White-Boxing RDMA with Packet-Granular Software Control

Frank Chenxingyu Zhao[1], Jaehong Min[1], Ming Liu[2], Arvind Krishnamurthy[1]

University of Washington[1]
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RDMA Transport Innovations are in Full Swing

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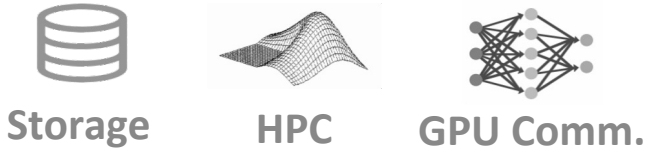
Driven by Workloads



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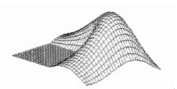

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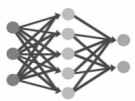

GPU Comm.

Driven by Deployments

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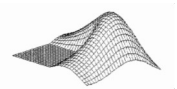
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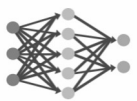
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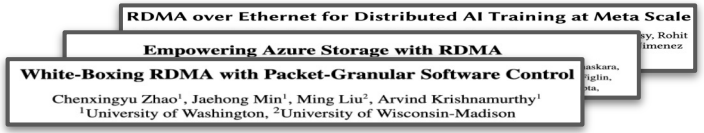
Driven by Deployments

Numerous Ideas


RDMA over Ethernet for Distributed AI Training at Meta Scale

Empowering Azure Storage with RDMA

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Past 5 years, 30+ NSDI/SIGCOMM papers explore RDMA innovations.

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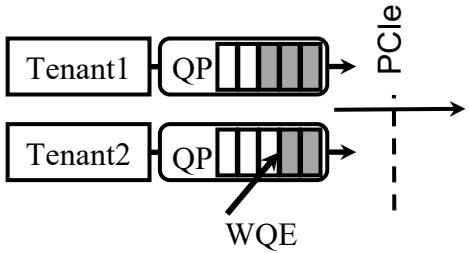

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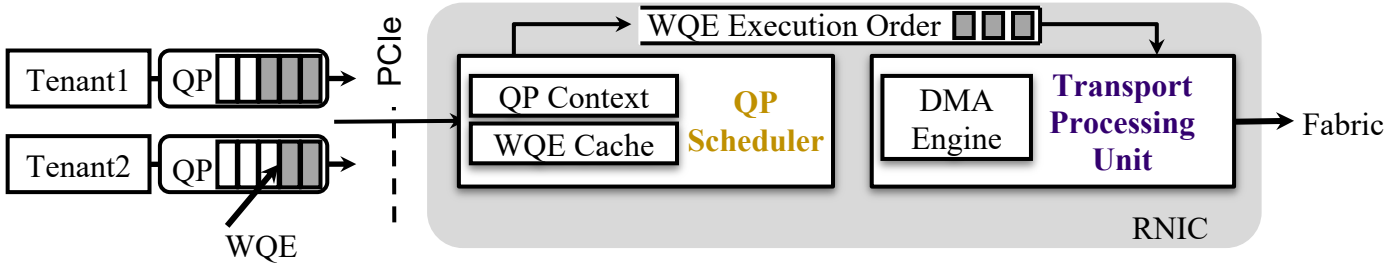

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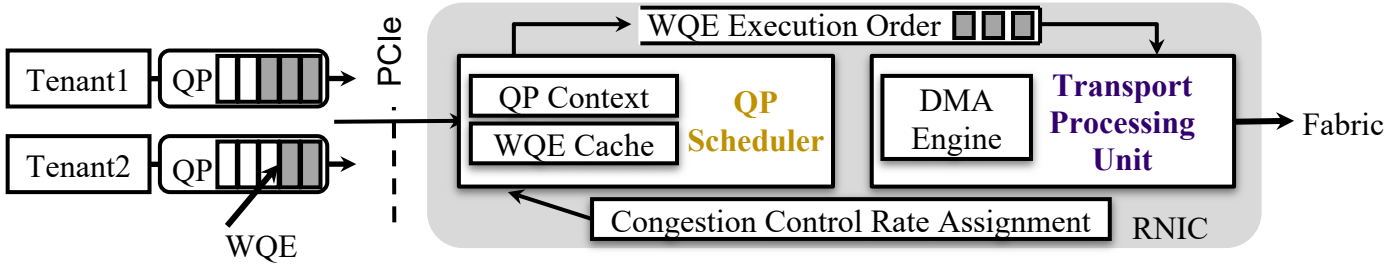

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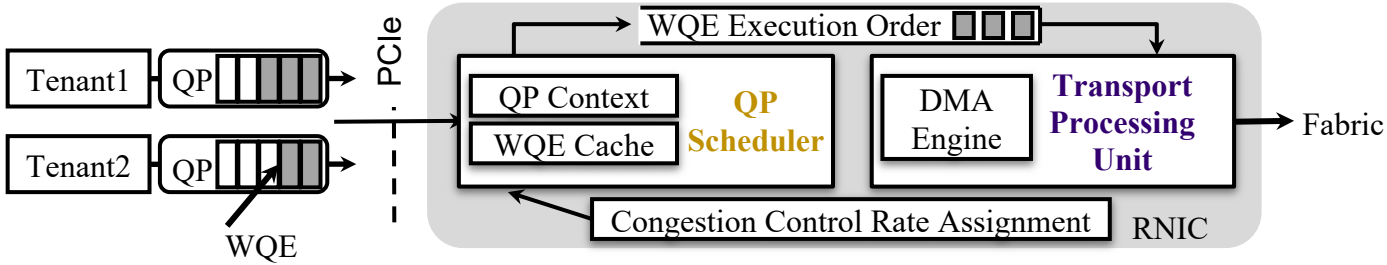

FPGA

High Dev. Cost

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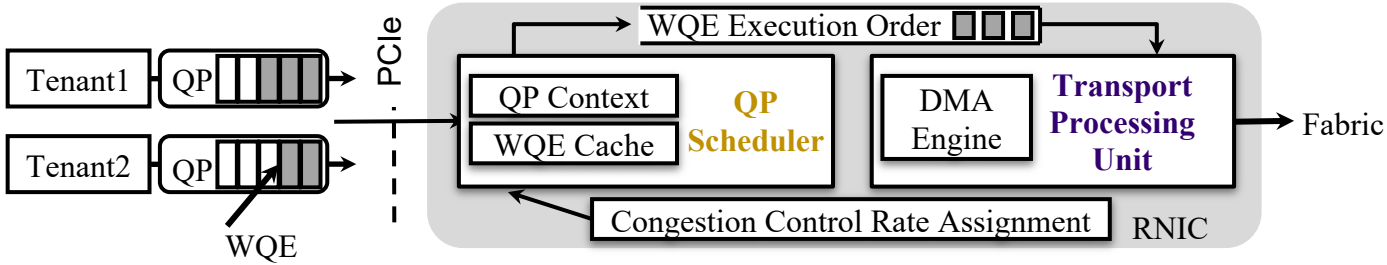

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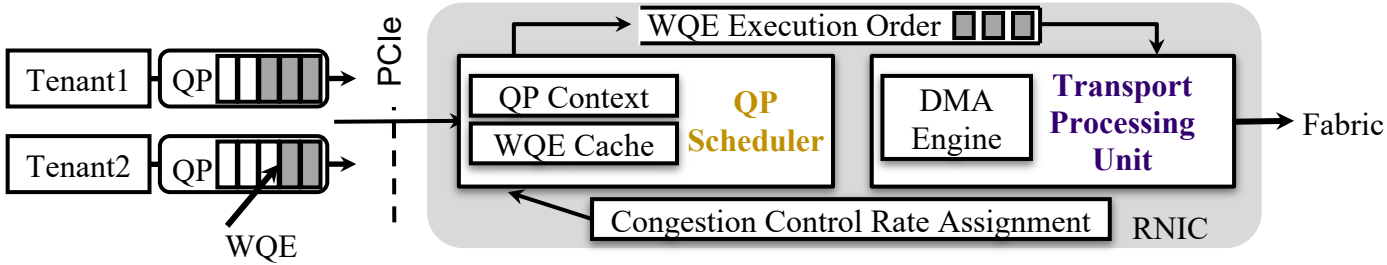

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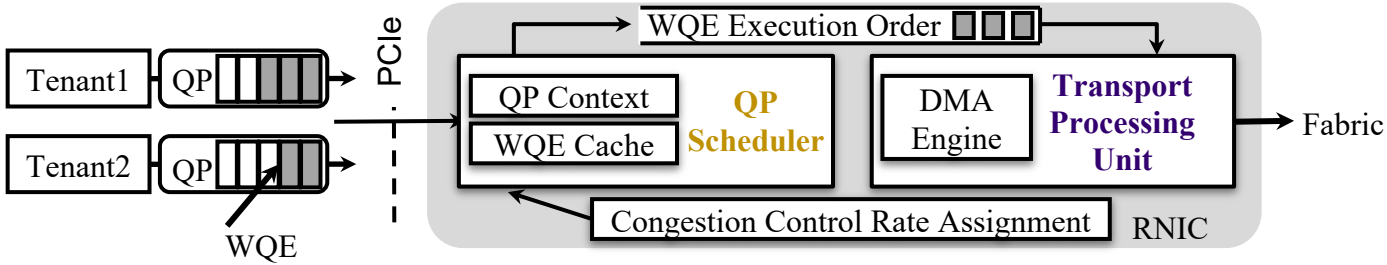

FPGA	**ASIC**	**SW Emulate**	**Whiteboxing**
High Dev. Cost	Wait for Years	Perf. Loss	SW Ctrl HW Data

- **Whiteboxing**: Inspired by SDN, control in software, data path in hardware

New RNICs with Lightweight Programmability

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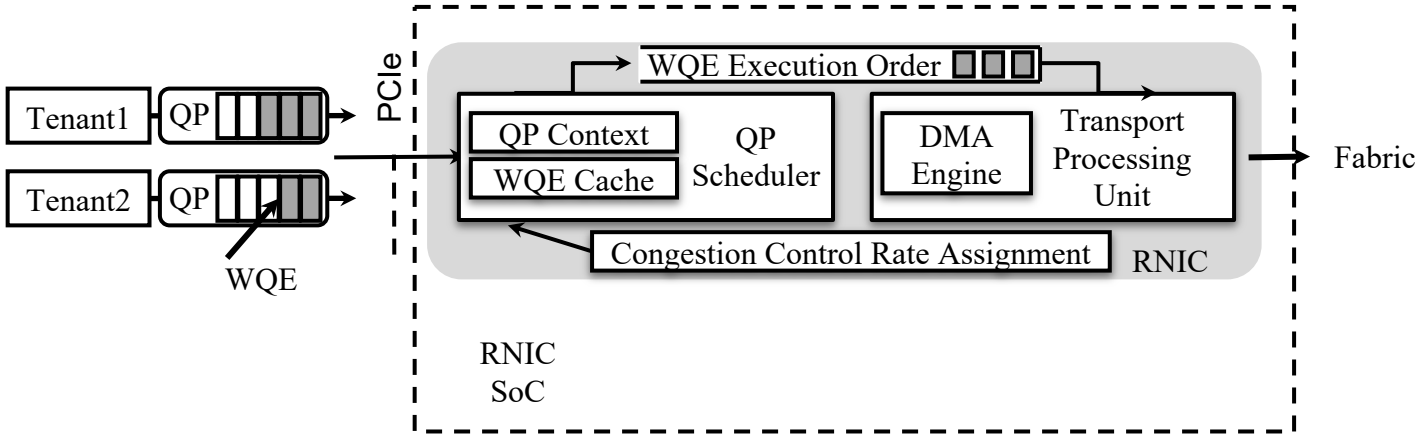

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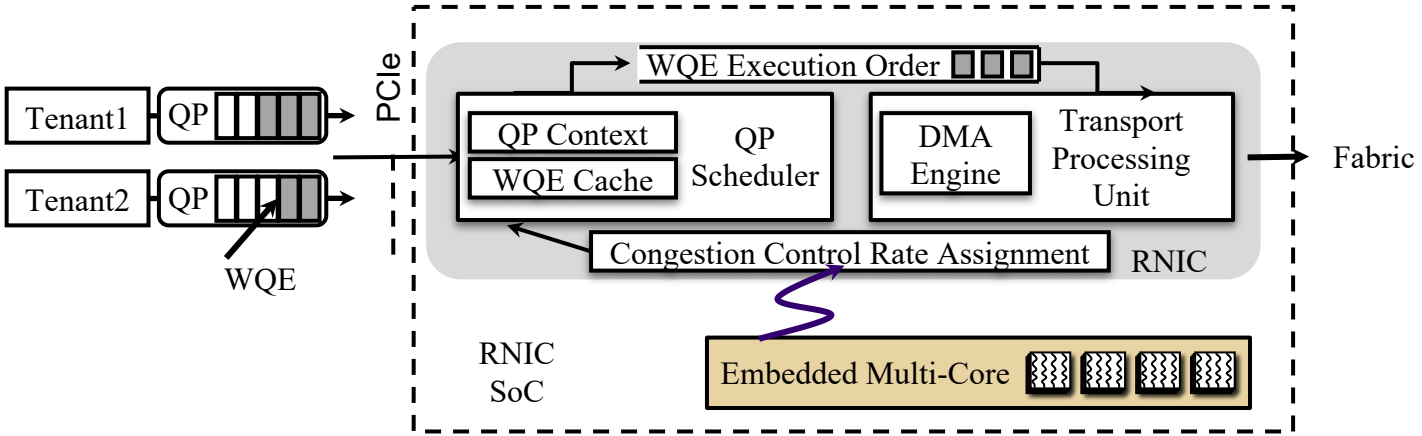

