Virtualization-based Bandwidth Management for Parallel Storage Systems

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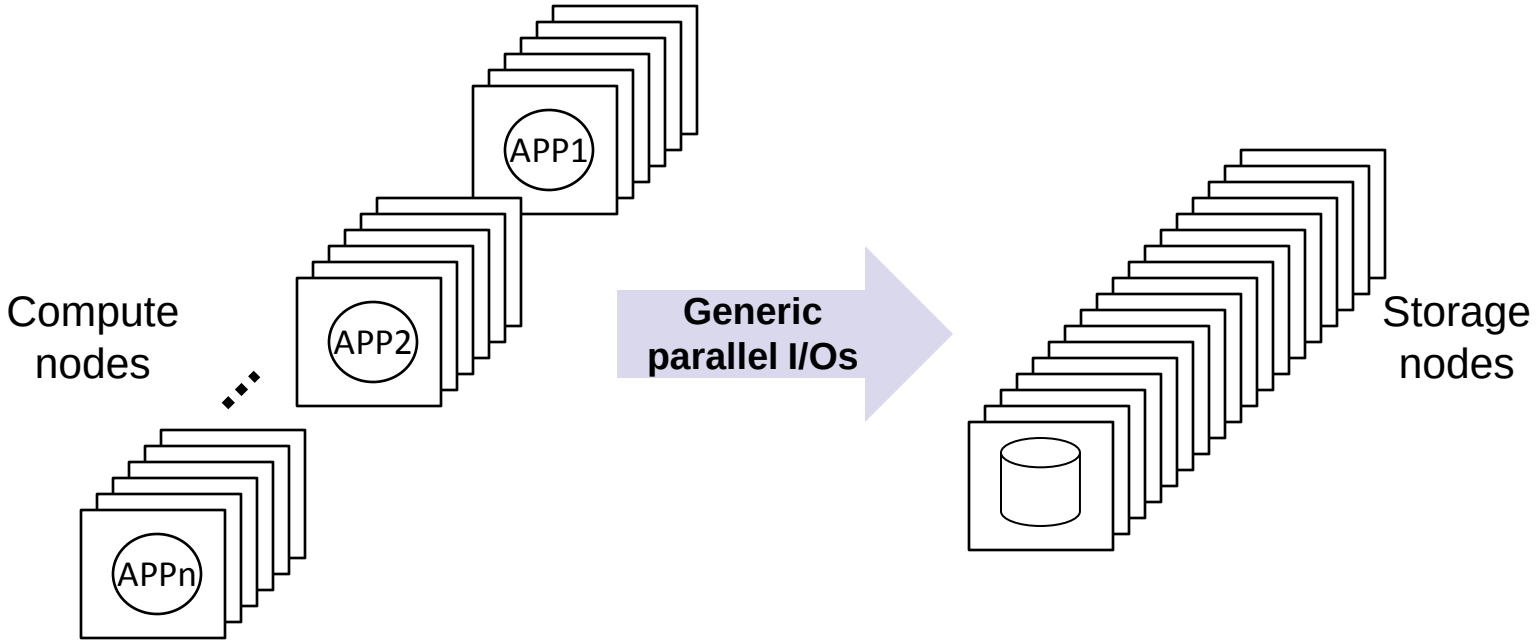
Motivation

- The lack of QoS differentiation in HPC storage systems
  - Unable to recognize different application I/O workloads
  - Unable to satisfy users' different I/O performance needs



Motivation

- The need for different I/O QoS from HPC applications
  - Diverse I/O demands and performance requirements
  - Examples:
    - WRF: Hundreds of MBs of inputs and outputs
    - mpiBLAST: GBs of input databases
    - S3D: GBs of restart files on a regular basis
- This mismatch will become even more serious in future ultra-scale HPC systems

