End-to-end Performance Isolation through Virtual Datacenters

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Enterprise datacenter
(single tenant)

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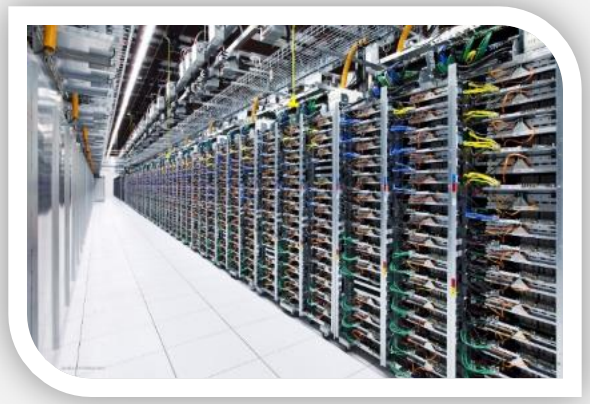


Cloud datacenters
(multiple tenants)

Cloud datacenters offer services implemented by appliances

- Persistent storage

Key-value store

Blockstore

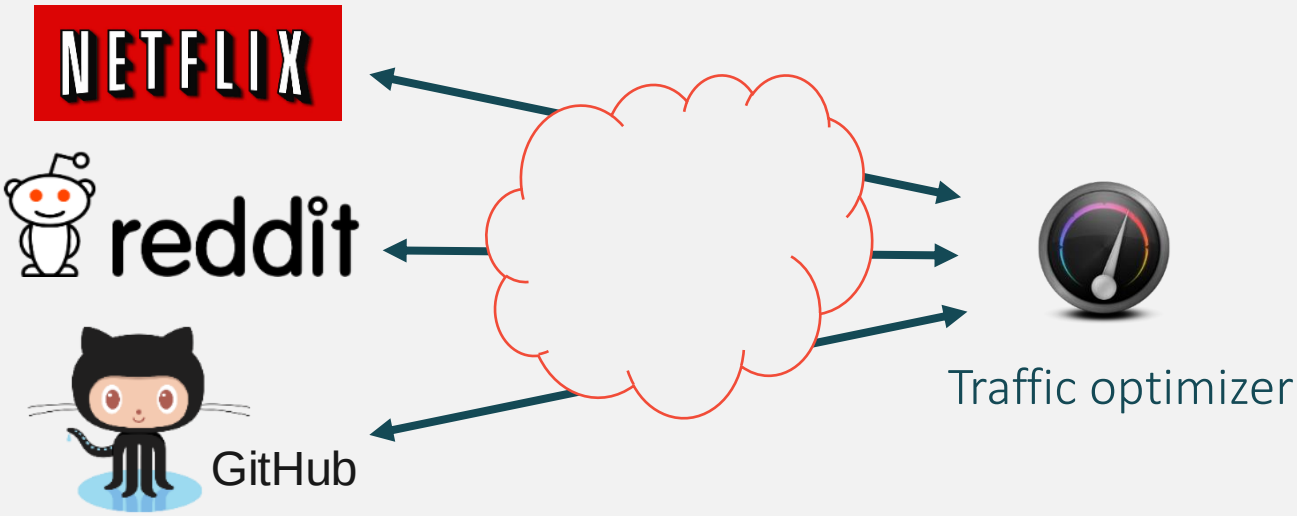
- Middleboxes

Load balancer

Encryption device

Traffic optimizer

Appliances (and the network) are shared among tenants



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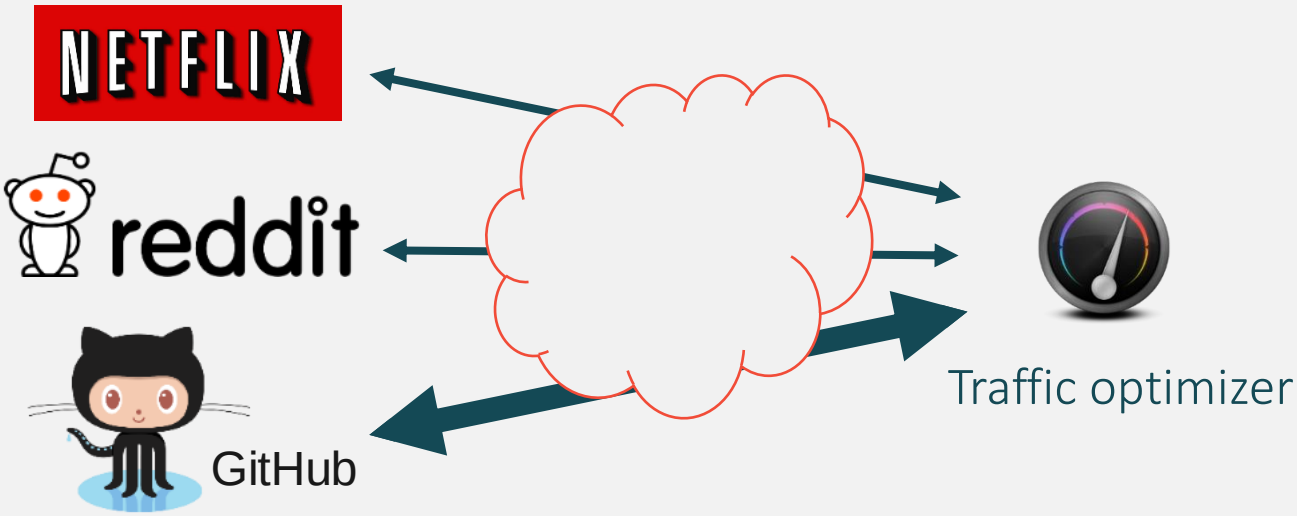

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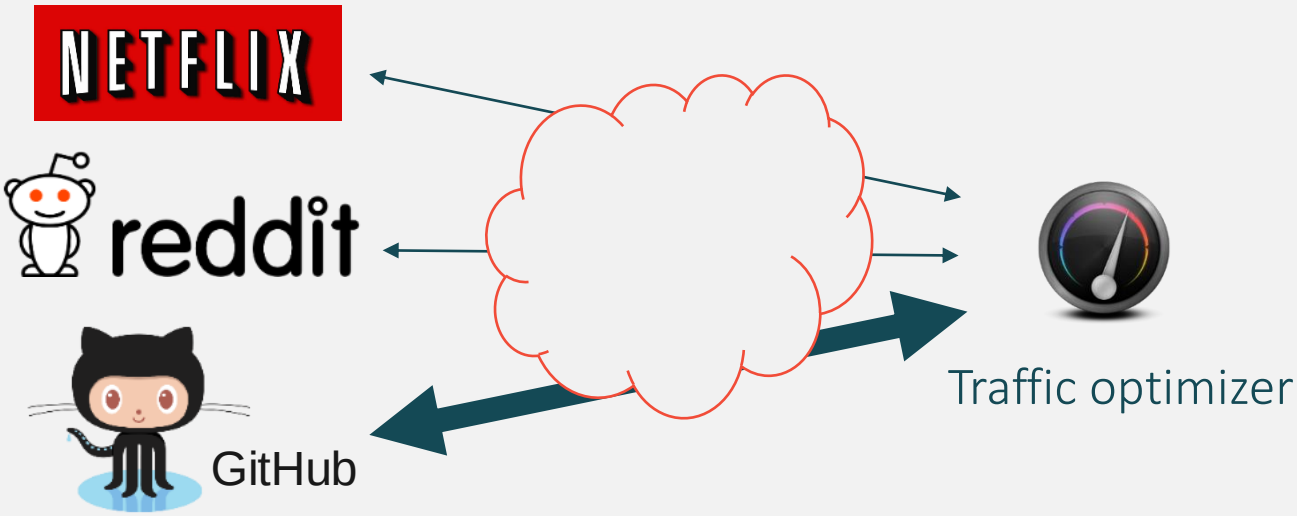

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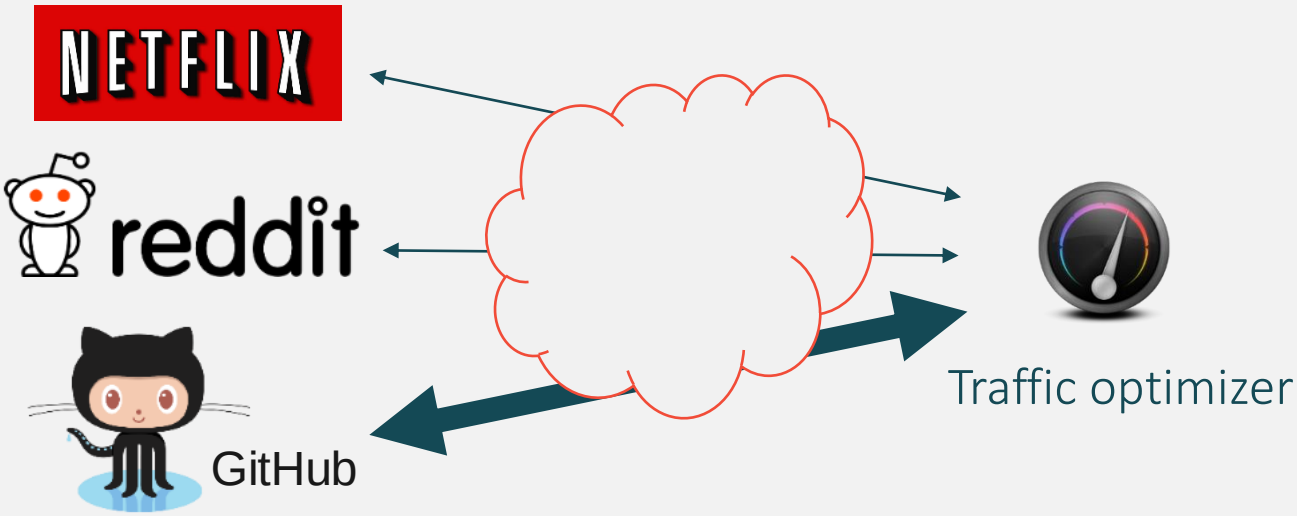

Network and appliance throughput varies by up to 5X in datacenters due to contention at shared resources [SIGCOMM'11]

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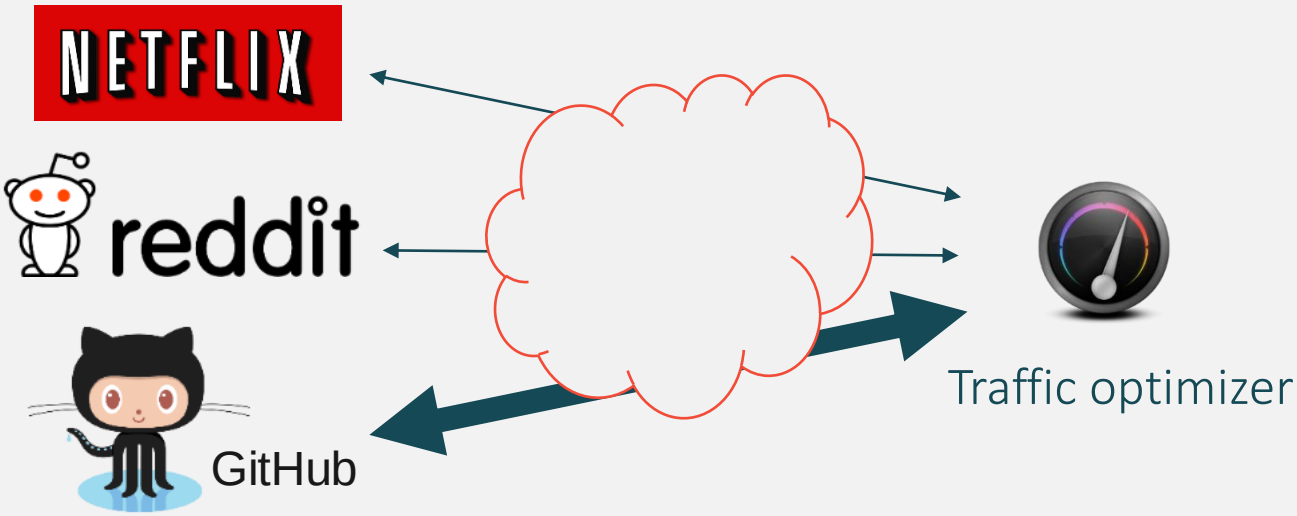

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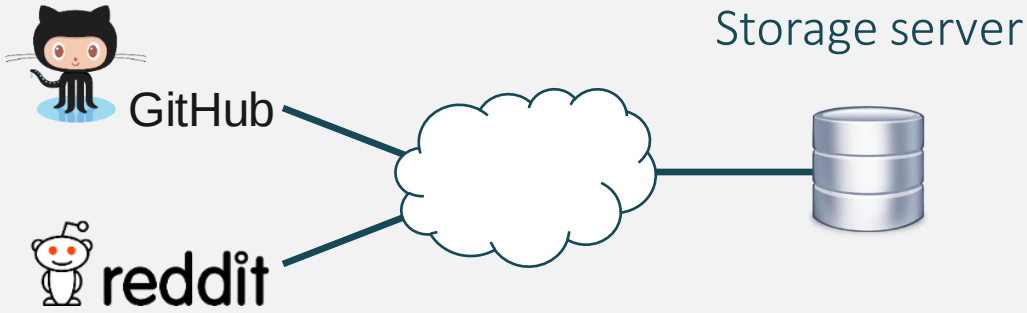
Applications experience degraded and unpredictable performance

Tenants should get end-to-end guarantees

- Isolate tenants across the network
  - Oktopus [SIGCOMM'11], ElasticSwitch [SIGCOMM'13]
- Isolate tenants at appliances
  - DRFQ [SIGCOMM'12], Pisces [OSDI'12], IOFlow [SOSP'13]

Enforcing per-resource guarantees is not sufficient



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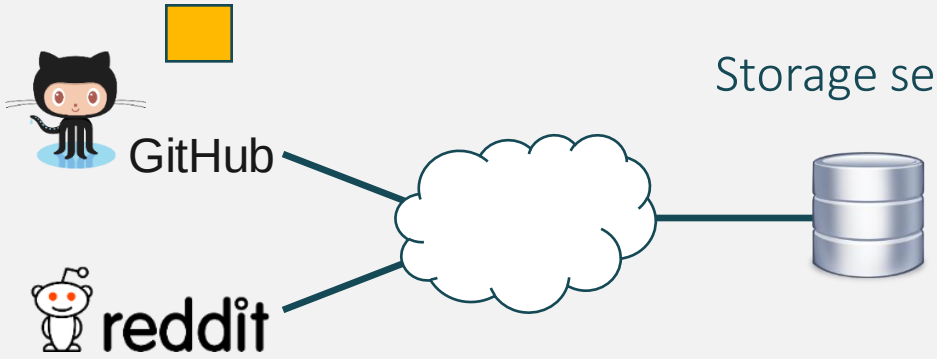
Large Read request (request itself is a tiny header)



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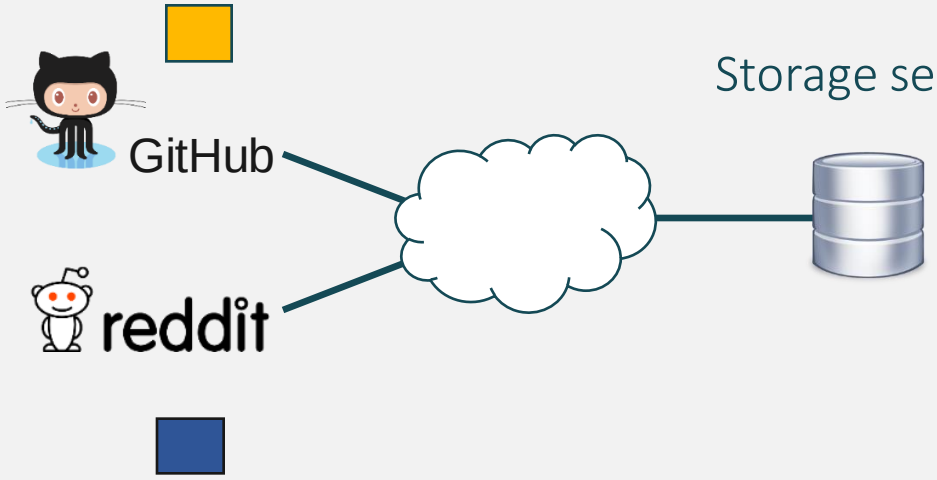

Large Write request (contains actual payload)

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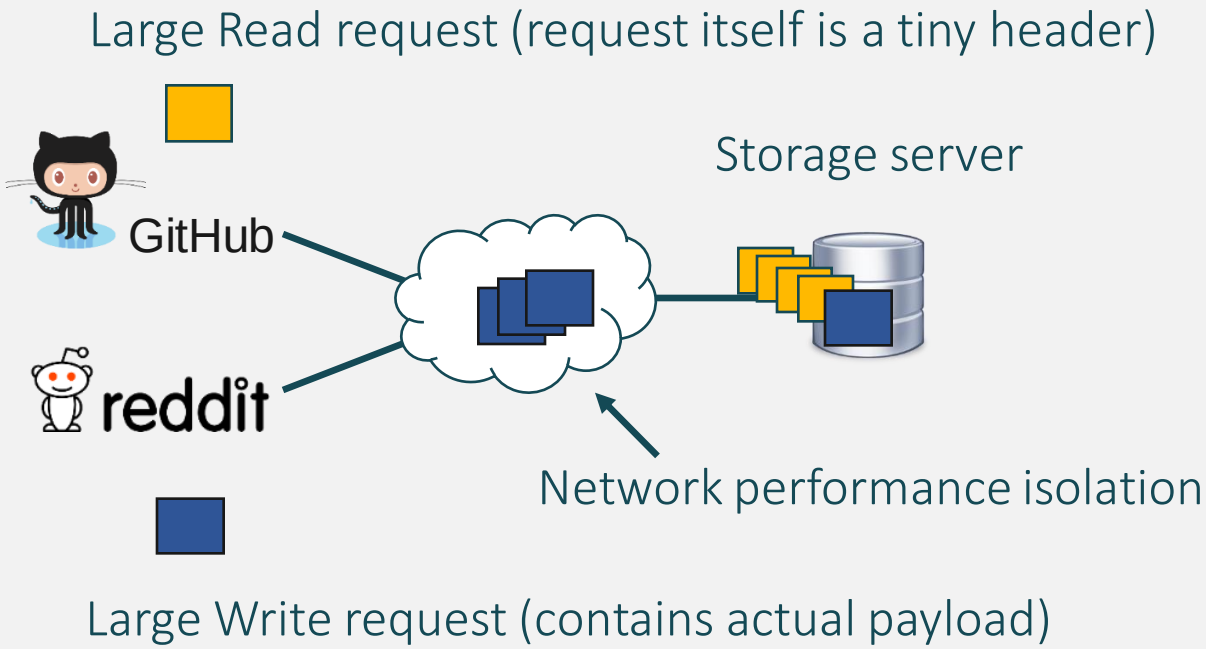

