IOFlow

A Software-Defined Storage Architecture

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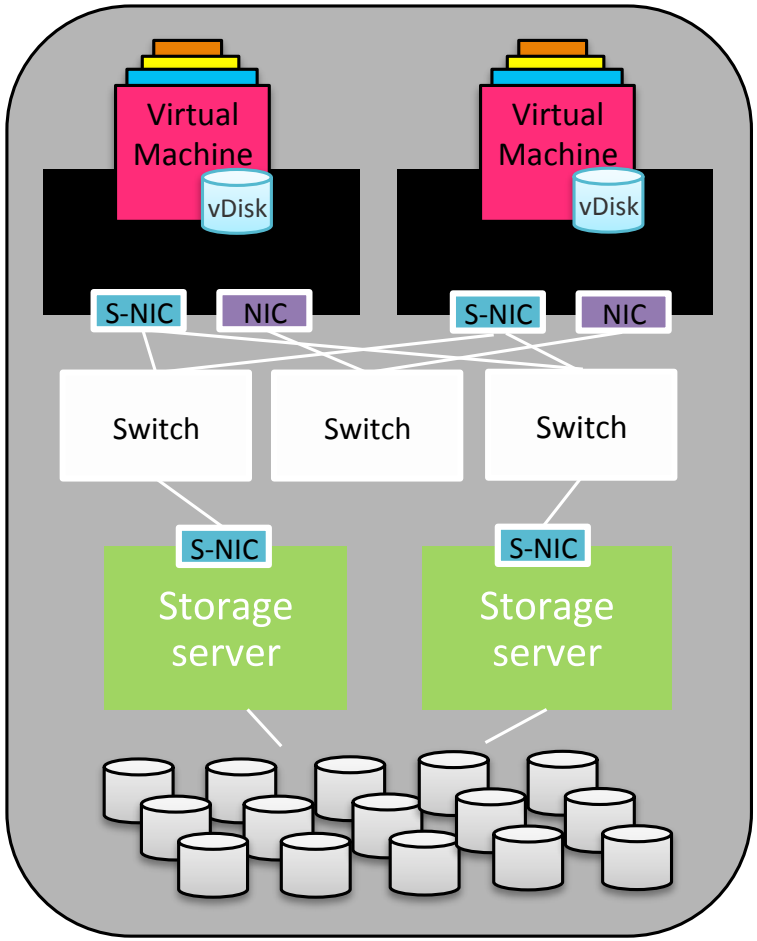
Some material borrowed from authors' SOSP 2013 presentation

Problem



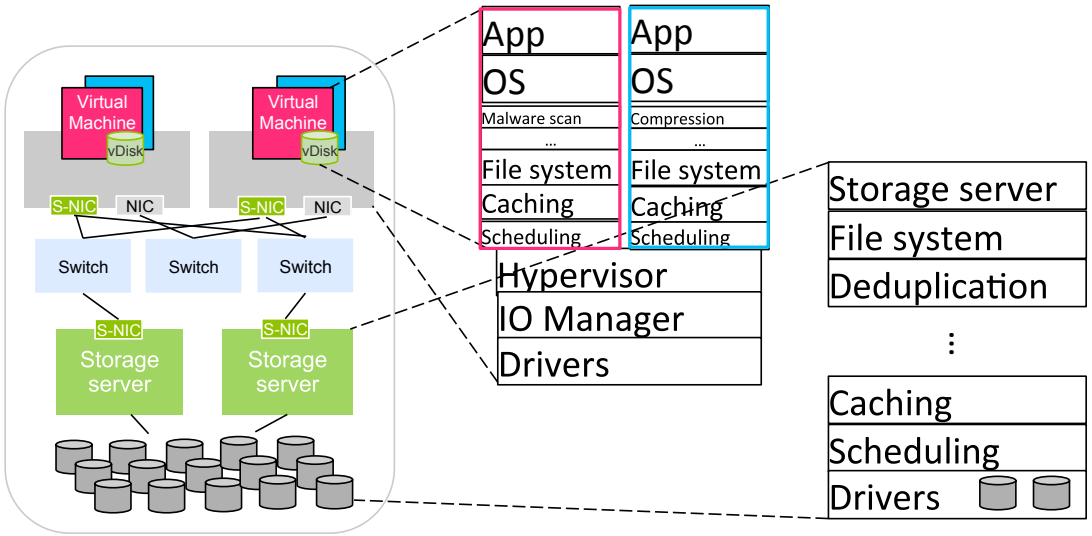
- Who: enterprise data centers (**virtualization** of servers and storage)
- What: **end-to-end** policies (*performance* and *routing*) are hard to enforce

Problem Challenges

1. many operations & layers (e.g. 18?!)

