulation approach:
  - Integrating real 5G measurements into TSN simulator
  - Only possibly through joint (contributions of various project partners)
  - Validation at very early stage of 6G development possible

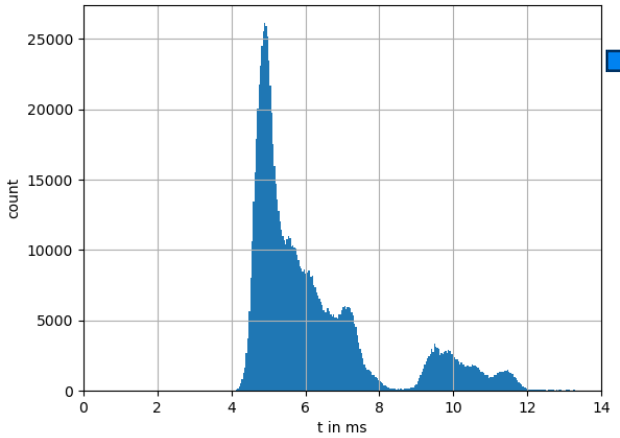
- **Available PD models and data sets[1]:**
  - 5G experimental platform (KTH Stockholm)
  - 5G testbed of industrial shop floor (Ericsson)
  - Wired TSN bridge (University of Stuttgart)

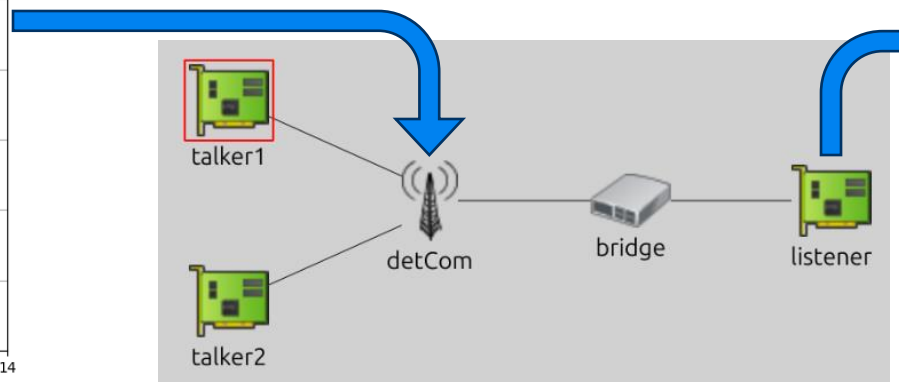
[1] Available on Github: https://github.com/DETERMINISTIC6G/deterministic6g_data

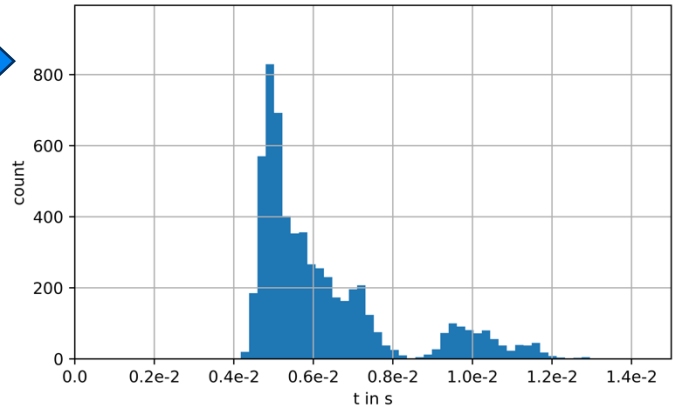
Network Simulation vs Network Emulation



Deterministic6G Simulation Framework: Architecture







Simulation Input

```
*.histogramContainer.histograms =
{uplink: "uplink.xml"}

*.detCom.dstt[0].delayUplink =
rngProvider("histogramContainer","uplink")
```

