Poseidon: Efficient, Robust, and Practical Datacenter CC via Deployable INT

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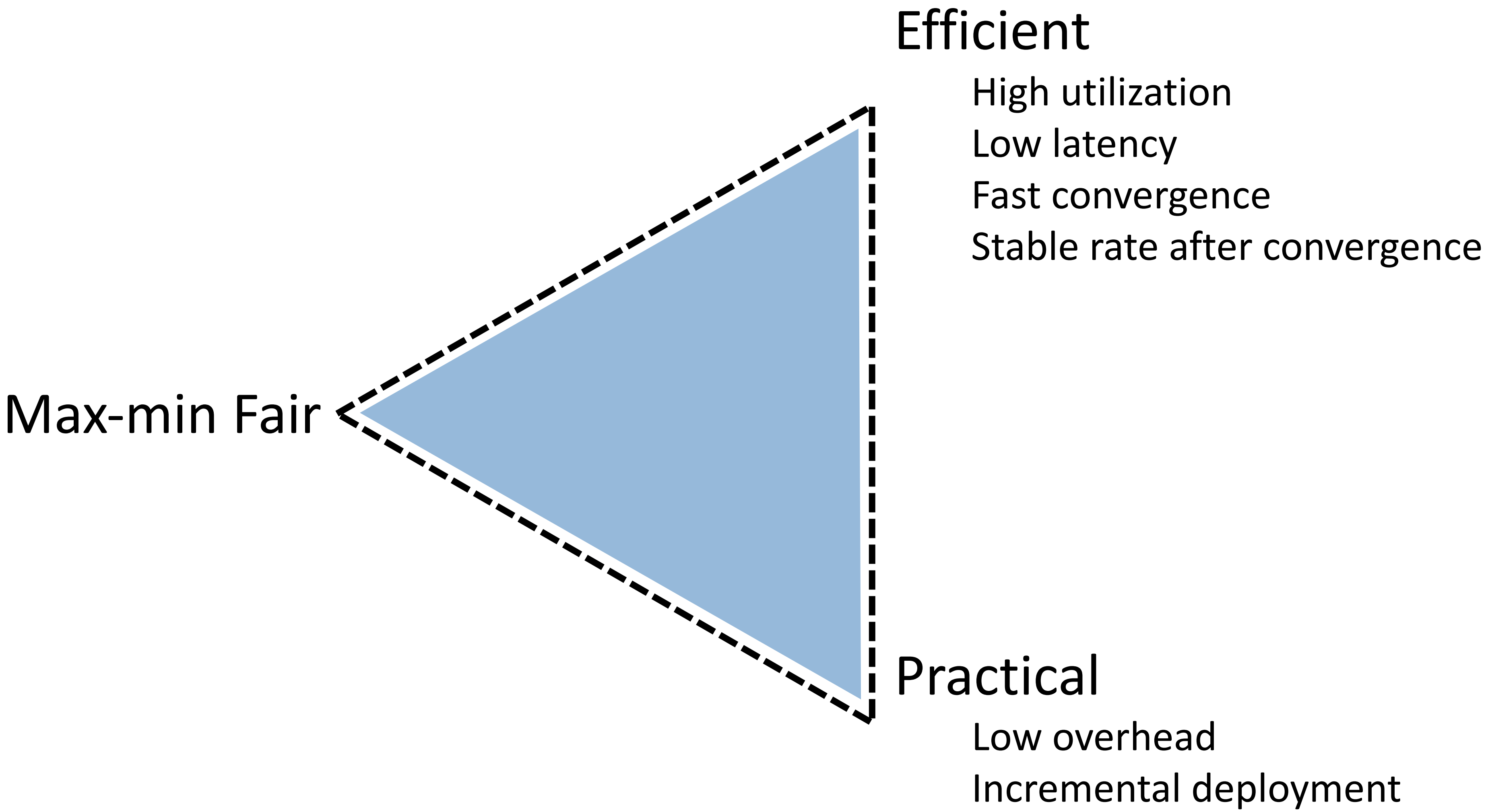
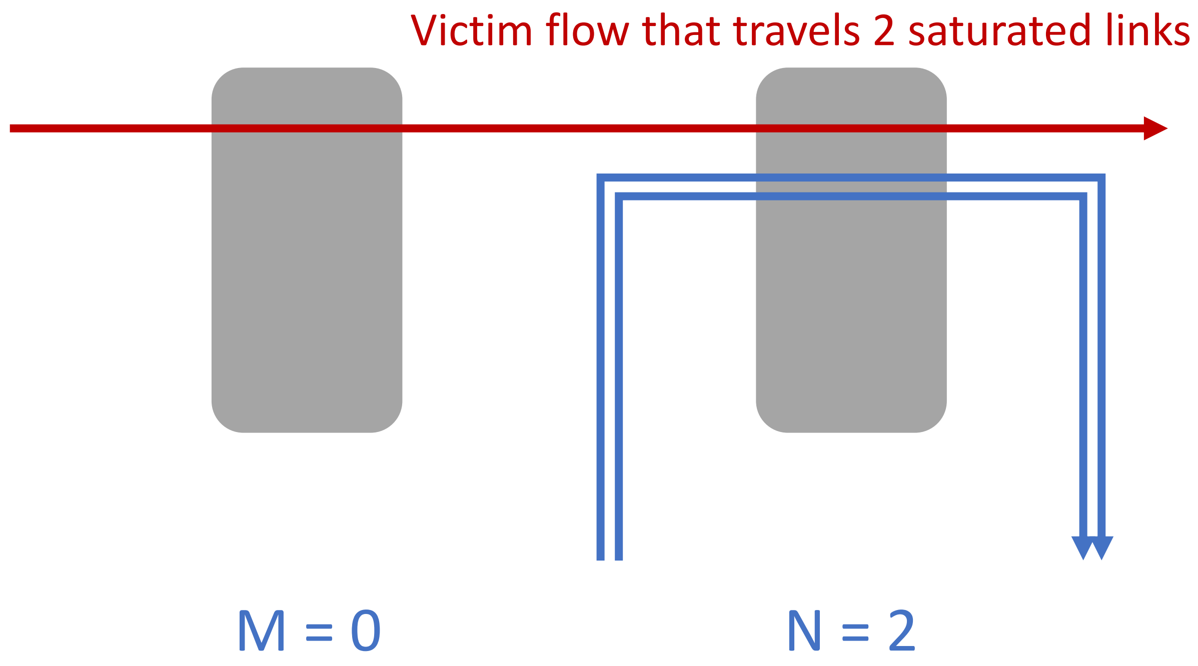
T. S. Eugene Ng, Neal Cardwell, Nandita Dukkipati

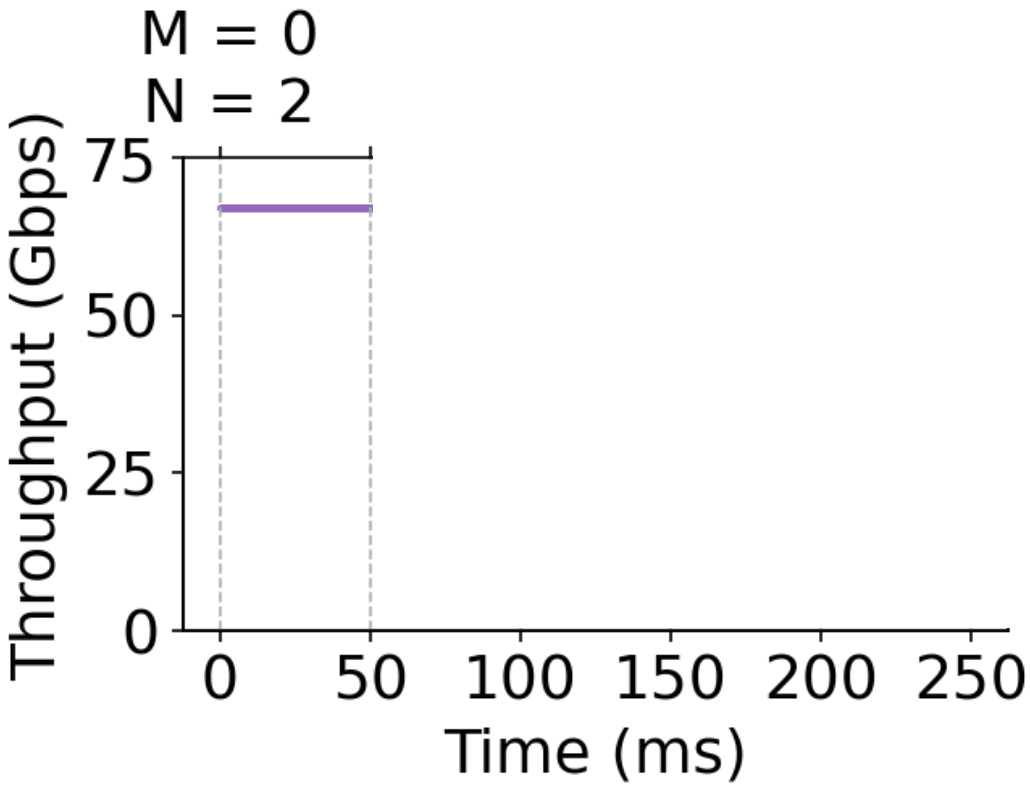
A Good Congestion Control Algorithm



Motivation 1: React to Every Congestion -> Not Max-min Fairness



Line rate: 200 Gbps



The fair-share for the victim flow changes when new flows join.

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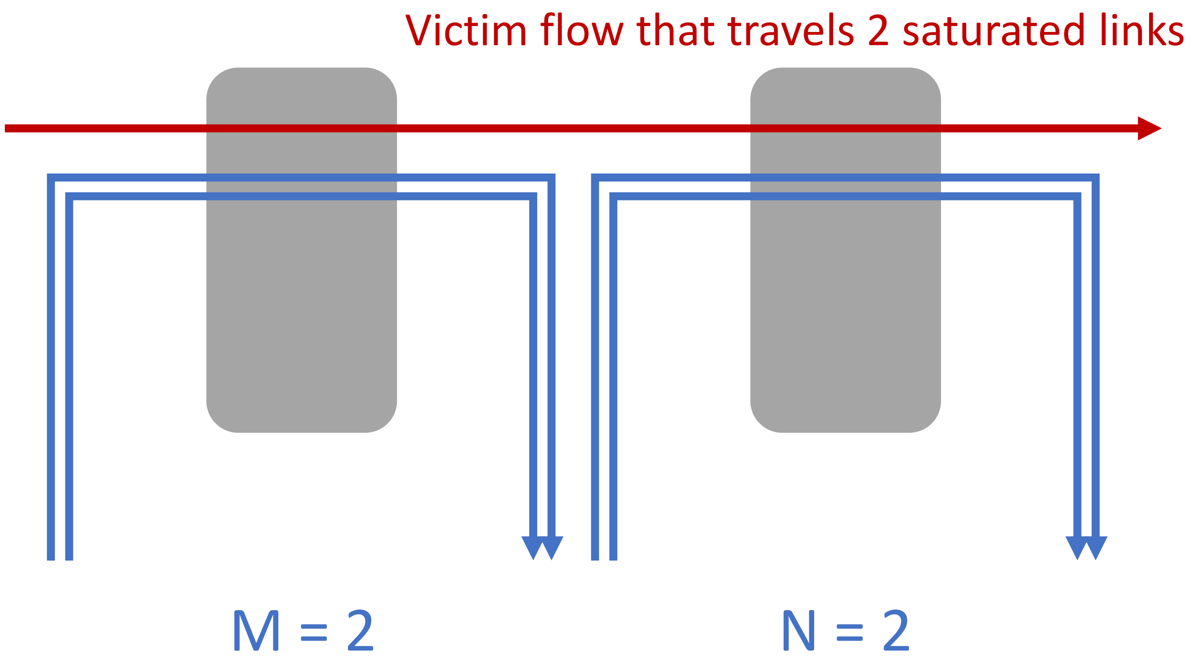

