University of Stuttgart
Institute of Parallel and Distributed Systems

NeSTiNg

A Network Simulator for Time-sensitive Networking

David Hellmanns

Agenda

- Our Motivation
- Discrete Event Simulation (DES): A primer
- Implementation
- Evaluation of Simulation Results
- Conclusion & Future Work

Our Motivation

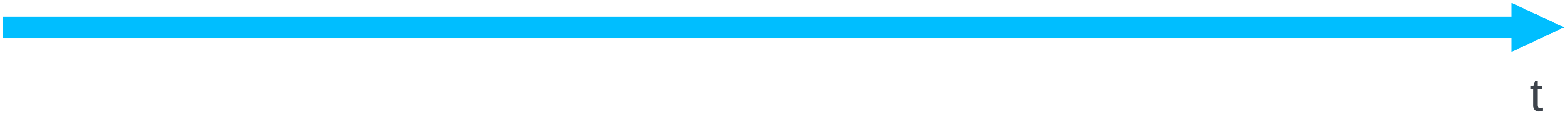
- TSN **evaluation** for our research
  - NeSTiNg started as an internal tool for TSN evaluation

  →Publication of code as a contribution to the research community
  - Simulation of functional behavior, not emulation of real systems

- Additional results of the development
  - Deeper understanding of standards
  - Awareness of edge cases and corner cases

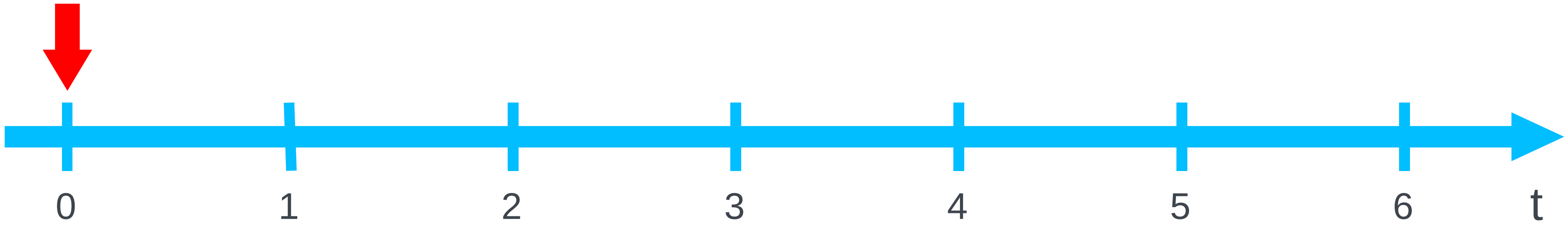
Discrete Event Simulation (DES): A primer

- Global simulation clock



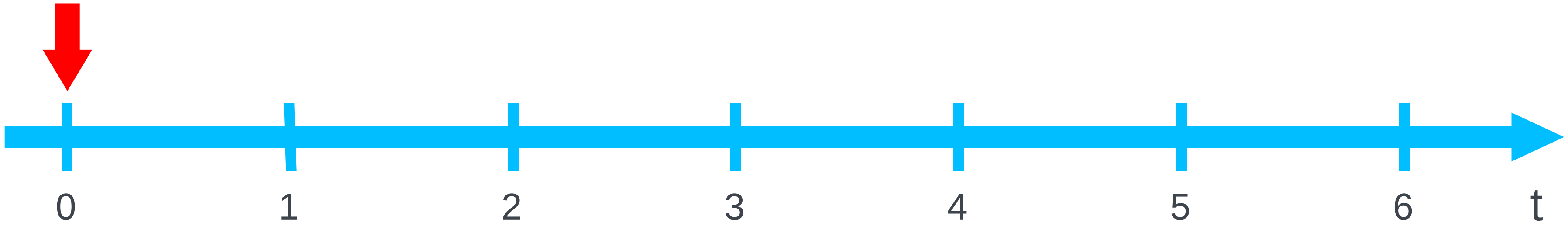
Discrete Event Simulation (DES): A primer

- Global simulation clock: Time domain is discrete



Discrete Event Simulation (DES): A primer

- Global simulation clock: Time domain is discrete
- Simulation framework maintains global event queue



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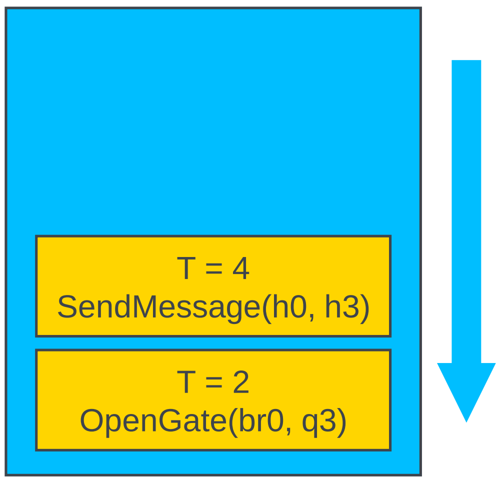
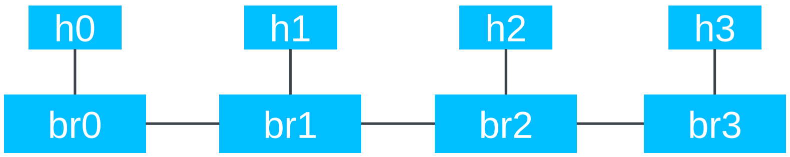
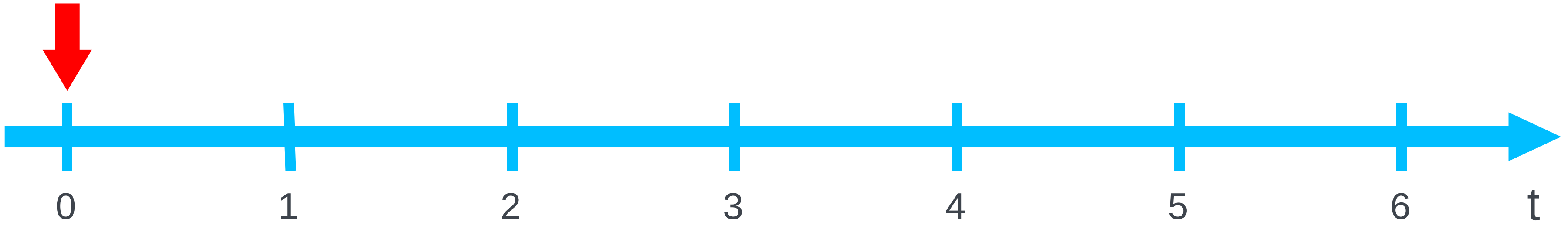


Global Event Queue





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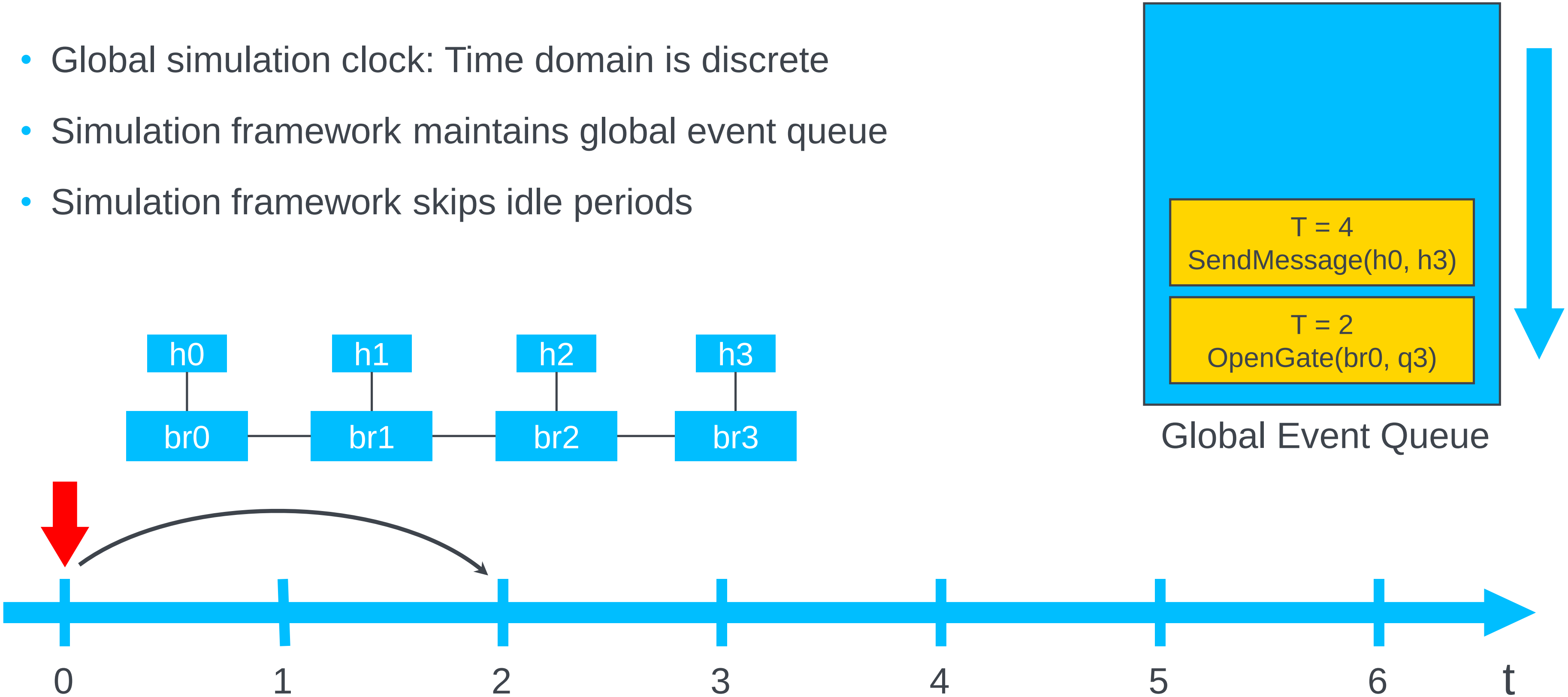
- Simulation framework maintains global event queue
- Simulation framework skips idle periods



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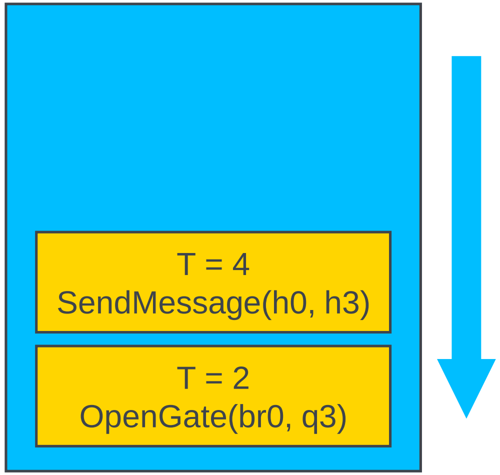

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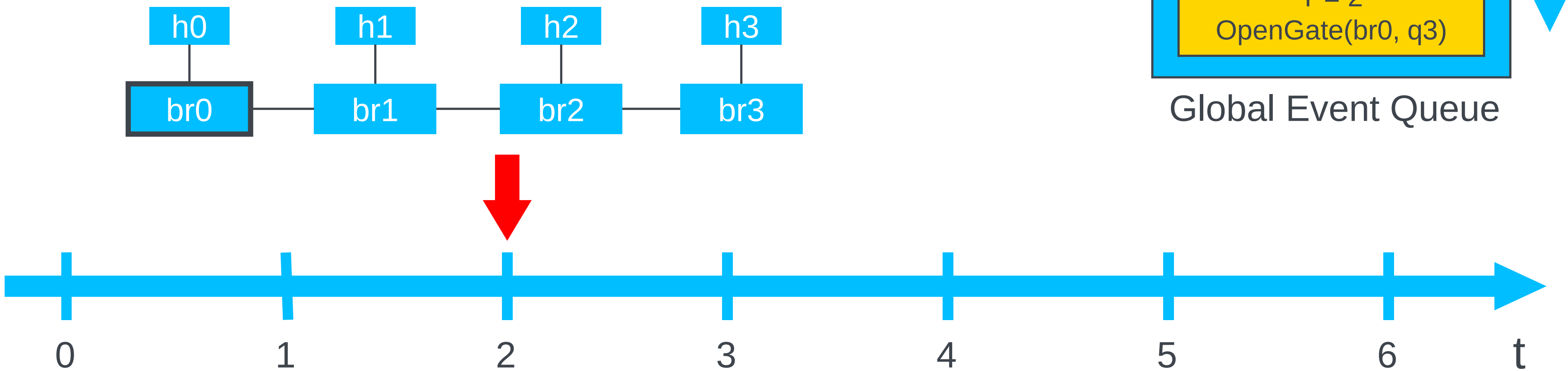

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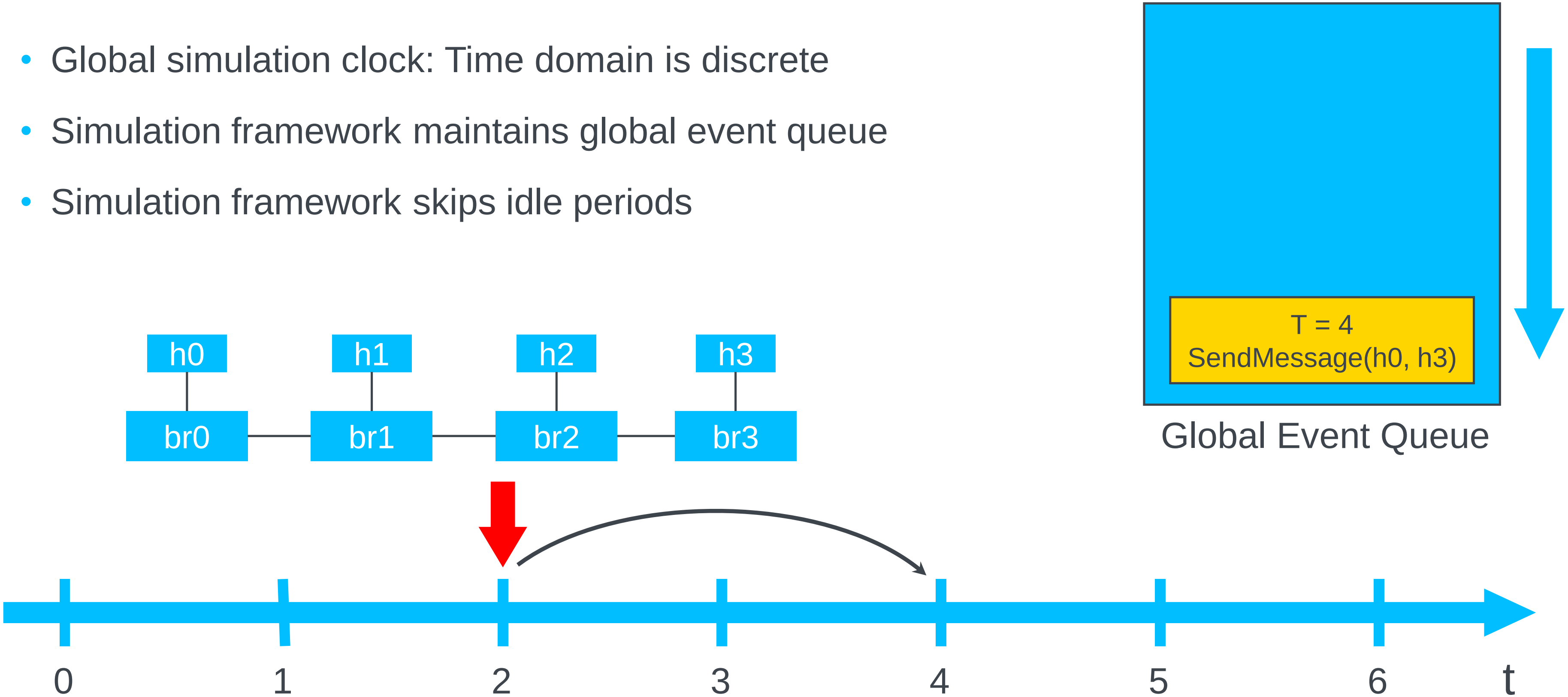

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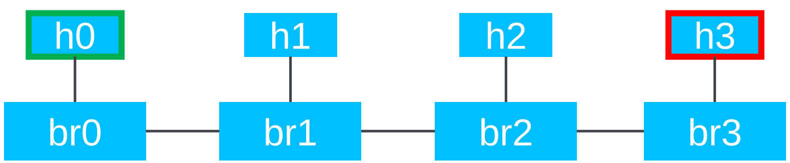

