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Argonne NATIONAL LABORATORY

ENABLING NVM FOR DATA-INTENSIVE SCIENTIFIC SERVICES

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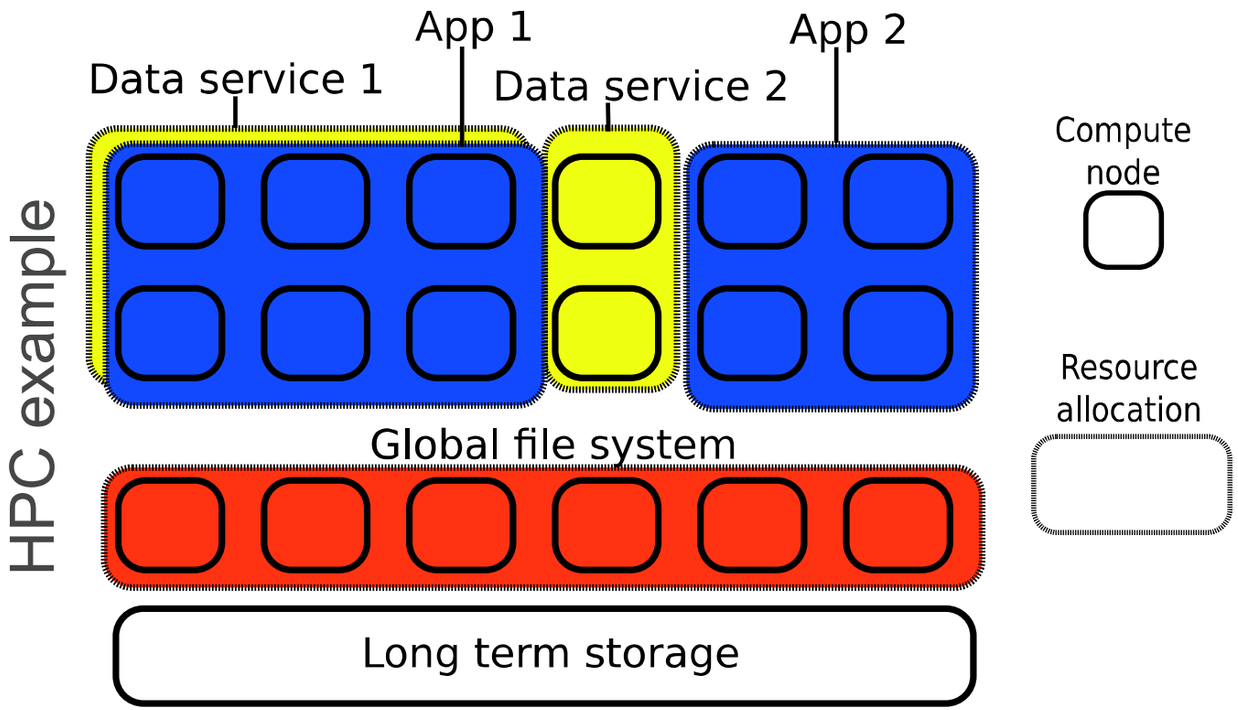
DATA-INTENSIVE SCIENTIFIC SERVICES



- Blue: applications
- Yellow: transient data services
- Red: persistent global file system

Transient data services allocated on demand to provide domain-specific functionality and semantics

- Use in-system storage devices
- Overlap with application resources in some cases
- Provision appropriate resources for the task at hand
- Supplement, not replace, conventional “global” file system

Specialized data services are already here!

Examples from HPC and cloud environments

	Provisioning	Comm.	Local Storage	Fault Mgmt. and Group Membership	Security
DataSpaces *Data store and pub/sub.*	Indep. job	Dart	RAM (SSD)	Under devel.	N/A
DataWarp *Burst buffer mgmt.*	Admin./ sched.	DVS/ Inet	SSD	Ext. monitor	Kernel, Inet
FTI *Checkpoint/restart mgmt.*	MPI ranks	MPI	RAM, SSD	N/A	N/A
Kelpie *Dist. in-mem. key/val store*	MPI ranks	Nessie	RAM (Object)	N/A	Obfusc. IDs
HDFS * *Dist. file system for MapReduce*	EMR or similar	TCP/IP	Disk, SSD	Zookeeper	Key encryption
Spark * *Data processing*	EMR or similar	TCP/IP	RAM	Zookeeper	Key encryption

* Persistent services such as HDFS, Spark, and others can be provisioned on-demand in cloud environments

WHAT'S NEXT?

