OPENFABRICS ALLIANCE

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Designing High-Performance MPI Collectives in MVAPICH2 for HPC and Deep Learning

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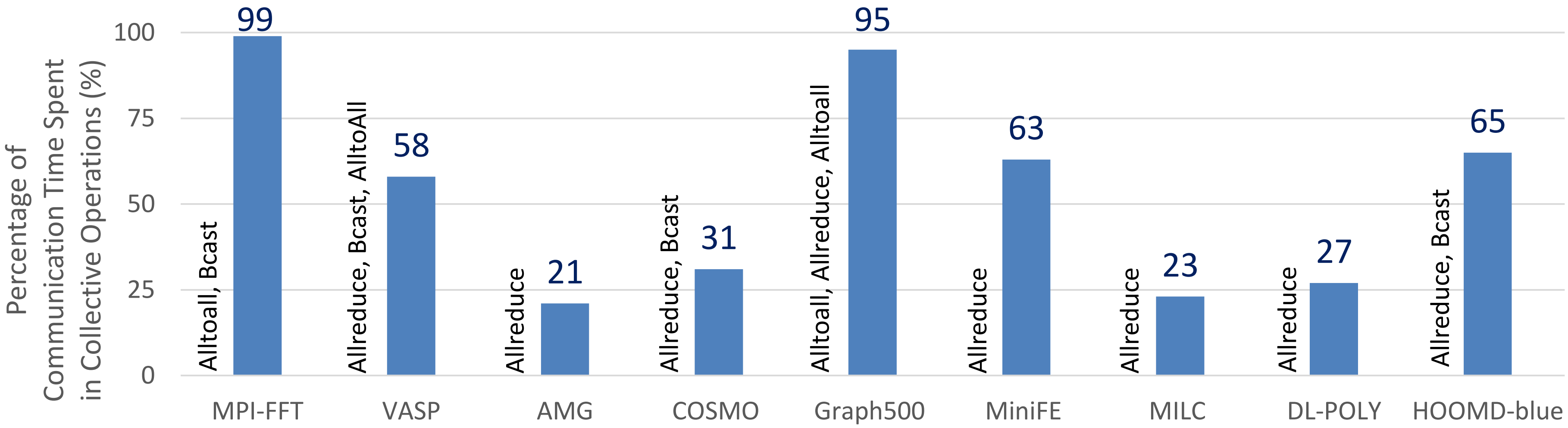
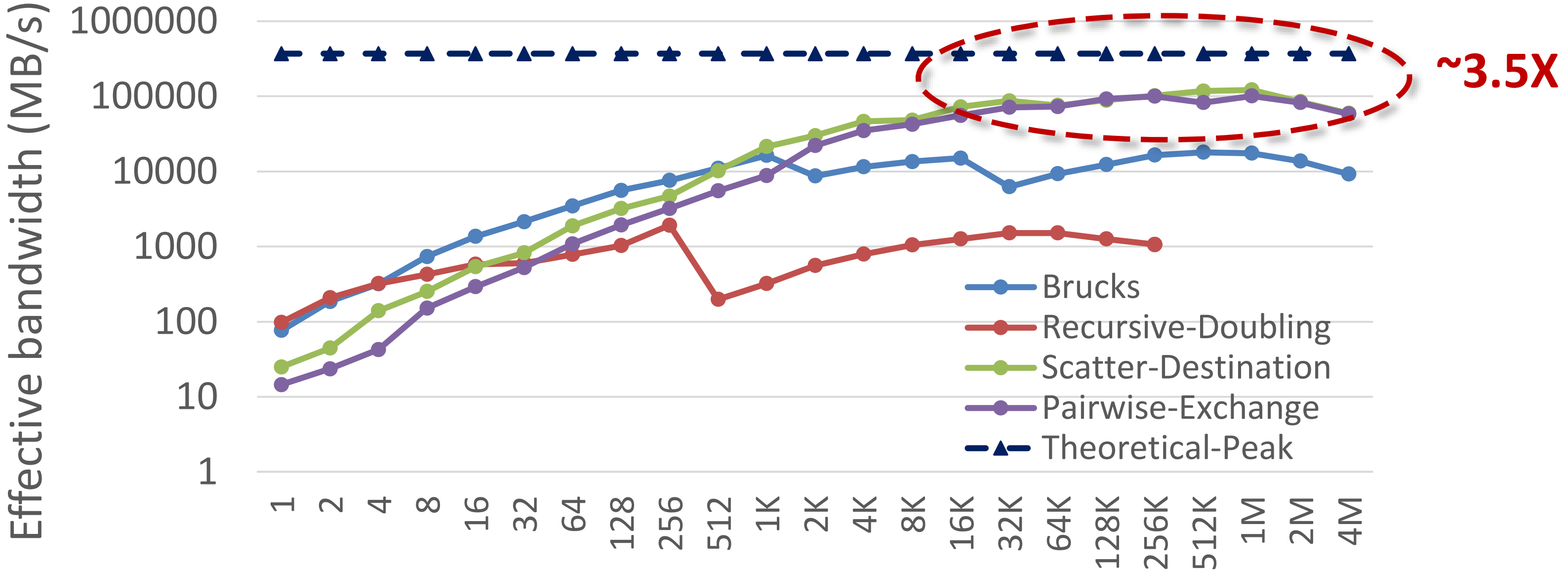
WHY COLLECTIVE COMMUNICATION MATTERS FOR HPC AND DL?



- Based on HPC Advisory Council (HPCAC) MPI application profiles
- Most application profiles show majority of time spent in collective operations
- Deep Learning applications are also sensitive to performance of collectives (all-reduce and broadcast)
- Optimizing the performance of collective communication is critical for the overall performance of HPC and DL applications

ARE COLLECTIVE DESIGNS IN MPI READY FOR MANYCORE ERA?



Alltoall Algorithms on single KNL 7250 in Cache-mode using MVAPICH2-2.3rc1

Why different algorithms of even a dense collective such as Alltoall do not achieve theoretical peak bandwidth offered by the system?

