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Policy-oriented AQM Steering

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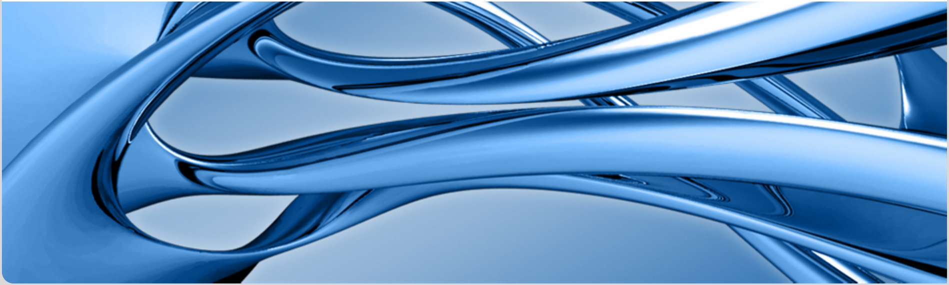
Karlsruhe Institute of Technology (KIT) – Institute of Telematics (TM)



Motivation

- Newer AQMs: CoDel, PIE, GSP
  - Try to be parameter-less (in normal operation)
  - Work reasonably well over wide range of traffic situations
- One crucial parameter remaining: *Target "delay setpoint"*
  → typically set to default value, e.g., 5 ms
- But: Achievable performance depends on traffic situation
  → especially: number of flows and their RTTs
- Possible outcome: Unnecessarily large delay or underutilization

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AQM Steering: Overview

- **Goal:** Improve AQM performance
- **AQM Steering:** External control loop around existing AQM
  → Adjust *"target delay setpoint"* to current traffic situation

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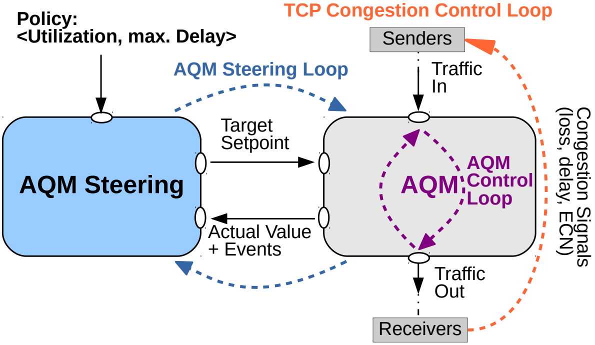
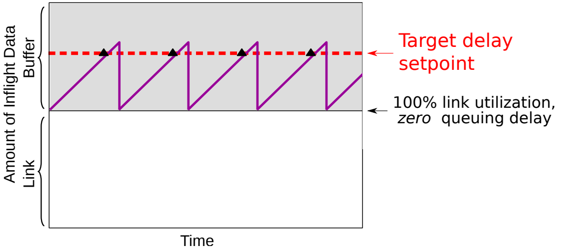


Target Delay Setpoints

- What is a *"target delay setpoint"*?
  - Newer AQMs try to keep queuing delay around specific target, e.g., 5 ms.
  - Visualization at bottleneck buffer:



- Example: *"Global Synchronization Protection" (GSP)*
  $\longrightarrow$ draft-lauten-aqm-gsp
  - Drop packet(s) if target delay setpoint is exceeded
  - Dynamically find suitable *dropping rate*

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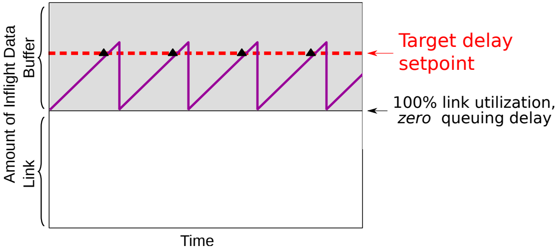

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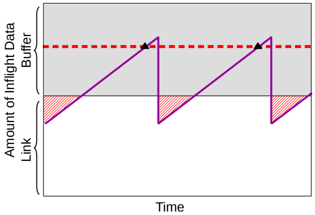
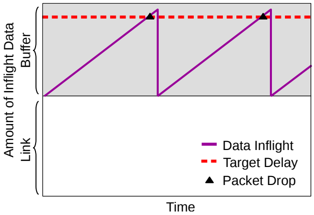
AQM Steering: Basic Idea

