Network Offloaded Hierarchical Collectives Using ConnectX-2's CORE-Direct

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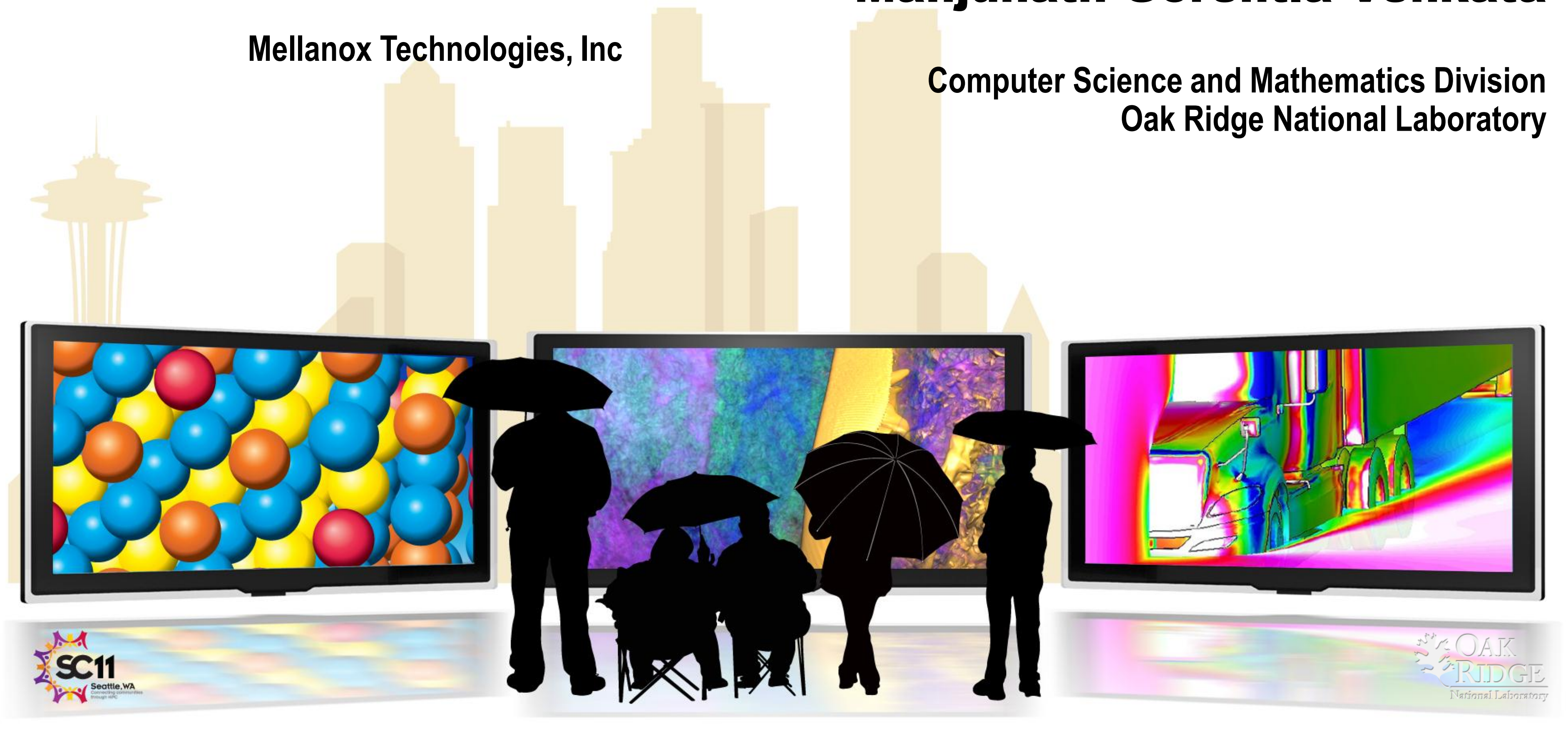

Acknowledgments

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  - www.hpcadvisorycouncil.com

Outline

- Problems being addressed
- InfiniBand overview
- New InfiniBand capabilities
- Software design for collective operations
- Results

Problems being addressed – collective operations

- Communication characteristics at scale
- Overlapping computation with communication—true asynchronous communications
  - **Goal:** Avoid using the CPU for communication processing
- System noise
- Application skew

➔ Scalability

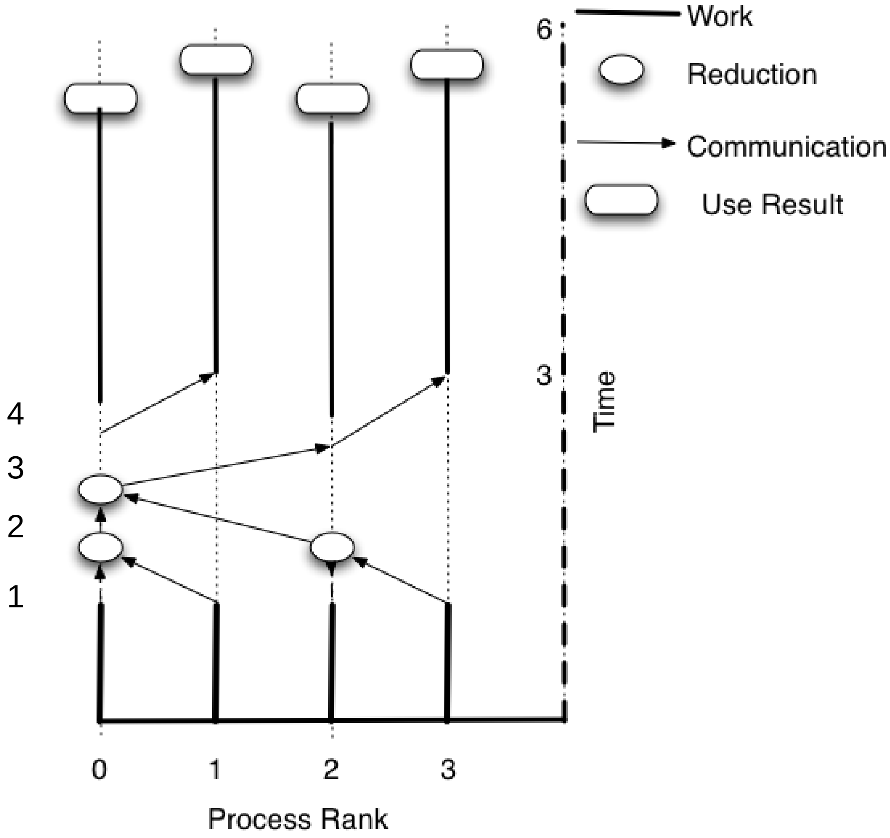
- Collective communication performance

Collective communications

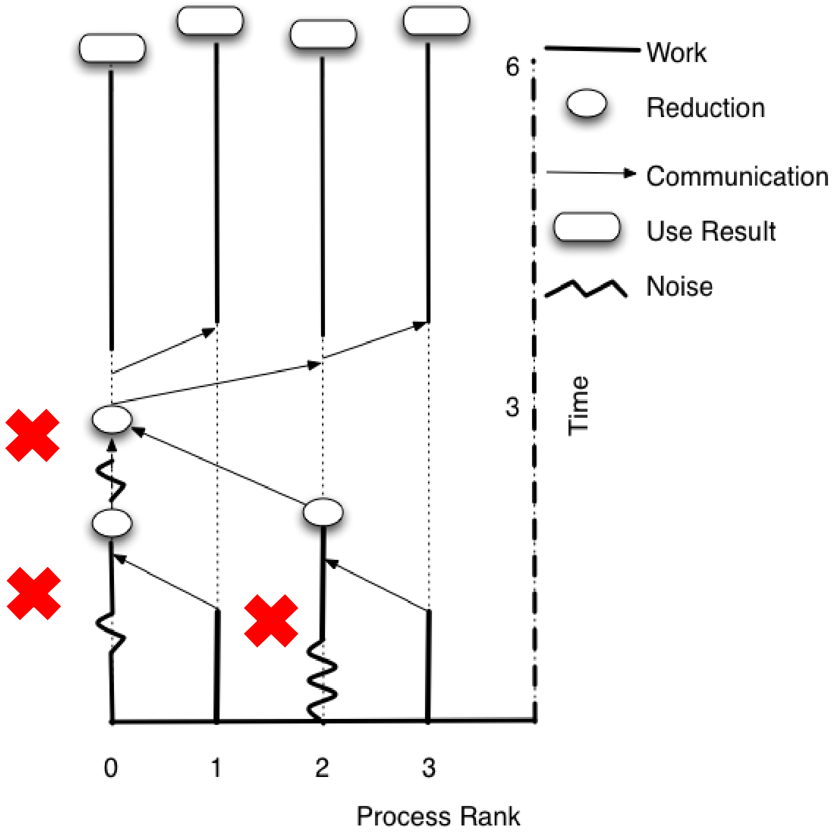
- Communication pattern involving multiple processes (in MPI, all ranks in the communicator are involved)
- Optimized collectives involve a communicator-wide data-dependent communication pattern
- Data needs to be manipulated at intermediate stages of a collective operation
- Collective operations limit application scalability
- Collective operations magnify the effects of system noise