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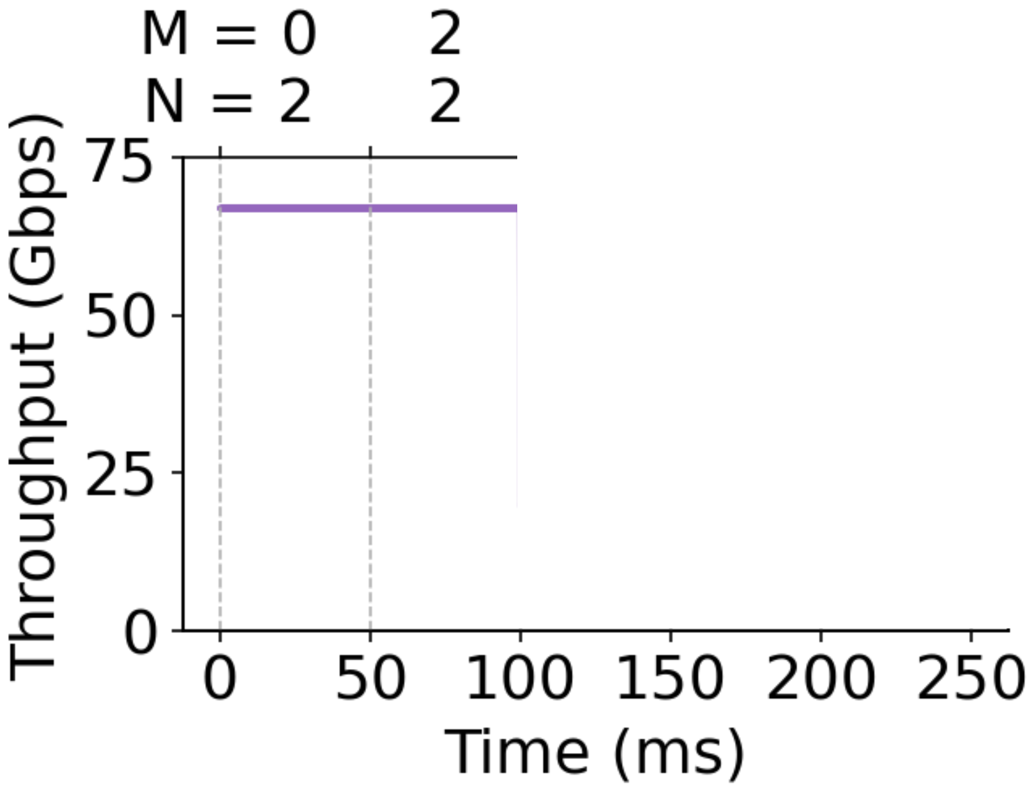

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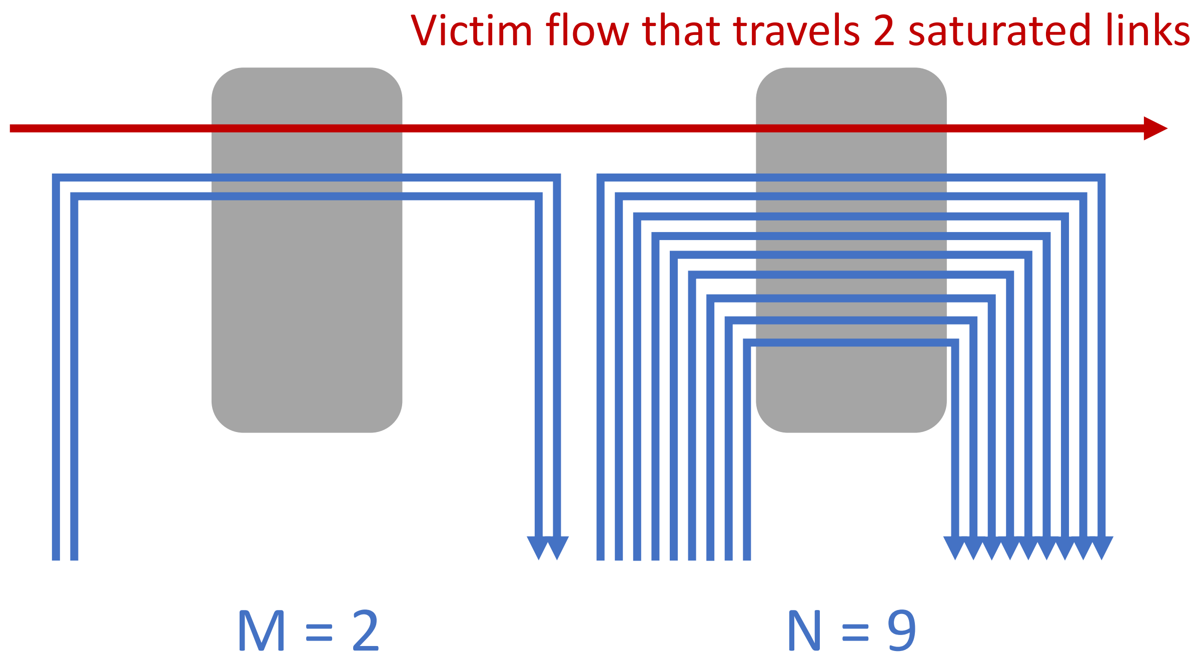

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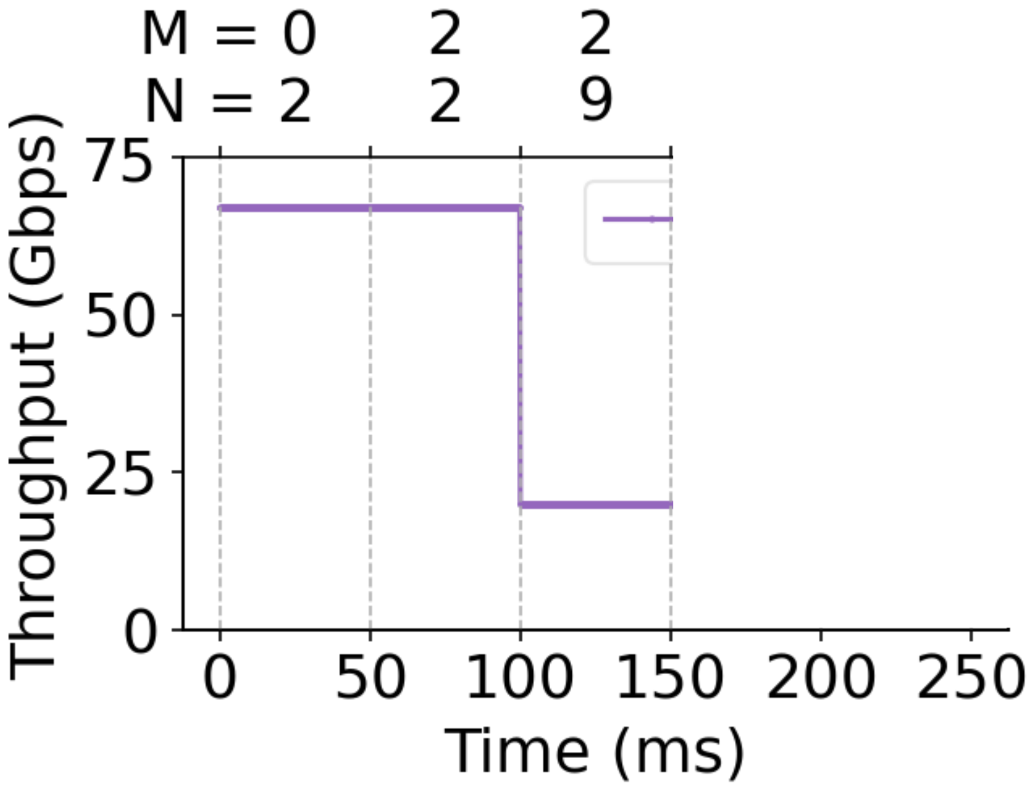

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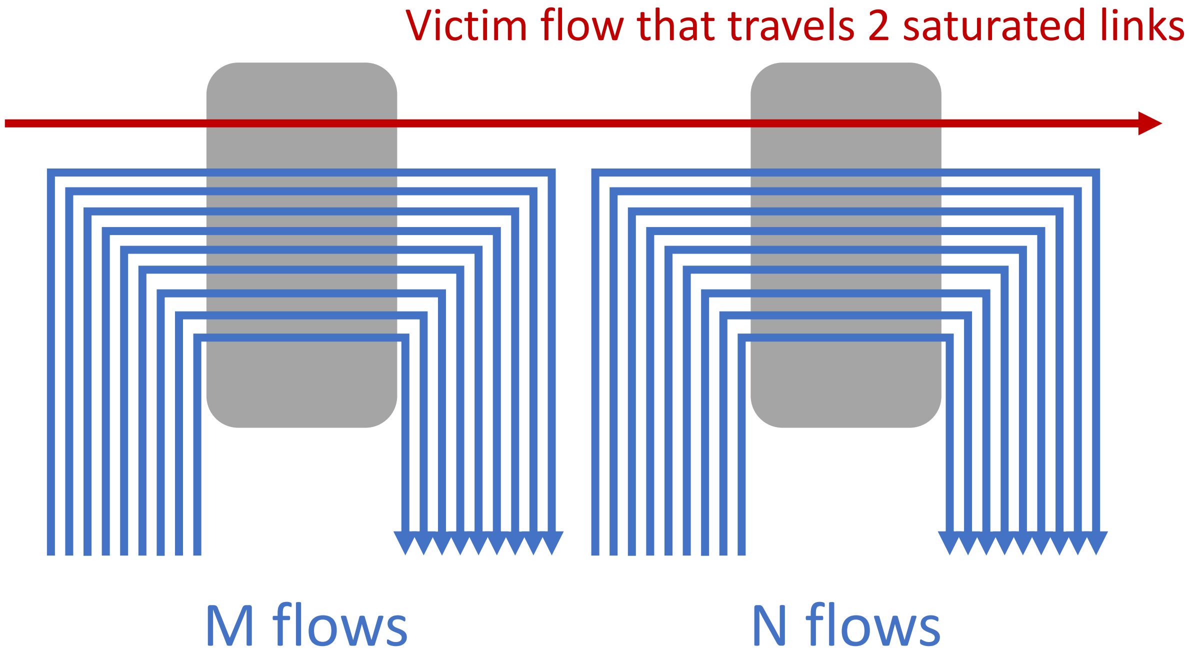

