MVAPICH
MPI, PGAS and Hybrid MPI+PGAS Library

The Ohio State University

Designing Hierarchical Multi-HCA Aware Allgather in MPI

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Outline

- **Motivation and Contributions**
- Designing Multi-HCA Aware (MHA) Allgather
- Accelerating Allreduce with MHA Allgather
- Performance Evaluation
  - Microbenchmark-level
  - Application-level
- Summary

Motivation

- **Multi-rail** networks in existing and upcoming exa-scale systems
  - Summit and Sierra [1]– **2** adapters per node
  - ThetaGPU system [2] – **8** adapters per node
  - Frontier [3] and El Capitan [4] – **Multiple** Slingshot **NICs**
- Advantages:
  - Fault-tolerance
  - **Performance**
- Have we **efficiently utilized** all **adapters** per node in the context of **MPI?**
  - **Yes**, at **point-to-point** level
  - **No**, at the **collective** level

    => Collective **designs** need to be **revisited** and **augmented**

Multi-rail Support at P2P Level

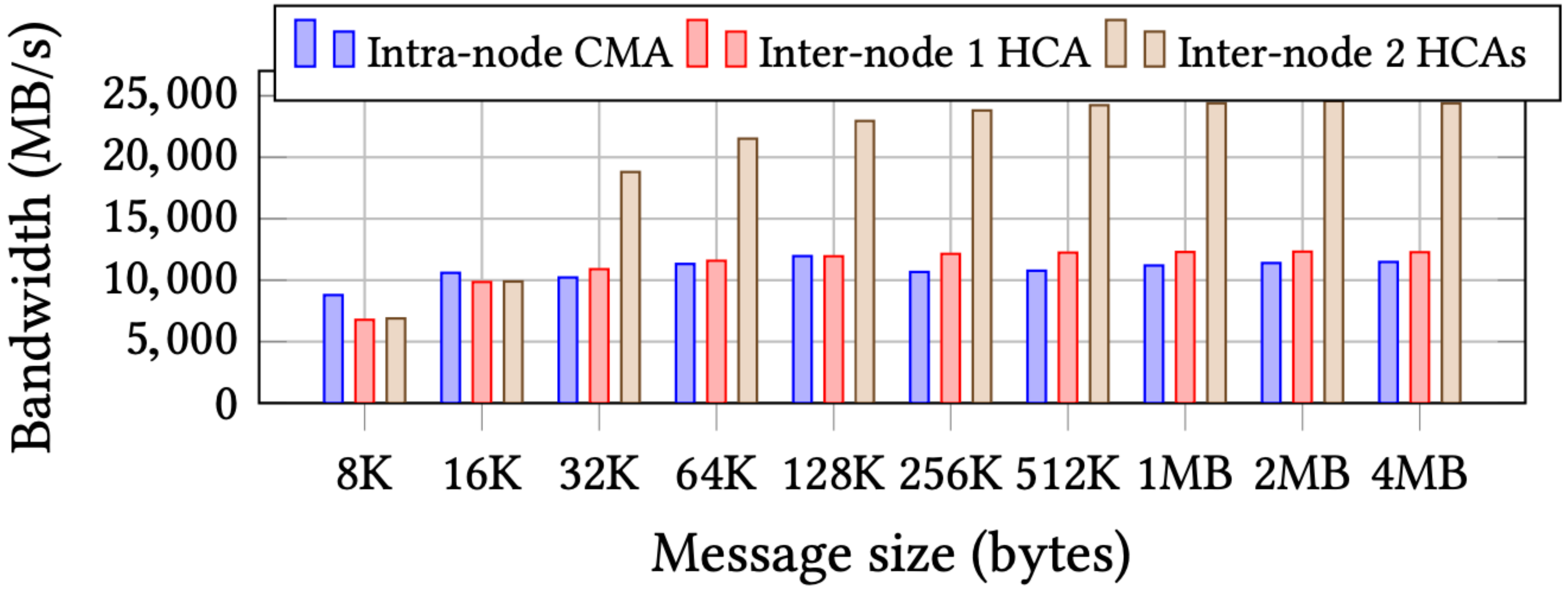
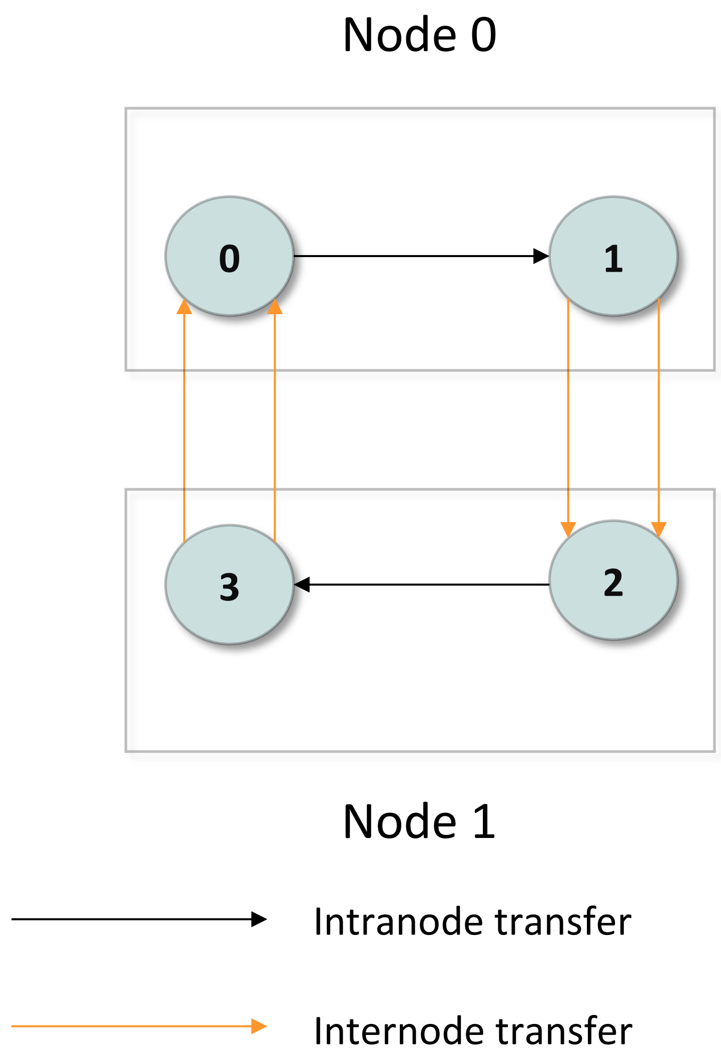


