MVAPICH

MPI, PGAS and Hybrid MPI+PGAS Library

Case Studies of MVAPICH2 Optimization on HPC Cloud Systems

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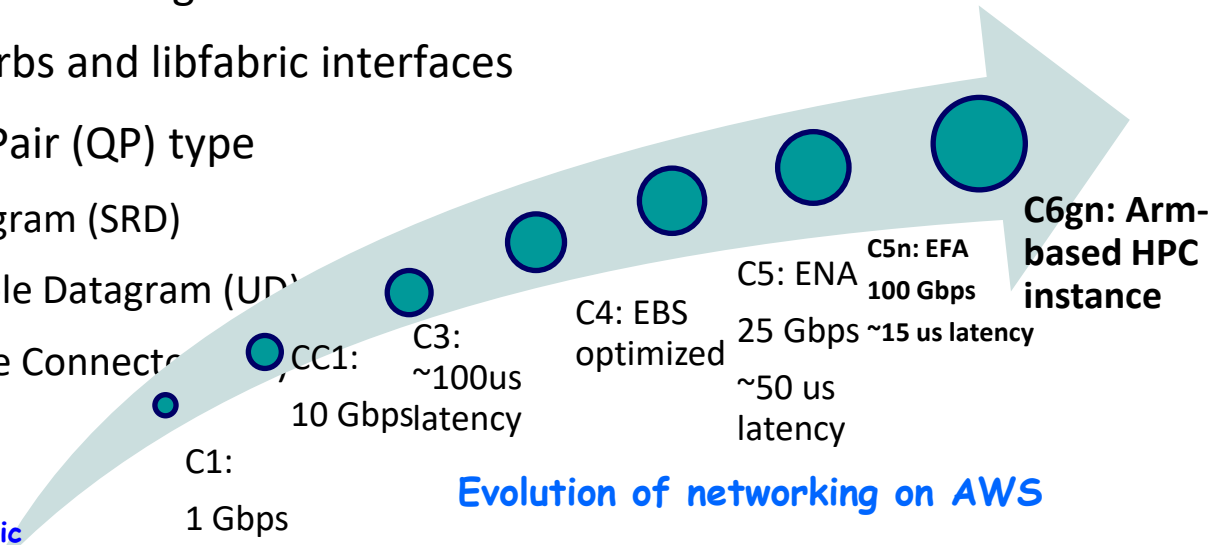
Overview

- Introduction
- MPI Optimization
- Performance Evaluation
  - Micro-benchmark level Performance
  - Application level Performance
- Conclusion

Amazon Elastic Fabric Adapter (EFA)

- Enhanced version of Elastic Network Adapter (ENA)
- Allows OS bypass, up to 100 Gbps bandwidth
- Network aware multi-path routing
- Exposed through libibverbs and libfabric interfaces
- Introduces new Queue-Pair (QP) type
  - Scalable Reliable Datagram (SRD)
  - Also supports Unreliable Datagram (UD)
  - No support for Reliable Connecto



Deep Dive on OpenMPI and Elastic Fabric Adapter (EFA) - AWS Online Tech Talks, Linda Hedges

Scalable Reliable Datagrams (SRD): Features & Limitations

Feature	UD	SRD
Send/Recv	✓	✓
Send w/ Immediate	✗	✗
RDMA Read/Write/Atomic	✗	✗
Scatter Gather Lists	✓	✓
Shared Receive Queue	✗	✗
Reliable Delivery	✗	✓
Ordering	✗	✗
Inline Sends	✗	✗
Global Routing Header	✓	✗
Max Message Size	4KB	8KB

- **Similar to IB Reliable Datagram**
  - **No limit on number of outstanding messages per context**
- **Out of order delivery**
  - **No head-of-line blocking**
  - **Bad fit for MPI, can suit other workloads**
- **Packet spraying over multiple ECMP paths**
  - **No hotspots**
  - **Fast and transparent recovery from network failures**
- **Congestion control designed for large scale**
  - **Minimize jitter and tail latency**

Amazon Elastic Fabric Adapter: Anatomy, Capabilities, and the Road Ahead, Raghu Raja, OpenFabrics Workshop 2019

