MPI Alltoall Personalized Exchange on GPGPU Clusters: Design Alternatives and Benefits

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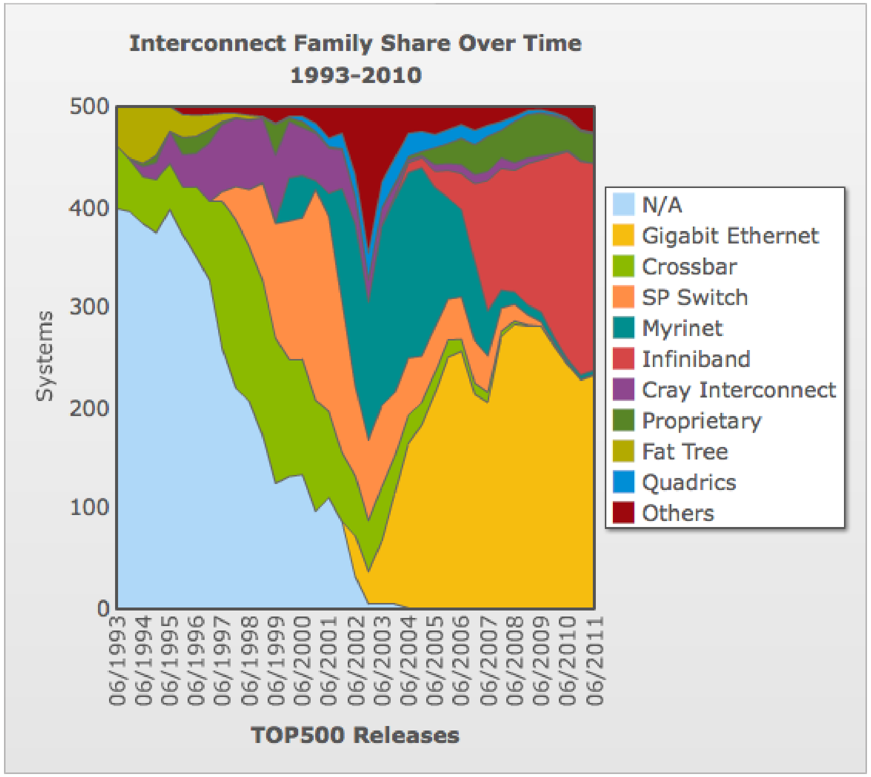
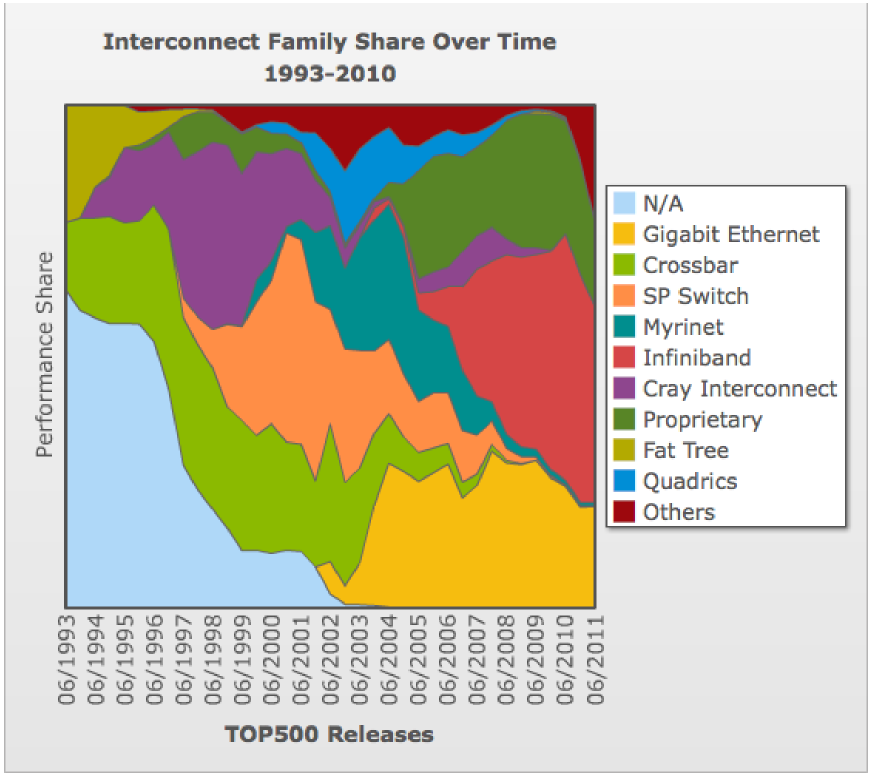
Outline

- Introduction
- Problem Statement
- Design Considerations
- Our Solution
- Performance Evaluation
- Conclusion and Future Work

InfiniBand Clusters in TOP500



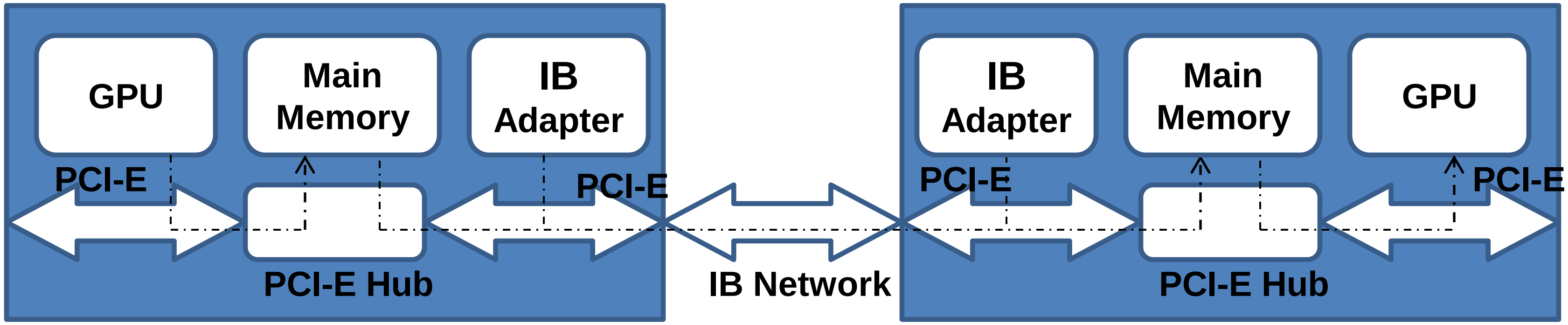


- Percentage share of InfiniBand is steadily increasing
- 41% of systems in TOP500 using InfiniBand (June ’11)
- 61% of systems in TOP100 using InfiniBand (June ‘11)