Figure 1: Bandwidth comparison between intra-node and inter-node communication

Collective Performance with Multi-rail Support at P2P Level



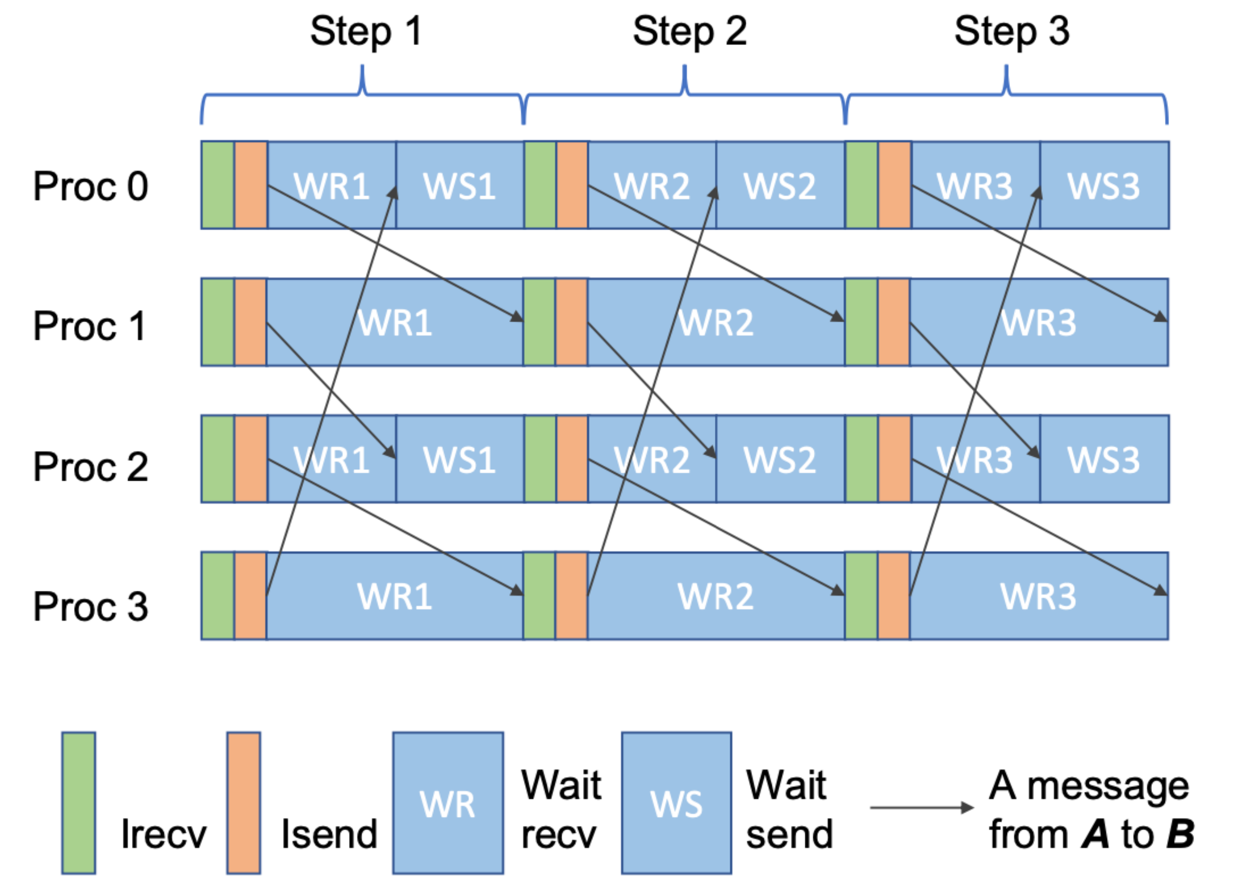


Figure 2: Allgather 2 Nodes, 2 PPN communication timeline visualization

Contributions

- **Design** and implementation of Multi-HCA Aware (MHA) **Allgather** to speed up both **intranode** and **internode** performance

- **Performance evaluation** at both **microbenchmark** and **application** levels with state-of-the-art MPI libraries, namely **MVAPICH2-X** and **HPC-X**

- **Accelerating Allreduce** with the proposed Allgather

- **Performance Model** of MHA Allgather

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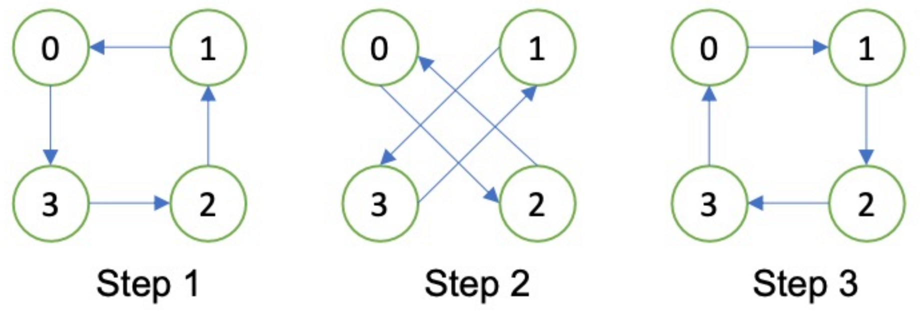
Intranode Design

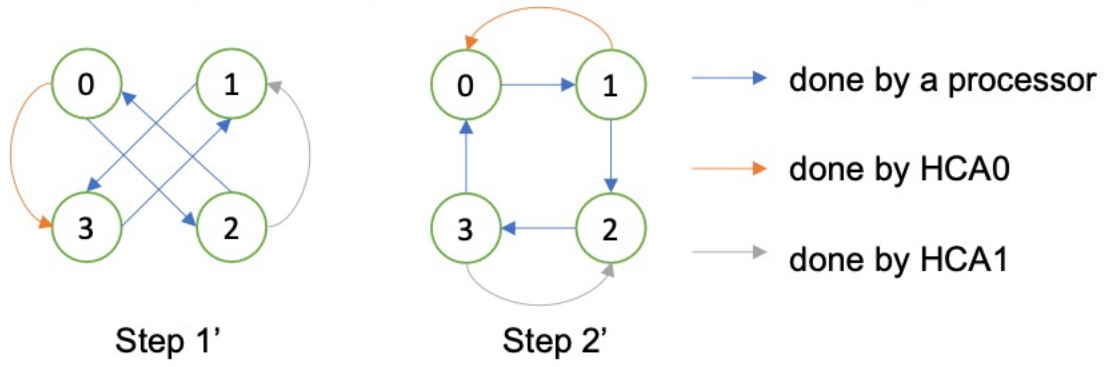
- For **pure intranode** communication
  - Intranode **transfers** performed by **CPUs**
  - Network **adapters** stay **idle**

=> **How** can we efficiently **utilize** the idle **adapters** to **accelerate** the communication?