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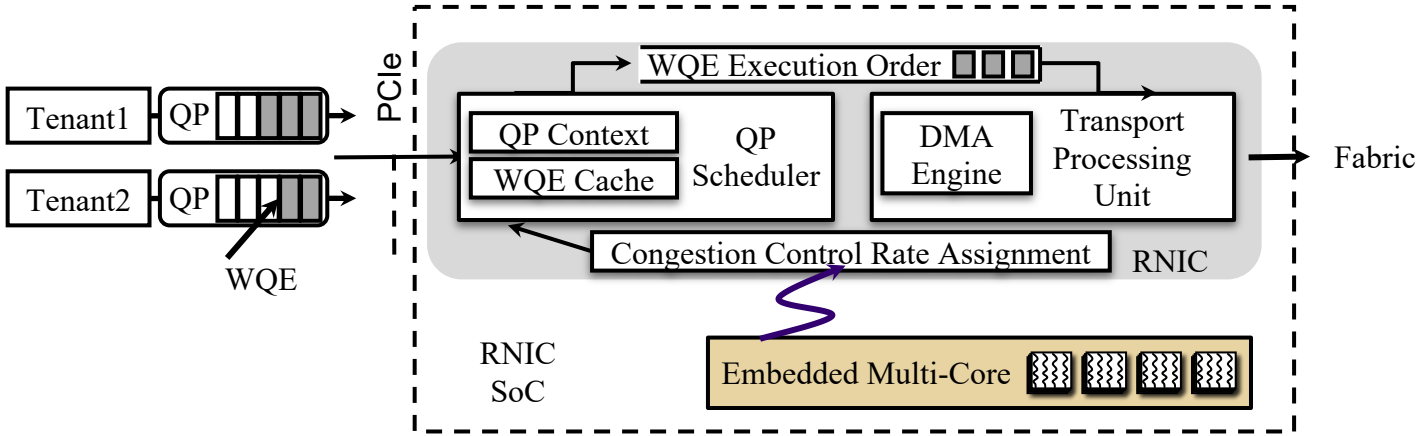

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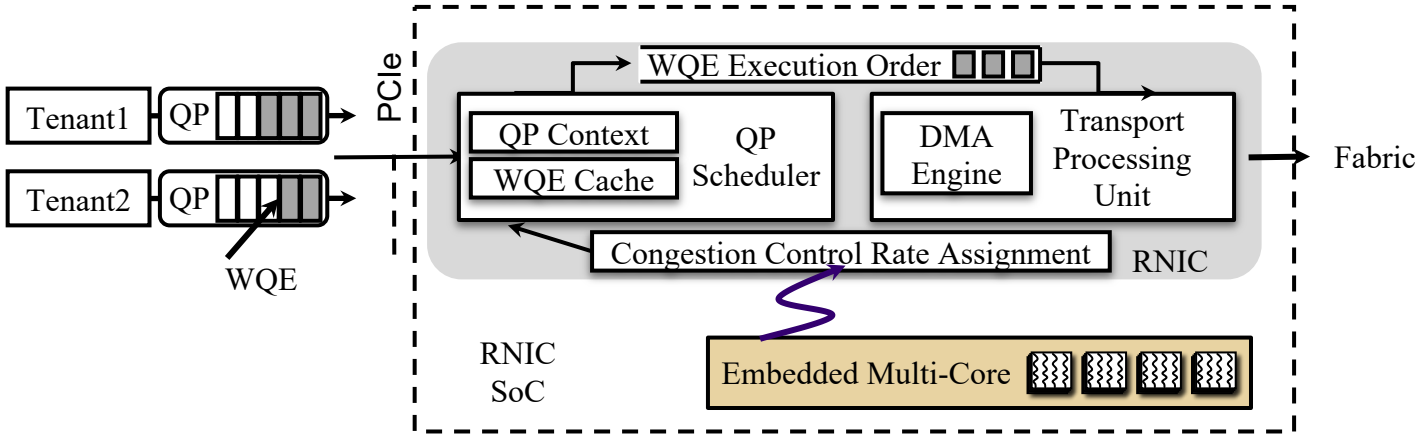

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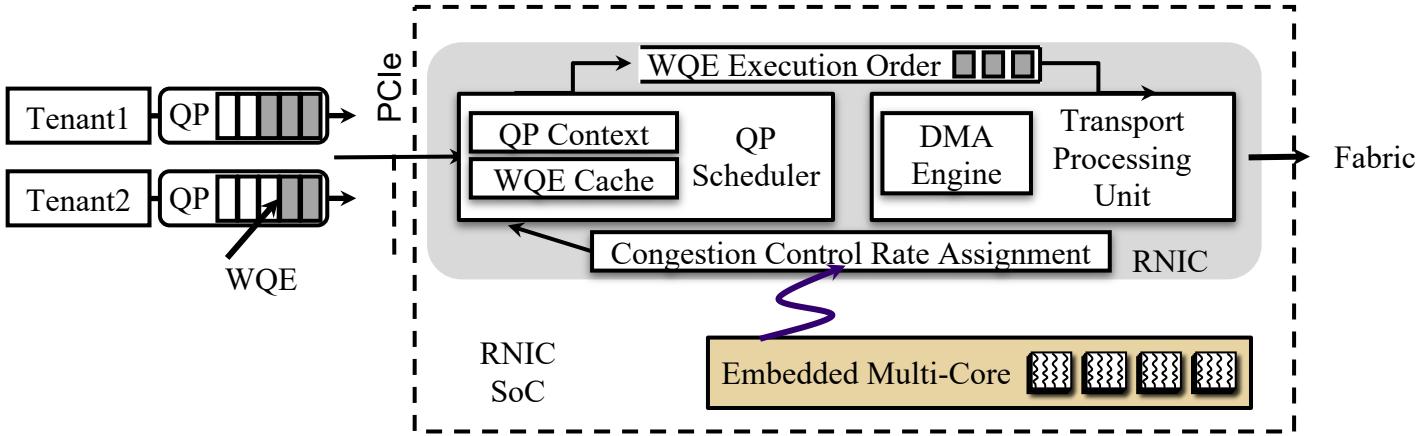

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General Computation	Rate Control Interface

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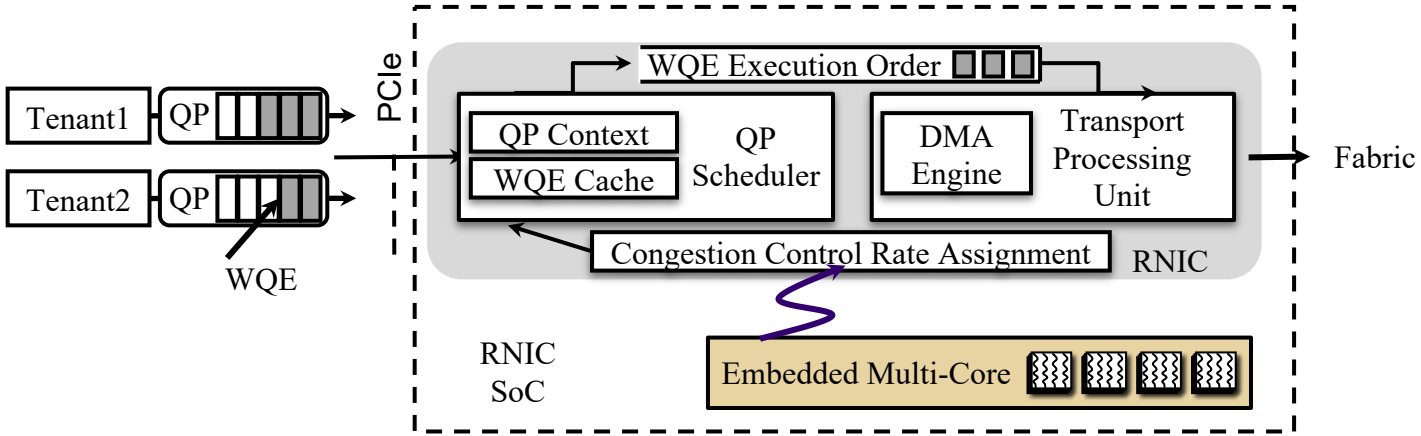

- Building blocks from embedded cores:

General Computation	Rate Control Interface	Congestion Events (e.g, ECN)

Challenges to Realize Whiteboxing RDMA

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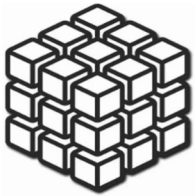

Granularity

Packet-Granular Events from High Line Rates

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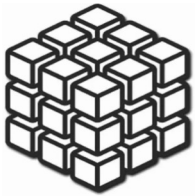

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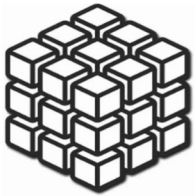

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- Next, we introduce **Software Controlled RDMA (SCR)** to achieve all.

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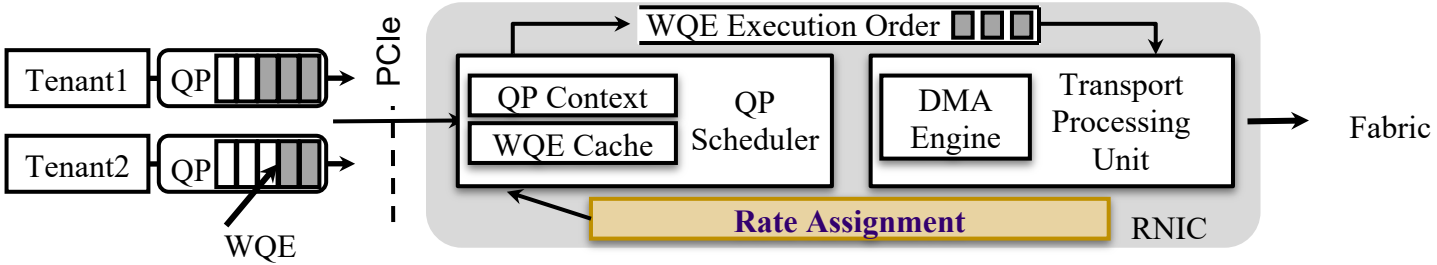

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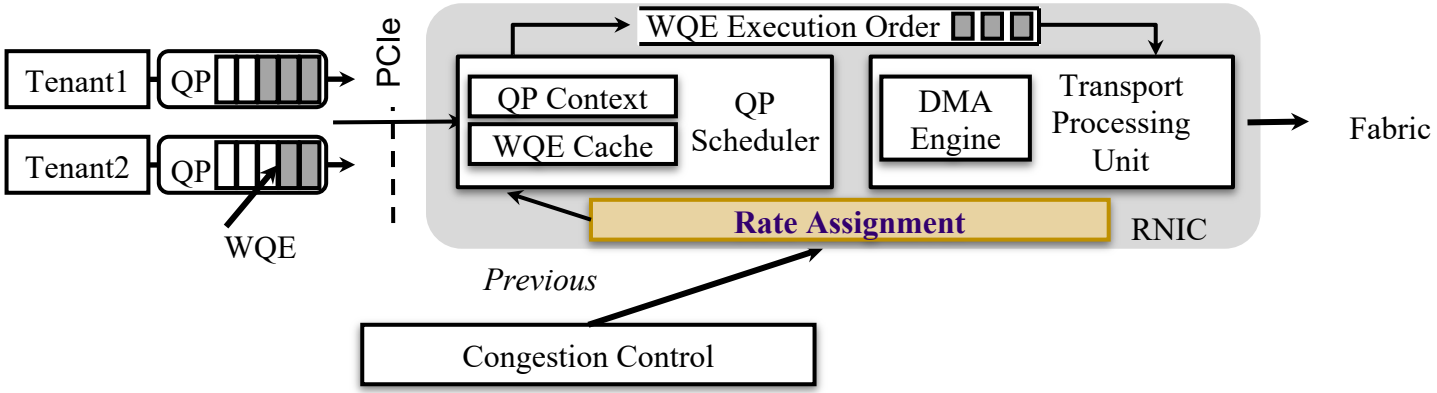

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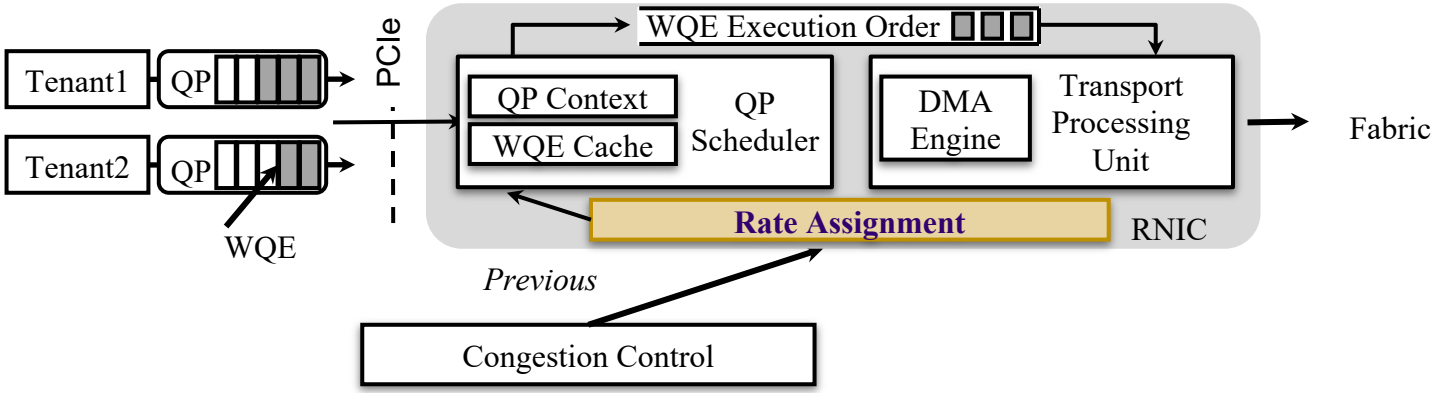

