SAND2008-2837P

Sandia HPC Network Infrastructure

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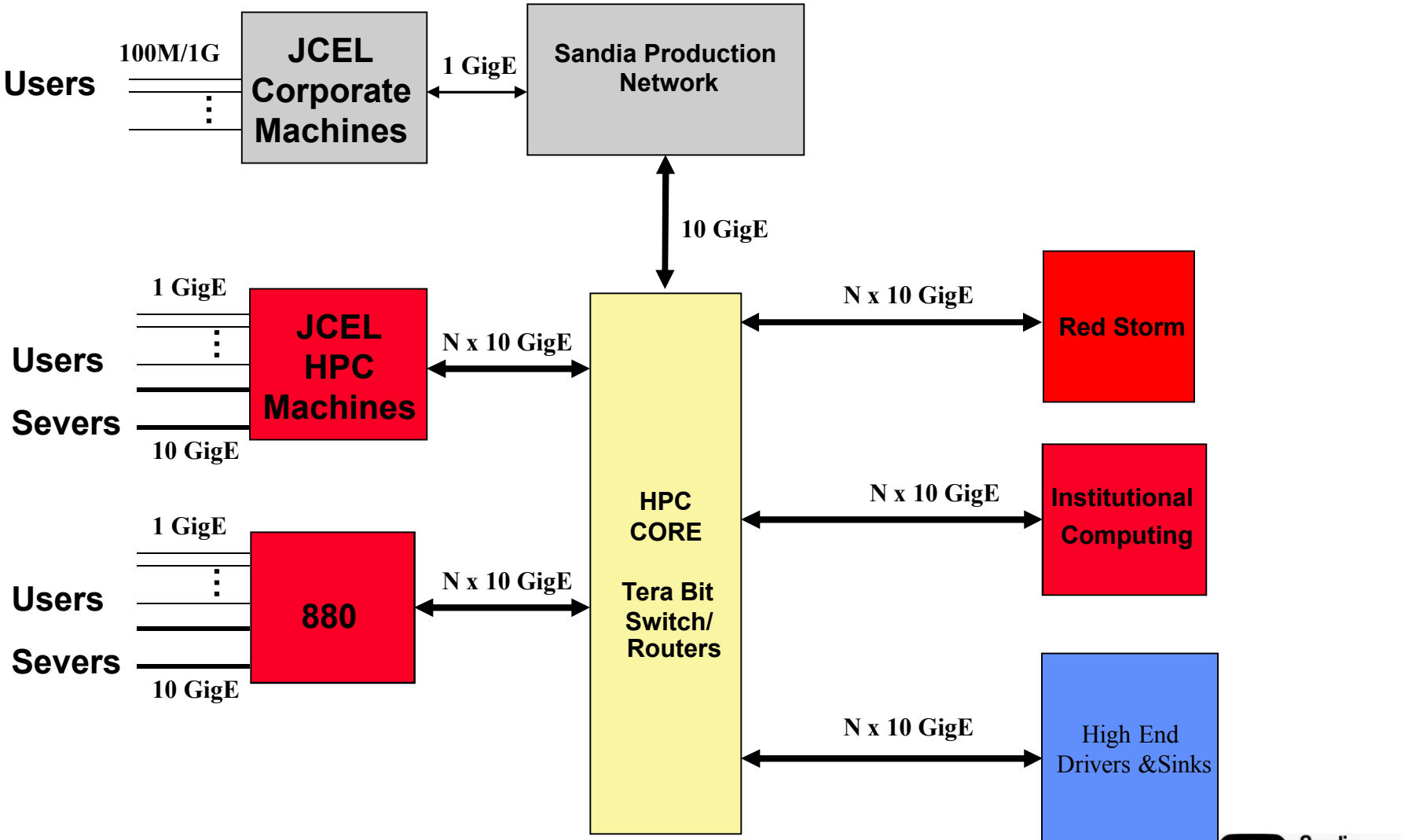
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Agenda

- Red Storm network infrastructure
- Large switch scaling work
- Improved protocol efficiency
- Sharing of Red Storm between isolated programs
- WAN update
- 10G Encryptor testing and plans

Enterprise Scientific Computing Data Network



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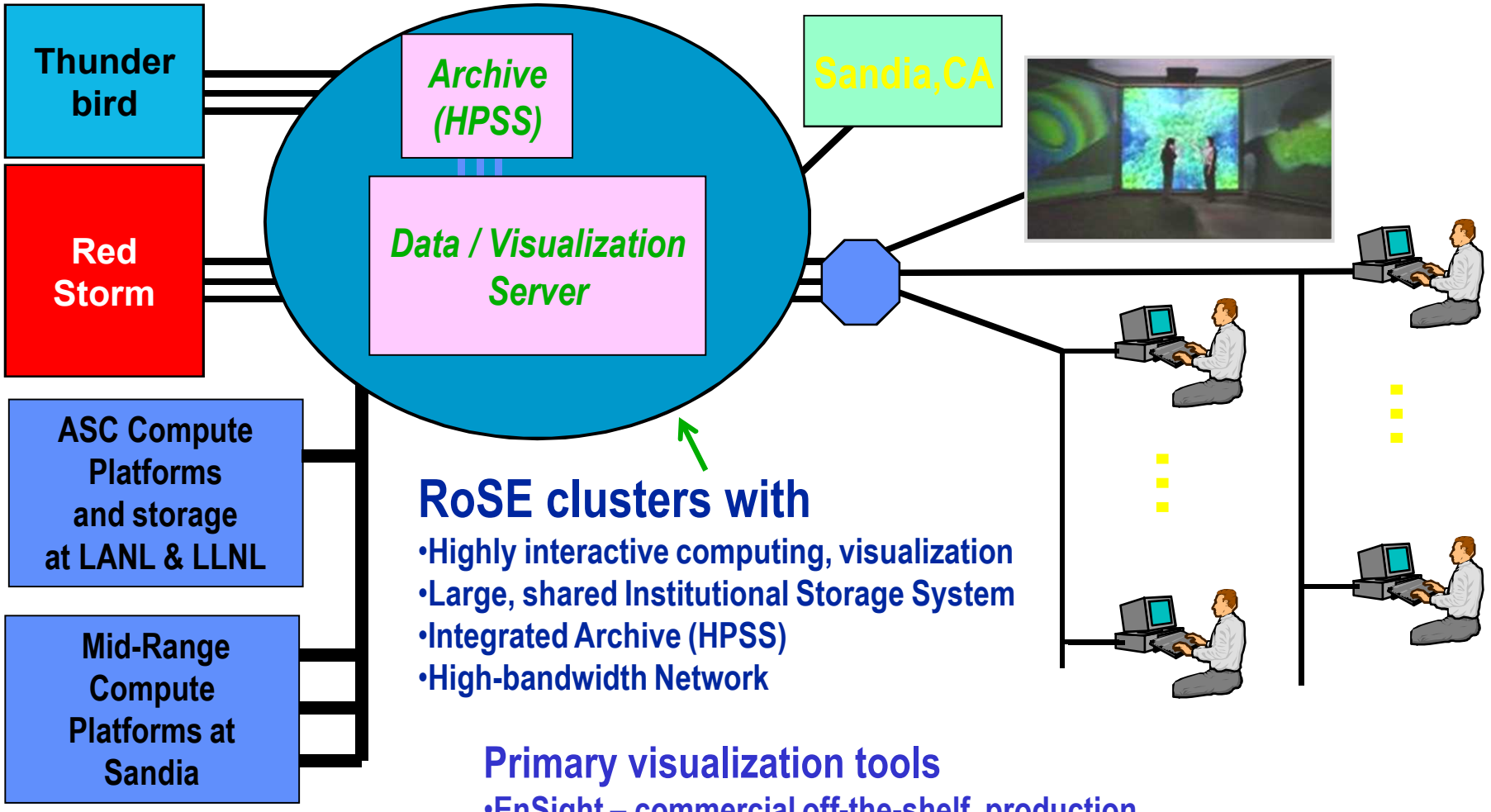
Scaleable Data / Visualization Services supporting a complete high-performance computing environment



RoSE clusters with

- Highly interactive computing, visualization
- Large, shared Institutional Storage System
- Integrated Archive (HPSS)
- High-bandwidth Network

Primary visualization tools

- EnSight – commercial off-the-shelf, production
- ParaView / VTK – open source, advanced capability

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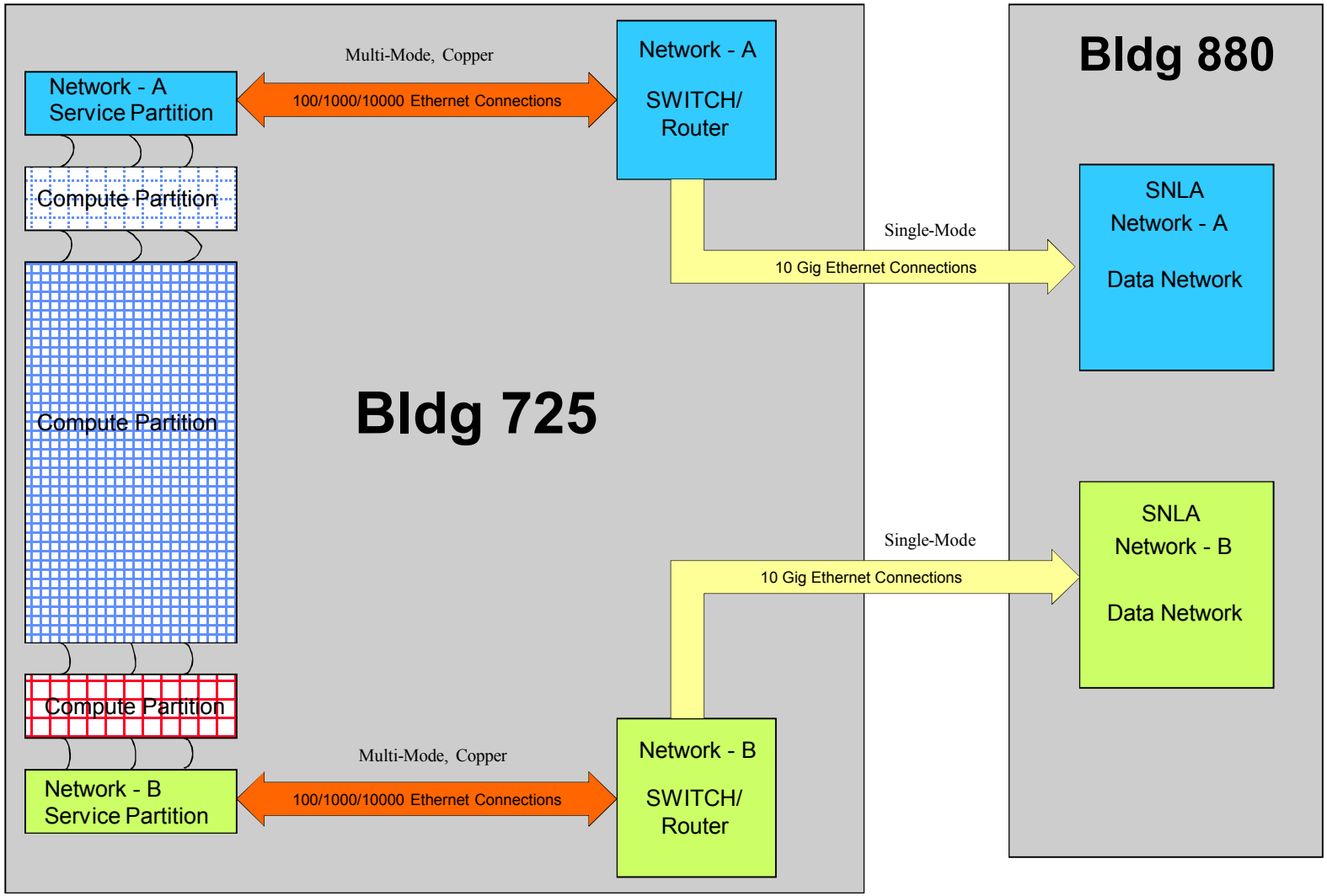
Red Storm Data Network



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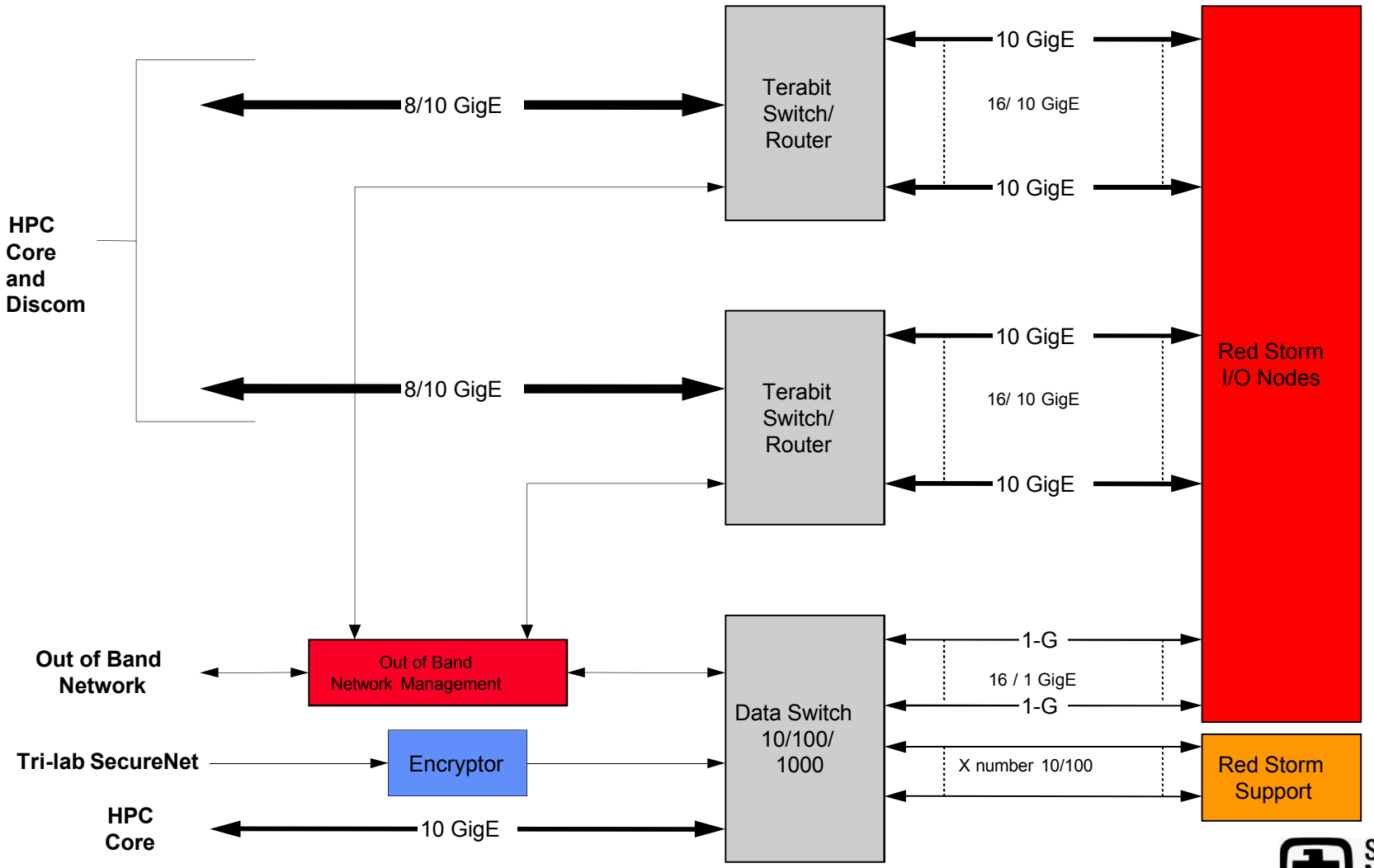
Previous Red Storm Connectivity