- Idea:
  - Each process **offloads** the same amount of **work** to **adapters**



(a) Direct Spread algorithm executes in 3 steps



(b) The proposed MHA-intra executes in 2 steps. Step 1' is step 2 overlapping with 1st half of step 1. Step 2' is step 3 overlapping with 2nd half of step 1.

Tuning Algorithm for Intranode Design

- What is the **optimal offload size**?
  - **Processes** and **adapters** need to **finish** at the **same time**
  - Otherwise, the **one** that takes **long time** will be a source of **bottleneck**

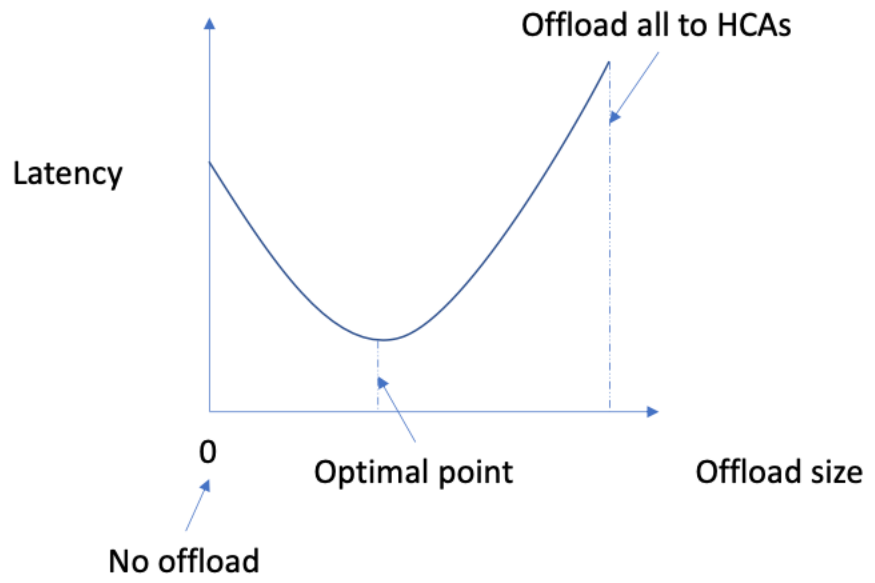
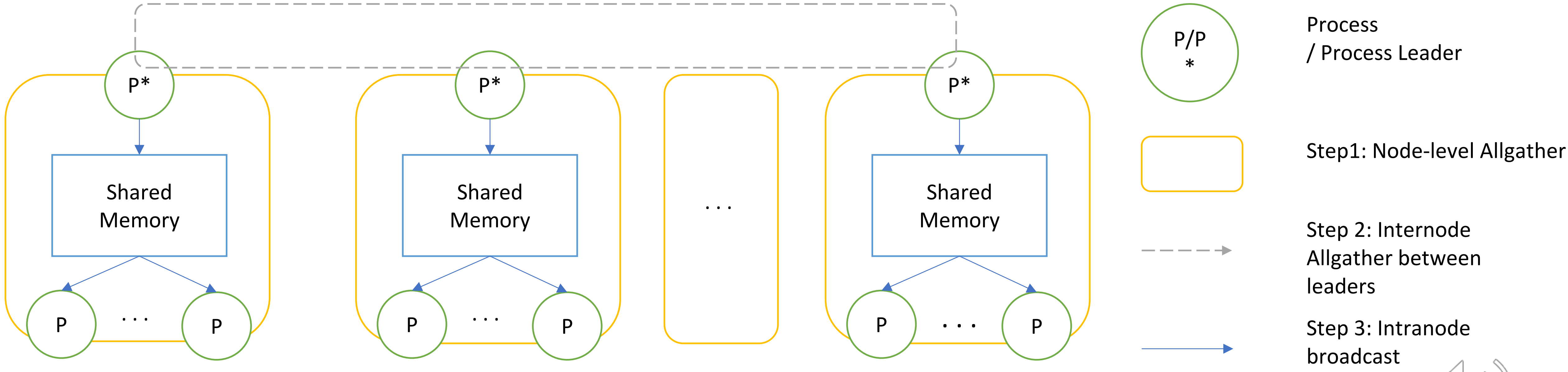


Figure 5: A chart showing the correlation between the offload size to adapters and latency

Internode Design

- Observations:
  - Intranode transfer is a source of bottleneck
  - Need to separate intranode and internode communication
- The proposed hierarchical MHA Allgather


P*
Shared Memory
P
. . .
P
P/P*
Process / Process Leader
Step1: Node-level Allgather
Step 2: Internode Allgather between leaders
Step 3: Intranode broadcast

