Performance Evaluation and Configuration in Time-Sensitive Networking

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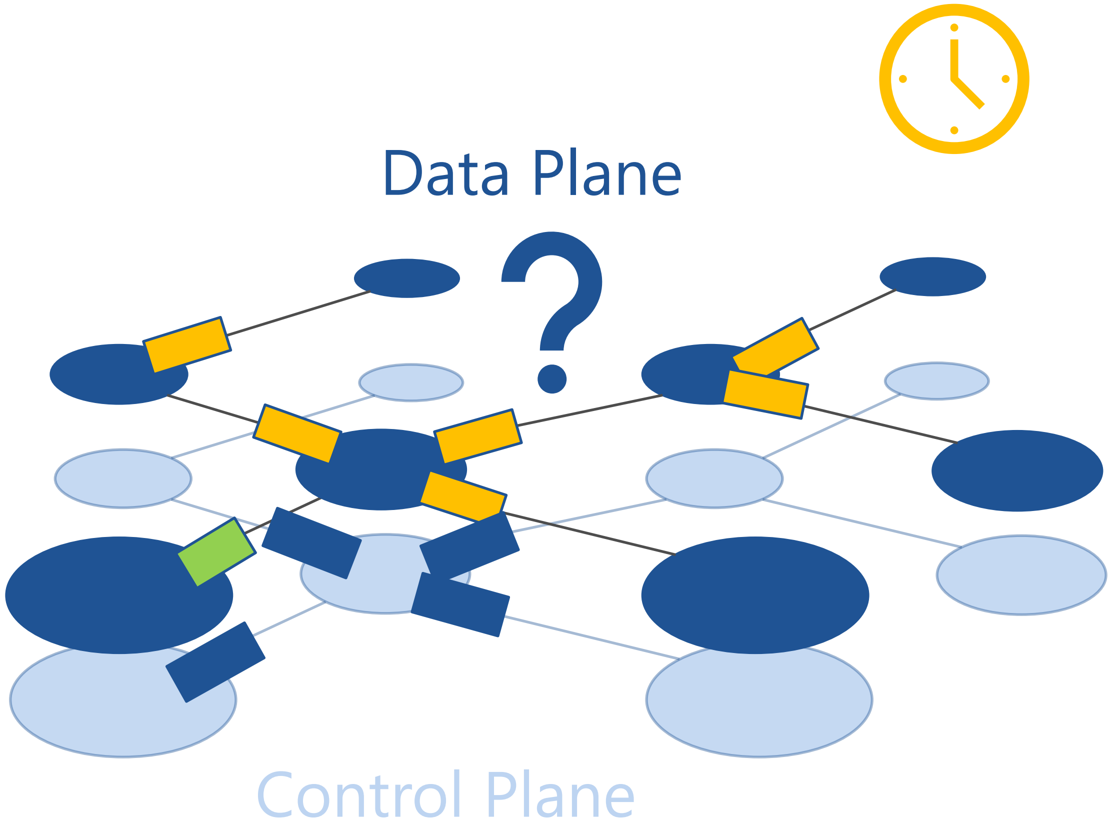
What is Time-Sensitive Networking?

- **Technically:** Collection of interacting IEEE standards
  - Still actively worked worked on
  - Few devices implement standards

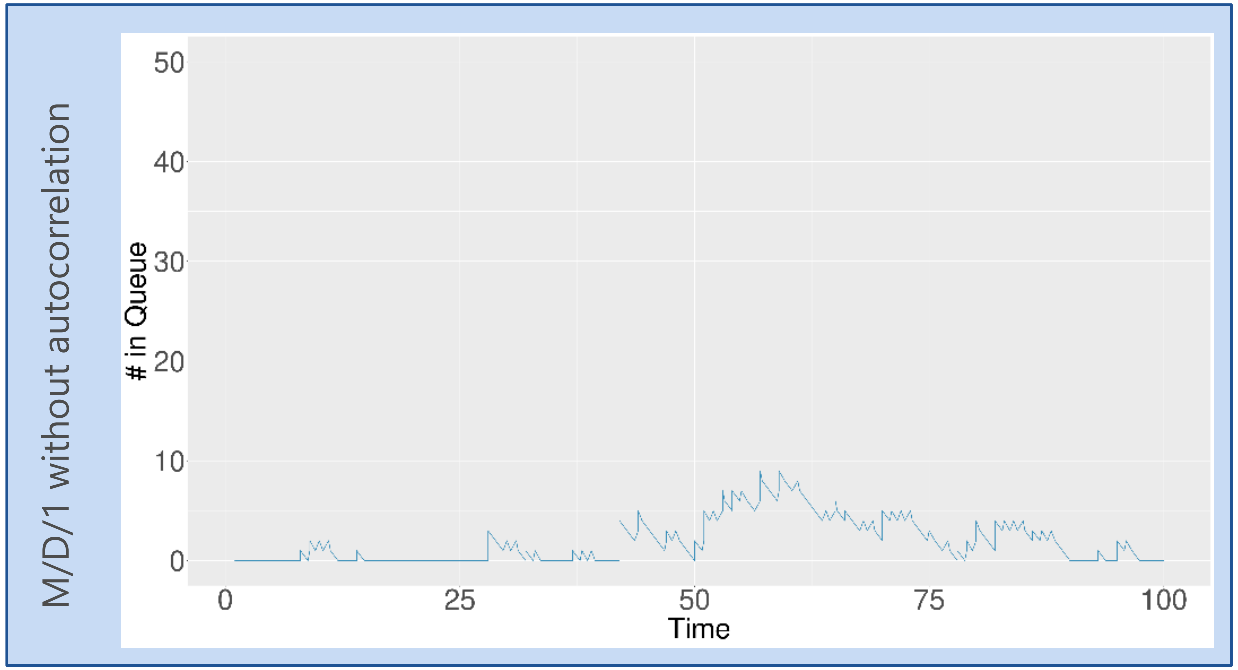
- **Simplified**: Ethernet with QoS-guarantees