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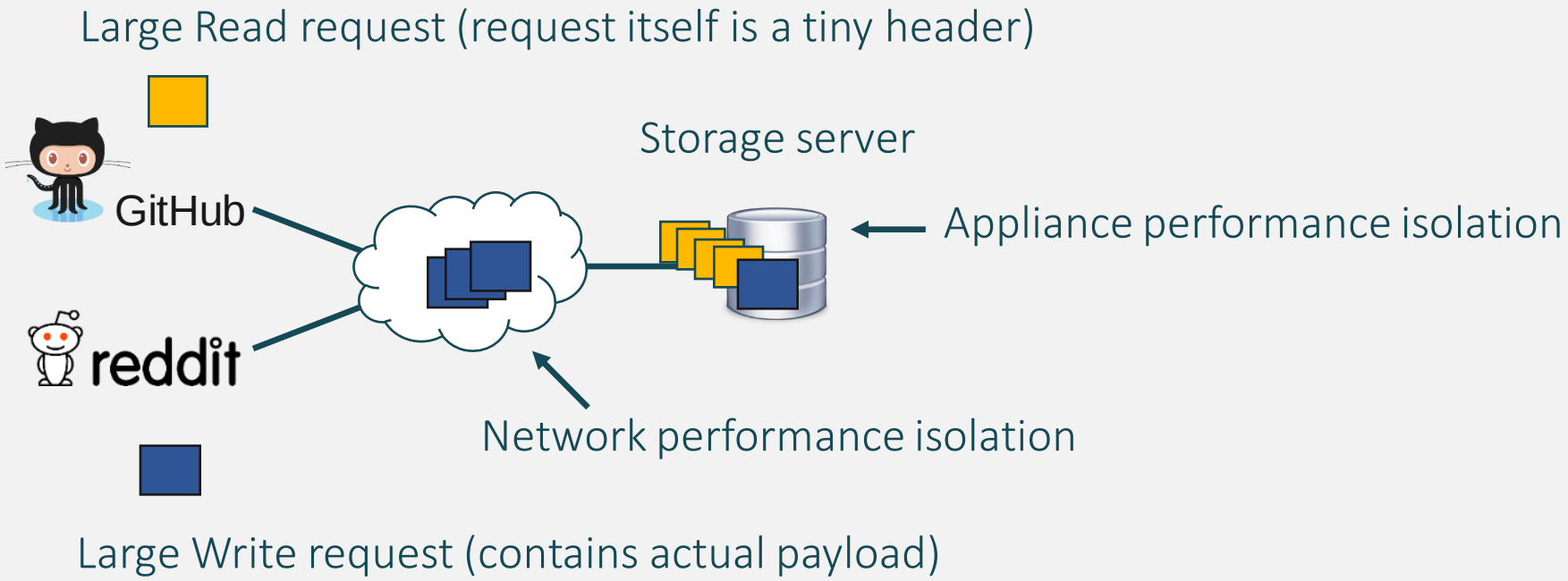

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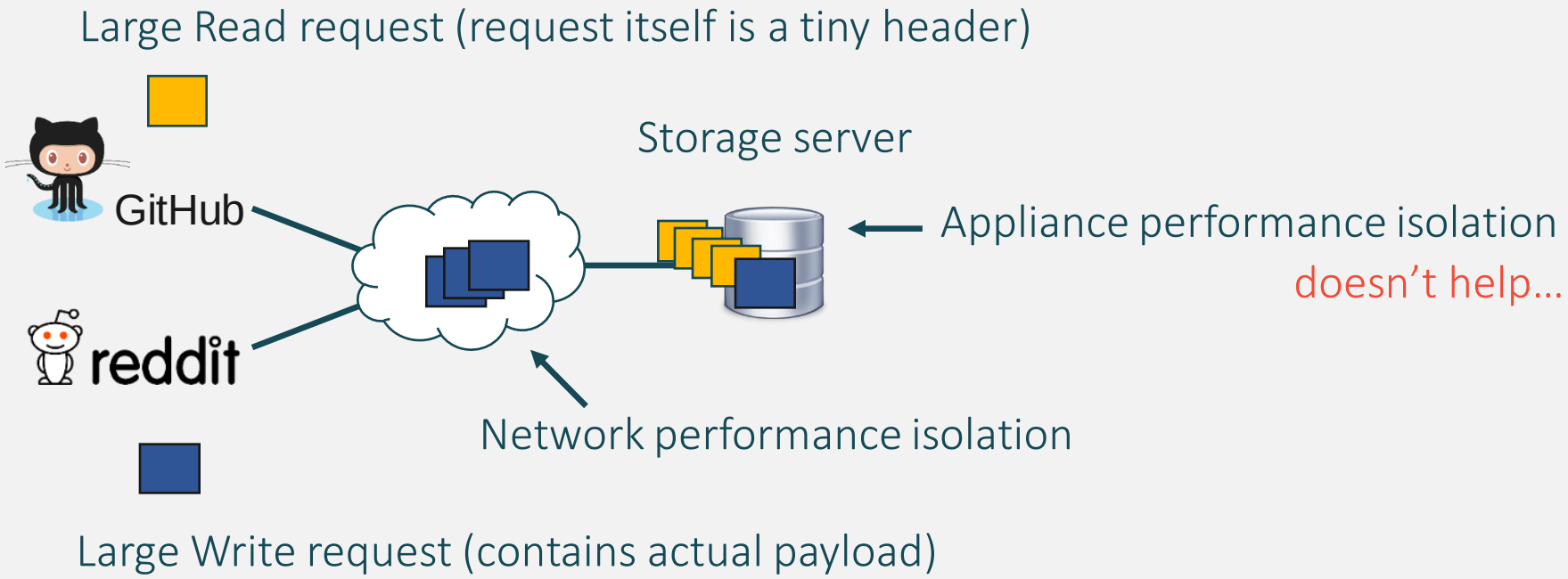

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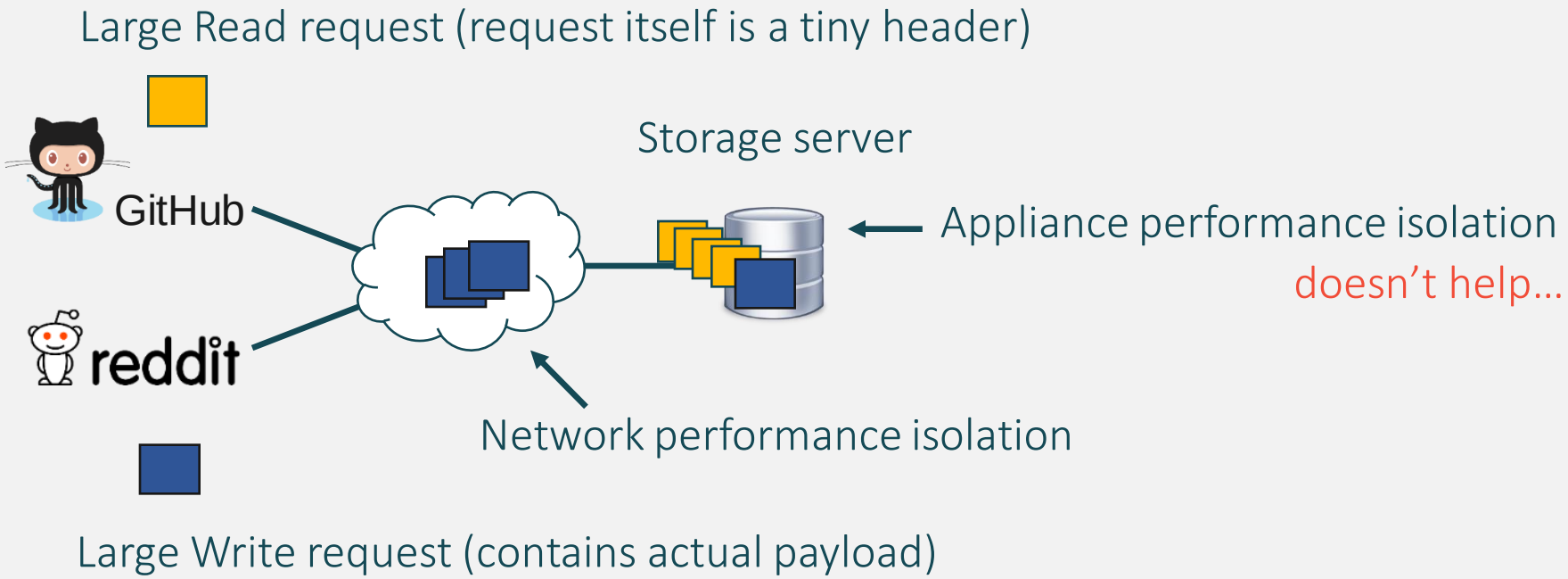
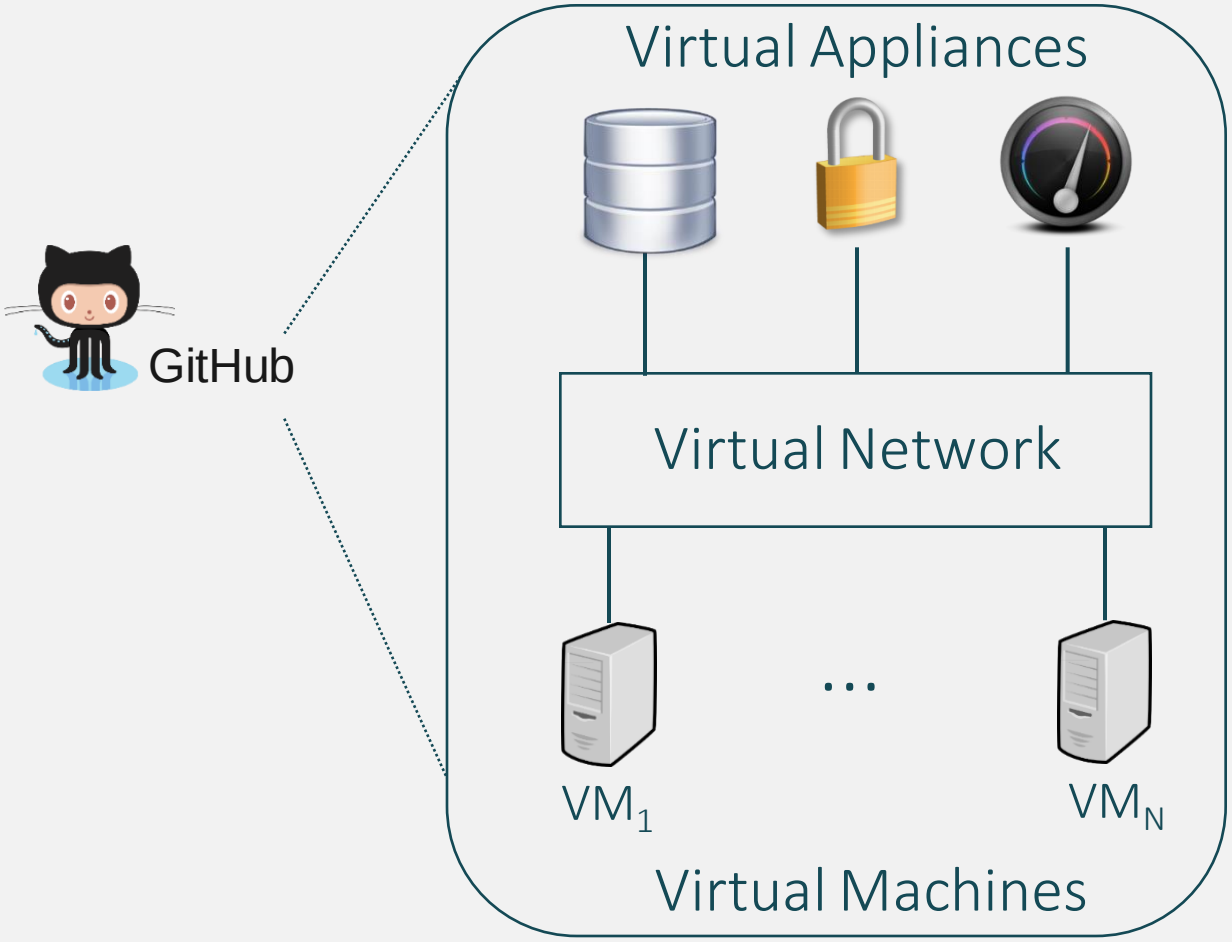


We need a new abstraction that encapsulates the semantics of end-to-end guarantees

Outline

- ✓Introduction
- Virtual Datacenter (VDC) abstraction
- Throughput metric
- Architecture of Pulsar
- Experimental evaluation

Virtual Datacenters (VDC) encapsulate end-to-end guarantees



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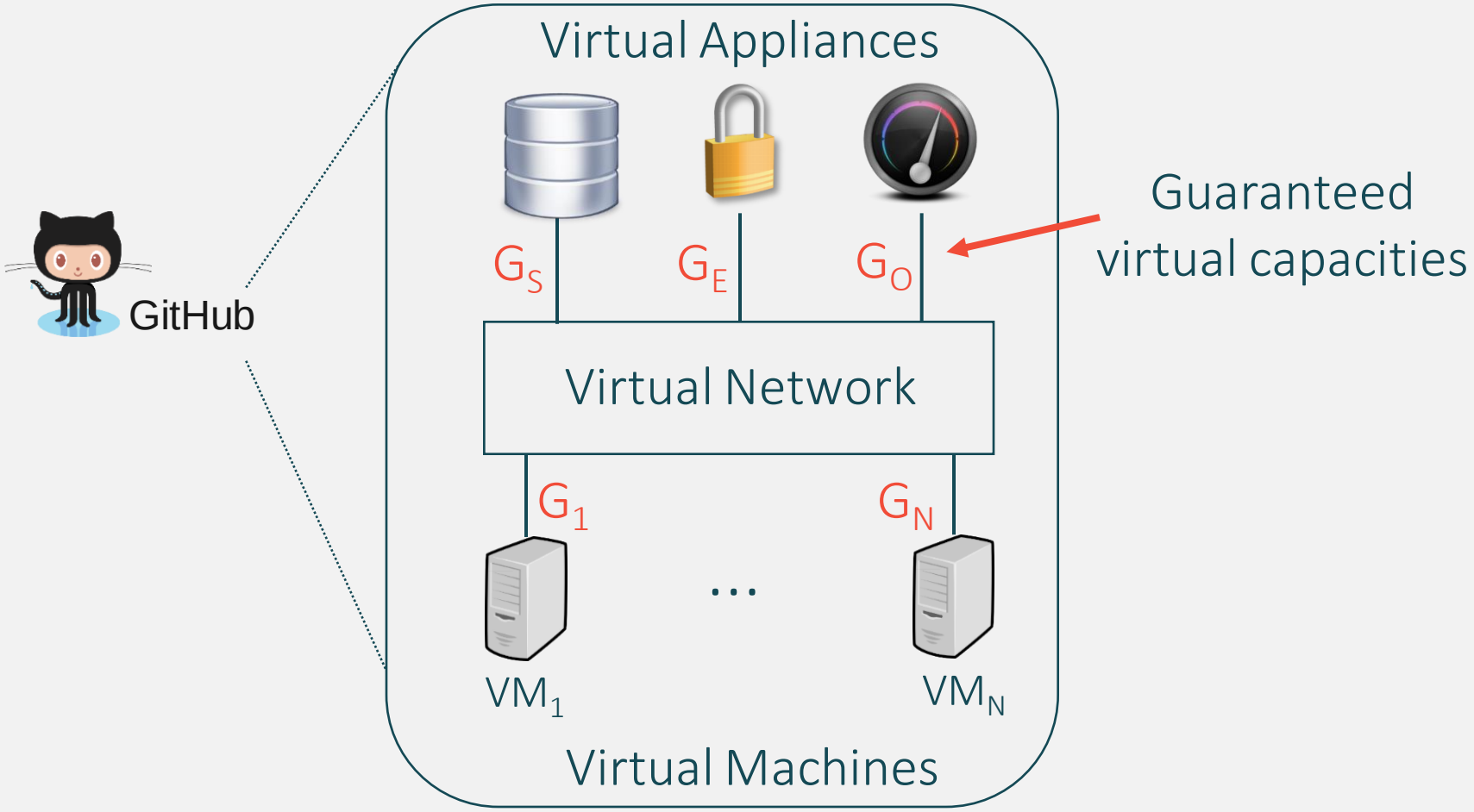