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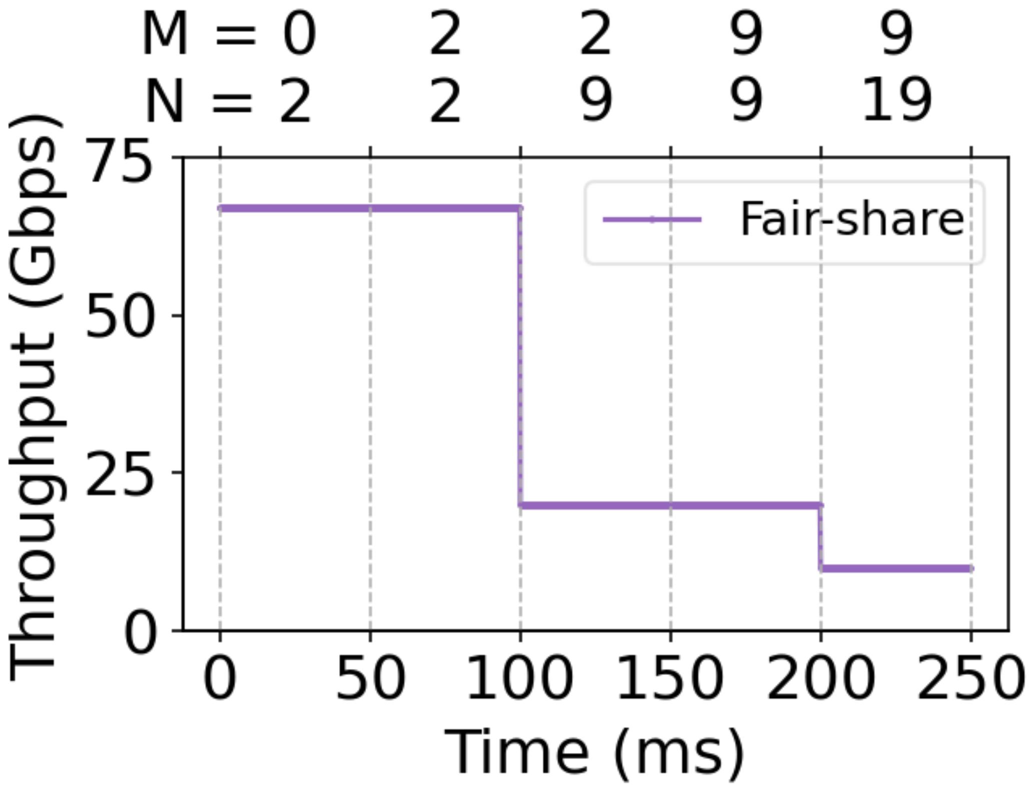

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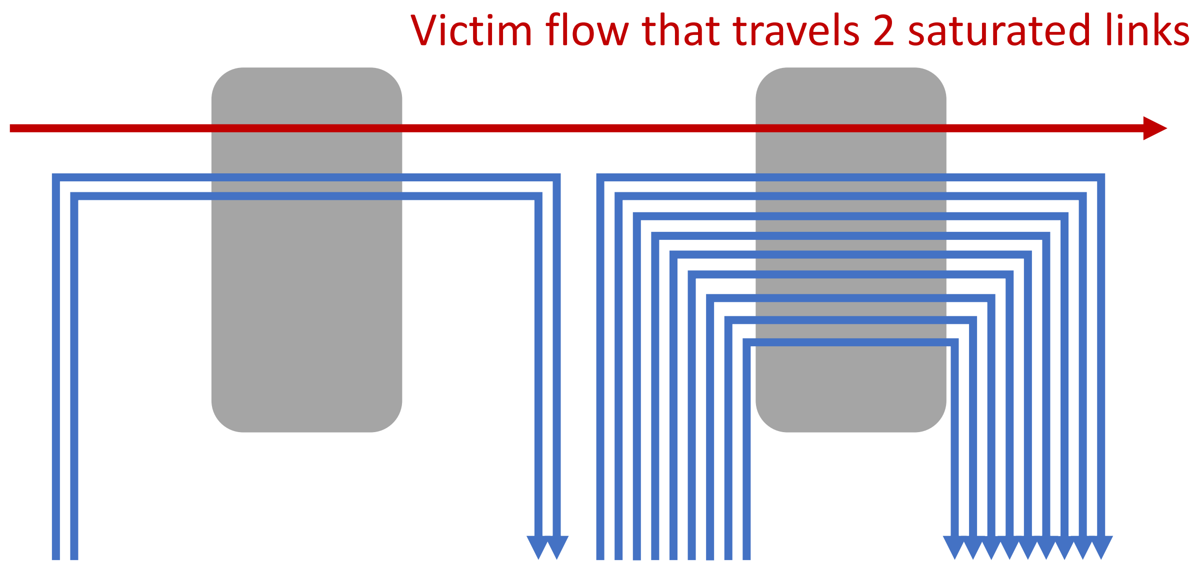

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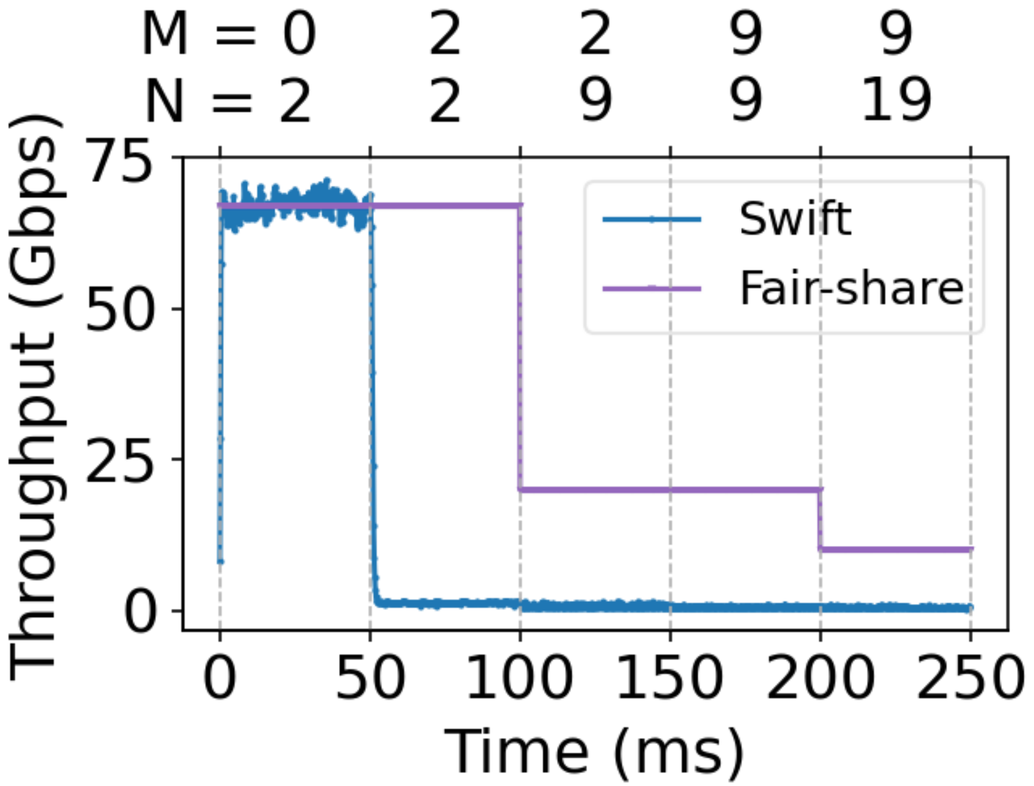

Swift reacts to end-to-end fabric delay, so the victim flow has a much higher fabric delay.

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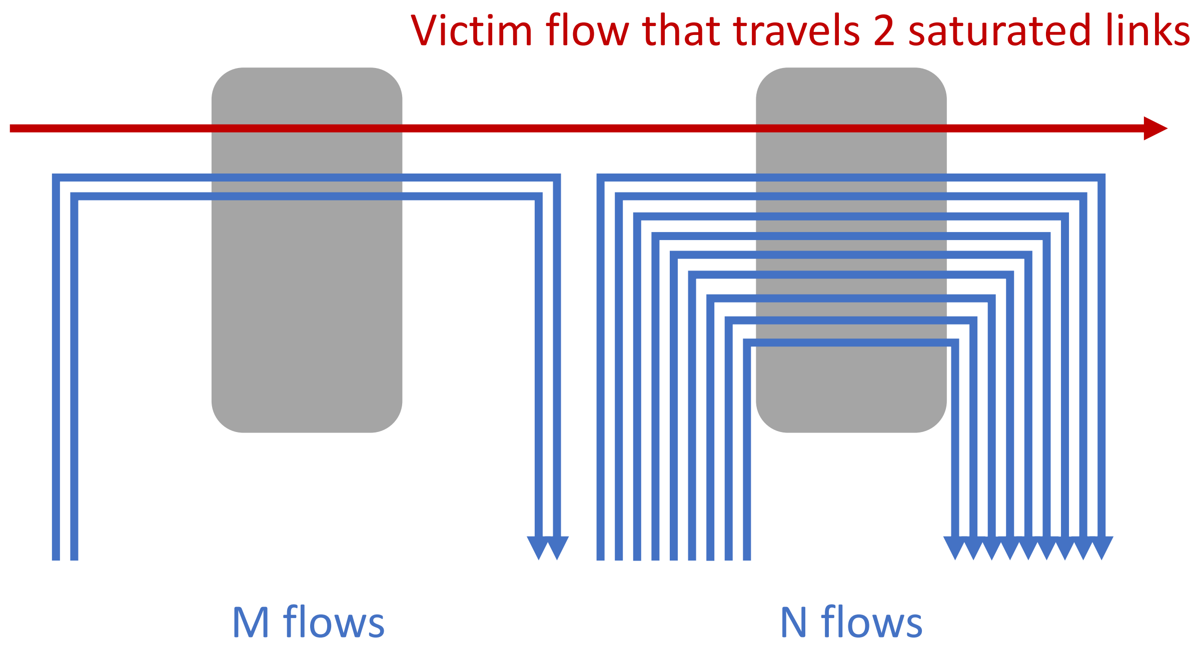