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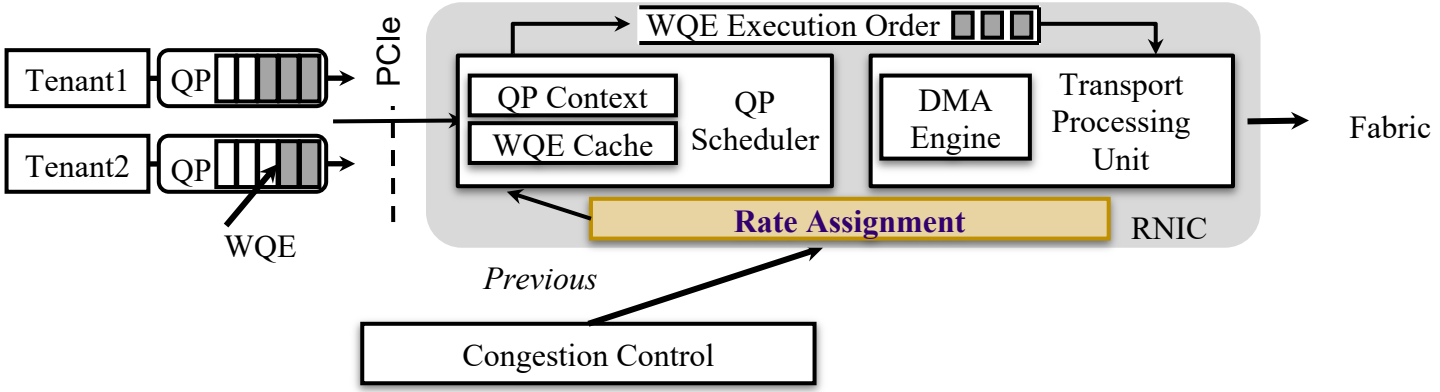

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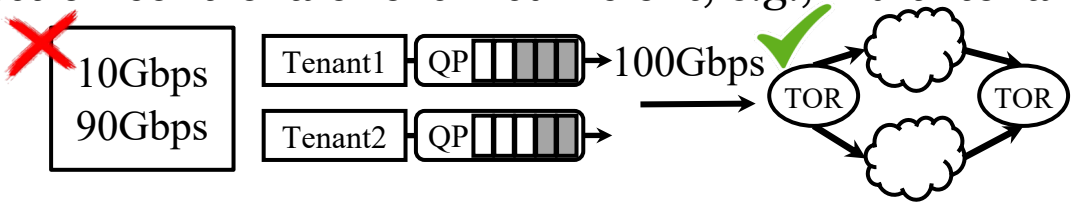

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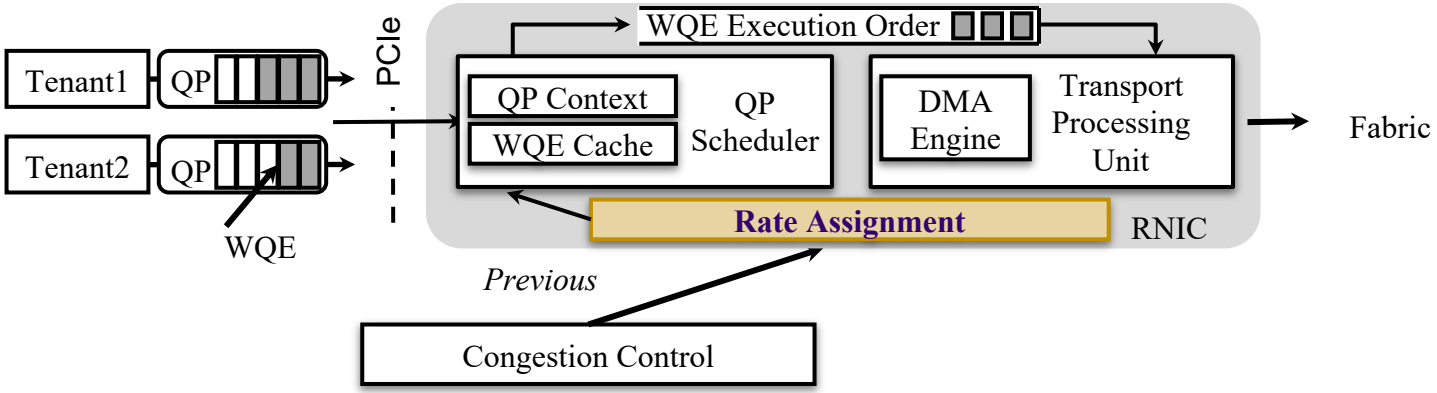

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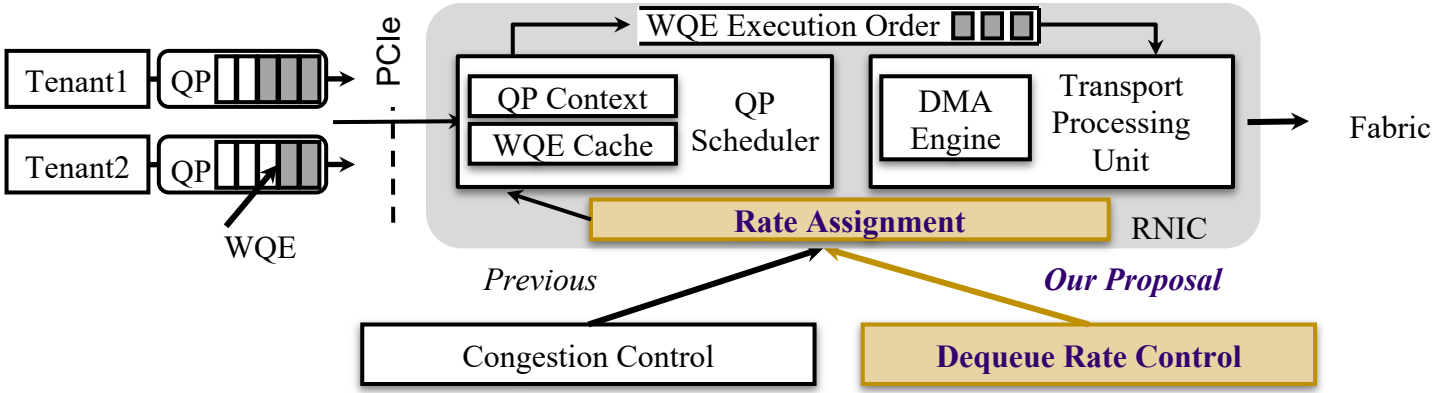

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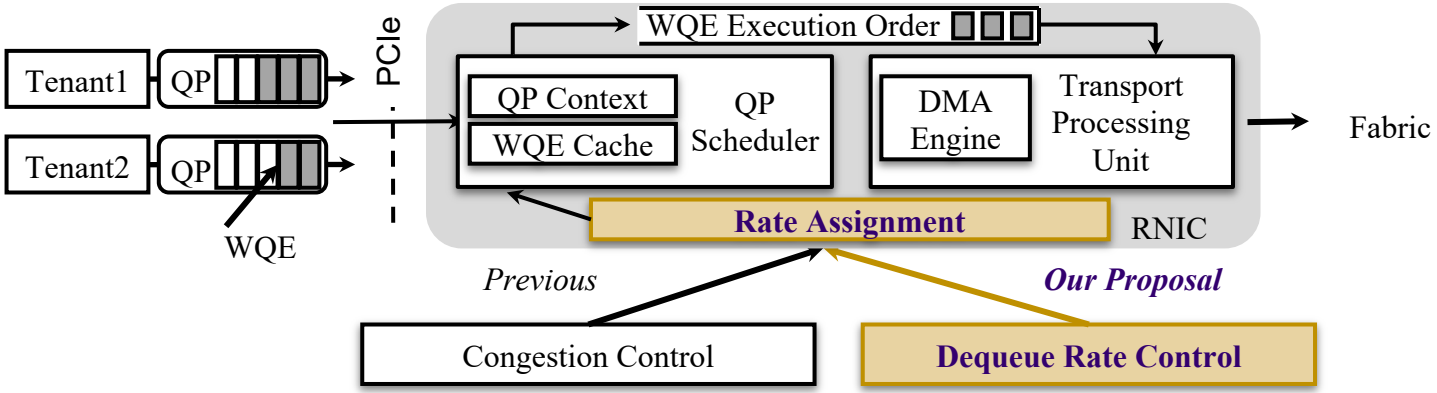

- Rate at which the RNIC retrieves messages from memory regions

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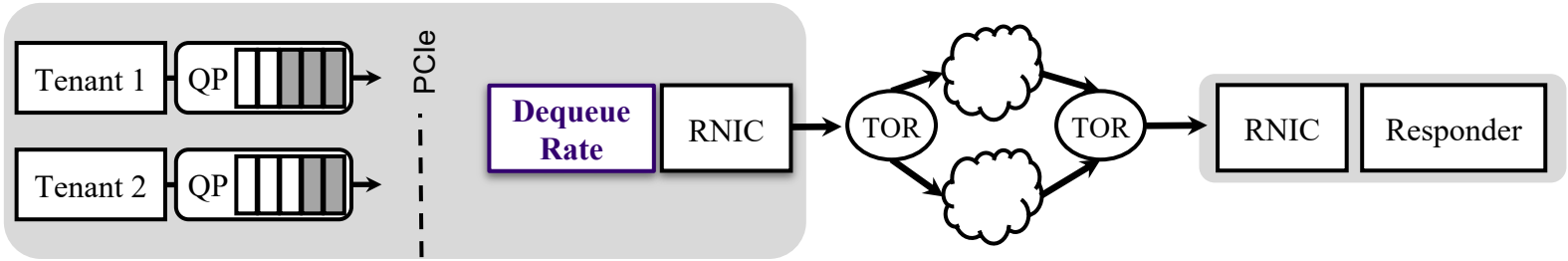

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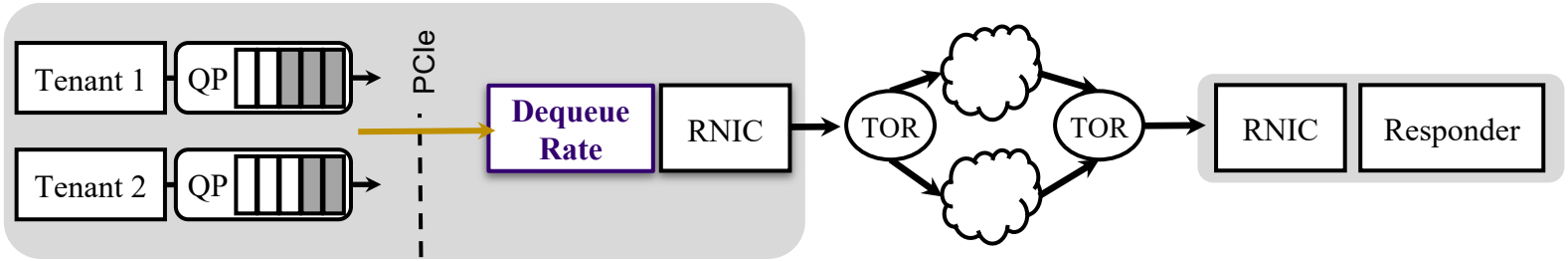

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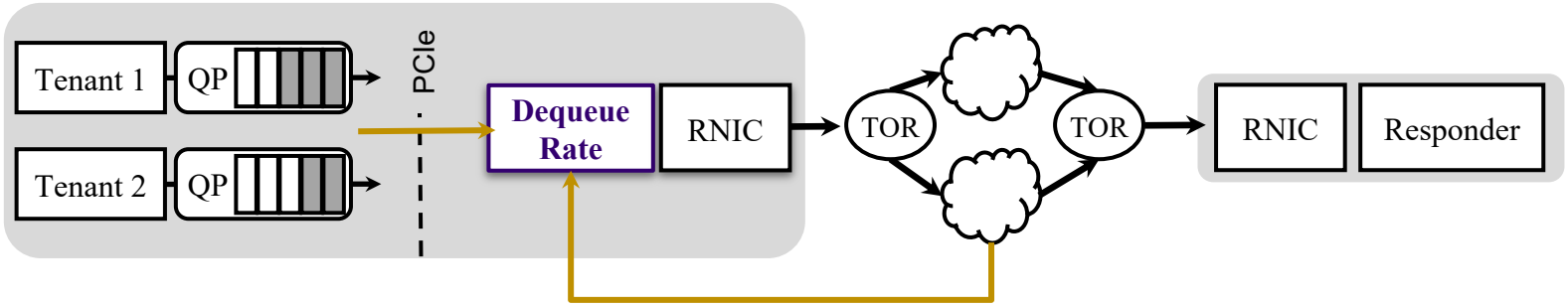

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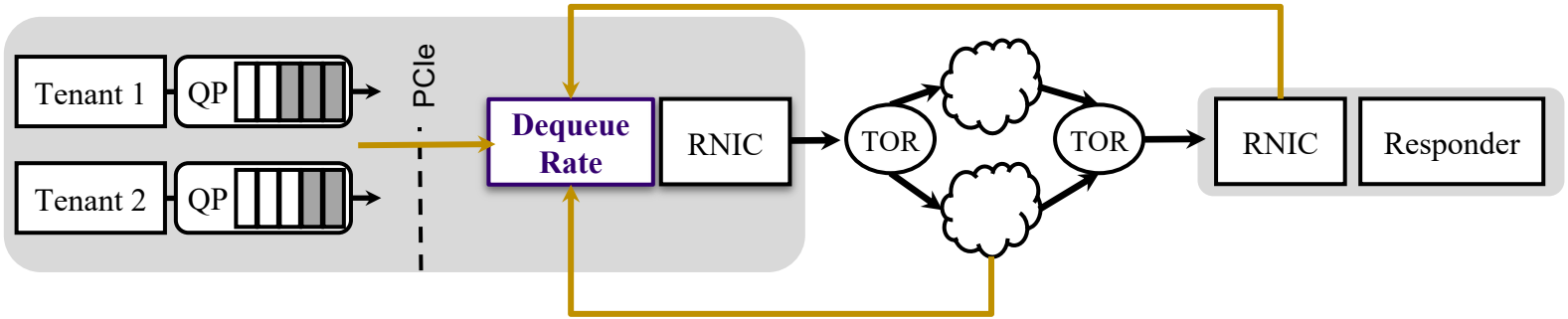

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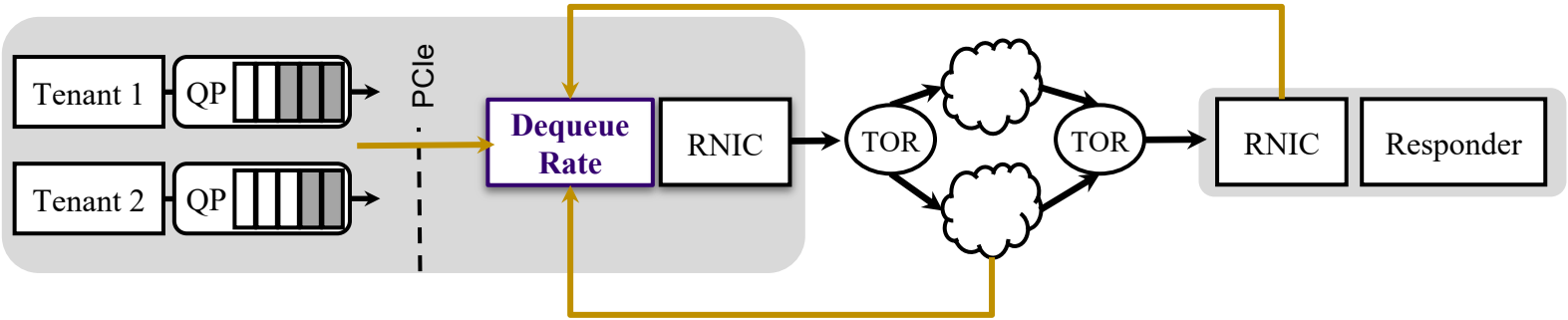

- See paper for multi-domain events and the collection process.

