Towards Simulation of Parallel File System Scheduling Algorithms with PFSsim

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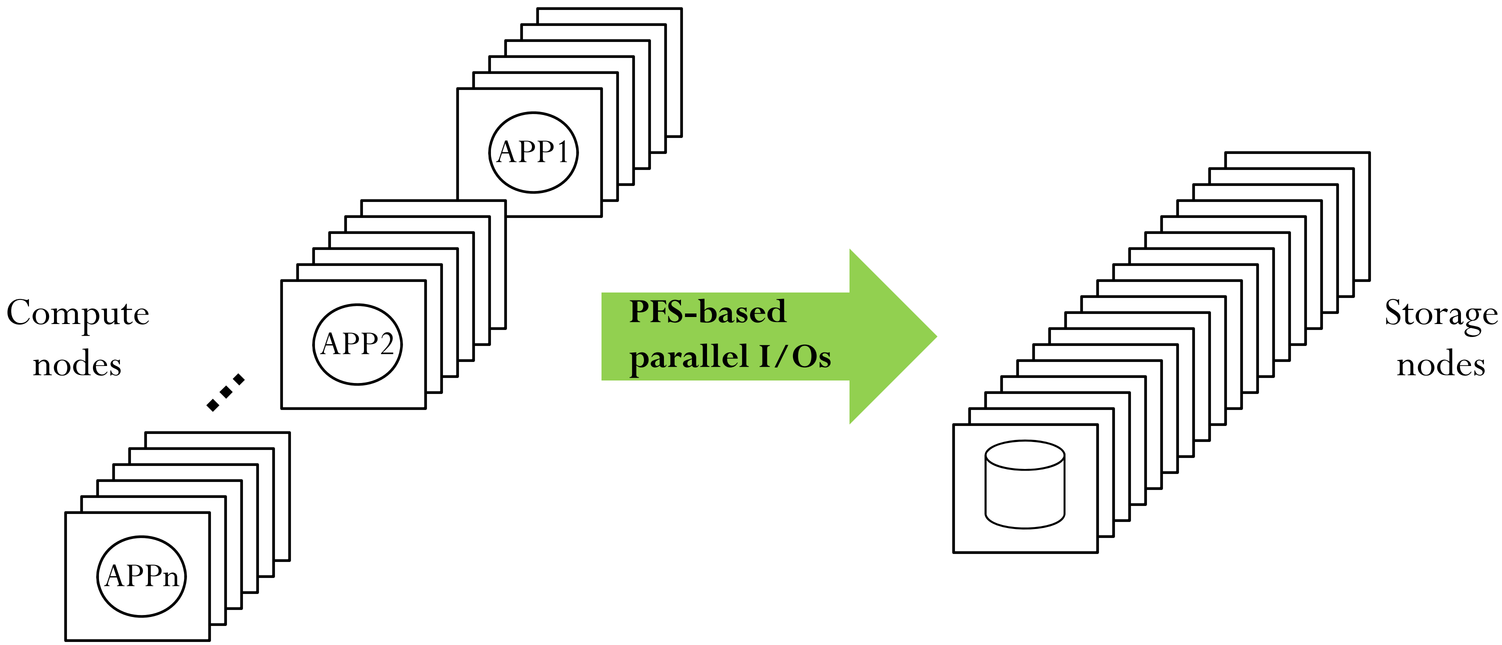
Introduction

- Parallel File Systems (PFSs) based storage
  - Widely used in high-performance computing systems
  - Examples: Lustre, PVFS2, PanFS, GPFS



