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The University of Texas at Austin

All the things you need to know about Intel MPI Library

Jerome Vienne
viennej@tacc.utexas.edu
Texas Advanced Computing Center
The University of Texas at Austin
Austin, TX

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A Heterogeneous Environment

MPI performance depends on many factors

- CPUs (Number of cores, Cache sizes, Frequency)
- Memory (Amount, Frequency)
- Network Speed (10,20,40 ... Gbit/s)
- Size of the job
- Type of code: Hybrid (ex: OpenMP+MPI) or Pure MPI

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MPI libraries have to make choices

- Why ? Because the number of combinations is too large.
- Are these choices optimal for my application ? Not necessarily.
- Can we change them ? Yes, this is why we are there.

Aim of this talk

- ”How to tune MPI” cannot be found easily inside books.
- Show that MPI libraries are not black boxes.
- Describe concepts that are common inside MPI libraries.
- Understand the difference between MPI libraries.
- Provide some useful commands for Intel MPI.
- Result: Help you to reduce the time and memory foot print of your MPI application

Before to start

Warnings !!!

- Talk based on Intel MPI (few references to MVAPICH2 and OpenMPI).
- All experiments were done on Stampede supercomputer at TACC.
- Tuning options are specific to a MPI library ! But concepts are common.
- Options can have counter-effects !
- MPI libraries have lot of options for tuning, we will only cover the most important ones.
- Tuning could be time consuming, but long-term, it might be worth it

Plan

- Basic Tuning
  The Choice of the Benchmark
  Profiling
  Hostfile
  Process Placement
  To conclude

- Intermediate Tuning
  Inter-node Point-to-Point Optimization
  Intra-node Point-to-Point Optimization
  Collective Tuning
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The Choice of Benchmarks

Different MPI library = Tuning Based on Different Benchmarks

- Intel MPI: Intel MPI Benchmarks (IMB)
- MVAPICH2: OSU Micro-Benchmarks (OMB)

The Choice of Benchmarks

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IMB or OMB, which one is the best to use ?

- Both are communication intensive without computation
- Depend on your application
- **The best benchmark is your application !**

The Choice of Benchmarks

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- MVAPICH2: OSU Micro-Benchmarks (OMB)

IMB or OMB, which one is the best to use ?

- Both are communication intensive without computation
- Depend on your application
- **The best benchmark is your application !**

But... let's take a look at them in detail !

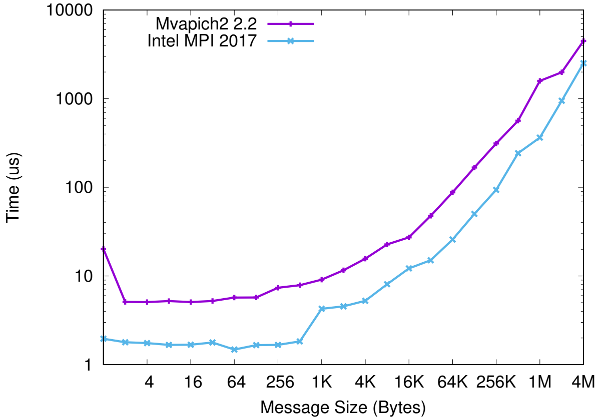
Intel MPI Benchmarks (IMB)

Details

- Originally know as Pallas MPI Benchmarks (PMB)
- Support Point-to-Point and Collective operations
- 1 program with lot of options for classical MPI functions (IMB-MPI1)
- Root changes after each iteration for collectives

Intel MPI Benchmarks (IMB)

Intel MPI vs MVAPICH2 using IMB Bcast with 256 cores



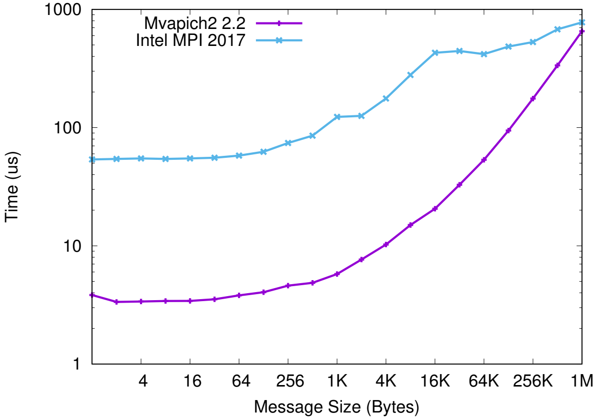
OSU Micro-Benchmarks (OMB)

Details

- Very simple to use
- Support Point-to-Point and Collective operations
- Multiples programs with simple options
- Keep the same root during all iterations + use barrier