Scalability of collective operations

Ideal Algorithm

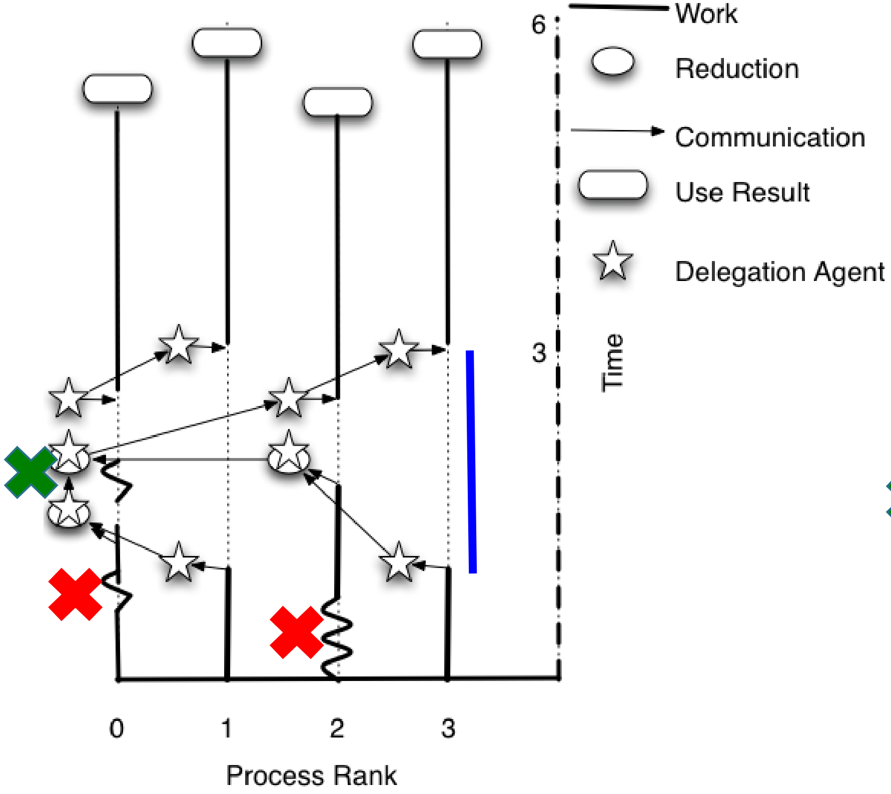


Impact of System Noise

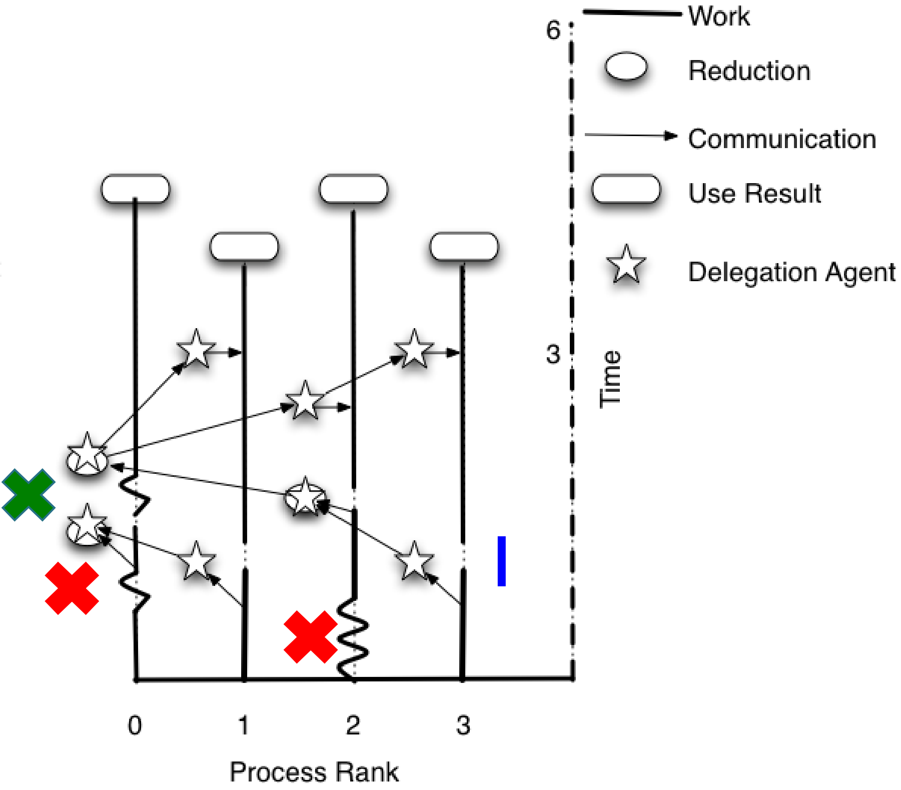


Scalability of collective operations II

Offloaded Algorithm



Nonblocking Algorithm



▎- Communication processing

InfiniBand collective offload – key idea

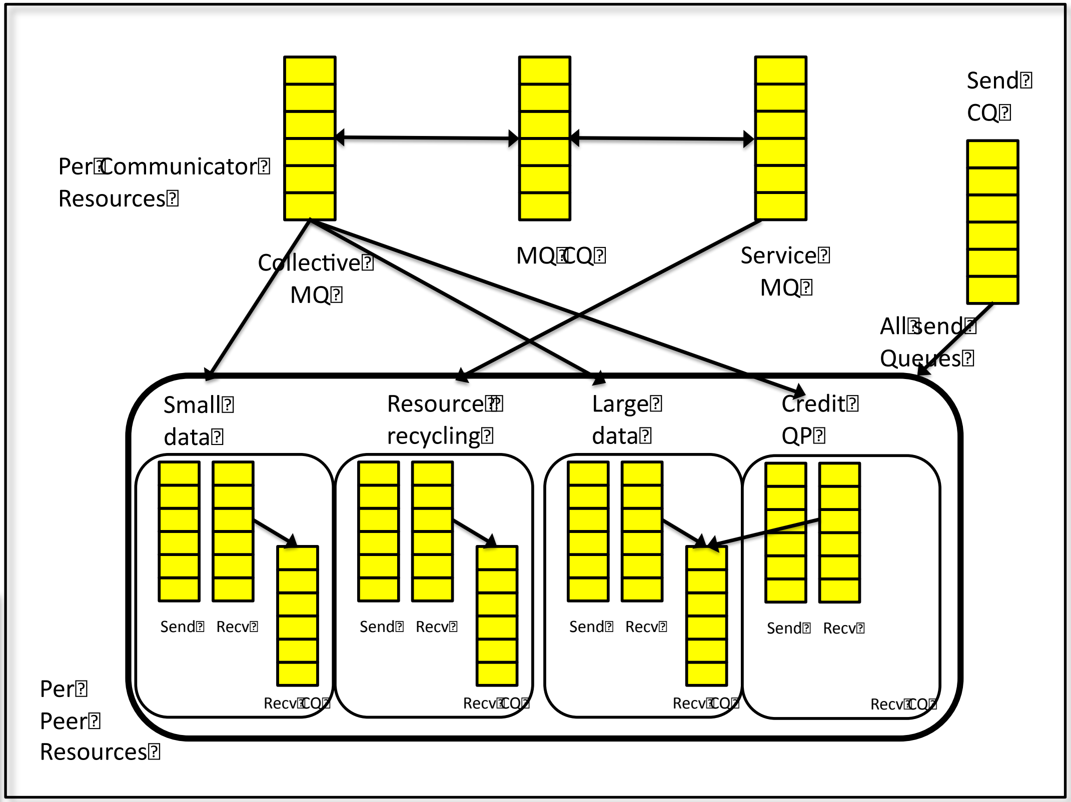
- Create local description of the communication patterns
- Hand the description to the HCA
- Manage collective communications at the network level
- Poll for collective completion
- Add new support for
  - Synchronization primitives (hardware)
    - Send Enable task
    - Receive Enable task
    - Wait task
  - Multiple Work Request
    - A sequence of network tasks
  - Management Queue

InfiniBand hardware changes

- Tasks defined in the current standard
  - Send
  - Receive
  - Read
  - Write
  - Atomic

- New support
  - Synchronization primitives (hardware)
    - Send Enable task
    - Receive Enable task
  - Calc Operations
- Wait task
  - Multiple Work Request
    - A sequence of network tasks
- Management Queue

