Portals 4 Exascale

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March 26, 2012

Outline

- Recap from last year
- Portals overview
- Portals 4.0 implementations
- OpenSHMEM on Portals 4.0
- Portals 4.0 triggered operations
  - MPI collective operations
  - MPI rendezvous protocol
- Linux XPMEM

Recap From Last Year

- Overview of Portals 4.0 API
- Research vehicle for NIC architecture co-design
- Description of IB reference implementation

Portals Network Programming Interface

- Network API developed by Sandia, U. New Mexico, Intel
- Previous generations of Portals deployed on several production massively parallel systems
  - 1993: 1800-node Intel Paragon (SUNMOS)
  - 1997: 10,000-node Intel ASCI Red (Puma/Cougar)
  - 1999: 1800-node Cplant cluster (Linux)
  - 2005: 10,000-node Cray Sandia Red Storm (Catamount)
  - 2009: 18,688-node Cray XT5 – ORNL Jaguar (Linux)
- Focused on providing
  - Lightweight “connectionless” model for massively parallel systems
  - Low latency, high bandwidth
  - Independent progress
  - Overlap of computation and communication
  - Scalable buffering semantics
  - Protocol building blocks to support higher-level protocols
- Supports MPI, SHMEM, ARMCI, GASNet, Lustre, etc.

Portals 4.0 Implementations

- OpenFabrics Verbs
  - Provided by System Fabric Works
  - Provides a high-performance reference implementation for experimentation
  - Help identify issues with API, semantics, performance, etc.
  - Independent analysis of the specification
- Shared memory
  - Offers consistent and understandable performance characteristics
  - Provides ability to accurately measure instruction count for Portals operations
  - Better characterization of operations that impact latency and message rate
  - Evaluation of single-core onloading performance limits
- Structural Simulation Toolkit (SST)
  - Partial implementation for exploring NIC structures for offload

OpenSHMEM on Portals 4.0

Barrett, Brightwell, Hemmert, Pedretti, Wheeler, Underwood. “Enhanced Support for OpenSHMEM Communication in Portals,” in Proceedings of the IEEE Symposium on High-Performance Interconnects, August 2011.

OpenSHMEM

- Proposed community standard for SHMEM
- Partitioned Global Address Space library
- Put, get, atomic operations, plus collective communication
- Encourages asynchronous, small message patterns

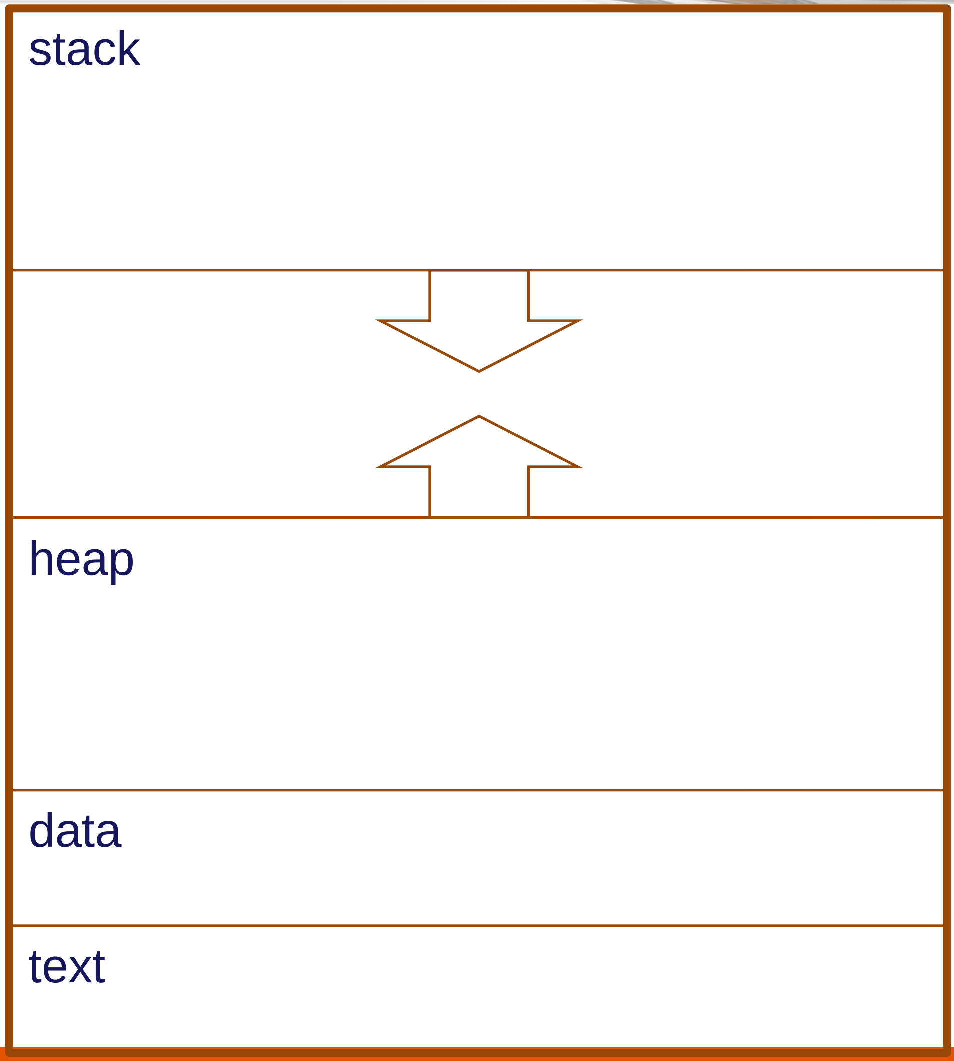
OpenSHMEM

- Communication calls
  - Elemental put, block put, strided put
  - Elemental get, block get, strided get
  - Atomic operations
  - All operations provide local completion
  - Read and read-write operations imply remote completion
- Operations must target symmetric memory
  - Global data: Global and static variables in C, Common block
  - Symmetric Heap: global dynamic memory
- Ordering / completion functions
  - Fence/quiet
  - Address wait

