Open MPI for HPE Cray EX Systems

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Introduction

- Goal: Provide a performant alternative MPI
  - Helpful to support different user needs
  - Aid in diagnosing application issues
- Work by ORNL & LANL to port and optimize Open MPI for HPE Cray EX systems
  - *Frontier* @ OLCF
  - *Aurora* @ ALCF
- Highlight key pieces involved in development & testing
  - Changes to Open MPI, Libfabric and OpenPMIx
  - Brief snapshot of current status

ECP OMPI-X Project

Open MPI Overview

- Developed & maintained by collaborators from
  - Academia, Industry and National Laboratories
- Open-source implementation of MPI-3 standard
- Supports resource manager interoperability via **OpenPMIx**
- Supports variety of network fabrics via UCX & **OFI libfabrics**

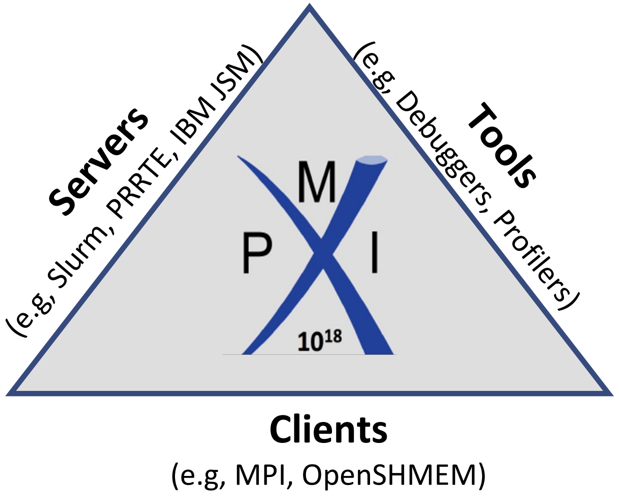
https://Open-MPI.org

Open MPI Project

OpenPMIx & PRRTE

- OpenPMIx: A feature complete implementation of PMIx Standard
  - Provides libraries and programming models portable and well-defined access to commonly available process management services
  - Implemented as C library for connecting PMIx-enabled clients (like Open MPI) with PMIx-enabled Tools (like debuggers) and PMIx-enabled Servers (like PRRTE, SLURM, IBM JSM)
- PRRTE: **P**MIx **R**eference **R**un**T**ime **E**nvironment
  - Portable and feature-rich runtime environment
  - Offers PMIx support even if host environment is not PMIx-enabled
- Open MPI relationship
  - Evolved from Open MPI's ORTE into stand-alone project
  - Next stable release of Open MPI requires PMIx-enabled server
  - Included as 3rd party packages in Open MPI tarballs

https://OpenPMIx.org



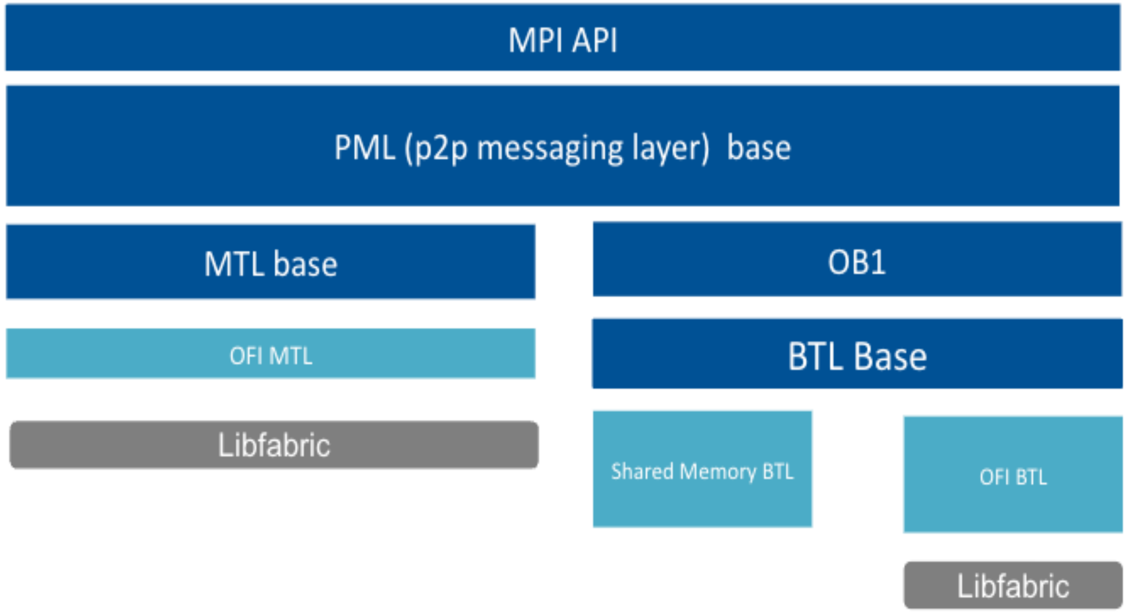
Source: https://PMIx.org

Runtime Details for Slingshot 11 Systems

- Slingshot with VNI enforcement enabled
  - VNI key allows clients to access fabric
  - Must launch PRRTE daemons with system resource manager for VNI key
    - Example: On SLURM based Frontier, use *srun* to start *prted*'s
- Enhancements to the job launch system for *Aurora*
  - PALS launcher support added to PRRTE frameworks
    - PLM: Process Launch Mechanism
    - ESS: Environment Specific Services
  - *Note: On Aurora, not plan to support direct launch of Open MPI because aprun lacks PMIx interface for launch mechanism.*