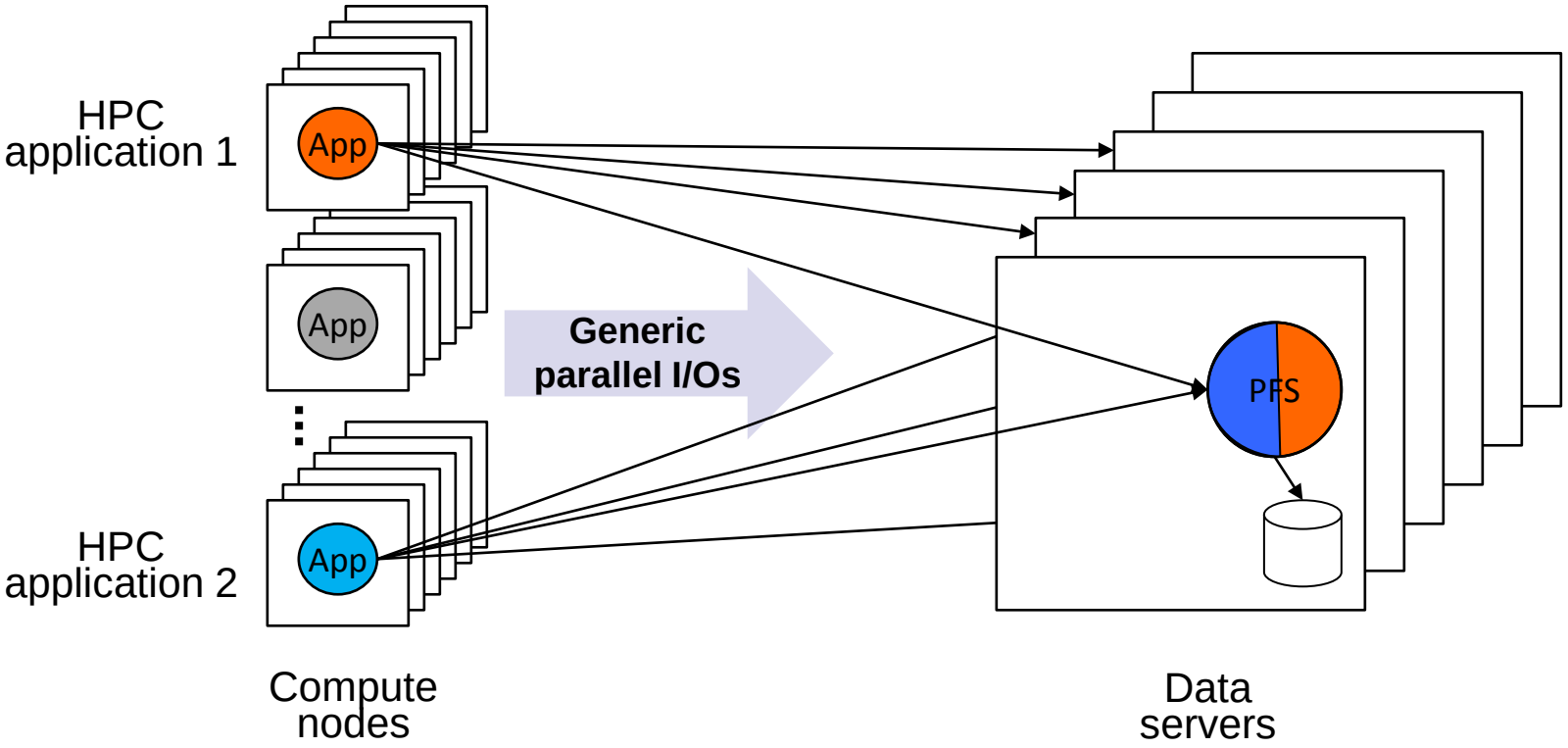
Objective

- Problem: Lack of per-application I/O bandwidth allocation
  - Static partition of storage nodes is inflexible
  - Compute nodes based partition is insufficient
- Proposed Solution: Per-application storage resource allocation
  - Parallel file system (PFS) virtualization
  - Per-application virtual PFSes

Outline

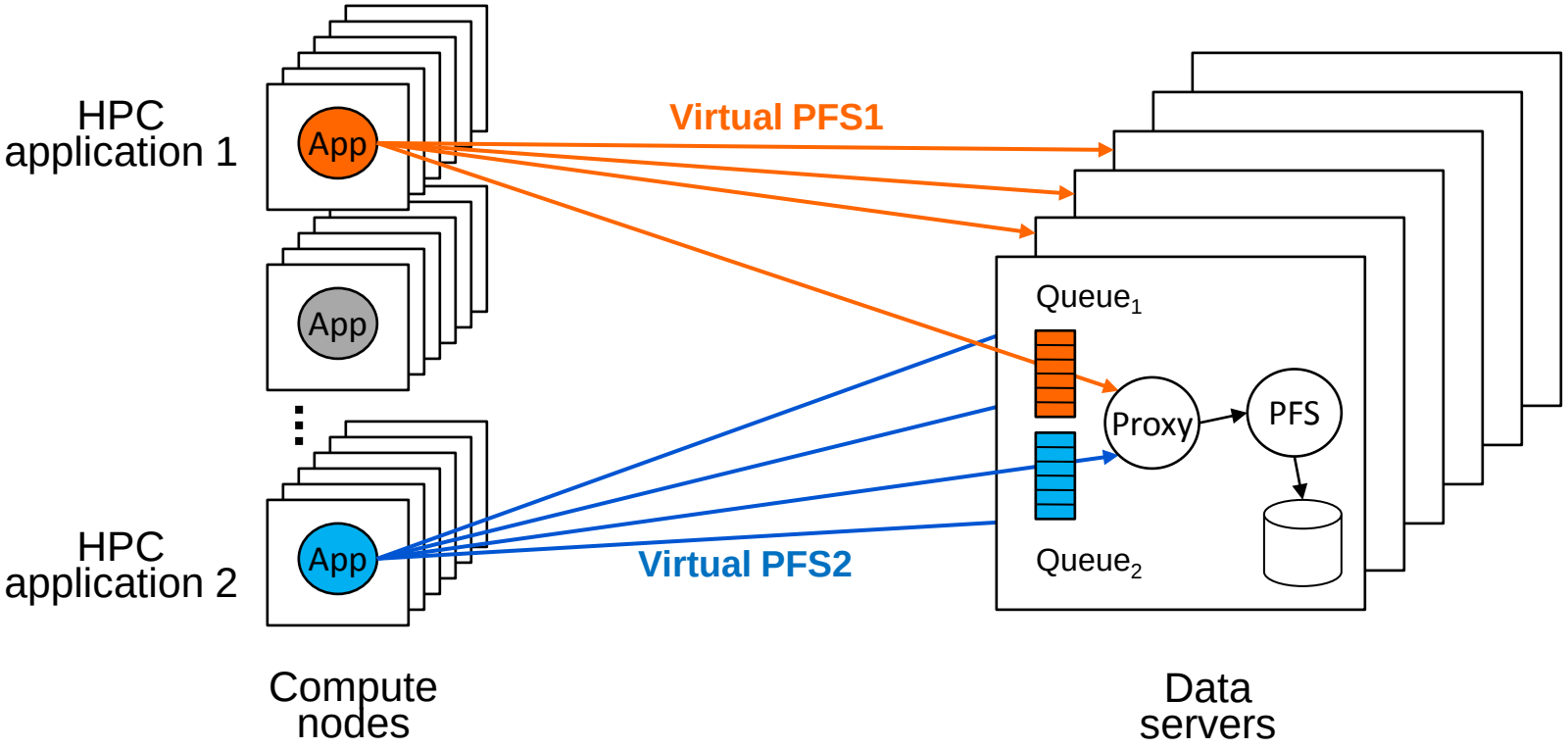
- Background
- Design
- Implementation
- Evaluation

Proxy-based PFS Virtualization (Before)



- Storage nodes are shared without any isolation
- No distinction of I/Os from different applications
- Lack of native scheduling support for bandwidth allocation