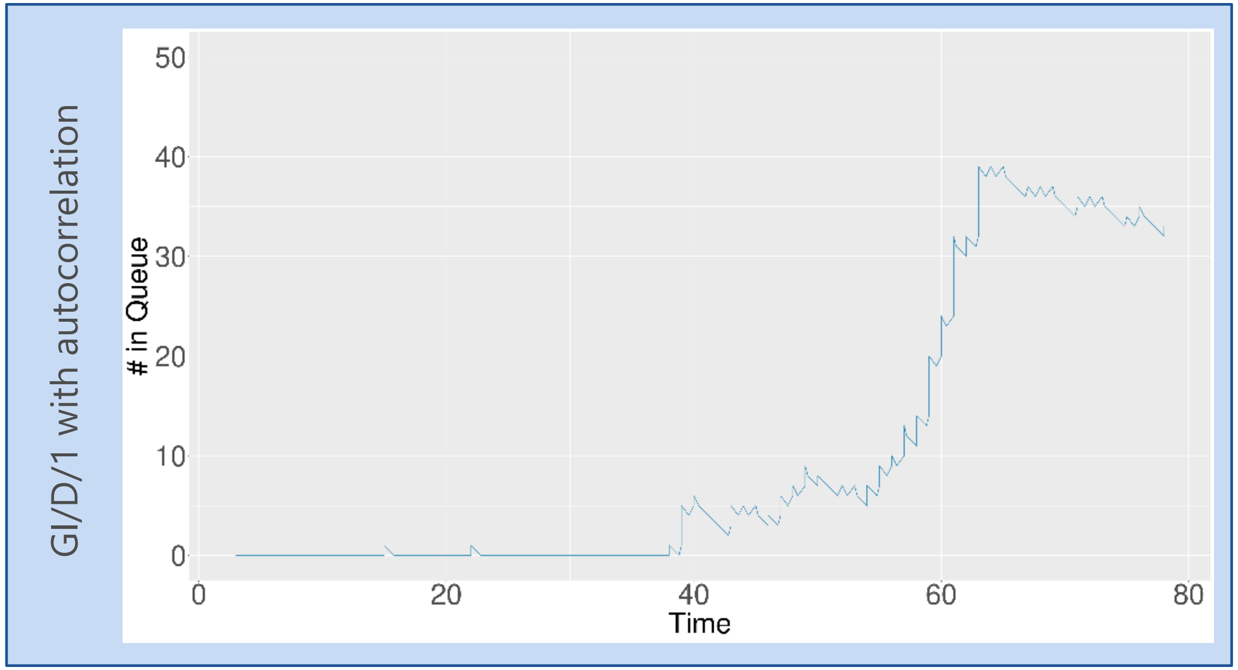
- Related Topics from our work
  - Autocorrelated traffic source modelling at Endpoints
  - Latency calculation on the Data Plane
  - Decentralized resource allocation on the Control Plane



Traffic source simulation

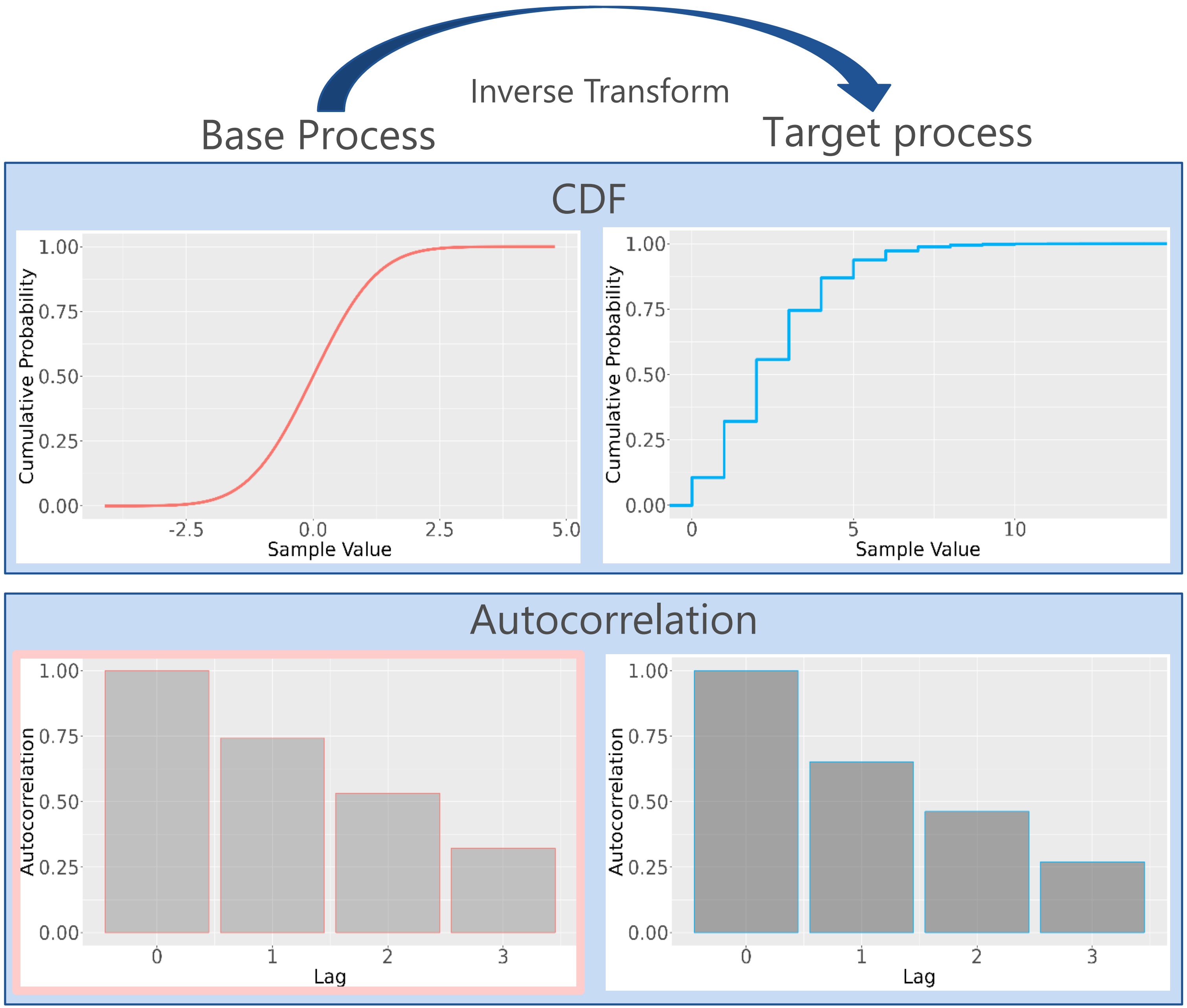
- TSN networks modelled as queueing systems ➔ Autocorrelation important
- Our choice: Discrete Event Simulation
- We introduced **DARTA**[1] for modelling discrete stationary time-series with
  - Any discrete marginal distribution
  - Any autocorrelation structure
- Present for arrivals in
  - Industrial Networks
  - IoT traffic
  - Consumer applications
- Currently subject of research at our chair





