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

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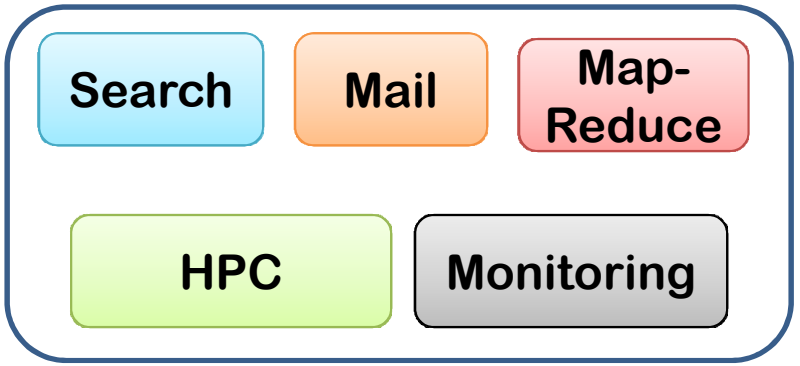
Data Center (DC) Applications

- **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

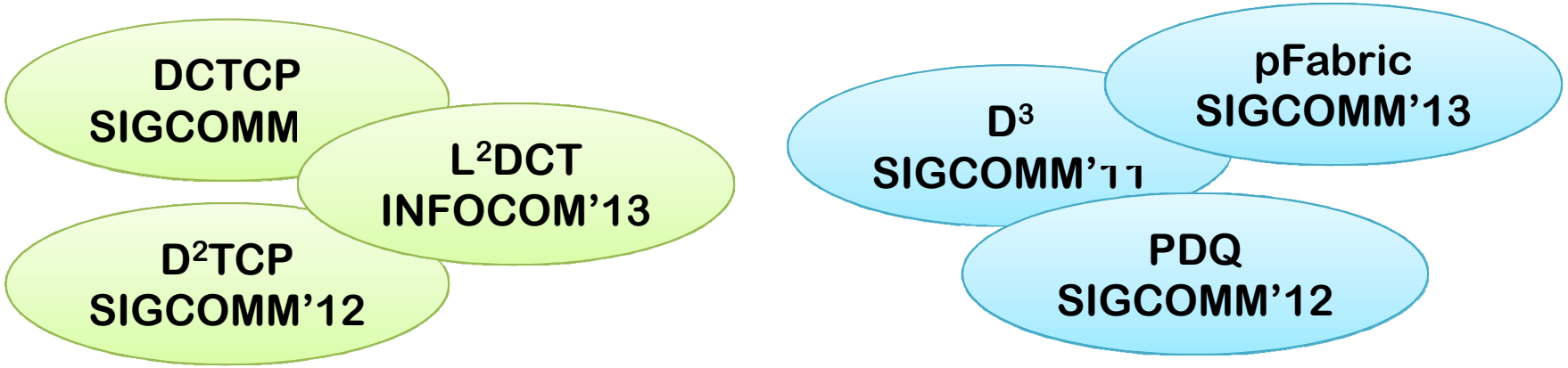
- **Fair Sharing**

  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



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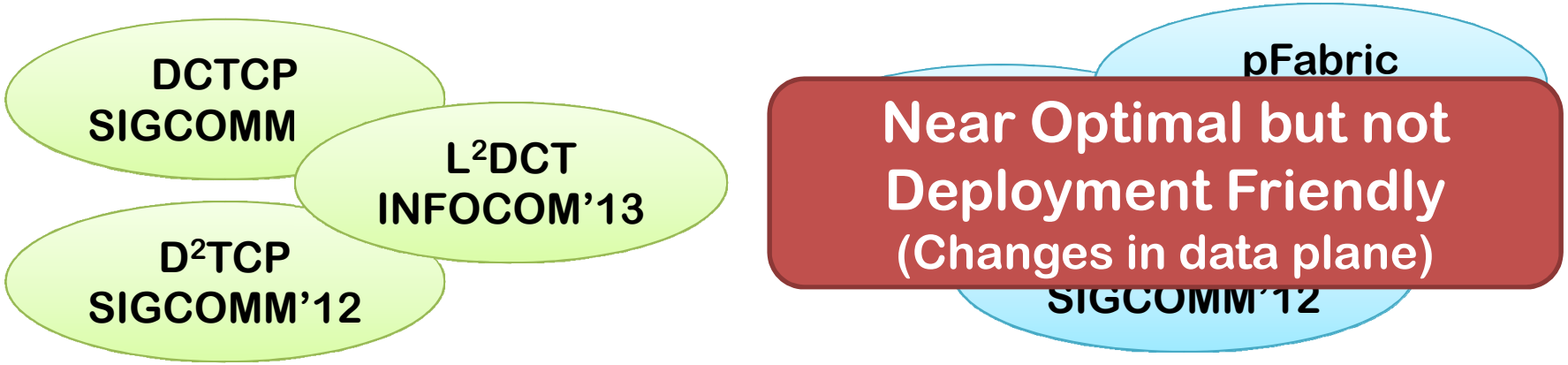

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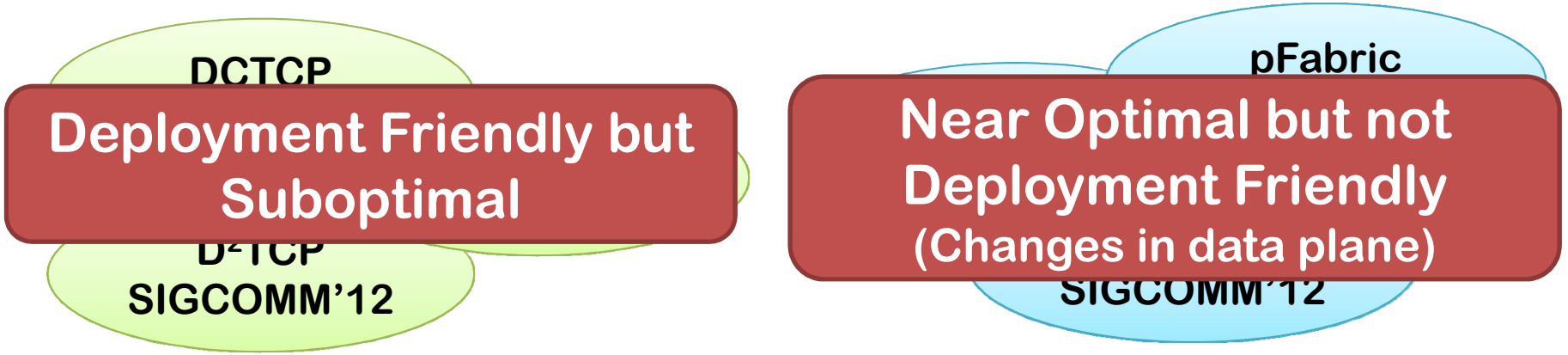

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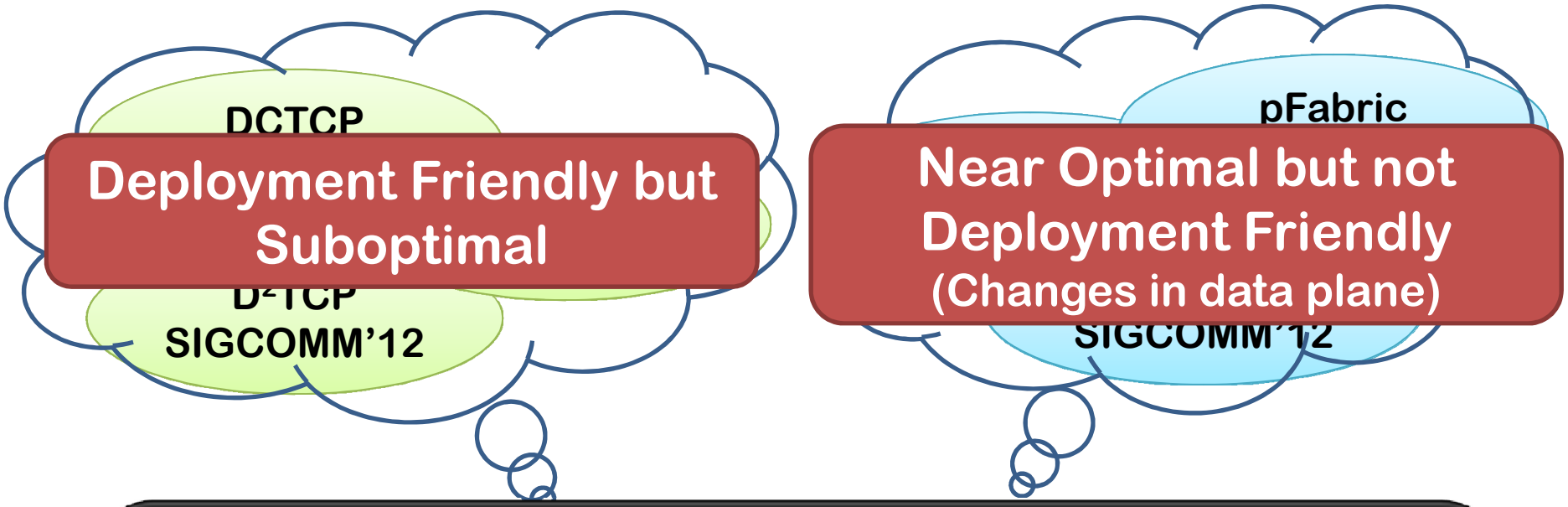
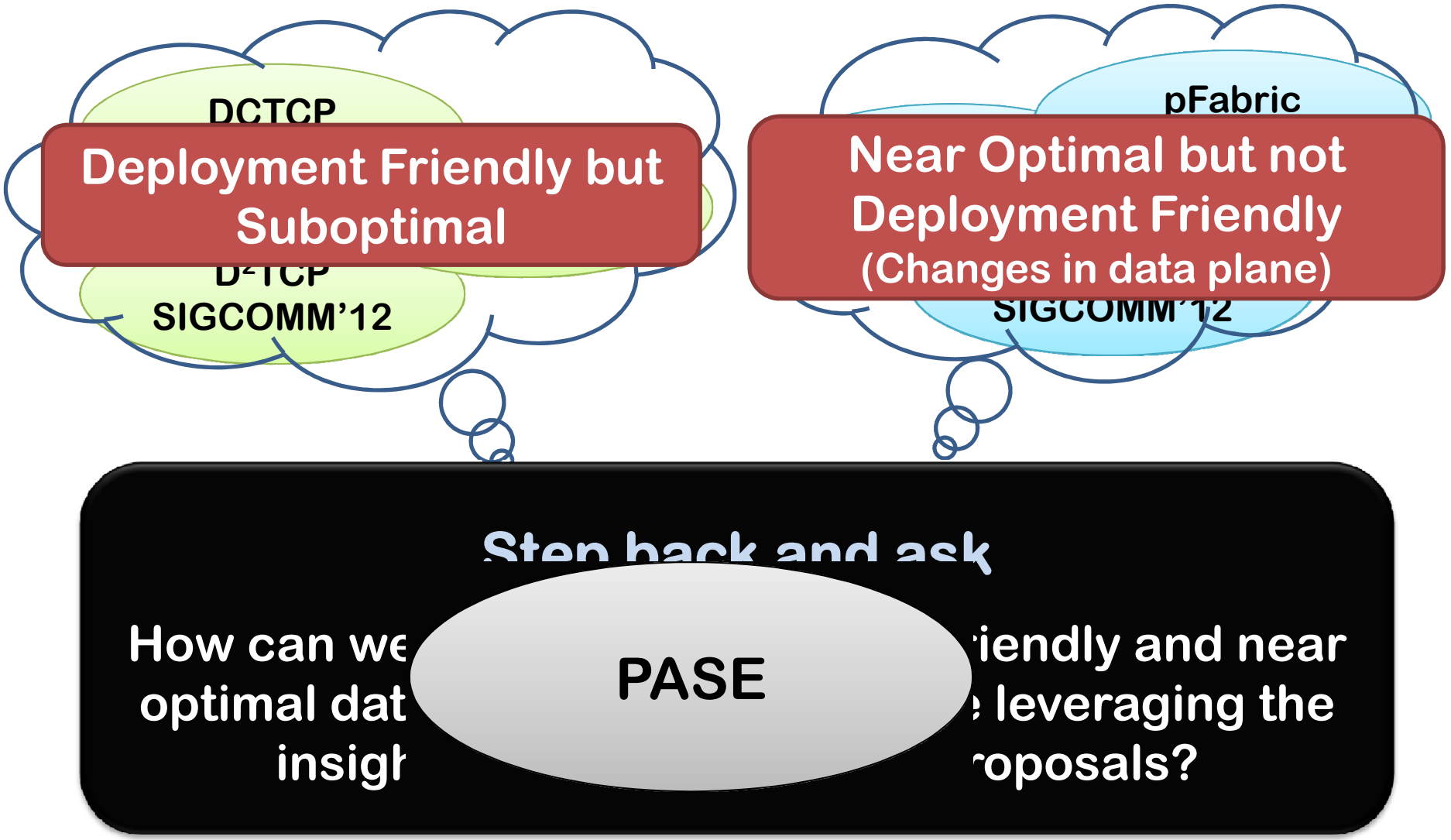