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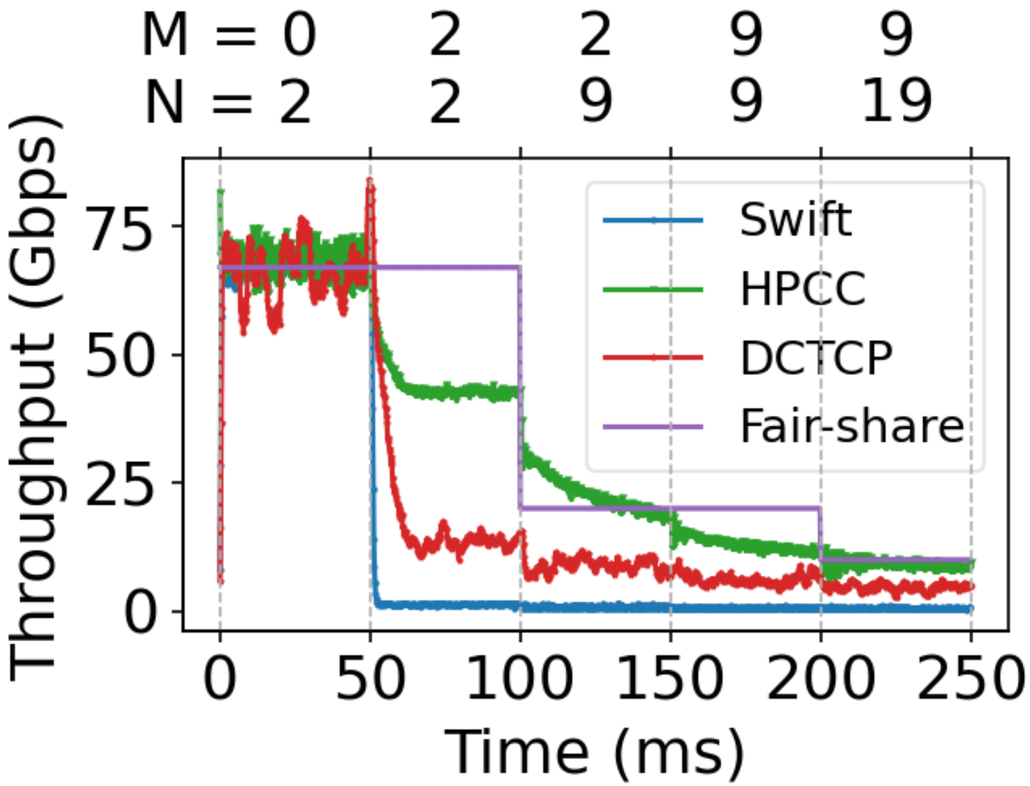
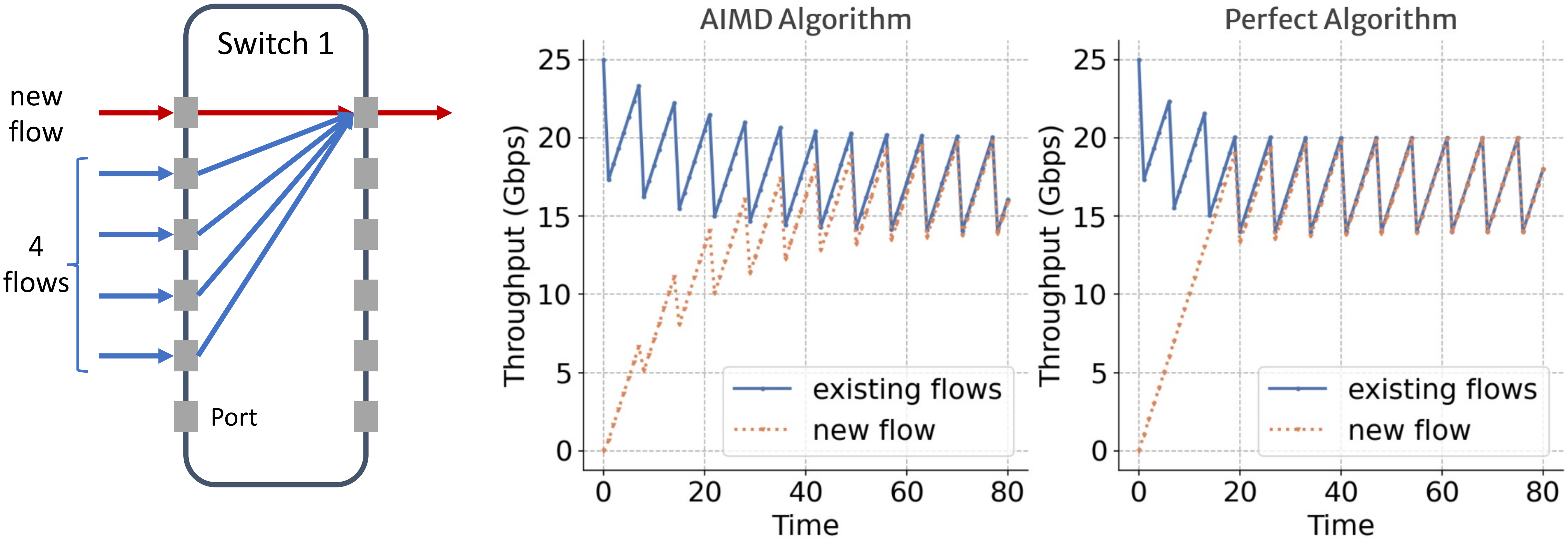


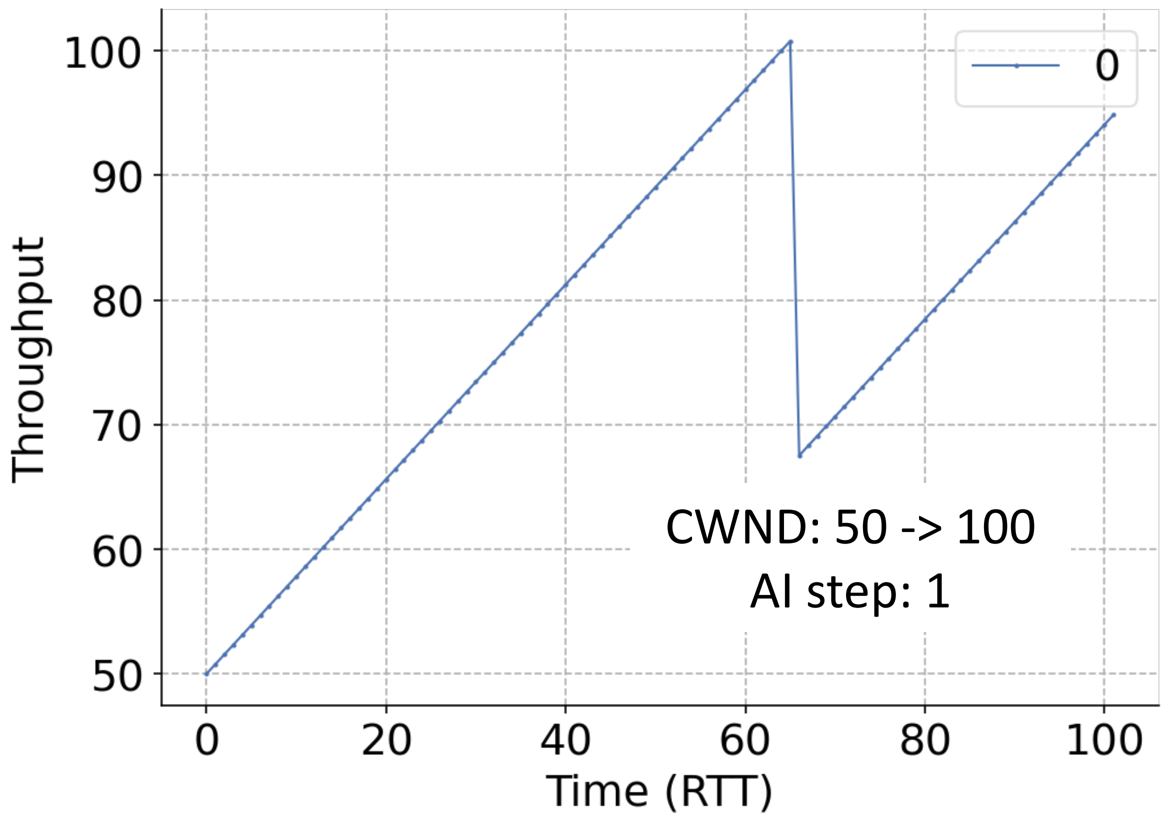
HPCC & DCTCP react to every congestion, so the victim flow does more MD operations.

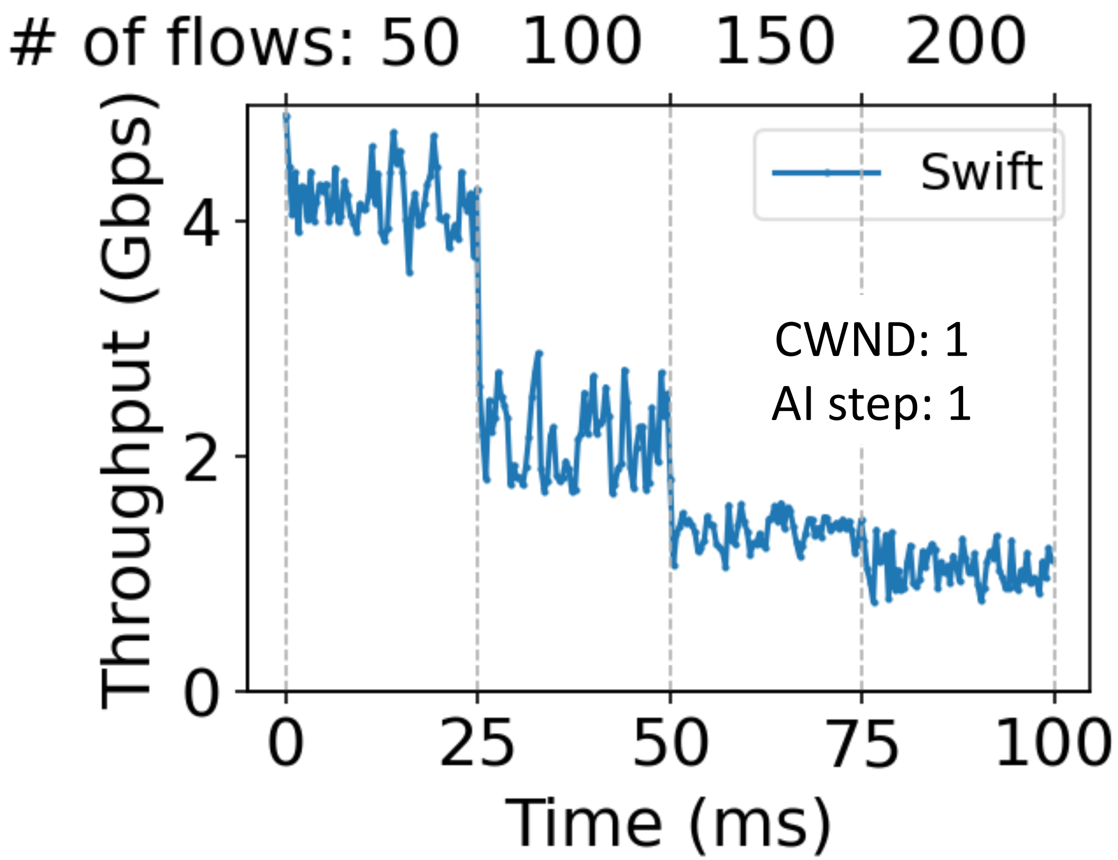
Motivation 2: Decrease rate below fair-share -> slow convergence



The flow that haven’t reached fair-share should not decrease rate.

Motivation 3: Convergence Speed & Stable Rate Trade-off





AIMD uses fixed AI step, so it cannot achieve both fast convergence and stable rate enforcement.

Not max-min Fairness

root cause

React to every congestion

Decrease before fair-share

Convergence & stability trade-off

root cause

AIMD demands same reaction from all flows

root cause

Binary signal

React to bottleneck congestion

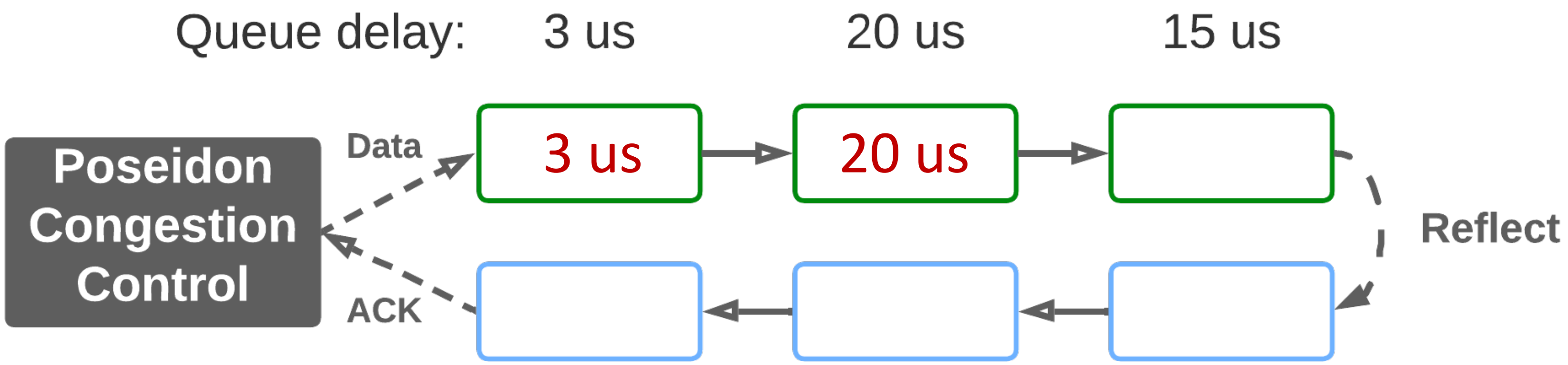
Quantitative signal

Enable

In-network Telemetry (INT)

