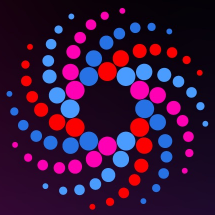

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Design and Performance Evaluation of UCX for Tofu-D Interconnect with OpenSHMEM-UCX on Fugaku

Yutaka Watanabe[1)2)], Mitsuhisa Sato [2)], Miwako Tsuji [2)], Hitoshi Murai [2)], Taisuke Boku [3)2)]

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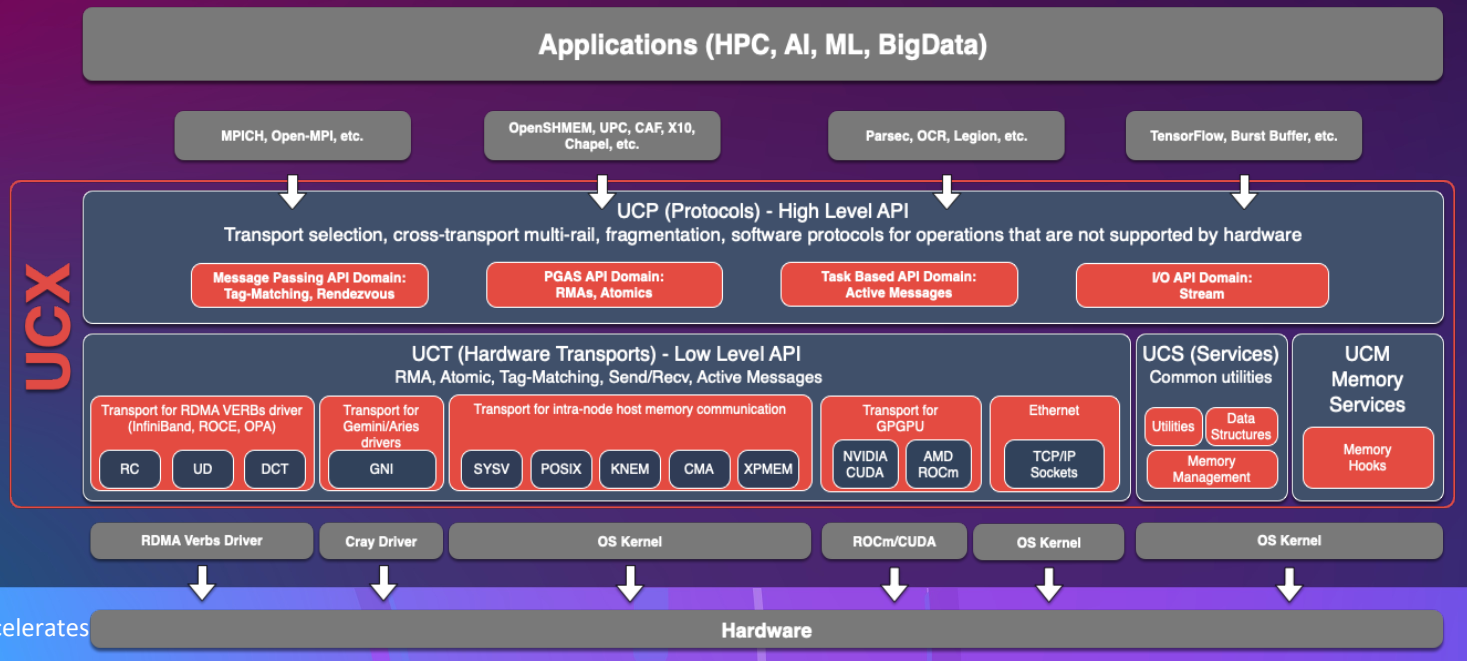
The 5th Annual Parallel Applications Workshop, Alternatives To MPI+X

Introduction and motivation

- The partitioned global address space (PGAS) model is recently getting attention as it is easy to describe remote data access
  - Mainly, one-sided communication is used in PGAS
  - One of the representative framework is OpenSHMEM
- UCX is a lower-level communication framework for modern, high-bandwidth, and low-latency networks
  - UCX is widely used in HPC; OpenMPI can use UCX as underlying network library, OpenSHMEM-UCX does so

UCX architecture[11, 12]



Introduction and motivation (Cont'd)

- UCX on Tofu-D for Fugaku supercomputer
  - Tofu-D is an interconnect network used in supercomputer Fugaku and FX1000 based systems
  - It enables lower, lightweight, and abstracted network library to users who want to use lower communication library than MPI but do not want to use library for Tofu-D (uTofu) directly. (e.g. for portability)
  - Users can take advantage Tofu-D's tightly coupled network and application-oriented topology with UCX

- RDMA based communication layers such as UCX are expected to perform better than MPI
  - We are interested in communication layer for multithreaded execution in manycore processors.
  - We found MPI has a performance problem with multithread communication, especially with many core processors.
  - We have a plan to implement a distributed task-based programming framework with abstracted network interface for portability

Tofu Interconnect D

- Tofu Interconnect D is a six dimensional mesh/torus network which is used on Fugaku and Fujitsu FX1000 based systems
  - The chip integrated to A64FX has 6 Tofu Network Interfaces which is an RDMA engine with 6.8GB/s capacity, 40.8GB/s aggregated bandwidth
  - Scalable Direct Network, designed for a large-scale MPP (over 150k nodes like Fugaku)