2. non-linear: `f(IO type, data locality, device type, request size) -> processing time`

3. deployability (cannot change existing OSs)



Design Goals

- Enable high-level flow policies, including for multi-point
- **Declarative** interface:

```
{[Set of VMs], [Set of storage shares]} → Policy
```

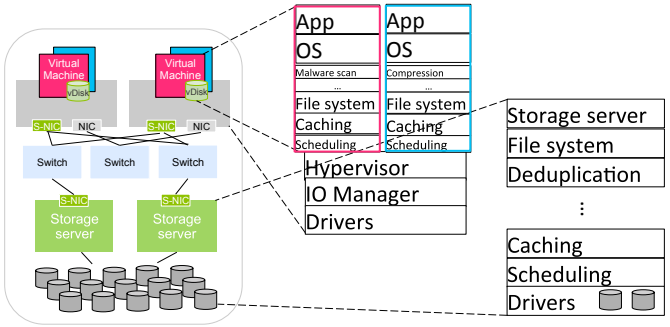
	Policy	Where to enforce?	What to enforce?
P1	$\{p, X\} \rightarrow B$	C(p) Or S(X)	Static rate limit
P2	$\{p, X\} \rightarrow$ Min B	C(p) Or S(X)	Dynamic rate limit
P3	$\{p, X\} \rightarrow$ Sanitize	C(p) Or S(X)	Static routing
P4	$\{p, X\} \rightarrow$ Priority	C(p) & S(X)	Static priority
P5	$\{[p, q, r], [X, Y]\} \rightarrow B$	C(p), C(q) & C(r) Or S(X) & S(Y)	Dynamic VM Or Server rate limits