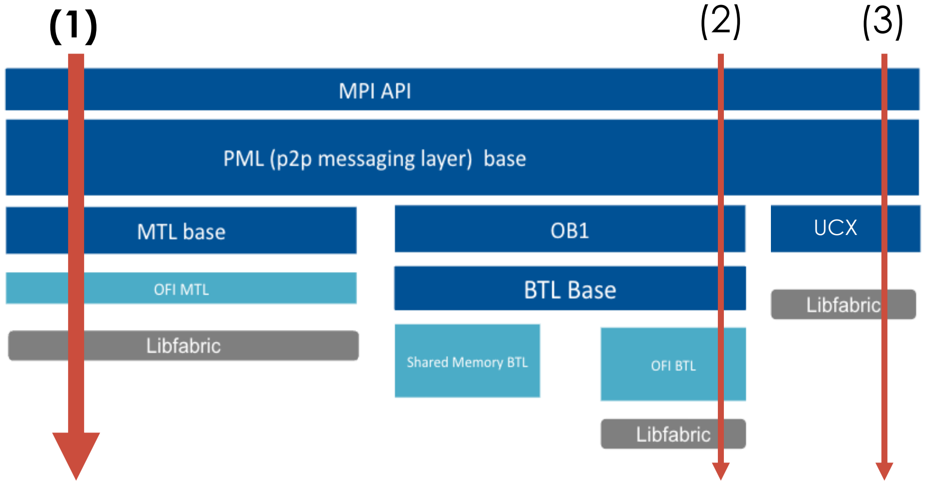
Open MPI Background

- Uses Modular Component Architecture (MCA)
  - Frameworks provide abstract interfaces
  - Frameworks have one or more components
  - Multiple ways to assemble/configure via MCA parameters
- Frameworks of interest
  - PML: Point-to-Point Messaging Layer
  - BTL: Byte Transport Layer
    - *Allows <u>multiple active</u> components*
  - MTL: Message Transport Layer
    - *Allows <u>1 active</u> component*