OVERVIEW OF THE MVAPICH2 PROJECT

- **High Performance open-source MPI Library for InfiniBand, Omni-Path, Ethernet/iWARP, and RDMA over Converged Ethernet (RoCE)**
  - MVAPICH (MPI-1), MVAPICH2 (MPI-2.2 and MPI-3.1), Started in 2001, First version available in 2002
  - MVAPICH2-X (MPI + PGAS), Available since 2011
  - Support for GPGPUs (MVAPICH2-GDR) and MIC (MVAPICH2-MIC), Available since 2014
  - Support for Virtualization (MVAPICH2-Virt), Available since 2015
  - Support for Energy-Awareness (MVAPICH2-EA), Available since 2015
  - Support for InfiniBand Network Analysis and Monitoring (OSU INAM) since 2015
  - **Used by more than 2,975 organizations in 88 countries**
  - **More than 529,000 (> 0.5 million) downloads from the OSU site directly**
  - Empowering many TOP500 clusters (Nov '18 ranking)
    - 3rd ranked 10,649,640-core cluster (Sunway TaihuLight) at NSC, Wuxi, China
    - 14th, 556,104 cores (Oakforest-PACS) in Japan
    - 17th, 367,024 cores (Stampede2) at TACC
    - 27th, 241,108-core (Pleiades) at NASA and many others
  - **http://mvapich.cse.ohio-state.edu**

Partner in the upcoming TACC Frontera System

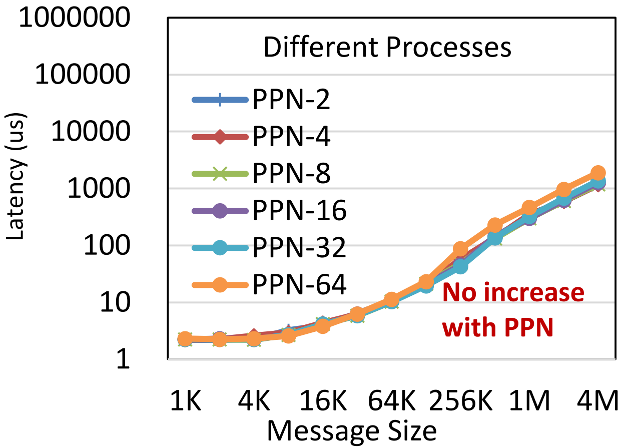
AGENDA

- Multiple directions being worked out by the MVAPICH2 project

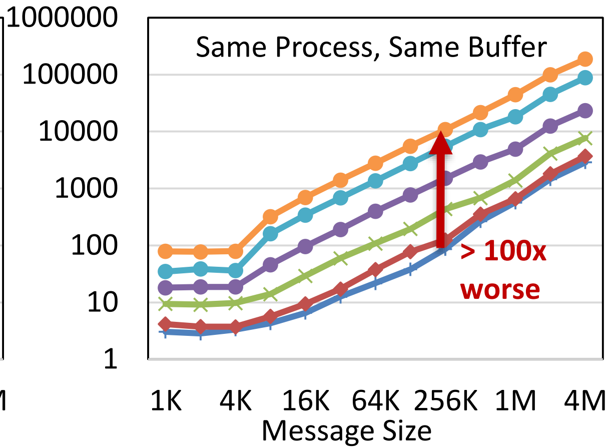
1. Contention-aware, kernel-assisted designs for large-message intra-node collectives (CMA collectives)
2. Integrated collective designs with SHARP
3. Designs for scalable reduction operations for GPUs
4. Shared-address space (XPMEM)-based scalable collectives

- Solutions have been integrated into the MVAPICH2 libraries and publicly available

