Using Multi-rail Networks in High-Performance Clusters

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with

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Multiple Independent Network Rails

Using multiple independent networks is an emerging technique to (1) overcome bandwidth limitations and (2) enhance fault-tolerance.

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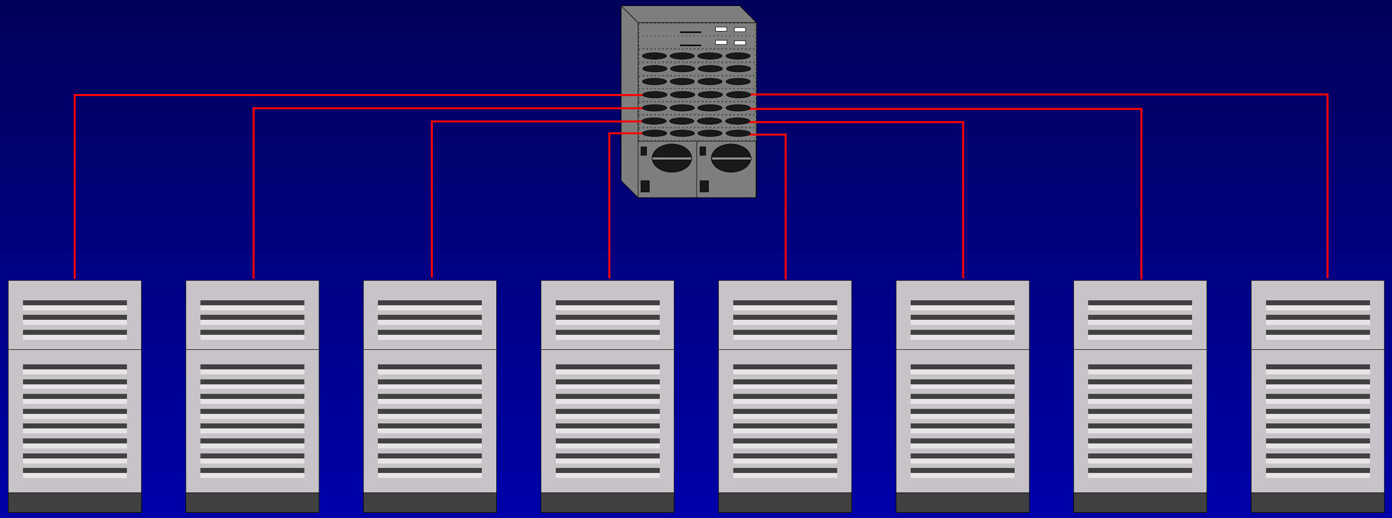

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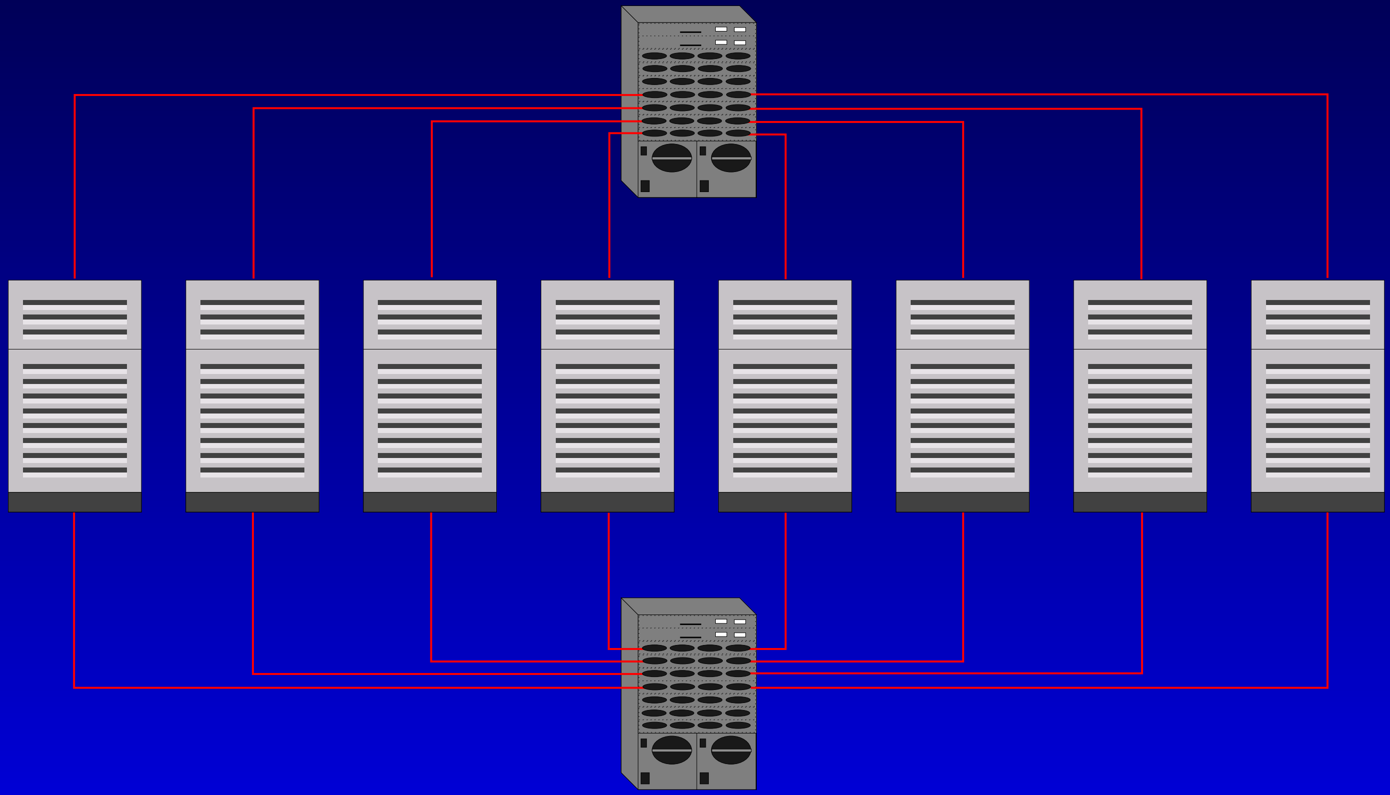


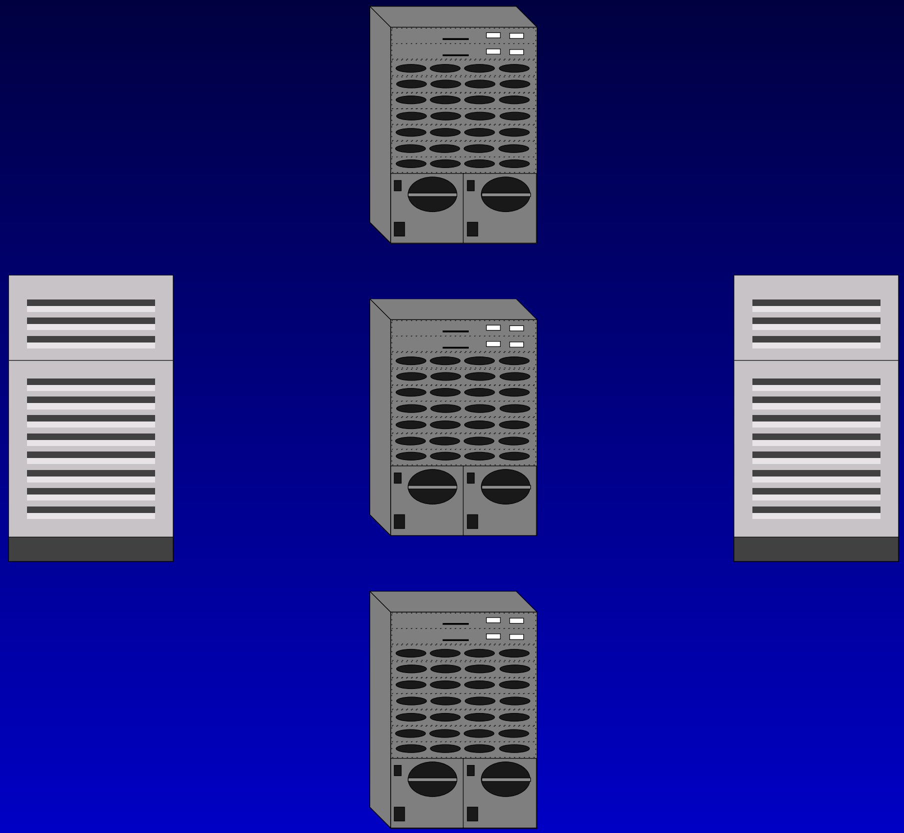
Examples of Multirailed Machines

- ASCI White at Lawrence Livermore National Laboratory (IBM SP)
- The Terascale Computing System (TCS) at the Pittsburgh Supercomputing Center (Quadrics)
- ASCI Q at Los Alamos National Laboratory (Quadrics)
- Experimental Linux clusters, with Infiniband, Quadrics and Myrinet

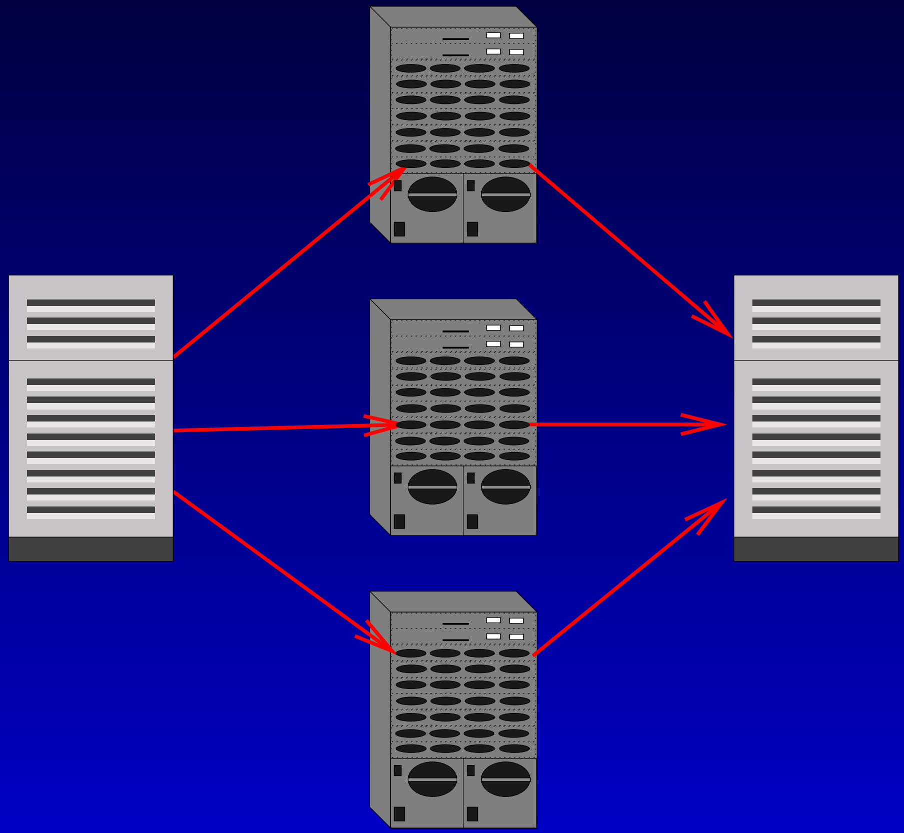
Challenges with Multirailed networks

- Rail assignment
- Striping over multiple rails
- Implementation of communication libraries (e.g., MPI, Cray Shmem)
- Interaction between NICs and I/O interfaces
- Congestion control: using multiple rails to decrease conflicts