Step back and ask

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

DC Transports



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

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Existing DC transport proposals use only one of these strategies

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

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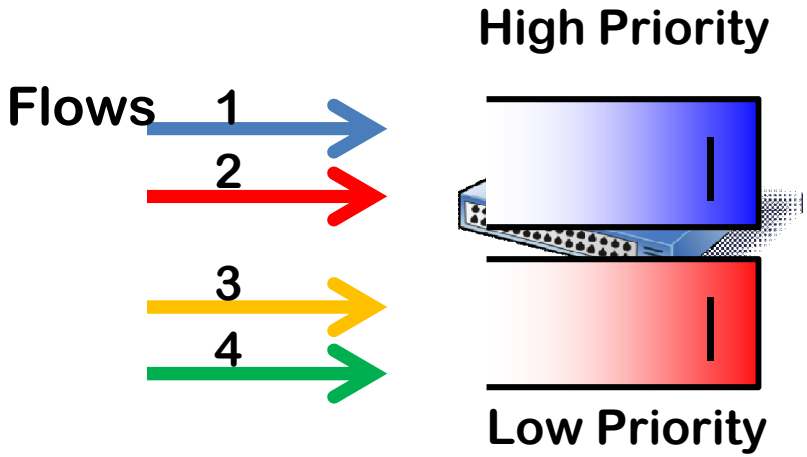
Transport Strategies in Unison

In-network Prioritization Alone

Limited # of queues

More # of flows (priorities)

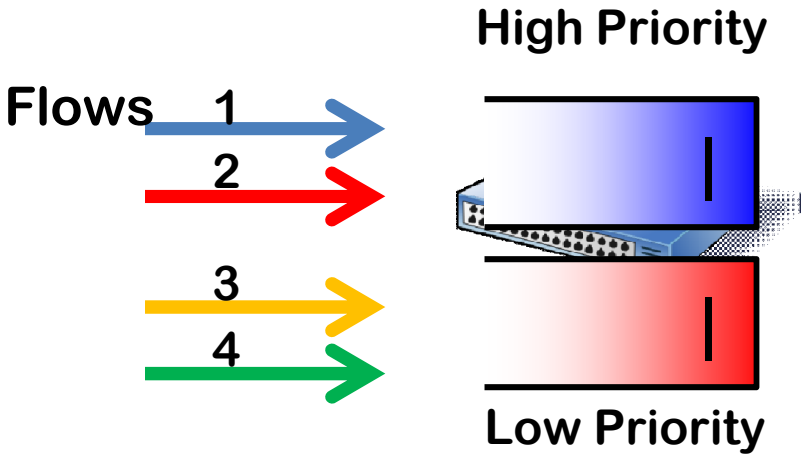


Transport Strategies in Unison

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!

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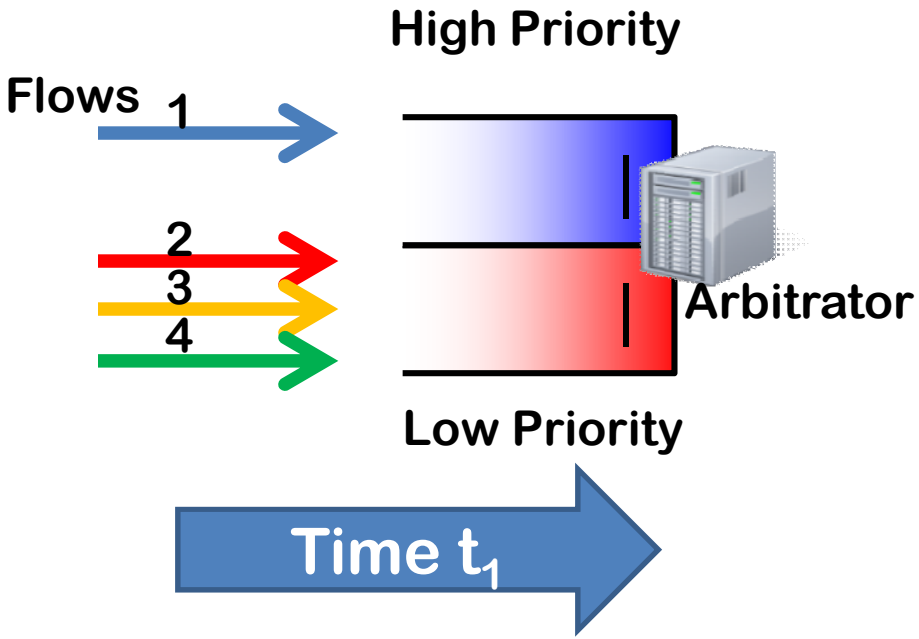

Transport Strategies in Unison

In-network Prioritization + Arbitration

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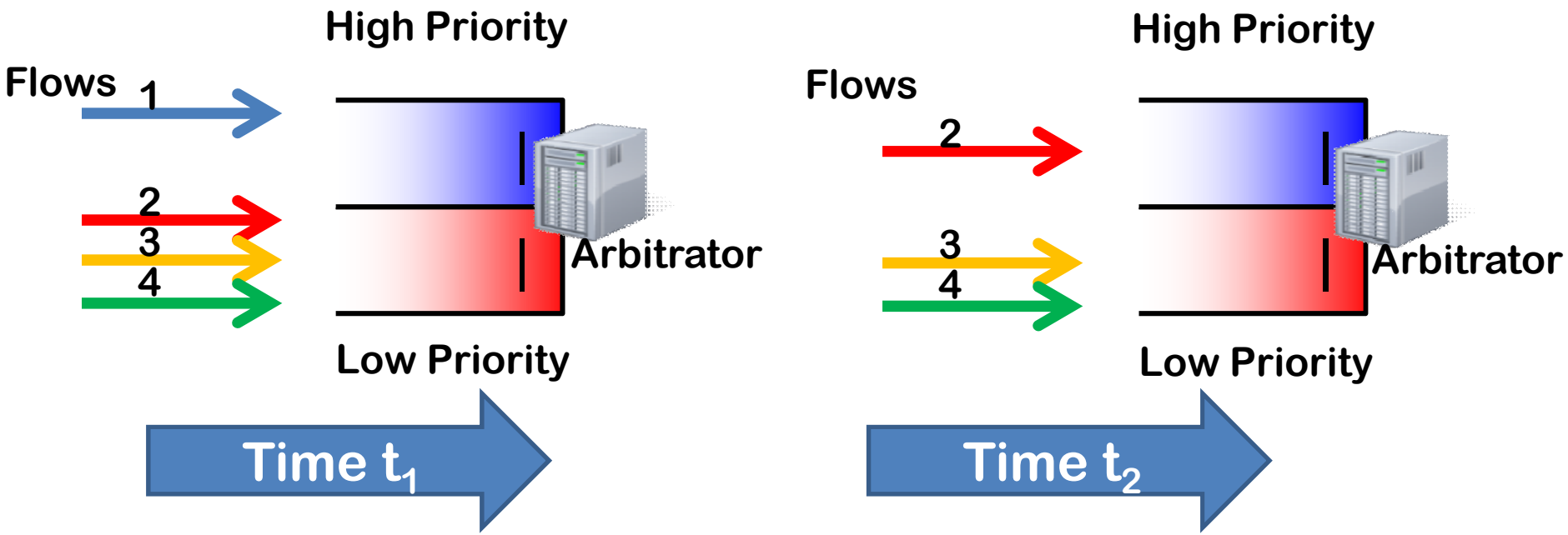

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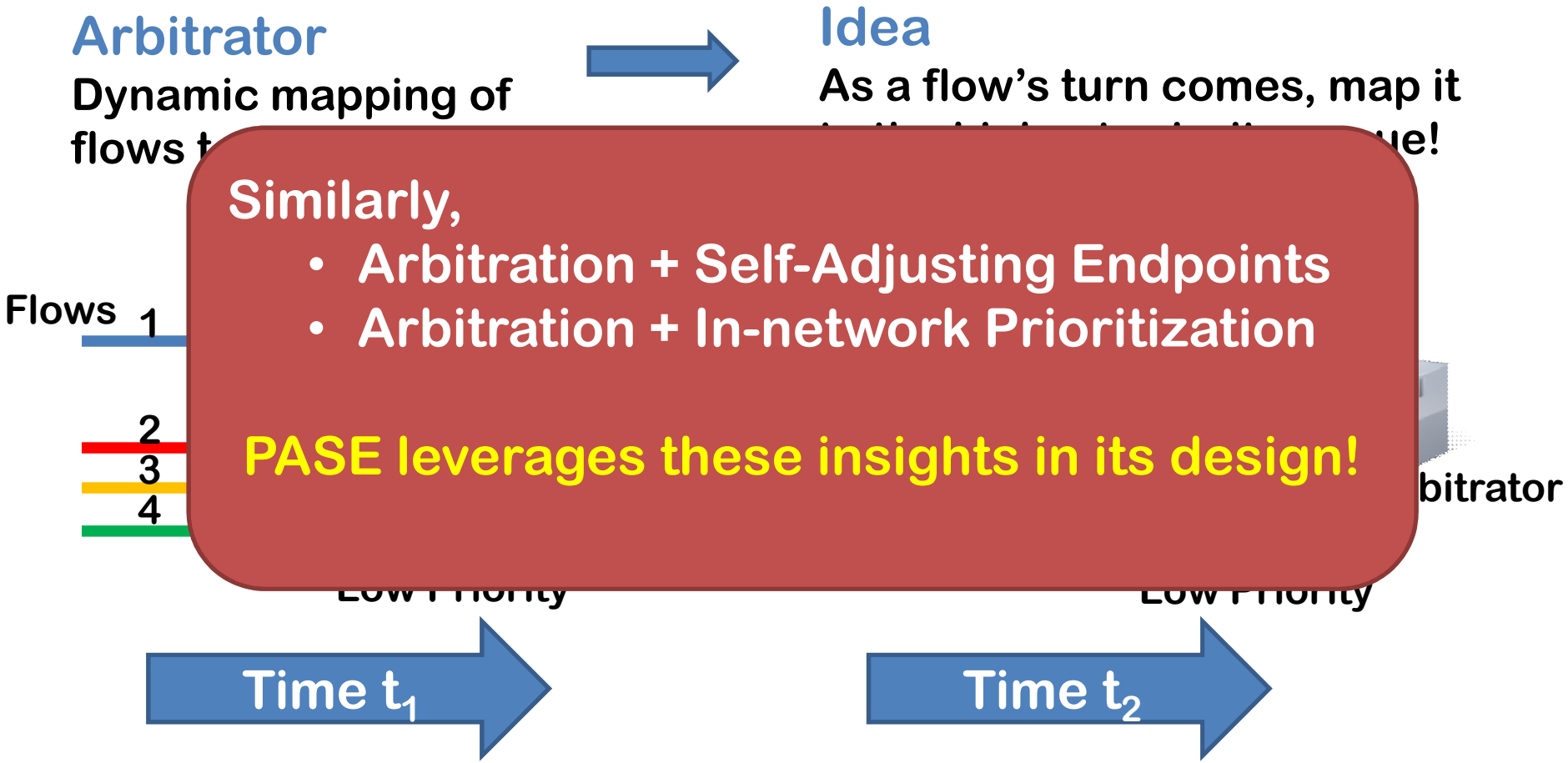


