Size-Based Queuing

An Approach to Improve Bandwidth Utilization in TSN Networks

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RTN'18 - Barcelona, Spain

In this talk

- Highest-priority (HP) messages may experience jitter due to blocking by lower-priority (LP) messages
  - In a TAS-enabled non-preemptive TSN network
- Guard bands
  - used to avoid this jitter
  - But also decrease bandwidth utilization
- Our approach to reclaim wasted bandwidth
- Provide an initial analysis of our approach

TSN and TAS primer

Ethernet and Time-Sensitive Networking

- Switched Ethernet is replacing existing network technologies
- Cheap, mature technology
- However: No timing/delivery guarantees

Ethernet and Time-Sensitive Networking

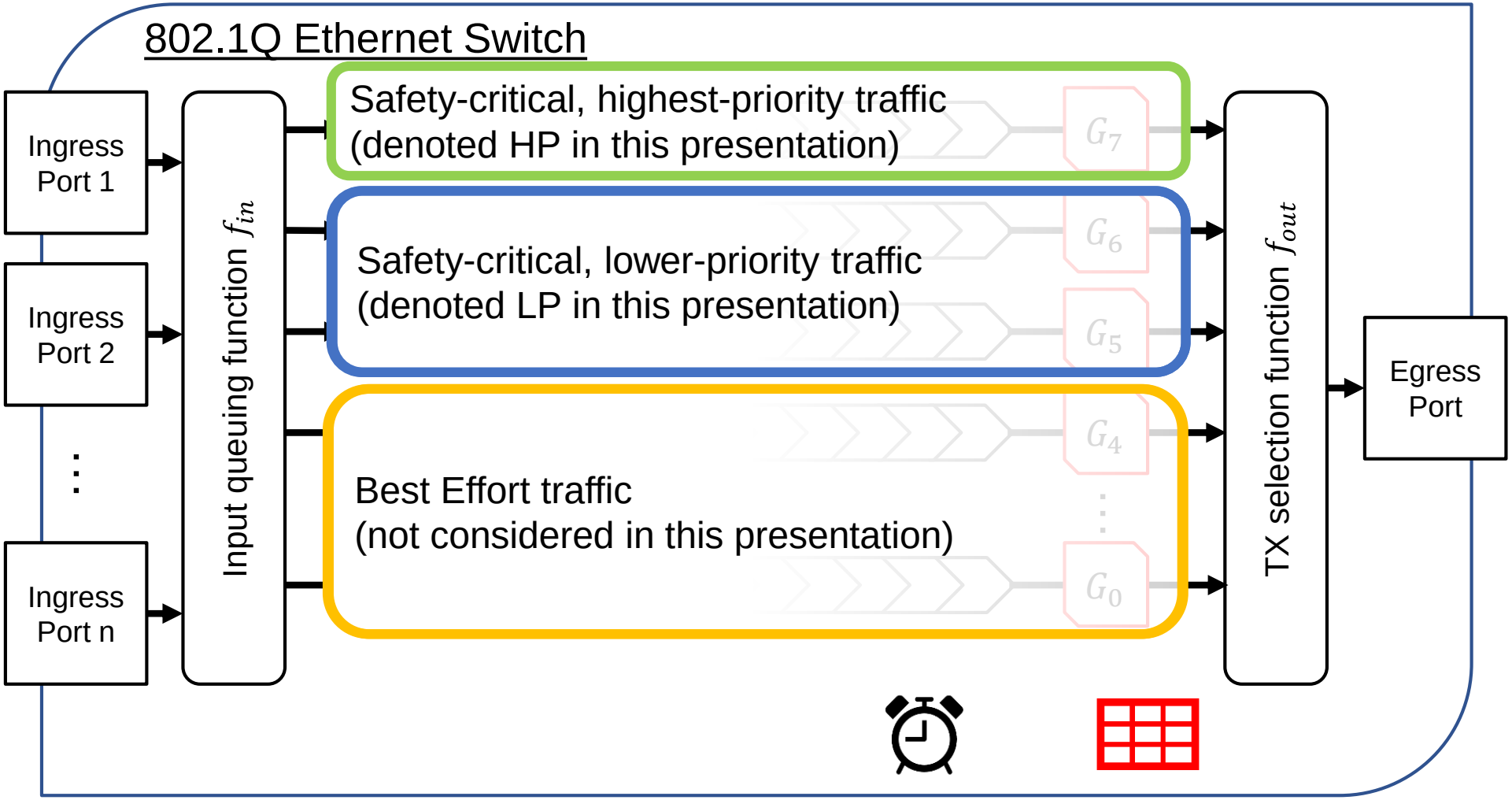
- Continuation of AVB TG
- Goal is to make Ethernet safety-critical
  - Automotive, Avionics, Factory automation
- Extend AVB, e.g.
  - higher precision clock sync
  - Frame preemption
  - Frame replication for redundancy

Time-Aware Shaper and Guard Bands

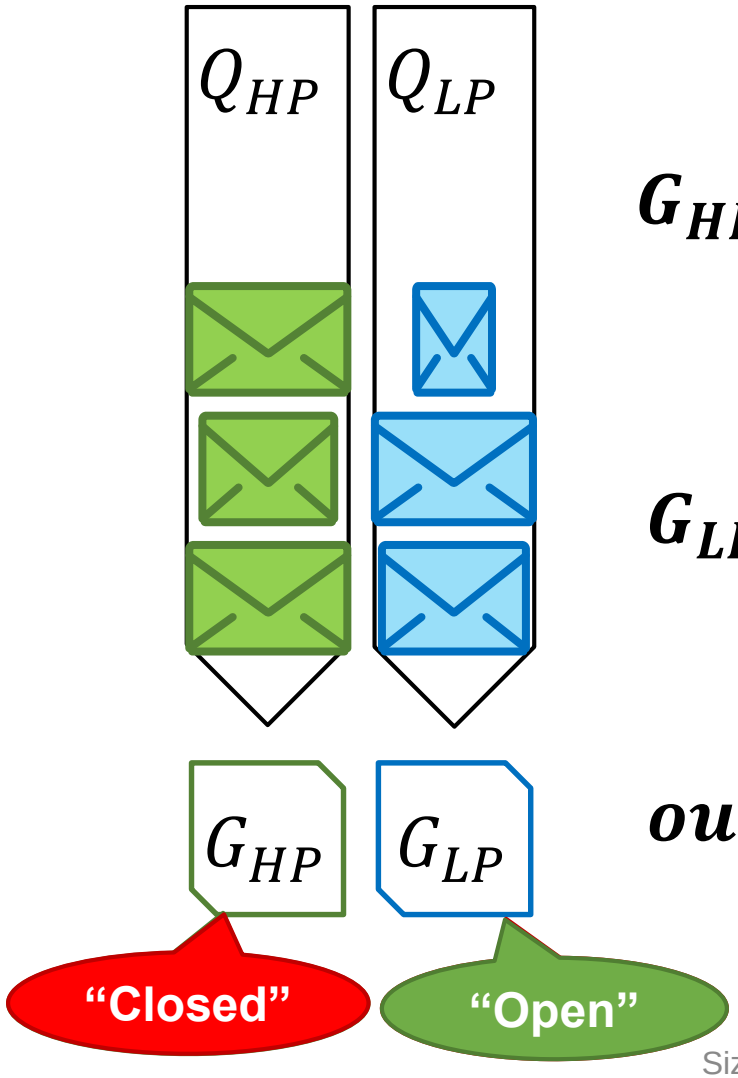
- Time-Aware Shaper (TAS) is part of TSN