Resulting end-to-end delay in simulation

Deterministic6G Simulation Framework: Features

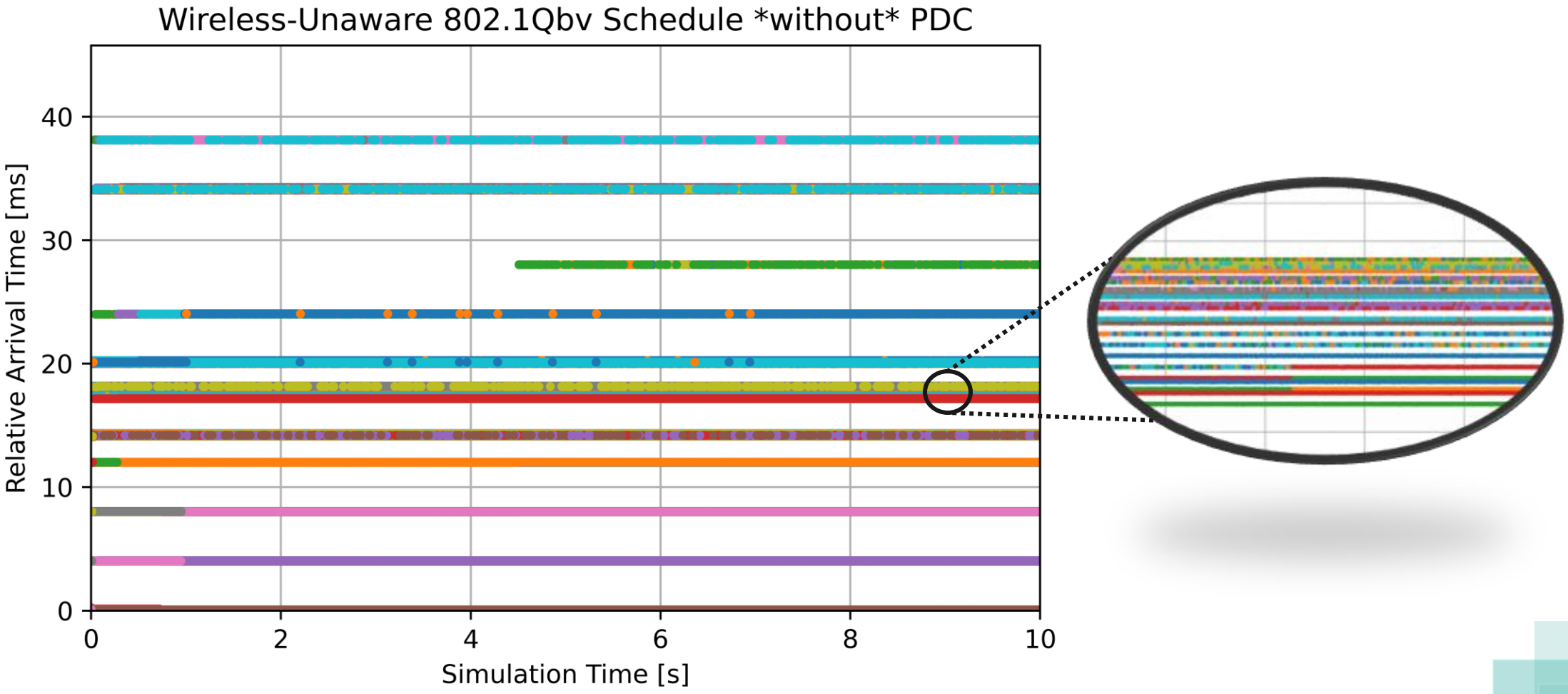
Simulation of characteristic Packet Delay (PD):

- ❑ Histograms from real-world PD measurements
- ❑ PD distribution functions (e.g., a normal distribution)
- ❑ Stochastic processes (e.g., a random walk process)
- ❑ Delay Traces

Additional features:

- ❑ Packet Delay Correction (PDC)
- ❑ Time Synchronization for Converged 5G/TSN network
- ❑ Dynamic Scenarios w/ Scheduler Integration

Example Usage:



Limitations

Usage of **histograms**:

- Values are independently identically distribuited (i.i.d)
- State of simulation/DetCom node does not affect delays

