High-Performance Computing Networks at BYU

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What makes a supercomputer, super?

HPC or High-Performance Computing, is characterized by workloads and hardware requirements

- Significantly larger compute capability than an average system
- Used to solve problems that are too large to easily be solved on a single, traditional system
- May utilize specialty hardware and software
- No specific threshold for capacity

Nature of HPC Computing

In HPC, speedup comes from one of two sources:

- Using faster resources (eg. faster clock speeds)
- Using more resources (eg. using more processors) or *Parallelism*

Physics generally limits us on the faster resources, so we spend more time on parallelism.

Parallelism and Communication Needs

- When utilizing multiple resources (eg. multiple processors), the program must:
  - Split up the workload
  - Provide necessary coordination among resources
- The algorithm and data determine the nature of communication needs
- In general, for HPC problems, communication is key.
  - For inter-process communication
  - For communicating with storage

What kinds of HPC systems are out there?

There are two major categories of HPC systems:

- Systems which utilize specialty hardware, including:
  - Processors
    - Vector Processors (eg. Cray)
    - Specialty Serial Processors (eg. Itanium, Power5, etc.)
  - Accelerators
    - Manycore (GPU & Intel MIC)
    - FPGA
    - Cell
  - Specialty/Proprietary Interconnects
    - Infiniband
    - NUMALink
- Commodity Hardware:
  - Stock processors (eg. x86, x86_64)
  - Stock interconnects (Ethernet)

What is Infiniband? And why do I care?

Infiniband is the most common high-performance interconnect used in HPC. It:

- is switched-fabric architecture (more like Fibre Channel than like Ethernet)
- utilizes multiple speeds, lanes, and links
- provides:
  - extremely high bandwidth
  - extremely low latency (one-way $< 10\ \mu$s, compared to approx. 32 μs for 1GbE)
- Speedup comes mostly from:
  - Short protocol stack (very little above layer 2)
  - Low-latency switching (very little decision making in the switch)
  - Remote Direct Memory Access (RDMA)

Terms

HCA
: Host Channel Adapter - The interface device that connects a host to the network

GUID
: Globally-unique Identifier; hardware address on each HCA or switch; like a MAC address

LID
: Logical Identifier (address) assigned by the subnet manager to the HCA; kinda like an IP, but resides in the upper part of layer 2

SM
: Subnet Manager, a hardware or software device that assigns LIDs to GUIDs, and pre-loads the switch forwarding tables

Lanes/Links/Speeds

Infiniband utilizes multiple lanes per physical link. Each link has a certain speed based on the standard:

	SDR	*DDR*	*QDR*	*FDR*
1x	2.5 Gb/s	5 Gb/s	10 Gb/s	14 Gb/s
4x	10 Gb/s	20 Gb/s	40 Gb/s	56 Gb/s
12x	30 Gb/s	60 Gb/s	120 Gb/s	168 Gb/s

Encoding Overhead

Infiniband uses bit-line encodings to guarantee bit transitions for clock synchronization:

- SDR, DDR, QDR - 8b/10b encoding (8 data bytes encoded in 10 bytes total; 20% overhead)
- FDR and beyond - 64b/66b encoding (64 data bytes encoded in 66 bytes total; 3% overhead)

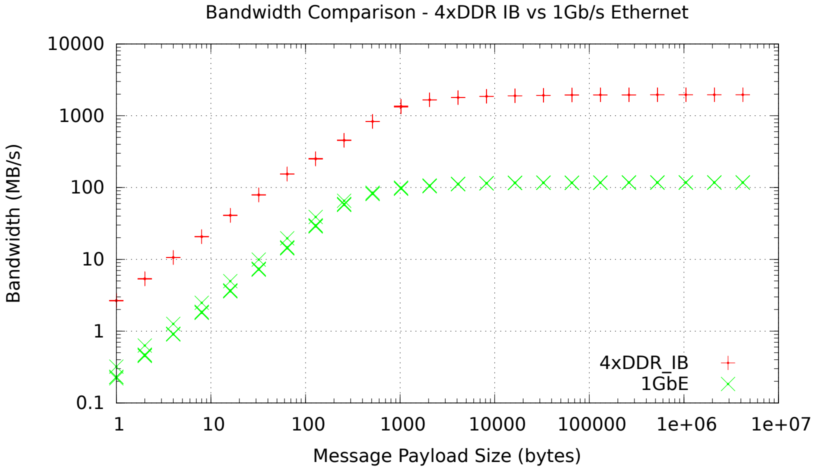
	SDR	*DDR*	*QDR*	*FDR*
1x	2.5 Gb/s raw 2 Gb/s net	5 Gb/s raw 4 Gb/s net	10 Gb/s raw 8 Gb/s net	14 Gb/s raw 13.6 Gb/s net
4x	10 Gb/s raw 8 Gb/s net	20 Gb/s raw 16 Gb/s net	40 Gb/s raw 32 Gb/s net	56 Gb/s raw 54.3 Gb/s net
12x	30 Gb/s raw 24 Gb/s net	60 Gb/s raw 48 Gb/s net	120 Gb/s raw 96 Gb/s net	168 Gb/s raw 162.9 Gb/s net