- AQM Steering adjusts setpoint to current traffic characteristics





Default setpoint

$\rightarrow$ Underutilization

Optimal setpoint

- Increase setpoint if necessary to achieve *desired* throughput
  - Trade-off: Higher throughput for higher delay
  - Limitations caused by used congestion control, e.g., CUBIC TCP

AQM Steering: Basic Idea

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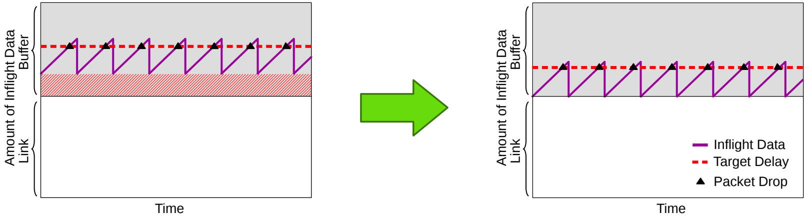

Default setpoint

→ Too high

Optimal setpoint

- Decrease setpoint if possible without sacrificing throughput
  - Default setpoint: Throughput achieved at a too high "price"
  - → Adapted setpoint: Same throughput, lower delay!

AQM Steering: Policies

- Trade-off: Throughput vs. delay
  - What is *your* priority?
  - → With fixed setpoint: Not much control!

- Easy to grasp policies
  - $\langle u_{low}, target_{max} \rangle$, optionally: u_{target}
    - Queuing Delay $\leq target_{max}$ (Upper delay bound)
    - Link utilization $\geq u_{low}$ (Lower utilization target)
    - Link utilization $\leq u_{target}$ (Upper utilization target)

- Meaningful parameters
  - $target_{max}$: "How much delay am I willing to trade for high throughput?"
  - u_{low}: "At which throughput am I not willing to trade delay anymore?"
  - u_{target}: "How much throughput am I willing to trade for ultra low delay?"

- Find best throughput vs. delay trade-off within these policy bounds

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AQM Steering: Challenges

1. When should the setpoint be assessed / adjusted?
2. To which value should the setpoint be changed?
3. How to achieve ultra low latencies with existing AQMs?

Challenge 1: When to Assess / Adjust Setpoint?

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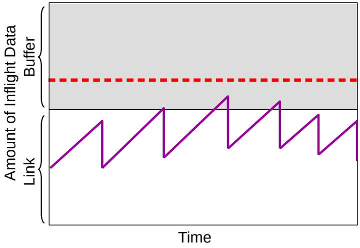
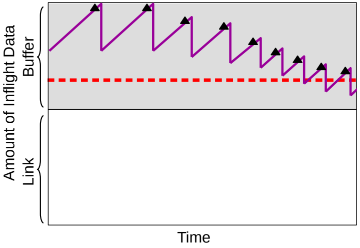
- AQM Steering observes interplay: AQM $\leftrightarrow$ congestion control



No bottleneck



Not converged, yet

- No packets dropped: Link is no bottleneck
  $\rightarrow$ Increasing setpoint will not increase throughput!
- Queuing delay persistently above setpoint: AQM is still adjusting!

Challenge 1: When to Assess / Adjust Setpoint?

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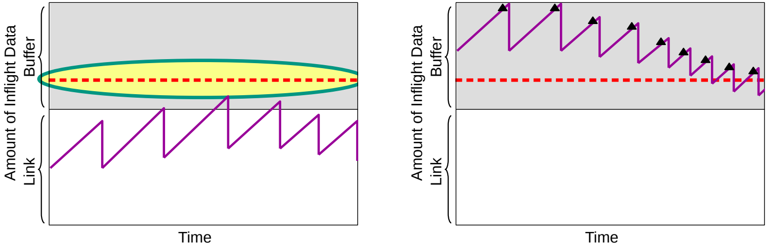

No bottleneck — Not converged, yet

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TeleMatics

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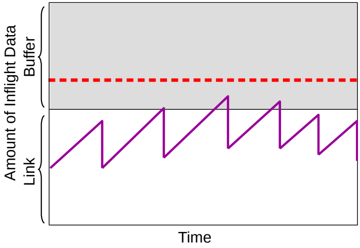

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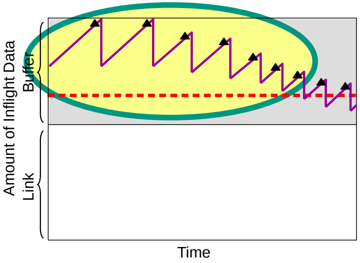