Overlapping Intranode and Internode Communication

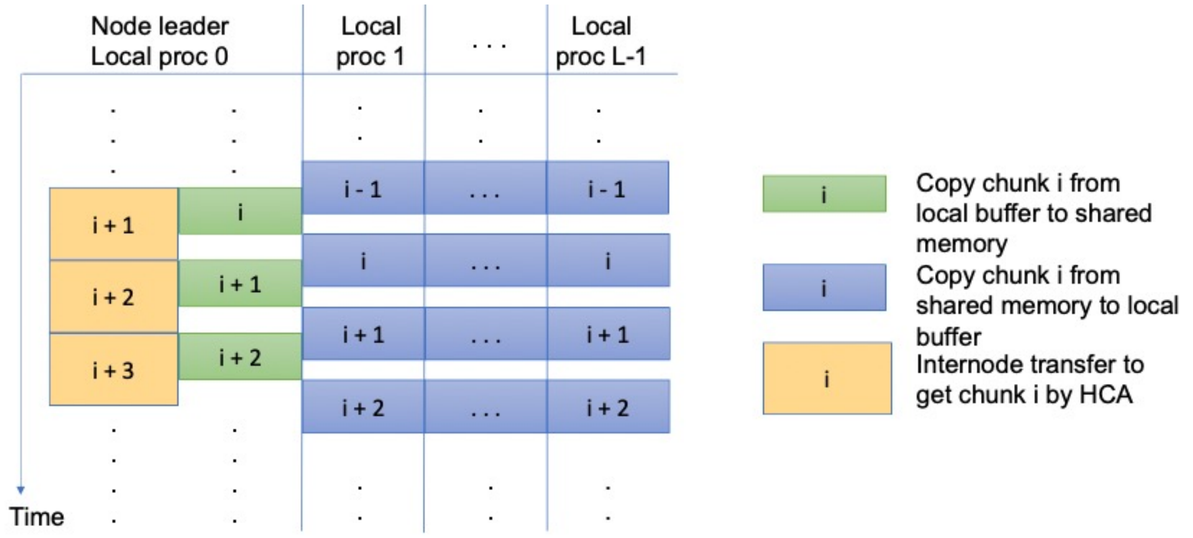

Node leader Local proc 0
Local proc 1
. . .
Local proc L-1
i - 1
i
i + 1
i + 2
i + 3
Time
Copy chunk i from local buffer to shared memory
Copy chunk i from shared memory to local buffer
Internode transfer to get chunk i by HCA

Figure 6: A timeline view of communication events of a node during interleader data exchange and node-level data distribution phases

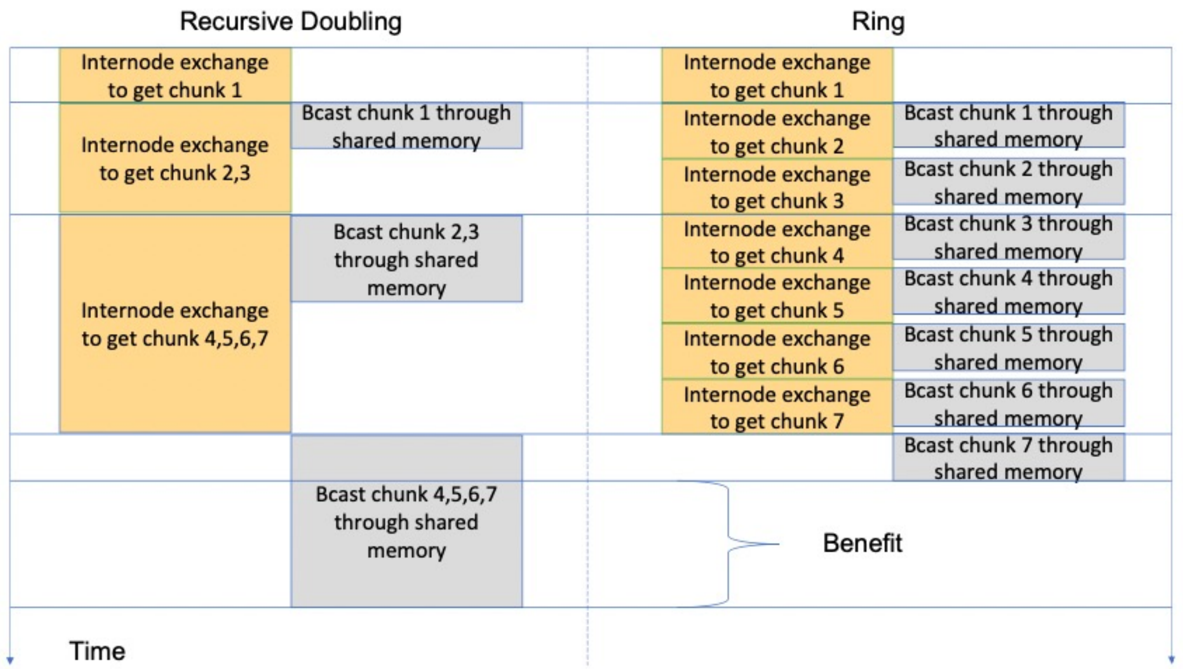

Recursive Doubling
Ring
Internode exchange to get chunk 1
Internode exchange to get chunk 2,3
Internode exchange to get chunk 4,5,6,7
Bcast chunk 1 through shared memory
Bcast chunk 2,3 through shared memory
Bcast chunk 4,5,6,7 through shared memory
Internode exchange to get chunk 2
Internode exchange to get chunk 3
Internode exchange to get chunk 4
Internode exchange to get chunk 5
Internode exchange to get chunk 6
Internode exchange to get chunk 7
Bcast chunk 2 through shared memory
Bcast chunk 3 through shared memory
Bcast chunk 4 through shared memory
Bcast chunk 5 through shared memory
Bcast chunk 6 through shared memory
Bcast chunk 7 through shared memory
Benefit
Time

Figure 7: A comparison of Recursive Doubling and Ring algorithms used in inter-leader data exchange phase