GPGPUs and Infiniband

- GPGPUs are becoming an integral part of high performance system architectures
- 3 of the 5 fastest supercomputers in the world use GPGPUs with Infiniband
  - TOP500 list features Tianhe-1A at #2, Nebulae at # 4 and Tsubame at # 5.
- Programming:
  - CUDA or OpenCL on GPGPUs
  - MPI on the whole system
- Manage memory issue
  - Prof. Van de Geijn just mentioned memory management is an issue, and the data granularity is important

Data Movement in GPU Clusters



- Data movement in InfiniBand clusters with GPUs
  - **CUDA: Device memory → Main memory [at source process]**
  - **MPI: Source rank → Destination process**
  - **CUDA: Main memory → Device memory [at destination process]**

MVAPICH/MVAPICH2 Software

- High Performance MPI Library for IB and HSE
  - MVAPICH (MPI-1) and MVAPICH2 (MPI-2.2)
  - Used by more than 1,710 organizations in 63 countries
  - More than 78,000 downloads from OSU site directly
  - Empowering many TOP500 clusters
    - 5th ranked 73,278-core cluster (Tsubame 2.0) at Tokyo Institute of Technology
    - 7th ranked 111,104-core cluster (Pleiades) at NASA
    - 17th ranked 62,976-core cluster (Ranger) at TACC
  - Available with software stacks of many IB, HSE and server vendors including Open Fabrics Enterprise Distribution (OFED) and Linux Distros (RedHat and SuSE)
  - http://mvapich.cse.ohio-state.edu

MVAPICH2-GPU: GPU-GPU using MPI

- Is it possible to optimize GPU-GPU communication with MPI?
  - *H. Wang, S. Potluri, M. Luo, A. K. Singh, S. Sur, D. K. Panda, "MVAPICH2-GPU: Optimized GPU to GPU Communication for InfiniBand Clusters", ISC'11, June, 2011*
  - Support GPU to remote GPU communication using MPI
  - P2P and One-sided were improved
  - Collectives can directly get benefits from p2p improvement
- How to handle non-contiguous data in GPU device memory?
  - *H. Wang, S. Potluri, M. Luo, A. K. Singh, X. Ouyang, S. Sur, D. K. Panda, "Optimized Non-contiguous MPI Datatype Communication for GPU Clusters: Design, Implementation and Evaluation with MVAPICH2", Cluster'11, Sep., 2011 (Thursday, TP6-A,1:30 PM)*
  - Support GPU-GPU non-contiguous data communication (P2P) using MPI
  - Vector datatype and SHOC benchmark are optimized
- How to optimize collectives with different algorithms?
  - In this paper, MPI_Alltoall on GPGPUs cluster is optimized

MPI_Alltoall

- Many scientific applications spend much execution time in MPI_Alltoall:
  - P3DFFT, CPMD
- Heavy communication in MPI_Alltoall
  - O(N^2) communication for N processes
- Different MPI_Alltoall algorithms:
  - Related with message size, process number, etc.
- What will happen if the data is in GPU device memory?

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Problem Statement

- High start-up overheads in accessing small and medium data inside GPU device memory:
  - Start-up time: the time to move the data from GPU device memory to host main memory, and vice versa
- Hard to optimize GPU-GPU Alltoall communication at the application level:
  - CUDA and MPI expertise is required for efficient data movement
  - Existing Alltoall optimizations are implemented in MPI library
  - Optimizations are dependent on hardware characteristics, like latency