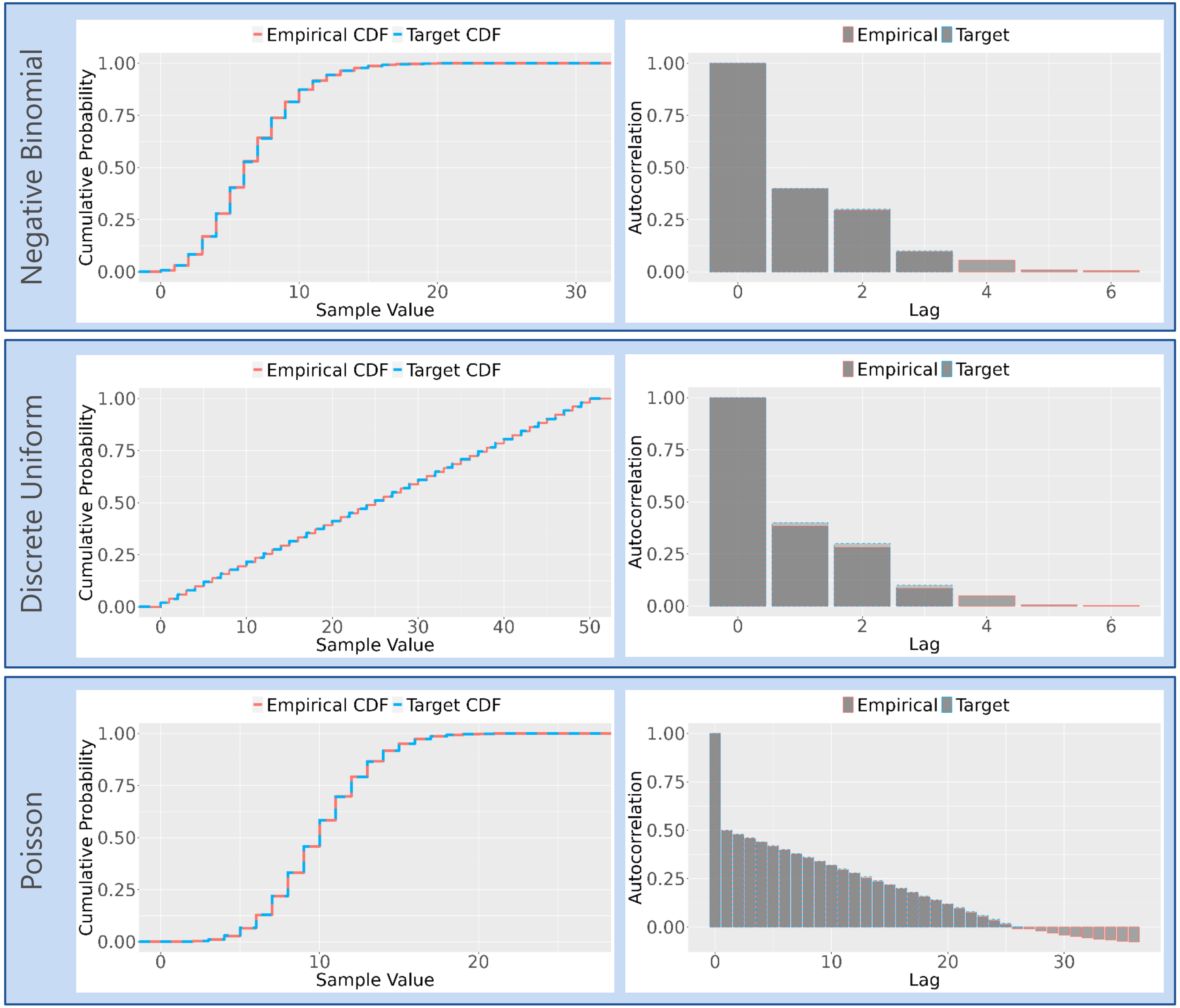
DARTA - Functionality

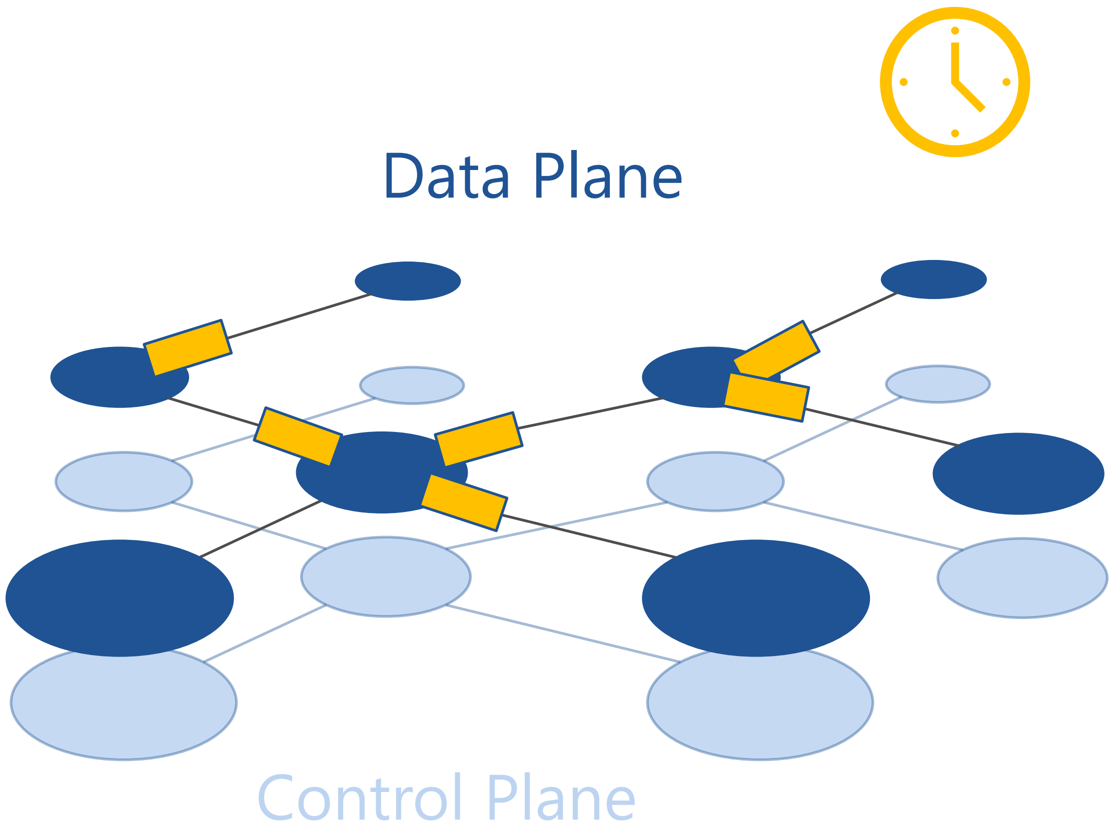
- Based on ARTA[2] mechanism
- Finds easily generatable Gaussian base process to transform to target process
- **Main problem**: Finding fitting autocorrelation for base process
- Main contribution is an integral approximation
- Mathematical proof is omitted here