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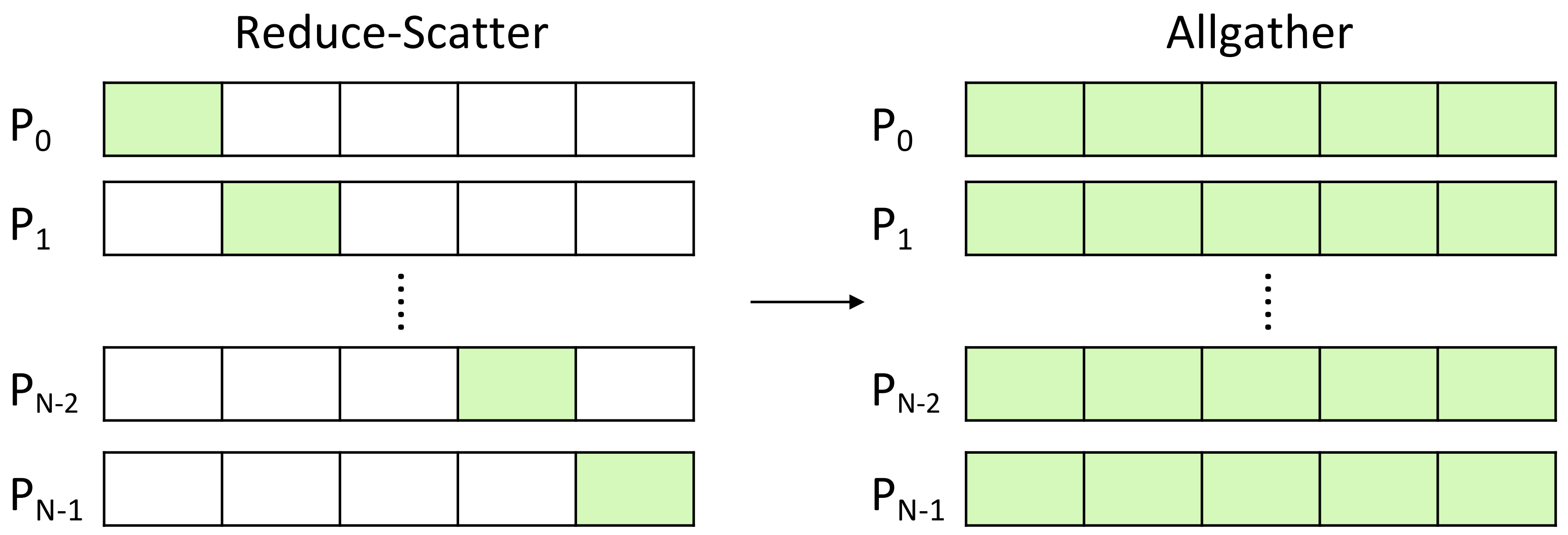
Accelerating Allreduce with MHA Allgather

- **Ring Allreduce** is proven to be **bandwidth-optimal**, which is particularly suitable for **large messages**
- The **algorithm** executes in **two phases**



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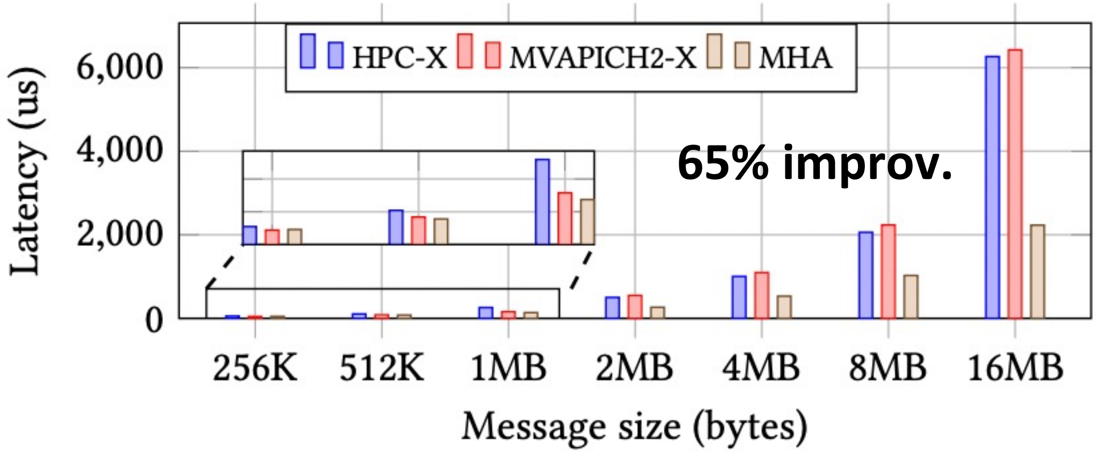
Experimental Setup

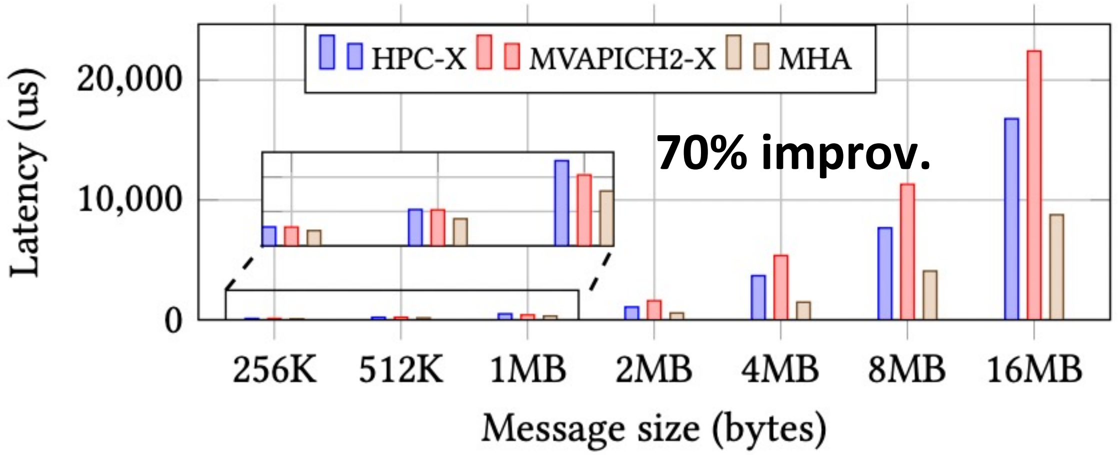
- Thor cluster of HPC Advisory Council
- Comparison with
  - MVAPICH2-X v2.3
  - HPC-X v2.10.0
- Application software
  - PyTorch v1.8.0
  - Horovod v0.20.0

Specification	Thor
Number of Nodes	32
Processor Family	Xeon Broadwell
Processor Model	E5-2697AV4
Clock Speed	2.6 GHz
Sockets	2
Cores per Socket	16
RAM (DDR4)	256 GB
GPU Family	Tesla V100
GPUs	1
GPU Memory	32 GB
Interconnect	2x IB-HDR (100Gb/s)