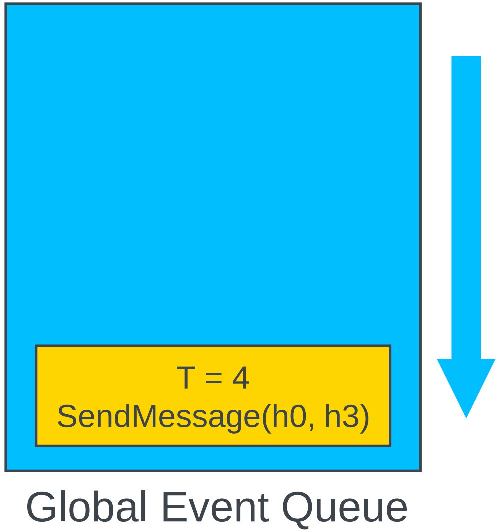

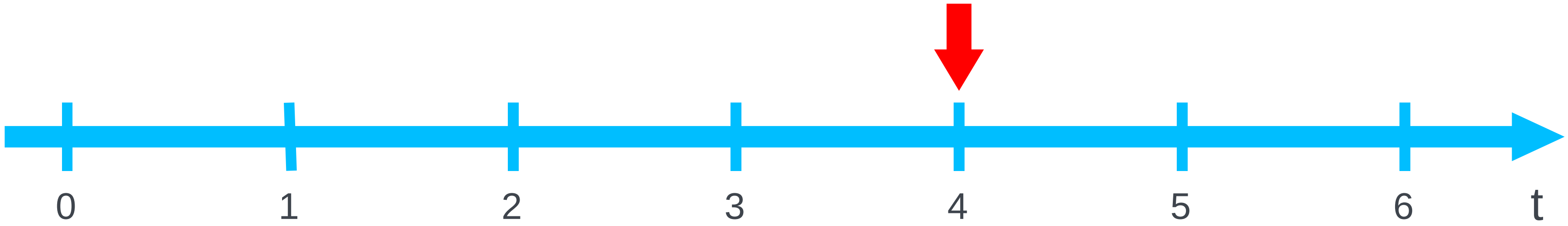

Discrete Event Simulation (DES): A primer

- Global simulation clock: Time domain is discrete
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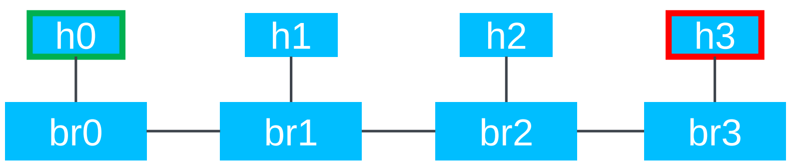
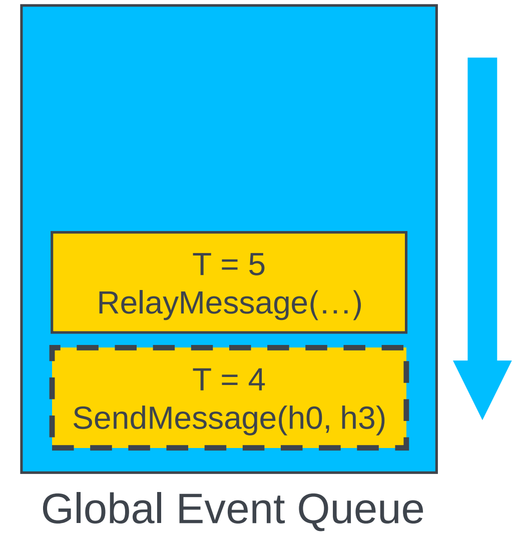
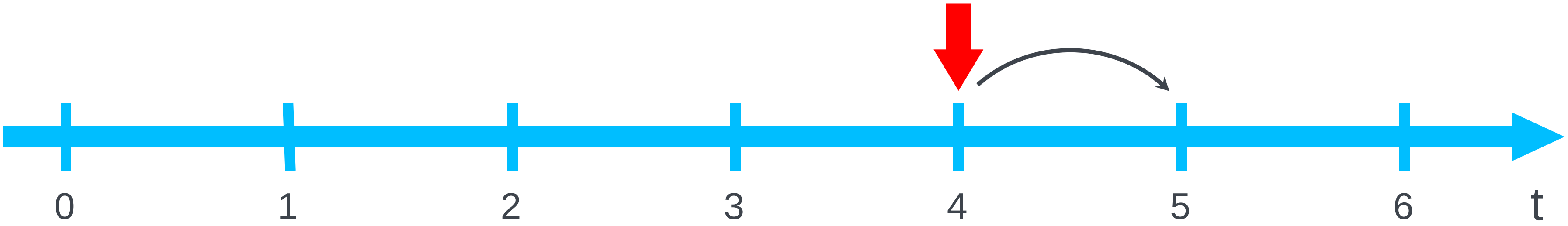
- Processing an event can create new events







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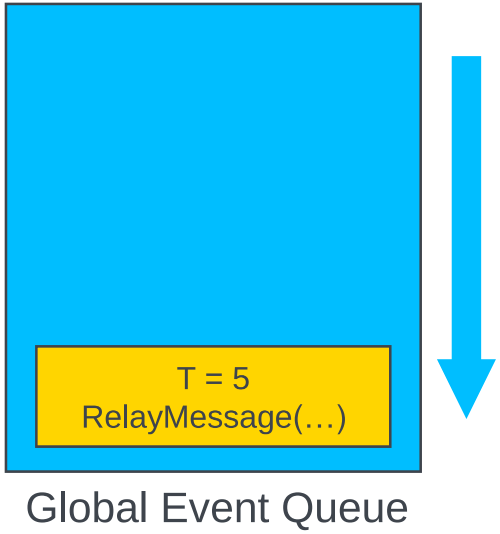
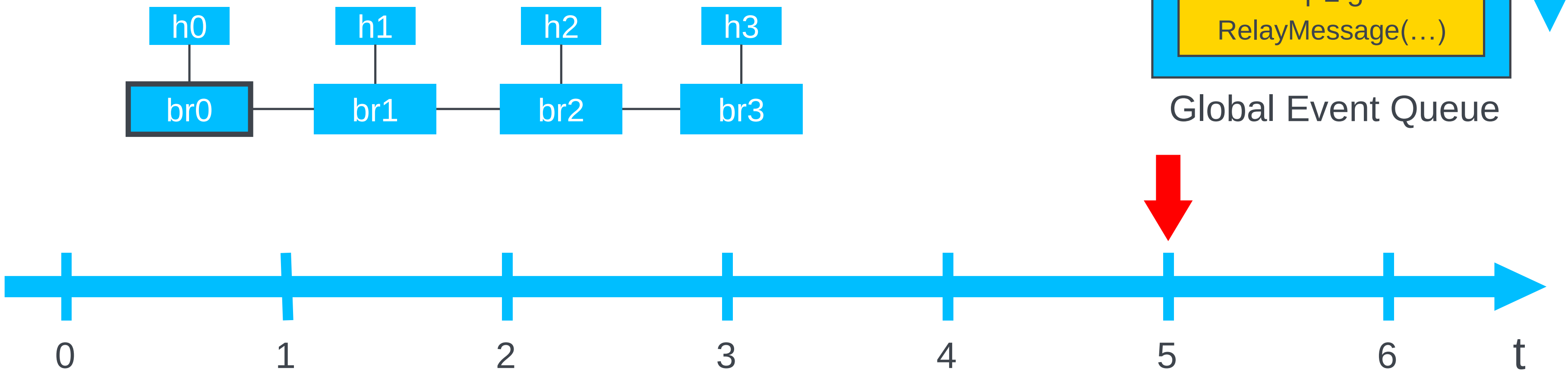




Building the Model

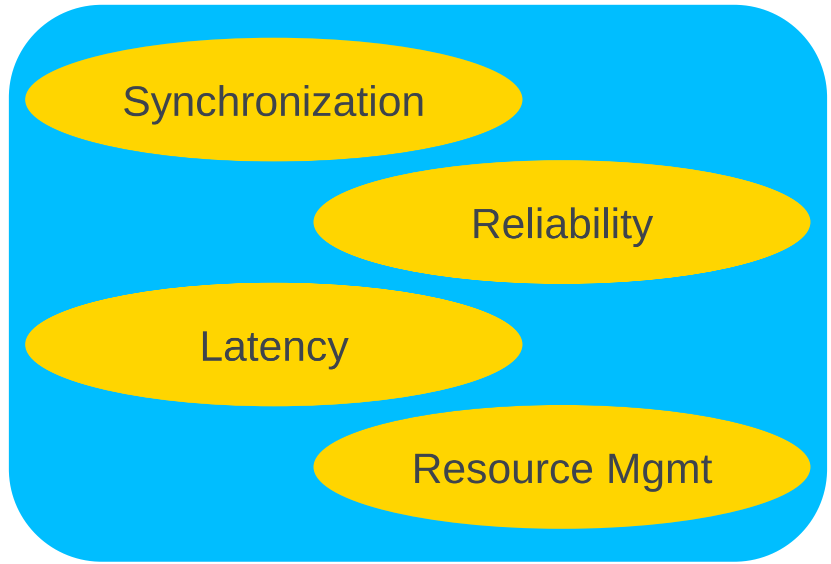
- A simulation model:
  - Abstraction of the real system
  - Reduced to critical parts

- Which TSN components do we want to simulate?

- Which abstractions can we make for our TSN model?

- Which auxiliary components are necessary to simulate our TSN model?

TSN Components

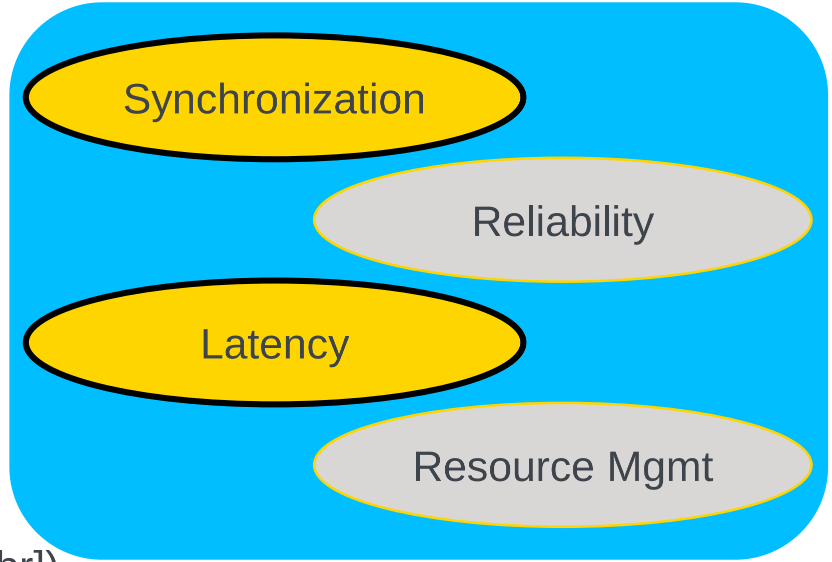


Courtesy of János Farkas

TSN Components

- Clock synchronization

- Latency
  - Scheduled Traffic (Qbv)
  - Credit Based Shaper (Qav)
  - Frame-Preemption (Qbu/[.3br])



Courtesy of János Farkas

Time-aware Shaping

- Affected Systems:
  - Bridges
  - End stations
- Required capabilities:
  - VLAN → PCP
  - Queuing
  - Gate Control
  - Scheduling
- Prerequisite: Time synchronization of network

Building Block: INET Framework

- “An open-source OMNeT++ model suite for wired, wireless and mobile networks.”

- We do not want to reinvent the wheel

- Already implements
  - Ethernet channels and Ethernet components
  - Higher Layer protocols

- Compatibility to INET allows simulation of **converged networks** by utilizing its higher layer components

Time Synchronization of Network

- Global simulation clock could be used to synchronize clocks of Bridges and End systems
  - Global simulation clock cannot be used to simulate **drift**, **jitter** or **PTP**

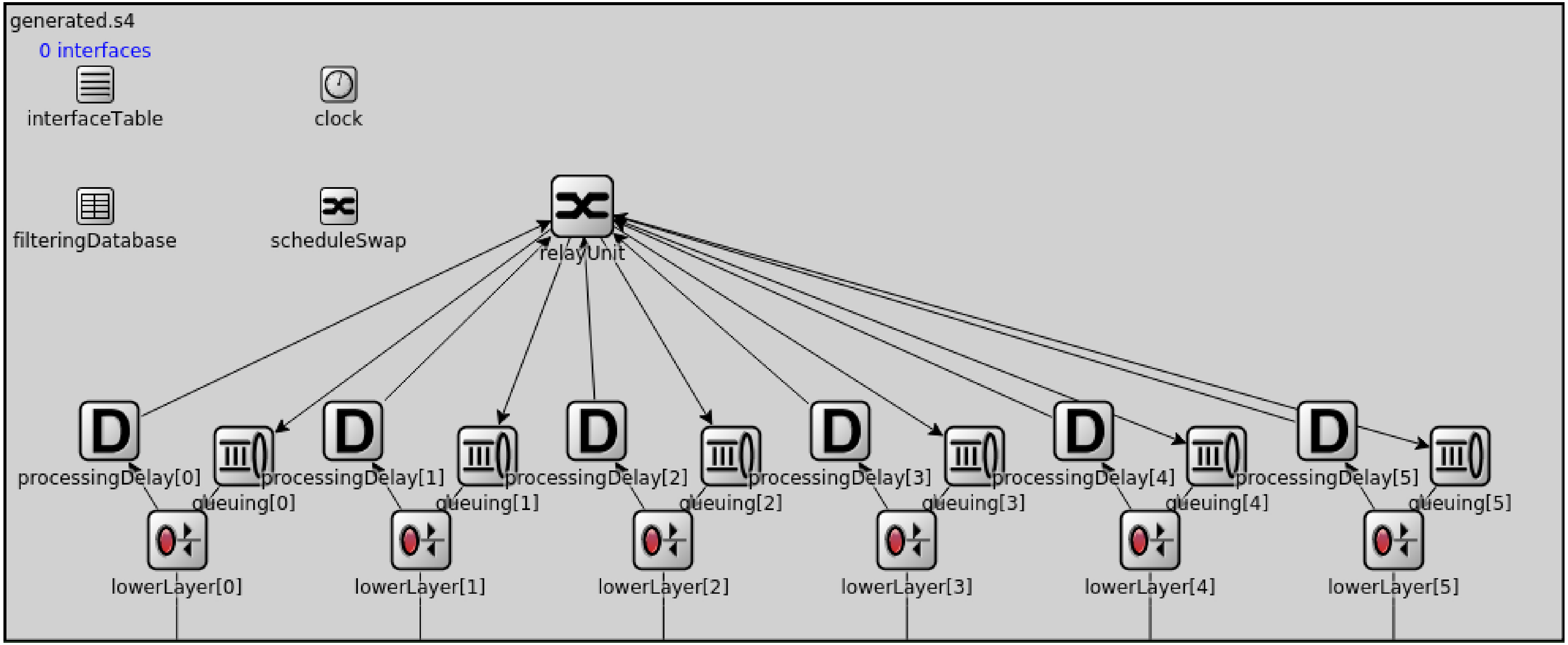
→Interface for a user-defined clock model

  - Currently only ideal clock is implemented

- User-defined clock may not simulate every tick
  → only interesting time points are being simulated (DES)

- Interested components can subscribe to ticks
  - Priority queue
  - Clocks notifies subscribed components if a tick occurs