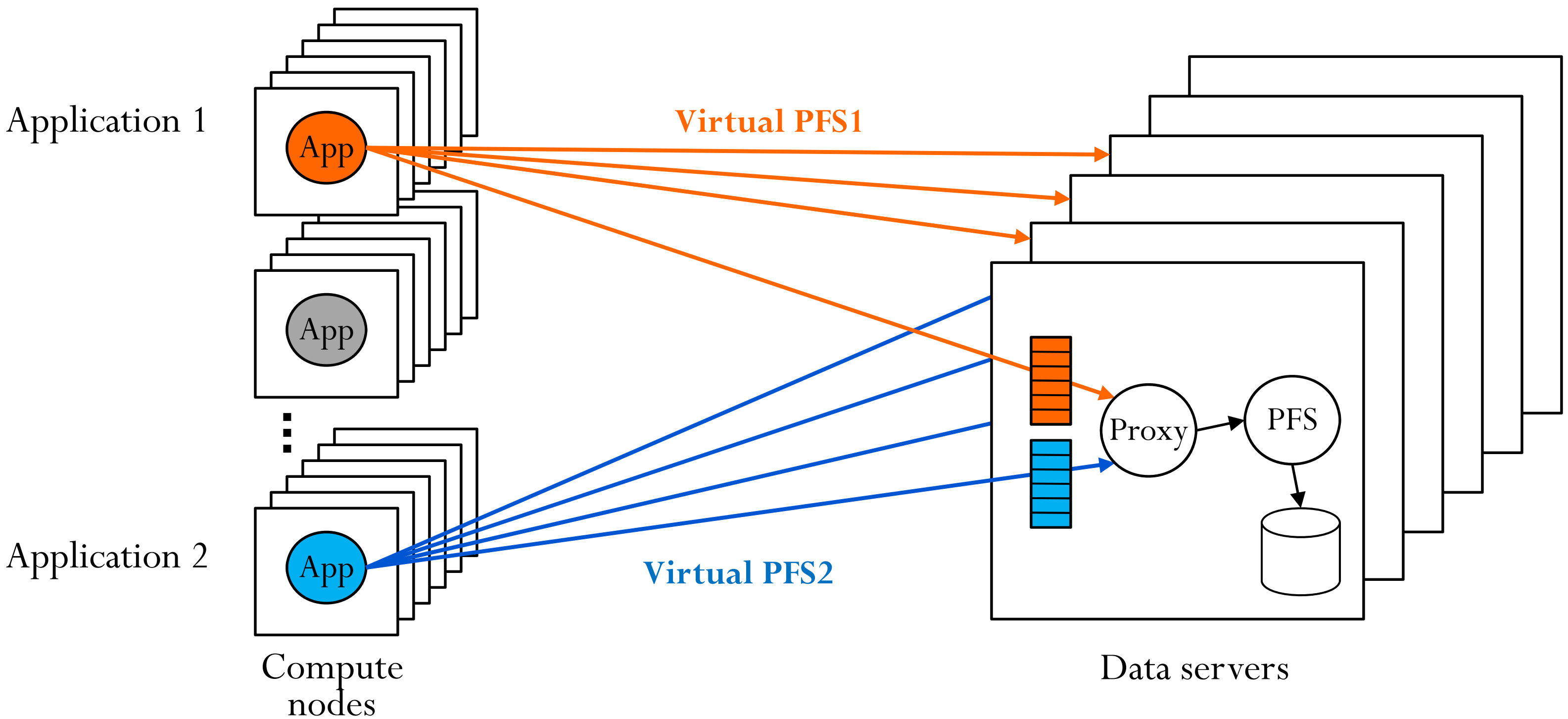
Challenge

- How to provide application-desired quality of service when the system has:
  - Many applications with large amount of I/O traffic
  - Diverse application access patterns
  - Diverse application QoS requirements
  - Examples: WRF, mpiBLAST, S3D

- This problem will only become even more serious as the scale HPC systems further increases

Virtualization-based Storage Management

- Creation of per-application virtual PFS*
- Ability to schedule I/Os on a per-application basis



*Y. Xu, et al., "Virtualization-based Bandwidth Management for Parallel Storage Systems", *PDSW'10*.

PFSsim

- Motivation
  - The need of evaluating parallel I/O scheduling algorithms
  - The need of a general-purpose parallel file system simulation framework

- Design goals
  - Easy-to-use
  - Flexible
  - Accurate
  - Scalable

Related Work

- IMPIOUS* by E. Molina-Estolano, et al.
  - Capable of fast evaluations of PFS designs
  - No simulation of metadata server and metadata operations
- The simulator developed by P. Carns, et al. **
  - Capable of evaluating the performance of I/O communications
  - Detailed simulation of network models
- SIMCAN*** by Alberto Núñez, et al.
  - Modulated design and statistical models
  - Complex system architecture
- No support for I/O scheduling simulations

* "Building a Parallel File System Simulator", *SciDAC'09*.

** "Using Server-to-server Communication in Parallel File System", *SC'08*.

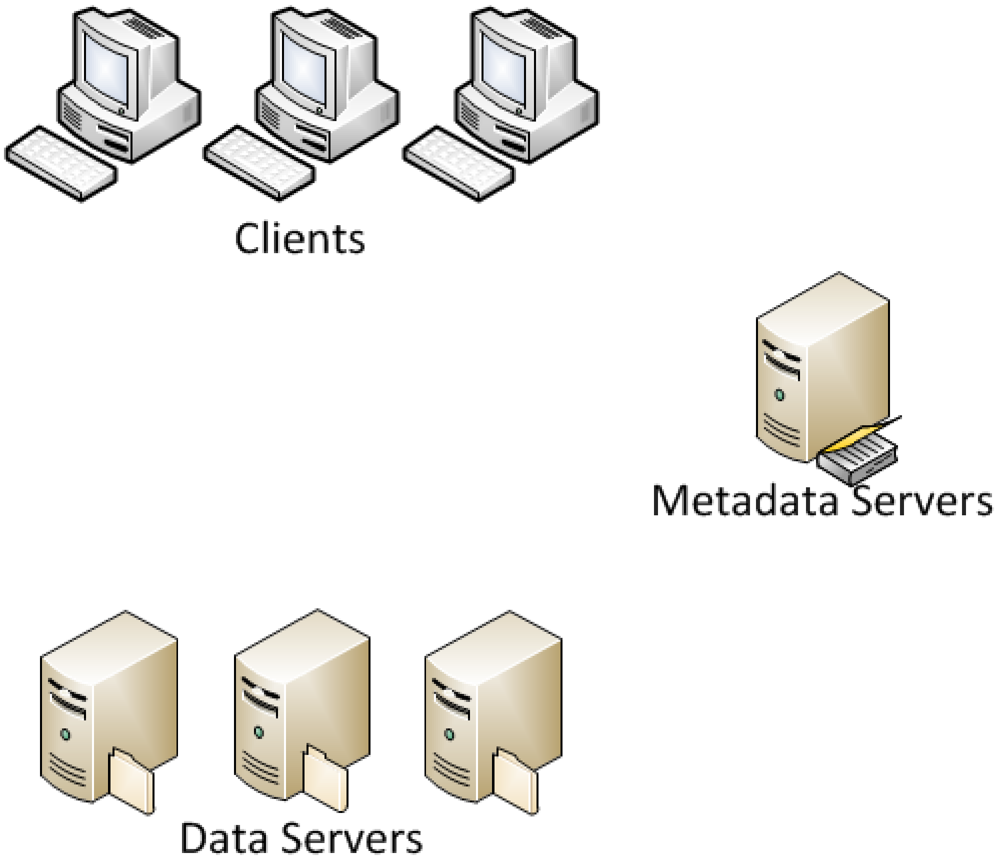
*** "SIMCAN: A Simulator Framework for Computer Architectures and Storage Networks", *OMNeT++'08*.