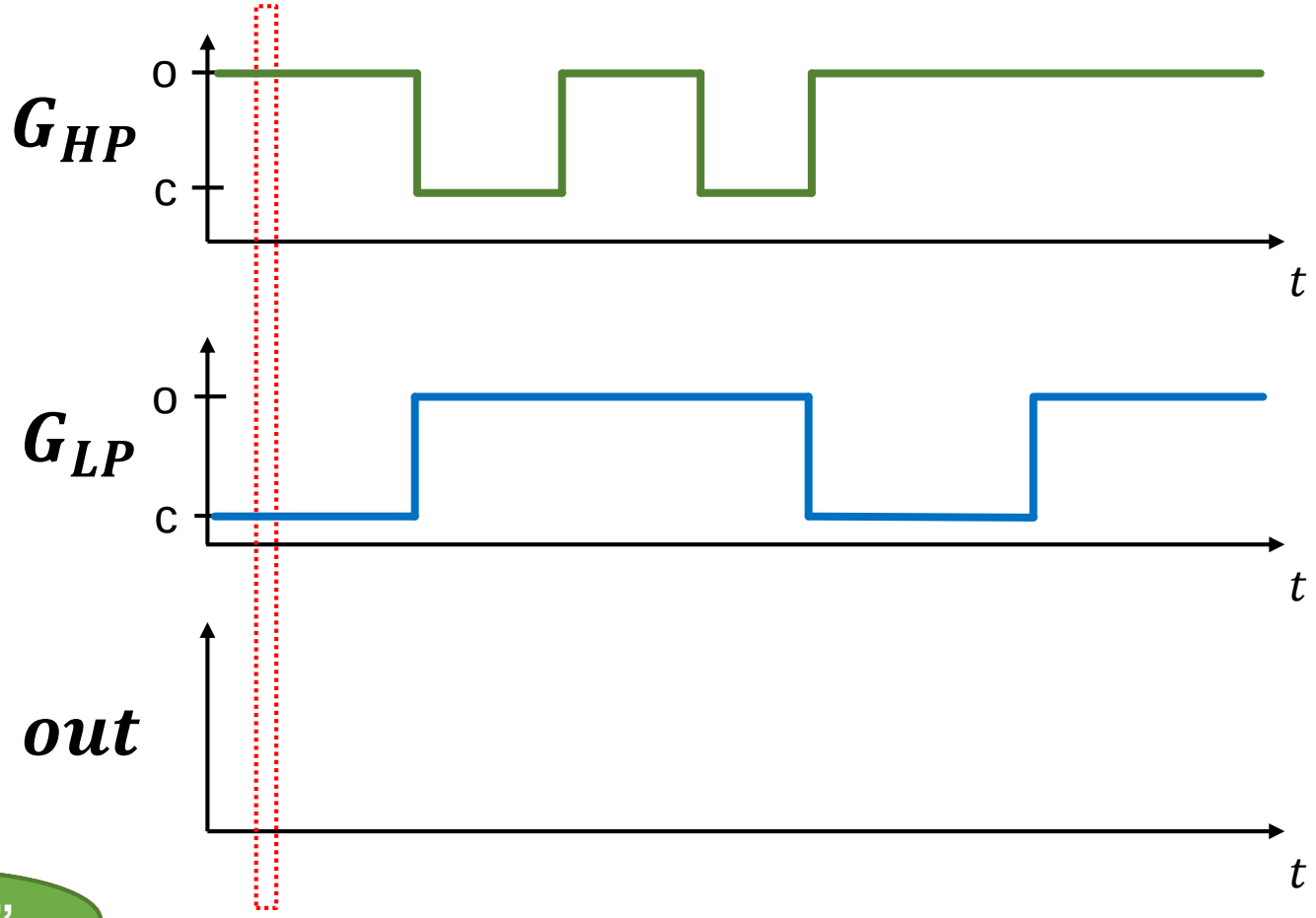
- TAS adds …
  - Gating mechanism for switch queues
  - Gate schedule to control the gates
- TAS enables …
  - Scheduled transmissions
  - Ways to provide exclusive network access to a queue