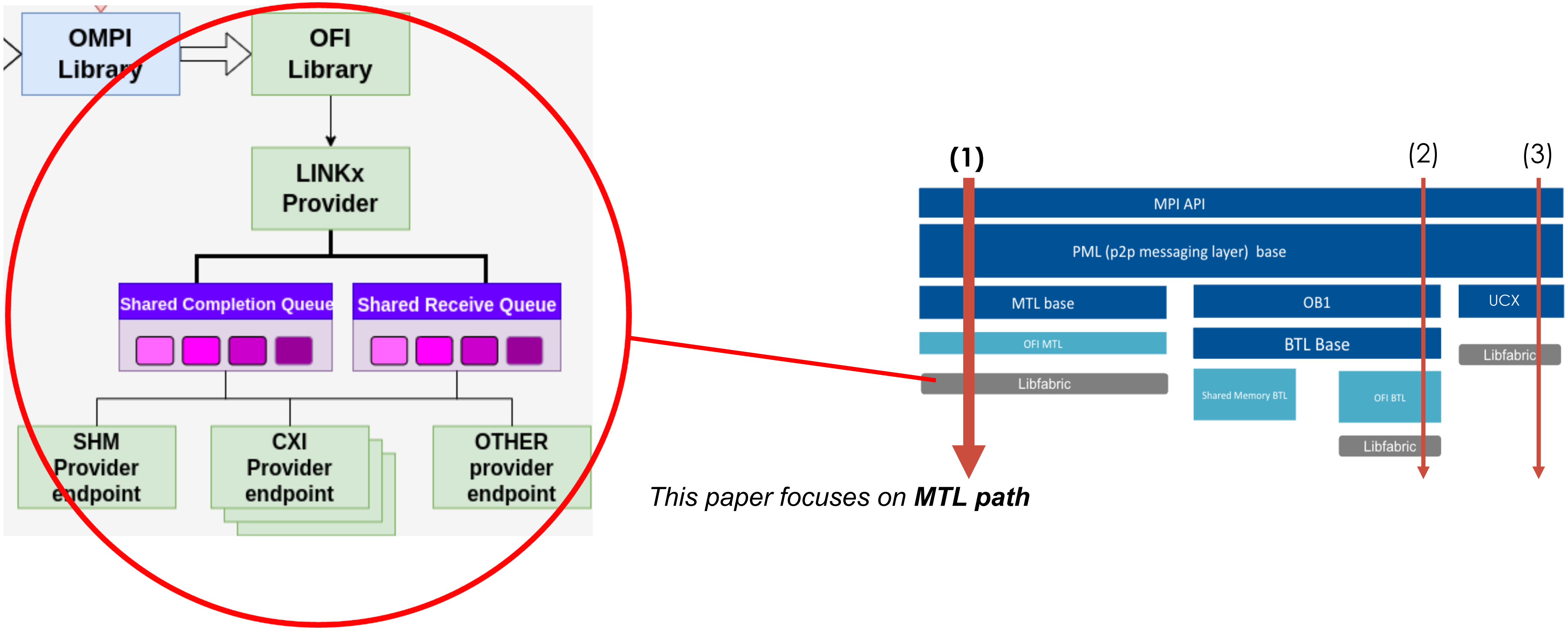
Slingshot 11 & Open MPI

- Cray supports Slingshot 11 via a new CXI libfabric provider
  - Supports communication with both host & device buffers
- CXI not directly support on-node communication
  - Functional but messages egress/ingress node
- Three potential solutions to use CXI provider with Open MPI
  1. **MTL path** – use libfabric tagged message interface
  2. BTL path – use MPI for tag matching & higher level logic, libfabric for byte transfer only
  3. UCX path – use UCX and integrate libfabric under the UCX API



*This paper focuses on **MTL path***

Where LINKx fits in Open MPI Architecture Diagram



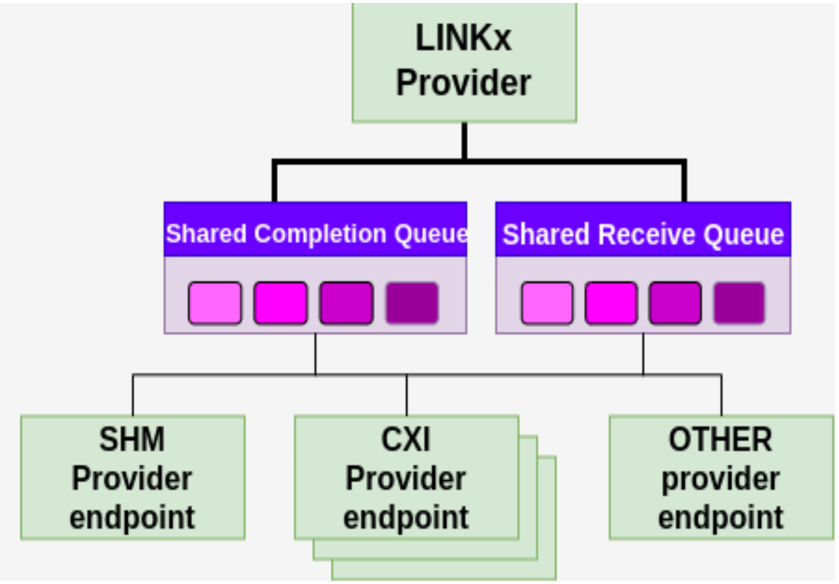
*This paper focuses on **MTL path***

Libfabric: ***LINKx*** provider

- A new OFI libfabric provider to link multiple providers
  - Terminology: LINKx links “core” providers
- Enables Open MPI to use single provider for local & remote communication
  - *Reminder: Open MPI’s MTL limited to 1 active component*
- Chooses endpoint provider based on peer locality
- Shares both its <u>completion queues</u> and <u>receive queues</u> to reduce communication and memory overhead
- Can potentially be expanded to handle multi-rail