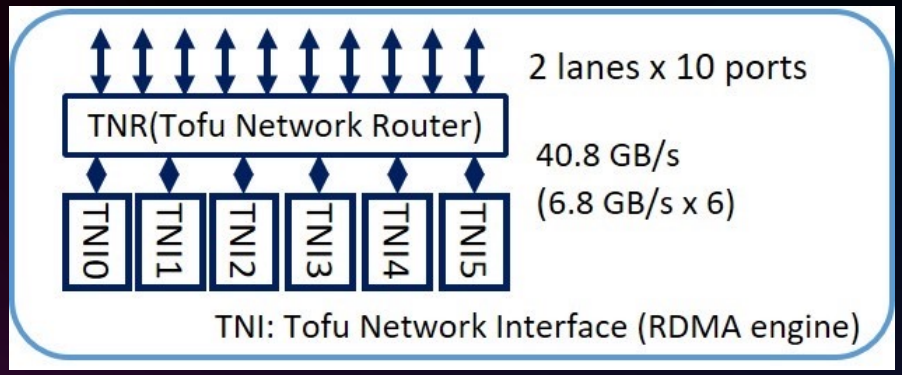
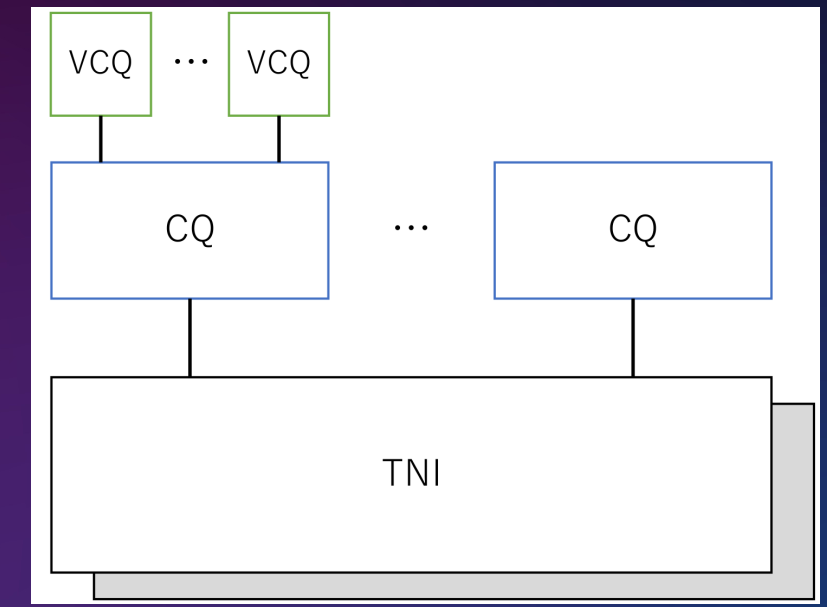


Diagram of Tofu-D[14]

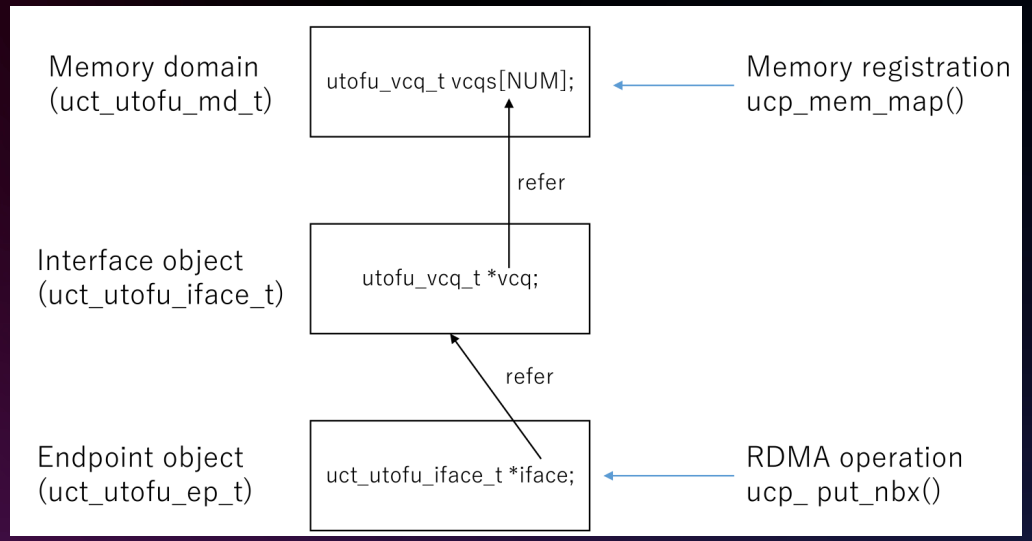
- The queue structure of Tofu is like right-below figure
  - hardware control queues (CQ) are on each TNI
  - Virtualized Control Queues (VCQ) are on each CQ



- With uTofu library (to use Tofu interconnect D from userland), those TNIs need to be explicitly managed by user
  - User creates VCQ on specific TNI
  - Memory registrations or RDMA operations are done thorough VCQ

Design and implementation: Mapping uTofu to UCT layer

- We have mapped uTofu library to UCT like above figure
  - VCQ is created on memory domain as all memory registration is done through memory domain
  - A interface object has a reference to VCQs on memory domain
  - A end point object has a reference to interface as all RDMA operation is done through endpoint object



- uTofu needs special address “steering address” for RDMA operation, not virtual address
  - Mapping remote’s steering address as rkey
    => exchange rkey with remote means
    exchange remote buffer address
  - register and de-register for local buffer address to get src steering address

```
ucs_status_t ucp_put_nbi(
    ucp_ep_h ep,
    const void *buffer,
    size_t length,
    uint64_t remote_addr,
    ucp_rkey_h rkey
)
```

```
int utofu_put(
    utofu_vcq_hdl_t vcq_hdl,
    utofu_vcq_id_t rmt_vcq_id,
    utofu_stadd_t lcl_stadd,
    utofu_stadd_t rmt_stadd,
    size_t length,
    uint64_t edata,
    unsigned long int flags,
    void *cbdata
)
```

Design and implementation: Scheduling Tofu Network Interfaces (TNIs)

- The scheduling of TNIs may be a design issue to improve performance
  - As Tofu Interconnect D has six TNIs and needs to be managed explicitly with uTofu library

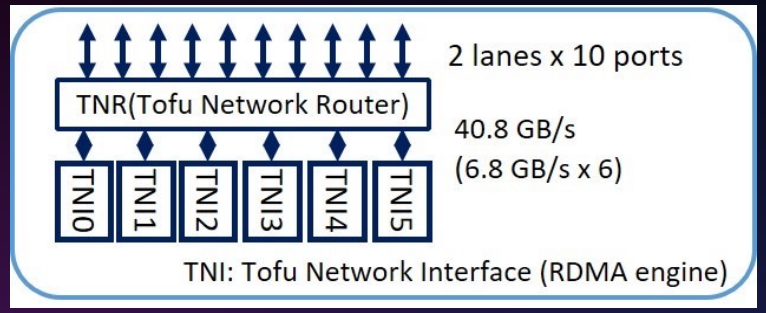


Diagram of Tofu-D[14]

