Graph500
Performance Benchmark and Profiling

March 2015

Note

- **The following research was performed under the HPC Advisory Council activities**
  - Participating vendors: Intel, Dell, Mellanox
  - Compute resource - HPC Advisory Council Cluster Center
- **The following was done to provide best practices**
  - Graph500 performance overview
  - Understanding Graph500 communication patterns
  - Ways to increase Graph500 productivity
  - MPI libraries comparisons
- **For more info please refer to**
  - http://www.dell.com
  - http://www.intel.com
  - http://www.mellanox.com
  - http://www.graph500.org

Graph500

- The Graph500 is a rating of supercomputer systems, focused on Data intensive loads
  - The project was announced on International Supercomputing Conference (ISC) in June 2010
  - The first list was published at the ACM/IEEE Supercomputing Conference in November 2010
- Graph500 Benchmark
  - Stresses communication subsystem, instead of counting double precision floating-point
  - Based on a breadth-first search in a large undirected graph
    - Model of Kronecker graph with average degree of 16
  - Contains two computation kernels in the benchmark:
    - 1st kernel is to generate the graph and compress it into sparse structures CSR or CSC
    - 2nd kernel does a parallel BFS search of some random vertices (64 search iterations per run).
  - Performance metric used to rank the supercomputers is GTEPS (10^9 Traversed edges/second)
  - For more information: http://www.graph500.org/referencecode

Objectives

- **The presented research was done to provide best practices**
  - Graph500 performance benchmarking
    - MPI Library performance comparison
    - Interconnect performance comparison
    - CPUs comparison
    - Compilers comparison
- **The presented results will demonstrate**
  - The scalability of the compute environment/application
  - Considerations for higher productivity and efficiency

Test Cluster Configuration

- **Dell PowerEdge R730 32-node (896-core) “Thor” cluster**
  - Dual-Socket 14-Core Intel E5-2697v3 @ 2.60 GHz CPUs. Turbo Mode disabled unless otherwise stated
  - Memory: 64GB memory, DDR4 2133 MHz, Memory Snoop Mode: Cluster-on-Die
  - OS: RHEL 6.5, OFED 2.3-2.0.5 InfiniBand SW stack
  - Hard Drives: 2x 1TB 7.2 RPM SATA 2.5” on RAID 1
- **Mellanox Connect-IB FDR InfiniBand adapters**
- **Mellanox ConnectX-3 QDR InfiniBand and 40GbE VPI adapters**
- **Mellanox SwitchX SX6036 VPI InfiniBand and Ethernet switches**
- **MPI: Mellanox HPC-X v1.2.0-292, Intel MPI 5.0.2.044**
- **Compilers: Intel Composer XE 2015.1.133, GNU Compilers 4.9.1**
- **Code Implementations:**
  - Graph500 Reference Implementation, version 2.1.4
  - Tuned MPI implementation with 2-D data distribution

PowerEdge R730

Massive flexibility for data intensive operations

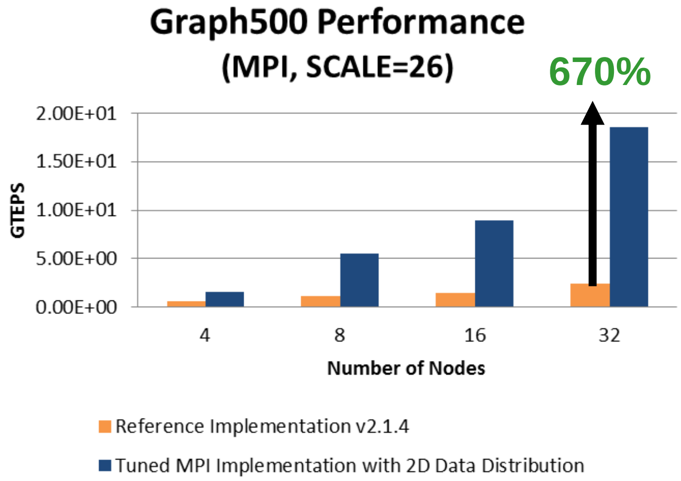
- **Performance and efficiency**
  - Intelligent hardware-driven systems management with extensive power management features
  - Innovative tools including automation for parts replacement and lifecycle manageability
  - Broad choice of networking technologies from GigE to IB
  - Built in redundancy with hot plug and swappable PSU, HDDs and fans
- **Benefits**
  - Designed for performance workloads
    - from big data analytics, distributed storage or distributed computing where local storage is key to classic HPC and large scale hosting environments
    - High performance scale-out compute and low cost dense storage in one package
- **Hardware Capabilities**
  - Flexible compute platform with dense storage capacity
    - 2S/2U server, 6 PCIe slots
  - Large memory footprint (Up to 768GB / 24 DIMMs)
  - High I/O performance and optional storage configurations
    - HDD options: 12 x 3.5” - or - 24 x 2.5 + 2x 2.5 HDDs in rear of server
    - Up to 26 HDDs with 2 hot plug drives in rear of server for boot or scratch