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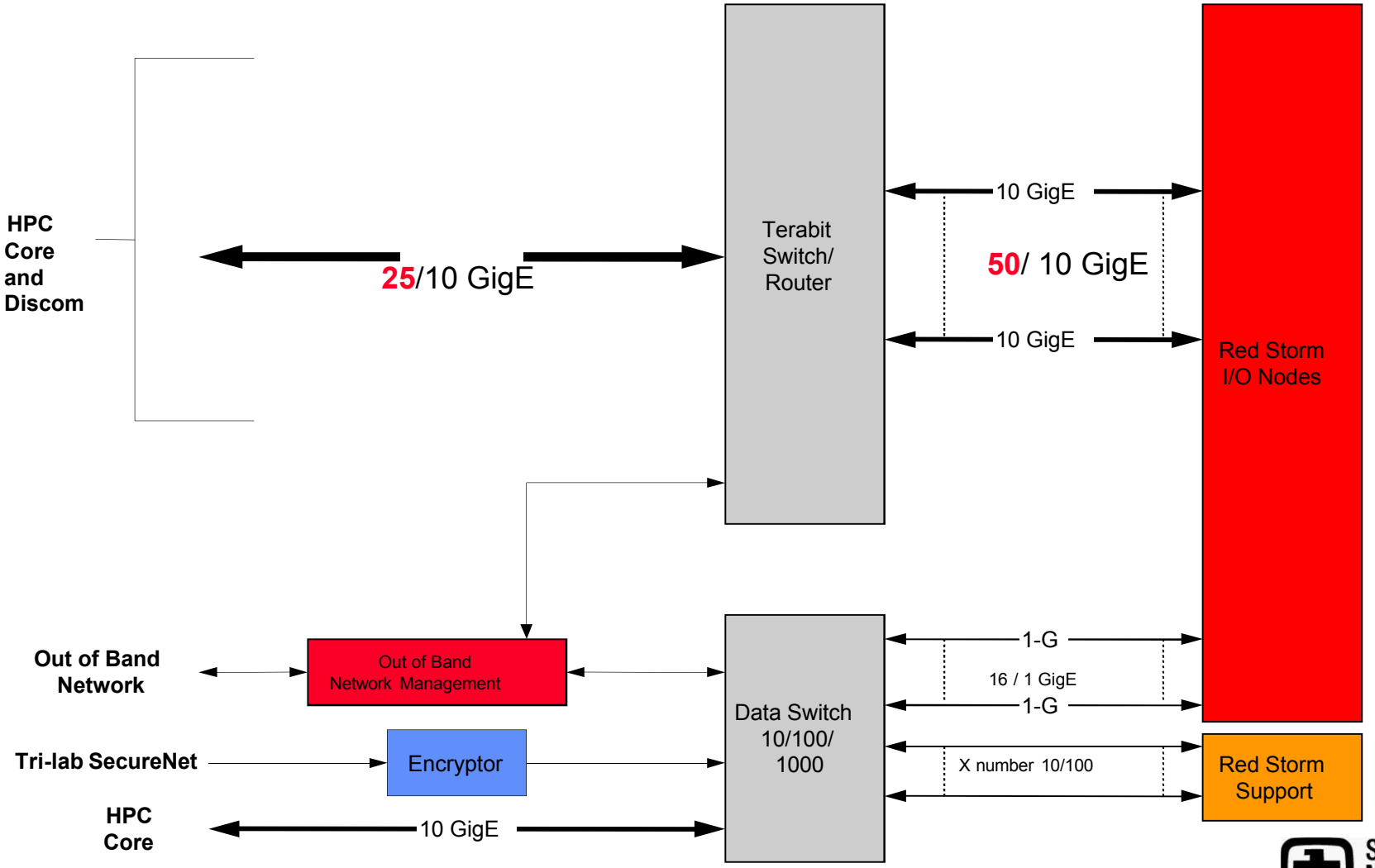
Post Upgrade
Red Storm Connectivity



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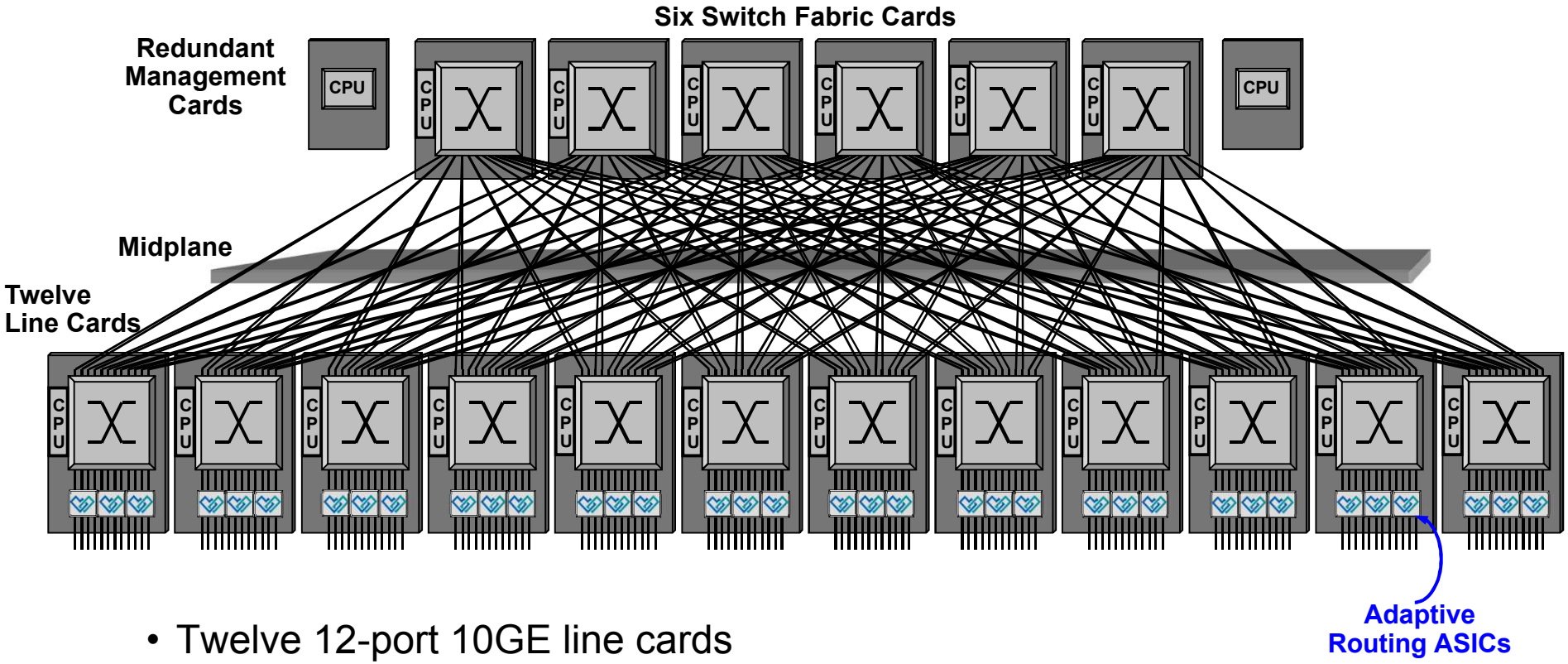
Recent HPC Upgrades

- Full 50 10GEthernet interfaces on Red Storm
  - Largest (128 port) top-tier Ethernet switches provide uniform HPC connectivity
  - Demonstrated 30GB/s concurrent bandwidth
  - Working to integrate new paths in to production
- 10G Ethernet interfaces to HPSS systems
  - Greatly expanded capability both to HPC systems and other corporate data needs
- 10G Ethernet in desktop environments
  - Fixed servers to effectively support 10GE
  - Demonstrated buss limitations in current desktops

The Problems

- Static routing is limiting the performance of interconnected switches
  - Most high port density systems use multiple connections between small radix switches
  - IB uses strict static routing
  - Ethernet uses static Hashes for LAG
  - Link oversubscription reduces performance
- Processing the TCP stack still consumes significant system resources
  - CPU, memory bandwidth, etc.
  - Particular problem for “gateway” nodes

Adaptive Routing Ethernet Switch



- Twelve 12-port 10GE line cards
- Fat-tree architecture similar to IB and Myricom
- ASICs at edge of switch perform adaptive routing: detects congestion and reroutes traffic around hot spots

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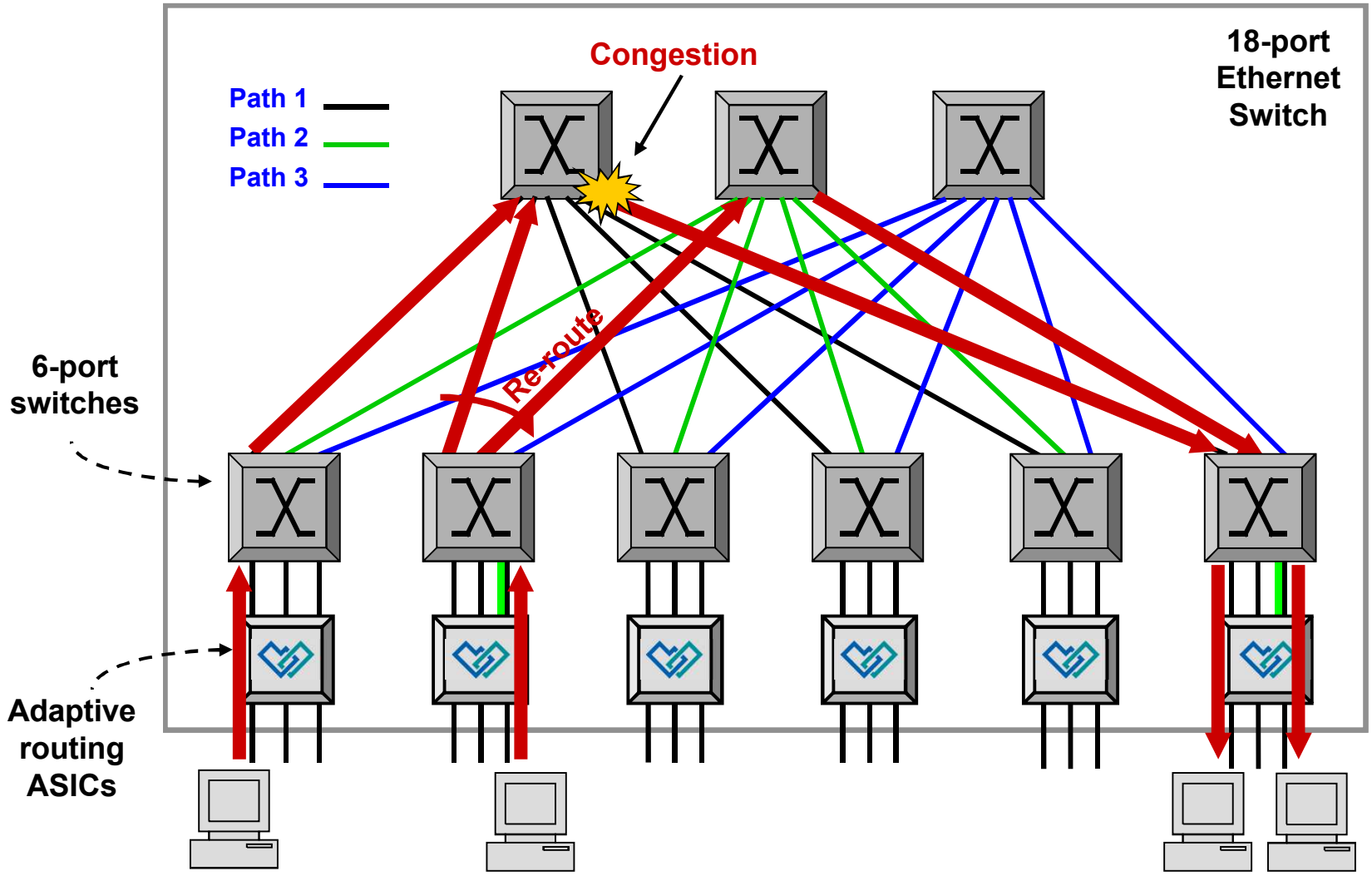
Ethernet Fabric using Multiple Paths and Adaptive Routing to Avoid Hotspots



WovenSystems

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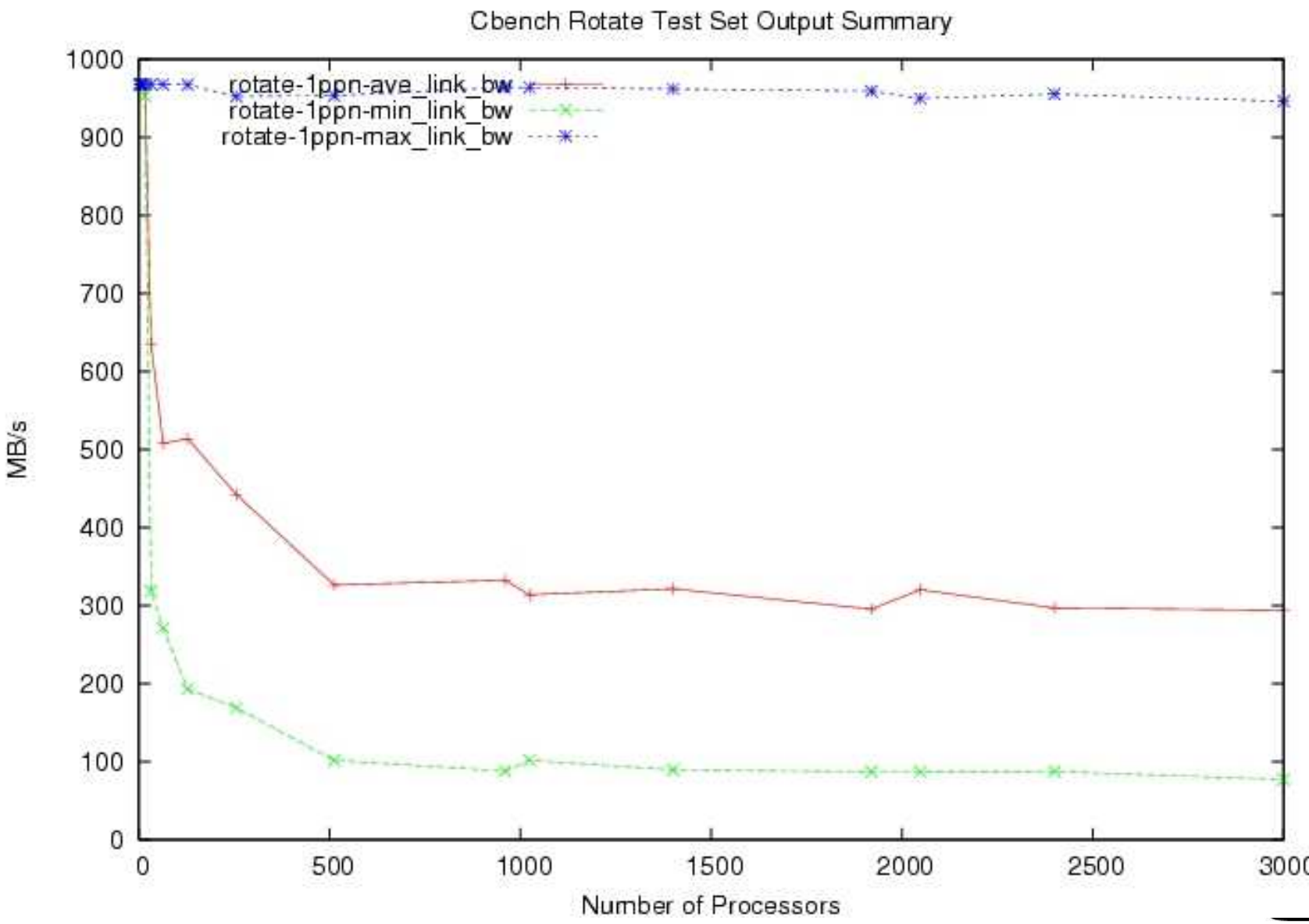
Per Pair Bisectional Bandwidth