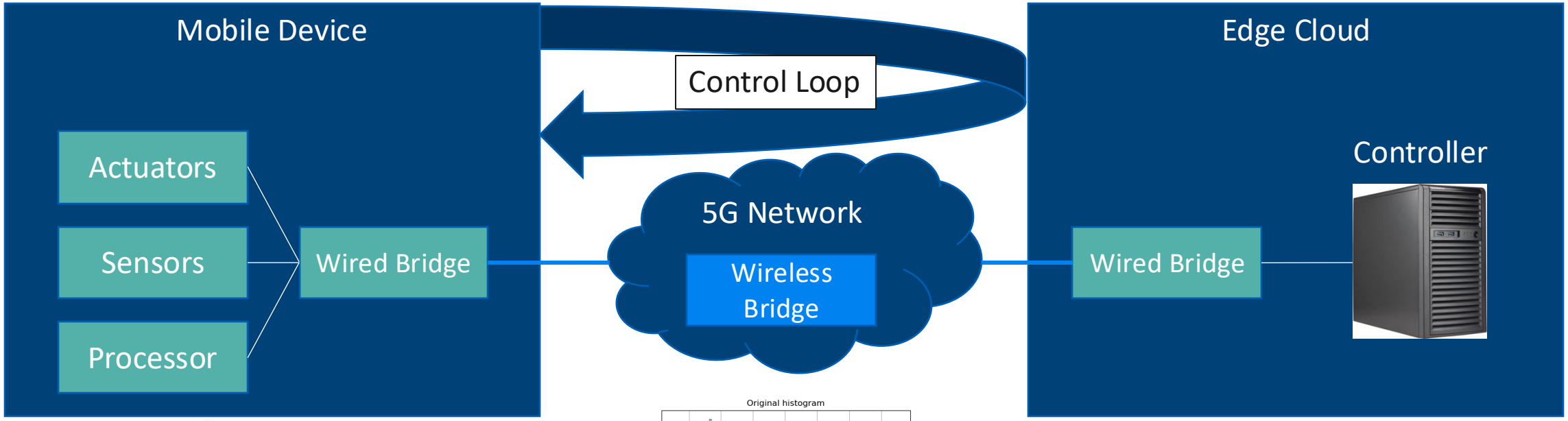
Usage of **delay traces**:

- Parameters such as packet size do not affect delay

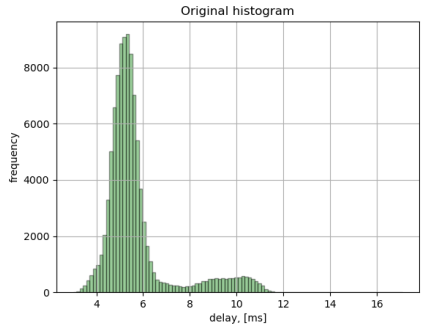
Both:

- TSN schedules or network load do not affect configured delays

Deterministic6G Emulation Framework: Architecture



Exo-Skeleton
(or Automated Guided Vehicle, drone, etc.)



Characteristic Packet Delay

Deterministic6G Emulation Framework: Architecture

Mobile Device

Real

Actuators

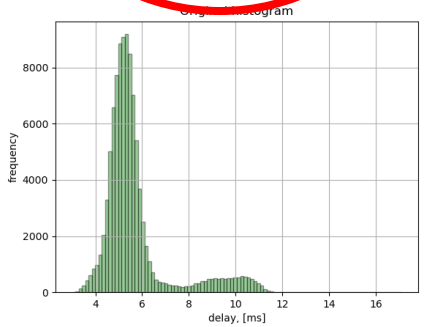
Sensors

Processor

Wired Bridge

Exo-Skeleton
(or Automated Guided Vehicle, drone, etc.)