Design 1: A Practical Low-overhead Quantitative Signal

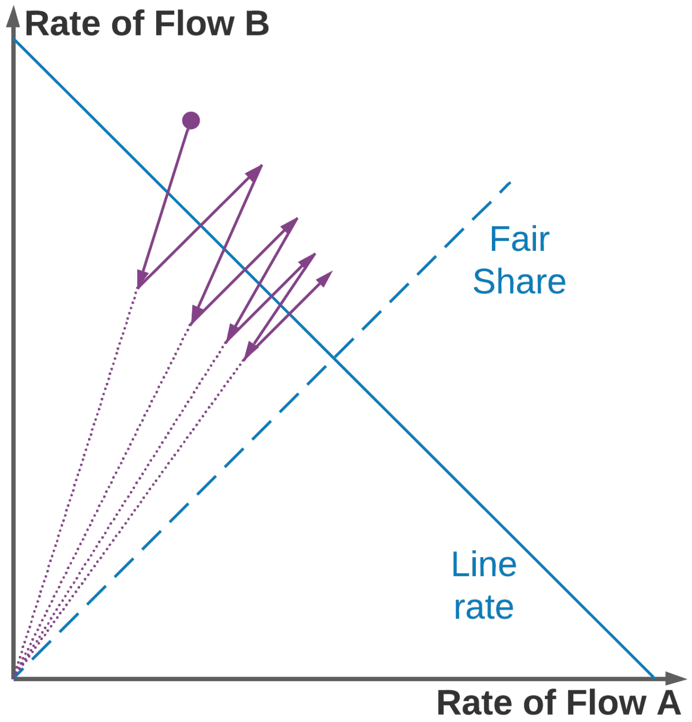
- Signal: maximum per-hop delay (**MPD**)
  - Fixed short length: 2 bytes
  - Collected along the forwarding path
  - Reflected to sender through ACK



Why does Existing CC with INT Have the Same Problems?

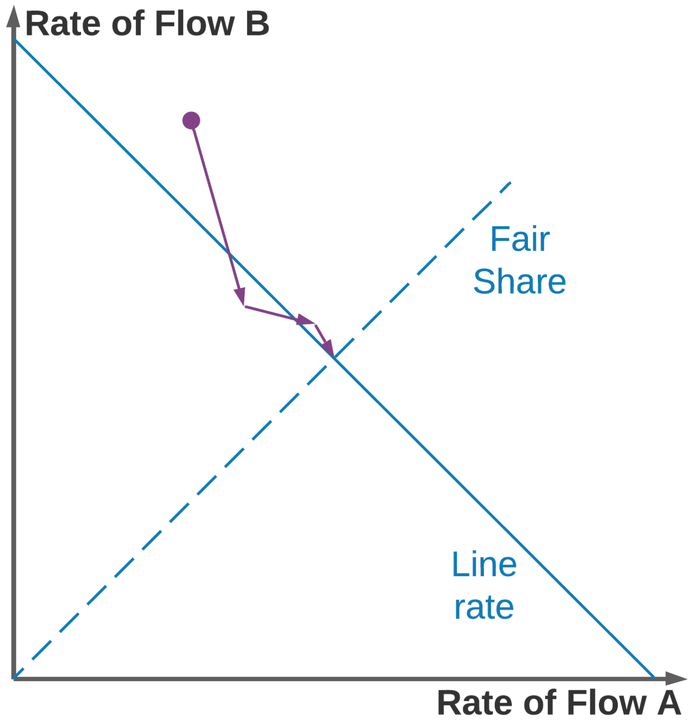
They still uses same idea as AIMD

Either all flows increase,
or all flows decrease



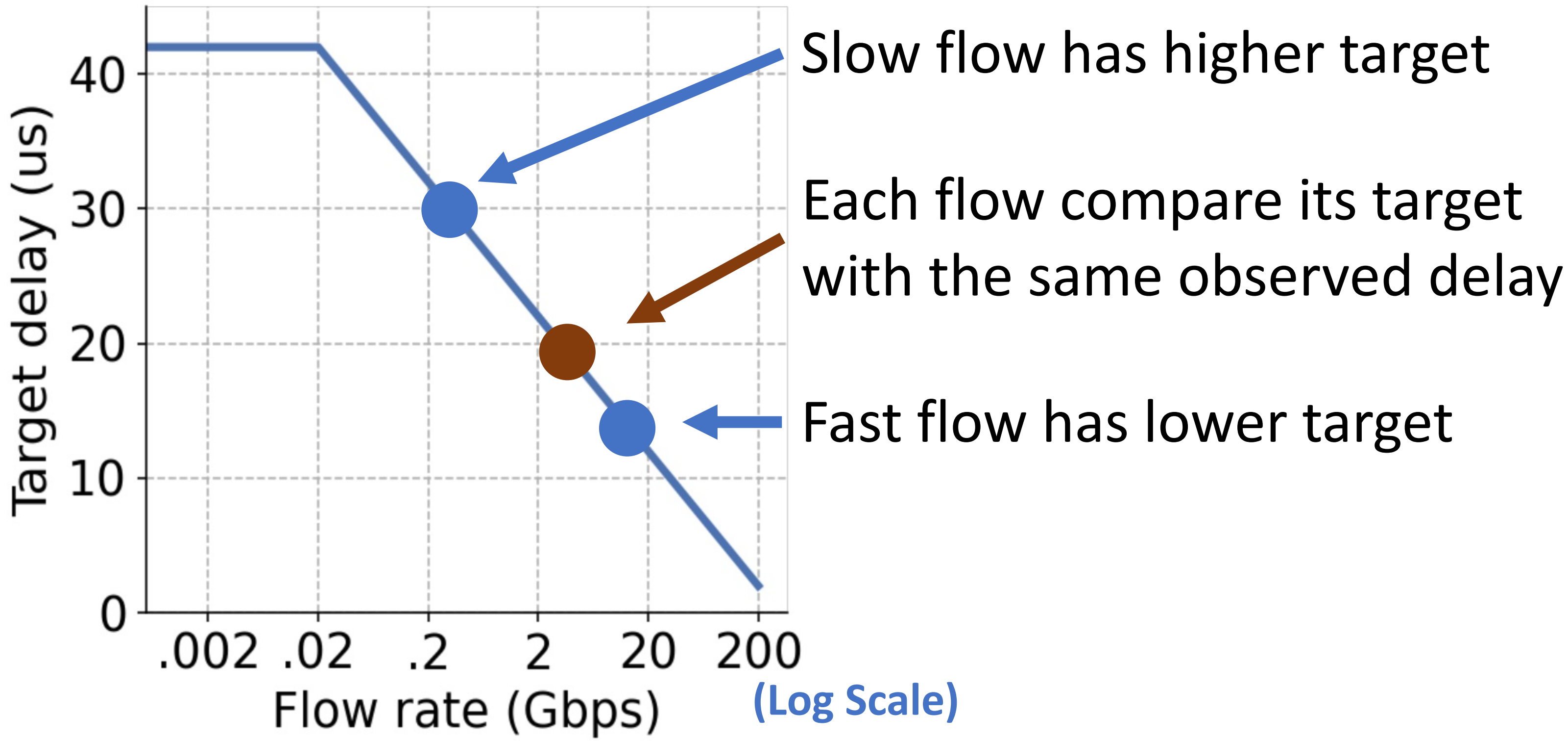
Poseidon decouples from AIMD

Every flow **reacts differently**,
Some increase, some decrease.



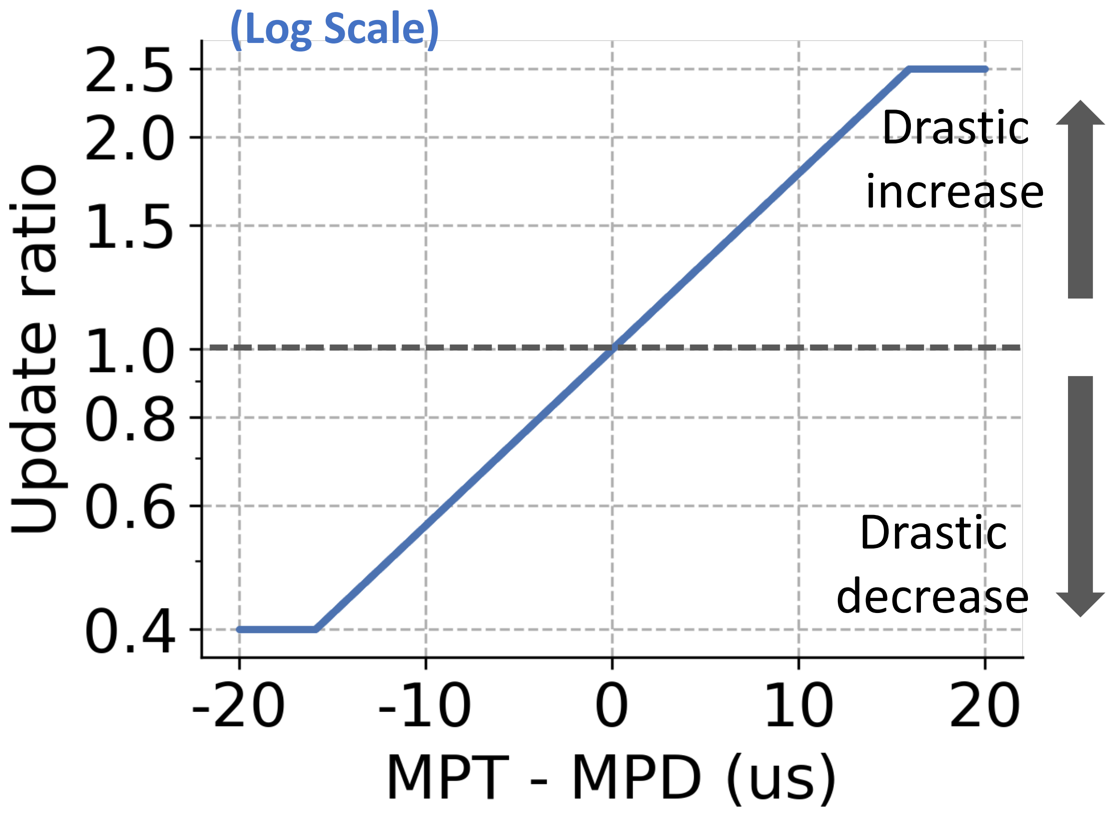
Design 2: Rate-adaptive Target Enables Different Reactions

- Each flow calculates its own max per-hop delay target (**MPT**)
  - MPT = T(rate)
  - **larger rate -> smaller target**



