Friends, not Foes – Synthesizing Existing Transport Strategies for Data Center Networks

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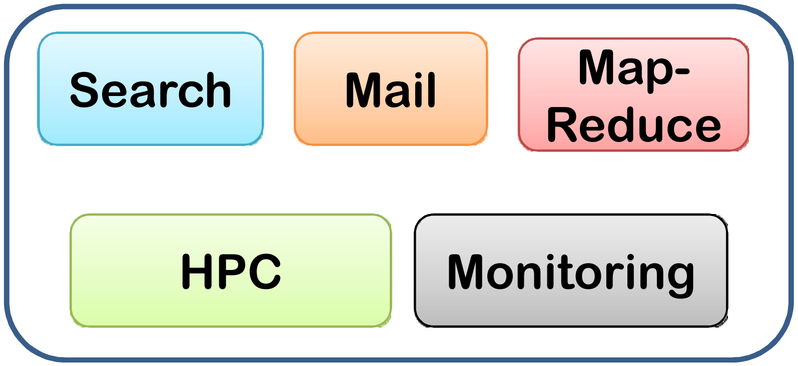
MICHIGAN STATE UNIVERSITY

LUMS

Microsoft Research

Data Center (DC) Applications

- Distributed applications
  Components interact via the network
  e.g., a bing search query touches > 100 machines



- Network impacts performance
  "10% of search responses observe 1 to 14 ms of network queuing delay"
  [DCTCP, SIGCOMM 10]

Image source: http://cdn.slashgear.com/wp-content/uploads/2012/10/google-datacenter-tech-13.jpg

DC Network Resource Allocation

- Fair Sharing

  Equal bandwidth sharing among jobs [TCP, DCTCP]

  - Increases completion time for everyone
  - Traditional "fairness" metrics less relevant

- QoS Aware

  Prioritize some jobs over other jobs (Priority Scheduling)

  - Minimize flow completion times [pFabric, L^2DCT]
  - Meet flow deadlines [D^3, D^2TCP]

DC Transports

DCTCP
SIGCOMM

L^2DCT
INFOCOM’13

D^2TCP
SIGCOMM’12

D^3
SIGCOMM’11

pFabric
SIGCOMM’13

PDQ
SIGCOMM’12

DC Transports

DCTCP
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L^{2}DCT
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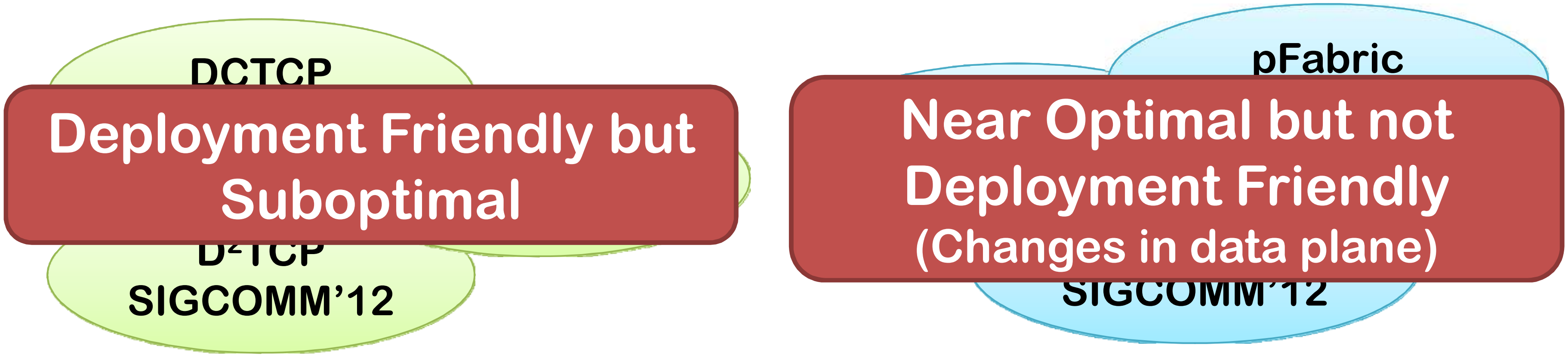
D^{2}TCP
SIGCOMM'12

pFabric

Near Optimal but not Deployment Friendly
(Changes in data plane)

SIGCOMM'12

DC Transports



Deployment Friendly but Suboptimal

Near Optimal but not Deployment Friendly

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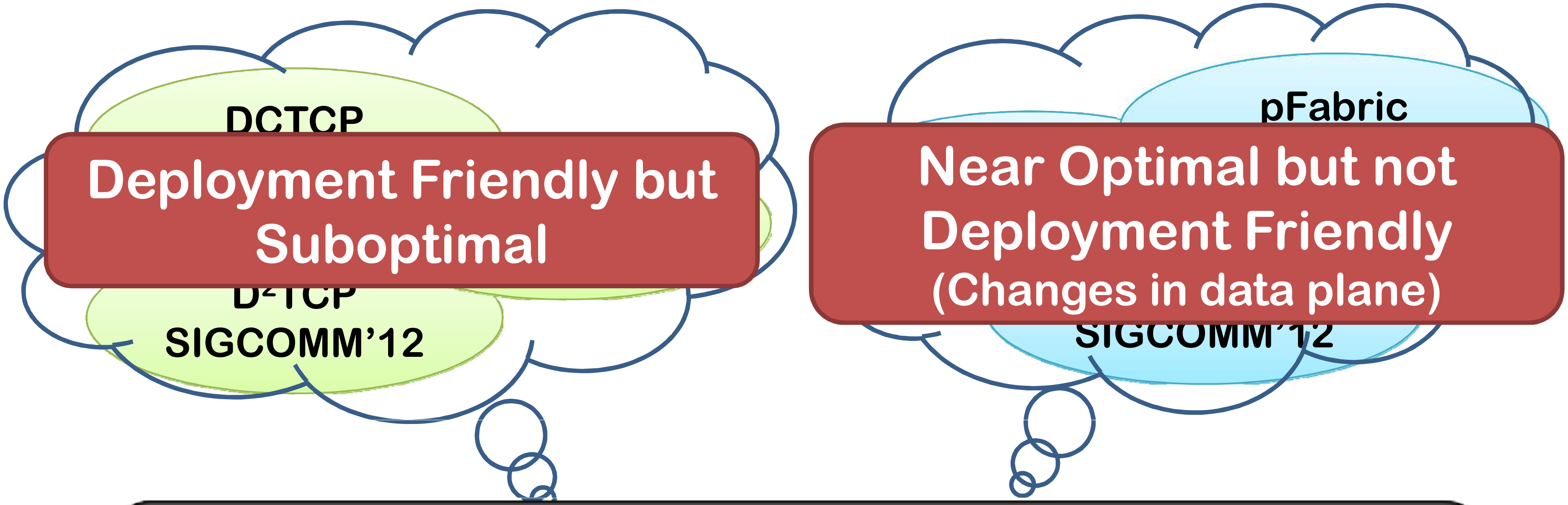

DCTCP

D²TCP
SIGCOMM’12

Deployment Friendly but Suboptimal

pFabric

SIGCOMM’12

Near Optimal but not Deployment Friendly
(Changes in data plane)

Step back and ask

How can we design a deployment friendly and near optimal data center transport while leveraging the insights offered by existing proposals?

DC Transports

DCTCP

Deployment Friendly but Suboptimal

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SIGCOMM'12

pFabric

Near Optimal but not Deployment Friendly
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PASE

Rest of the Talk …

- DC Transport Strategies
- PASE Design
- Evaluation

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DC Transport Strategies

- Self-adjusting endpoints e.g., TCP, DCTCP, L^2DCT
  - senders make independent decisions and adjust rate by themselves
- Arbitration e.g., D^3, PDQ
  - a common network entity (e.g., a switch) allocates rates to each flow
- In-network prioritization e.g., pFabric
  - switches schedule and drop packets based on the packet priority

DC Transport Strategies

- Self-adjusting endpoints e.g., TCP, DCTCP, L²DCT
  - senders make independent decisions and adjust rate by themselves
- Ar
  - es

Existing DC transport proposals use only one of these strategies

- In-network prioritization e.g., pFabric
  - switches schedule and drop packets based on the packet priority

Transport Strategies in Isolation

Transport Strategy	Example	Pros	Cons
Self-Adjusting Endpoints	DCTCP, D^2TCP, L^2DCT		
Arbitration	PDQ, D^3		
In-network Prioritization	pFabric		

Transport Strategies in Isolation

Transport Strategy	Example	Pros	Cons
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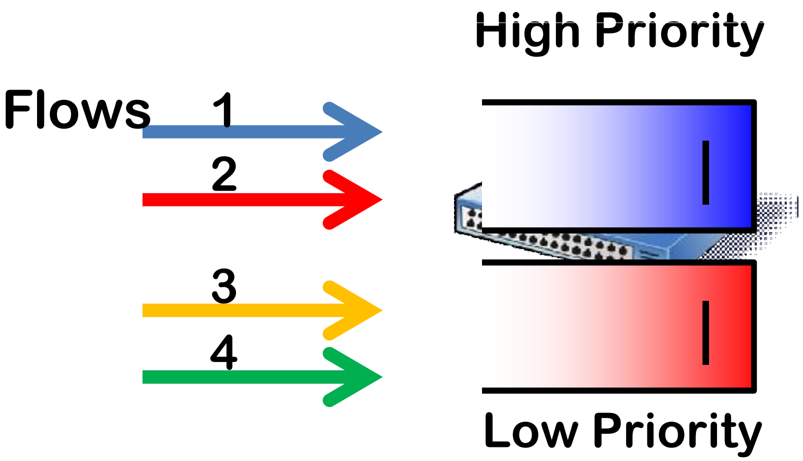
Transport Strategies in Unison

In-network Prioritization Alone

Limited # of queues

More # of flows (priorities)



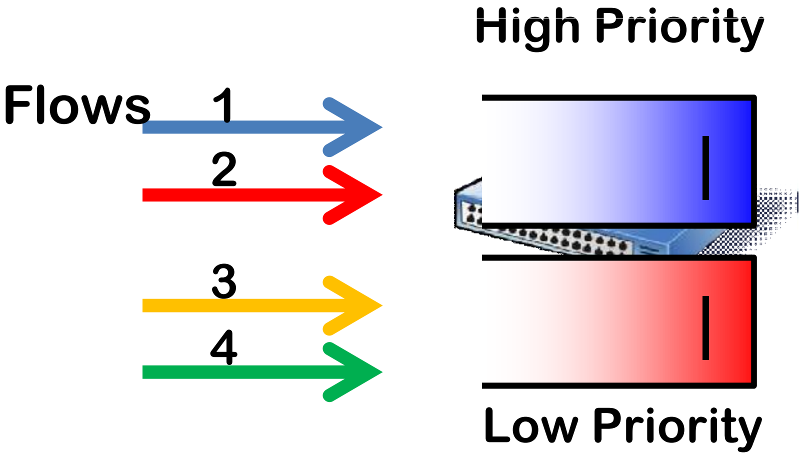
Transport Strategies in Unison

In-network Prioritization Alone

Limited # of queues
More # of flows (priorities)

→

Flow Multiplexing
Limited performance gains!



Any static mapping mechanism degrades performance!

Transport Strategies in Unison

In-network Prioritization + Arbitration

Arbitrator

Dynamic mapping of flows to queues

→

Idea

As a flow’s turn comes, map it to the highest priority queue!