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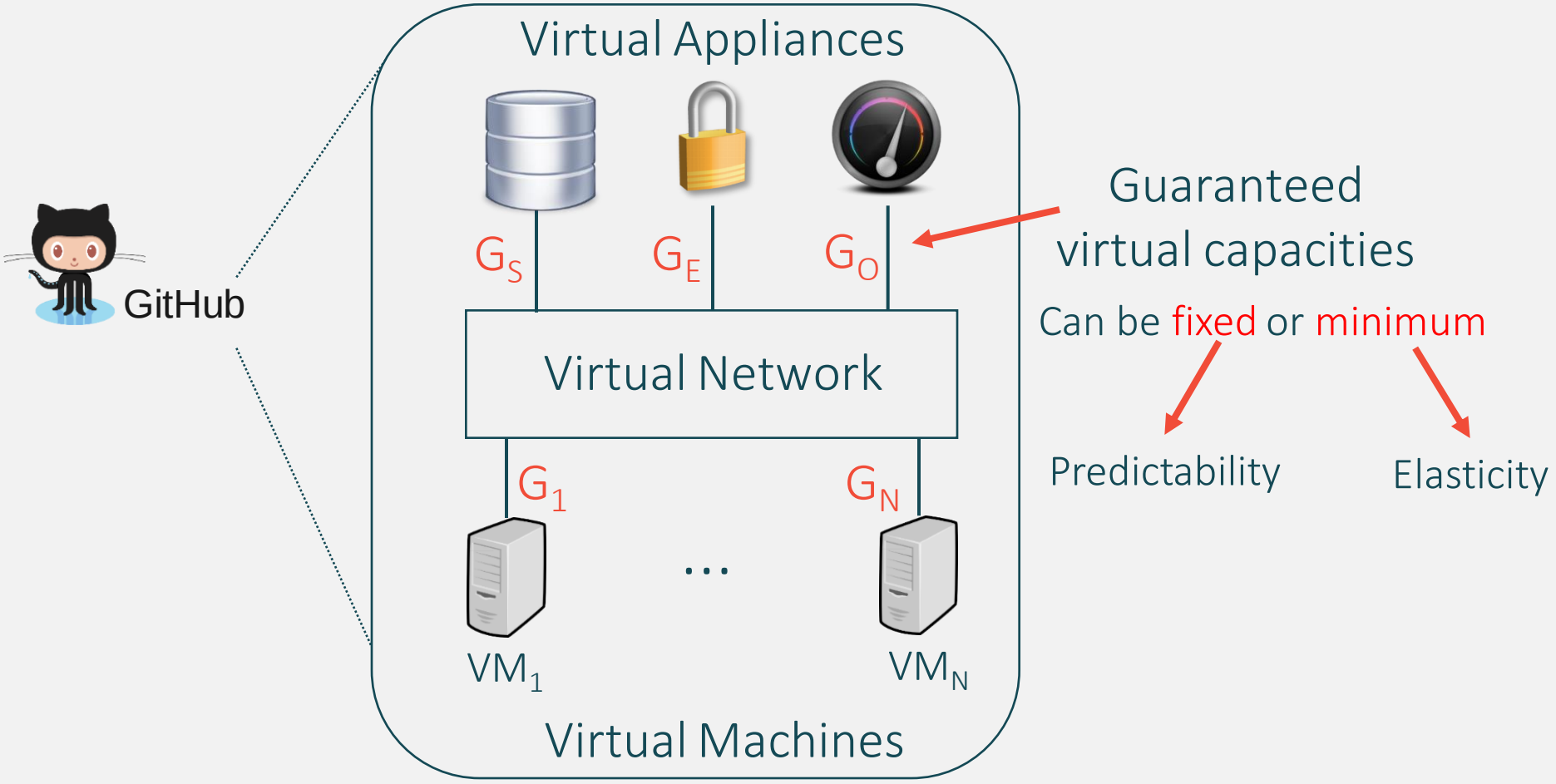
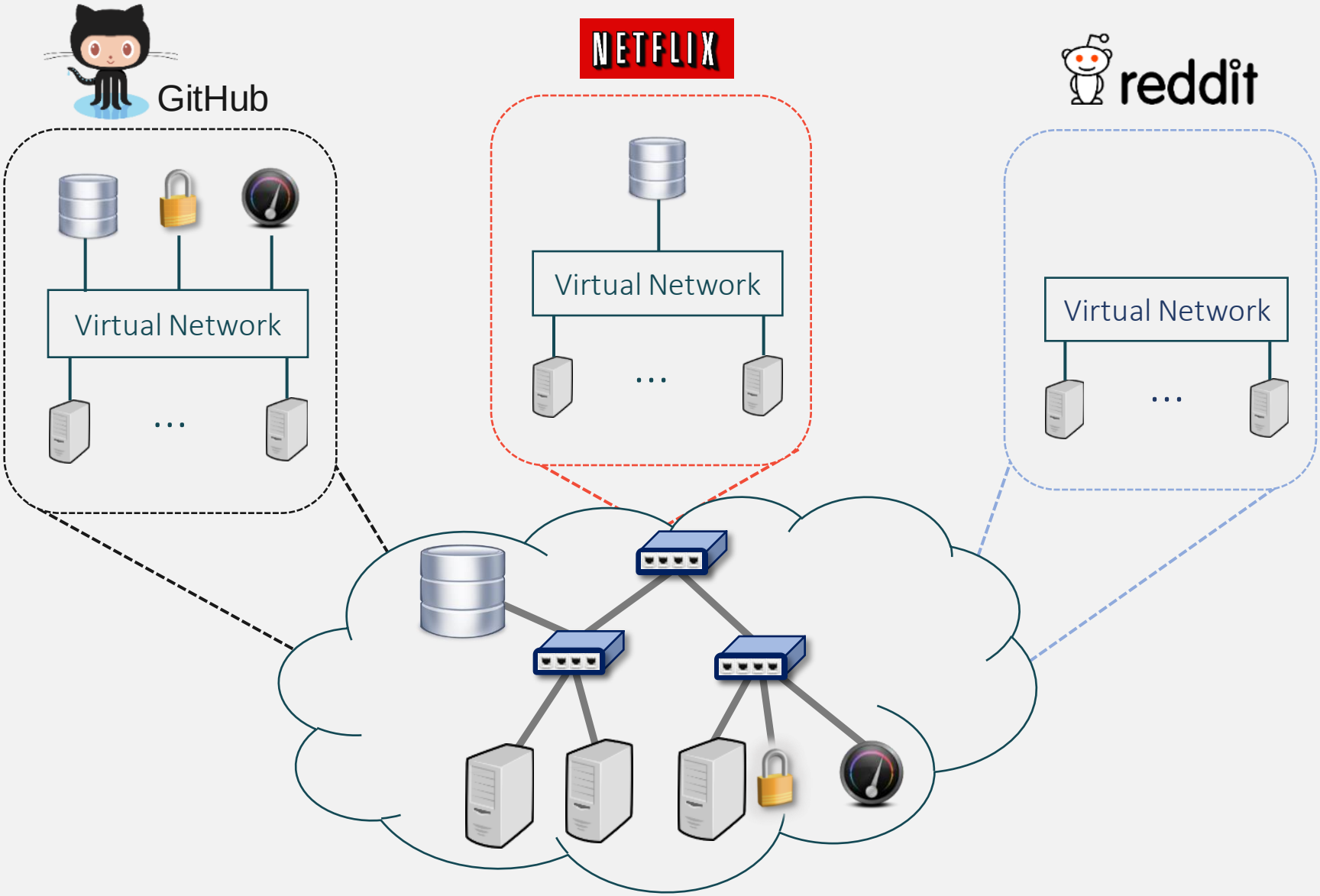


Admission control is performed when placing tenants' VDCs



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Standard throughput metrics have major tradeoffs

- Relative metrics: % share of the appliance
  - ✓ Provider: easy provisioning
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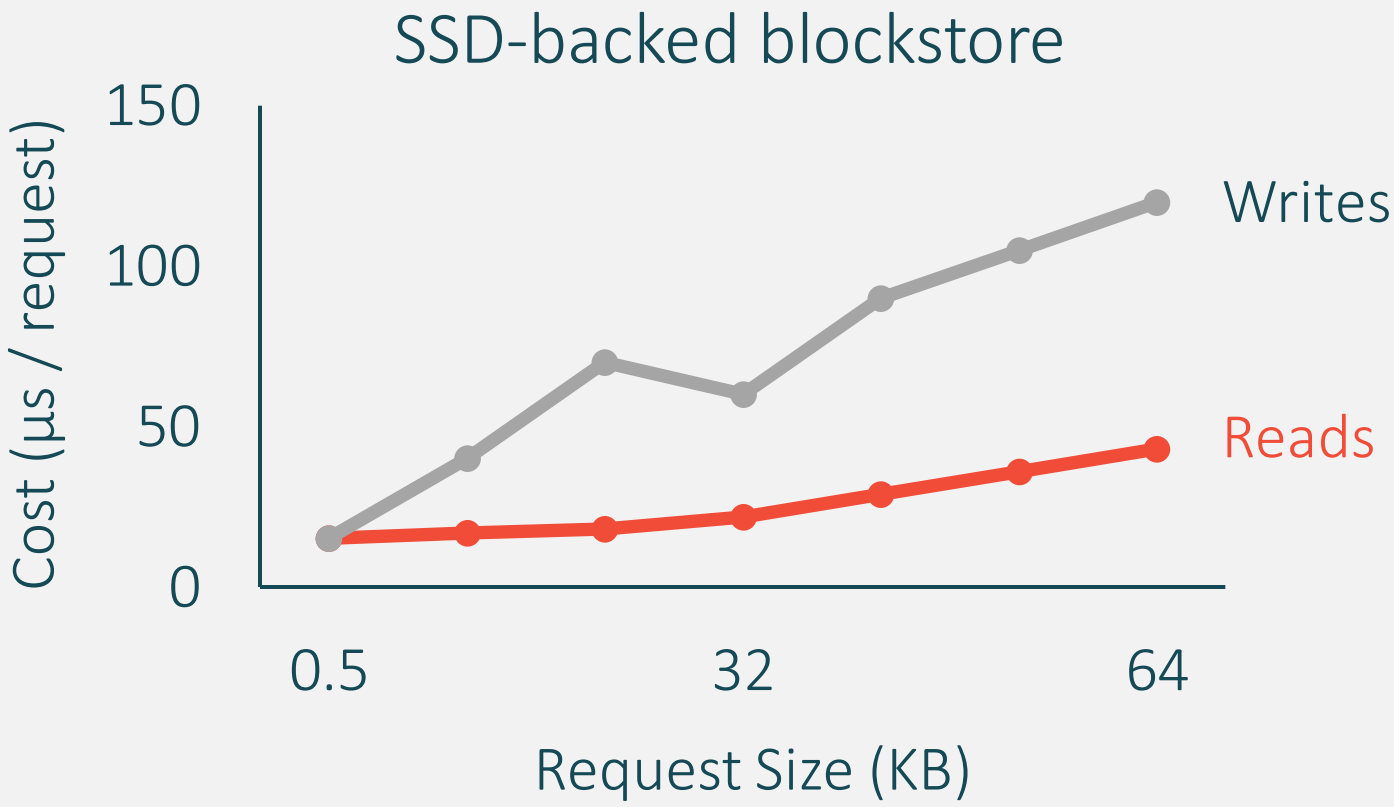
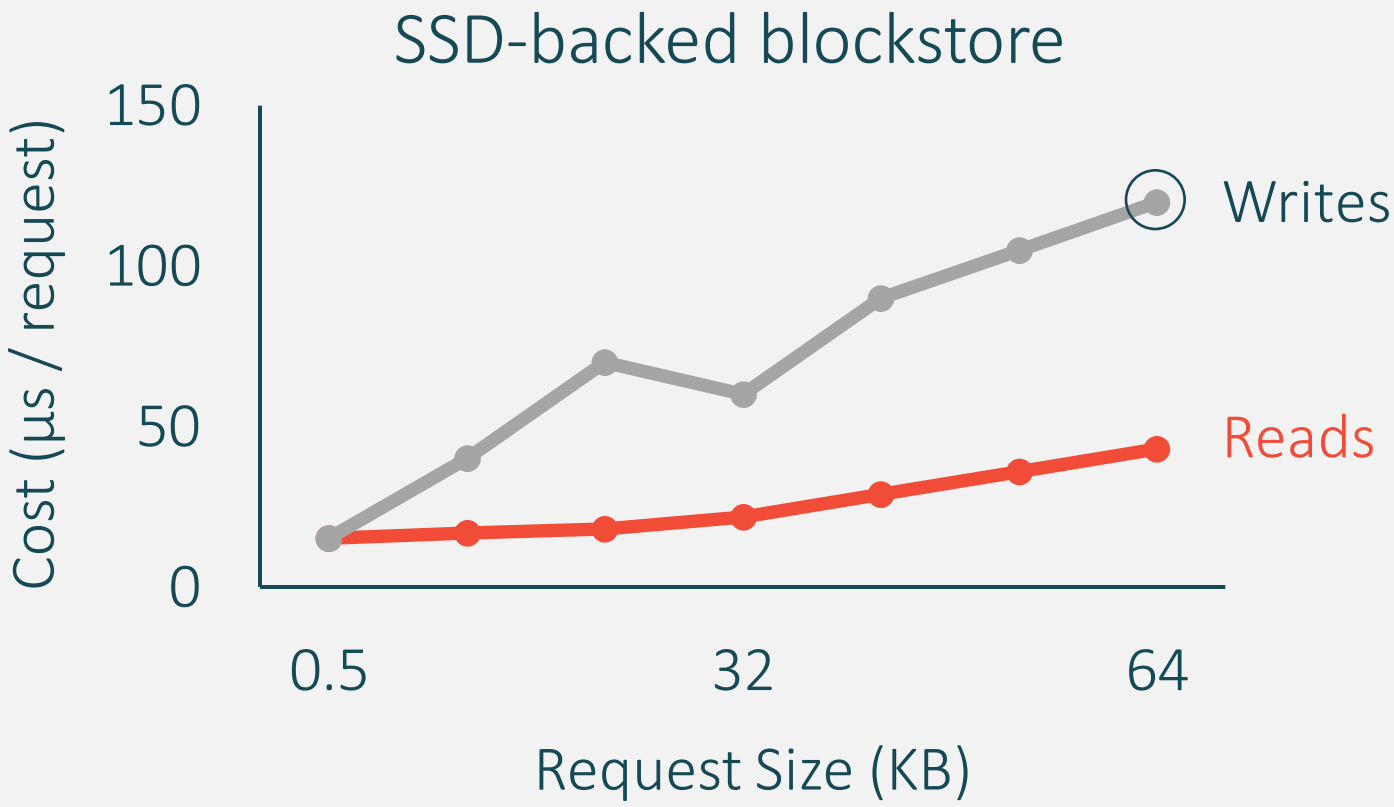
- Relative metrics: % share of the appliance
  - ✓ Provider: easy provisioning
  - ✗ Tenants: performance variability still present
- Absolute metrics: requests/second or bytes/second
  - ✗ Provider: provisioning based on costliest request
  - ✓ Tenants: absolute throughput guarantees

Request cost varies with request characteristics



Request cost varies with request characteristics

Guaranteeing requests/second requires conservative provisioning



Virtual request cost (in tokens)

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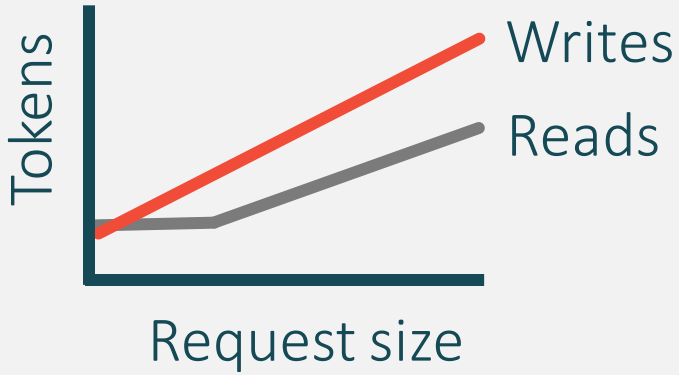
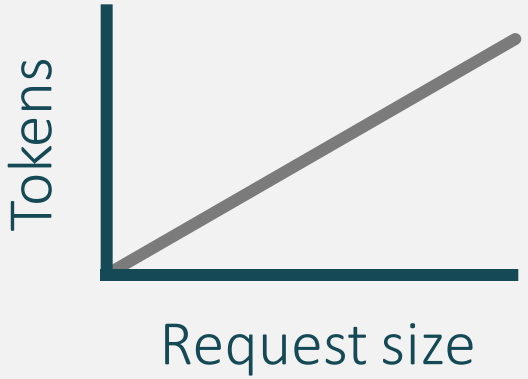
SSD-backed blockstore



Network Links / NICs



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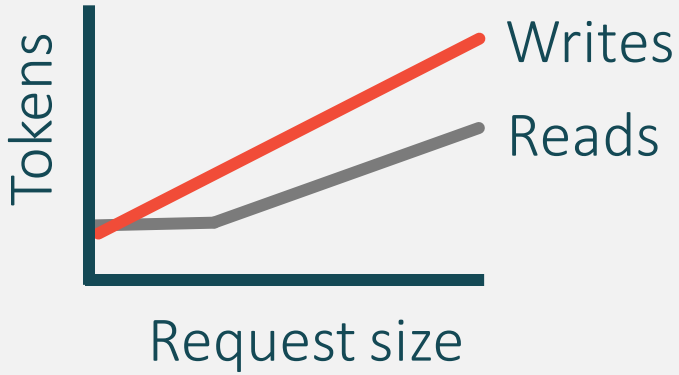

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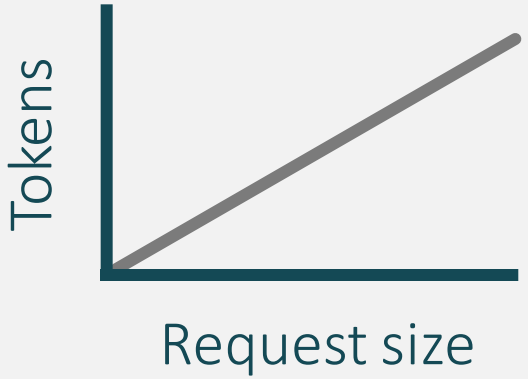

- Guaranteed virtual capacities are defined in tokens/sec

Virtual request cost (in tokens)

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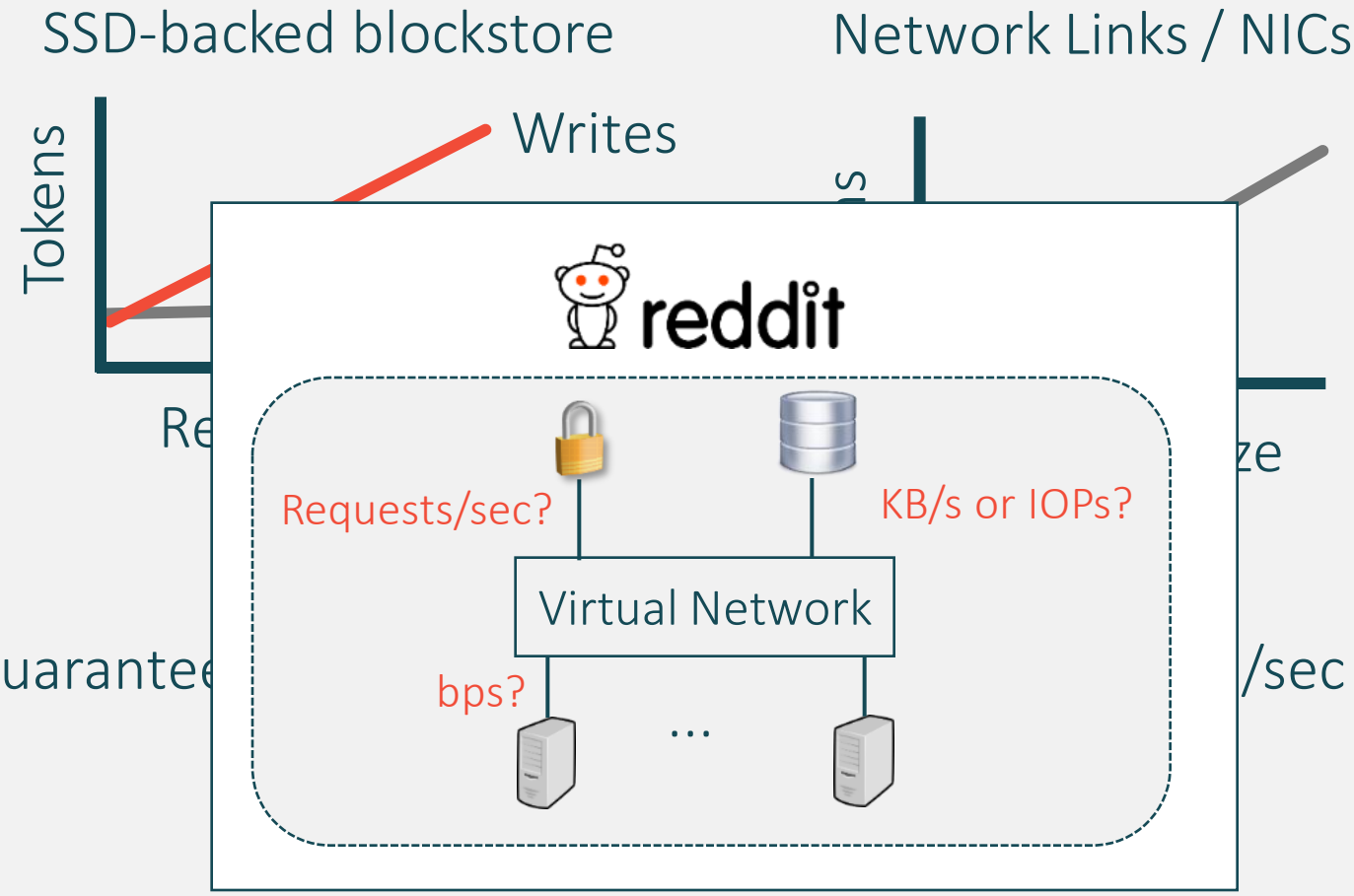