Outline

- Introduction
- Related Work
- Design and Implementation
- Validation and Evaluation
- Conclusion
- Future Work

PFSsim: Abstraction of PFSs

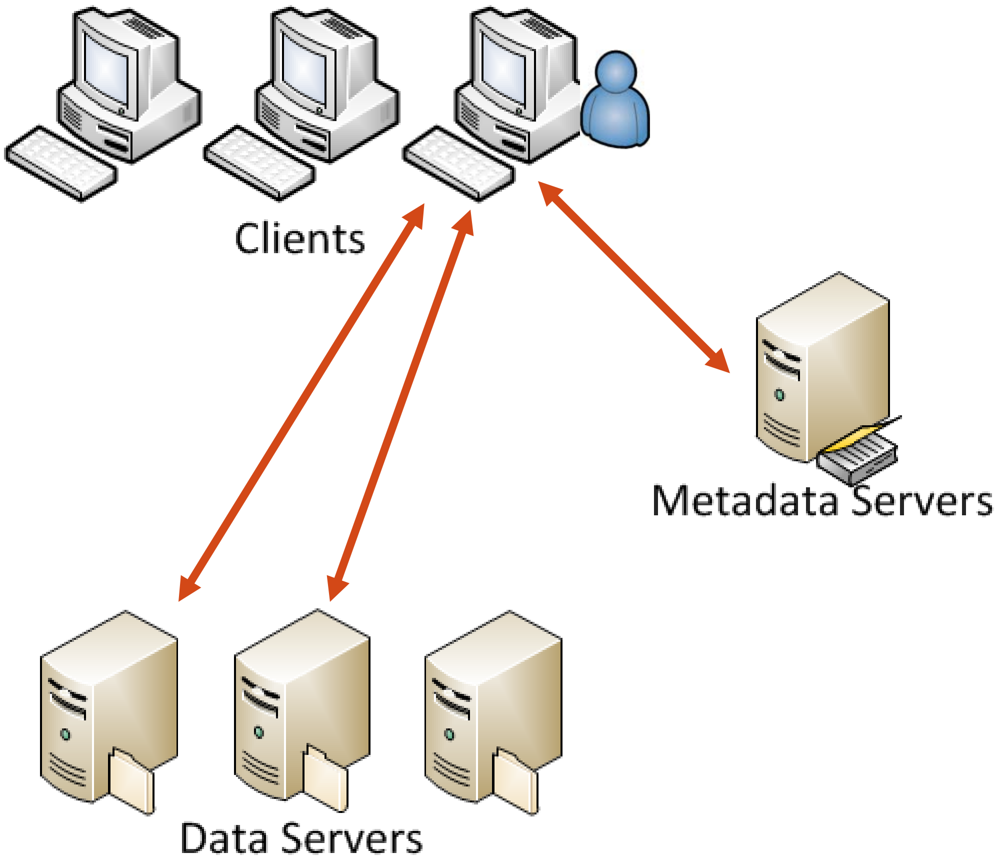
- Essential components and their functionalities



- Data Servers
  - Built based on the local file systems /block devices
  - Store application data in fixed-sized objects

Abstraction of PFSs

- A typical file data access (read/write) operation



- Application I/O request
  - {op, file_path, off, size} to the client

Four Important Aspects

- Metadata management
  - Can significantly impact application performance*
- Data placement strategy
  - Determine server load balance and I/O parallelism
- Data replication model
  - Writes can be slower due to updating multiple copies
- Data caching policy
  - Generally speed up data access, but consistency management also incurs overhead