Graph500 Performance – Graph500 Implementations

- **There are 2 implementations that can be obtained from Graph500 web site**
- **Reference Implementation version 2.1.4**
  - Default version
  - http://www.graph500.org/sites/default/files/files/graph500-2.1.4.tar.bz2
  - Workaround is applied in the mpi_workarounds.h for problems with hanging processes
- **Tuned MPI implementation with 2-D data distribution**
  - Implementation by Indiana University
  - http://www.graph500.org/sites/default/files/files/mpi-tuned-2d.tar.bz2
  - This implementation has a dependency on libhugetlbfs

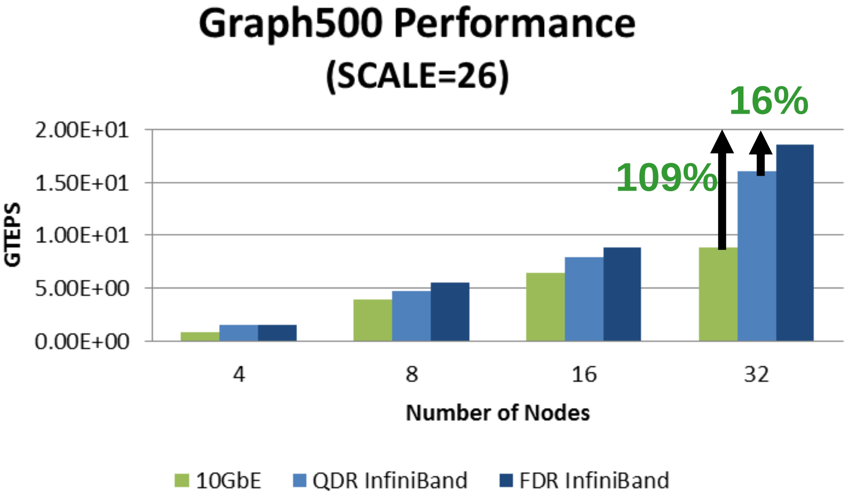
Graph500 Performance – Graph500 Implementations

- **Tuned Impl. with 2-D data distribution outperforms Reference Implementation**
  - Outperforms the reference implementation by over 6.7 times
- **Most implementations in listings are defined as “Custom” implementation**
  - There are many custom (code) implementations, but they are not publically obtainable
  - The algorithm used in code can vary the performance, and can dramatically improve performance



Graph500 Performance – Network Interconnect

- **FDR InfiniBand delivers higher performance than other network interconnects**
  - FDR IB outperforms QDR IB by 16% at 32 nodes, 10GbE by 109% at 32 nodes
  - InfiniBand outperforms Ethernet in MPI_Alltoallv performance
  - The hybrid MPI-OpenMP case is used