The evolution of data-intensive scientific services

- Support emerging hardware
  - NVM (byte-addressible non-volatile memory) to accelerate data access
  - See Aurora (ANL), Summit (ORNL), and others
- Lower the barrier to entry
  - Avoid building new services from the ground up
  - Reuse existing toolkit/framework/library for critical functionality
  - "Microservice" model: lightweight *composable* building block services
  - Performance portability
- Example microservices: key/value storage, object storage, group membership, replication, namespace management
- Example composed scientific service: "Genomics Query Service"

CASE STUDY:
AN OBJECT STORAGE MICROSERVICE

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GOAL

Low-latency, high-throughput access to *distributed* NVM, using an object storage API, that embodies the microservice concept for data-intensive science

- Why not just use local NVM devices through local APIs?
  - Ability to share data across tasks or ensembles
  - Support imbalanced workloads
  - NVM devices may not be present on every node
- Challenges for remotely accessible object storage service:
  - **High concurrency** is the norm (thousands of application processes)
  - **Network portability** for big data and HPC environments
  - **Latency** (software overheads won't be masked by slow disks)
  - Being a **"friendly neighbor" to co-located applications** and services

COMPONENTS USED IN PROTOTYPE*

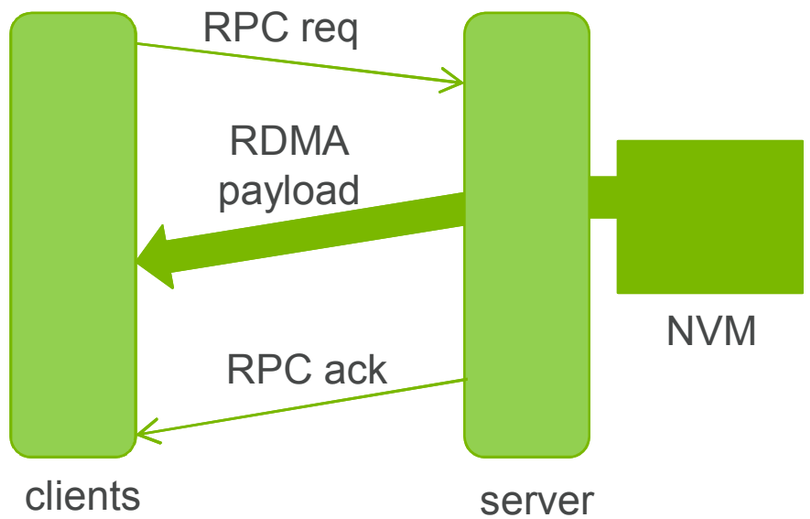
- Local NVM access: **libpmemobj** (Intel)
  - Object abstraction for local NVM access
- Network abstraction: **Common Communication Interface** (ORNL)
  - High-performance network abstraction with concise primitives
- RPCs: **Mercury** (HDF Group and ANL)
  - HPC-oriented RPC framework with RDMA path for data
- Concurrency: **Argobots** (ANL)
  - User-level threading and tasking
- Bindings: **Margo** and **abt-snoozer** (ANL)
  - Maps communication to threads with custom scheduling

*See URLs for source code at end of presentation

CHALLENGE: HIGH CONCURRENCY

How do we avoid overwhelming services under large-scale, highly-concurrent workloads?

- Put services in charge of coordinating the following at shared resource (contention) points:
  - Flow control and memory consumption
  - Coherency
  - Staging to/from slower storage tiers
  - Access rights
- To accomplish this:
  - Clients initiate access using explicit RPCs
  - Servers drive payload transfers with RDMA
  - Can we still get reasonably low latency with this model?
- Trade off latency for ability to optimize concurrent access



CHALLENGE: NETWORK PORTABILITY

Can we support a variety of networks effectively?