no one has done it before


CONTROL ALL THE THINGS!
hyperboleandahalf.blogspot.com

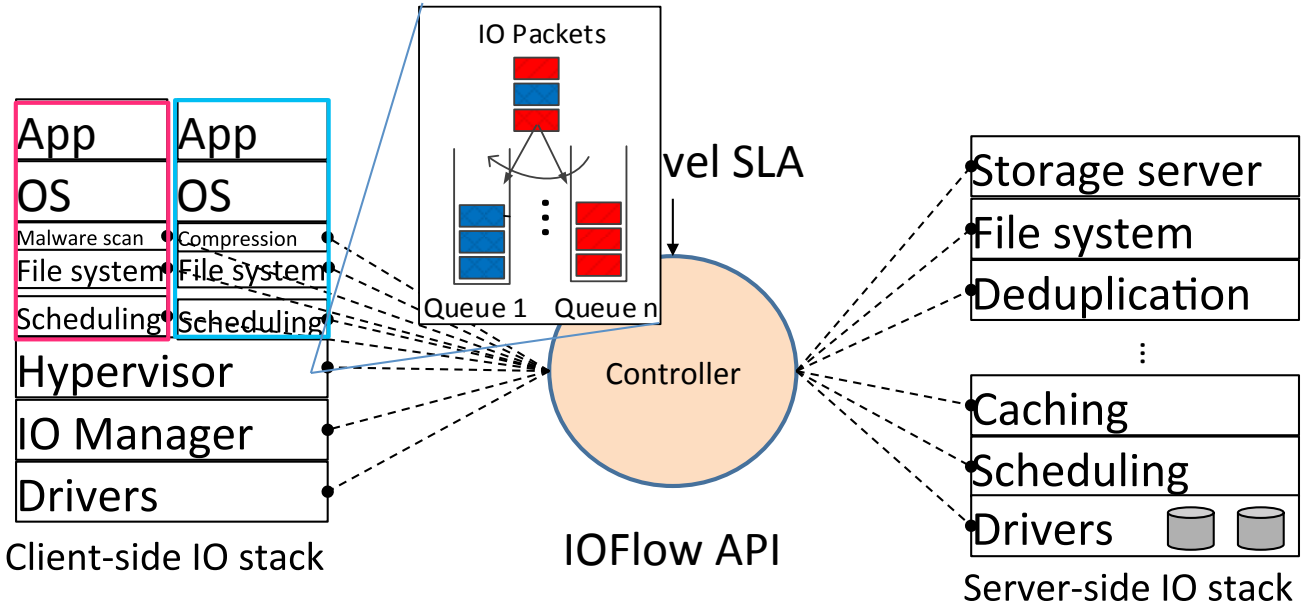
Centralized Control*

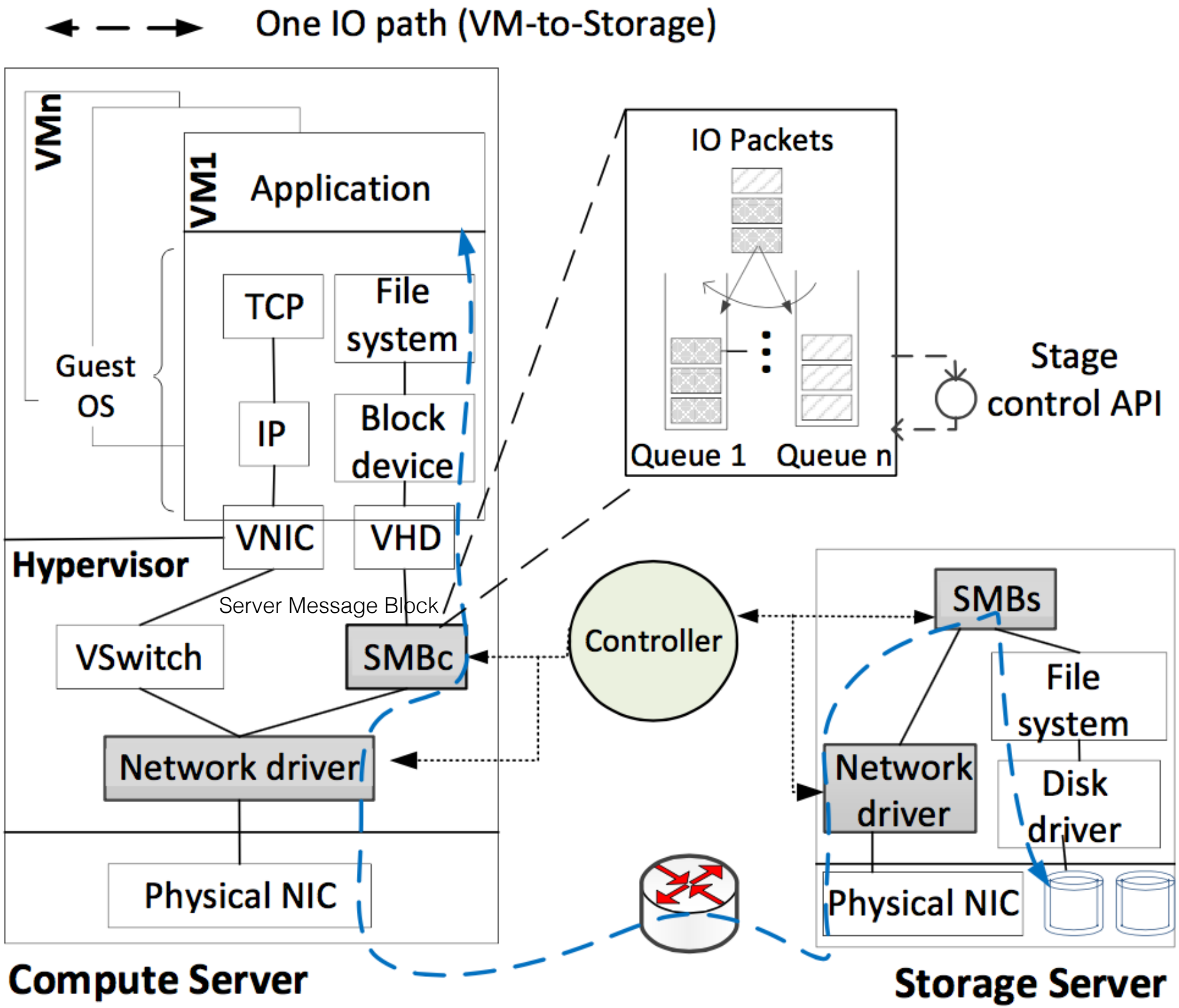
- Inspired from software-defined networking (SDN), thus “software-defined storage architecture”, but it’s much harder
- Stages
  - storage driver in hypervisor
  - storage server
- *But distributed enforcement