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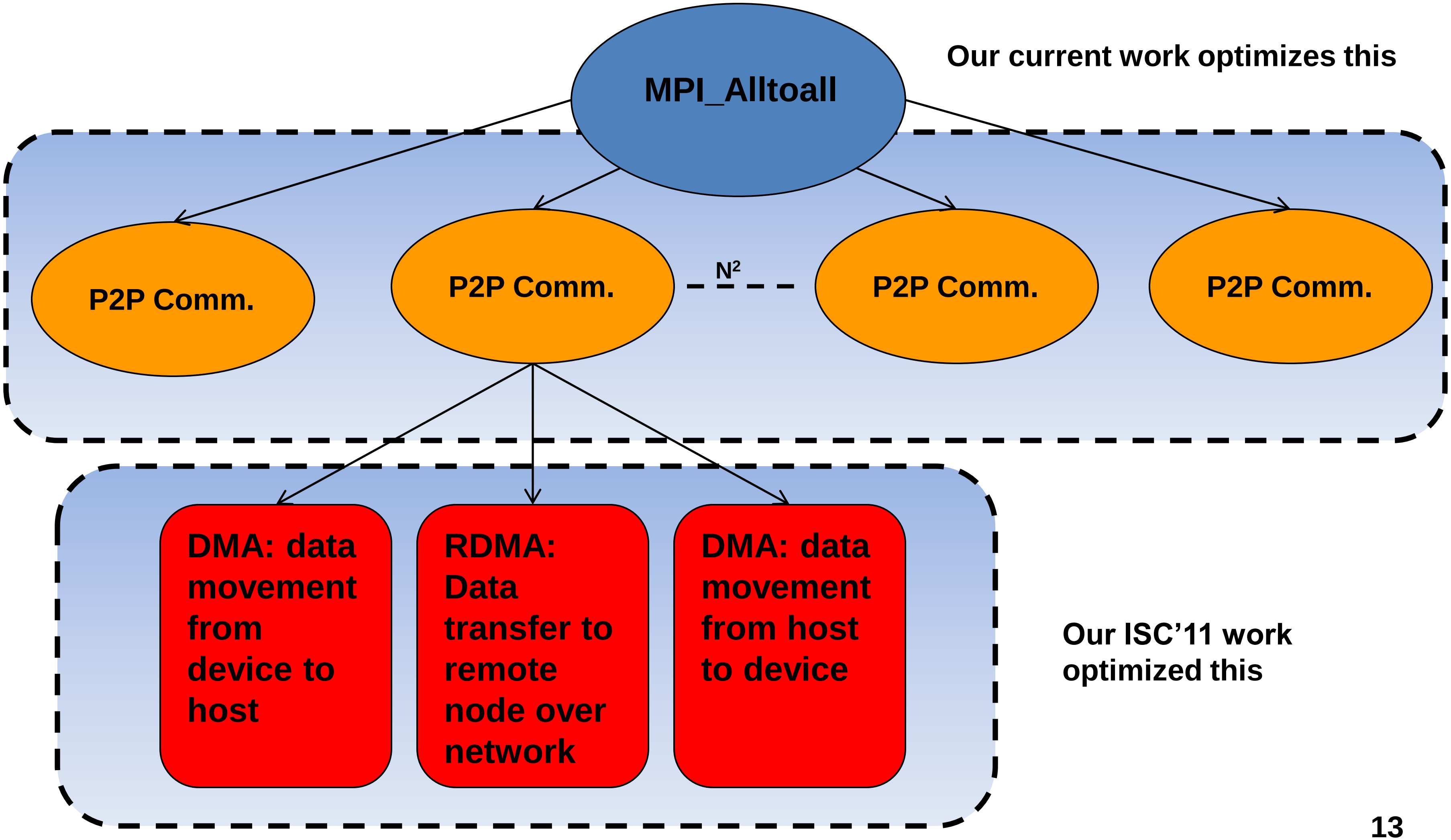
Alltoall Algorithms

- Hypercube algorithm (Bruck's) proposed by Bruck et. al, for small messages
  - requires (logN) steps, for N processes
  - additional data movement in the local memroy
- Scattered destination (SD) algorithm for medium messages
  - a linear implementation of Alltoall personalized exchange operation
  - uses non-blocking send/recv to overlap data transfer on network
- Pair-wise exchange (PE) algorithm for large messages
  - network contention (SD) becomes the bottleneck, switch to PE
  - uses blocking send/recv; in any step, a process communicates with only one source and one destination

Design Considerations


MPI_Alltoall
P2P Comm.
P2P Comm.
N^2
P2P Comm.
P2P Comm.
DMA: data movement from device to host
RDMA: Data transfer to remote node over network
DMA: data movement from host to device