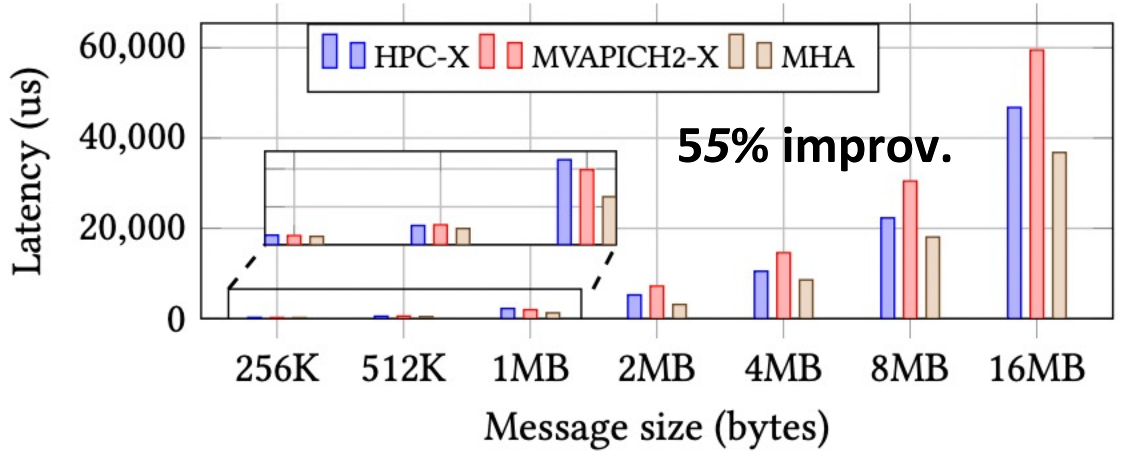
OMB - Intranode Allgather Evaluation



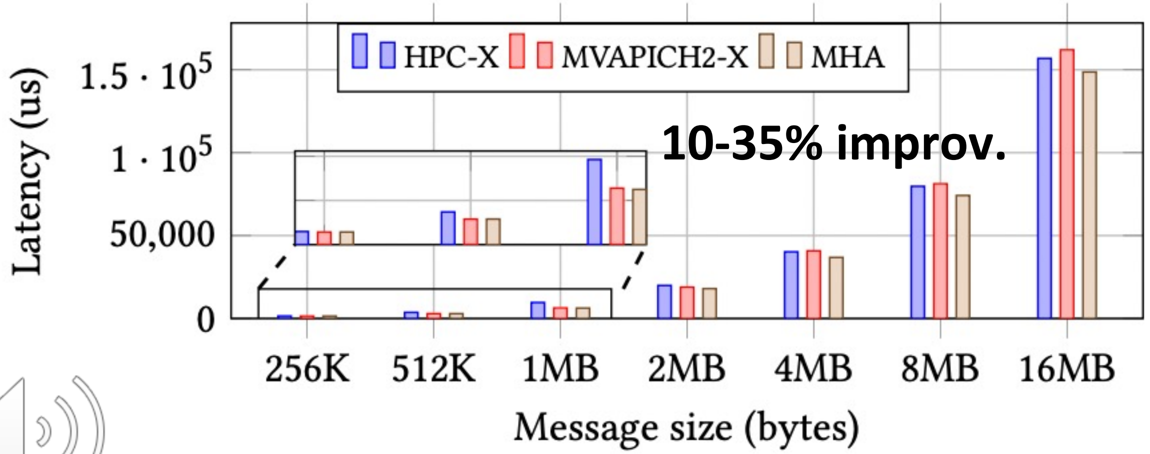
(a) 2 Processes



(b) 4 Processes

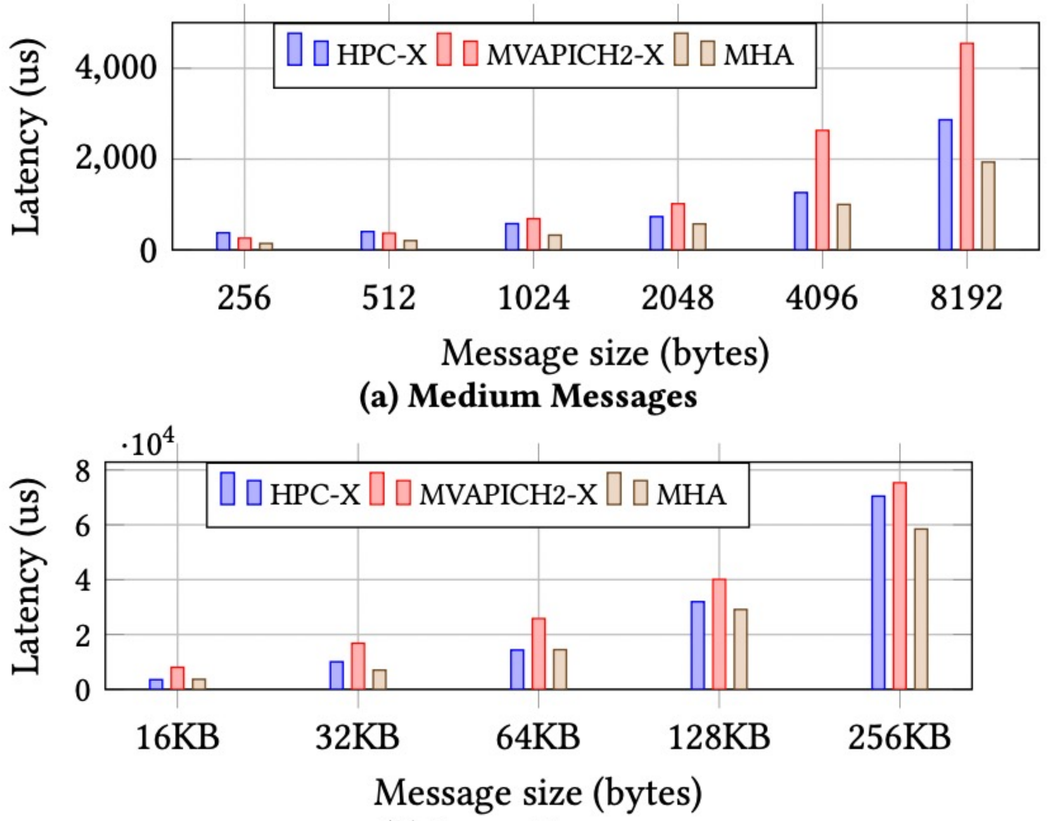


(c) 8 Processes



(d) 16 Processes

OMB - Internode Allgather Evaluation

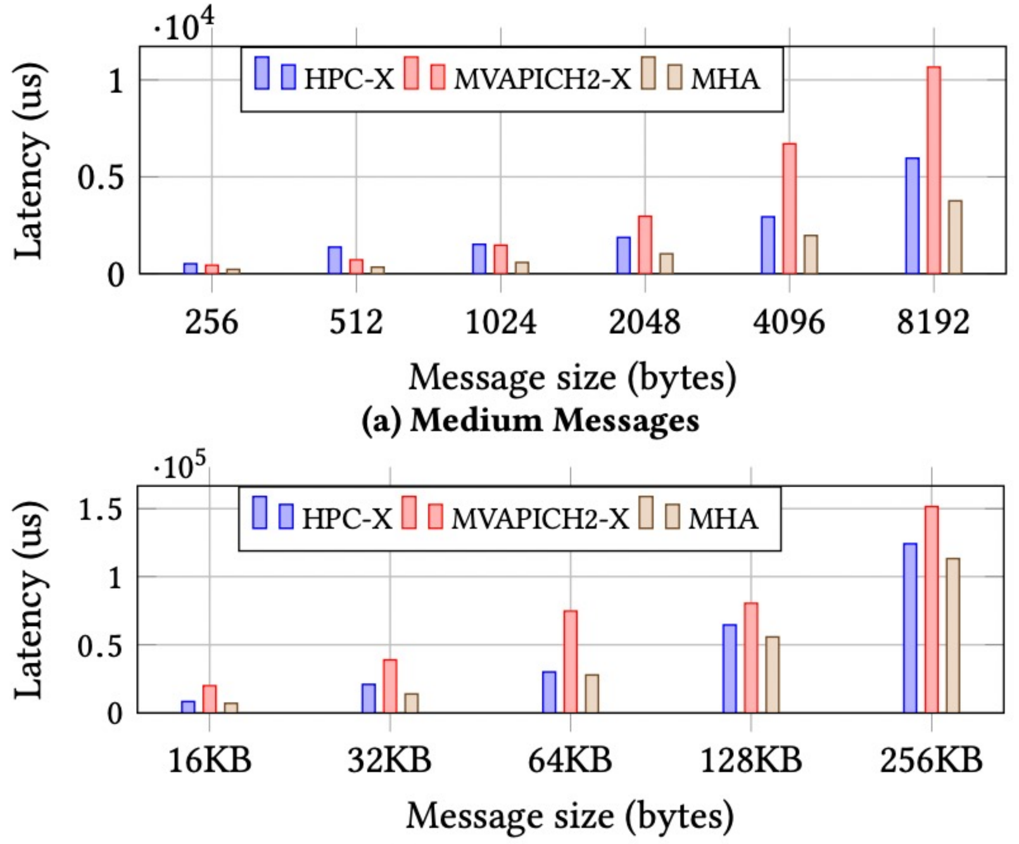


(a) Medium Messages

(b) Large Messages

