

High-Performance Computing Networks at BYU

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- 1 Outline
- 2 HPC Introduction
 - What is HPC?
 - Types of HPC
- 3 Types of Communication
- 4 Infiniband
 - Physical Layer Characteristics
 - Encoding
 - Measured Performance
 - Bandwidth Comparison
 - Latency Comparison
 - Subnet Management
- 5 Topologies
 - Evaluating Topologies
- 6 Where things are going
- 7 Conclusions
- 8 Questions

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
- Therefore for HPC problems, communication is key.
 - For inter-process communication
 - For communicating with data storage

What kind of communication are we talking about?

- Programs that utilize multiple processors to split up work, need to communicate between threads or processes, to coordinate efforts, report on results, etc.
- Communication between threads/processes on the same host (“*Intra-node*” communication) is extremely fast (usually via shared memory)
- If the processes are on different hosts, we have to go out to some communication fabric (“*Inter-node*” communication)
 - There's a lot of research in speeding up *intra-node* communication, but that's more of a Computer Science or Electrical Engineering problem. We'll spend our time today on *inter-node* communication

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 $< 5 \mu\text{s}$, compared to approx. $22 \mu\text{s}$ 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)

Lanes/Links/Speeds

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

	<i>SDR</i>	<i>DDR</i>	<i>QDR</i>	<i>FDR</i>
<i>1x</i>	2.5 Gb/s	5 Gb/s	10 Gb/s	14 Gb/s
<i>4x</i>	10 Gb/s	20 Gb/s	40 Gb/s	56 Gb/s
<i>12x</i>	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)

	<i>SDR</i>	<i>DDR</i>	<i>QDR</i>	<i>FDR</i>
<i>1x</i>	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
<i>4x</i>	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
<i>12x</i>	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

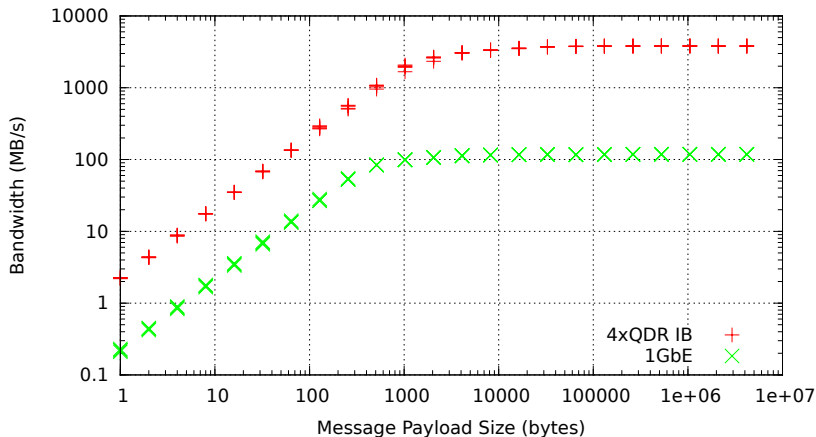
Performance at BYU's FSL

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

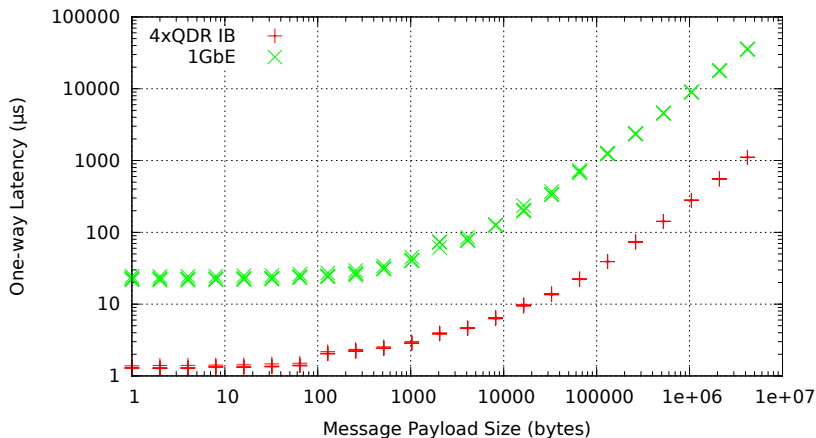
- All tests were performed host-to-host with one intervening switch (eg. host-switch-host)
- All tests utilize increasing message sizes, to demonstrate where one effect ends and the other starts
- Tests were performed using the “osu_bw” and “osu_latency” binaries from the OSU Micro-Benchmarks for MPI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