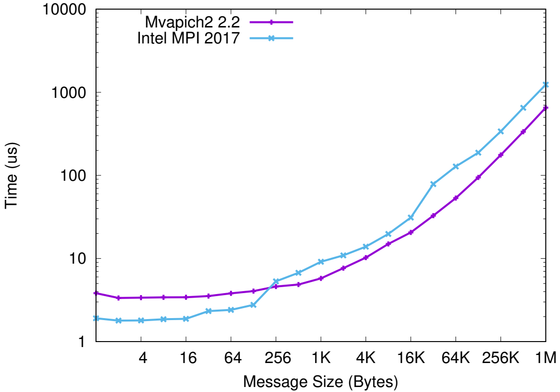
OSU Micro-Benchmarks (OMB)

Intel MPI vs MVAPICH2 using OMB Bcast with 256 cores



OSU Micro-Benchmarks (OMB)

Tuned Intel MPI vs MVAPICH2 using OMB Bcast with 256 cores



Benchmarks: What you need to know

To resume

- Don't trust them !
- They have different behaviors: so, KNOW your benchmark !
- Don't provide you necessarily the best results by default.
- Be sure that you tune things correctly if you want to compare two MPI libraries
- Collective tuning for a particular benchmark/application could be painful, we will see it later :)

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To know what you need to tune first

Why MPI profiling is important ?

- To identify which MPI functions are used, you have two choices:
  - Look at the code
  - Profile your application
- Profiling provides you all the information regarding MPI communications (size, time spent, functions called etc...)
- Could be integrated in the MPI library (ex: Intel MPI)
- Lot of tools can help you to profile your application (TAU, Scalasca, IPM, mpiP ...)

How to profile ?

With Intel MPI at runtime

mpiexec -genv I_MPI_STATS=ipm I_MPI_STATS_FILE=myprofile.txt ....

Tools

- MPI Performance Snapshots (MPS)
- Intel Trace Analyzer and Collector (ITAC)

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Impact of the hostfile

Example of command:

mpirun -np 4 -hostfile host ./a.out

- Hostfile provides the list of nodes that will be used
- Depending on the MPI library, **the same hostfile** could lead to different results !

A Quick Performance Example

NAS SP-MZ on Stampede

2 nodes, 2 MPI tasks/node with 8 OpenMP threads

```
mpirun -np 4 -hostfile host ./sp-mz.C.4
```

node1
node2

A Quick Performance Example

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Mvapich2

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Mvapich2

- Default: 176 sec.

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- Correct Hostfile: 176 sec.

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node2

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- Default: 176 sec.
- Correct Hostfile: 176 sec.
- + Process Placement: 19 sec.

Intel MPI

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Mvapich2

- Default: 176 sec.
- Correct Hostfile: 176 sec.
- + Process Placement: 19 sec.

Intel MPI

- Default: 51 sec.

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- Default: 176 sec.
- Correct Hostfile: 176 sec.
- \+ Process Placement: 19 sec.

Intel MPI

- Default: 51 sec.
- Correct Hostfile/Command: 19 sec.

How the MPI tasks are propagated?

mpirun -np 4 -hostfile host ./a.out on Stampede

node1
node2

Mvapich2	Open MPI	Intel MPI
Rank 0 on node1	Rank 0 on node1	Rank 0 on node1
Rank 1 on node2	Rank 1 on node1	Rank 1 on node1
Rank 2 on node1	Rank 2 on node2	Rank 2 on node1
Rank 3 on node2	Rank 3 on node2	Rank 3 on node1

How to set correctly your hostfile?

Mvapich2

node1:2
node2:2

Open MPI

node1 slots=2
node2 slots=2

Intel MPI

I_MPI_PERHOST=2
or
mpirun -perhost 2
or
mpirun -ppn 2

Result

Rank 0 on node1
Rank 1 on node1
Rank 2 on node2
Rank 3 on node2

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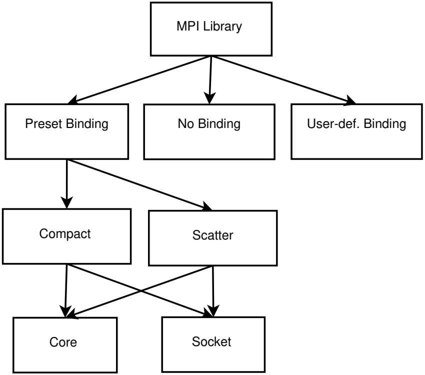
Generic Way to Map Processes