Proxy-based PFS Virtualization (After)



- Indirection of application I/O access
- Creation of per-application virtual PFS
- Dynamically spawned on the server

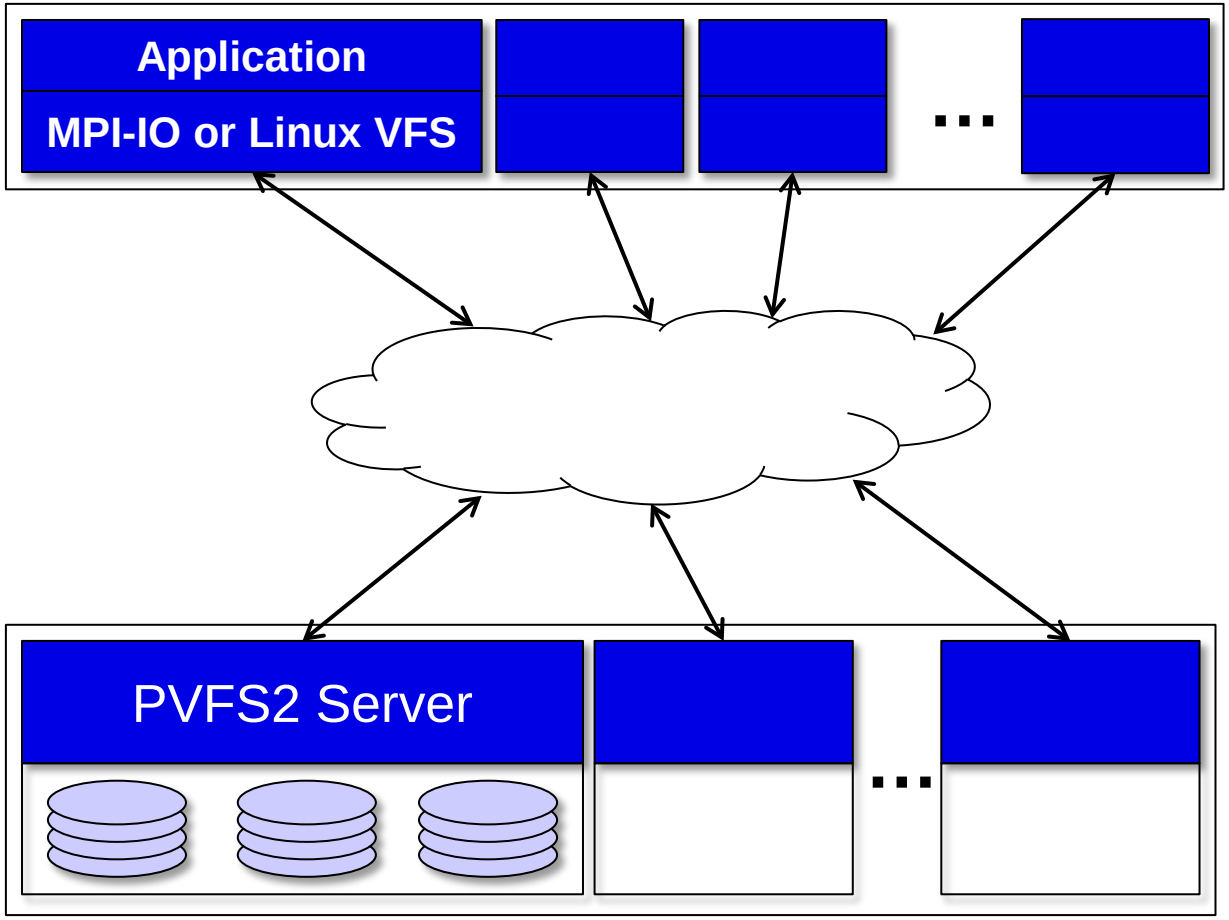
Virtualization Benefits and Costs

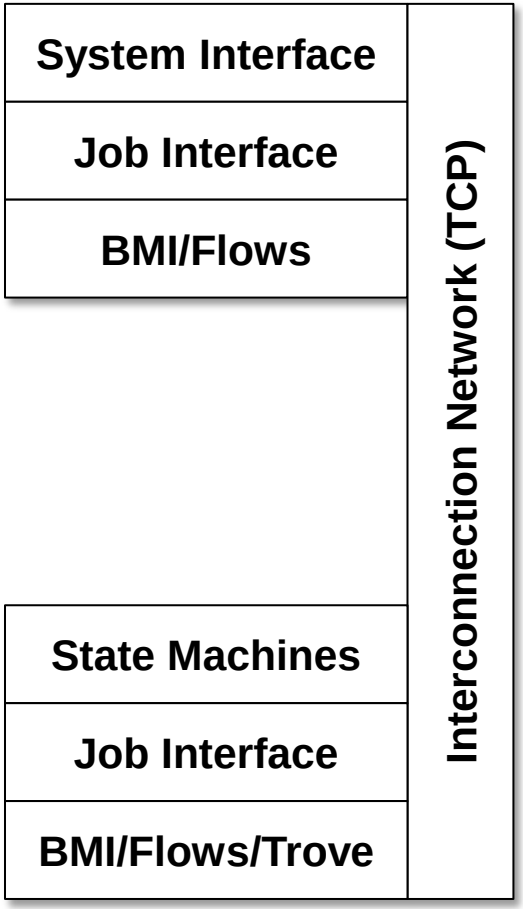
- Benefits
  - Enable various scheduling algorithms
    - SFQ(D) – proportional sharing algorithm
    - EDF – deadline based scheduling
  - Transparent to the existing PFSes
    - No change in existing implementation needed
    - Support different parallel storage systems
- Costs
  - Overhead involved in user-level proxy
  - Extra processing of data and communication

