Toward MPI Asynchronous Progress on Cray XE Systems

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Overview

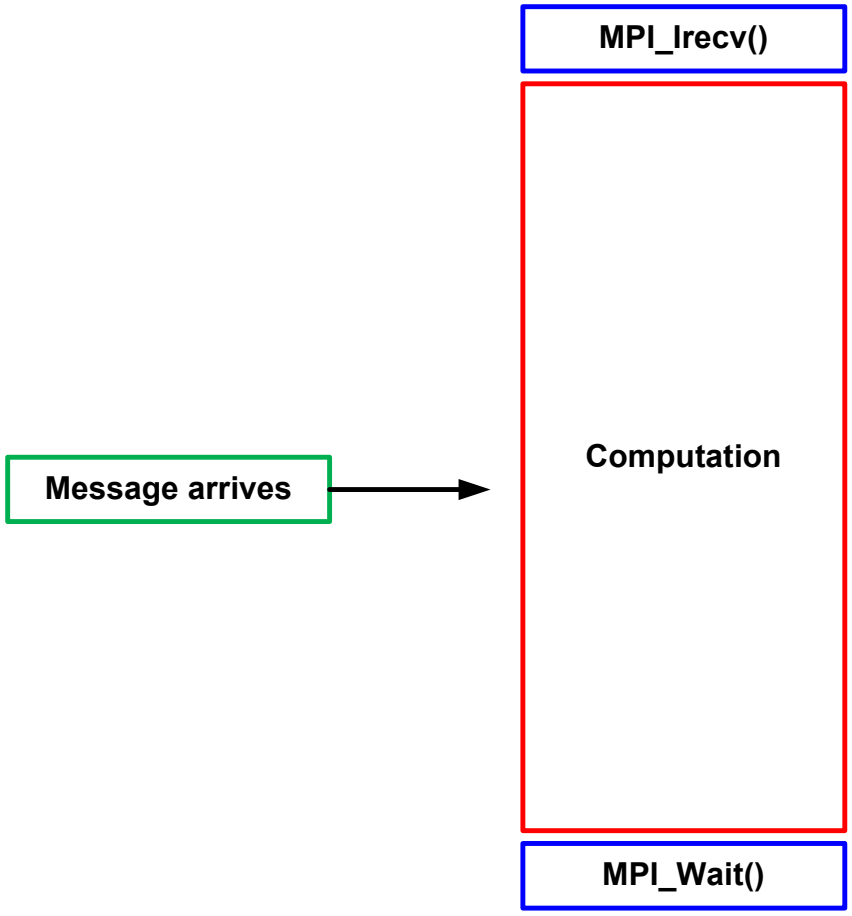
- MPI Progress - what is it?
- XE6 (Gemini) Features relevant to MPI progress
- MPICH2 Enhancements for MPI progress on Gemini
- Core Specialization and MPI progress
- Benchmark and application results
- Future work

MPI Progress Rule

- **Determines how an MPI communication operation completes once it has been initiated**
- **Strict interpretation**
  - *Once a communication has been initiated no further MPI calls are required in order to complete it*
- **Weak interpretation**
  - *An application must make further MPI library calls in order to make progress*
- **Primarily an issue for point-to-point calls, but also relevant to non-blocking collectives – to be introduced in MPI version 3.**

Receive side progression example

- *A well written application should post its receives early so as to overlap data transfer with computation*
- But messages typically arrive during the computation
- Matching occurs and bulk data transfer starts in the next MPI call, MPI_Wait() if only weak MPI progression interpretation supported
- How do we achieve independent progression?
  - Asynchronous progress thread(s)
  - Offload to the NIC



What Gemini Hardware Provides

Gemini Hardware Features and MPI Progress

- **DMA Engine with four virtual channels**
  - Local interrupt can be generated along with a Completion Queue Event (CQE) upon completion of a TX descriptor (RDMA transaction)
  - Remote interrupt and remote CQE can be generated at a target node when a RDMA transaction has completed
  - RDMA fence capability
- **Completion Queues configurable for polling or blocking (interrupt driven)**
- **Gemini has low overhead method for a process operating in user-space to generate an interrupt at a remote node (along with a CQE)**
- **No explicit support for MPI**

MPICH2 Enhancements to Support Asynchronous Progress

MPICH2 on XE - Basics

- Based on Argonne National Lab (ANL) MPICH2 Nemesis CH3 channel
- A GNI Nemesis Network Module (Netmod) interfaces the upper part of MPICH2 to the XE network software stack
- Full support for MPI-2 thread safety level MPI_THREAD_MULTIPLE
- Progress thread infrastructure (although simplistic) already exists in the library

MPICH2 on XE Basics (2)

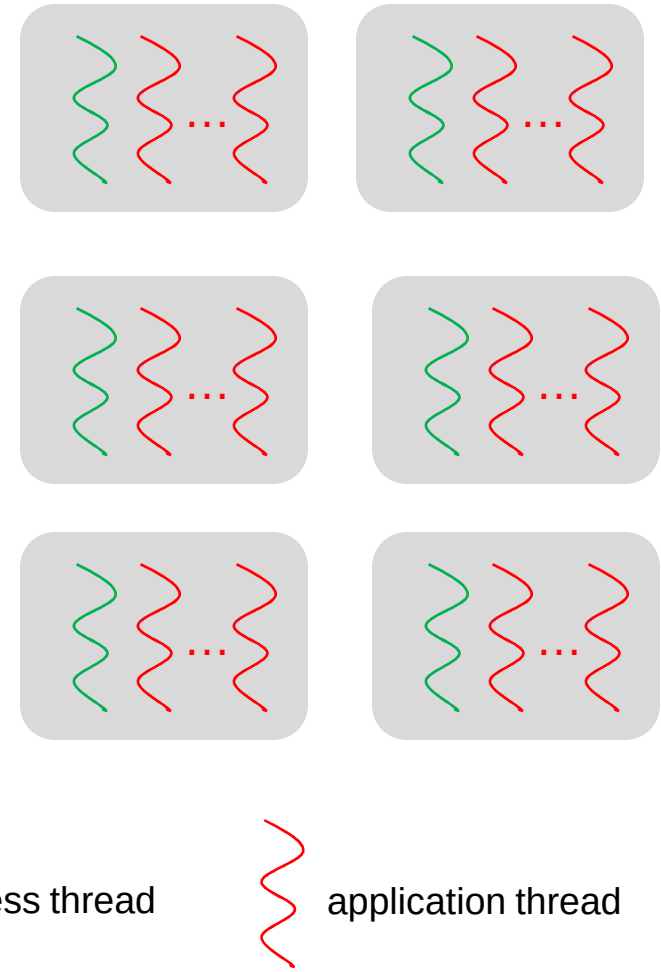
- **The eager protocol both for intra-node and inter-node messaging is CPU intensive and not suitable for asynchronous progress**
- **The rendezvous path for intra-node messages is also CPU intensive and not suitable for asynchronous progress**
- **The rendezvous – Long Message Transfer (LMT) – path for inter-node messages is not CPU intensive (usually):**
  - Rendezvous messages up to 4 MB in size normally use a RDMA read LMT protocol
  - Messages larger than 4 MB, or in the case of shorter messages when hardware resource depletion is occurring, use a cooperative RDMA write LMT protocol
  - The Gemini DMA engine (BTE) is normally used for these transfers

