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Storage Quality of Service for Enterprise Workloads

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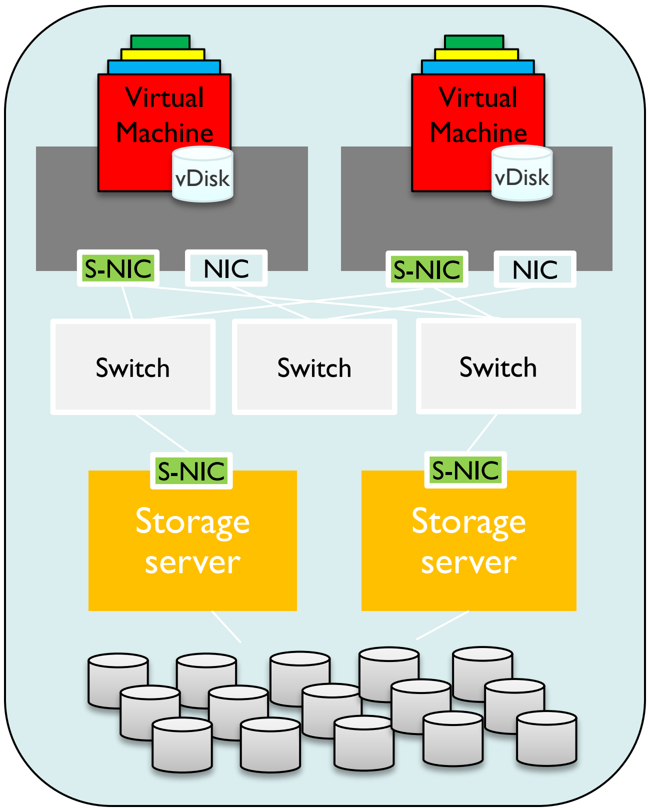
Outline

- Problem Statement
- Classification, Control and Costing
- Controller and Policies
- Demo
- Details
- Q&A

SDC 14

Background: Enterprise data centers



- General purpose applications
- Application runs on several VMs
  - E.g. a multi-tier service
- Separate networks for VM-to-VM traffic and VM-to-Storage traffic
- Storage is virtualized
- Resources are shared
  - Filesharing protocols deployed

The Storage problem

- First things first
  - In a datacenter, storage is a shared resource
  - Many tenants (customers)
    - Contention between tenants in the datacenter
  - Many workloads
  - Many backend device types and throughputs
  - Network resources are also shared
  - Provisioning key to providing cost-effective SLAs

More storage problems

- Storage throughput (capacity) changes with time
- Storage demand also changes with time
- SLAs do not

- Variety of storage protocols
  - **SMB3**, NFS, HTTP, …

SMB3 challenges

- Multichannel – Many to Many
  - Many SMB3 sessions (flows) on one channel
  - Many SMB3 channels used for each session
- SMB Direct
  - RDMA offload of bulk transfer – stack bypass
- Live Migration
  - Memory-to-memory with time requirements
  - Starvation of other flows must be avoided

Service Level Agreement (SLA) Examples

- Minimum guaranteed ("Not less than…")
  - Storage bandwidth
  - Storage I/Os per second
- Maximum allowed ("Not more than…")
- Opportunistic use ("If available…")
  - Bandwidth/IOPS can use additional resources when available (and authorized)
- All limits apply across each tenant's/customer's traffic

Storage SLA Challenges

- Diverse operations mix
  - E.g. SMB3 Create, Read/Write, metadata
  - Resources, latencies, IO size diversity
- Dynamic, diverse workload
  - E.g. database tier vs web frontend vs E-mail
  - Small-random, large-sequential, metadata
- Bi-directional
  - Read vs write differing costs, resources

Can’t We Just Use Network Rate Limits?