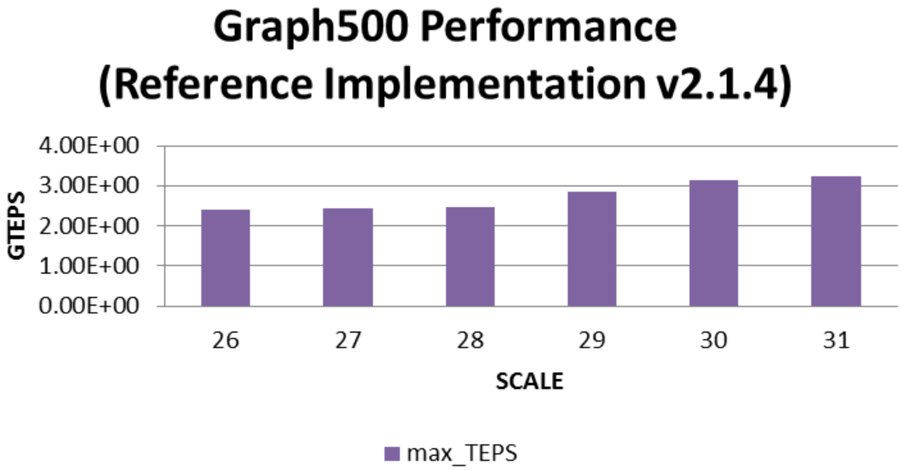


Tuned MPI implementation with 2-D data distribution

4 MPI tasks Per Node

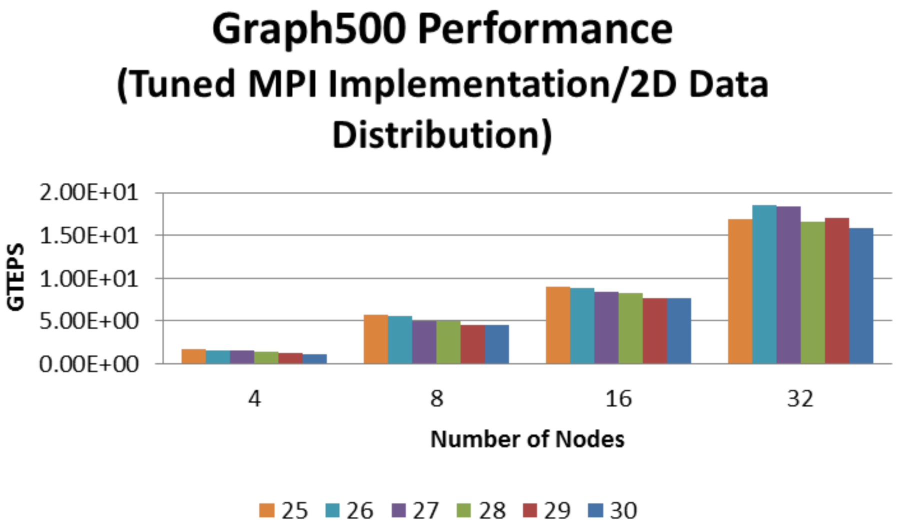
Graph500 Performance – Scale Sizes

- **For the referenced implementation:**
  - Increasing the scale parameter would increase memory consumption
  - Higher Scale value would gradually increase the GTEPS results



Graph500 Performance – Scale Sizes

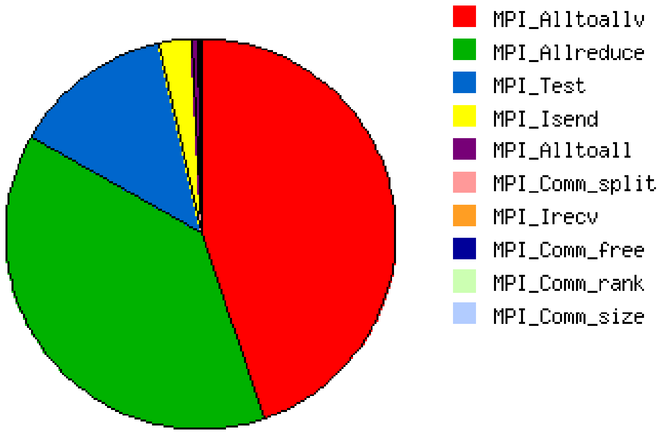
- **For the tuned MPI implementation with 2-D data distribution:**
  - Increasing the scale parameter would also increase memory consumption
  - Higher scale sizes does not seem to increase the GTEPS results