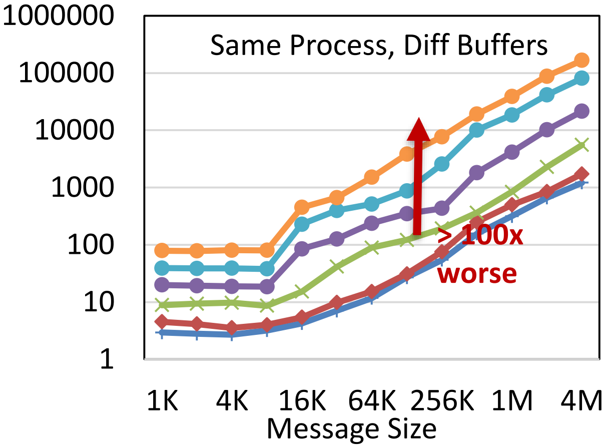
IMPACT OF COLLECTIVE COMMUNICATION PATTERN ON CMA COLLECTIVES



No increase with PPN



> 100x worse

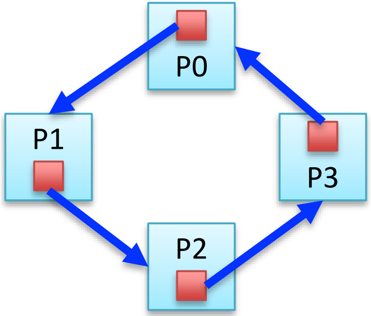


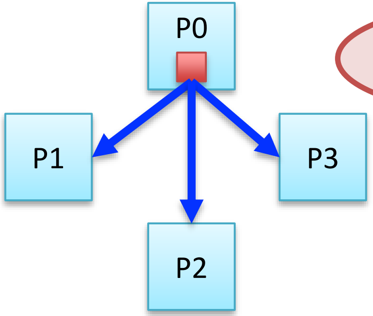
> 100x worse

All-to-All – Good Scalability

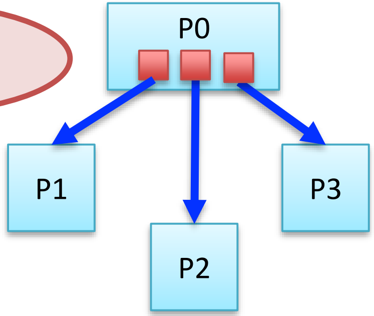
One-to-All - Poor Scalability

One-to-All – Poor Scalability

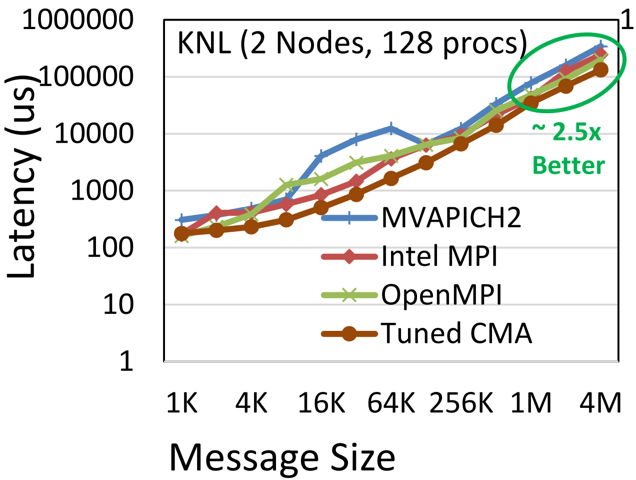


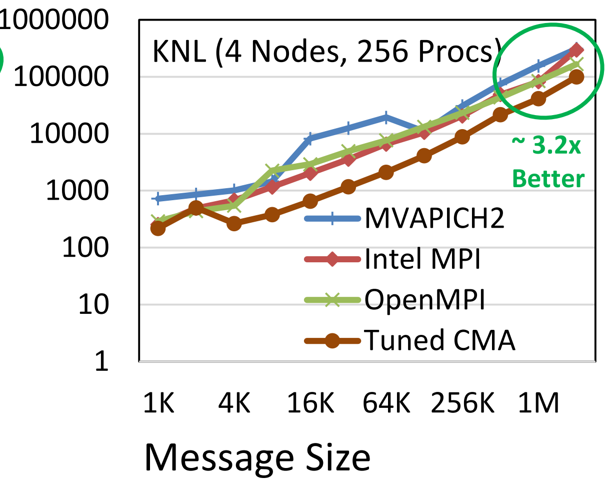


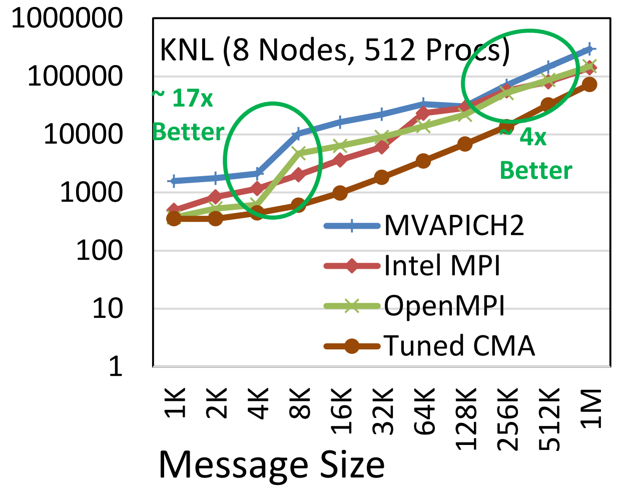
Contention is at Process level



MULTI-NODE SCALABILITY USING TWO-LEVEL ALGORITHMS





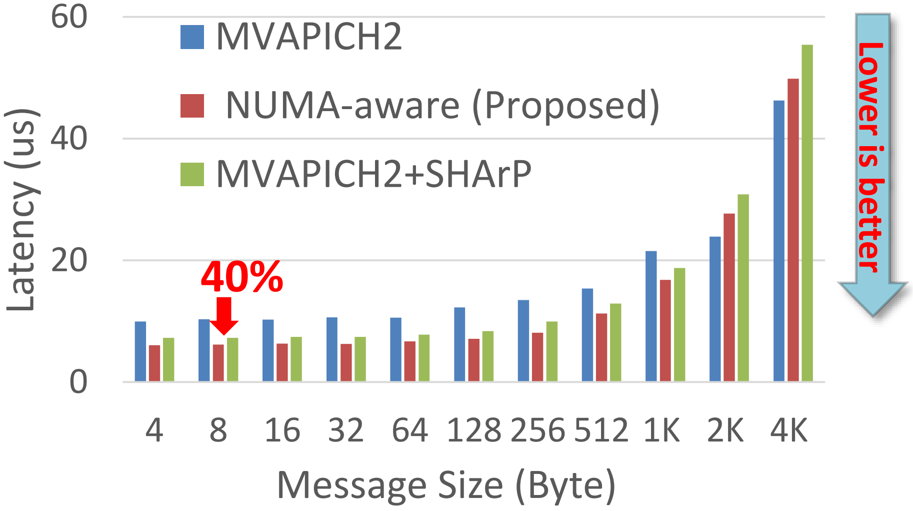


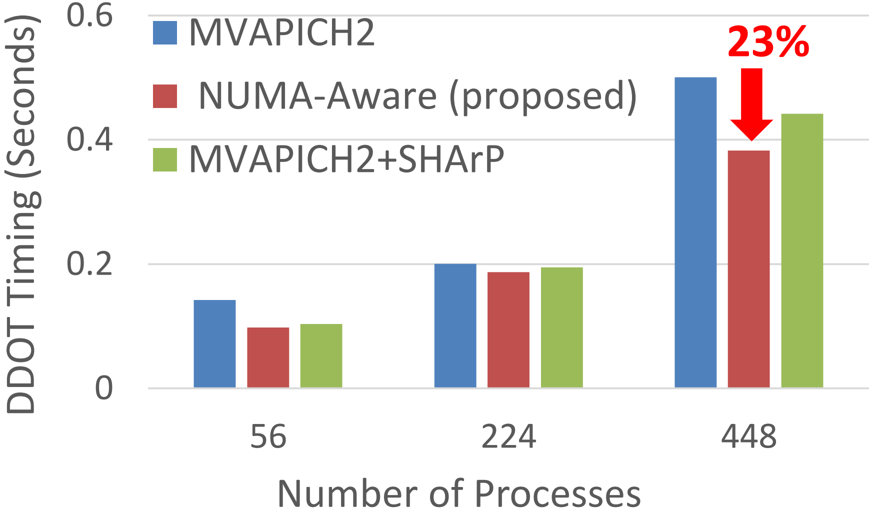
- Significantly faster intra-node communication
- New two-level collective designs can be composed
- 4x-17x improvement in 8 node Scatter and Gather compared to default MVAPICH2

S. Chakraborty, H. Subramoni, and D. K. Panda, Contention Aware Kernel-Assisted MPI Collectives for Multi/Many-core Systems, *IEEE Cluster '17*, ***BEST Paper Finalist***

Available since MVAPICH2-X 2.3b

PERFORMANCE OF NUMA-AWARE SHARP DESIGN ON XEON + IB CLUSTER





OSU Micro Benchmark (16 Nodes, 28 PPN)

HPCG (16 nodes, 28 PPN)