Rail Allocation



Rail Allocation



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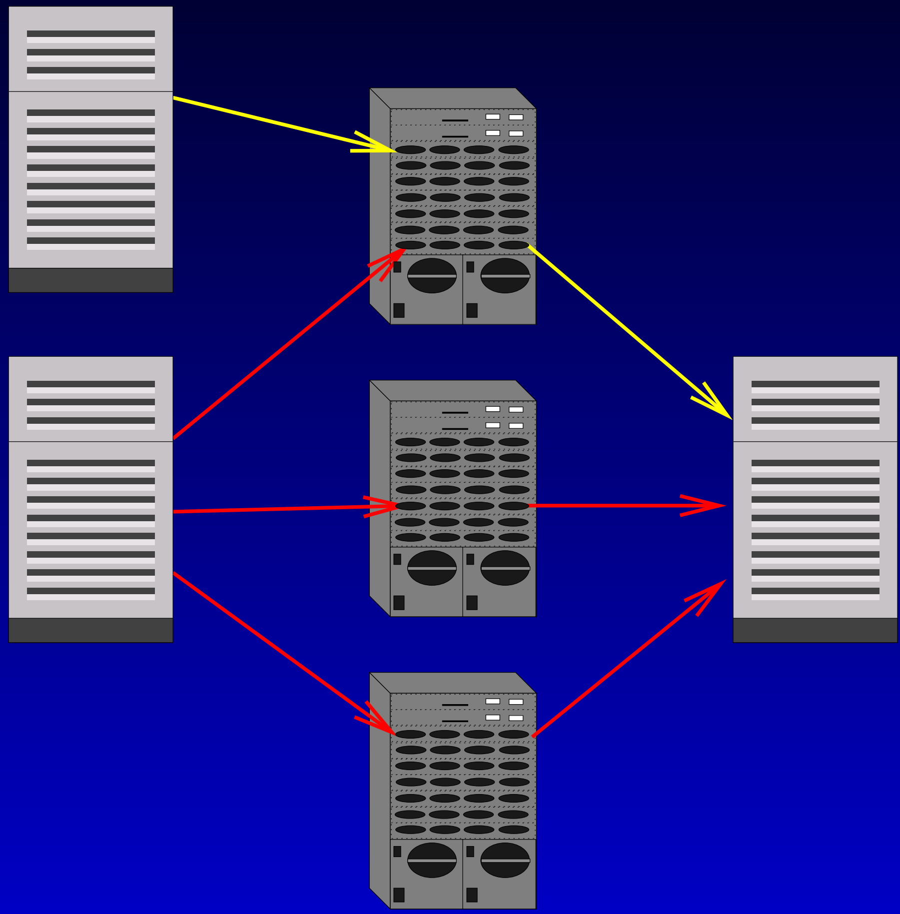

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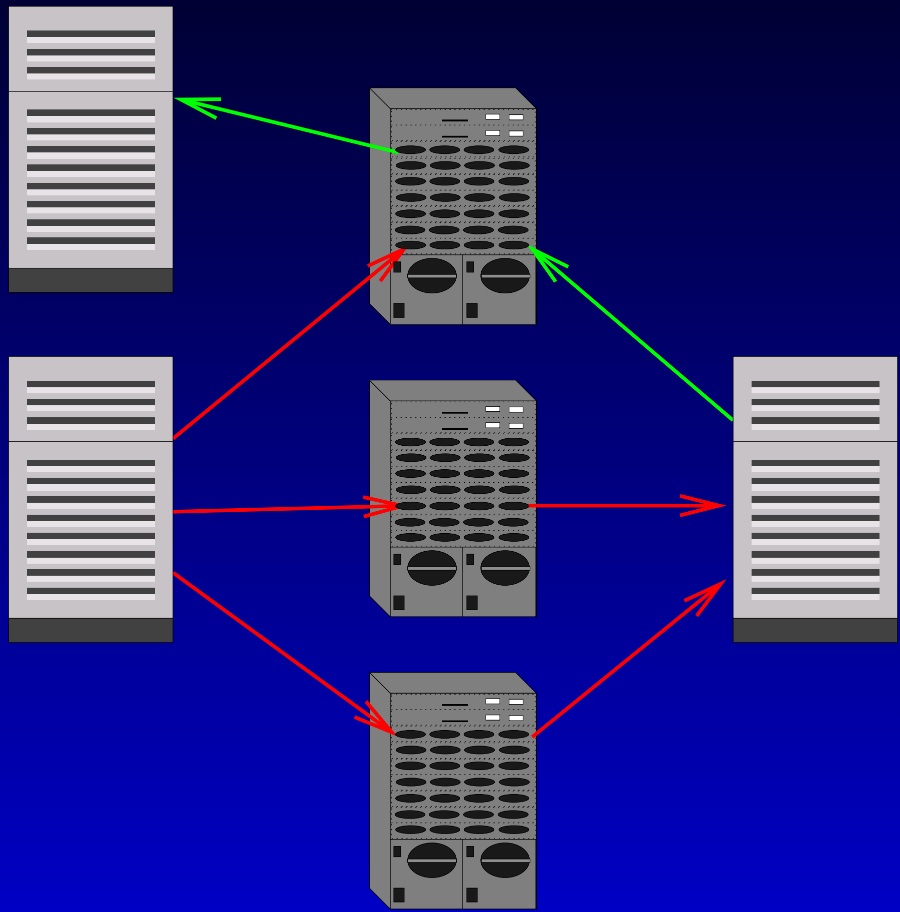

Bidirectional Traffic on the I/O bus

- Most PCI busses cannot efficiently handle bidirectional traffic with high performance networks
- Typically, aggregate bidirectional bandwidth is only 80% of the unidirectional one (Intel 840, Serverworks HE, Compaq Wildfire)
- PCI-X implementations (e.g., those based on the Intel 870) also suffer from performance degradation in bidirectional traffic
- Bidirectional traffic is very common in ASCI applications

Simple Rail Allocation

- A common algorithm to allocate messages to rails is to choose the rail based on the process id of the destination process (rail = destination_id $\bmod$ RAILS)
- Multiple processes can compete for the same rail even if other rails are available
- No message striping
- No attempt to minimize bidirectional traffic

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Outline

- Basic Algorithm
- Static rail allocation
- Dynamic rail allocation with local information
- Dynamic rail allocation with global information
- Experimental evaluation
- Hybrid algorithm
- Conclusions

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Basic (Round-Robin) Algorithm

- The basic algorithm doesn't use any communication protocol
- Whenever a node needs to send a message, it sends it on one rail, choosing it in round-robin fashion, blocking while it's busy
- Negligible overhead, but doesn't account for bidirectional traffic and congestion

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Static Rail Allocation

- With static rail allocation each network interface can either send or receive messages, and the direction is defined at initialization time.
- Initially proposed for ASCI Q, with 384 SMPs and 8 rails (ASCI Q is now 2048 SMPs and 2 rails)
- How many rails do we need for static allocation of n SMPs?

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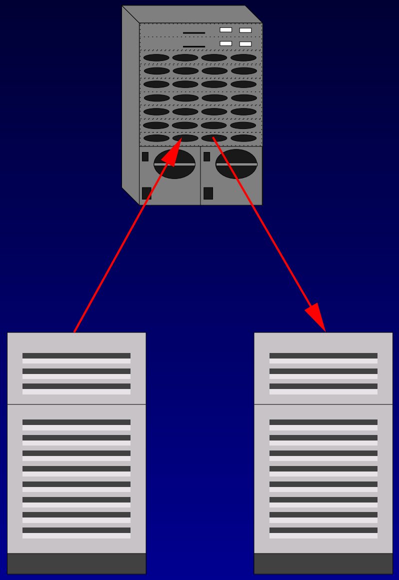
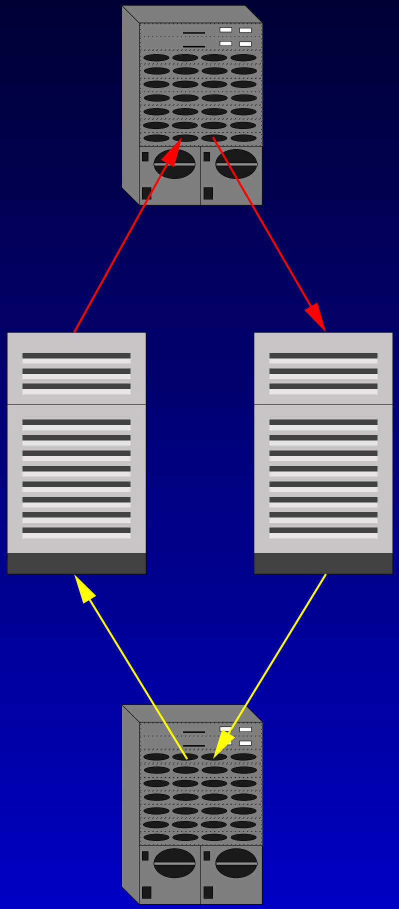
Static Rail Allocation Examples



Static Rail Allocation Examples



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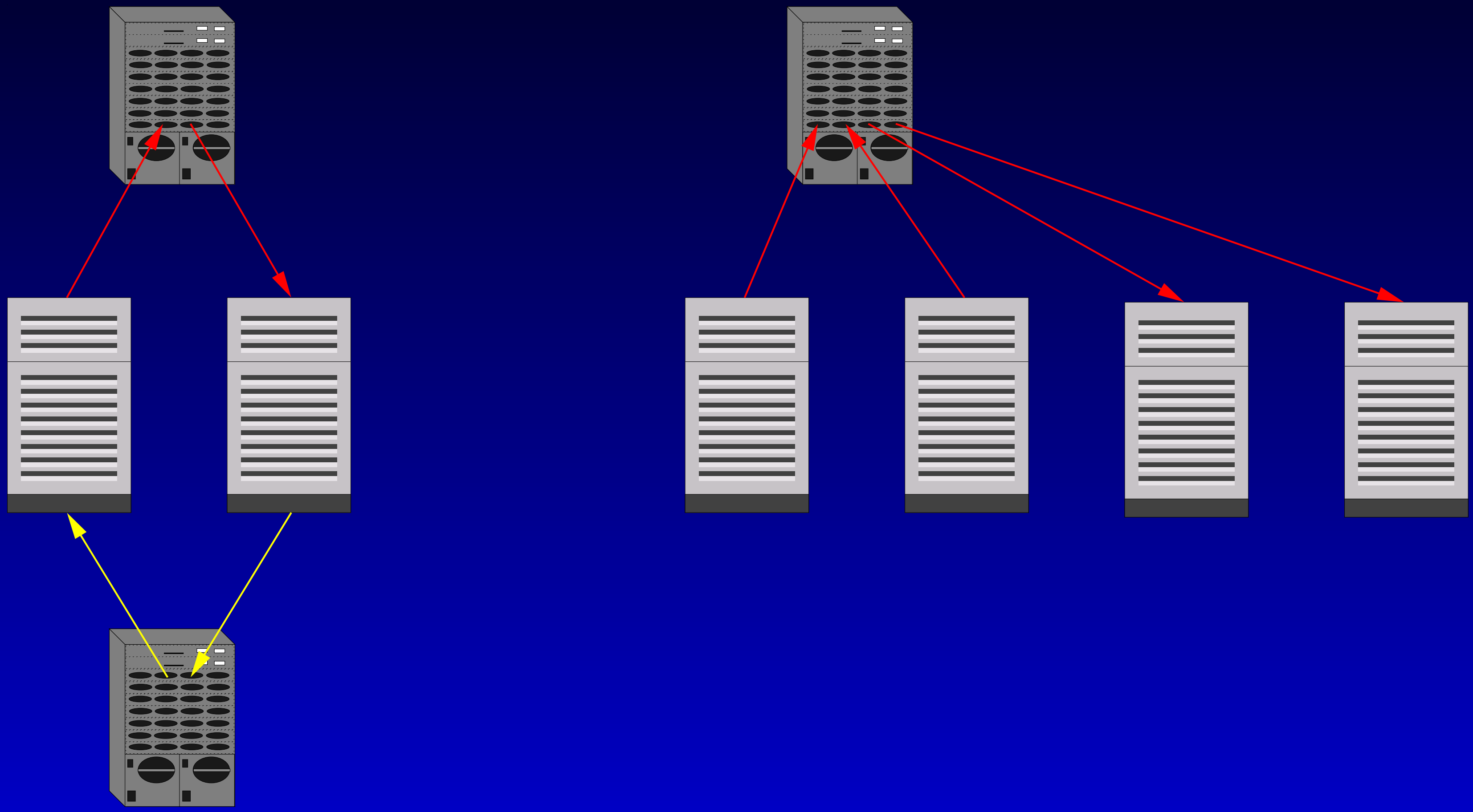