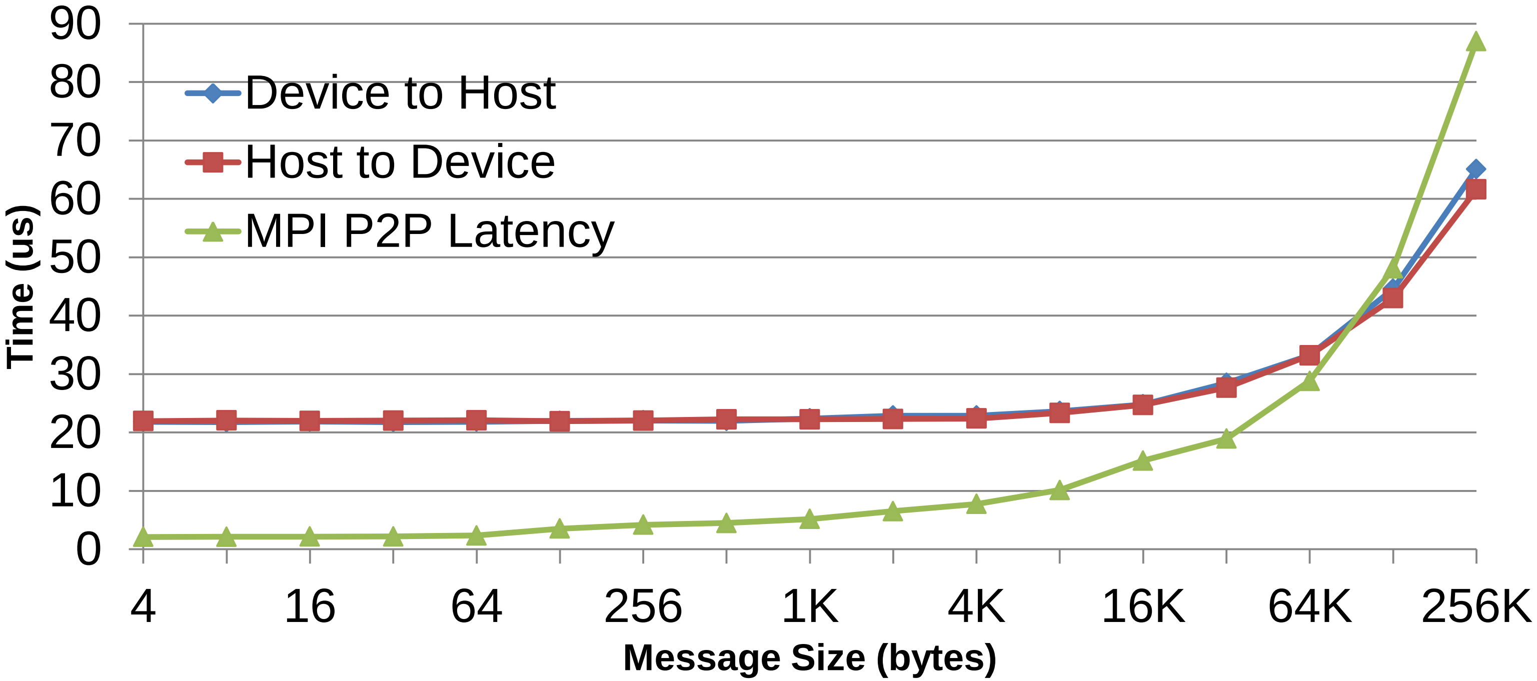
Our current work optimizes this

Our ISC’11 work optimized this

Design Considerations

- Message size
  - not enough to consider data movement in local memory (Bruck’s)
  - Start-up overhead must be considered
- Network transfer
  - not enough to overlap different p2p transfer on networks (SD)
  - data movement between device and host (DMA) can be overlapped with data transfer (RDMA) in each peer on networks
- Network contention
  - blocking send/recv (in PE) will harm the overlapping (DMA and RDMA)
  - possible to overlap DMA and RDMA on multiple channels until the network contention dominates the performance again

Start-up Overhead



- Data movement cost (GPU and host) remains constant until a threshold
  - 16 KB is the threshold in our cluster
  - compared with MPI p2p latency, start-up cost dominates GPU-GPU performance at small and medium datasize

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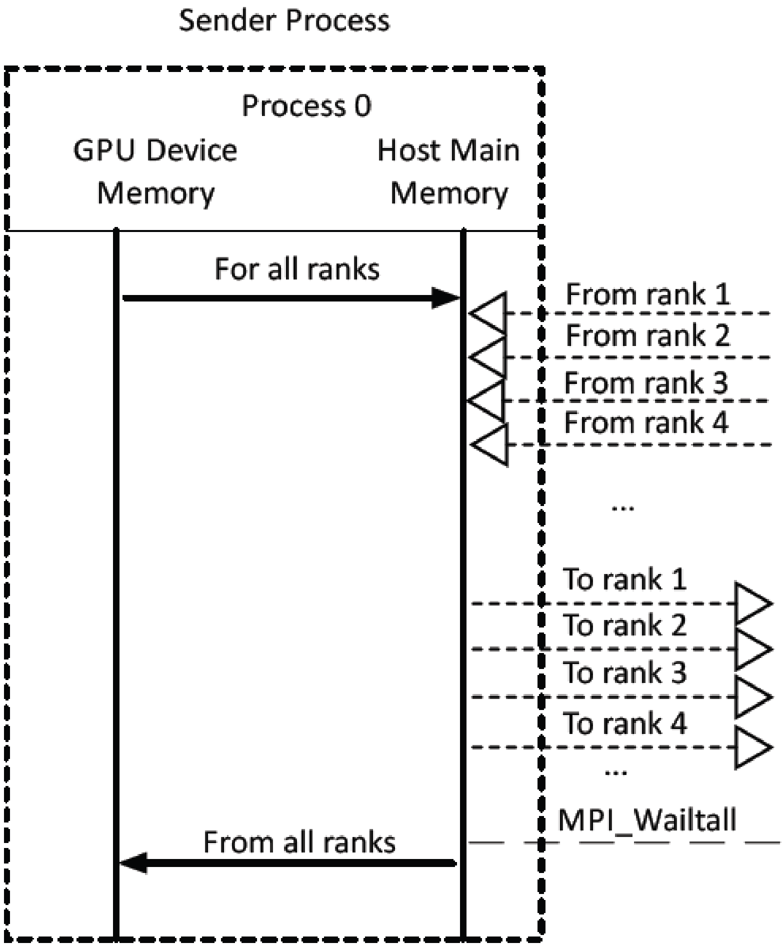
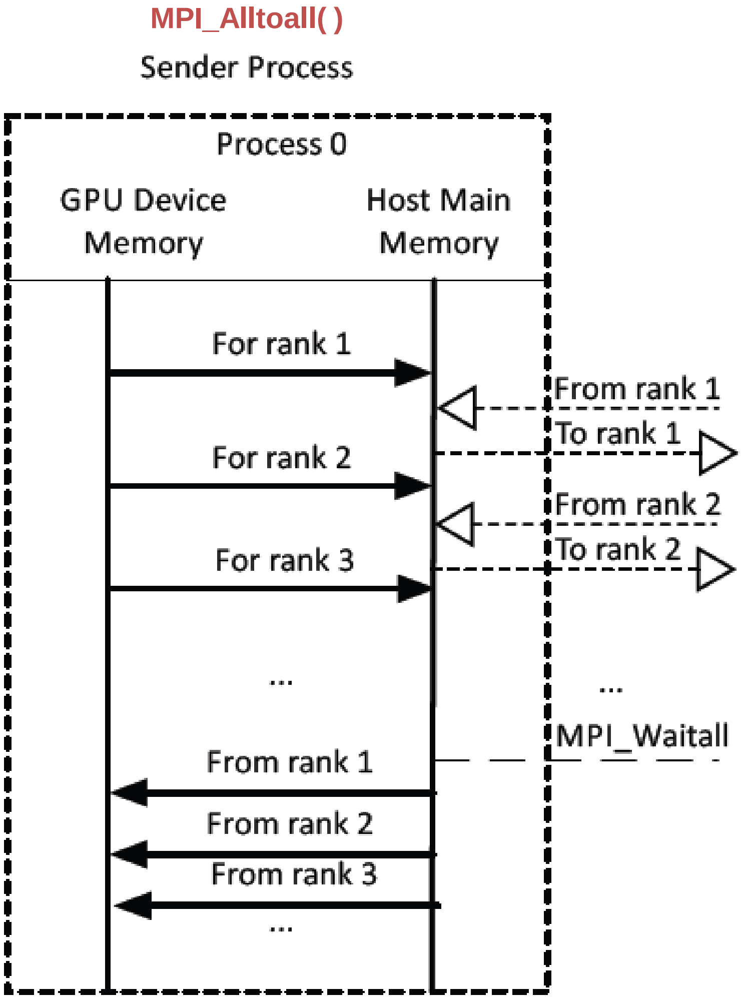
No MPI Level Optimization

cudaMemcpy( ) + MPI_Alltoall( ) + cudaMemcpy( )