Implementation



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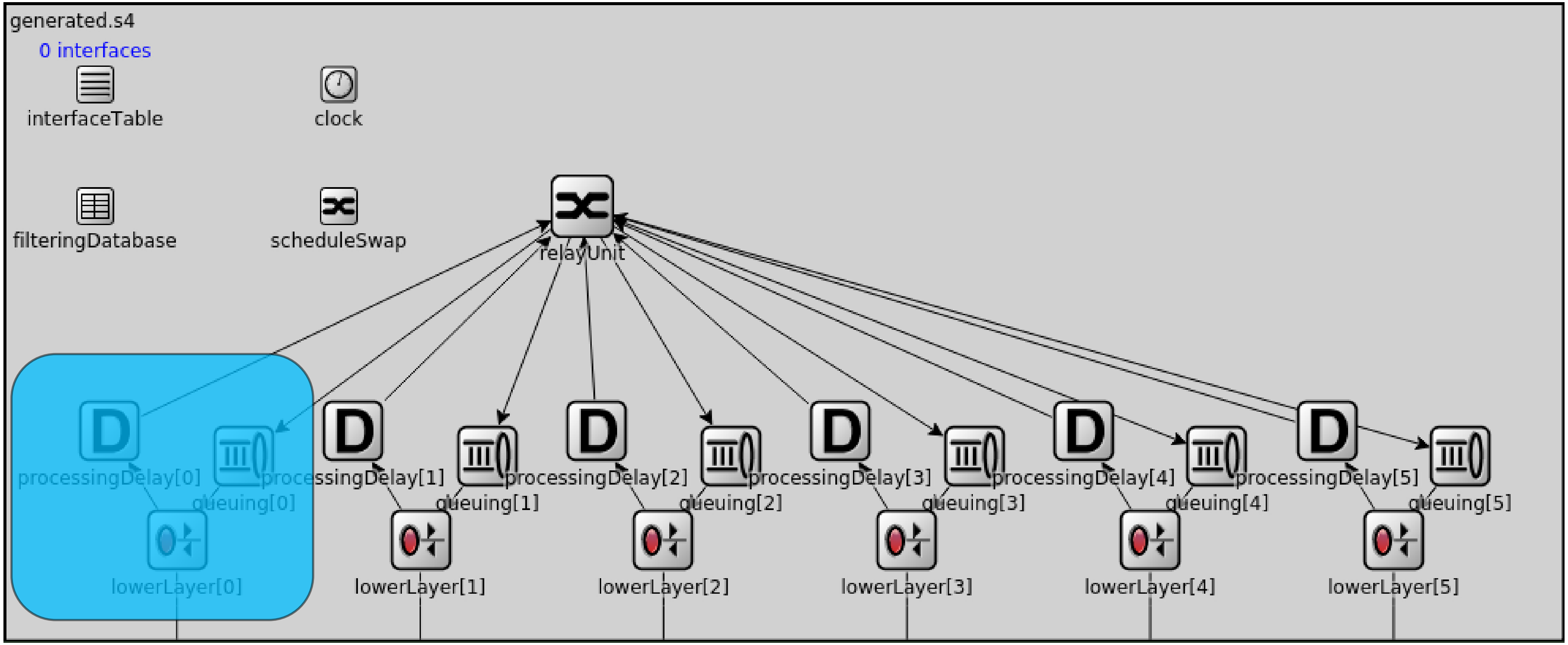

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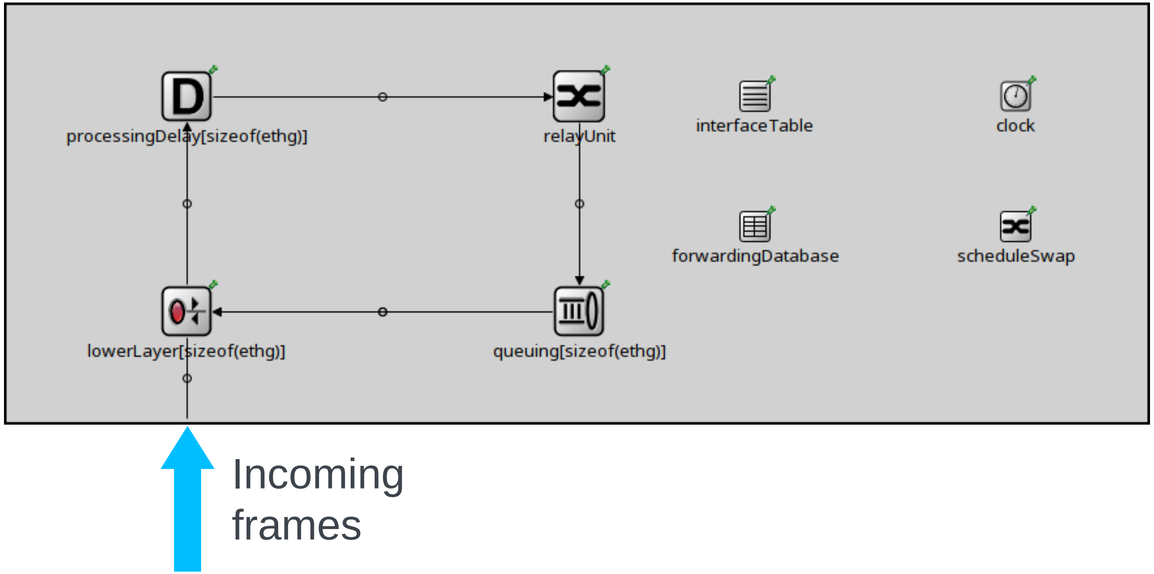
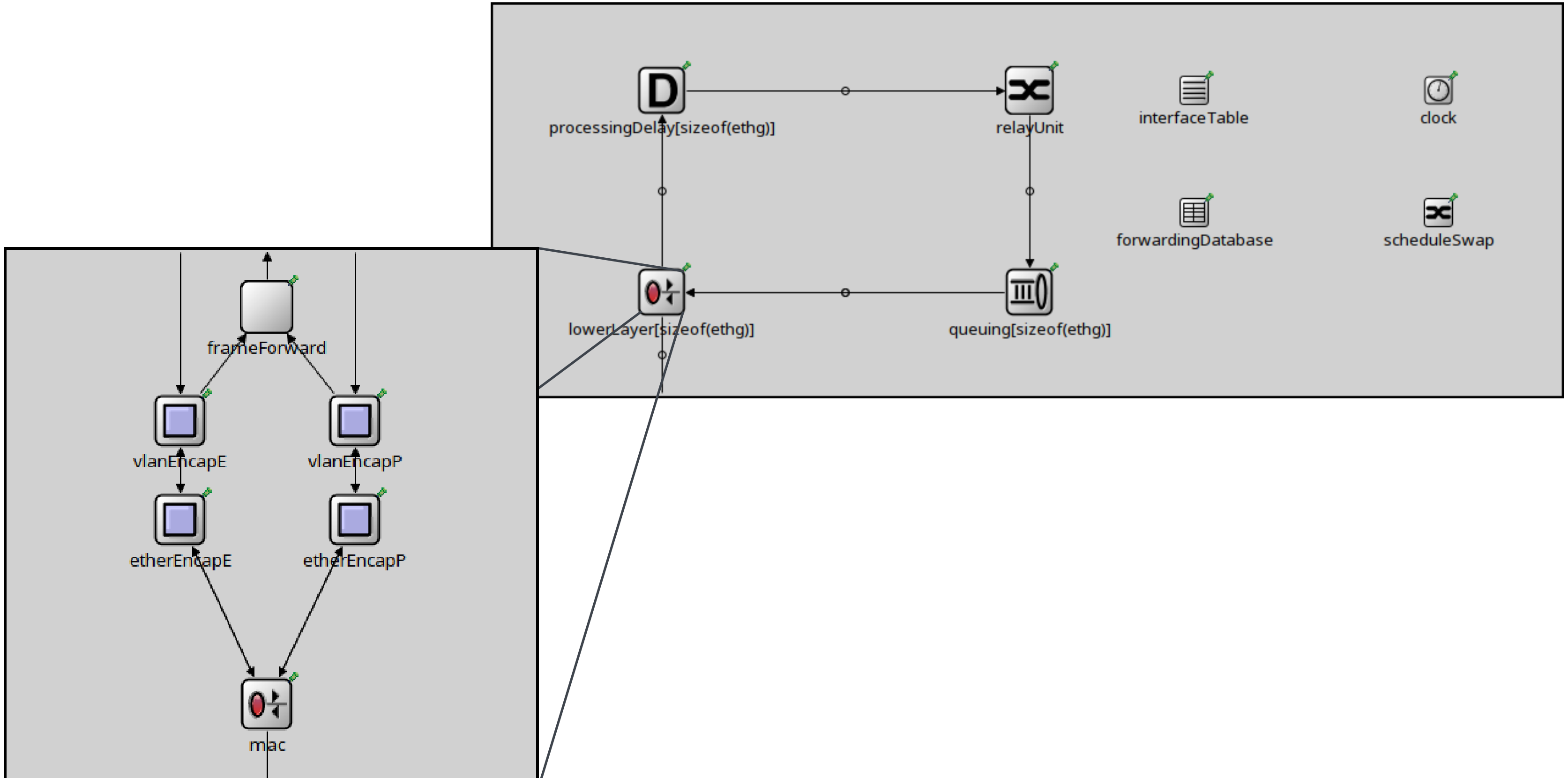
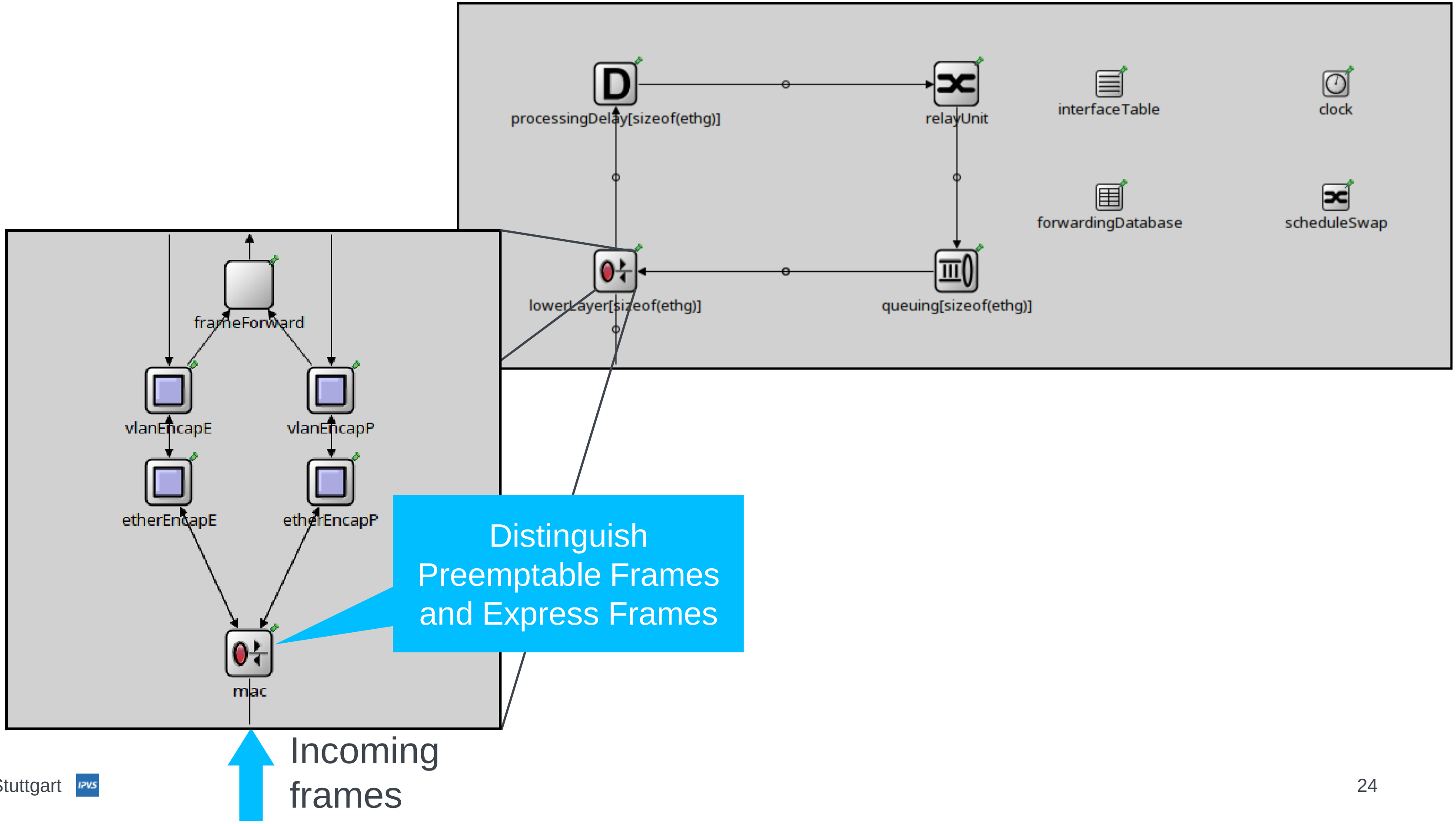


Implementation: Frame Preemption (Inbound)



Incoming frames

Implementation: Frame Preemption (Inbound)



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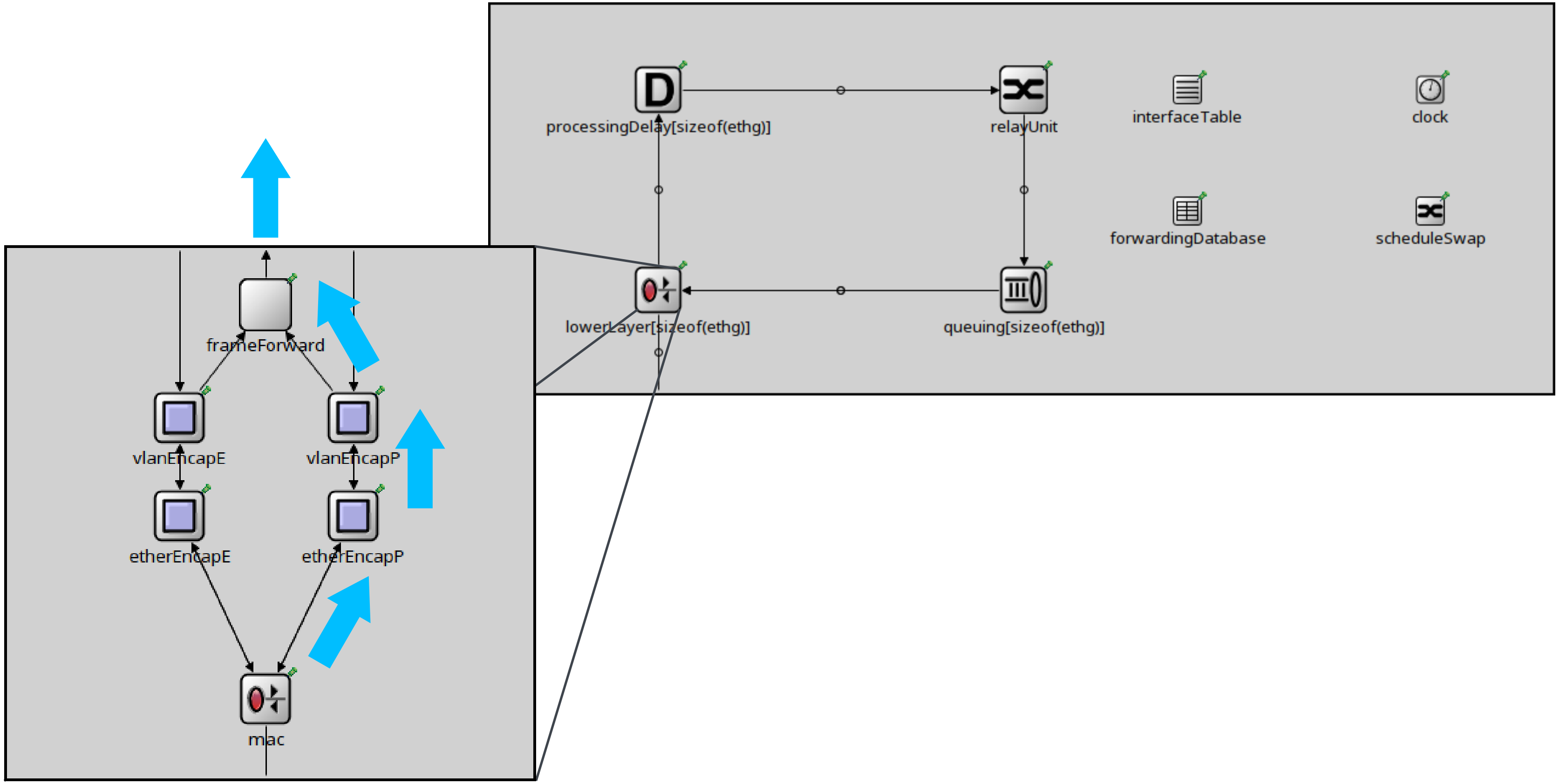