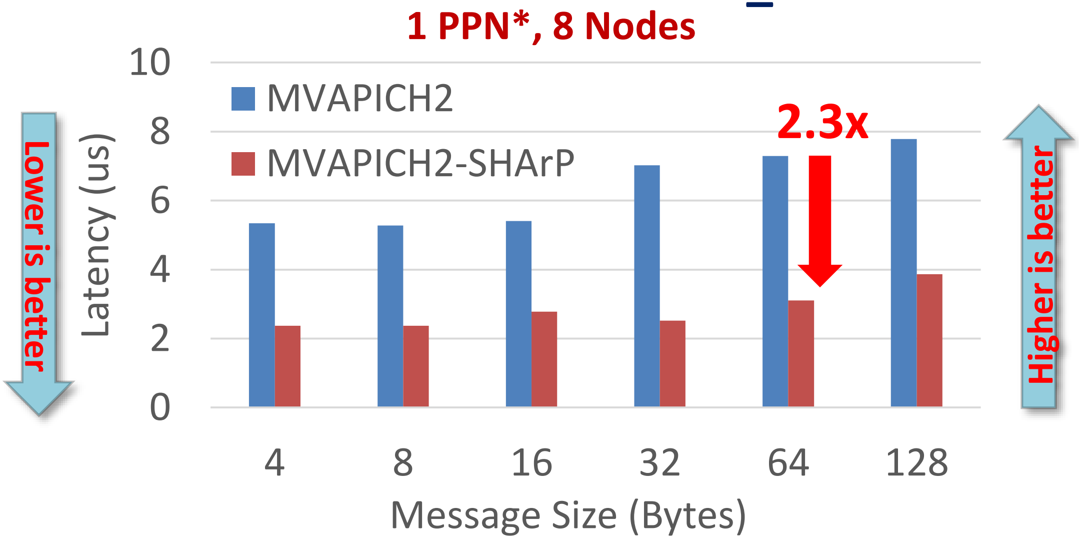
- As the message size decreases, the benefits of using Socket-based design increases
- NUMA-aware design can reduce the latency by up to 23% for DDOT phase of HPCG

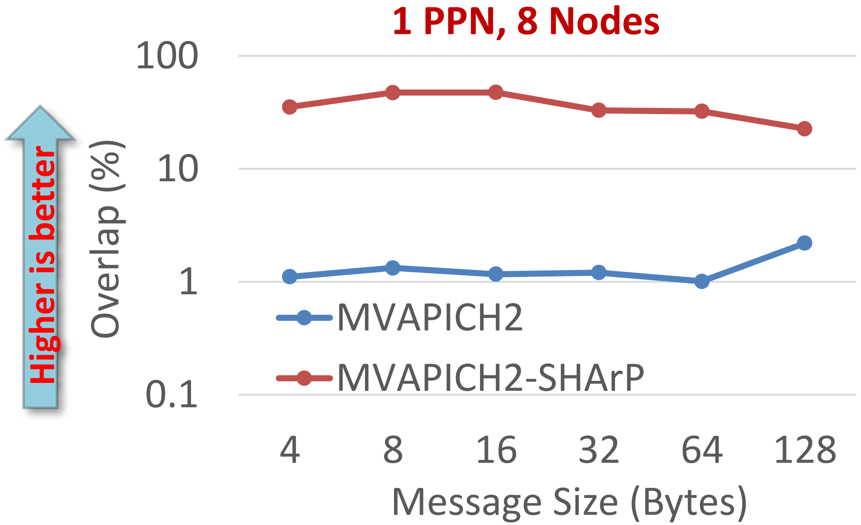
M. Bayatpour, S. Chakraborty, H. Subramoni, X. Lu, and D. K. Panda, Scalable Reduction Collectives with Data Partitioning-based Multi-Leader Design, SuperComputing '17.

Available since MVAPICH2-X 2.3b

SHARP BASED NON-BLOCKING ALLREDUCE IN MVAPICH2

MPI_Iallreduce Benchmark





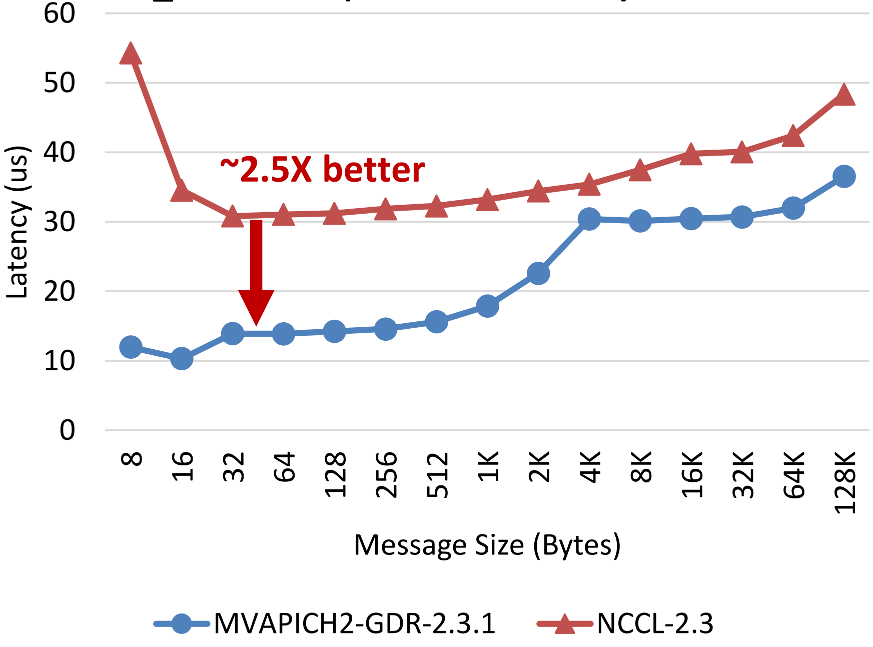
- Complete offload of Allreduce collective operation to "*Switch*"
    - Higher overlap of communication and computation

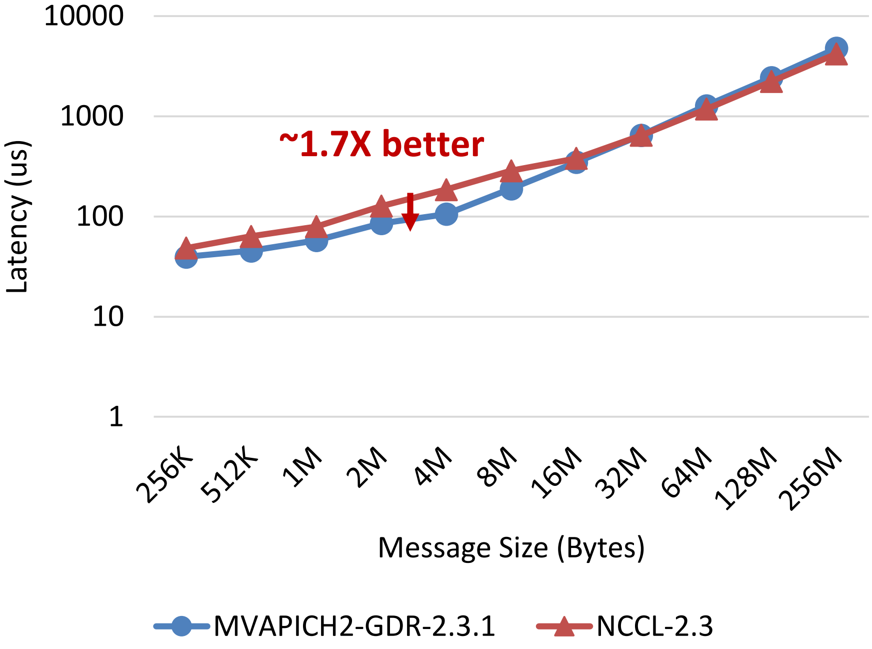
**PPN: Processes Per Node*

Available since MVAPICH2 2.3a

MVAPICH2-GDR VS. NCCL2 – ALLREDUCE ON DGX-2 (PRELIMINARY RESULTS)