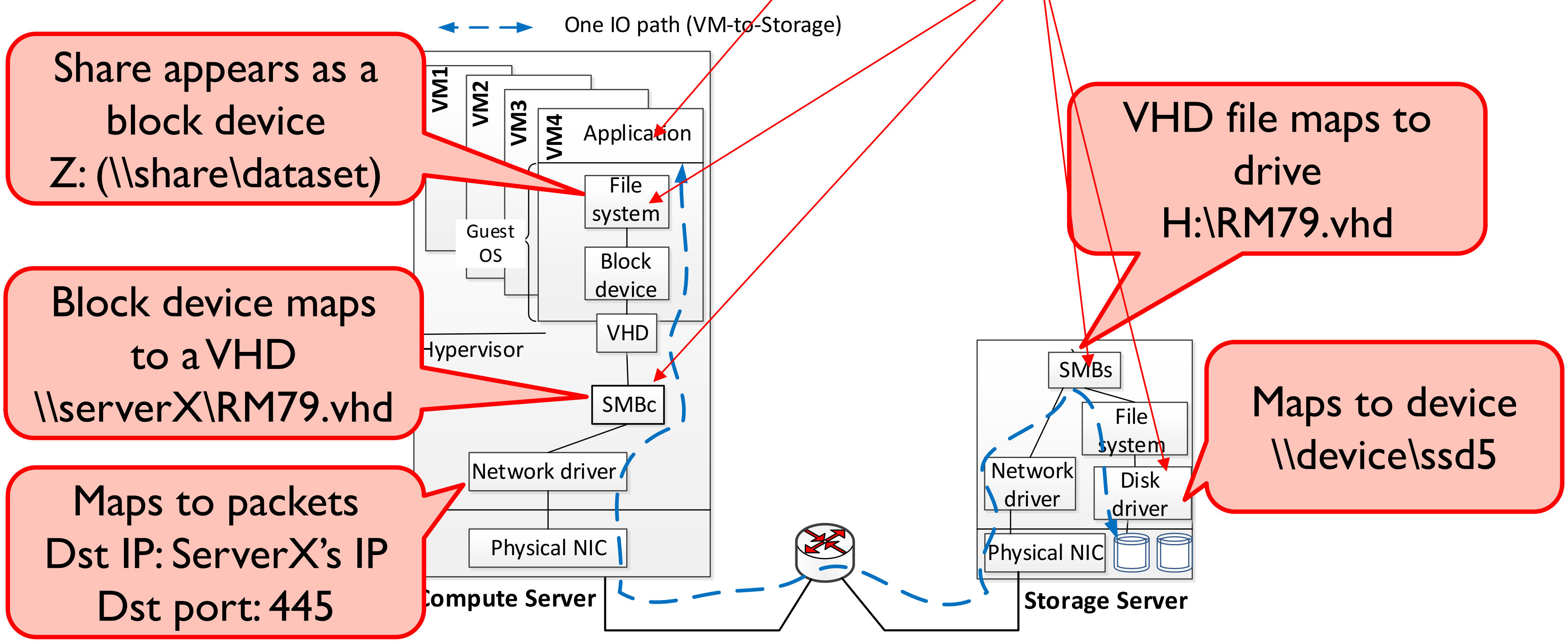
- No. Consider:
  - The network flow is a 4-tuple which names only source and destination
  - Does not distinguish:
    - Read from write
    - Storage resources such as disk, share, user, etc
    - Even deep packet inspection doesn't help
      - Can't go that deep – not all packets contain the full context
      - Might be encrypted
  - SMB multichannel and connection sharing
    - Many-to-many – mixing of adapters, users, sessions, etc
  - RDMA
    - Control and data separated, and offloaded

Classification – Storage "Flow"

1. Classify storage traffic into Flow buckets
   - Pre-defined "tuple" of higher-layer attributes
     - Can have *any number* of elements, and wildcards
     - Can therefore apply across many connections, users, etc.
   - For example (SMB3 and virtual machine):
     - VM identity
     - \\Servername\Sharename
     - Filename
     - Operation type
2. Identify each operation as member of Flow
3. Apply policy to Flow

Elements of an IO classification

- Simple classifier tuple: { VM4 , \\share\dataset }

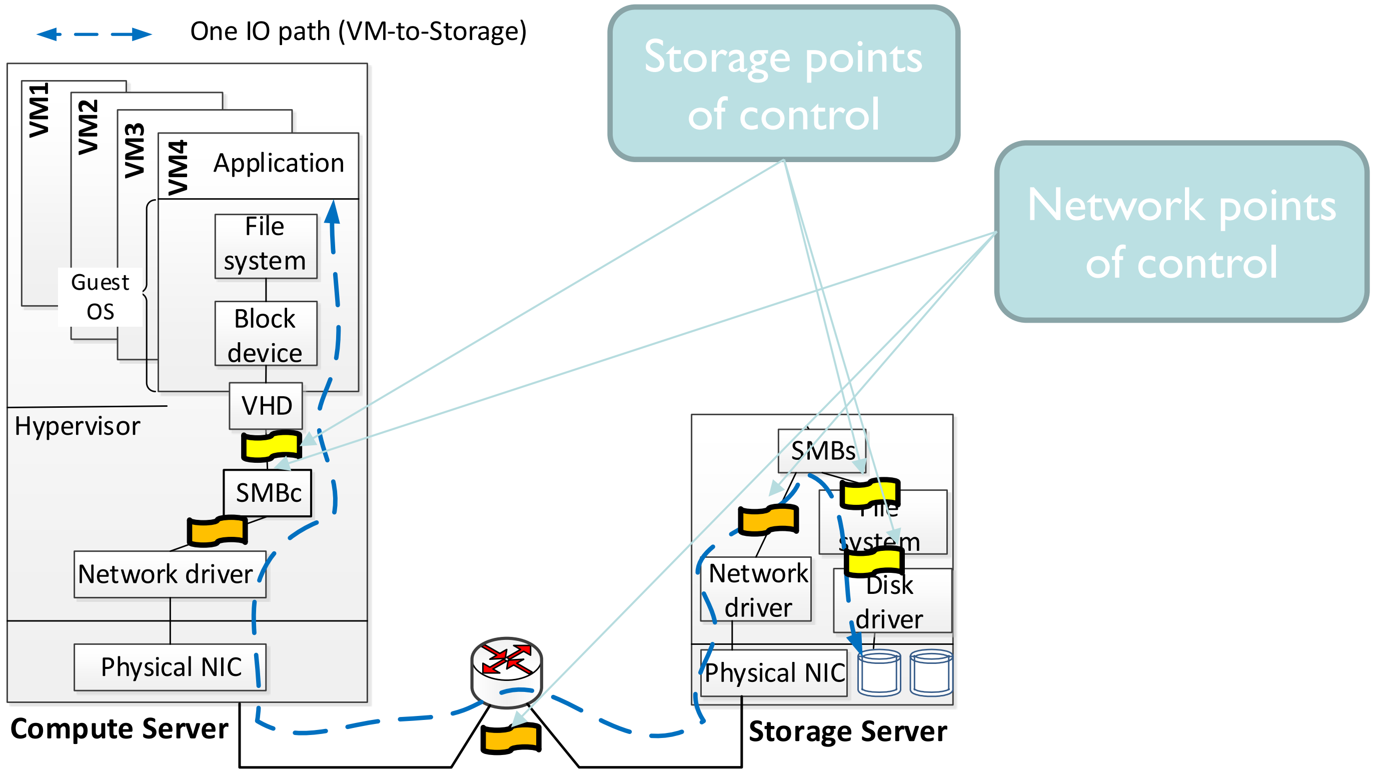


Control (Rate Limiting)