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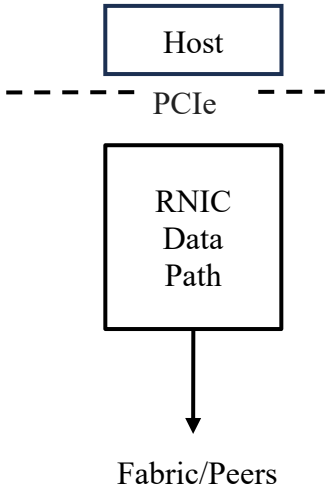

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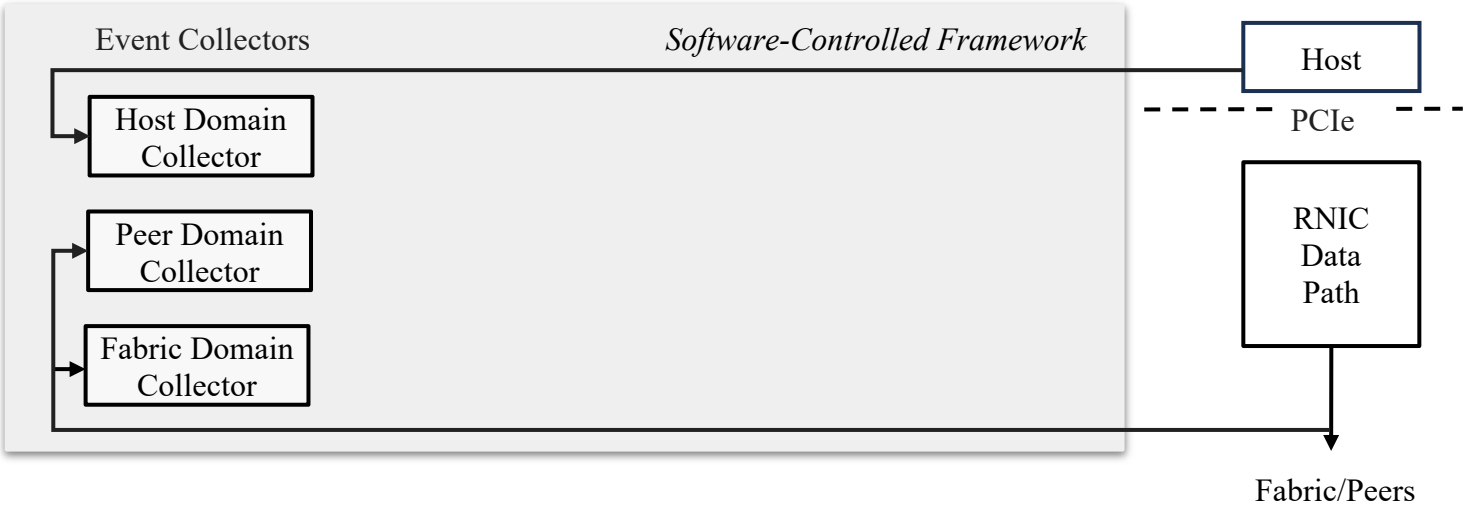

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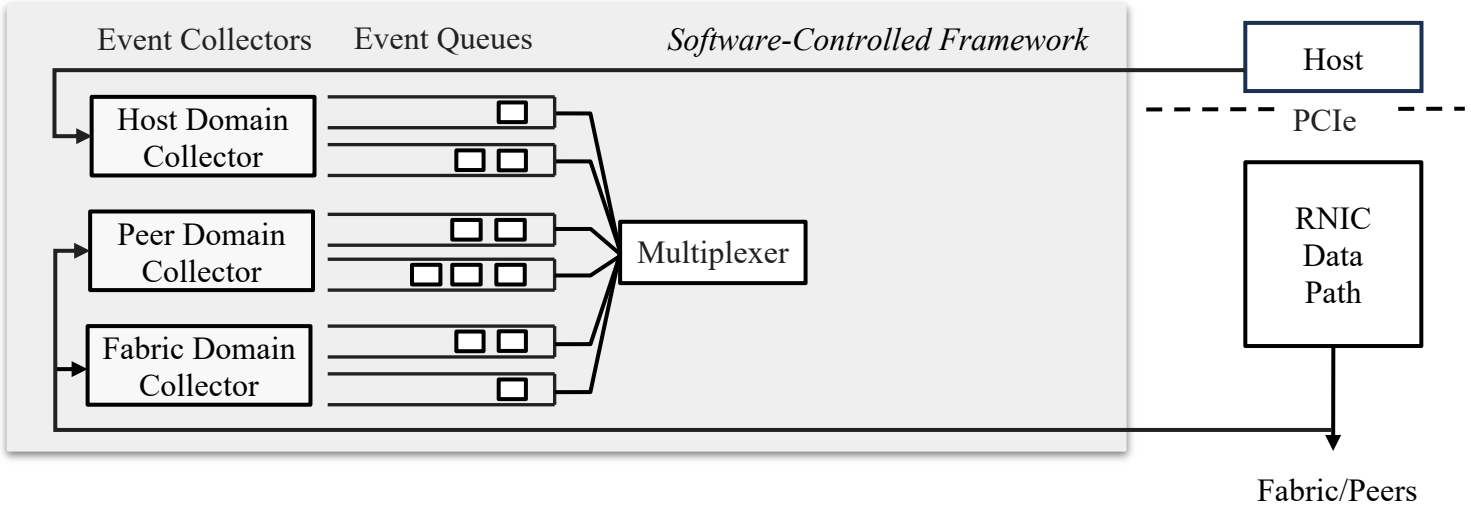

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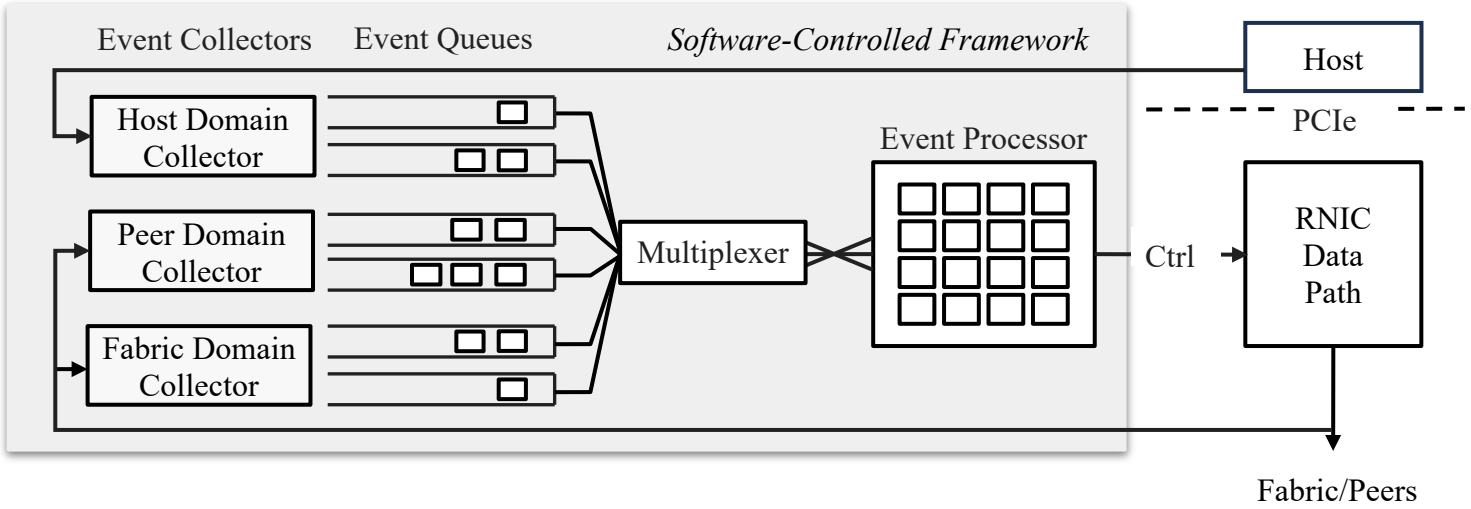

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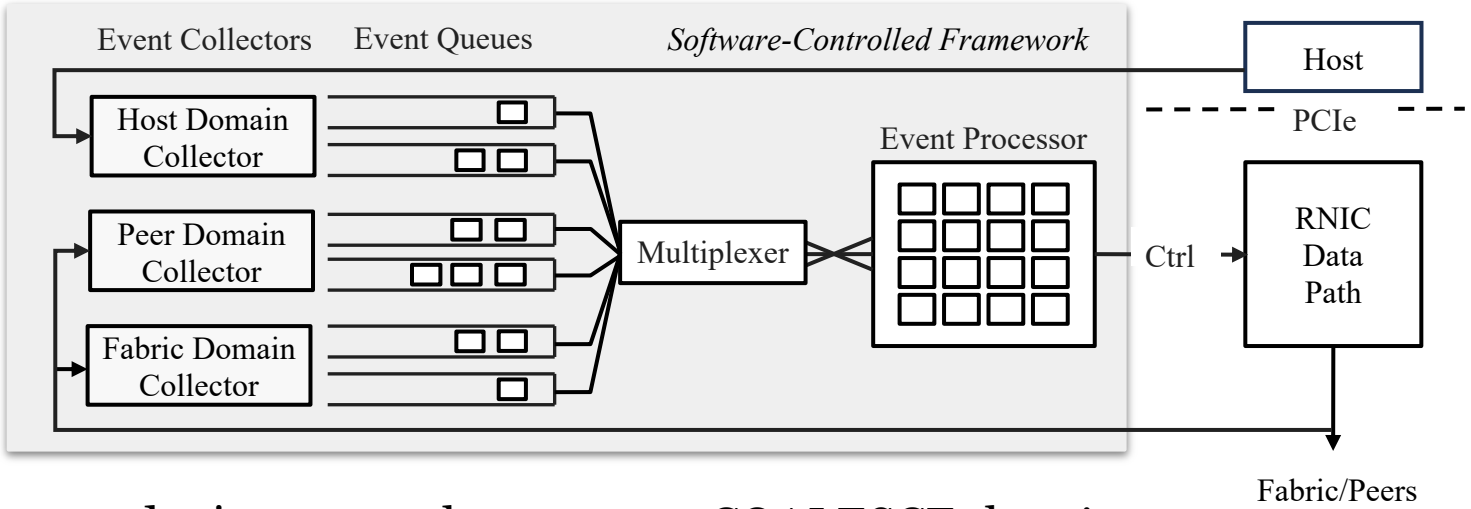

- Queues don't matter when you can COALESCE them!

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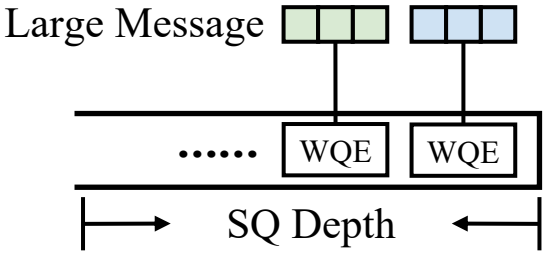

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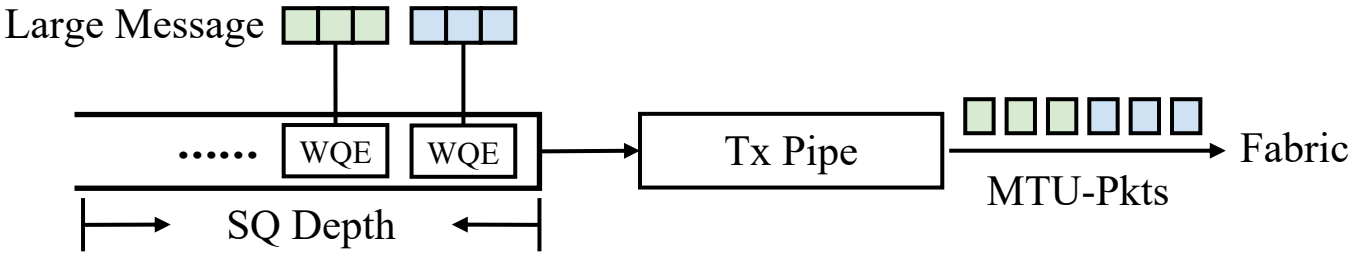

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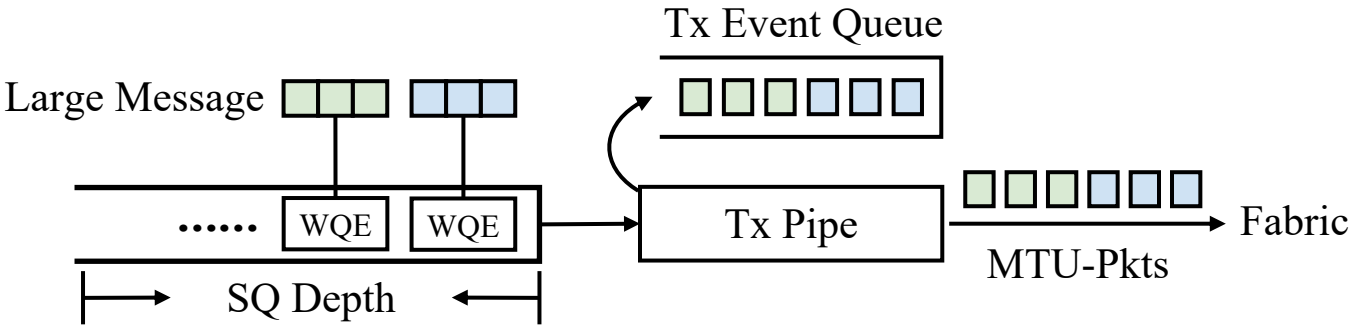