Enhancing MPICH2 on XE for Better MPI Progress - Goals

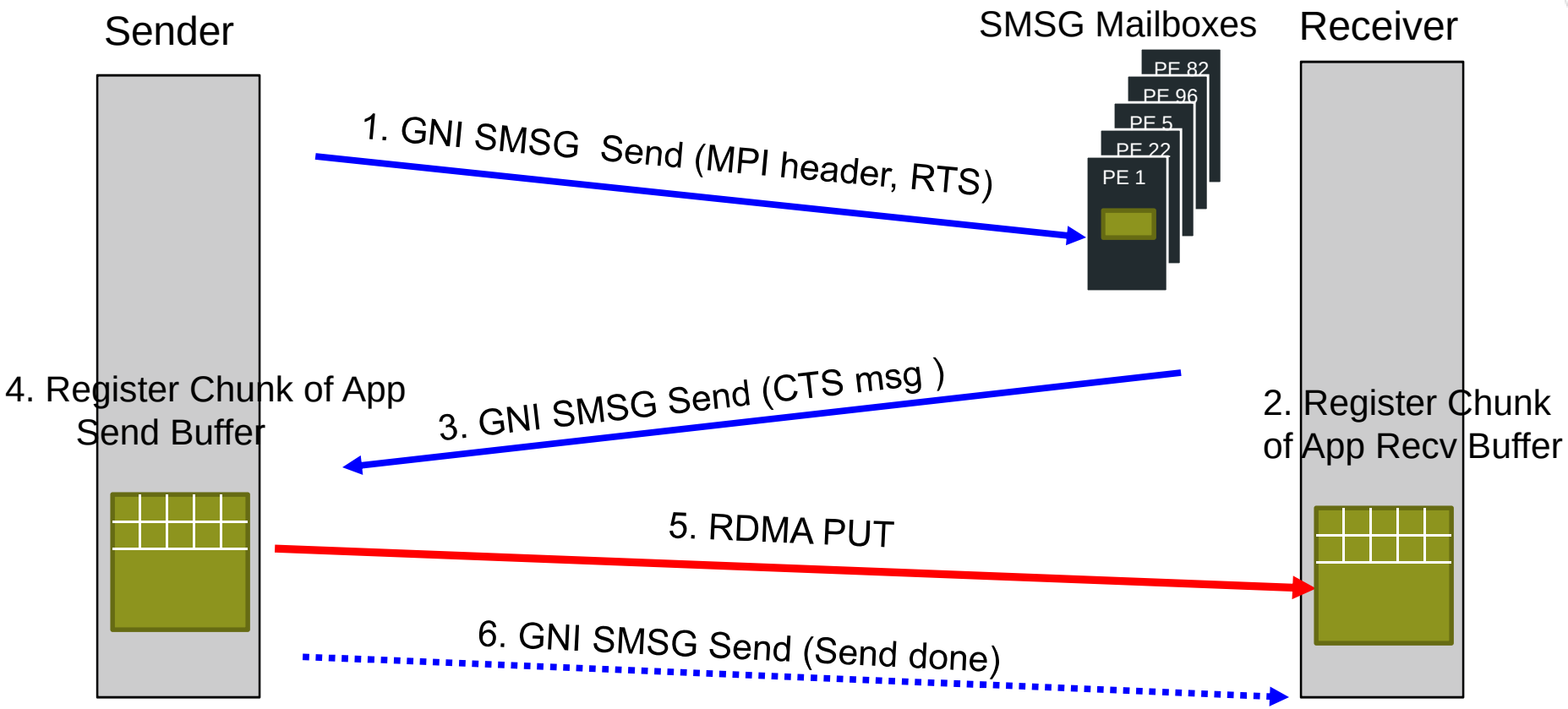
- Keep complexity/new software to a minimum
- Minimize impact on short message latency/message rate
- Don’t focus on a single message transfer protocol path for providing MPI progress (e.g. don’t focus just on RDMA read protocol)
- First phase focuses on better progression of longer message sizes (32 – 64 KB or longer)