Recent updates in AWS EC2 Instances for HPC Workloads

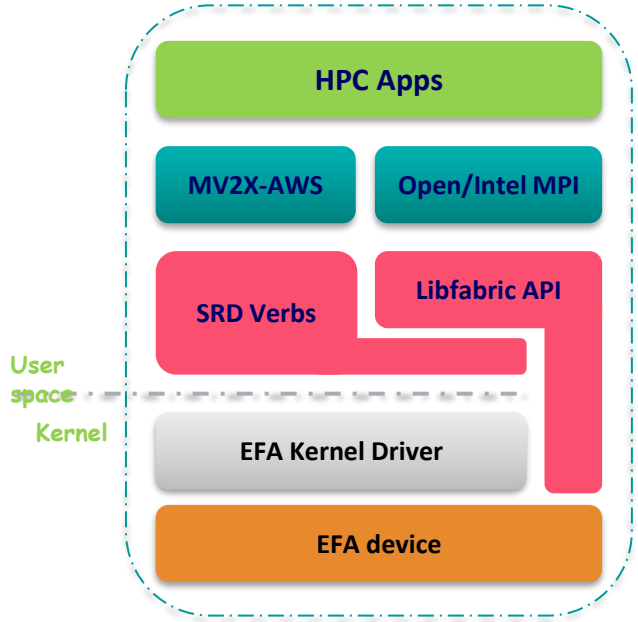
- Various hardware selection
  - Support both x86 (Intel/AMD) & Arm based CPU types
  - Support multiple hardware configuration choices including vCPUs count, storage and network bandwidth

- Recent supported Arm-based HPC instances
  - Custom-built by AWS using 64-bit Arm Neoverse cores to enable the best price performance for workloads running in Amazon EC2
  - Support up to 100 Gbps networking bandwidth, 38 Gbps Elastic Block Store (EBS) bandwidth

- Quickly deploy HPC environments with AWS Parallelcluster
  - Support multiple instance types and job schedulers like Slurm
  - Support OS type Amazon Linux2, CentOS 7, Ubuntu 18.04 and 20.04
  - Flexible cost effective allocation, launch when need

MpI libraries on AWS EC2 HPC instances

- Supports MPI libraries on instances with EFA support
- OpenMPI & IntelMPI are based on Libfabric API
  - Libfabric Bypass the OS kernel and can communicate directly with EFA device
- MVAPICH2-X-AWS is based directly on SRD verbs API
  - Different to Open MPI and IntelMPI, directly invokes SRD verbs API to implement MPI level communication
  - Detail design is included in this paper:
    - Designing Scalable and High-performance MPI Libraries on Amazon Elastic Fabric Adapter, S. Chakraborty , S. Xu , H. Subramoni , DK Panda, HotI 19, Aug 2019



Get started with EFA and MPI, https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/efa-start.html

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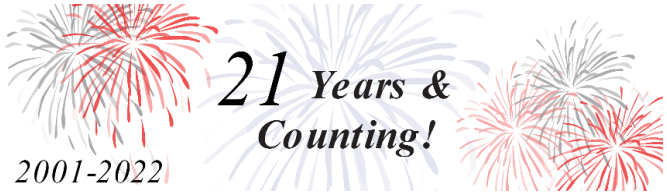
Overview of the mvapich2 project

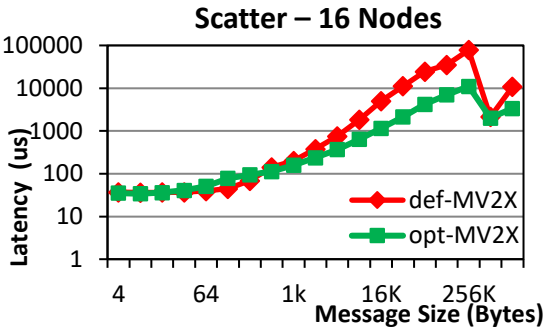
- High Performance open-source MPI Library
- Support for multiple interconnects
  - InfiniBand, Omni-Path, Ethernet/iWARP, RDMA over Converged Ethernet (RoCE), AWS EFA, Rockport Networks, and Slingshot
- Support for multiple platforms
  - x86, OpenPOWER, ARM, Xeon-Phi, GPGPUs (NVIDIA and AMD)
- Started in 2001, first open-source version demonstrated at SC '02
- Supports the latest MPI-3.1 standard
- http://mvapich.cse.ohio-state.edu
- Additional optimized versions for different systems/environments:
  - MVAPICH2-X (Advanced MPI + PGAS), since 2011
  - MVAPICH2-GDR with support for NVIDIA (since 2014) and AMD (since 2020) GPUs
  - MVAPICH2-MIC with support for Intel Xeon-Phi, since 2014
  - MVAPICH2-Virt with virtualization support, since 2015
  - MVAPICH2-EA with support for Energy-Awareness, since 2015
  - MVAPICH2-Azure for Azure HPC IB instances, since 2019
  - MVAPICH2-X-AWS for AWS HPC+EFA instances, since 2019
- Tools:
  - OSU MPI Micro-Benchmarks (OMB), since 2003
  - OSU InfiniBand Network Analysis and Monitoring (INAM), since 2015