Transport Strategies in Unison

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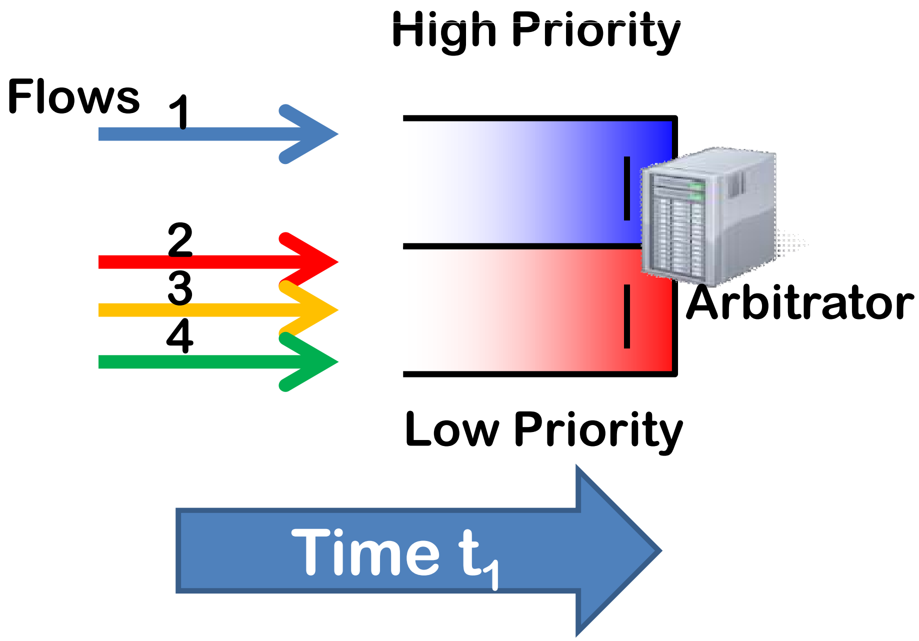

Transport Strategies in Unison

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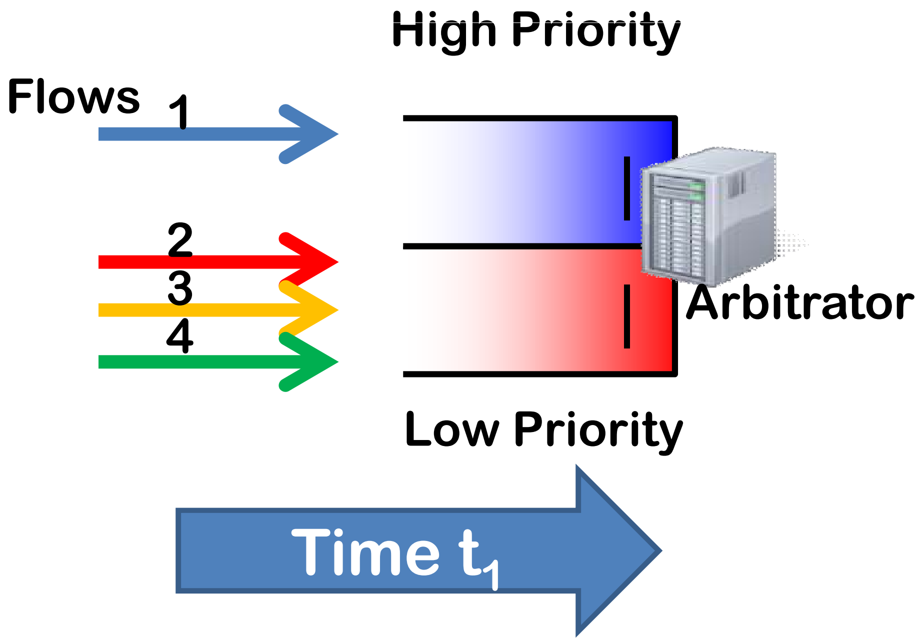


High Priority

Flows

1

2

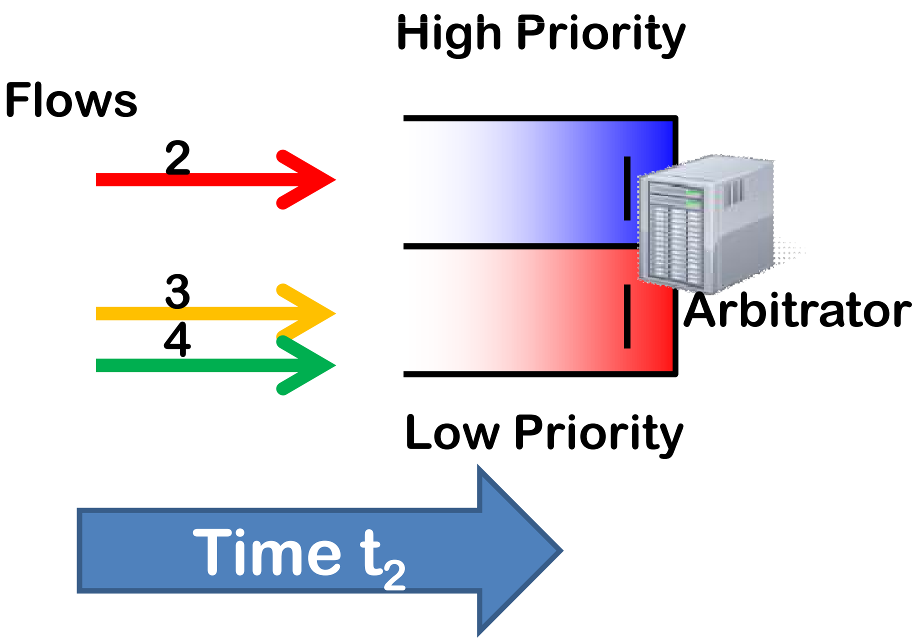
3

4

Arbitrator

Low Priority

Time t_1



High Priority

Flows

2

3

4

Arbitrator

Low Priority

Time t_2

Transport Strategies in Unison

In-network Prioritization + Arbitration

Arbitrator

Dynamic mapping of
flows t

Idea

As a flow's turn comes, map it
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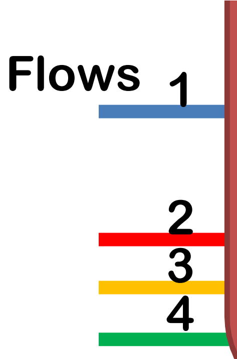
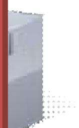
Similarly,

- Arbitration + Self-Adjusting Endpoints
- Arbitration + In-network Prioritization

PASE leverages these insights in its design!





Low Priority

Low Priority

Time t_1

Time t_2

Rest of the Talk …

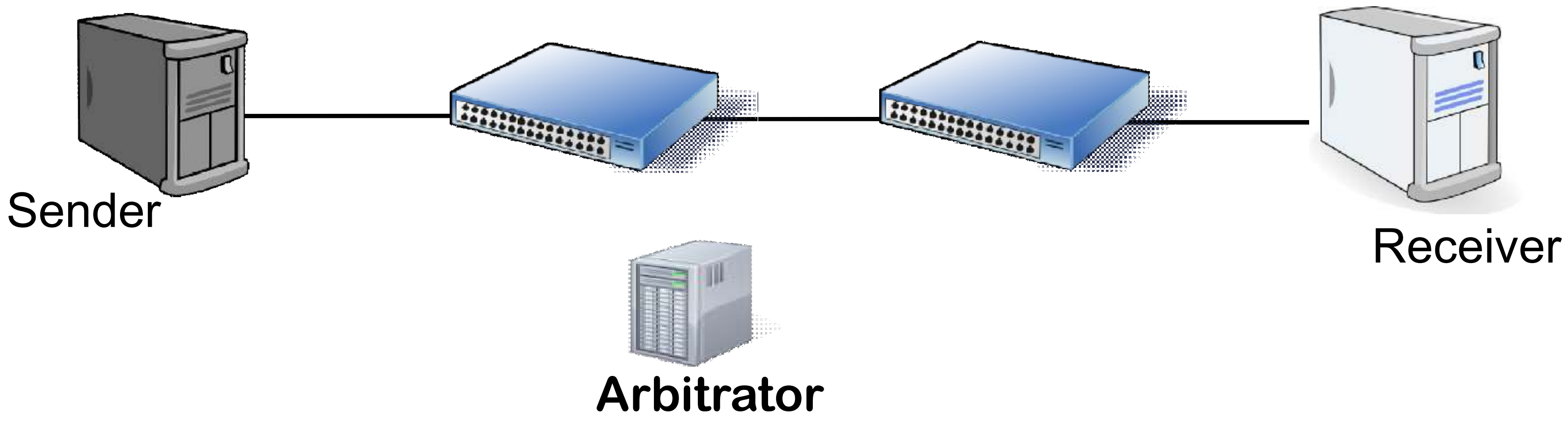
- DC Transport Strategies
- **PASE Design**
- Evaluation

PASE Design Principle

Each transport strategy should focus on what it is best at doing!

- Arbitrators
  - Do inter-flow prioritization at coarse time-scales
- Endpoints
  - Probe for any spare link capacity
- In-network prioritization
  - Do per-packet prioritization at sub-RTT timescales

PASE Overview



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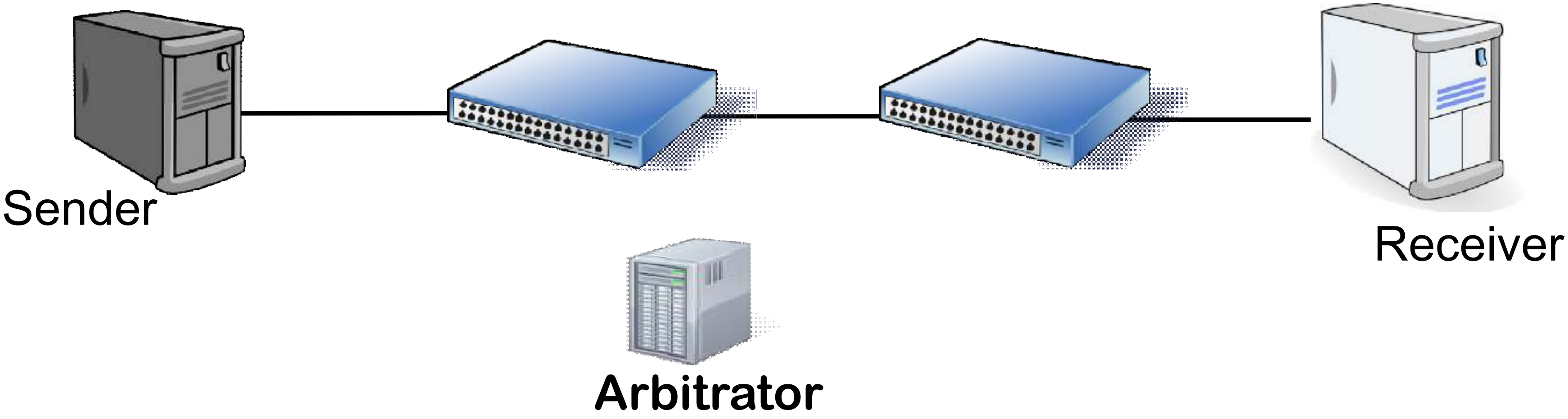

- Arbitration: Control plane

Calculate “reference rate” and “priority queue”