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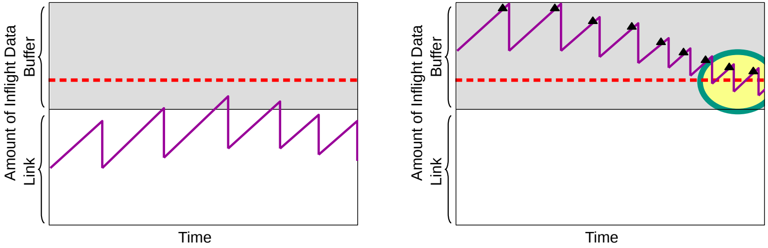

No bottleneck

Converged, finally

- No packets dropped: Link is no bottleneck
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TeleMatics

Challenge 2: Determine New Setpoint

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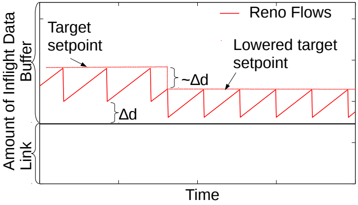
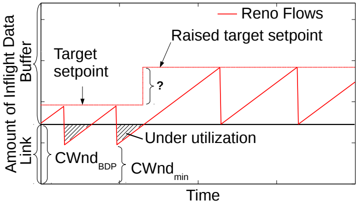
- Different strategies required for increase and decrease



Decrease



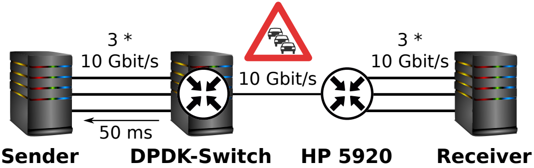
Increase

- Reduction by Δd maintains high throughput
  - Δd can be measured within the AQM, but is noisy
  - → Smoothing, averaging, variance
- Increase depends on bdp/RTT (not known by AQM)
  - → Appropriate amount cannot be determined directly → probing required!

Evaluation

Evaluation

- Implementation based on the AQM *"GSP"*
  → **GSP-AS ("GSP with AQM Steering")**
  - *DPDK-based* prototyping switch
  - Intel's *"Data Plane Development Kit"* (for high speed network functions)
- Testbed:



- Comparison
  - GSP-AS $\langle u_{low} = 99\,\%, target_{max} = 30\ ms \rangle$
  - CoDel, GSP, (setpoint = 2.5 ms)
  - Taildrop (small buffer (2.5 ms) / large buffer (30 ms))

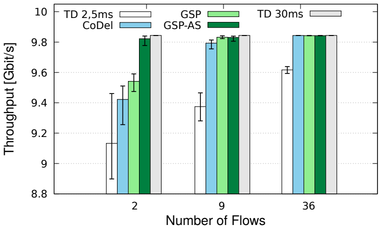
Evaluation

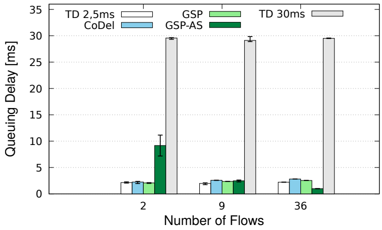
Selected Experiments

- Experiment 1: Proof general idea: Steady state, long lived flows
  - GSP-AS is able to trade off throughput vs. delay, according to the policy
  - Regular AQMs: Fixed delay target, performance depends on traffic situation
  - Tail drop: High throughput *or* low delay — depends on buffer size
- Experiment 2: Transition behavior

Evaluation

- Experiment 1: Steady state, long lived flows





- Lower number of flows → low loss de-synchronization
  - GSP-AS: High throughput, increased delay
  - AQMs: Underutilization (fixed setpoint too low)
  - Tail drop (small / large): Low throughput / high delay

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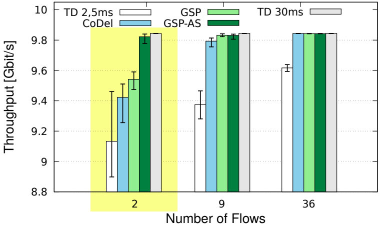
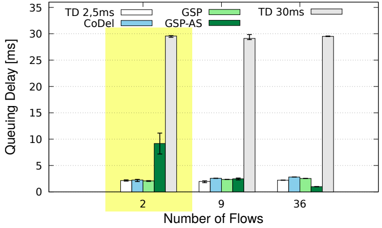
- Experiment 1: Steady state, long lived flows