6GDetCom
Delay Emulator



Characteristic Packet Delay

Edge Cloud

Real

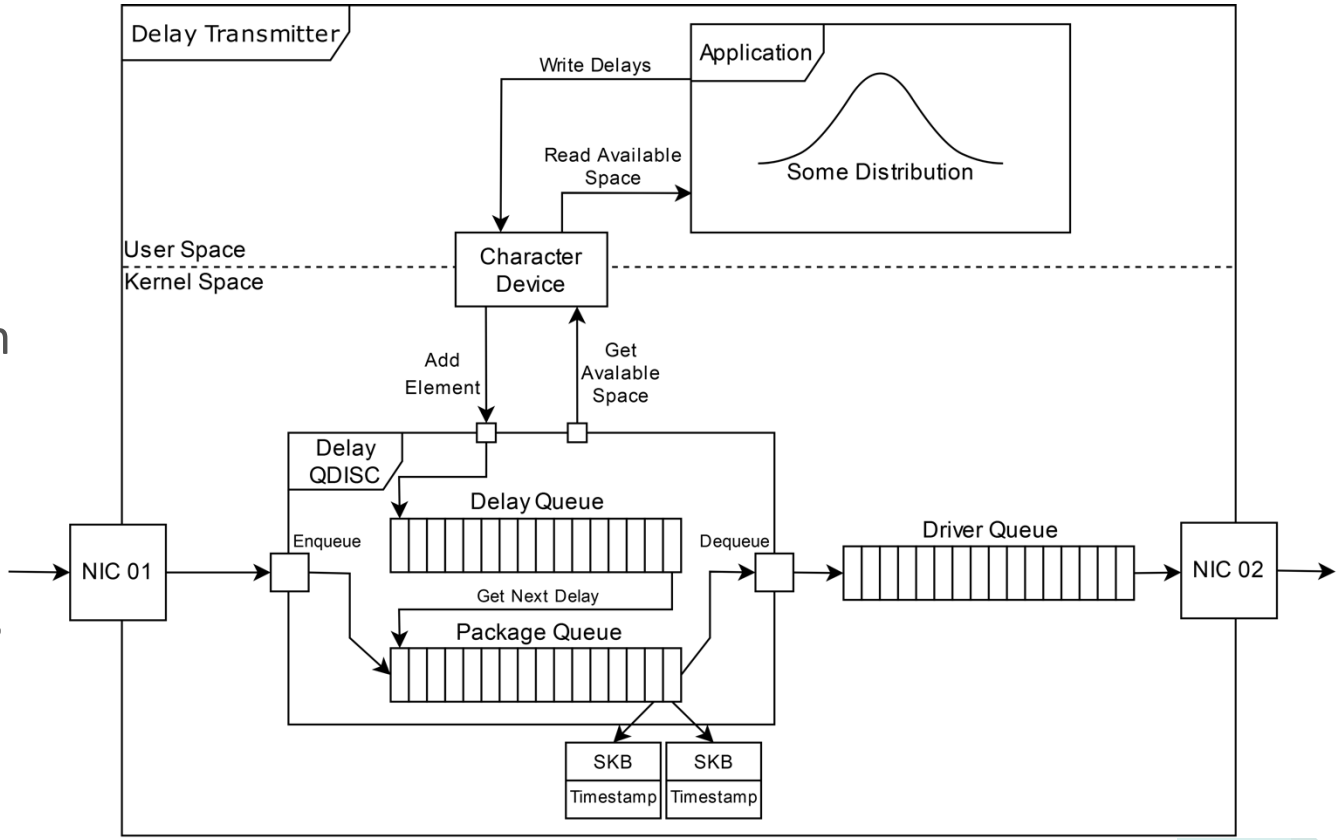
Controller

Wired Bridge

Deterministic6G Emulation Framework: Architecture

- High flexibility and extensibility to define packet delays:
  - Generate by user application
  - Histograms (from datasets)
  - Probability Density Functions (e.g. from numpy)