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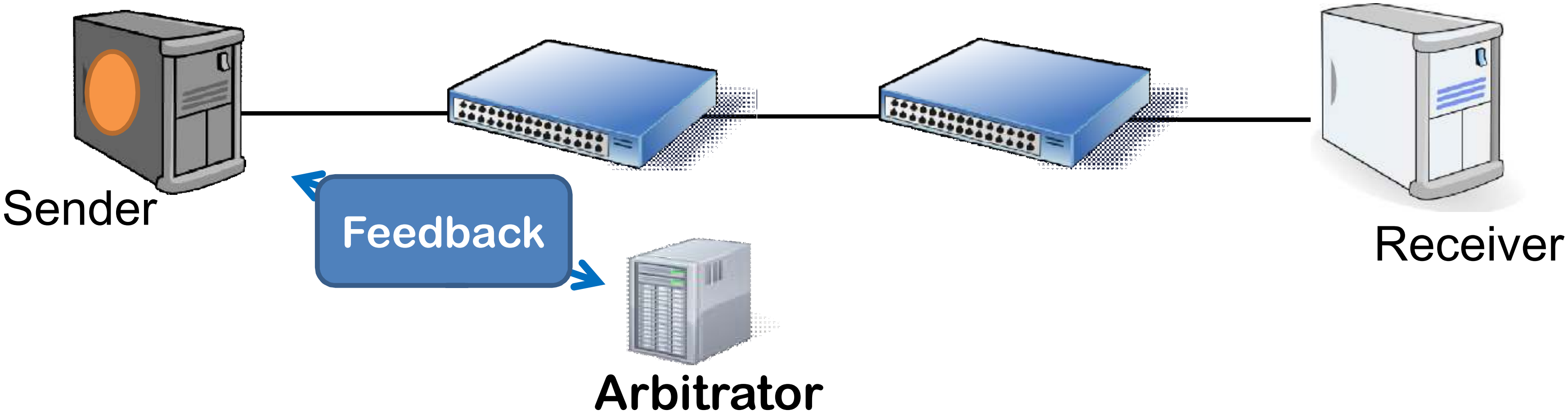

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Use arbitrator feedback as a pivot

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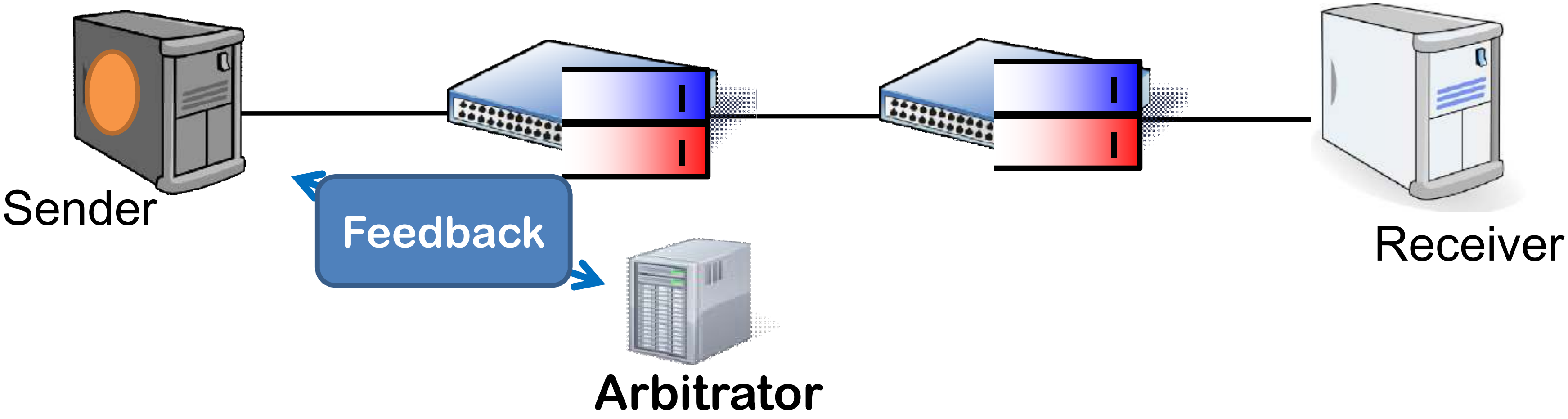

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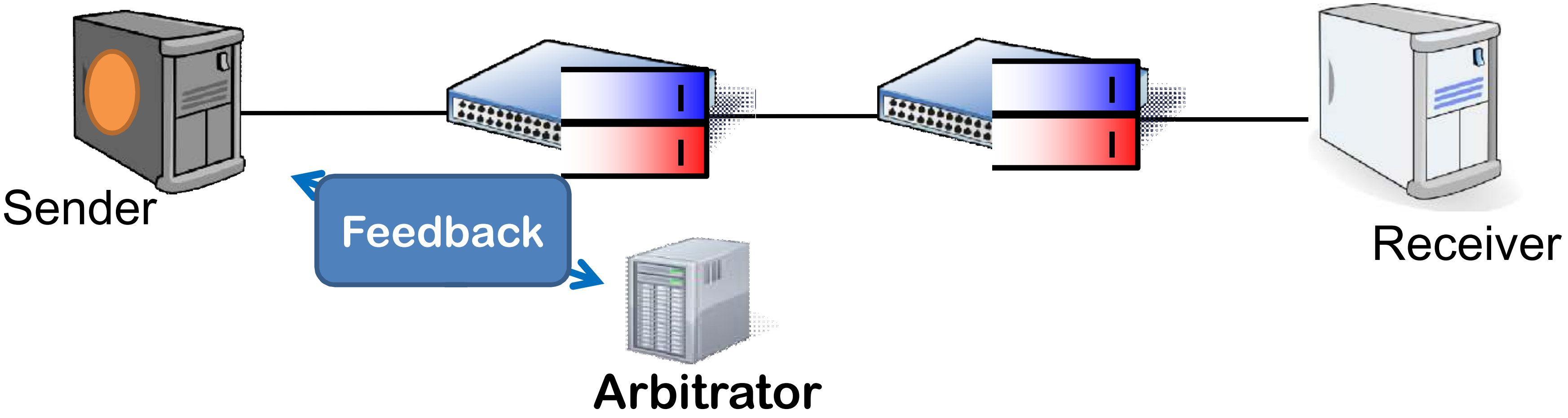

- **Arbitration: Control plane**
  Calculate “reference rate” and “priority queue”
- **Self-Adjusting Endpoints: Guided rate control**
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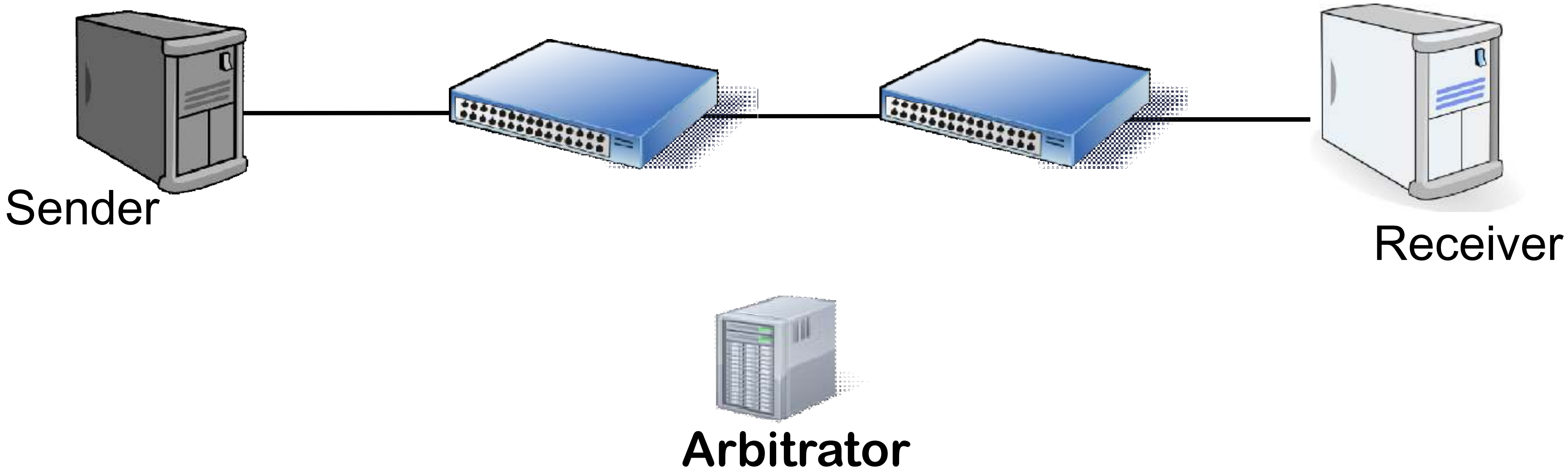
- **In-network Prioritization: Existing priority queues**

Key Components

PASE Arbitration



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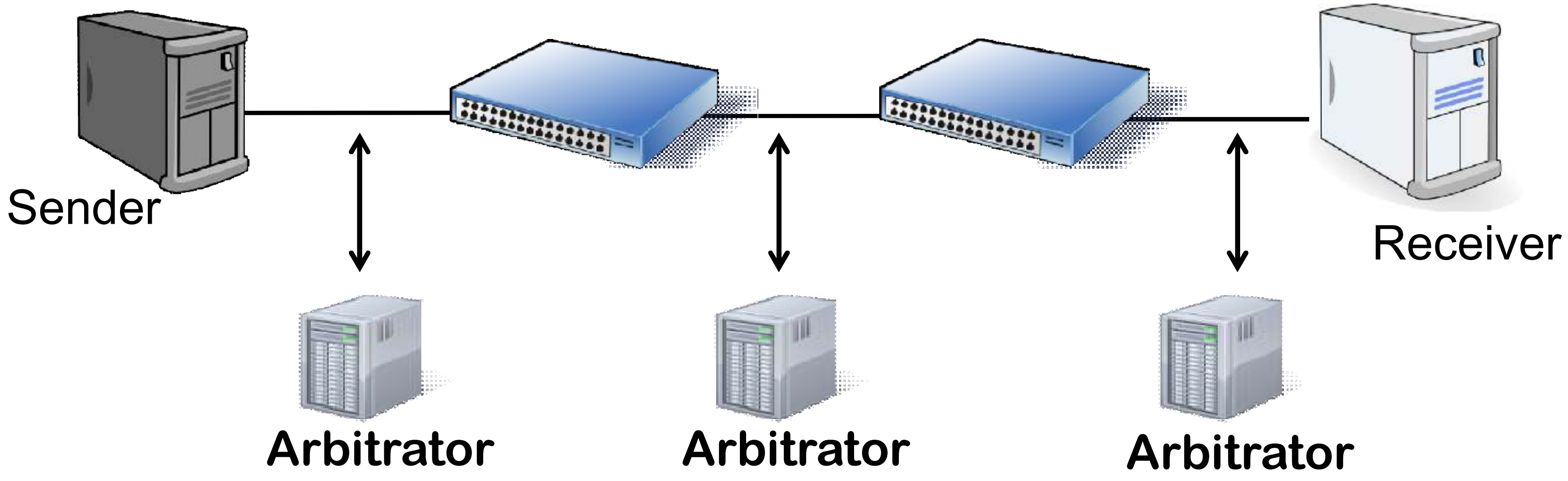
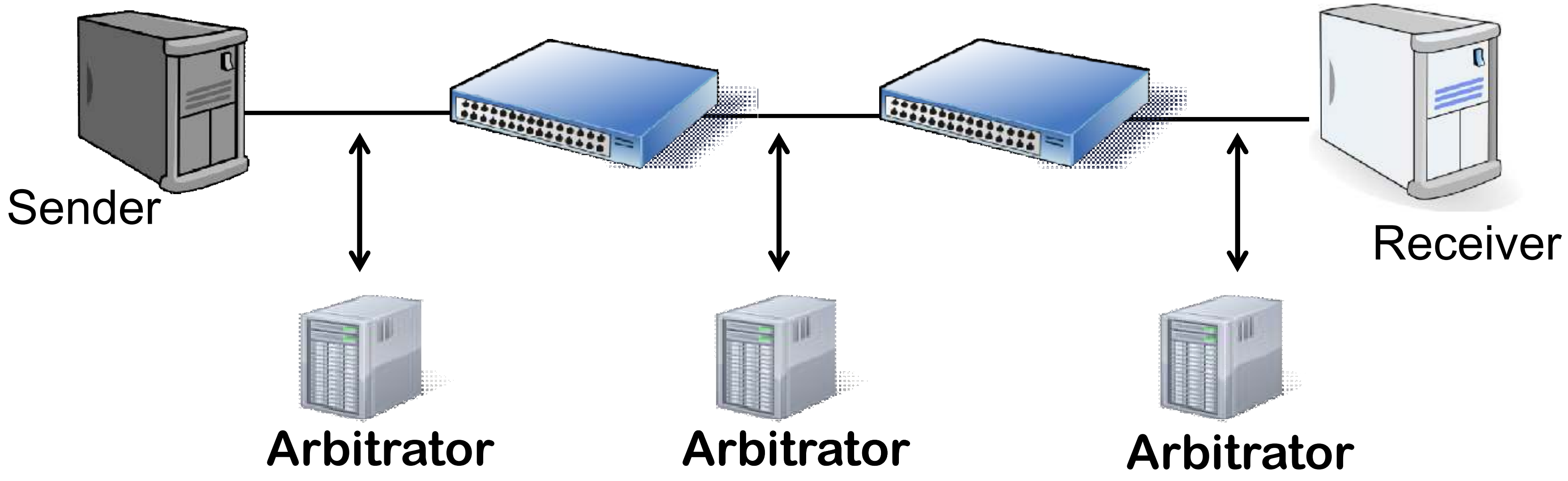