MPI queue design



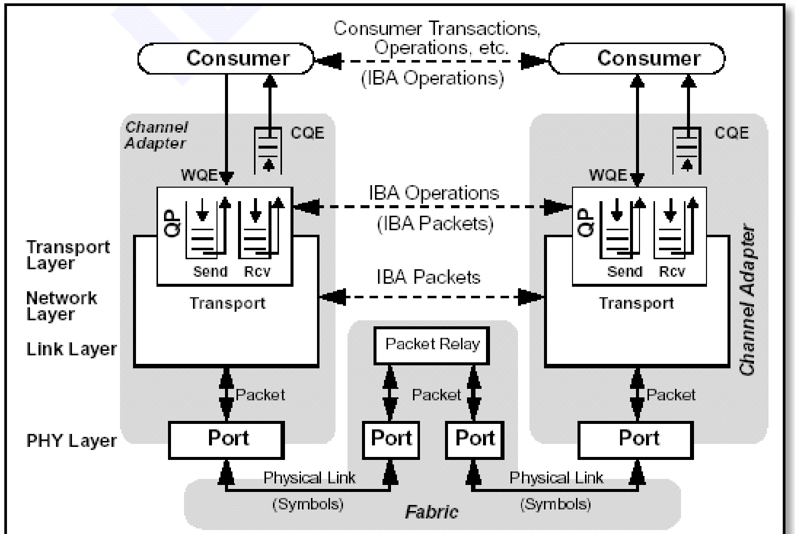
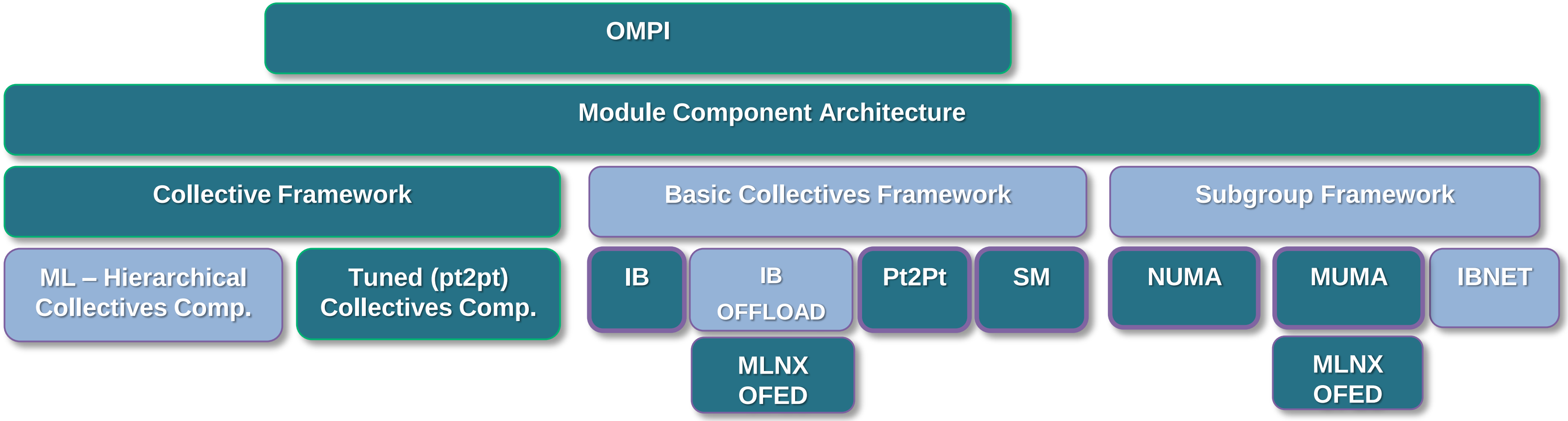
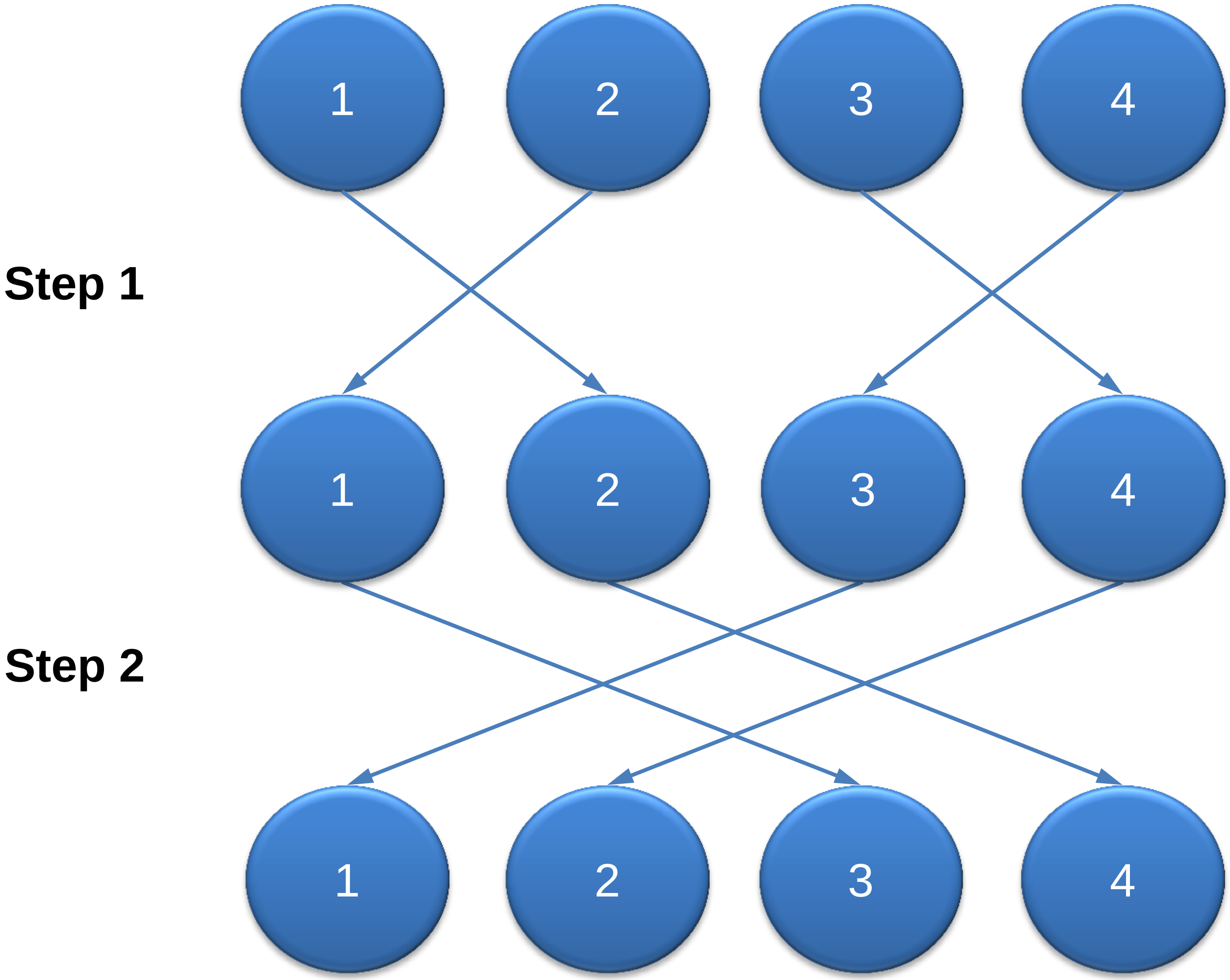


Figure 13 IBA Communication Stack

Collectives – software layers


OMPI
Module Component Architecture
Collective Framework
Basic Collectives Framework
Subgroup Framework
ML – Hierarchical Collectives Comp.
Tuned (pt2pt) Collectives Comp.
IB
IB OFFLOAD
Pt2Pt
SM
NUMA
MUMA
IBNET
MLNX OFED
MLNX OFED

Example – 4 process recursive doubling



4 Process barrier example

Algorithm

Proc 0	Proc 1	Proc 2	Proc 3
Exchange with proc 1	Exchange with proc 0	Exchange with proc 3	Exchange with proc 2
Exchange with proc 2	Exchange with proc 3	Exchange with proc 0	Exchange with proc 1

MWR

Proc 0	Proc 1	Proc 2	Proc 3
Send to proc 1	Send to proc 0	Send to proc 3	Send to proc 2
Wait on recv from 1	Wait on recv from 0	Wait on recv from 3	Wait on recv from 2
Send to proc 2	Send to proc 3	Send to proc 0	Send to proc 1
Wait on recv from 2	Wait on recv from 3	Wait on recv from 0	Wait on recv from 1