- Anecdote: Argonne (ALCF) machine room has production systems with the following transports and fabric:
  - TCP/IP (Ethernet)
  - Verbs (multistage InfiniBand)
  - uGNI (dragonfly)
  - PAMI (torus)

- Can't afford to tune all the way to metal while supporting wide range of big data and HPC deployments
- Mercury RPC API is network agnostic, provides RDMA path for bulk data transfer
  - RDMA is emulated on networks that don't support it
- CCI communication library (used within Mercury as an optional transport) supports TCP, Verbs, uGNI, shared memory, and others

CHALLENGE: LATENCY

How do we prevent software from becoming the bottleneck for high-performance storage devices?

- All threads are **user-level threads** implemented by Argobots
  - Spawn with low overhead (for incoming requests)
  - Schedule and context switch cooperatively (when blocked on I/O resources)
  - No OS-level context switching
- Make path from network to storage as direct as possible
  - Server drives RDMA directly to libpmemobj regions when appropriate
  - Memory copy is more efficient than memory registration in some cases, though. More on this later.
- Avoid extraneous serialization by eschewing POSIX semantics and name-space rules when they aren't needed

CHALLENGE: FRIENDLY CO-LOCATION

How do we minimize interference when microservices run on the same node as an application?

- No busy-spinning (at least by default) for network events; requires considerations within multiple components:
  - CCI exposes file descriptor to block callers until events are ready
  - Mercury decouples event management from network “progress”
  - Abt-snoozer scheduler for Argobots gracefully idles (but resumes promptly) when all threads are blocked on I/O
- Constrain CPU core usage
  - Argobots allows fine grained control of which threads and taskets execute on which cores (execution streams)

EVALUATION:

WHAT KIND OF PERFORMANCE CAN WE ACHIEVE UNDER THESE CONSTRAINTS?

PERFORMANCE MEASUREMENT

- Prototype API model is similar to libpmemobj, but tailored for remote access:
  - Explicit reads and writes rather than load/store access
  - Allow concurrent access to objects from many clients simultaneously
  - No transaction grouping
- Benchmarks:
  - Create new plugin for IOR (HPC concurrent I/O benchmark) to read and write to distributed objects rather than files
  - Create custom microbenchmark for access latency
    - Measure latency of a sequential set of write or read operations
    - Does not persist on write