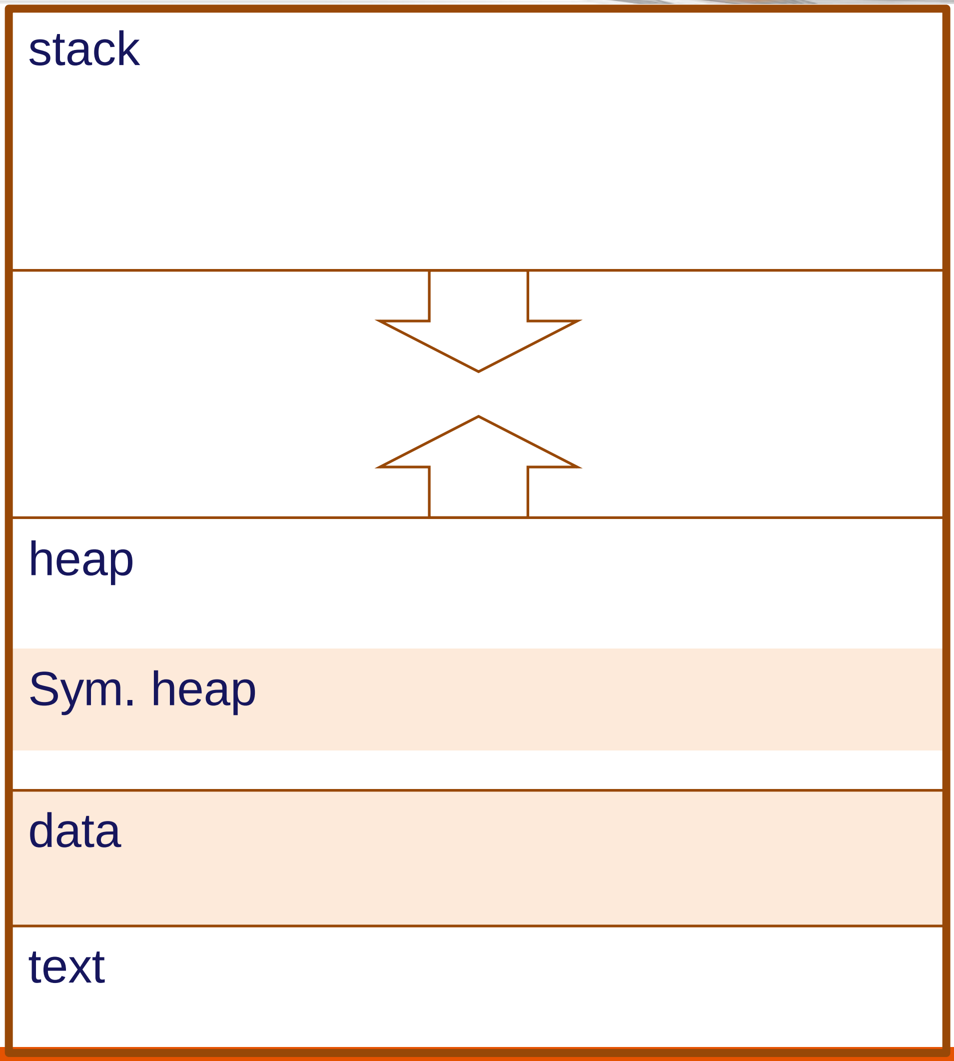
Portals 4.0

- Communication Calls
  - Non-blocking Put, Get, Atomic
  - Matching or non-matching receive interfaces
- Completion Semantics
  - Completion events for local and remote completion
  - Counters of events / bytes for light-weight messaging
- Memory Model
  - Generally, no atomicity / data ordering guarantees
  - Maximum message size for atomic operations
  - Maximum size for single-byte write-after-write ordering
  - May provide more general write-after-write ordering
  - Maximum size for local completion of put/atomic operations