4 Process barrier example – queue view

Send QP

Proc 0	Proc 1	Proc 2	Proc 3
Send to proc 1 – enabled	Send to proc 0 – enabled	Send to proc 3 – enabled	Send to proc 2 – enabled
Send to 2 – not enabled	Send to 3 – not enabled	Send to 0 – not enabled	Send to 1 – not enabled

MQ

Proc 0	Proc 1	Proc 2	Proc 3
Recv wait from 1	Recv wait from 0	Recv wait from 3	Recv wait from 2
Send enable 1	Send enable 0	Send enable 3	Send enable 2
Recv wait from 2	Recv wait from 3	Recv wait from 0	Recv wait from 1

8 Process barrier example – queue view – no MQ, view at rank 0

QP 1	QP 2	QP 4
Send QP 1	Wait QP 1	Wait QP 1
	Send QP 2	Wait QP 2
		Send QP 4
		Wait QP 4

Cheetah Core-DIRECT component status

- Supported Collectives (blocking and nonblocking)
  - Barrier
  - Bcast
  - AlltoAll
  - Allgather
  - Fan-in/out
- Offloaded protocols
  - Small messages protocol with support for heterogeneous communication layers
  - Zero-Copy offload for large messages

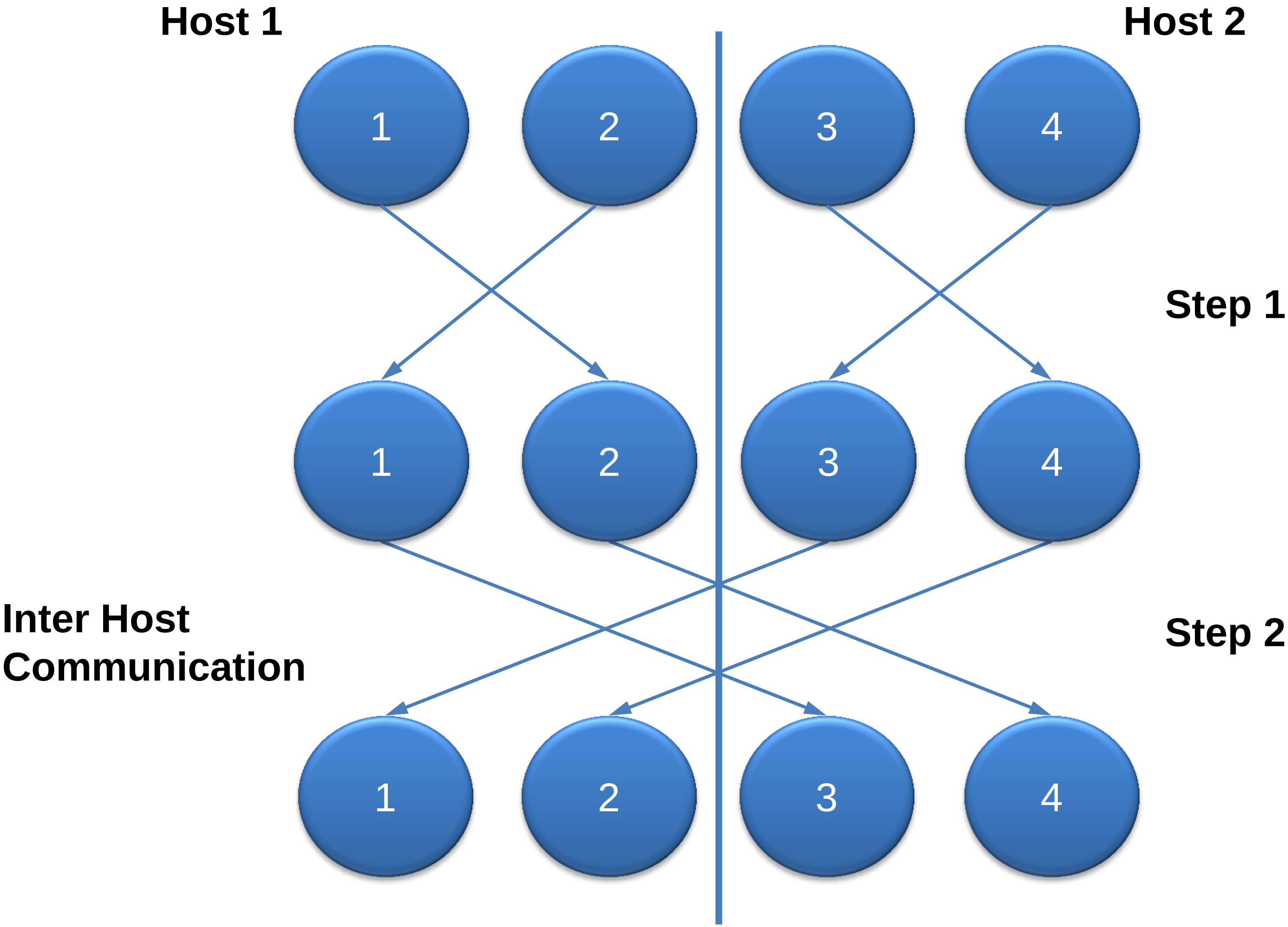
Benchmarks

System setup

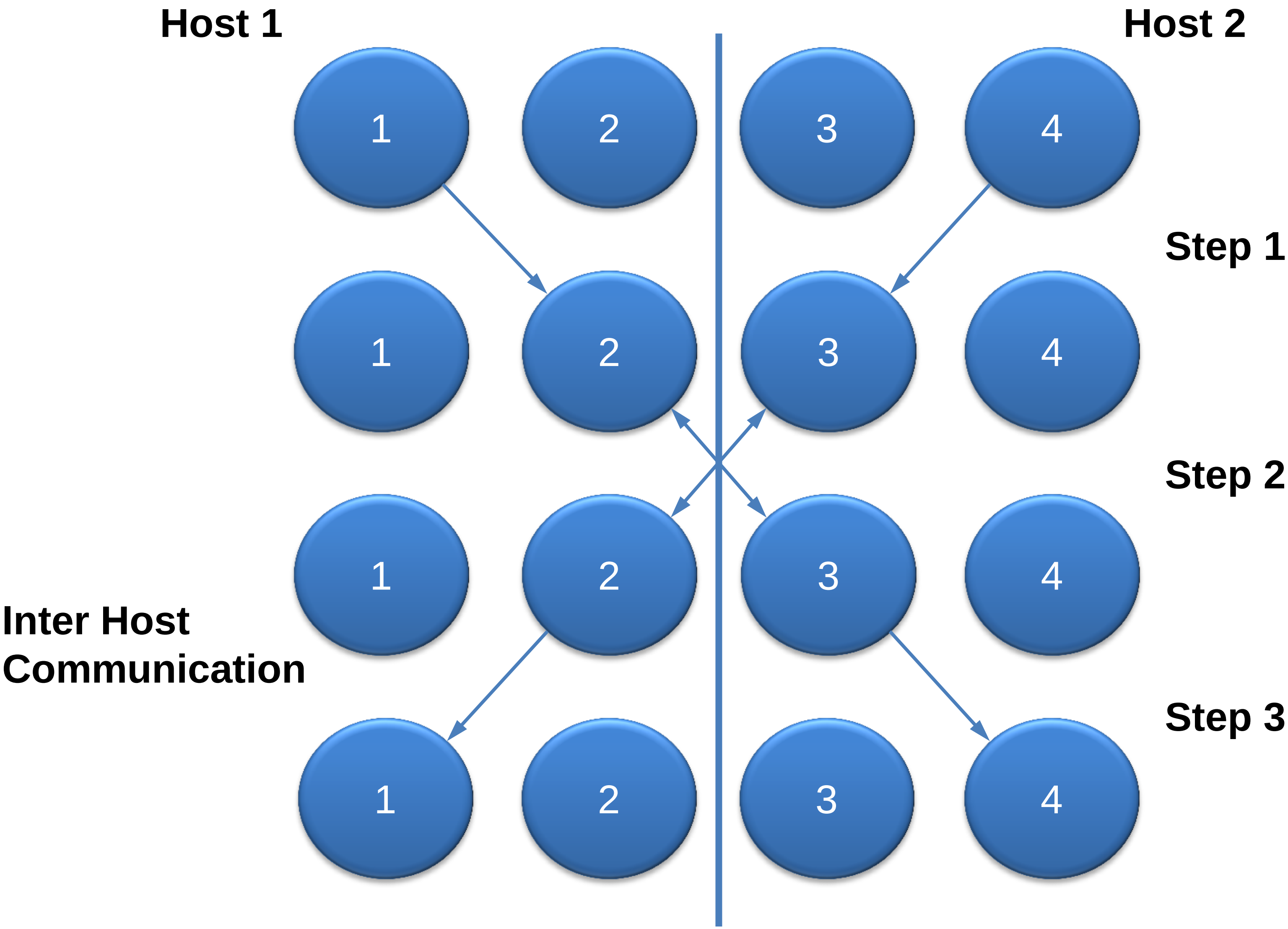
- 8 node cluster
- Node architecture
  - 3 GHz Intel Xeon
  - Dual socket
  - Quad core
- Network
  - ConnextX-2 HCA
  - 36 port QDR switch running prerelease firmware