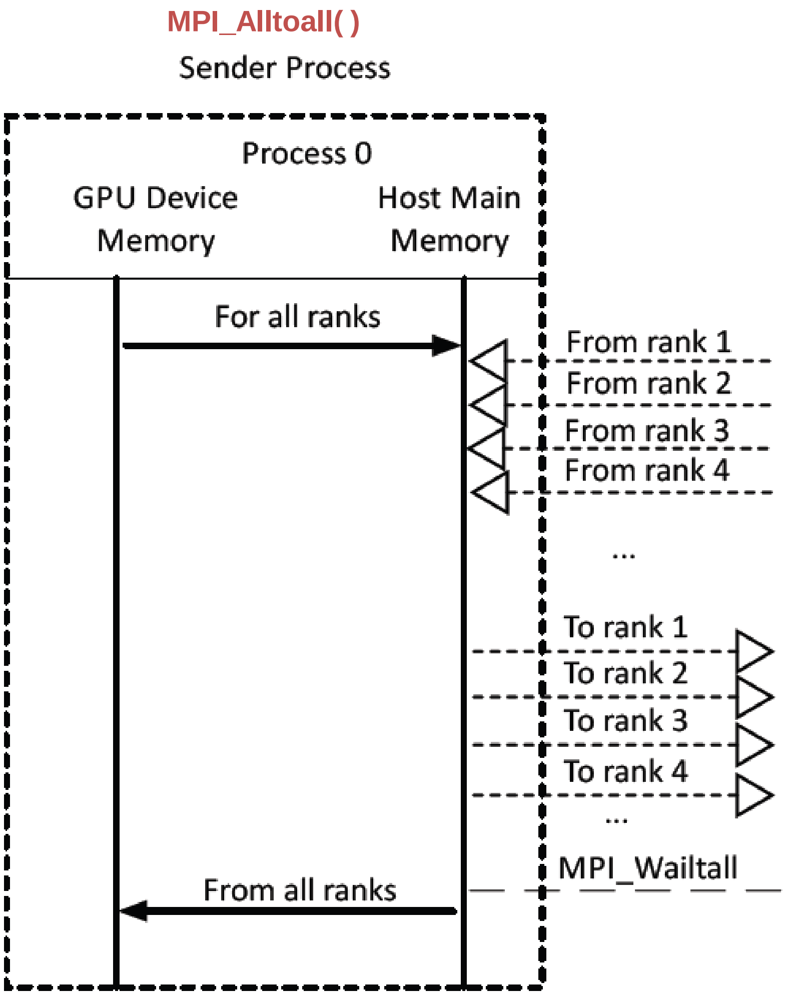
- No MPI level optimization:
  - can be implemented at user level
  - doesn’t requires any changes in MPI library
- Reduce programming productivity:
  - adds extra burden on programmer to manage data movement and corresponding buffers
  - hard to overlap DMA and RDMA to hide memory transfer latency since MPI_Alltoall() is blocking

Point-to-Point Based



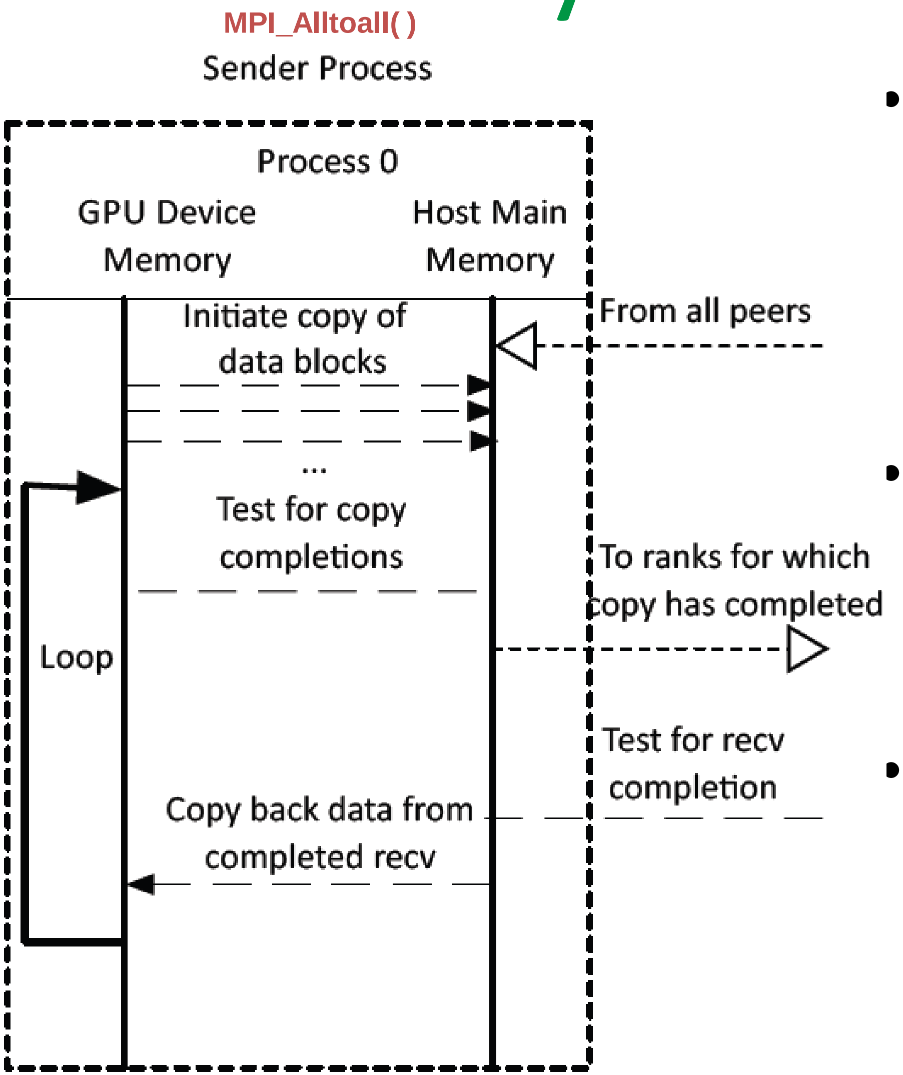
- Basic way to enable collectives for GPU memory
  - for each p2p channel, moves the data between device and host, and uses send/recv interfaces
  - handle GPU-to-GPU transfer with Send/Recv interfaces
- High start-up overhead to move data between device and host (for small and medium data)