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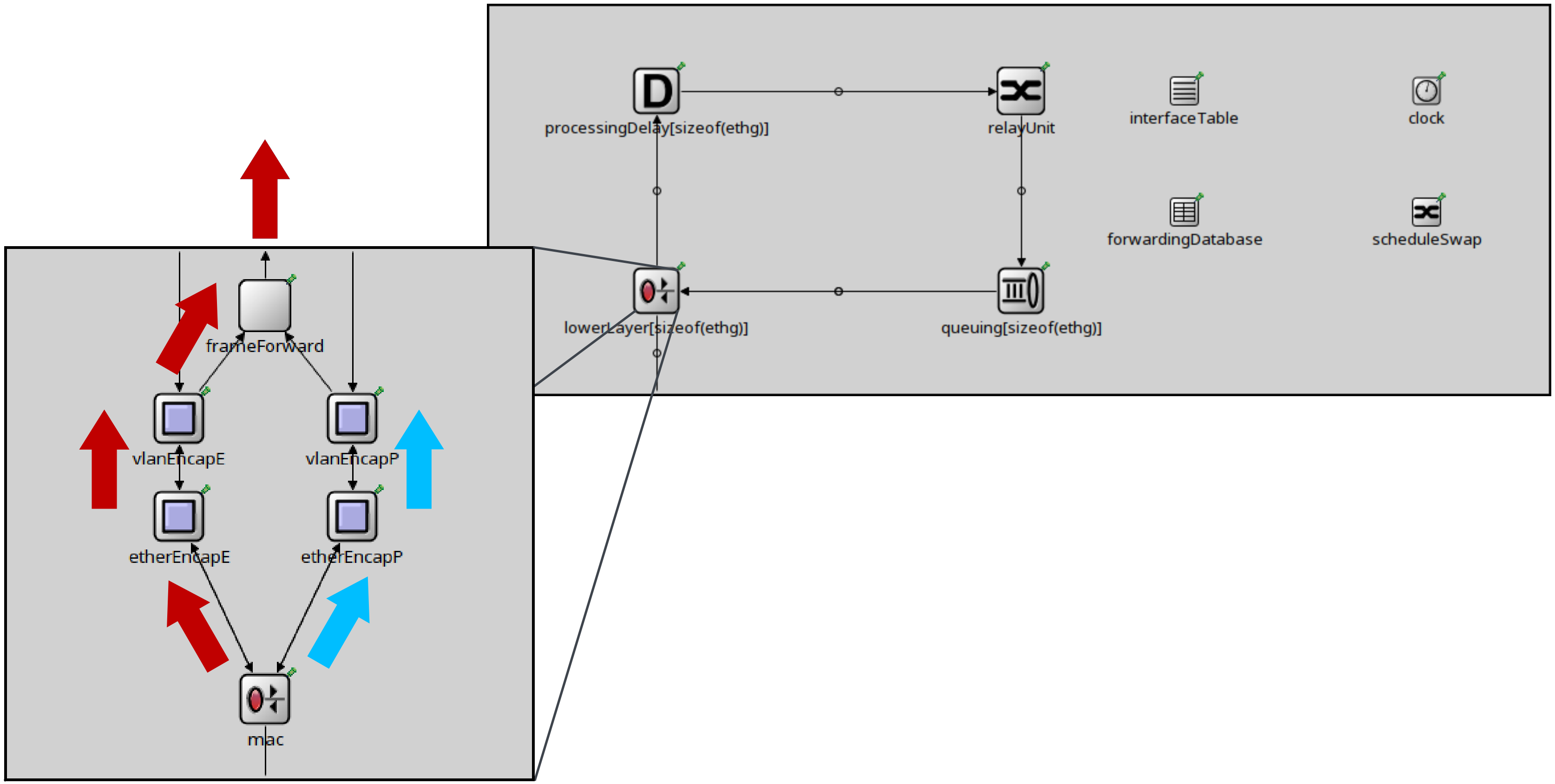

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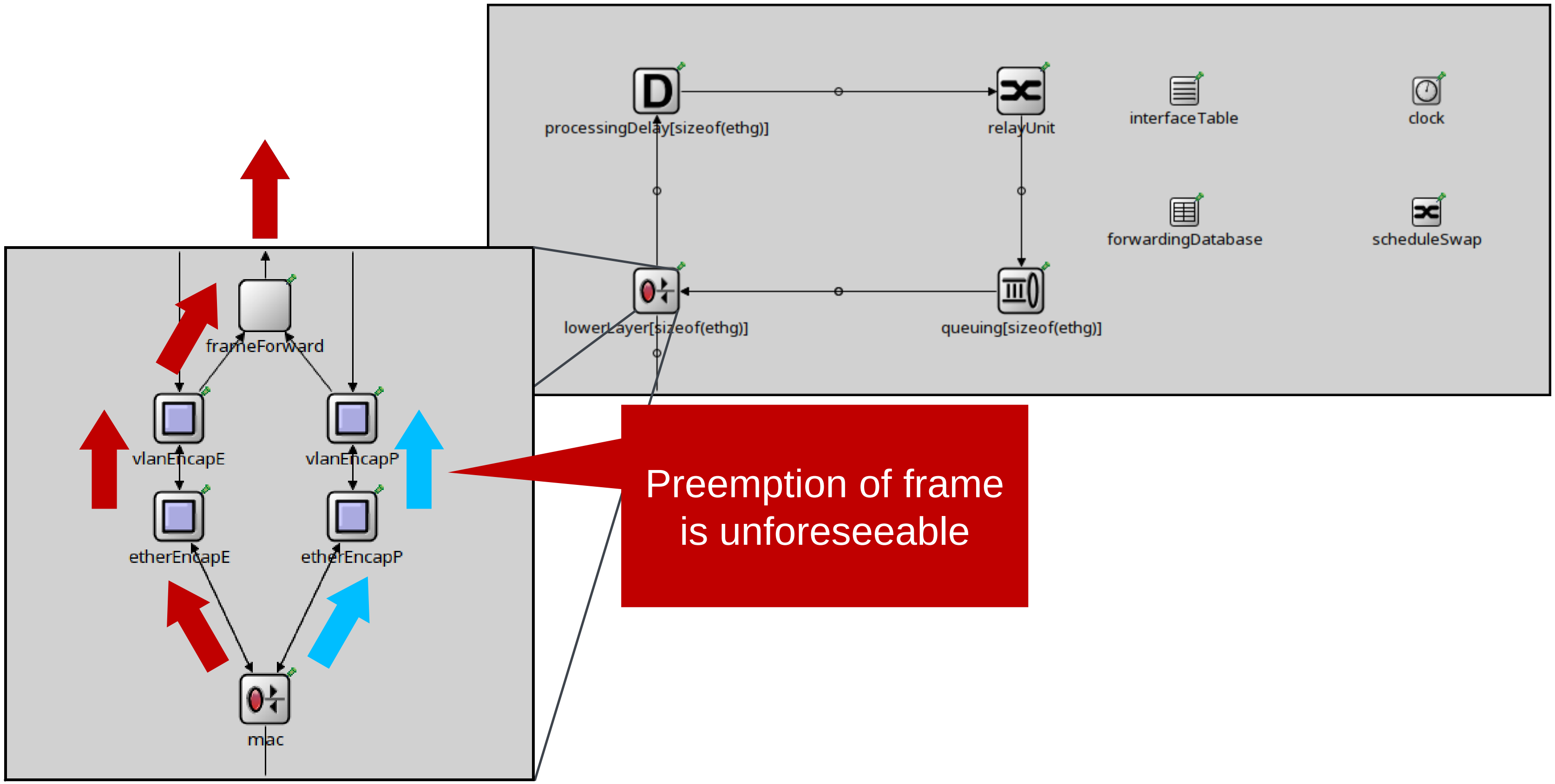

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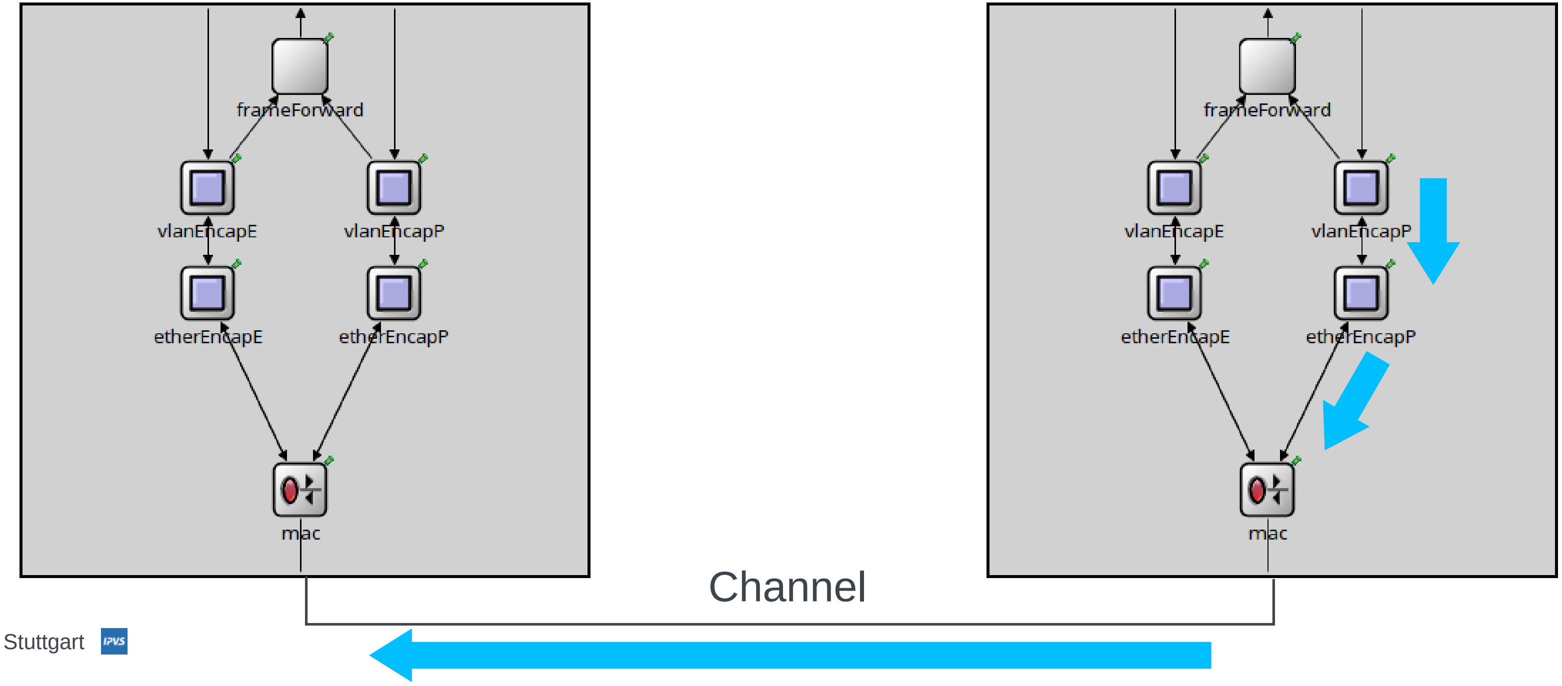

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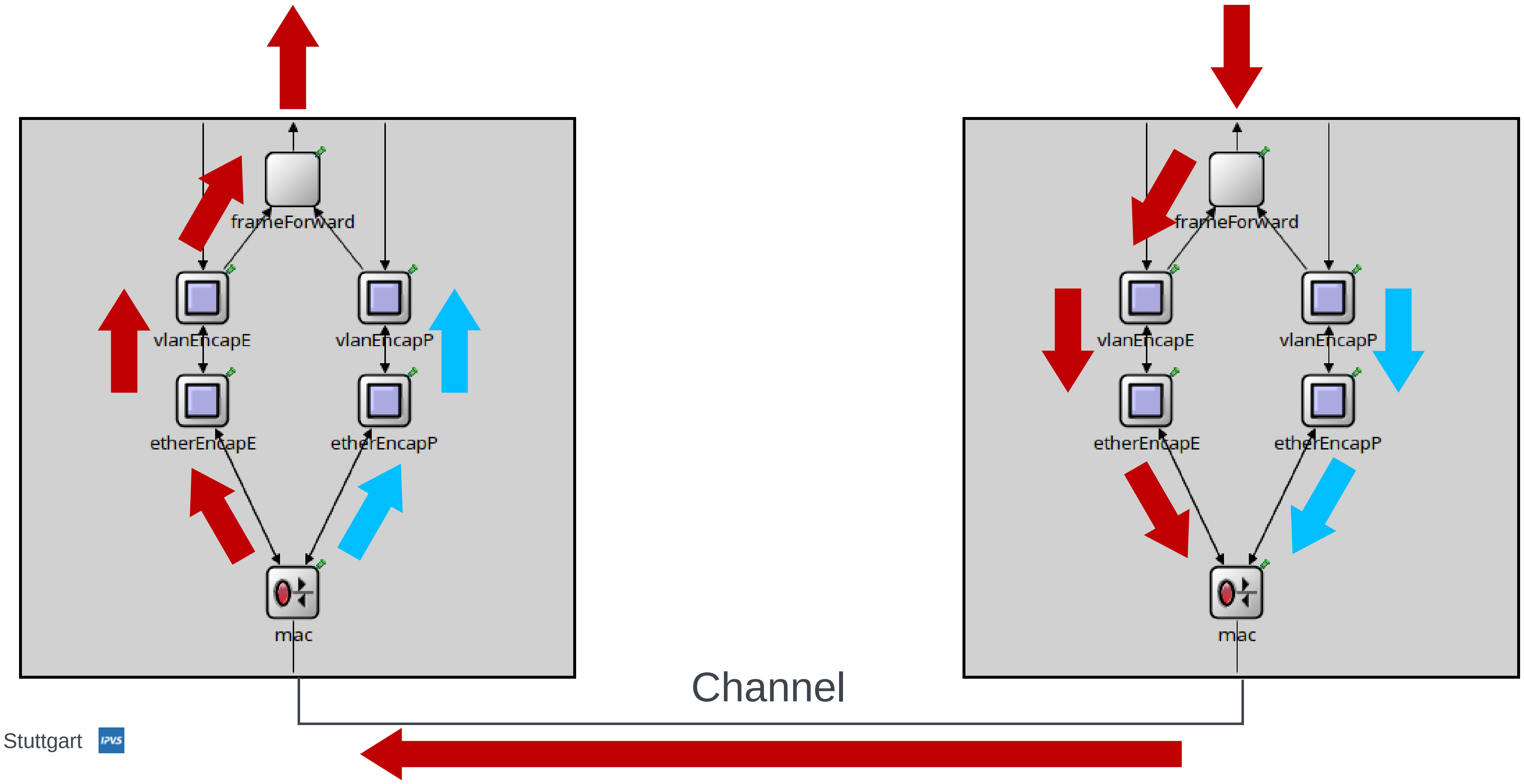