Design 3: Adaptive MIMD Rate Update

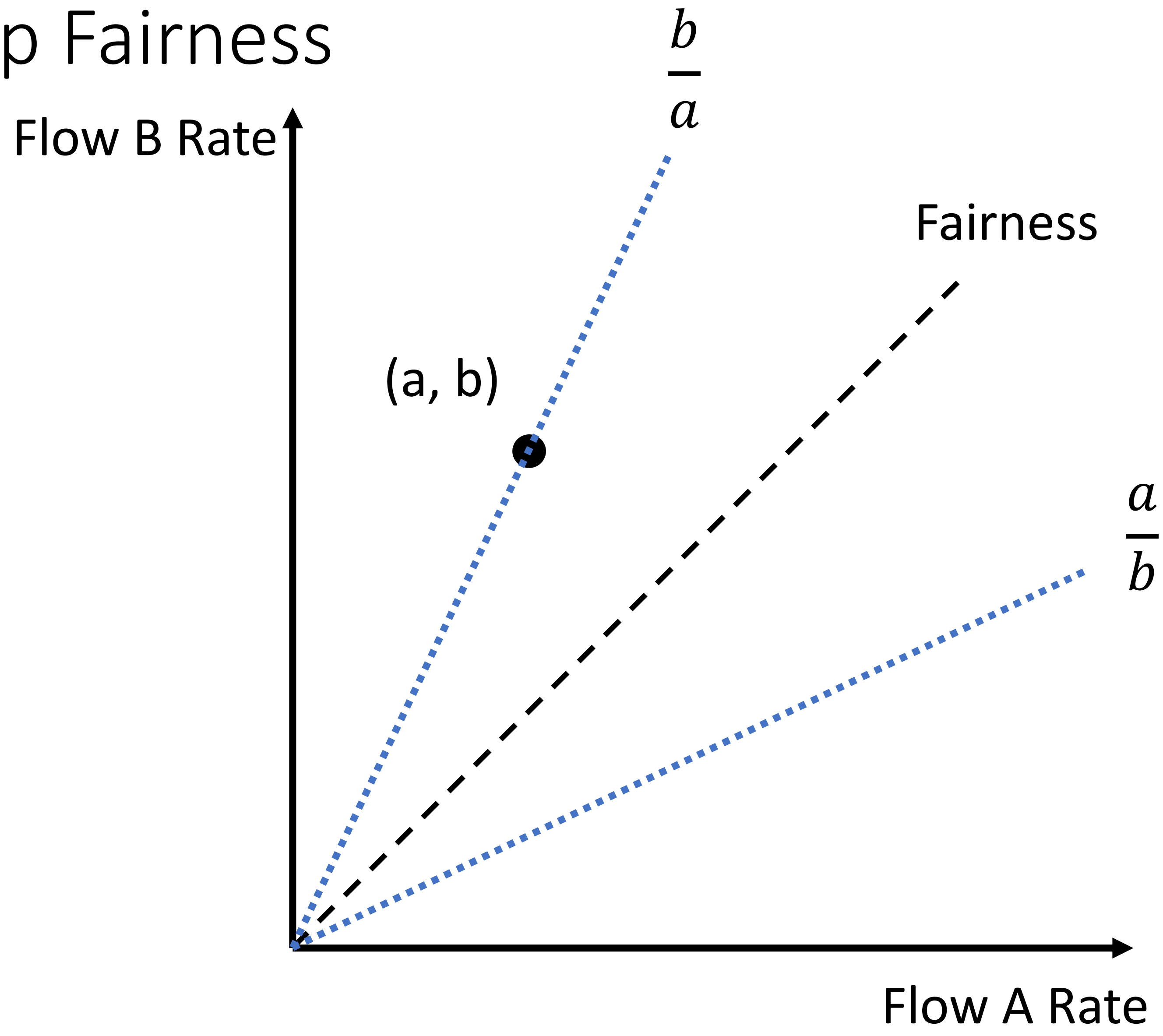
- Each flow updates rate multiplicatively (MIMD)
  - update_ratio = U(MPT, MPD)
  - new_rate = rate * update_ratio
- MPT < MPD, decrease
  - MPT << MPD, decrease more drastic
- MPT > MPD, increase
  - MPT >> MPD, increase more drastic



Convergence to Single-hop Fairness

Flow A rate: a

Flow B rate: b   (assume a < b)



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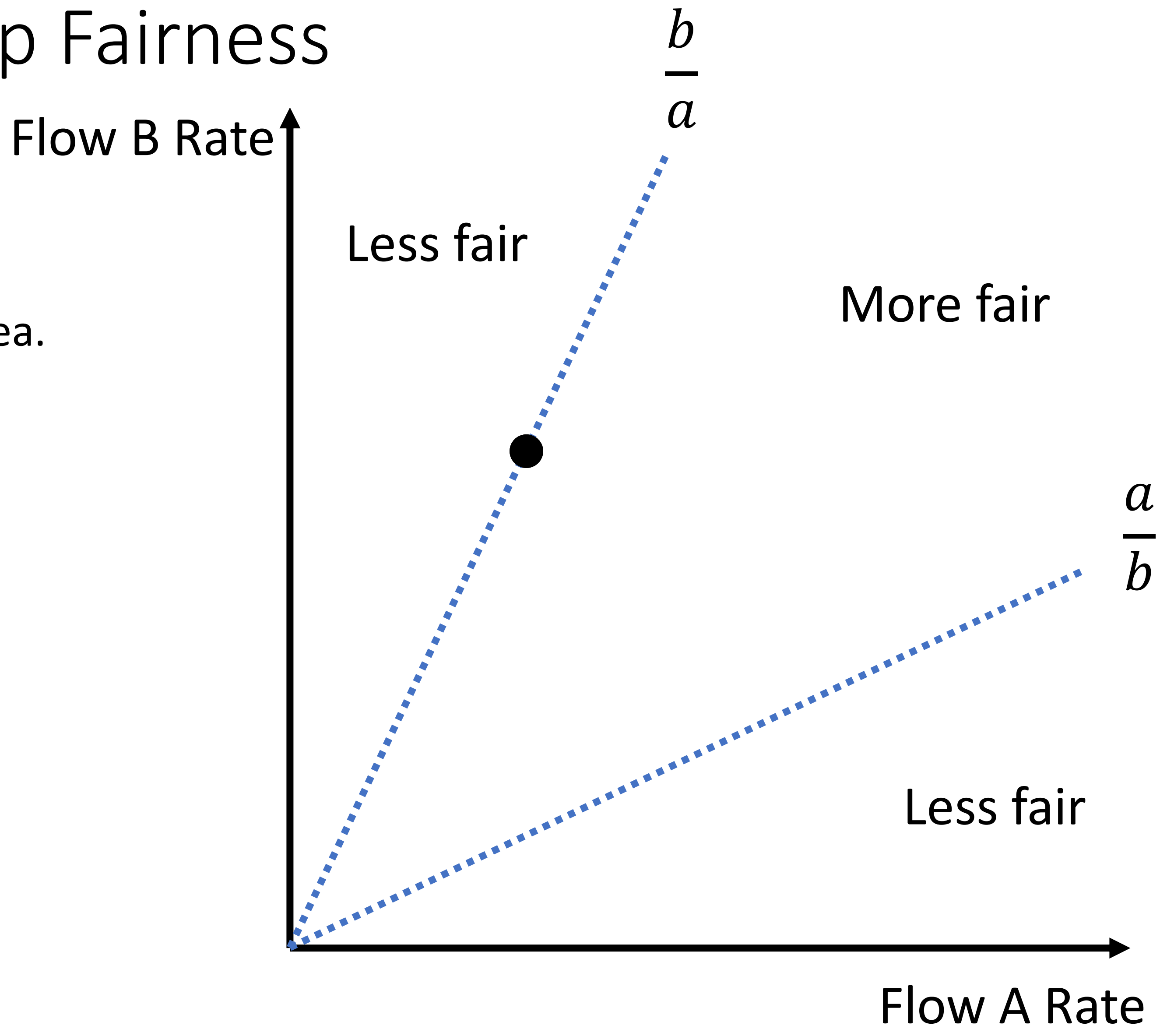
Goal: update the rates to be in "more fair" area.



Convergence to Single-hop Fairness

Flow A rate: a

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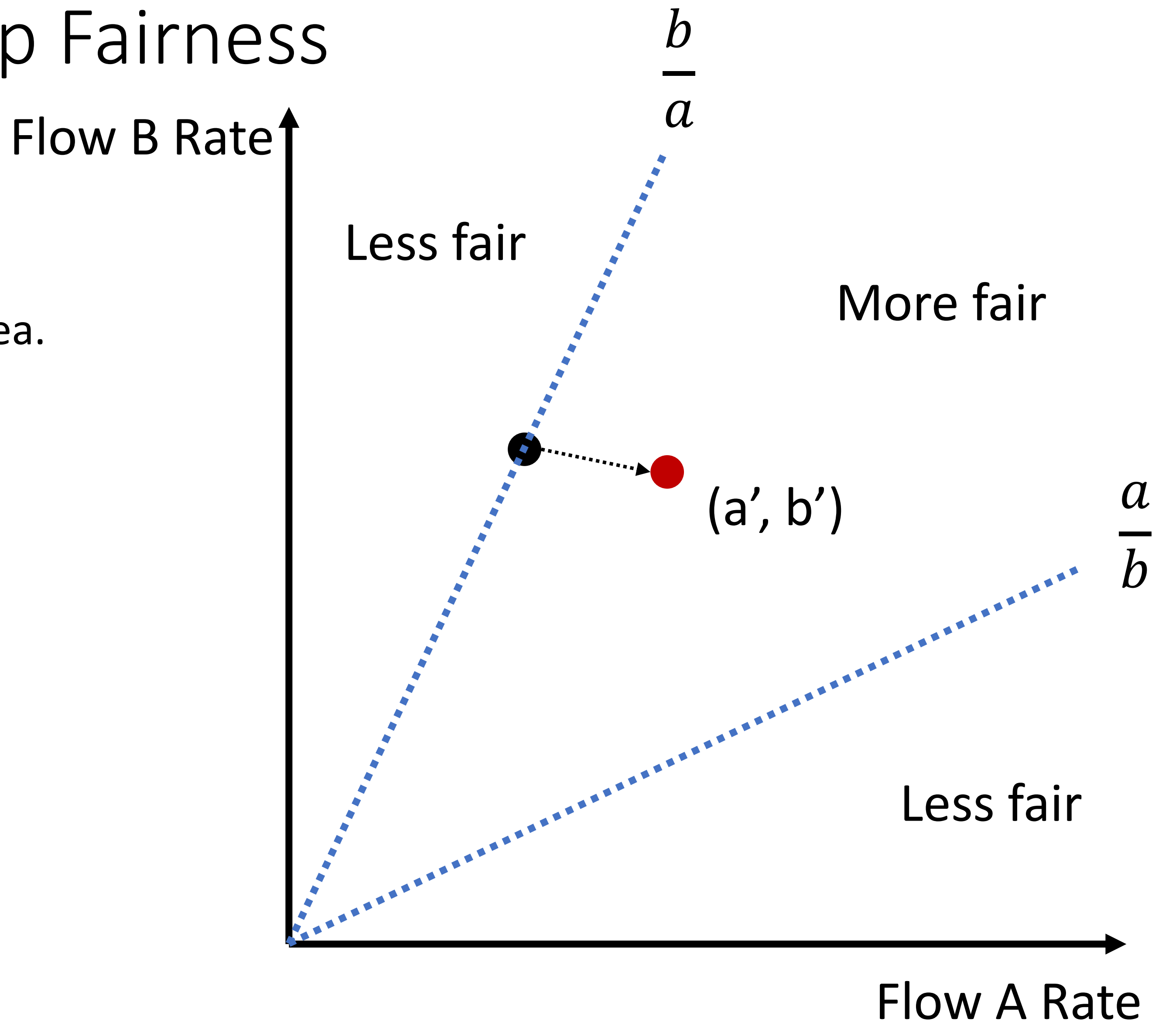
Given any delay D, the rate updates are:

$$a' = a \cdot U(T(a), D)$$
$$b' = b \cdot U(T(b), D)$$

To guarantee convergence:

$$\frac{a}{b} < \frac{b'}{a'} < \frac{b}{a}$$



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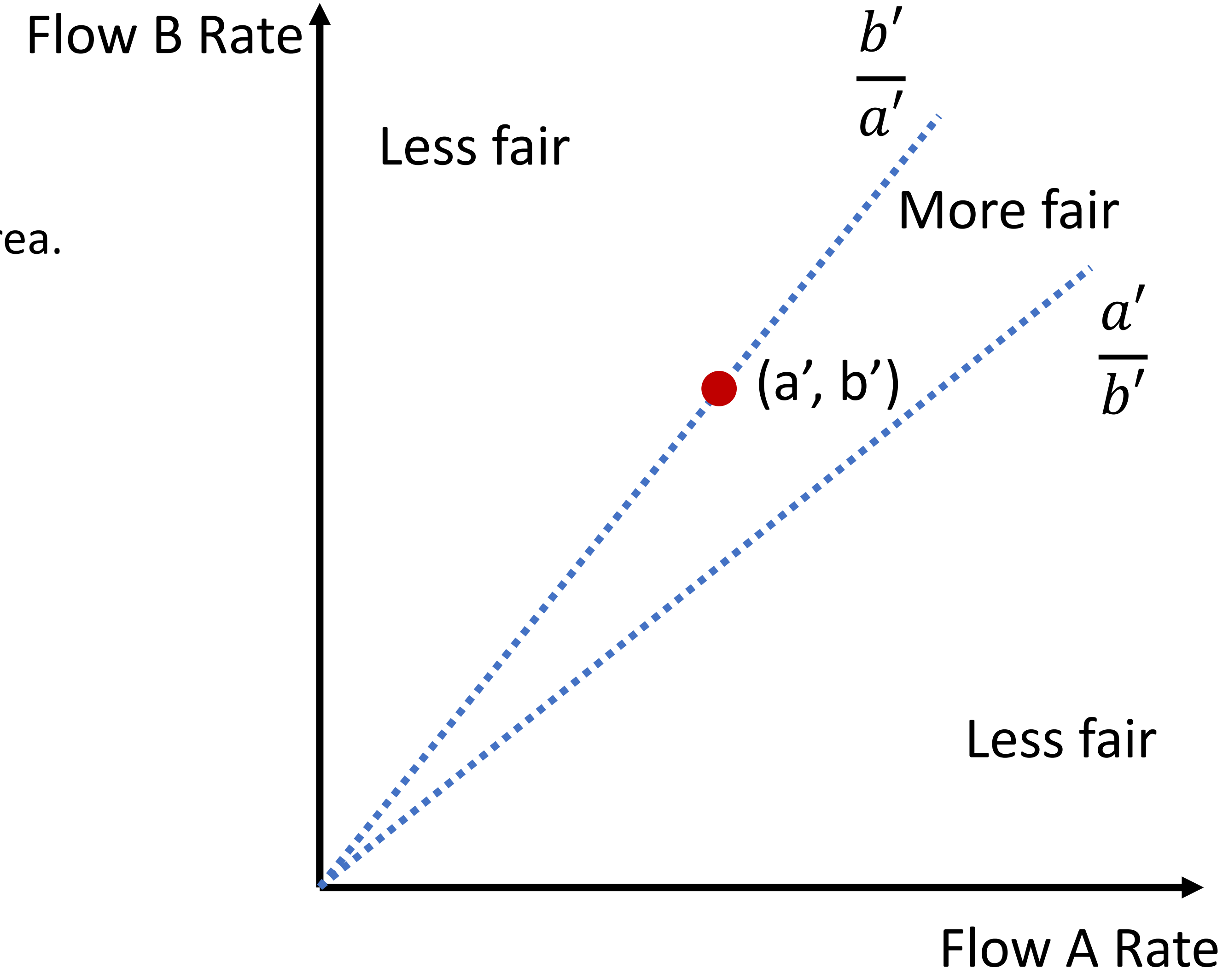
Repeat until converge.



Note: The complete proof with corner cases discussion is in the paper.

Convergence to Single-hop Fairness

Flow A rate: a

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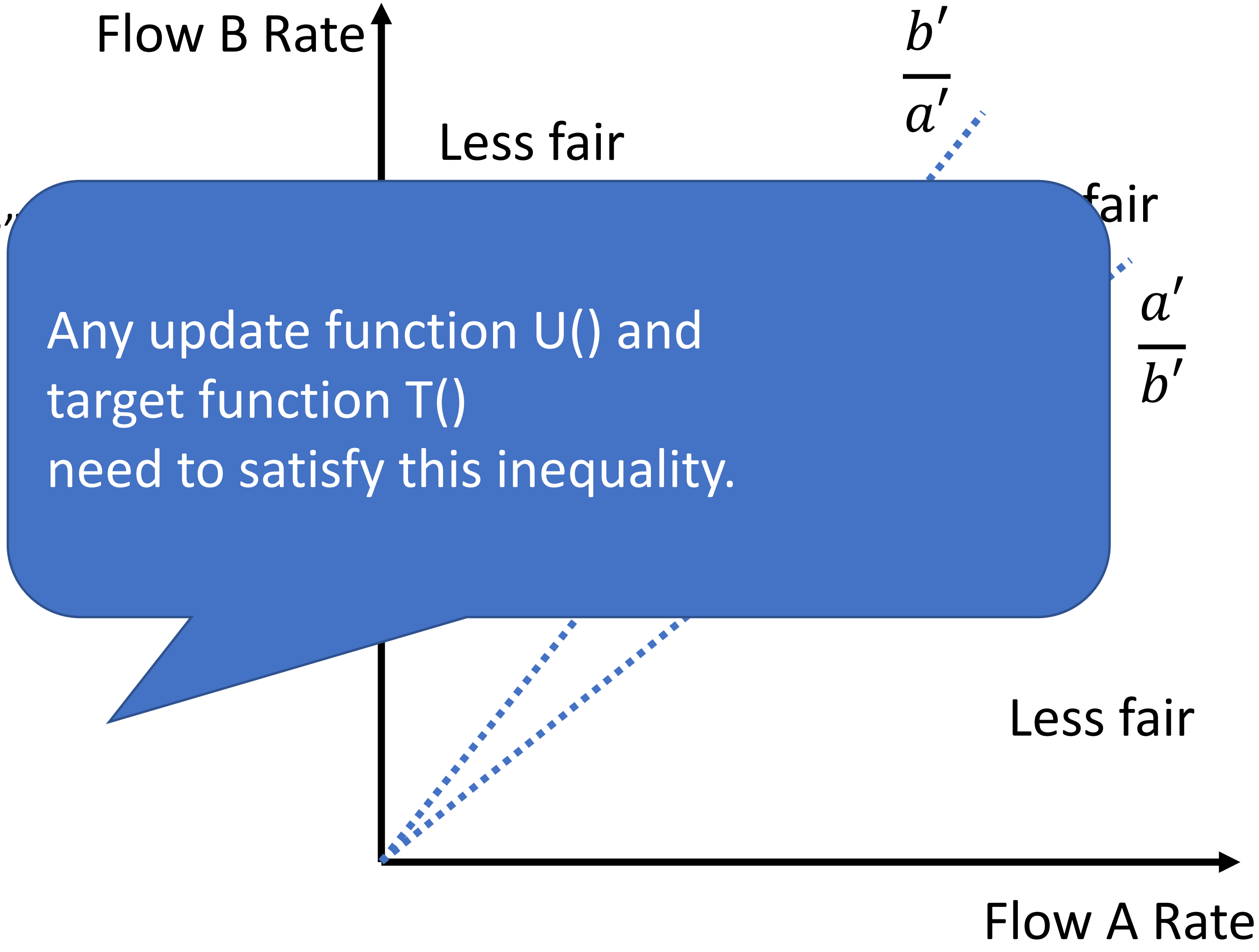

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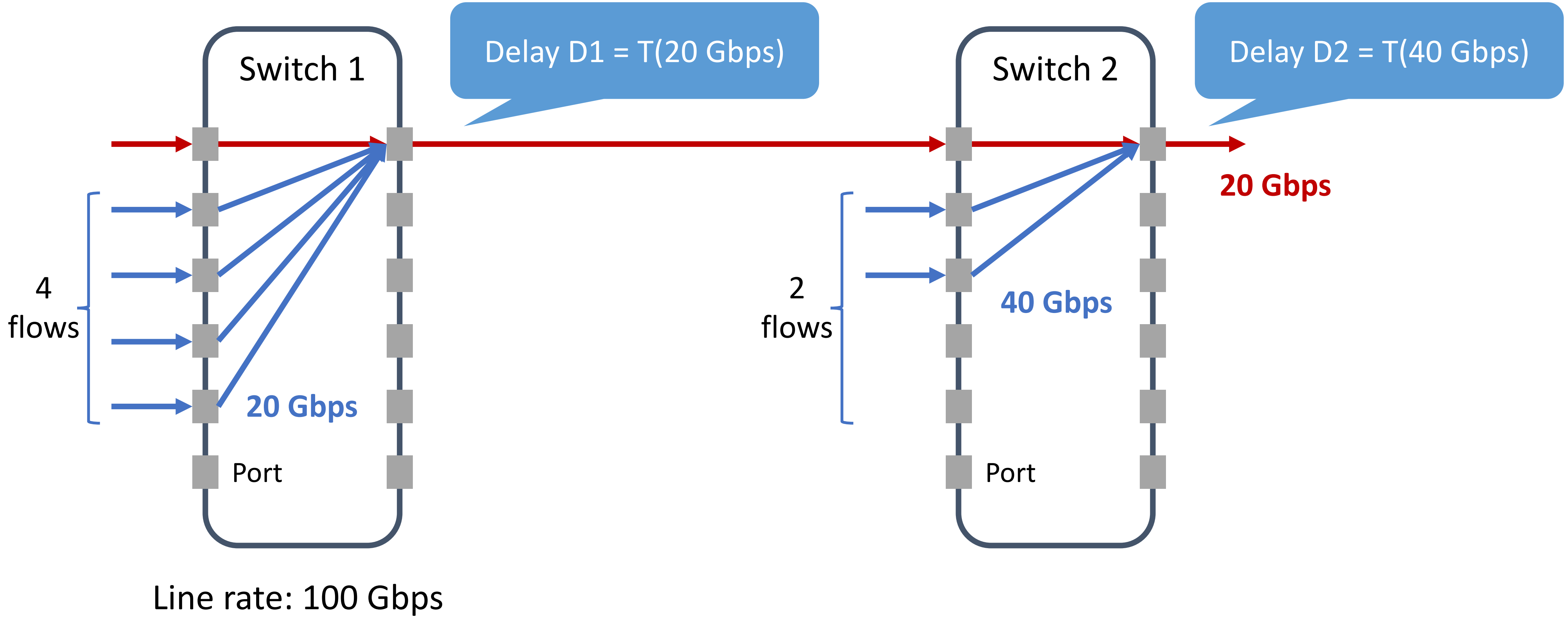
Convergence to Max-min Fairness in a Network



Red flow's MPD = max(D1, D2) = D1

The bottleneck always has the largest delay. We proved this leads to max-min fairness.