LINKx Shared Data Structures

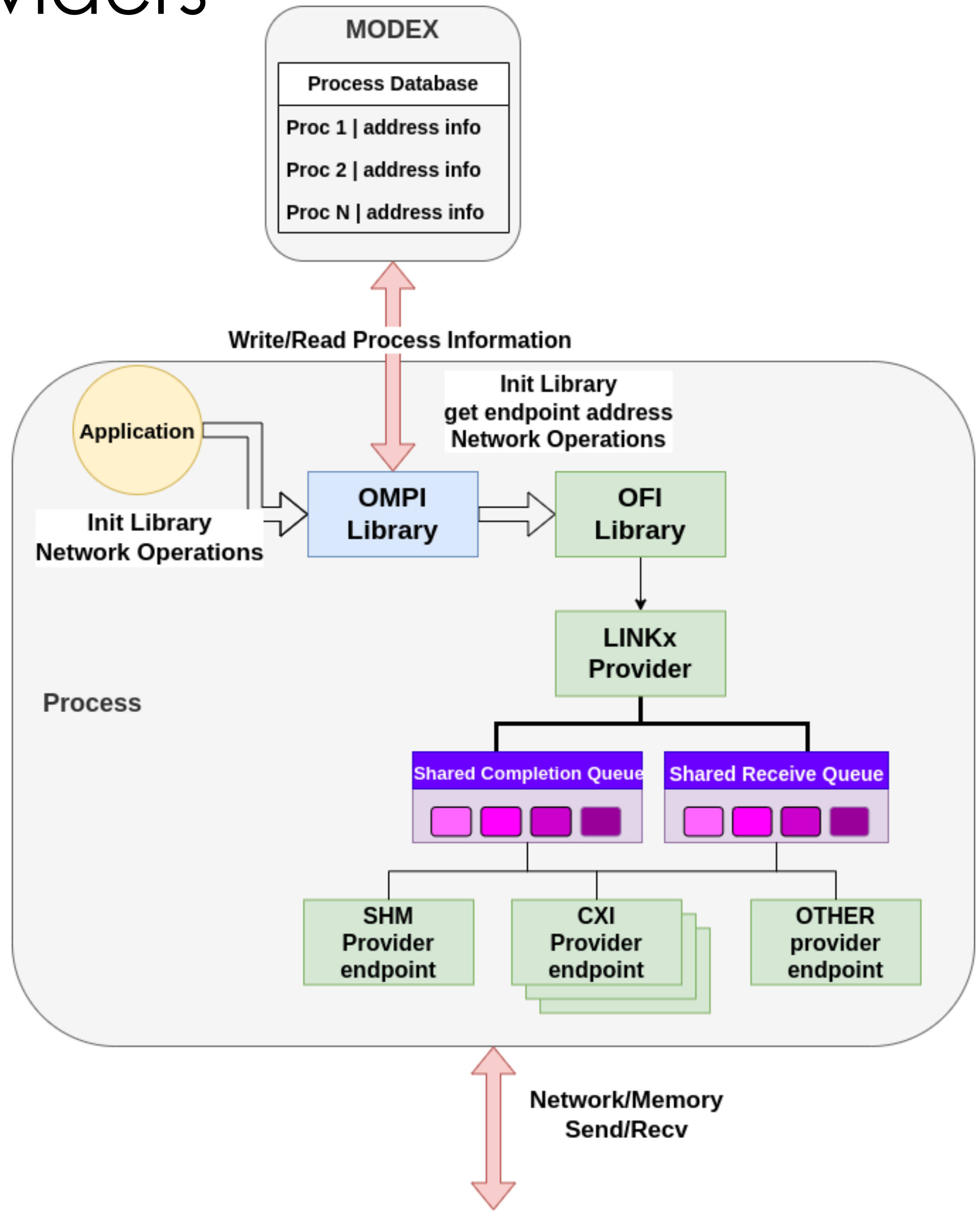
- Unified completion & receive queues
  - LINKx exports queues
  - Core providers in link use exported queues
- Shared queues
  - Avoids each provider needing to maintain separate queues
  - Avoids LINKx needing to search multiple queues
- Matching with LINKx
  - Disable hardware assisted tag matching
  - Use software matching to avoid ambiguity between linked providers



Flow: LINKx joining SHM & CXI providers

Example of Open MPI initialization with LINKx

1. Initialize libfabric to get LINKx provider with SHM+CXI
2. Application does typical libfabric setup for provider
3. LINKx builds structures to track linked providers
4. Open MPI MODEX: Before exchange, LINKx concatenates all addresses in link and publishes
5. Open MPI MODEX: After exchange, Open MPI reads all addresses, LINKx parses & sets up linked providers
6. Open MPI uses libfabric APIs to communicate with peers. At runtime, LINKx examines peer & selects best provider based on locality.



Improvements to Libfabric Shared Memory (SHM)

- New features to SHM provider for MPI use cases
  - Full support for ROCm HSA APIs
  - Add Asynchronous ROCm IPC support
  - Add IPC caching mechanism
  - Add XPMEM support
    - Allows mapping remote process memory space locally; provides efficient method of sharing memory
    - Optimization for H2D case to leverage XPMEM to directly copy into Device memory
    - Support XPMEM export for specific memory regions (instead of entire address space)
  - Add ROCm HIP API support (intended as reference implementation)

Improvements for Collectives

- Key changes to help bring performance closer to Cray MPI
  - Selection of the optimal network interface for a process
  - SHM locking improvements
    - SHM provider locking was very course, causing serialization between processes
    - Moved to more lock free strategy to minimize serialization

Frontier Supercomputer

- HPE Cray EX system
  - 74 cabinets
  - 9,472 AMD EPYC CPUs
  - 37,888 MI250x GPUs
    - Each MI250x GPU has 2 GCDs (Presents as 8 devices/node)
  - Slingshot 11 interconnect