DARTA - Results

- DARTA works!
- Distributions and Autocorrelations can be approximated with high accuracy
- Extreme cases can introduce difficulties
- Currently researching realistic use-cases

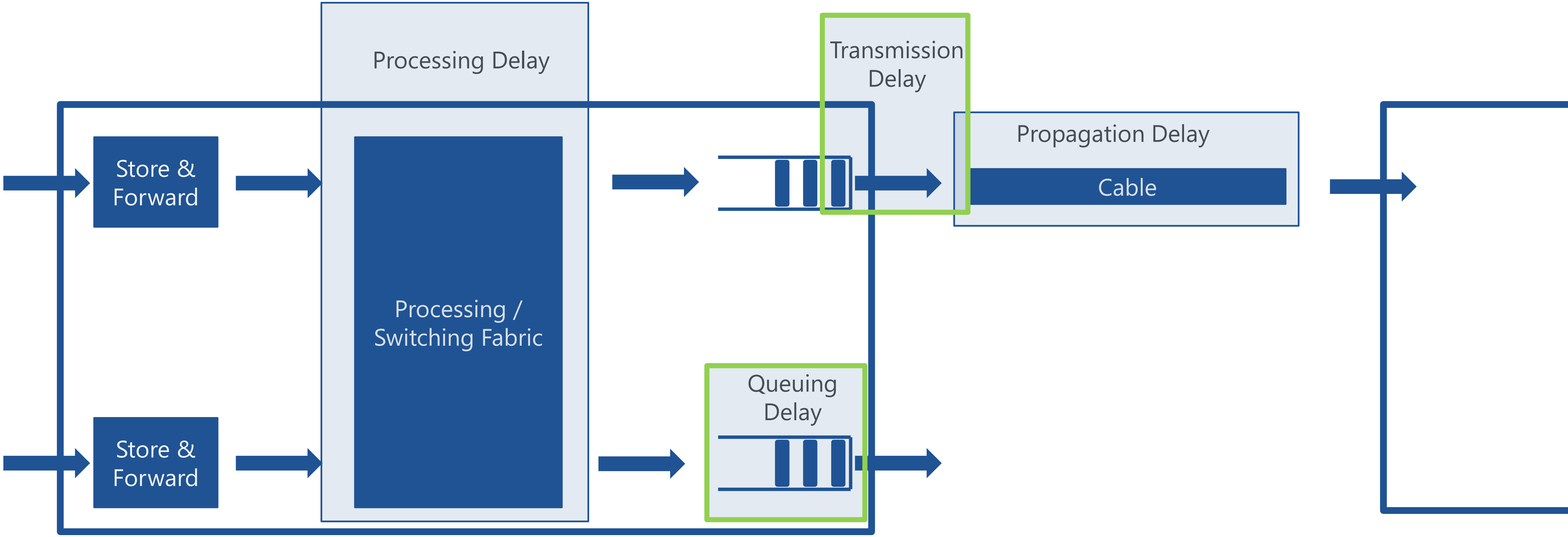




LATENCY CALCULATION[3]

[3] Bounded Latency with Bridge-Local Stream Reservation and Strict Priority Queuing by Grigorjew, Alexej; Metzger, Florian; Hoßfeld, Tobias; Specht, Johannes; Götz, Franz-Josef; Chen, Feng; Schmitt, Jürgen in 11th International Conference on Network of the Future (2020)

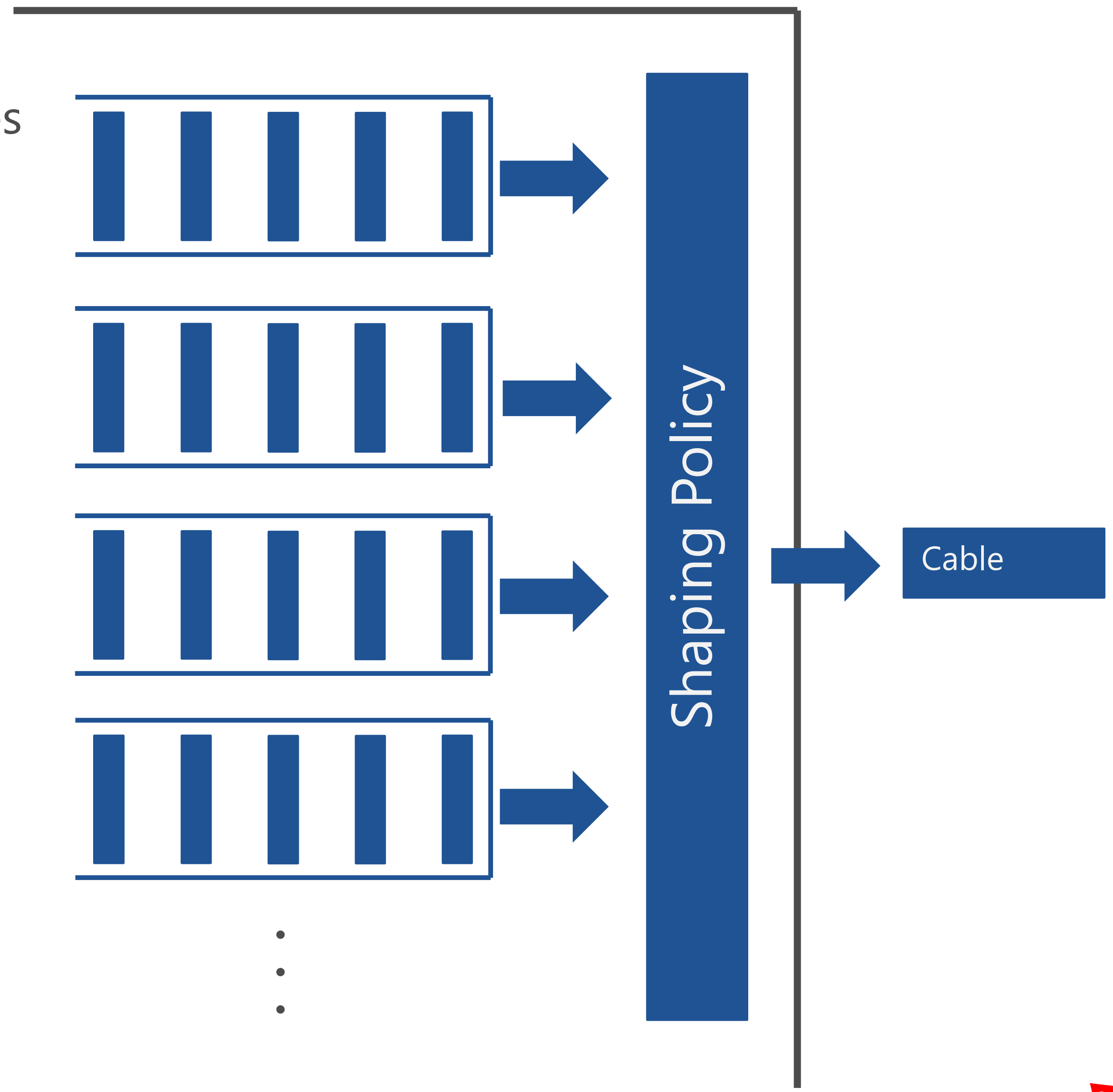
Where does Delay come from?