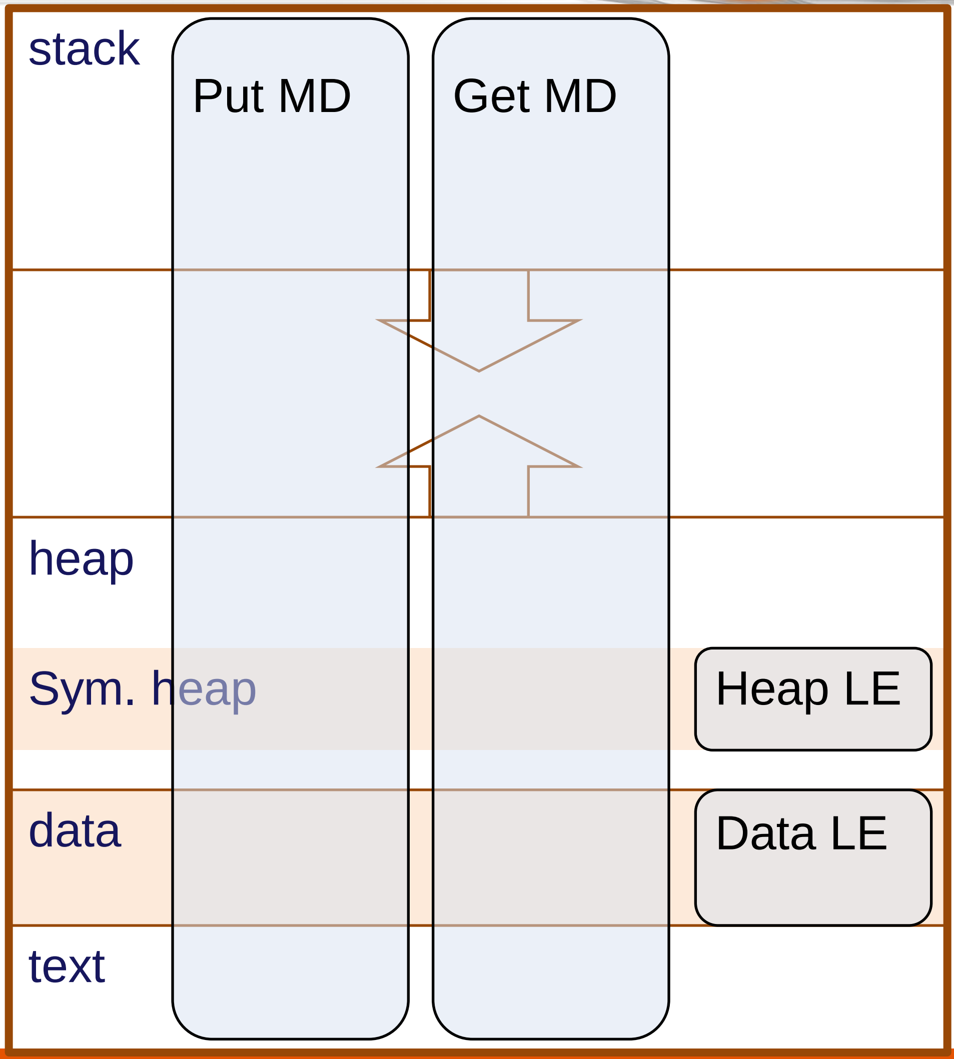
Memory Layout



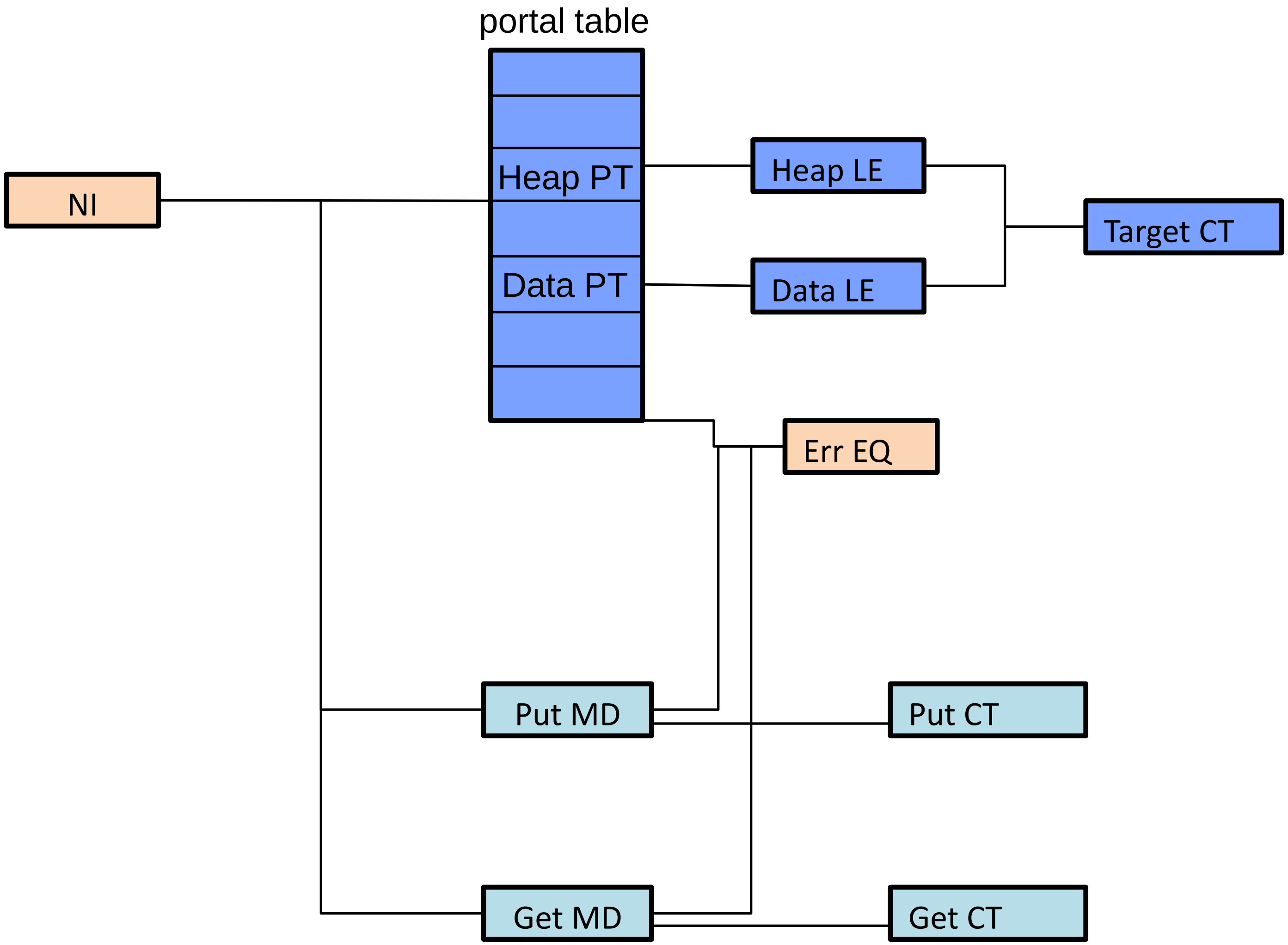
Memory Layout



Memory Layout



Portals Data Structures



Put Operations

```
void shmem_long_p(long *addr, long value, int pe) {
    ptl_process_t peer;
    ptl_pt_index_t pt;
    long offset;
    peer.rank = pe;
    GET_REMOTE_ACCESS(target, pt, offset);

    PtlPut(shmem_internal_put_md_h,
           (ptl_size_t) &value,
           sizeof(value),
           PTL_CT_ACK_REQ,
           peer,
           pt,
           0,
           offset,
           NULL,
           0);
}
```

Get Operations

```
void shmem_double_get(double *target, const double *source,
                      size_t len, int pe) {
    …
    ptl_ct_event_t ct;
    peer.rank = pe;
    GET_REMOTE_ACCESS(source, pt, offset);

    PtlGet(shmem_internal_get_md_h,
                 (ptl_size_t) target,
                 len * sizeof(double),
                 peer,
                 pt,
                 0,
                 offset,
                 0);
    shmem_internal_pending_get_counter++;
    PtlCTWait(shmem_internal_get_ct_h,
              shmem_internal_pending_get_counter,
              &ct);
}
```

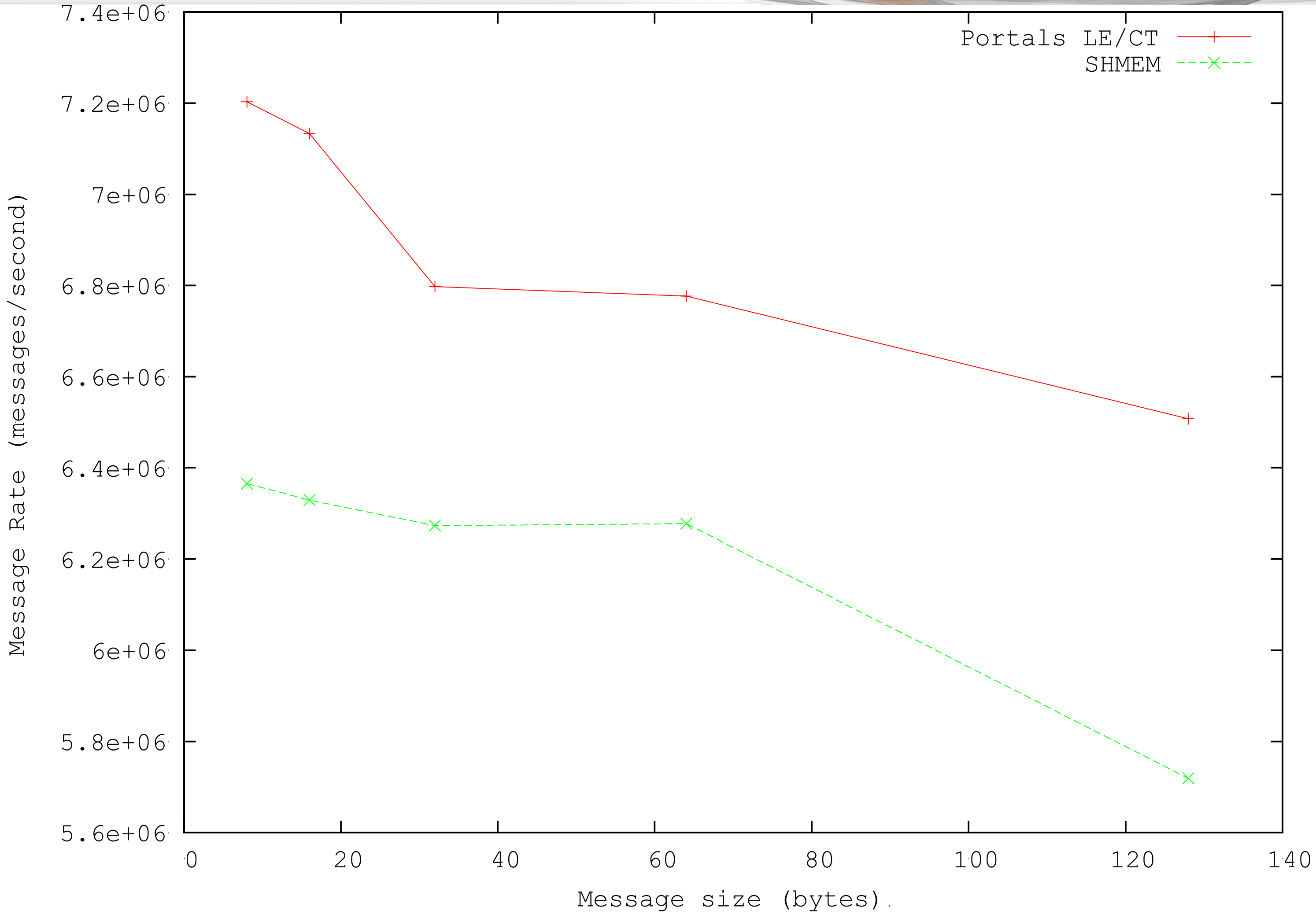
Results

- Running SHMEM codes over both shared memory and InfiniBand
- Results shown for shared memory
- 3.33 GHz Westmere EP w/ 1333 DDR3 Linux system