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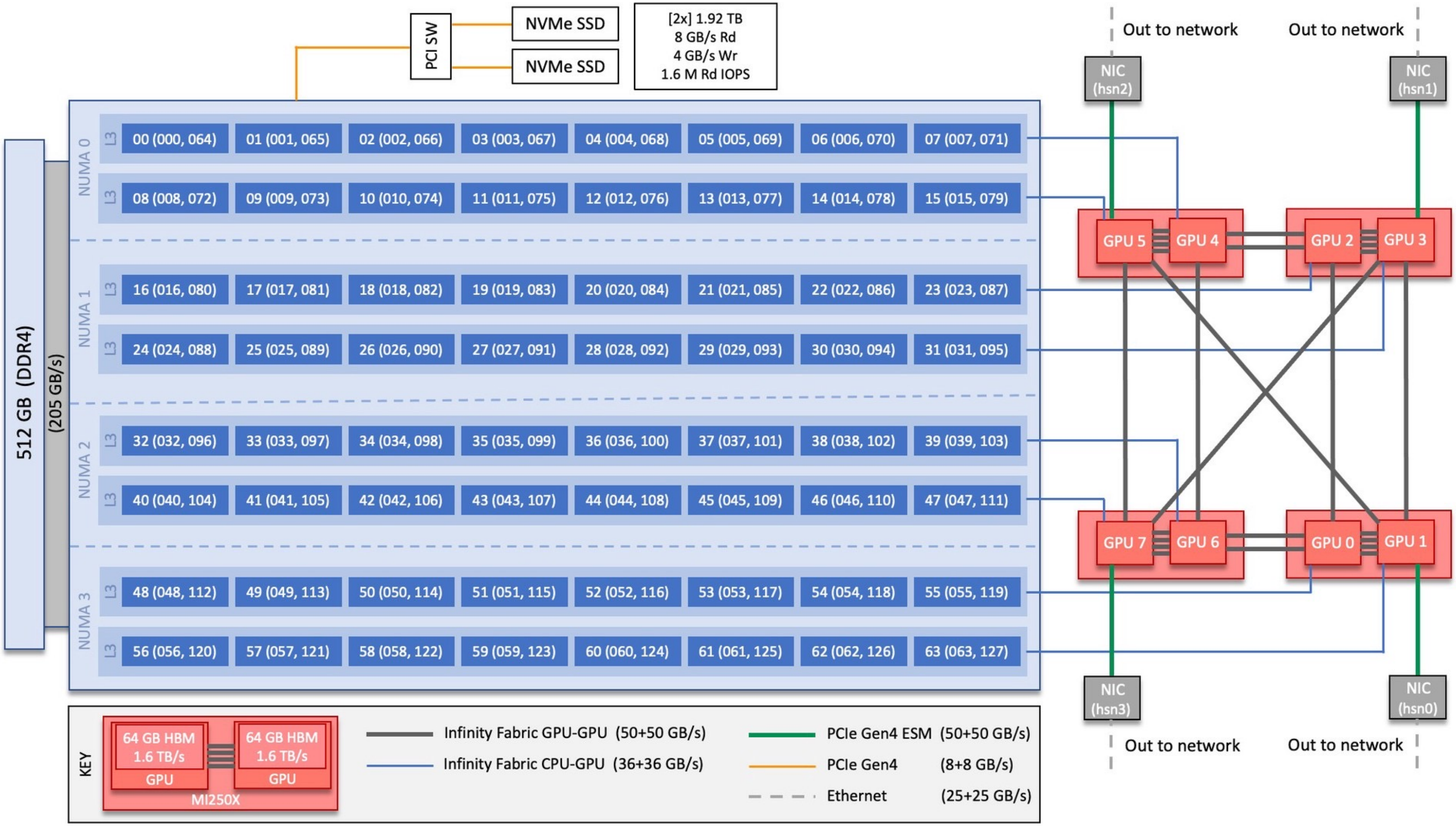
Frontier Supercomputer - Node Specifications



NUMA 0	L3	00 (000, 064)	01 (001, 065)	02 (002, 066)	03 (003, 067)	04 (004, 068)	05 (005, 069)	06 (006, 070)	07 (007, 071)
	L3	08 (008, 072)	09 (009, 073)	10 (010, 074)	11 (011, 075)	12 (012, 076)	13 (013, 077)	14 (014, 078)	15 (015, 079)
NUMA 1	L3	16 (016, 080)	17 (017, 081)	18 (018, 082)	19 (019, 083)	20 (020, 084)	21 (021, 085)	22 (022, 086)	23 (023, 087)
	L3	24 (024, 088)	25 (025, 089)	26 (026, 090)	27 (027, 091)	28 (028, 092)	29 (029, 093)	30 (030, 094)	31 (031, 095)
NUMA 2	L3	32 (032, 096)	33 (033, 097)	34 (034, 098)	35 (035, 099)	36 (036, 100)	37 (037, 101)	38 (038, 102)	39 (039, 103)
	L3	40 (040, 104)	41 (041, 105)	42 (042, 106)	43 (043, 107)	44 (044, 108)	45 (045, 109)	46 (046, 110)	47 (047, 111)
NUMA 3	L3	48 (048, 112)	49 (049, 113)	50 (050, 114)	51 (051, 115)	52 (052, 116)	53 (053, 117)	54 (054, 118)	55 (055, 119)
	L3	56 (056, 120)	57 (057, 121)	58 (058, 122)	59 (059, 123)	60 (060, 124)	61 (061, 125)	62 (062, 126)	63 (063, 127)

8 GCDs:
4 GPUs x 2 GCD each

4 NICs :
1 per GPU

Experiment Setup

- Data gathered on *Crusher* (smaller, but same HW as *Frontier*)
- System software
  - SUSE Linux 15 SP4 / Linux 5.14.31 (cray-shasta environment)
  - SLURM 22.05.7 with core specialization enabled
  - ROCm v5.3.0, CCE 15.0.0, xpmem v2.5.2
- MPI versions
  - Cray MPI version 8.1.23 with Cray PMI v6.1.8
    - Libfabric: v1.15.2.0
  - Open MPI v5.0.0rc11 with 1 patch*
    - Libfabric: ‘ornl-main’ branch with LINKx & shared memory provider enhancements