- Optimized designs in upcoming MVAPICH2-GDR offer better/comparable performance for most cases
- MPI_Allreduce (MVAPICH2-GDR) vs. ncclAllreduce (NCCL2) on 1 DGX-2 node (16 Volta GPUs)

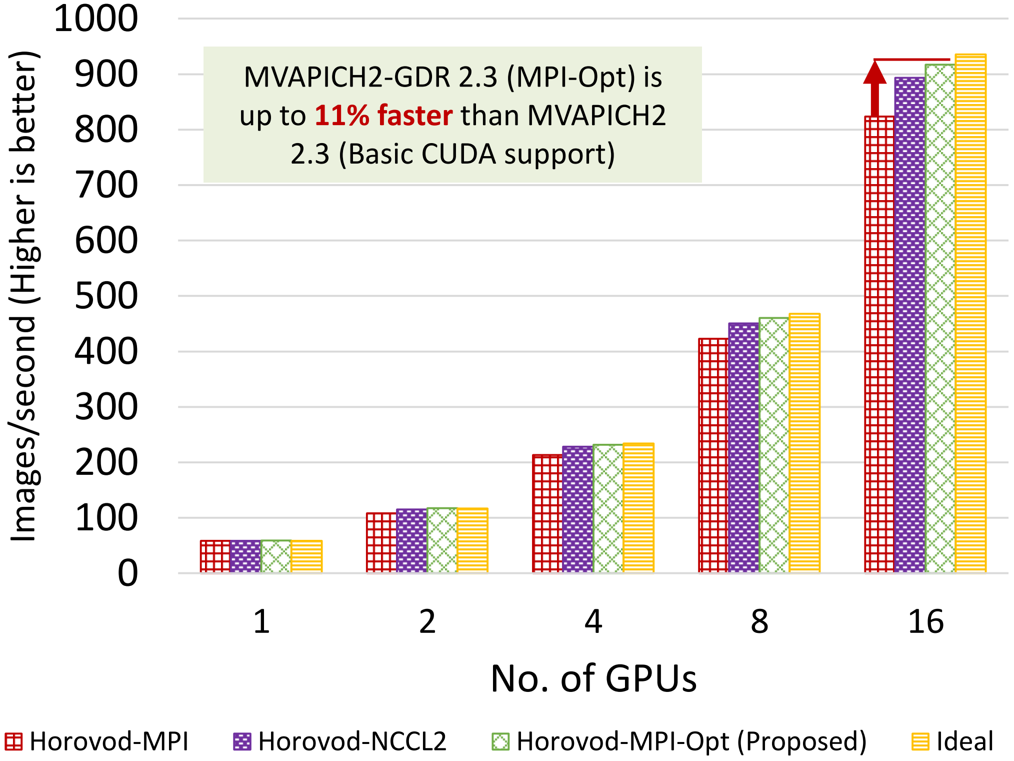




Platform: Nvidia DGX-2 system (16 Nvidia Volta GPUs connected with NVSwitch), CUDA 9.2

EXPLOITING CUDA-AWARE MPI FOR TENSORFLOW (HOROVOD)

- MVAPICH2-GDR offers excellent performance via advanced designs for MPI_Allreduce.
- Up to 11% better performance on the RI2 cluster (16 GPUs)
- Near-ideal – 98% scaling efficiency

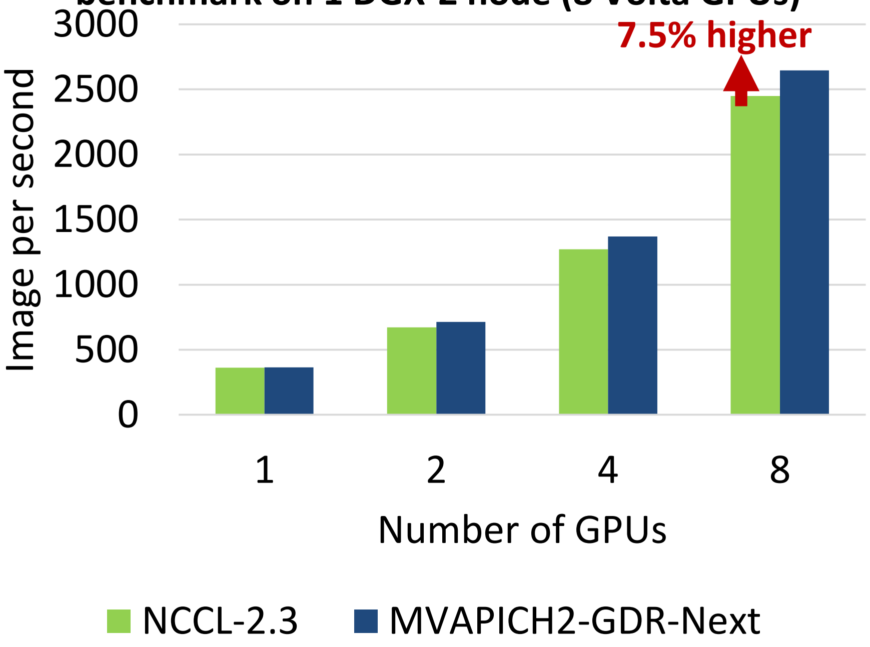


MVAPICH2-GDR 2.3 (MPI-Opt) is up to **11% faster** than MVAPICH2 2.3 (Basic CUDA support)