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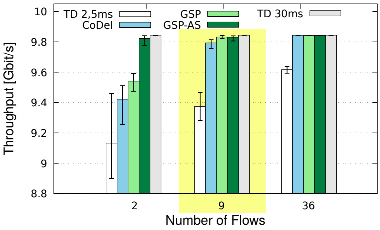
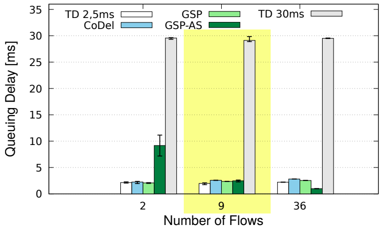
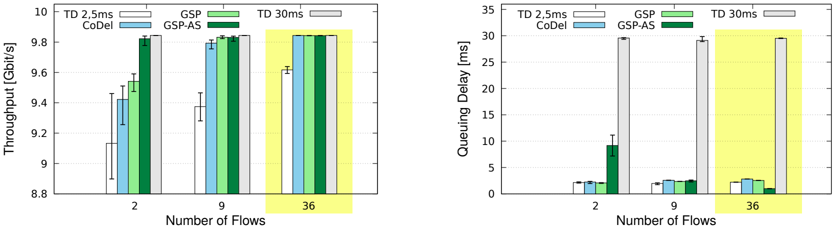




- “Right” number of flows → reasonable loss de-synchronization
  - AQMs: Given setpoint suitable for this traffic situation
  - GSP-AS: adjusts to similar values (setpoint, delay, throughput)
  - Tail drop (small): Still *low* loss de-synchronization!

Evaluation

- Experiment 1: Steady state, long lived flows



- Higher number of flows → high loss de-synchronization
  - GSP-AS: High throughput, very low delay
  - AQMs: Unnecessarily large delay (fixed setpoint too high)
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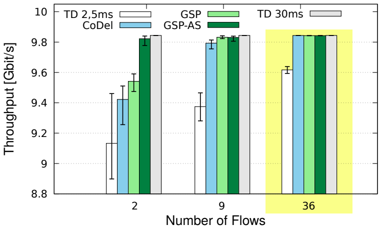

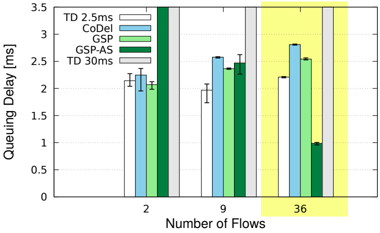

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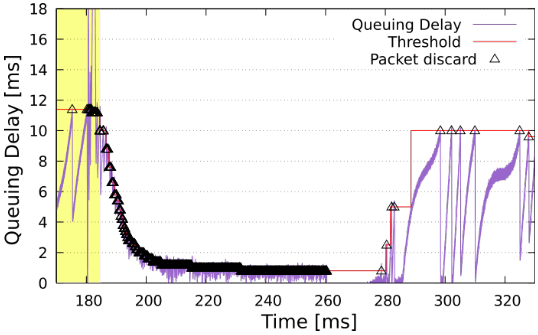
- Experiment 2: Transition behavior
  - # Flows changed: $2 \rightarrow 36 \rightarrow 2$



- Two flows:
  - Setpoint increased to ≈ 11 ms

  $\rightarrow$ Necessary to keep throughput policy

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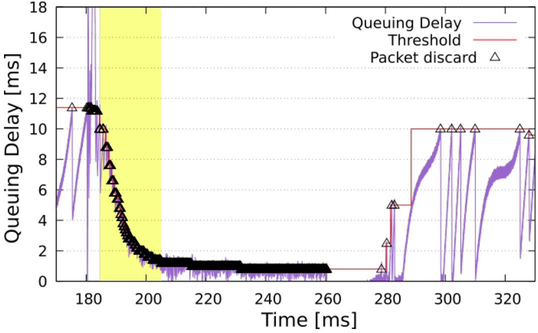

- Sudden increase in # flows (2 → 36):
  - Setpoint smoothly adjusts to new traffic situation
  - → Smoothing prevents overreactions