Components

1. logically centralized controller
2. data-plane queues
3. interface between the controller and control applications (*visibility*!)



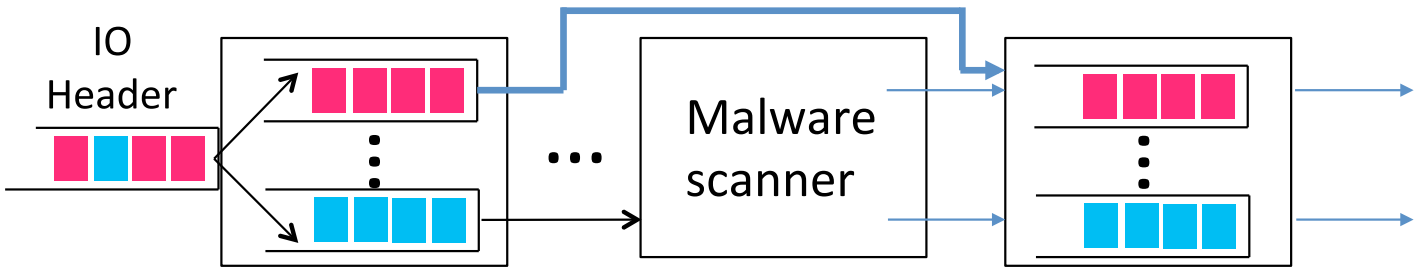

One IO path (VM-to-Storage)
VMn
VM1
Application
Guest OS
TCP
File system
IP
Block device
VNIC
VHD
Hypervisor
Server Message Block
VSwitch
SMBc
Network driver
Physical NIC
Compute Server
IO Packets
Queue 1
Queue n
Stage control API
Controller
SMBs
File system
Network driver
Disk driver
Physical NIC
Storage Server

Design Challenges

- Admission control: is the policy **possible**?
- **Distributed** enforcement: **differentiated** costs at different stages
  - access SQL data files: from guest OS > hypervisor > network switch > storage server OS > disk array
- Performance: queues at stages must be fast
- Incremental deployability/resilience
- Dynamic control: e.g. min bandwidth

Data Plane Queues

1. Classification [IO Header -> *Queue*]
2. Queue servicing [Queue -> *<token rate, priority, queue size>*]
3. Routing [Queue -> *Next-hop*]



Controller API

A0	**`getQueueInfo`** () returns kind of IO header stage uses for queuing, the queue properties that are configurable, and possible next-hop stages
A1	**`getQueueStats`** (Queue-id *q*) returns queue statistics
A2	**`createQueueRule`** (IO Header *i*, Queue-id *q*) creates queuing rule $i \rightarrow q$
A3	**`removeQueueRule`** (IO Header *i*, Queue-id *q*)
A4	**`configureQueueService`** (Queue-id *q*, <token rate,priority, queue size>)
A5	**`configureQueueRouting`** (Queue-id *q*, Next-hop stage *s*)
A6	**`configureTokenBucket`** (Queue-id *q*, <benchmark-results>)

flexible

responsive

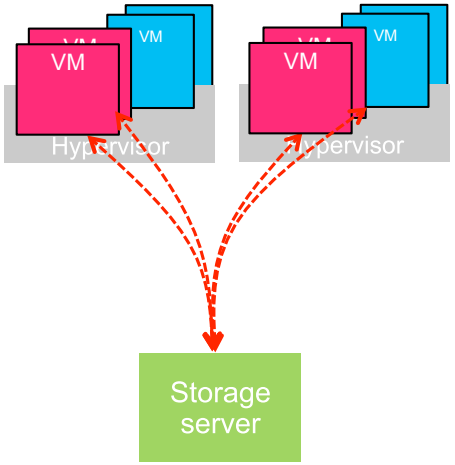
accurate

resilient

scalable

Rate Limiting

- Service request: token-bucket abstraction (simple)
- Storage request: **benchmarks** the storage devices to measure the cost of IO requests as a function of their type and size, *IoMeter.* *(RAM, SSDs, disks: read/write ratio, request size)*
- Max-min fair sharing