¹<http://mvapich.cse.ohio-state.edu/benchmarks/>

Bandwidth Comparison - 4xQDR IB vs 1Gb/s Ethernet



One-way Latency Comparison - 4xQDR IB vs 1Gb/s Ethernet



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

Infiniband 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

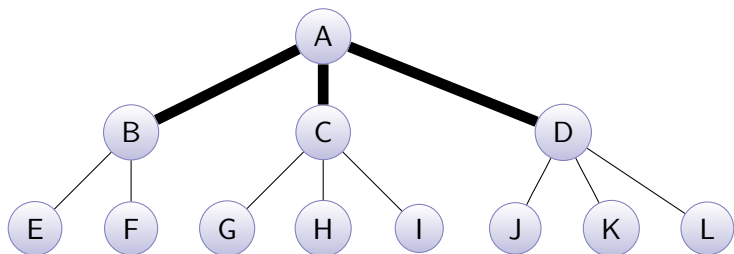
²Technically you can use any topology with Ethernet as well. It just takes a huge amount of very-messy work, for very little benefit. I don't recommend trying it.

Possible Topologies

- Tree/Fat-Tree
- Fully-connected Mesh
- Torus
- Hypercube
- Folded-Clos Network

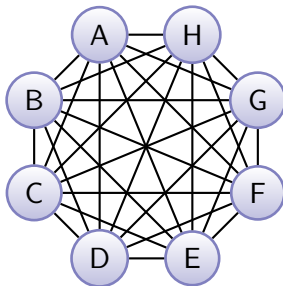
Fat Tree Example

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



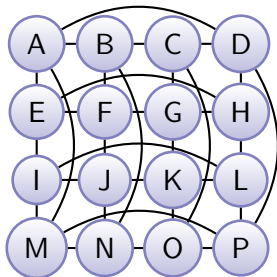
Fully-connected Mesh Example

- 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.



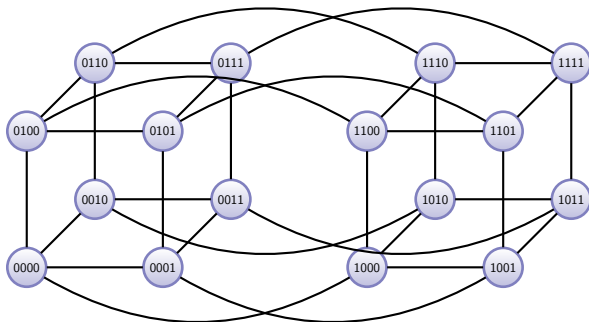
Torus example

- Pro: Excellent for large topologies (no core switches to buy)
- Con: Higher hop count than other options, depending on size and shape
- Con: Less desirable bandwidth ratios (MBB to Client BW; discussed later)



Hypercube example (4-dimensional)³

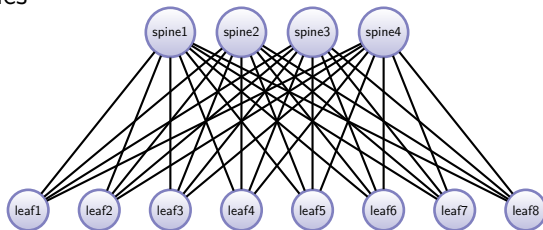
- Pro: for d dimensions, no more than d hops from any other point in the topology
- Con: cables/ports at each endpoint increase linearly with the dimension



³Note that this is really just a special case of a Torus.

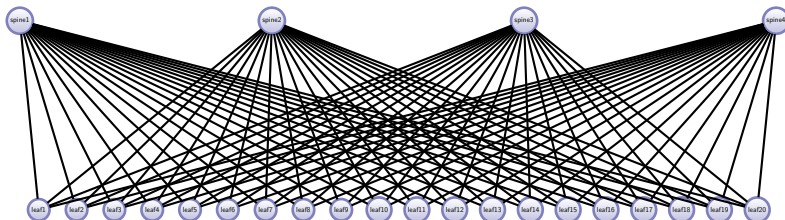
Folded Clos Network Example

- 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
 - Easy to expand (up to the port count of the switches)
- Con: Scalability limited by the port count of spine & leaf switches



BYU Supercomputing's Clos Network

Note that this only shows the switches involved; there are 16 hosts attached to each leaf switch.



What are some important characteristics for evaluating networks and topologies?

