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Traffic Scheduling with the TAS: Past Research and Future Directions

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About Me

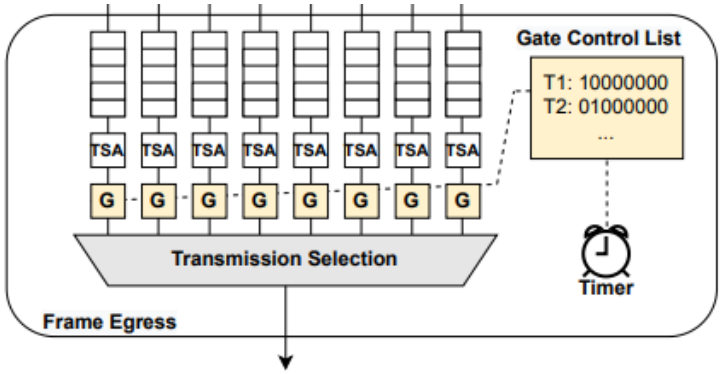
- Lukas Osswald
  - M.Sc. in computer science from Universität Tübingen
  - PhD student since Nov. 2020
- Research Interests
  - Time-Sensitive Networking (TSN)
  - Signaling and admission control

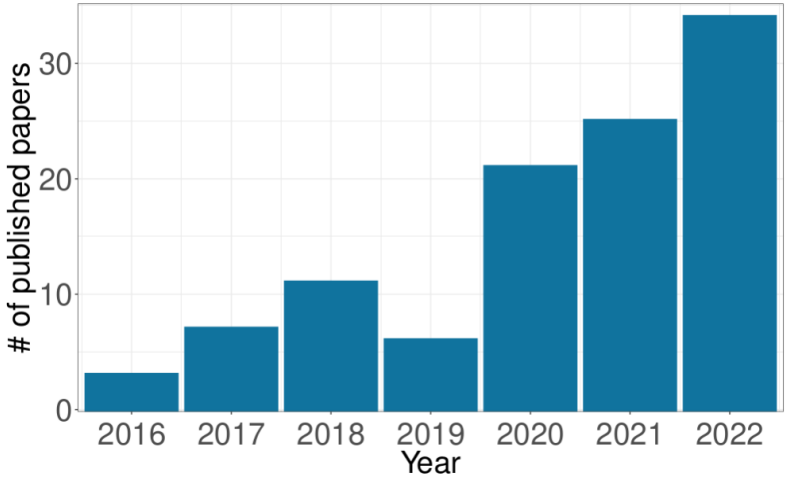
Lukas Osswald

Thomas Stüber

Time Aware Shaper

- Time Aware Shaper (TAS)
  - IEEE 802.1Qbv
  - Scheduling
    - offline per-flow planning of transmission times
  - Scheduler
    - Algorithm which computes a GCL
    - Model, optimization method, objective function





- Scheduling algorithms for the TAS has been a hot topic for many years
  - More than 100 works were published
  - Still increasing...

- Literature study: **Thomas Stüber, Lukas Osswald, Steffen Lindner, and Michael Menth. A Survey of Scheduling Algorithms for the Time-Aware Shaper in Time-Sensitive Networking (TSN). IEEE Access, 2023**

Scheduling Models

- Models focusing on different problem variations
  - Joint routing and scheduling
    - Compute schedule and simultaneously optimize the path of the stream
  - Dynamic reconfiguration (online scheduling)
    - Modify an existing schedule to admit novel streams incrementally
  - Increased reliability
    - Compute schedule robust against non-determinism, e.g., time-synchronization jitter
  - Queuing
    - With, without and restricted queuing
  - GCL synthesis
    - Compute schedule + GCLs simultaneously
  - Lower priority traffic
    - Compute schedule such that QoS of AVB/BE/etc traffic is maximized
  - Joint task scheduling
    - Compute TAS schedule and schedule for tasks of an operating system simultaneously

Optimization Methods

- Various solving methodologies
  - Integer Linear Programming (ILP)
  - Satisfiability Modulo Theories (SMT)
  - Constrained Programming
  - Genetic algorithms, list scheduling, custom heuristics, …
- Objective functions
  - Latency, jitter, and other QoS metric, ...
- Evaluation of proposed schedulers
  - Focus heavily on runtimes of solvers (aka "scalability")
  - Fewer works: solvability, schedule quality, ...

Observations

- Many works propose new slightly modified problem variations...
  - ...which are then solved by standard methods
- No recent breakthrough w.r.t. performance
  - Mostly x% faster than previous works...
- Most evaluations focus on runtime and scalability
  - Important!
  - But: often “unfair” comparison, e.g., algorithms with different run-time complexity
  - Schedule quality and solvability is often neglected
- No clear direction
  - We conclude: TAS is not the general TSN solution
  - Problems variations are specialized and diverse
  - → TAS should be seen as specialized tool for hard problems

Advancing TAS Research

- Reproducibility and evaluations must be improved to advance research!
  - Publish or at least describe
    - Problem instances
    - Reference implementation
  - Evaluations
    - Apply multiple problem instances
    - Compare novel scheduling algorithms to
      - Similar models and solving methodologies
  - Evaluate run-time, solvability, quality of schedule, ...

- **T. Stüber, M. Eppler, L. Osswald, M. Menth: "Performance Comparison of Offline Scheduling Algorithms for the Time-Aware Shaper (TAS)", Transactions on Industrial Informatics, 2024**

- Open problems
  - Dynamic reconfiguration
    - How can we resolve scheduling conflicts?
  - Reliable schedules
    - Many schedules can only work in theory
    - In a real test bed there is a lot of additional delays and jitters which needs to be modeled
  - Integrate TAS with other
    - QoS algorithms: ATS, CBS, ...
    - Technologies: Wifi, 5G/6G, ...

- Find more specialized use-cases
  - to uncover more problem variations
  - Question to industry in the room!

Discussion

Questions and Discussion