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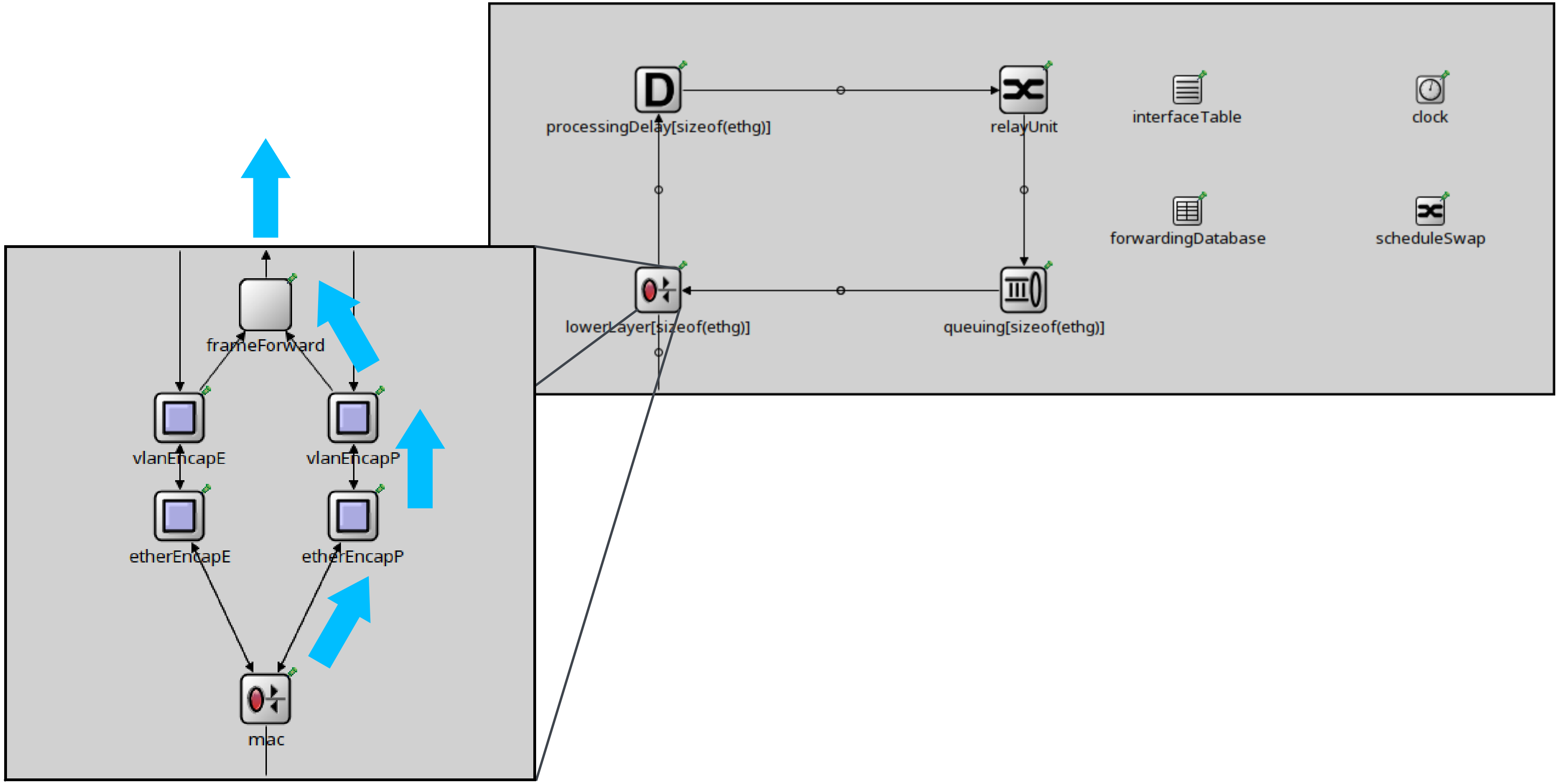
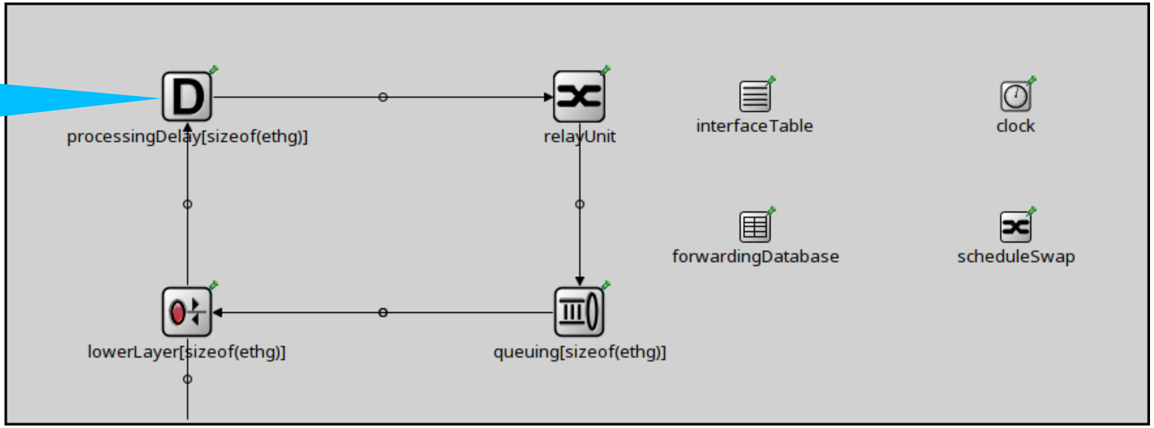
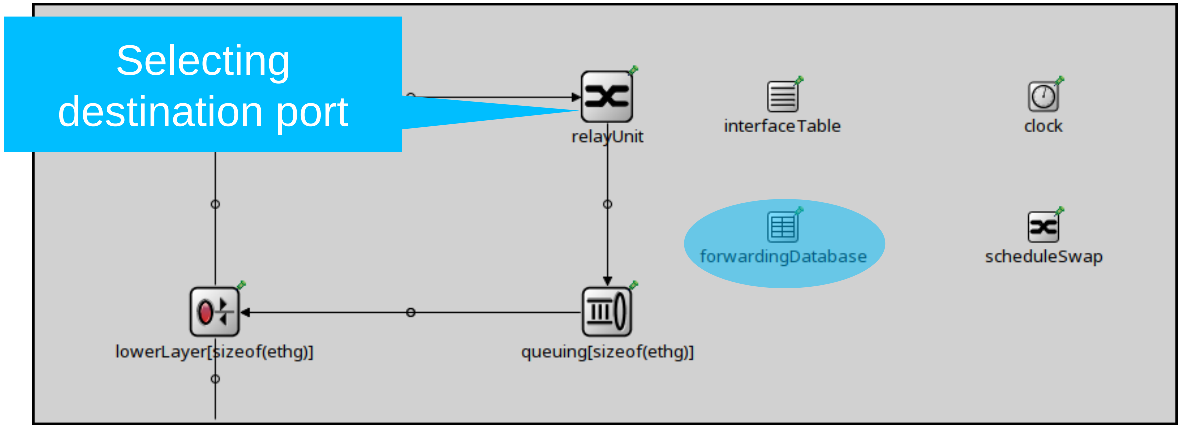