Model of a Switch

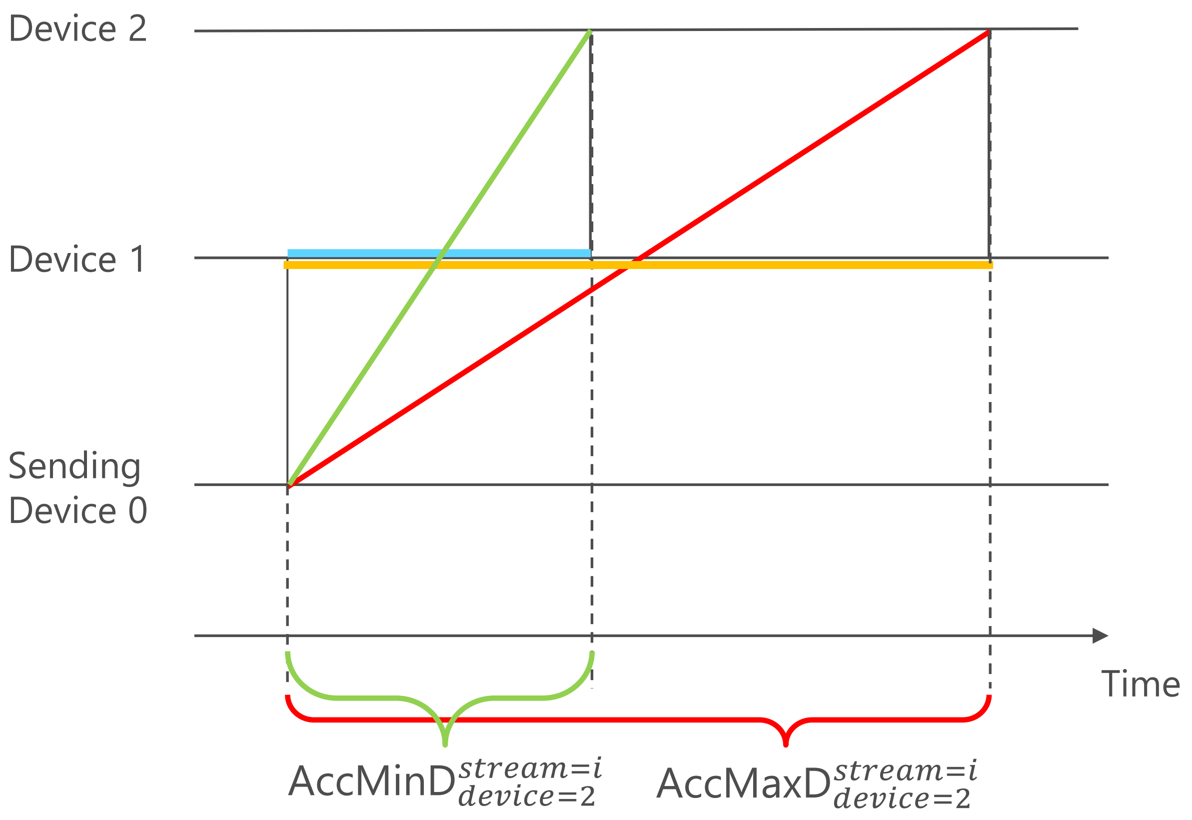
Shaping

- Streams are shaped at each port
  - All streams destined for port arrive in queues
  - One queue for each of 8 priorities
  - FIFO queues
- Many shaping mechanisms available
  - Credit Based Shaping
  - Asynchronous Traffic Shaping
  - <u>Strict Priority</u>
  - …
- Consider strict priority for now
  - Selects highest priority available element
  - Does not pre-empt frames



Delay Accumulation

- Each stream i has a maximum burst rate r_i and a priority p_i
- n-th device visited by i has
  - Maximum latency δ_n^p per priority (configured)
  - Minimum processing time (hardware contraint)
- At each device/hop, a minimum/maximum accumulated delay can be computed
- We have some research on fitting choices for maximum latency