Rest of the Talk …

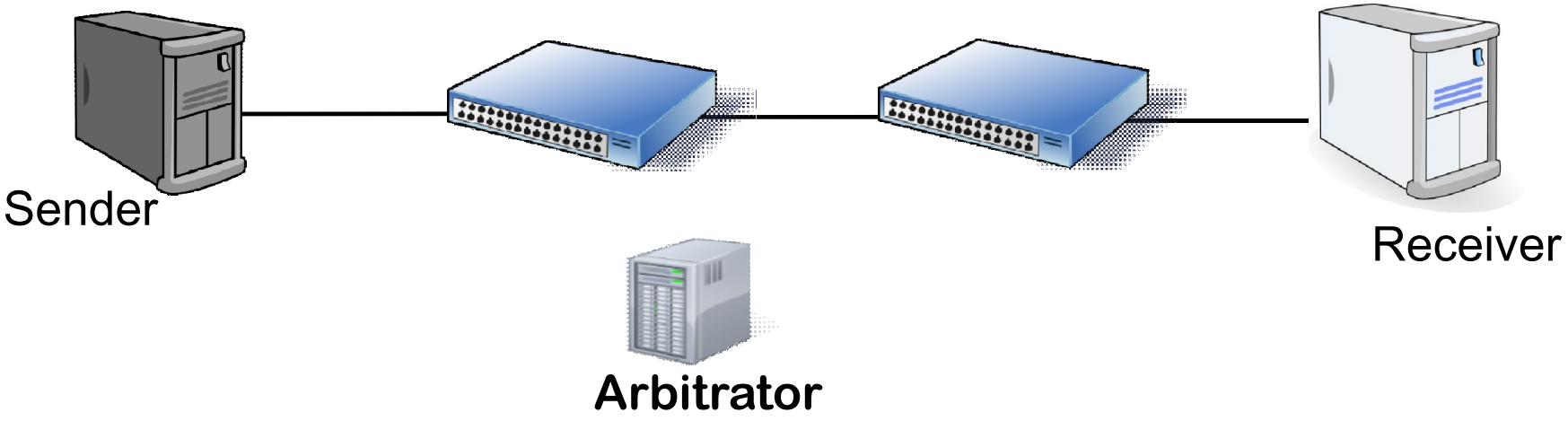
- DC Transport Strategies
- **PASE Design**
- Evaluation

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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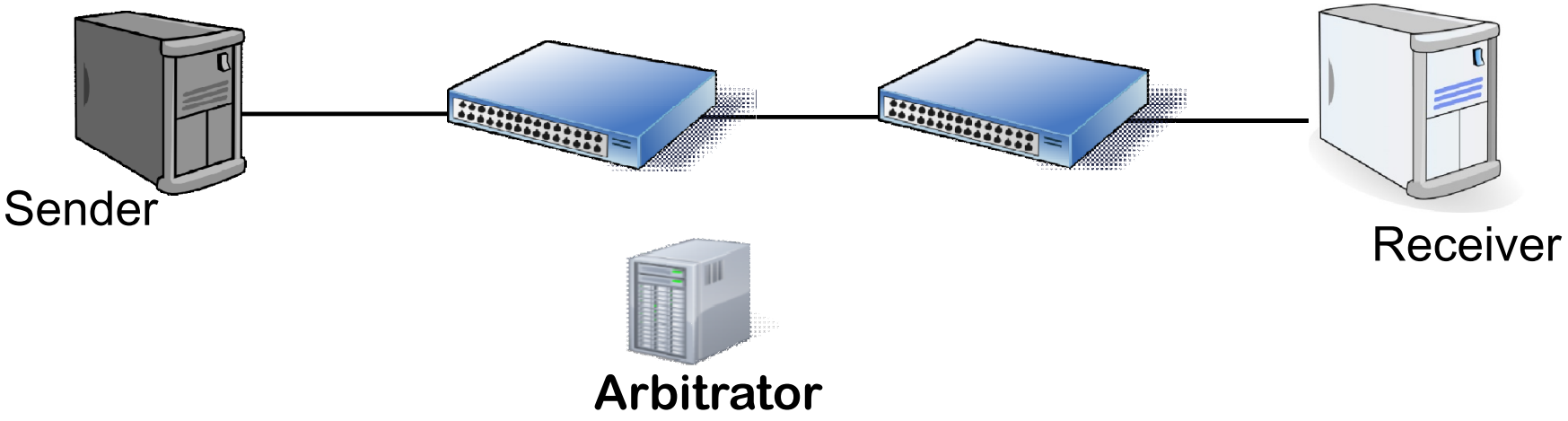

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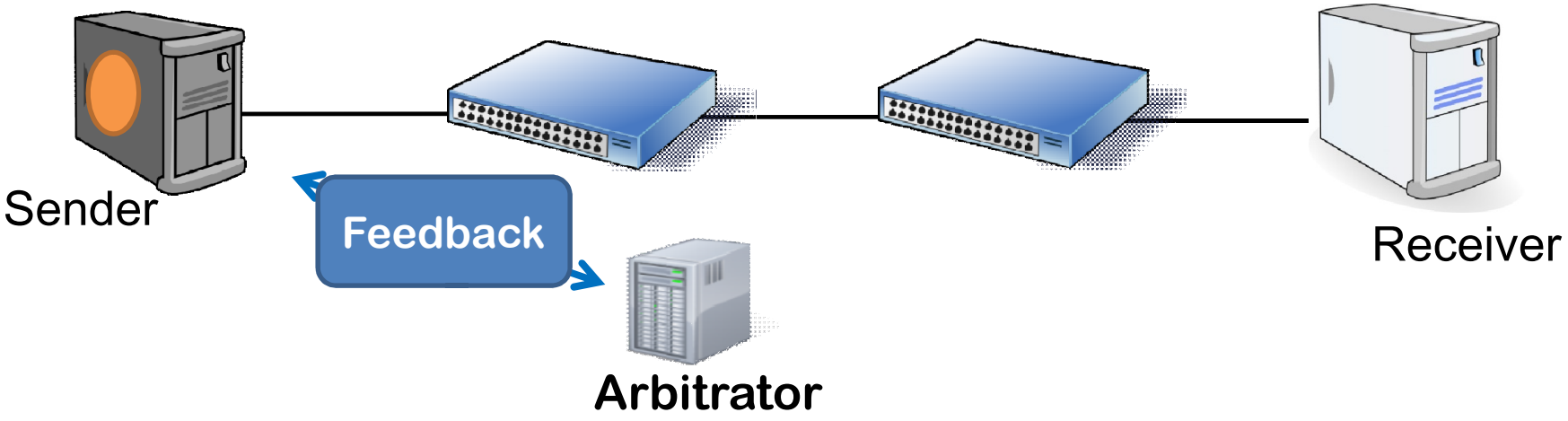

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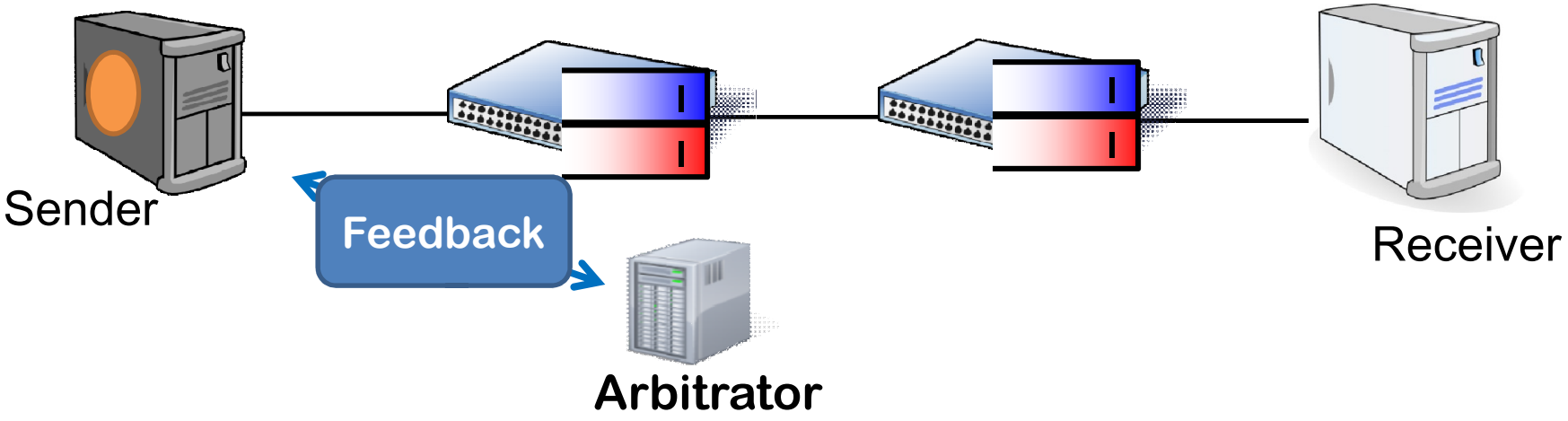

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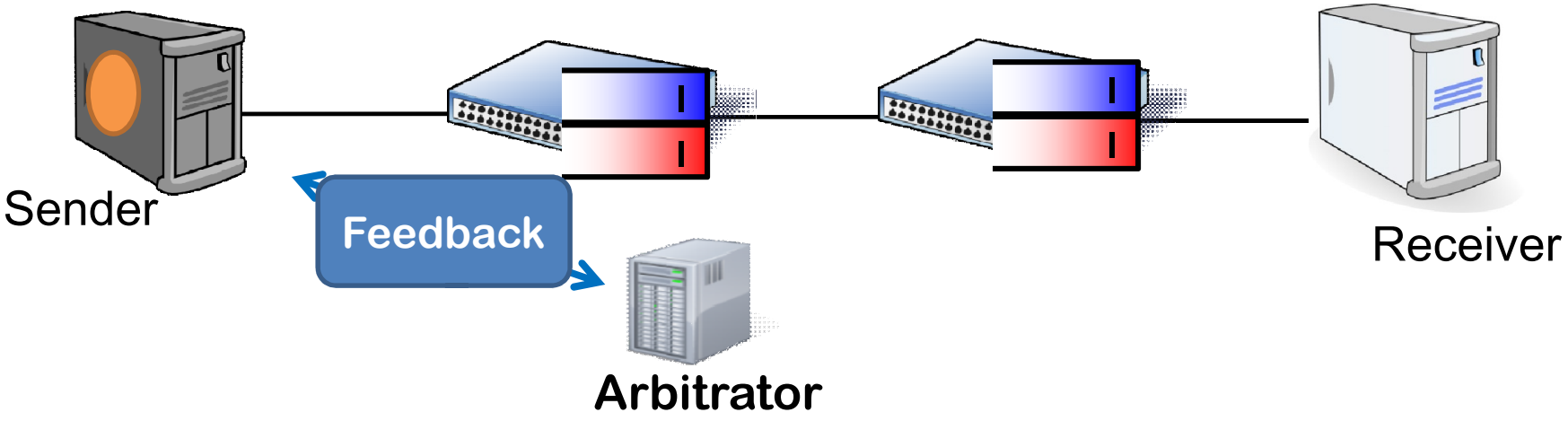