MPICH2 - Progress Thread Model

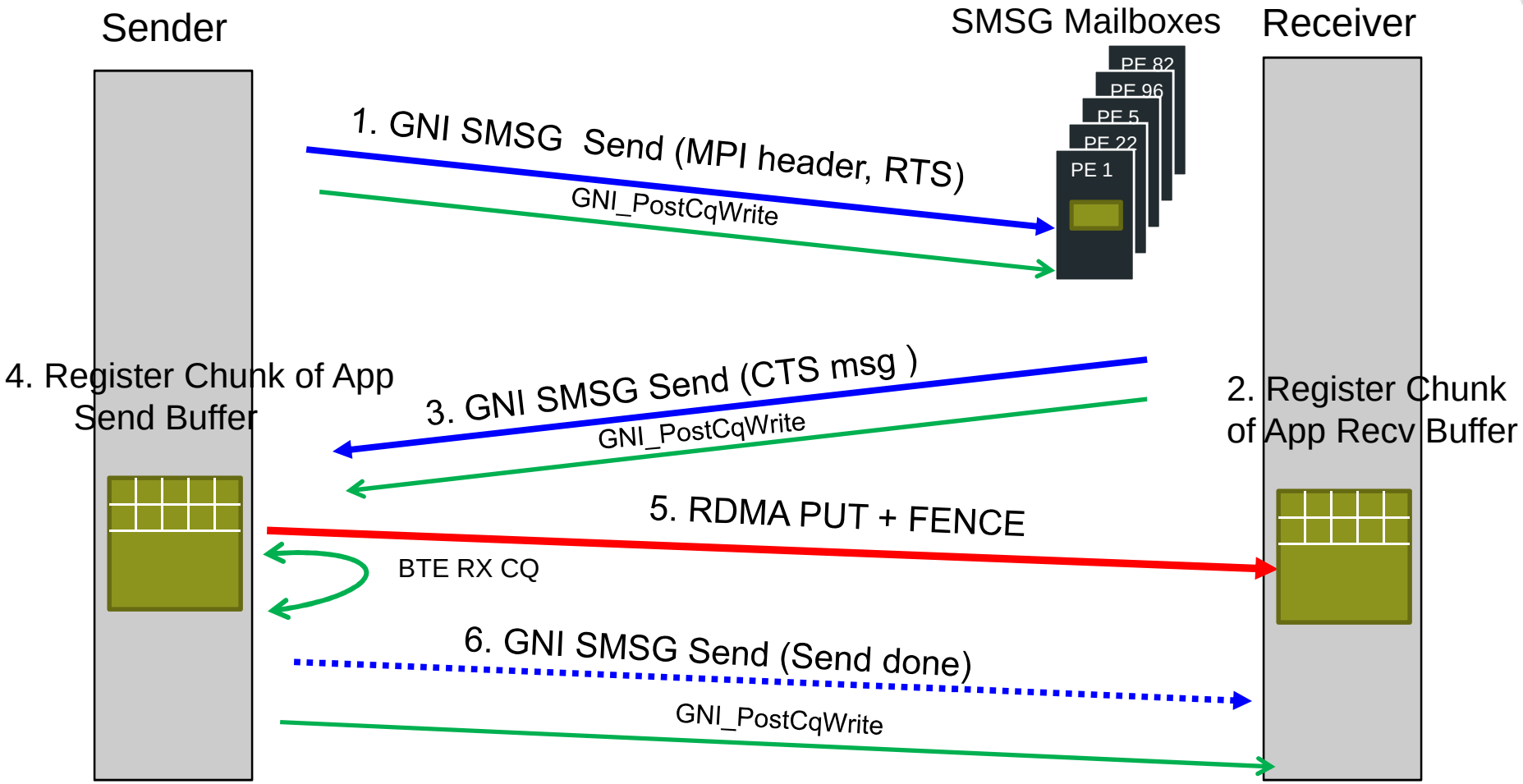
- Each MPI rank on a node starts an extra progress thread during MPI_Init.
- An extra completion queue (CQ) is created with blocking attribute during MPI_Init
- The progress threads call *GNI_CqWait* and remain blocked in the kernel until an interrupt is delivered by the Gemini NIC indicating progress on an MPI message receive or send
- Interrupts are only generated when progressing inter-node LMT (rendezvous) messages



LMT RDMA Write Path – No Progress



LMT RDMA Write Path – With Progress



Core Specialization and MPI Progress

Core Specialization

- Modifications to the Linux kernel to allow for dynamic partitioning of the cores on a node between application threads and OS kernel threads and system daemons
- Provides an interface to allow application libraries to specify whether threads/processes it creates are to be scheduled on the application partition or the OS partition
- User of a parallel application specifies at launch time how many cores, if any, per node to reserve for the OS partition

Core Specialization and MPI progress

- Typical HPC application threads tend to run **hot**, i.e. they don't typically make calls that result in yielding of the core on which they are scheduled
- Because of this, MPI progress threads need to have at least one core of a *compute unit* available per node for efficient handling of interrupts received from Gemini
- Core Specialization provides a convenient way to partition cores on a node between **hot** application threads, and **cool** system service daemon threads as well as MPI progress threads.

Job Container/Corespec Example

Tell job container package that the next thread/process created by this process should not be placed like an application thread/process.

Tell CoreSpec package that this task (thread) should be scheduled on OS partition if one is available, otherwise use default Linux scheduler policy.

```
int disable_job_aff_algo(void) {
    int rc;
    int fd = open("/proc/job", O_WRONLY);
    if (fd == -1){
        return -1;
    }
    rc = write(fd, "disable_affinity_apply",
     strlen("disable_affinity_apply"));
    if (rc < 0){
        close(fd);
        return -1;
   }
   close(fd);
   return 0;
}

int task_is_not_app(void) {
    size_t count;
    FILE *f;
    char zero[]="0";
    char   filename[PATH_MAX];

    snprintf(filename, sizeof(filename),"/proc/self/task/%ld/task_is_app",
             syscall(SYS_gettid));
    f = fopen(filename, "w");
    if (!f) {
        return -1;
    }

    count = fwrite(zero,sizeof(zero),1,f);
    if (count != 1) {
        fclose(f);
        return -1;
    }
    fclose(f);
    return 0;
}
```

MPI Asynchronous Progress - enabling

- export MPICH_NEMESIS_ASYNC_PROGRESS=1
- export MPICH_MAX_THREAD_SAFETY=multiple

Results

Sandia MPI Benchmark (mpi_overhead)

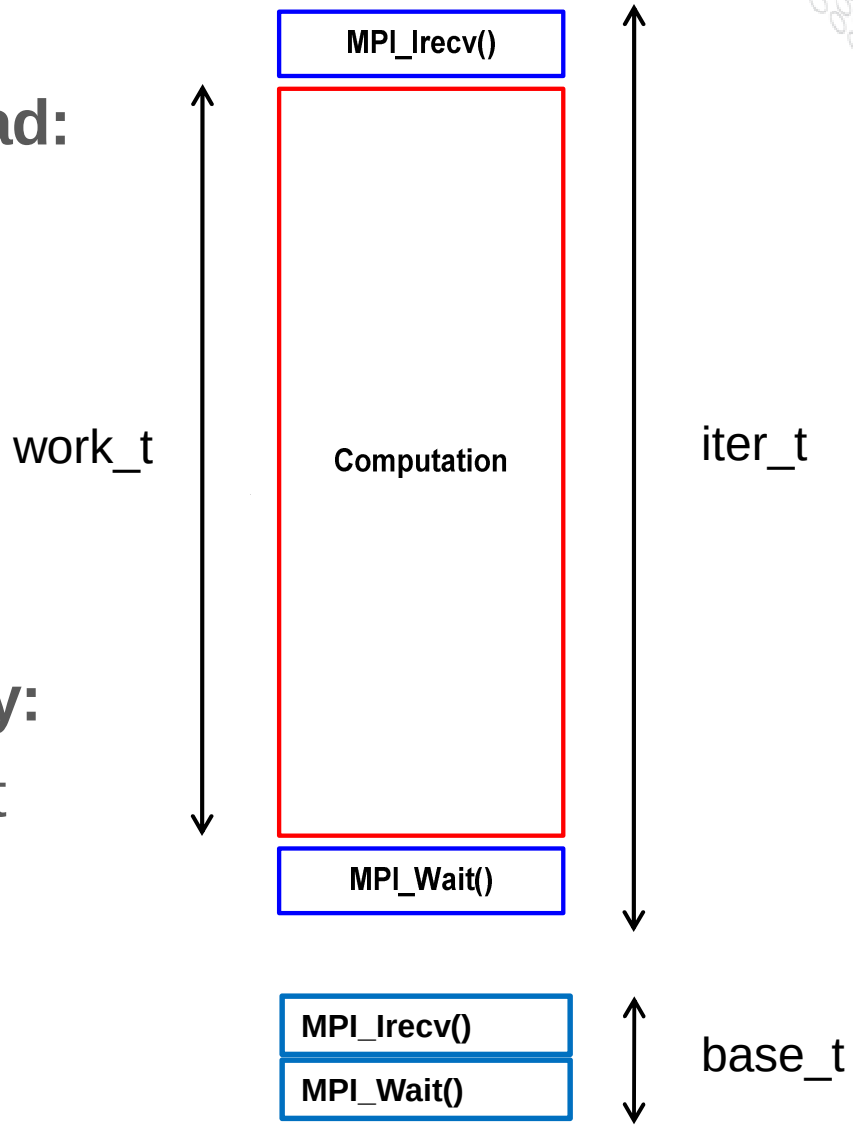
Measures MPI message overhead:

overhead = iter_t – work_t

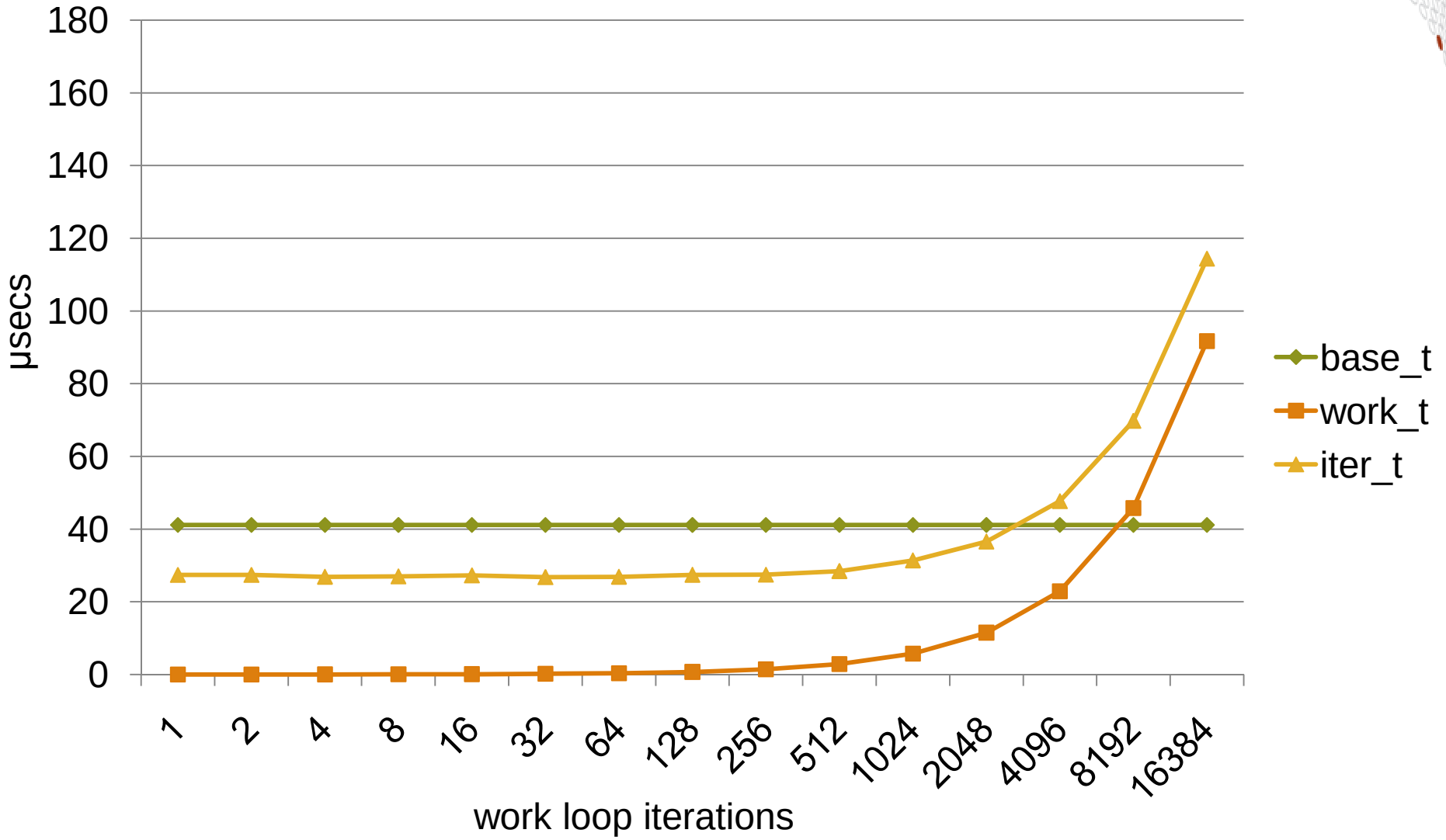
Measures application availability:

avail = 1 – (iter_t – work_t)/base_t

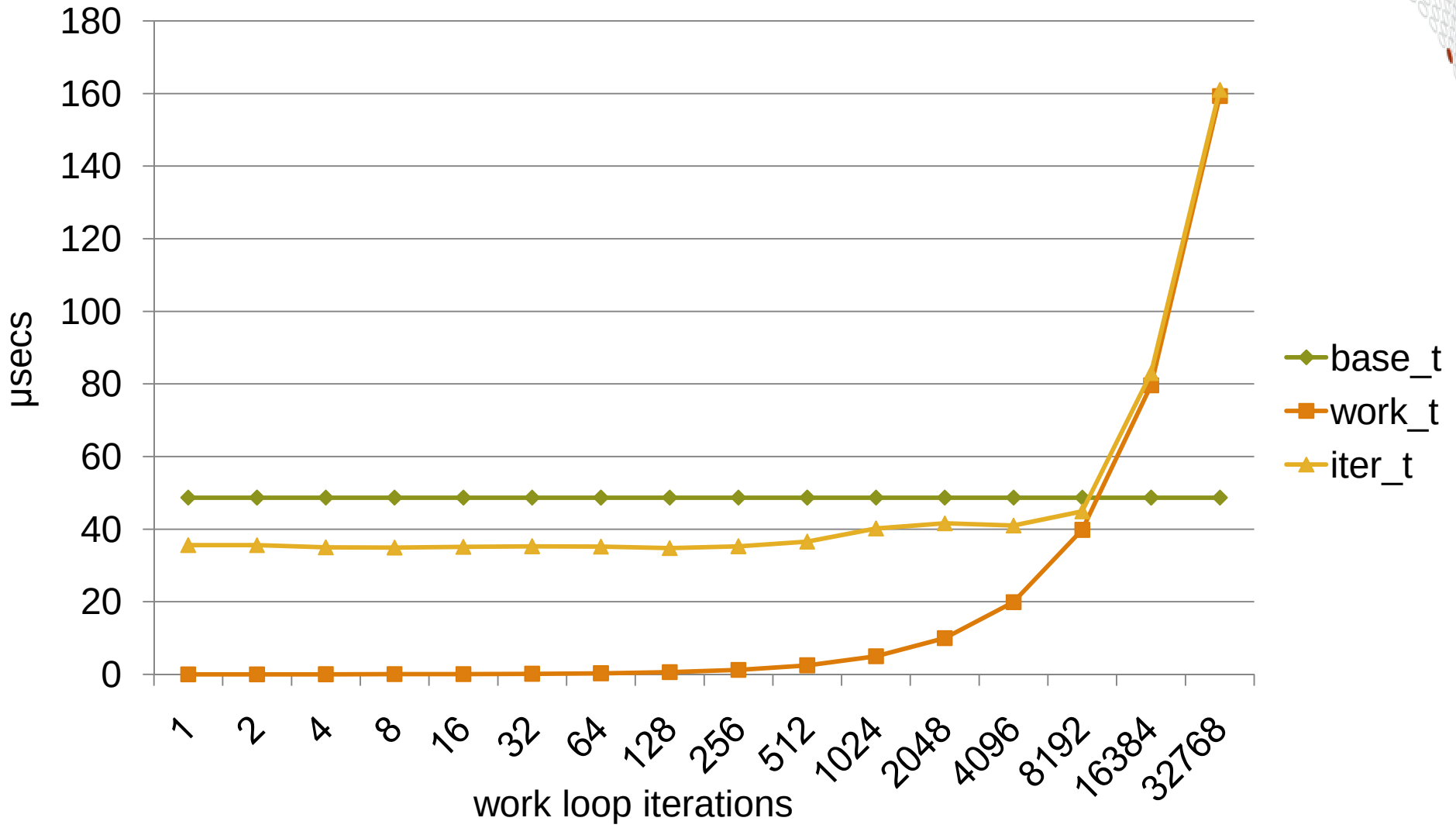
http://www.cs.sandia.gov/smb/index.html



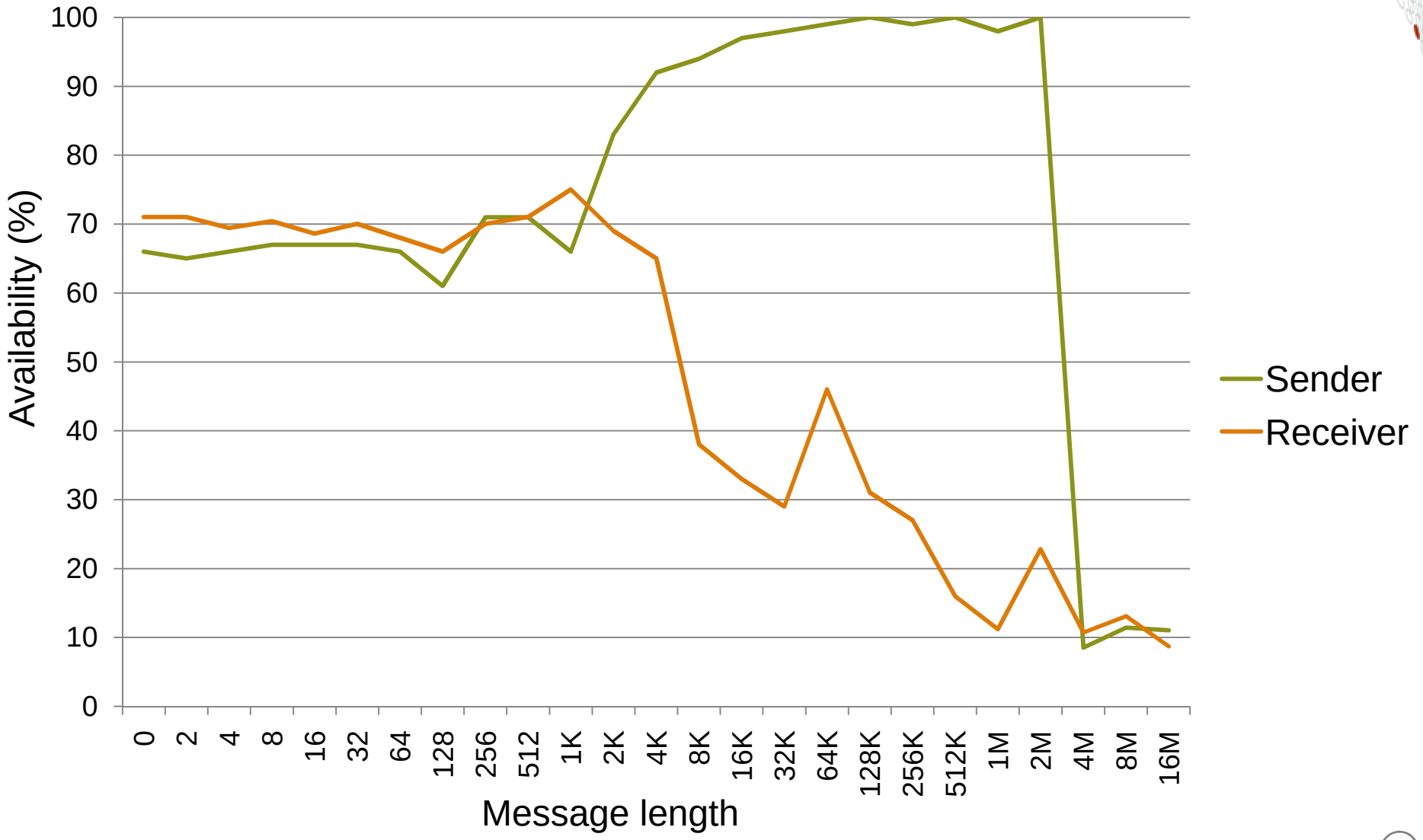
SMB – Receive side 64 KB message size (no progress)