Distributed Arbitration

- per link arbitration done in control plane
- existing protocols implement in data plane

PASE Arbitration



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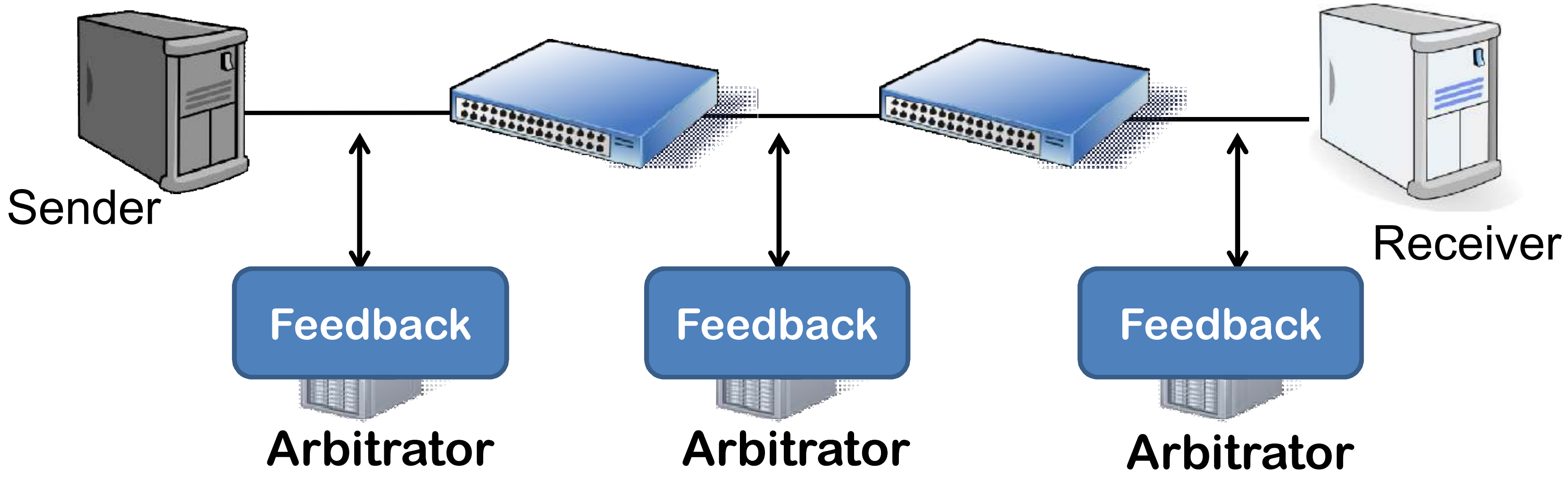

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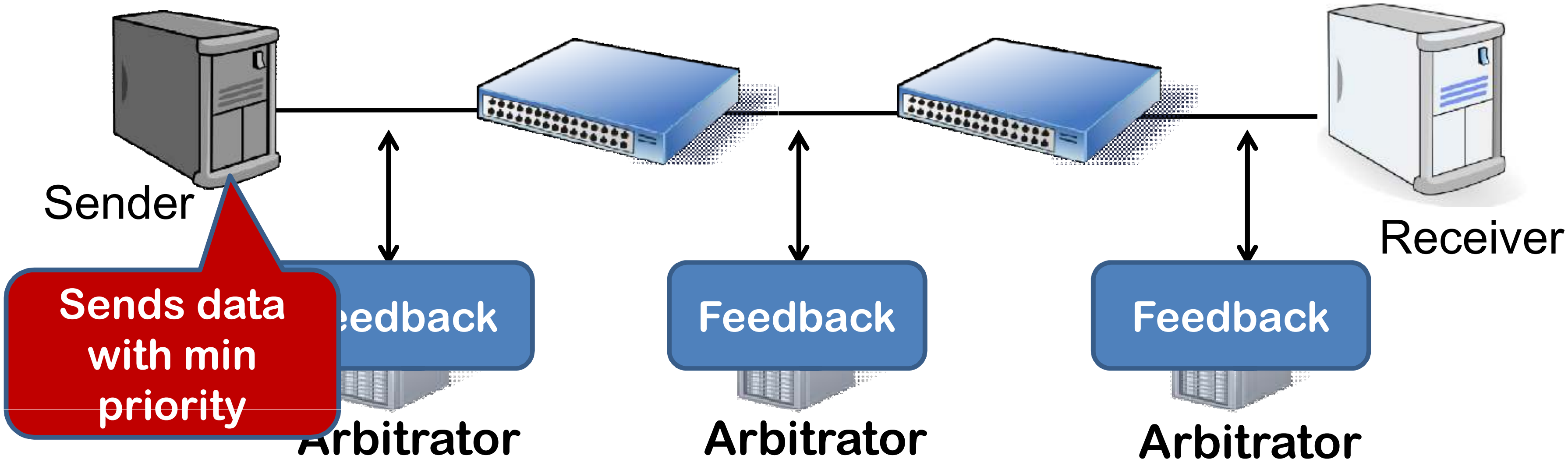

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PASE Arbitration – Challenges

- Challenges
  - Arbitration latency
  - Processing overhead
  - Network overhead

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Solution: Leverage the tree-like structure of typical DC topologies

Bottom Up Arbitration

- **Leverage Tree Structure**
  from leaves up to the root

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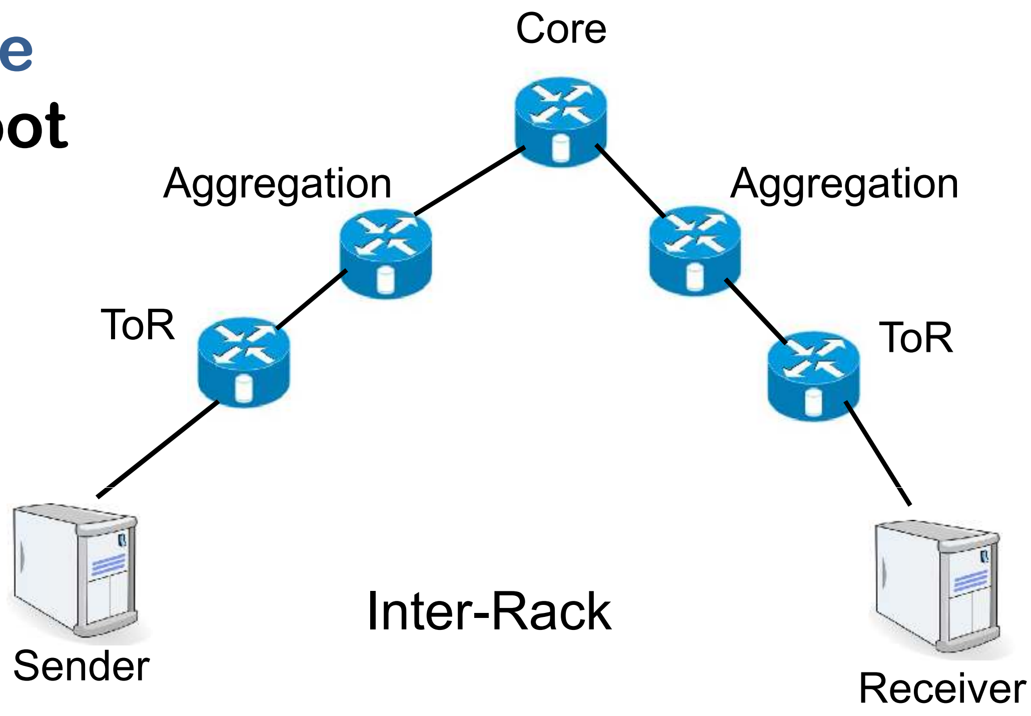

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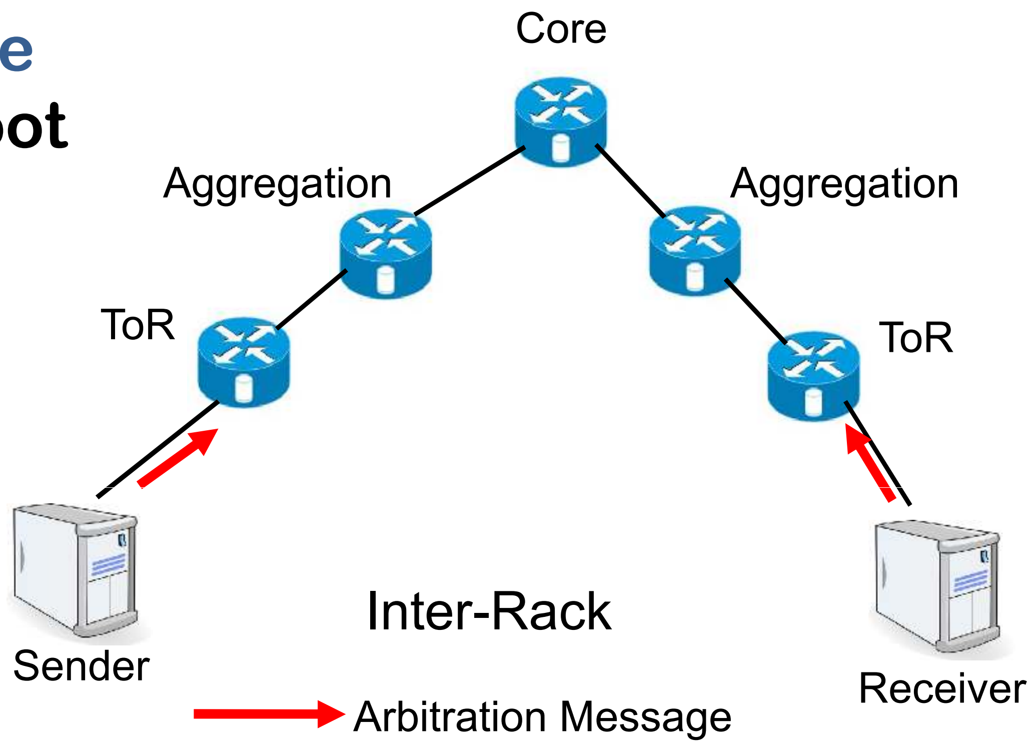