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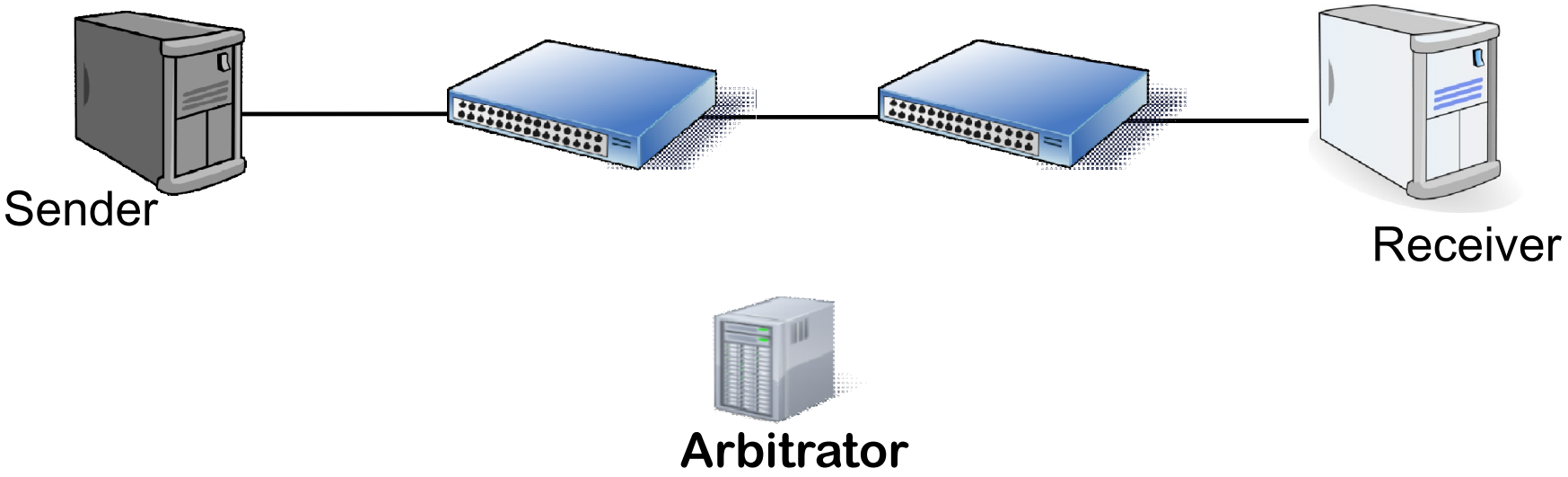
Key Components

PASE Arbitration



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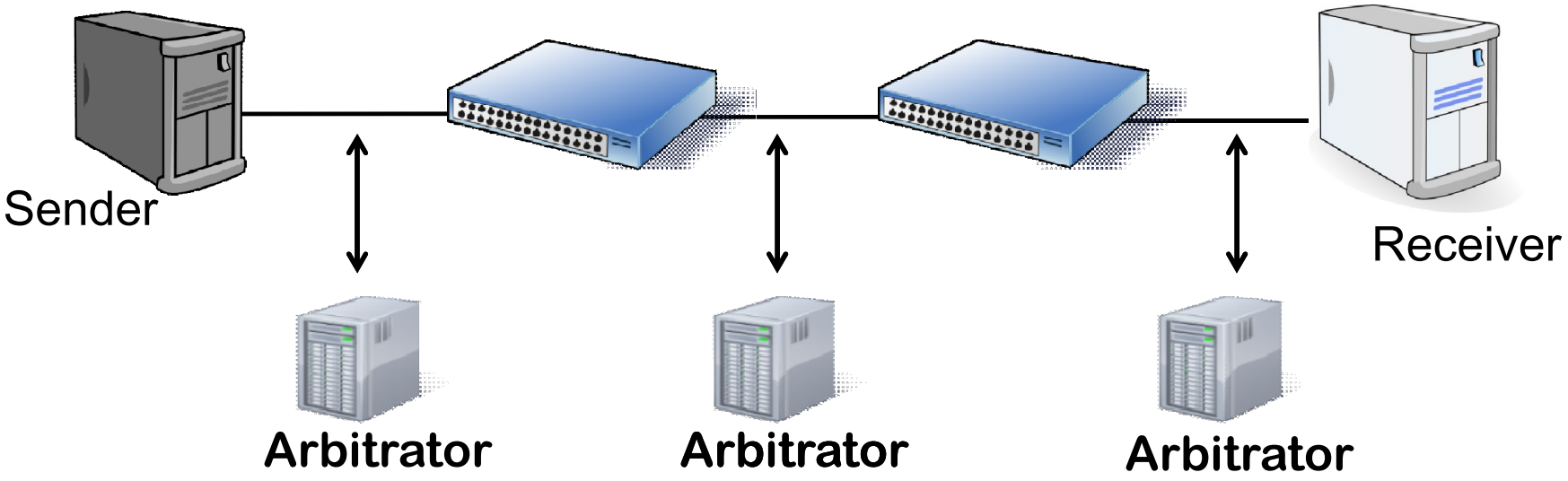

Distributed Arbitration

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

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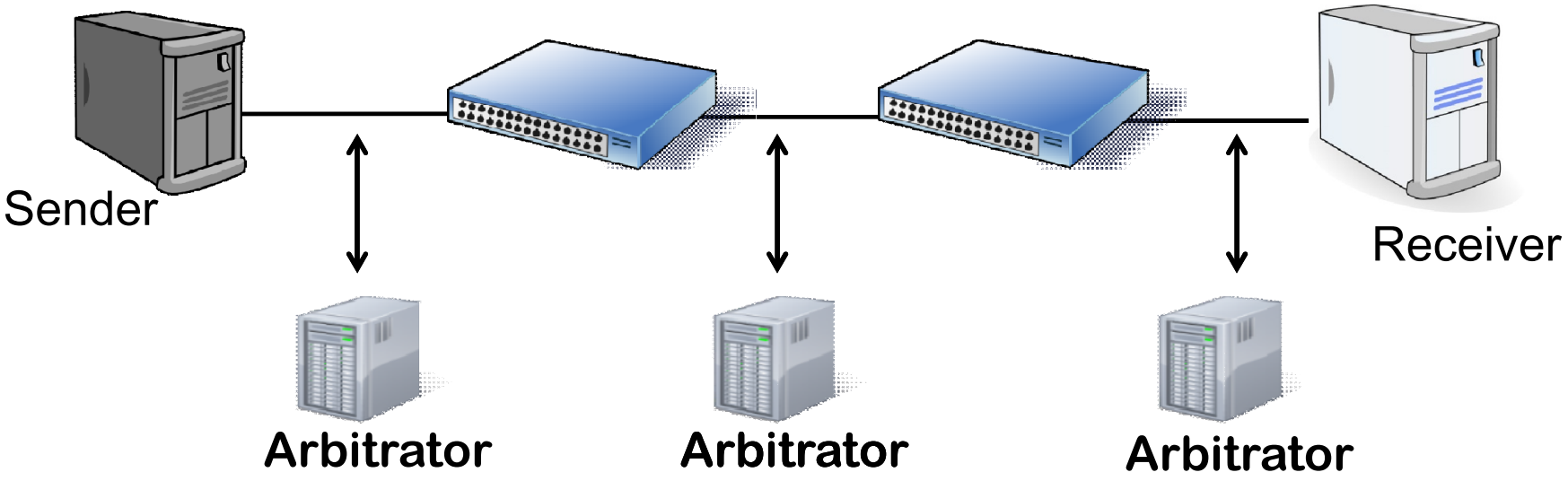

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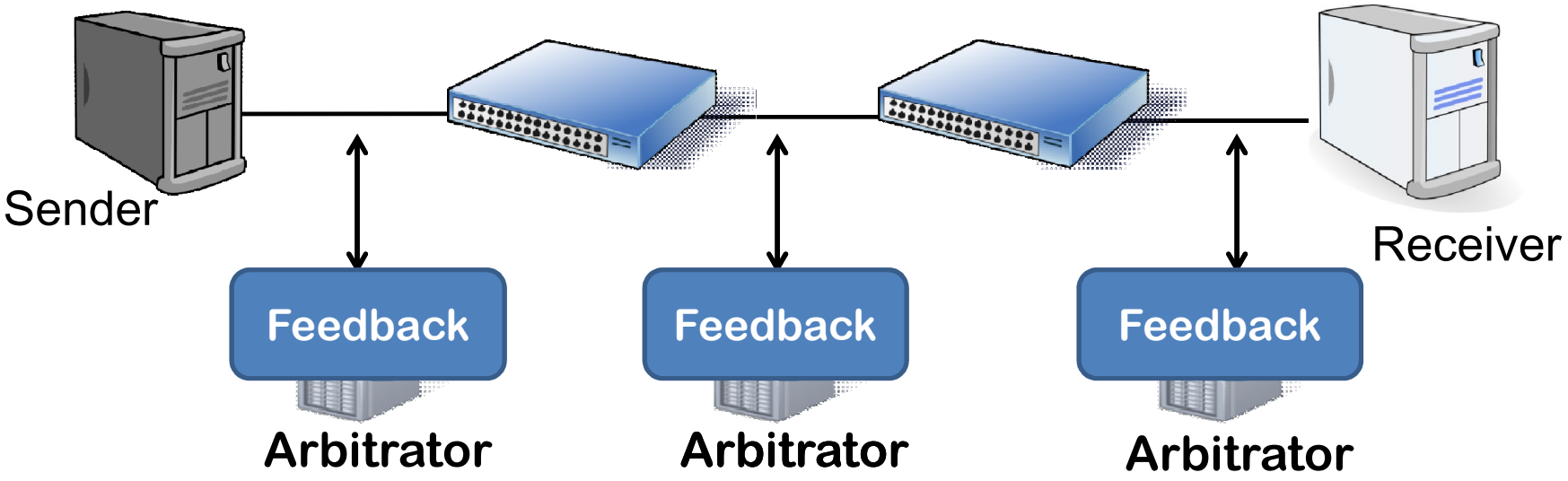

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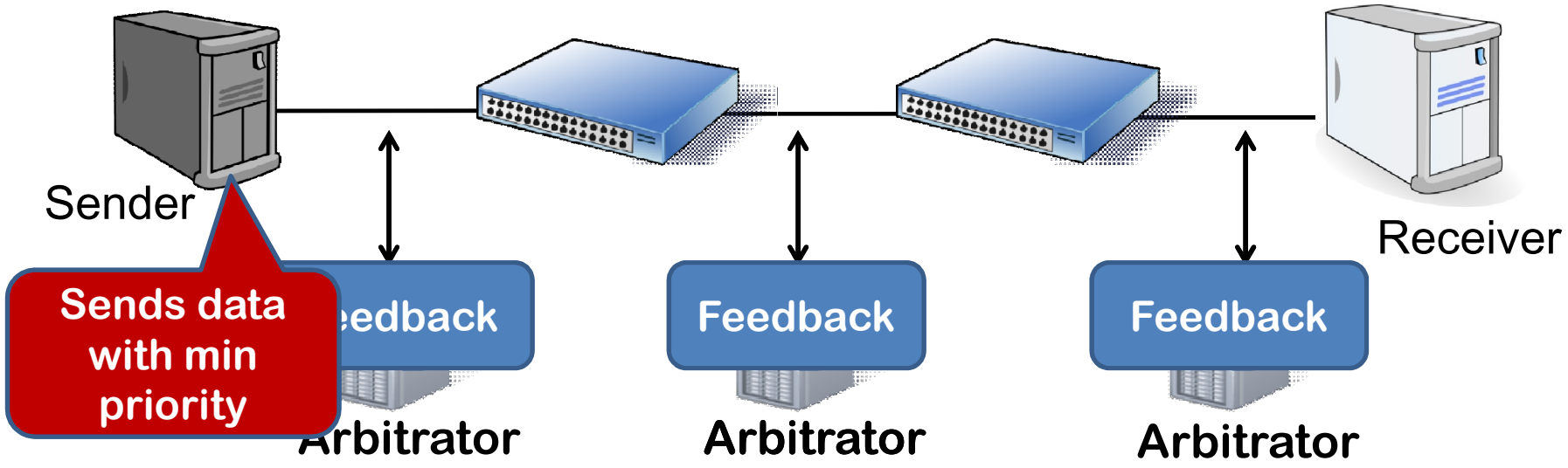