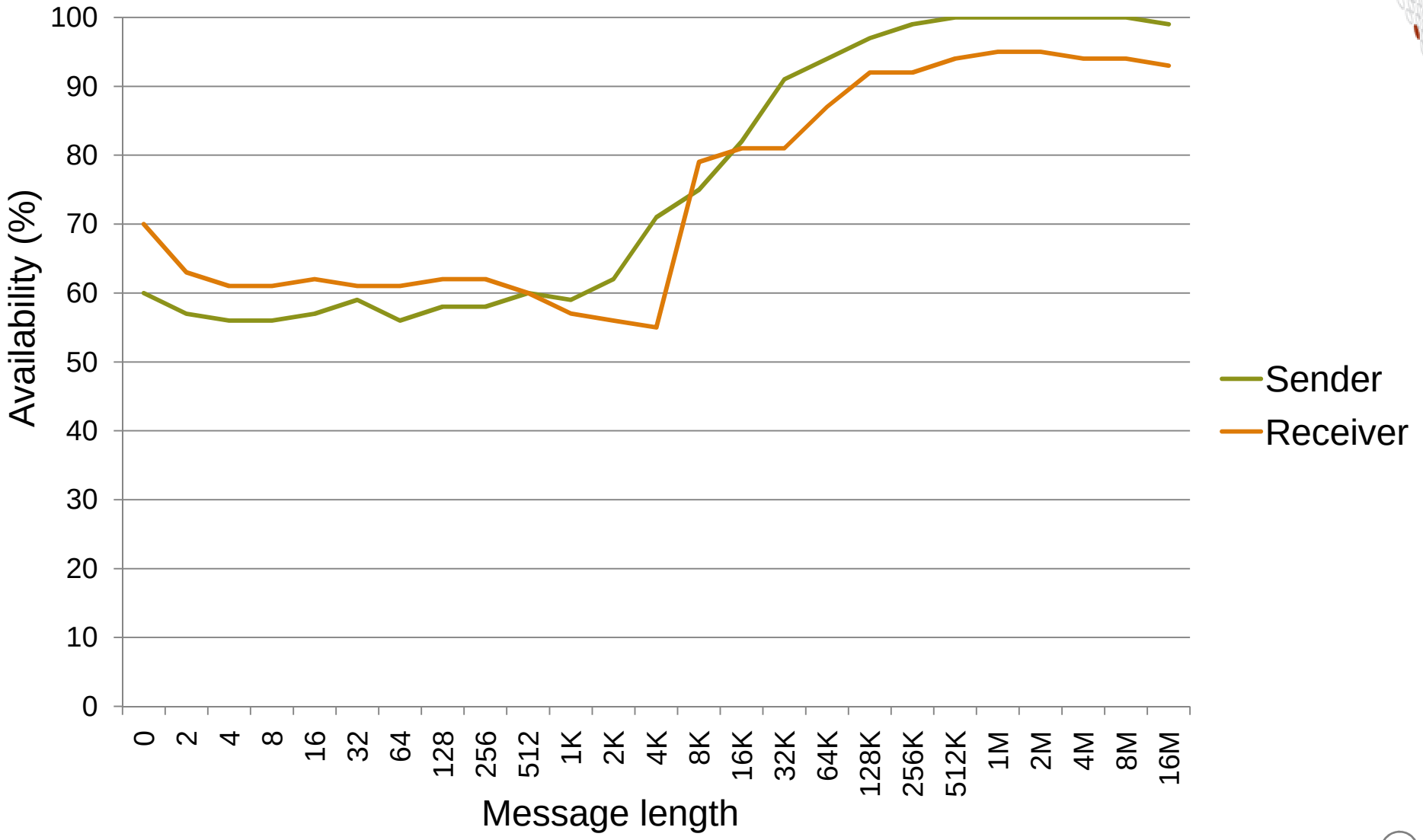
SMB – Receive side 64 KB message size (progress enabled)