Barrier Data

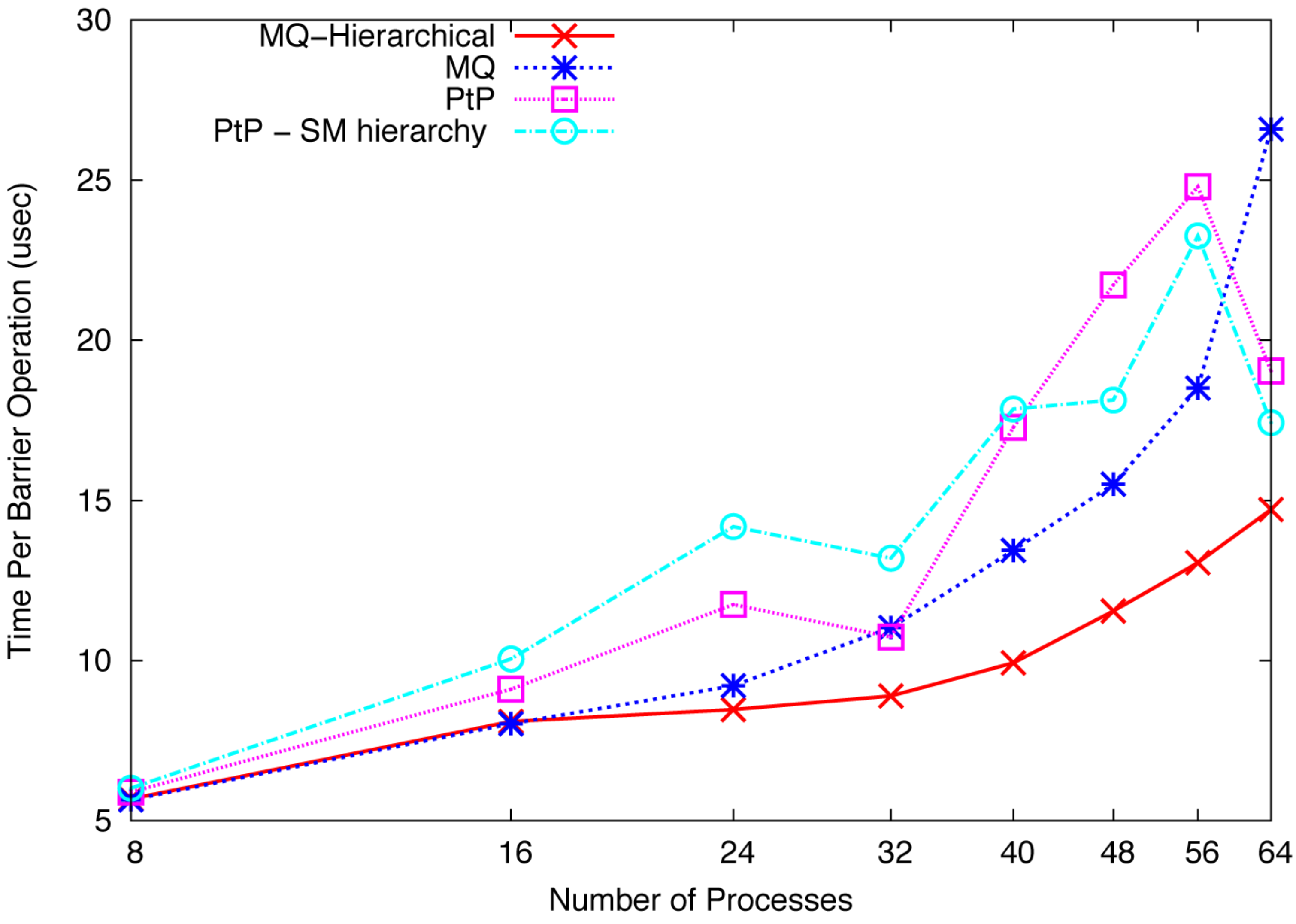
Flat barrier algorithm



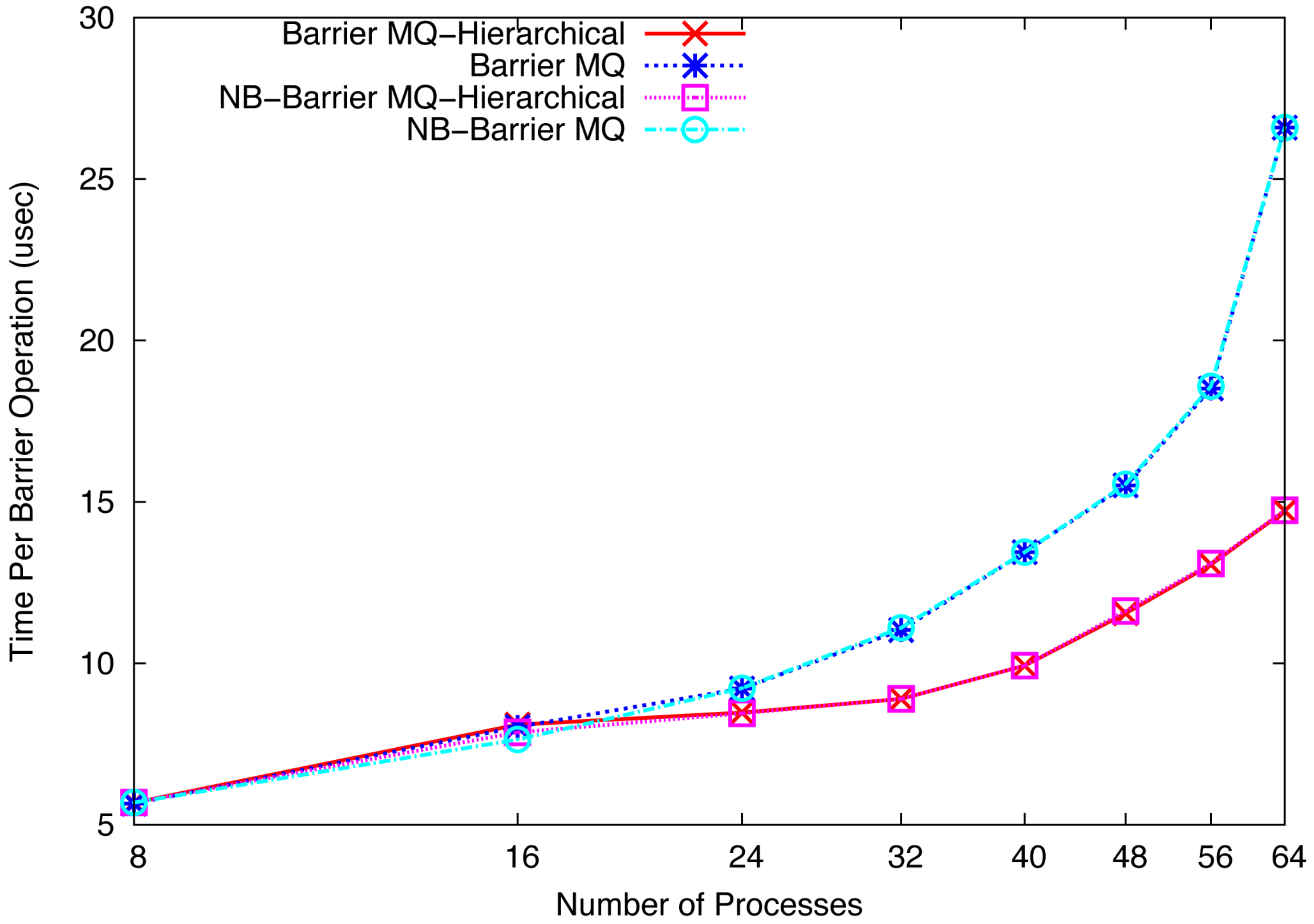
Hierarchical barrier algorithm



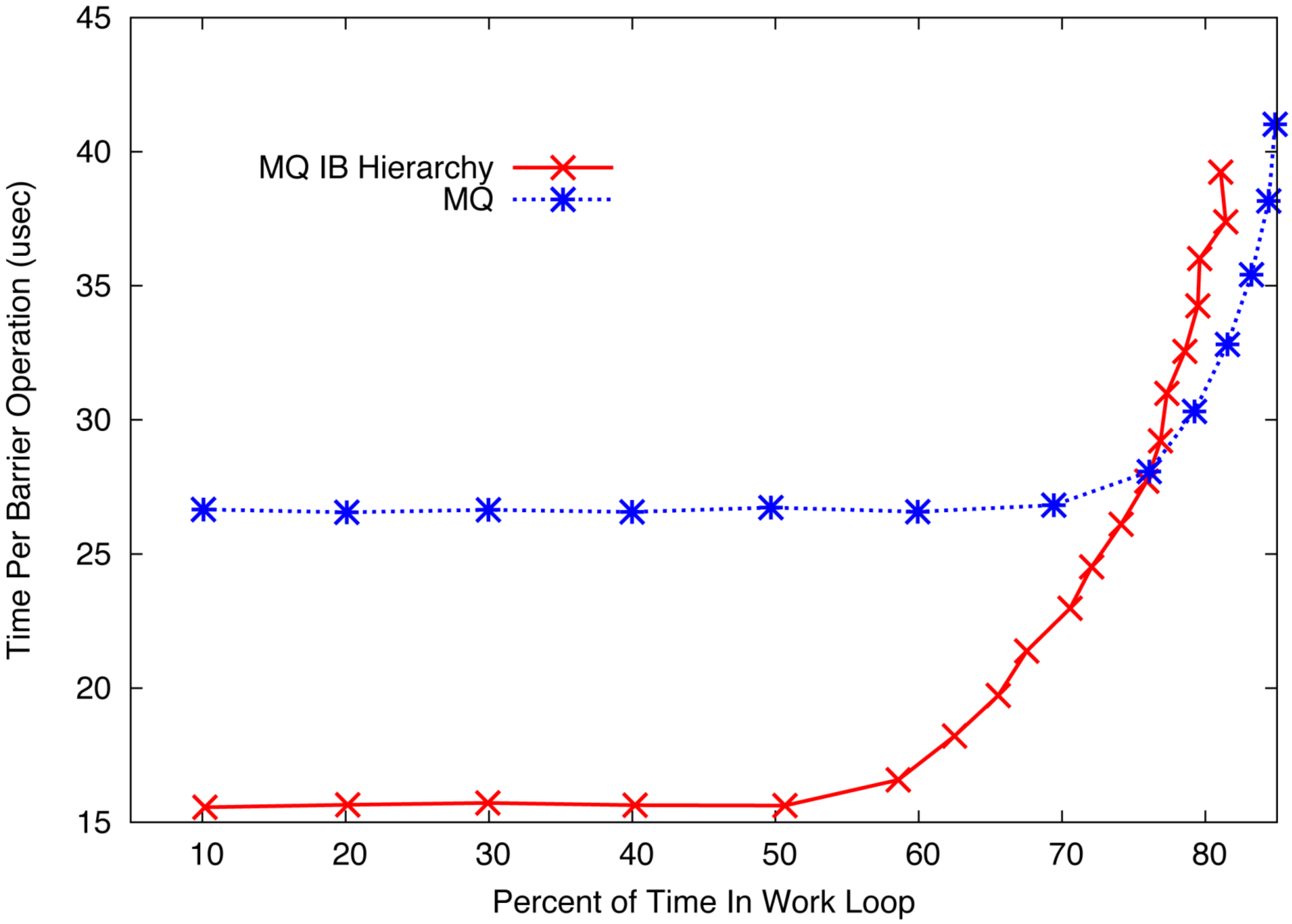
MPI barrier timings



Barrier timings – blocking vs. nonblocking



Nonblocking barrier overlap

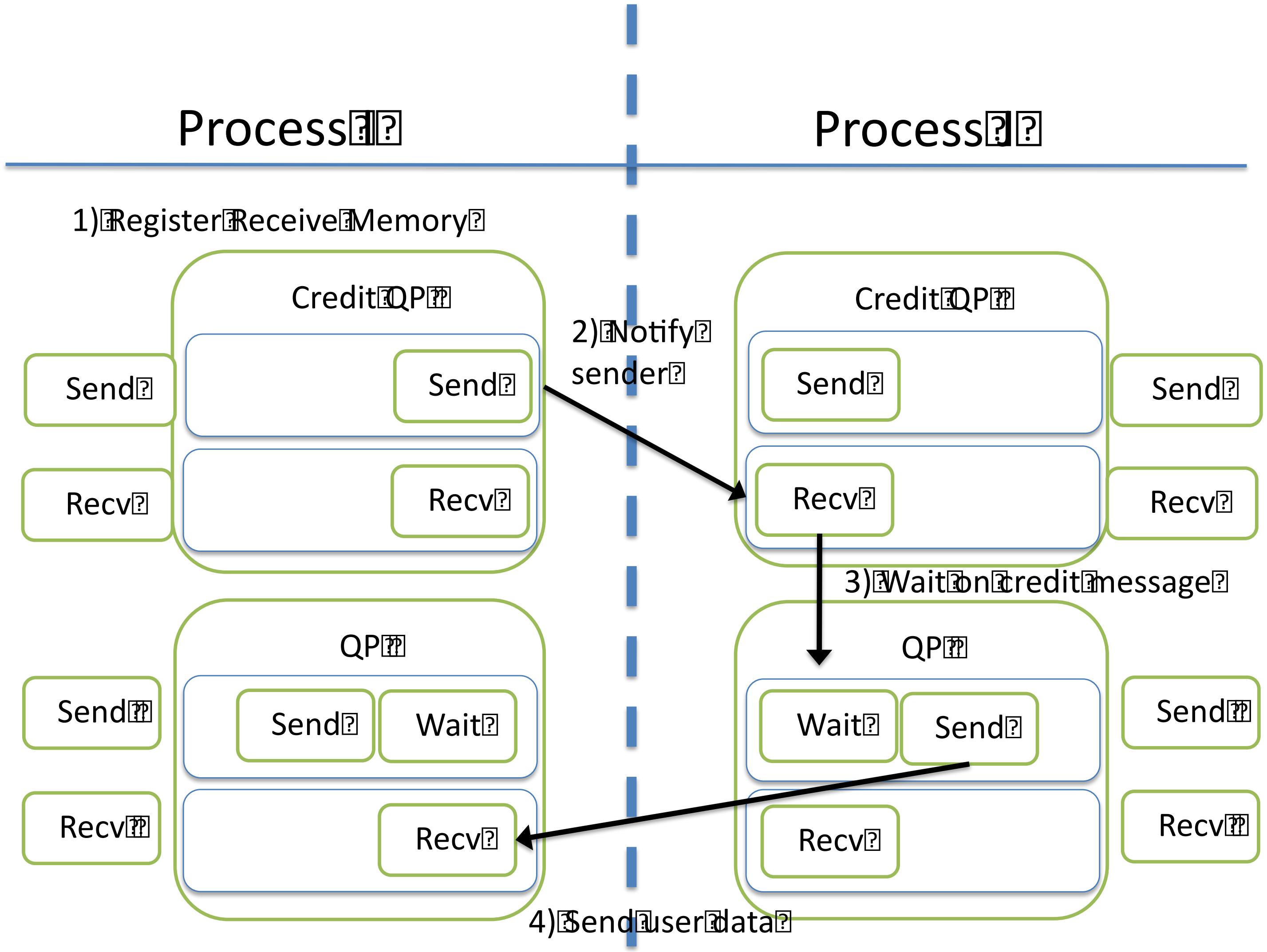