- We have implemented two type methods for the use of TNIs
  - 1) TNI-RR: select specific TNI per remote node; the TNI will be selected by round-robin manner
  - 2) TNI-LU: using the least-used TNI for each communication

- TNI-RR will be better in terms of low overhead, but may result in load-imbalance between TNIs
- TNI-LU will be better in terms of load balancing, but requires extra overhead to find the least-used TNI

Mixed use of UCX and MPI

- OpenSHMEM-UCX relies on scholl library for collective operations
  - scholl implements collective operations with UCX
- uTofu has hardware-assisted operations like barriers and reduction, but not be able to utilize from UCX
  - This could affect performance on Fugaku
- The solution is to make use of MPI with UCX on OpenSHMEM-UCX, as MPI and uTofu can be mixed in a single program
  - Currently, global barrier of OpenSHMEM-UCX is modified to use MPI_Barrier for Fugaku

Performance evaluation

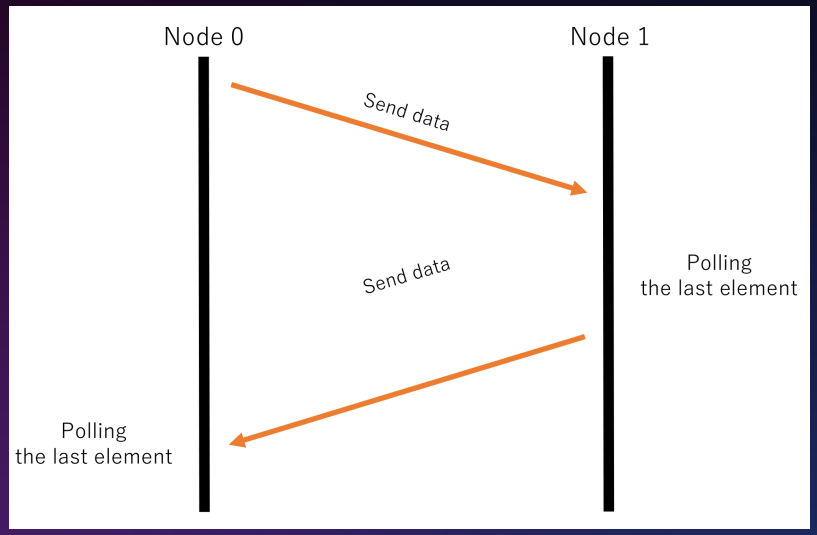
- We conducted performance evaluation on supercomputer Fugaku

- We have evaluated with three kind of benchmnarks
  - Simple pingpong benchmark with Fujitsu MPI, UCX, and uTofu
  - OpenSHMEM implentation of OSU Micro Benchmark with OpenSHMEM-UCX and OSHMPI
  - Oak Ridge OpenSHMEM Benchmarks with OpenSHMEM-UCX and OSHMPI

Fugaku specification and used softwares	
CPU	Fujitsu Arm A64FX Processor 48 compute cores + 2or4 assistant cores at 2.0GHz
Interconnect	Tofu Interconnect D
OS	Red Hat Enterprise Linux 8.5
Linux Kernel	4.18.0-348.20.1.el8 5.aarch6
MPI	Fujitsu Technical Computing Suite 4.8.0
Base UCX	Commit ID 5f357ae0215868a89bc09a05c5392c710eb6e7da
OSHMPI	Commit ID a51874c829e66d83486974b9f7ce076f3687934
Base OpenSHMEM-UCX	Commit ID a51874c829e66d83486974b9f7ce076f3687934

Pingpong benchmark on Fugaku: uTofu, UCX, and MPI RDMA

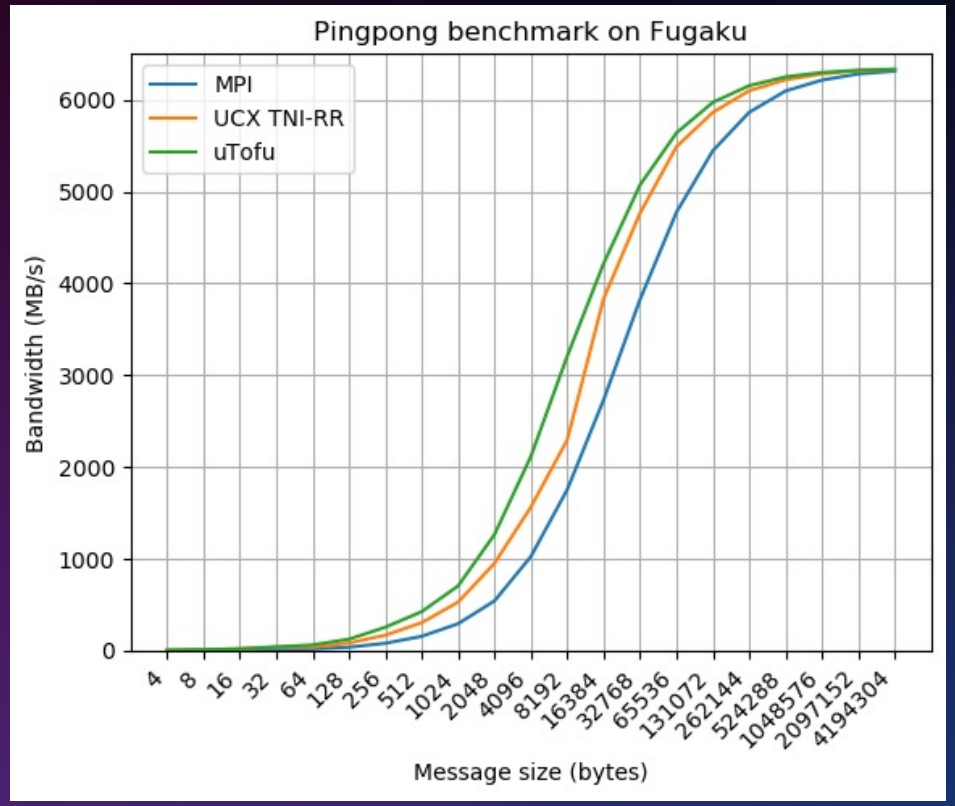
- We have implement a pingpong benchmark to evaluate and compare the RDMA write performance of Fujitsu MPI, UCX, and uTofu on Fugaku
  - For Fujitsu MPI, we used window lock based mechanism