Implementation

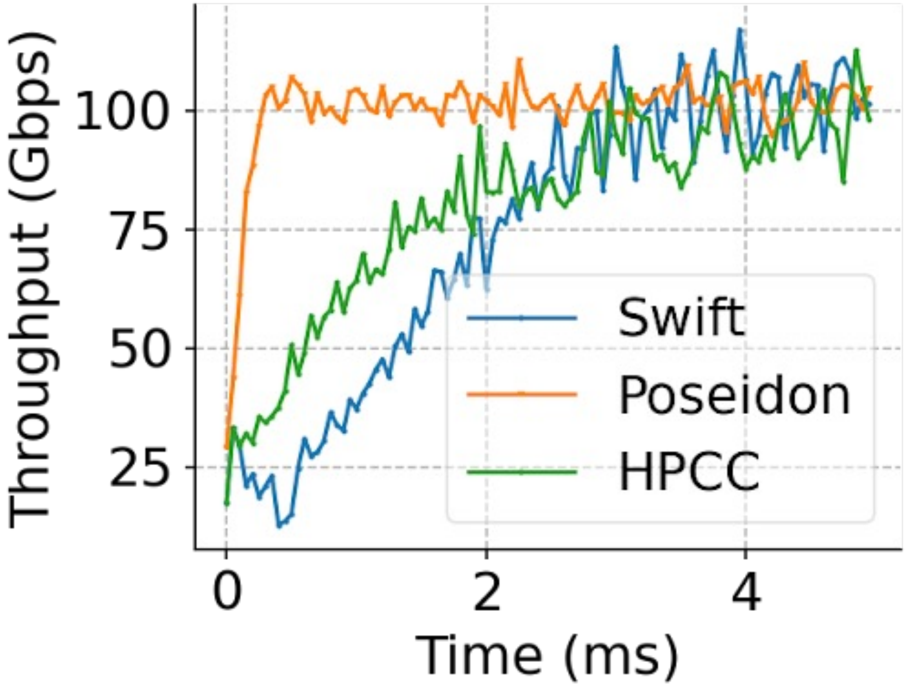
- Testbed
  - Implementation
    - **2 lines** of core P4 code to **obtain INT signal**
    - Small changes to Swift algorithm in **Pony Express**
  - Topology
    - 2 hosts (virtualized into 16 hosts) + 2 Tofino-2 switches

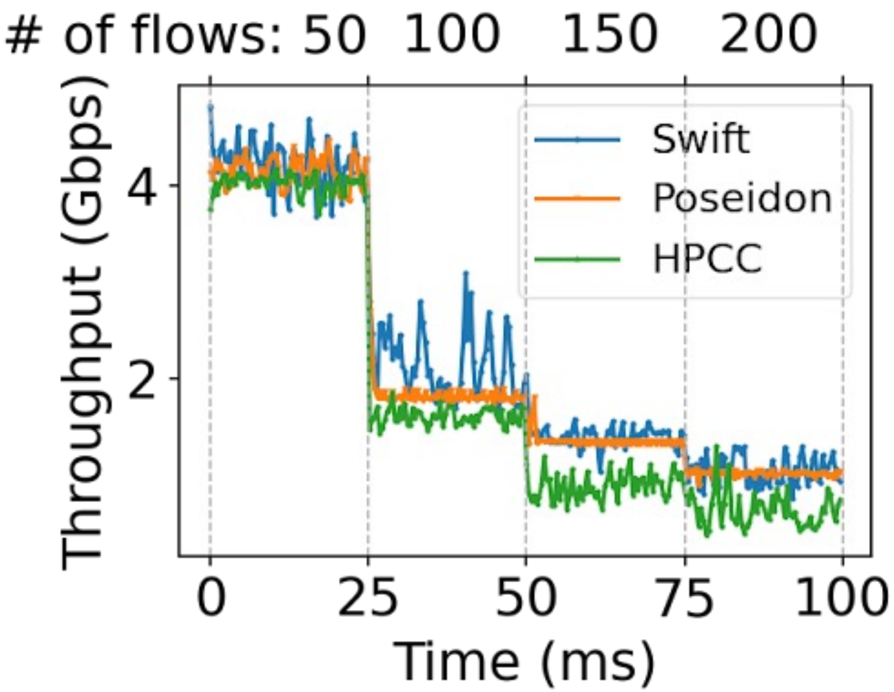
- Simulator
  - Customized OMNeT++ packet simulator
  - Topology
    - Clos network with 64 racks

Evaluation Summary

- **Efficiency**
  - **12x** faster convergence
  - **24x** more stable throughput
  - **3x** lower RTT
  - **Full** utilization
  - **1.78x** faster median and **27x** faster tail op latency (FCT)
- **Robustness - max-min fairness**
  - Max-min fair in **multi-hop** congestion
  - Max-min fair in **reverse-path** congestion
- **Practical**
  - Implementation on production networking stack with no NIC changes
  - **Incremental gain** for incremental deployment
  - Bounded unfairness during partial deployment

Fast Convergence and Stable Throughput

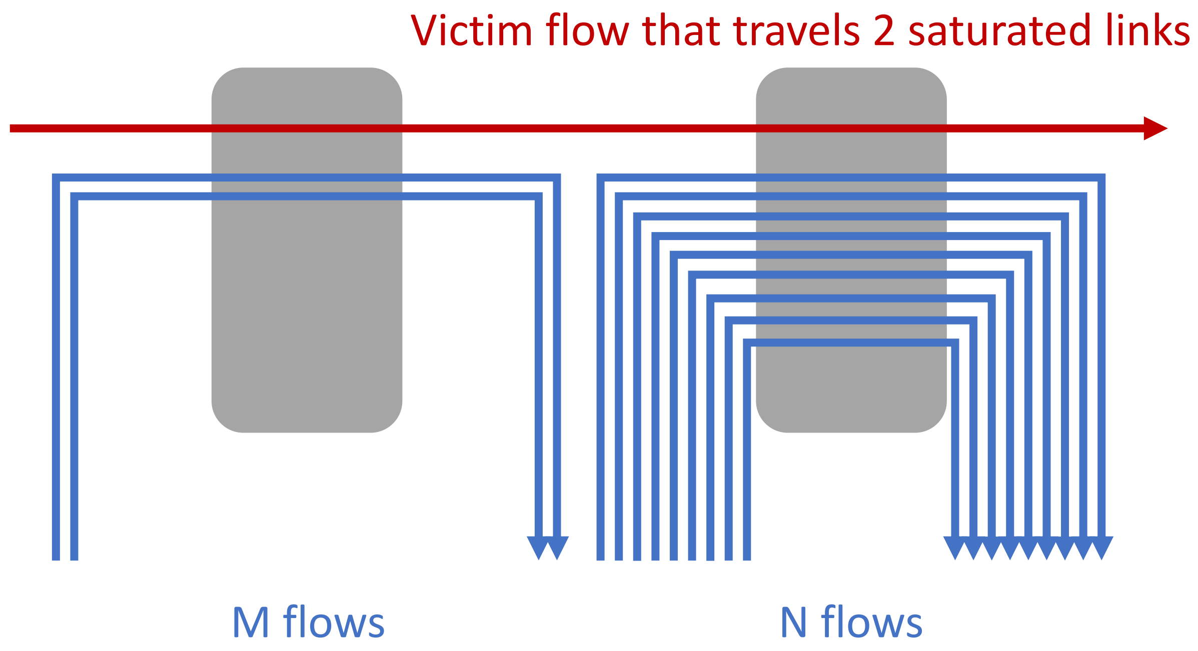


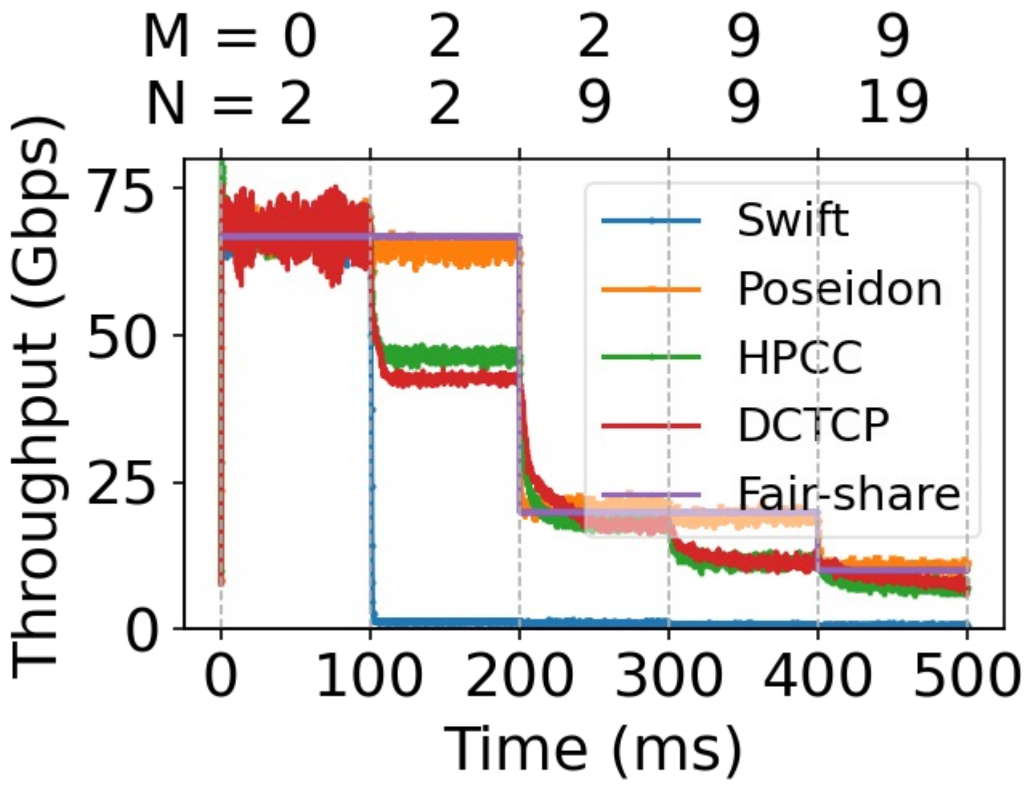


12x Faster Convergence
Faster multiplicative increase.
Ramp-up without any decrease.

24x More Stable Throughput
Do not need additive increase.
Update U() = 1.0 after converge.

Poseidon Achieves Max-min Fairness





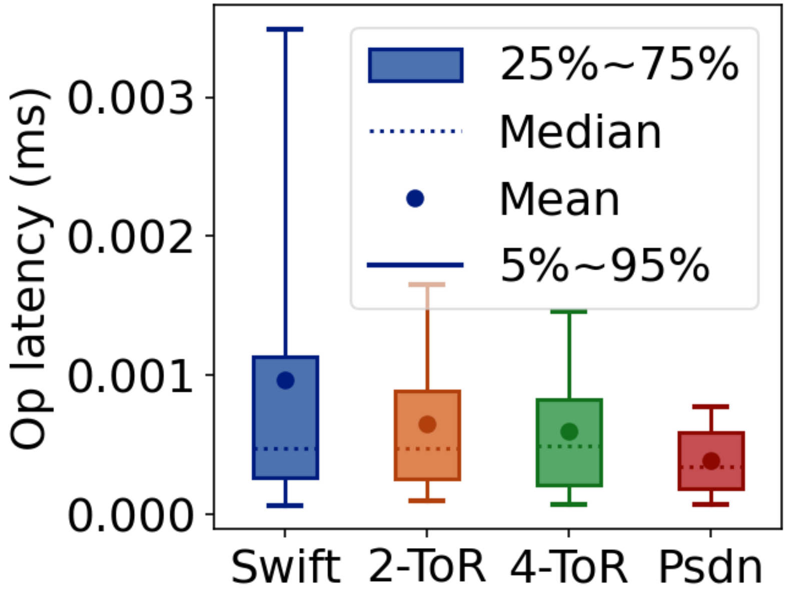
Line rate: 200 Gbps

Poseidon achieves max-min fair rate for all flows, including the victim flow.

Performance Gain for Incremental Deployment

4 racks send traffic to each other

- Swift: baseline with Swift CC
- 2-ToR Poseidon: 2 ToR switches support INT
- 4-ToR Poseidon: 4 ToR switches support INT
- Poseidon: all switches support INT



Performance improves as more switches support INT feature.

Conclusion

- Poseidon algorithm uses quantitative per-hop INT:
  - **Decouples fairness from AIMD**
    - Gives a cluster of functions that can achieve fairness
    - Picks adaptive MIMD algorithm for outstanding performance
  - **Achieves max-min fairness**
    - Multi-hop congestion & reverse-path congestion
  - **Supports incremental deployment**
    - Performance improves when only ToR switches provide INT
- Poseidon is now open-sourced in ns-3 (developed based on the paper)
  - https://github.com/Clark5/Poseidon