Broadcast Data

Broadcast algorithm features

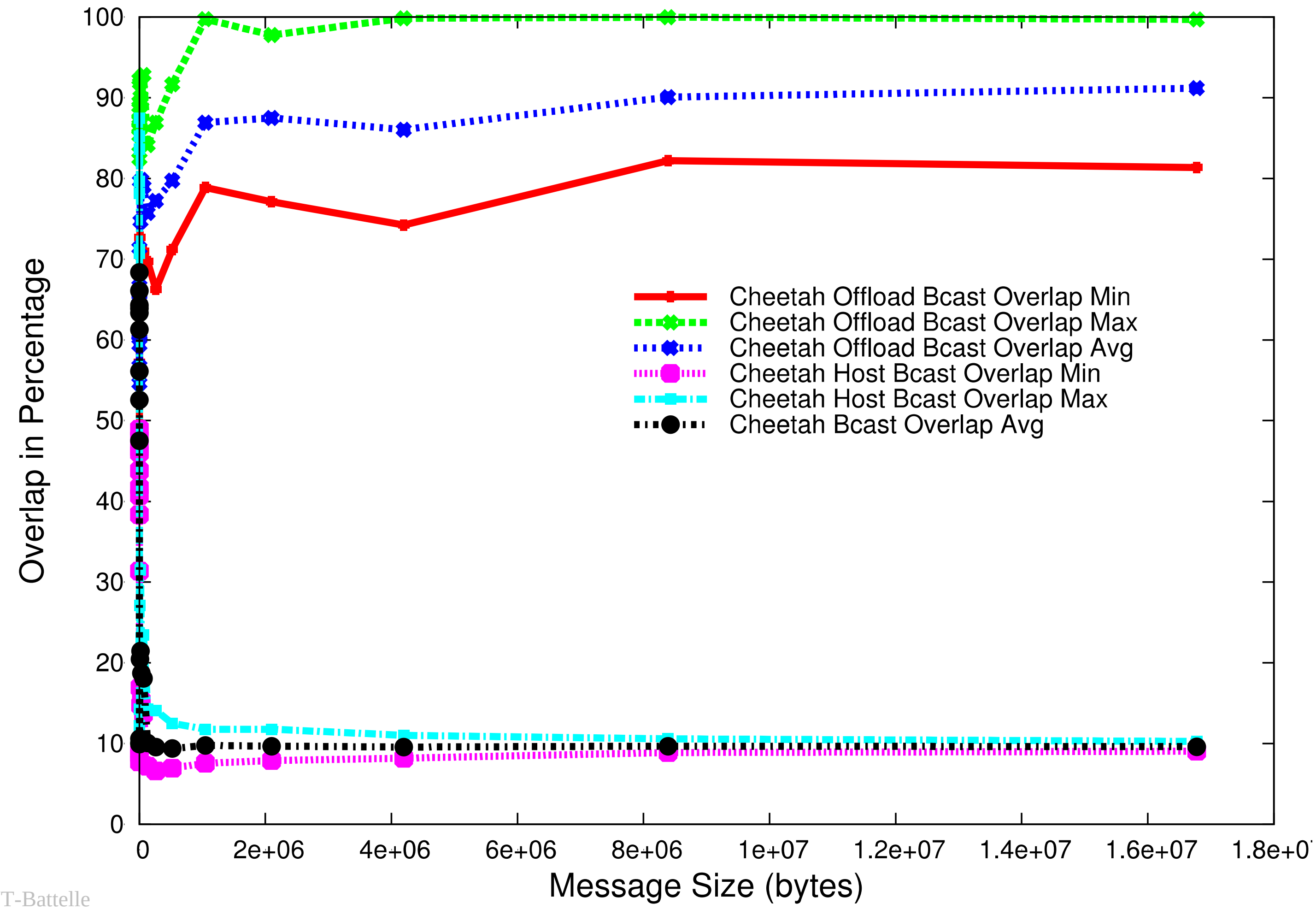
- Reduced memory footprint
  - K-nomial tree: (K-1)$\mathrm{Log}_k(N)$ connections
- Reduced memory overhead
  - Memory blocks are shared between multiple communication layers
  - Novel Zero-Copy offload for large messages