* PR #11565 “ofi: NIC selection”
https://github.com/open-mpi/ompi/pull/11565

Experiment Setup

- Testing tool sets `HIP_VISIBLE_DEVICES` to best setting for Crusher
- 8 MPI processes per node (one per GCD)
  - Mapping: 1 process per L3cache (--map-by ppr:1:l3cache)
    - Except for P2P inter-node tests, map 1 process per node (--map-by ppr:1:node)
  - Bind processes to core

Example run lines

Open MPI with LINKx enhanced libfabric

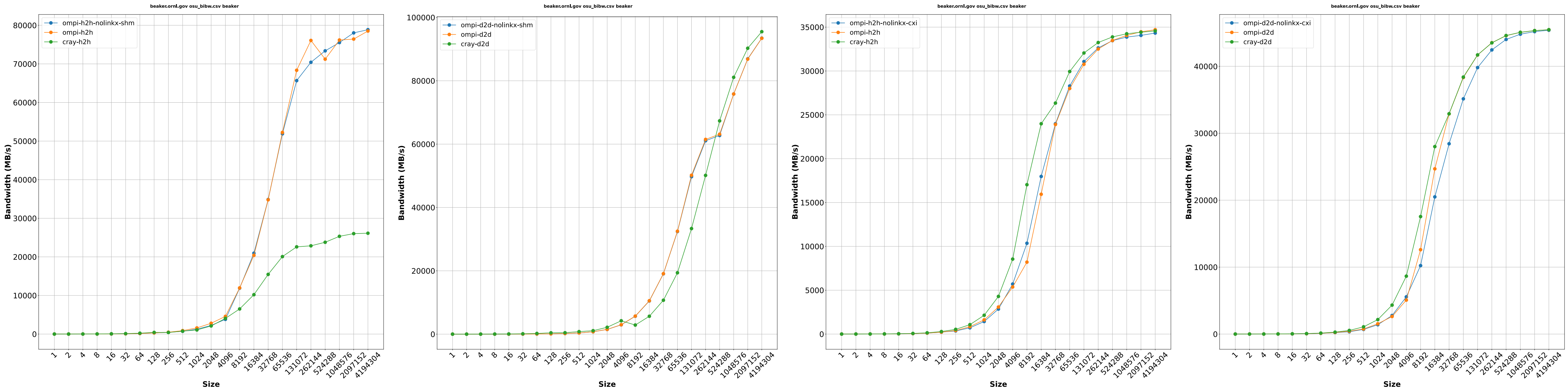
```
mpirun \
-x FI_USE_XPMEM -x LD_LIBRARY_PATH \
--mca btl ^tcp,ofi,vader,openib \
--mca pml ^ucx --mca mtl ofi \
--mca opal_common_ofi_provider_include "shm+cxi:linkx" \
 --map-by ppr:1:l3cache  --bind-to core \
--display mapping,bindings --np 512 \
<osu-exe> H H
# -- or --
<osu-exe> -d rocm D D
```

** Note: Most of these parameters set via modulefile*

CrayMPICH with system libfabric

```
srun \
--cpu-bind=v,cores \
--ntasks 512 \
--ntasks-per-node 8 \
-N 64 \
-t 10000 \
<osu-exe> H H
 # --or--
<osu-exe> -d rocm D D
```

Point-to-Point Bi-directional Bandwidth (osu_bibw)



(a) H2H intra-node

(b) D2D intra-node

(c) H2H inter-node

(d) D2D inter-node

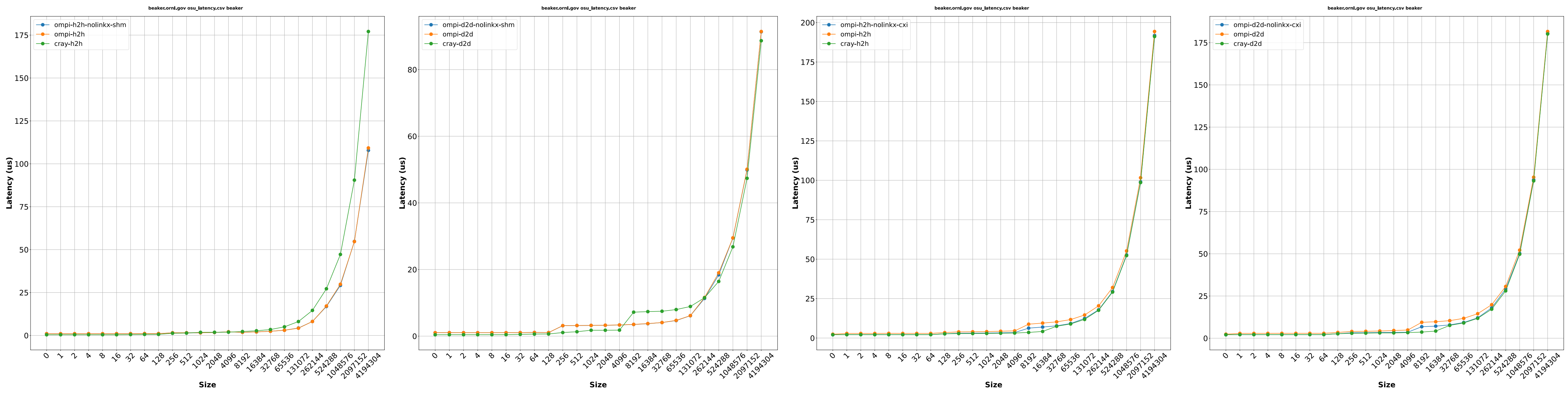
Fig. 4: Point-to-Point Bidirectional Bandwidth `osu_bibw`