Static Staging



- Reduce the number of DMA operations:
  - merge all ranks’ data to one package, and move between device and host
- Compared with no MPI level method, only MPI_Alltoall needed
  - similar performance
  - better programming productivity
- Problem:
  - aggressively merge all ranks’ data into one large package maybe increase the latency

Dynamic Staging


MPI_Alltoall( )
Sender Process
Process 0
GPU Device Memory
Host Main Memory
Initiate copy of data blocks
From all peers
...
Test for copy completions
To ranks for which copy has completed
Loop
Test for recv completion
Copy back data from completed recv

- Group data
  - group data based on a threshold
  - use non-blocking function to move data between device and host
- Pipeline
  - overlap DMA data movement between host and device and RDMA transfer on network
- Hard to implement at user level
  - MPI_Alltoall is a blocking function
  - hardware latency dependent

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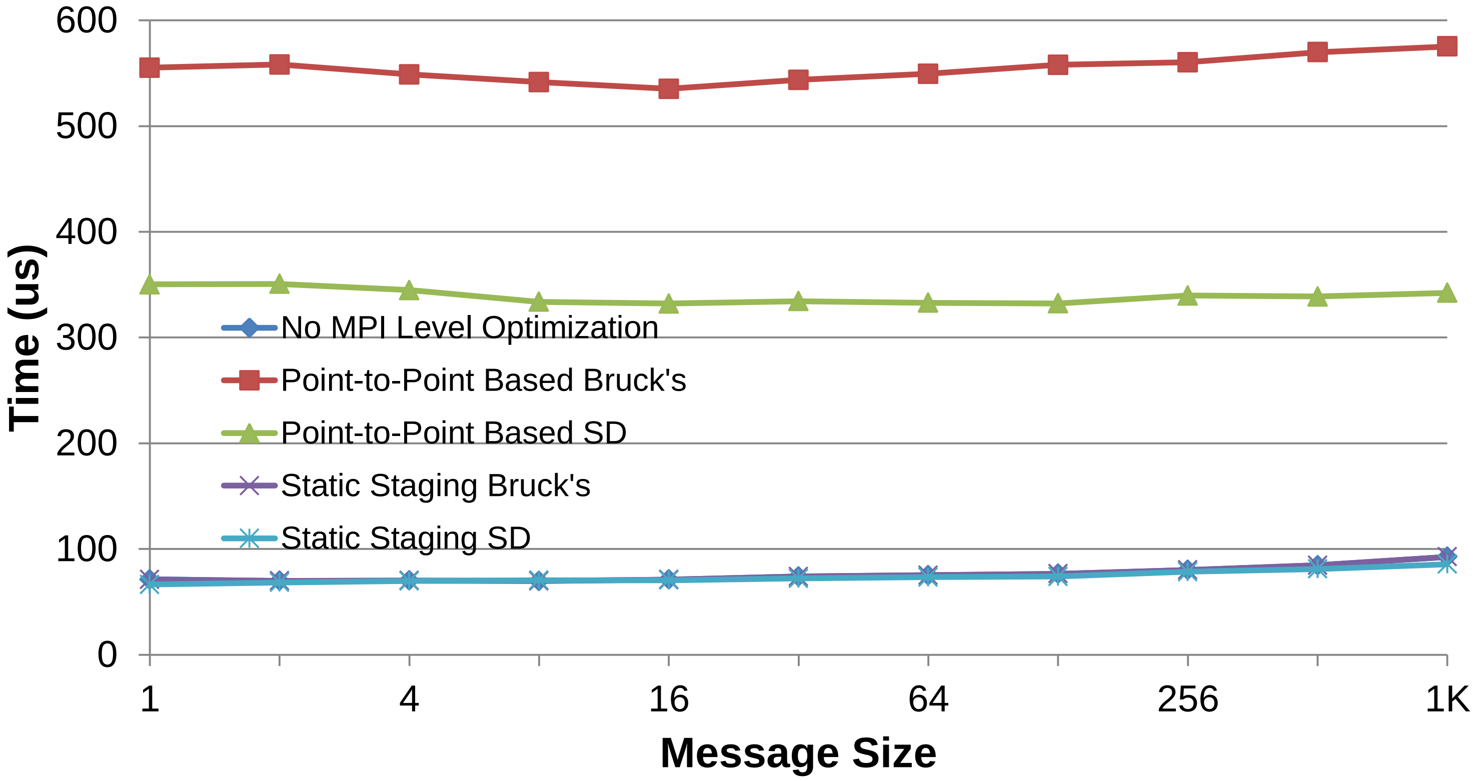
Performance Evaluation