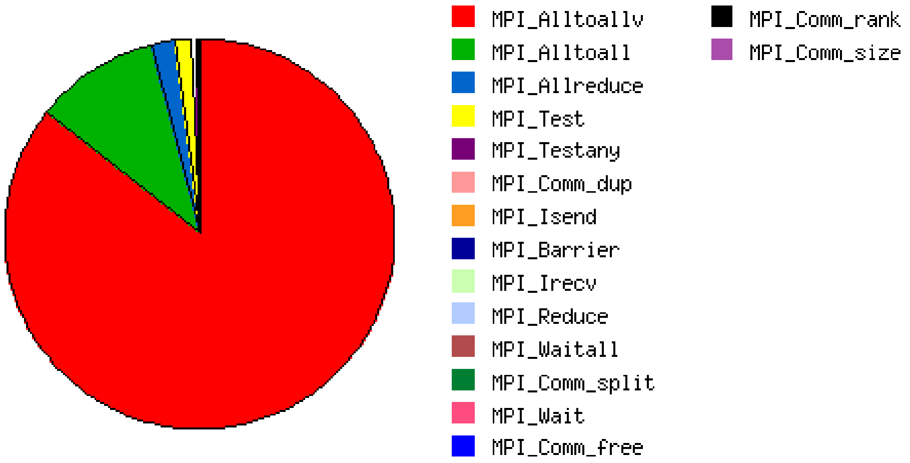
Graph500 Performance – MPI Profiles

- **Both Graph500 implementation shows high usage for MPI Collective Operations:**
  - MPI_Alltoallv affects Graph500 performance for both of the implementations
  - Ref Imp: MPI_Alltoallv (97%), MPI_Allreduce (1%), MPI_Test (0.8%)
  - Tuned MPI: MPI_Alltoallv (44%), MPI_Alltoall (38%) MPI_Allreduce (13%)
  - This shows MPI collective communications has a direct impact on Graph500 performance

Reference Implementation – 32 nodes



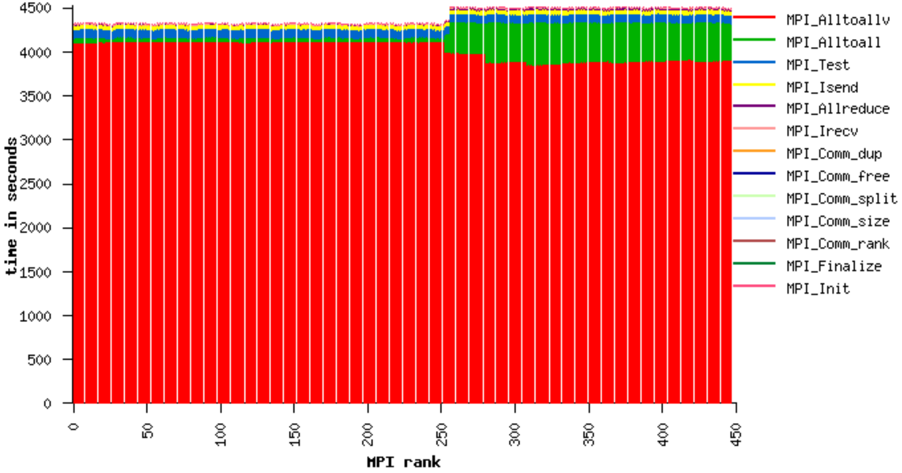
Tuned MPI implementation with 2-D data distribution – 32 nodes



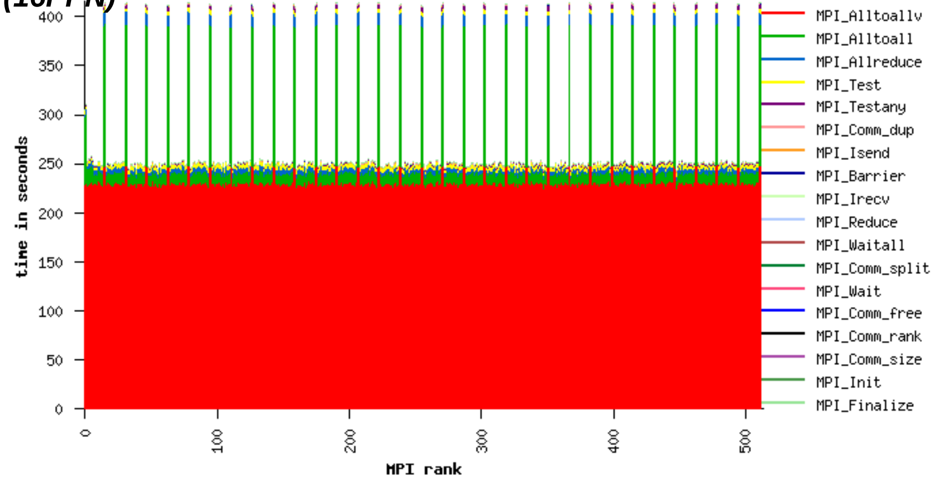
Graph500 Profiling – MPI calls

- **Both implementations appeared to have a substantial use in MPI_Alltoallv**
  - MPI_Alltoallv is a collective op for all processes send data to and receive data from all other processes
  - MPI Collective operations appears to have a direct impact on Graph500 performance
  - FDR InfiniBand outperforms other network interconnect on the performance of collective operations