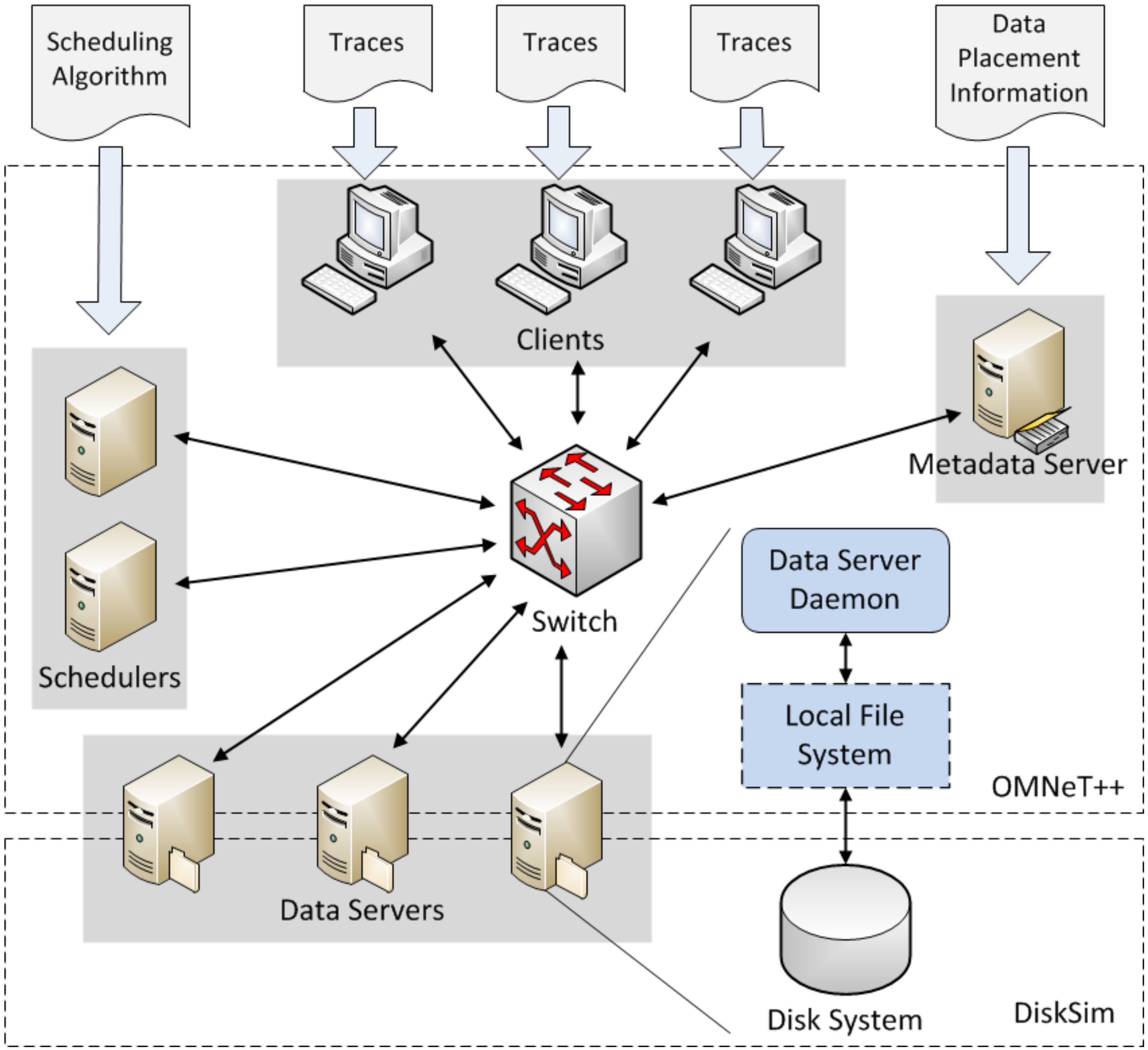
* R. Oldfield, et al. "Modeling the Impact of Checkpoints on Next-Generation Systems", MSST'07.

Abstraction of PFS Schedulers

- Schedulers in storage systems are deployed in different ways:
  - On the gateways/proxies/data servers
  - Centralized/decentralized

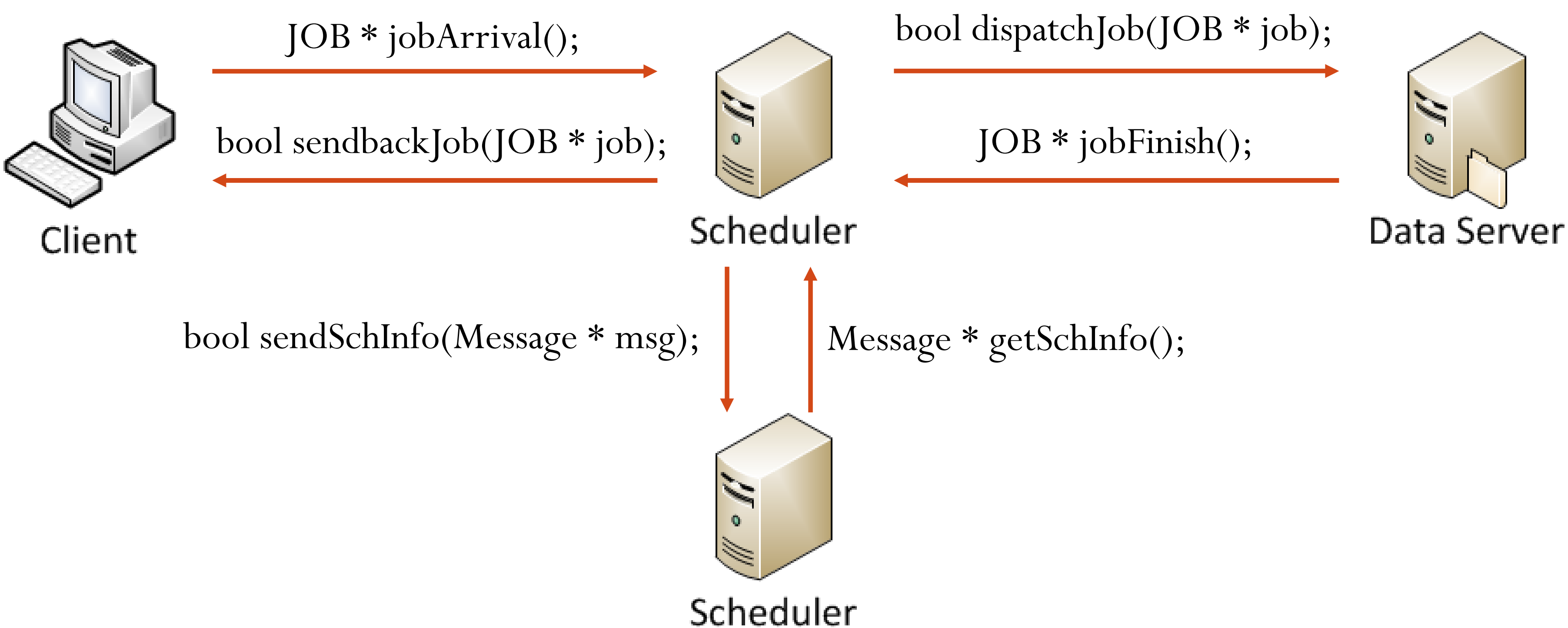
- In PFSsim, the schedulers can be modeled flexibily:
  - Stand-alone/coupled with the network entities
  - Inter-scheduler communications are supported