- Guarantee

Virtual request cost strikes a good compromise between tenants and the provider

- Tenants can translate their guarantees to other metrics for their workloads

- Provider has more flexibility when provisioning the datacenter

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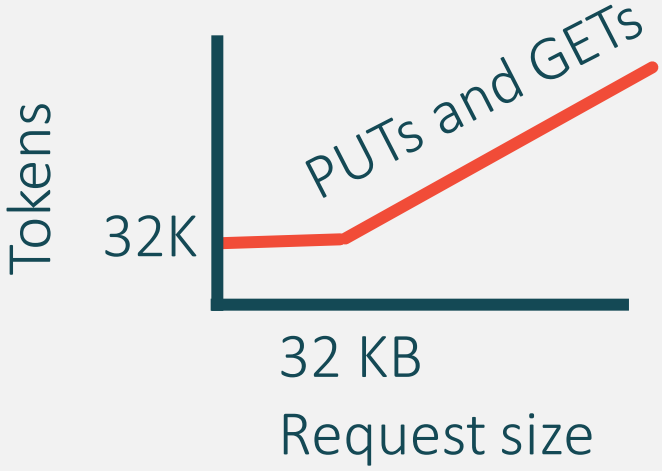

Guarantee: 32 Ktokens/sec

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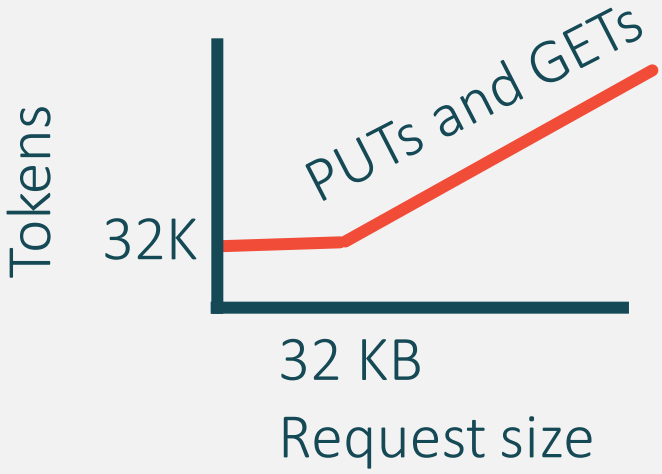

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Workload:

- 8 KB PUTs --> 2 PUT/sec
- 32 KB GETs --> 1 GET/sec

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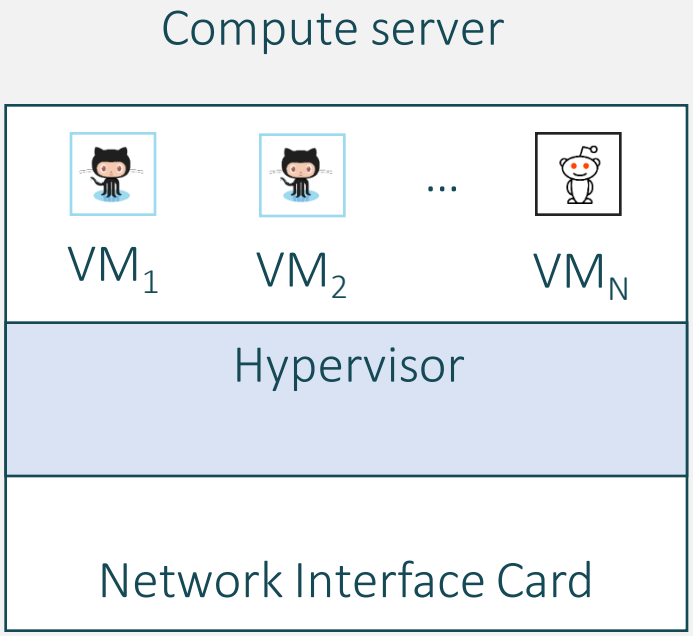
- Enable rich policies that are easy to change
  - Simplicity is key
  - Perform coordination through a centralized control plane

Pulsar’s architecture



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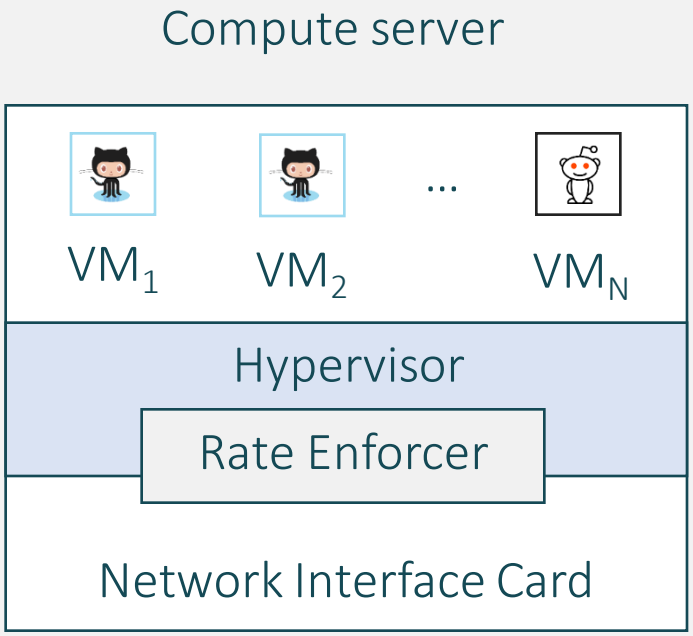

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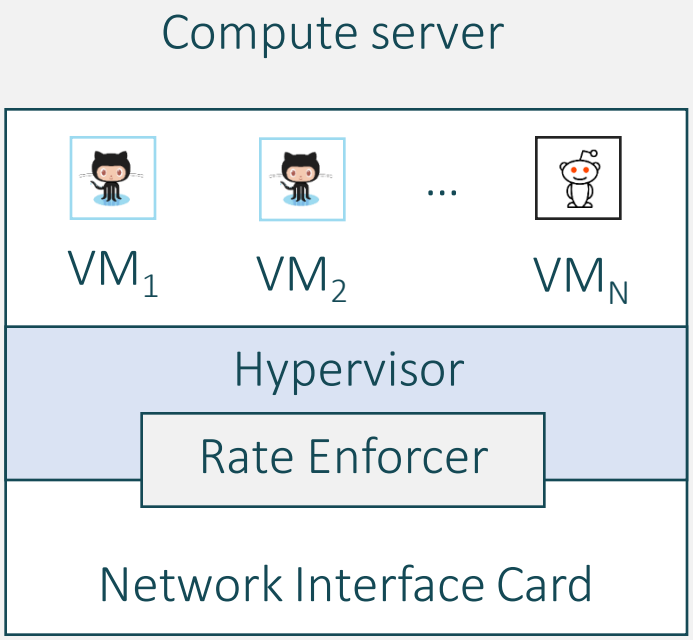

Rate enforcer

- Estimates the demand of every VM
- Emulates request cost at different resources by applying cost functions
- Enforces allocation provided by controller

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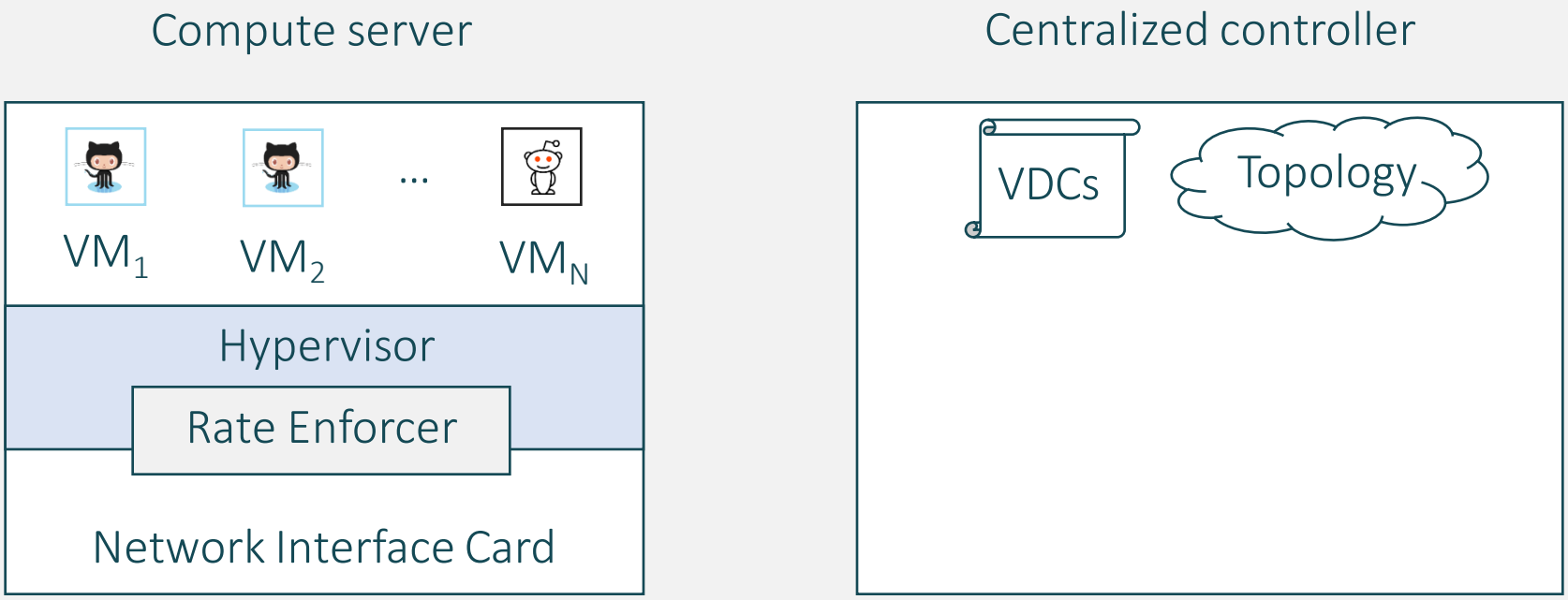

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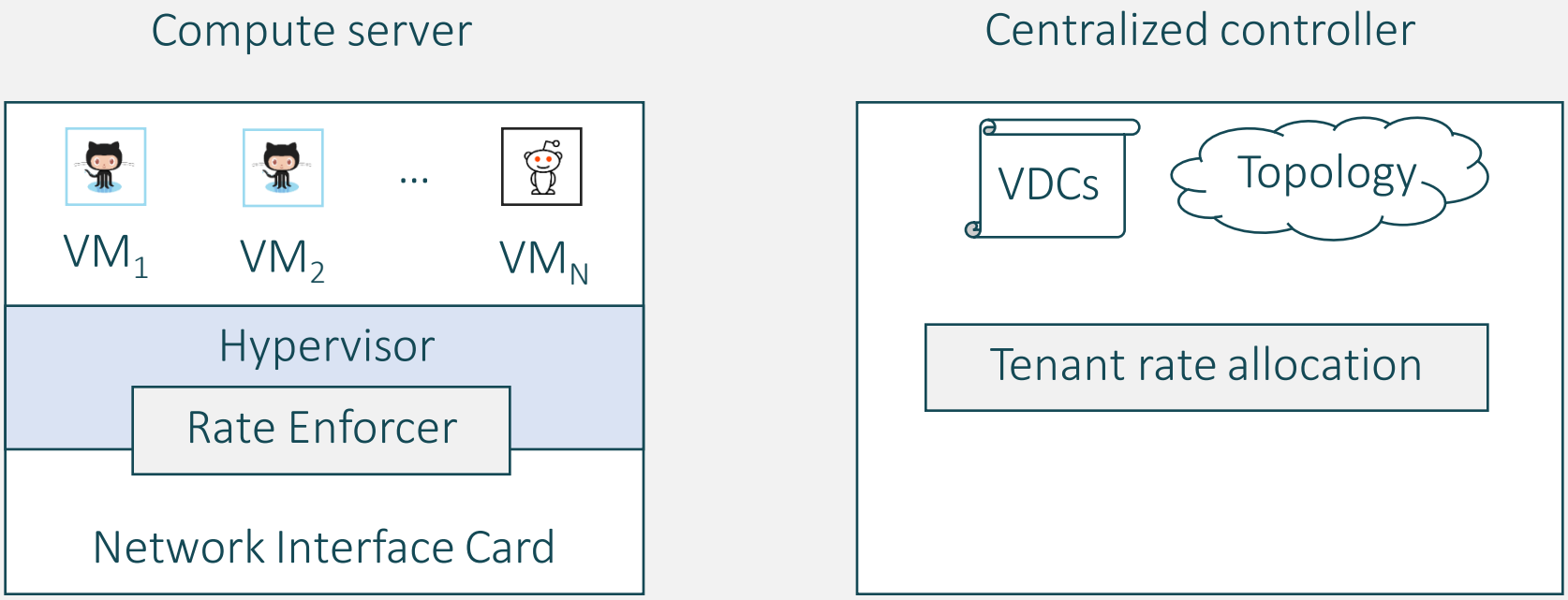

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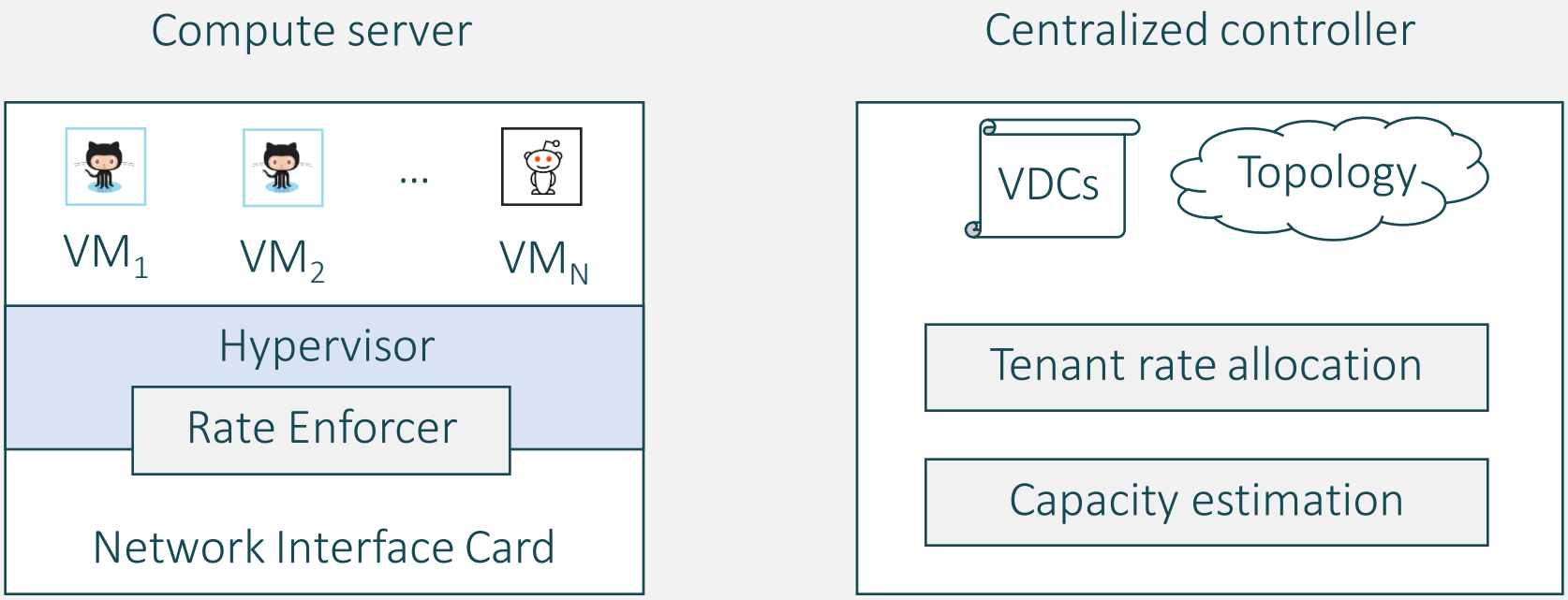

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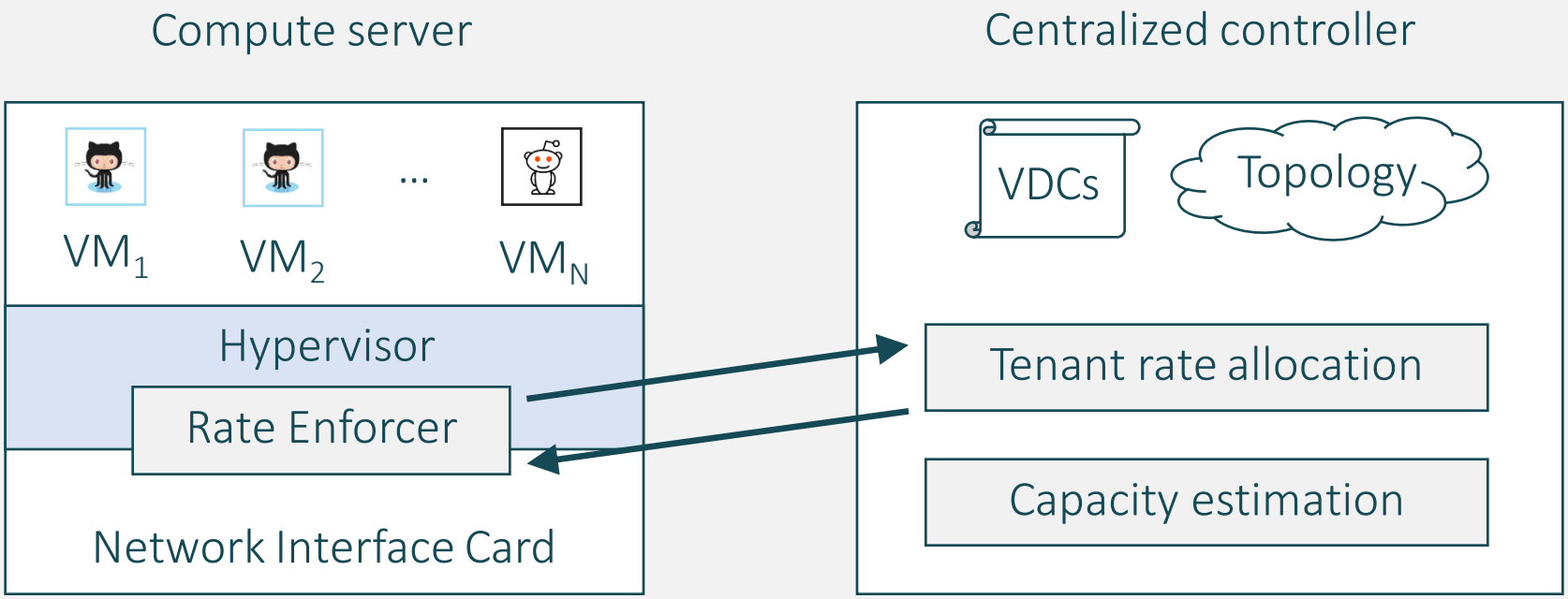