Time-Aware Shaper and Guard Bands



Time-Aware Shaper and Guard Bands





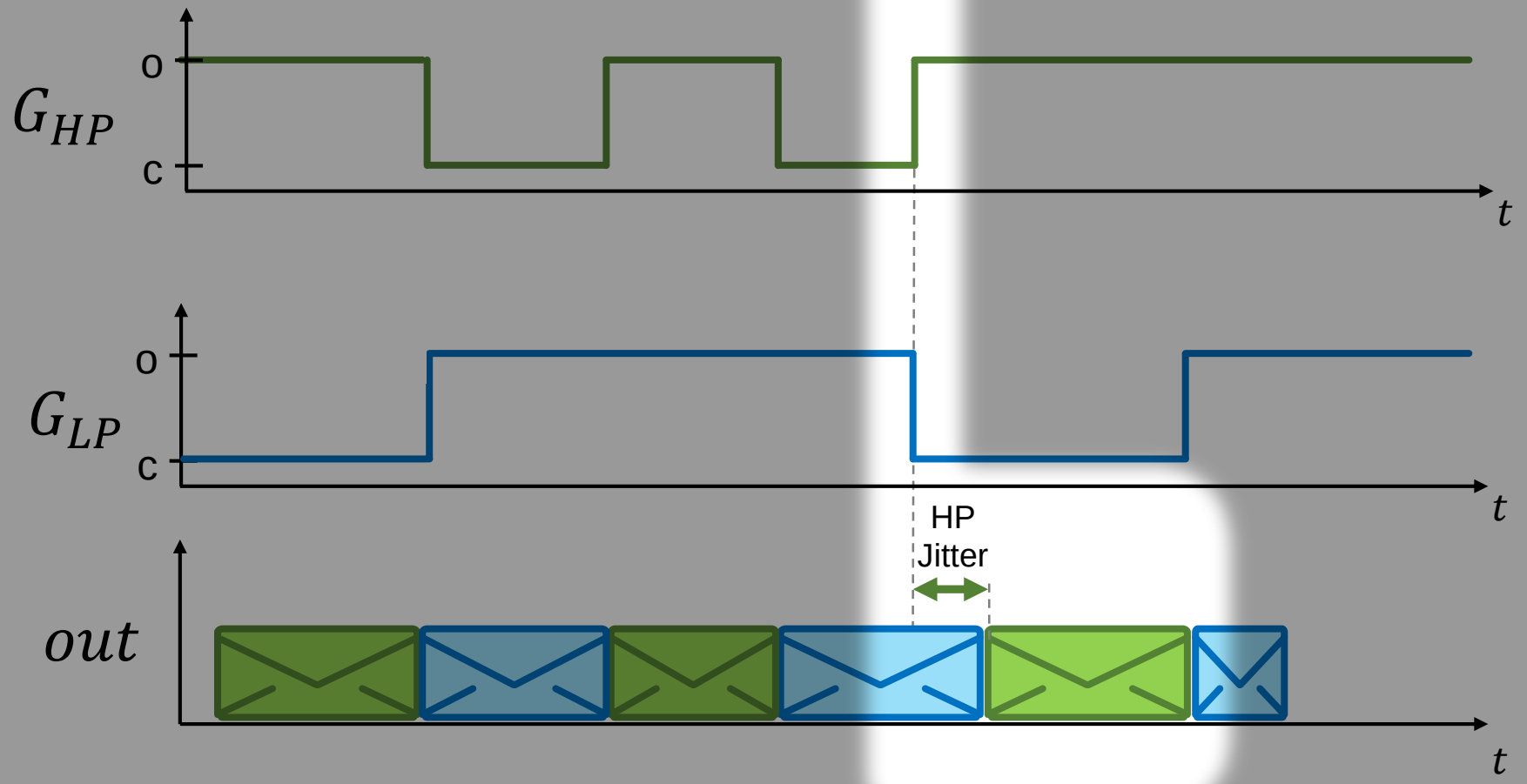
Time-Aware Shaper and Guard Bands

- Highest priority (HP) messages may experience blocking by lower priority (LP) messages

Unless:

- Network provides message preemption functionality
  - Not considered in this work
- Gate schedules are modified to avoid blocking
  - Guard bands (GB): Preemptively close gate of LP messages to ensure idle network once HP gate opens

Time-Aware Shaper and Guard Bands



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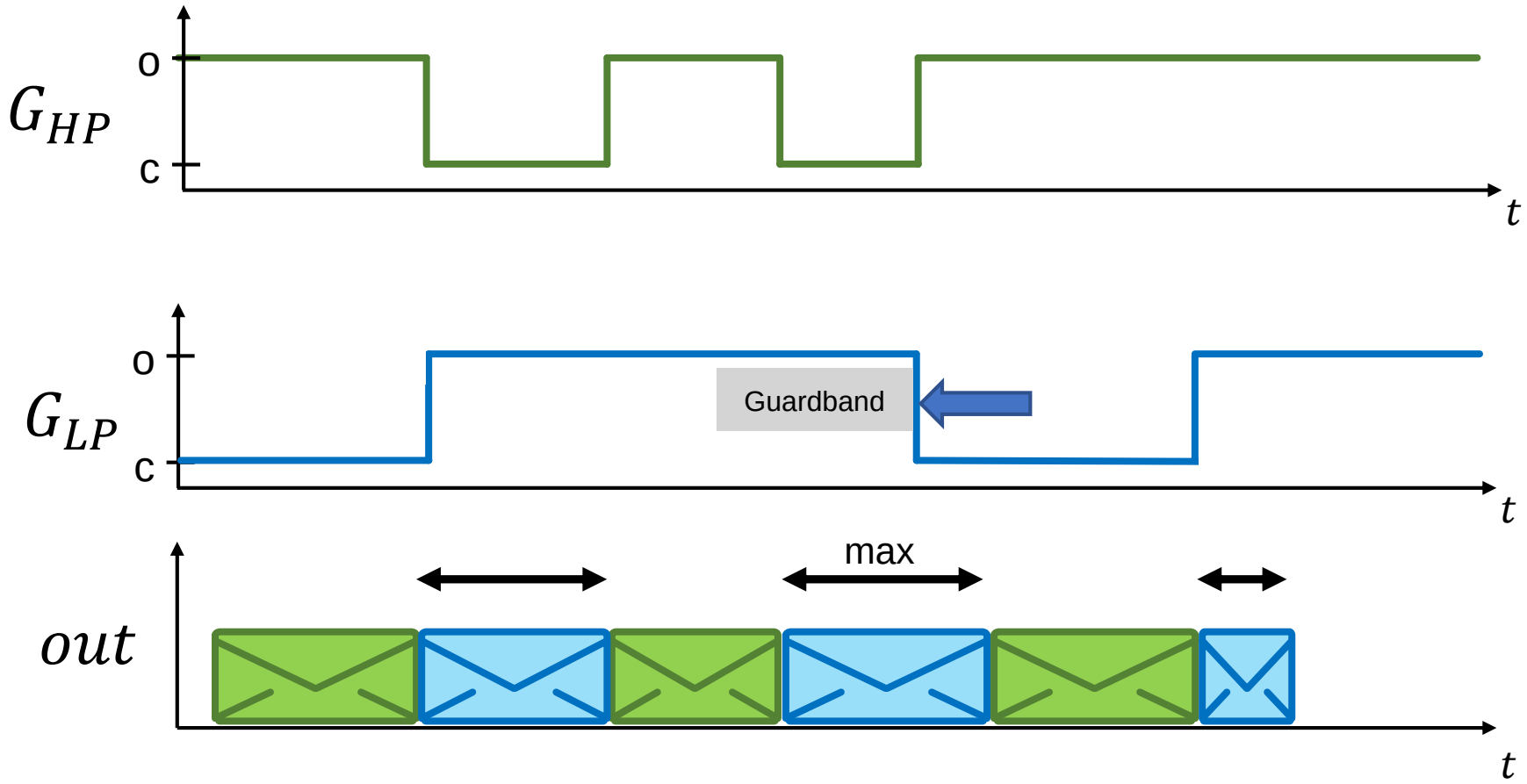
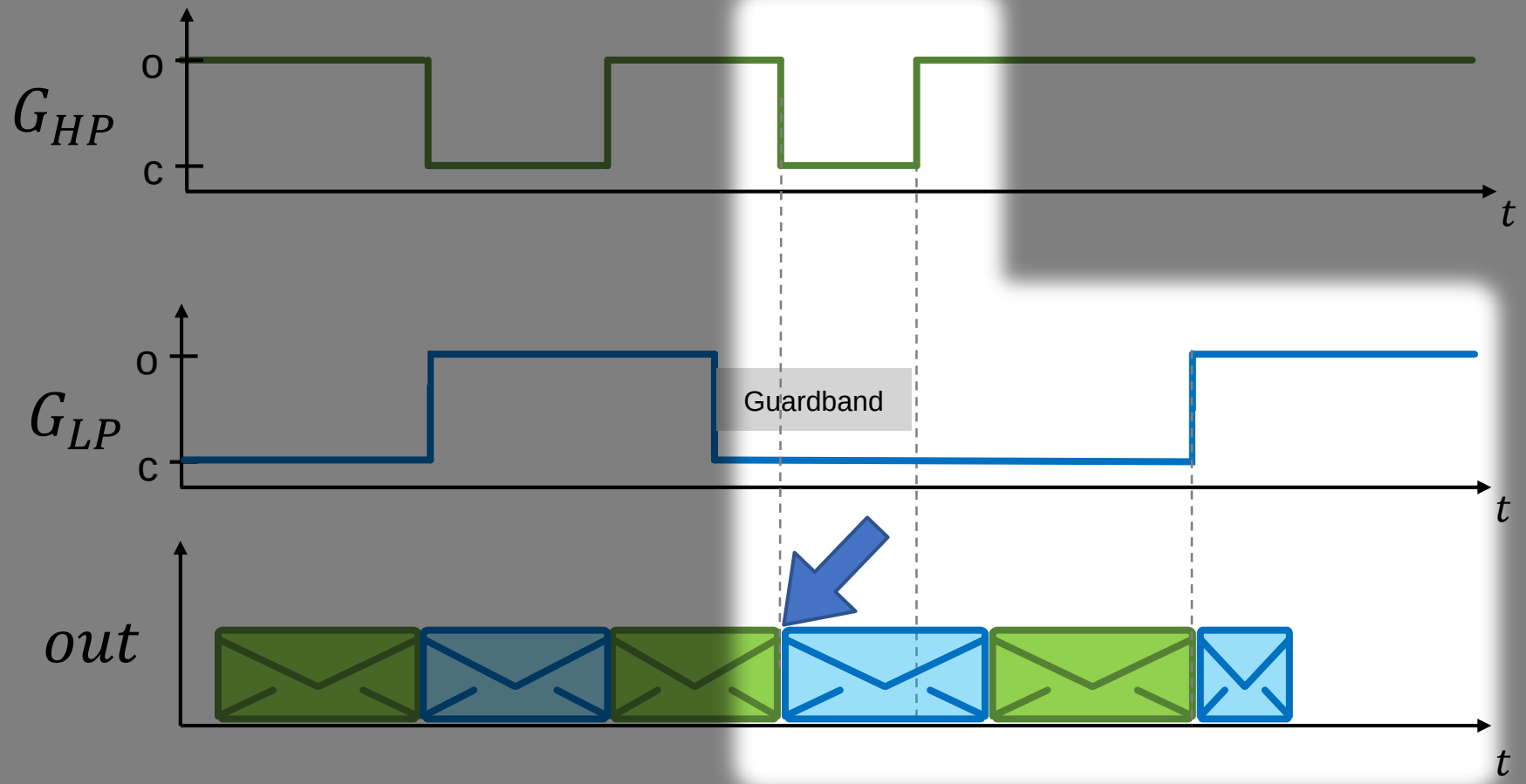