- Apply limits (max) / guarantees (min) to each flow
- Rate-control operations to meet these
- Control at:
  - Initiator (client)
  - Target (server)
  - Any point in storage stack

Rate Limiting along the Flow

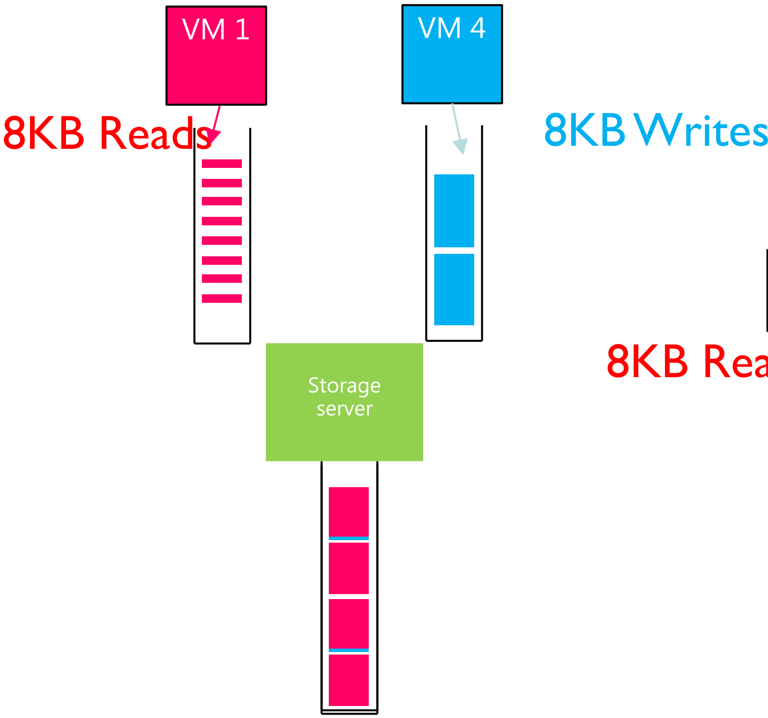
- Simple classifier tuple: { VM4 , \\share\dataset }



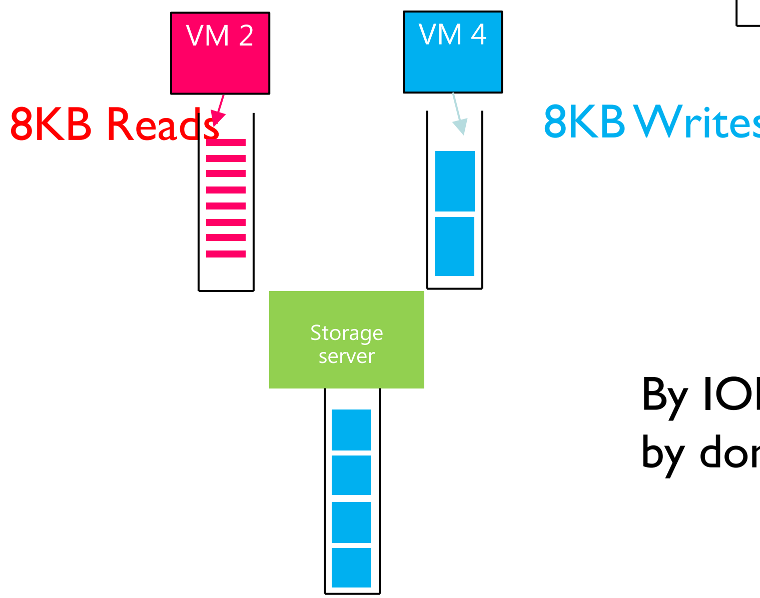
Control based on simple Classification?

- Again, no
- Taking the example SLA
  - <VM 4, \\share\dataset> --> Bandwidth B
  - With contention from other VMs
- Comparing three strategies
  - By “payload” – actual request size
  - By “bytes” – read and write size
  - By “IOPS” – operation rate

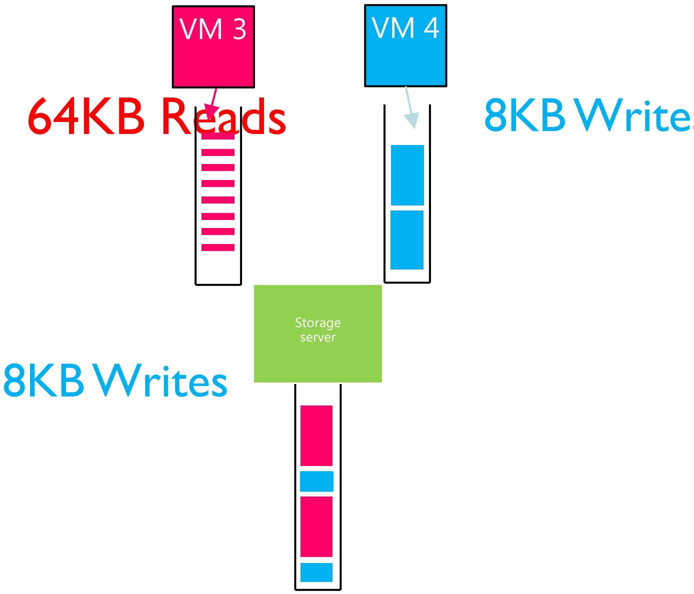
Classification-only Rate Limit Fairness?