Tricks

- Split IO requests into smaller buckets
- Zero-copying of requests moving from stage to stage
- Min-heap-based selection of which queue to service next within a stage
- Heuristics for deciding enforcement layer

```
1: getQueueInfo (); returns "File IO"
2: createQueueRule (<VM 4, //server X/*>, Q1)
3: createQueueRule (<*, *>, Q0)
4: configureQueueService (Q1, <B,0,1000>)
5: configureQueueService (Q0, <C-B,0,1000>)
```

Controller

Blocking, but it doesn't really matter

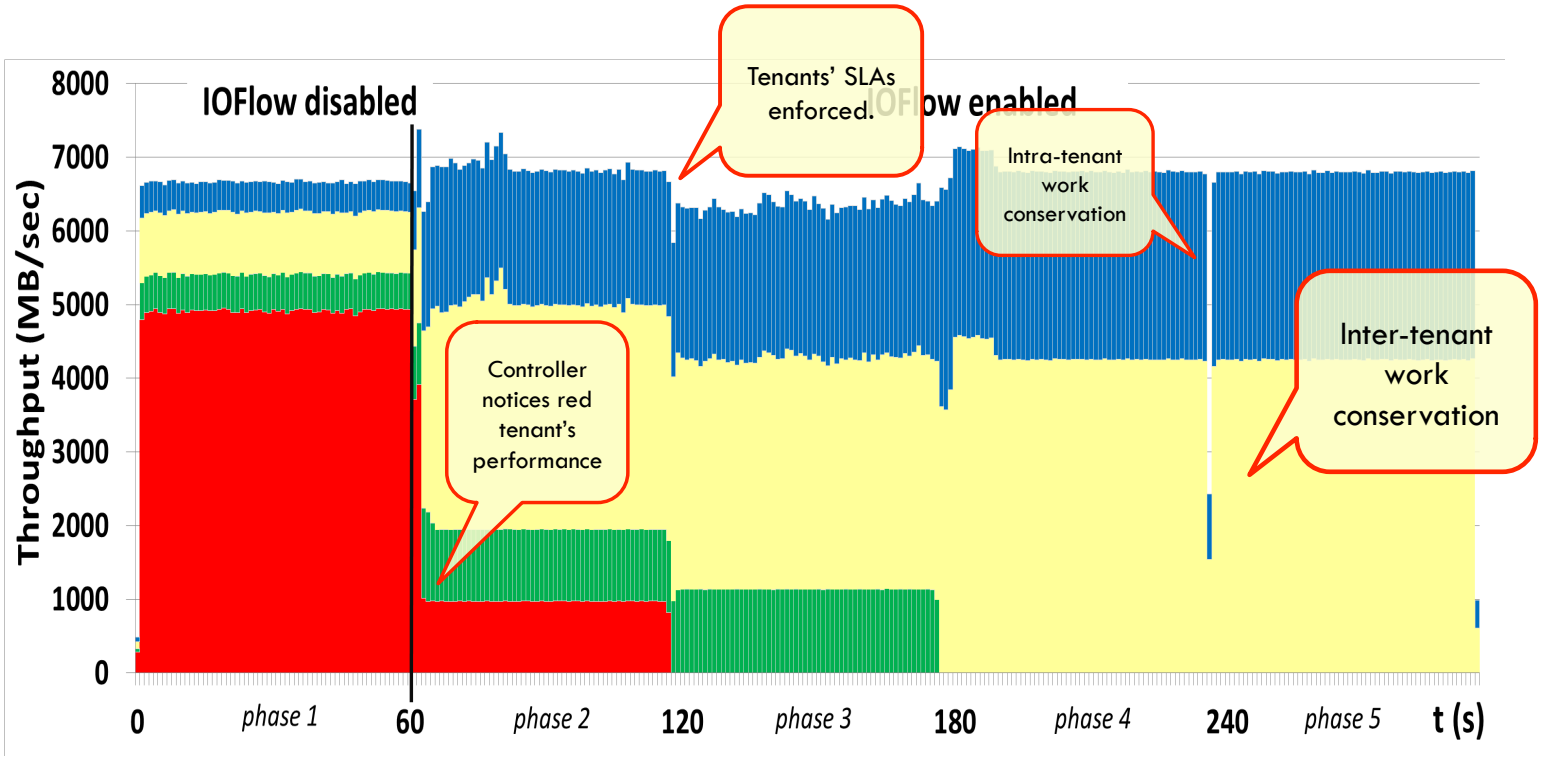
```
1: IO Header <VM1, //server X/file F> → Queue Q1
2: IO Header <VM2, //server Y/*> → Queue Q2
3: IO Header <VM3, *> → Queue Q4
4: <*, *> → Queue Q3
```