Availability – no progress



Availability – progression enabled



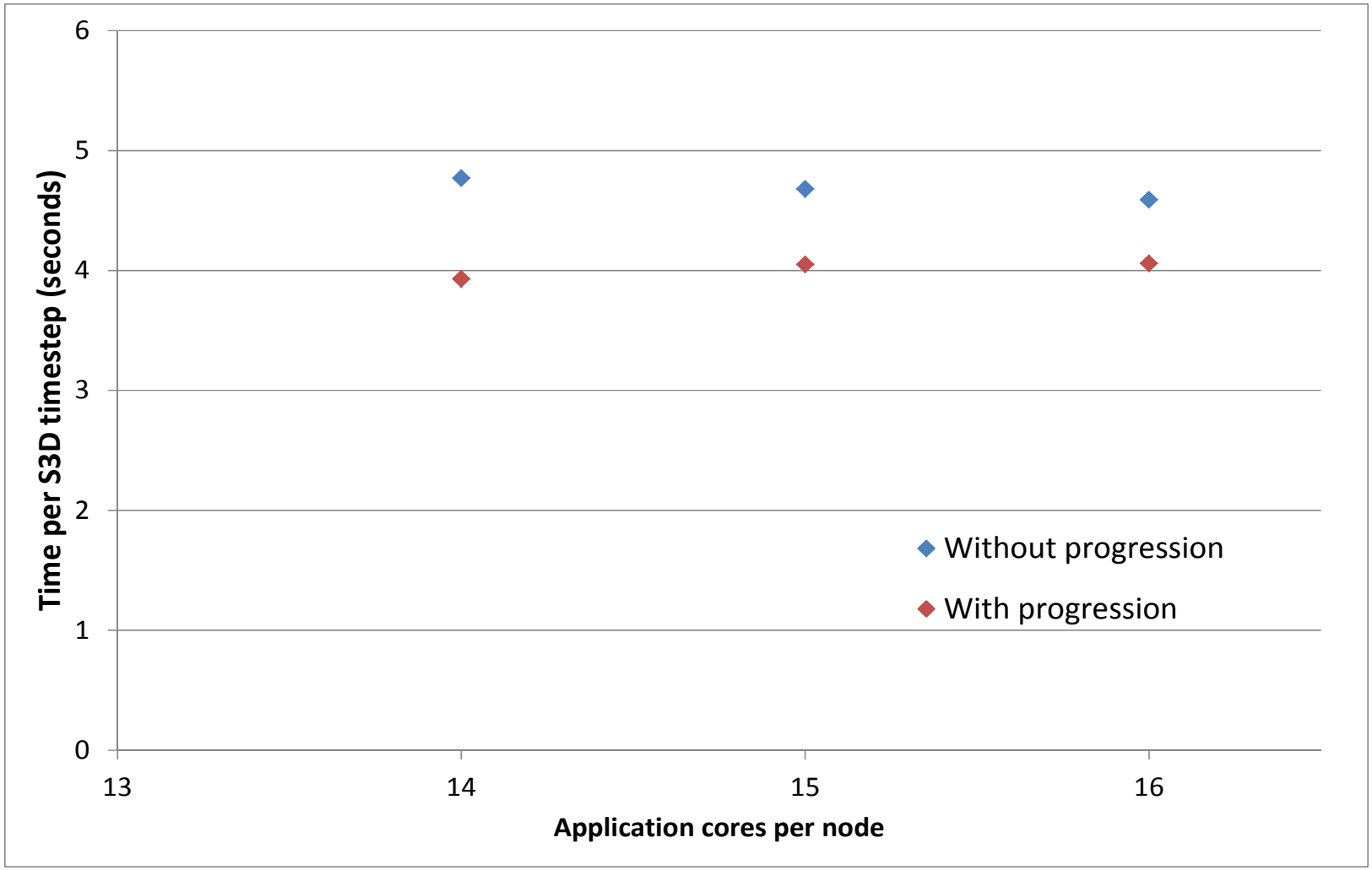
S3D Application

- Hybrid MPI/OpenMP
- Joint work by ORNL and Cray to prepare app for either using accelerators or OpenMP only on node
- Large messages for the data set considered

```
|-----------------------------------------------------
| Time%   | Time       | --  |   Calls |Total
|-----------------------------------------------------
100.0%    | 333.554284 | --  | 2022296 |Total
|-----------------------------------------------------
|  56.7%  | 189.059471 | --  |  605408 |USER
||====================================================
|  38.3%  | 127.905679 | --  |  869027 |MPI
||----------------------------------------------------
||  23.7% |  78.906595 | --  |   61200 |mpi_waitall_
||  11.8% |  39.426609 | --  |    6960 |mpi_wait_
||   2.4% |   7.933348 | --  |  399480 |mpi_isend_
||====================================================
|   4.1%  |  13.729663 | --  |  546009 |OMP
|…
```

MPI Msg Bytes	MPI Msg Count	< 16 Bytes	16 – 256B Bytes	256 – 4K Bytes	4K – 64K Bytes	64 K – 1M Bytes
22238303636	401311	1795	27	100806	2	298681

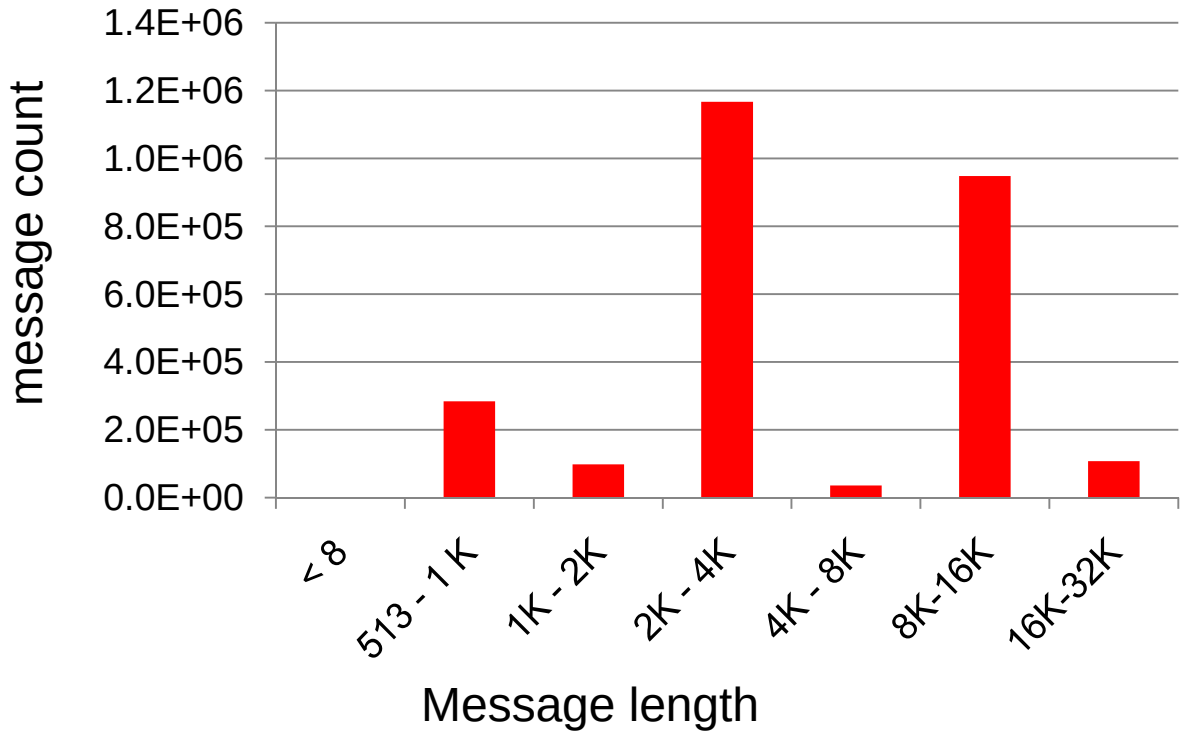
S3D Timings with and without Progression