Prototype Implementation

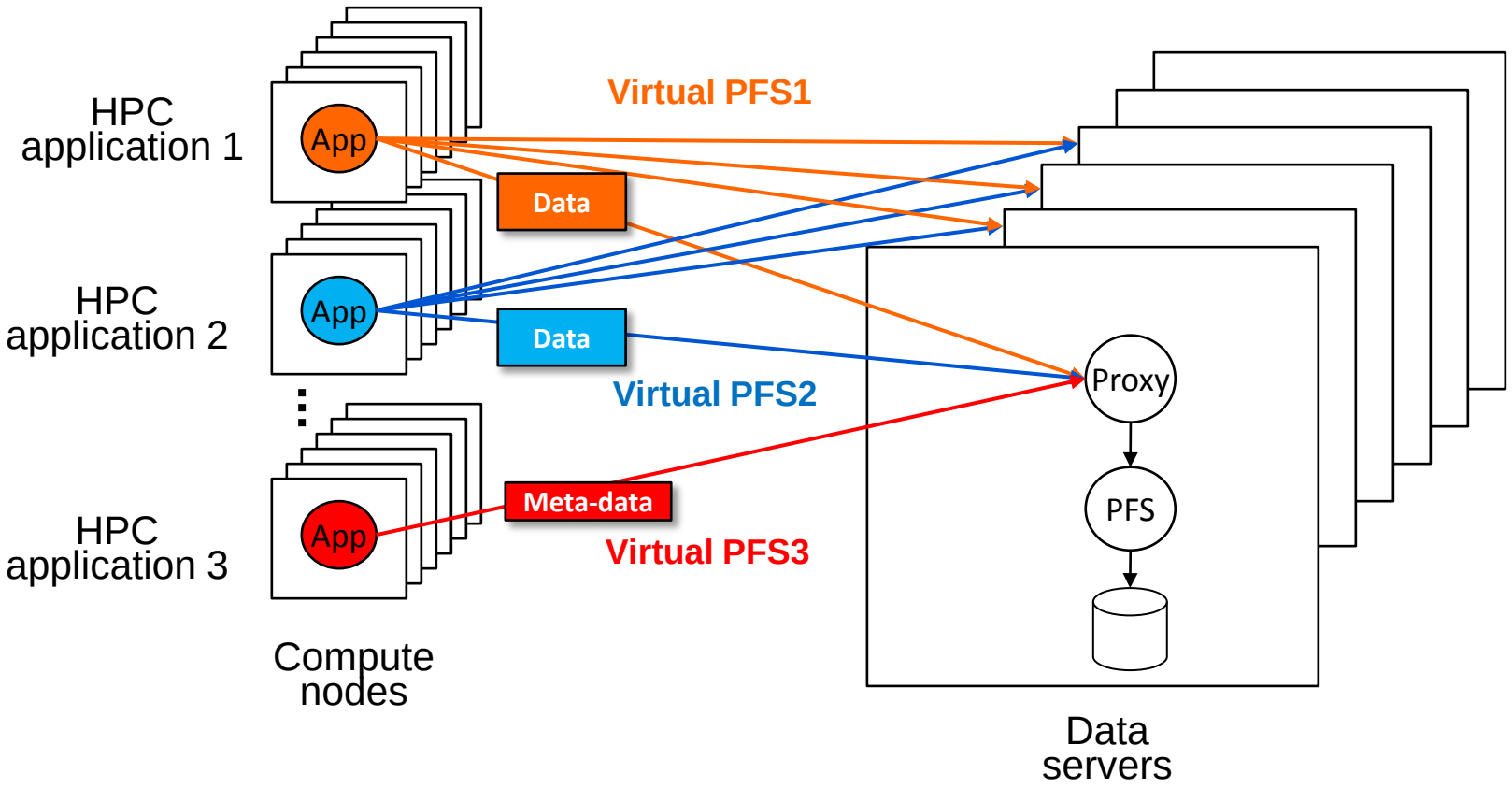
- A PVFS 2.8.2 (Parallel Virtual File System) proxy
  - Deployed on every data server
  - Intercepts and forwards PVFS2 messages
  - Asynchronous I/O for less overhead
  - Identifies I/Os from different applications
  - Dynamically configured by a configuration file
- Proxy implements SFQ(D) scheduling
  - Supports a generic scheduling interface for other algorithms

PVFS2 Background





PVFS2 Proxy



- Non-I/O messages are not scheduled
- Extra processing for I/O messages at proxy side