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PASE Arbitration – Challenges

- 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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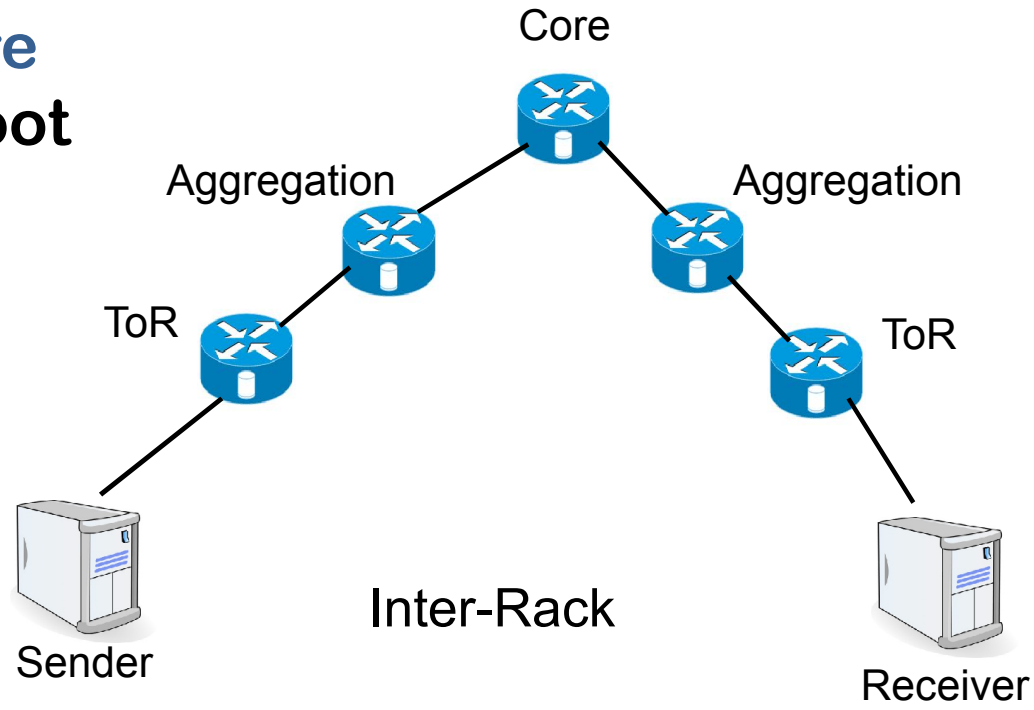

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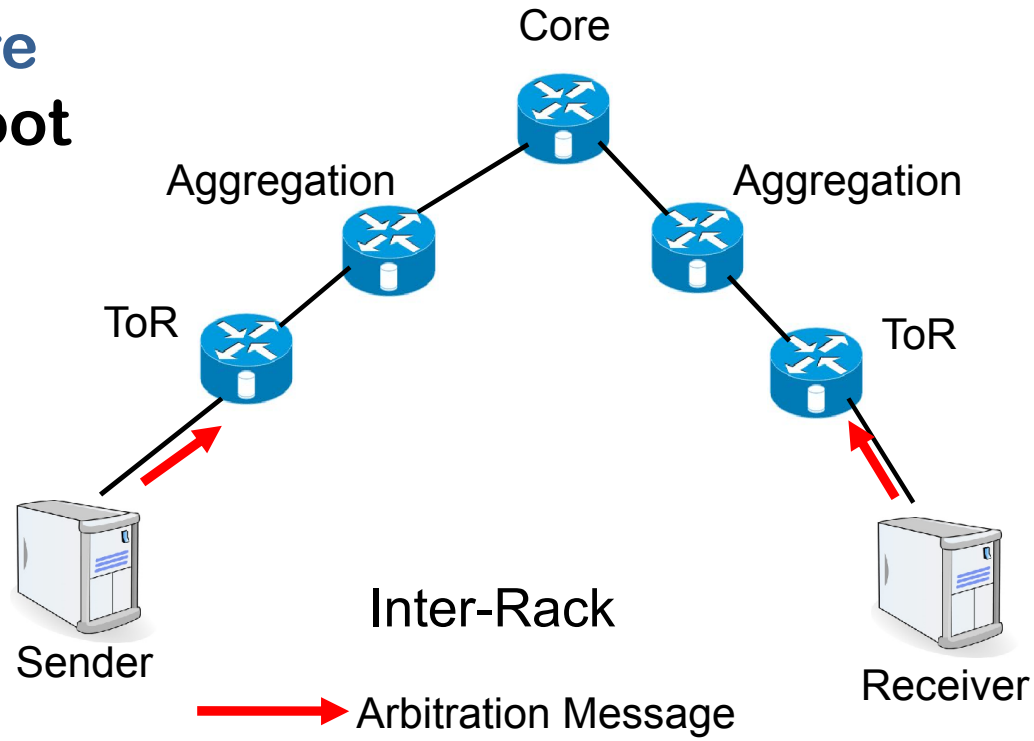

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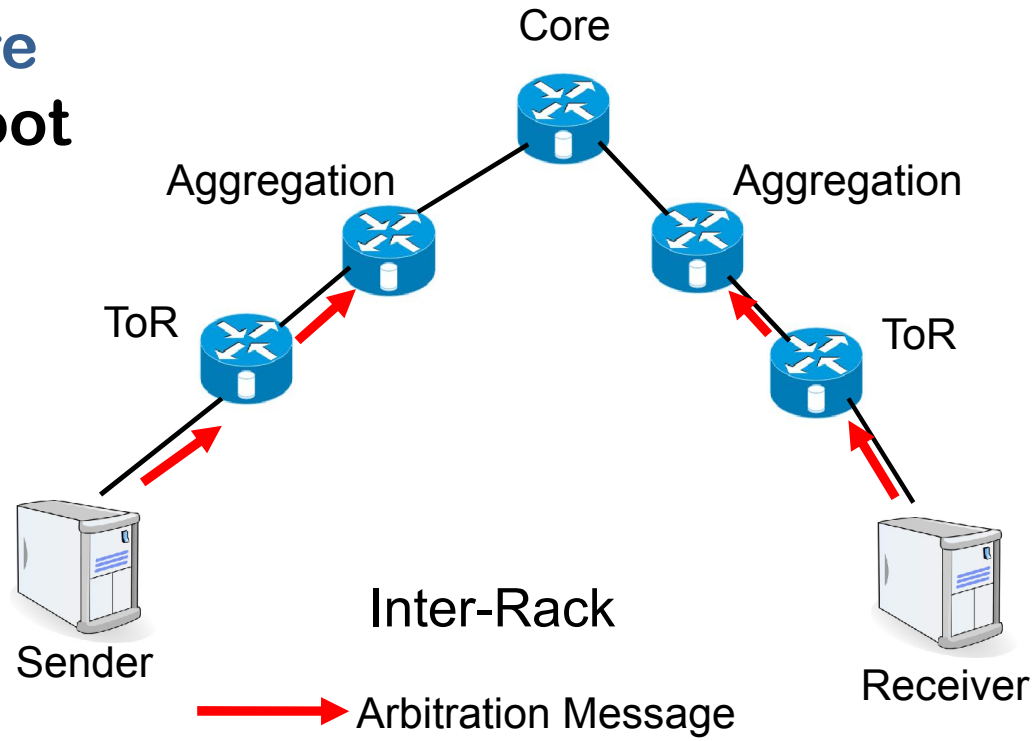

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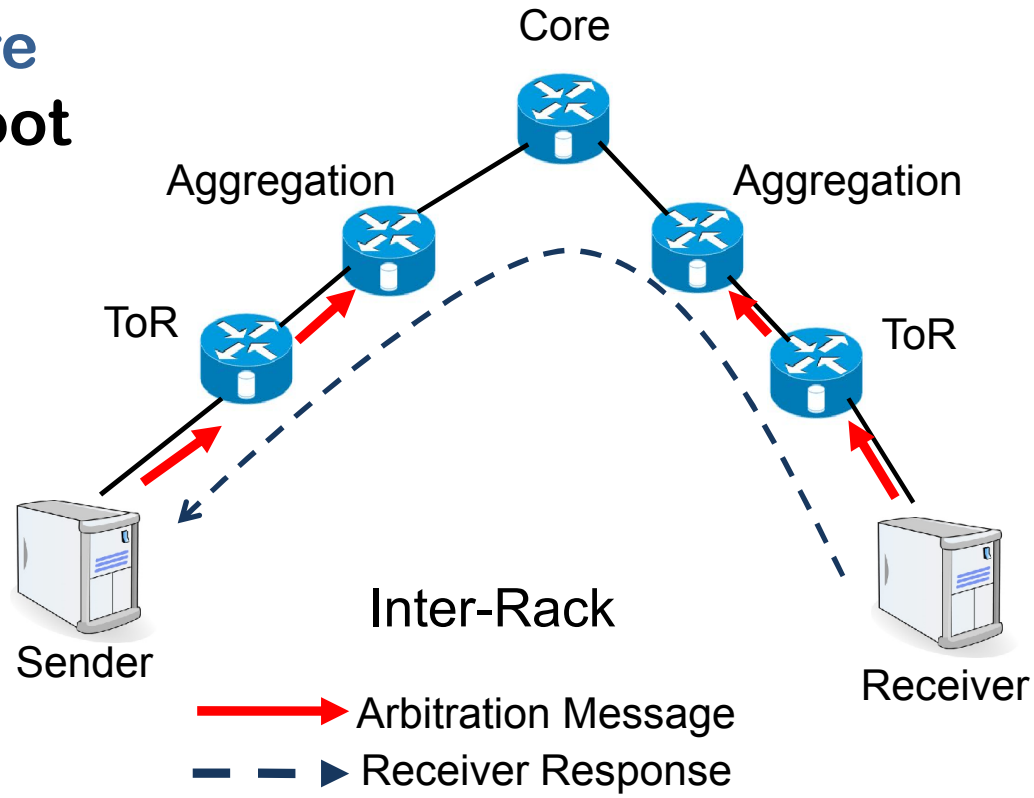

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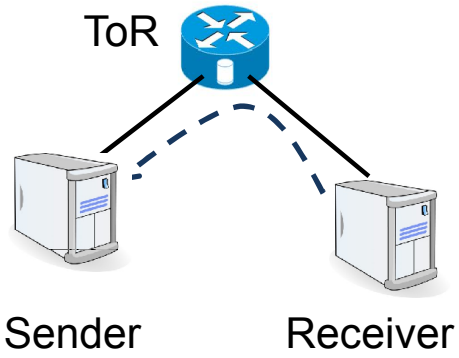
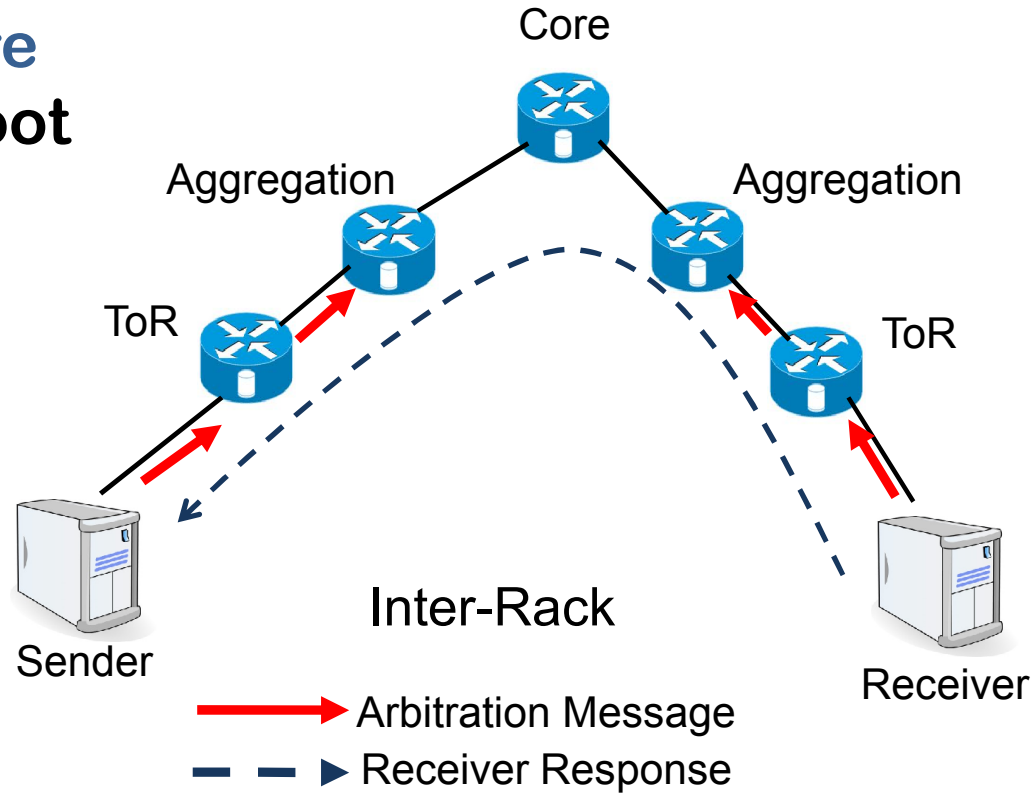


Intra-Rack

No external arbitrators required!