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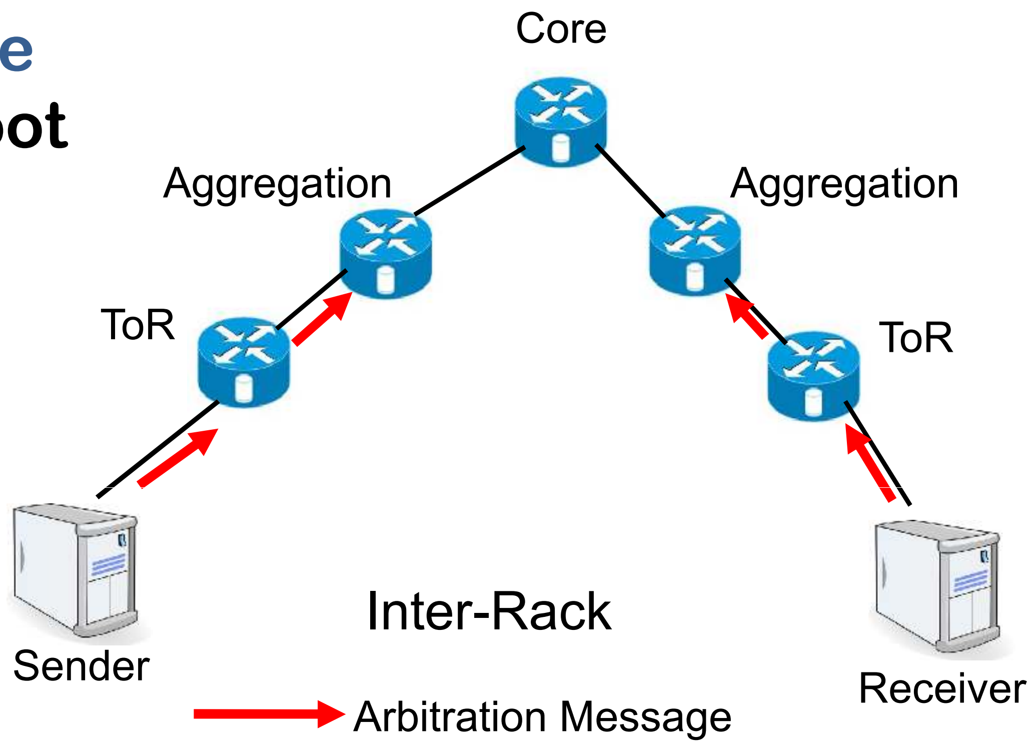

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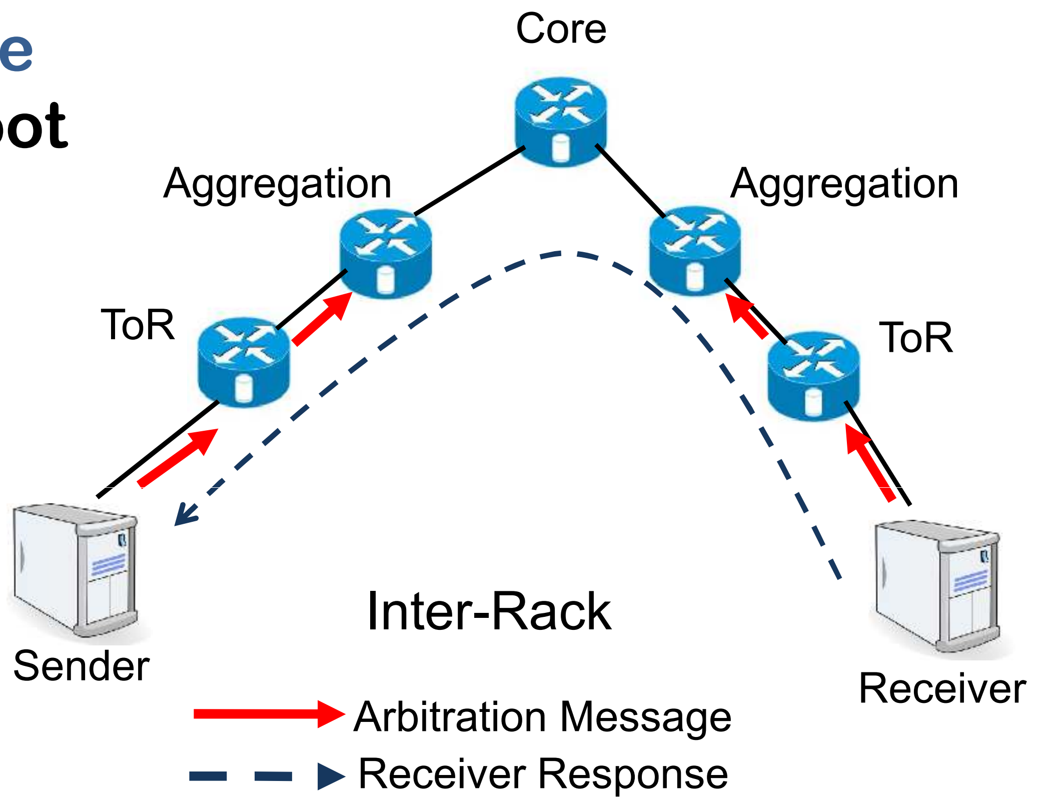

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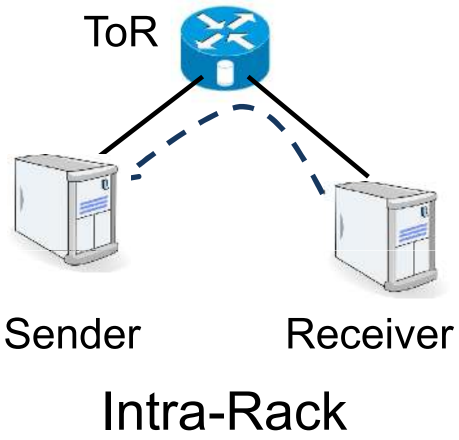

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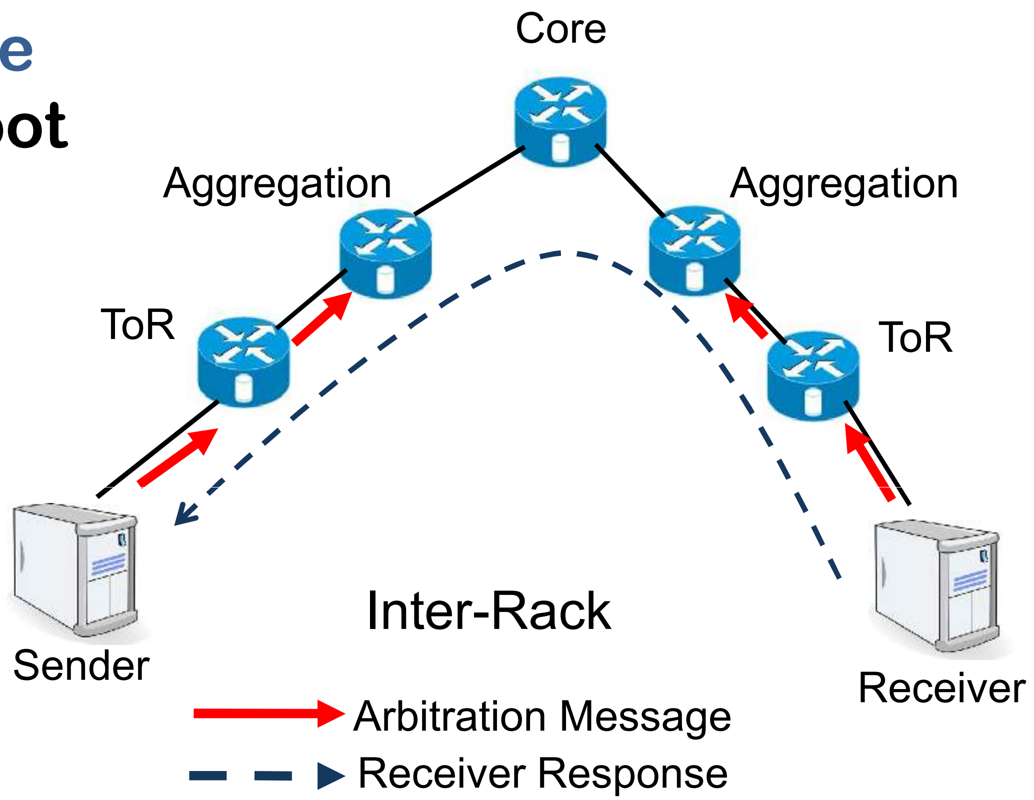

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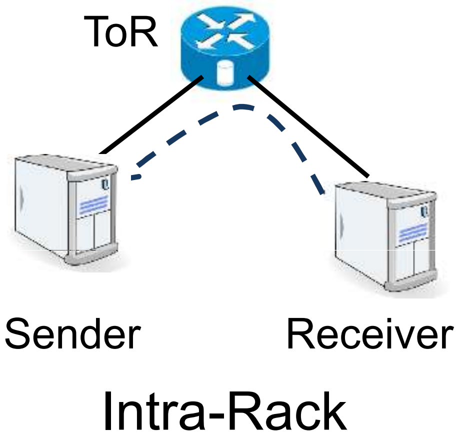

