PADLL

Taming Metadata Burstiness of HPC Jobs Through Application-level QoS Control

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1 PROBLEM STATEMENT

EFFECTIVELY ENSURING STORAGE QOS GUARANTEES IN LARGE-SCALE HPC SYSTEMS IS NOT TRIVIAL:

⊗ Manual intervention

- In HPC facilities, sysadmins manually stop jobs with aggressive I/O behavior
- Reactive approach that is only triggered when concurrent jobs were already harmed

⊗ Intrusive to I/O layers

- Existing solutions are tightly coupled to core layers of the HPC stack (e.g., Parallel File System (PFS), job scheduler)
- Require profound system refactoring

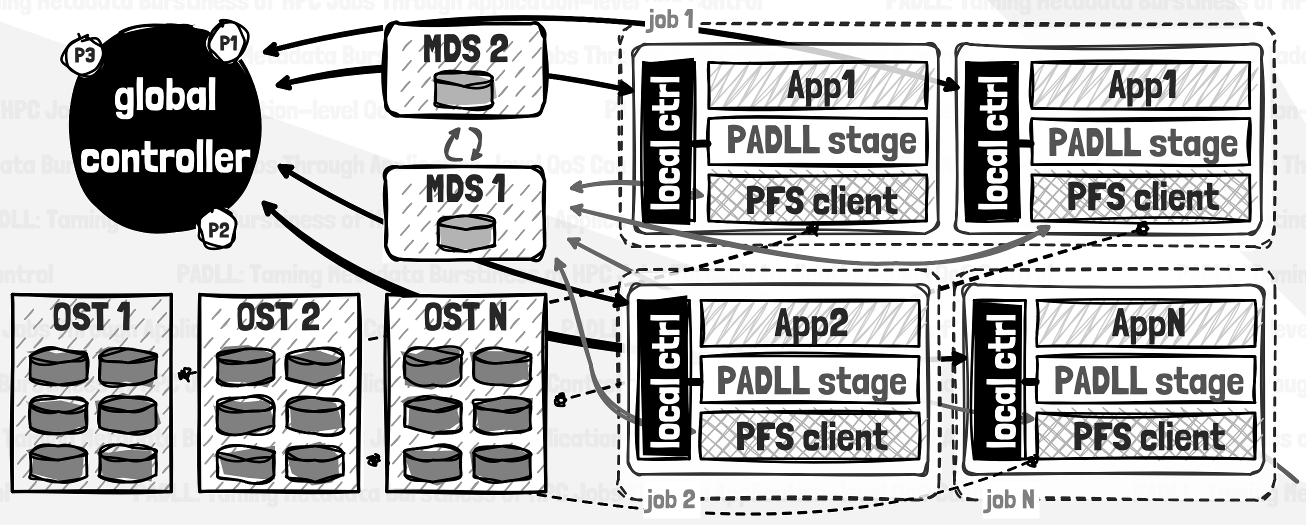
⊗ Partial visibility and I/O control

- Compute node-level solutions actuate in isolation (i.e., agnostic of other jobs)
- Unable to coordinate the I/O generated from multiple jobs that compete for shared storage

⊗ Metadata remains overlooked

- Existing proposals mainly focus on achieving QoS over data workflows
- Metadata operations of a single job can saturate the PFS metadata resources

2 PADLL STORAGE MIDDLEWARE



Software-Defined Storage architecture

- PADLL is organized in multiple data plane stages that differentiate and rate limit I/O workflows, and a hierarchical control plane that manages all stages to ensure storage QoS policies

Application and PFS agnostic

- PADLL sits between applications and the PFS, and does not require changing any core layer of the HPC I/O stack (LD_PRELOAD)
- Compatible with POSIX-compliant storage systems

Fine-grained I/O control

- Classifies, differentiates, and enforces I/O requests with different levels of granularity (e.g., operation type, class, and job)

Global visibility

- Coordinated control of all I/O workflows destined towards the PFS, preventing I/O contention and unfair usage of shared resources

PADLL IS AN APPLICATION AND FILE SYSTEM AGNOSTIC STORAGE MIDDELWARE THAT ENABLES QOS CONTROL IN HPC STORAGE SYSTEMS

3 CONTROL ALGORITHMS

Uniform rate distribution

- Jobs are throttled with a fixed rate throughout their execution, regardless of their size, duration, and workload
- Even distribution of resource shares