MVAPICH2

Compact-Core

Intel MPI

Scatter-Shared Socket or Core

Open MPI

Before 1.7.4: No Binding
After 1.7.4: Scatter-Core|Socket

Quick Examples with Intel MPI

Osu_latency results between cores

	Latency (us)		Description
Pair	0 byte	8 k-byte	
2-4	0.2	1.77	Same socket, shared L3, best performance
0-2	0.2	1.80	Same socket, shared L3, but core 0 handles interrupts
2-10	0.41	2.52	Different sockets, does not share L3
0-8	0.42	2.53	Different sockets, does not share L3, core 0 handles interrupts

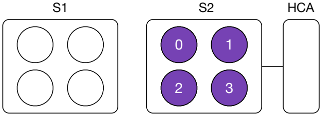
NAS SP-MZ (Do you remember it ?)

2 Nodes, 2 MPI Tasks/node with 8 OpenMP threads using MVAPICH2

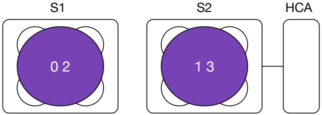
- Default Mapping: 176 seconds
- Optimal Mapping: 19 seconds

TACC

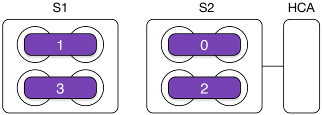
Default MPI library mappings of four MPI tasks (each with two OpenMP threads) to the two 4-core processors of a dual-socket node.



(a) MVAPICH2 2.1

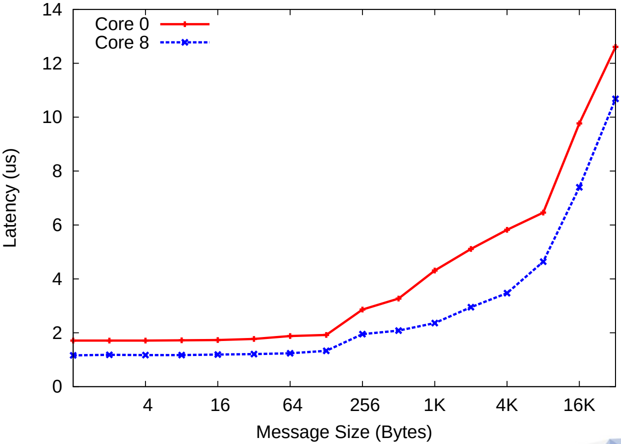


(b) Open MPI 1.8.8

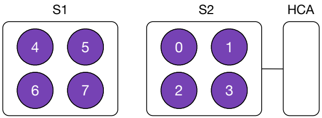


(c) Intel MPI 5.0.2

Impact of Mapping (MVAPICH2 / osu_latency)



Default MPI library mappings of eight pure MPI tasks to the two 4-core processors of a dual-socket node.



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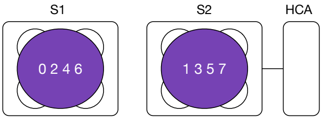

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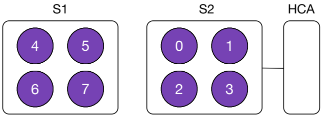

(c) Intel MPI 5.0.2

Setting the Mapping

Intel MPI

- I_MPI_PIN_PROCESSOR_LIST: Define a processor subset and mapping rules for MPI processes pinning to separate processors of this subset
- I_MPI_PIN_DOMAIN (For Hybrid code)

MVAPICH2

- MV2_CPU_BINDING_POLICY=*bunch*|*scatter*
- MV2_CPU_BINDING_LEVEL=*core*|*socket*|*numanode*
- Manual: MV2_CPU_MAPPING=0:8:9-15:1-7

Reporting the Mapping

Most of the MPI libraries provide a mechanism to report the mapping

- Intel MPI: -print-rank-map
- MVAPICH2: MV2_SHOW_CPU_BINDING=1
- OpenMPI: --report-bindings

Example

```
c421-502$ mpirun_rsh -np 2 -hostfile hosts MV2_CPU_MAPPING=2-4:10-12 MV2_SHOW_CPU_BINDING=1 ./osu_latency
-------------CPU AFFINITY-------------
RANK:0 CPU_SET: 2 3 4

RANK:1 CPU_SET: 10 11 12
```

Basic Level

Benchmarking Needed to evaluate the performance and to tune a MPI library, but it is important to know the behavior of the benchmark to do a correct evaluation

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Mapping Important specially for hybrid code.

These 4 'basic' things are easy to do and can really improve the performance of your code !