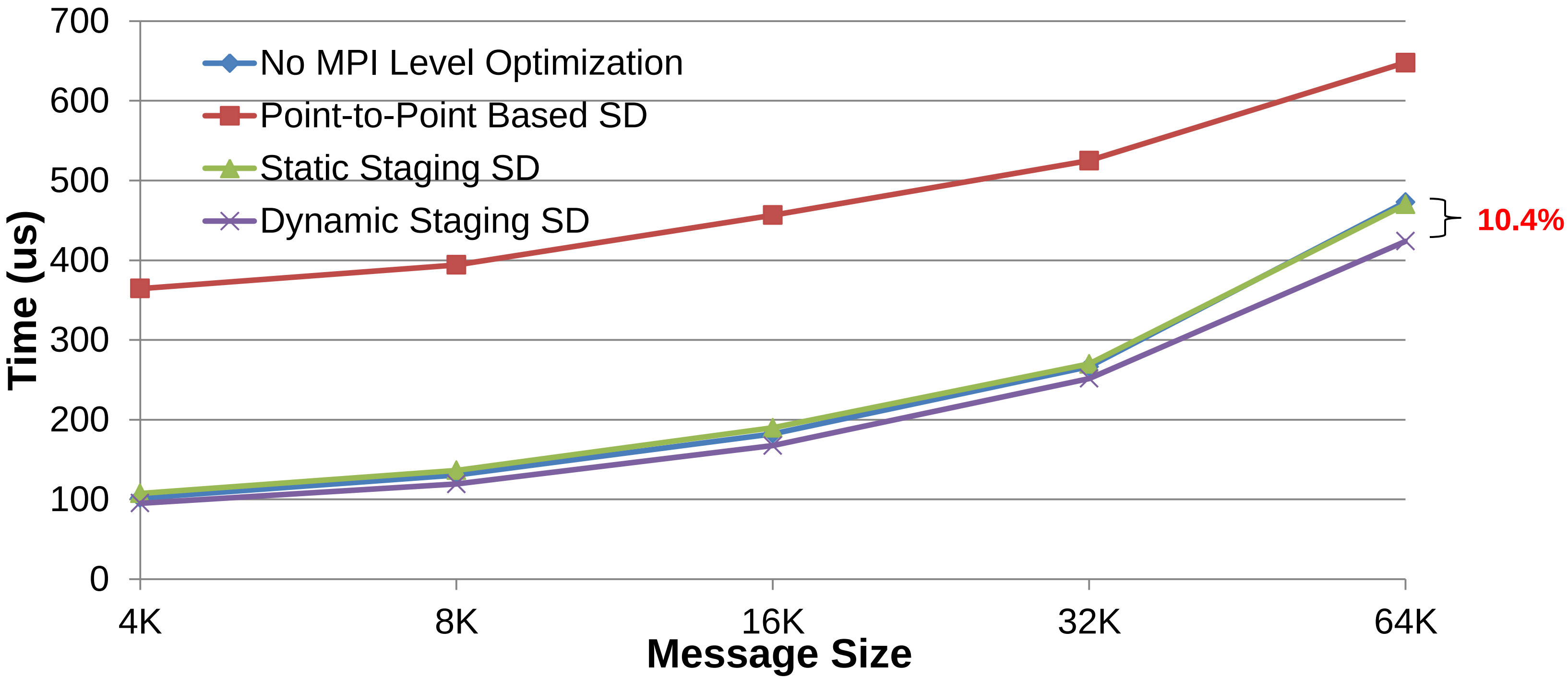
- Experimental environment
  - NVIDIA Tesla C2050
  - Mellanox QDR InfiniBand HCA MT26428
  - Intel Westmere processor with 12 GB main memory
  - MVAPICH2 1.6, CUDA Toolkit 4.0
- OSU Micro-Benchmarks
  - The source and destination addresses are in GPU device memory
- Run one process per node with one GPU card (8 nodes)

Alltoall Latency Performance (small)



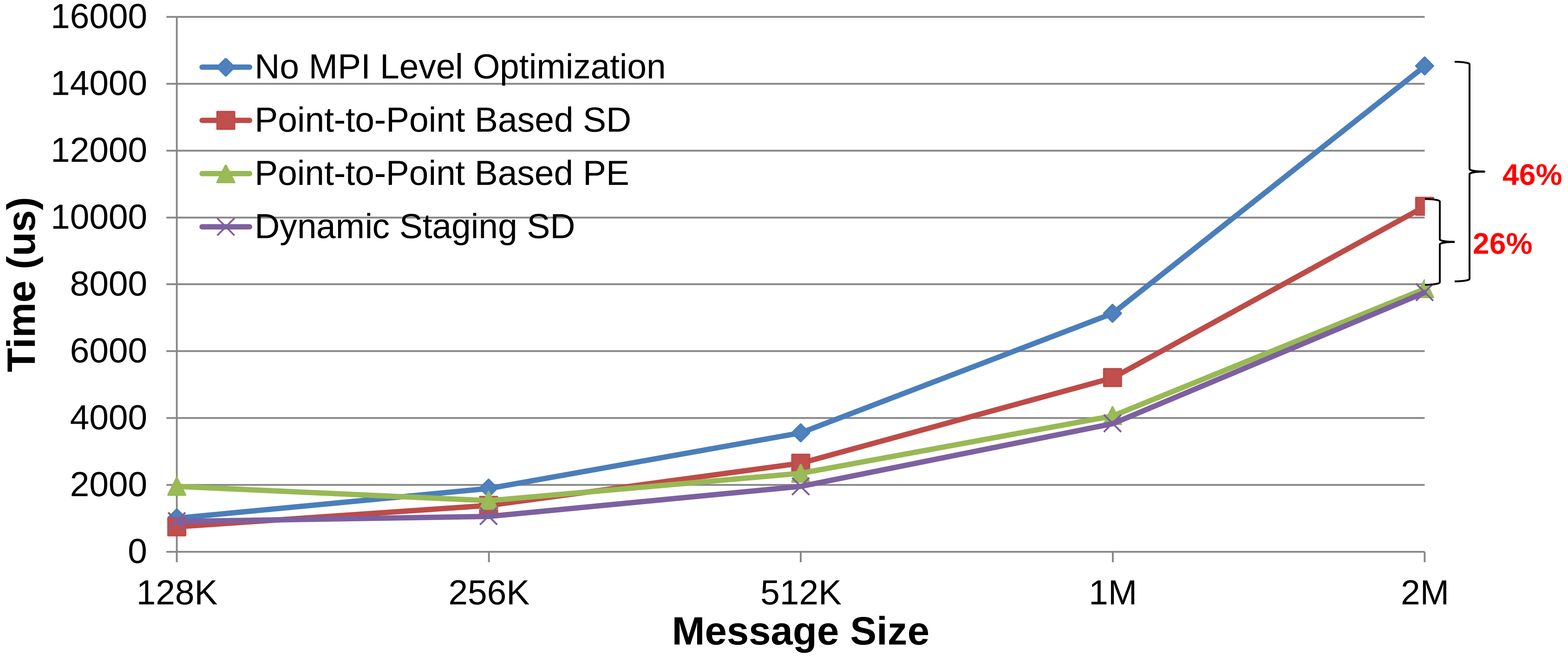
- High start-up overhead in P2P Based algorithms
- Static Staging method can overcome high start-up overhead
  - performs only slightly better than No MPI Level implementation
- We didn’t group small data size to enable pipeline between DMA and RDMA