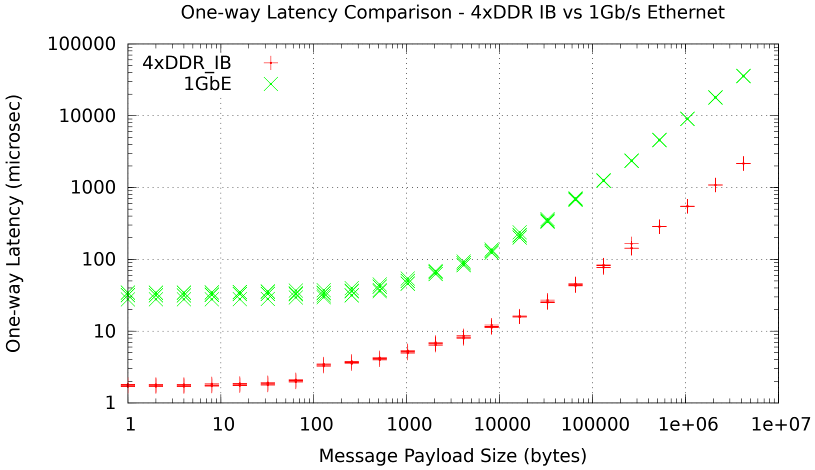
Performance at BYU's FSL

The graphs shown in the next couple of slides represent the bandwidth and latency performance of 4xDDR Infiniband vs 1Gb/s Ethernet at the Fulton Supercomputing Lab.

- All tests were performed host-to-host with one intervening switch (eg. host-switch-host)
- All tests utilize increasing message sizes, to demonstrate where one effect ends and the other starts
- Tests were performed using the "osu_bw" and "osu_latency" binaries from the OSU Micro-Benchmarks for MPI (a.k.a. "OMB")[1]

[1] http://mvapich.cse.ohio-state.edu/benchmarks/


Bandwidth Comparison - 4xDDR IB vs 1Gb/s Ethernet
Bandwidth (MB/s)
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000
1e+06
1e+07
Message Payload Size (bytes)
4xDDR_IB
1GbE


One-way Latency Comparison - 4xDDR IB vs 1Gb/s Ethernet
4xDDR_IB
1GbE
One-way Latency (microsec)
100000
10000
1000
100
10
1
Message Payload Size (bytes)
1
10
100
1000
10000
100000
1e+06
1e+07

How Infiniband is Managed

Infiniband is designed as a trusted network. The network is managed by a *subnet manager* which does the following:

- Periodically sweep the network, looking for topology changes, checking for errors, etc.
- Build a cohesive model of the network topology
- Load the switch forwarding tables with the LID/Port mapping

Infiniband Topologies

Infinband puts very little restriction on the physical topology of the network.

- The Subnet Manager loads all the forwarding tables into the switches
  - as long as you can build an appropriate graph parsing algorithm, and implement it in a subnet manager, you can use a topology
  - allows some much more interesting topologies than those commonly Ethernet and TCP/IP networks usually use.[2]

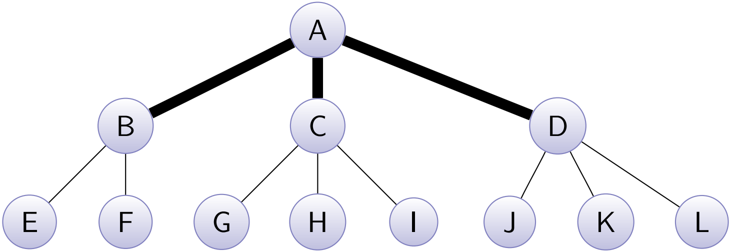
[2] Technically you can use any topology with Ethernet as well. It just takes a huge amount of very-messy work, for very little benefit. I don't recommend trying it.

Possible Topologies

- Tree/Fat-Tree
- Fully-connected Mesh
- Rectangular Mesh
- Toroidal Mesh
- Hypercube
- Folded-Clos Network

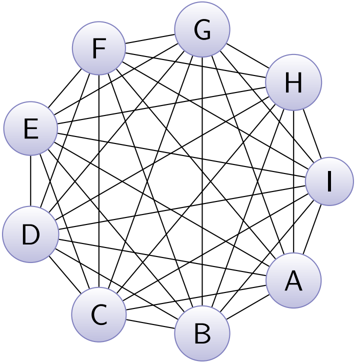
Fat Tree Example

A *Fat Tree* is basically a tree with increased bandwidth (faster links or more links) between upper tiers relative to lower tiers; Ethernet has no problems with this one, so it's not terribly exciting



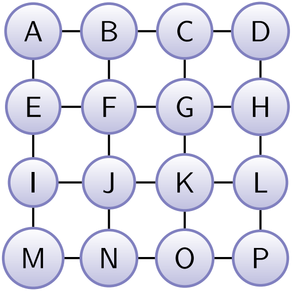
Fully-connected Mesh Example

- Pro: Shortest hop-count (1 hop) from any point to any other point
- Con: takes a huge amount of cables, and the cable count increases very, very quickly.