Time-Aware Shaper and Guard Bands

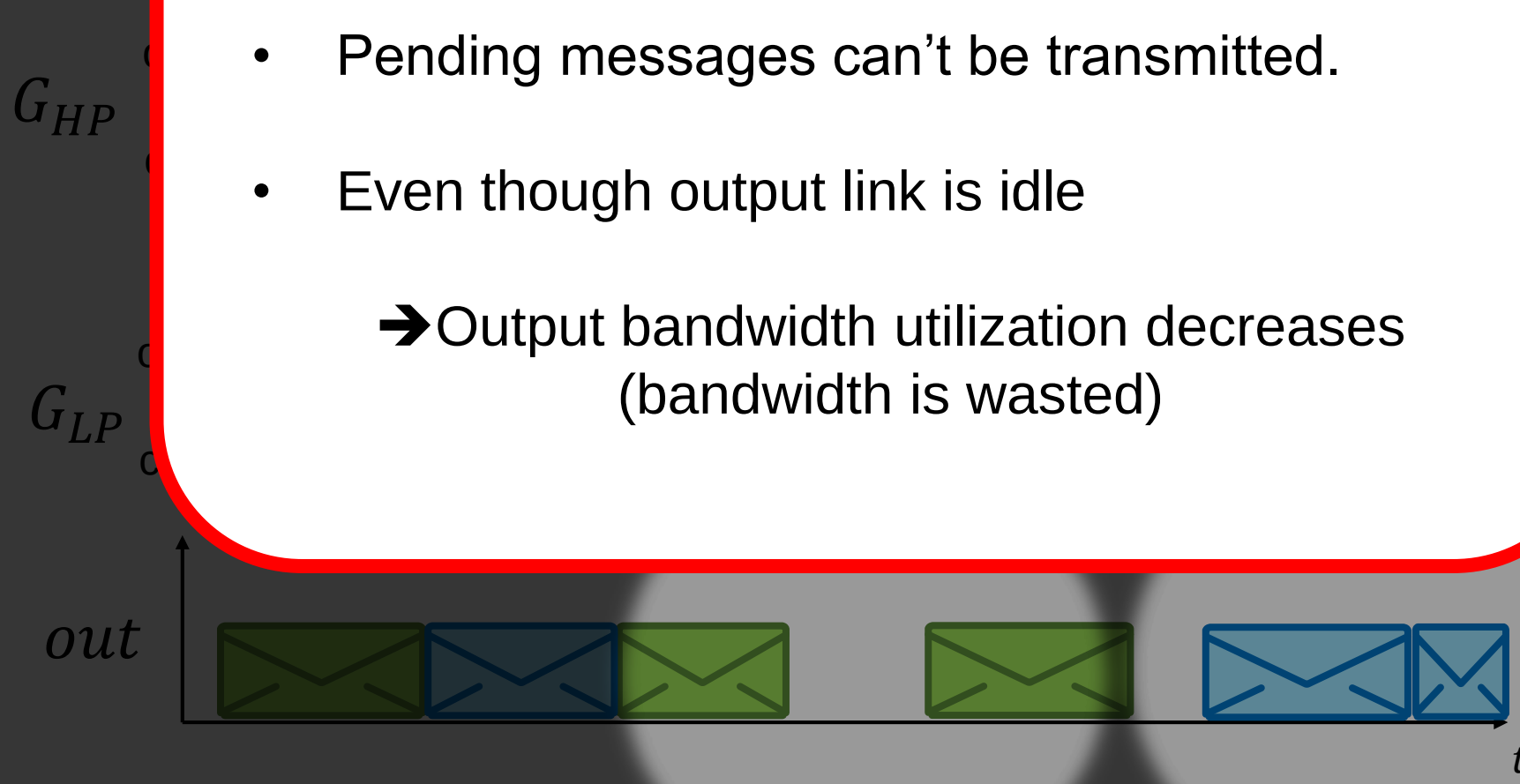


Problem description

Bandwidth

- Guard bands cause time intervals where all gates are closed
- Pending messages can’t be transmitted.
- Even though output link is idle

➔Output bandwidth utilization decreases (bandwidth is wasted)



Approaches to reduce Jitter of HP messages

- Guard Bands
  - Can result in reduced bandwidth utilization
  - Because we always need to consider largest message

- Our approach: Size Based Queuing (SBQ)
  - Builds on the guard band approach

Our approach: Size-Based Queuing

Size-Based Queuing

- Non-preemptive network +
  Low Jitter requirement of HP messages ➔ guard bands unavoidable

- Can we modify existing guard bands?