Delay Accumulation

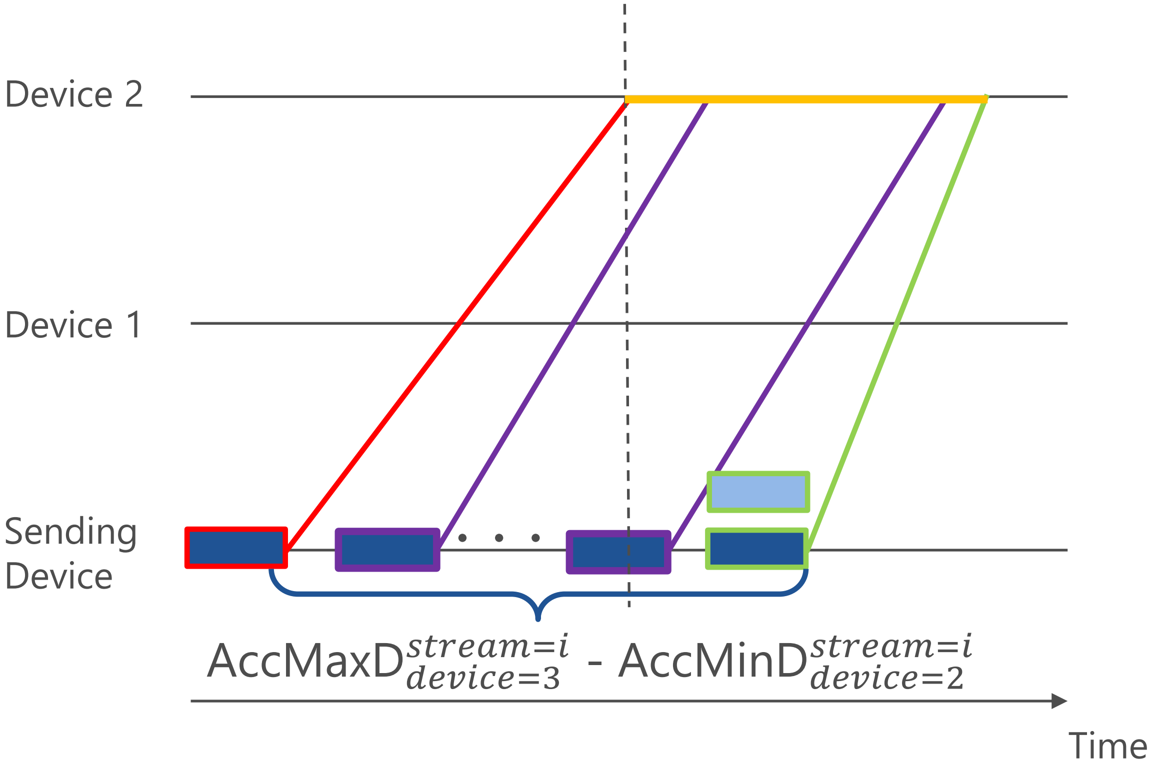
- How much data **from its own stream** *i* can be in queue before packet A?

Device 2 Egress Queue

- Look at worst case:
  - Packet A has minimum delay (packets in front have less time processing)
  - Packet B is just leaving device 2 (device 2 has a latency bound)
  - Data in front could only be sent in between A and B

$$m^{stream=i}_{device=n} = \left(\mathrm{AccMaxD}^{i}_{n+1} - \mathrm{AccMinD}^{i}_{n}\right) \cdot r_i$$

- Also true for **other streams of same priority**

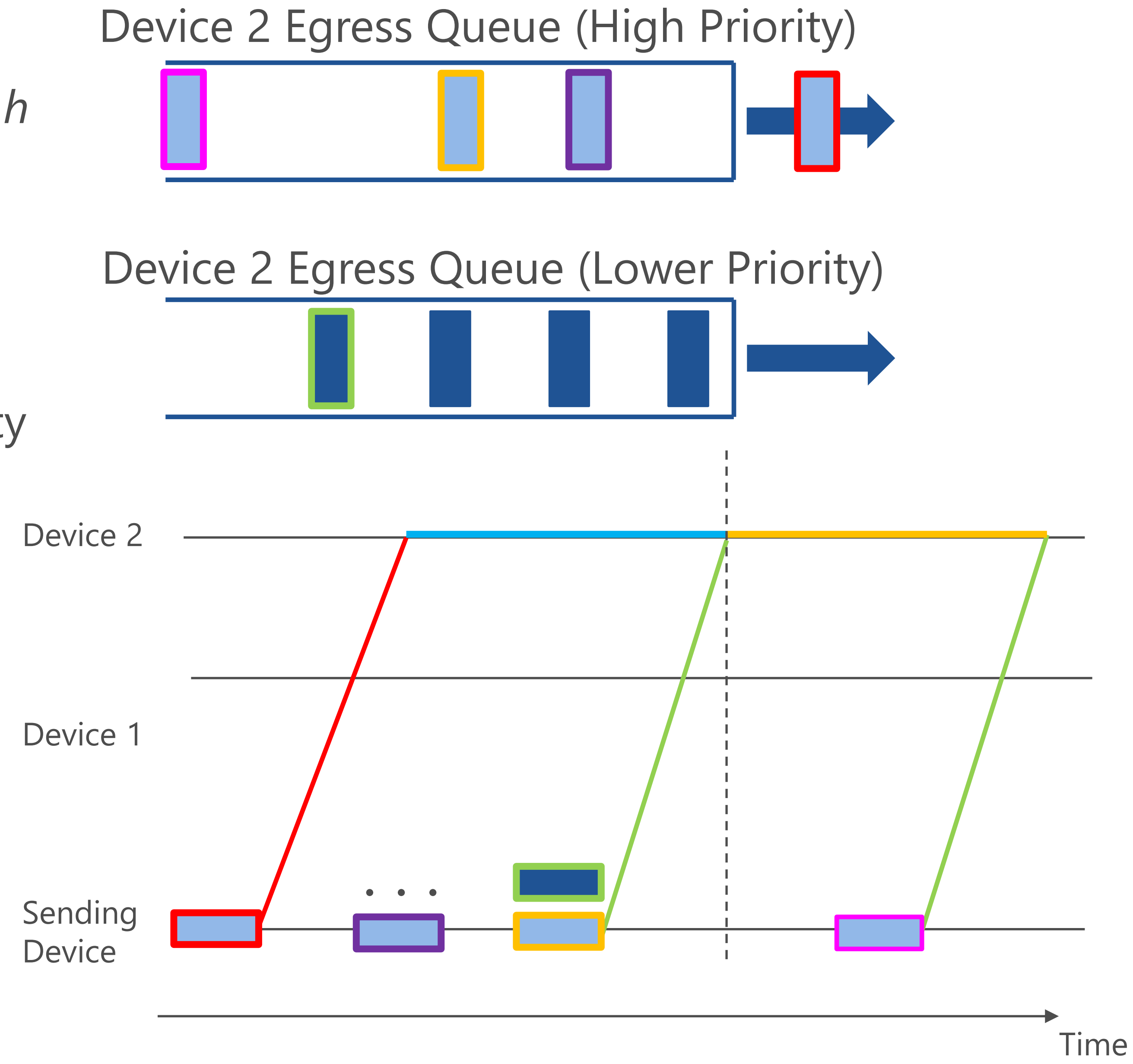


Delay Accumulation

- How much data of **higher priority stream** *h* can be processed while packet A is in line?