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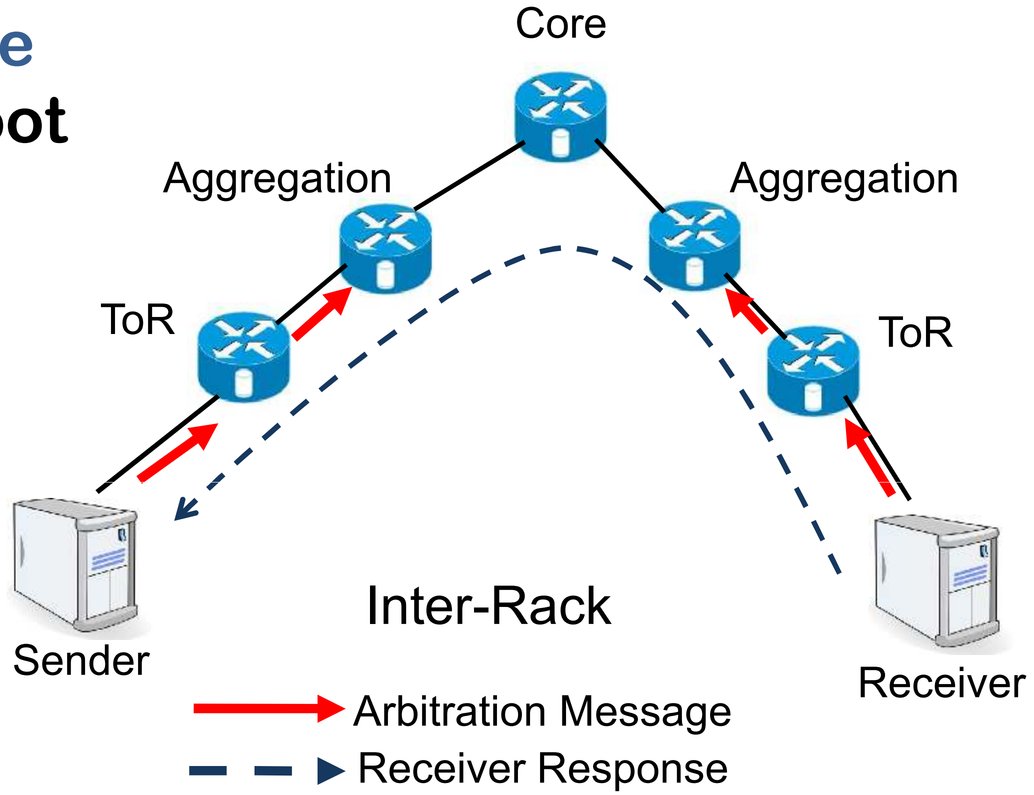
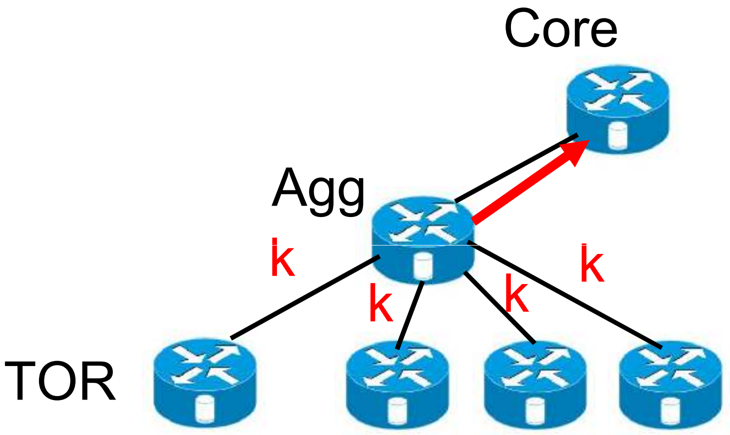


Facilitates inter-rack optimizations (early pruning & delegation) to reduce arbitration overhead.

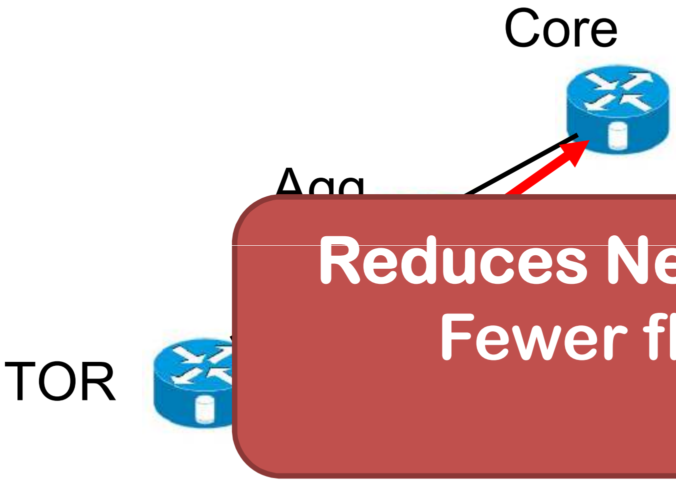
Early Pruning



Arbitration involves sorting flows and picking **top k** for immediate scheduling

Flows that won’t make it to top k queues should be pruned at lower levels

Early Pruning



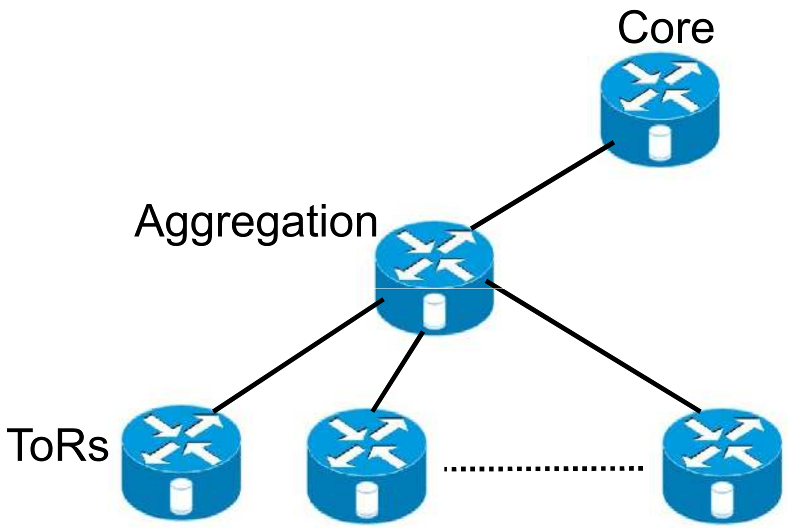
Arbitration involves sorting flows and picking **top k** for immediate scheduling

Flows that won't make it to top k queues should be pruned at lower levels

Reduces Network and Processing overhead
Fewer flows contact the higher level arbitrators!

Delegation

Key Idea: Divide a link into virtual links and delegate responsibility to child arbitrators



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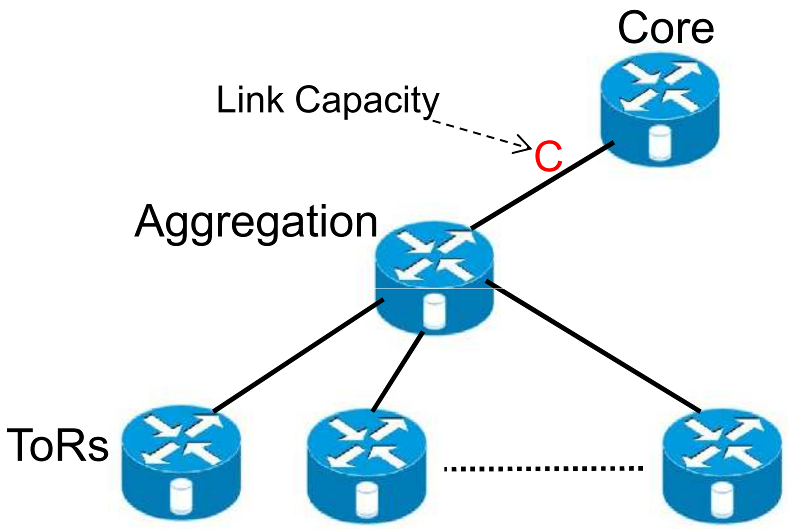

- **Algorithm**

  Link capacity C is split in N virtual links

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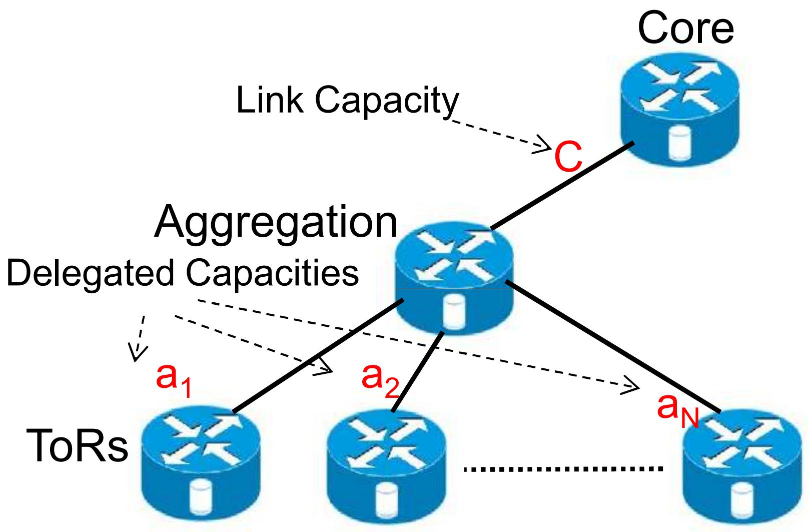

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  ⇓

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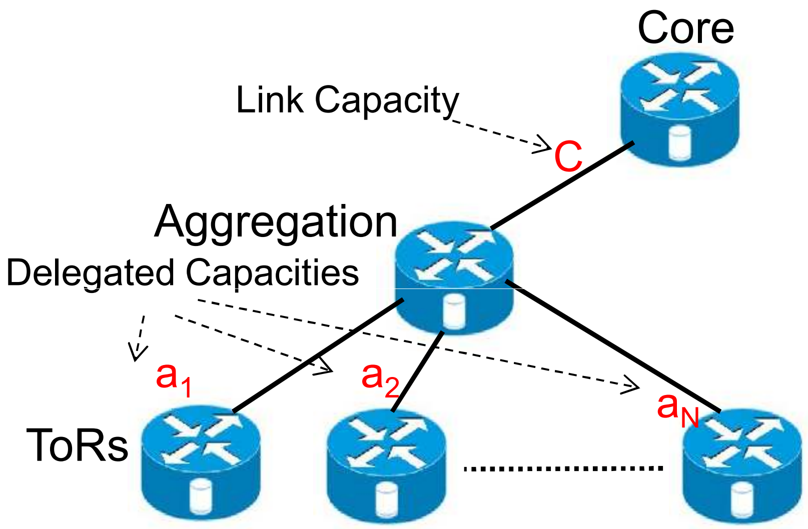

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Child arbitrator does arbitration for virtual link

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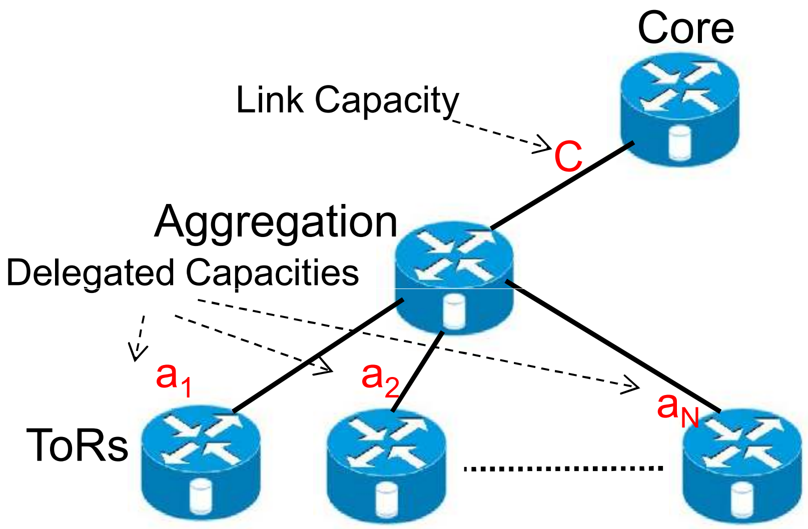