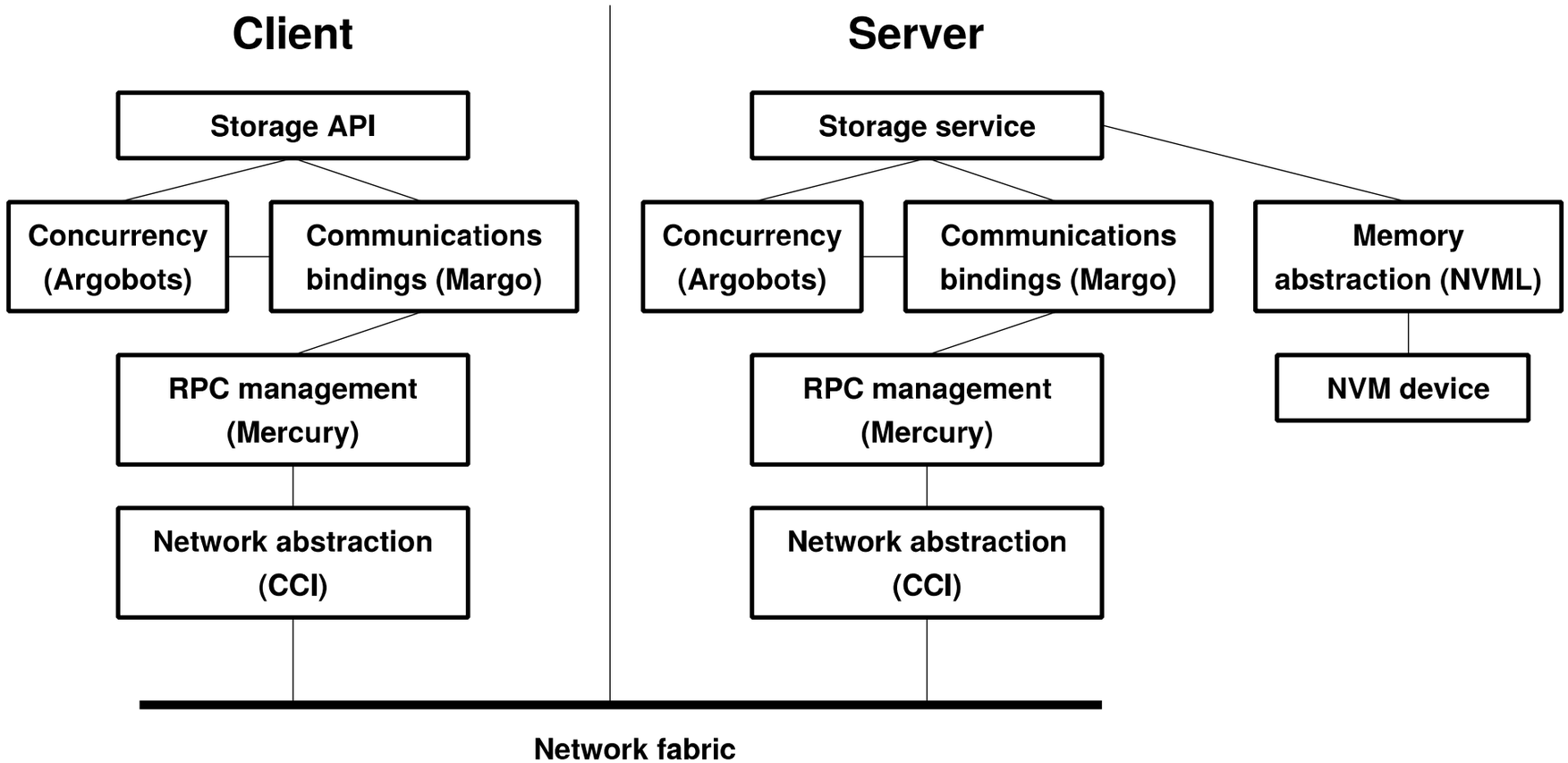
THE TESTBED

Cooley cluster at ALCF

- 126 Linux nodes, each with 12 Haswell CPU cores
- FDR InfiniBand fabric with multistage switch
- 384 GiB RAM per node (used to emulate NVM in these experiments)