- Same as before for when A arrives, but Packet B has latency guarantee $\delta_n^{p_h}$
- But even after A is enqueued, higher priority traffic may arrive
- Only limited by latency guarantee $\delta_n^{p_i}$ for A

$$m_{device=n,\, block=h}^{stream=i} = \left(\mathrm{AccMaxD}_{n+1}^{h} - \mathrm{AccMinD}_{n}^{h} + \delta_n^{p_i}\right) \cdot r_i$$



Summary of Delay Computation

- What is the total delay for a stream I at device n?

- Need to consider all streams of higher priority H_{p_i} or equal priority E_{p_i}

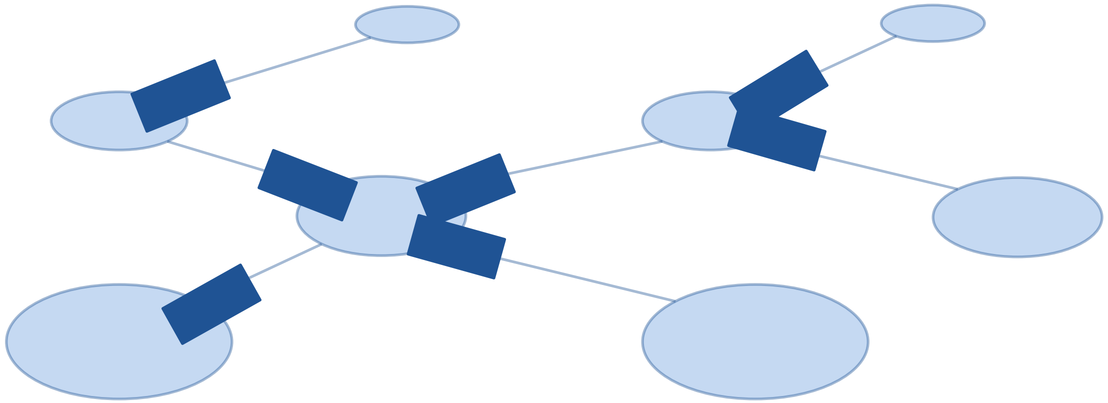
$$\delta_{device=n}^{stream=i} = \sum_{h \in H_{p_i}} \frac{m_{device=n,block=h}^{stream=i}}{r_n} + \sum_{e \in E_{p_i}} \frac{m_{device=n}^{stream=e}}{r_n} + \max_{l \in L_{p_i}} \frac{l}{r_n}$$

?

- Packet from lower priority streams L_{p_i} may be transmitted when packet A arrives

- Formula only relies on previously computed values

- Can be used for decentralized delay computation



DECENTRALIZED RESOURCE ALLOCATION

Classification of TSN Models

Centralized vs Decentralized

- Centralized system has **single** controller doing all work
- Decentralized system requires nodes to
  - Allocate resources
  - Maintain routing tables
  - Propagate information
- But it is *probably* more resilient

Static vs Dynamic

- Static: System can be configured optimally before use
- Dynamic: Traffic sources and QoS requirements are updated on the fly
- But it *seems* more flexible

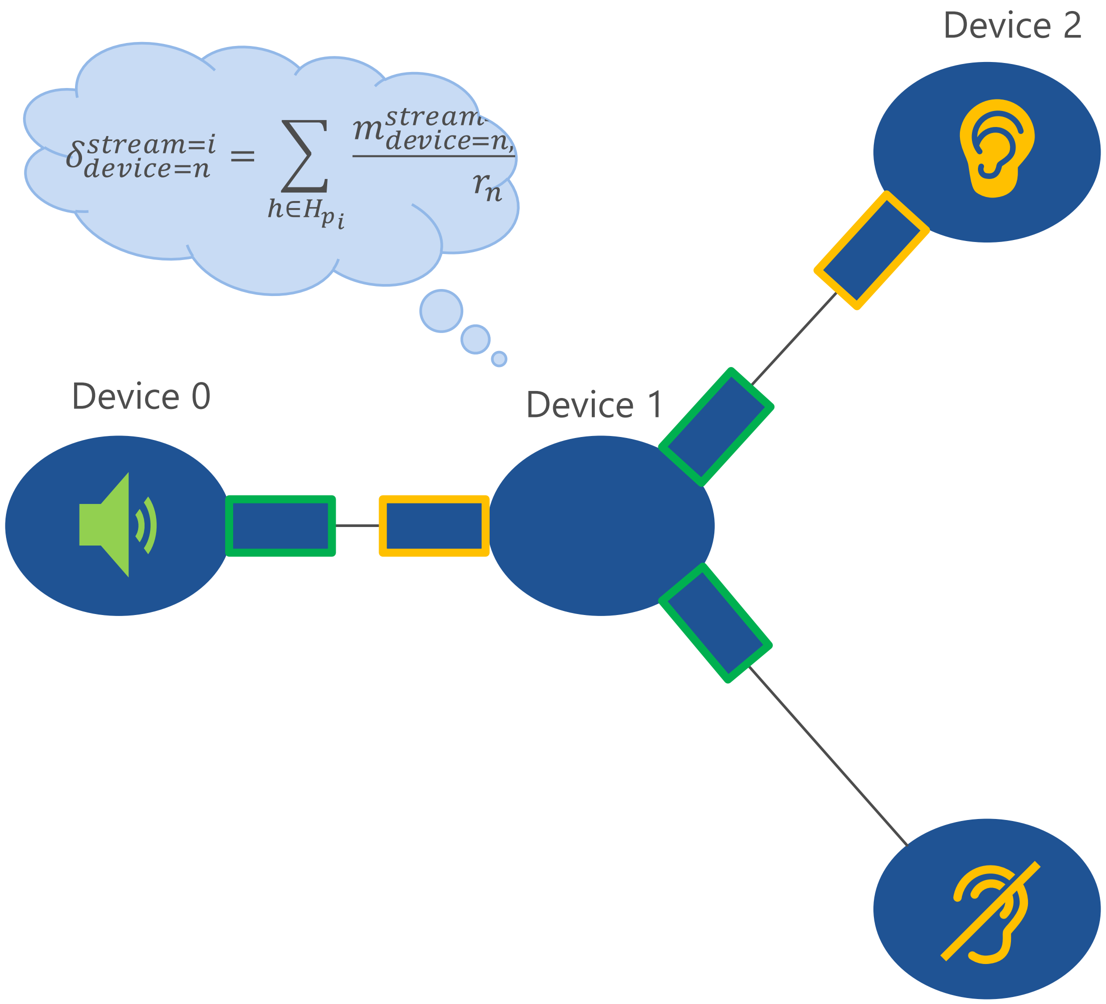
- **Question:** How to allocate resources in decentralized, dynamic system?