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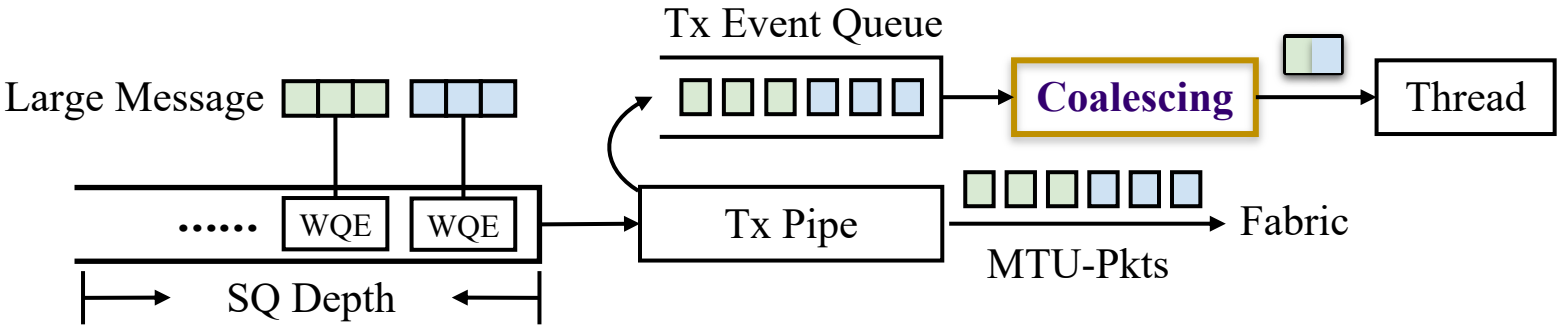

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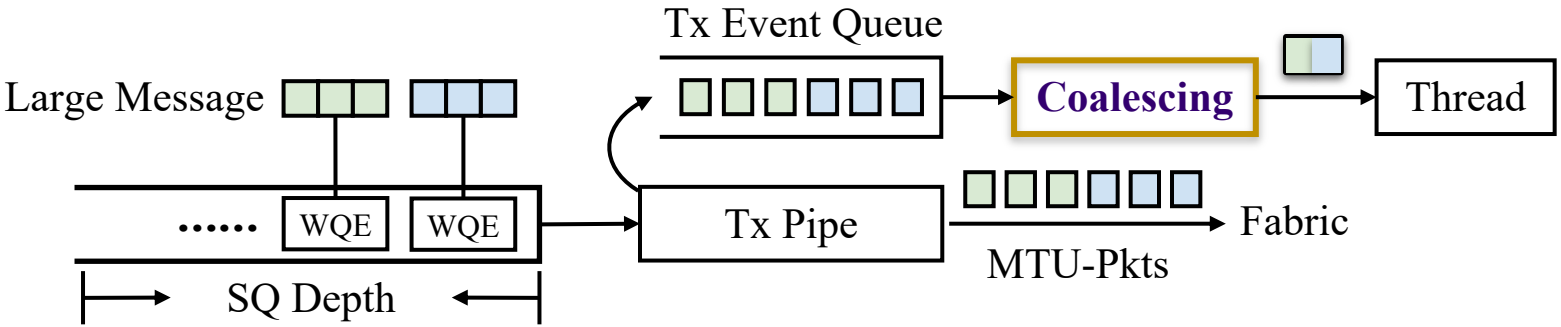

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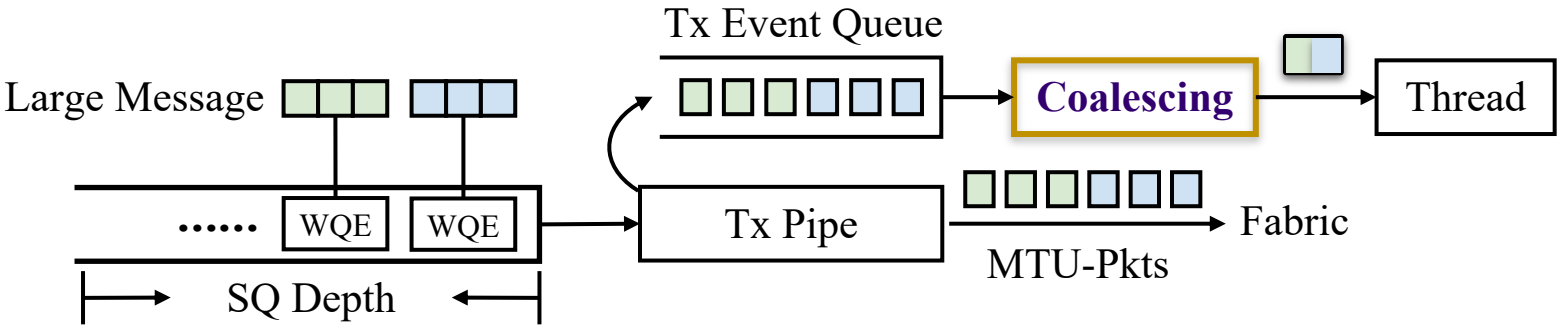

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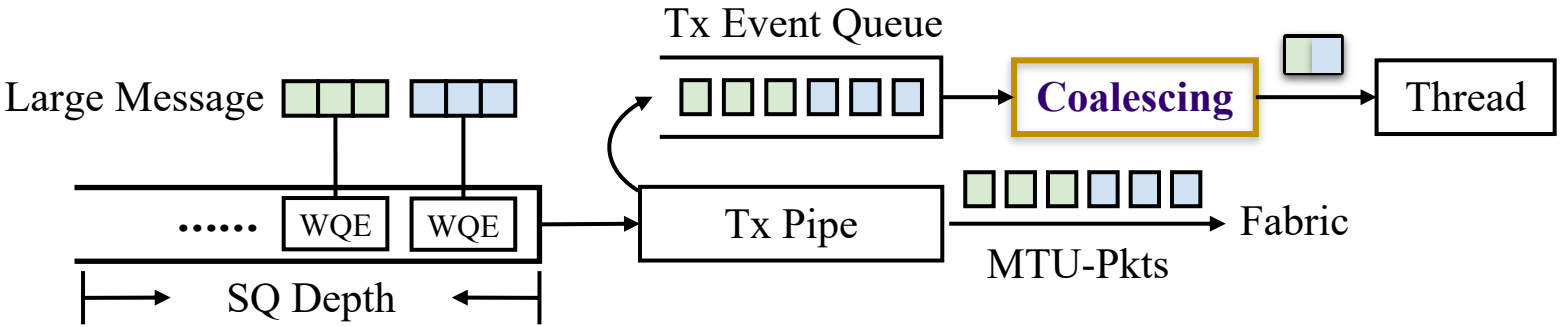

- HW/SW Hybrid Coalescing:
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  - SW coalescing is programmable:
    - E.g., keep latest RTT, drop others.

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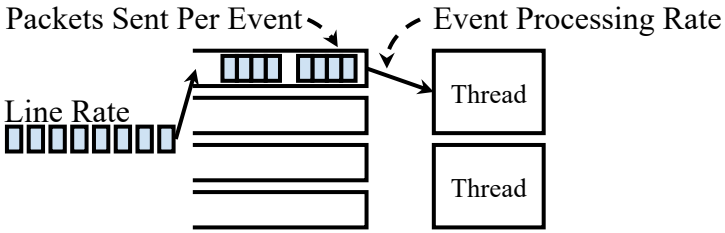

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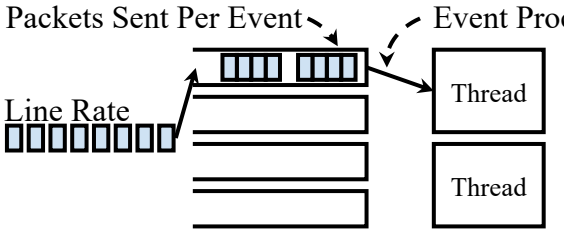

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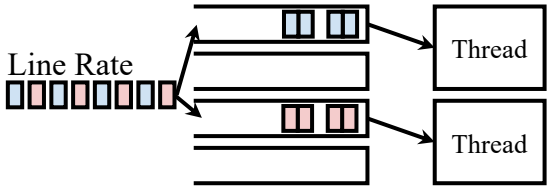

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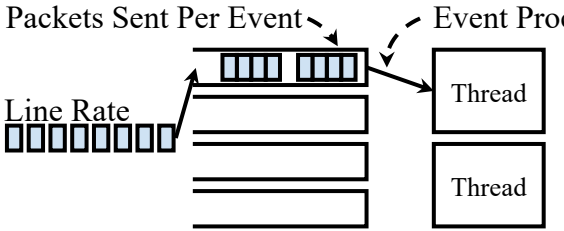

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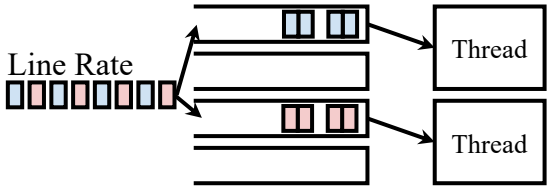

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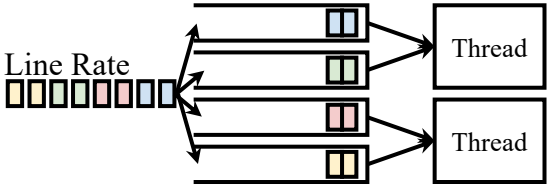

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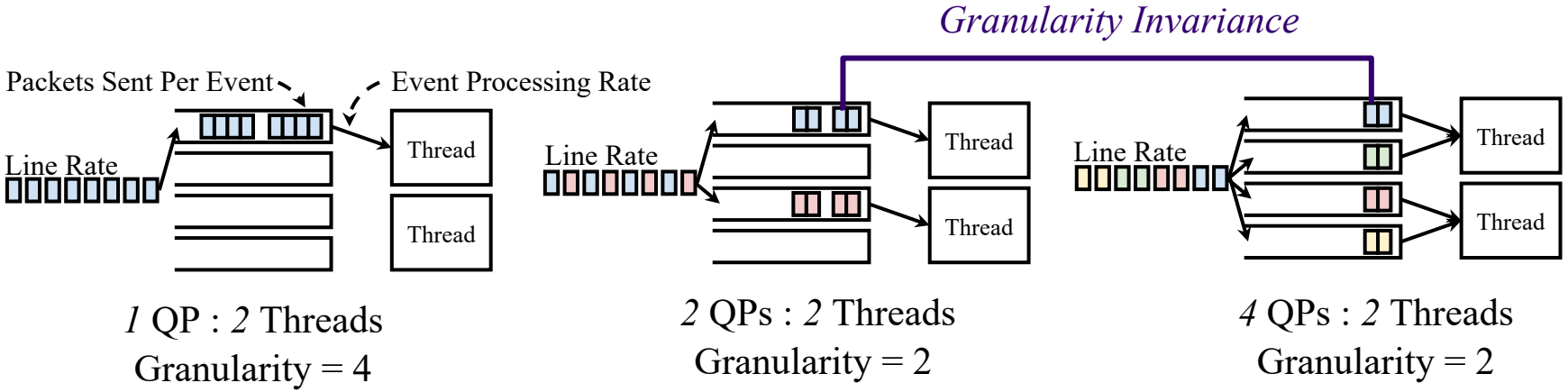

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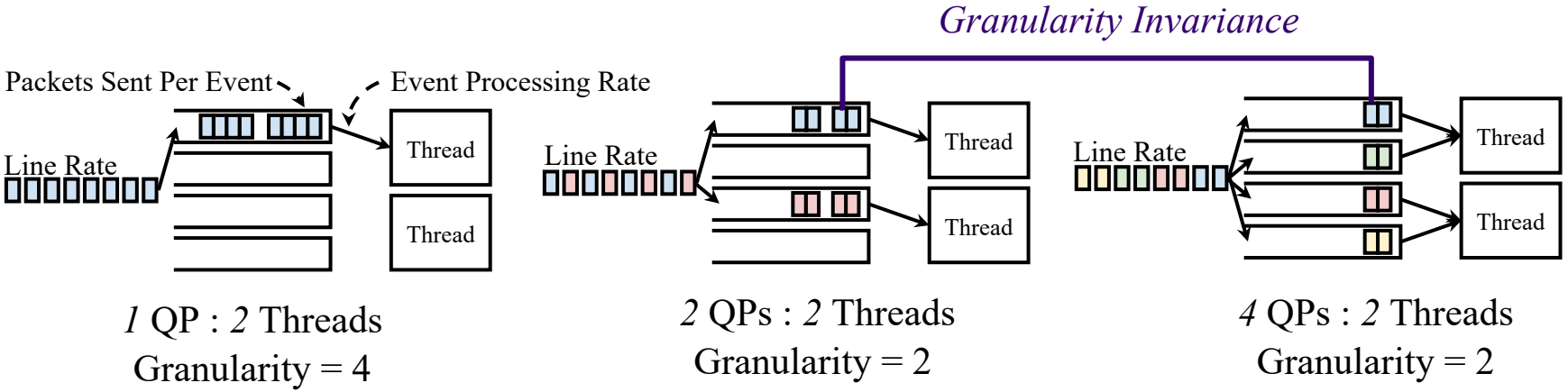