~4000 Node IB Cluster



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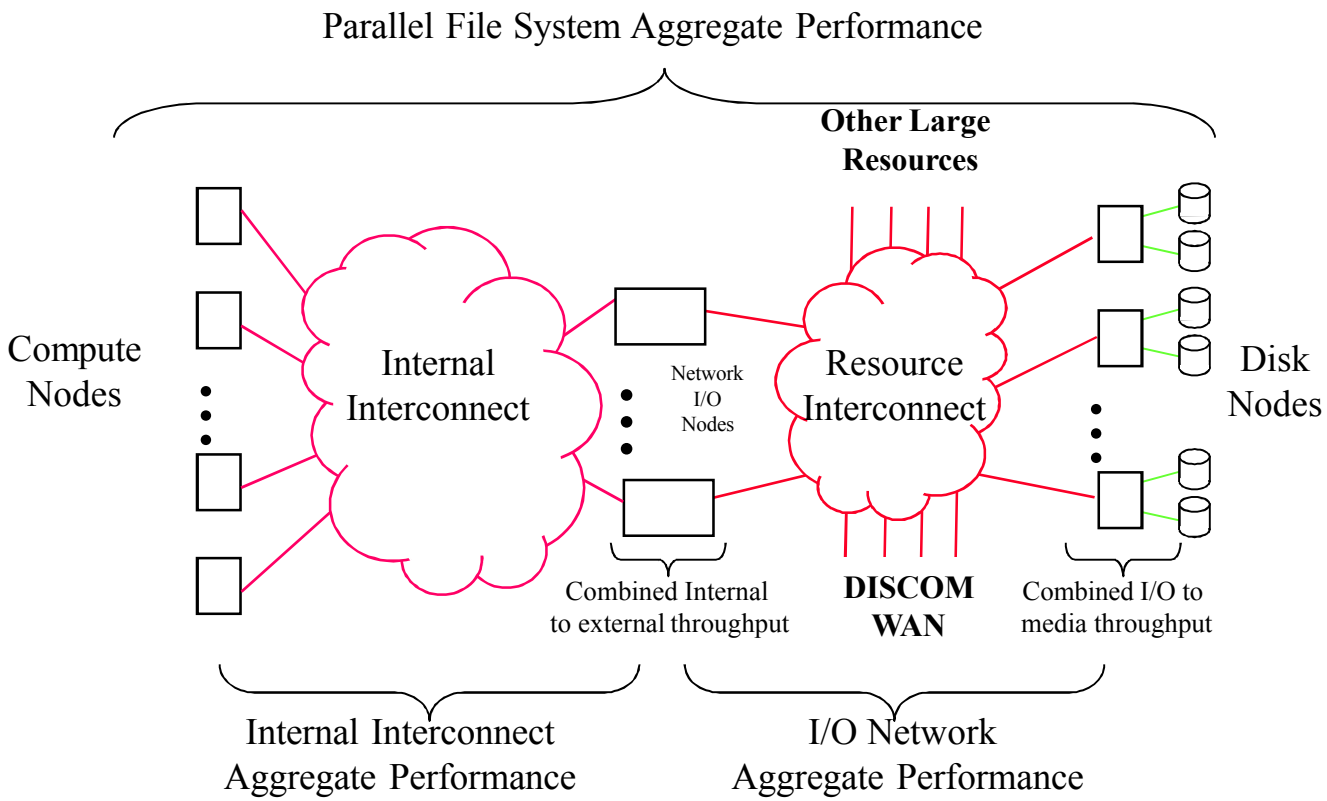
Where Do We See The Problems?

- Computational Clusters
  - Synchronous data flows limited by slowest link
- Supercomputer to parallel File Systems
  - Sustained data flows to/from disk also limited by slowest link
  - PetaScale File Systems pushing 2000 ports
- Large Server Farms

Generic Global Parallel File System Architecture



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What Are We Doing?

- Investigating and supporting dynamic routing implementations
- Investigating and supporting OpenFabrics iWarp RDMA scaled implementations
- Formed a collaboration to demonstrate one particularly promising environment
  - Woven active congestion management
  - Chelsio 10GE RNICs using OpenFabrics stack
  - Sandia 128 node cluster (Talon)

Goals of the Collaboration

- Demonstrate scalability of a high-density 10GbE switching infrastructure
- Demonstrate effectiveness of dynamic routing over static routing for low radix switch interconnects
- Evaluate Low Latency 10 GbE with RDMA as an alternative for deploying:
  - Common I/O infrastructure between PetaScale resources (compute, vis, disk, tape, etc)
  - Cluster interconnect
- Utilize simulation and analysis to project results to larger scales

Sandia CBench Suite

- Sandia's CBench Suite includes industry standards:
  - HPCC, Intel MPI Benchmarks, OSU, NAS, etc.
- Also includes benchmarks developed to stress bi-sectional bandwidth and latency
  - "Rotate Bandwidth" pair-wise transmits 80MB of data from half of the nodes to the other half. Repeat that test for many different bi-sections and report Min, Average, and Max individual throughput
  - "Rotate Latency" performs similar strategy as Rotate Bandwidth but tests simultaneous small packet latency instead of throughput

Testbed Configuration and Startup

- Testbed Details
  - 128 Dell 1850 Nodes running 2.6.9-55.0.9 Linux kernel
  - Chelsio T3 RNICs using the 1.0.109 driver + patches
  - OFED 1.2.5 with included MVAPICH2
  - 1 Topspin SDR IB switch with SDR HCA per host
  - 1 Woven 144 port EFX-1000 switch
- Many issues to work through
  - Significant manpower to maintain cluster
  - Bugs in new implementations of switch/NICs
  - Bugs in scaling OpenFabrics RDMA implementation
  - Many knobs to tweak in switch/NIC tuning
  - HP Linpack and benchmark tuning always time consuming

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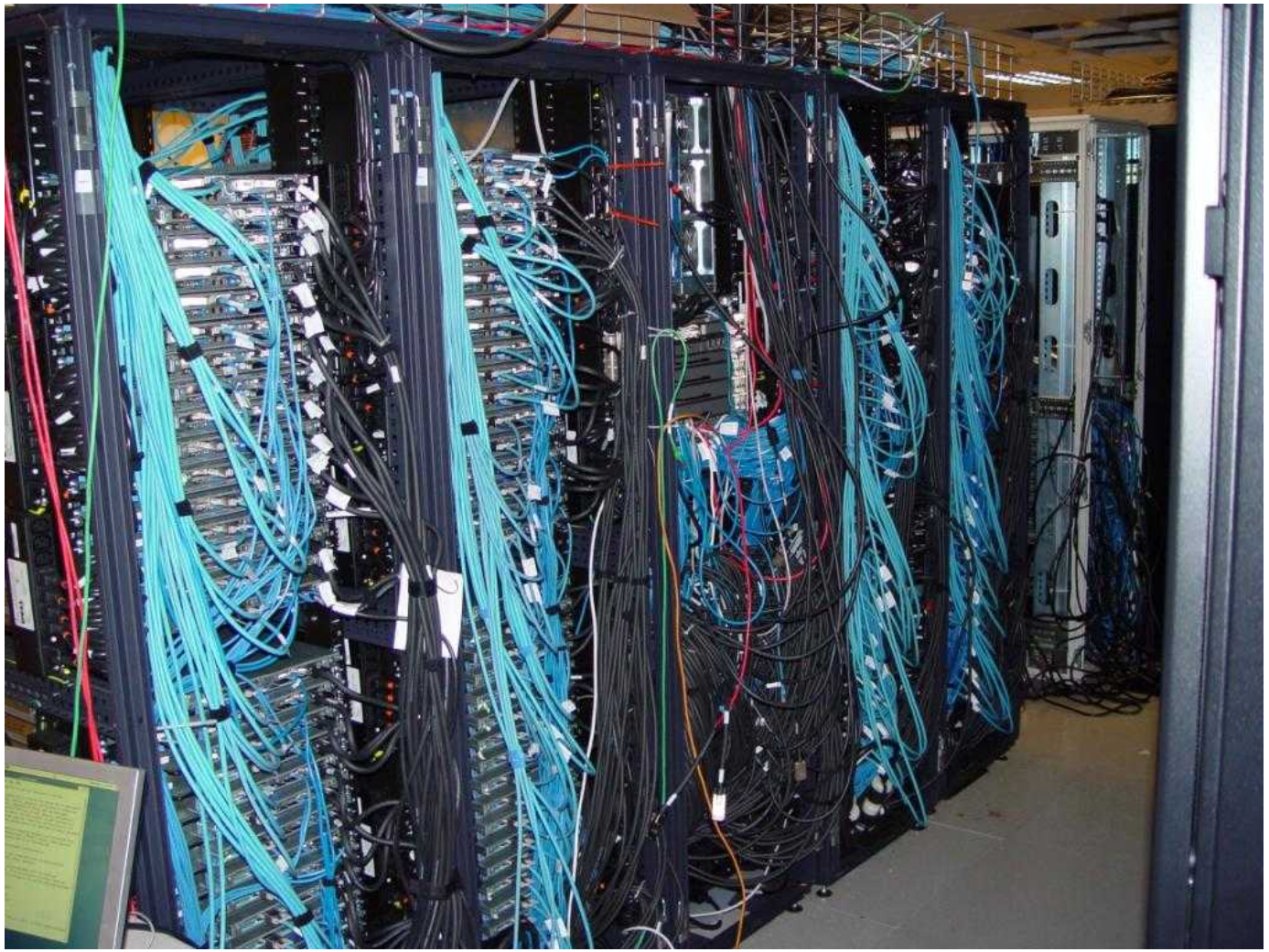
Talon Cluster



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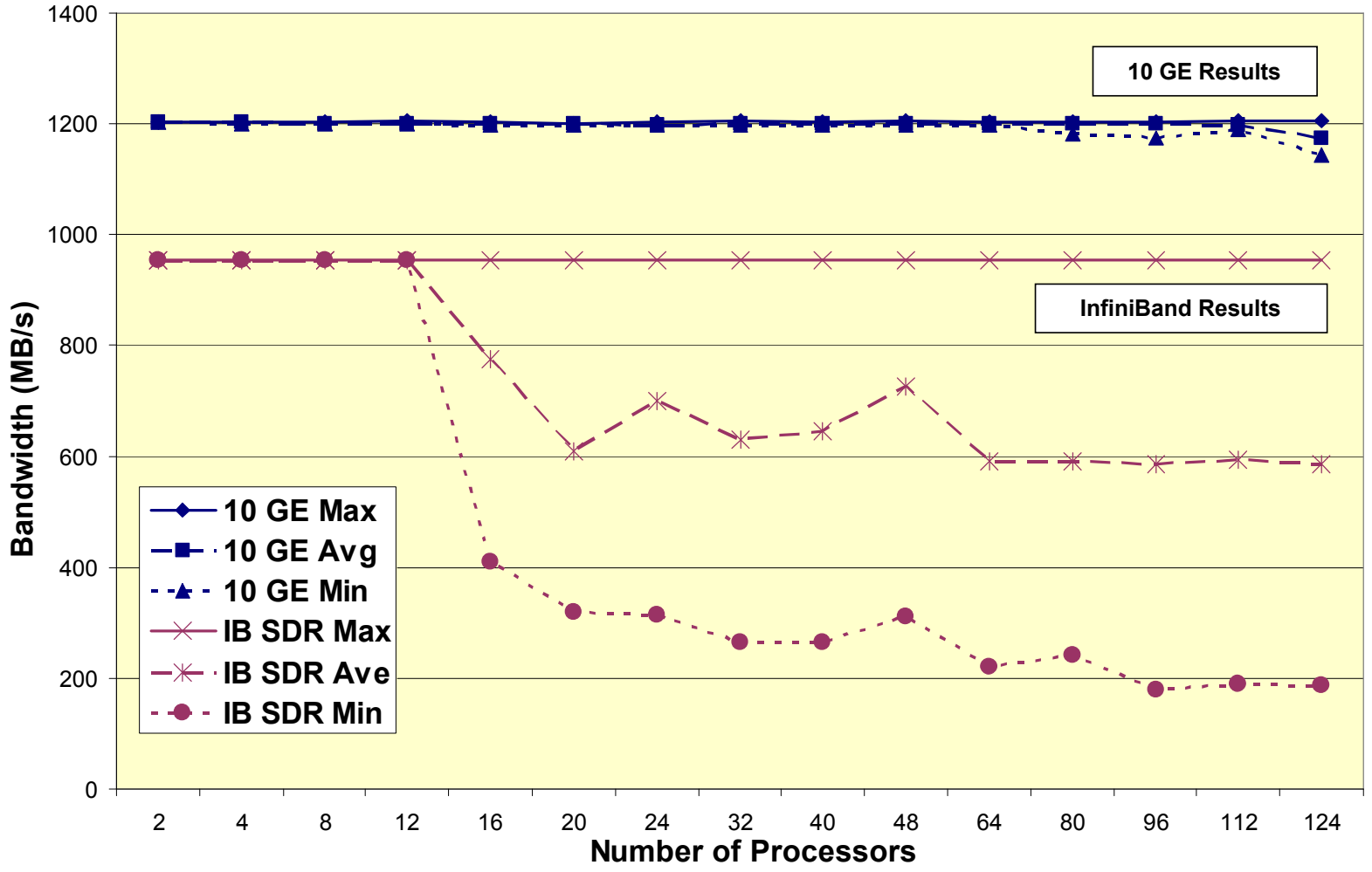
Tuning and Configuration

- Utilized 9000 Byte MTU
- Enabled/disabled adaptive routing functionality
  - Not normally exposed to users
- Compared strict versus relaxed packet ordering
- Enabled/disabled RX/TX Pause frames on edge ports
- Chelsio enhanced driver to tune the hardware stack
  - Traffic scheduling and management; fast error recovery
- Tuned several switch and NIC internal parameters to optimize for interconnect performance
  - Many were incorporated in to vendors' default configurations, contact vendors for help with performance issues