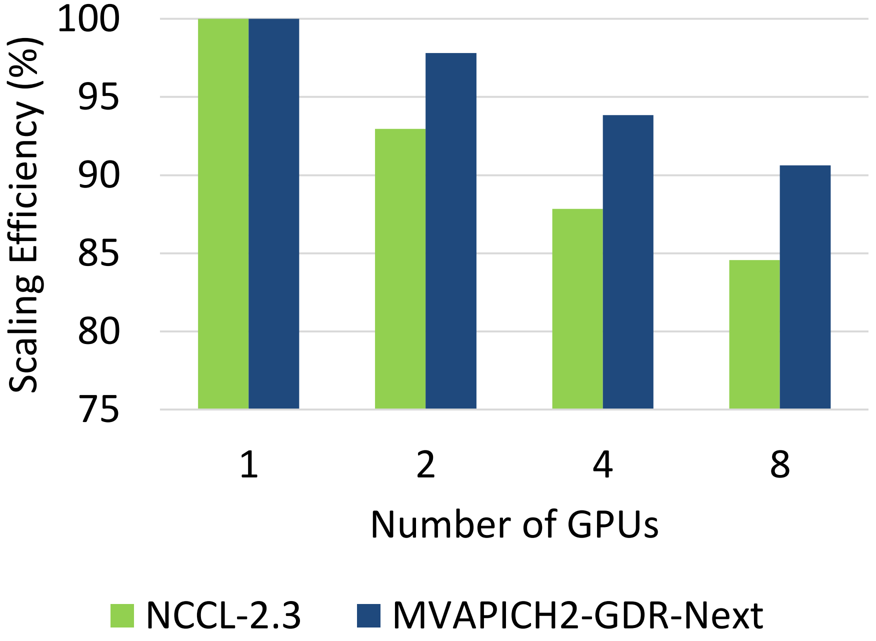
A. A. Awan et al., "Scalable Distributed DNN Training using TensorFlow and CUDA-Aware MPI: Characterization, Designs, and Performance Evaluation", Under Review, https://arxiv.org/abs/1810.11112

MVAPICH2-GDR VS. NCCL2 – RESNET-50 TRAINING

- **ResNet-50 Training using TensorFlow benchmark on 1 DGX-2 node (8 Volta GPUs)**



$$\text{Scaling Efficiency} = \frac{\text{Actual throughput}}{\text{Ideal throughput at scale}} \times 100\%$$



Platform: Nvidia DGX-2 system (16 Nvidia Volta GPUs connected with NVSwitch), CUDA 9.2

SHARED ADDRESS SPACE (XPMEM-BASED) COLLECTIVES

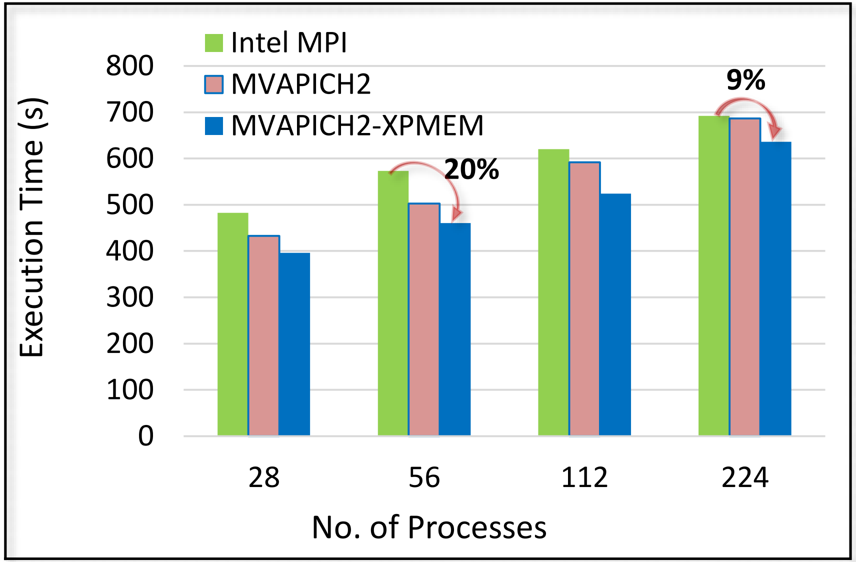
- **Offload Reduction computation and communication to peer MPI ranks**
  - Every Peer has direct "load/store" access to other peer's buffers
  - Multiple pseudo roots independently carry-out reductions for intra-and inter-node
  - Directly put reduced data into root's receive buffer
- ***True "Zero-copy"*** **design for Allreduce and Reduce**
  - No copies require during the entire duration of Reduction operation
  - Scalable to multiple nodes
- ***Zero contention*** **overheads as memory copies happen in "*user-space*"**

Available since MVAPICH2-X 2.3rc1

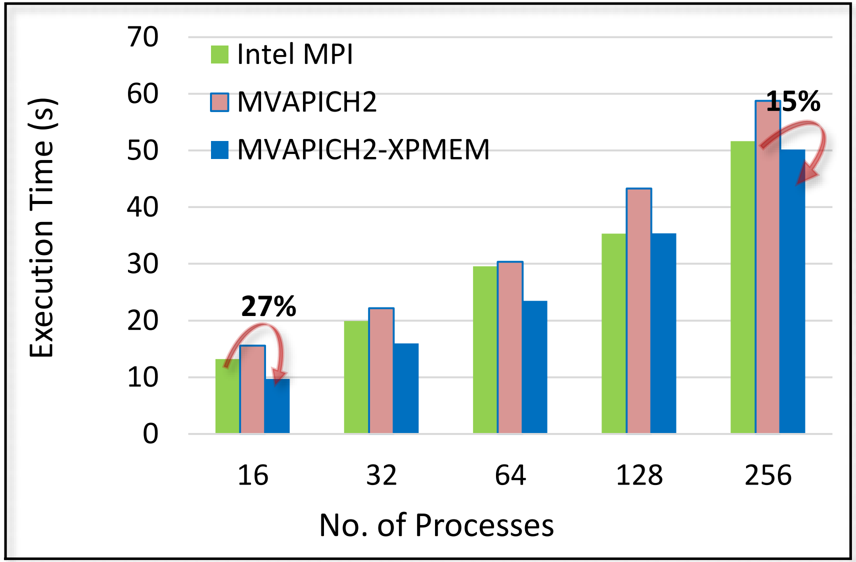
J. Hashmi, S. Chakraborty, M. Bayatpour, H. Subramoni, and D. Panda, Designing Efficient Shared Address Space Reduction Collectives for Multi-/Many-cores, International Parallel & Distributed Processing Symposium (IPDPS '18), May 2018.