By payloads- reads beat writes by dominating queue



By bytes – writes beat reads by dominating (e.g. SSD) expense



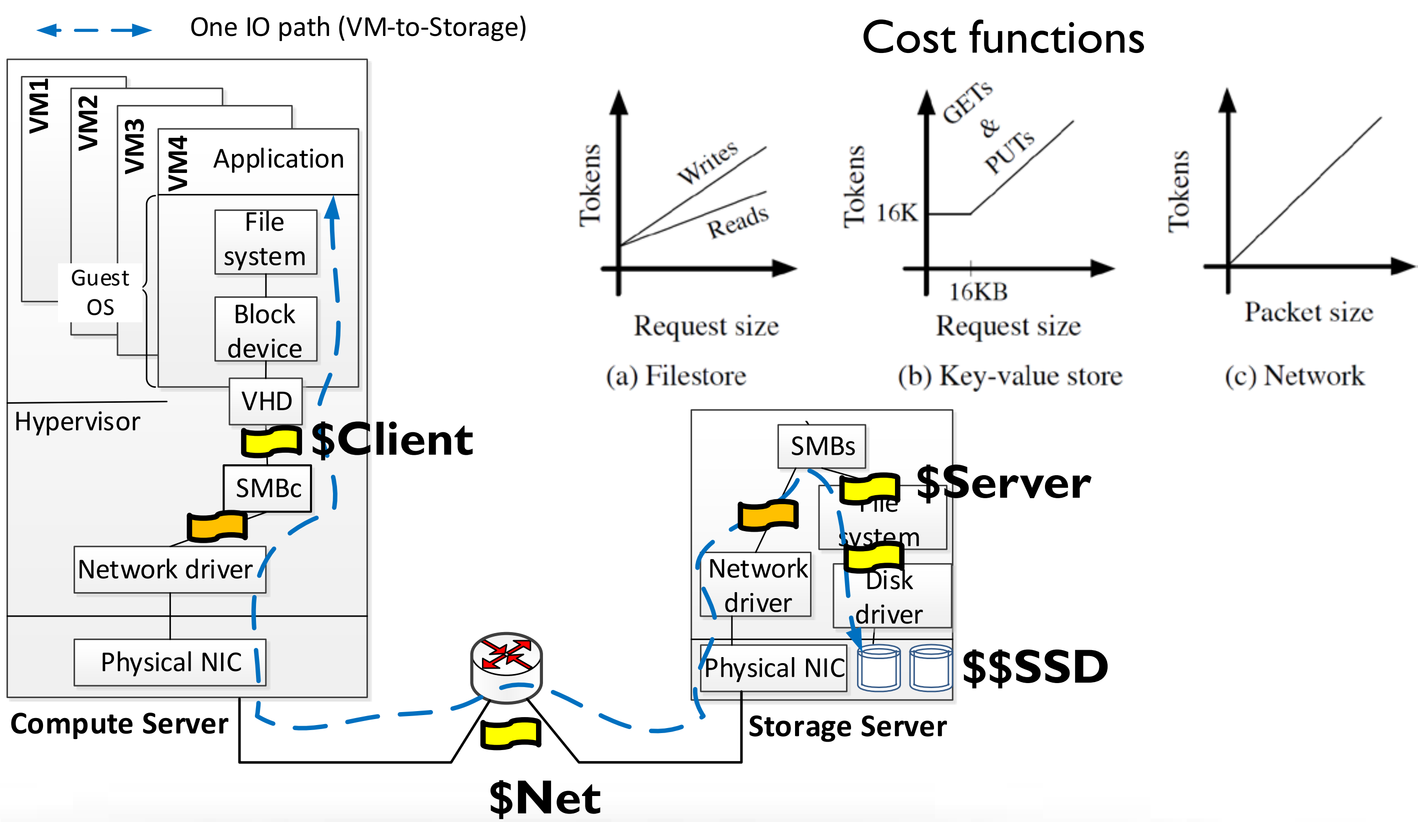
By IOPS - large beats small by dominating bandwidth

Solution - Cost

- Compute a **cost** to each operation within a flow, and to a flow itself
- “Controller” function in the network constructs empirical cost models based on:
  - Device type (e.g. RAM, SSD, HDD)
    - Server property
  - Workload characteristics (r/w ratio, size)
    - “Normalization” for large operations
    - Client property
  - Bandwidths and latencies
    - Network and storage property
  - Any other relevant attribute
- Cost model is assigned to each rate limiter
- Cost is managed globally across flows by distributed rate limiters