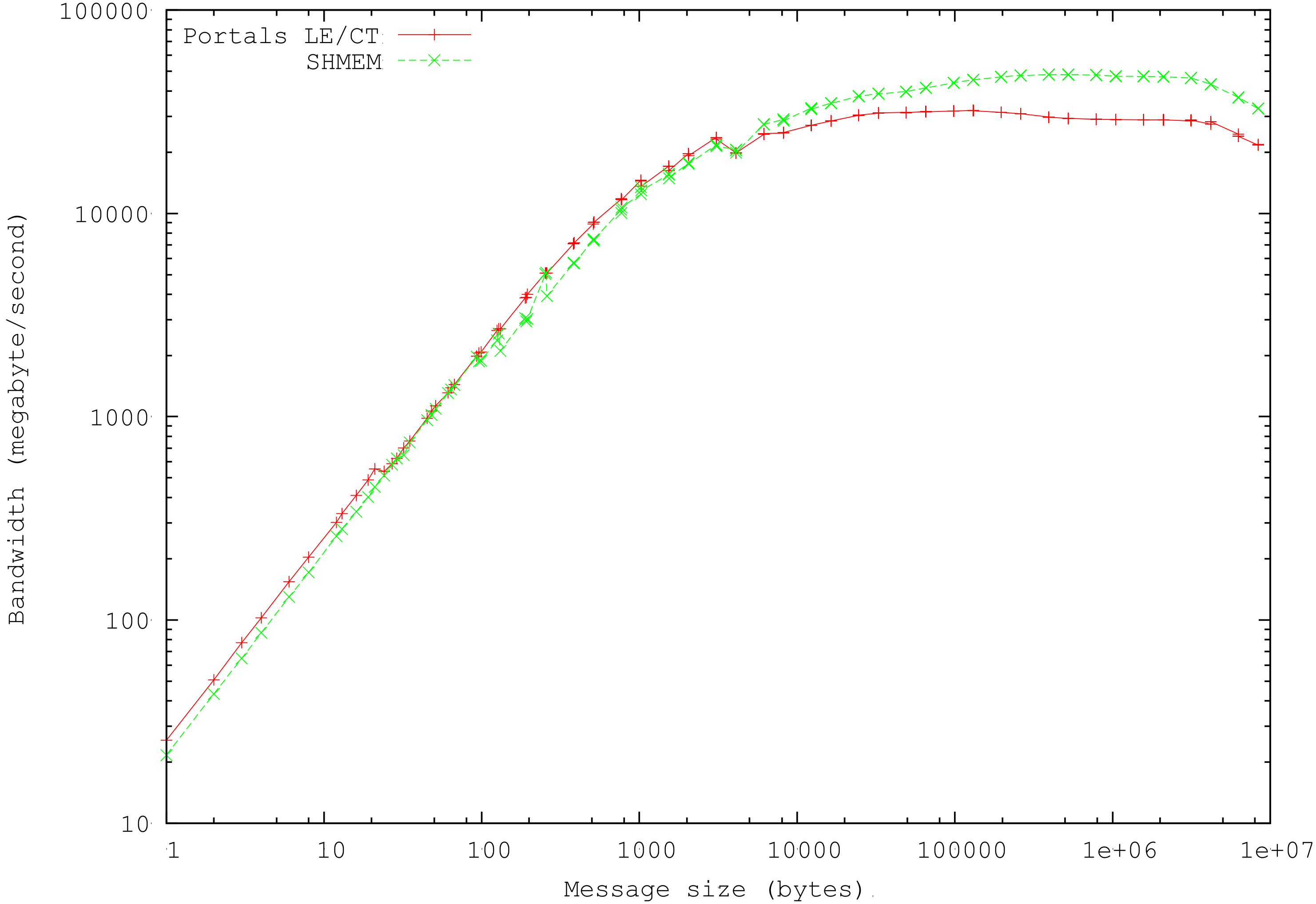
- ½ Round Trip Latency:
  - Raw Portals: 0.43 µs
  - OpenSHMEM: 0.39 µs

  - Numbers misleading; slightly more work on receive side for Raw Portals

Message Rate



NetPIPE Bandwidth



Triggered Operations for Collective Communication

Underwood, et al. “Enabling Flexible Collective Communication Offload with Triggered Operations,” in Proceedings of the IEEE Symposium on High-Performance Interconnects, August 2011.

Motivation

- Collectives are important to a broad array of applications
  - As node counts grow, it becomes hard to keep collective time low
- Offload provides a mechanism to reduce collective time
  - Eliminates portion of Host-to-NIC latency from the critical path
  - Relatively complex collective algorithms are constantly refined and tuned
- Building blocks provide a better
  - Allow algorithm research and implementation to occur on the host
  - Provides a simple set of hardware mechanisms to implement
- A general purpose API is needed to express the building blocks

Triggered Operations

- Lightweight events are counters of various network transactions
  - One counter can be attached to multiple different operations or even types of operations
  - Fine grained control of what you count is provided
- Portals operation is "triggered" when a counter reaches a threshold specified in the operations
  - Various types of operations can be triggered
  - Triggered counter update allows chaining of local operations