- Take-away: Trend is following CrayMPICH

(Unexplained problem w/ CrayMPICH H2H)

Key:
Open MPI no LINKx (cxi or shm)
Open MPI with LINKx
CrayMPICH

Point-to-Point Latency (osu_latency)



(a) H2H intra-node (b) D2D intra-node (c) H2H inter-node (d) D2D inter-node

Fig. 5: Point-to-Point Latency `osu_latency`

- Take-away: Trend is following CrayMPICH

(Unexplained problem w/ CrayMPICH H2H)

Key:
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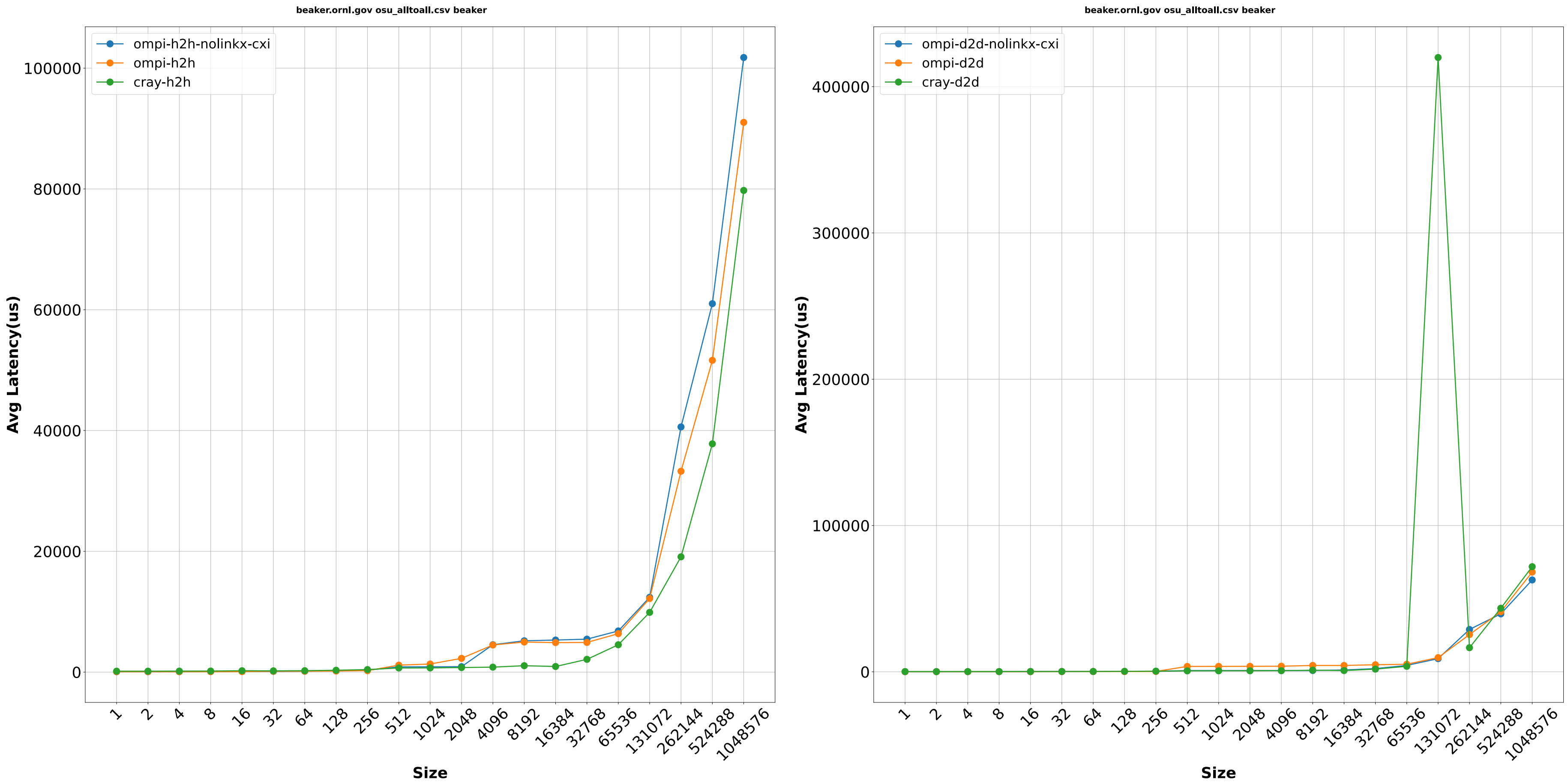
Collective Alltoall (osu_alltoall)