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↓

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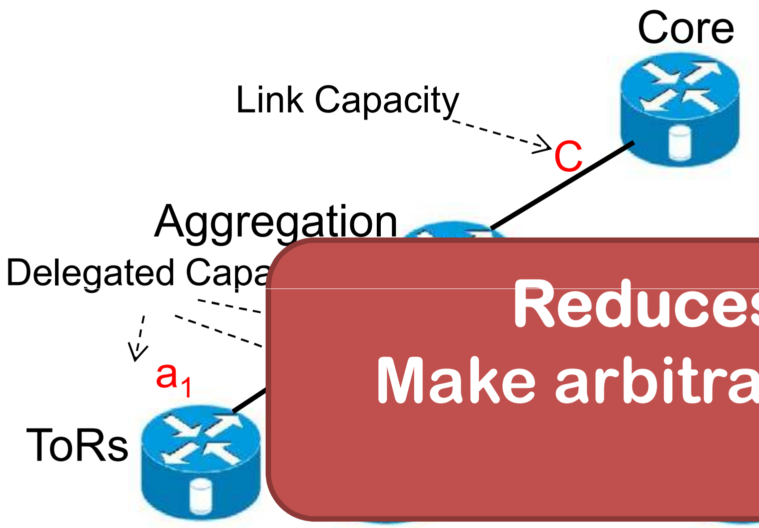


- **Algorithm**

  Link capacity C is split in N virtual links

  ates

  rator

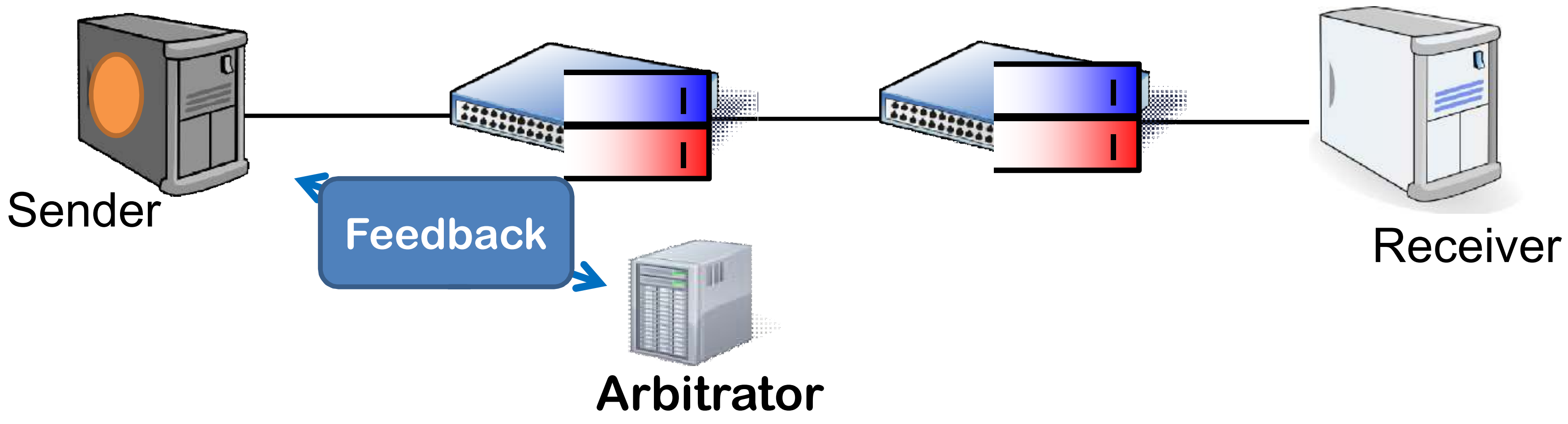
Child arbitrator does arbitration for virtual link

Virtual link capacity is periodically updated based on the top k flows of all child arbitrators

Reduces Arbitration Latency

Make arbitration decision close to the sources

PASE Overview



- Arbitration: Control plane
  Calculate “reference rate” and “priority queue”
- Self-Adjusting Endpoints: Guided rate control
  Use arbitrator feedback as a pivot
- In-network Prioritization: Existing priority queues

PASE Endhost Transport

- Rate Control

- Loss Recovery Mechanism

PASE Endhost Transport

- Rate Control

  Use reference rate and priority feedback from arbitrators

  – Use reference-rate as pivot, and

  – Follow DCTCP control laws

- Loss Recovery Mechanism

PASE Endhost Transport

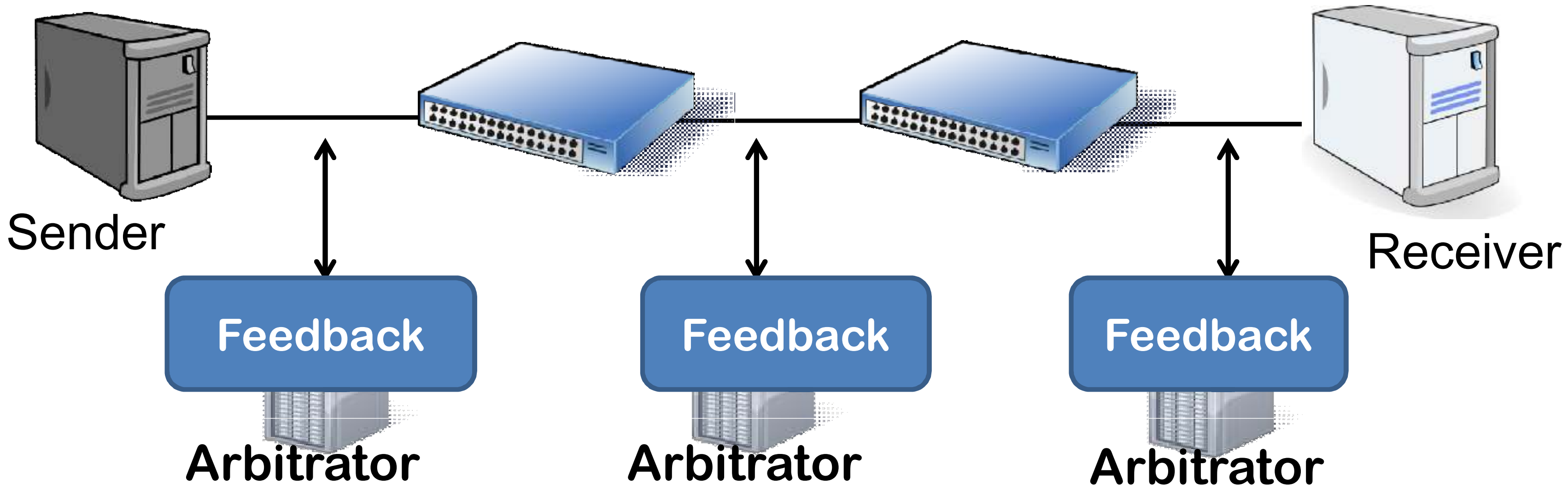
- Rate Control

  Use reference rate and priority feedback from arbitrators

  - Use reference-rate as pivot, and
  - Follow DCTCP control laws

- Loss Recovery Mechanism
  - Packets in lower priority queues can be delayed for several RTTs
    - large RTO OR small probe to avoid spurious retransmissions

PASE -- Putting it Together



- Efficient arbitration control plane
- Simple TCP-like transport
- Existing priority queues inside switches