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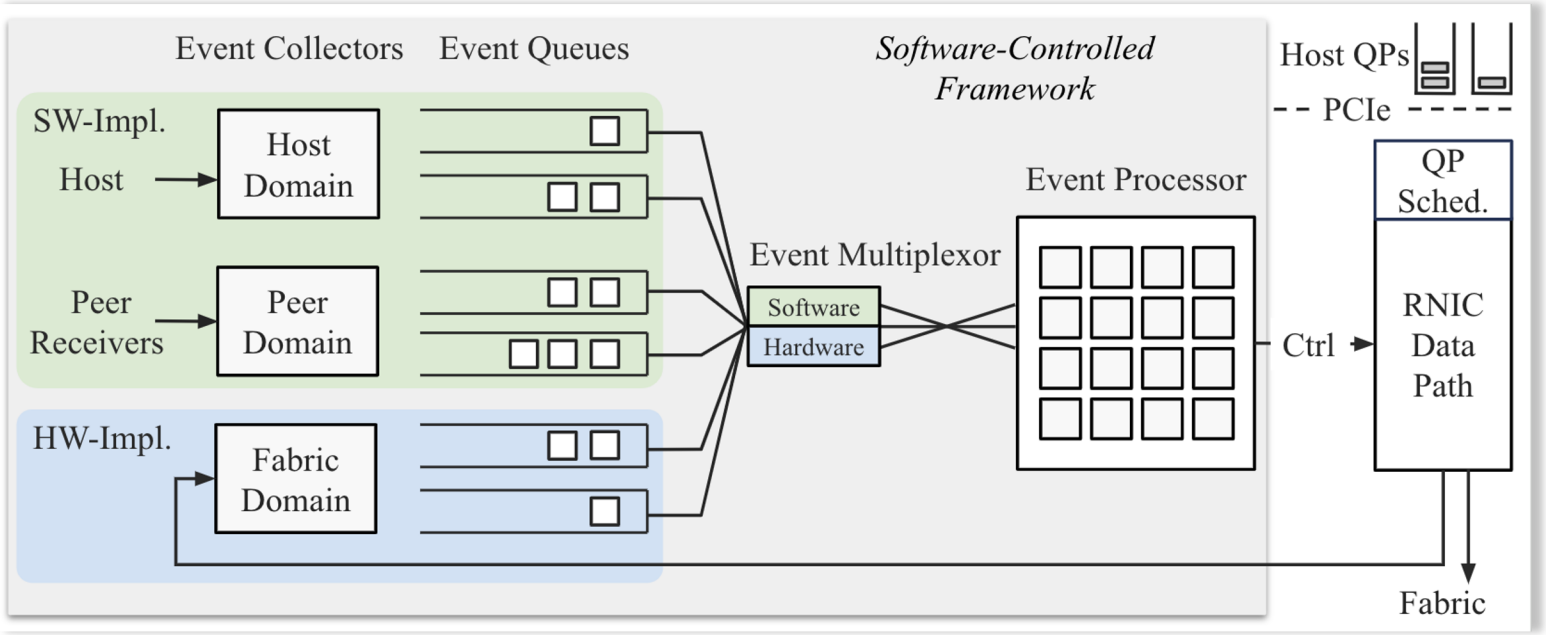
  - Principle: Line rate is invariant—catch up, done!

Addressing Challenges, SCR Framework



Implementation: SCR on BlueField-3 DPA

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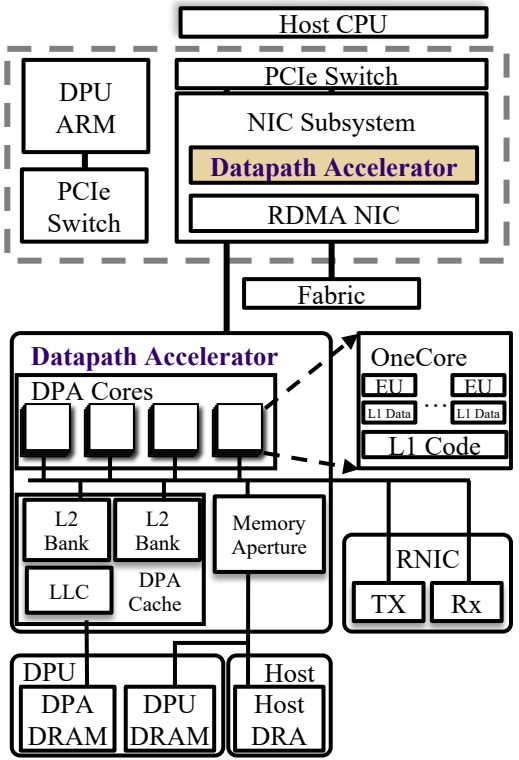

[Figures are from NVIDIA Public Information]

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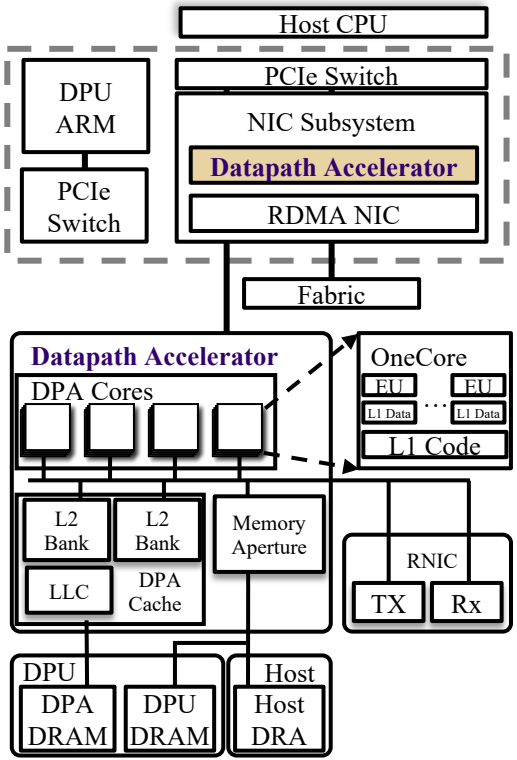

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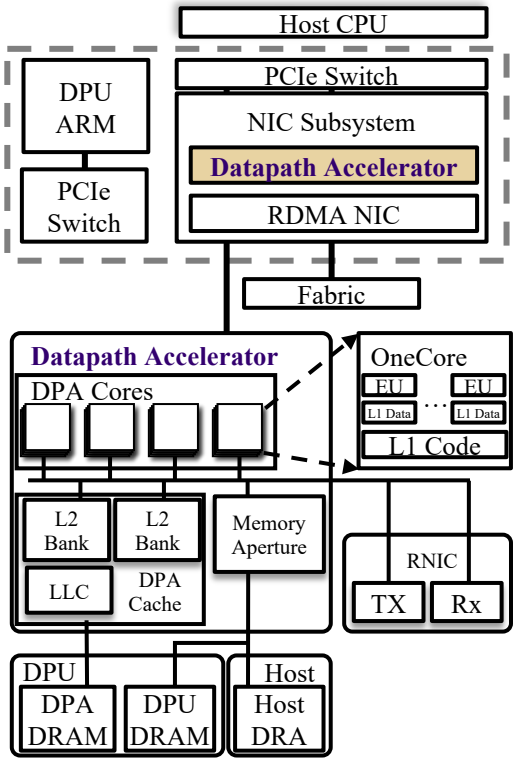

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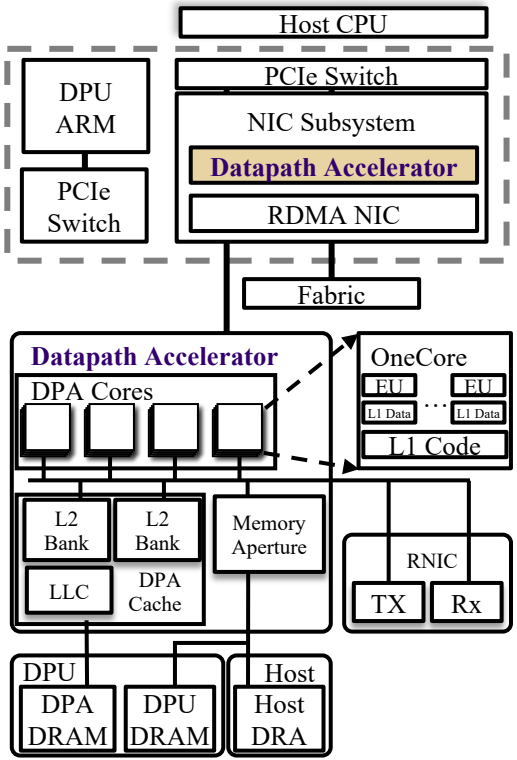
- See paper for detailed characterization on new hardware!



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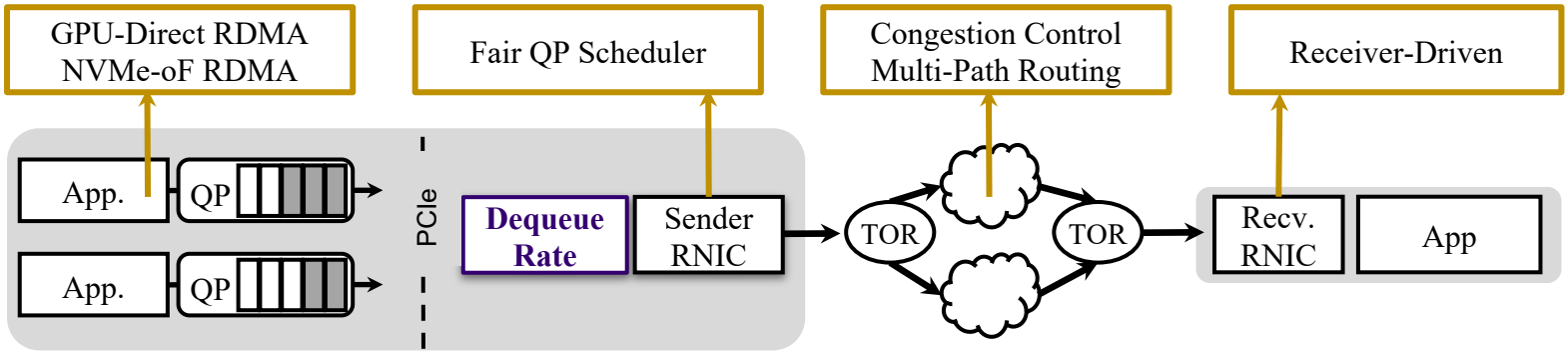

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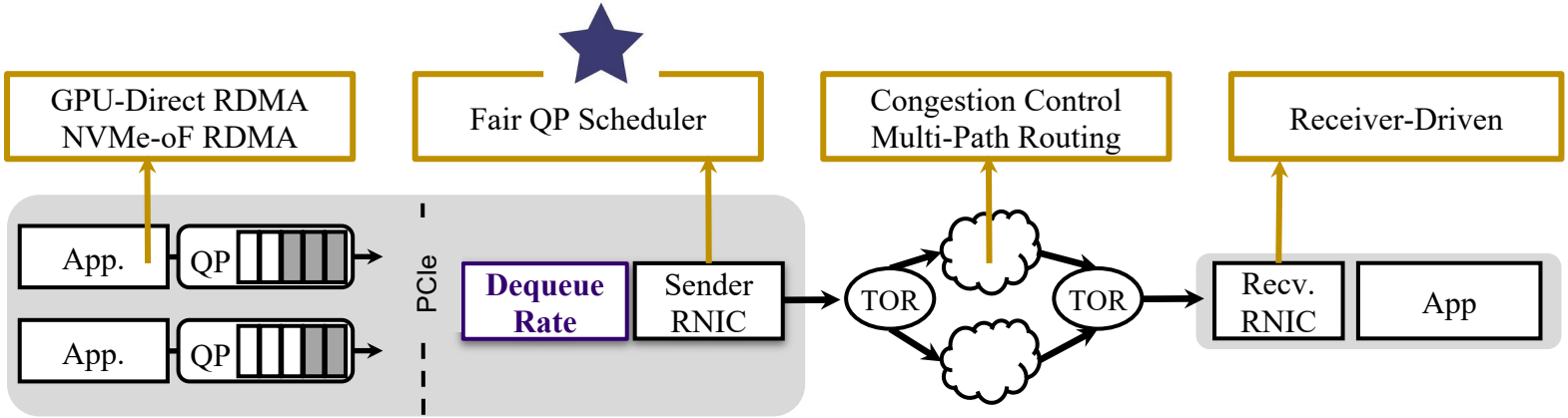
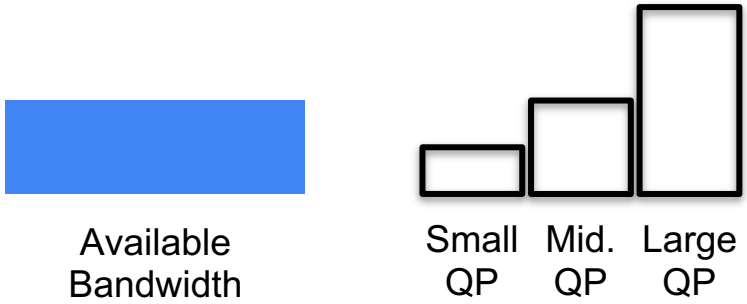


Use Case #1: Fair QP Scheduler

- Bandwidth Allocation Problem
  - Multi QPs: small/middle/large message sizes
  - Metrics: Fairness and Utilization
  - SCR can express three example algorithms



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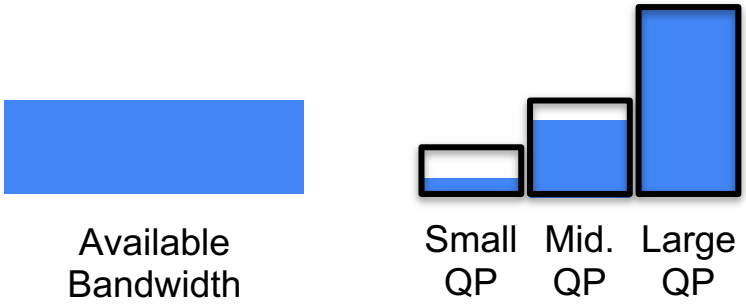

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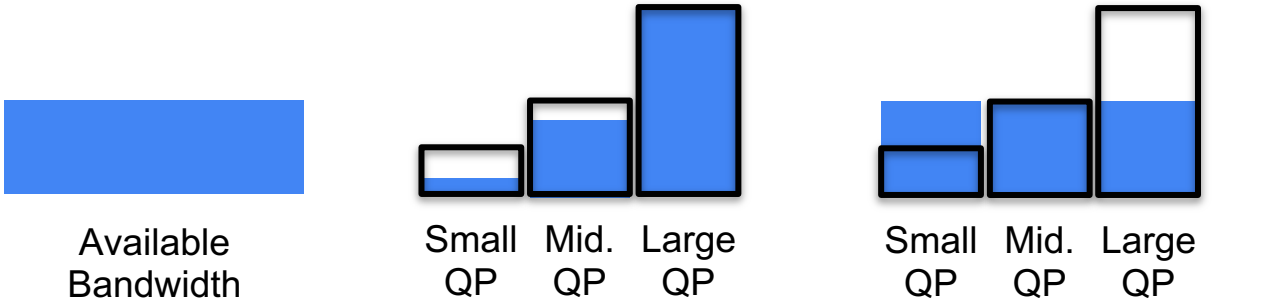

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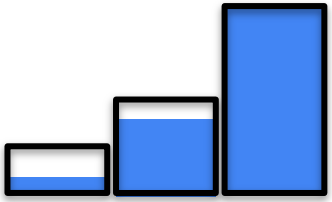

Small QP | Mid. QP | Large QP

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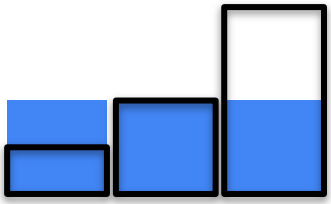

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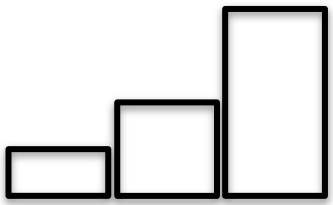

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Water Filling
Fair and High Util.