Cost of operations along the Flow

- Simple classifier tuple: { VM4 , \\share\dataset }



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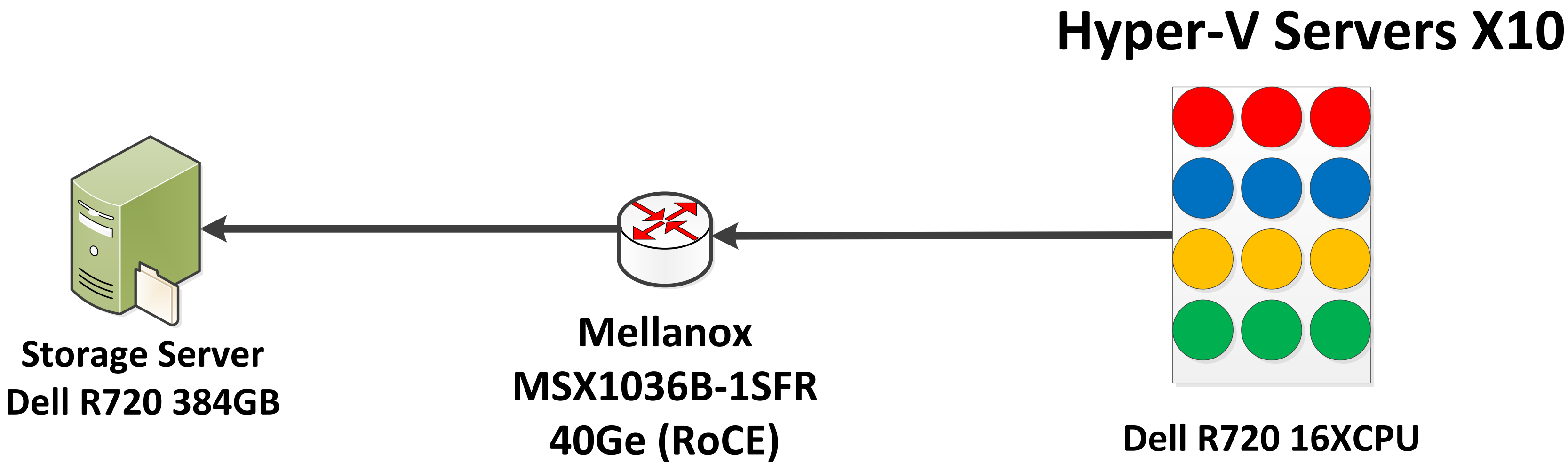
Demo of storage QoS prototype

- Four tenants: Red, Blue, Yellow, Green
  - Each tenant
    - Rents 30 virtual machines on 10 servers that access shared storage
    - Pays the same amount
    - **Should achieve the same IO performance**
  - Tenants have different workloads
    - **Red** tenant is aggressive: generates more requests/second

Demo setup



Mellanox ConnectX-3 40Ge RNIC (RoCE)

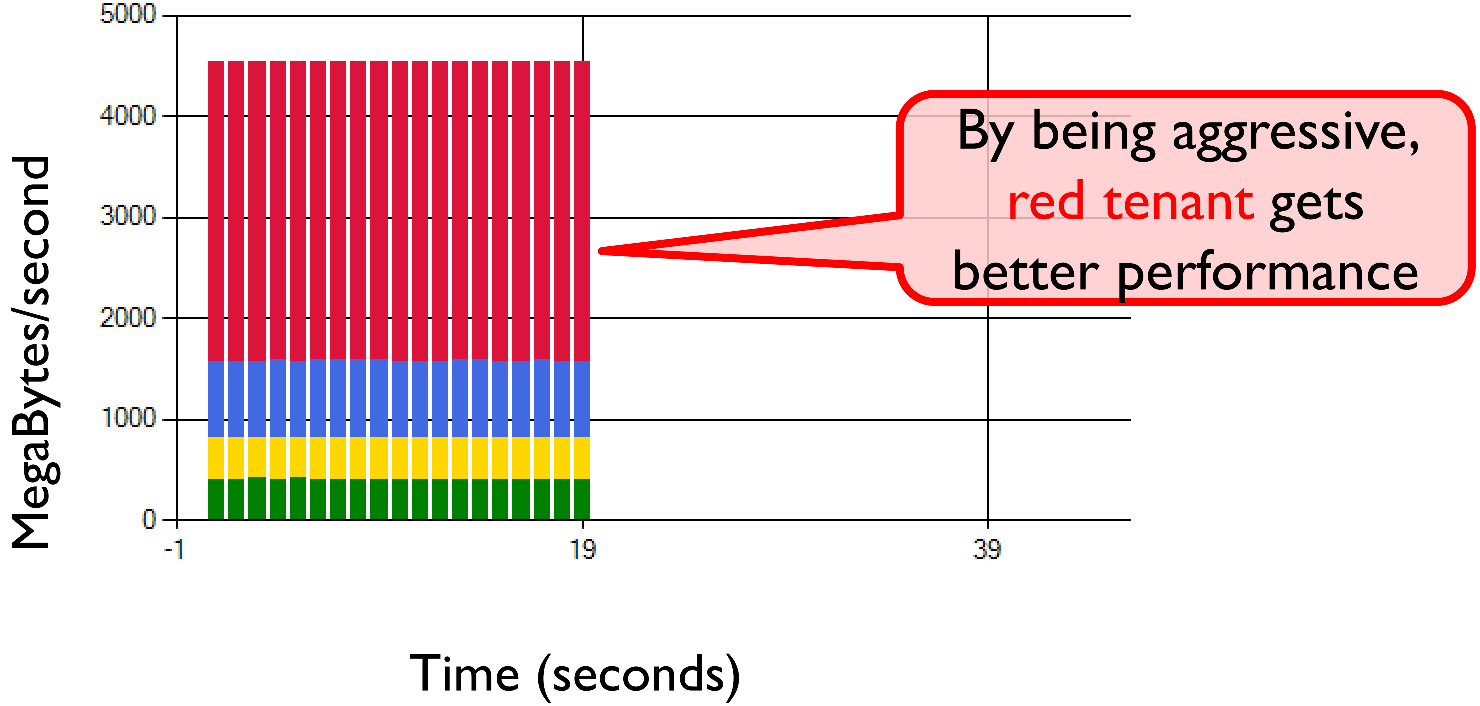
120 one-Core VMs across 10 Hyper-V servers