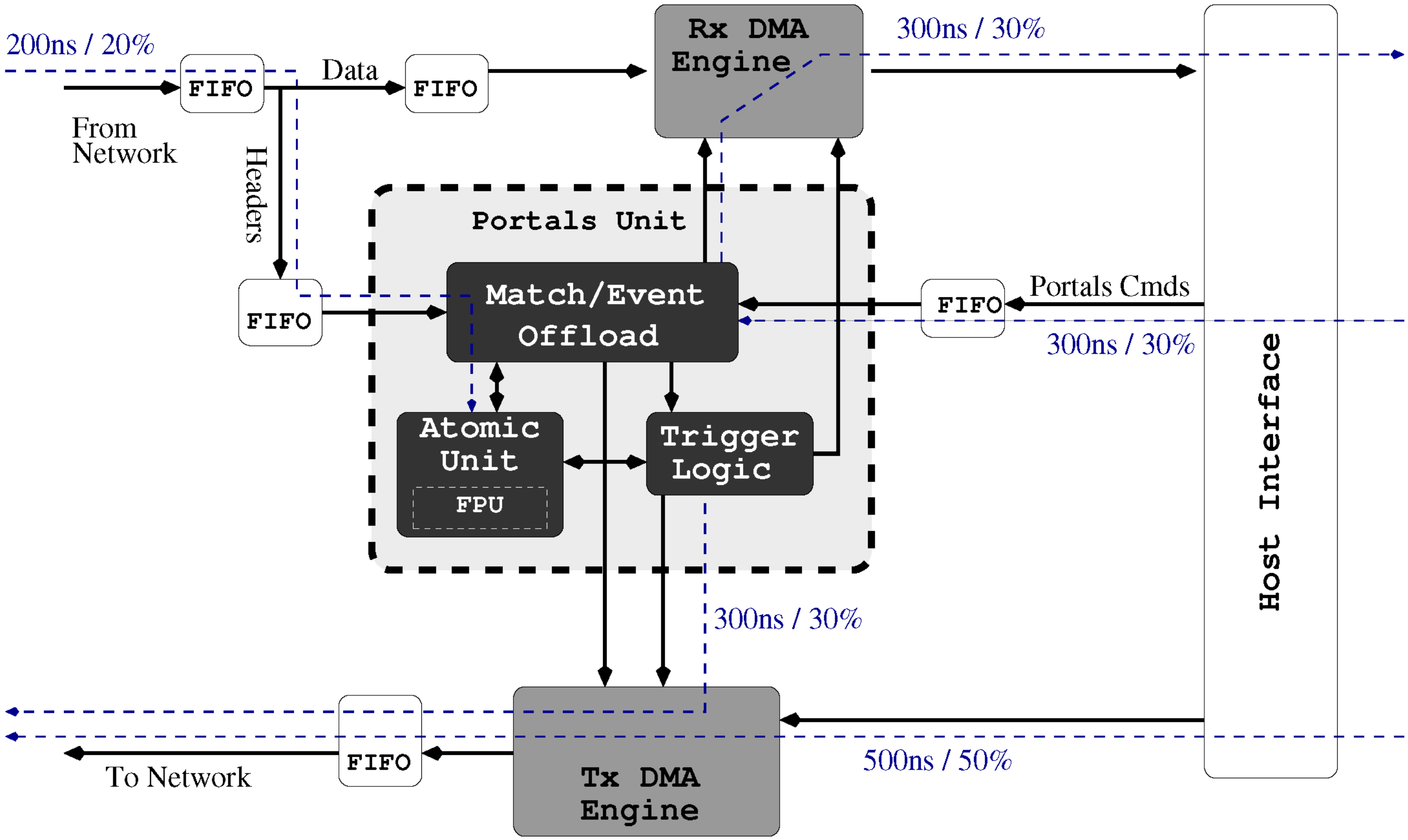
Generality of Triggered Operations

- Numerous collectives have been implemented so far
  - Allreduce
  - Bcast
  - Barrier
- Numerous algorithms have been implemented for multiple collectives
  - Binary tree
  - k-nomial tree
  - Pipelined broadcast
  - Dissemination barrier
  - Recursive doubling

Simulation Methodology

- Utilized SST simulator developed at Sandia
- Modeled processor and NIC as separate state machines
  - Fixed delays between states to model delays and overhead
  - Single state machine for processor, multiple for NIC to model concurrent hardware blocks
- Modeled several combinations of parameters defined by latency and message rate
  - Allocated delay to various units that were modeled

High-Level NIC Architecture



Simulation Settings

(a) simulation parameters

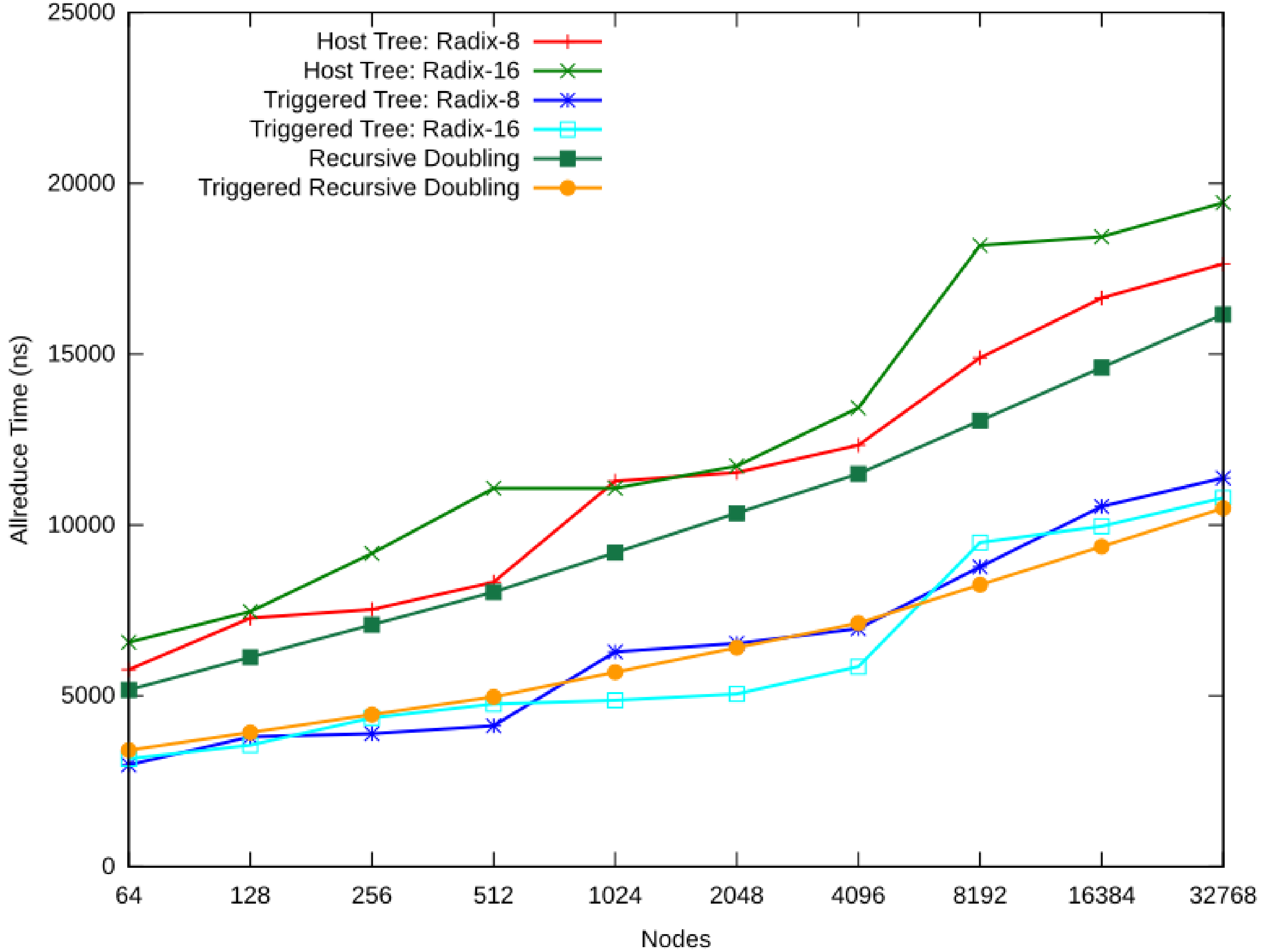
Property	Range
Msg Latency	500 ns, 1000 ns, 1500 ns
Msg Rate	5 Mmsgs/s, 10 Mmsgs/s
Overhead	$\frac{1}{MsgRate}$
NIC Msg Rate	62.5 Mmsgs/s
Rtr Latency	50 ns
Setup Time	200 ns
Cache Line	64 Bytes
Miss Latency	100 ns
Noise	250 ns @ 100KHz, 25 μs @ 1KHz, 2.5 ms @ 10Hz