(a) H2H

(b) D2D

Fig. 7: Collective Alltoall `osu_alltoall`

- Take-away: Trend is following CrayMPICH

Key:
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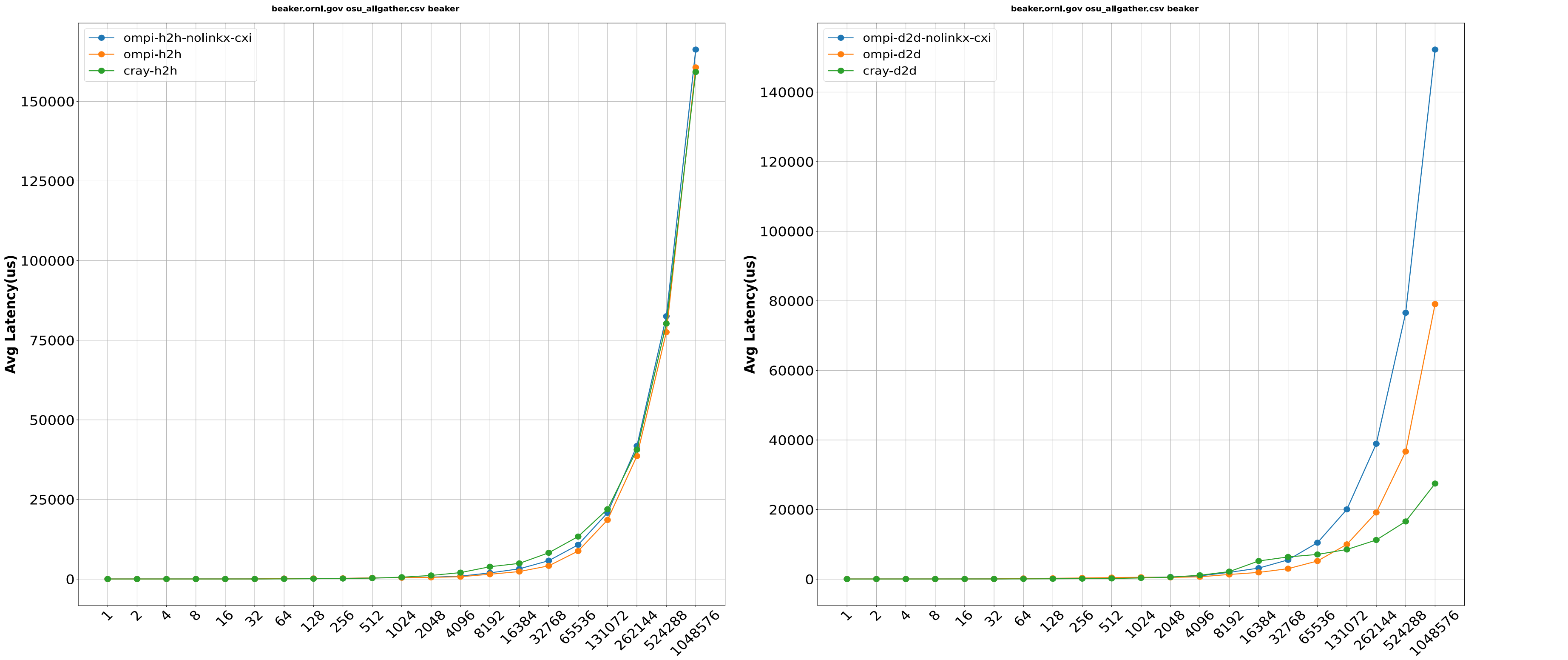
Open MPI with LINKx
CrayMPICH

Collective Allgather (osu_allgather)



(a) H2H

(b) D2D

Fig. 9: Collective Allgather `osu_allgather`

- Take-away: D2D needs work as size grows

Key:
Open MPI no LINKx (cxi or shm)
Open MPI with LINKx
CrayMPICH

Future Work

- MPI
  - Performance improvements (small messages, collectives)
  - Finalize open issue for MPI one-sided support
- Libfabric
  - Complete LINKx support for all libfabric APIs
  - Productize LINKx and test linking multiple providers
  - Upstream changes
  - Multi-rail support via LINKx
- Other
  - Support Intel GPUs on Aurora

Summary

- Outlined key challenges addressed to bring Open MPI up on Frontier with good performance
  - Still improvements to be made, function and performance shows good trends compared to vendor’s well tuned CrayMPICH
  - Experiments highlight importance of process affinity to GPU/Network
- Presented status of Open MPI with Slingshot 11
  - Summary of new LINKx provider (joins SHM & CXI provider)
  - LINKx used for Open MPI’s MTL/OFI framework
  - Highlighted improvements (SHM provider, ROCm & XPMEM support)

Questions?

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