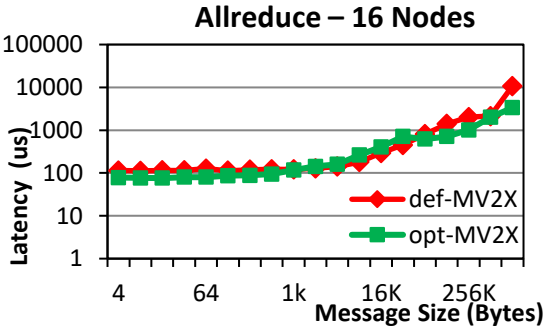


- **Used by more than 3,200 organizations in 89 countries**
- **More than 1.57 Million downloads from the OSU site directly**
- **Empowering many TOP500 clusters (Nov '21 ranking)**
  - **4th , 10,649,600-core (Sunway TaihuLight) at NSC, Wuxi, China**
  - **13th, 448, 448 cores (Frontera) at TACC**
  - **26th, 288,288 cores (Lassen) at LLNL**
  - **38th, 570,020 cores (Nurion) in South Korea and many others**
- **Available with software stacks of many vendors and Linux Distros (RedHat, SuSE, OpenHPC, and Spack)**
- **Partner in the 13th ranked TACC Frontera system**
- **Empowering Top500 systems for more than 16 years**

Mpi Optimization

- Collective algorithm tuning
  - Systematically iterate through different MVAPICH2 collective algorithms for all ***number_of_nodes*** x ***ppn*** combinations, and determine algorithms with best performance for each scenario.
- XPMEM kernel module optimization
  - User-level API for multiple processes share address space
  - Automatically detect XPMEM module in OS, and apply optimization if it is loaded.
    - Using *dlopen* to open *libxpmem* on runtime
  - Improve point-to-point & collective intra-node large message communication performance.
- Examples of collective performance difference are shown on the right





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  - **Experimental Setups**
  - **Micro-benchmark level Performance**
  - **Application level Performance**
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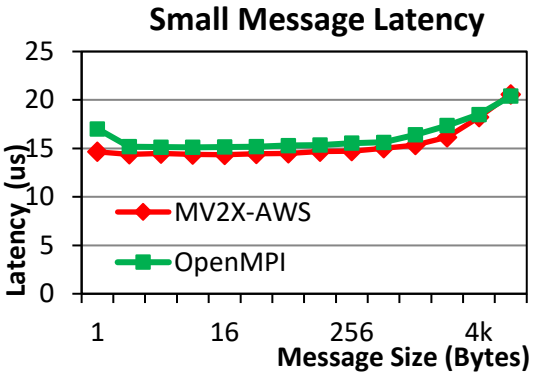
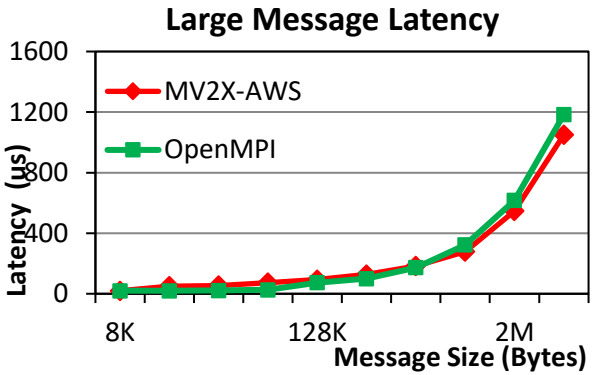
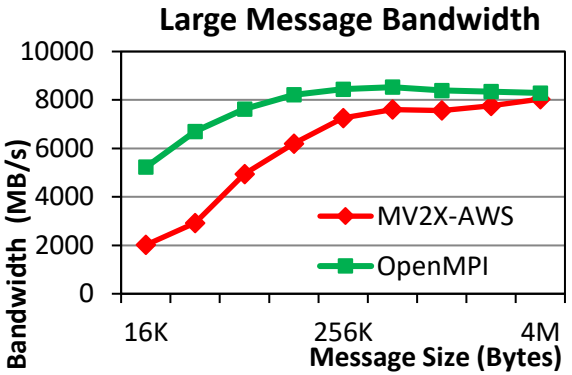
Experimental setup