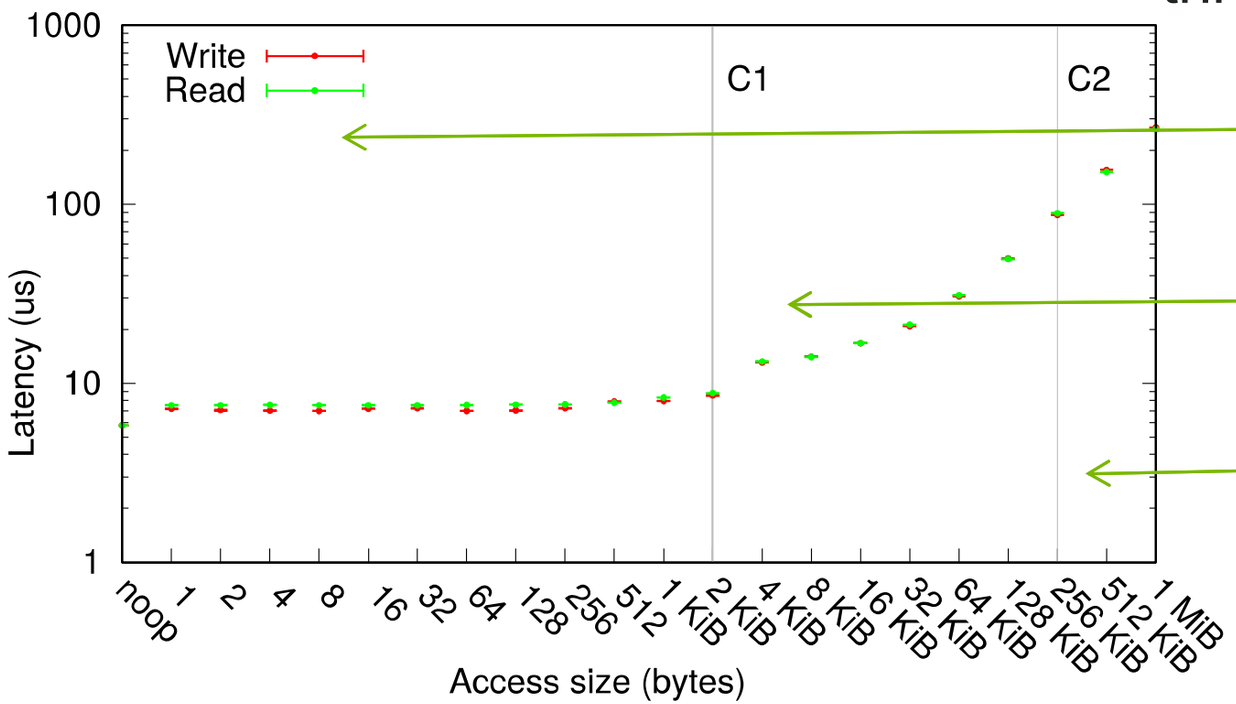
PUTTING THE COMPONENTS TOGETHER

A prototype object storage service architecture



ACCESS LATENCY

How much latency do those software layers add?



- Components are “thin”: no context switches or extra memory copies
- Recall that there is no busy polling
- Each access is at least one network round trip, one libpmem access, and one new thread

Protocol modes:

- Eager mode, data is packed into RPC msg
- Data is copied to/from pre-registered RDMA buffers
- RDMA “in place” by registering memory on demand

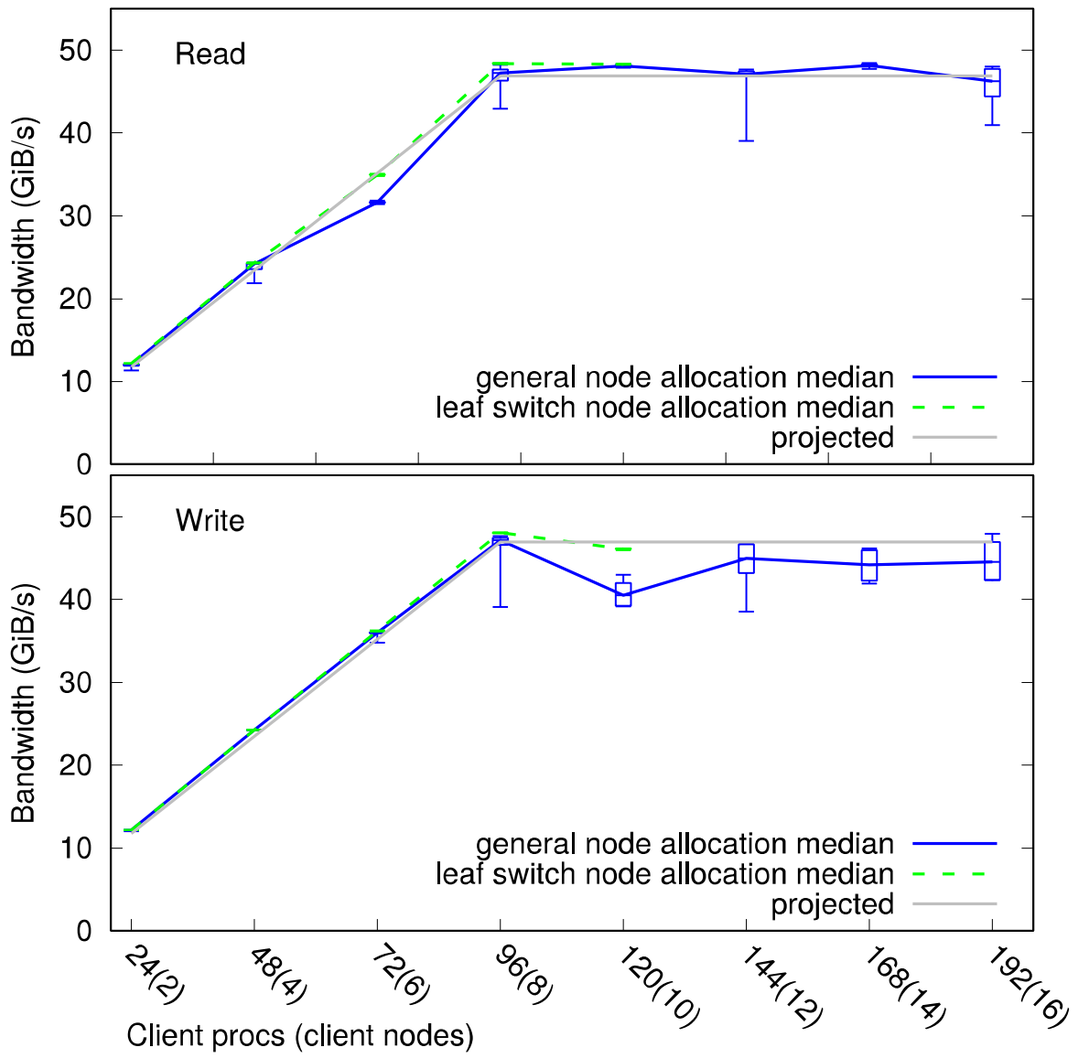
Crossover points would be different depending on transport