Architecture of a Simulated System



Scheduler Implementation

- The schedulers are implemented by inheriting a base class with several essential methods:



Network Implementation

- Network links are simulated by the channel components in OMNeT++
  - Configurable bandwidth/latency/bit error rate
- Detailed real-world network protocols are omitted
  - Can be extended with the INET framework*
- Basic wired network devices are simulated
  - Such as switches, routers
  - Can be customized or extended by users

* "http://inet.omnetpp.org"

Local File System Implementation

- Memory component is simulated for data caching/buffering
  - Configurable memory size and page replacement policies

- Files are mapped to disk blocks in a contiguous manner
  - Real-world disk block management schemes are hard to simulate, dependent on many factors (file system, file size and disk usage)*
  - Possible simulation using statistical models in future work

* A. Nunez, "New Techniques for Modeling File Data Distribution on Storage Nodes"

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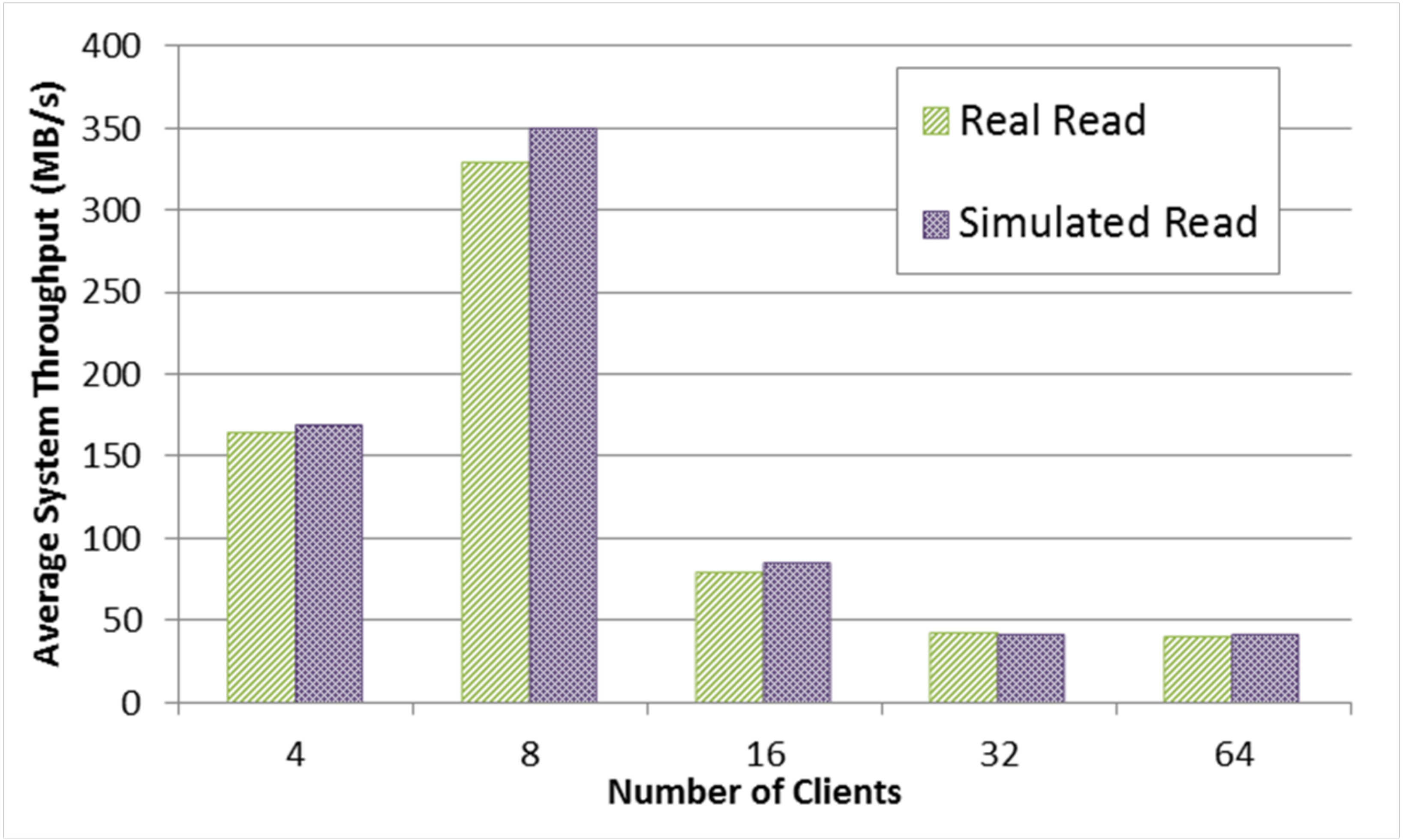
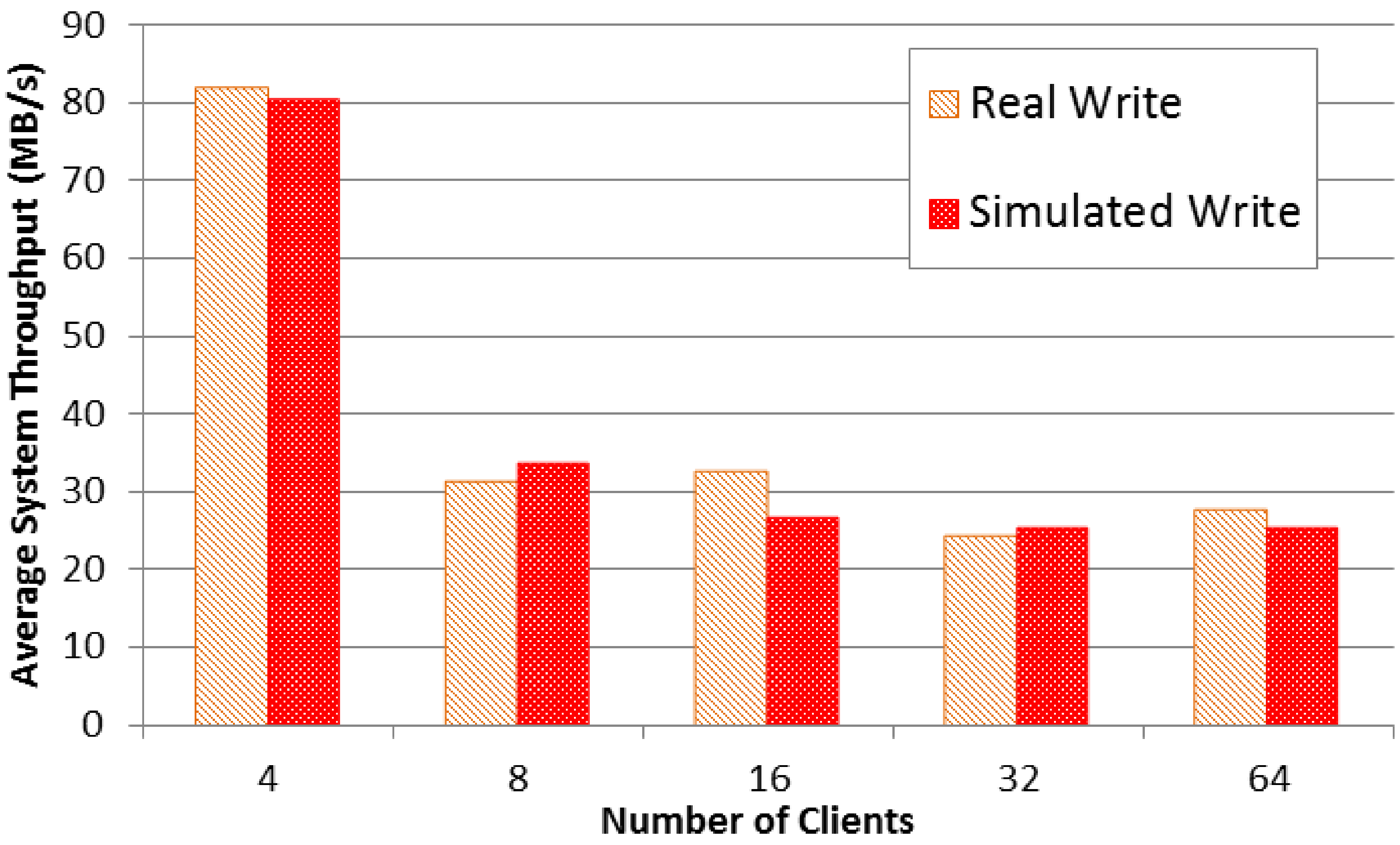
PFSsim Validation

- Validate the I/O throughput and latency under different workloads
- Benchmark system
  - PVFS2: 4 data servers/1 metadata server/varying number of clients
  - Each client/server has one 2.4GHz CPU/1GB RAM
  - PVFS2, stripe size set to 256KB, round-robin distribution
- Traces
  - Each client sequentially writes 400MB, 1MB per write
  - Each client sequentially reads 400MB, 1MB per read
  - Reads are conducted on the same files right after write