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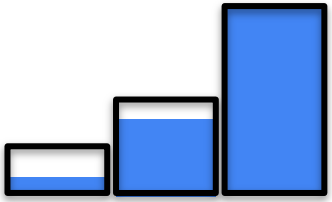

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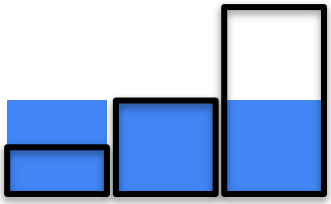

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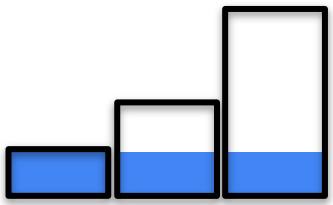

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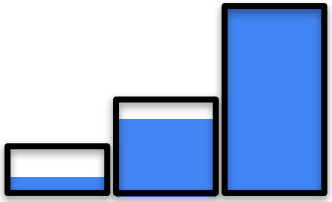

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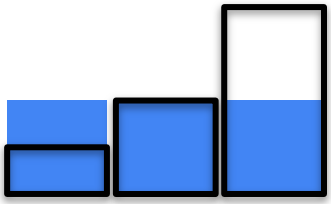

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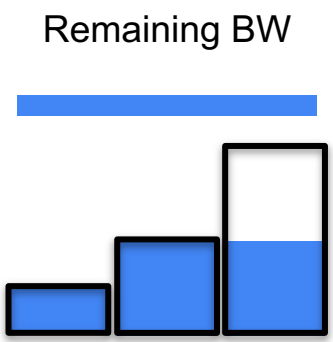

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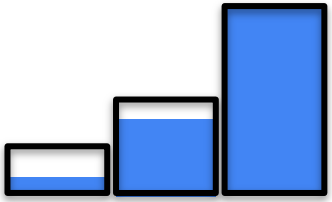

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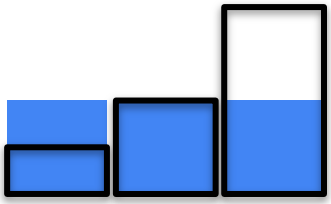

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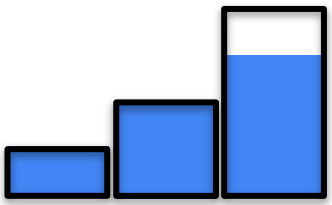

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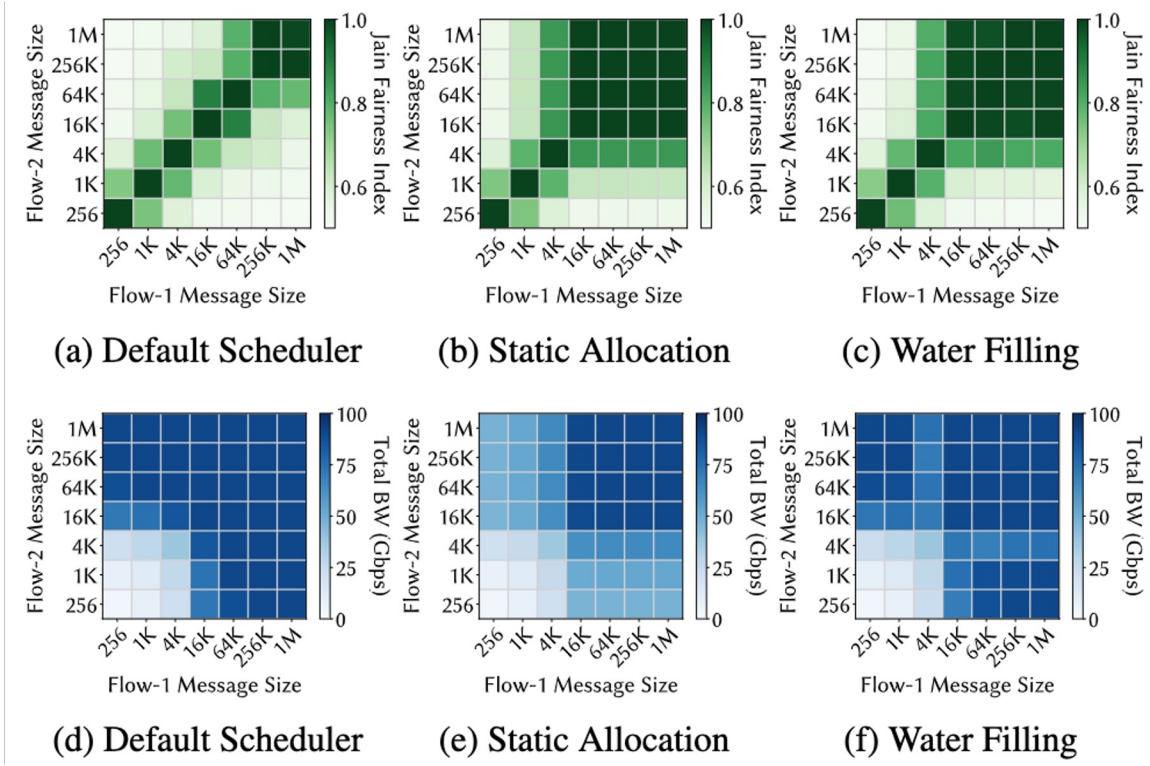

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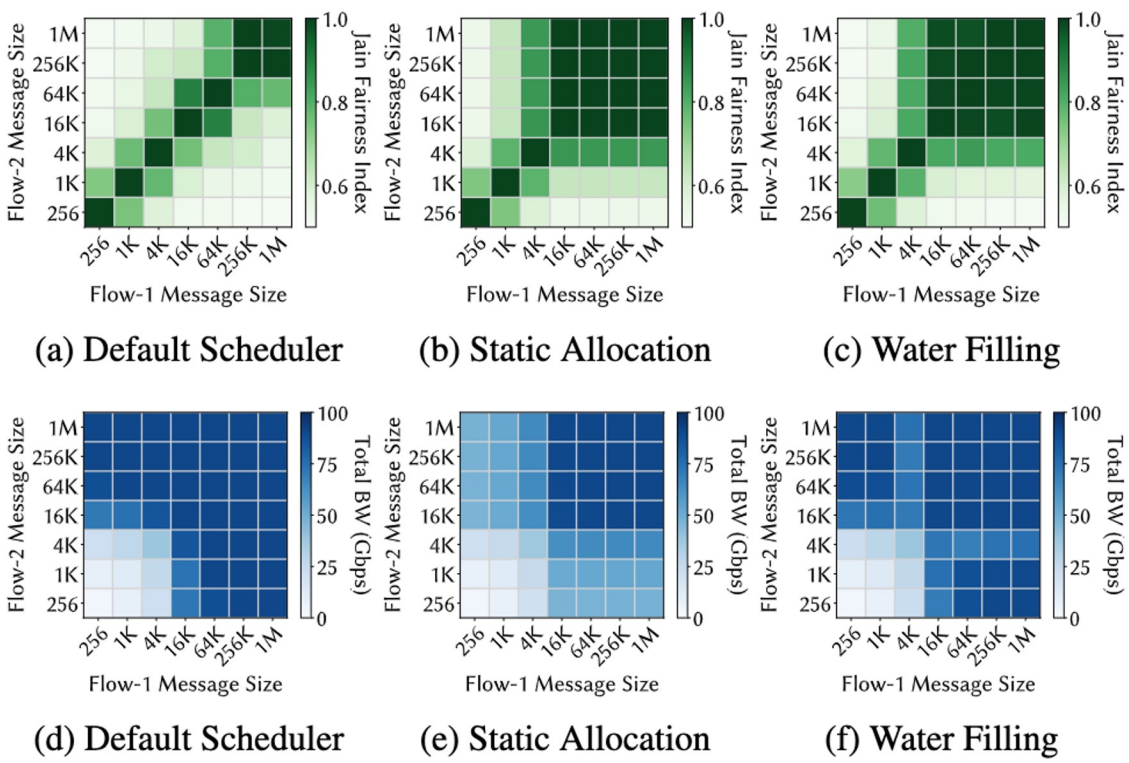
[Takeway]
SCR enables better algorithms!



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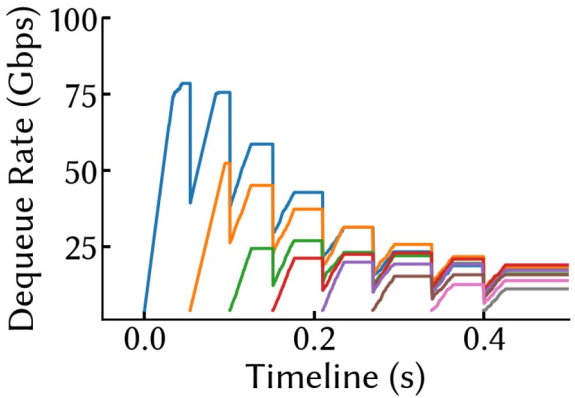

Heuristic Stateless Strategy

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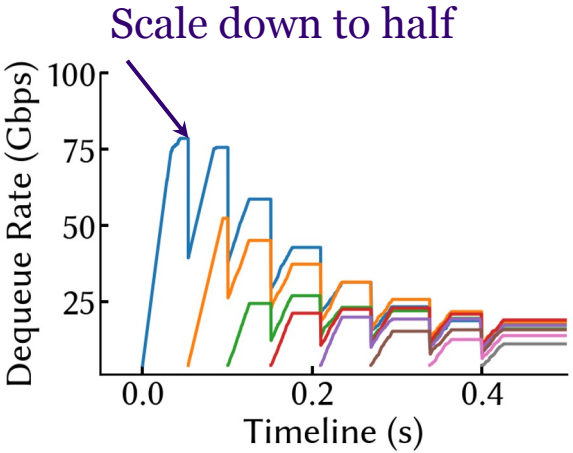

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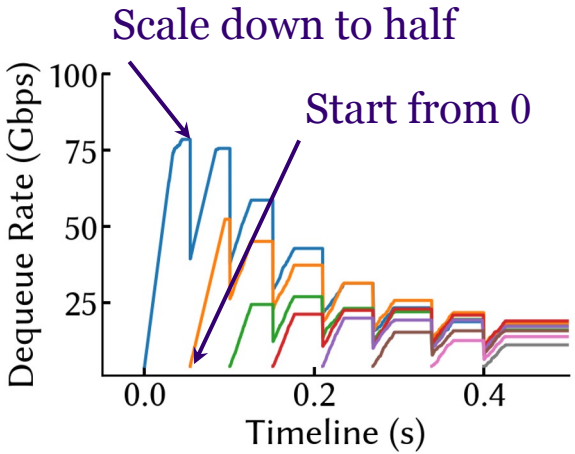

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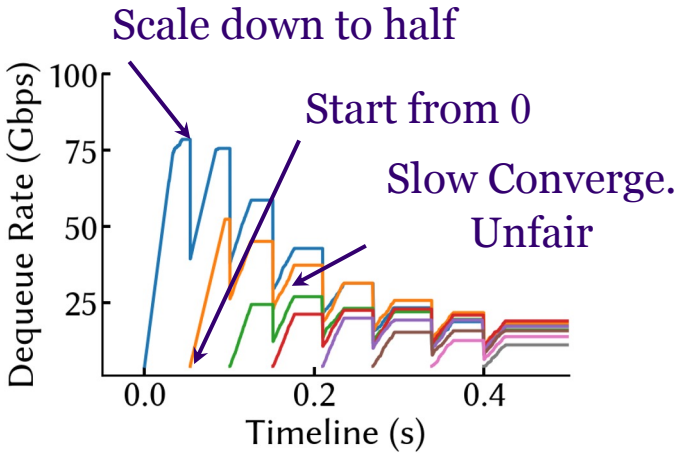

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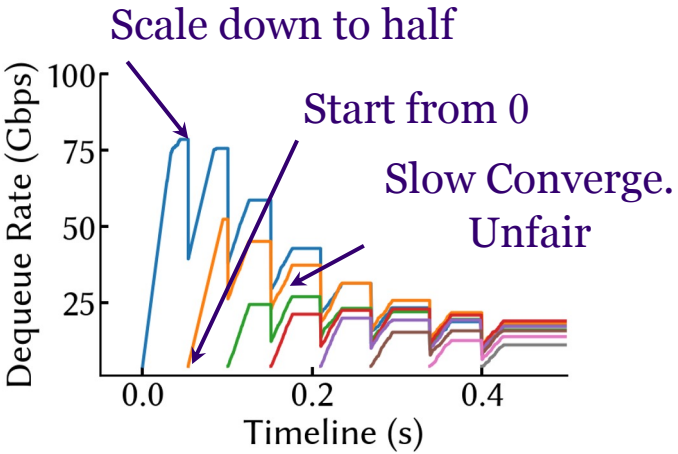