Hypervisor

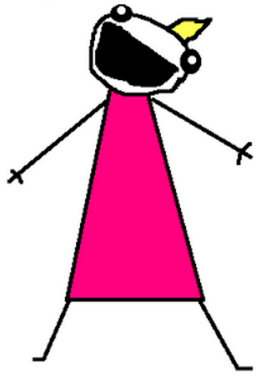
```
1: IO Header <SID S1, H:/File F> → Queue Q1
2: IO Header <SID S2, H:/File G> → Queue Q1
3: IO Header <SID S2, H:/Directory A/*> → Queue Q2
4: <*, *> → Queue Q3
```

Storage Server

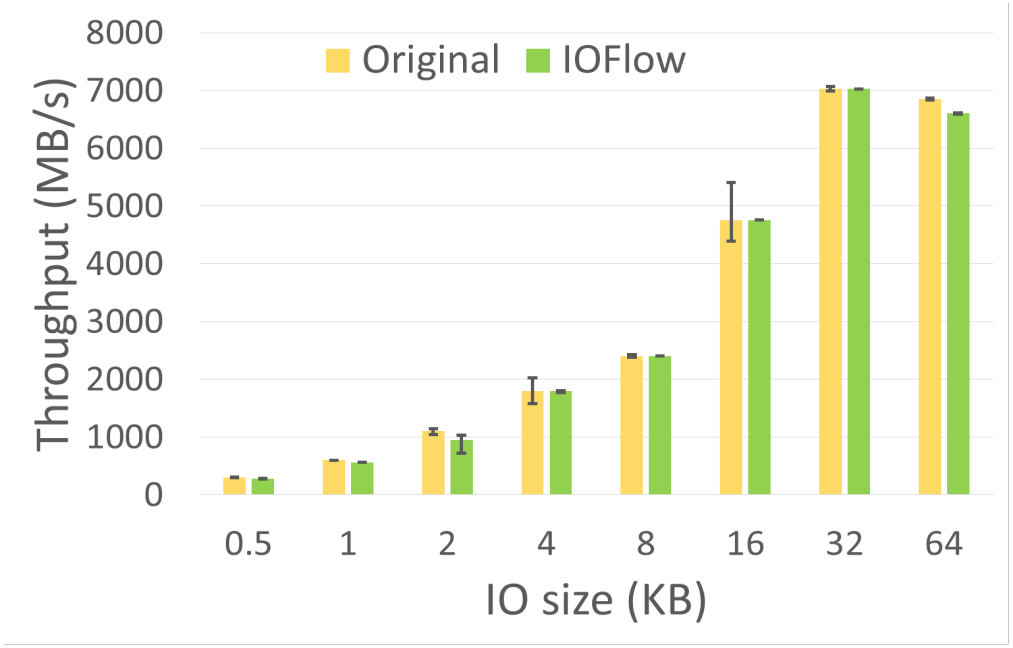
Performance



Tenant	SLA
Red	{VM1 – 30} -> Min 800 MB/s
Green	{VM31 – 60} -> Min 800 MB/s
Yellow	{VM61 – 90} -> Min 2500 MB/s
Blue	{VM91 – 120} -> Min 1500 MB/s