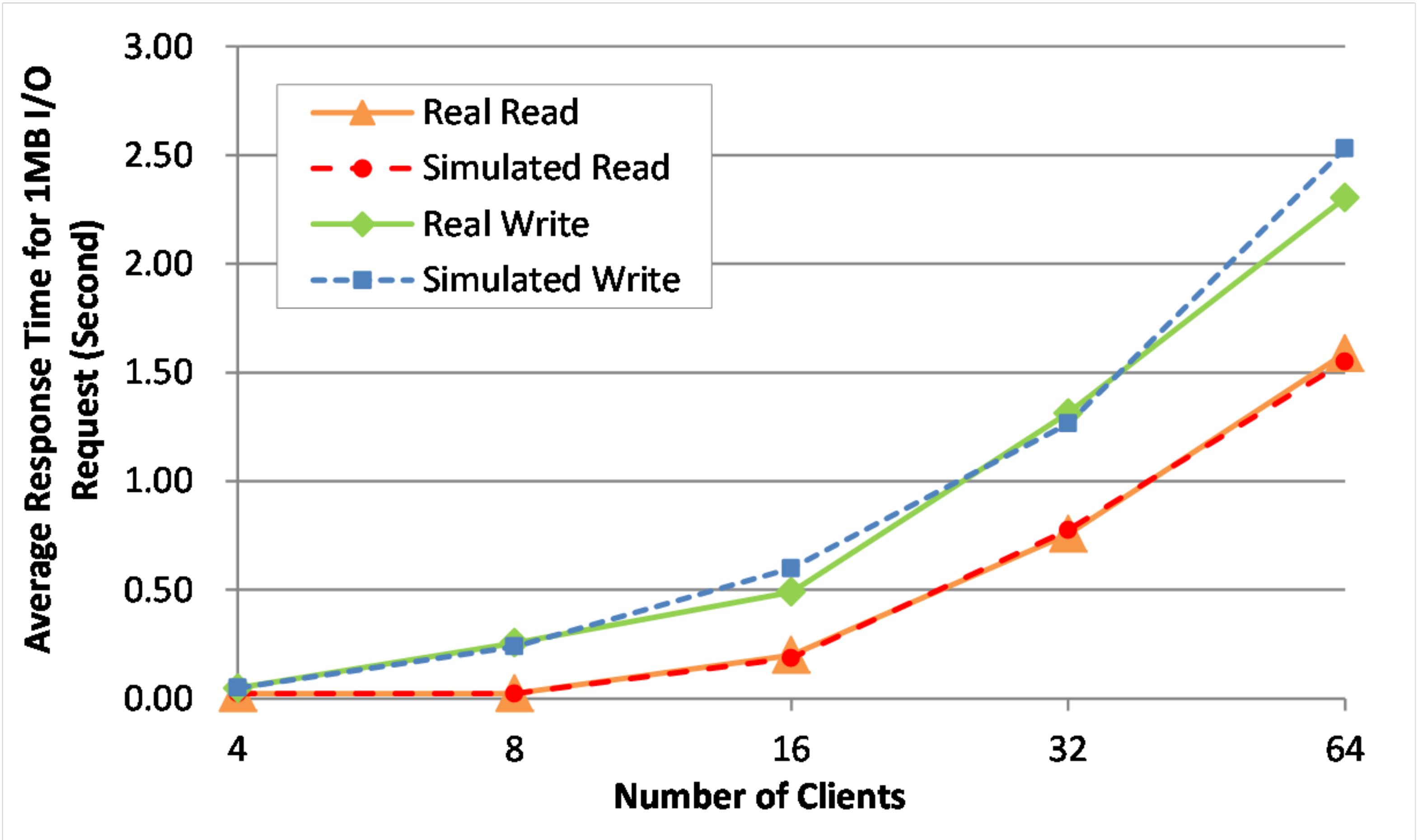
Read Throughput



Write Throughput



Response Time



Scheduler Validation

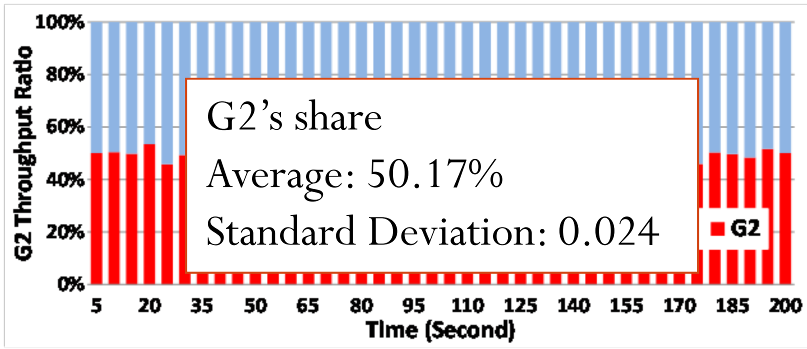
- Validate SFQ(D)* algorithm with different proportional sharing ratios
- Benchmark system and traces
  - PVFS2: 4 data servers/1 metadata server
  - 16 clients in Group1(G1) / 16 clients in Group2(G2)
  - SFQ(D) is deployed on each scheduler (D=4)
  - One scheduler per data server
  - Each client sequentially writes to 400MB, 1MB per write
- Varying sharing ratio between G1 and G2

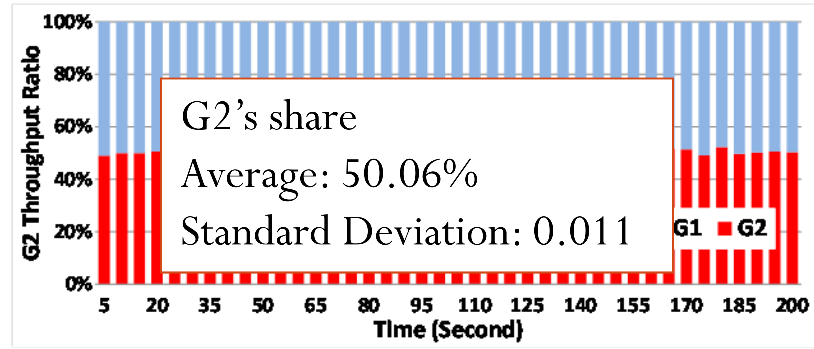
* W. Jin, et al., "Interposed Proportional Sharing For A Storage Service Utility", SIGMETRICS'04.