- Experiment System Specification
  - Instance Type: c6gn.16xlarge
  - RAM (DDR4): 128 GB
  - Libfabric version: 1.13.2
  - Parallel cluster: 3.0.2
- MPI libraries & benchmark Specification:
  - MVAPICH2: Latest Mvapich2-X-AWS
  - OpenMPI: 4.1.0 (Parallelcluster built-in)
  - OSU Micro-benchmarks: 5.8

Performance Evaluation

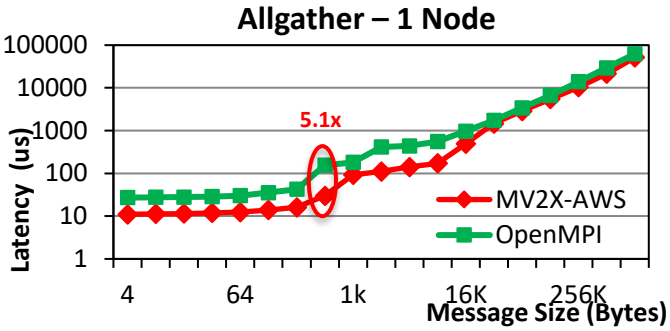


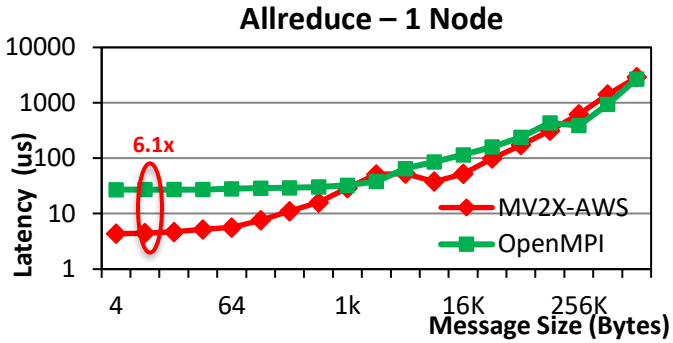


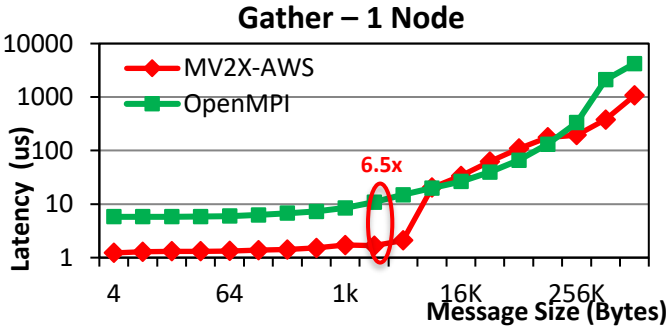


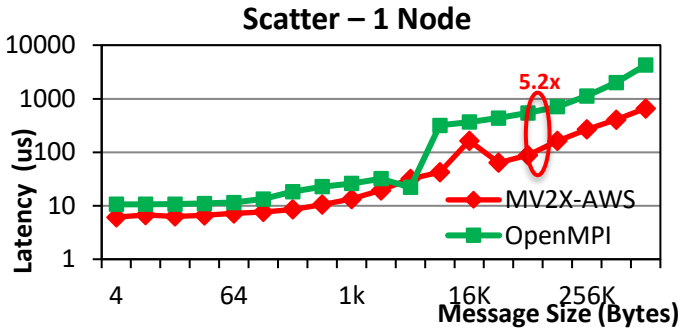
- Point-to-point communication performance