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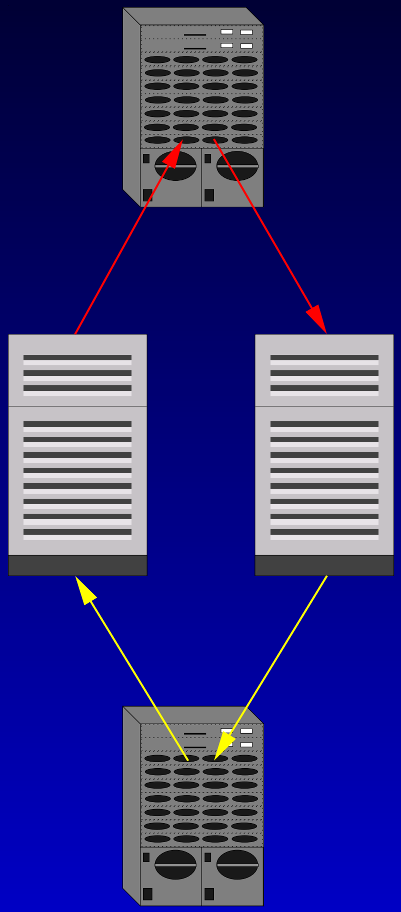

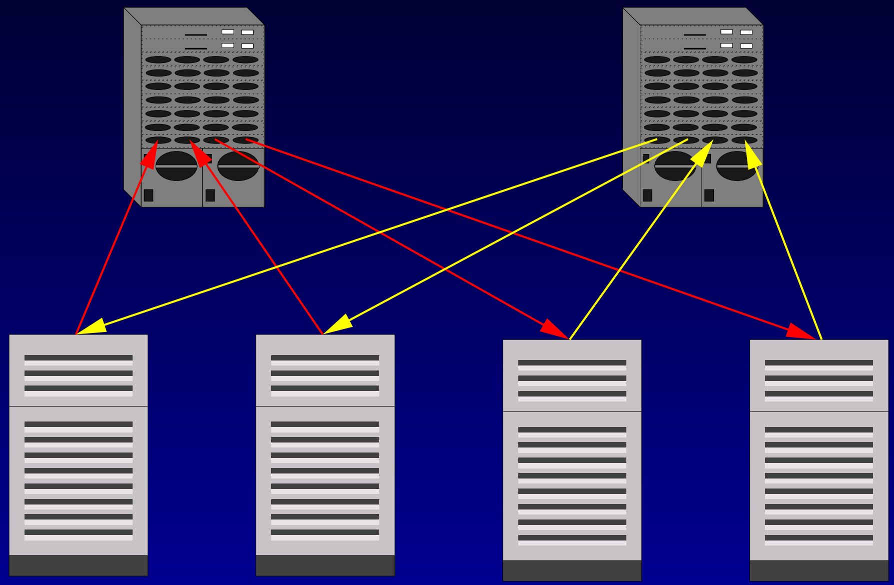

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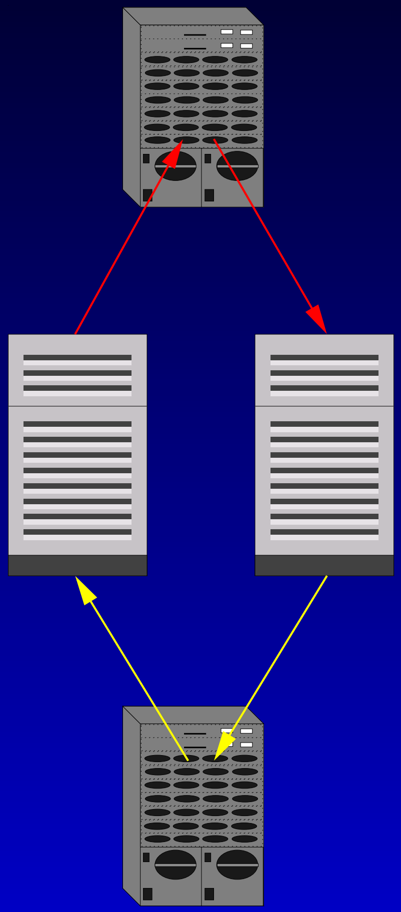

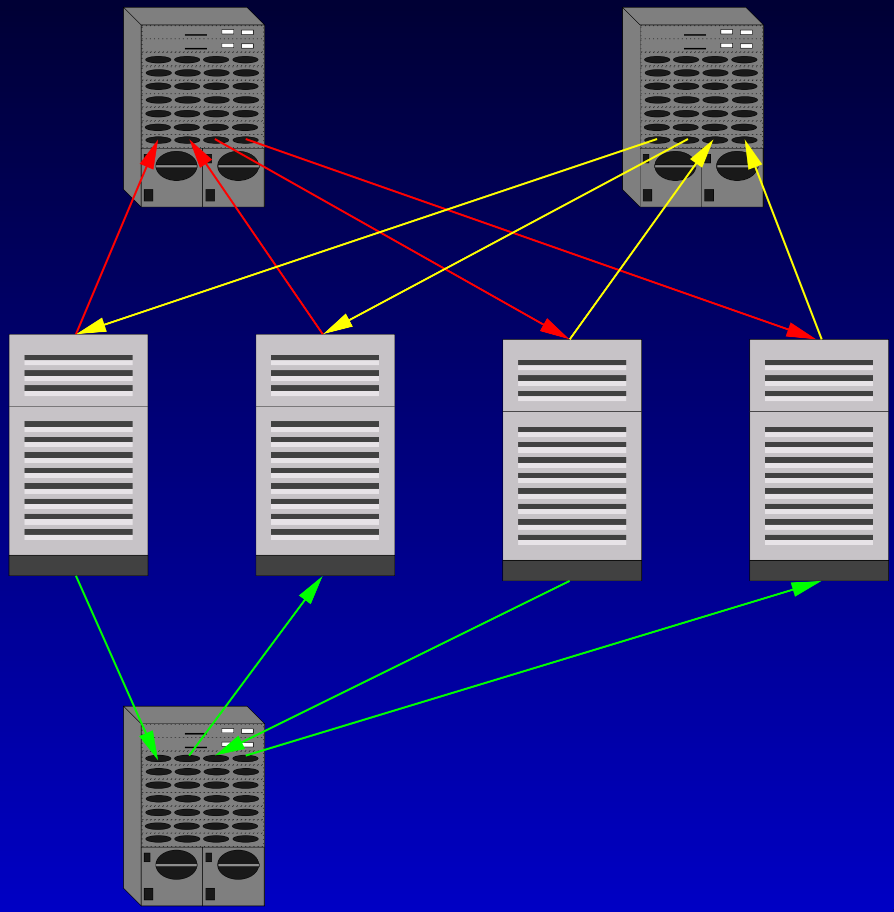

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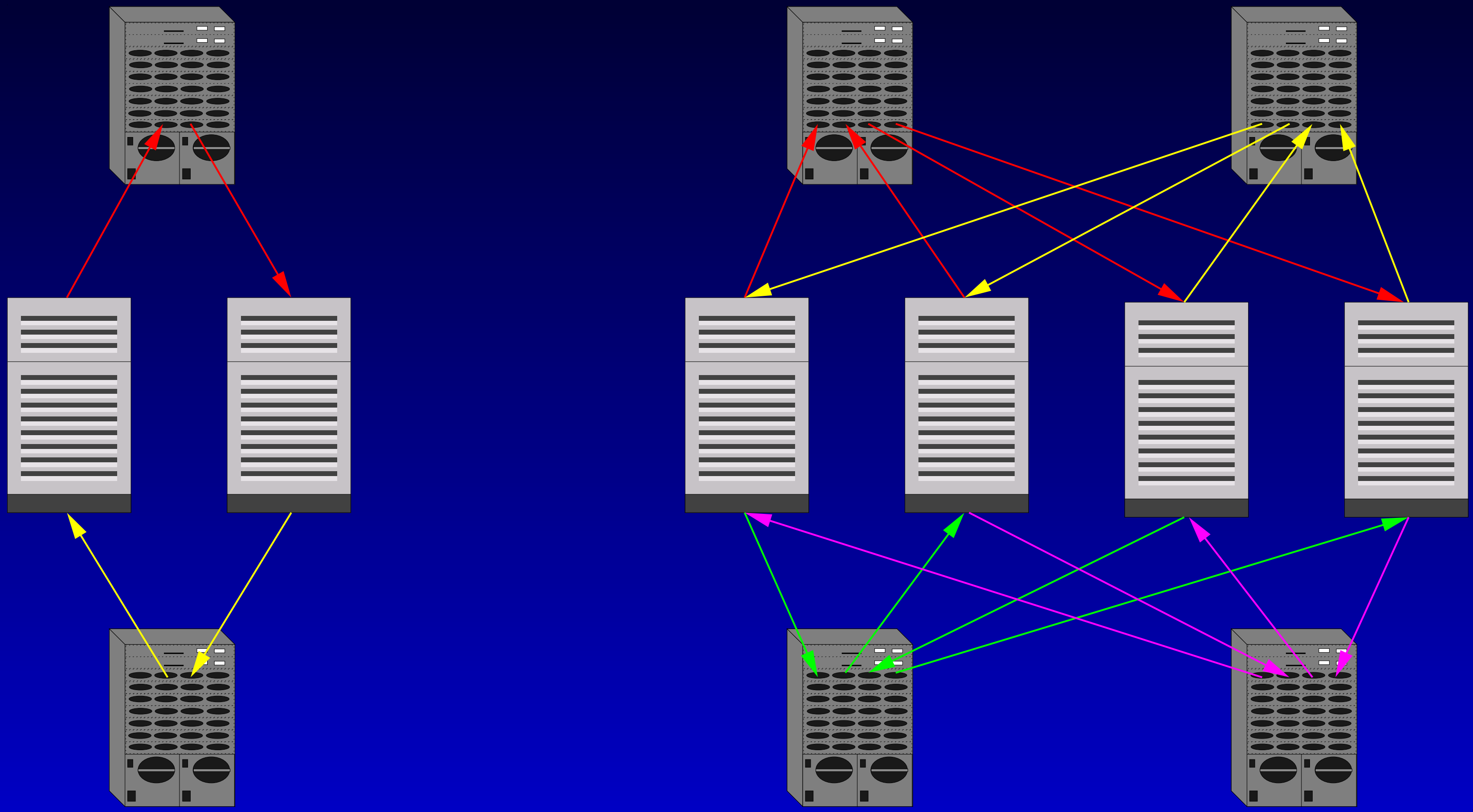

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Lower Bound with Static Rail Allocation

What is the minimal number of rails to connect a cluster if:

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Is this optimal?

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Using binary matrix notation, what is the maximum number of columns n for r rows, so that for every two columns, a row exists with a '0' and another with a '1'?