Implementation: Processing Delay

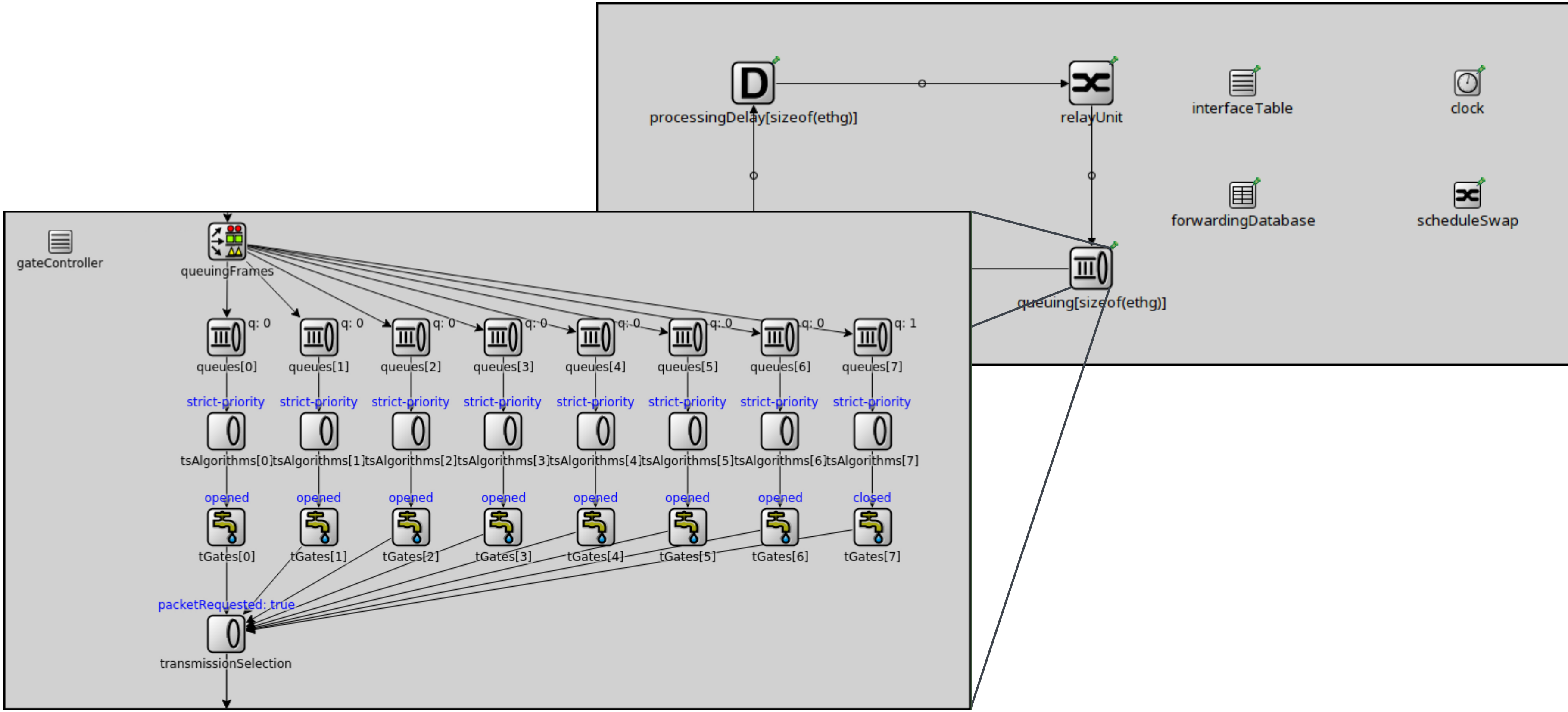
Adding bridge-specific delay



Implementation: Relay Unit

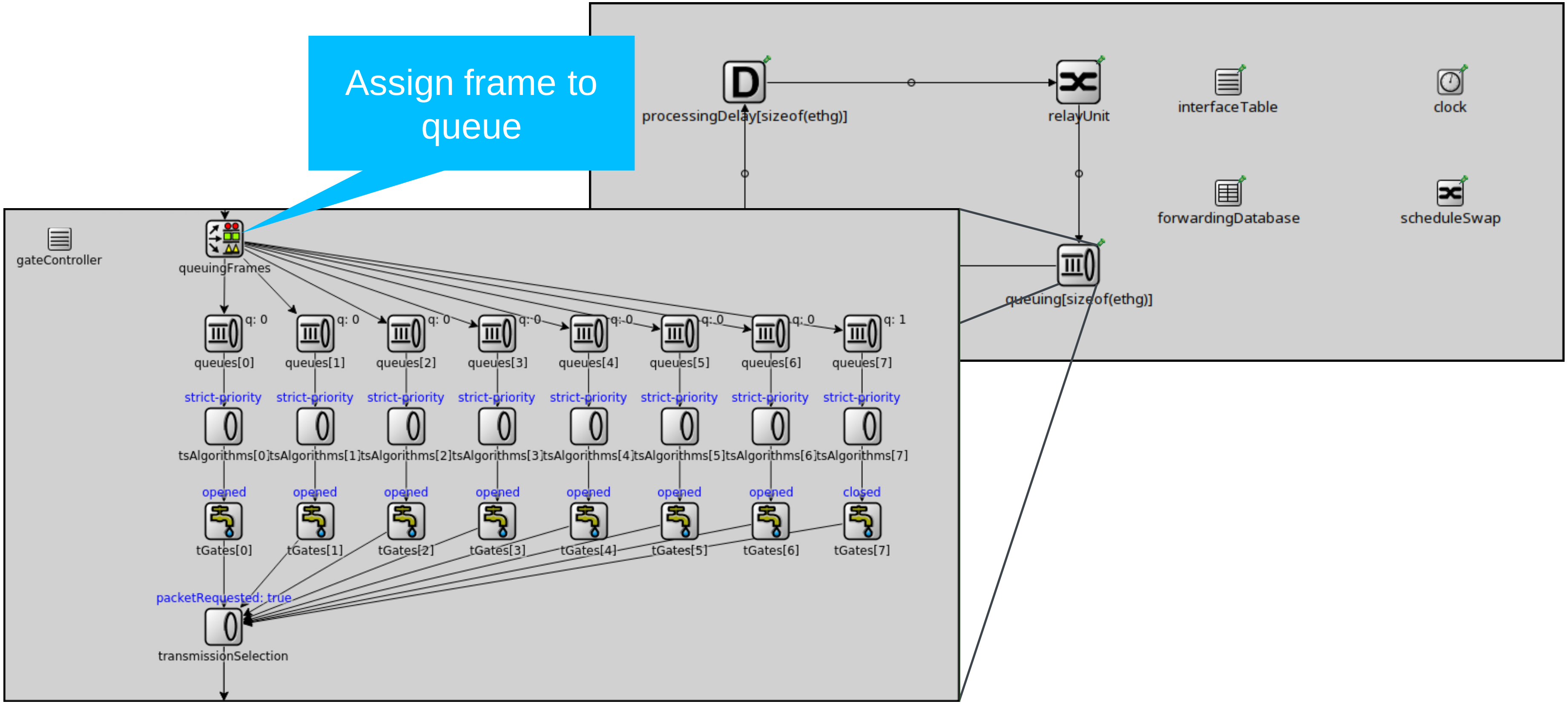


Implementation: Queuing

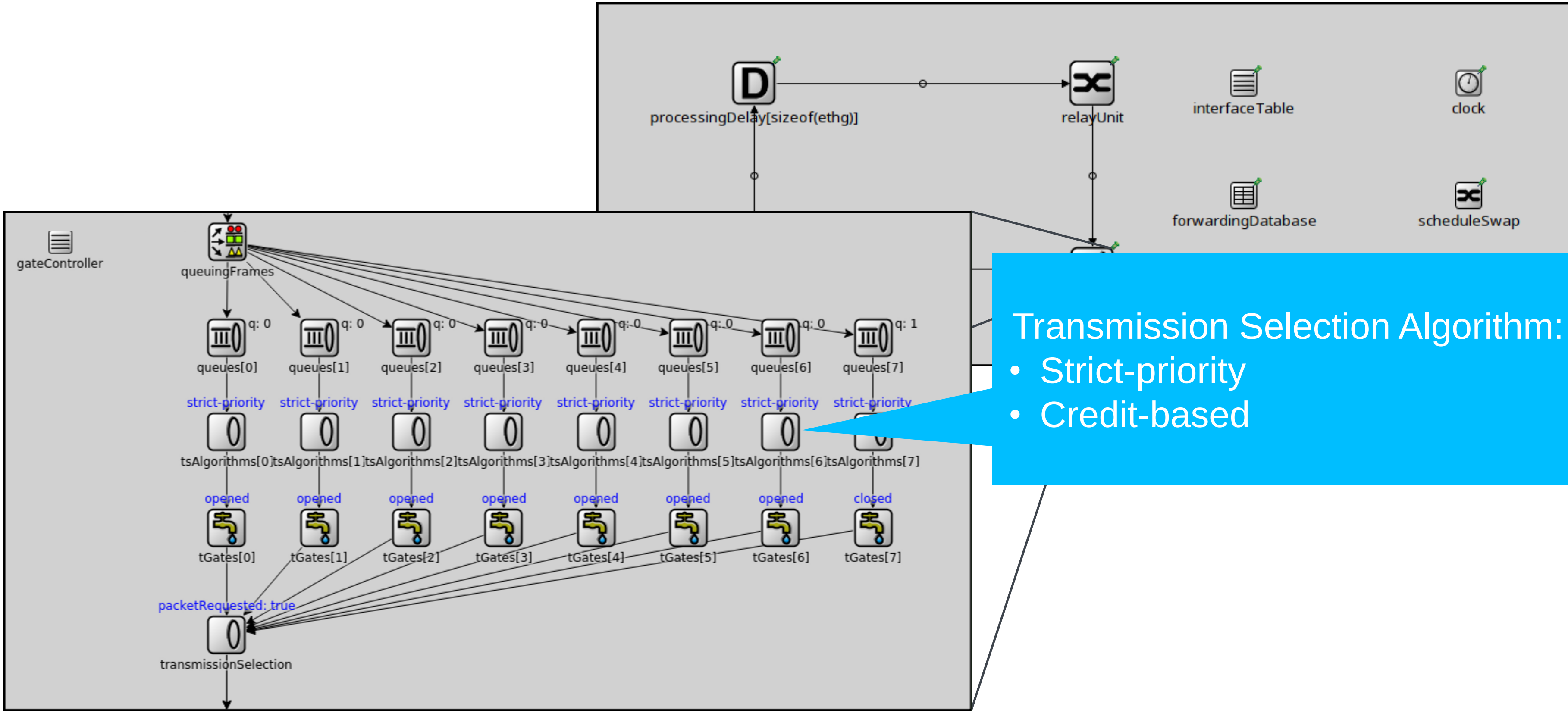


Implementation: Queuing

Assign frame to queue



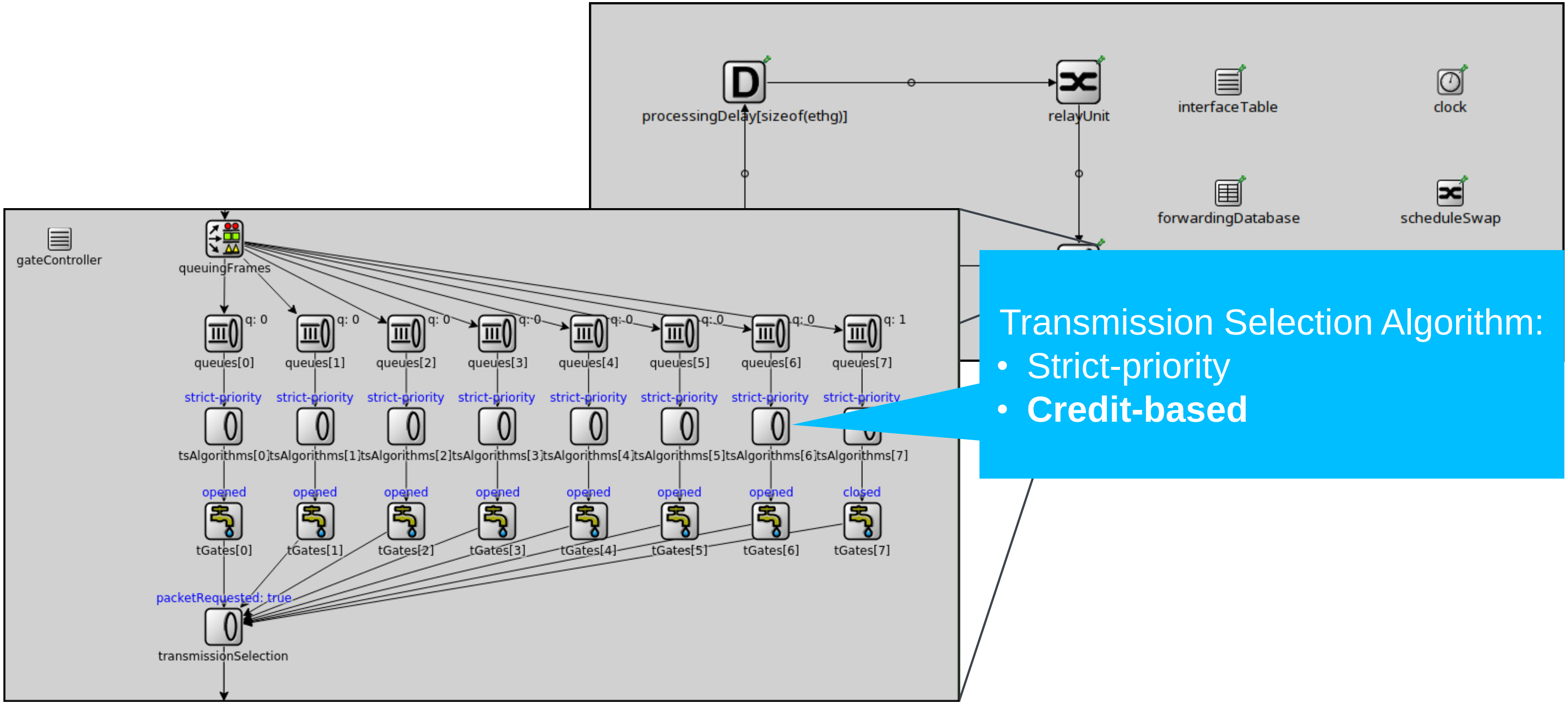
Implementation: Transmission Selection Algorithm



Transmission Selection Algorithm:

- Strict-priority
- Credit-based

Implementation: Transmission Selection Algorithm



Transmission Selection Algorithm:
- Strict-priority
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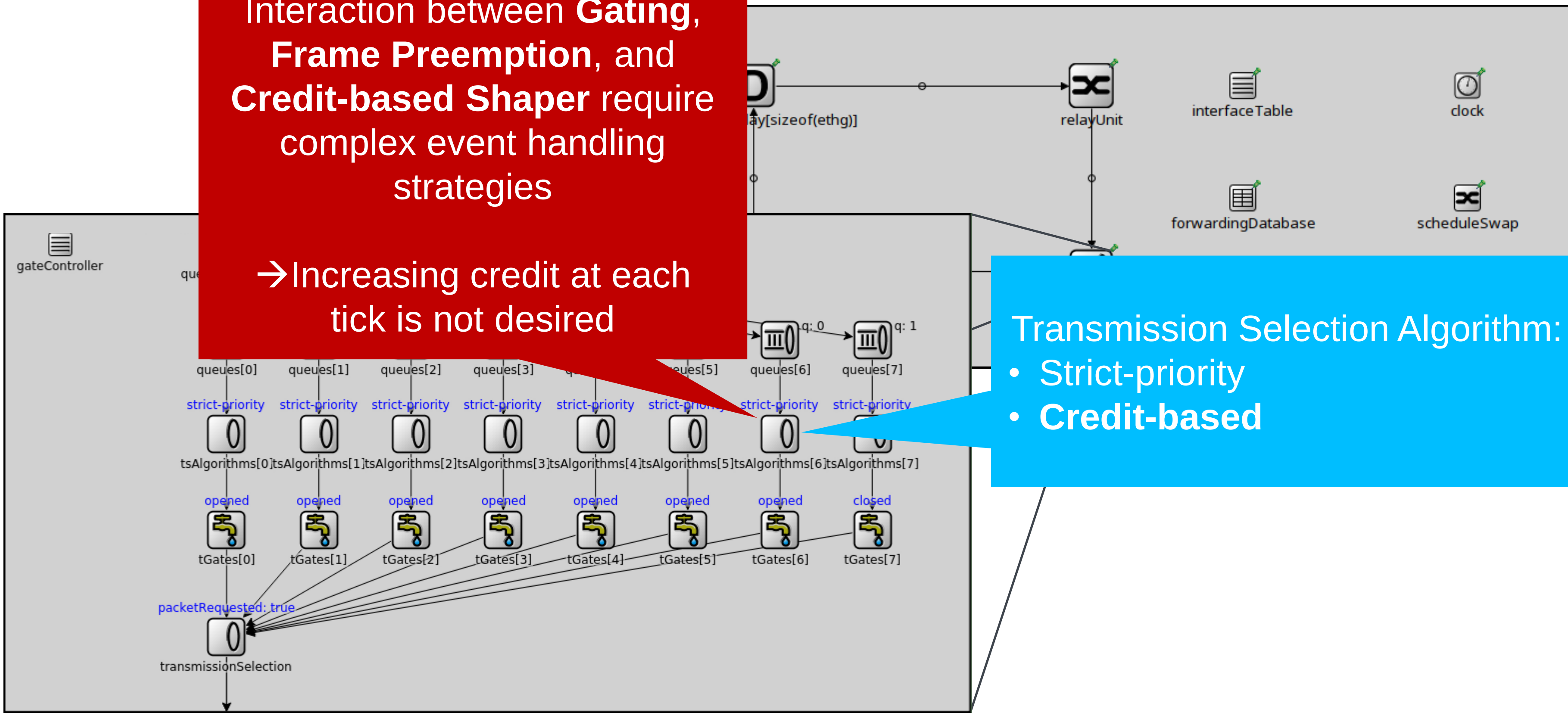
Implementation: Transmission Selection Algorithm

Interaction between **Gating**, **Frame Preemption**, and **Credit-based Shaper** require complex event handling strategies

→Increasing credit at each tick is not desired



Transmission Selection Algorithm:

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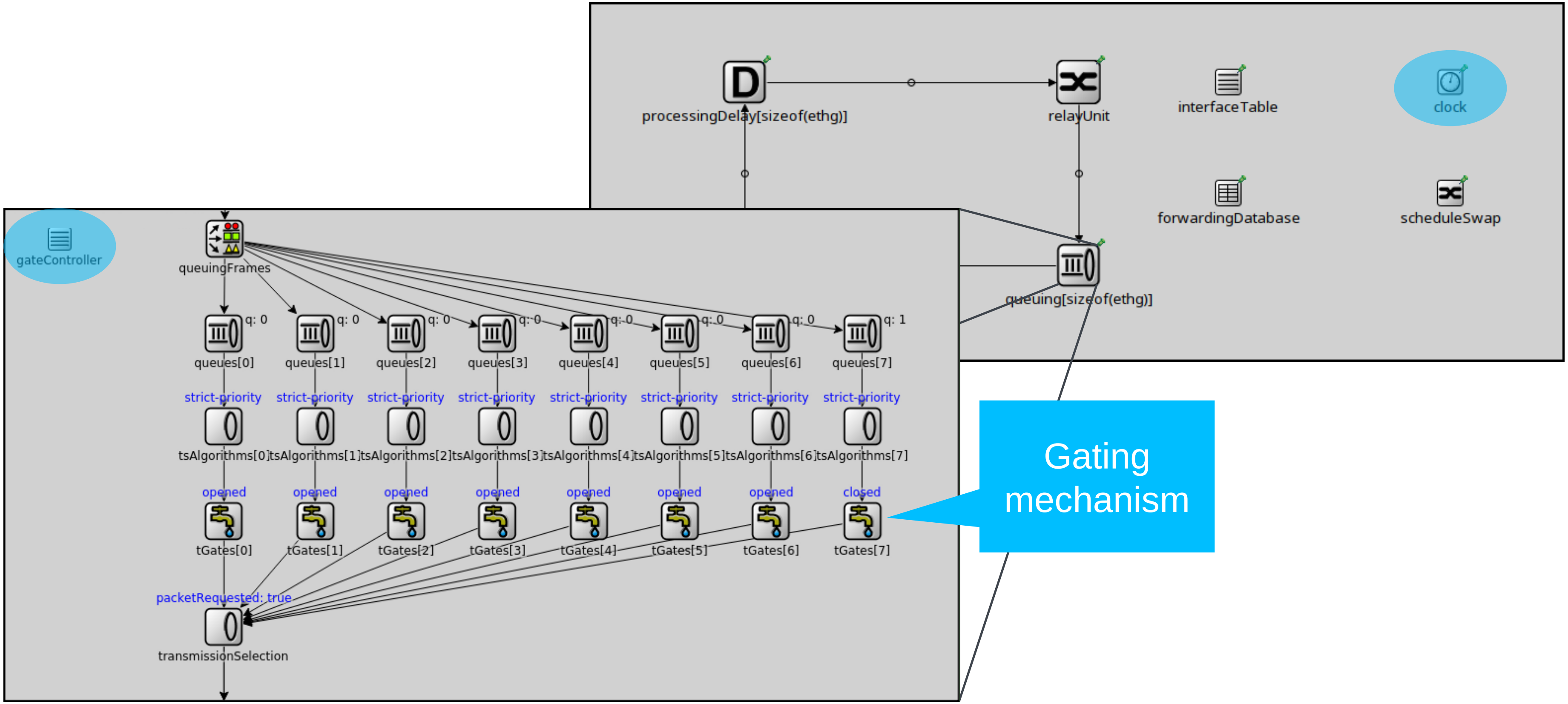
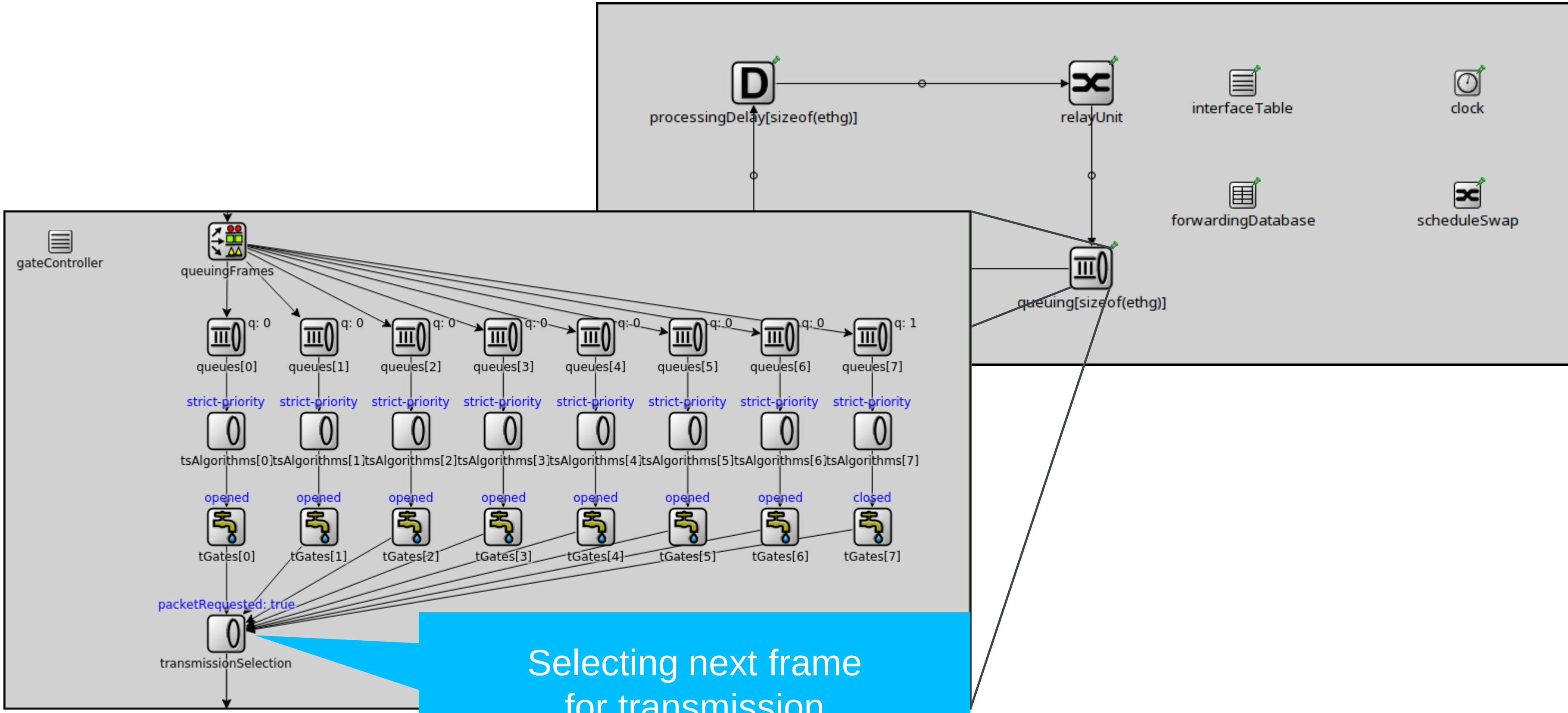
Implementation: Gating mechanism

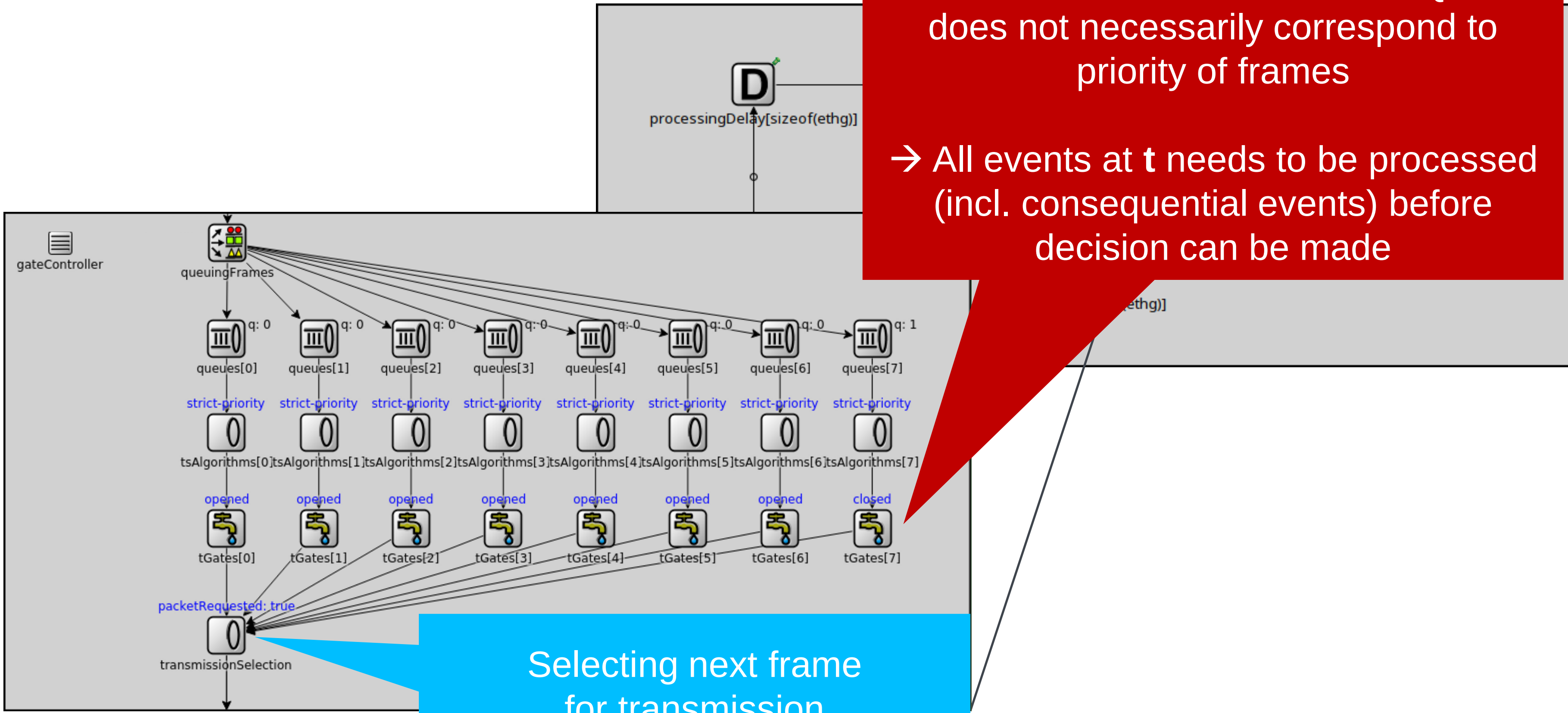


Implementation: Transmission Selection



Selecting next frame
for transmission
(incl. Length-aware Scheduling)