Pingpong benchmark on Fugaku: uTofu, UCX, and MPI RDMA

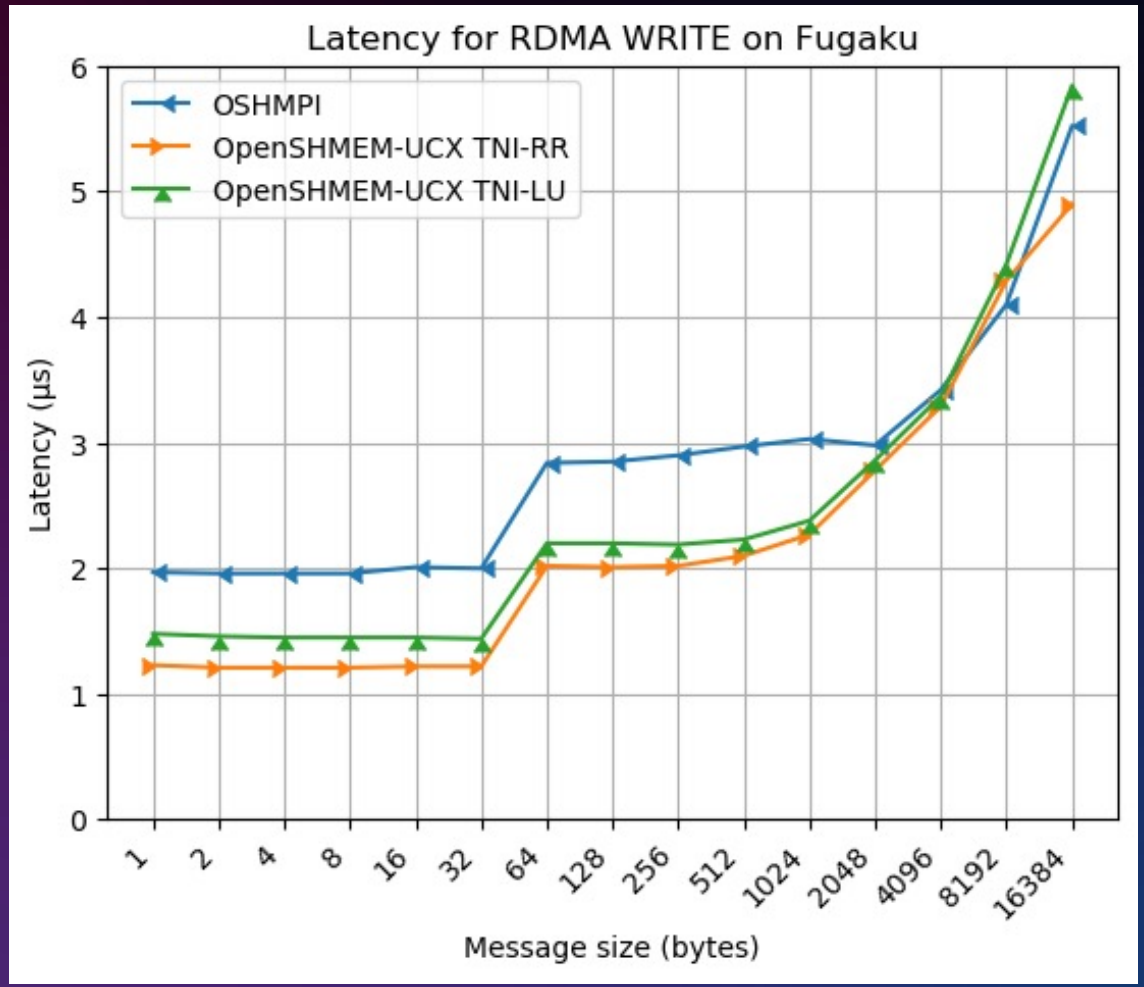
- uTofu shows the best performance, followed by UCX (TNI-RR) and MPI RDMA respectively.

- One of the reason for the difference between uTofu and UCX is caused by memory registration cost in uTofu layer on UCX
  - Source buffer is registered and de-registered every time (except up to 32byte message)
  - Improving memory management is not done yet



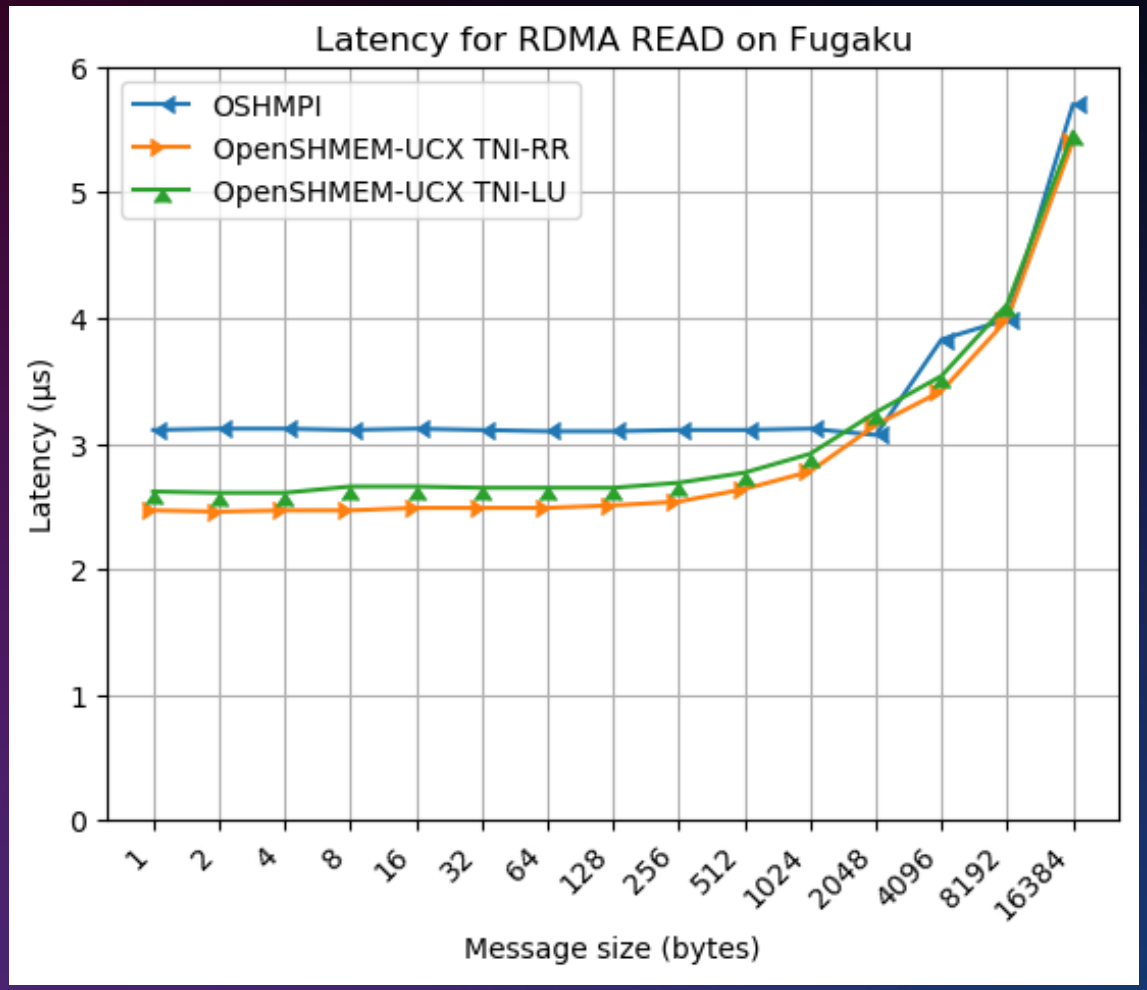
OSU Micro Benchmarks on Fugaku: OSHMPI and OpenSHMEM-UCX with RDMA WRITE