Runs done on 64 XK nodes

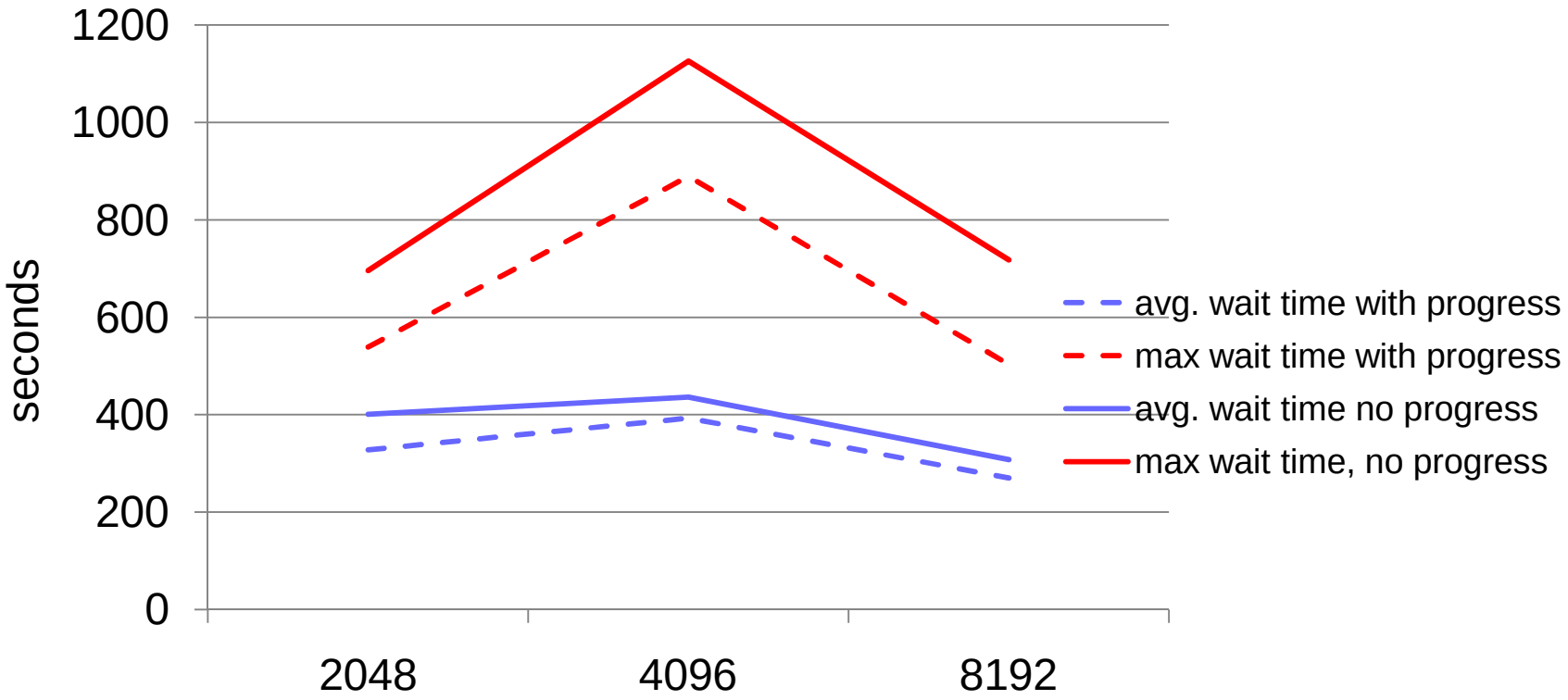
MILC Application

- Flat MPI application
- Message sizes more varied, both eager and rendezvous protocols are being used
- Significant amount of intra-node messaging



MILC Application – MPI_Wait time

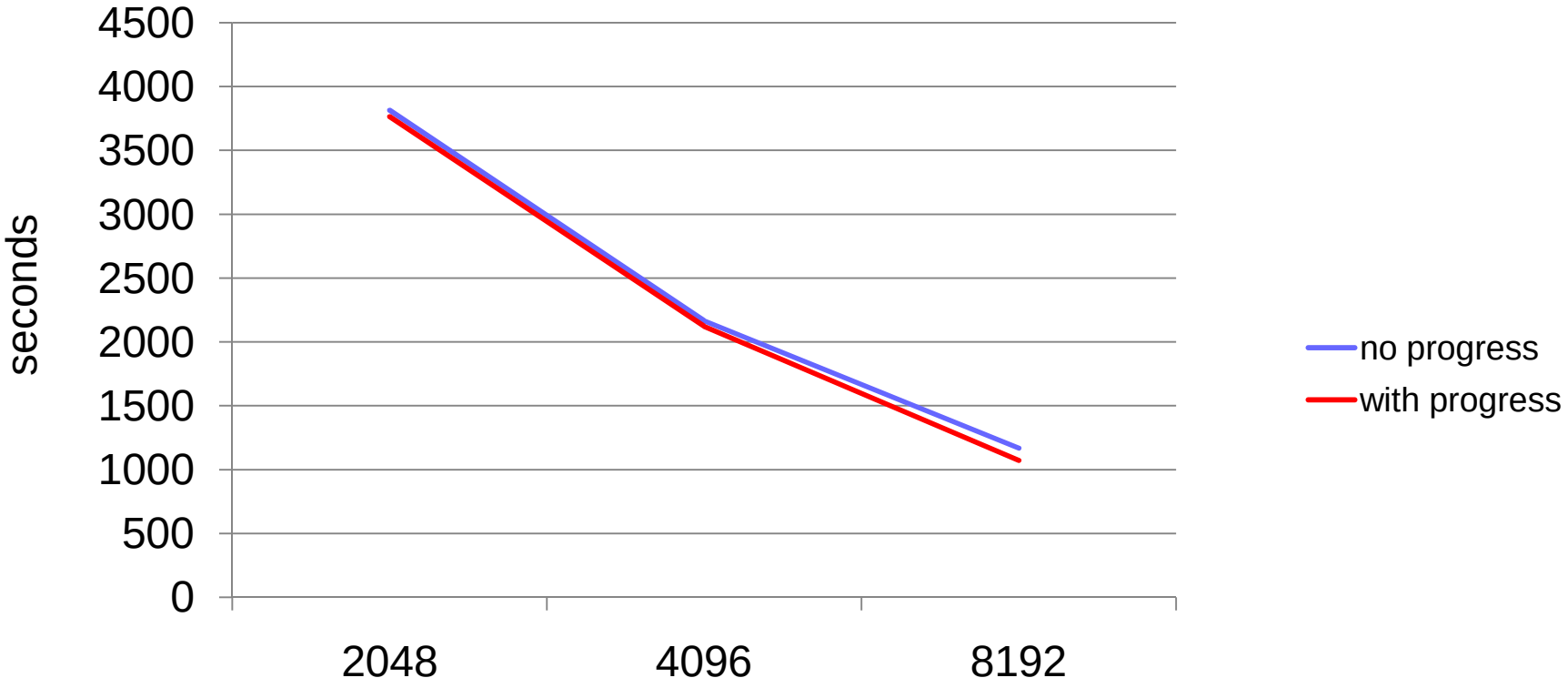
- App was modified to measure time spent in core gather/scatter communication scheme
- Non-blocking send/recvs used with some intervening work
- Max MPI_Wait time reduced significantly



2048 runs had to be run 16 ranks/per nod due to memory size

MILC Application – actual runtime

- The actual runtime changed much more modestly
- Load imbalance and MPI_Allreduce sync points may limit the actual speedup for this particular job type for MILC
  - ~8 % improvement at 8192 ranks
  - ~2 % improvement at 4096 ranks



Conclusions

- Thread-based method to progress does show some promise based on micro-benchmarks
- The current approach can be effective for applications with larger messages (at least 32 KB), but a mixture of messages using eager and rendezvous path limits the usefulness of the progress threads
- Not shown in the data here, but in the paper, that for flat MPI codes, CoreSpec is highly recommended when trying to use this thread-based progress mechanism

Future Work

- Enhance GNI interface to allow for more efficient use of the DMA (BTE) engine, allowing for better handling of shorter MPI messages (< 32KB)
- Use extensions to the CoreSpec/job package to schedule the progress threads on unused hyperthreads for next generation of Gemini interconnect
- Enhancements to GNI to more efficiently wake up progress threads
- Integrate the improved progress thread framework back into mainline Nemesis MPICH2 code

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