(b) simulation configurations

	500 ns	1000 ns	1500 ns
5 Mmsgs/s		X	X
10 Mmsgs/s	X	X	

Allreduce

500ns, 10 Mmsgs/s

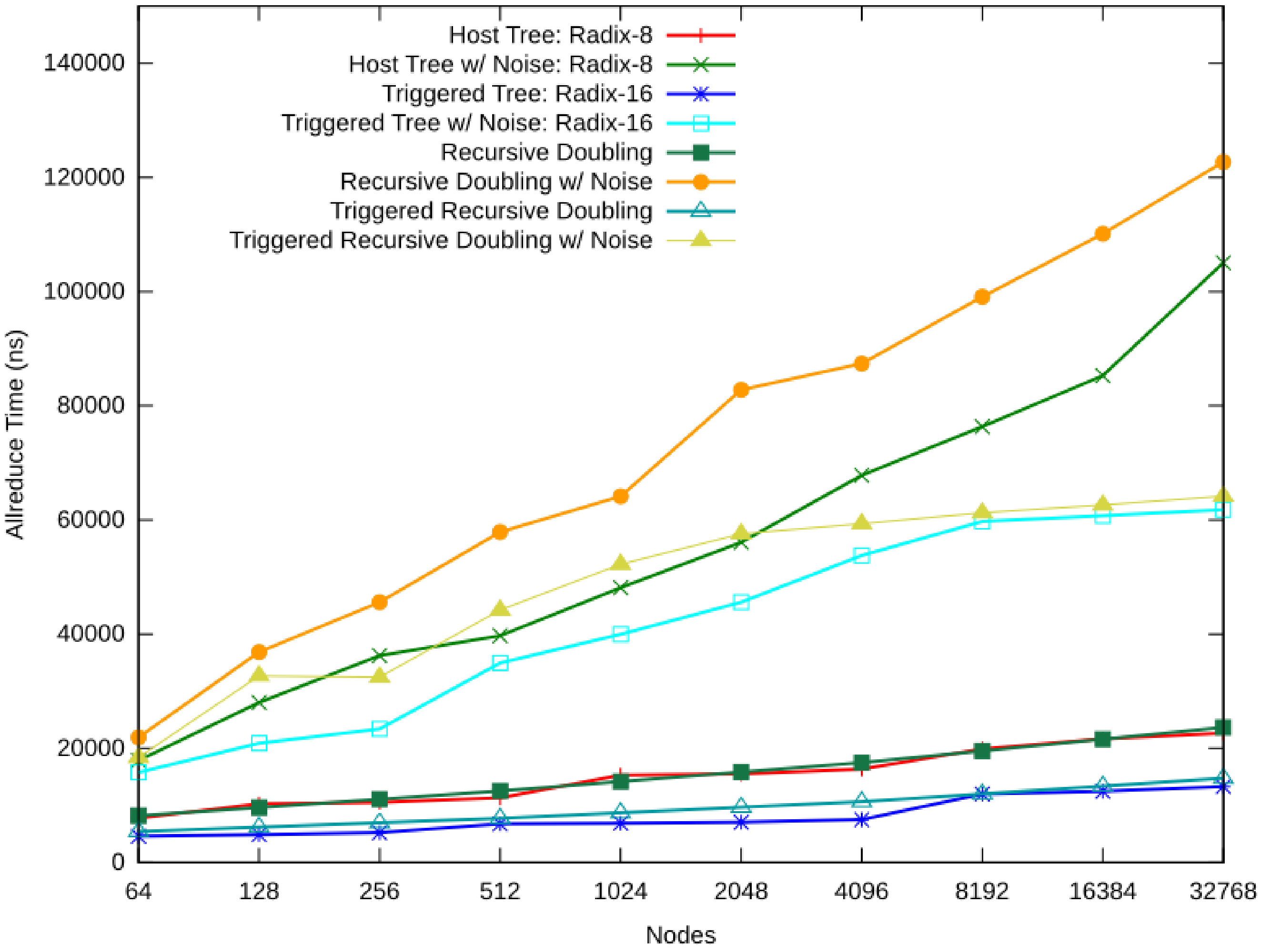


Noise Simulations

- Three noise profiles were simulated (2.5% noise for each)
  - 250 ns @ 100KHz
  - 25 μs @ 1KHz
  - 2.5 ms @ 10Hz
- Noise events were randomly distributed
  - Stopped all host processing during a noise event
  - NIC processing continued
- Timed individual collective operations (first entry to last exit)

Allreduce With Noise

25 us @ 1 KHz



Noise Simulation Results

- Recursive doubling has poor noise tolerance
- Offload gives significant improvement in noise tolerance
  - Partly from reduced time
  - Partly from reduced host participation
  - Synchronizing operation still cannot complete until everyone contributes a value
- Interesting shape of curves in middle noise case
  - Host based latency continues to grow with node count
  - NIC based latency plateaus

Interesting Things We Learned

- Time to initiate a transaction from the host to the NIC makes things difficult
  - Even with a high NIC rate, can be rate limited by the host
  - Limitation of using host to initiate all operations instead of offloading algorithm
  - If transactions are posted in correct order, limitation is effectively mitigated
- Proper message scheduling is important
  - Time between message initiations on the host (gap) matches network hop latency: send the far away ones first!
- k-nomial trees are better, but the work at the root limits the maximum value of k
- You can have speed or reproducibility, but…