<u>Idea</u>

- Guard band size ⇔ Size of largest message in queue
- Distribute messages into multiple queues according to their size

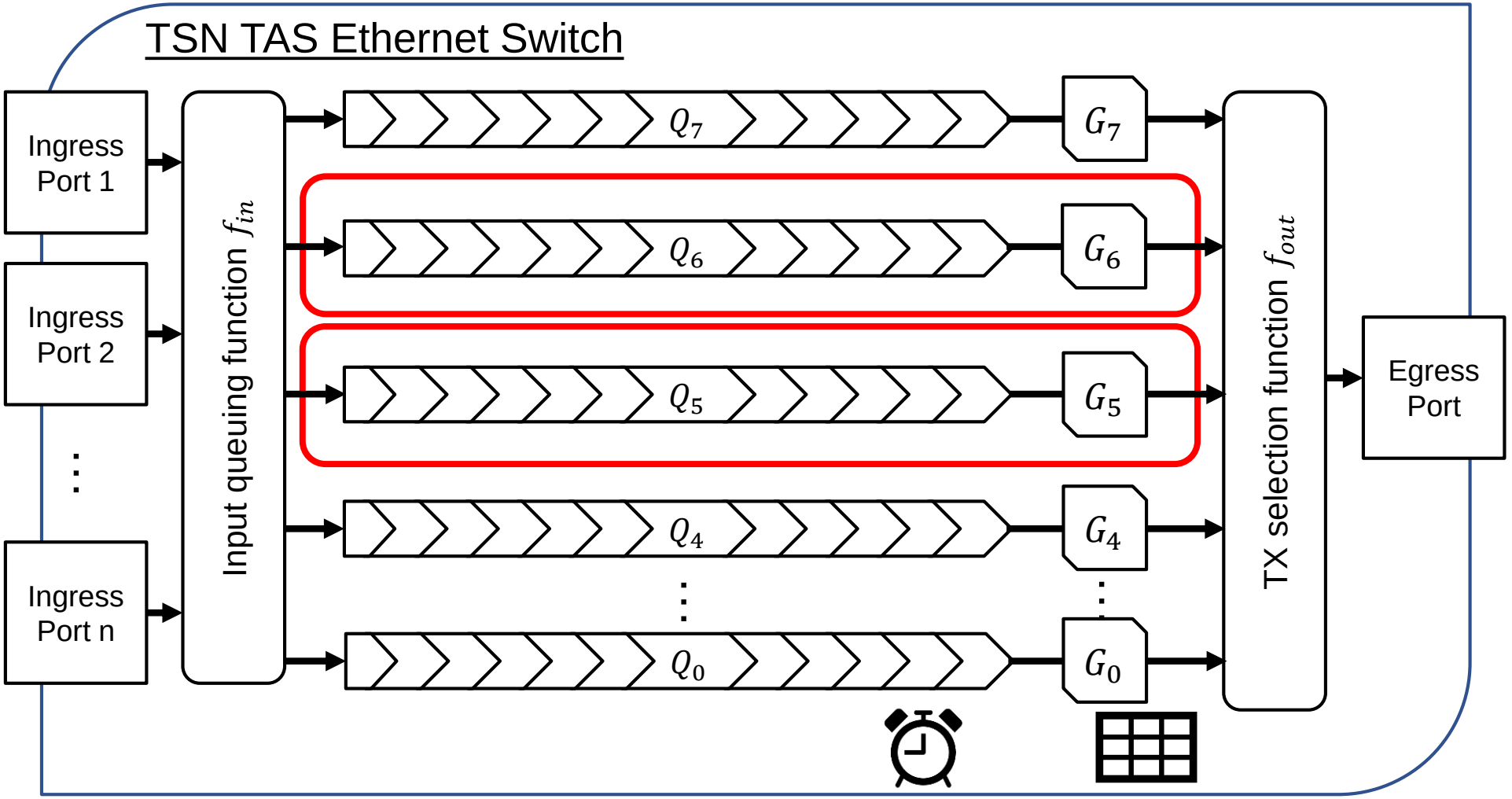
- Control the size of the largest message in each queue
  ➔Shrink guard bands
  ➔Improve bandwidth utilization

Size-Based Queuing

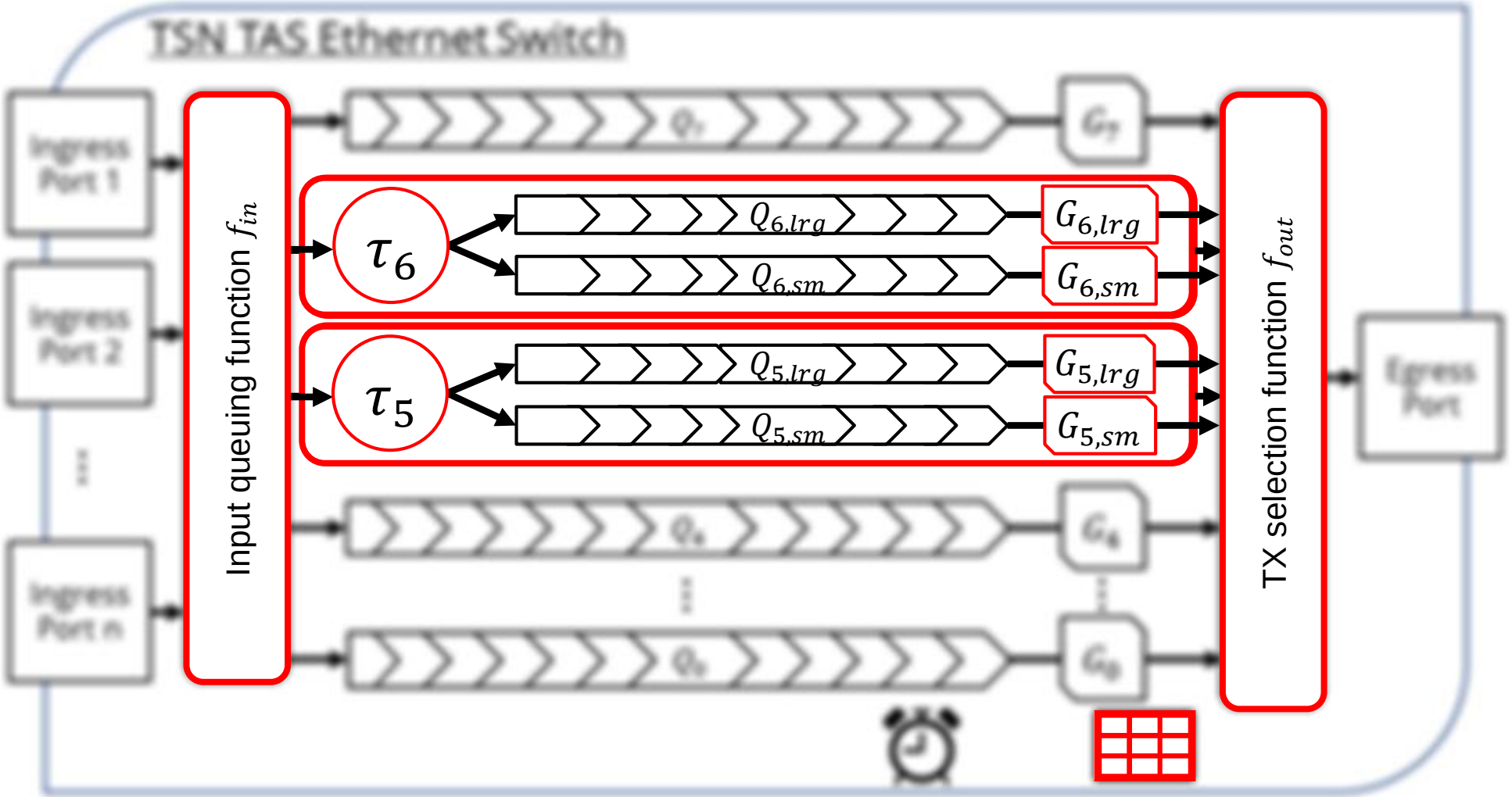
- Method overview

1. Split some/all LP queues into queue-sets
2. Define size-thresholds
3. Modify f_{in} to distribute messages according to thresholds
4. Add new gates for the new queues
5. Update gate schedule or modify f_{out} to handle new queues
6. Shrink guard bands where applicable