Priority-based rate distribution

- PFS resources are distributed based on a given priority
- Can lead to both under-provisioning (e.g., leftover I/O resources) and over-provisioning (e.g., resource shares larger than needed)

Proportional sharing (psharing)

- Traditional max-min fair share control algorithm (feedback loop) that enforces per-job rate reservations (IOFlow, Retro, PAIO)
- Suited for workloads with sustained I/O load, but suboptimal under volatile workloads (over-provisioning)

Proportional sharing without false resource allocation (psfa)

- New max-min fair share algorithm (feedback loop) that ensures storage QoS under volatile workloads
- Assigns resource shares based on the actual I/O usage of each job and their respective metadata demands

4 EXPERIMENTAL TESTBED

Goal

- Limit overall metadata load in the PFS (110 kops/s), while assigning different I/O priorities to jobs

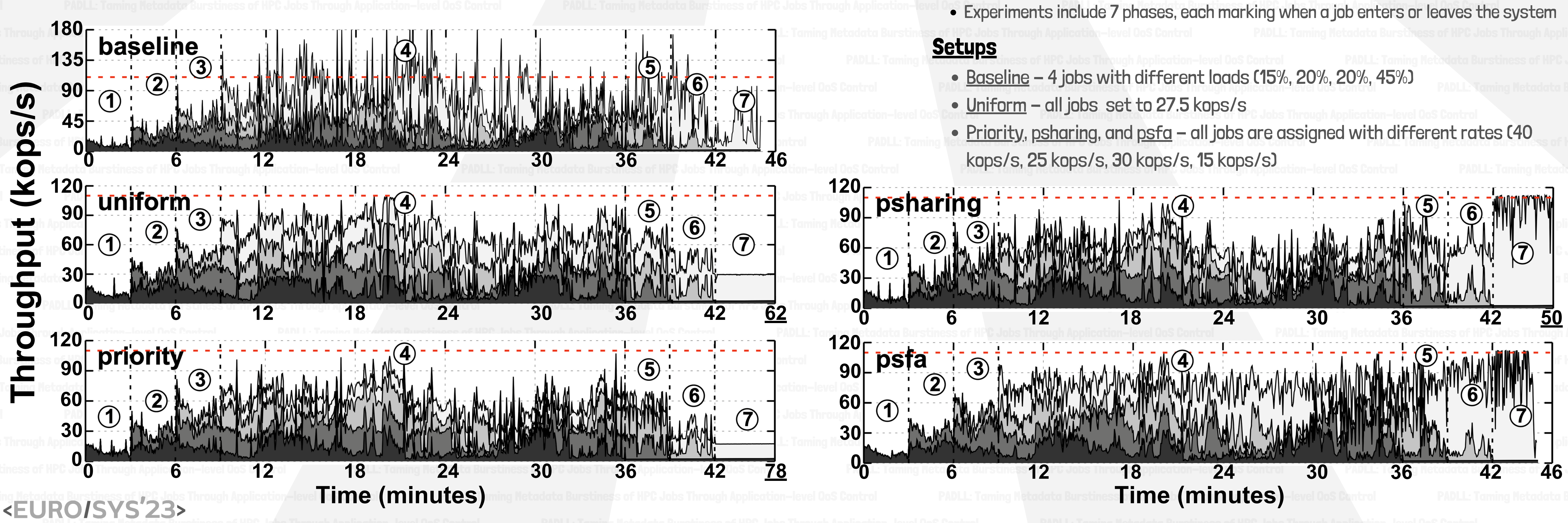
Experimental environment

- Per-job QoS control in the ABCI supercomputer, hosted by AIST
- Metadata traces from a production Lustre file system
- Experiments include 7 phases, each marking when a job enters or leaves the system

Setups

- Baseline – 4 jobs with different loads (15%, 20%, 20%, 45%)
- Uniform – all jobs set to 27.5 kops/s
- Priority, psharing, and psfa – all jobs are assigned with different rates (40 kops/s, 25 kops/s, 30 kops/s, 15 kops/s)

5 PER-JOB METADATA CONTROL



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https://arxiv.org/abs/2302.06418