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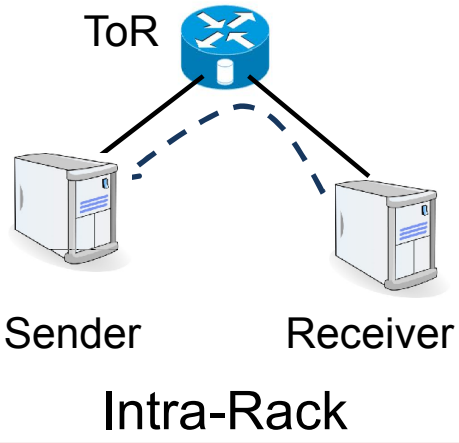

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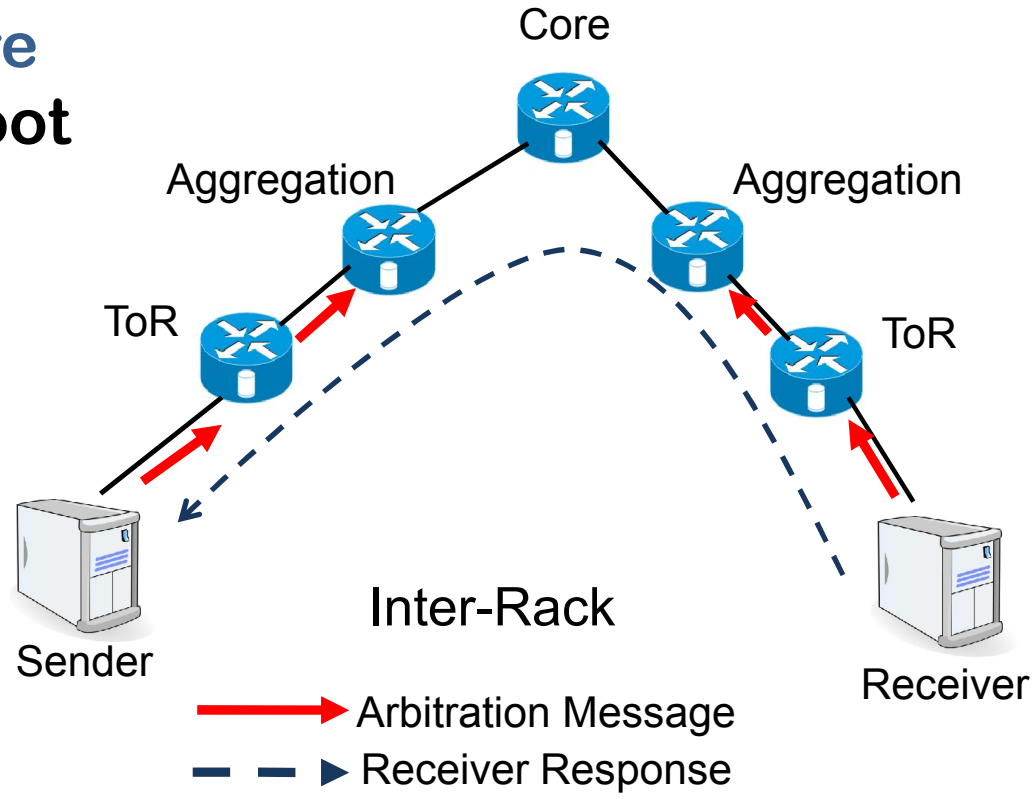
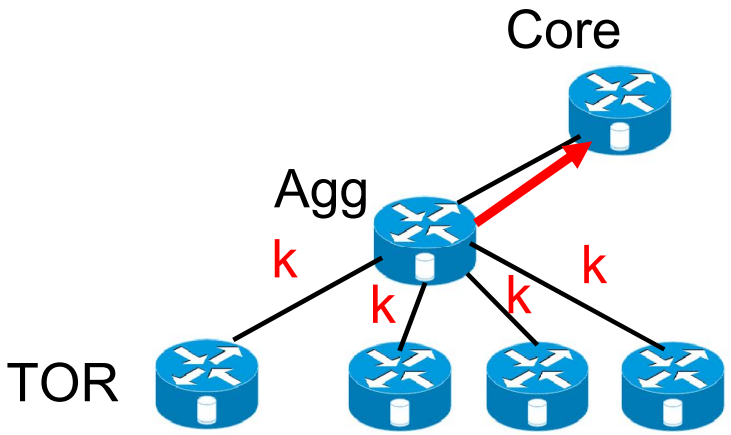


Facilitates inter-rack optimizations (early pruning & delegation) to reduce arbitration overhead.

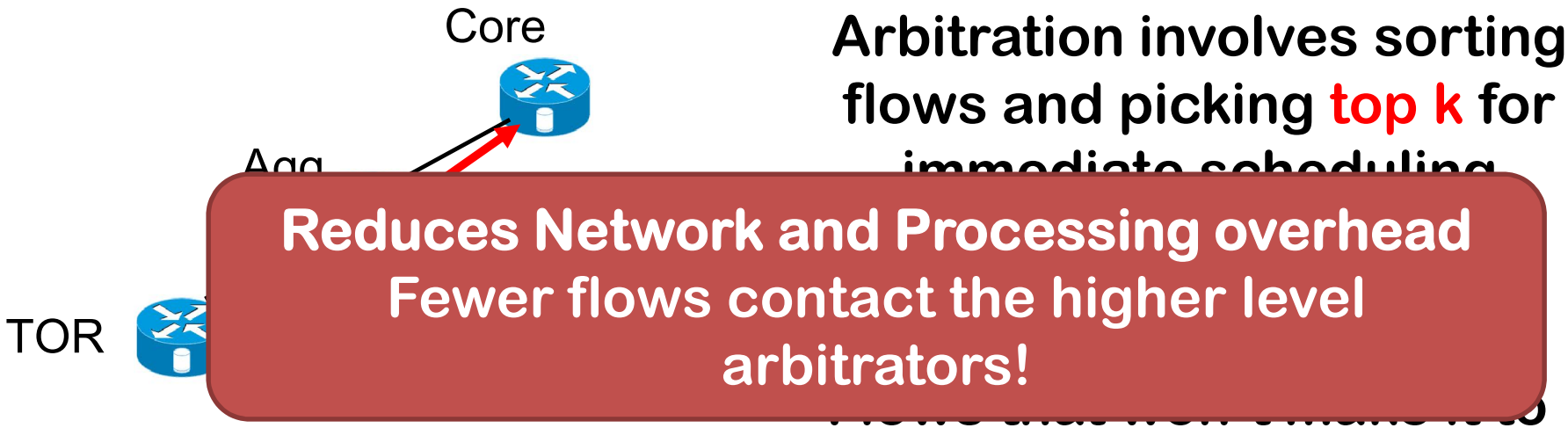
Early Pruning



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



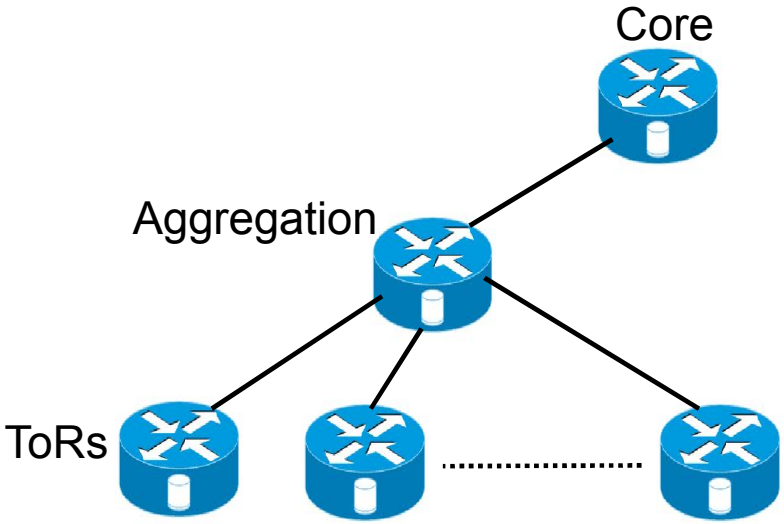
Arbitration involves sorting flows and picking top k for immediate scheduling

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

top k queues should be pruned at lower levels

Delegation

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



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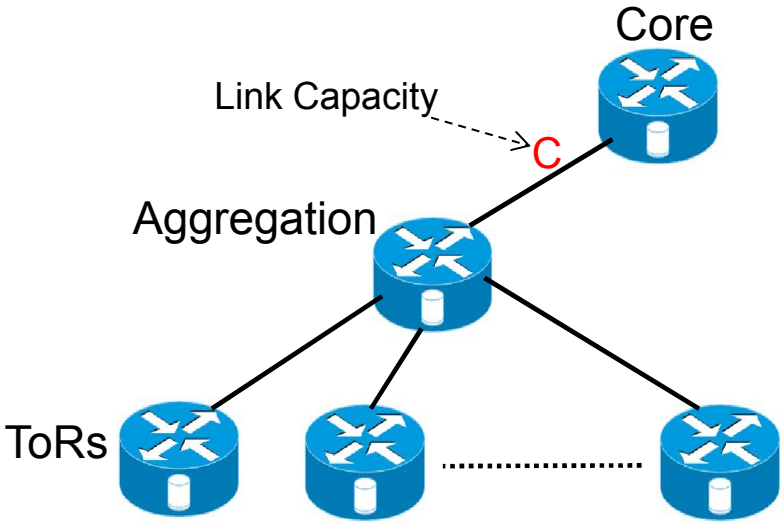

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  Link capacity C is split in N virtual links

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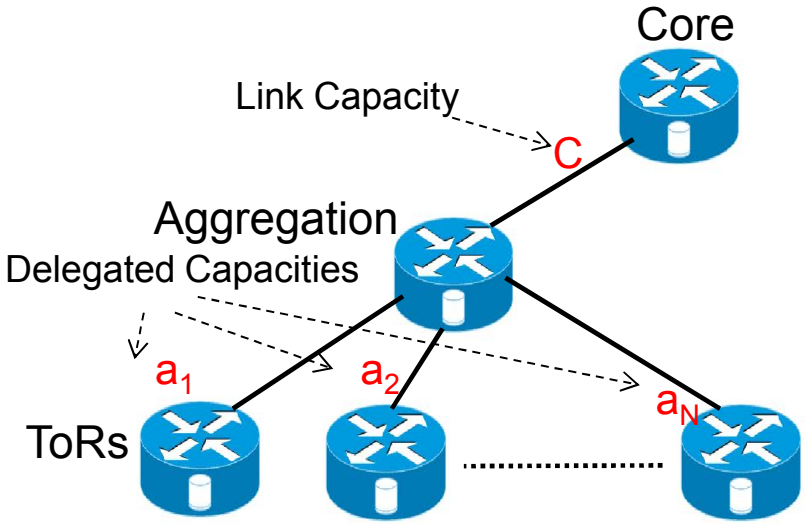