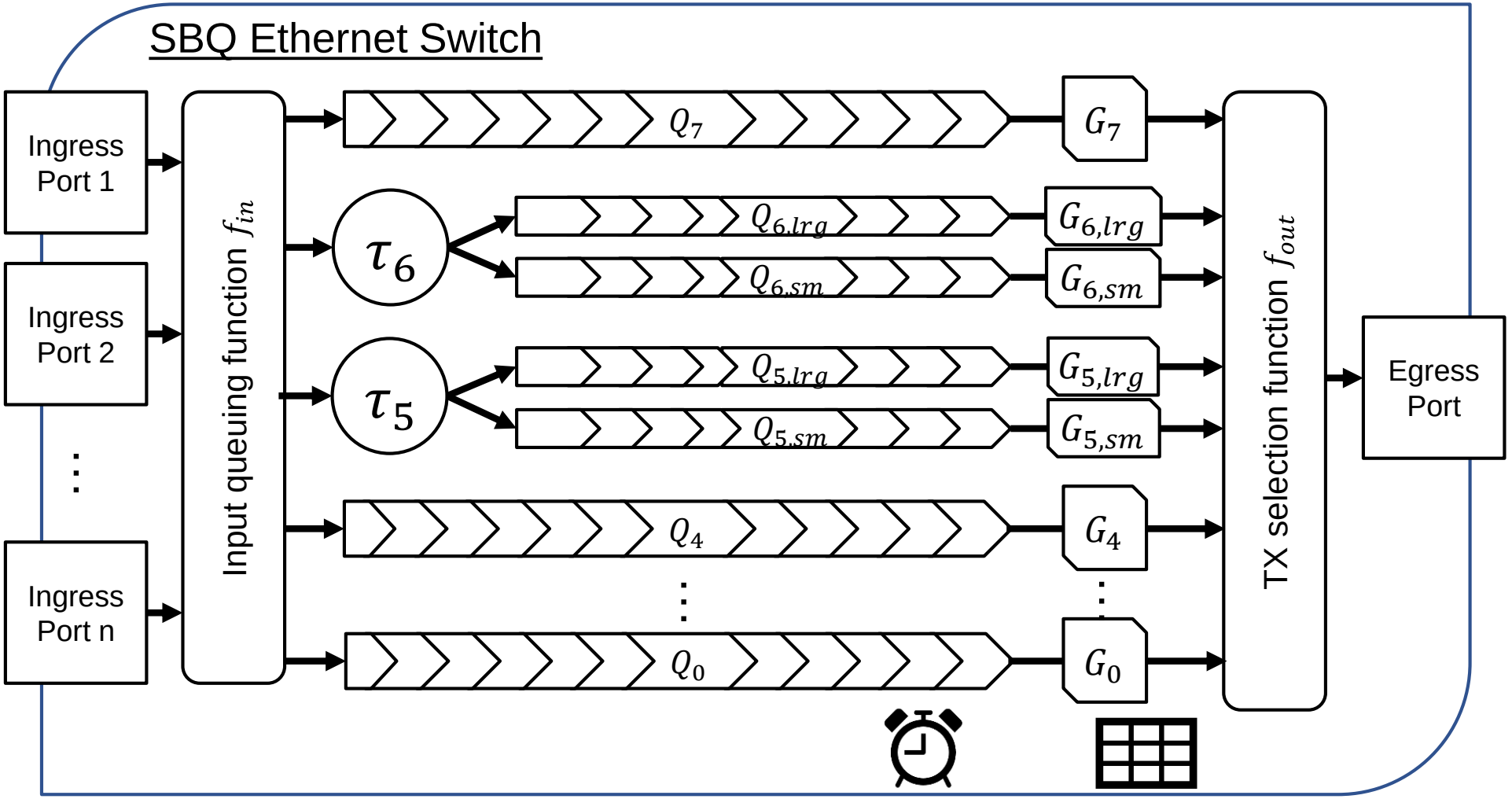
SBQ Implementation Example



SBQ Implementation Example

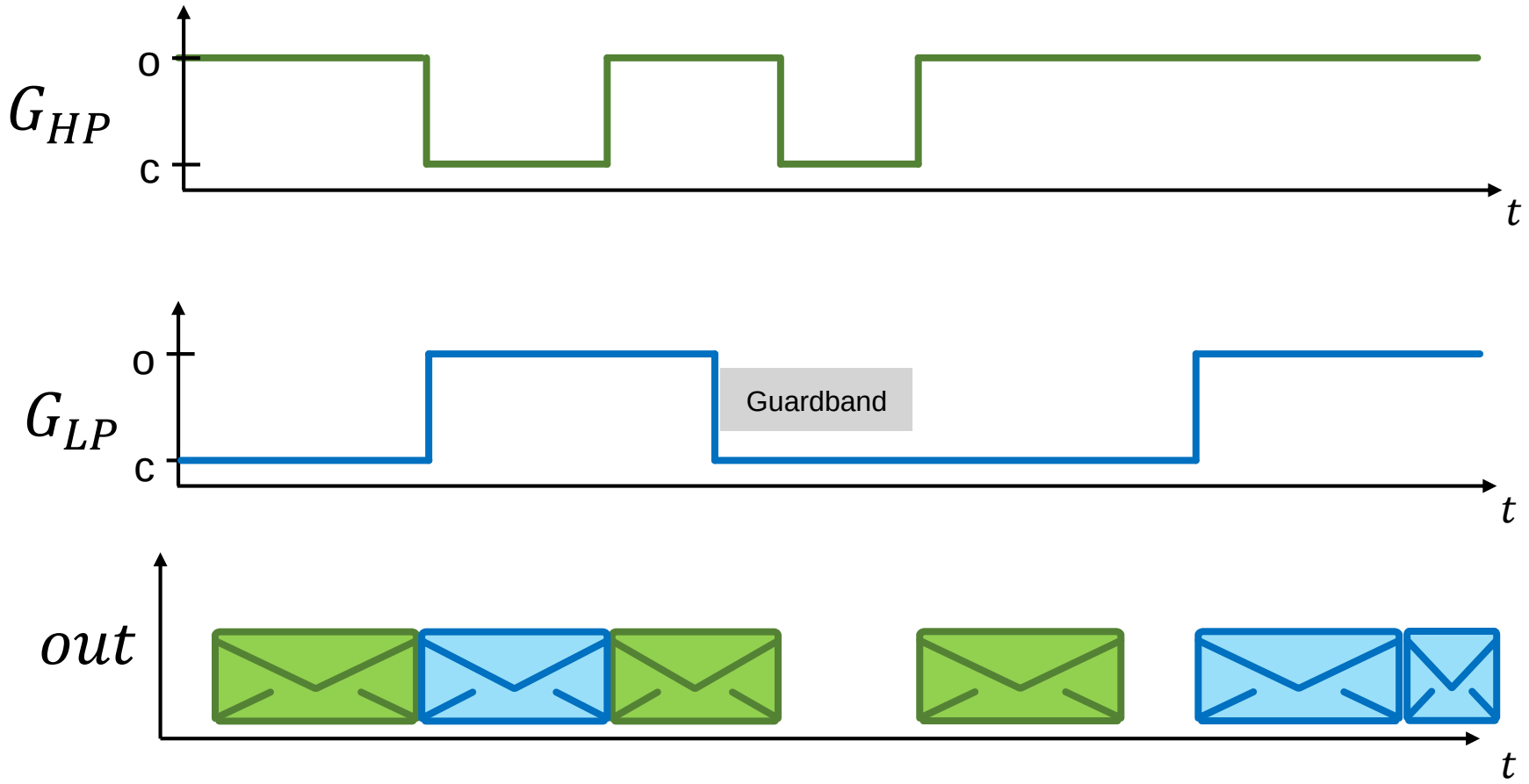


SBQ Implementation Example



Analysis

