Bandwidth-Aware Resource Management for Extreme Scale Systems

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***Abstract*—As systems scale towards exascale, many resources will become increasingly constrained. While some of these resources have historically been explicitly allocated, many, like network bandwidth, I/O bandwidth, or power, have not. As systems continue to evolve, we expect many such resources to become explicitly managed. This change will pose critical challenges to resource management and job scheduling. In this paper, we explore bandwidth-aware resource management for Blue Gene systems, where the partition-based interconnect architecture provides a unique opportunity to explicitly allocate bandwidth to jobs. In this paper we investigate the value of bandwidth awareness and further present a bandwidth-aware resource management design for Blue Gene systems.**

I. Introduction

The insatiable demand for more computing power continues to drive the deployment of ever-growing supercomputers. Production systems today already contain hundreds of thousands of processors, and they are headed to millions [1]. These systems utilize shared resources such as the communication infrastructure to achieve higher performance while controlling costs. These systems are used to tackle scientific problems of increasing size and complexity. These scientific applications have diverse requirements and exhibit different characteristics with regard to their resource requirements such as communication. *As high performance computing continues to evolve, the shared resources are becoming increasingly constrained*[2].

Torus-based networks are commonly used in high-end supercomputers due to their linear scaling on per node cost as well as their competitive communication performance. To address the potential performance issues (e.g., job interference and communication contention) caused by shared torus networks, IBM Blue Gene series [3][4][5][6] systems adopt a *network partitioning* mechanism, where the network interconnect is reconfigured to provide private, per-job networks to compute nodes [7]. Once a network partition is established, the job running on the partition can benefit from the dedicated synchronization network where all required hardware is dedicated to the job. Although a partition-based system provides jobs with dedicated network resources and bandwidth, the use of partitions introduces a new problem: network partitioning is accomplished through the allocation of shared network resources to a single job, inducing resource contention. In this case, contention results are unusable configurations of node resources, regardless of node state. This issue is analogous to fragmentation in many ways, and can diminish both job response times as well as system utilization.

To address the problem, in this paper we investigate the value of bandwidth awareness and further present a bandwidth-aware resource management design for Blue Gene systems. The partition-based design in Blue Gene systems provides us a unique opportunity to explicitly allocate bandwidth to jobs, in a way that isn't possible on other systems. While this capability is currently rare, we expect it to become more common in the future.

II. Background

A. Mira: The IBM Blue Gene/Q at Argonne

Mira is a 10 PFLOPS (peak) Blue Gene/Q system operated by Argonne National Laboratory for the U.S. Department of Energy. Time on Mira is primarily awarded through the Innovative and Novel Computational Impact on theory and Experiment (INCITE) program [8] and the ASCR Leadership Computing Challenge (ALCC) program. Blue Gene/Q is the third generation in the Blue Gene family. Blue Gene/Q systems are comprised of individual racks that are connected together, each rack containing 1,024 sixteen-core nodes, for a total of 16,384 cores per rack.

B. Torus versus Mesh Partitions

One unique feature of the Blue Gene/Q architecture is the ability to explicitly allocate network performance to jobs. When building a partition, a shared pool of network resources are allocated to a single partition at a time. If sufficient resources are dedicated to a partition, it will have a torus network. That is, the partition will have each side connected to its conjugate face on the opposite side of the partition. Alternatively, if fewer resources are allocated, the partition will only have a mesh network, where the outside

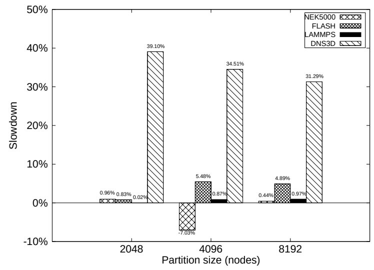


Figure 1. Application slowdown of leadership applications from torus partitions to mesh partitions

faces of the mesh aren't connected, except where internal midplane faces connect to one another. Intermediate configurations are also possible within a partition, whereby some dimensions are wrapped (torus) while others are not (mesh). The performance of full torus networks is considerable better than the comparable mixed or all mesh network.

III. Application Benchmarking

The results of application benchmarking on torus and mesh partitions are shown in Figure 2(c). For NEK5000, FLASH and LAMMPS, there is neglectable slowdonw in the application runtime. But for DNS3D which heavilty relies on the all-to-all communication, the performance degradation is above 30%.

IV. Bandwidth-Aware Scheduling Policy

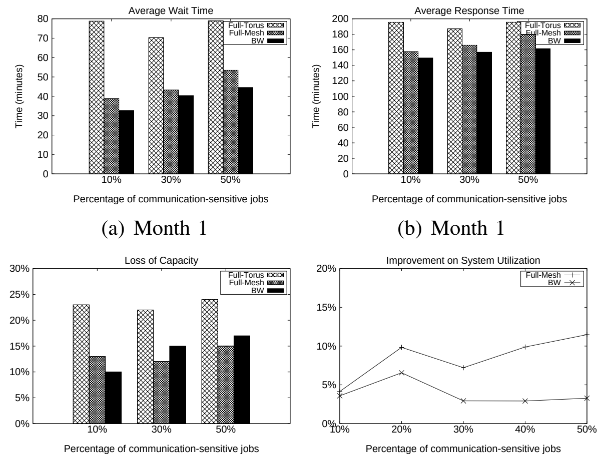
As described earlier, Blue Gene/Q partitions can be configured with mixed torus and mesh dimensions. According to application benchmarking and the availability of mixed partitions, we propose *a bandwidth-aware (BW) scheduling scheme* for the partition-based production systems like Mira. Intuitively, jobs running at the problem sizes (such as 1K, 4K and 32K) would be routed to mesh partitions. Jobs exhibiting nontrivial slowdowns should be explicitly submitted to torus partitions of these size. This would allow the majority of jobs to run with smaller resource footprint while still allowing users requiring the full torus partition to have it.

V. Scheduling Study

In this section, we conduct a comparative study of several scheduling policies under a variety of workload configurations using trace-based simulation. In particular, we compare three resource management schemes that are: full-torus, full-mesh, and bandwidth-aware. The goal is to investigate the benefit brought by bandwidth-aware scheduling over the current bandwidth-oblivious scheduling.

A. Experimental Results

The preliminary results of simulation are presented in Figure 2. Using our bandwidth-aware scheduling policy (BW) can significantly reduce the average wait time and response time. Although the full-mesh configuration gets better loss of capacity (LoC) and sysem utiliation improvement, the tradeoff is based on the sacrifice of applications' performance.



(a) Month 1

(b) Month 1

(c) Month 1

(d) Month 1

Figure 2. Comparison of scheduling performance using different scheduling policies, where application slowdown is set to 20% for communication-sensitive jobs

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