Figure 13: Proposed MPI_Allgather against state of the art libraries via OSU Microbenchmarks on 512 processes (16 nodes 32 PPN)

44-53% improv.



(a) Medium Messages

(b) Large Messages

Figure 14: Proposed MPI_Allgather against state of the art libraries via OSU Microbenchmarks on 1024 processes (32 nodes 32 PPN)

61% improv.

OMB - Allreduce Evaluation

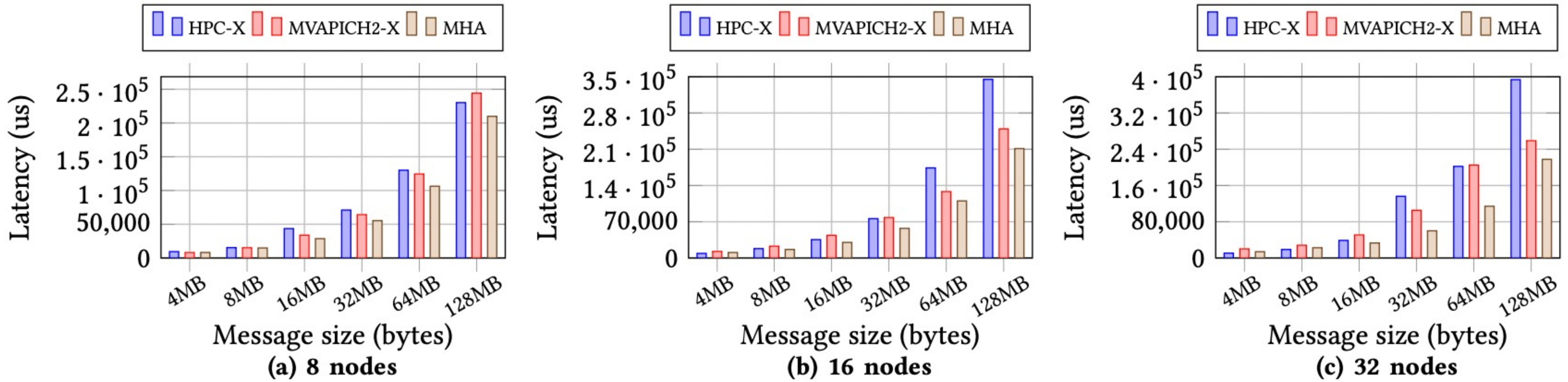
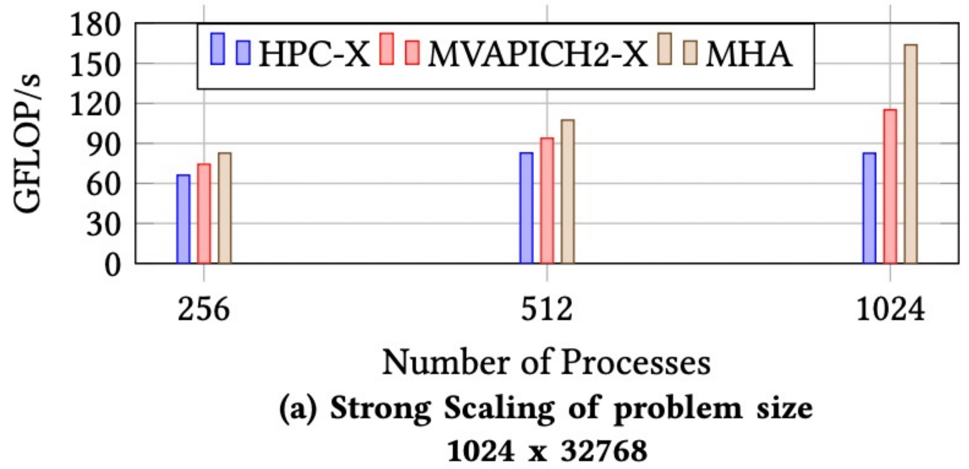