Single Node Collective Performance

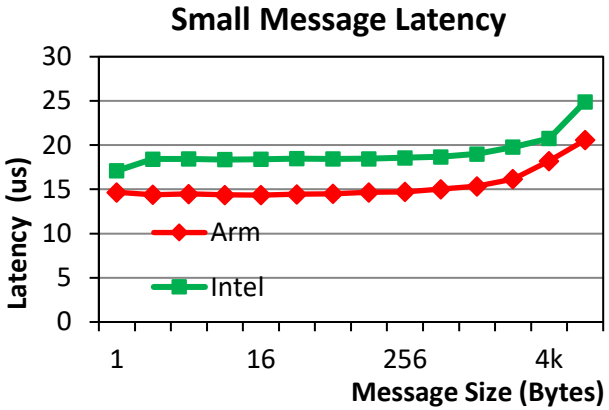


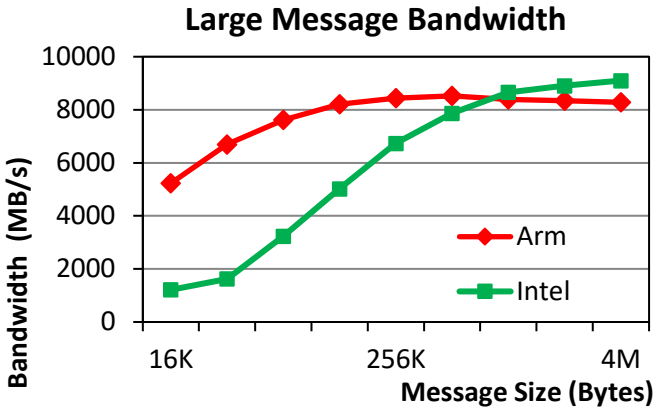






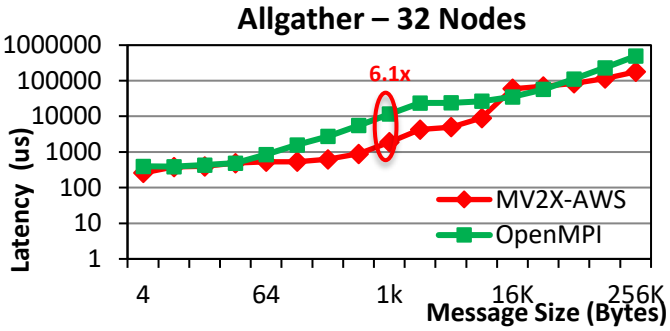
MVAPICH2-x-AWS Cross Architecture Comparison