Pulsar's architecture

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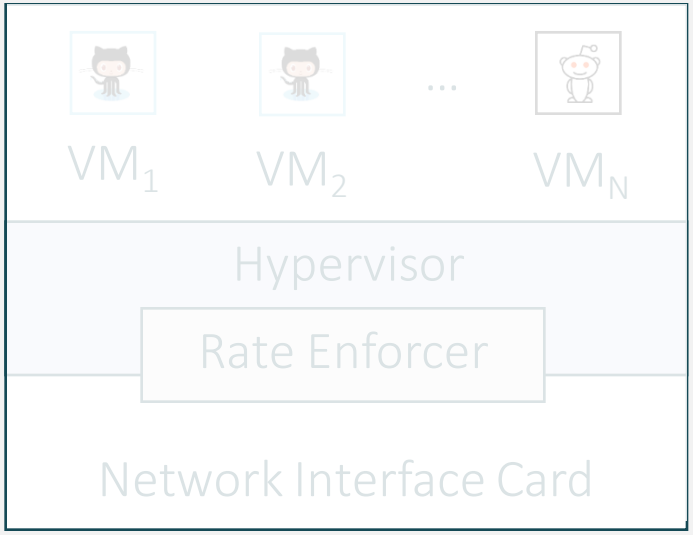
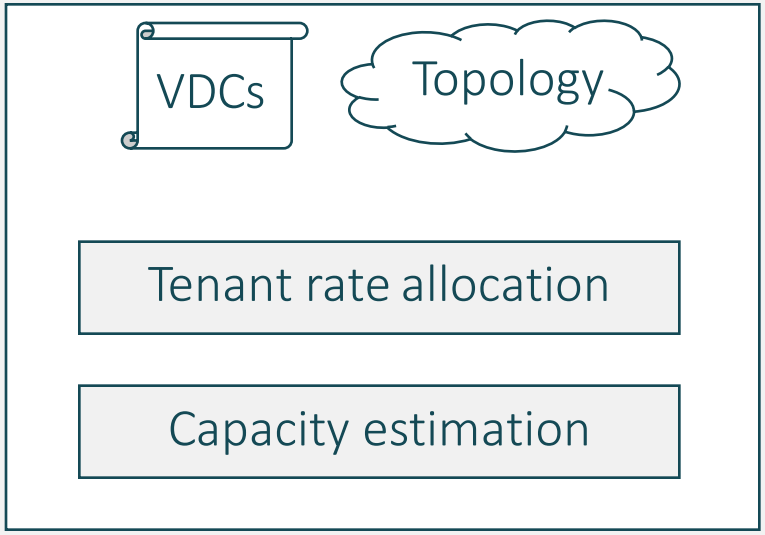
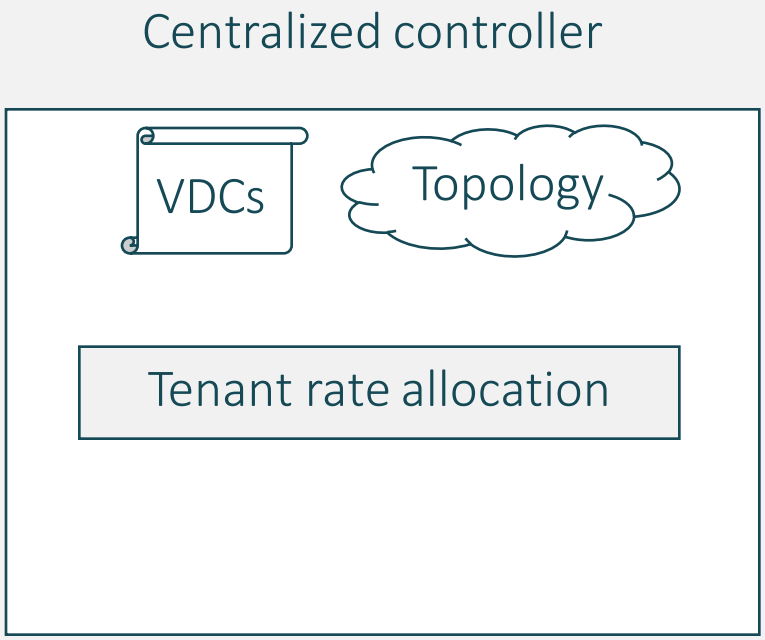


Centralized controller



Pulsar allocates resources to each VM-VM pair



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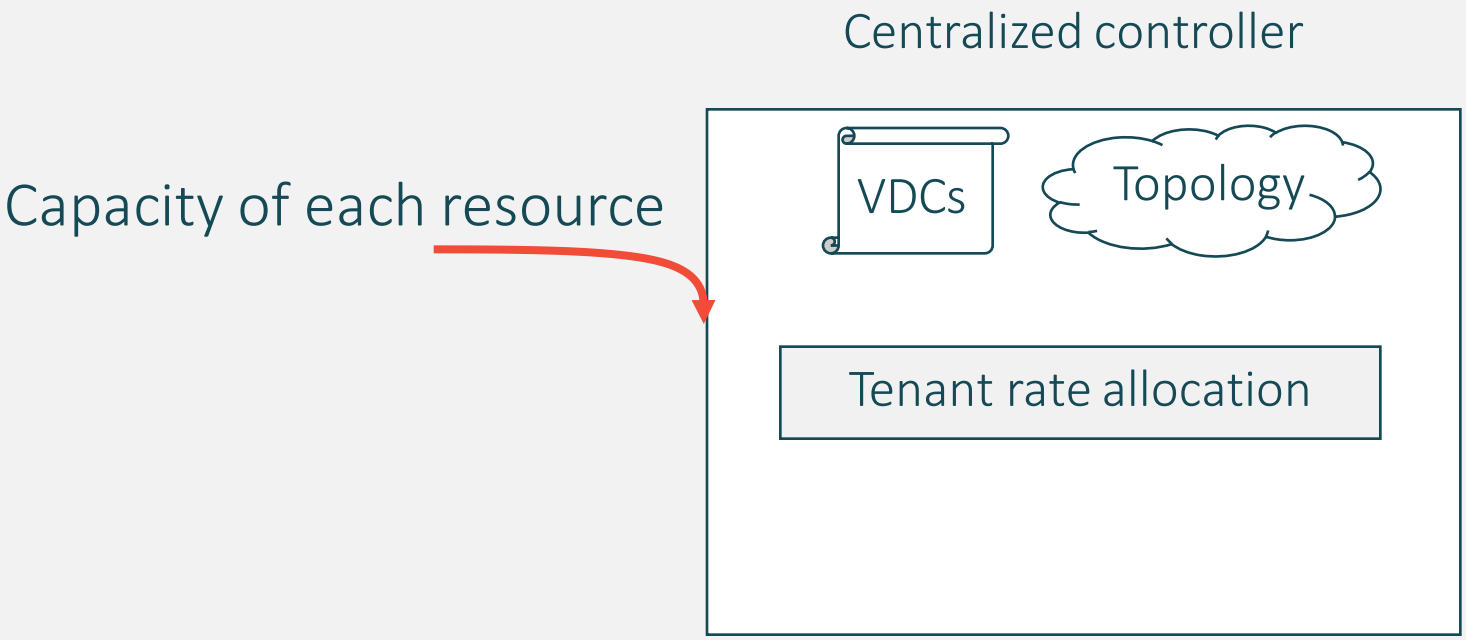

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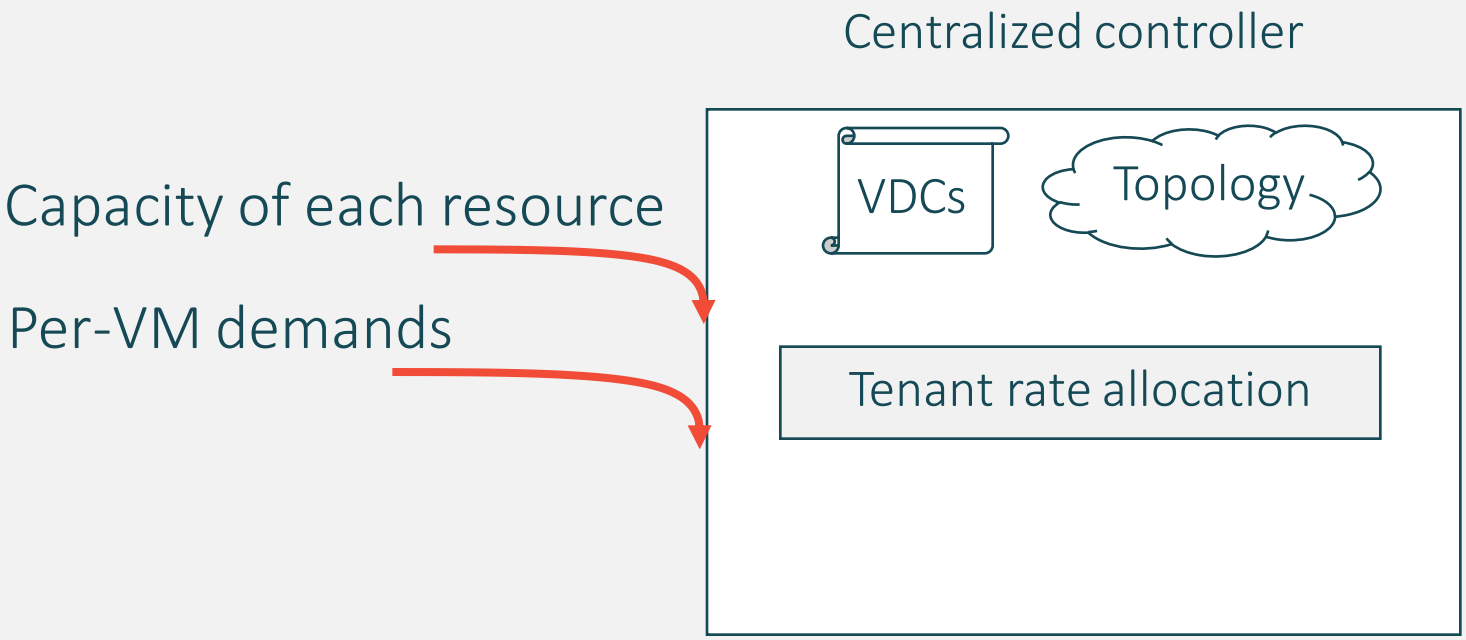

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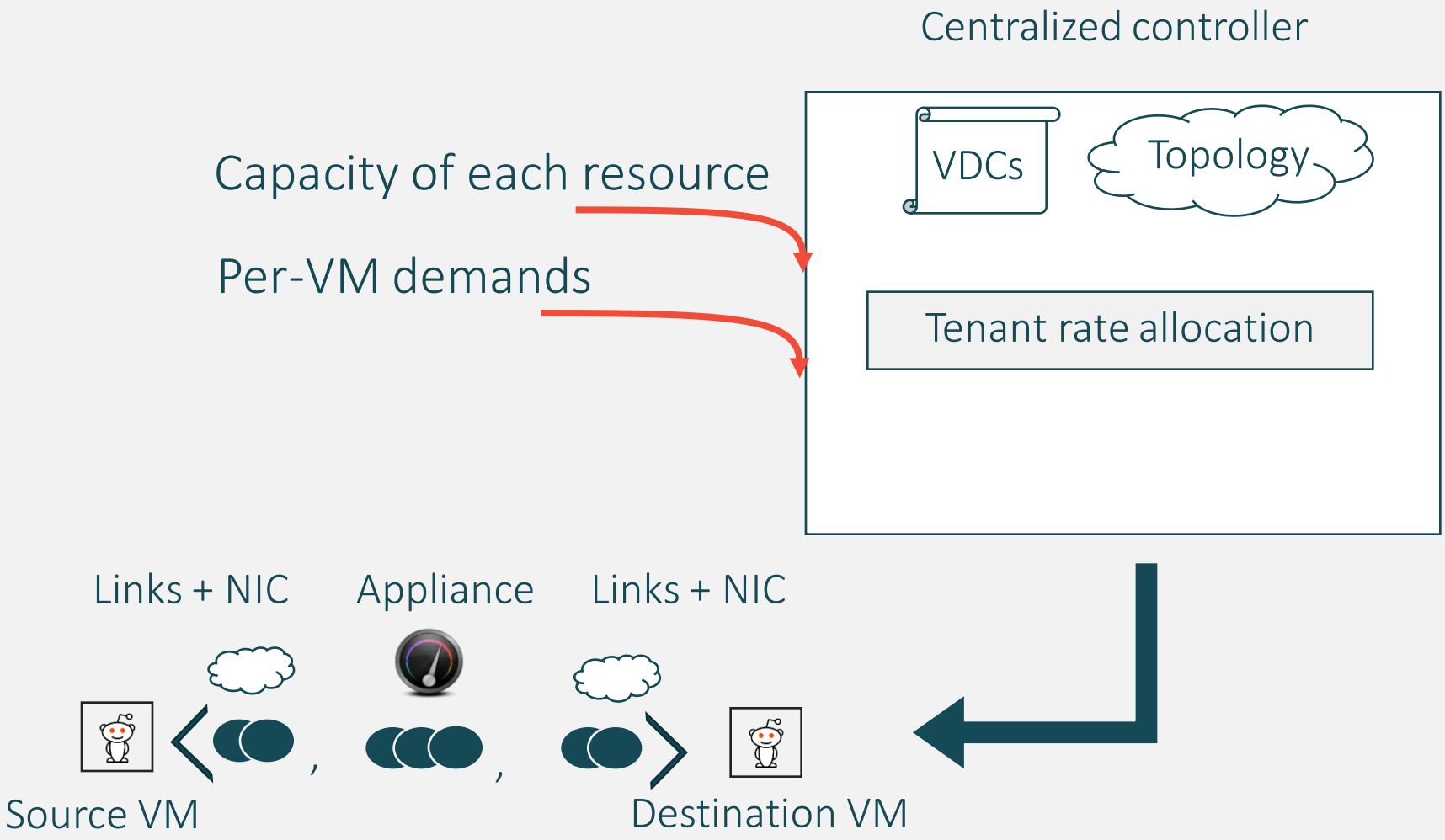

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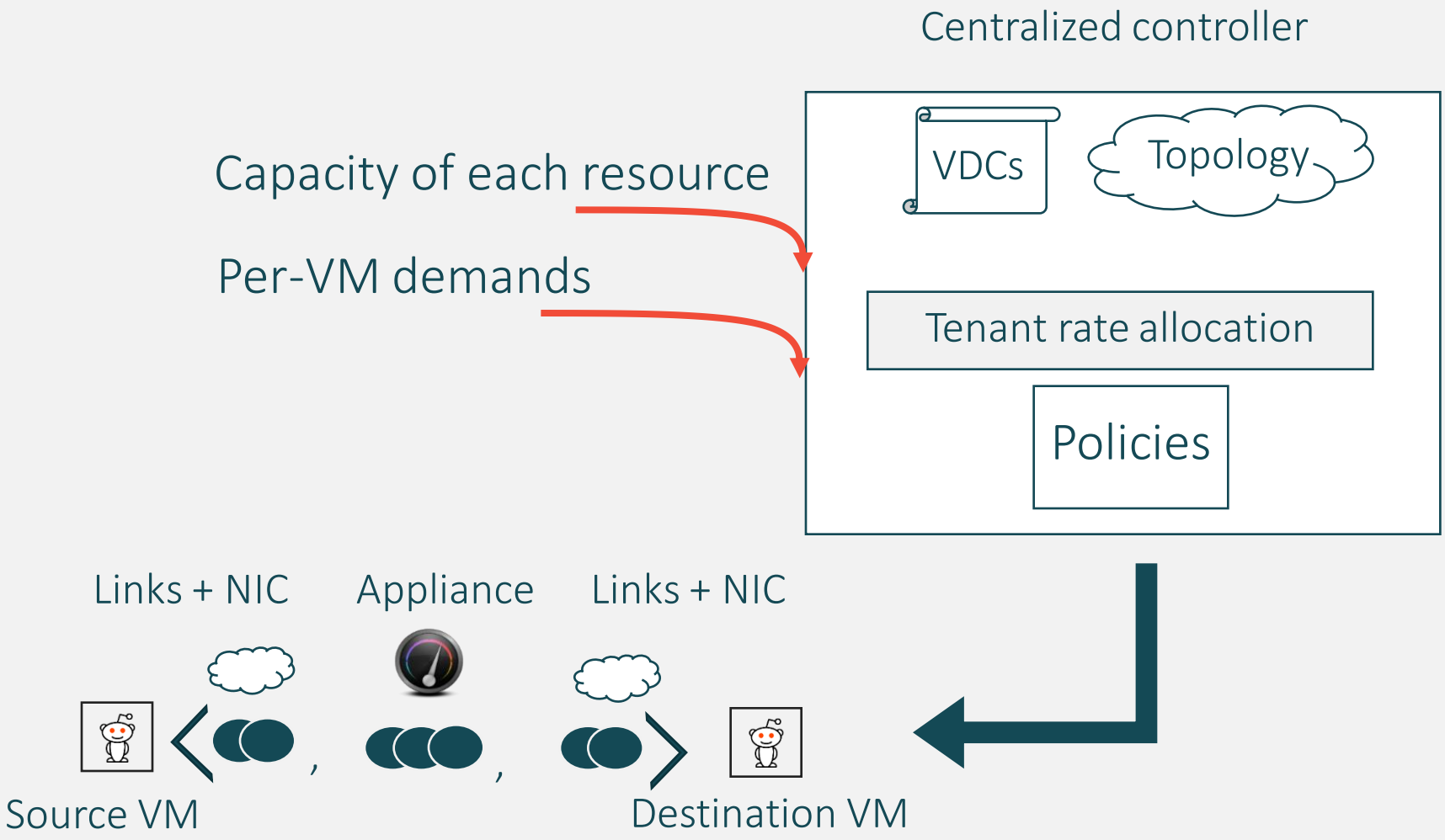

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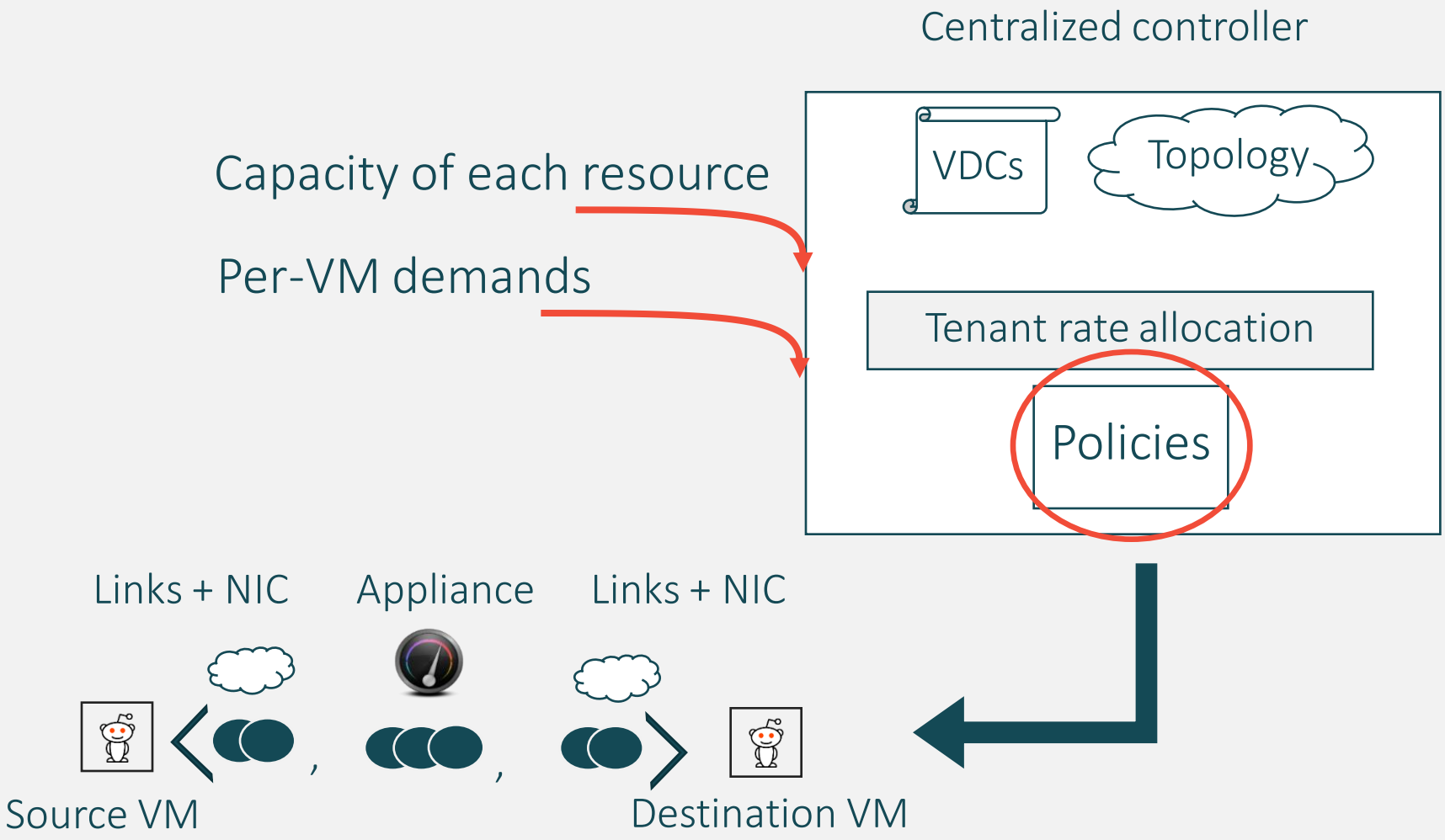