- Both OpenSHMEM-UCX shows lower latency up to 16384 than OSHMPI except with 8192 byte message
  - TNI-RR is about 1.5x faster than OSHMPI with up to 32 byte message
- TNI-RR shows lower latency than TNI-LU
  - The additional cost of calculating which TNI is the most least is affecting the performance
- The latency increase after 32 byte is because of different utofu
  - Up to 32 byte message uses more efficient utofu_put_piggyback function, which reduces the cost of local memory access



OSU Micro Benchmarks on Fugaku: OSHMPI and OpenSHMEM-UCX with RDMA READ

- Both OpenSHMEM-UCX shows lower latency up to 16384 byte message than OSHMPI except 2048 byte message
  - TNI-RR mode is about 1.28x faster than OSHMPI with 1 byte message
- TNI-RR shows lower latency than TNI-LU same as WRITE
  - The additional cost of calculating which TNI is the most least is affecting the performance



OSU Micro Benchmarks on Fugaku: OSHMPI and OpenSHMEM-U

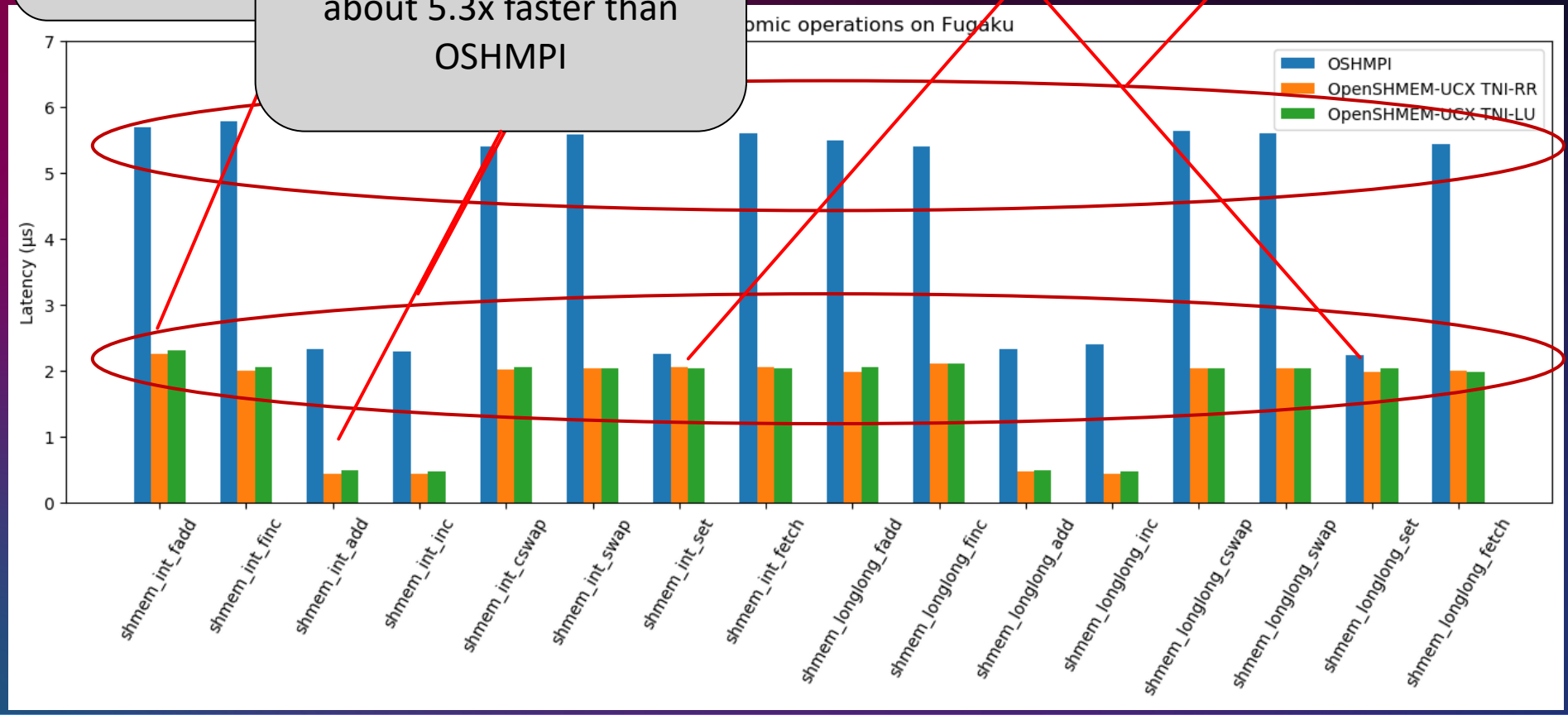
For 4byt
OpenSHMEI
about 2.5x fas

For 4byte add, OpenSHMEM-UCX is about 5.3x faster than OSHMPI

For 4 or 8 byte set, OSHMPI is slightly slower than both OpenSHMEM-UCX

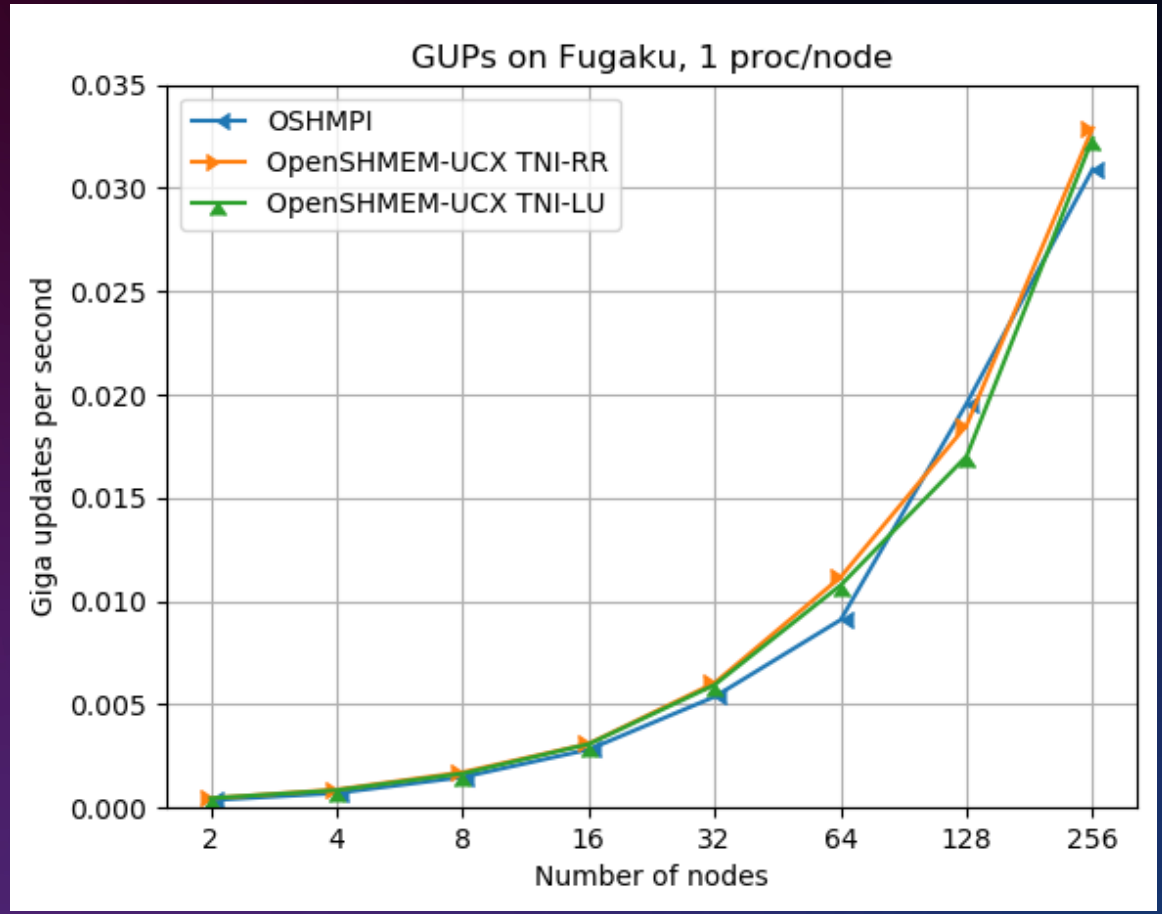
Some atomic operation fo OpenSHMEM-UCX shows
alr nction are used
fa add{4,8}
dd{4, 8}
wap{4, 8}

s shows
y than
M-UCX



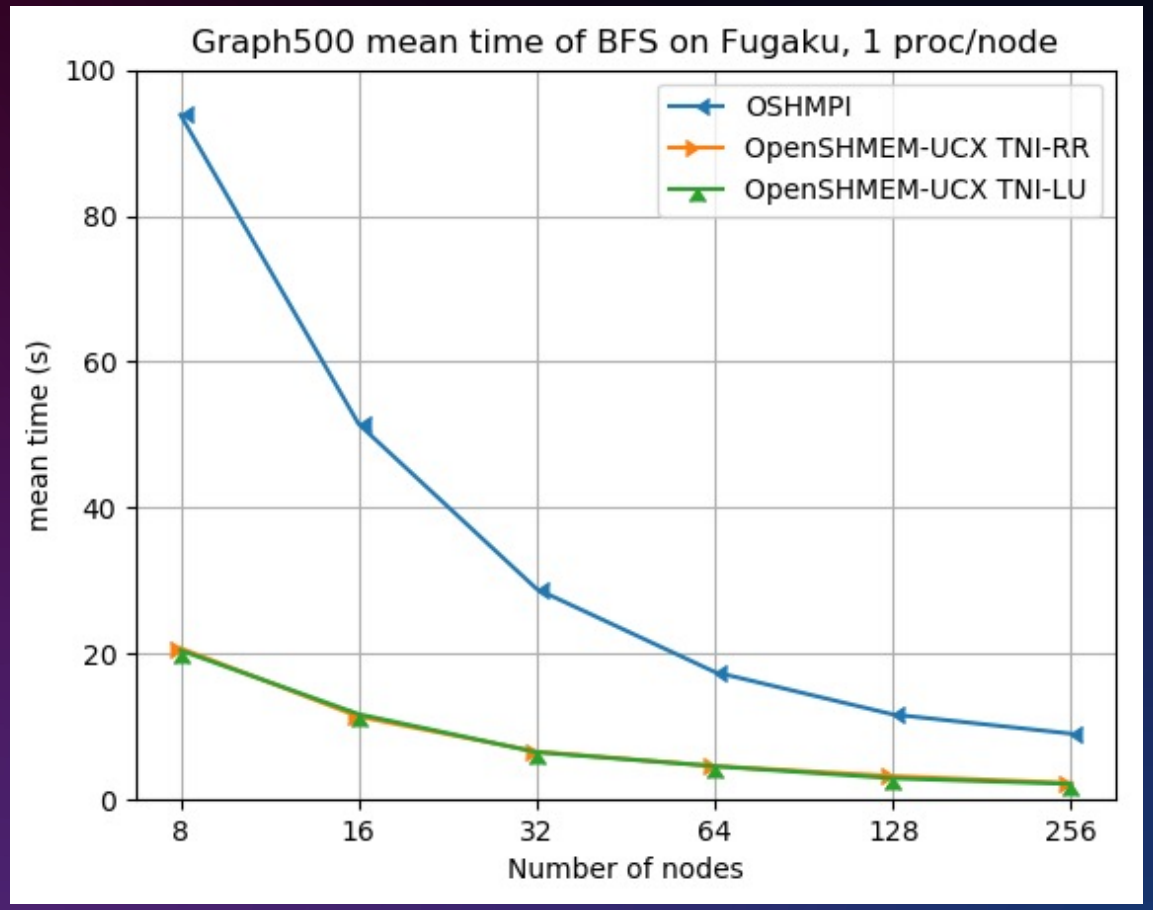
Oak Ridge OpenSHMEM benchmarks on Fugaku: OSHMPI and OpenSHMEM-UCX with GUPs