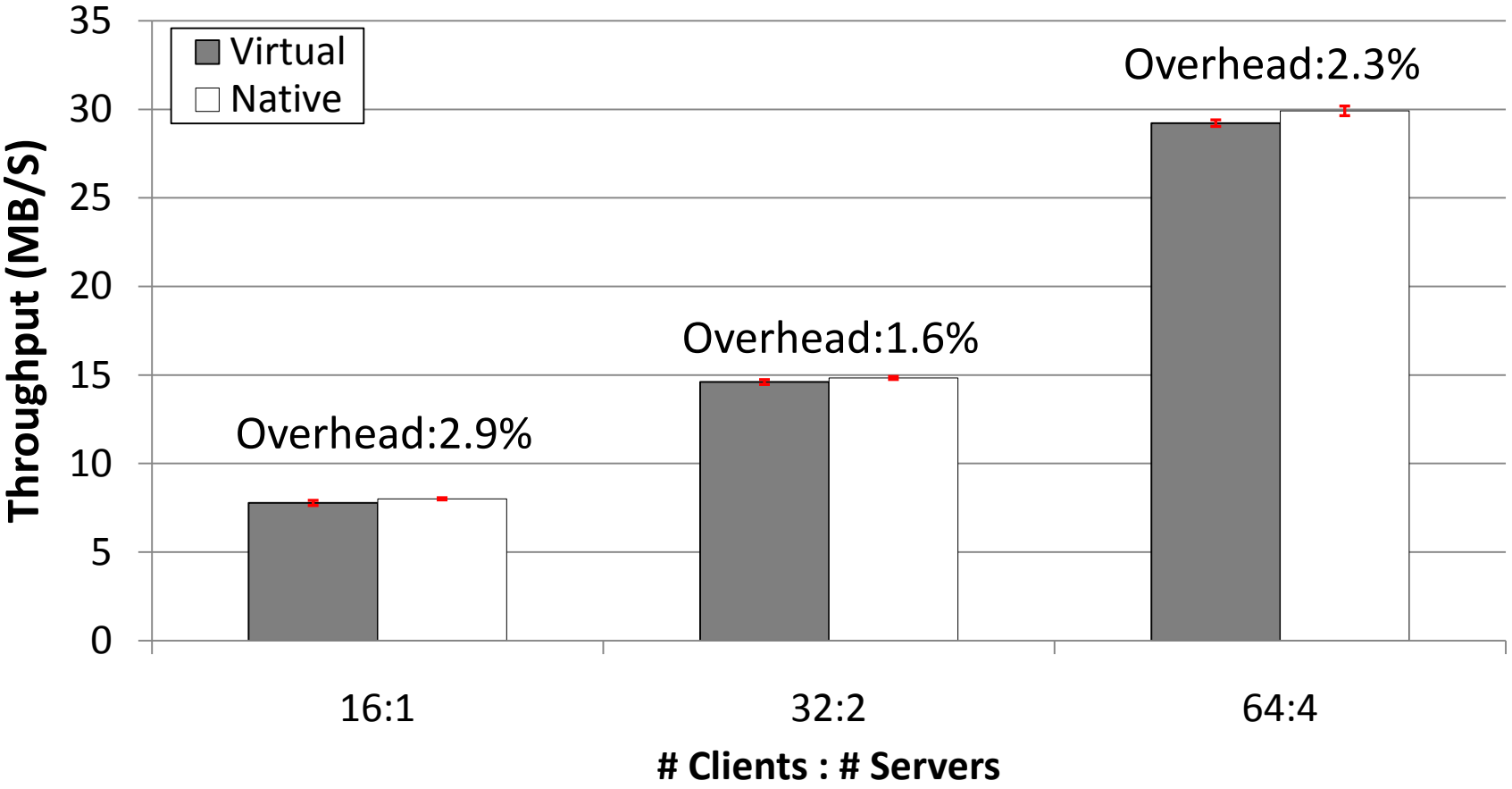
SFQ – Start Time Fair Queuing

- SFQ
  - Originally designed for network packet scheduling
  - Work-conserving, proportional sharing-based scheduling
  - Adapts to variation in server capacity
- SFQ(D)
  - Extended from SFQ
  - Adds depth to allow and control concurrency
  - Multiplexes storage bandwidth and enhance utilization

Evaluation

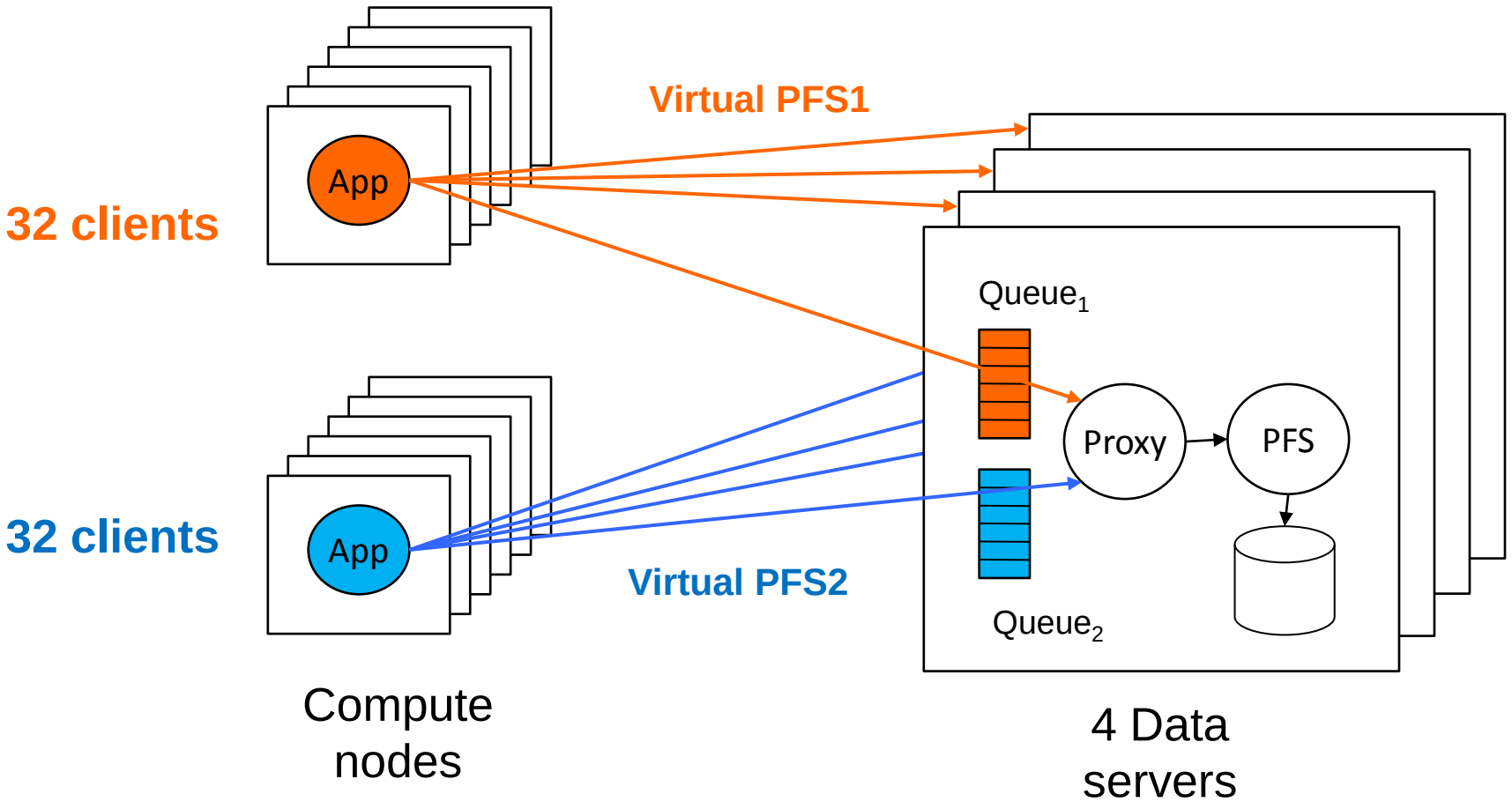
- A virtual machine based testbed
  - A cluster of 8 DELL PowerEdge 2970 servers
  - Ubuntu 8.04, Kernel 2.6.18.8
  - Up to 64 PVFS2 clients and 4 PVFS2 servers (version 2.8.2)
  - 2 competing parallel applications
- Benchmark: IOR version 2.10.3 with sequential writes
- Proxy implements performance monitoring
- Experiments:
  - Virtualization overhead
  - Effectiveness of proportional sharing