- Run IoMeter 64K Read from 3GB VHD

Things to look for

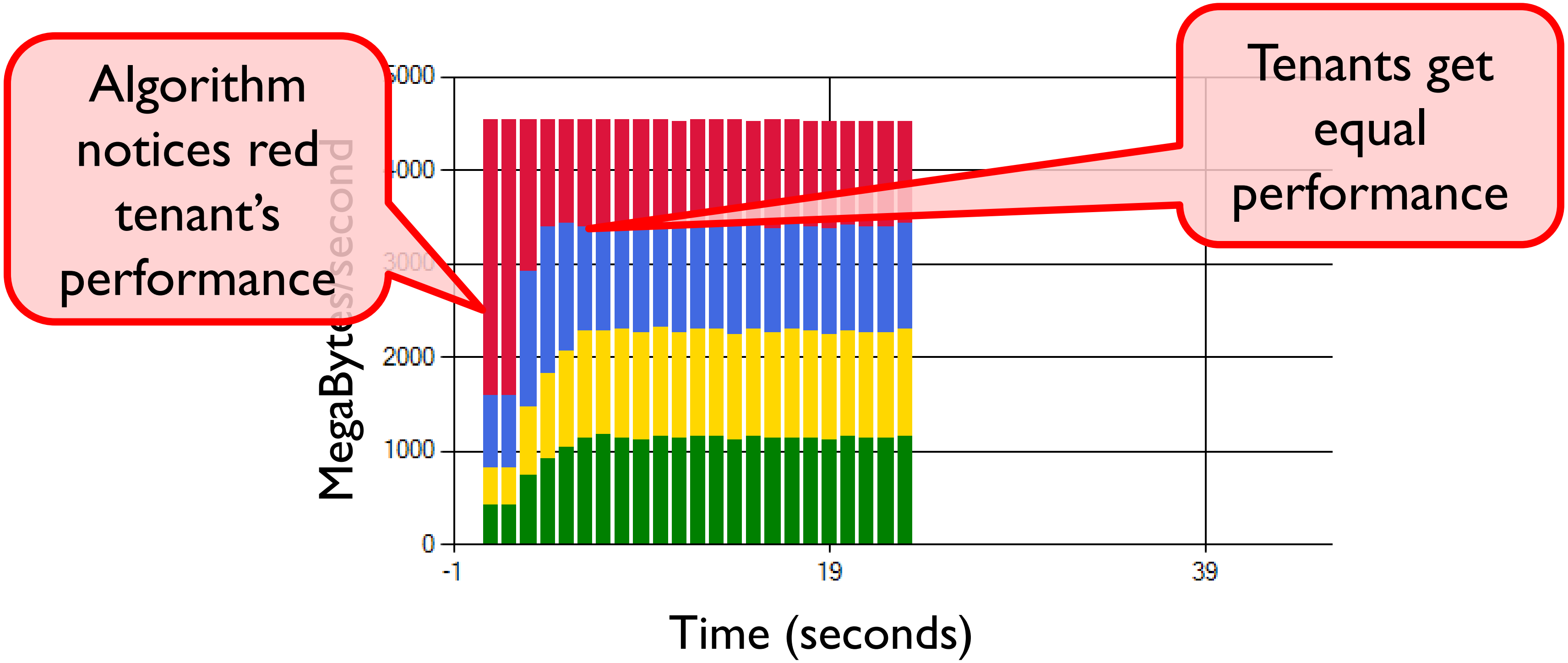
- Enforcing storage QoS across 4 competing tenants
  - Aggressive tenant under control
- Inter-tenant work conservation
  - Bandwidth released by idle tenant given to active tenants
- Intra-tenant work conservation
  - Bandwidth of tenant’s idle VMs given to its active VMs