Implementation: Transmission Selection



Order of events in Global Event Queue does not necessarily correspond to priority of frames

→ All events at **t** needs to be processed (incl. consequential events) before decision can be made

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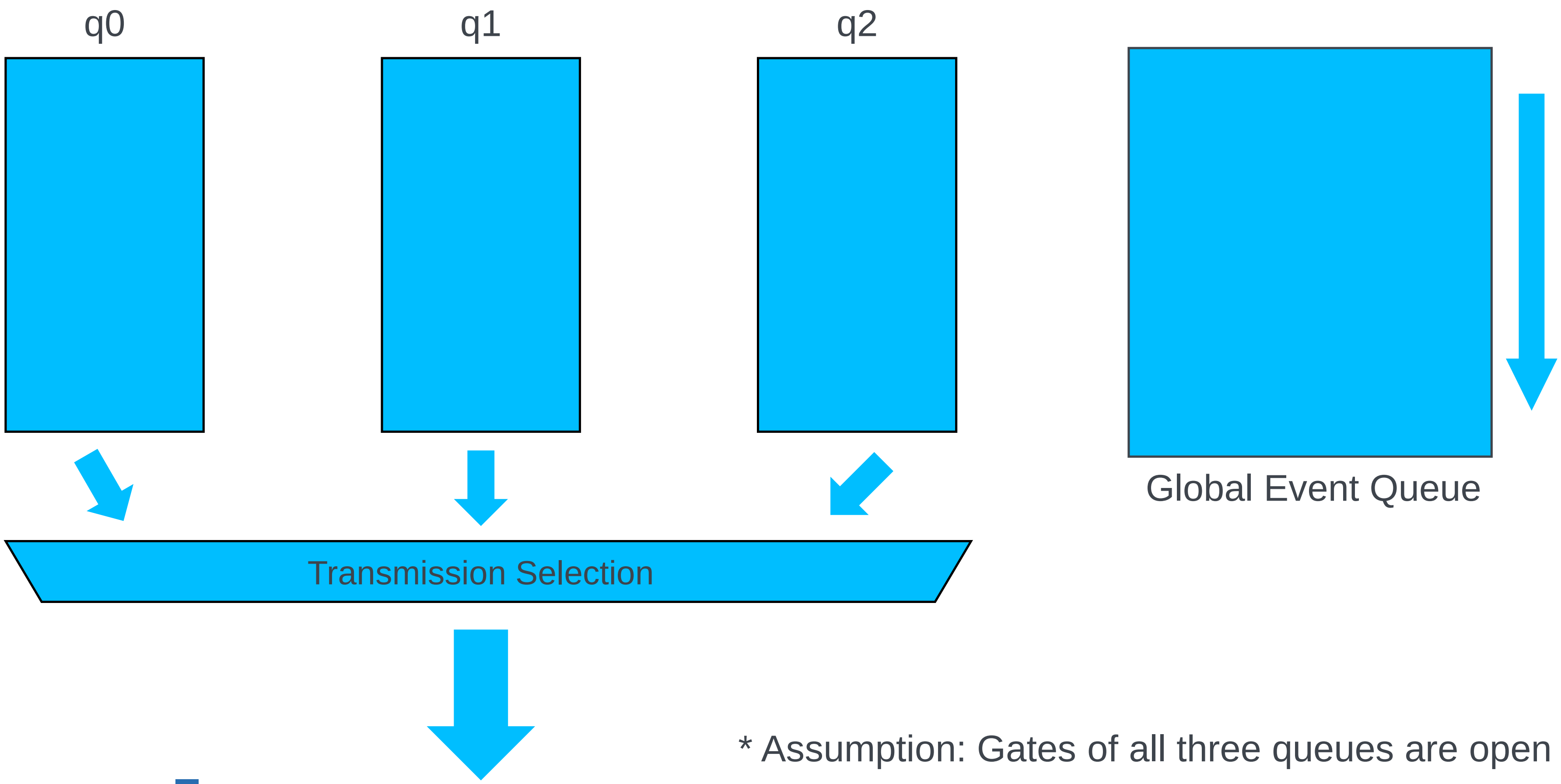
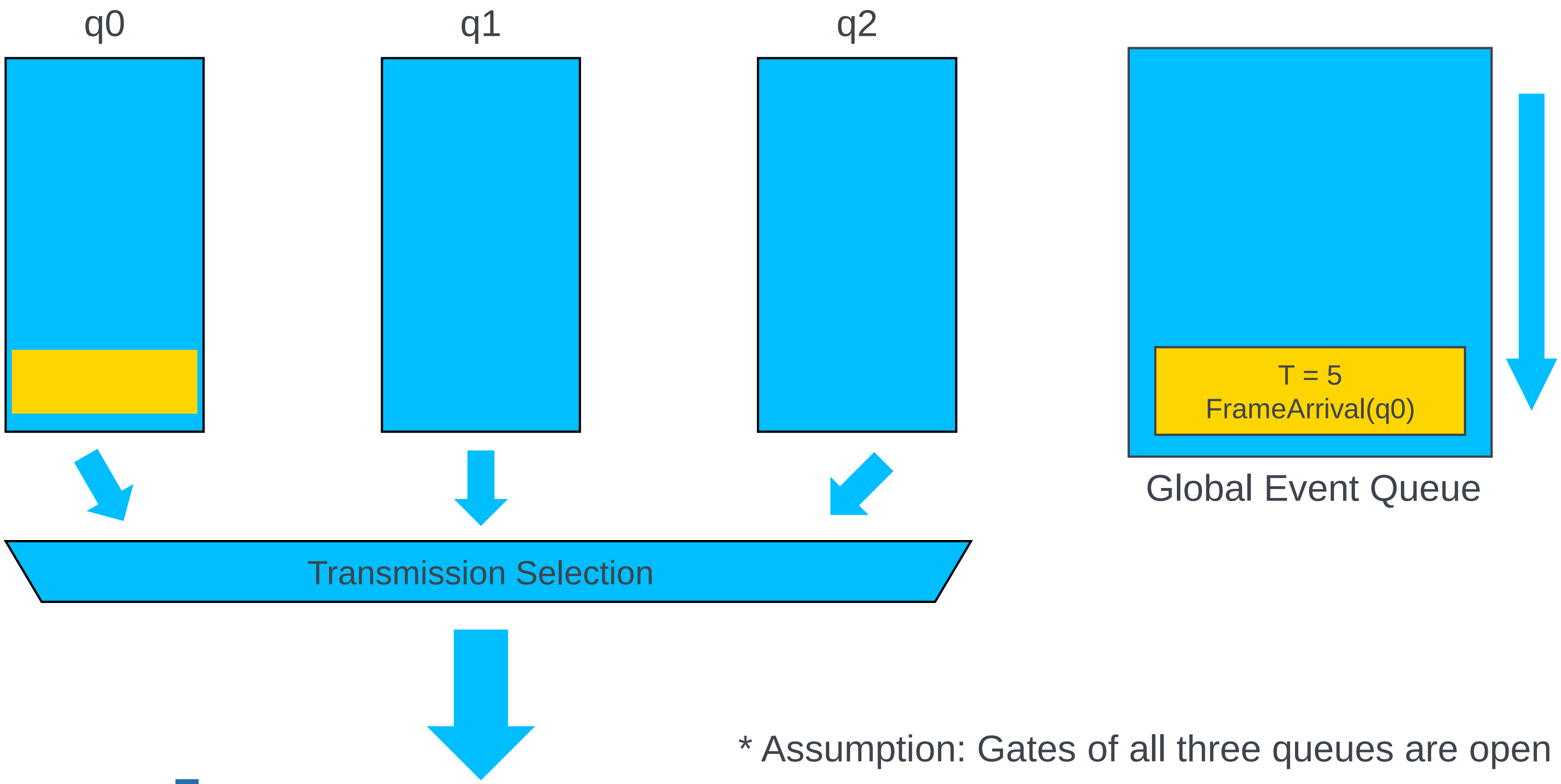


* Assumption: Gates of all three queues are open

Implementation: Transmission Selection



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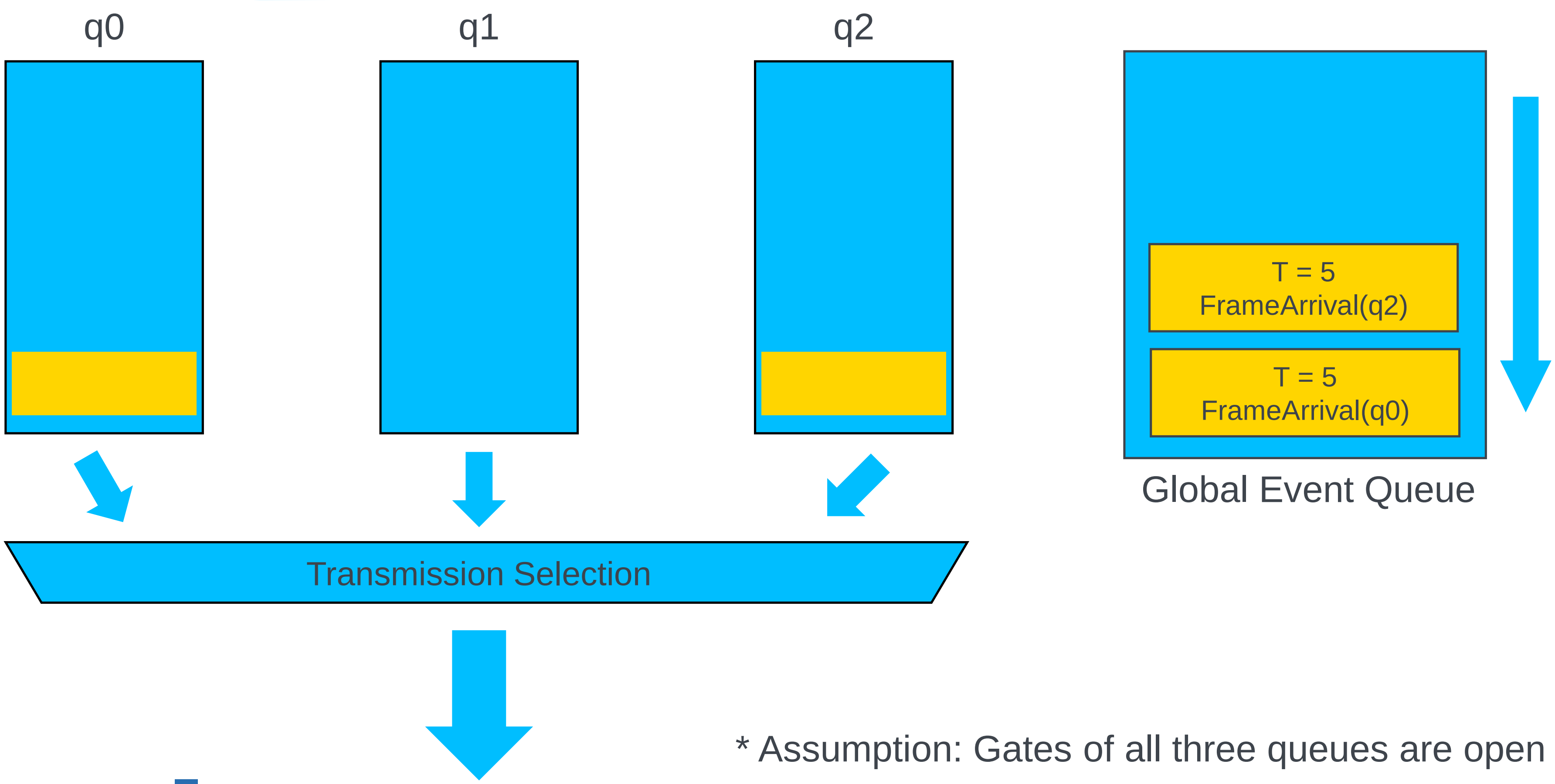

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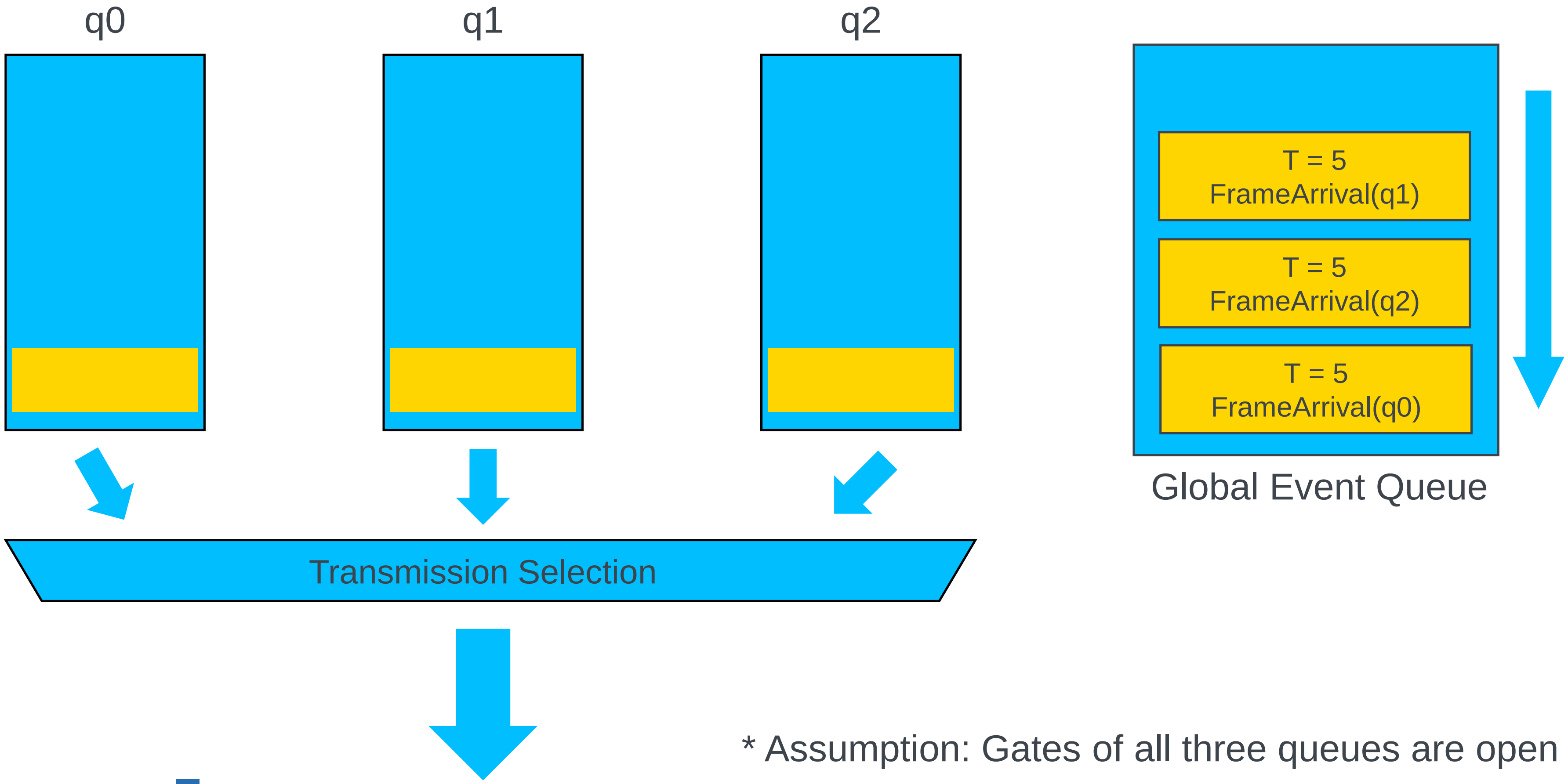