Figure 15: Evaluation of Proposed Inter-node MPI_Allreduce Design against state of the art libraries via OSU Microbenchmarks at scale (32 PPN)

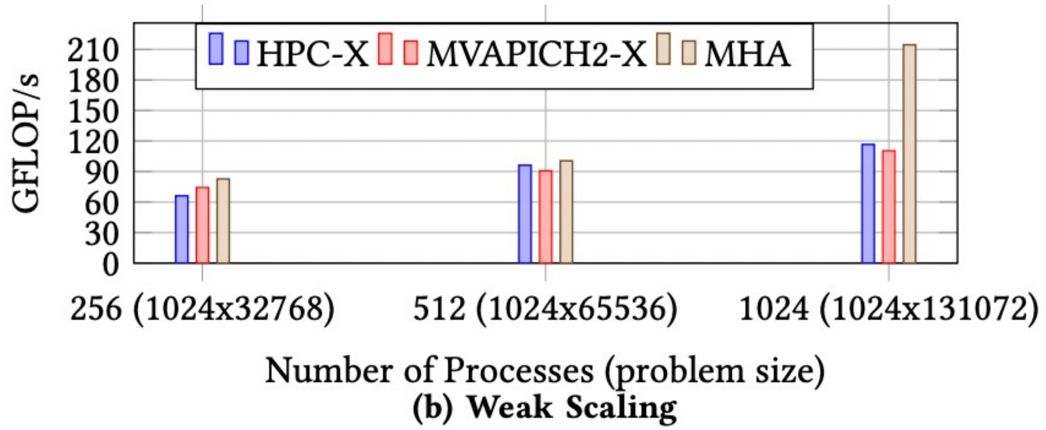
15-34% improv. **31-39% improv.** **44-56% improv.**

Matrix-Vector Multiplication Kernel

- 1D row layout partition
- The proposed Allgather **outperforms** both **HPC-X** and **MVAPICH2-X**
  - By up to **1.98x** and **1.42x** for strong scaling
  - And **1.84x** and **1.94x** for weak scaling experiments with **1024 processes**



(a) Strong Scaling of problem size 1024 x 32768

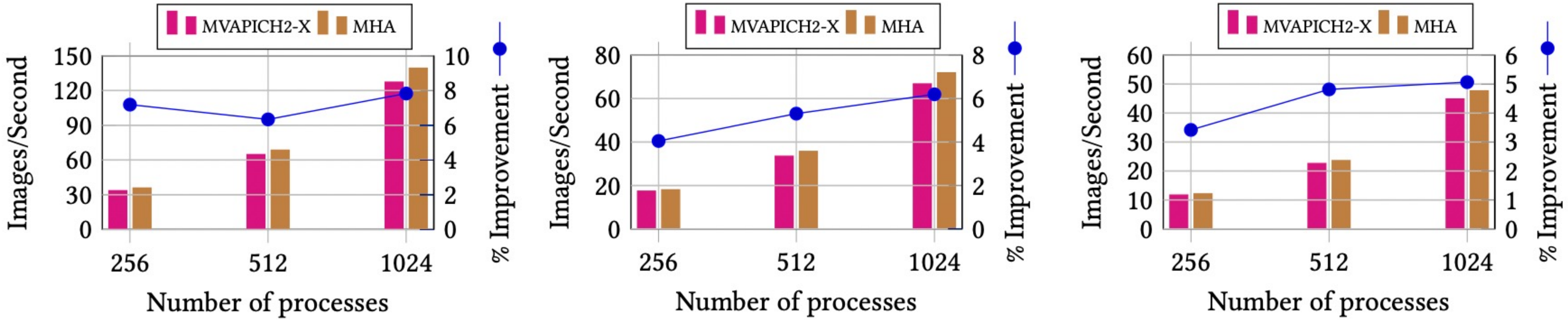


(b) Weak Scaling

Figure 16: Performance Evaluation of MHA against state of the art MPI libraries in a Matrix-Vector Multiplication kernel for Weak and Strong Scaling

Deep Learning Training

- **CPU-based** training
- The three neural networks are **ResNet50**, **ResNet101**, and **ResNet152**
  - with **25.6**, **44.7** and **60.4** millions of parameters, respectively
- Up to **7.83%** better than **MVAPICH2-X**



(a) ResNet-50 (b) ResNet-101 (c) ResNet-152

Figure 17: Proposed MHA design against MVAPICH2-X via PyTorch + Horovod DL Performance Evaluation: Images Per Second

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Summary

- This paper proposed a **Multi-HCA Allgather** that
  - Utilizes all the available network adapters within a node
  - Provides high overlap between inter-node and intra-node communication
- At the micro-benchmark level
  - The Improvements are up to **62%** and **61%** better than **HPC-X** and **MVAPICH2-X** for 1024 processes
  - The design also boosts the performance of Ring **Allreduce** by **56%** and **44%** compared to HPC-X and MVAPICH2-X
- At the application level
  - The enhanced Allgather shows **1.98x** and **1.42x** improvement in a **matrix-vector multiplication kernel** when compared to HPC-X and MVAPICH2-X
  - Allreduce performs up to **7.83%** better in **deep learning training against** MVAPICH2-X

Thank You!

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http://nowlab.cse.ohio-state.edu/

The High-Performance MPI/PGAS Project
http://mvapich.cse.ohio-state.edu/

The High-Performance Big Data Project
http://hibd.cse.ohio-state.edu/

The High-Performance Deep Learning Project
http://hidl.cse.ohio-state.edu/

References

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3. https://www.olcf.ornl.gov/frontier/
4. https://www.hpe.com/us/en/newsroom/press-release/2020/03/hpe-and-amd-power-complex-scientific-discovery-in-worlds-fastest-supercomputer-for-us-department-of-energys-doe-national-nuclear-security-administration-nnsa.html