Analysis - Bandwidth Utilization



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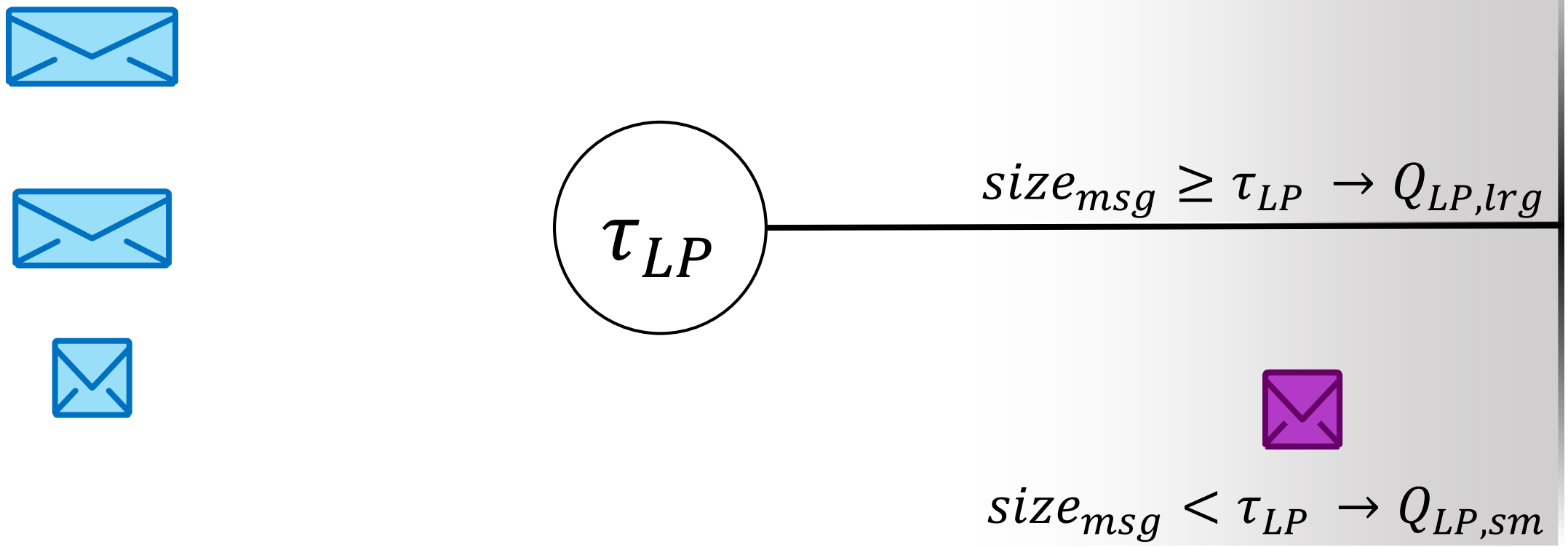
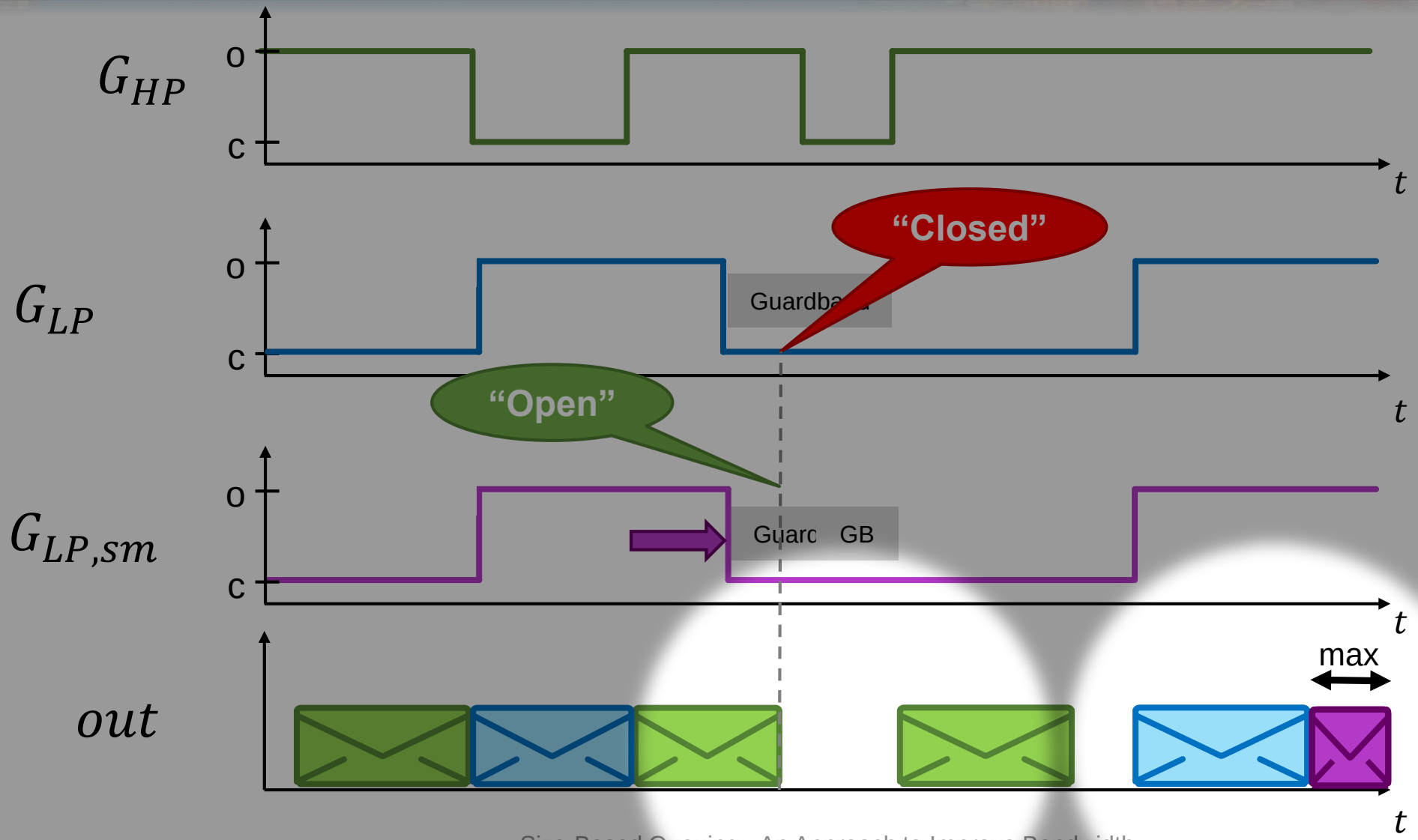