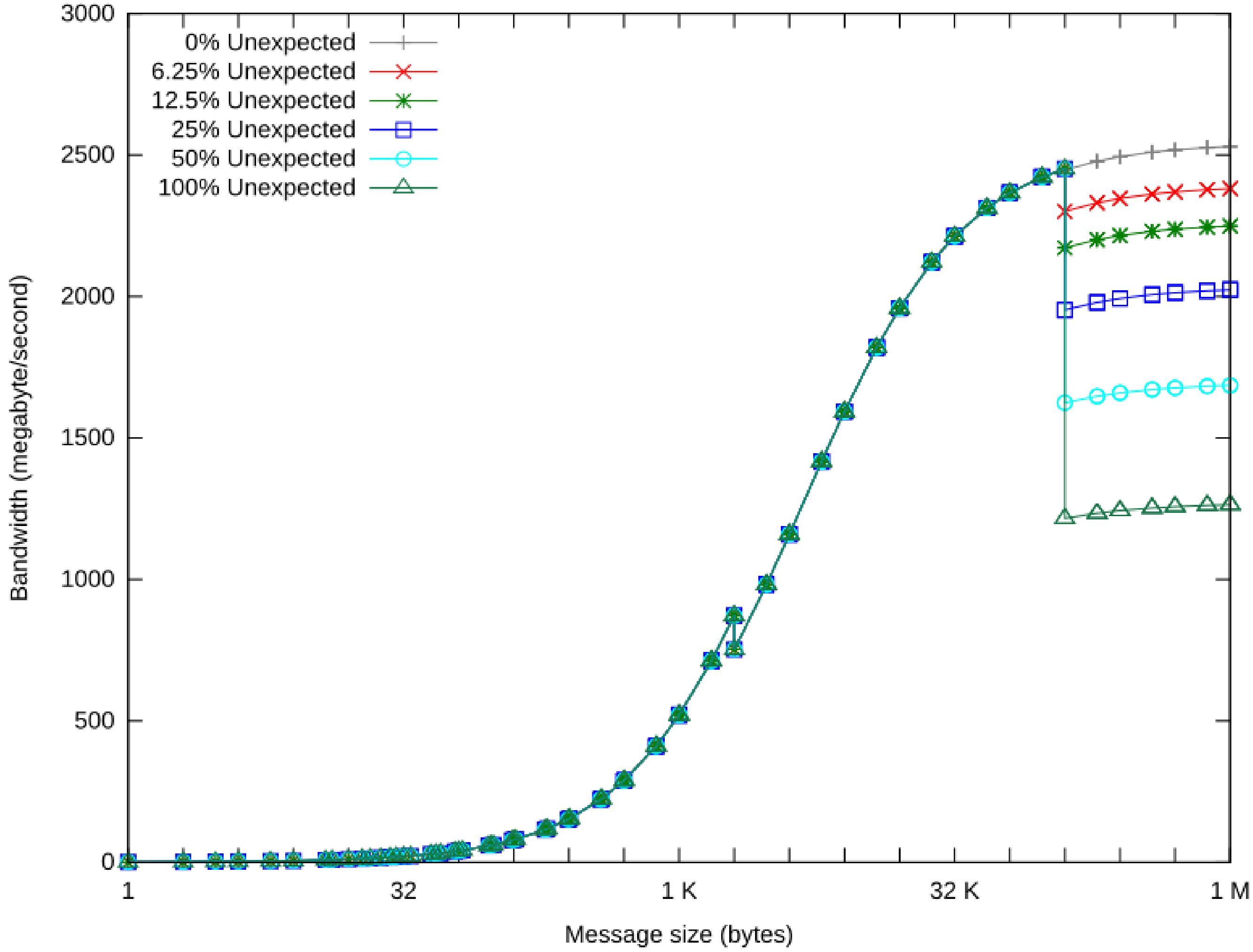
Triggered Collectives Summary

- Triggered operations provide a general set of building blocks
  - Supports a variety of collective operations
  - Supports a variety of algorithms
  - Has usage beyond just collectives offload
- Collective offload has limited performance upside versus idealized host implementation
  - 2x performance improvement due to improved latency and improved message rate
  - Performance could be improved somewhat by having host "push" data
- Noise sensitivity substantially reduced when operations are offloaded

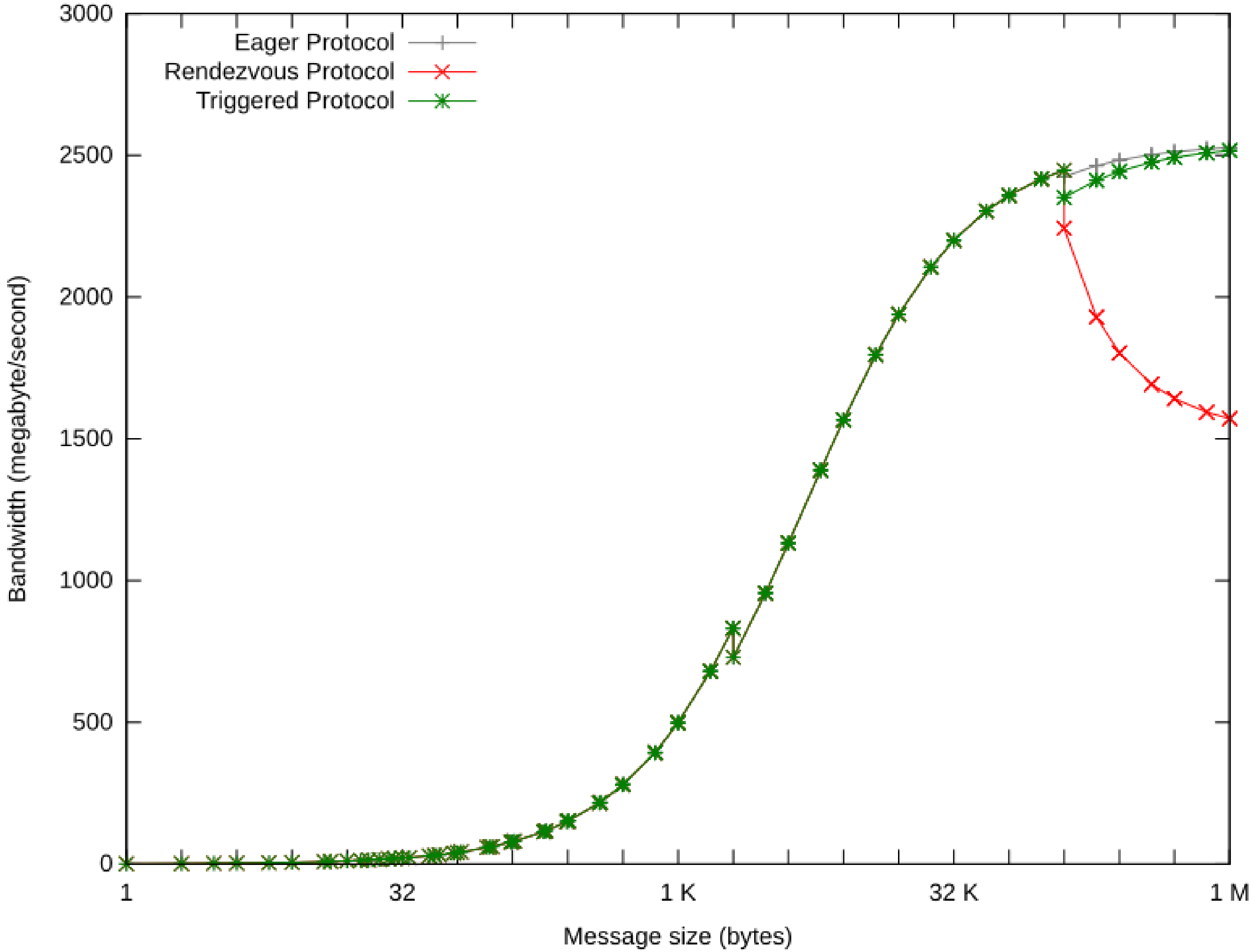
Triggered Operations for a Rendezvous Protocol

Barrett, Brightwell, Hemmert, Wheeler, Underwood. “Using Triggered Operations to Offload Rendezvous Messages,” in Proceedings of the European MPI Users’ Group Conference, September 2011.