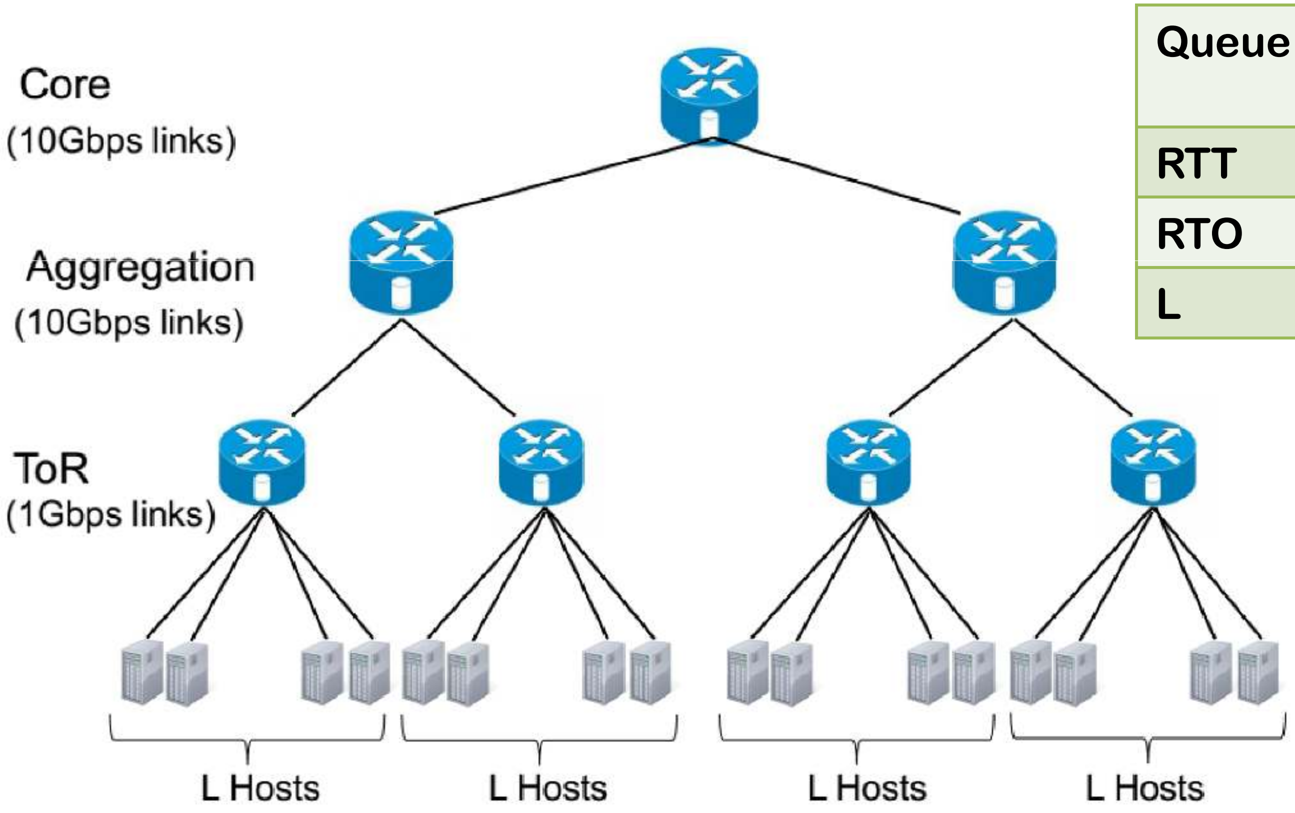
Rest of the Talk …

- DC Transport Strategies
- PASE Design
- Evaluation

Evaluation

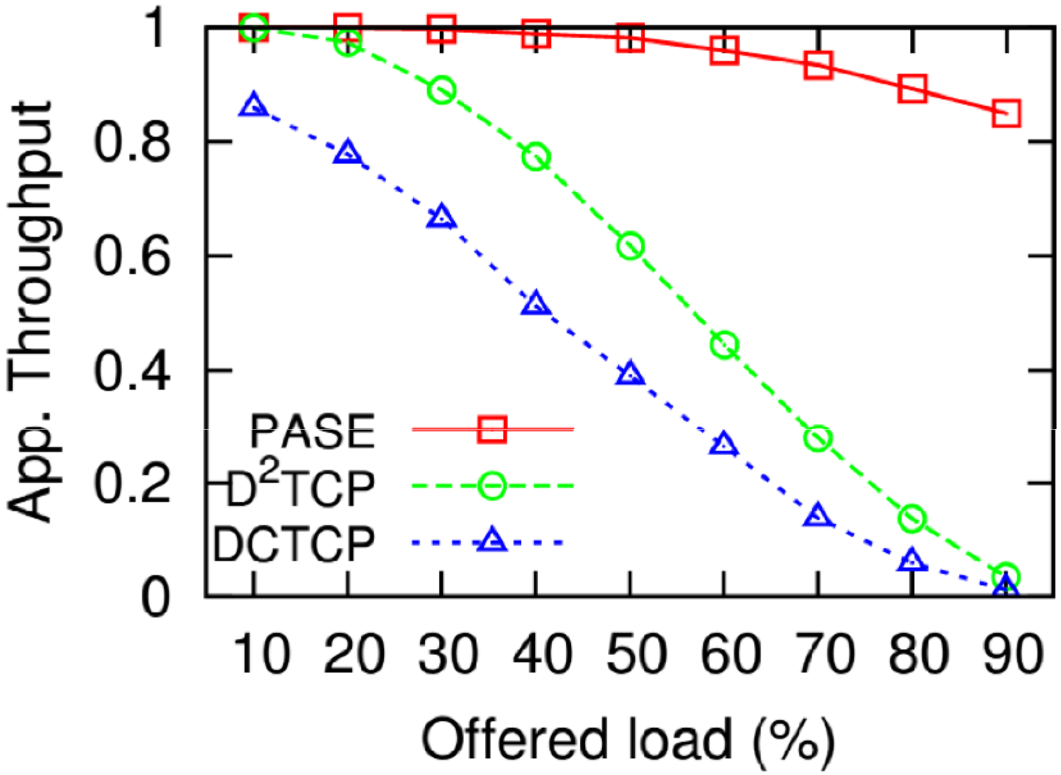
- Platforms
  - Small scale testbed
  - NS2
- Workloads
  - Web search (DCTCP), Data mining (VL2)
- Comparison with deployment friendly
  - DCTCP, D^2TCP, L^2DCT
- Comparison with state of the art
  - pFabric

Simulation Setup



Queue Size	250KB (per queue)
RTT	300usec
RTO	1 msec
L	40

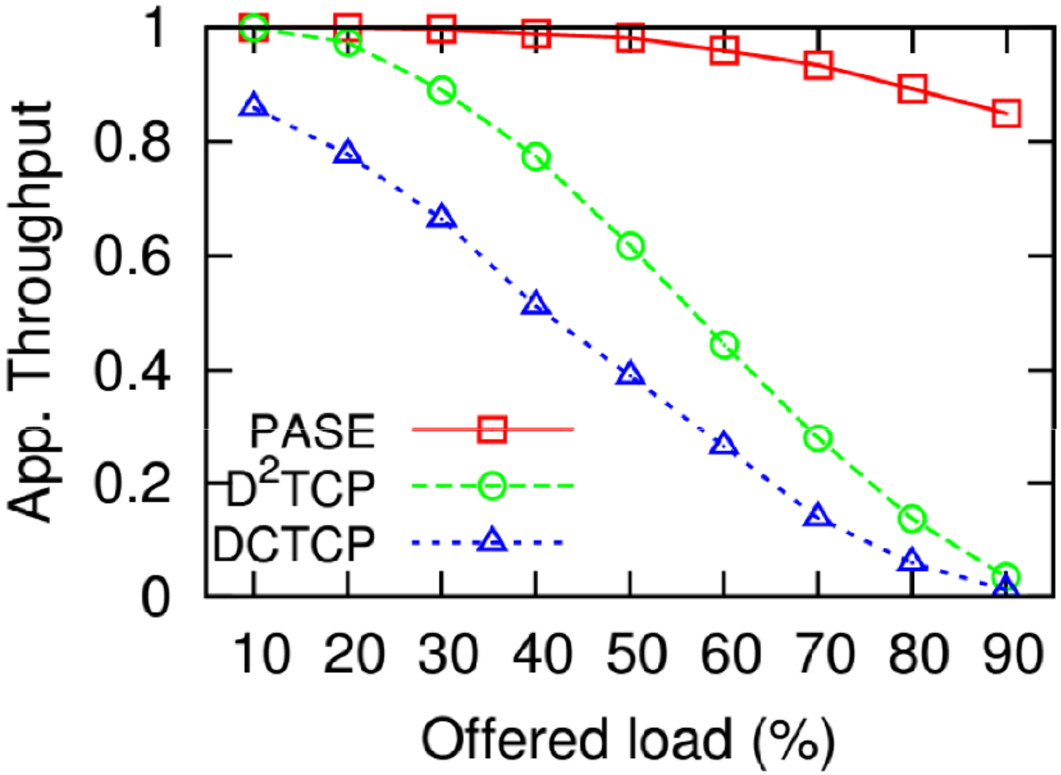
Comparison with Deployment Friendly



Settings similar to D^{2}TCP

- **Flow Sizes: 100-500KB**
- **Deadlines: 5-25msec**

Comparison with Deployment Friendly



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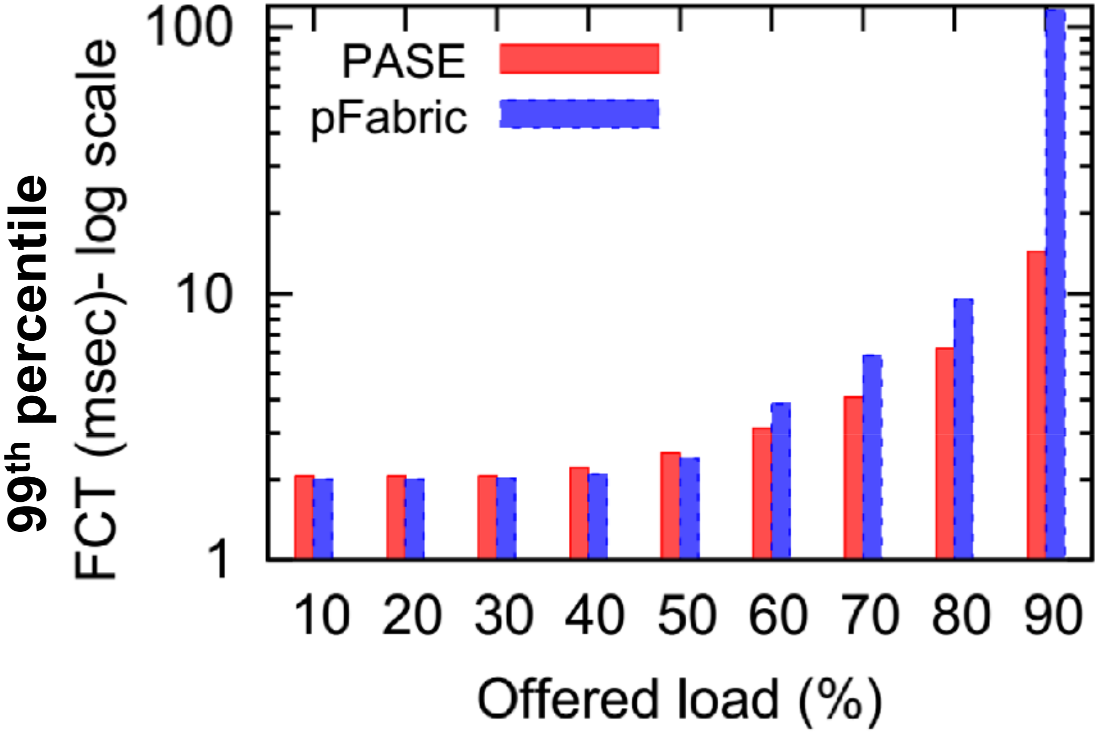
PASE is deployment friendly yet performs BETTER than existing protocols!

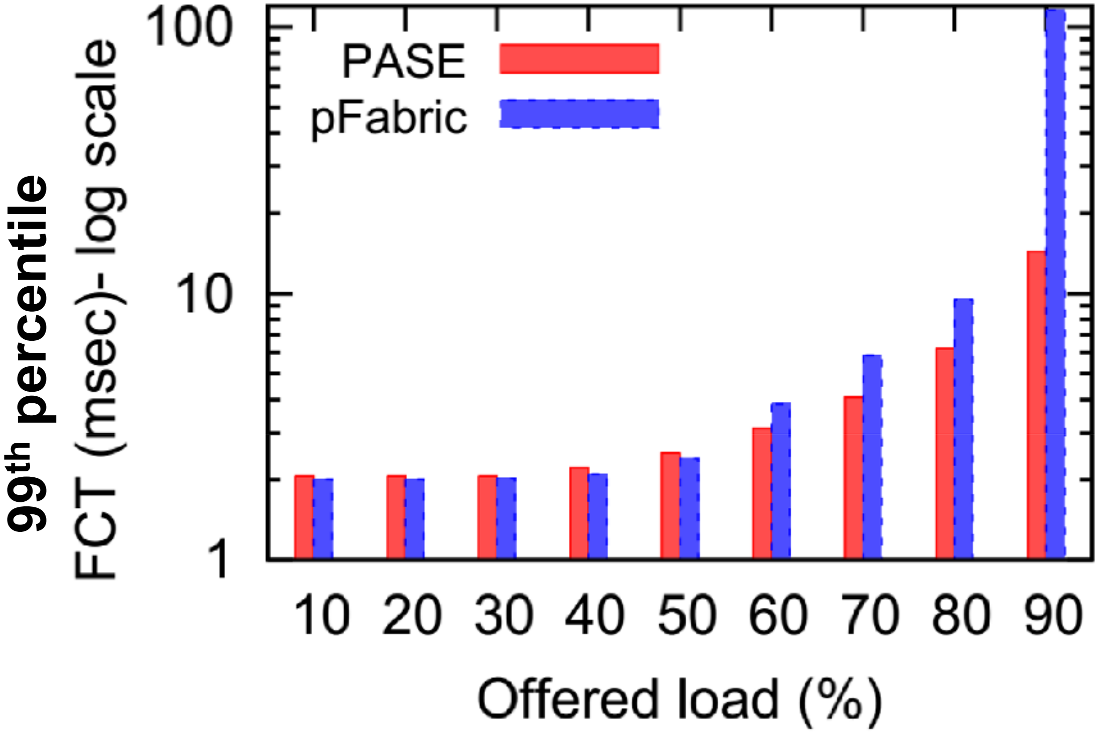
Comparison with State of the Art



Settings

- **Flow Sizes: 2-98KB**
- **Left-to-right traffic**

Comparison with State of the Art



Settings

- **Flow Sizes: 2-98KB**
- **Left-to-right traffic**

PASE performs comparable and does not require changes to data plane

Summary

- Key Strategies for Existing DC Transport
  - Arbitration, in-network Prioritization, Self-Adjusting End-points
  - Complimentary rather than substitutes
- PASE
  - Combines the three strategies
  - Efficient arbitration control plane; simple TCP-like transport; leverages existing priority queues inside switches
- Performance
  - Comparable to or better than earlier proposals that even require changes to the network fabric

Thank you!