Significant Issues

- Port Sharing between Kernel and offload stacks
  - TCP ports used by offload stack are not known by the kernel stack and vice versa, could cause application failure
  - Proper fix requires overcoming resistance from kernel stack maintainers
  - Used a patch by Steve Wise to address this issue
- ARP scaling problem was discovered and fixed
  - Connections weren't being accepted for stale ARP entries
- Completion Queue
  - Mvapich2 would hang due to completion queue overrun
  - Used MV2_DEFAULT_MAX_CQ_SIZE=6000 for benchmarks
  - Must overcome contiguous memory limitation to scale to larger clusters

Cbench Rotate Benchmark Test (Relaxed Ordering)



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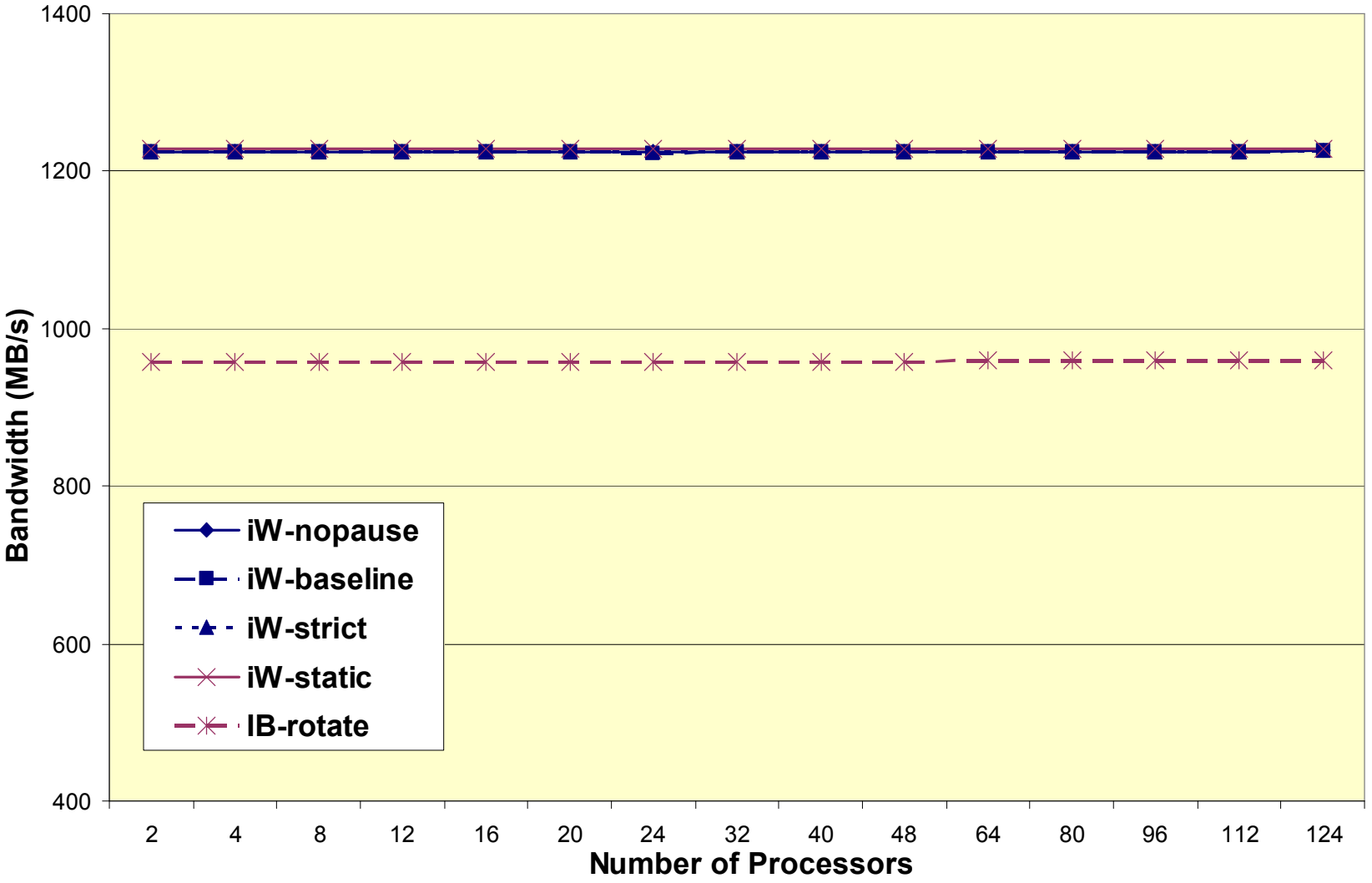
Maximum Bandwidth Rotate Test



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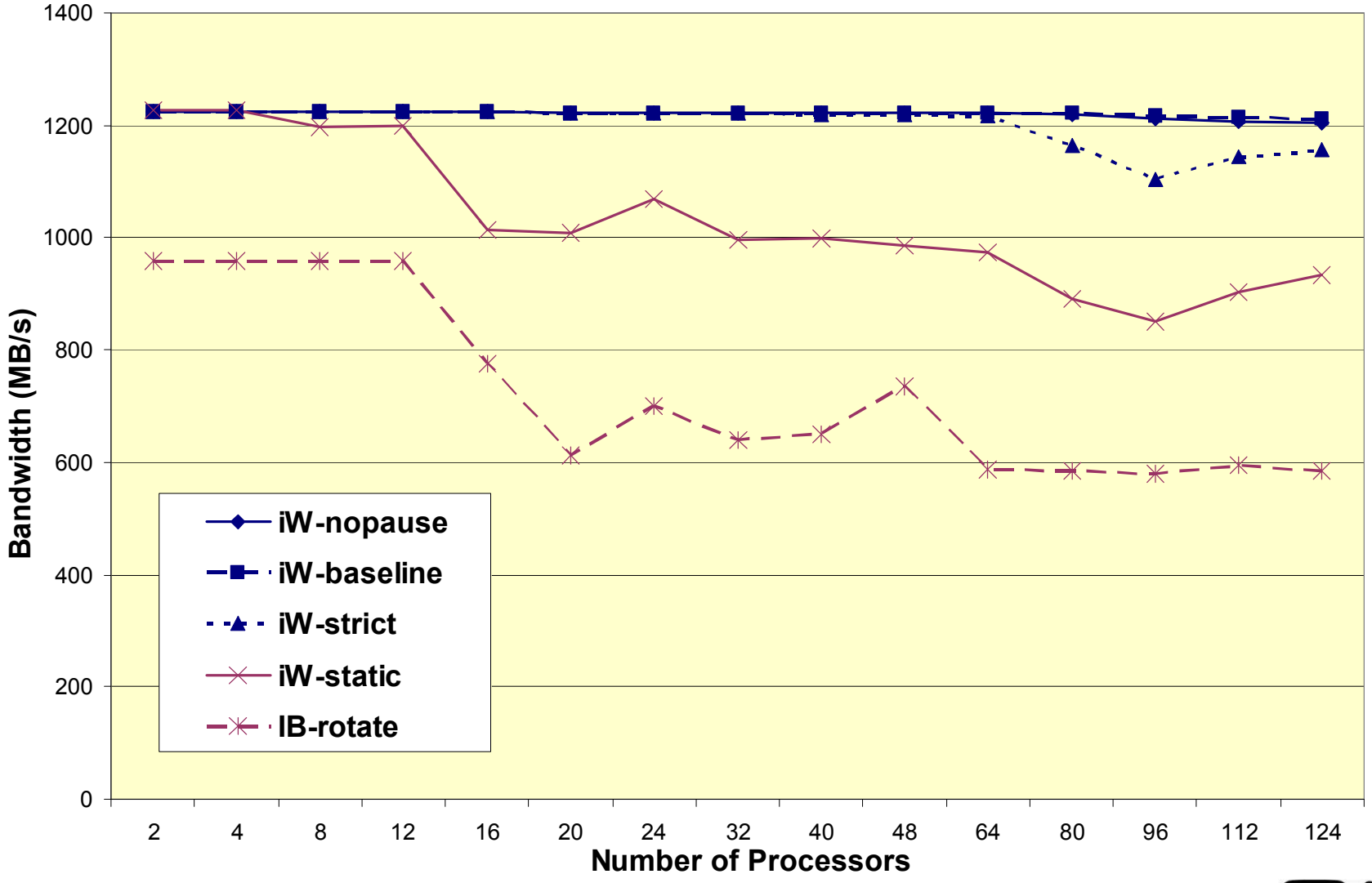
Average Bandwidth Rotate Test



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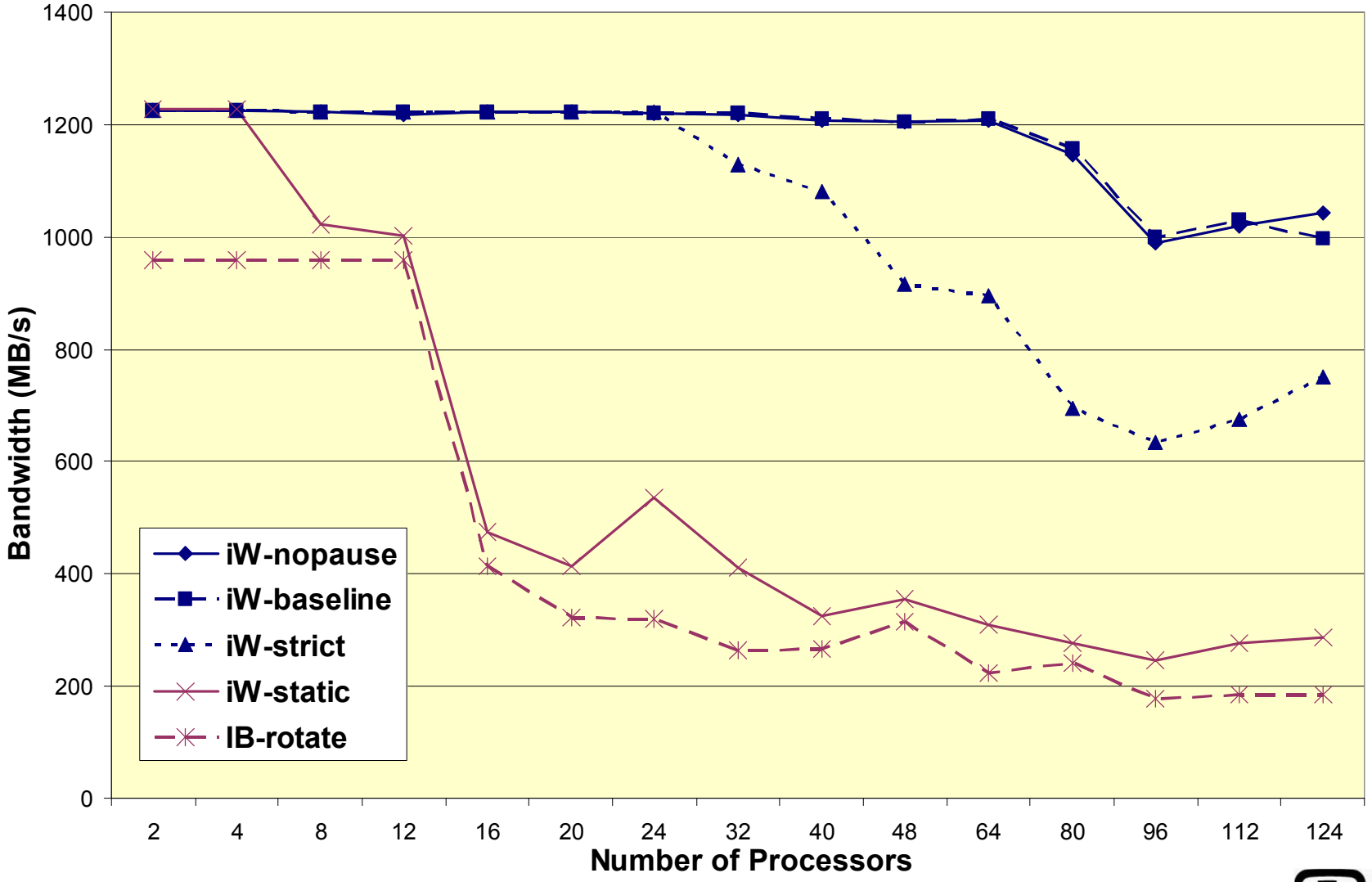
Minimum Bandwidth Rotate Test



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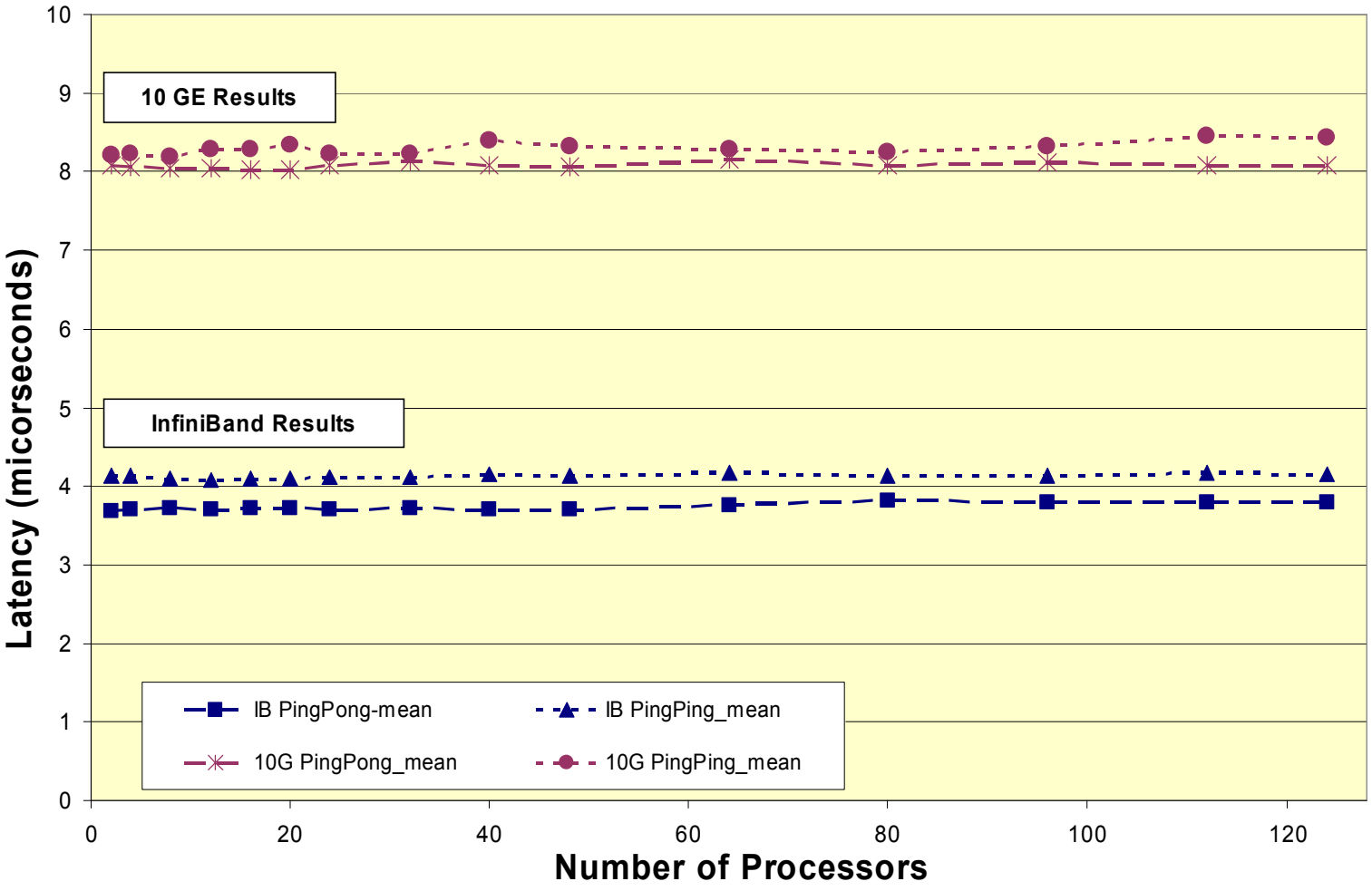
Intel MPI Latency Benchmark Test