- We currently work on simulation of the Resource Allocation Protocol[4]

[4] Draft Standard for Local and Metropolitan Area Networks — Bridges and Bridged Networks — Amendment: Resource Allocation Protocol

Resource Allocation Protocol Simulation

- Simple publish-subscribe model
- Device 0 sends talker announce (TA)
- Bridges check QoS constraints
- Gets broadcast through the system
- Device 2 subscribes with listener attach (LA)
- Devices check constraints and allocate resources
- When LA arrives at device 0, configuration is completed successfully



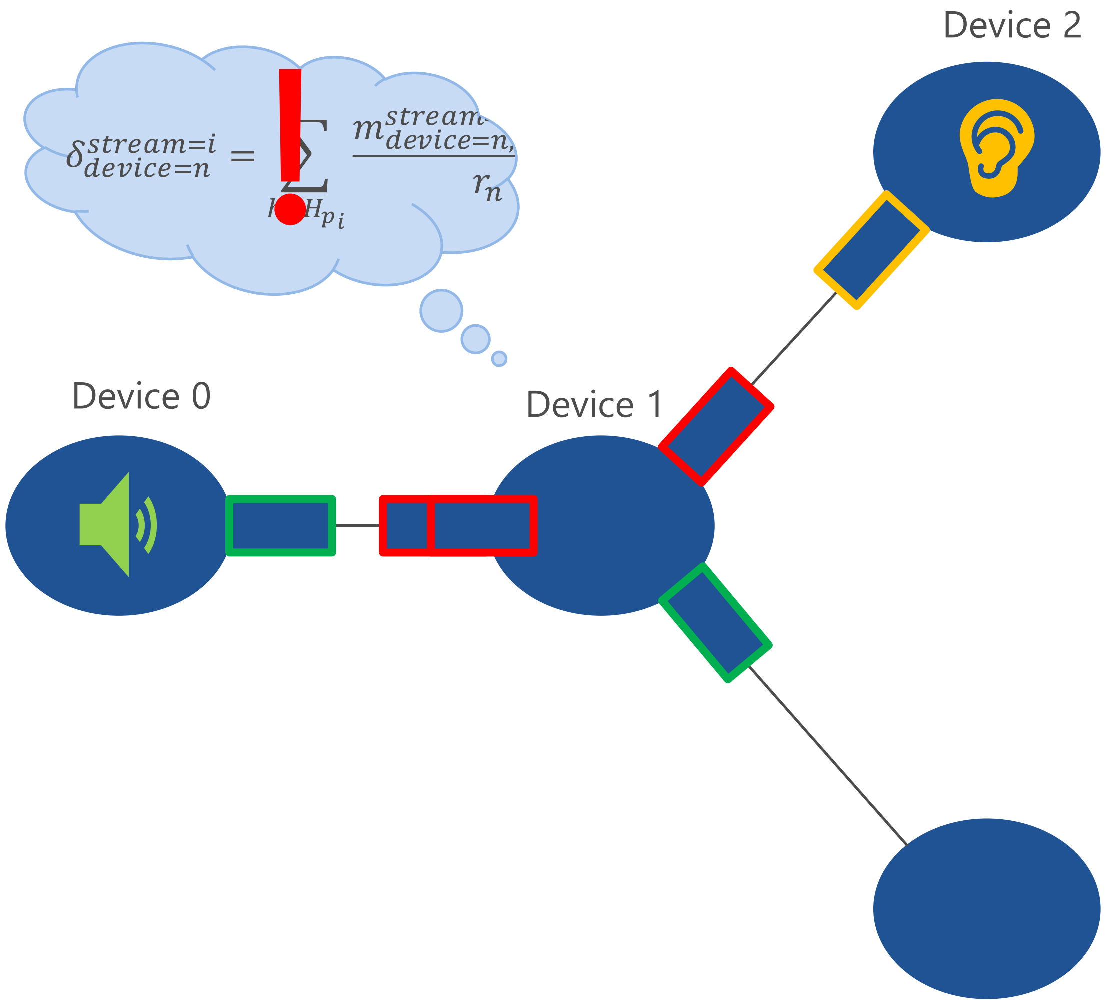
Check failures

- Delay bound checks can occur in 2 places

- During TA propagation
  - Device computes delay check failure
  - Flag is set on TA
  - TA is broadcast further

- During LA propagation
  - Device computes delay check failure
  - Flag is set on LA
  - LA device is informed of failure
  - LA is sent further

- Process is not entirely standardized



Conclusion

- We covered three aspects of our TSN research

- Traffic source modelling
  - Success highly dependent on distribution and autocorrelation
  - We are currently testing for realistic parameter sets

- Delay computation
  - More complex shapers available
  - Some require time synchronization ➔Comes with own challenges (and protocols)

- Decentralized dynamic TSN
  - Approach is greedy
  - Still largely untested in the wild
  - May only work well with certain topologies

- Standards still in development

Sources

[1] DARTA: Generation of Autocorrelated Random Numbers using Discrete AutoRegression To Anything by Geißler, Stefan; Raunecker, David; Lange, Stanislav; Hossfeld, Tobias at *ITC 35th - Networked Systems and Services (2023)*

[2] Autoregressive to anything: Time-series input processes for simulation by Cario, Marne C.; Nelson, Barry L. in *Operations Research Letters (1996)*

[3] Bounded Latency with Bridge-Local Stream Reservation and Strict Priority Queuing by Grigorjew, Alexej; Metzger, Florian; Hoßfeld, Tobias; Specht, Johannes; Götz, Franz-Josef; Chen, Feng; Schmitt, Jürgen in *11th International Conference on Network of the Future (2020)*

[4] ***Draft Standard for Local and Metropolitan Area Networks — Bridges and Bridged Networks — Amendment: Resource Allocation Protocol***