Demo: Red tenant dominates! ☹



- Tenant performance is not proportional to its payment

Research Prototype: With Storage QoS ☺

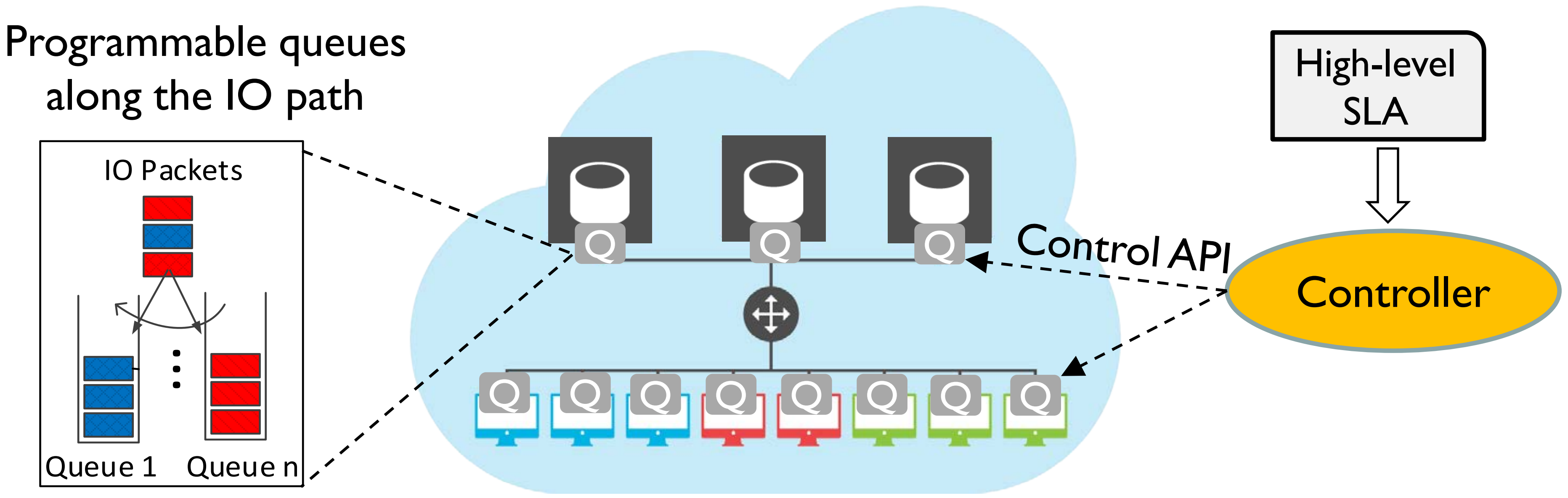


- Tenant performance is proportional to its payment

Demo

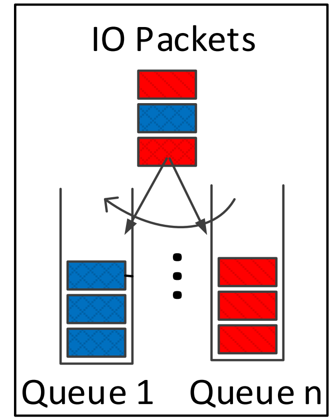
Behind the scenes: how did it work?

Data-plane Queues + Centralized controller



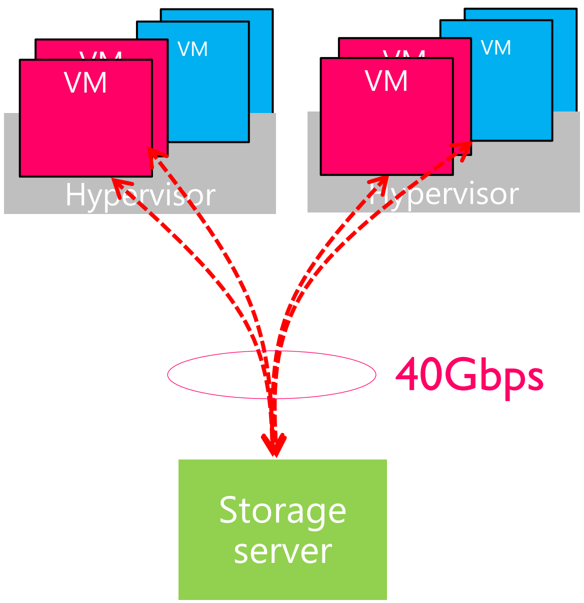
Data plane queues

1. Classification
   - [IO Header -> *Queue*]
2. Queue servicing
   - [Queue -> *<rate, priority, size>*]



Controller: Distributed, dynamic enforcement

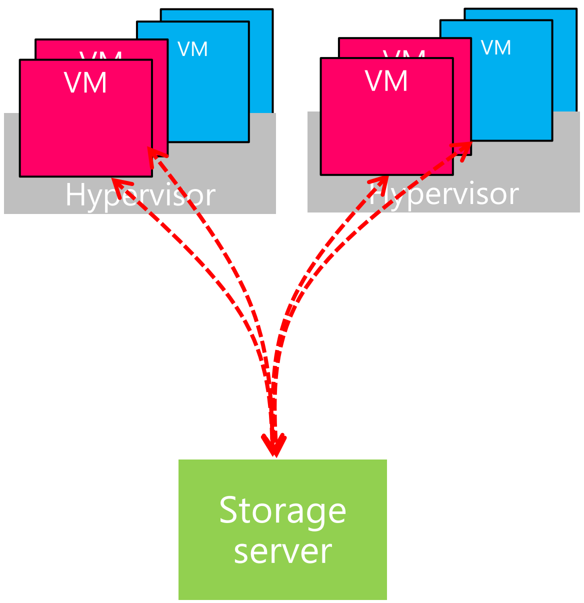
- <{Red VMs 1-4}, *, * //share/dataset> --> Bandwidth 40 Gbps



- SLA needs per-VM enforcement
- Need to control the aggregate rate of VMs 1-4 that reside on different physical machines

- Static partitioning of bandwidth is sub-optimal

Work-conserving solution



- VMs with traffic demand should be able to send it as long as the aggregate rate does not exceed 40 Gbps
- **Solution:** *Max-min fair sharing*

Max-min fair sharing (intuition)