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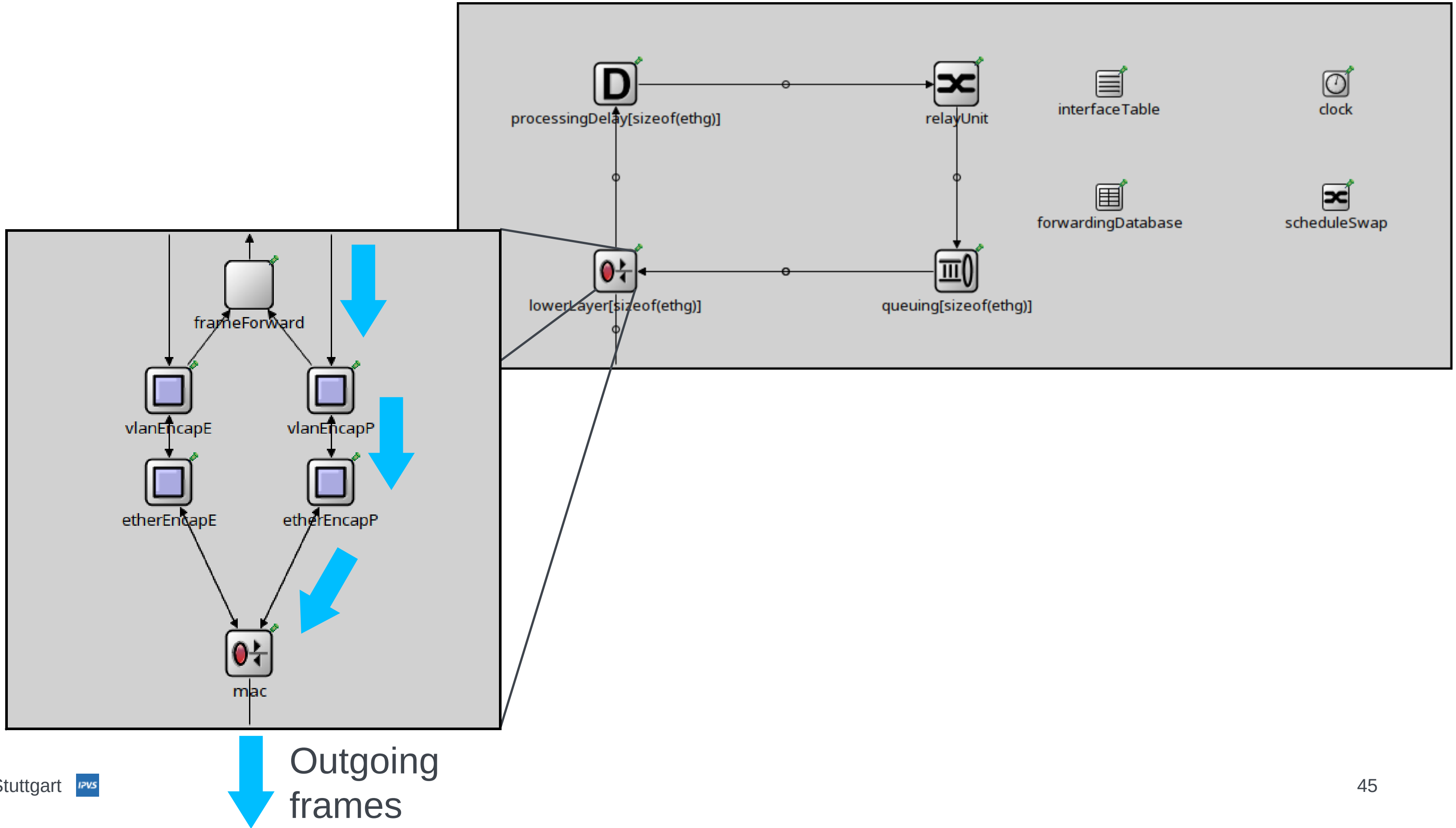

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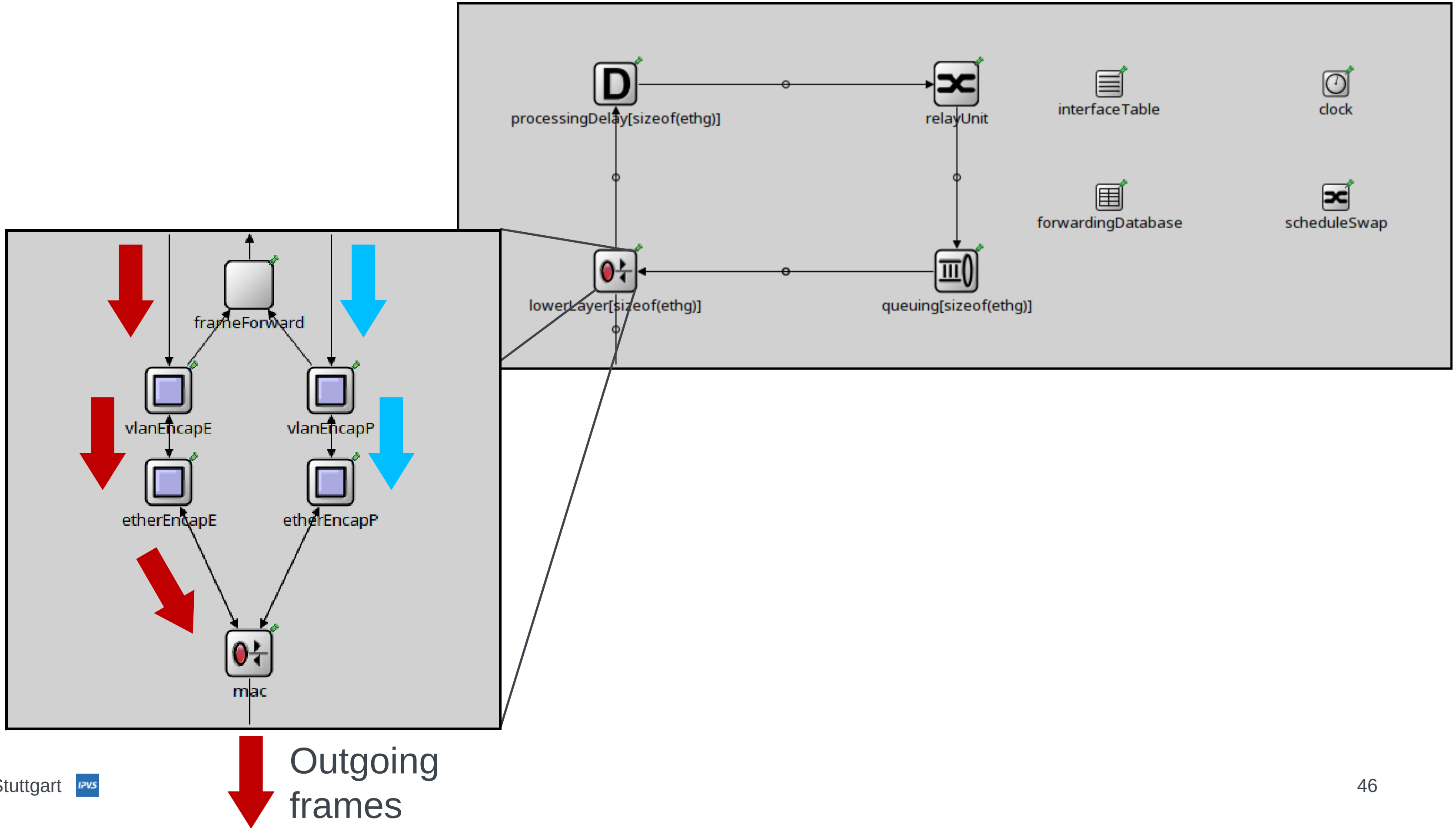

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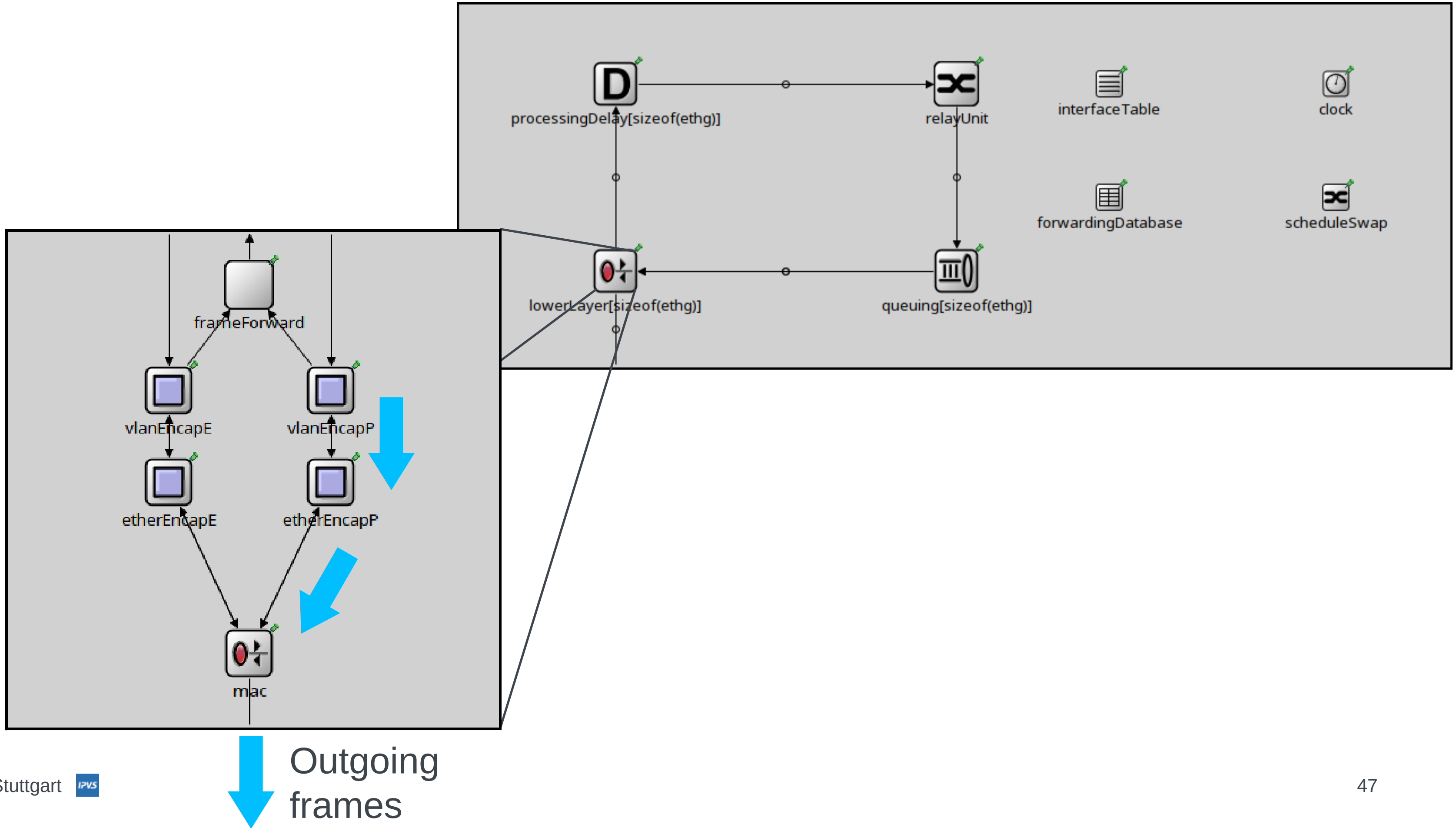
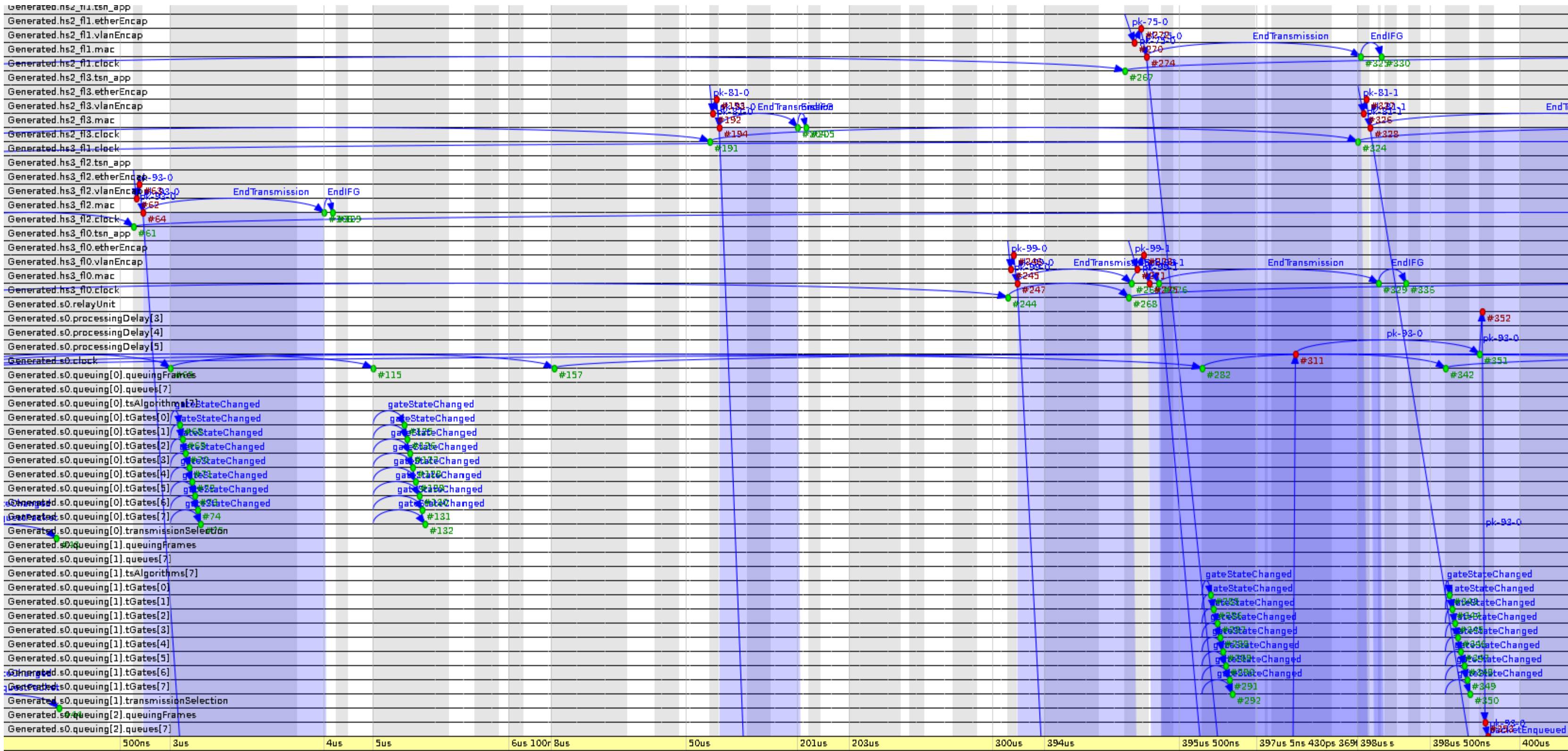


Analysis of Simulation Results

- OMNeT++ logs general data automatically
  - For special interests (e.g. deadlines) additional code is mandatory
- scavetool: An internal result analysis tool of OMNeT++
  - Can be used to have a casual view of the data
  - Is capable of filtering, sorting, and joining data to prepare it for export
- Toolchain for extensive evaluation of results
  - scavetool for data export
  - (Excel)
  - Python SciPy Stack / R

Analysis of Simulation Results



Conclusion & Future Work

- NeSTiNg implements a basic set of TSN synchronous shaping features
- Standard compliance is a key driver
- Publication of code as contribution to the research community
- Compatibility with INET allows simulation of converged networks
- Future Work
  - Migration to INET 4.0
  - Further extension of the model (e.g. Ingress Policing and Filtering)
  - Extensive evaluation
  - Validation
- https://1.ieee802.org/protocol-simulations/