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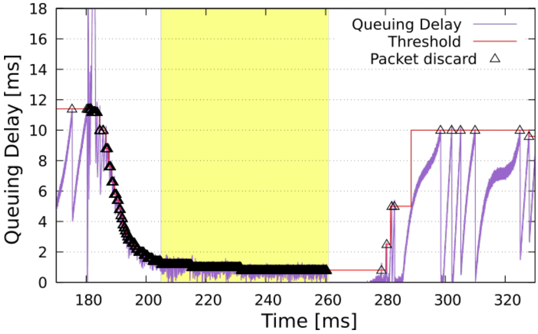

- 36 flows:
  - Low setpoint sufficient to keep throughput policy
  - → Notice: Only small fluctuations of in-flight data

Evaluation

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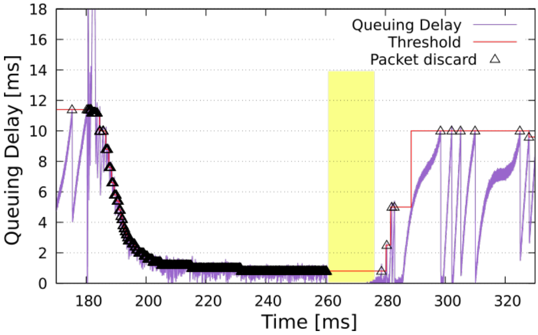
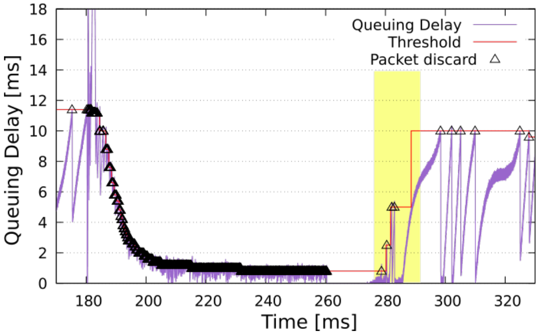


- 34 flows suddenly stop (36 → 2):
  - Temporary underutilization!

→ Congestion control needs some time to reclaim free bandwidth

Evaluation

- Experiment 2: Transition behavior
  - $\#$ Flows changed: $2 \rightarrow 36 \rightarrow 2$



- Utilization target not fulfilled ($36 \rightarrow 2$):
  - AQM Steering adjusts to new traffic situation

  $\rightarrow$ Step-wise increment of setpoint

Evaluation

- Experiment 2: Transition behavior
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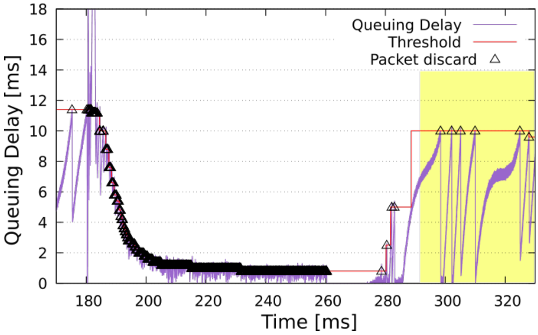


- Two flows:
  - Necessary setpoint regained $\approx 10\,\text{ms}$
- $\rightarrow$ Notice: In-flight data fluctuates between empty buffer and setpoint

Conclusion

- AQM Steering: Improvement of (existing) AQMs
  - Avoid unnecessarily large delays
  - Achieve high utilization
  - → Find best trade-off: Throughput vs. delay under given policy
- External control loop around existing AQM
- Evaluation in physical high speed testbed (10 Gbit/s bottleneck)
  - GSP-AS is able to trade off throughput vs. delay, according to the policy
  - Adapts to changing traffic
  - → Improves performance of existing AQMs
- Paper:
  `https://doc.tm.kit.edu/2018-kit-aqm-steering-authors-copy.pdf`

End

Thank you very much for your attention!

Questions?