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A network with *r* rails can support no more than *n* nodes, where

$$n \leq \binom{r}{\lfloor \frac{r}{2} \rfloor}$$

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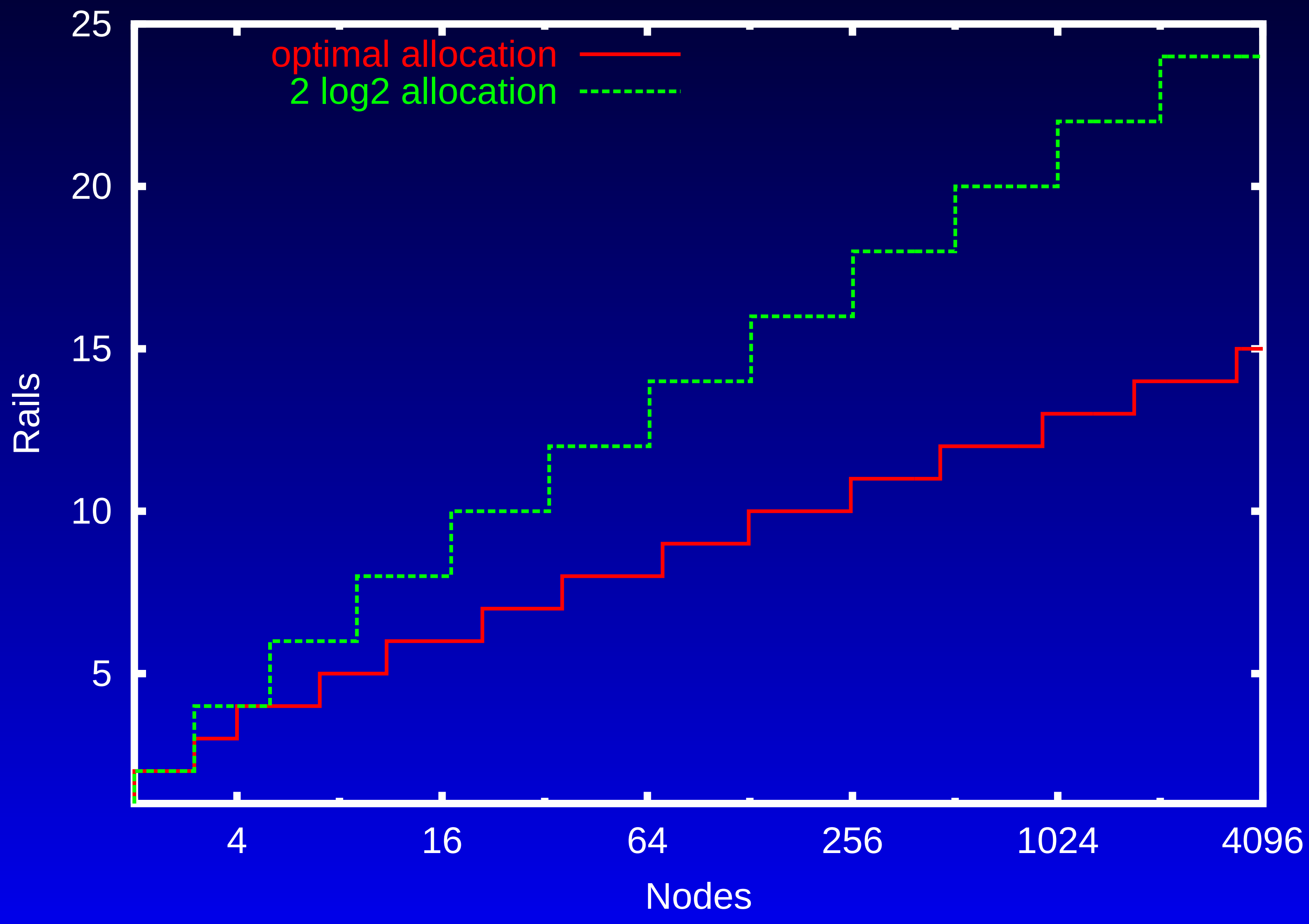
Comparison of bounds



Dynamic Algorithm with Local Information

- With the dynamic algorithms the direction in which each network interface is used can change over time
- The *local-dynamic* algorithm allocates the rails in both directions, using local information available on the sender side
- Messages are sent over rails that not sending or receiving other messages
- Messages can be striped over multiple rails
- There is no guarantee that traffic will be unidirectional

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Dynamic Algorithm with Global Information

- The *dynamic* algorithm tries to reserve both end-points before sending a message
- In its core there is a sophisticated distributed algorithm that (1) ensures unidirectional traffic at both ends and (2) avoids deadlocks, potentially generated by multiple requests with a cyclic dependency

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Dynamic Algorithm: Implementation Issues

- The efficient implementation of this algorithm requires some processing power in the network interface, which needs to process control packets and perform the reservation protocol without interfering with the host
- For example, the Quadrics network interface is equipped with a thread processor that can process an incoming packet, do some basic processing and send a reply in as few as $2\mu s$

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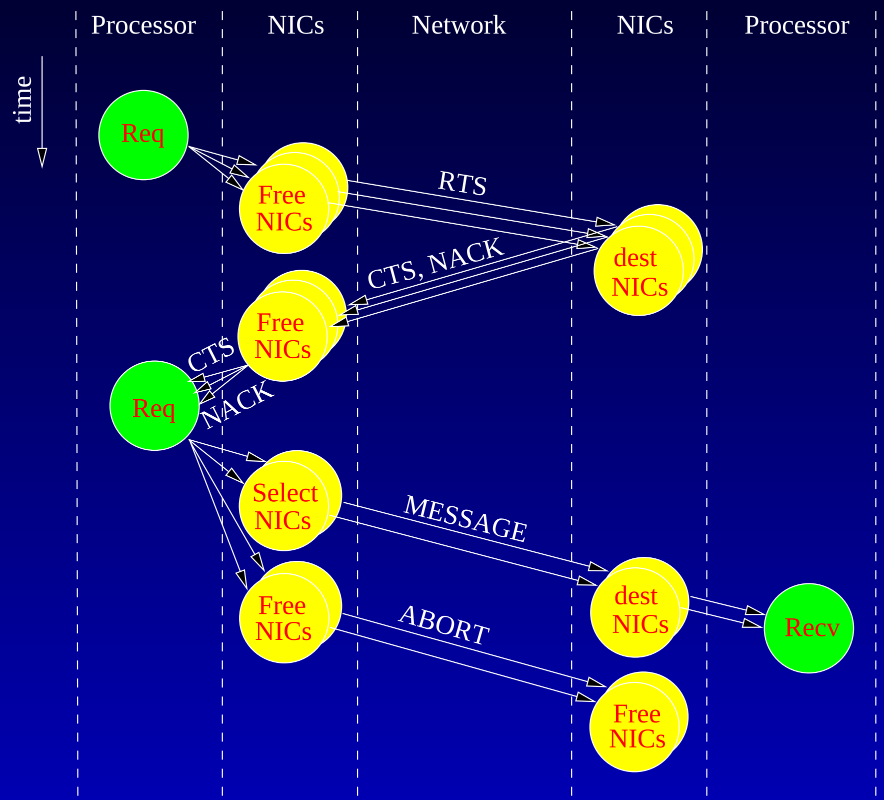
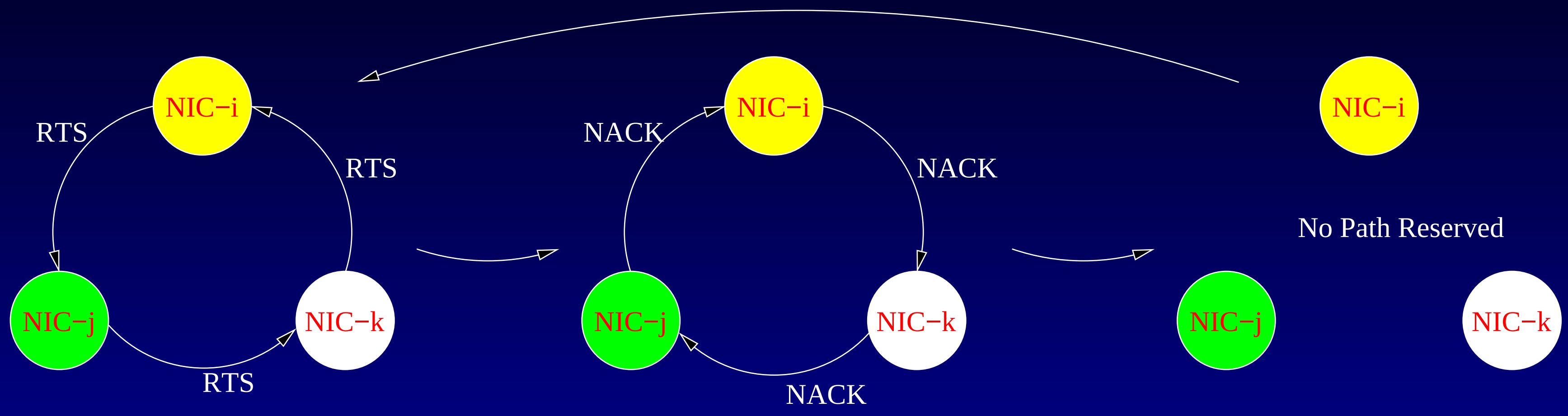
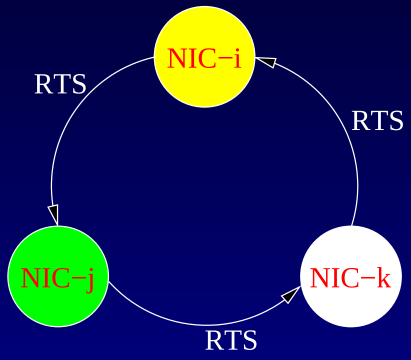
Dynamic Algorithm



Deadlock (Livelock) in the Dynamic Algorithm



Deadlock Avoidance in the Dynamic Algorithm



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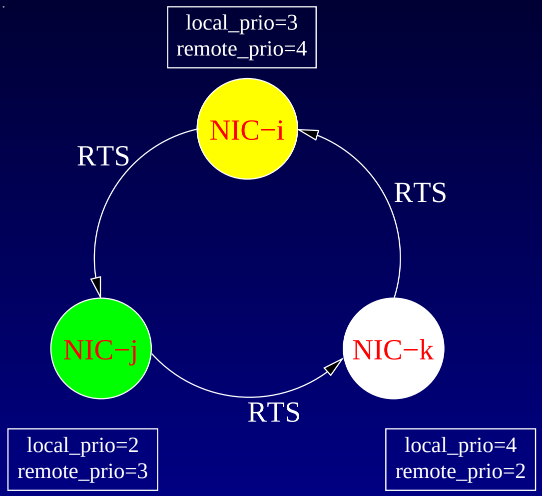

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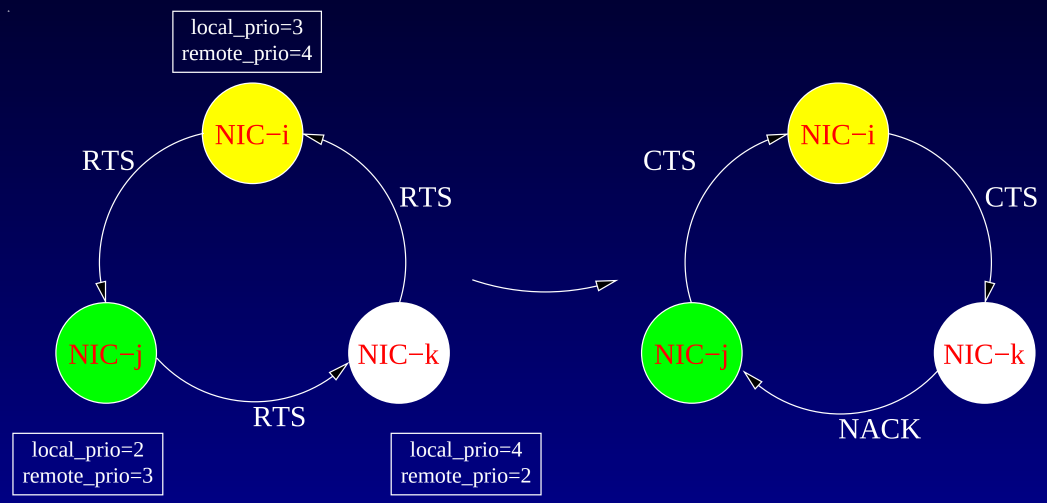

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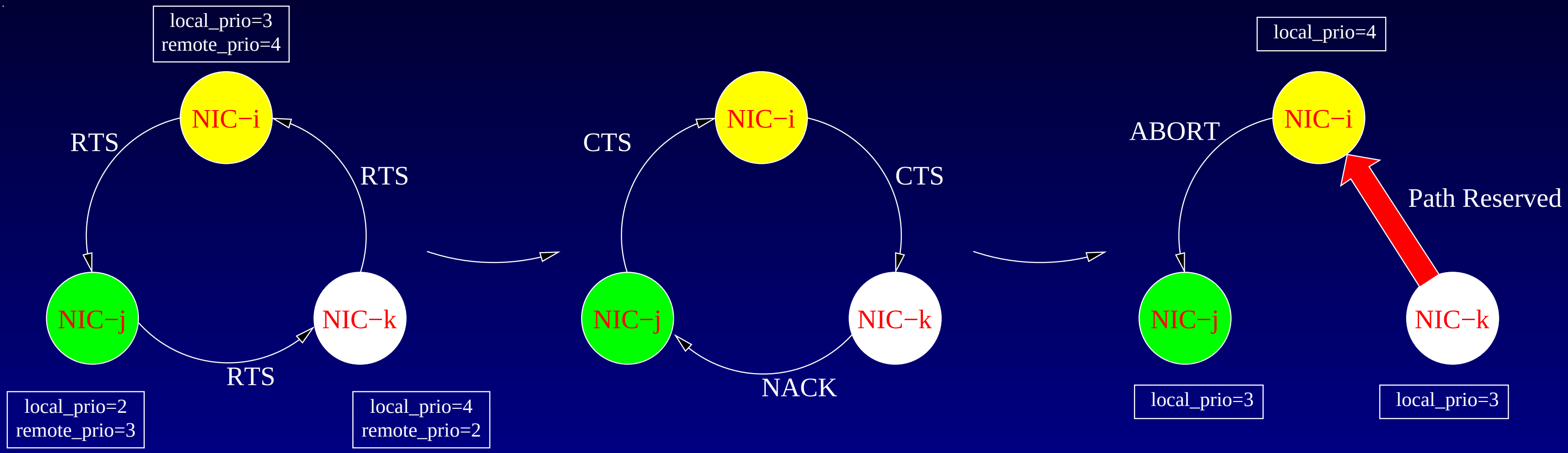