APPLICATION-LEVEL BENEFITS OF XPMEM-BASED COLLECTIVES

CNTK AlexNet Training
(Broadwell, B.S=default, iteration=50, ppn=28)

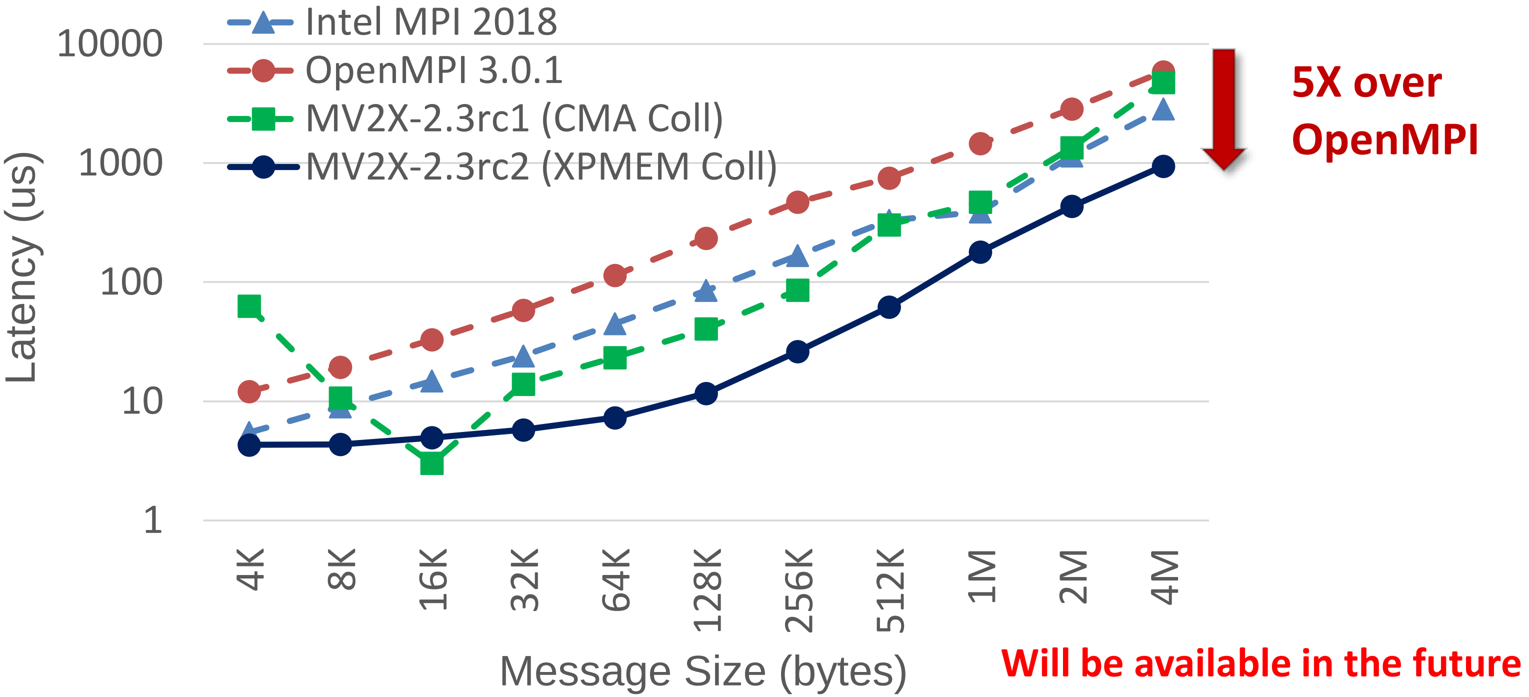


MiniAMR (Broadwell, ppn=16)



- Up to **20%** benefits over IMPI for CNTK DNN training using AllReduce
- Up to **27%** benefits over IMPI and up to **15%** improvement over MVAPICH2 for MiniAMR application kernel

BENEFITS OF XPMEM BASED MPI_BCAST

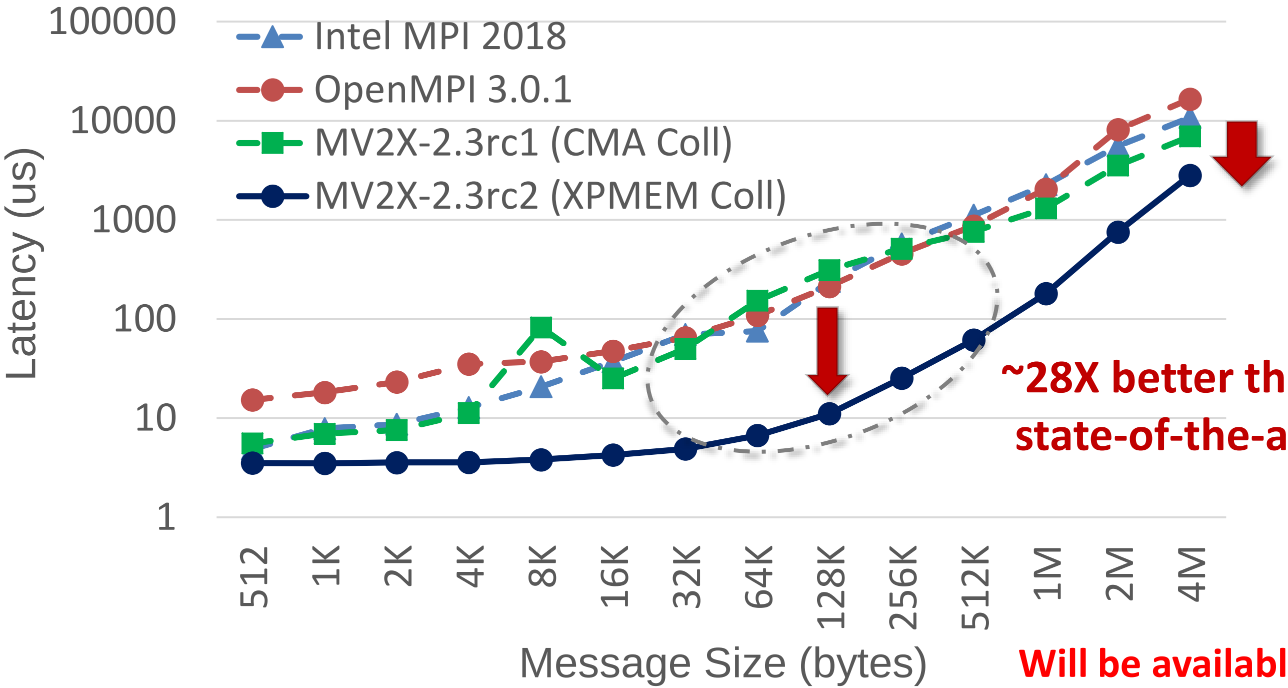


5X over OpenMPI

Will be available in the future

- **28 MPI Processes** on single dual-socket Broadwell E5-2680v4, 2x14 core processor