ACCESS LATENCY

Observations and questions

- Single digit microsecond access latencies, but could it be tuned further?
  - Consider adaptive polling
  - Optimize memory allocation
- What about the long tail?
  - Previous slide shows confidence interval for 10,000 samples at each point, and the intervals are quite narrow
  - But outliers are present: one of the noop samples was > 70 microseconds
- The cost of memory copy vs. registration is a key factor in choosing protocol crossover points

AGGREGATE BANDWIDTH



- 8 server nodes, with one service daemon per node
- 2 to 16 client nodes, with 12 application processes per node (one per core)
- Grey line is projected maximum
- Blue line is normal, random allocation
  - Whiskers (min and max) have significant variance
- Green line is special allocation with all nodes on one leaf switch
  - Whiskers (min and max) have very little variance

AGGREGATE BANDWIDTH

Observations and questions

- InfiniBand switches are not true crossbars, no matter how much us computer scientists would like them to be
  - Consider switch routing and congestion-avoidance algorithms?
  - Would better internal service instrumentation help?
  - Are we going to observe similar phenomena on other networks?
- The service can saturate bandwidth aggregate bandwidth relatively easily
- No drop-off up to 192 application processes accessing 8 daemons
  - What if we scale higher?
- What about a real scientific application?

CONCLUSIONS AND FUTURE WORK

WHAT'S NEXT?

- Initial results are encouraging
- Continue tuning and developing best practices
  - Investigate performance outliers
  - Isolate latency costs
- What can be done to further evaluate concept?
  - Real applications
  - Larger scale
  - More architectures
  - Real NVM hardware
  - Stage in and out to long term storage
- Update microservice model to allow remote or local access under consistent API
- Continue to leverage new techniques from the community

AVAILABLE CODE

Key components are already open-sourced under permissive licenses

- CCI: https://github.com/CCI/cci
  - Network abstraction
- Mercury: https://mercury-hpc.github.io
  - RPC framework
- Argobots: https://github.com/pmodels/argobots
  - User-level threading
- Margo: https://xgitlab.cels.anl.gov/sds/margo
  - Mercury/Argobots bindings
- Abt-snoozer: https://xgitlab.cels.anl.gov/sds/abt-snoozer/
  - Argobots I/O-aware scheduler

THANK YOU!