Paper: `https://doc.tm.kit.edu/2018-kit-aqm-steering-authors-copy.pdf`

Additional Slides

Challenge 3: Ultra low latencies

- Approach: Keep link utilization below 100 % (u_{target})
- Challenge
  - Targeted AQMs work on queuing delay
  - Cannot react before a queue builds up
- Solution: Virtual Queues
  - Simulate virtual egress rate $rate_{virt} < rate_{phy}$
  - Calculate queue size / delay that *would* build up

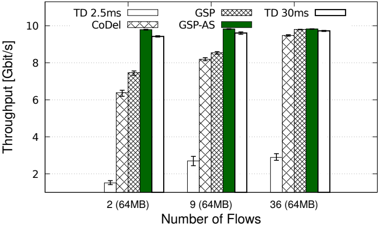
$$\dot{q}_{real} = \begin{cases} rate_{in} - rate_{phy} & \text{if } q > 0, \\ (rate_{in} - rate_{phy})^{+} & \text{if } q = 0 \end{cases} \qquad \dot{q}_{virtual} = \begin{cases} rate_{in} - rate_{virt} & \text{if } q > 0, \\ (rate_{in} - rate_{virt})^{+} & \text{if } q = 0 \end{cases}$$

$\rightarrow$ Do *not* shape traffic (since actual queues would build up)!

- AQM is seamlessly switched between virtual queue and physical queue

Additional Slides

Evaluation: Further Experiments



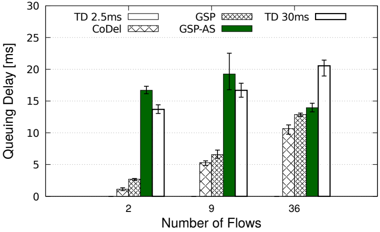


Figure: Steady state, long lived flows + short lived flows

- Much higher delay required to keep high throughput
  - Reduced throughput for fixed AQMs
  - GSP-AS can adapt
- Small tail-drop buffer problematic!

Additional Slides

Evaluation: Further Experiments

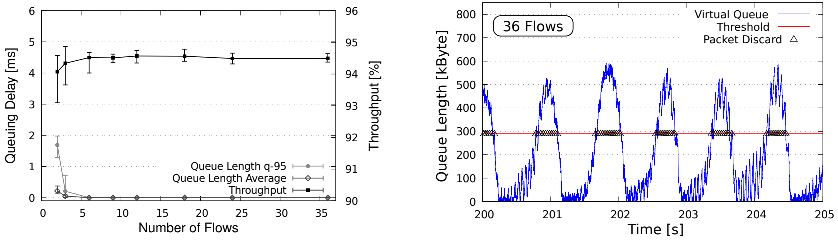
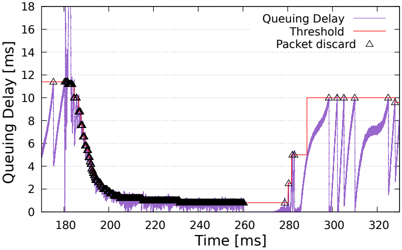


Figure: Interplay of physical and virtual queue ($u_{target} = 95\%$)

- Low number of flows
  - Physical queue required to fulfill policy ($u_{low} = 0.94$)
- Higher number of flows
  - No physical queue necessary to fulfill lower delay bound (u_{low})
  - Virtual queue required to fulfill upper delay bound (u_{target})
  - → (Sufficiently) high throughput, *no queuing delay* at all.

Additional Slides

Evaluation: Further Experiments



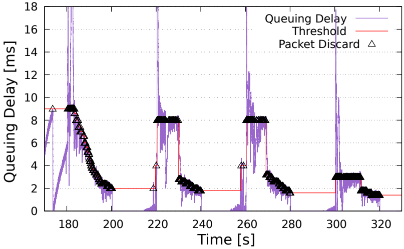


Figure: Transition behavior

- Adjusting to sudden changes in traffic
- Traffic changed during adaptation
  - GSP-AS control loop does not destabilize
  - Quick increase, slow decrease

Discussion

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- AQM Steering cannot always achieve u_{low}!
  - If link is no bottleneck u_{low} is irrelevant
  - $target_{max}$ can be lower then necessary
- When converged, throughput comparable with large tail-drop buffer
  - Throughput $\geq \min\left(u_{low}, thr_{taildrop}(target_{max})\right)$
    - $thr_{taildrop}(\ldots)$: throughput with tail-drop buffer of given size
- Reclaim of free bandwidth is different!
  - When a flow disappears, total in-flight data is suddenly reduced (by its *CWnd*)
  - Sudden drop in delay (large queues) or link utilization (small queues)

$\rightarrow$ Can conceptually *not* be compensated by AQM Steering

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