Virtualization Overhead

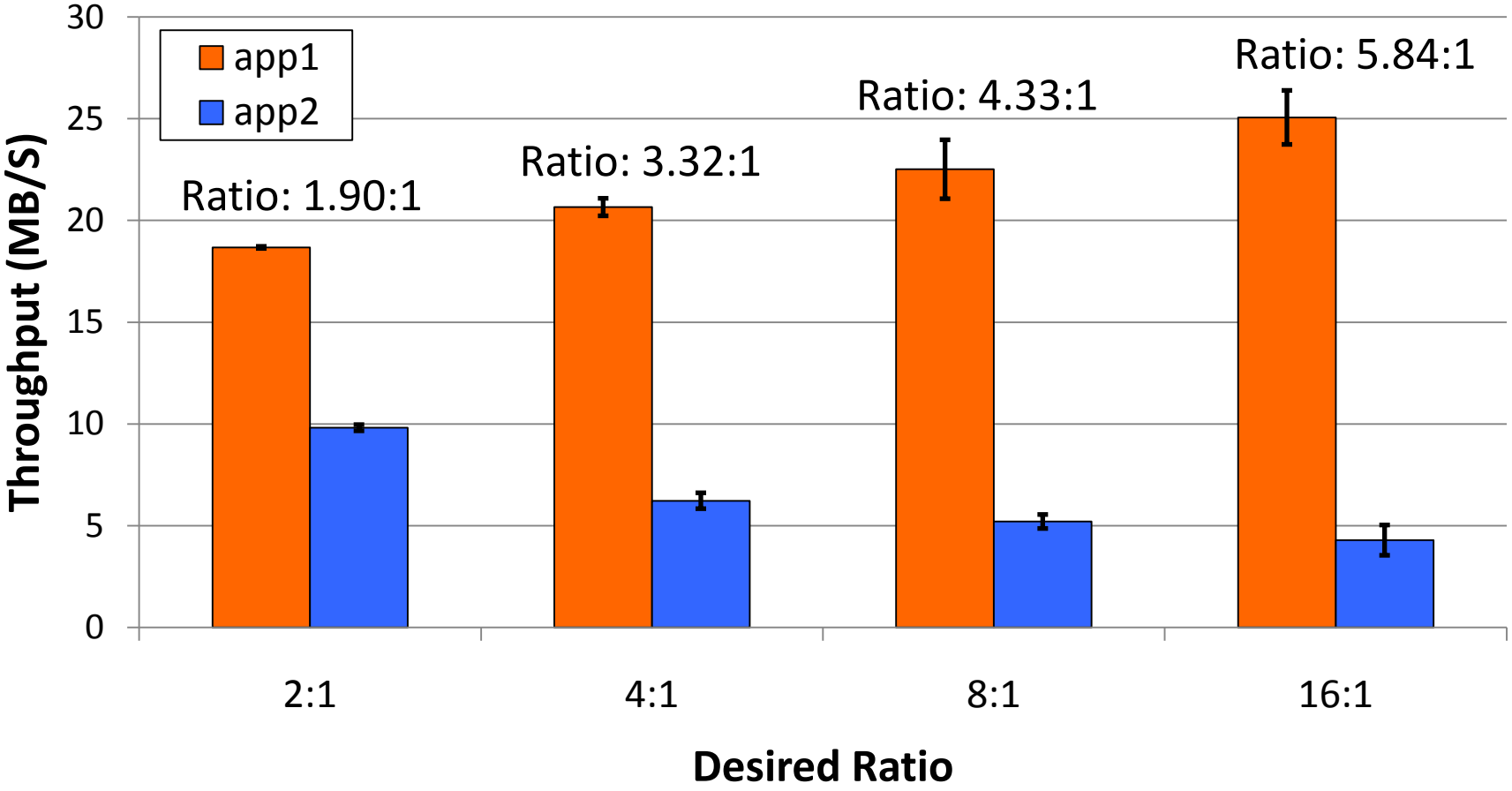


- Throughput overhead is small
- About 3% Proxy CPU and 1MB RAM usage on each node