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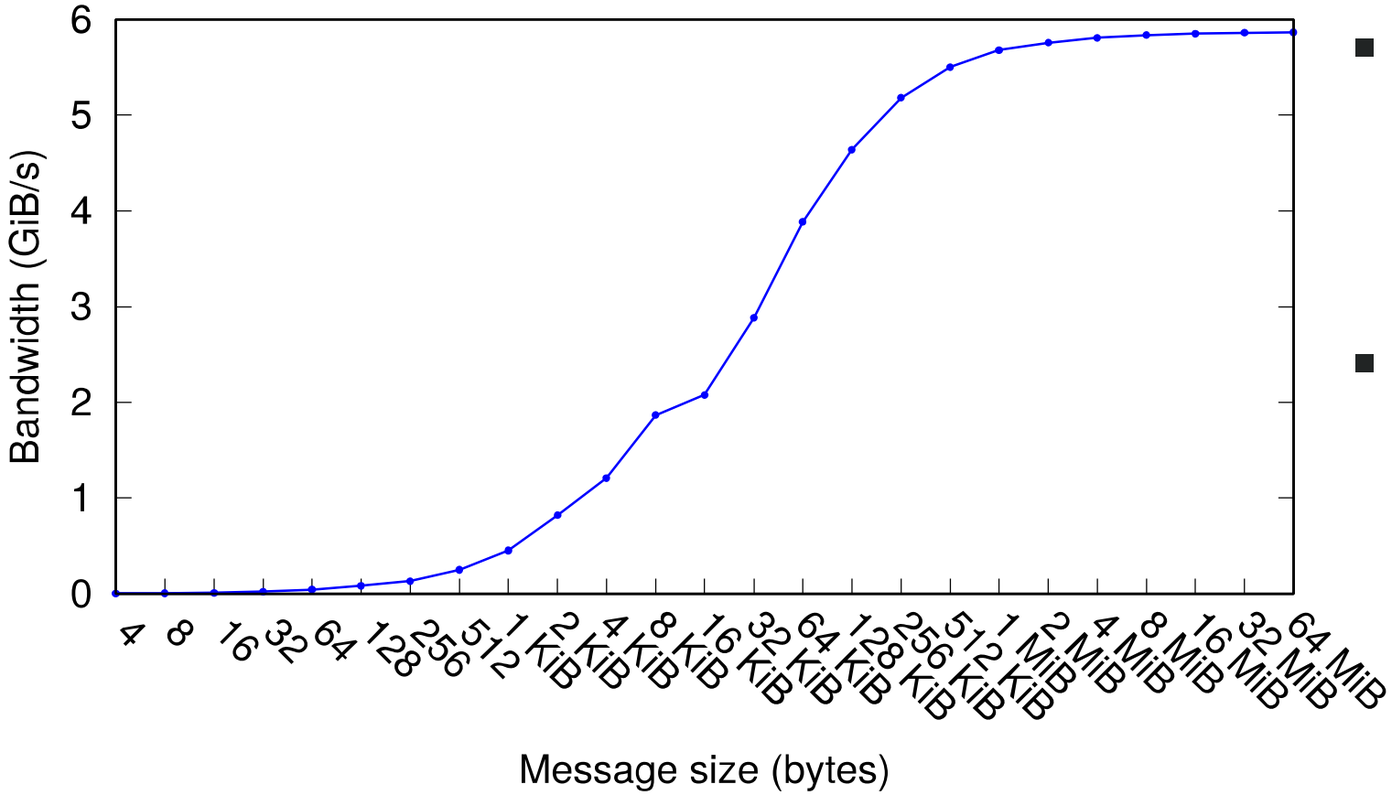
BASELINE PERFORMANCE

How did we come up with projected bandwidth and access latency values?



- We used *mpptest* benchmark atop the *MVAPICH* MPI implementation to gather baseline numbers
- 5.9 GiB/s max bandwidth and 2.6 microsecond min round-trip latency with two-sided asynchronous messaging