Ping-Pong Bandwidth



Ping-Pong Bandwidth



Linux XPMEM for Progress

- Based on SGI IRIX sproc lightweight process
  - sprocs were able to attach segments of other sprocs to their address space
  - Segments of other sprocs mapped at an offset in virtual address space
  - Used to implement SHMEM and MPI on SGI systems
- SGI Altix
  - Ran separate Linux images or “partitions”
  - “Cross-partition” memory module allowed sharing address space between processes in separate partitions (with hardware help)
  - Also works for processes in the same OS partition
  - XPMEM user-level API
    - xpmem_make()
      - Returns a unique handle representing a segment of the address space
    - xpmem_get()
      - Returns handle that can be used to map the segment of another process
    - Xpmem_attach()
      - Returns the starting virtual address of a mapping for a given handle
- Exploring using XPMEM for progress rather than threads
- http://code.google.com/p/xpmem

Acknowledgments

- Sandia
  - Brian Barrett
  - Scott Hemmert
  - Kevin Pedretti
  - Mike Levenhagen
- Intel
  - Keith Underwood
  - Jerrie Coffman
  - Roy Larsen
- System Fabric Works

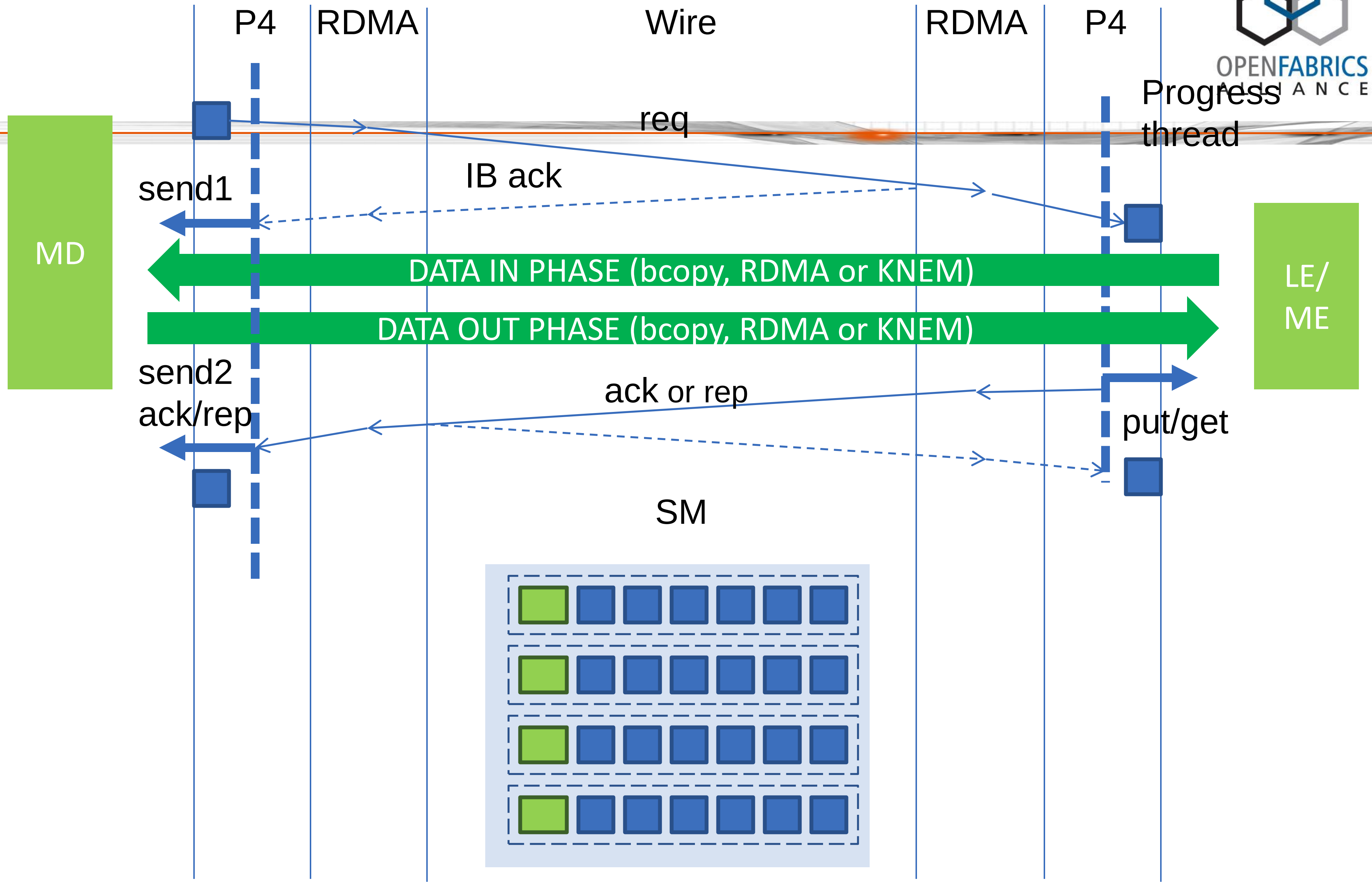
Portals4 over IB+SM

Work by Frank Zago & Bob Pearson

Supported by Sandia and Intel

Progress Report

- 2010 base
  - Focus was on supporting the spec not performance
  - IB only
- 2011 changes
  - Merged IB and SM (KNEM) implementations
  - Implemented correct overflow behavior
  - Implemented late MR mapping
  - Performance tuning, focused on latency
  - All shmem and MPI tests passing, tests up to 32 nodes (Stan Smith @intel)


P4
RDMA
Wire
RDMA
P4
Progress thread
req
IB ack
send1
MD
DATA IN PHASE (bcopy, RDMA or KNEM)
DATA OUT PHASE (bcopy, RDMA or KNEM)
LE/ ME
send2
ack/rep
ack or rep
put/get
SM

Performance

Test	SM Transport	IB Transport
LE/CT short message latency	610 nsec	3.28 usec
ME/EQ short message latency	690 nsec	3.18 usec
Short message rate	3.26 M msg/sec	1.07 M msg/sec

Measurements made on 2GHz Magny-cours nodes
with CX2 QDR HCA and 1 QDR switch
i.e. old and slow

2012 Work Plan

- Maintenance
  - Track spec changes (mostly minor)
  - Continue testing and shoot bugs
- Code refactoring
  - Reduce lines of code and cleanup three implementations: ib, sm, mc
- Performance tuning
  - Reduce CPU utilization is the focus
  - Implement shared progress engine (XPMEM based)

Where to find the code

- http://code.google.com/p/portals4/
  - Then source->browse->svn->trunk
  - Follow the directions in README, or

- % svn checkout http://portals4.googlecode.com/src/trunk/ portals4-read-only