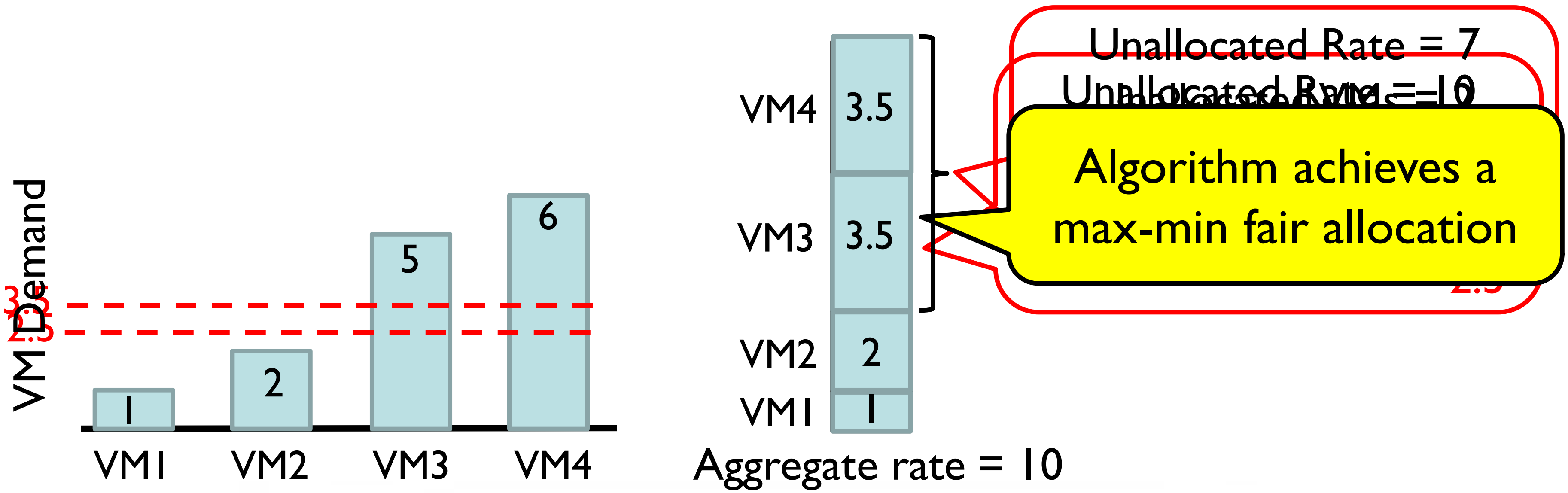
- Well-accepted notion of allocating a shared resource
  - Basic idea: Maximize the minimum allocation
- Formally, VMs [1..n] sharing rate B
  - Demand D_i for VM *i*
  - Max-min fair share *f* ensures that
    - if the rate allocated to VM *i* is $R_i = min(f, D_i)$
    - then $\sum Ri \leq B$

No VM is given more than its demand

Total allocated rate doesn't exceed B

Distributed rate limiting algorithm

- Allocate rate to VMs based on their demand
  - No VM get a rate higher than its demand
  - VMs with unmet demand get the same rate

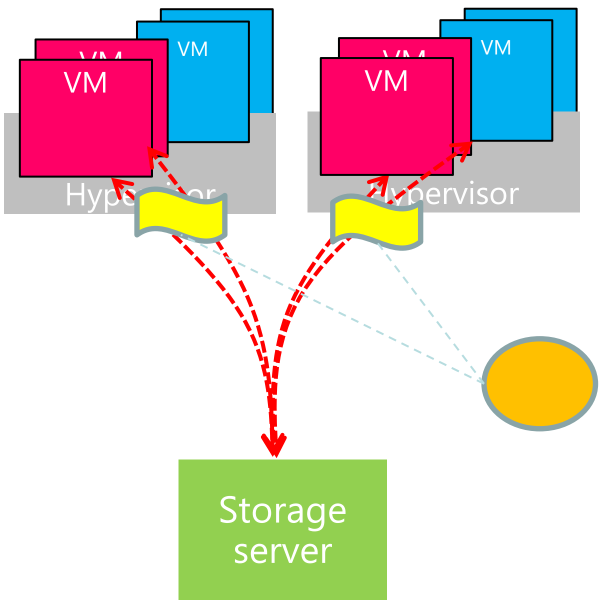


Max-min fair sharing (recap)

- Well studied problem in networks
  - Existing solutions are distributed
    - Each VM varies its rate based on congestion
    - Converge to max-min sharing
  - *Drawbacks*: complex and requires congestion signal
- But we have a centralized controller
  - Converts to simple algorithm at controller

Controller decides *where* to enforce

Minimize # times IO is queued and distribute rate limiting load



SLA constraints

- Queues where resources shared
- Bandwidth enforced close to source
- Priority enforced end-to-end

Efficiency considerations

- Overhead in data plane ~ # queues
- Important at 40+ Gbps

Centralized vs. decentralized control

Centralized controller allows for simple algorithms that focus on SLA enforcement and ***not*** on distributed system challenges

Analogous to benefits of centralized control in software-defined networking (SDN)

Summary and takeaways

- Storage QoS building blocks
  - Traffic classification
  - Rate limiters
  - Logically centralized controller

References / Other Work

- Predictable Data Centers
  - http://research.microsoft.com/datacenters/
  - Storage QoS - IOFlow (SOSP 2013)
    - http://research.microsoft.com/apps/pubs/default.aspx?id=198941
  - Network + storage QoS (OSDI 2014)
    - http://research.microsoft.com/apps/pubs/default.aspx?id=228983
- SMB3 Rate Limiter (Jose Barreto's blog)
  - http://smb3.info
  - http://blogs.technet.com/b/josebda/archive/2014/08/11/smb3-powershell-changes-in-windows-server-2012-r2-smb-bandwidth-limits.aspx