Proportional Sharing in a Symmetric Setup

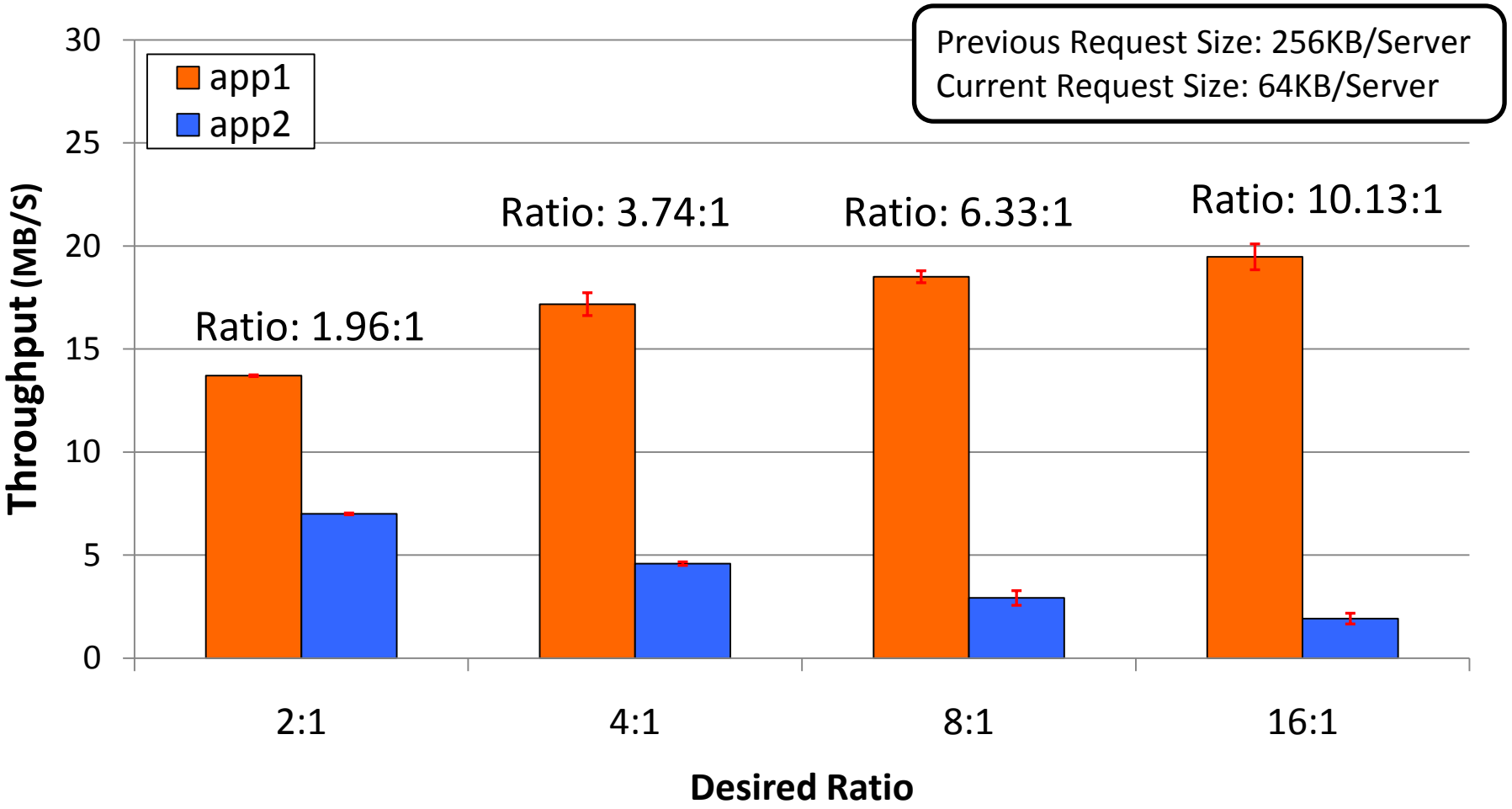


Proportional Sharing with Varying Ratios



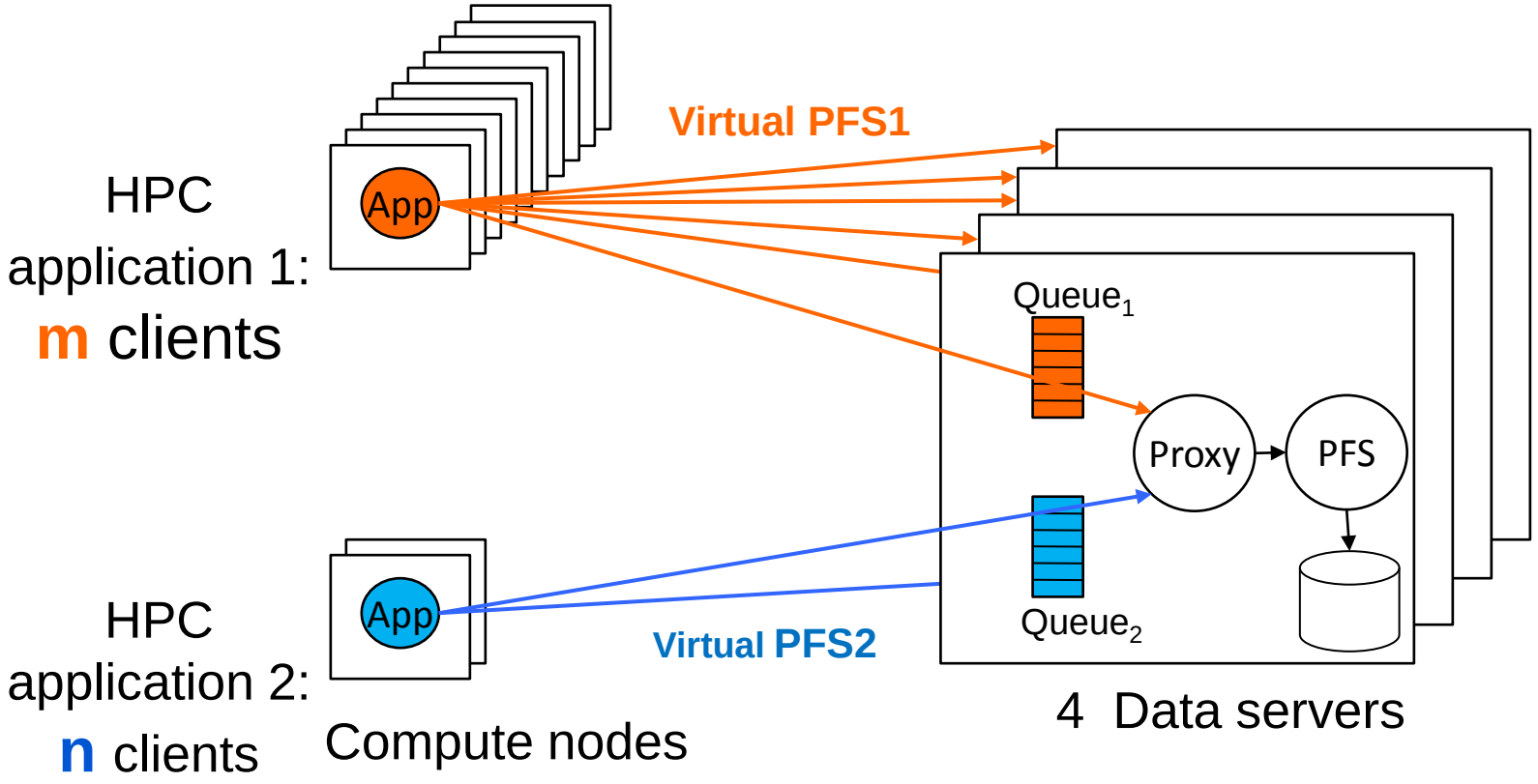
- Good proportional sharing can be achieved
- The actual ratio drops when the desired ratio is high