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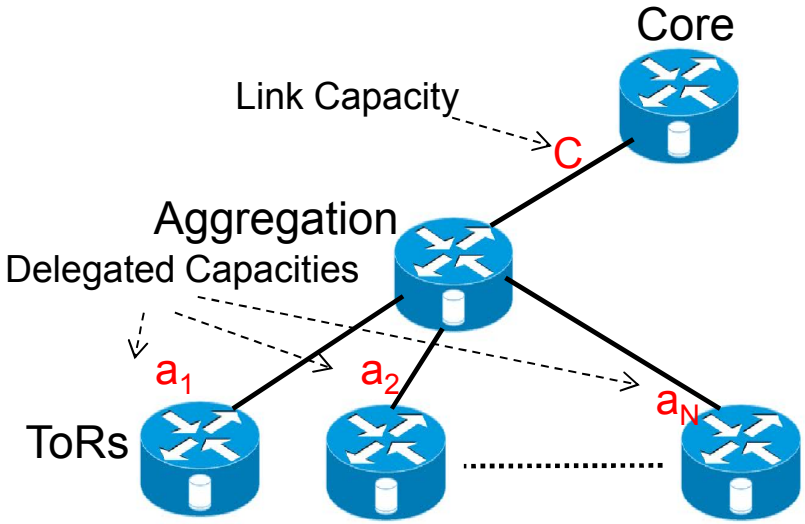

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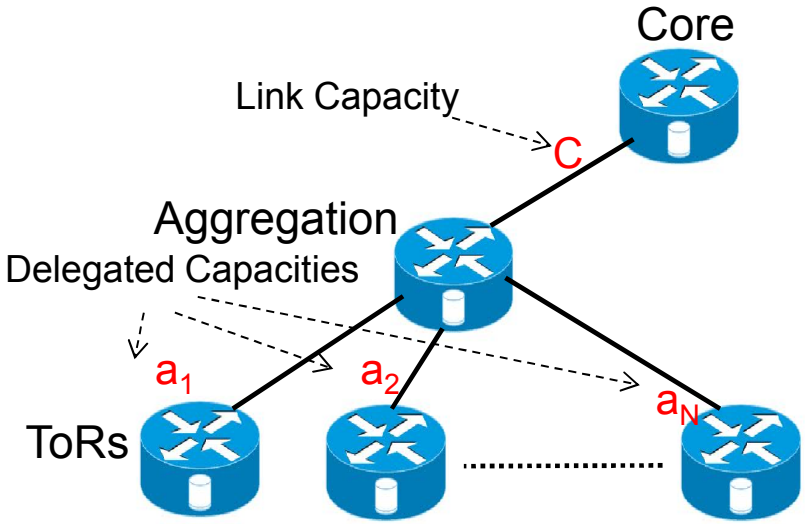

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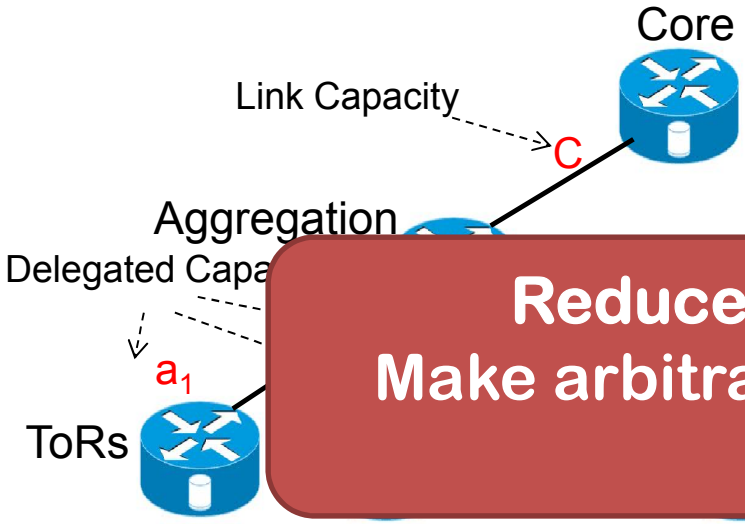

- **Algorithm**

  Link capacity C is split in N virtual links

  ates

  rator

Reduces Arbitration Latency
Make arbitration decision close to the sources

Child arbitrator does arbitration for virtual link

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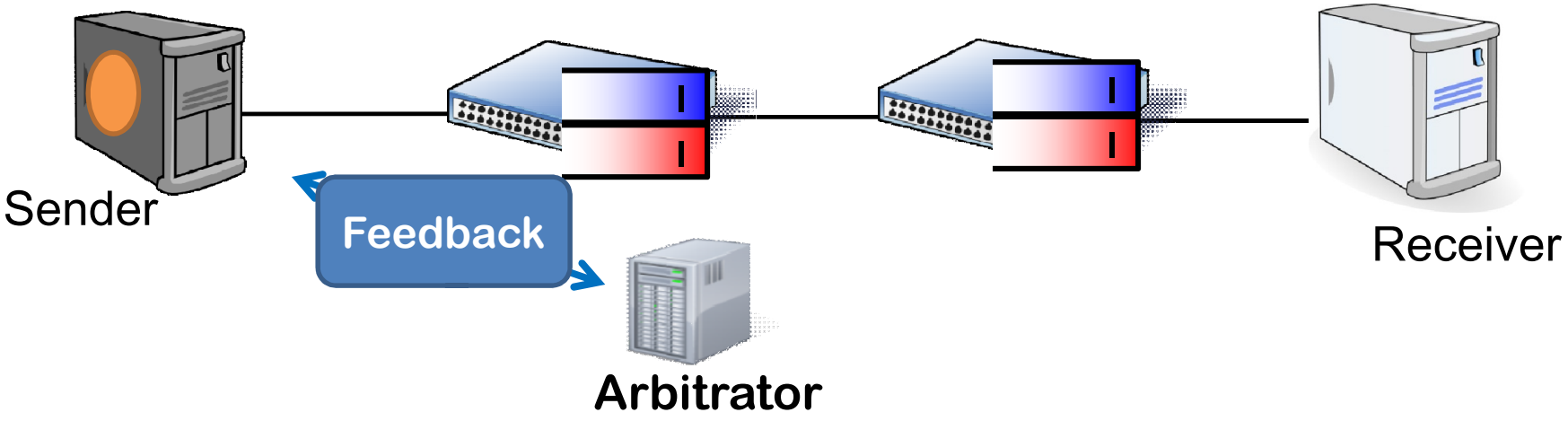
PASE Overview



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  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**

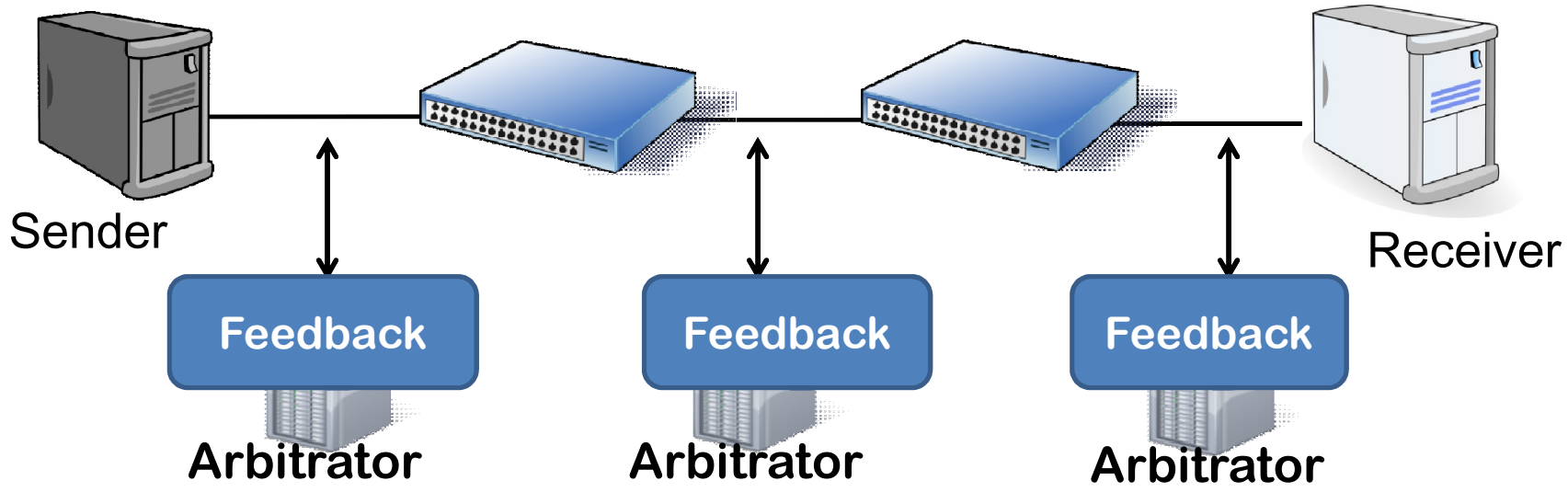
  Use reference rate and priority feedback from arbitrators