- Parallel execution on multiple communication layers
- Support for Blocking and Non-Blocking Broadcast

Zero-Copy Offload Algorithm for large message broadcast



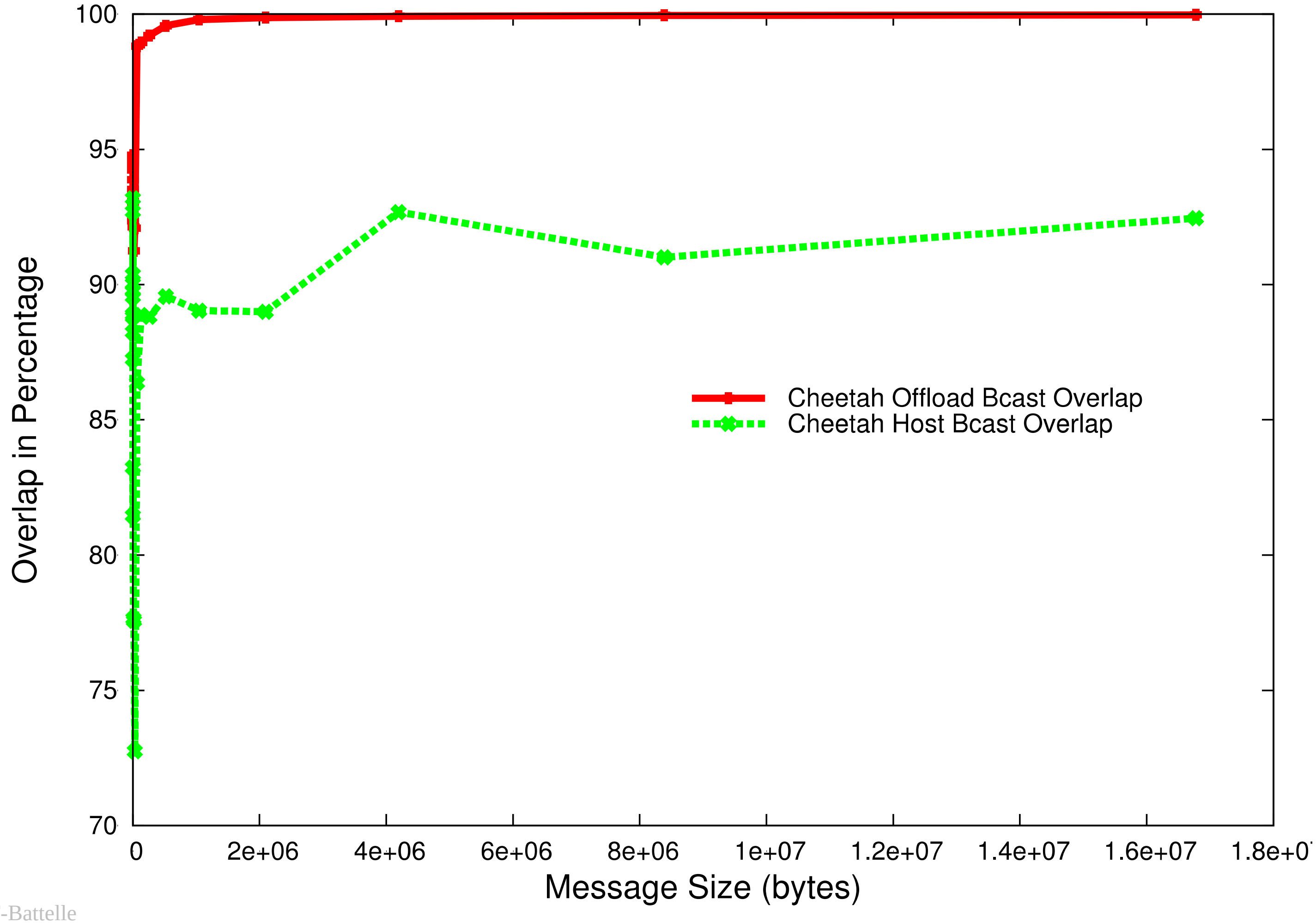
Broadcast Overlap – Wait Based

- **Percentage of the nonblocking broadcast available for work as measured with the wait-based test**