- Measuring GUPS (Giga Updates Per Second) following the RandomAccess test from the HPC Challenge
  - Evaluated with 2 to 256 nodes
- Both OpenSHMEM-UCX shows better performance than OSHMPI except with 128 nodes
  - TNI-RR is about 1.09x better than OSHMPI with 256 nodes
- TNI-RR is better than TNI-LU, similar to previous evaluation



Oak Ridge OpenSHMEM benchmarks on Fugaku: OSHMPI and OpenSHMEM-UCX with Graph500 mean time

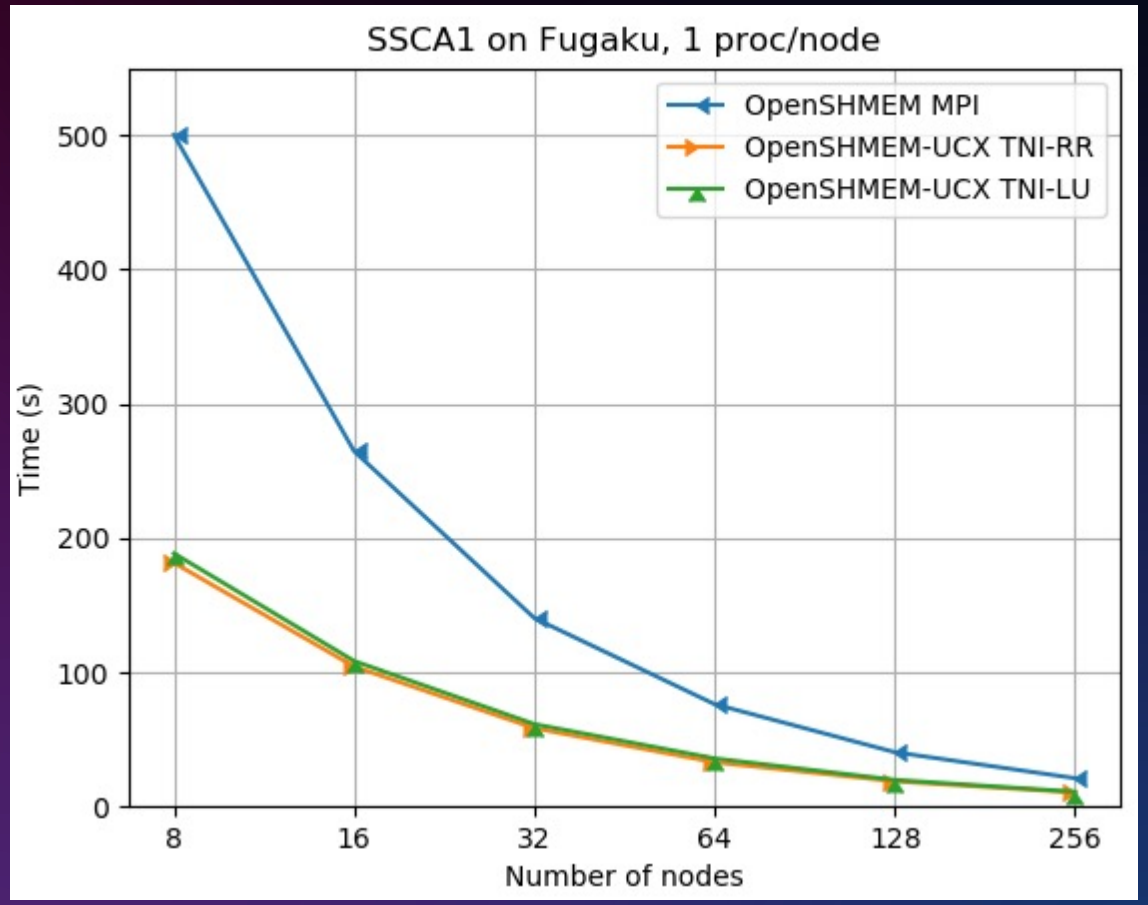
- Problem setup
  - SCALE: 20, Edge factor:16
  - Evaluated with 8 to 256 nodes
- Both OpenSHMEM-UCX method are faster than OSHMPI
  - OpenSHMEM-UCX TNI-RR is about 3.9x faster than OSHMPI with 256nodes, more difference than observed with OMB
- Almost same performance between TNI-RR mode and TNI-LU mode with OpenSHMEM-UCX



Oak Ridge OpenSHMEM benchmarks on Fugaku: OSHMPI and OpenSHMEM-UCX with SSCA1

- SSCA1 is a sequence alignment algorithms
- Problem setup
  - SCALE: 27
  - Evaluated with 8 to 256 nodes