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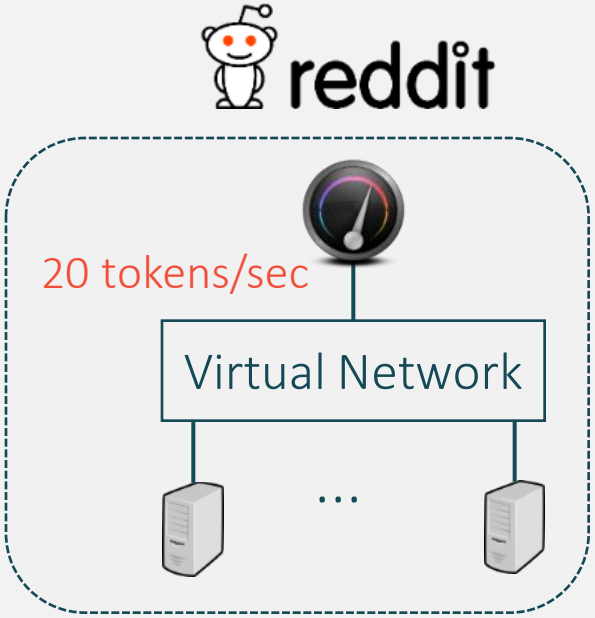

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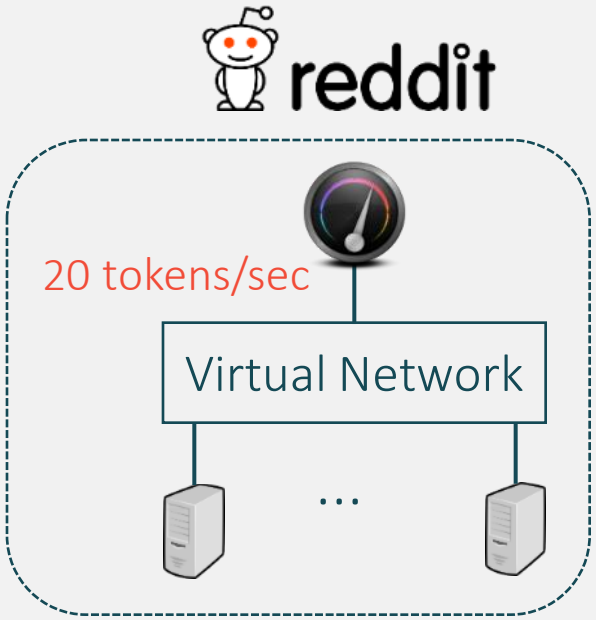

Example policies:

- Divide 20 tokens/sec fairly across all active VMs
- Give all 20 tokens/sec to VM 3 (whenever it is active)

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- Provider-specified policy
  - Specifies how spare resources are given to tenants' VMs

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- Provider-specified policy
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  Example policies:

  - Distribute spare resource fairly across all tenants' VMs
  - Distribute spare resources in a way that maximizes profit

Pulsar's architecture

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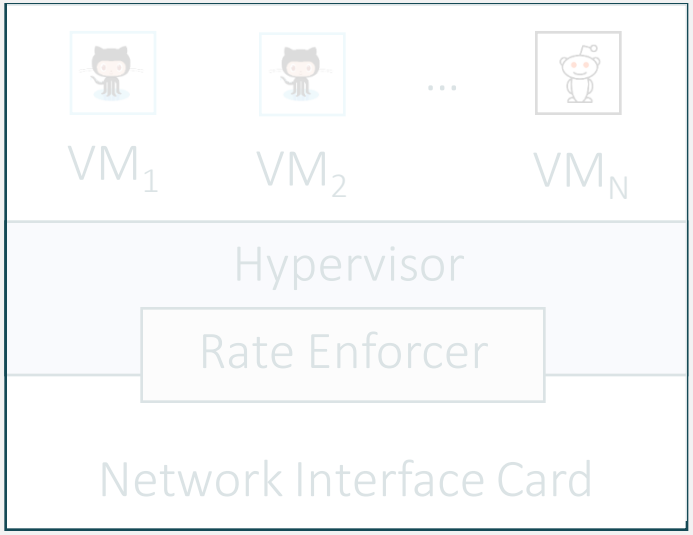
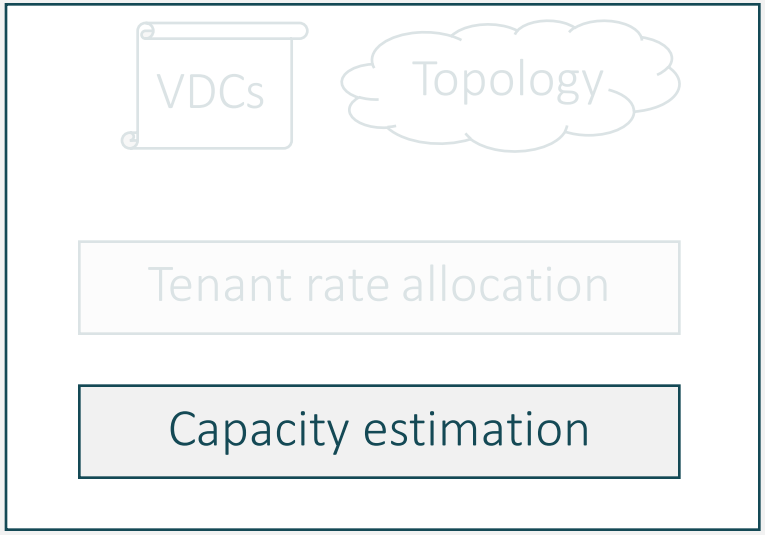


Centralized controller



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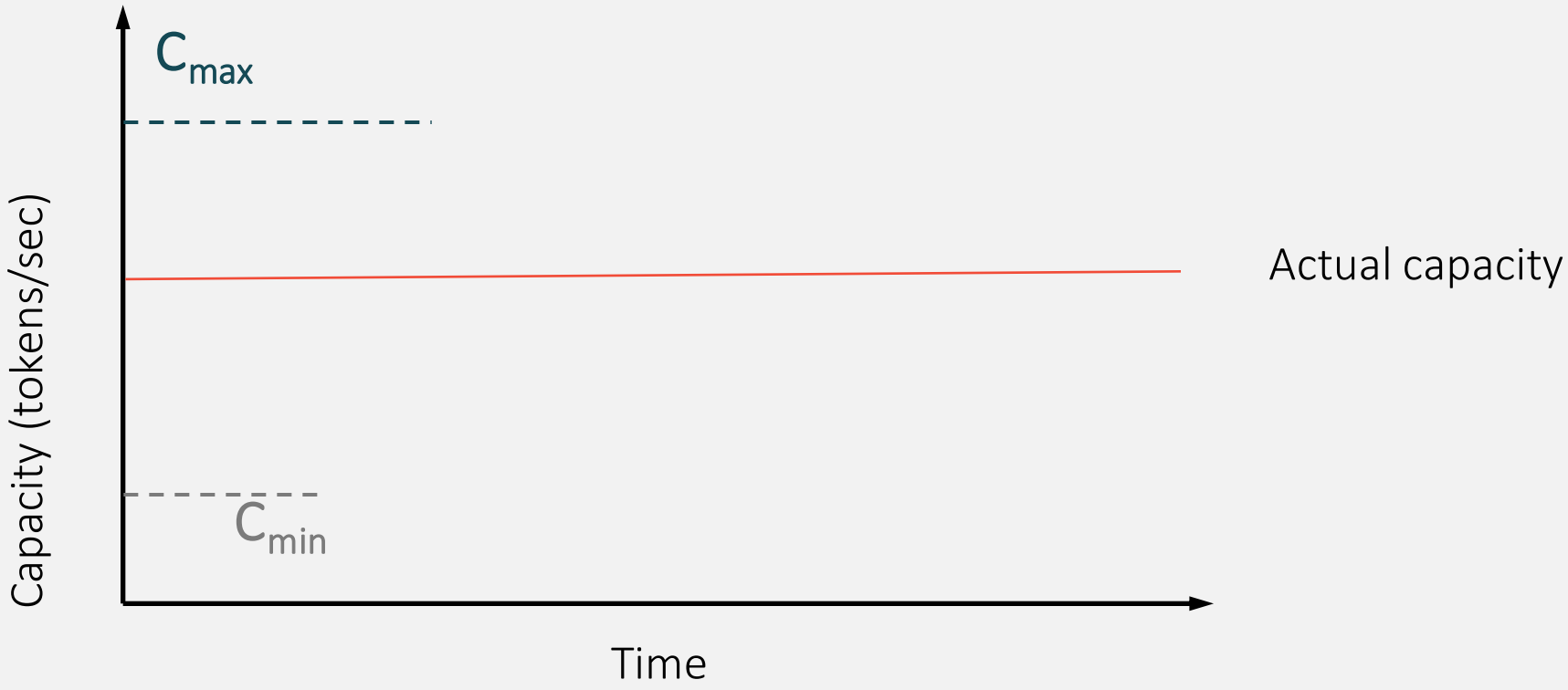
  - Each network flow probes for a higher capacity estimate
  - Decreases allocation on observing congestion
- Challenges
  - Congestion signals are not present or noisy
  - Distributed operation is complex
  - Estimation is tightly coupled with allocation

Centralized estimation algorithm

- Maintain window for capacity estimate
- Refine window based on congestion signals

Controller-based capacity estimation



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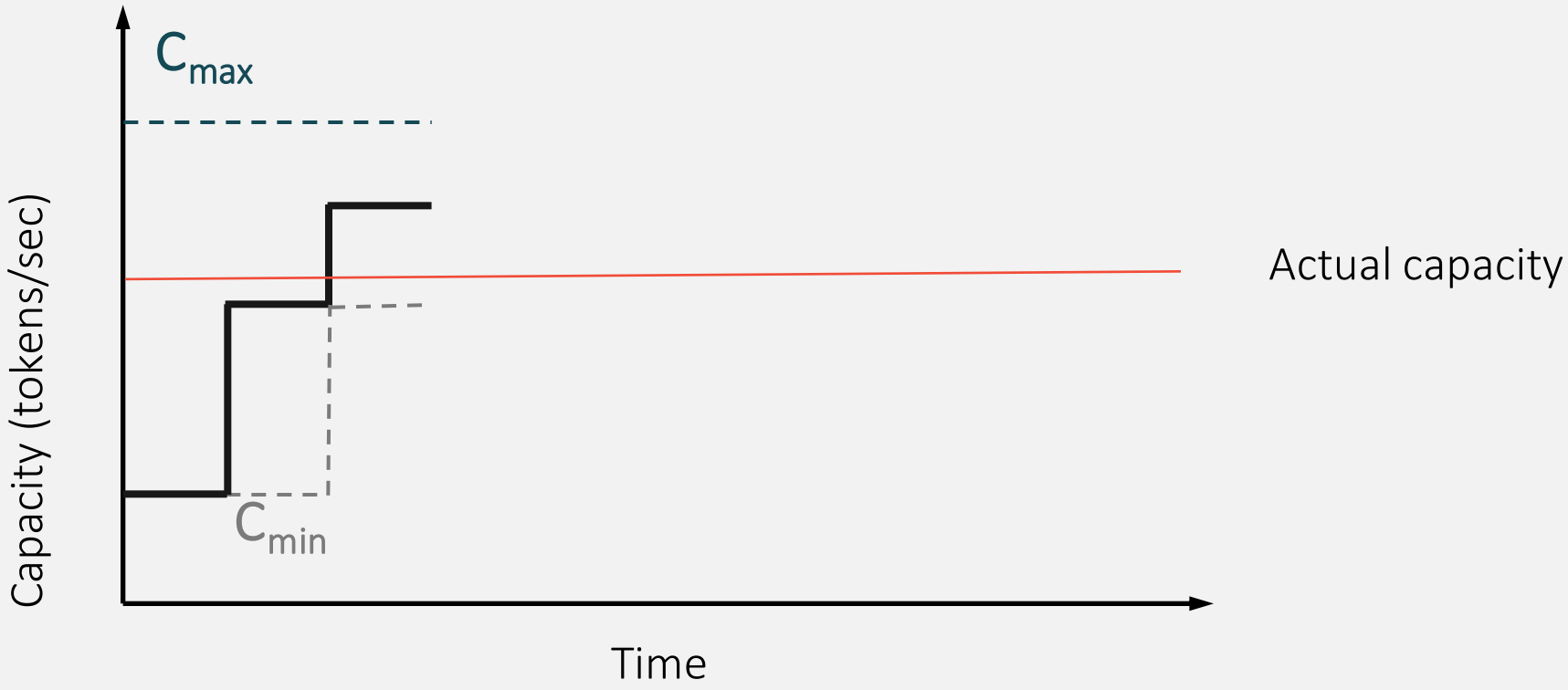
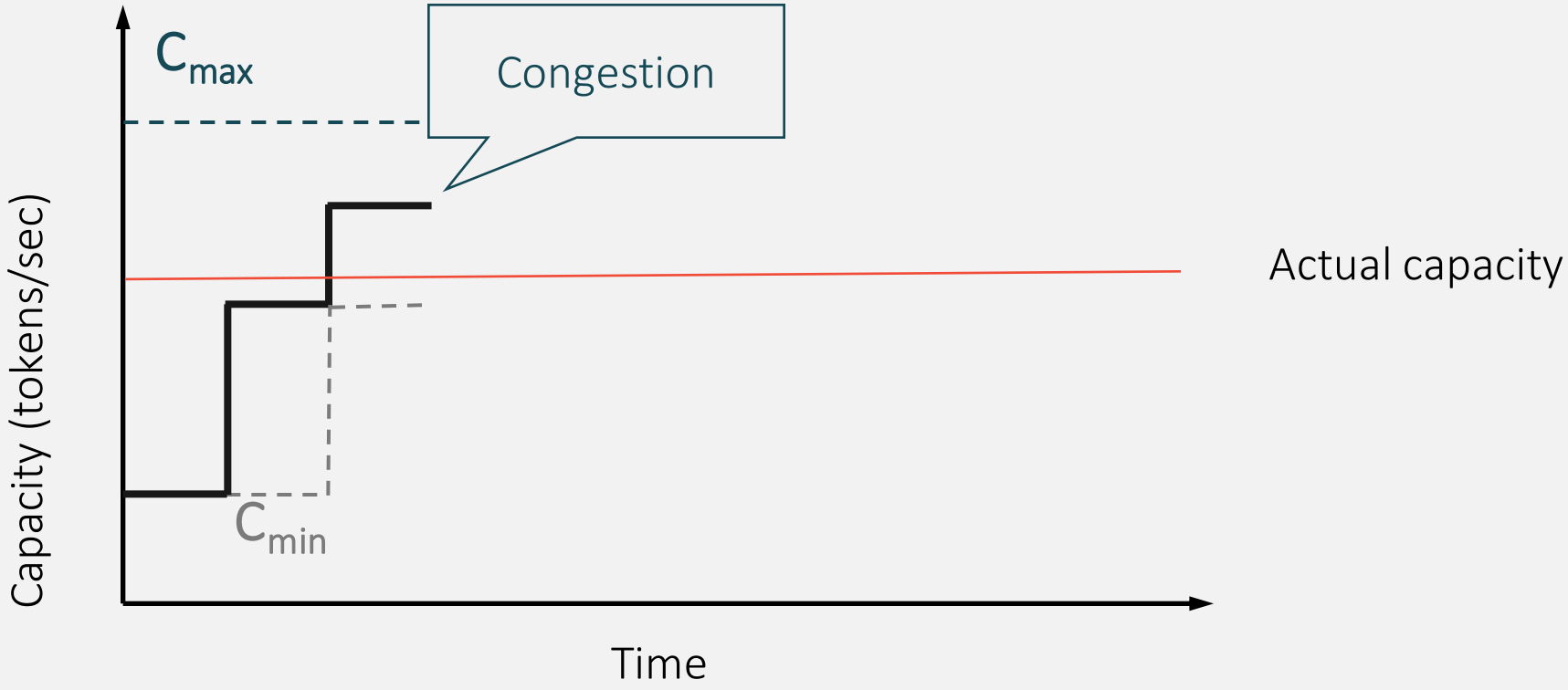


Controller-based capacity estimation



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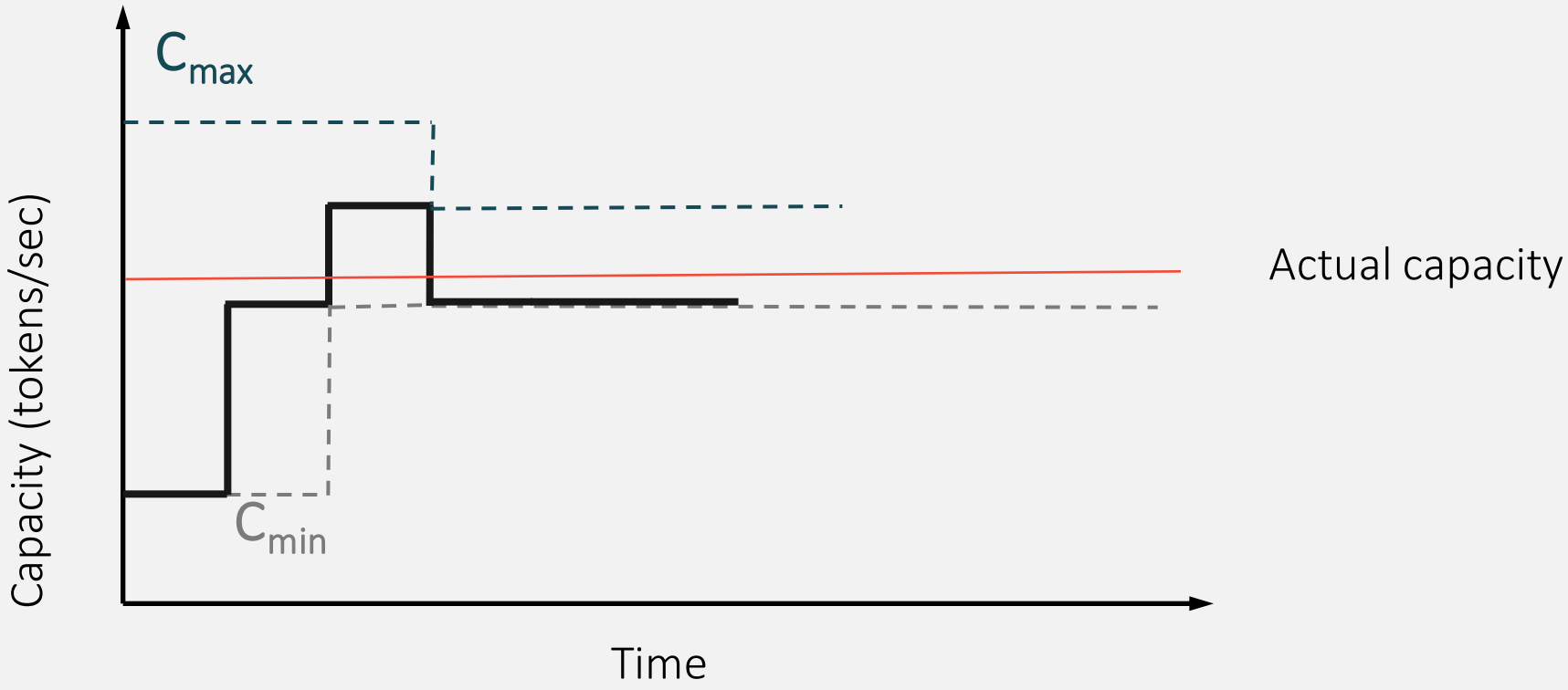