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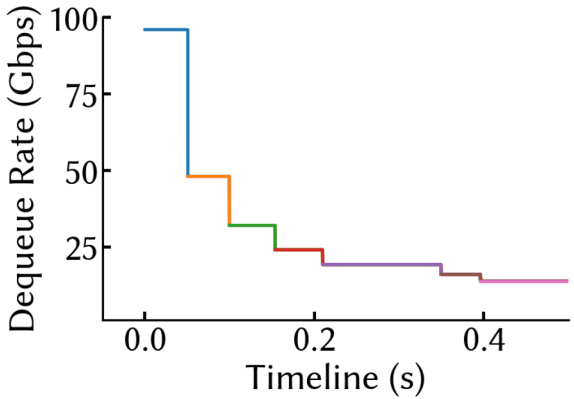

With SCR tracking states (*e.g.*, flow_num *n*)

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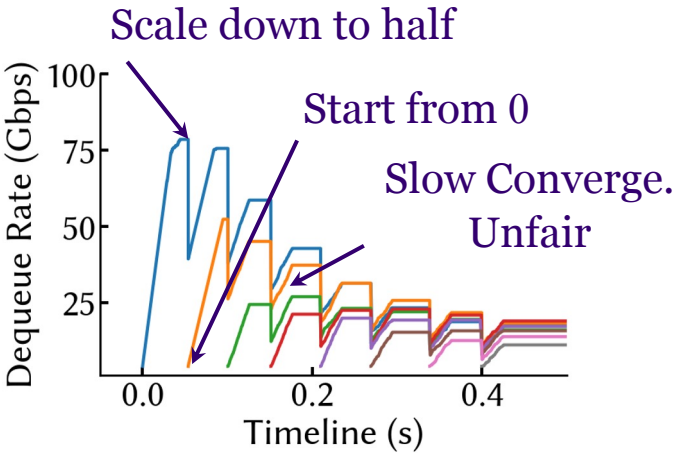

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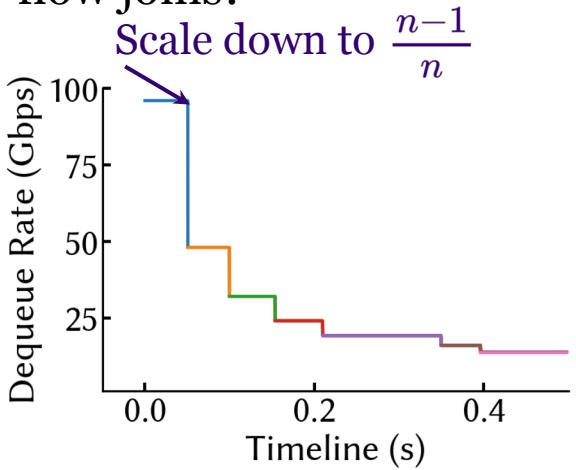

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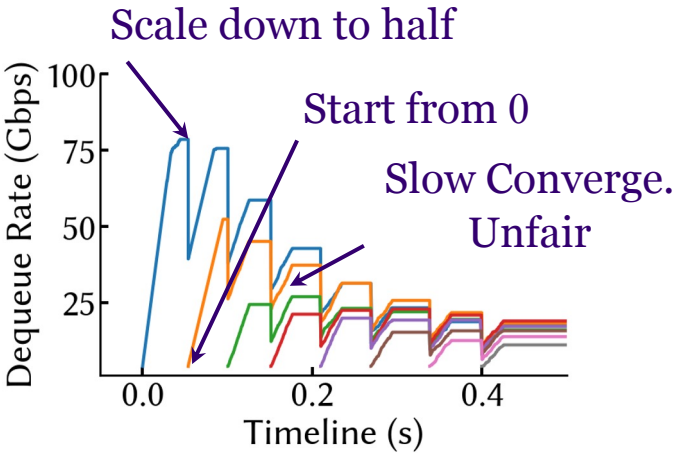
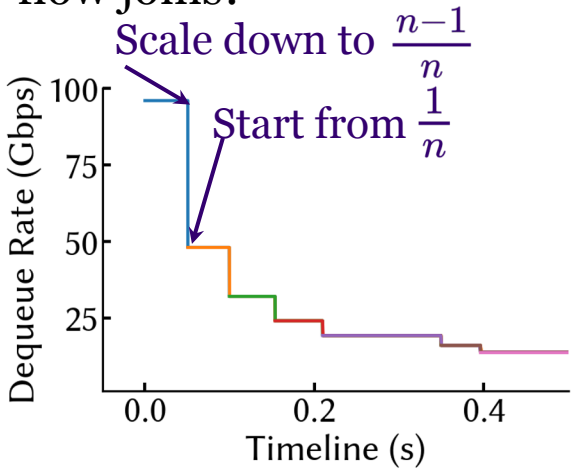


Heuristic Stateless Strategy



With SCR tracking states (*e.g.*, flow_num n)

Use Case #1: Further Customize Water Filling

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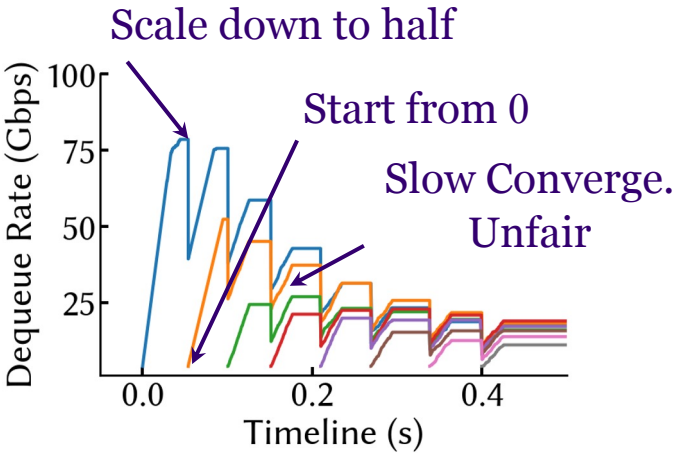
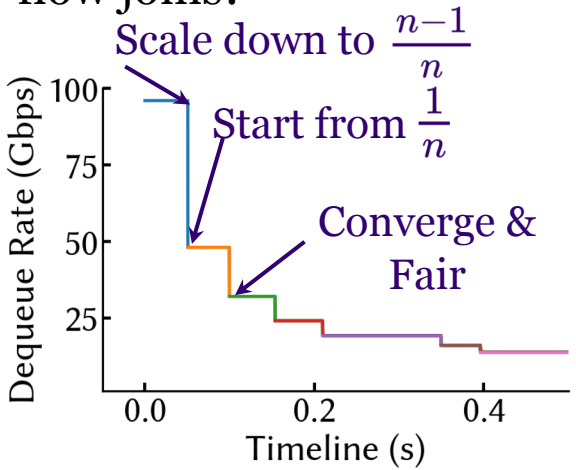


Heuristic Stateless Strategy



With SCR tracking states (*e.g.*, flow_num n)

Use Case #1: Further Customize Water Filling

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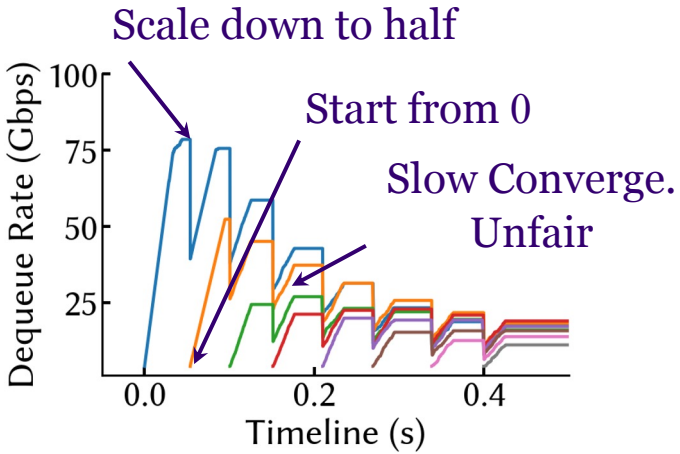
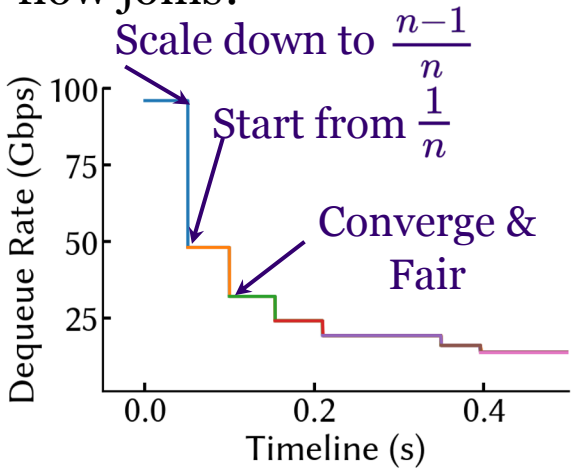


Heuristic Stateless Strategy



With SCR tracking states (*e.g.*, flow_num n)

[Takeway] SCR enables stateful customizability!

More Use Cases

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- Case#1: GPU-Direct/NVMe-oF workloads

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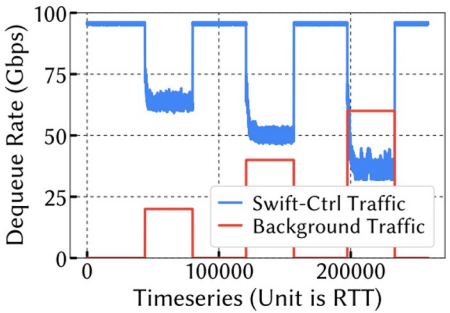
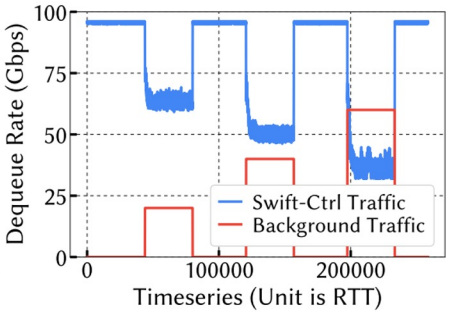
- Case#2: RTT-based congestion control (Swift Algorithm)



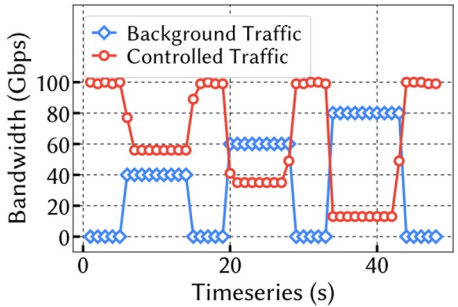
[Case#2]

More Use Cases

- Case#1: GPU-Direct/NVMe-oF workloads
- Case#2: RTT-based congestion control (Swift Algorithm)
- Case#3: Receiver-driven flow control to accurately allocate bandwidth



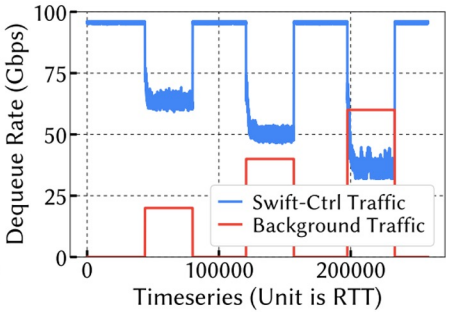
[Case#2]



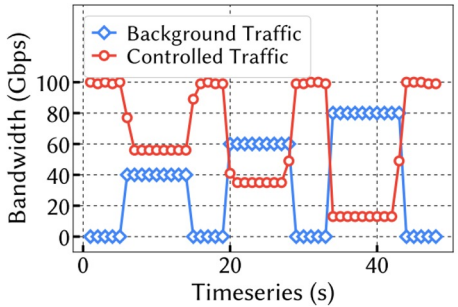
[Case#3]

More Use Cases

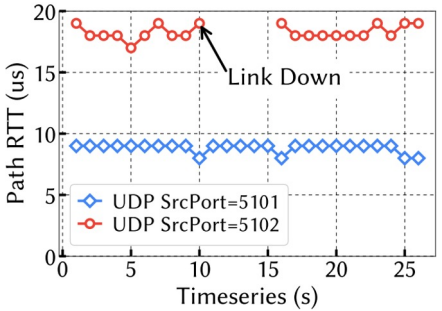
- Case#1: GPU-Direct/NVMe-oF workloads
- Case#2: RTT-based congestion control (Swift Algorithm)
- Case#3: Receiver-driven flow control to accurately allocate bandwidth
- Case#4: Multipath monitoring to help make routing decision



[Case#2]



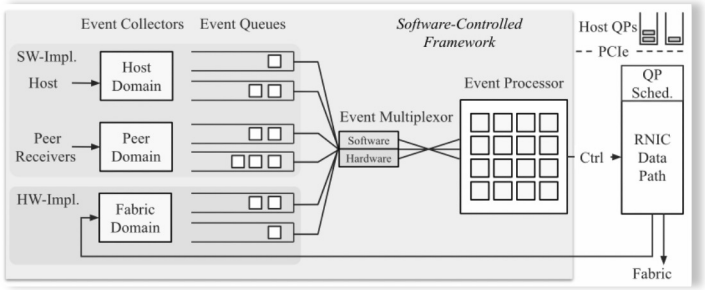
[Case#3]

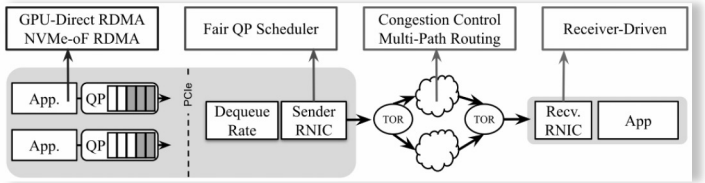


[Case#4]

Conclusion

- Whiteboxing RDMA Methodology
  - SW Ctrl; HW Data
- Software-Controlled RDMA (SCR)
  - Flexibility
  - Packet-Granularity
  - Scalability
- Land New Customizations
  - Multi-Tenant Isolation
  - Congestion Control
  - Routing
  - Flow Control





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