Simulation Framework

- Focus our attention on a family of fat-trees interconnection networks, ranging from 32 to 128 processing nodes (4-way SMPs)
- Up to 8 independent rails
- Low level simulation of the network (network model based on the Quadrics network)
- Simulate the communication processor in the NIC
- Test the network using a synthetic communication benchmark
- Exponential distribution for message size & interarrival time, destinations are chosen randomly (uniform)
- Measure two parameters, the overall *accepted bandwidth* and the message *latency*

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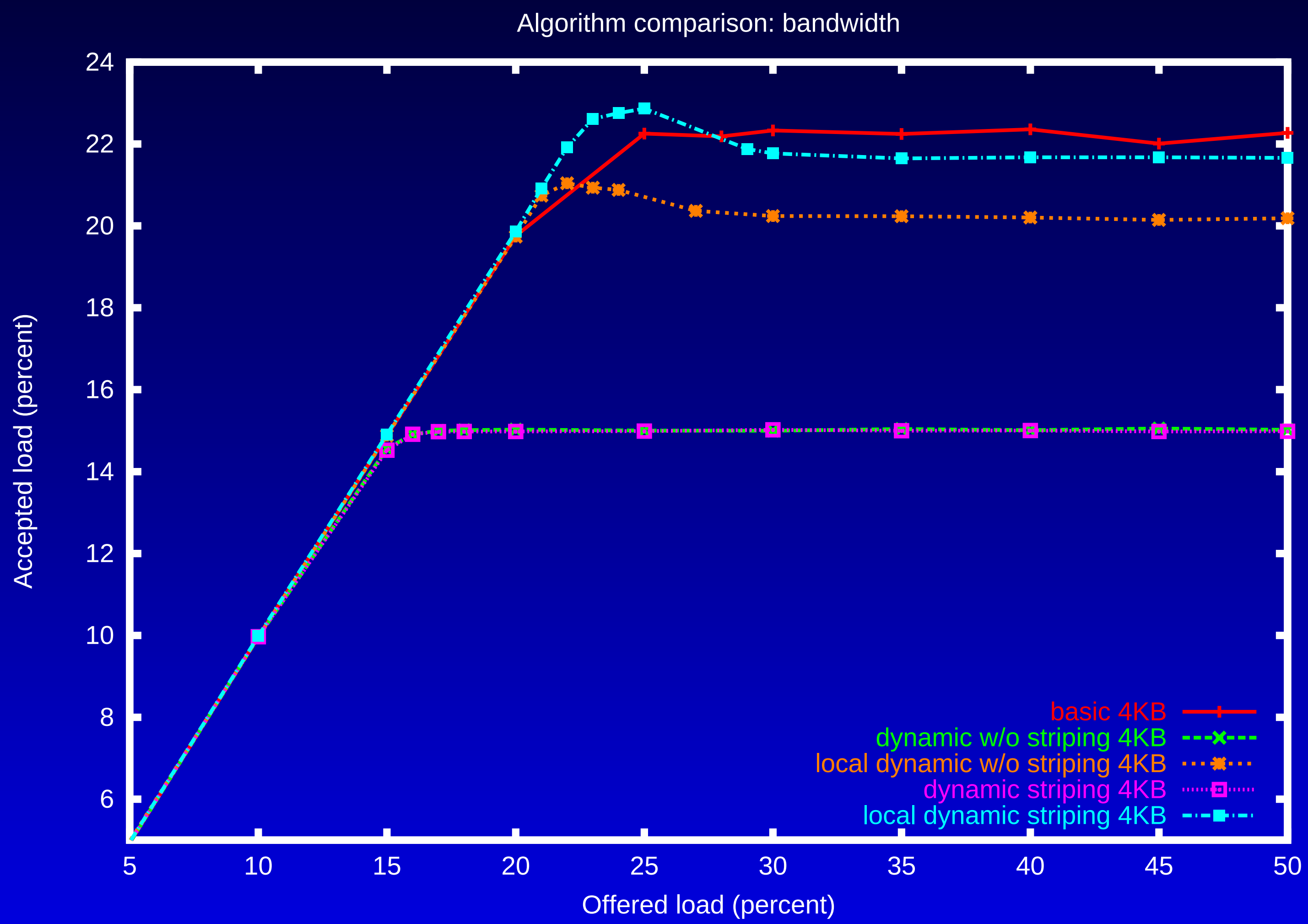
Results - Bandwidth

128 Nodes (4-way), four rails, 4KB average messages



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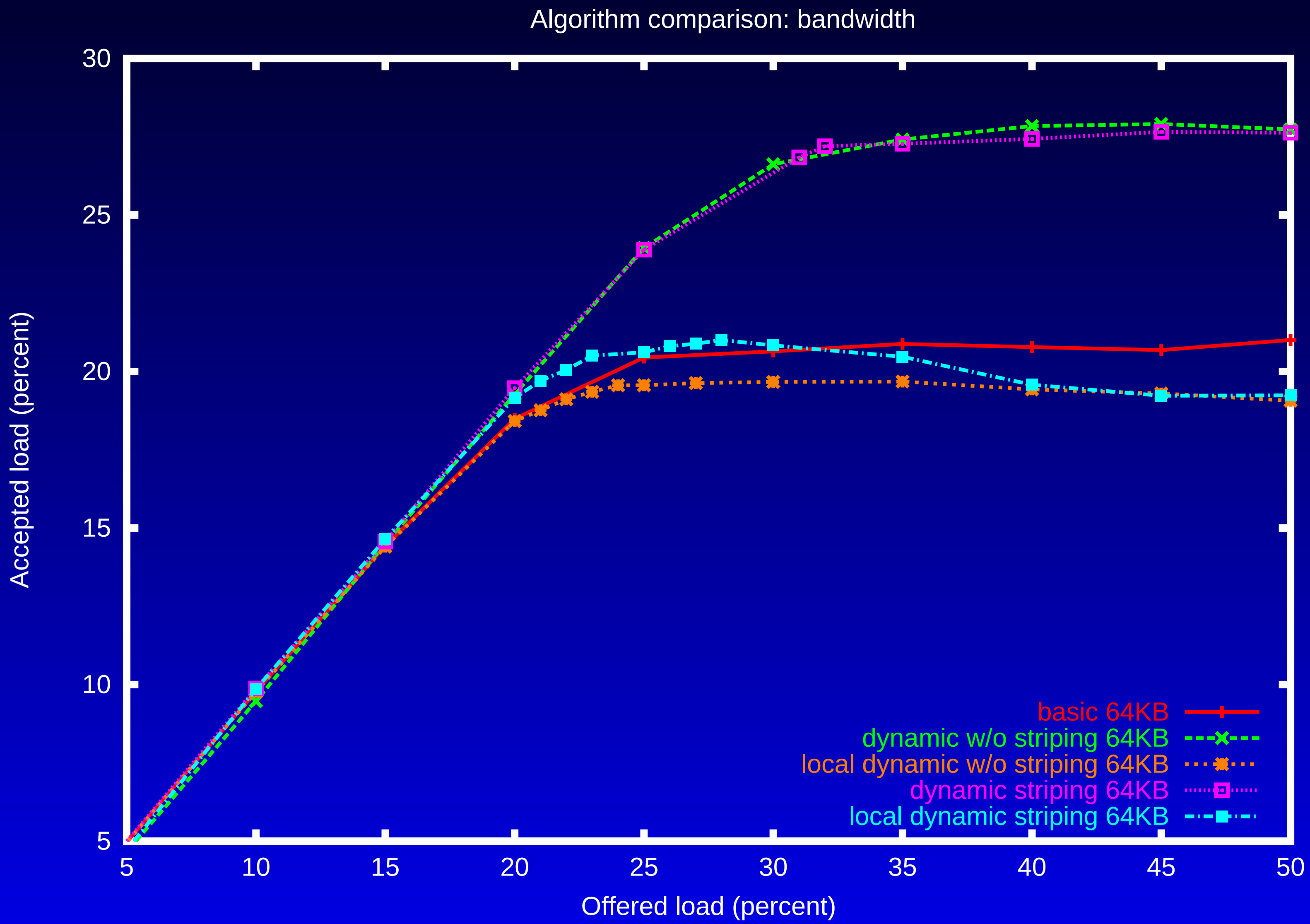
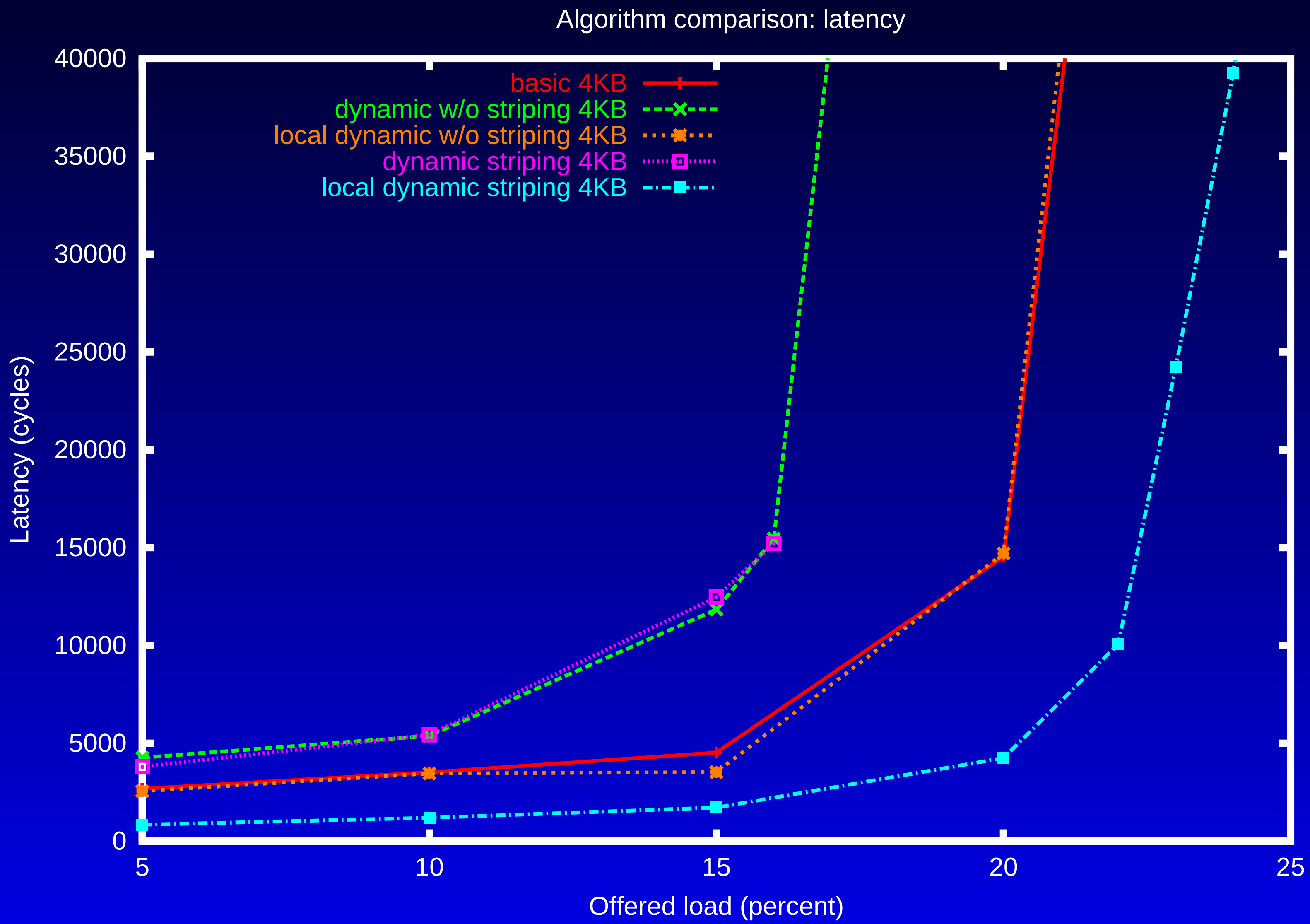
Bandwidth, 64KB Messages