Scheduler Validation

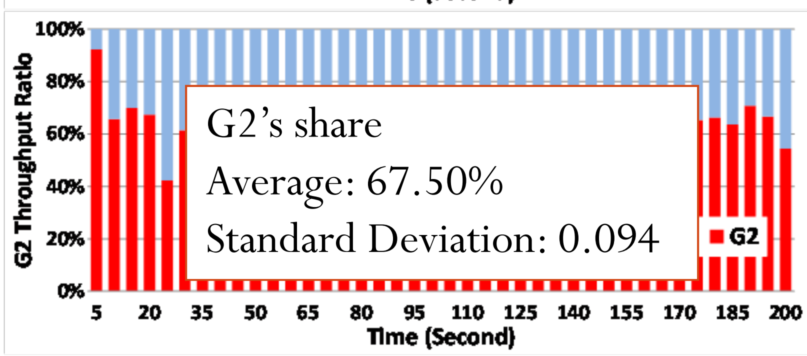
Real System Results | Simulated Results

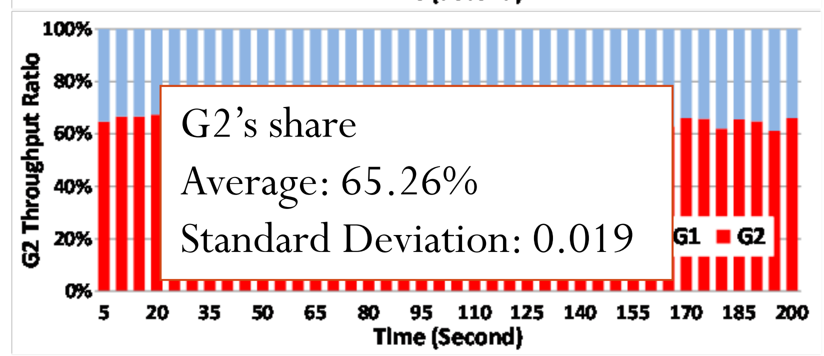
G1:G2 =1:1



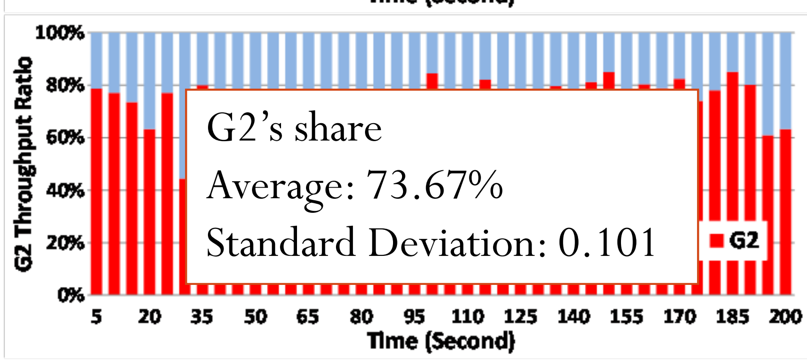


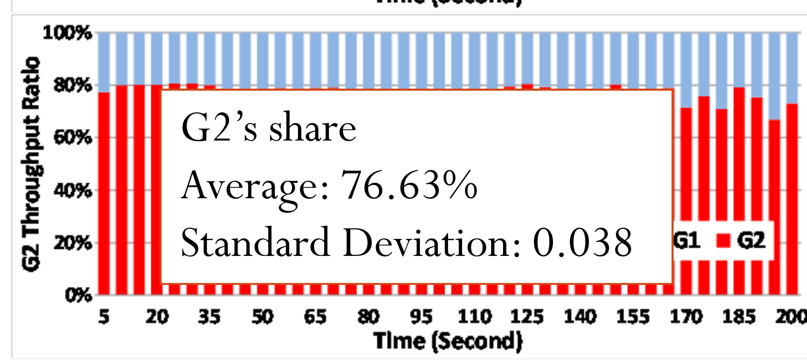
G1:G2 =1:2





G1:G2 =1:4





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Conclusion

- Progress towards the four basic design goals
  - Easy-to-use
    - Modular system design, object-oriented code
  - Flexible
    - Highly tunable parallel file system configuration, scheduler parameters, and network topology
  - Accurate
    - Good simulation accuracy shown in the validation results
  - Scalable
    - Able to simulate 512 clients and 32 servers in half an hour on a PC with 2.13GHz Intel i3 CPU and 2GB RAM

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Future Work

- Validate PFSsim against more realistic benchmarks
- Integrate a synthetic trace generator
- Simulate disk block management using statistical models
- Explore ways to support the simulation of very large scale systems

Acknowledgement

- Research team
  - VISA lab at FIU
    - Yiqi Xu, Dulcardo Clavijo, Lixi Wang, Dr. Ming Zhao
  - ACIS lab at UF
    - Yonggang Liu, Dr. Renato Figueiredo
- Sponsor: NSF HECURA CCF-0937973/CCF-0938045
- More information:
  - http://visa.cis.fiu.edu/hecura
  - https://github.com/myidpt/PFSsim

Thank You!