  - 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

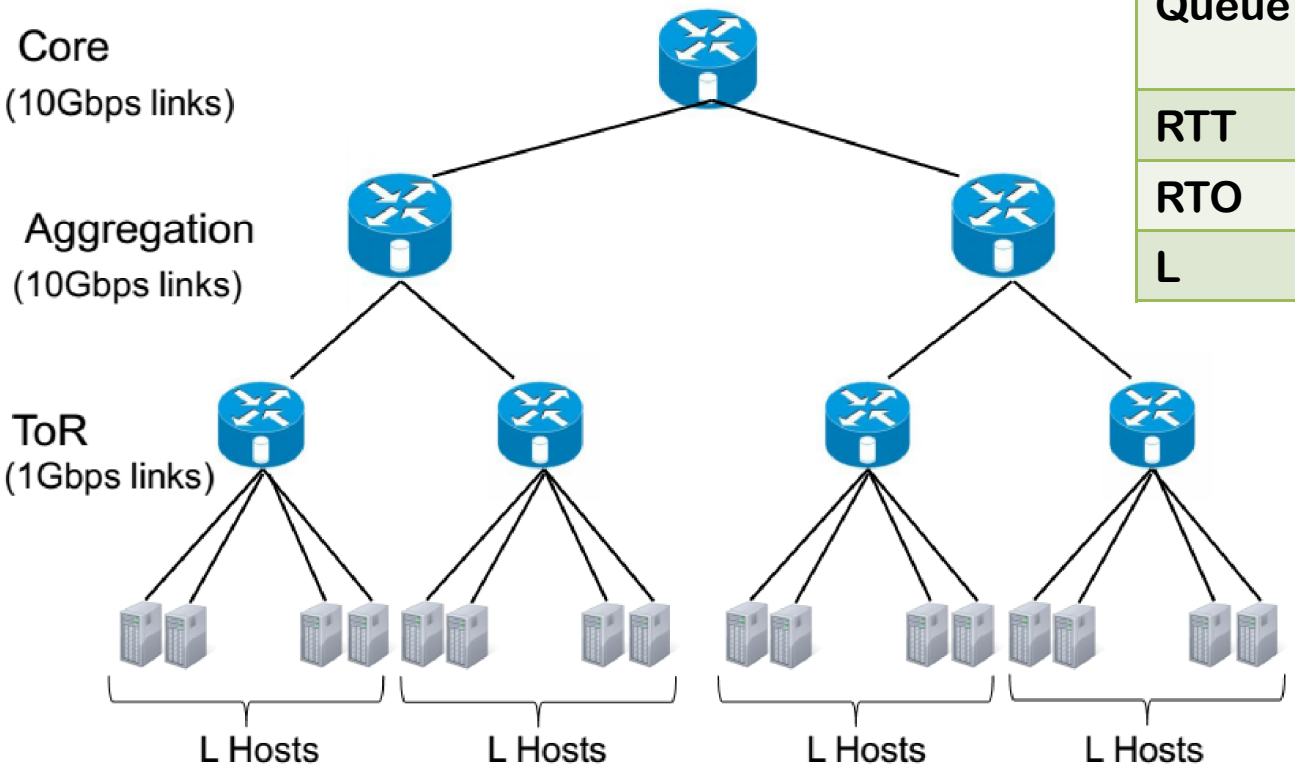
Rest of the Talk …

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

Evaluation

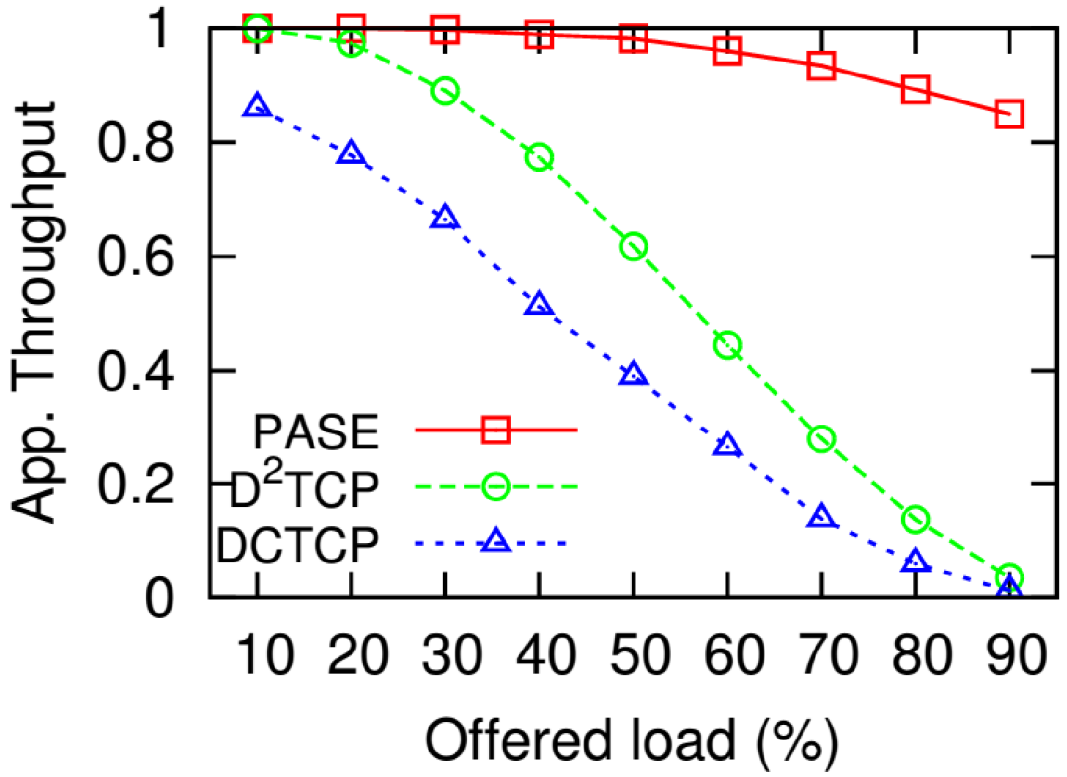
- **Platforms**
  - Small scale testbed
  - NS2
- **Workloads**
  - Web search (DCTCP), Data mining (VL2)
- **Comparison with deployment friendly**
  - DCTCP, D^2TCP, L^2DCT
- **Comparison with state of the art**
  - pFabric

Simulation Setup



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

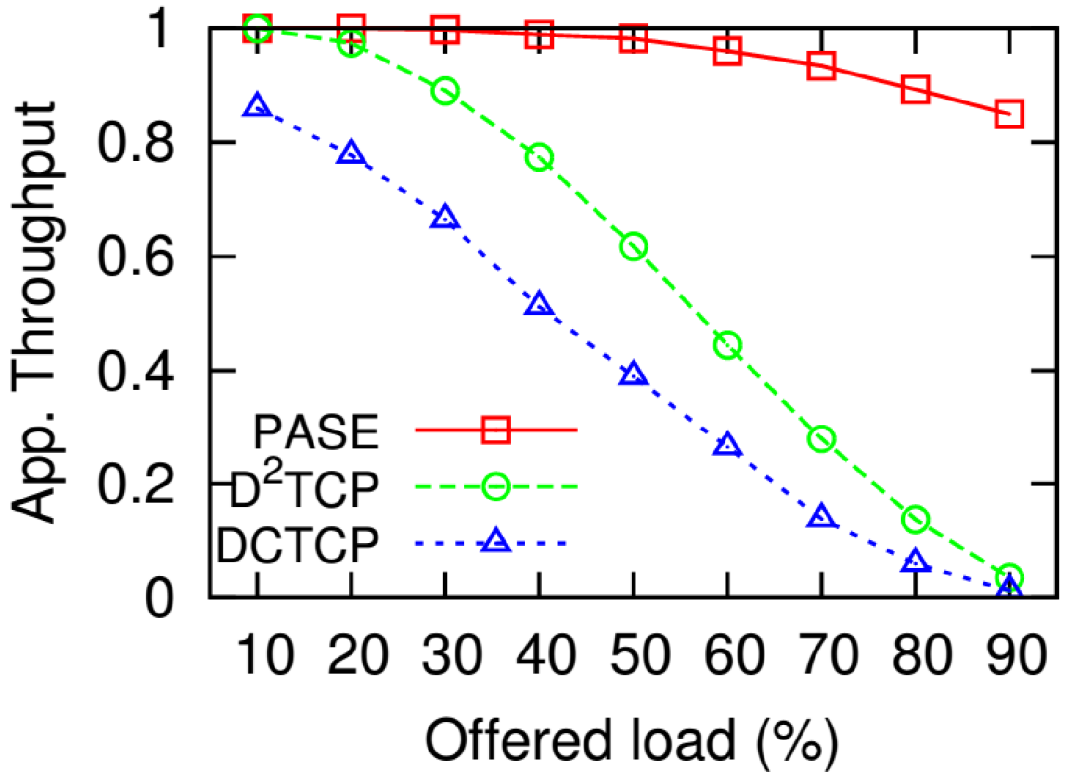
Comparison with Deployment Friendly



Settings similar to D²TCP

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

Comparison with Deployment Friendly

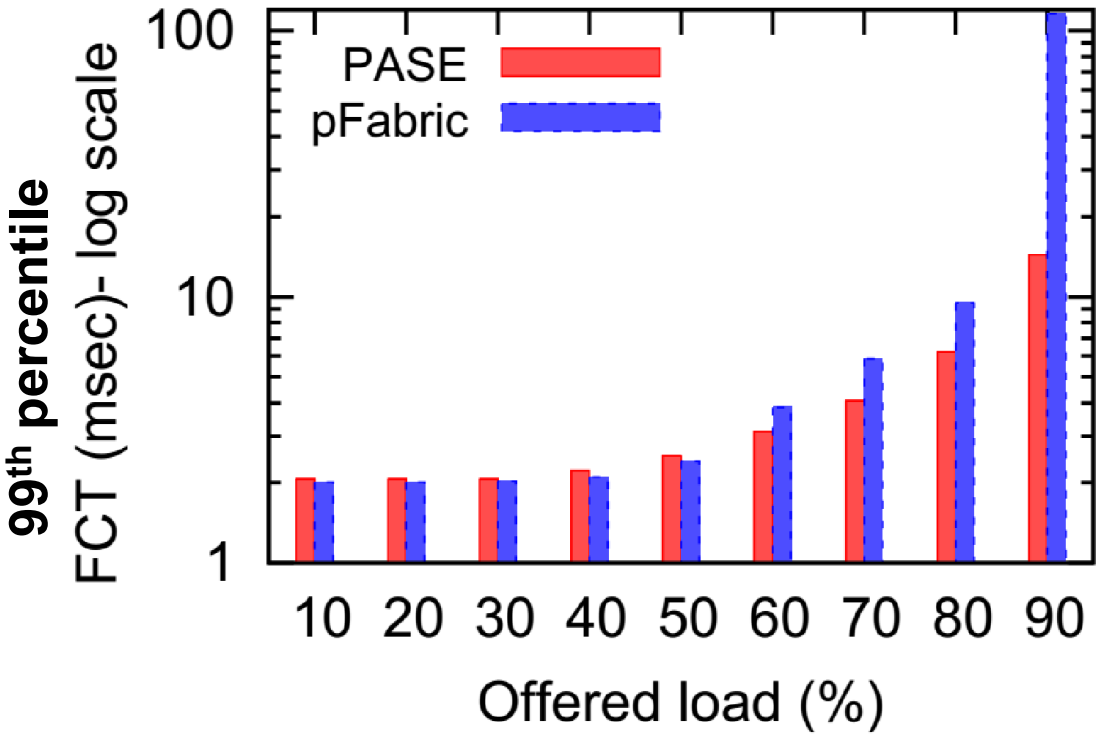


Settings similar to D²TCP

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

PASE is deployment friendly yet performs BETTER than existing protocols!

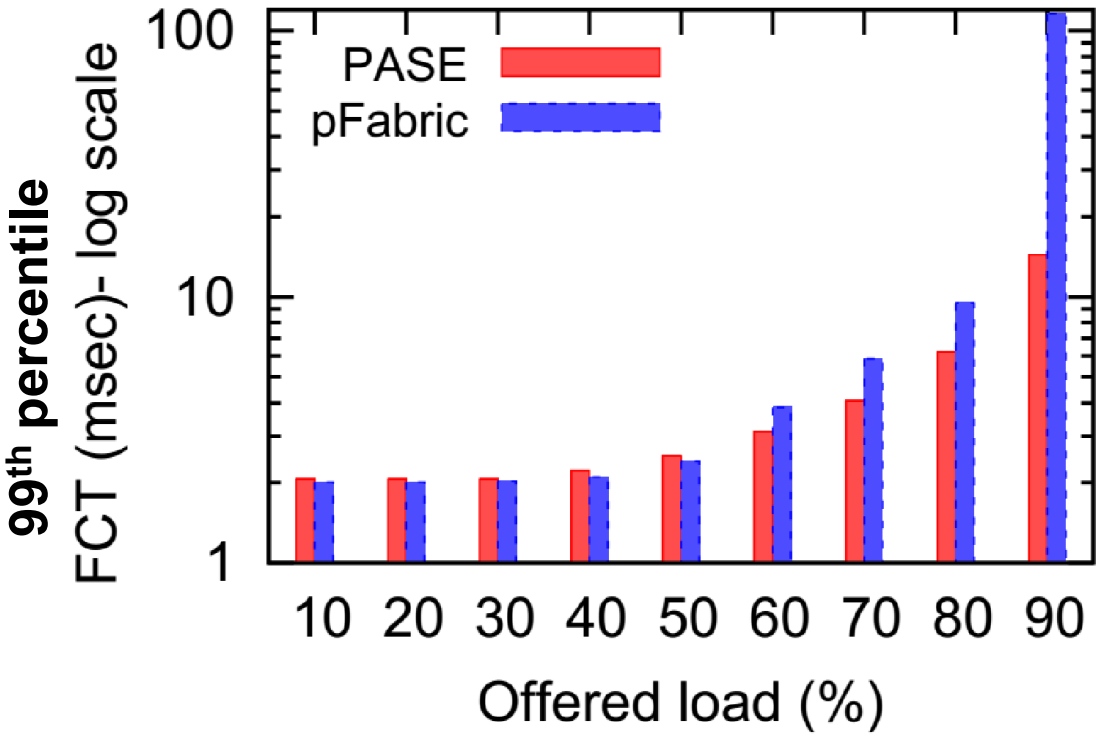
Comparison with State of the Art



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!