Results - Latency, 4KB Messages



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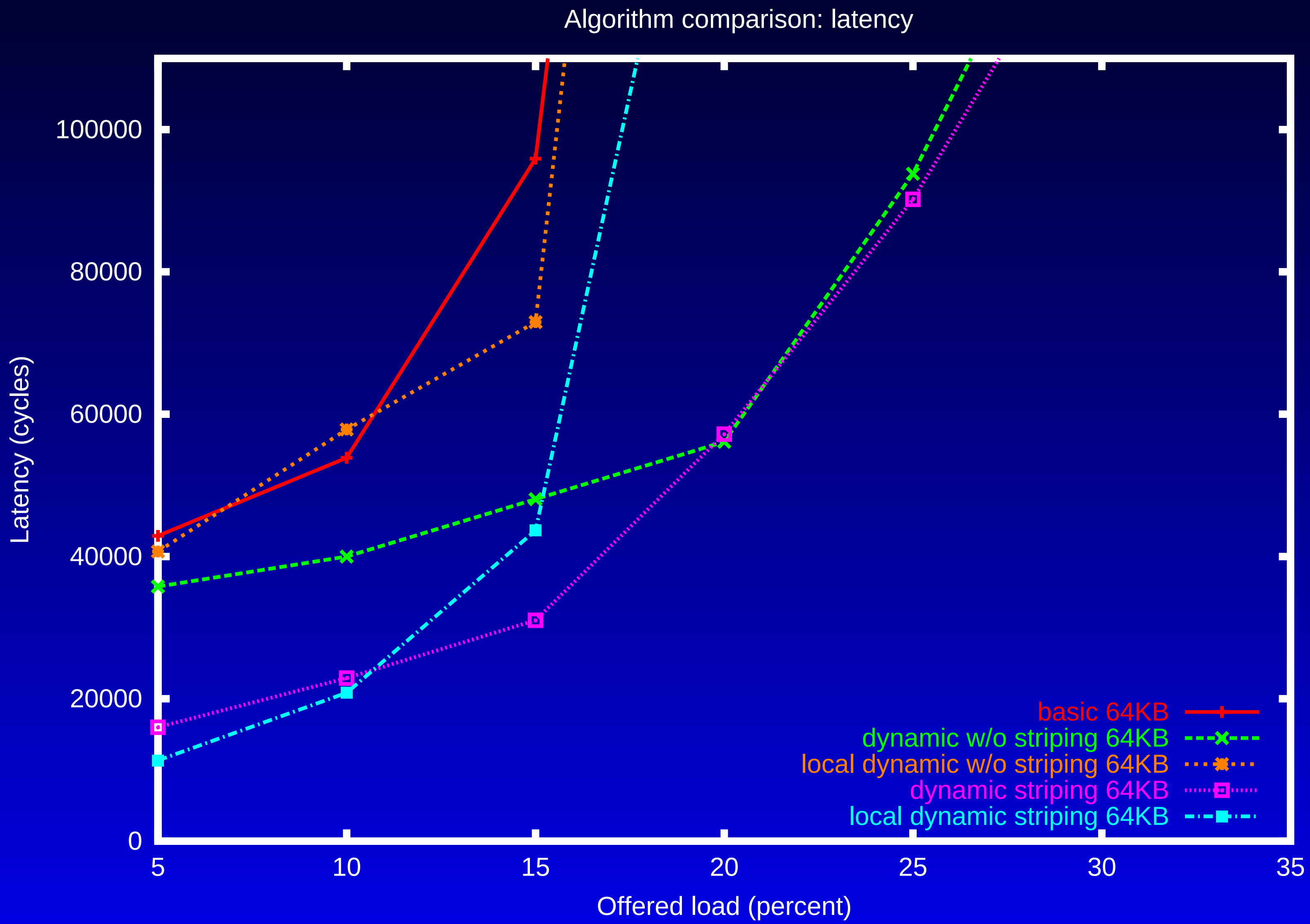
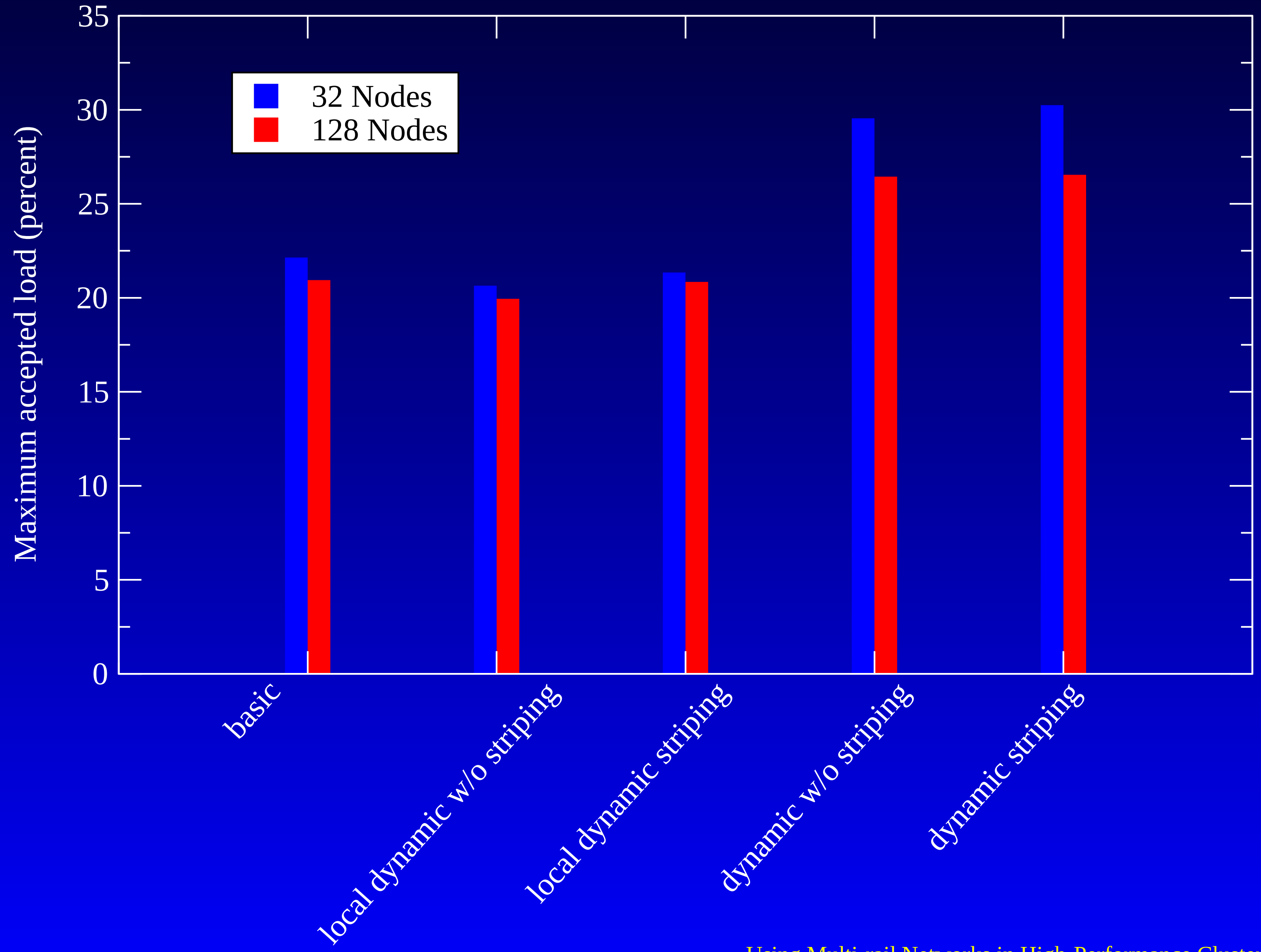