Reference Implementation – 16 nodes



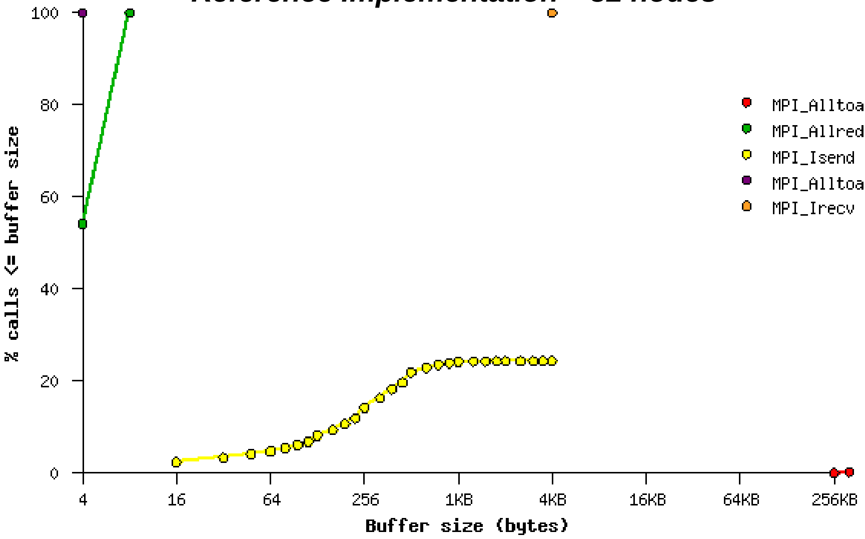
Tuned MPI implementation with 2-D data distribution – 32 nodes (16PPN)



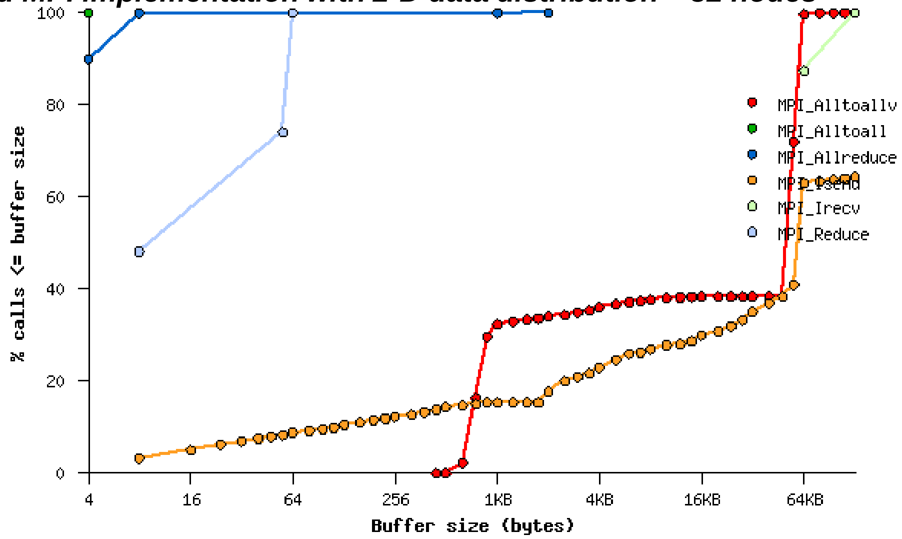
Graph500 Profiling – MPI Message Distribution

- **MPI_Alltoallv communications is the most time consuming MPI communication**
  - In Reference Implementation: Alltoallv seems to concentrated at 256KB and beyond
  - In Tuned Implementation: Alltoallv appears to be between 512B and 1KB, and 57KB and 64KB

Reference Implementation – 32 nodes



Tuned MPI implementation with 2-D data distribution – 32 nodes



Graph500 Summary

- **Performance of Graph500 depends on the implementation used**
  - Tuned MPI implementation with 2D distribution outperforms Reference Implementation by over 6 times
  - Other implementations of Graph500 exist and likely to improve performance, however not freely obtainable
- **InfiniBand FDR is the most efficient cluster interconnect for Graph500**
  - FDR InfiniBand outperforms QDR IB by 16%, and 10GbE by 109% at 32 nodes
  - InfiniBand outperforms Ethernet in MPI_Alltoallv performance
- **Graph500 Profiling**
  - Both Graph500 implementation shows high usage for MPI Collective Operations:
  - MPI_Alltoallv affects Graph500 performance for both of the implementations
  - Ref Imp: MPI_Alltoallv (97%), MPI_Allreduce (1%), MPI_Test (0.8%)
  - Tuned MPI: MPI_Alltoallv (44%), MPI_Alltoall (38%) MPI_Allreduce (13%)
  - This shows MPI collective communications has a direct impact on Graph500 performance

Thank You

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