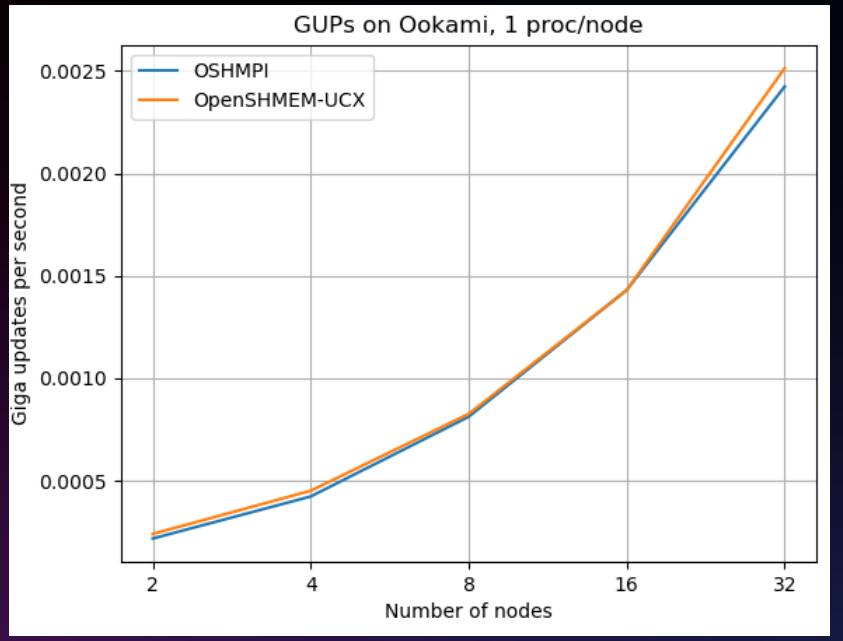
- Both OpenSHMEM-UCX method are faster than OSHMPI
  - OpenSHMEM-UCX TNI-RR is about 2x faster than OSHMPI with 256nodes, more difference than observed with OMB but similar to Graph500

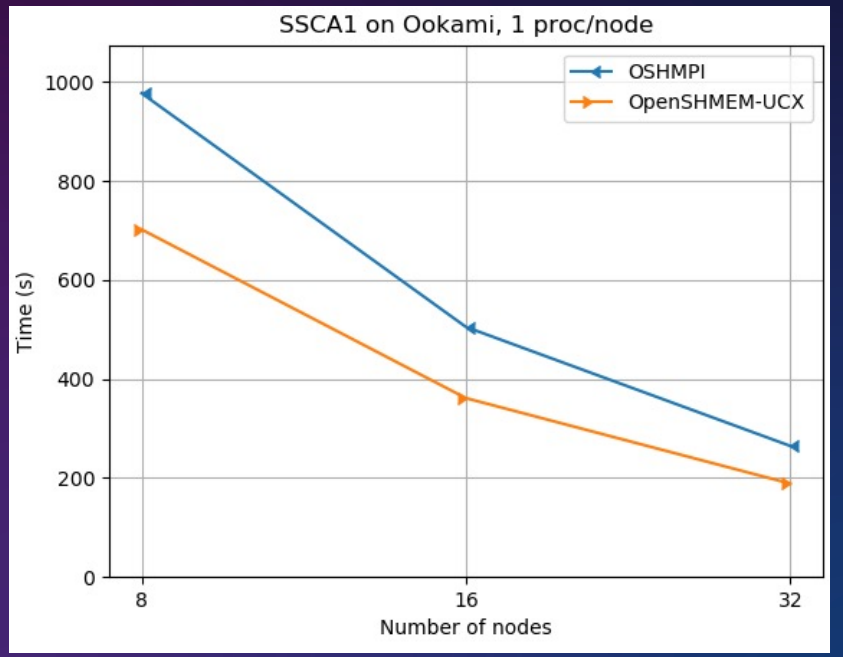


Discussion

- The large difference observed in Graph500 and SSCA1 application
  - We have evaluated on Ookami cluster
  - Unfortunately, Graph500 didn't run correctly

Ookami specification and used softwares	
CPU	Fujitsu Arm A64FX Processor 48 compute cores at 1.8GHz
Interconnect	**InfiniBand HDR100 PCIe Gen3 x16**
OS	Rocky Linux 8.4
Linux Kernel	4.18.0-305.25.1.el8 4.aarch64
MPI	OpenMPI 4.1.4
UCX	1.11.2
OSHMPI	Commit ID 62e1ec0267cd3be05e764de2ee54dbfe40311132
OpenSHMEM-UCX	Commit ID a51874c829e66d83486974b9f7ce076f3687934





- With GUPs benchmarks, as similar to Fugaku, OpenSHMEM-UCX shows better performance than OSHMPI
- With SSCA1 benchmarks and from 8 to 32 nodes, as similar to Fugaku, larger difference is observed
  - This would mean the reason of this difference is not simply due to between UCX and MPI, but also between OpenSHMEM-UCX and OSHMPI
  - While the root cause of this is not identified yet, users can benefit more OpenSHMEM-UCX on than OSHMPI on Fugaku

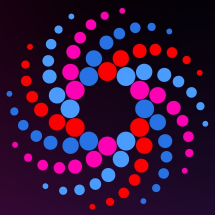
Discussion:
UCX and Tofu Interconnect D

- For collective operations with multiple nodes
  - Tofu-D has hardware assisted operations like barrier and reduction
  - UCX would not be able to utilize them because of the architecture

- One of the solution for this is to mix MPI and UCX as Fujitsu MPI and uTofu can be used in a single program
  - This requires additional cost to users, but users would take advantages of UCX's lightweight RDMA operations
  - UCC project might be the alternative solution?

Conclusion and future work

- We have designed and implemented uTofu layer for UCX
  - UCX on Fugaku shows better performance than MPI with RDMA based benchmarks, and is expected as more lightweight and portable network library.
  - Scheduling TNIs for Tofu-D improves performance slightly.
  - UCX can be used as a efficient RDMA lower communication layer for Fugaku supercomputer than MPI in portable way.
  - Our design of uTofu layer for UCX would be helpful for users who try to port UCX for any kind of network interface
- For future works
  - Improving memory management like fewer registration/de-registration cost which could reduce the latency and close to uTofu raw performance
  - Evaluation and Optimization of our UCX on Tofu-D for thread-to-thread communication in distributed task-based programming framework for parallel manycore processors system such as Fugaku



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