Alltoall Latency Performance (medium)



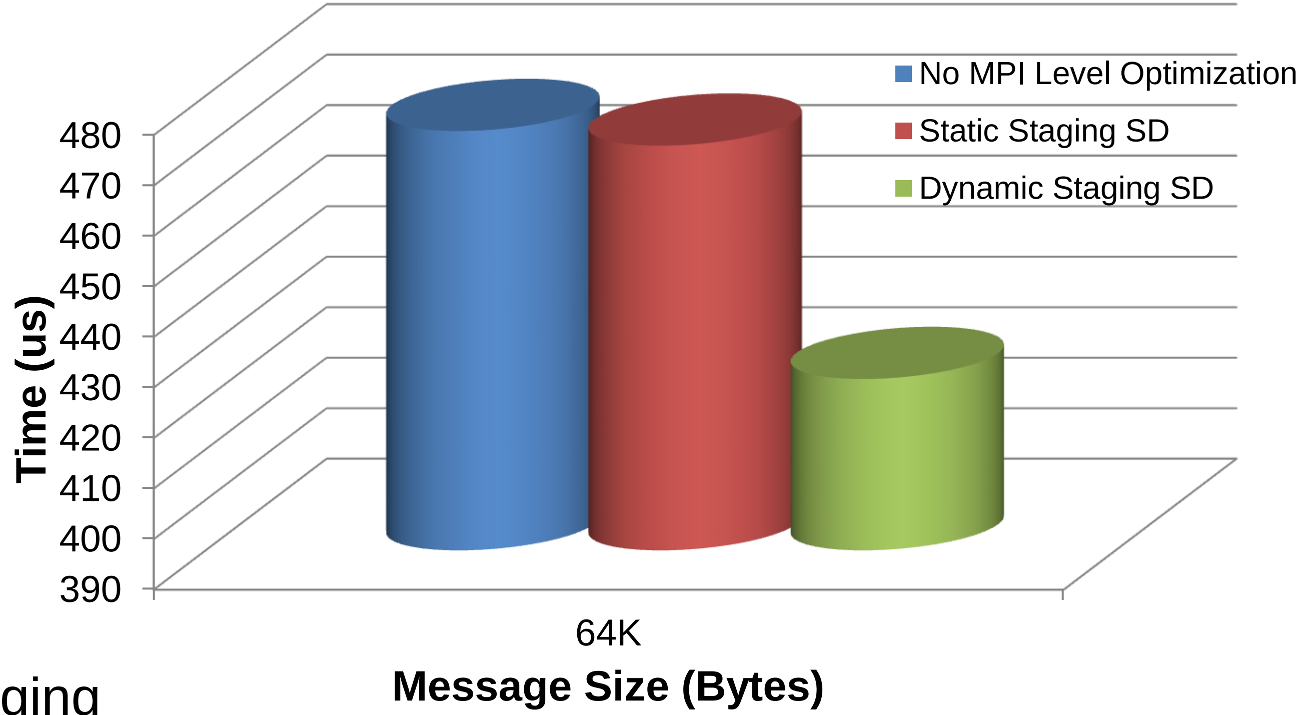
- P2P Based SD lost performance because of multiple times data movement between device and host
- Without pipeline design, No MPI Level Optimization method can’t hide DMA data movement latency with RDMA data transfer
- *Up to 10.4% improvement from Dynamic Staging SD over No MPI Level Optimization method*

Alltoall Latency Performance (large)



- P2P Based
  - Pipeline is enabled for each P2P channel (ISC'11); better than No MPI Level Optimization
- Dynamic Staging
  - not only overlap DMA and RDMA for each channel, but also for different channels
  - *up to 46% improvement for Dynamic Staging SD over No MPI Level Optimization*
  - *up to 26% improvement for Dynamic Staging SD over P2P Based method SD*

Staging Benefit



- Static staging
  - Move data for all ranks in one package can’t get better performance beyond a threshold
- Dynamic Staging
  - group data for in a threshold size package (128KB)
  - overlap DMA and RDMA for all channels

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Conclusion and Future Work

- MPI_Alltoall optimizations on GPU clusters (MVAPICH2-GPU)
  - support GPU to GPU alltoall communication with MPI_Alltoall; improve the programming productivity
  - resolve high start-up overhead between device and host for small and medium datasize
  - improve alltoall performance through Dynamic Staging method
  - get up to 46% latency improvement of Dynamic Staging compared with No MPI Level Optimization method

- Future work
  - integrate this design into MVAPICH2 future releases
  - improve applications' performance (3DFFT and CPMD)
  - investigate other collectives performance with MVAPICH2-GPU

Thank You!

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

MVAPICH Web Page

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