BENEFITS OF XPMEM BASED MPI_SCATTER

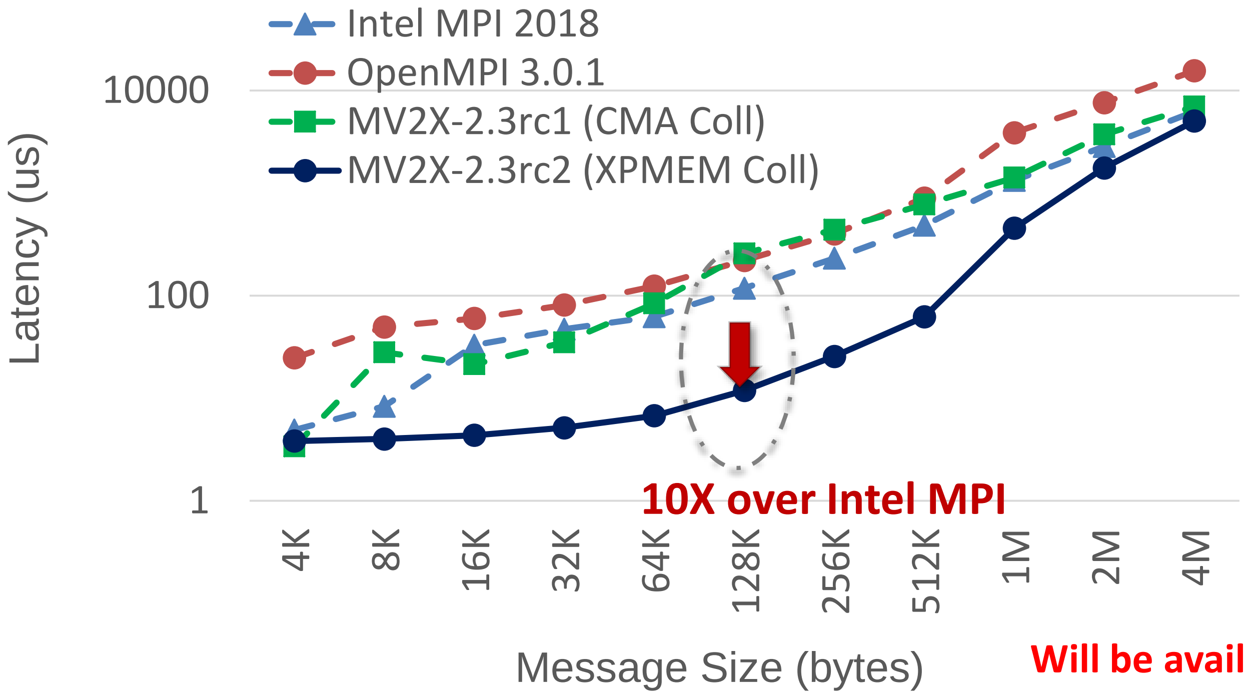


~28X better than state-of-the-art

Will be available in the future

- High cache-locality and **contention-free access** compared to CMA

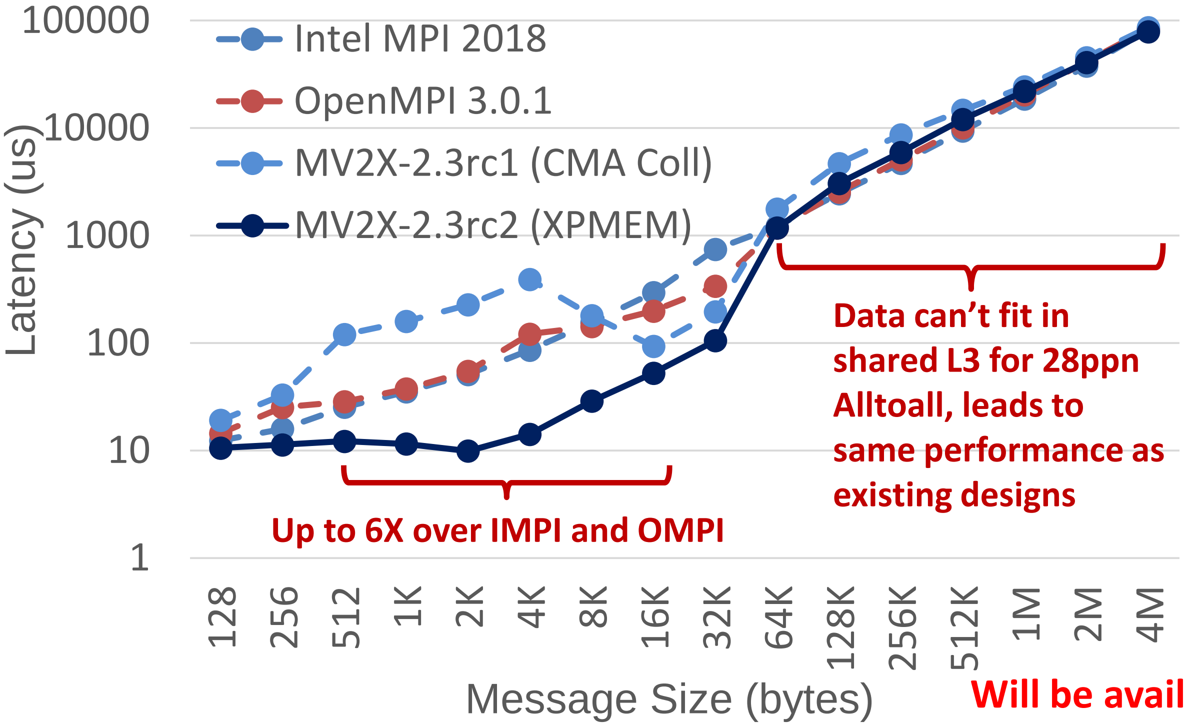
BENEFITS OF XPMEM BASED MPI_GATHER



Will be available in the future

- High cache-locality for medium messages and contention-free access

BENEFITS OF XPMEM BASED MPI_ALLTOALL



Up to 6X over IMPI and OMPI

Data can’t fit in shared L3 for 28ppn Alltoall, leads to same performance as existing designs

Will be available in the future

- **28 MPI Processes** on single dual-socket Broadwell E5-2680v4, 2x14 core processor

CONCLUDING REMARKS

- Many-core nodes will be the foundation blocks for emerging Exascale systems
- Communication mechanisms and runtimes need to be re-designed to take advantage of the high concurrency offered by manycores
- Presented a set of novel designs for collective communication primitives in MPI that address several challenges for modern clusters
- Demonstrated the performance benefits of our proposed designs under a variety of multi-/many-cores and high-speed networks and a range of HPC and DL applications
- These designs are already available in MVAPICH2 libraries

THANK YOU!

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Network Based Computing Laboratory

Network-Based Computing Laboratory
http://nowlab.cse.ohio-state.edu/

MVAPICH
MPI, PGAS and Hybrid MPI+PGAS Library

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

HiDL
High-Performance Deep Learning

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