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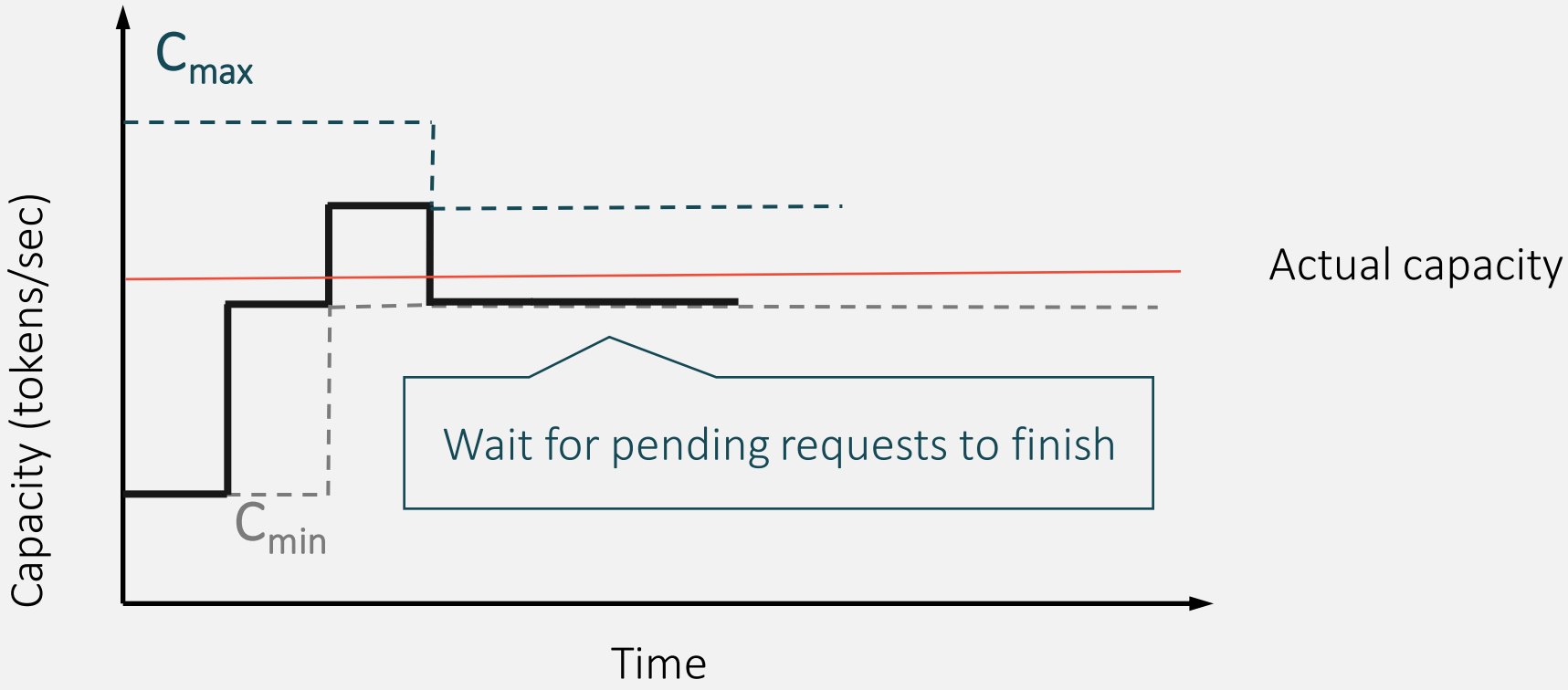

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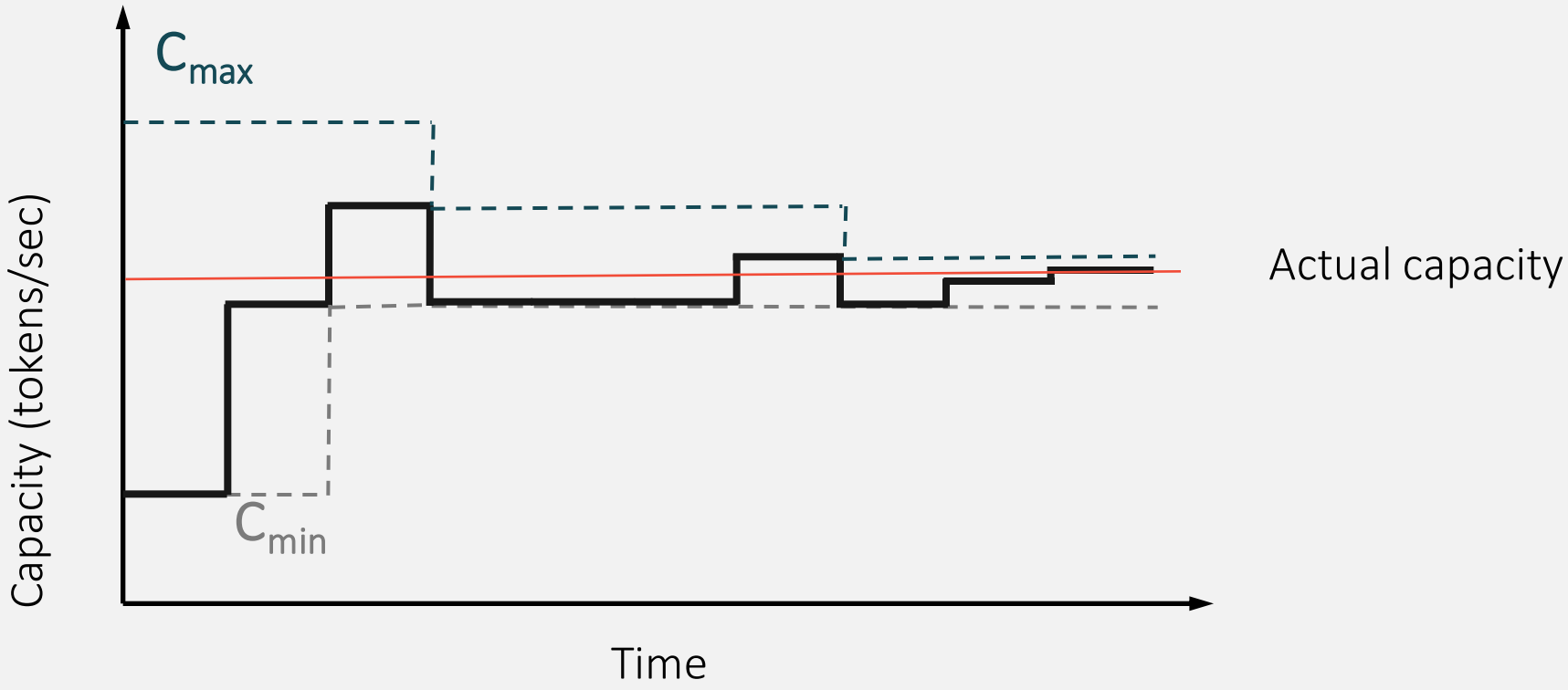

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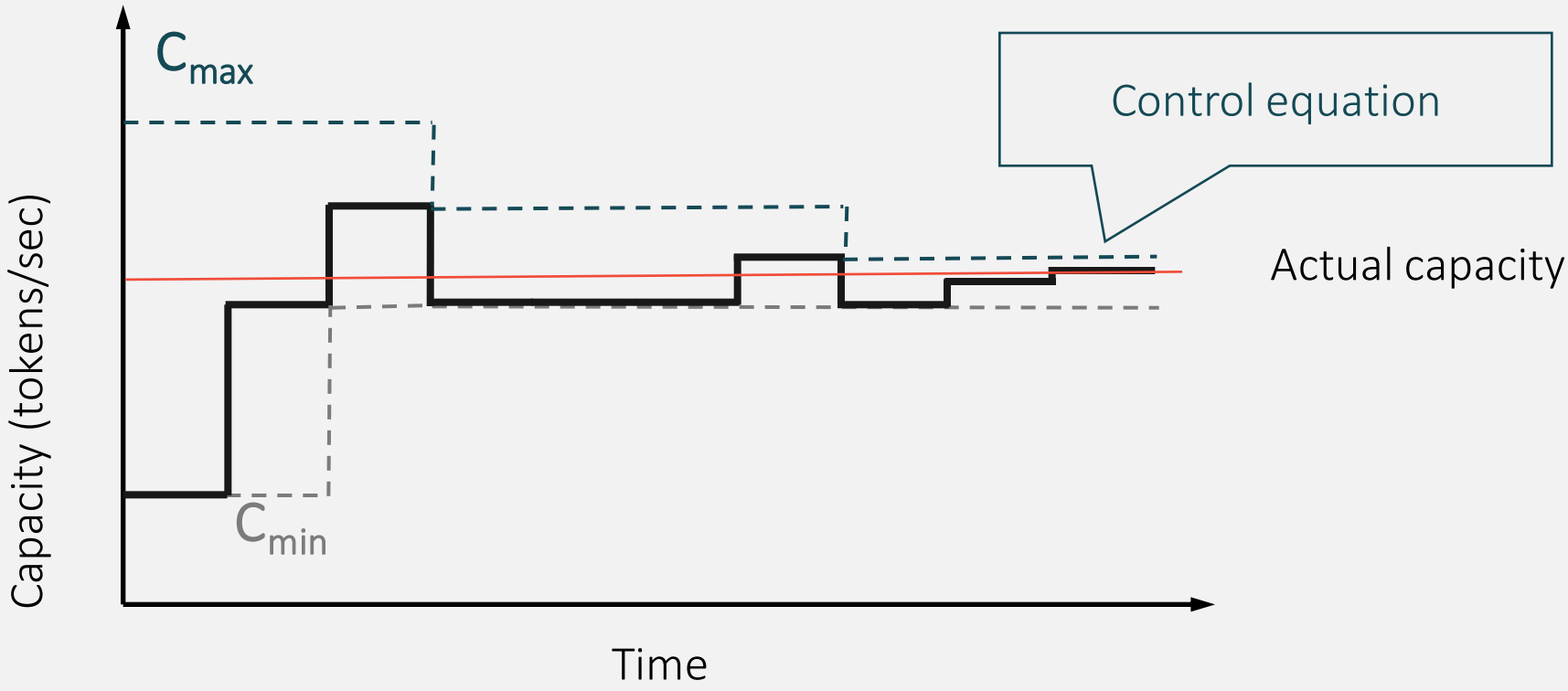

We rely on two congestion signals

- Aggregate throughput < Capacity estimate
- VDC-compliant workload
  - Helps find capacity for VDC-compliant workload
  - Detailed example in the paper!

Implementation

- Rate enforcer
  - Filter driver running on Hyper-v
  - Enforces allocations using a multi-resource token bucket
- Controller
  - Stand-alone server
  - Allocation mechanisms include DRF [NSDI'11], H-DRF [SOCC'13]
  - Installs relevant cost functions in rate enforcers

Evaluation questions

1. Can Pulsar isolate tenants and meet their guarantees?

2. Can Pulsar estimate appliance capacity?

3. What are the data- and control-plane overheads?

Experimental setup and testbed

- 3 Appliances:

In-memory key-value store Blockstore (6 SSDs) Encryption device

- Network: Mellanox 40 Gbps RDMA RoCE full-duplex

- 10 compute servers (total of 113 VMs)

Workloads and expected throughput

- 4 Tenants: A—D (tenants share at least one resource)
- Workloads are generated with parameters from Hotmail traces

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- Workloads are generated with parameters from Hotmail traces
- Expected throughput (tokens/second):

Tenant	A*	B	C*	D
Guarantee	400 M	1600 M	800 M	800 M
VMs	49 (many flows)	48	8 (large IO window)	8

Pulsar achieves tenants' guarantees

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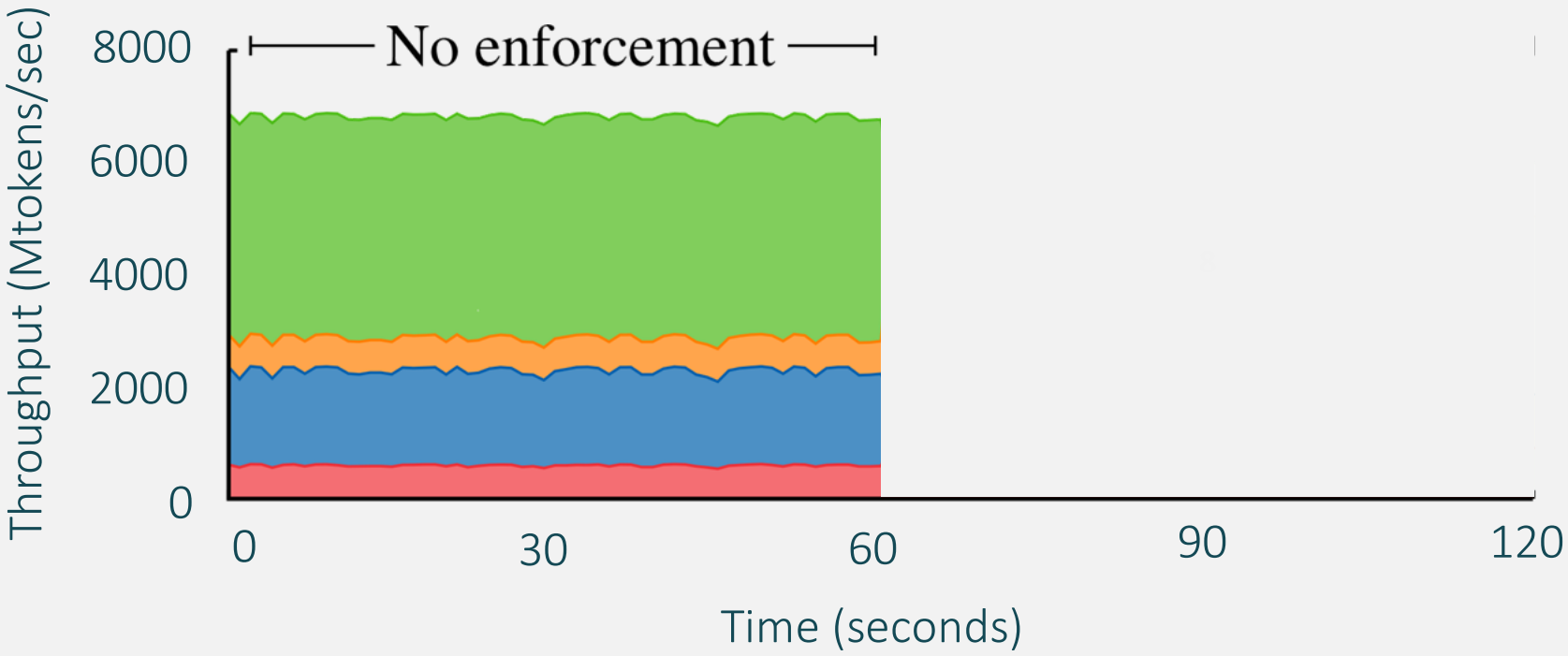

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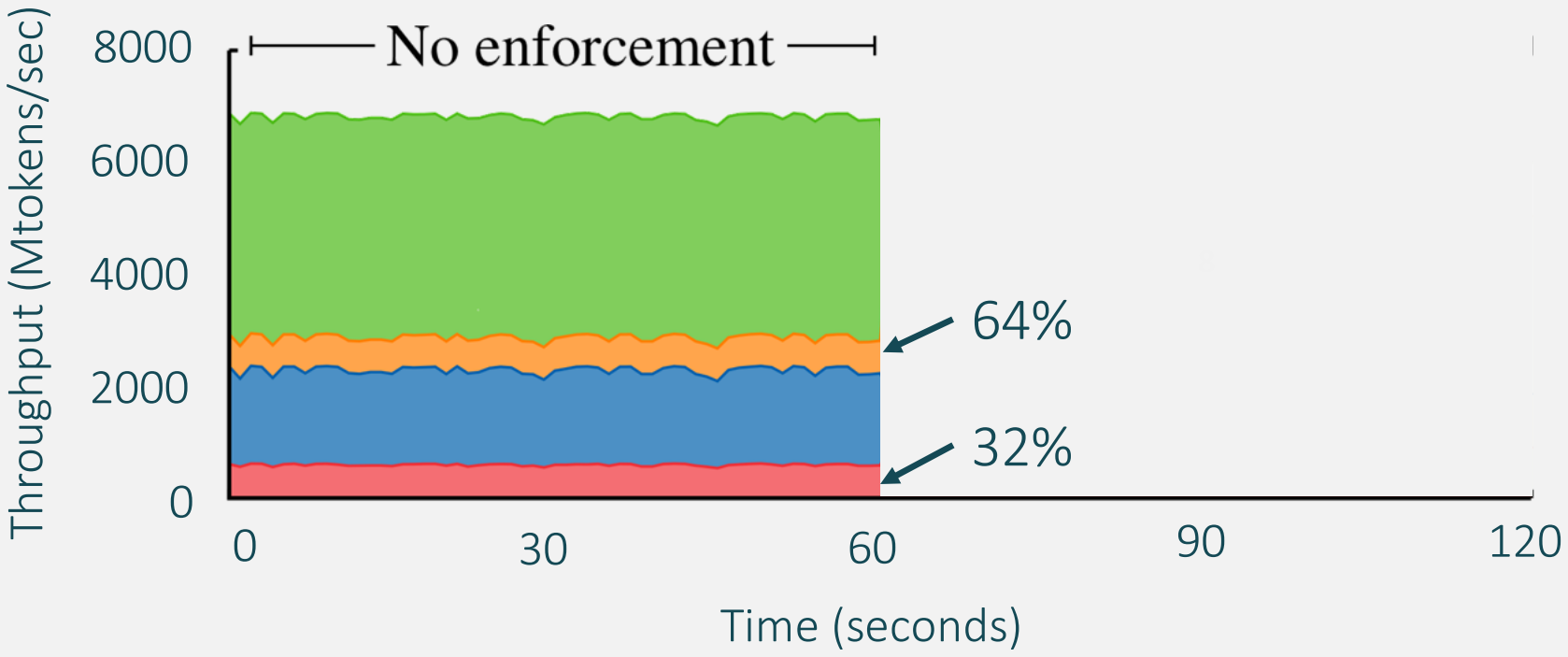