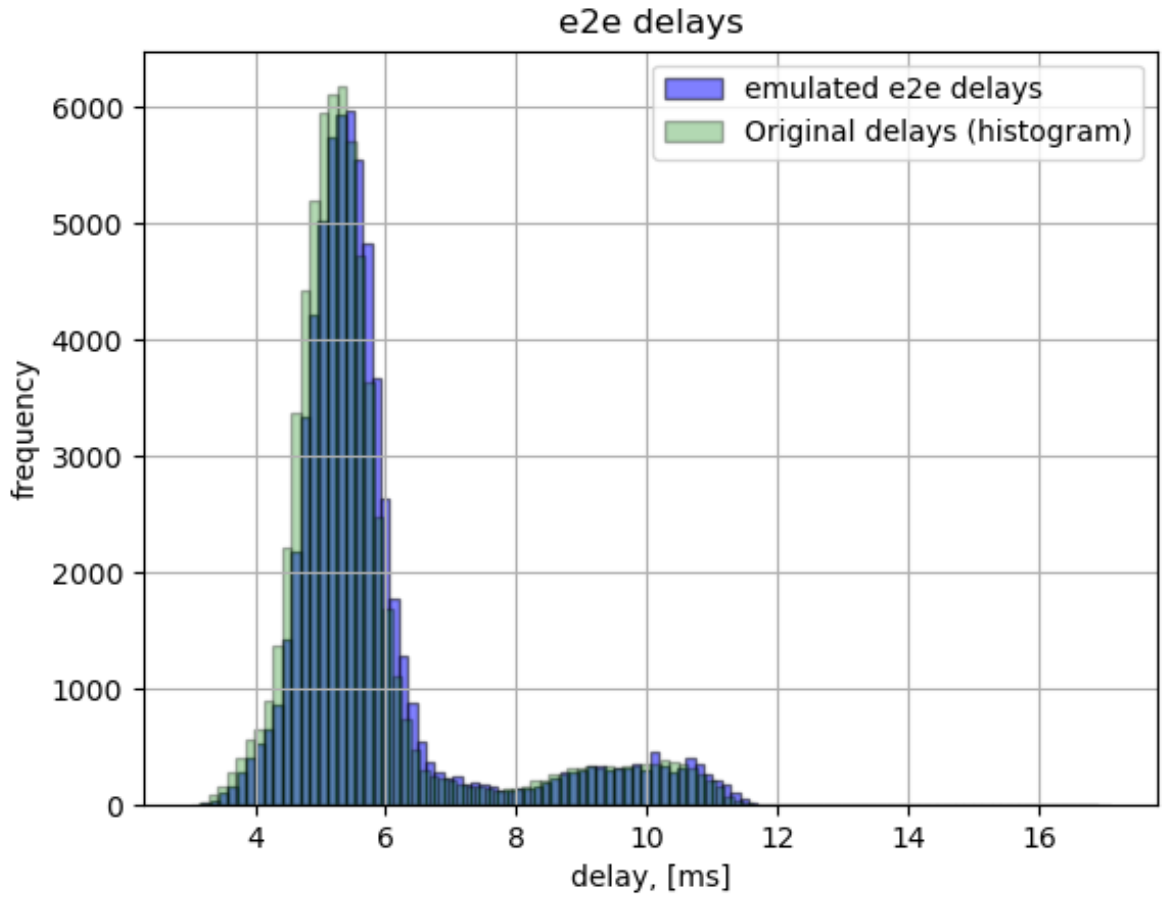
- Modular due to QDisc concept
  - Combination with existing Linux QDiscs and filters (packet classifiers)
  - Integration with Linux virtual Bridge



Deterministic6G Emulation Framework: Performance

Good performance for a software solution:

- Max throughput ~ 1 Gbps
- Min delay ~ 100-150 us
  - ➔ Milli-seconds range of delay OK
    < 100 us not OK



Limitations

Delays are calculated **in advance** and **buffered** in kernel:

- **Dynamic (non-stationary) delay distributions only at coarse time granularity**
  - Takes long time to change from Delay Distribution A to Distribution B
  - Or if distribution changes continuously: **long dead time**
- Delays are i.i.d.

Deterministic6G Emulation Framework: Comparison

Simulation Framework	Emulation Framework
Great to evaluate new models/approaches	Great to test real-world applications
Simplified model of real-world devices	Real-world devices can be evaluated with emulated 5G/TSN bridge
Delay distribution models are exactly configurable	Emulation as a software-component introduces additional error

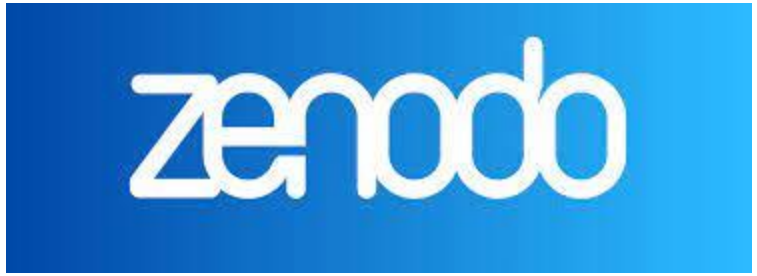
Conclusion

- Data-driven evaluation platform for converged 5G/TSN networks
- Based on realistic delay models from real-world measurements

- **6GDetCom Simulator** and **Emulator** publicly available on GitHub
- **Datasets** publicly available on Zenodo

Open Source Code & Data

https://github.com/DETERMINISTIC6G



https://zenodo.org/communities/deterministic6g/

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