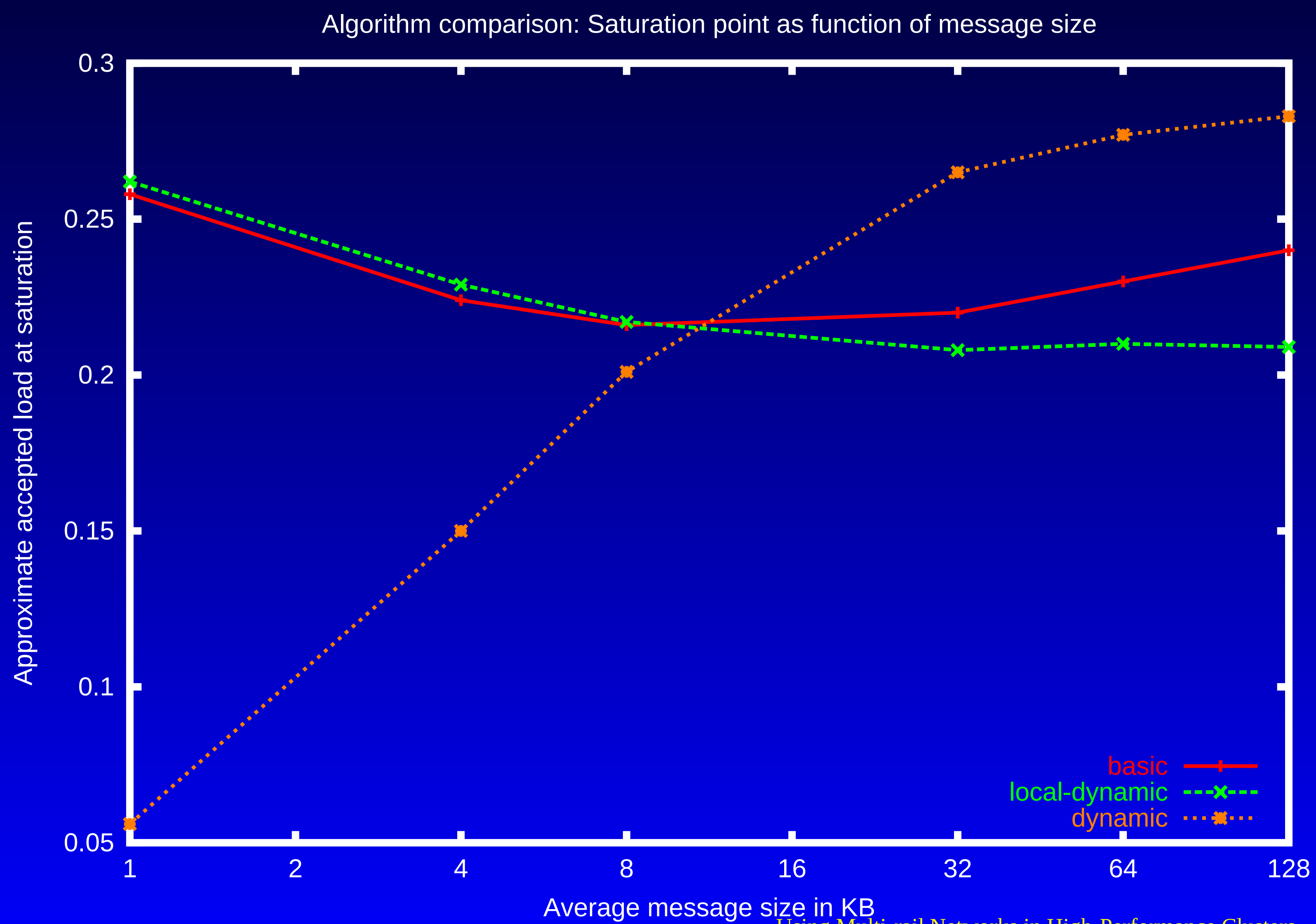
Maximum Accepted Load by Network Size

Using 4 rails and average message size of 32KB

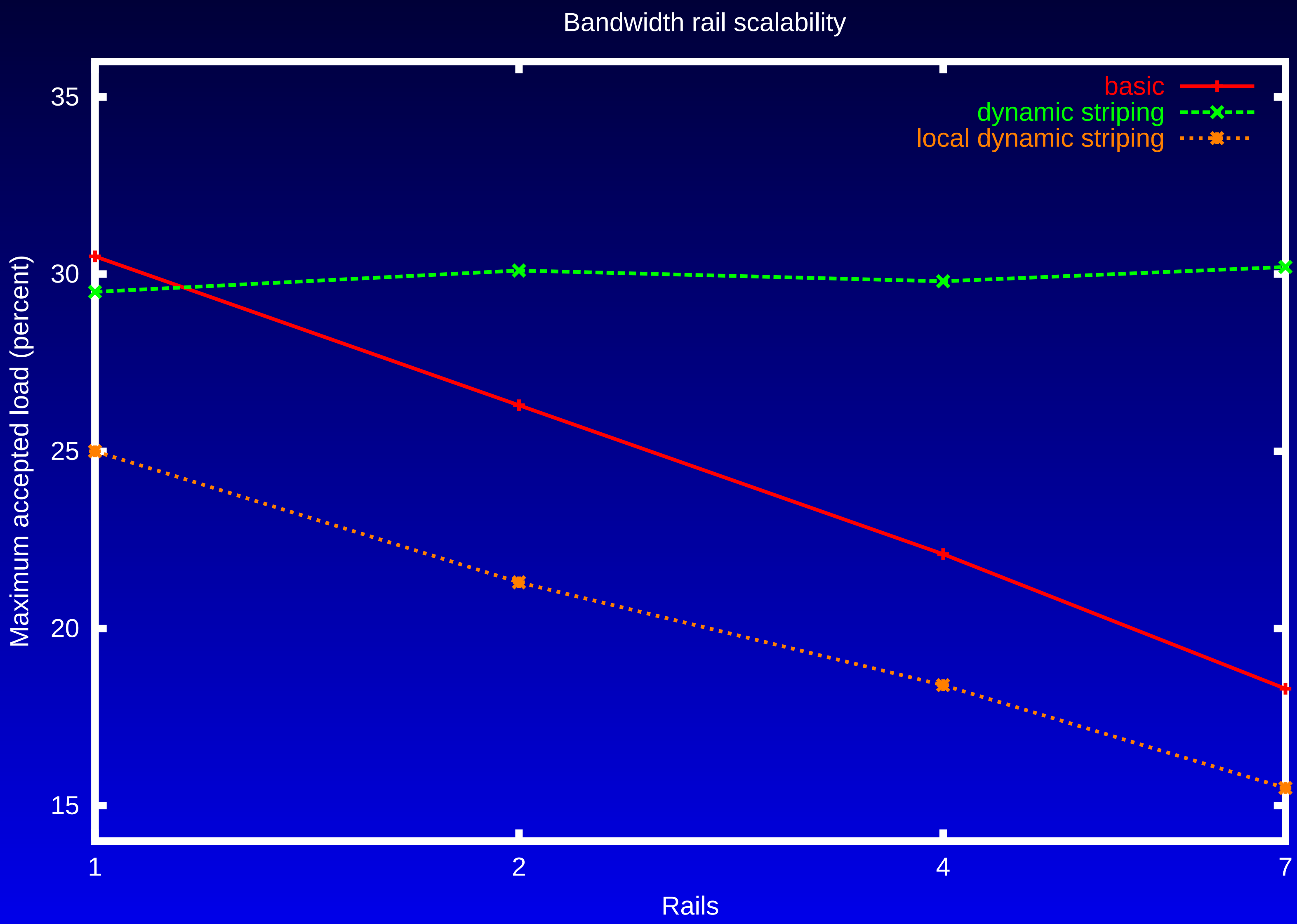


Saturation Points vs. Message Size

Striping and non-striping converge at high loads



Bandwidth vs. Number of Rails (32 Nodes)



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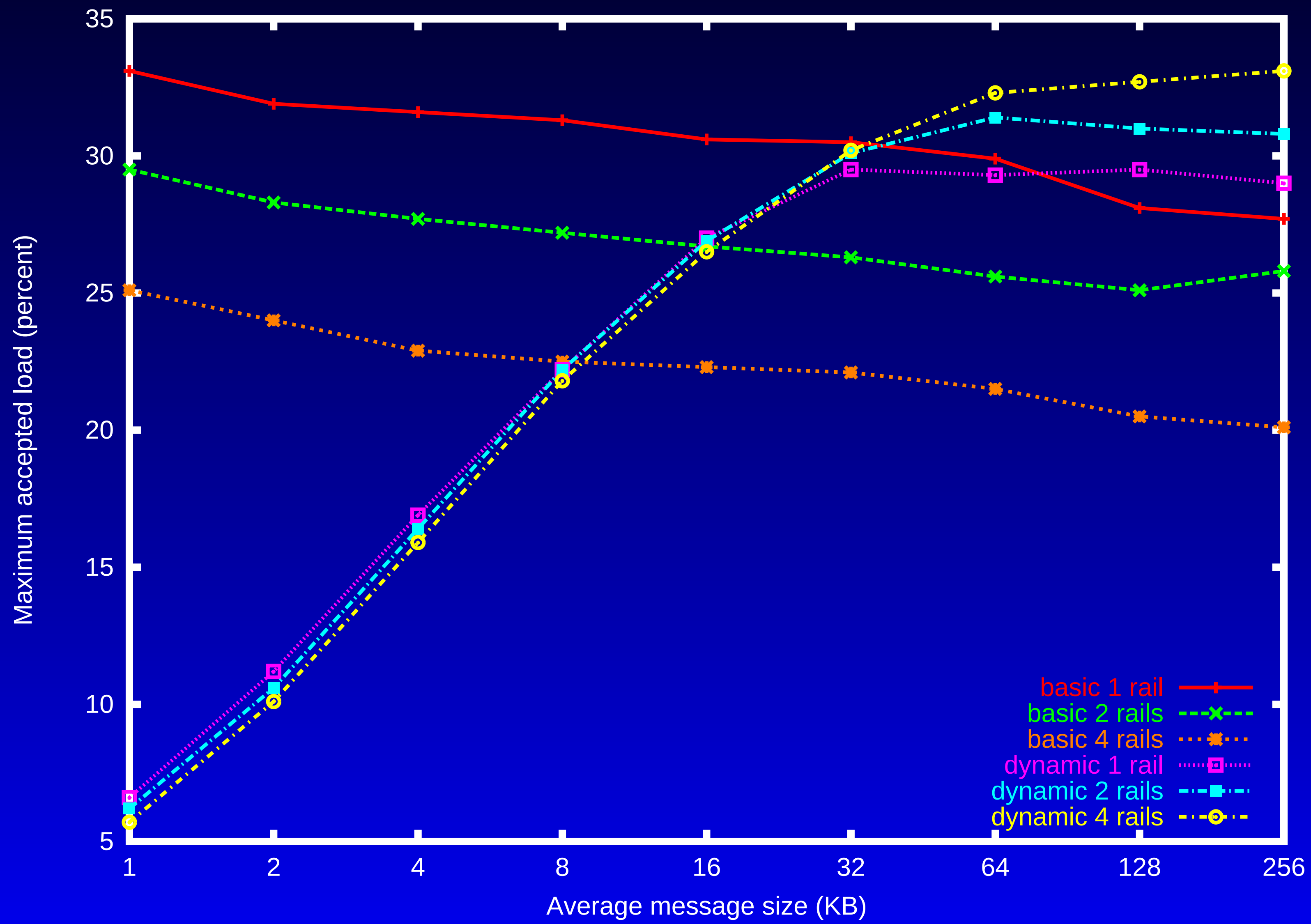
Rail Scalability vs. Message Size



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Hybrid Algorithm

- The dynamic algorithm incurs a substantial overhead, for every message size.
- The hybrid algorithm sends short message without a reservation protocol
- Short messages are not striped
- It can cause bidirectional traffic for a short time
- We evaluate 128 nodes, 32KB average message size, 4 rails

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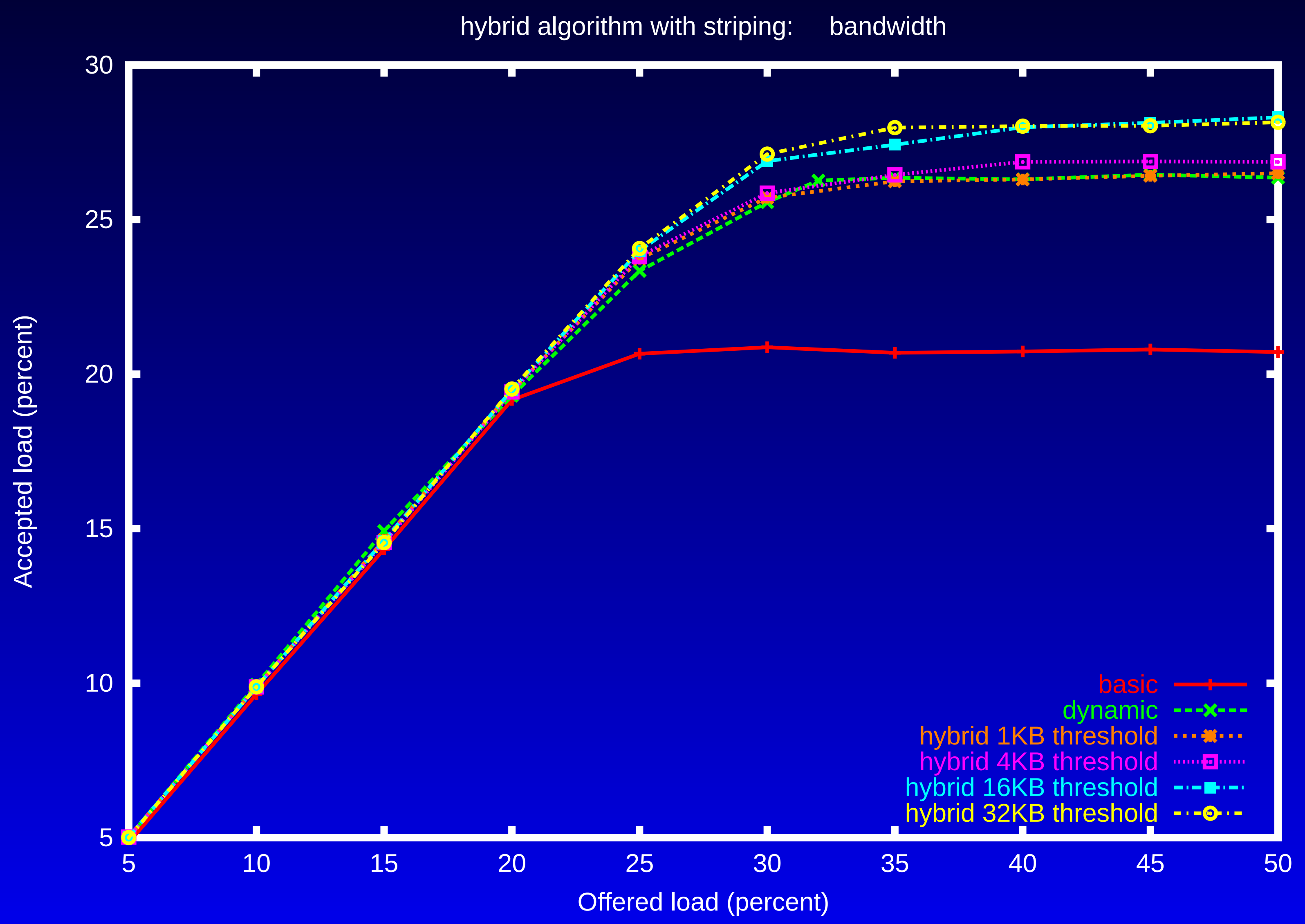
Hybrid, Bandwidth with Striping