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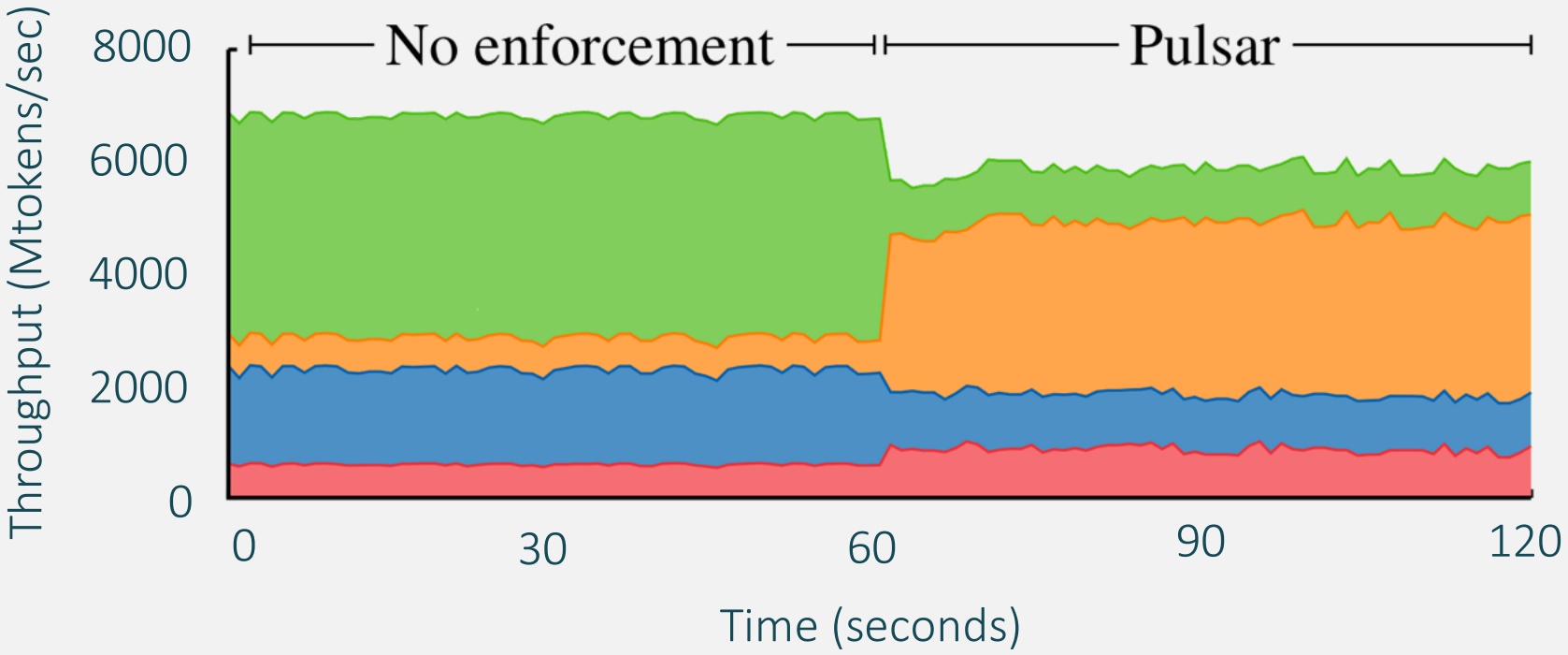

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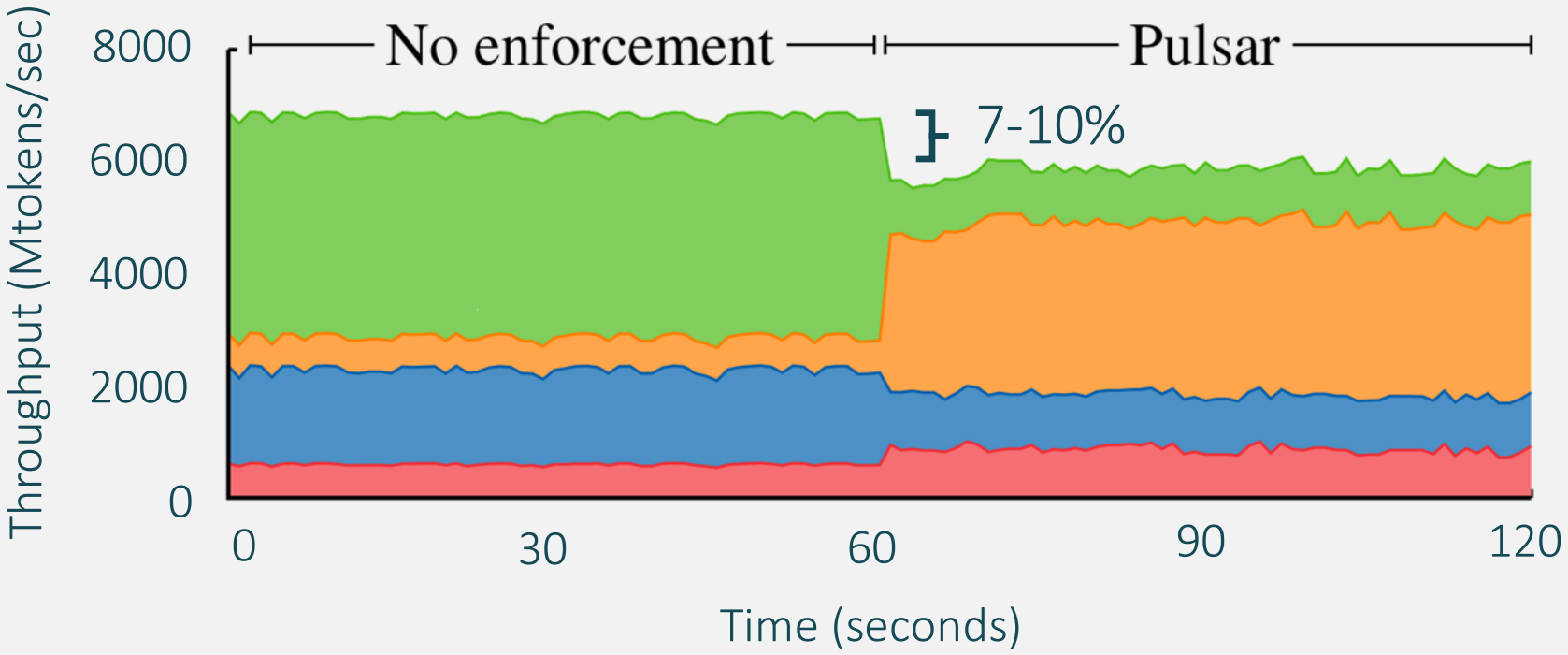
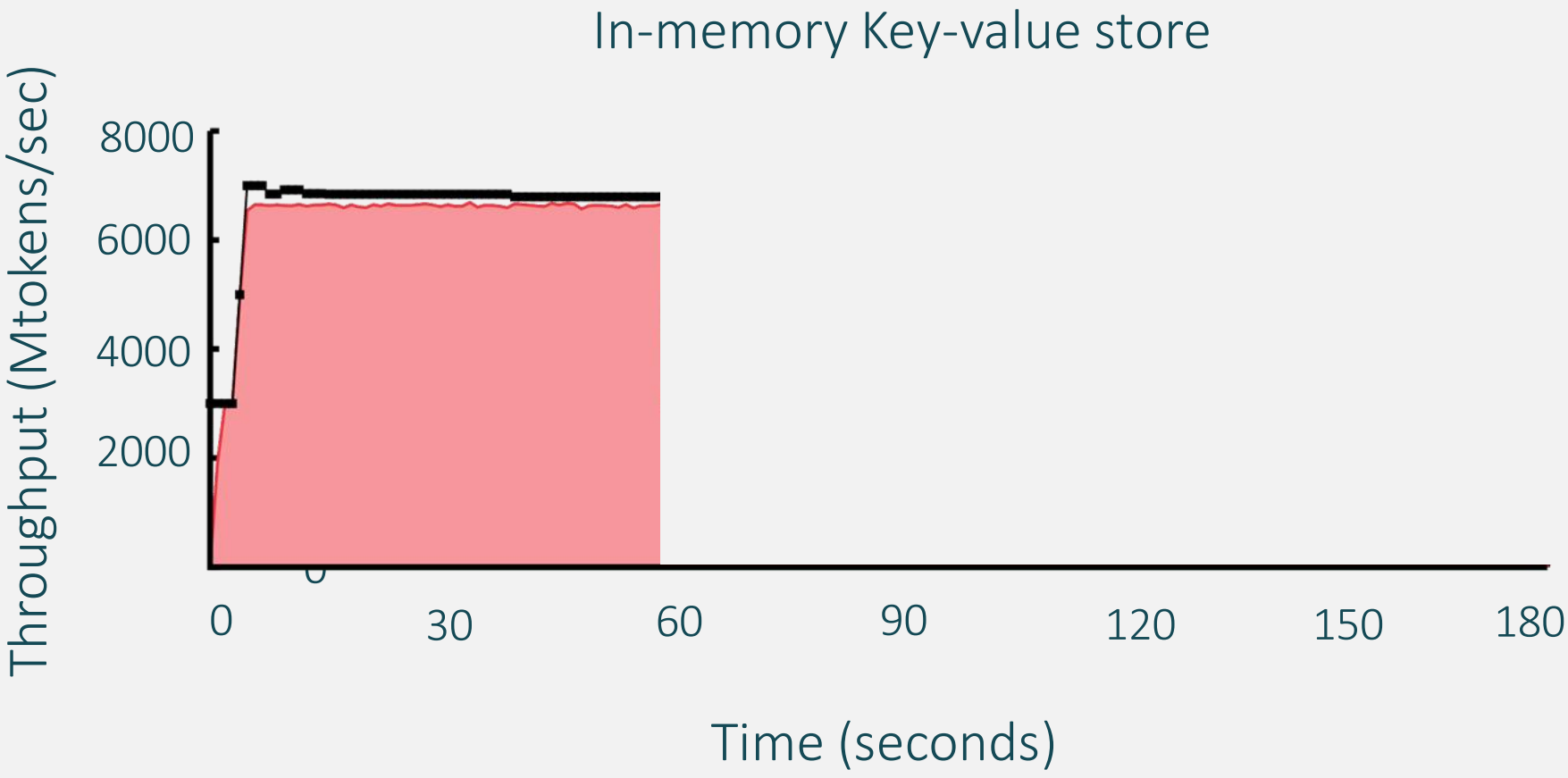


Can Pulsar estimate appliance capacity?

Pulsar estimates capacities and copes with changing workloads



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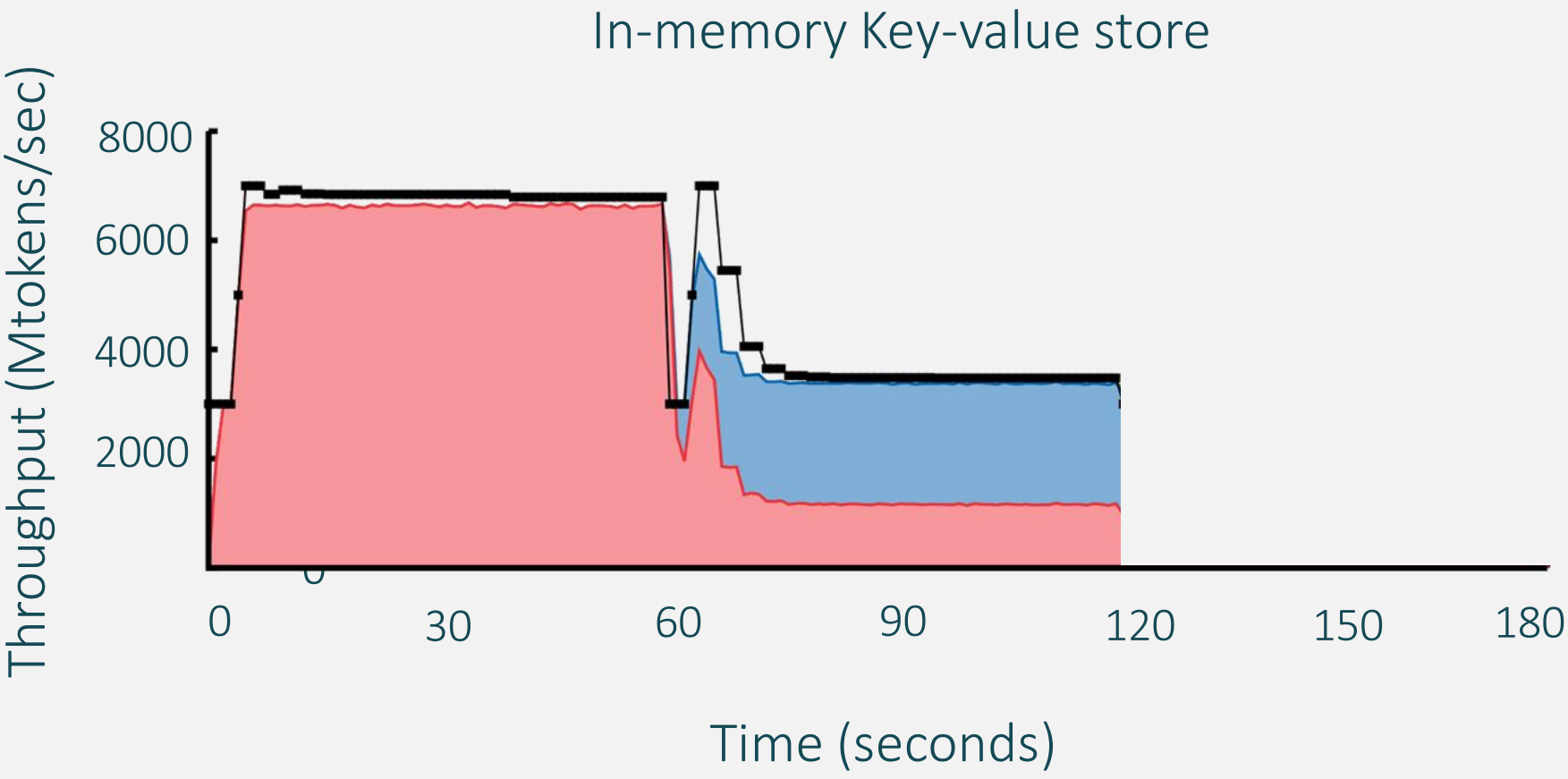

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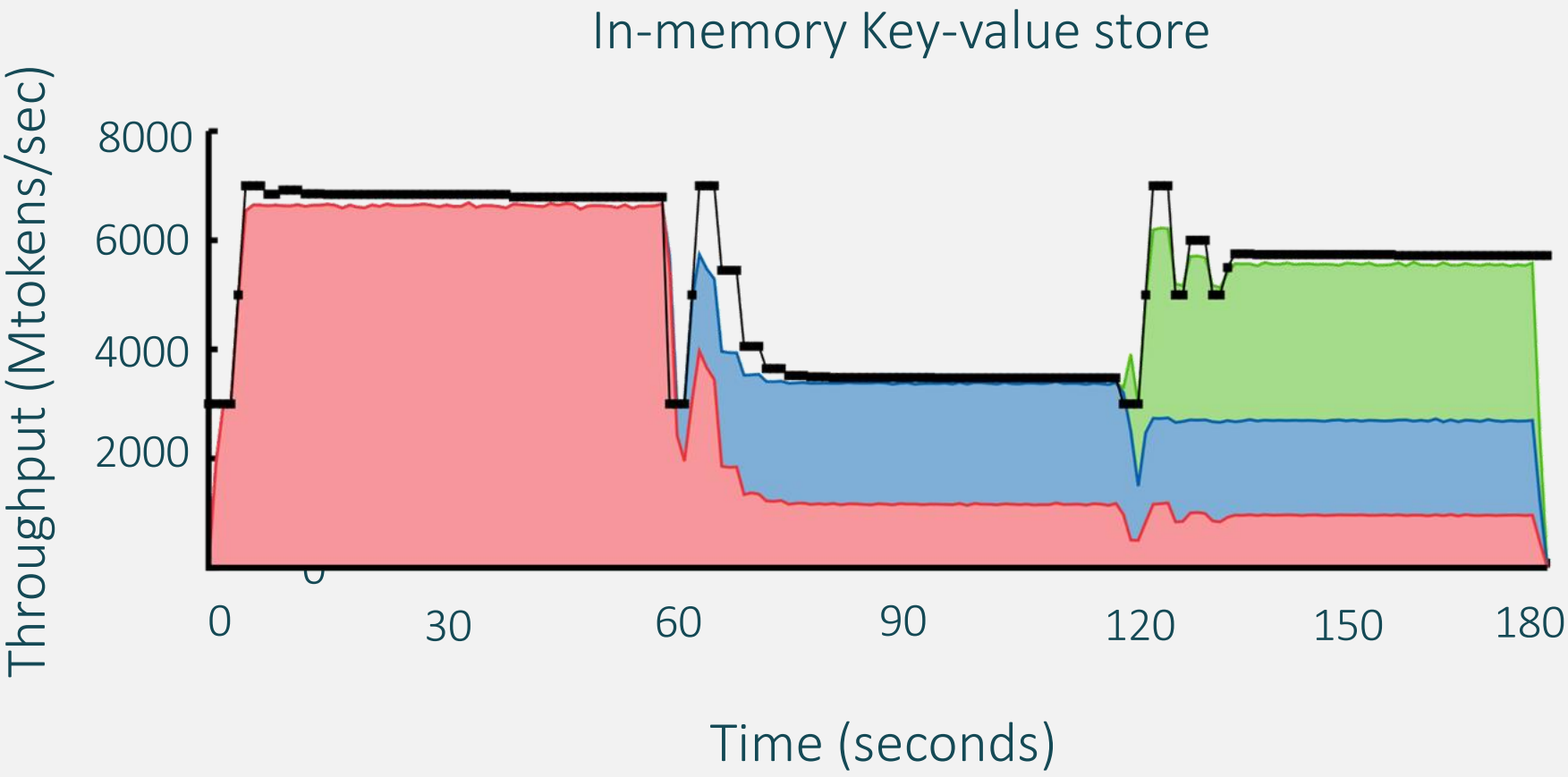

What are the data- and control-plane overheads?

Data- and control-plane overheads are reasonable

Data-plane

- Overhead from rate enforcer < 2% (15% for small requests)

Control-plane

- 256 bytes/sec for each VM
- Setting up cost functions at rate enforcers takes 83 µs
- Can compute rich policies for 24K VMs and 200 appliances

Summary

- Virtual Datacenter (VDC) abstraction
  - Captures tenants' end-to-end throughput guarantees
- Pulsar implements the VDC abstraction
  - Simple data-plane rate limiting and centralized control-plane
  - No changes to appliances, switches, guest OSes, and apps
  - Reasonable data- and control-plane overheads
- See you at the poster session!