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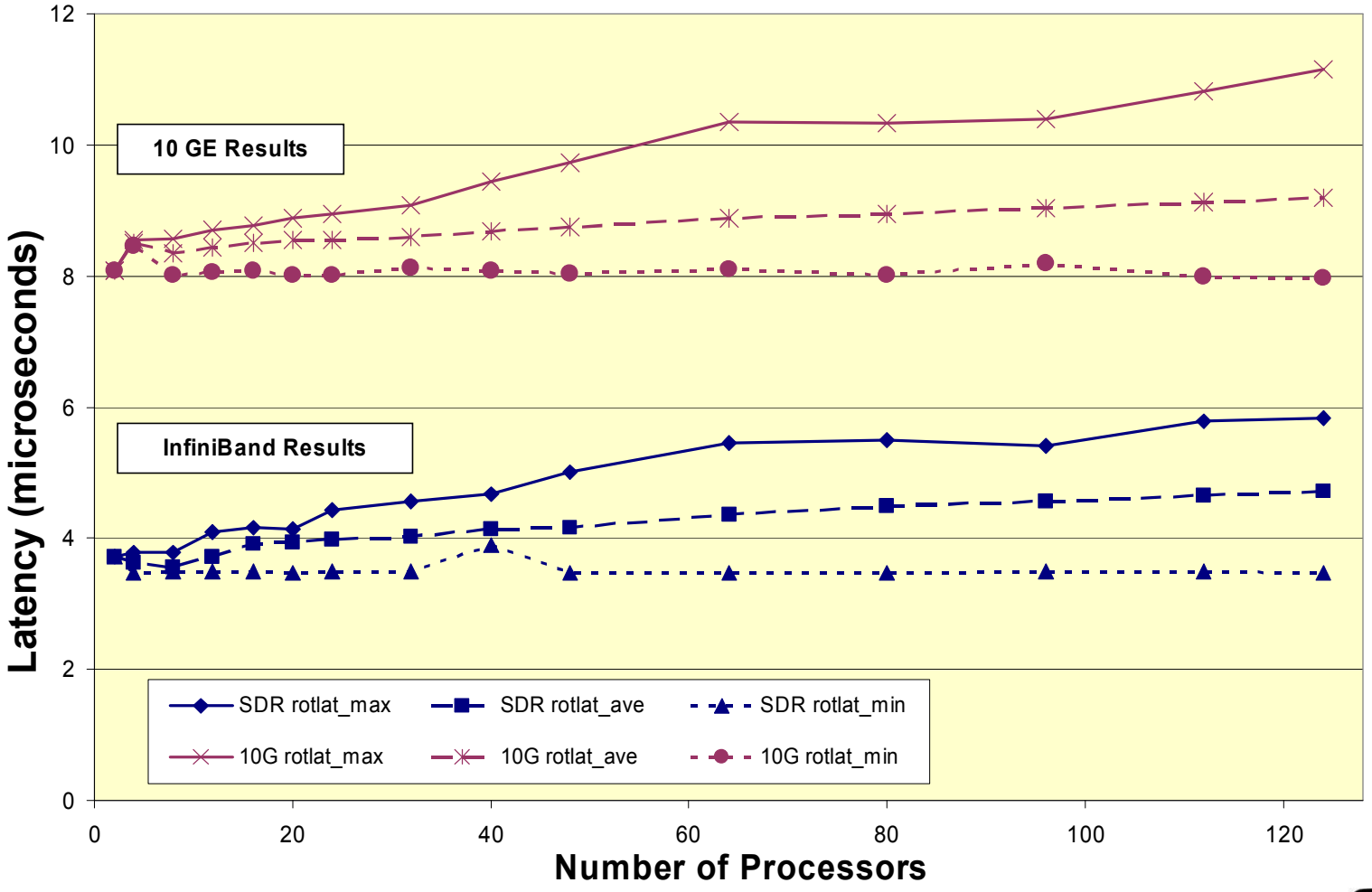
Cbench Rotate Latency Benchmark Test



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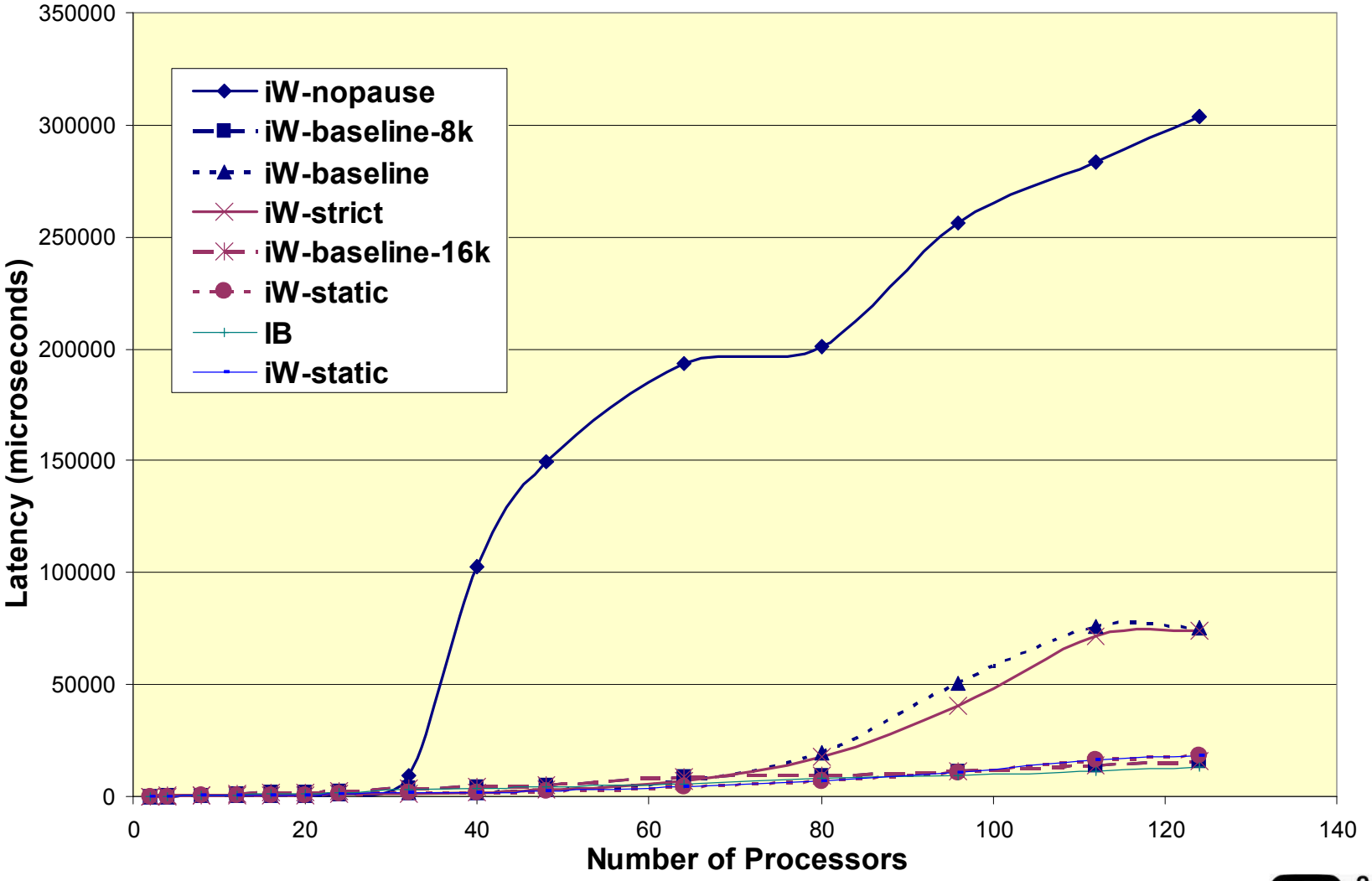
Switch, NIC, and Application Tuning

- Switch required significant tuning
  - Buffer management
  - Rerouting timing
  - Pause functionality
- NIC tuning
  - Tuned to provide good performance across all of the applications we investigated
- Most tuning is part of standard deployment now
- Refer to vendors for more details
- MPI tuning avoided some pathological cases

All-to-All 32KB Message Latency Results



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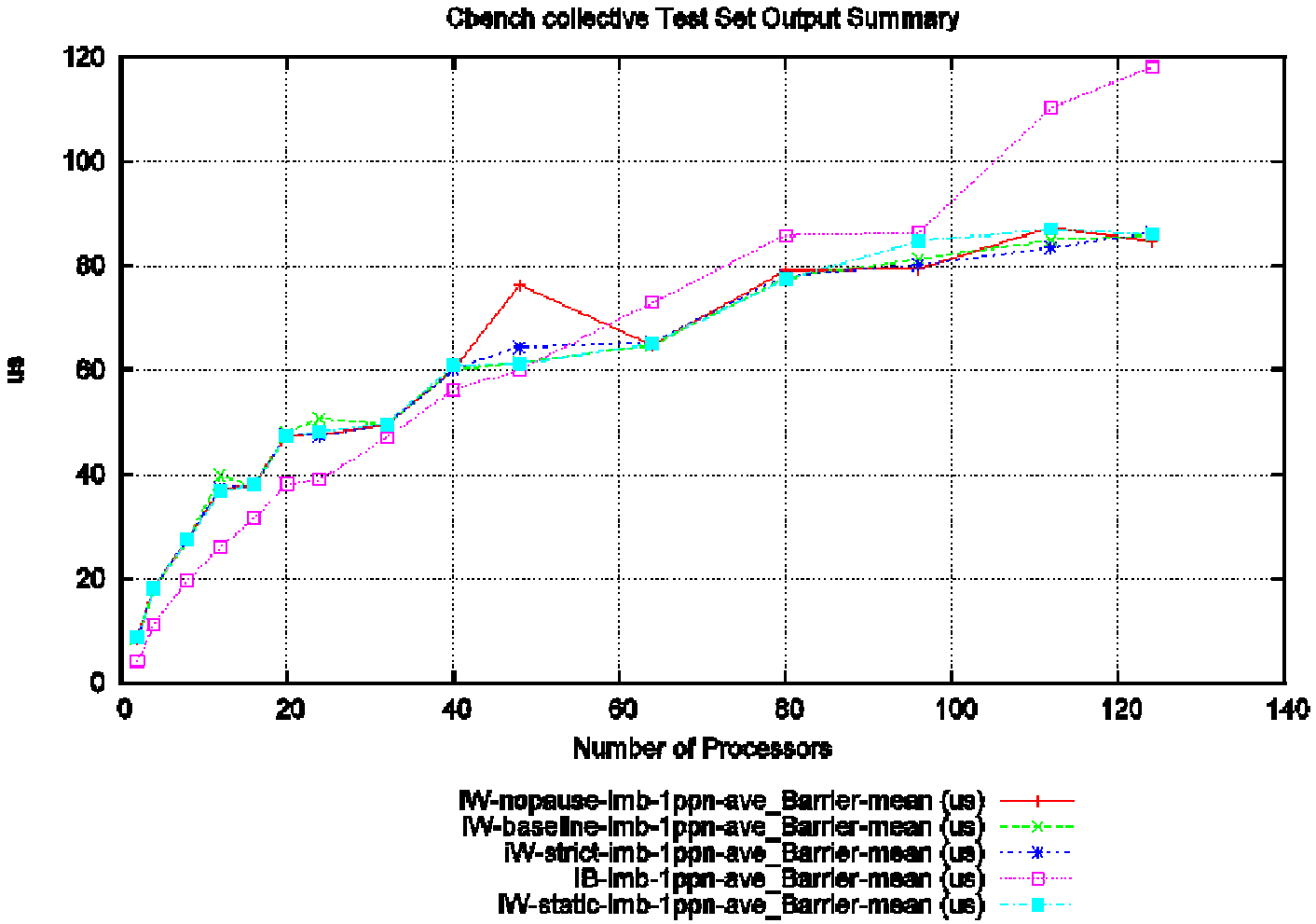
Barrier Collective Latency Result



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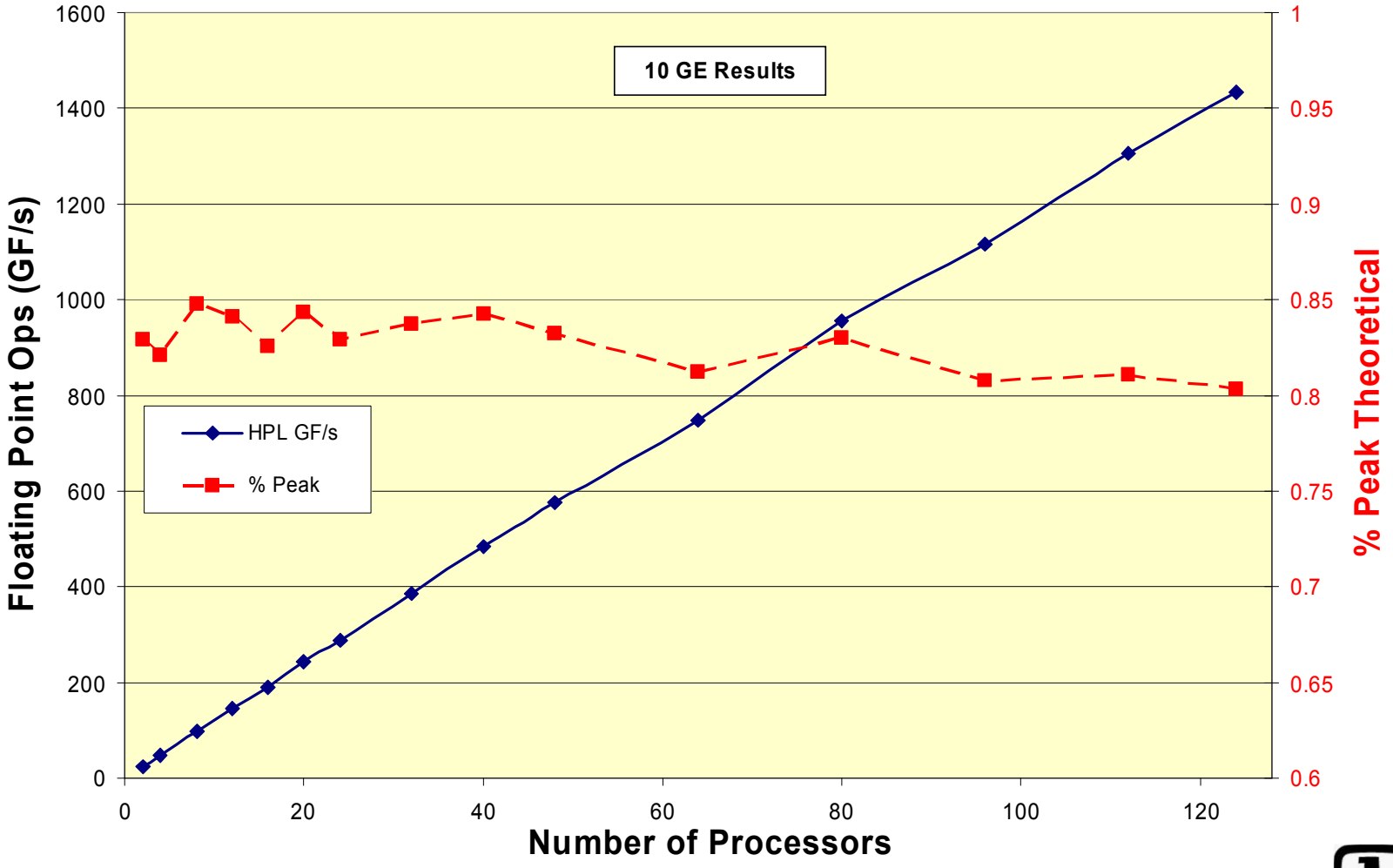
Congestion Management Issues