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Eager/Rendezvous protocol I

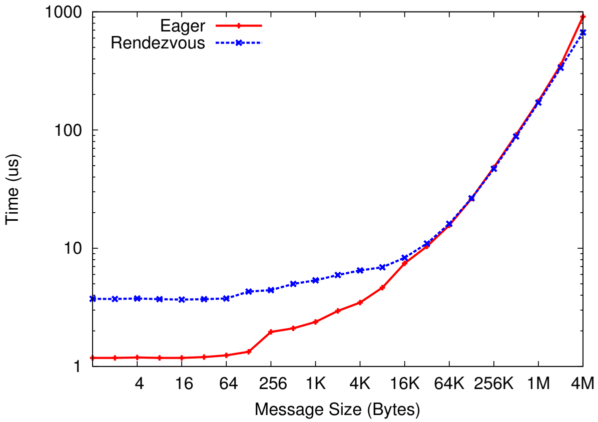
- There are multiple different protocols for sending messages.
- We will only focus here on eager / rendezvous protocol.
- Switch point between these two protocols can be called *threshold*, *eager threshold* or *eager limit*.
- It is an implementation technique, it is not part of the MPI standard

Eager
: The sender process *eagerly* sends the entire message to the receiver. Typically used for 'short' messages.

Rendezvous
: Based on 'Request To Send' / 'Clear To Send' (RTS/CTS) techniques. Typically used for 'long' messages.

Eager vs Rendezvous

Osu_latency and MVAPICH2



Eager/Rendezvous: Pro/Con

Eager

Pro: Reduces synchronization delays
Best for latency

Con: Significant buffering may be required to provide space for messages
Can cause memory exhaustion / program termination when receive process buffer is exceeded

Rendezvous

Pro: Scalable
Robustness by preventing memory exhaustion

Con: Delay due to handshaking between sender and receiver

Setting the eager threshold

Intel MPI

I_MPI_EAGER_THRESHOLD= $<$ *nbytes* $>$

MVAPICH2

MV2_IBA_EAGER_THRESHOLD= $<$ *nbytes* $>$

Open MPI

--mca btl_openib_eager_limit $<$ *nbytes* $>$
--mca btl_openib_rndv_eager_limit $<$ *nbytes* $>$

The threshold could be, by default, platform specific (MVAPICH2, OpenMPI) or identical for all platforms (IMPI)

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Intra-node optimization

Different mechanisms exist:

With the number of cores per node increasing in modern clusters, an efficient implementation of intra-node communications is critical for application performance.

We will introduce here two different mechanisms:

- Shared Memory
- Kernel Assisted

Shared Memory

- Used by all MPI implementations
- Double-copy implementation involves a shared buffer space used by local processes to exchange messages.
- Best approach for small messages
- Not ideal for large messages (tie down CPU, cache pollution)

Kernel Assisted I

- Single copy mechanism
- Preferred approach for medium or large messages
- You need to use:
  - Kernel module: LiMIC or KNEM
  - Kernel feature: CMA

Kernel Assisted II

CMA

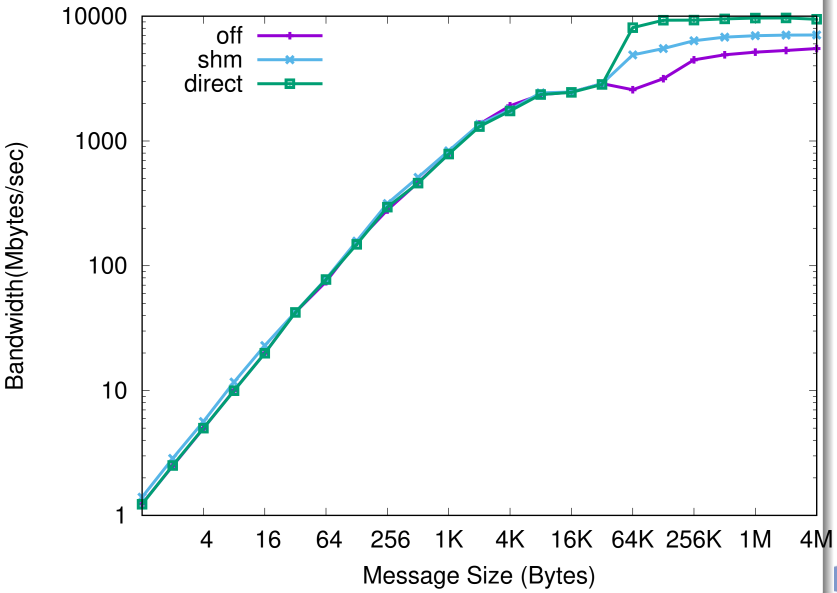
- **C**ross **M**emory **A**ttach
- Introduced with Linux kernel 3.2 and has been back-ported to some Linux distribution
- Available on Stampede, supported by Intel MPI (since 5.0u2), MVAPICH2, OpenMPI etc...
- CMA will be enable automatically for large messages since 5.1u2.