Proportional Sharing with Smaller I/Os

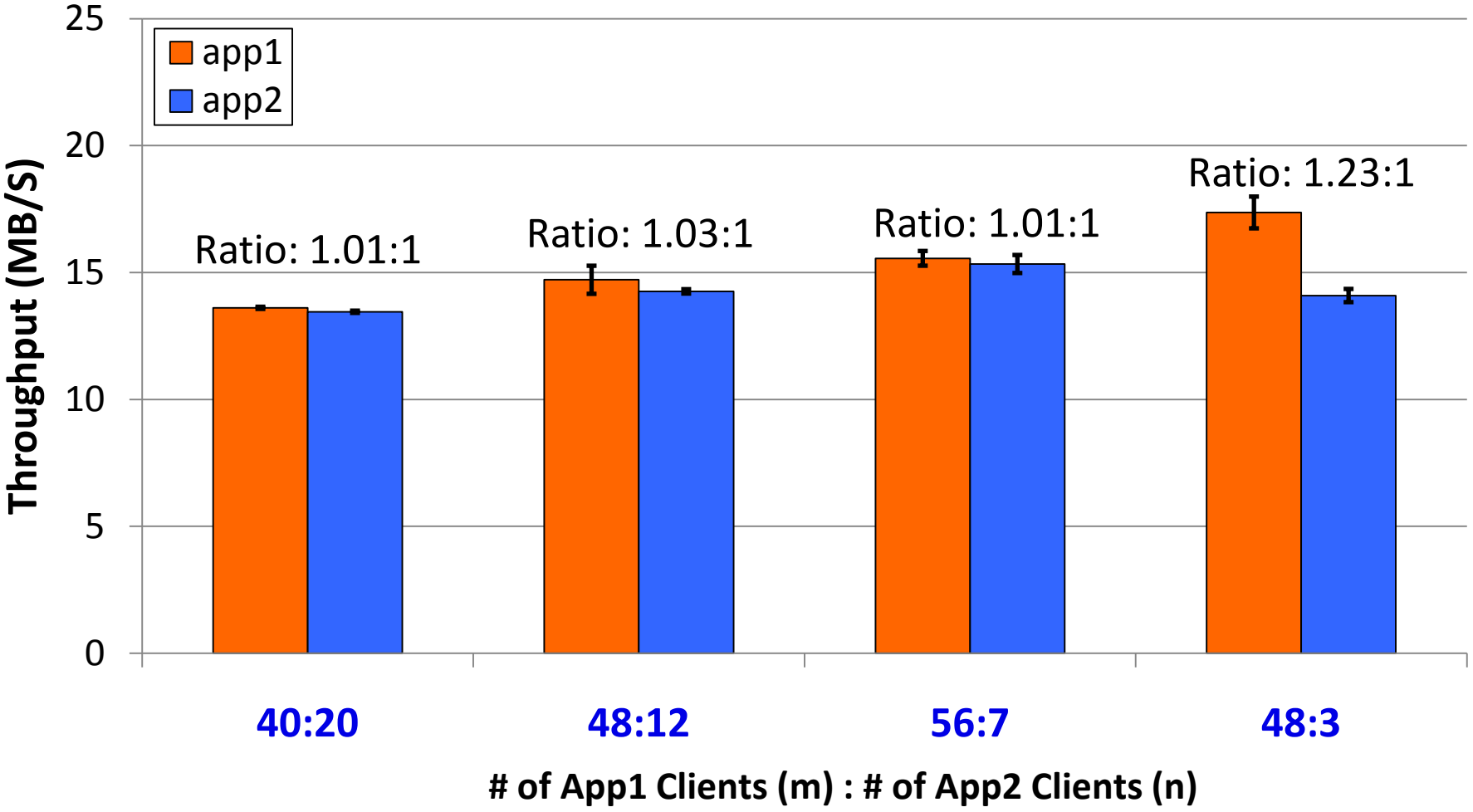


- Increasing request rate improves the actual ratio
- Can be further improved by increasing number of clients

Proportional Sharing in an Asymmetric Setup



Proportional Sharing in an Asymmetric Setup



- Almost perfect fairness can be achieved

Conclusions and Future Work

- Conclusions
  - Proxy-based PFS virtualization is feasible with negligible overhead
  - Effective proportional bandwidth sharing using SFQ(D)
- Future work
  - More scheduling algorithms
    - Global proportional sharing
    - Deadline based scheduling
  - Evaluate on applications' access patterns and I/O requirements with more diversities

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Thank You!