- Total host bandwidth
- Latency/hop-count
- Cost
- Ease of expansion
- Minimum Bisection Bandwidth
- MBB to Client BW Ratio

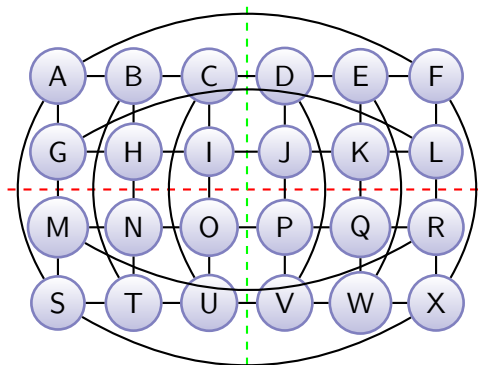
What's “Minimum Bisection Bandwidth”?

- If you were to draw a line across a topology, such that half the clients/switches/whatever are on each side of the line, the total bandwidth of all the links “cut” by that line is the *bisection bandwidth*
- Of all the possible *bisection bandwidth* lines, the one with the minimum bandwidth is called the *minimum bisection bandwidth*

MBB Example - Torus

Which bisection line represents the minimum bandwidth bisection (assume all links are the same speed)?

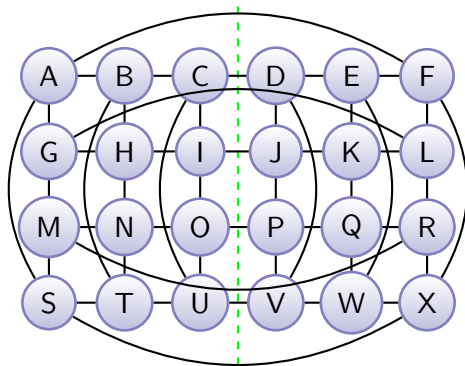
- Green line cuts 8 links; red line cuts 12 links; Green is the *minimum*



Why is MBB important?

- MBB represents the available bandwidth during a worst-case scenario:
 - All the clients on one side of the MBB line are trying to communicate with someone on the other side of the line, as fast as possible

MBB Example - Torus



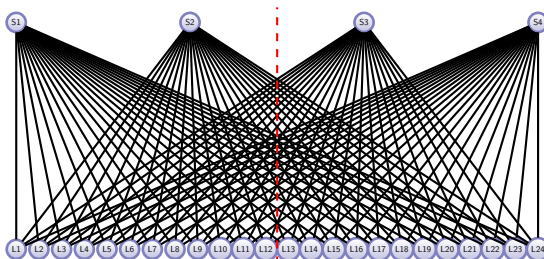
MBB vs Client BW - Torus

- Frequently we compare MBB to total Client Bandwidth on one side of the MBB line
- Generally the smaller the ratio of MBB:Half-client-bandwidth, the better
- For example, using the diagram on the Torus slide:
 - Assuming each node is a switch, with 16 hosts hanging off it, what is the MBB:HalfClientBW ratio for the Green (MBB) line?
 - assume host-switch and switch-switch links are the same BW
 - Each half has 12 switches, or $12 \times 16 = 192$ hosts, and the green line bisects 8 links, for a ratio of 24:1

MBB vs Client BW - Clos

Anyone want to try this one?

- Assume that 16 hosts are attached to each of the 24 switches at the bottom, and none to the 4 on the top
- 4 links coming out of each of the 24 switches on the bottom (1 to each of 4 core switch)



MBB vs Client BW - Clos

- Bisection line cuts 2 of 4 links per leaf switch (48 total links cut)
- 12 switches per half * 16 clients = 192 clients
- $192:48 \Rightarrow 4:1$

Multi-path Ethernet and TCP/IP

- Current efforts are underway to create multi-path options for more-common Ethernet and TCP/IP networks
- Some approaches:
 - ECMP - Equal Cost Multi-Path Routing (layer 3)
 - Several layer 3 routing protocols support ECMP, including OSPF, IS-IS, and EIGRP
 - TRILL - Transparent Interconnection of Lots of Links - Multi-path layer-2 Ethernet, standardized by IETF⁴
 - SPB - Shortest Path Bridging - Another Multi-path layer-2 Ethernet protocol, standardized by IEEE, competing with TRILL

⁴The best reference I'm aware of is *Introduction to Trill* by Radia Perlman and Donald Eastlake, available at <http://www.ipjforum.org/?p=582>

Software Defined Networking

- New standards are being adopted that
 - Separate out the routing/switching decisions (a.k.a. “Control Plane”) into a separate software layer
 - Allow for integration of higher-level data into the network decision-making process

What do I need to learn from this?

- Not everything is Ethernet and TCP/IP
- A Tree-like topology may not be the best arrangement for a specific application, especially in data centers
- You absolutely *must* understand the communication patterns of your application, in order to select the correct technology and topology
- What you're used to doing now, may change in the future

Questions?

Any questions?