- Long-term contention: multiple flows contending for single port
  - Time scale much greater than switch latency
  - Example: flows for parallel file system, w/more clients than servers
  - Using pause results in head-of-line blocking
  - Must reduce per-flow offered load – need congestion indication
    - Dropped packets can be recovered via TCP fast retransmit
    - Explicit congestion notification (ECN) might help
- Short-term congestion: synchronized, bursty traffic
  - Time scale similar to switch latency
  - Example: flows for all-to-all algorithms where all send to all
  - Short messages mean dropped packets recovered via TCP retransmit timeout
  - Use pause to prevent packet loss
- Need both pause and per-flow congestion events to handle all traffic profiles
- Current pause implementations problematic
- IEEE 802.1au congestion notification could help as well

HP Linpack Benchmark Test



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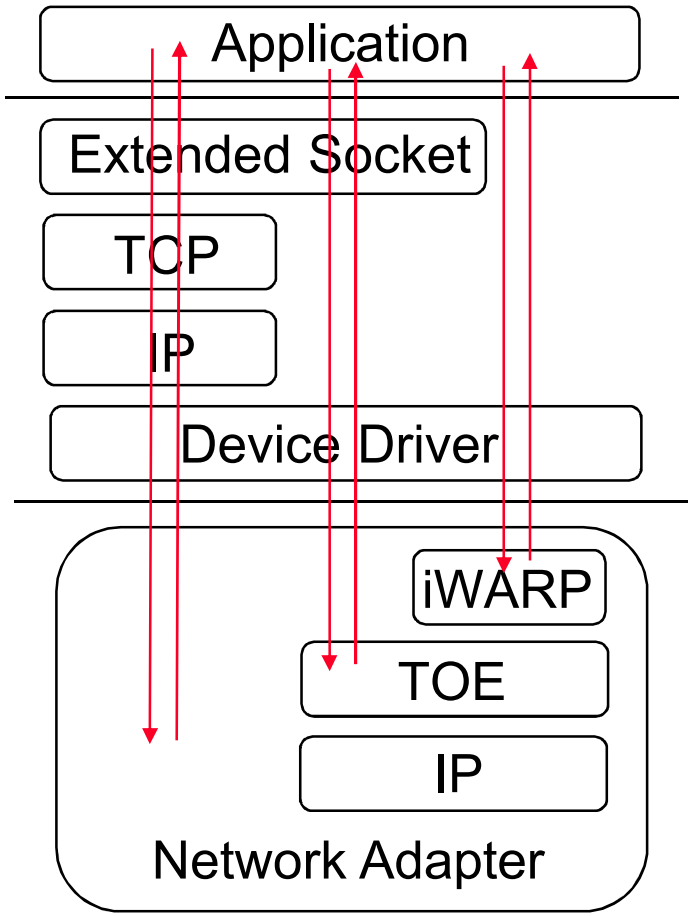
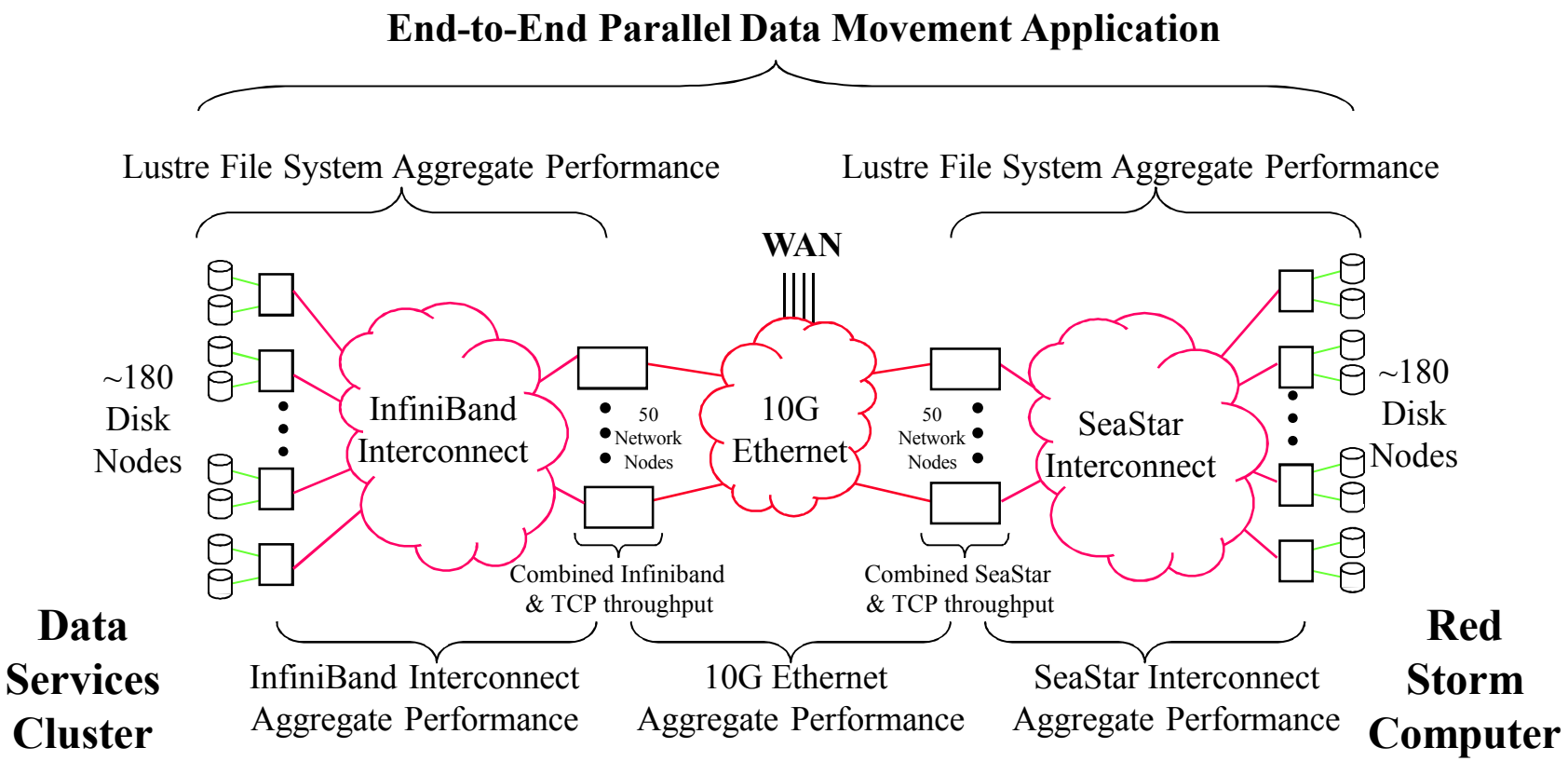
iWARP - RDMA protocol for TCP/IP

- iWARP is the suite of RDMA protocols for TCP/IP
- RNIC is a RDMA capable NIC with offloaded iWARP as well as TCP/IP (TOE)
- RNIC typically exposes NIC, TOE and iWARP interfaces to upper layer applications



Example Red Storm Architecture



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Example of Inefficiency Impact in Gateway Nodes

- **32 10GE paths from RedStorm to viz. Cluster**
  - **Planned for 50% efficiency: 16GBytes/s**
  - **Network sustained full 16GB/s using real HPSS application from memory to memory**
    - **~95% CPU utilization, ~500MB/s per path**
  - **When using real disk, performance dropped to ~170MB/s with 100% CPU utilization**
  - **With sendfile (no user memory copy): ~340MB/s**
  - With TOE: >600MB/s with ~15% CPU!

RDMA Results

- Interaction with Linux Kernel contentious
  - TCP stack in hardware similar to TOE
  - Some interaction with Kernel (ARP, IP port sharing, etc.) still required
- OpenFabrics concept working well
  - Same CBench executables run on IB or 10GE
  - Some IB capabilities not implemented for 10GE
- Yet to run detailed CPU comparison tests
  - Preliminary indications looking good

Major Results

- Bi-sectional bandwidth scaling looks excellent
- Latency is getting close to SDR IB RDMA
- Linpack is in same efficiency range as IB
- Switch strict-order delivery impacts bandwidth
  - Relaxed ordering working well
- Both Pause and per flow congestion management important for optimum performance
- Tuning of switch, NIC and application required to achieve maximum performance
- Issues that appear only at scale are difficult to debug

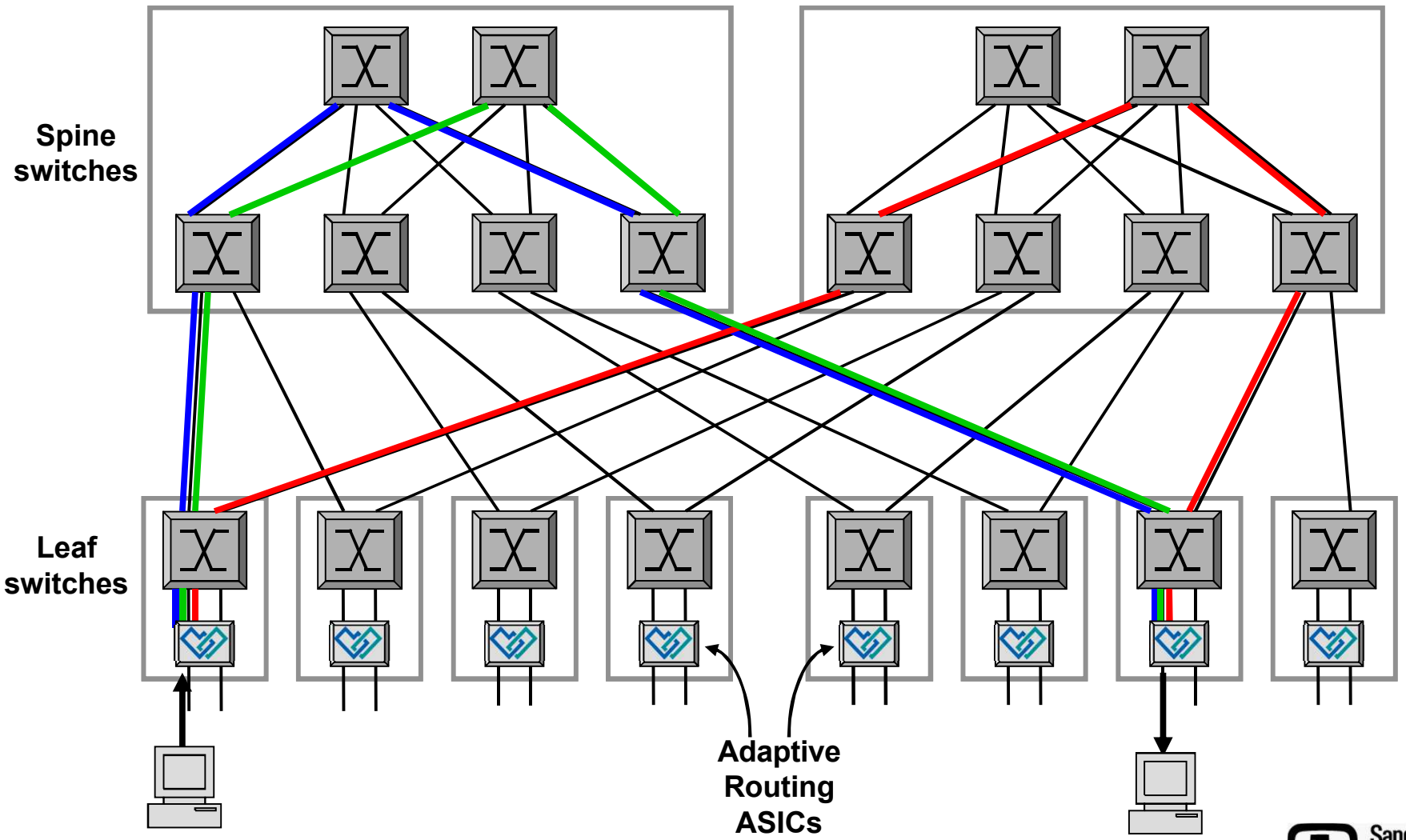
Summary

- Dynamic routing significantly improves the measurable bi-sectional bandwidth
- RDMA over 10G Ethernet seems to be very efficient and effective for a cluster interconnect
- We need to pay close attention to system scaling issues
  - Build and debug is inefficient and expensive
- The iWarp RDMA over 10G Ethernet was very stable after debugging and tuning completed
  - Ran thousands of batch jobs over several days with no failures

Future Work

- Production interoperability testing of RNICs
  - NetEffect NICs coming on line now
- Multi-tier switch operation
- Other flows (small packet, etc)
- Comparison with DDR
- Comparison with TOE
- Lustre/pNFS etc. testing with RDMA
- Open MPI testing