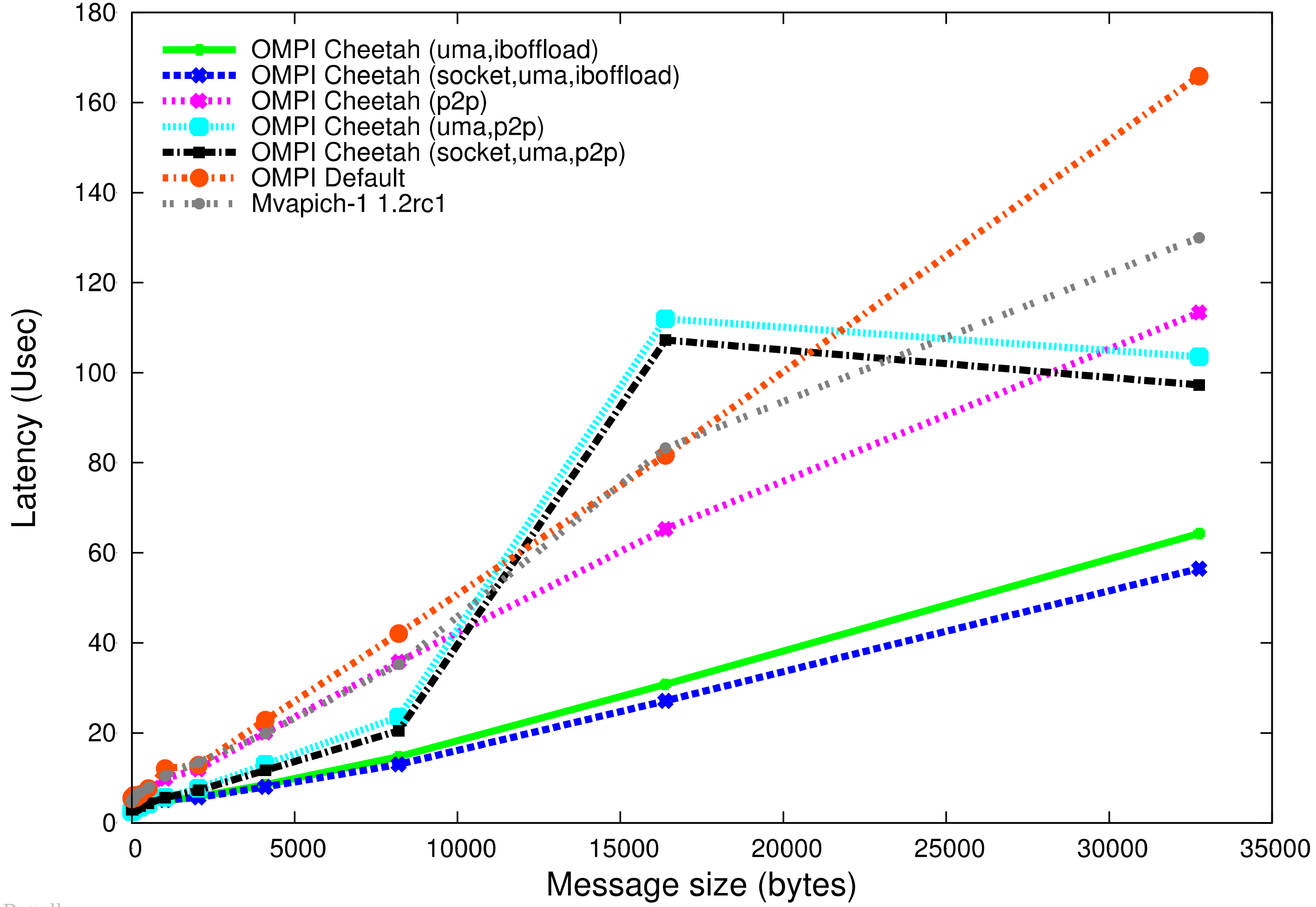
Broadcast Overlap – Polling Based

- Percentage of the nonblocking broadcast available for work as measured with the polling-based test



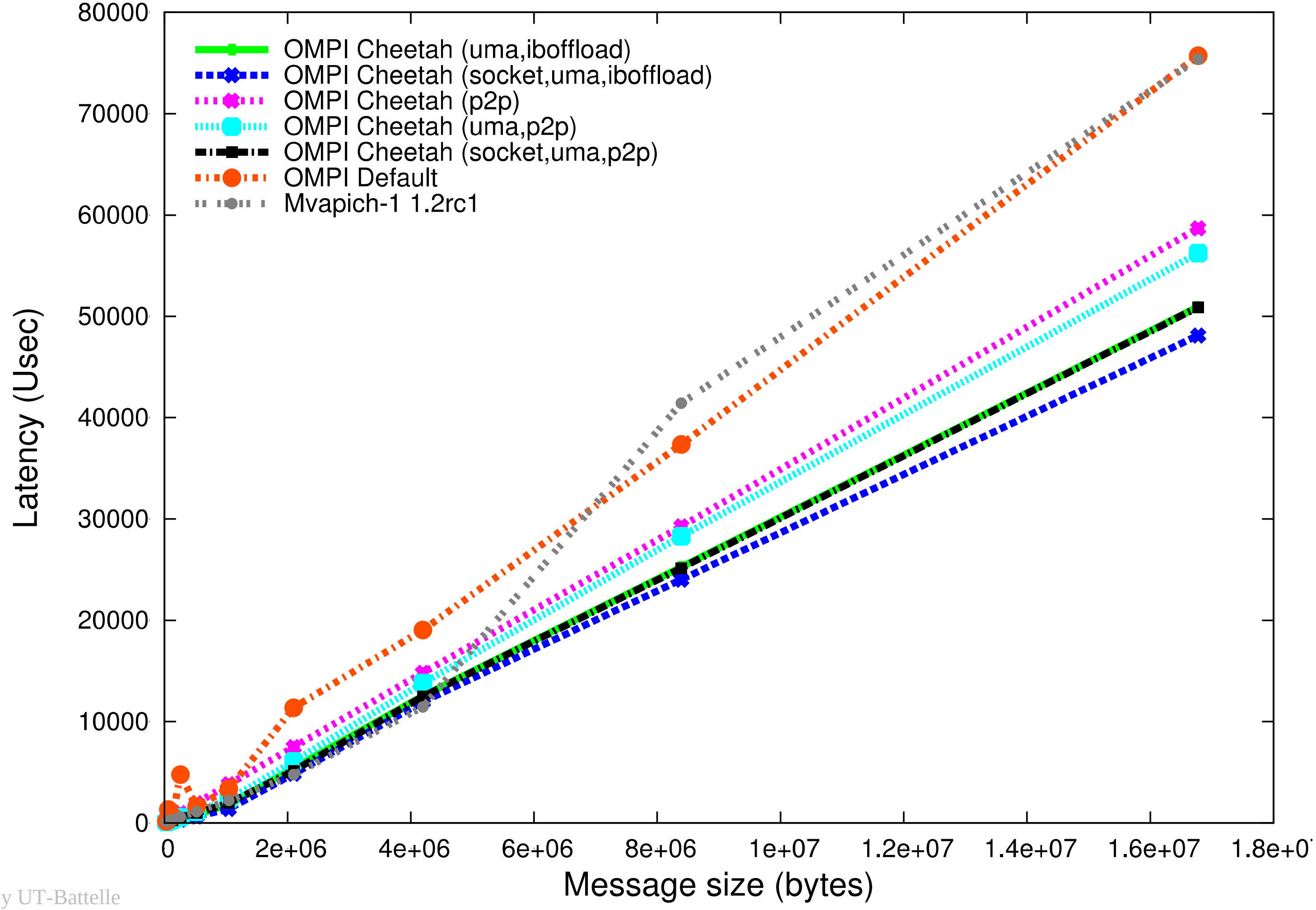
Broadcast latency (small messages)

- Small data algorithm broadcast latency as a function of message size and implementation, and 64 ranks. Message sizes very from one byte to 32 KB.



Broadcast latency (large messages)

- Large-data algorithm broadcast latency as a function of message size and implementation, and 64 ranks. Message sizes very from 32 KB to 16MB



Summary

- Added hardware support for offloading collective operations
- Developed MPI-level support for asynchronous collectives
- Good barrier and broadcast performance
- Good overlap capabilities

Publications

- Pavel Shamis, Richard L. Graham, Manjunath Gorentla Venkata, Joshua S. Ladd. "Design and Implementation of Broadcast Algorithms for Extreme-Scale Systems," IEEE Cluster 2011, accepted for publication.

- Joshua Ladd, Manjunath Gorentla Venkata, Richard Graham, Pavel Shamis. "Analyzing the Effects of Multicore Architectures and On-host Communication Characteristics on Collective Communications," The Seventh International Workshop on Scheduling and Resource Management for Parallel and Distributed Systems (SRMPDS 2011), accepted for publication.

- Manjunath Gorentla Venkata, Richard Graham, Joshua Ladd, Pavel Shamis, Ishai Rabinovitz, Vasily Filipov and Gilad Shainer. "ConnectX-2 CORE-Direct Enabled Asynchronous Broadcast Collective Communications," The 1st Workshop on Communication Architecture for Scalable Systems (CASS2011), May 2011.

- Richard Graham, Manjunath Gorentla Venkata, Joshua Ladd, Pavel Shamis, Ishai Rabinovitz, Vasily Filipov and Gilad Shainer. "Cheetah: A Framework for Scalable Hierarchical Collective Operations," The 11th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid2011), May 2011.

- Ishai Rabinovitz, Pavel Shamis, Richard L. Graham, Noam Bloch, Gilad Shainer. "Network Offloaded Hierarchical Collectives Using ConnectX-2's CORE-Direct capabilities," EuroMPI 2010 - Stuttgart, Germany, September 2010

- Richard L. Graham, Steve Poole, Pavel Shamis, Gil Bloch, Noam Bloch, Hillel Chap- man, Michael Kagan, Ariel Shahar, Ishai Rabinovitz, Gilad Shainer. "ConnectX-2 InfiniBand Management Queues: First investigation of the new support for network offloaded collective operations," The 10th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid2010), May 2010

- Richard L. Graham, Steve Poole, Pavel Shamis, Gil Bloch, Noam Bloch, Hillel Chap- man, Michael Kagan, Ariel Shahar, Ishai Rabinovitz, Gilad Shainer. "Overlapping computation and communication: Barrier algorithms and ConnectX-2 CORE-Direct capabilities," The 10th Workshop on Communication Architecture for Clusters (CAC 2010), April 2010

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