To resume

Which one is the best ?

- For short messages (eager protocol): Shared Memory is better
- For large messages (rendezvous protocol): Kernel assisted is better
- I_MPI_SHM_LMT= shm | direct | off

IMB Pingpong on Compute Node, Intra-socket



NAS results on large memory node with 32 cores using Intel MPI

Benchmark	Class	Shared (s)	CMA (s)	Speedup
CG	C	10.29	9.66	+6.12%
EP	C	3.89	3.88	+0%
FT	C	16.04	12.07	+24.75%
IS	C	1.37	1.04	+24.08%
CG	D	381.95	382.03	-0.02%
EP	D	62.07	62.08	+0.8%
FT	D	365.84	289.32	+20.91%
IS	D	26.1	20.92	+19.8%

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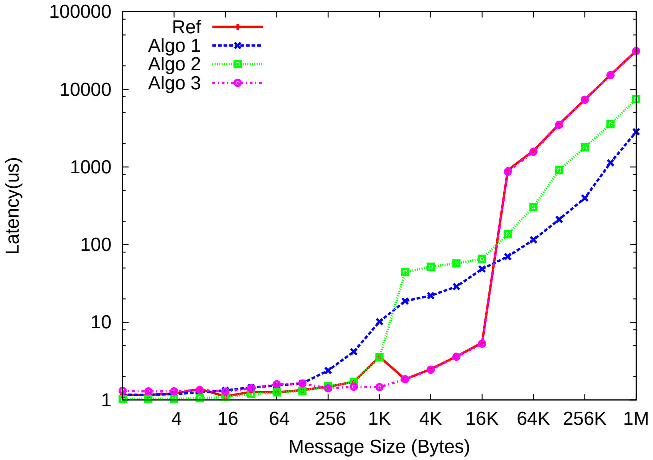
Collective tuning

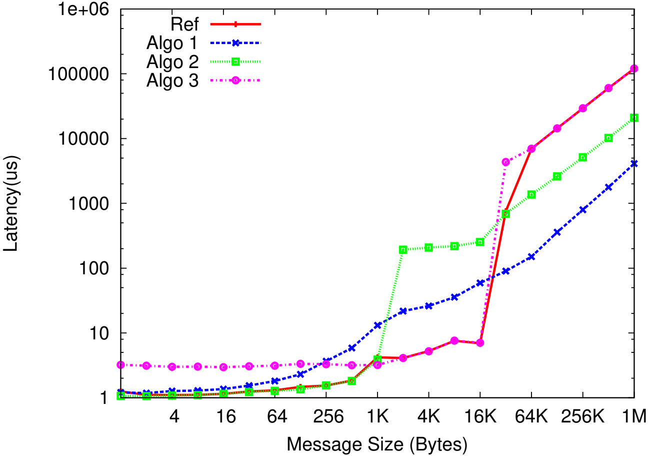
Collective communications

- Used when a communication involves more than 2 MPI tasks
- Behind each collective, there are many algorithms (Binomial Tree, Recursive Doubling, Ring Exchange etc...)
- The choice of the algorithm depends on many parameters (number of cores, network speed, architecture, message size etc...)
- Default tuning is not necessarily the best one for you.
- MPI libraries provide mechanisms to select which algorithms need to be used.

osu_gather with Intel MPI 256 cores (I_MPI_ADJUST_GATHER)



osu_gather with Intel MPI 1024 cores (I_MPI_ADJUST_GATHER)



Intermediate Level

Inter-node
: You can play with the eager threshold to improve the performance of your communication, but it will cost you more memory !

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Collectives
: There are different algorithms for each collectives, if you see that your code is spending a lot of time inside one of them, try to see if changing the algorithm could help.

Intermediate Level

Inter-node: You can play with the eager threshold to improve the performance of your communication, but it will cost you more memory !

Intra-node: Different mechanisms exist to improve the performance of large messages.

Collectives: There are different algorithms for each collectives, if you see that your code is spending a lot of time inside one of them, try to see if changing the algorithm could help.

Inter-node and collective tuning can be time consuming but intra-node optimization could be simple and provides very good results !

Plan

Conclusion

Every good things has an end...

We saw today a lot of things, don't panic if you don't remember of everything. Keep in mind the following things:

- Read the documentation :)
- MPI libraries behave differently
- Mechanisms exists to improve easily the performance of your code (Process Mappping, CMA...)
- Mechanisms exists also to reduce the memory footprint of your MPI library
- Don't be afraid to ask for help