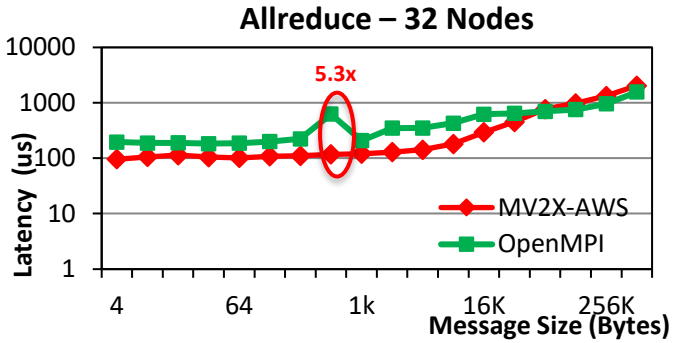


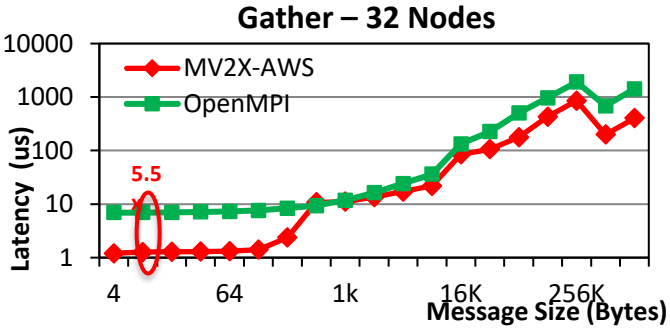


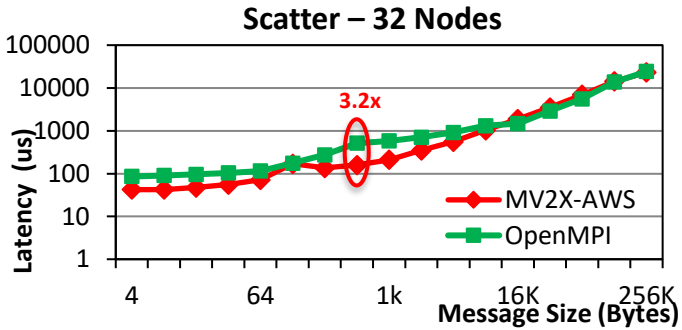
- Comparing basic MPI point-to-point performance on AWS Arm (c6gn.16xlarge) vs. x86 (c5n.18xlarge)
- AWS Arm system has similar point-to-point latency performance trend, there is a small gap which is due to different resource allocation
- MVAPICH2-X-AWS has higher point-to-point bandwidth in medium message sizes on Arm systems, and higher large message bandwidth with large message sizes (>= 1MB)

32 Nodes Collective Performance



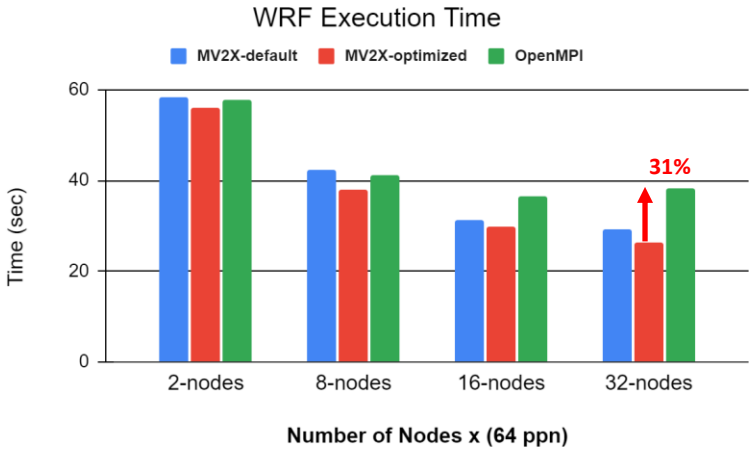


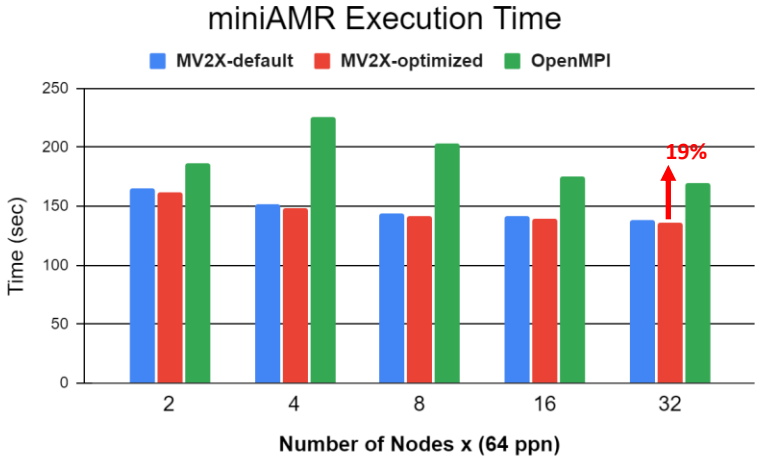




Application Performance

- Application level performance comparison:
  - WRF with strong scaling input dataset from 12km resolution case over the Continental U.S. domain
  - miniAMR using default benchmarking input mesh size





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Conclusion and Future Plans

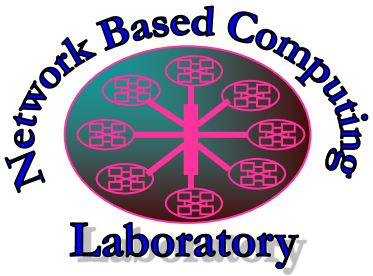
- Arm-based Cloud Systems has become a competitive option for HPC application users with compute-intensive workloads

- Performance optimization for MPI libraries leads to significant improvements as well as traditional HPC systems with x86 CPU

- Future Plans:
  - Further performance optimization on coming Graviton Gen3 System on AWS
  - Similar performance optimization for MVAPICH2 on other HPC cloud systems
  - Performance optimization for Arm-based GPU systems on AWS or other cloud systems

Q&A

Thank You!



Network-Based Computing Laboratory
http://nowlab.cse.ohio-state.edu/

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The High-Performance MPI/PGAS Project
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HiBD
High-Performance
Big Data

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