Analysis - Bandwidth Utilization



Analysis – Design Time Overheads

- Queues added by SBQ have to be considered during network design
- Generate schedules that provide service to all queues
- Make use of TSN shapers (CBS, BLS, etc.)
- Use additional algorithms to arbitrate within queue-sets
  - E.g. Round-Robin

Analysis - Latency

- Changing the way messages are queued affects their latency through a switch
- Only LP messages affected
- HP unaffected
- (we don’t care about BE)

Analysis - Latency

- Individual queues of a queue set get only a portion of the bandwidth

➔Time before message reaches front of queue is longer

➔ Latency increases 

Analysis - Latency

- Messages are distributed into queue-set, message has to compete against less other messages inside a queue

➔Message reaches front of the queue faster

➔ Latency decreases

Analysis - Latency

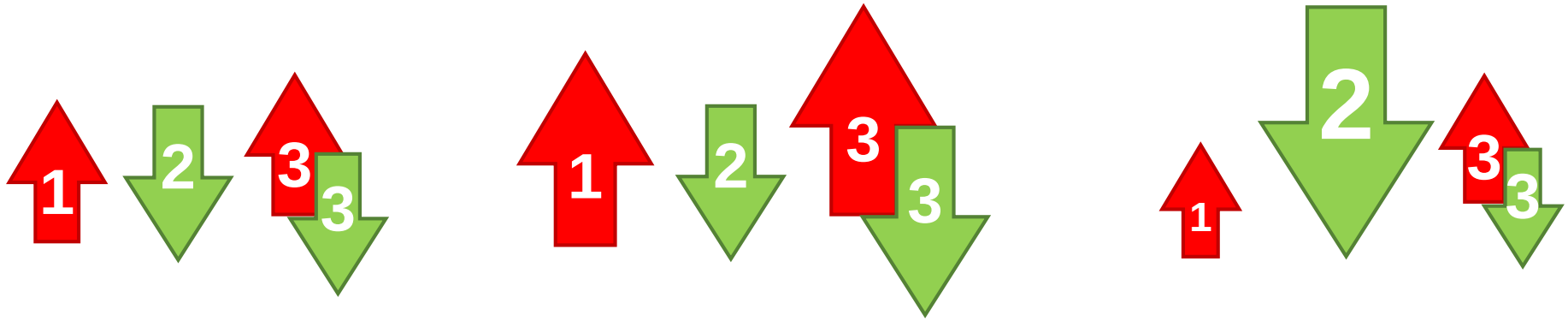
- (depending on arbitration scheme)
- Arbitration within queue-sets affects latency of all LP messages

➔Latency of lower relative priority messages increases

➔Latency of higher relative priority messages decreases

Analysis - Latency

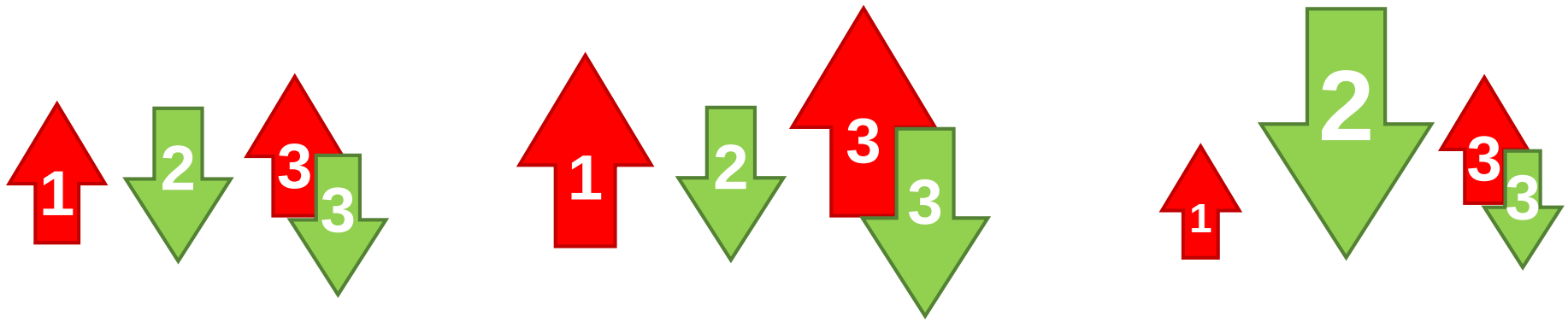
- Actual number depend on SBQ parameters
  - Number of queues in a queue-set
  - Values of thresholds
  - Schedule/intra queue-set arbitration (algorithm, priorities)
- Impact differs for each queue of the queue-set



Analysis - Latency

However

- Average latency of all messages is improved
  - Because of reclaimed bandwidth



Analysis – Hardware Overheads

- SBQ introduces additional HW requirements
- Increased Memory requirements
  - for additional queues
- Increased complexity
  - Input queuing function
  - Transmission (TX) selection function

Analysis - Summary

- Result in better bandwidth utilization
- Lowers average latency of messages
- Without affecting HP message transmissions
- At the cost of hardware/design time overheads and latency of some of the LP messages
- Plug and Play with legacy TSN devices
- Flexible (w.r.t. which priorities, ports, switches)

Conclusion and Future Work

Conclusion

- TAS enabled TSN networks without preemption may incur lowered bandwidth utilization caused by guard bands
- SBQ can reclaim some of this wasted bandwidth and thus improve average latency
- Exact impact and cost TBD

Future Work

- Experimental evaluation / simulation of SBQ
- How does each SBQ parameter affects latency/bandwidth
- Evaluate different approaches w.r.t. f_{out} (RR, SP, etc.)
- Check which other metrics of messages we can make use of (P802.1Qcr)

Thank you!

… Questions?

Backup – Message Overtaking

- Message overtaking can occur with SBQ
- E.g. small messages overtake large messages
- Also present in e.g. IEEE 802.1CB (FRER)

- Should be fixed on higher OSI layers

Or:

- Keep message size of a flow fixed