Adaptive Routing over a Multi-tier Fat Tree Topology



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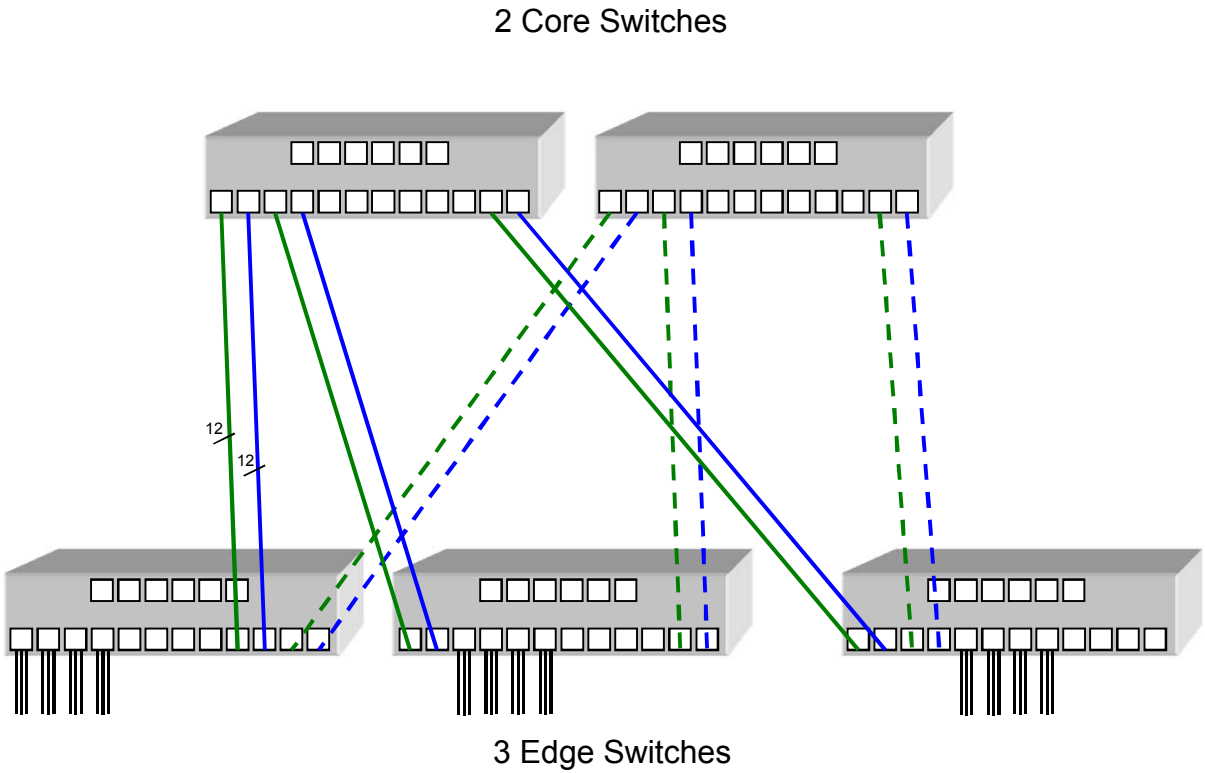
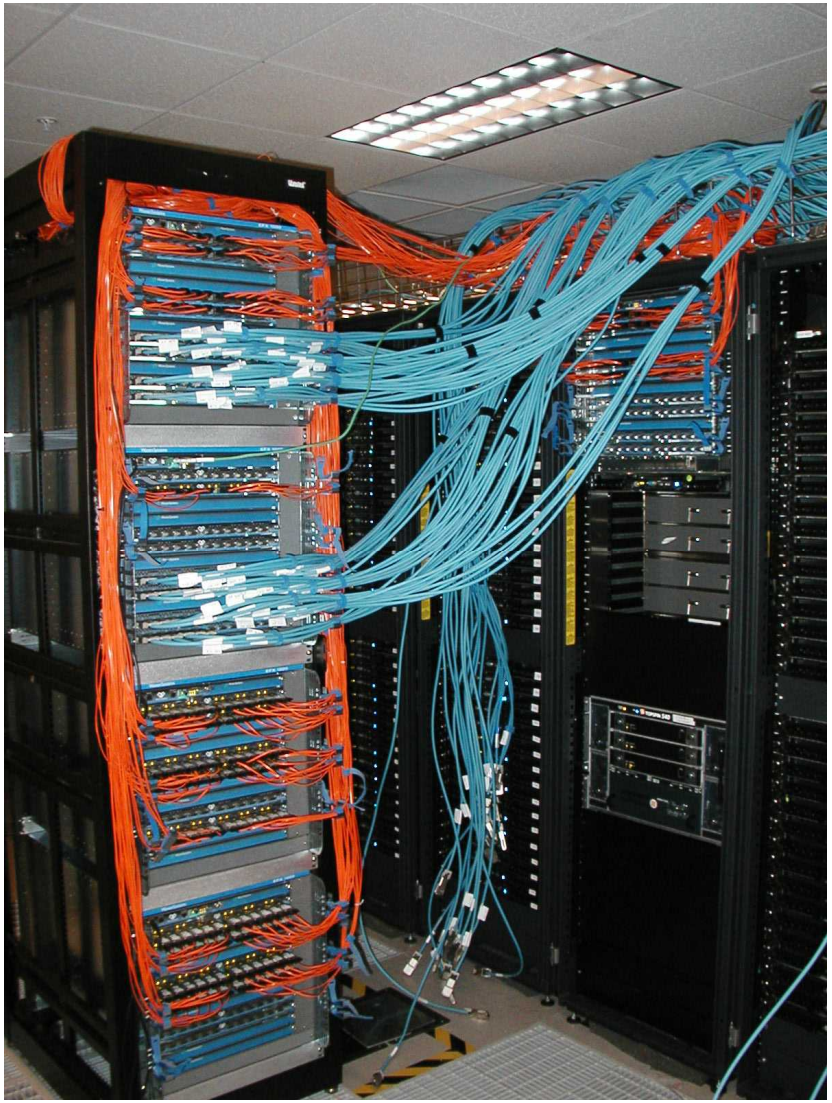
Multi-Chassis Configuration



Multi-Chassis Hardware



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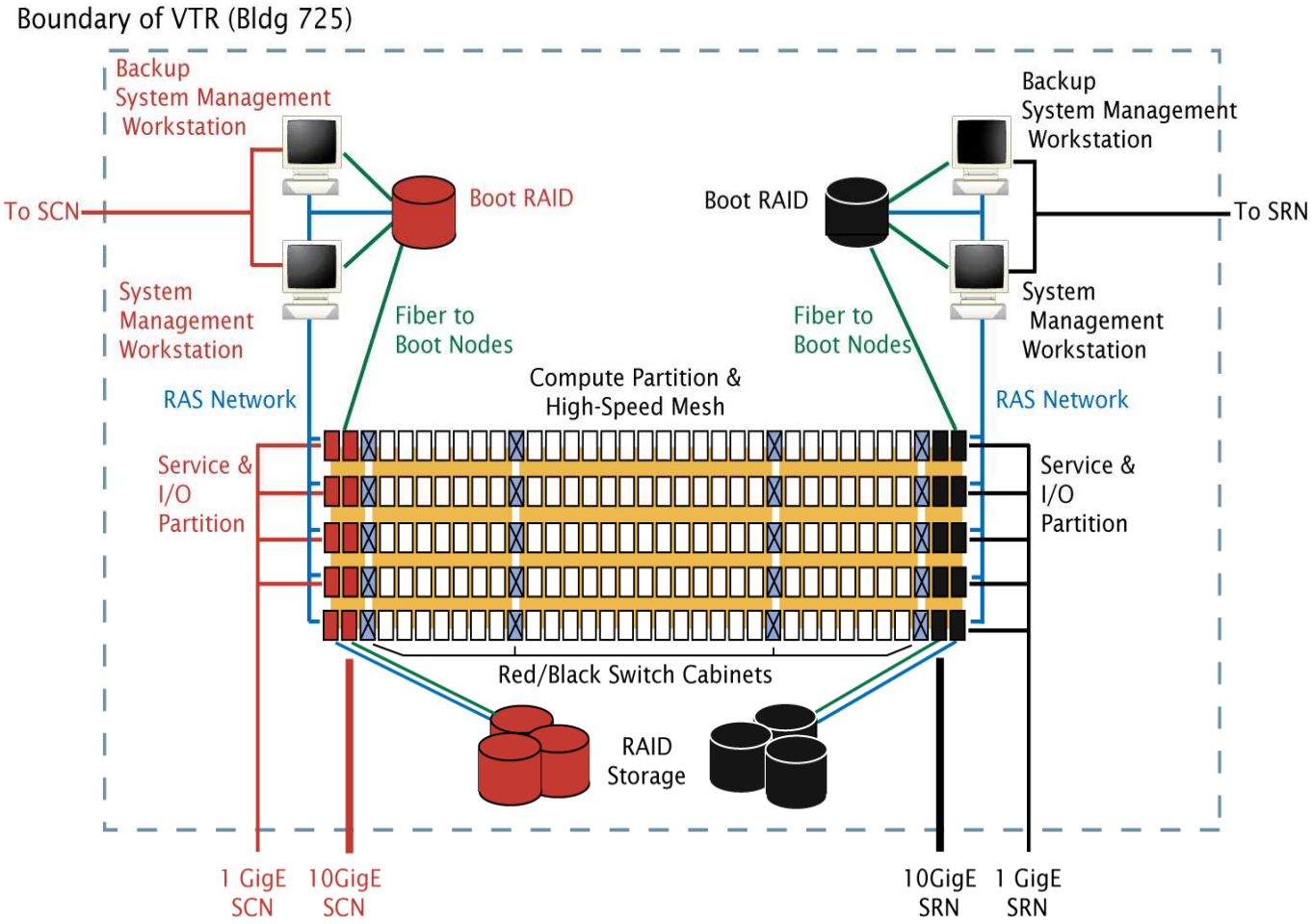
The NNSA Red Storm platform was built to operate in two separate security environments



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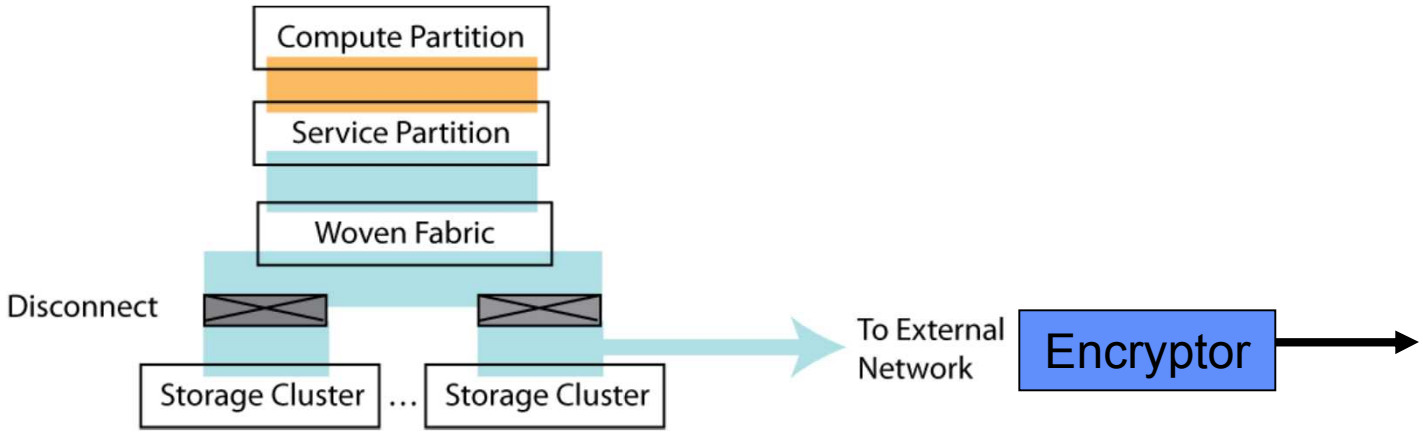
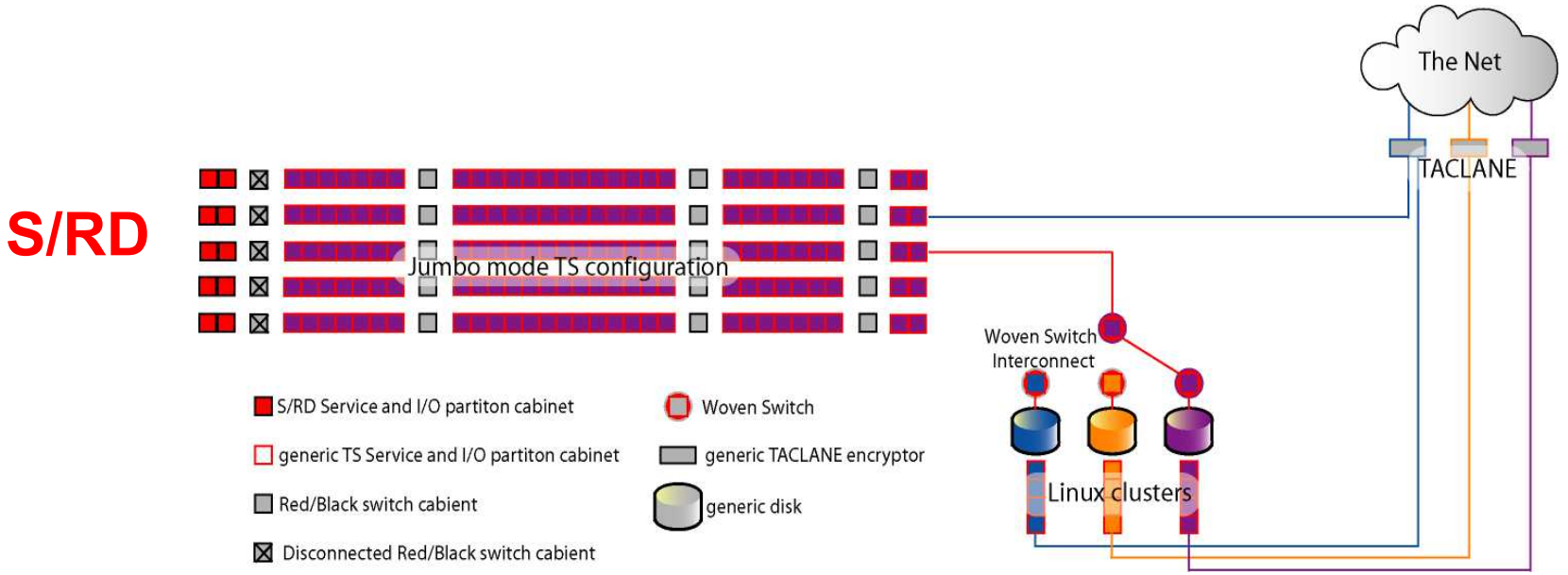
Option: Acquire and configure separate storage clusters to serve multiple isolated programs

By providing external, network attached storage, connected to Red Storm via 10Gb ethernet connections and a newly available Woven Switch, several separate security environments can be provided and administered separately, sharing portions of the Red Storm compute resources while operating independently during dedicated time slots. External network access to data would remain available through existing networks, and encrypted connections if necessary, as shown below.



Configuration Options redeploy existing equipment and add separate storage clusters to serve multiple TS programs.

By providing external, network attached file systems, connected to Red Storm via 10Gb ethernet connections and a newly available Woven Switch, several separate environments (including TS/SCI) can be provided and administered separately, sharing portions of the Red Storm compute resources while operating independently in dedicated time slots. External access to data would remain available through existing networks and encrypted connections if necessary as shown below.