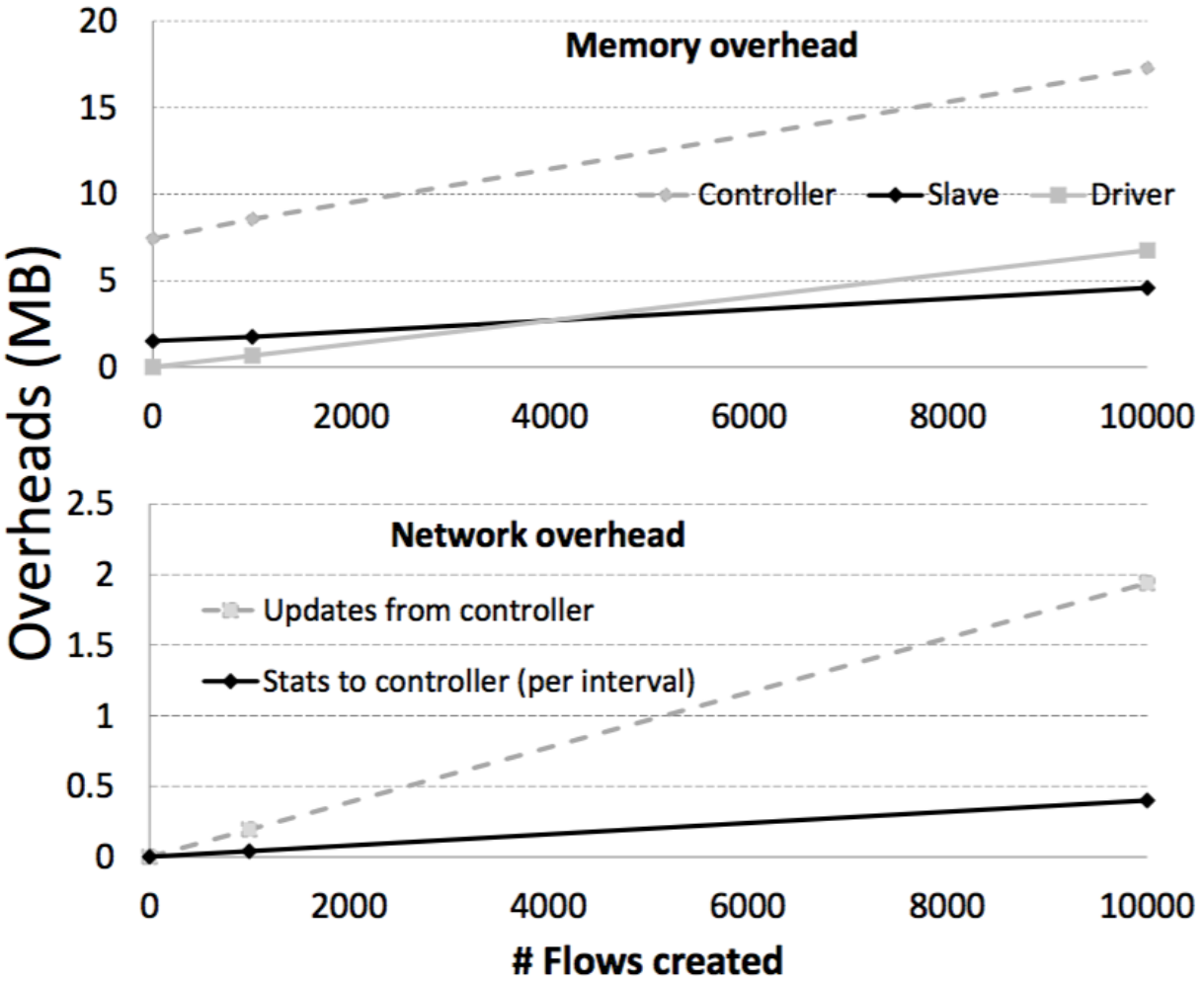


Data Plane Overhead



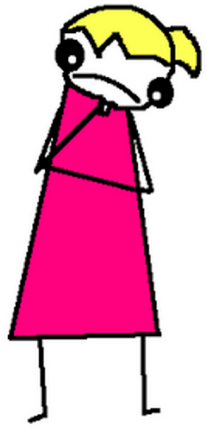
- Worst case CPU consumption at hypervisor is less than 5%
- Worst case reduction in throughput:
  RAM – 14%
  SSD – 9%
  Disk – 5%

Control Plane Overhead



Checking Assumptions

- performance bottleneck is at the storage servers
- small IO requests are typically interrupt limited
- large requests are limited by the bandwidth of the storage back-end or the server's network link



Questions/Ideas

- What more does it take to **scale**?
  - Controller bottleneck?
  - Ad hoc access patterns (bad prediction)
- Too many nobs, hard to tune?
- Extend to optimize for co-requests?