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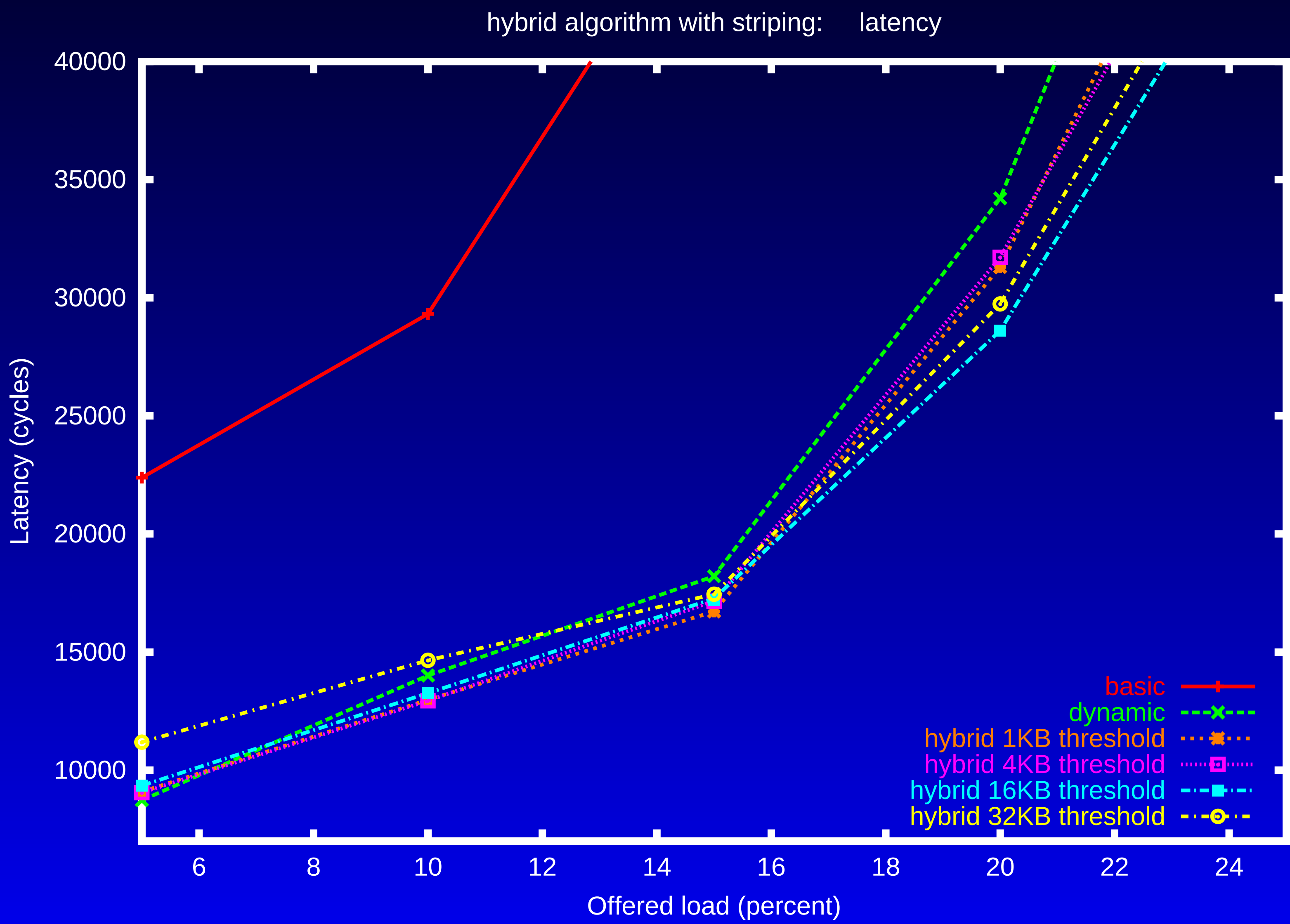

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Static Algorithm

- For completeness, we also evaluated the static algorithm's performance, despite its high resource cost
- We use 32 nodes with 7 rails, 32KB average message size
- Outgoing messages have to compete over fewer rails: no bidirectional traffic, but more contention on the source

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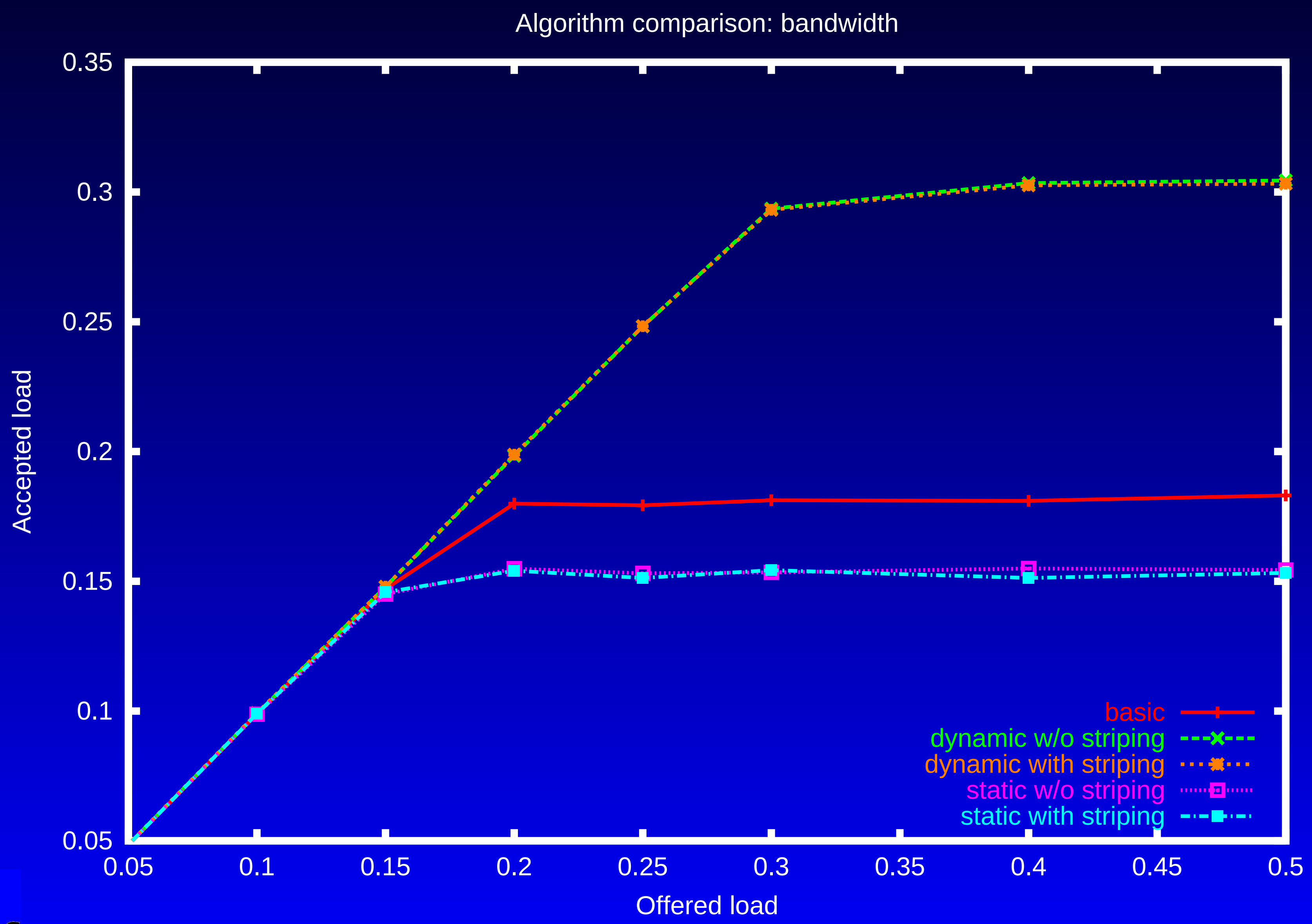
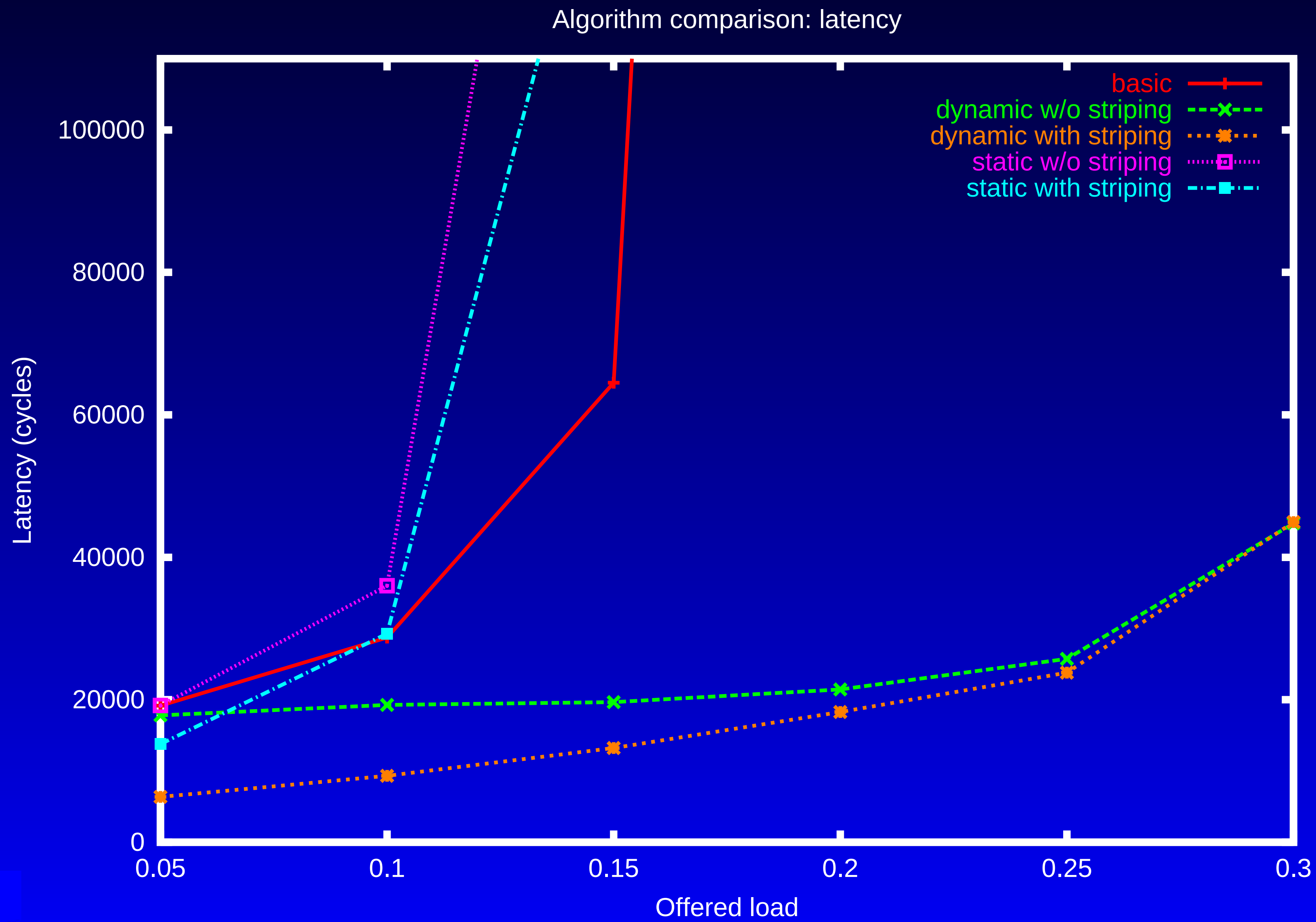
Static Bandwidth



Static Latency



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- This algorithm is scalable with the number of rails
- Incorporating protocol-free short message handling in the hybrid algorithm furtherly increases performance of the dynamic algorithm

Resources

- More information can be found at or

http://www.cs.huji.ac.il/~etcs

- Or by sending an email to

eitanf@lanl.gov