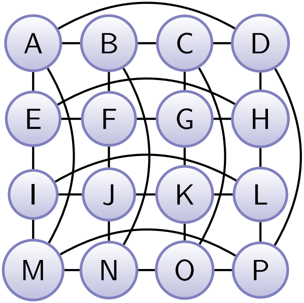


Rectangular/Toroidal Mesh Example

- Pro: Excellent for large topologies (no spine switches to buy)
- Con: Higher hop count than other options, depending on size and shape



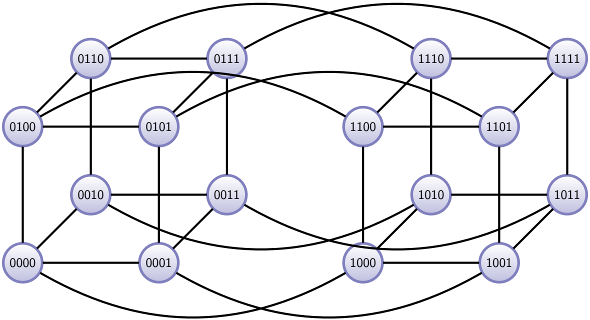
(a) Rectangular



(b) Toroidal

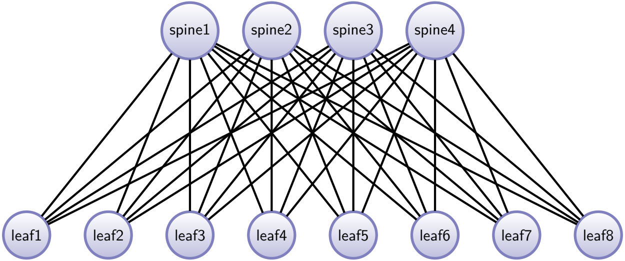
Hypercube example (4-d)

- Pro: for *d* dimensions, no more than *d* hops from any other point in the topology
- Con: cables/ports at each endpoint increase linearly with the dimension

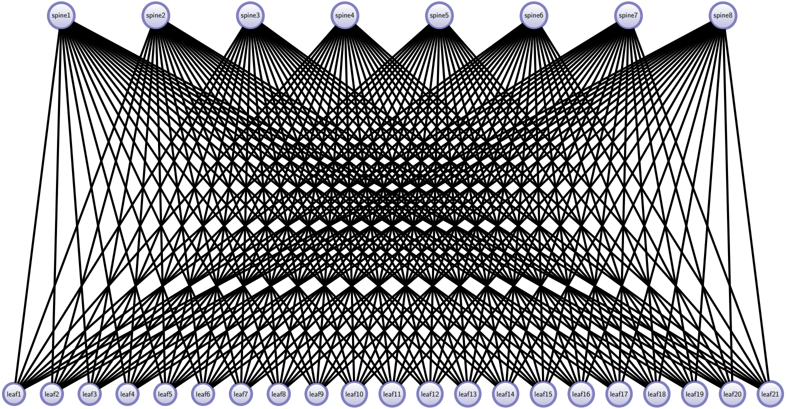


Folded Clos Network Example

- Pros:
  - Most common approach for small or medium-scale Infiniband fabrics
  - Well understood (how larger IB switches are designed internally)
  - Redundant; 1 link from each leaf to each spine
- Con: Scalability limited by the port count of spine & leaf switches



BYU Supercomputing's Clos Network



Upper Layer Stack

The protocol stack includes several optional components to enable application communication:

SRP
: SCSI RDMA Protocol - Block Storage Protocol; competing with iSER

iSER
: iSCSI extensions for RDMA - Block Storage Protocol; competing with SRP

IPoIB
: IP over Infiniband - not the most efficient, but works

Verbs
: Native IB API for general application use

SDP
: Sockets Direct Protocol - basically sockets protocol for IB

Other (usu. Proprietary) Extensions

Other extensions exist, usually implemented in a proprietary fashion, including the following:

- **FCoIB** Fibre-Channel traffic over IB
- **ETHoIB** Ethernet over IB
- **FlexBoot** PXE-like network booting

Message Passing

- In HPC, most applications use a message-passing library like MPI, which in turn uses the Verbs API to do its work.
- Several dozen MPI implementations exist, but the most common that can utilize Infiniband are:
  - OpenMPI
  - MVAPICH
  - Intel MPI
  - HP/Platform MPI

Costs

In general:

- Gigabit Ethernet comes on-board for most hosts, so it has very little cost
- 10-Gigabit Ethernet is coming on-board for some hosts
- Per-port cost for 4xQDR Infiniband (40 Gb/s) is usually less than 10-Gigabit Ethernet, but this changes over time
- 4xQDR (40Gb/s) HCAs can be repurposed (via firmware change) to be 10-Gigabit Ethernet NICs

Questions?

Any questions?