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ASC WAN Circa 2005

- High Speed Network Connecting Three Laboratories at Four Sites
  - SNL NM & CA, LANL, LLNL
  - Point to Point Links
  - OC-48 CY2001 to Cy2005 utilizing ATM and Sonet technologies capable of increased bandwidth as needed

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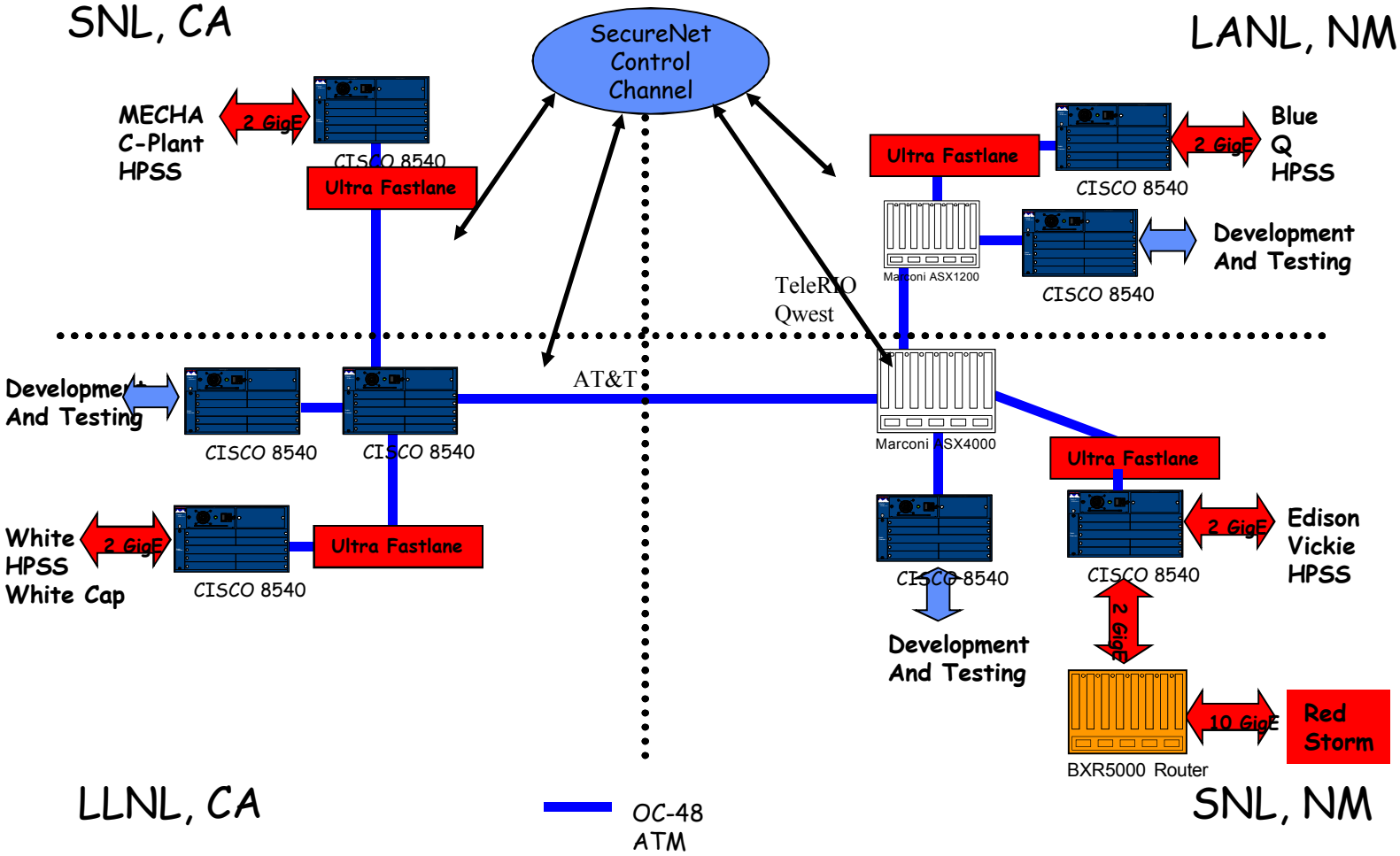
ASC WAN 2005



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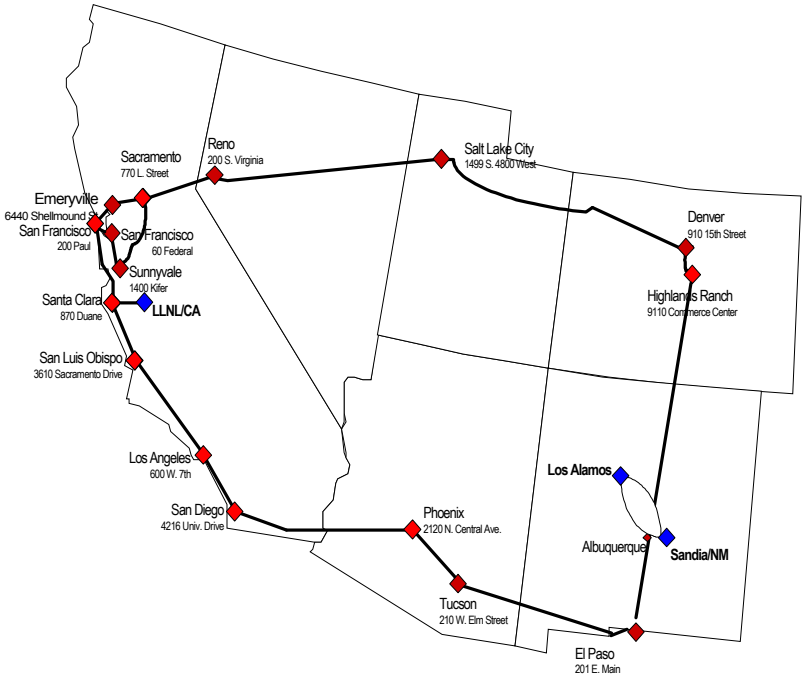
ASC Wide Area Network Now

- Schedule for New WAN
  - RFQ Released late 2005
  - Contract Awarded to QWEST
  - 10 GE Links Operational May 2006
- Dual CA to NM 10 GE links installed as part of a ring topology
  - Provides a level of redundancy
    - OSPF on cipher text side
    - BGP on clear text through crypto
  - Delivers four times the capacity at one half the cost



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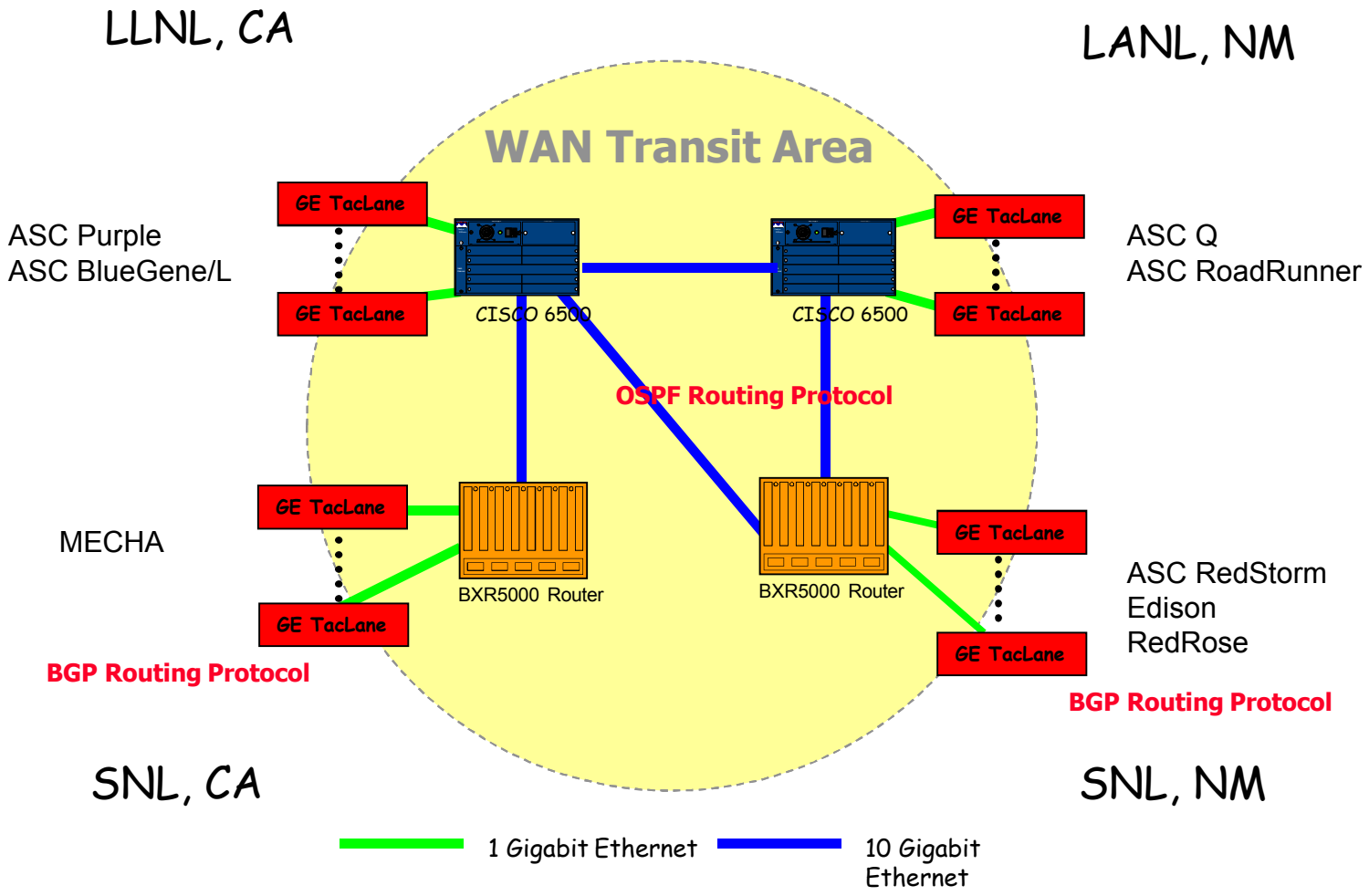
ASC WAN 2007



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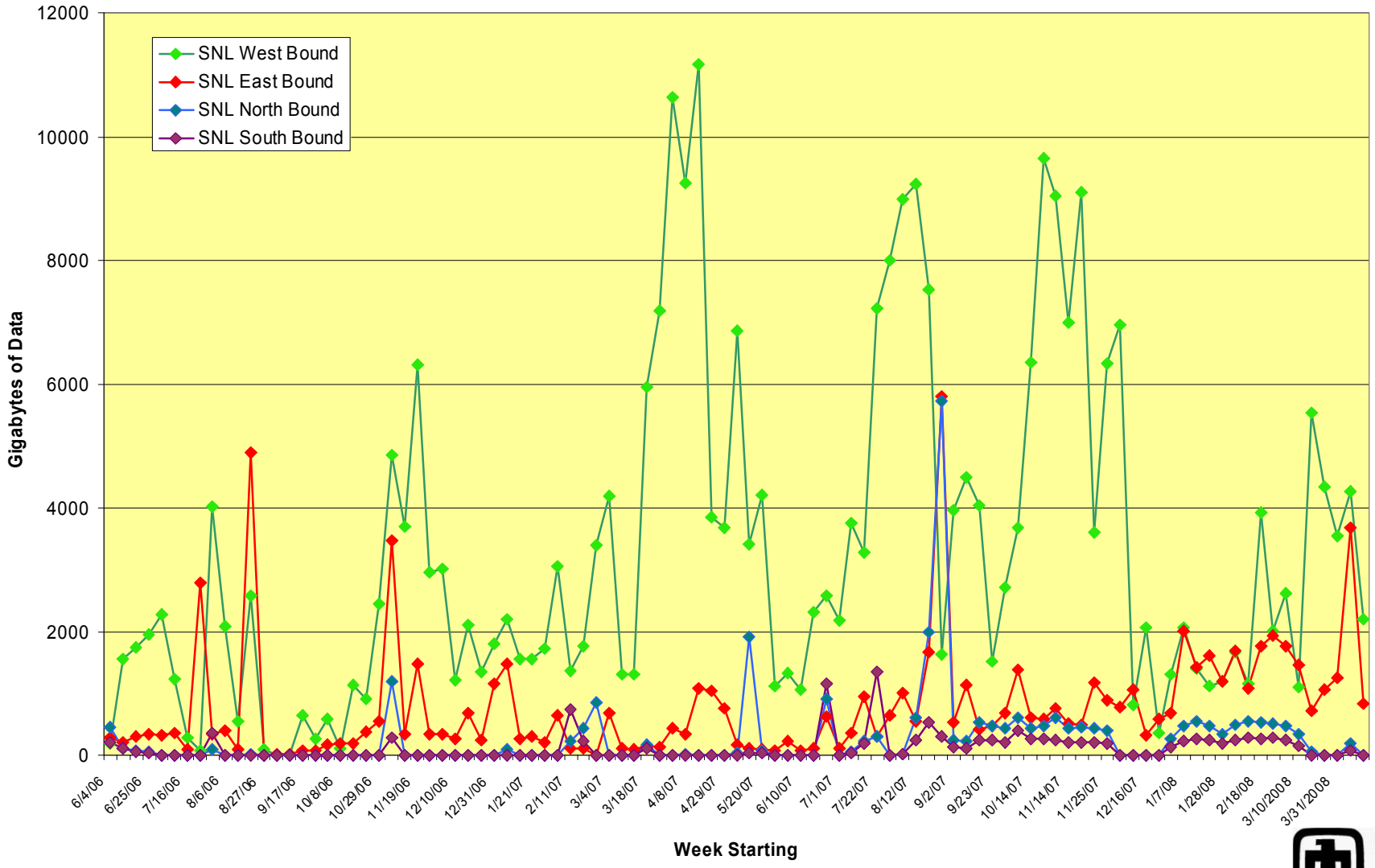
ASC WAN Status

- Parallel Architecture
  - Agreed on 4 way stripe of 1 GE
  - 4 ea GE IP encryptors at LLNL, LANL, SNL/CA and SNL/NM
  - Logical Stripes Aggregated to One 4 Gigabit Encrypted Stream
- Applications
  - Parallel data movement applications and scripts have been deployed for production.
    - PFTP client or server installed on most platforms
    - Computational servers, file servers, visualization servers
- ASC WAN Performance
  - Testing indicates 200 MBytes/Sec typical performance
  - Demonstrated 400 MBytes/Sec disk-to-network with tuned configurations
- Reliability Issues
  - Very difficult for Quest to locate problems and debug
  - Per link reliability much less than previous SONET link
  - Ring architecture with OSPF provides excellent reliability

Tri-lab ASC Ring Traffic
From Sandia New Mexico Perspective



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10G Encryptor Testing

- L3 initial 1G device very disappointing
- No longer need a separate device for management
  - Still some unfortunate quirks to work around
    - Switching back and forth and 4 mistypes
- Performance testing is promising
  - Host testing with iperf
    - 1500Byte MTU, no fragmentation: 7.5 Gb/s
    - 9000Byte MTU, no fragmentation: 8.6 Gb/s
  - Adtec traffic tester
    - 1440 Byte MTU, no fragmentation: 9.48 Gb/s
    - 1500 Byte MTU with fragmentation: 680 Kb/s
    - 9000 Byte MTU, no fragmentation: 9.91 Gb/s
    - Packet bursts up to 32MB
    - 125 concurrent call setups
- Interoperability with 1G GD TacLane works well
  - Must avoid fragmentation

10G Encryptor Testing Continued

- WAN testing using Discom link to California (30ms latency)
  - Adtec traffic tester
    - 1400 Byte MTU, no fragmentation: 9.4Gb/s
    - 9000 Byte MTU, no fragmentation: 9.8 Gb/s
    - Bidirectional 9000 Byte MTU: 9.3 Gb/s each direction!
  - Currently working to get sufficient hosts to test

- Plans:
  - Sandia New Mexico to Sandia California will use 10G encryptors in production
  - After Tri-labs becomes comfortable with operations, will move Discom to all 10G encryptors