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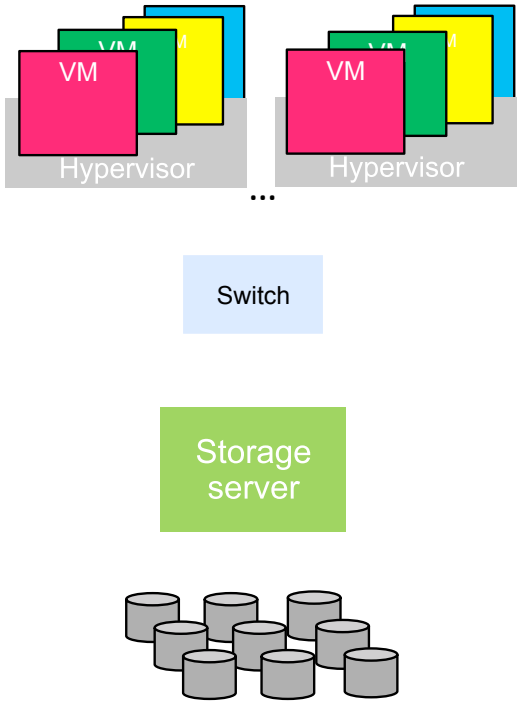
Experiment Setup



Clients:10 hypervisor servers, 12 VMs each
4 tenants (Red, Green, Yellow, Blue)
30 VMs/tenant, 3 VMs/tenant/server

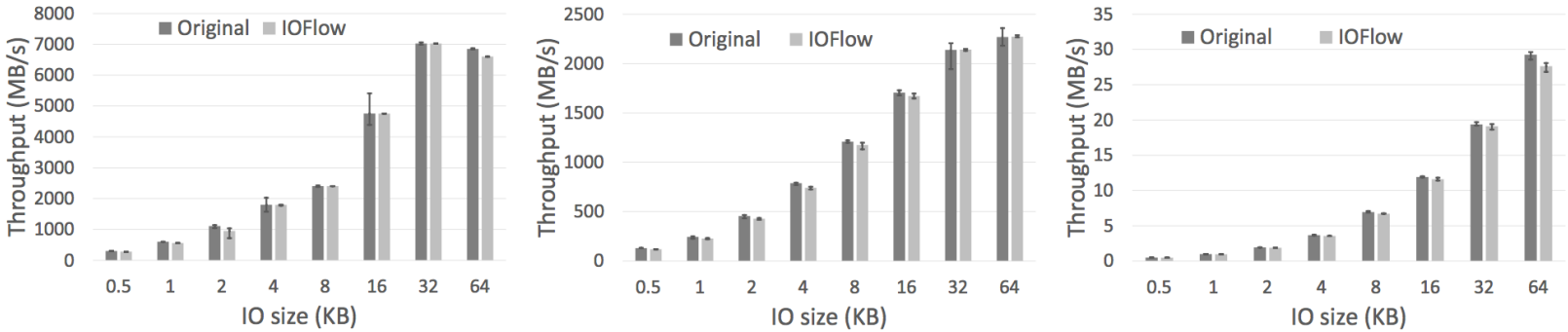
Storage network:
Mellanox 40Gbps RDMA RoCE full-duplex

1 storage server:
16 CPUs, 2.4GHz (Dell R720)
SMB 3.0 file server protocol
3 types of backend: RAM, SSDs, Disks

Controller: 1 separate server
1 sec control interval (configurable)

Resilience/Consitency

- When controller is unreachable, use default policy.
- Allow for inconsistencies



(a) RAM store (b) SSD store (c) Disk store