TECHNISCHE UNIVERSITÄT DRESDEN

Center for Information Services and High Performance Computing (ZIH)

Deadlock-Free Oblivious Routing for Arbitrary Topologies

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Outline

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Basics and previous work

- InfiniBand interconnect
- InfiniBand subnet manager – OpenSM
- Motivation
- Previous work

InfiniBand interconnect

- Based on an open standard, developed by the InfiniBand Trade Association
- One of the most widely used interconnect in the field of HPC

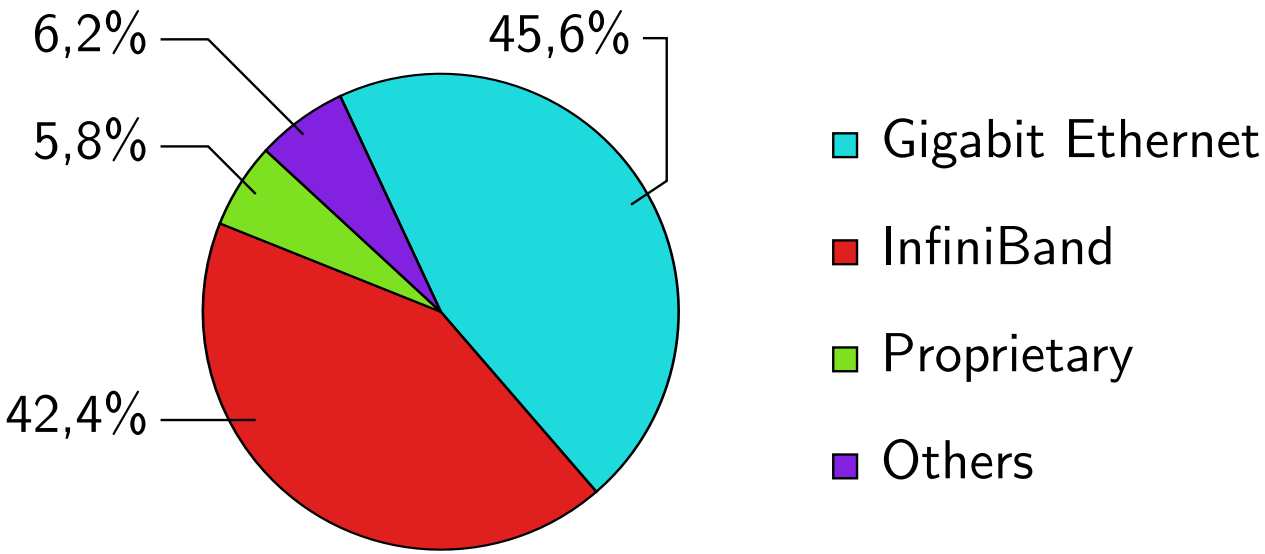


Figure: Top500 List, Interconnects, Nov. 2010

InfiniBand subnet manager – OpenSM

Tasks

- Scan the components of the IB subnet
- Initialize the IB ports
  - Calculate paths for each port pair in the subnet
  - Generate linear forwarding tables (LFT)
  - Configure the IB ports with additional preferences, e.g. QoS
- Reconfiguration, if the subnet changes

InfiniBand subnet manager – OpenSM

Implemented static/destination-based routing algorithms

- MinHop
- Up*/Down*
- Fat-Tree
- LASH
- DOR

Motivation

General problems for most of the routing algorithms

- No global balancing of the traffic $\Rightarrow$ congestions reduce the bandwidth
- Only designed for a small set of topologies
- Not deadlock-free for every topology
- Not usable for production systems, because of long runtime

The algorithm should support irregular topologies, because

- HPC-systems grow in their lifetime
- Additional node like I/O or login nodes are connected
- Network components can fail

Previous work

Single-source-shortest-path routing algorithm

- "Optimized Routing for Large-Scale InfiniBand Networks" [Hoefler et al., 2009] presented SSSP
- Minimizes congestions thru global balancing
- Higher effective bisection bandwidth compared to others algorithms
- Disadvantage of the presented approach
  - Algorithm is not deadlock-free
  - LFT are calculated by an external program (not OpenSM)

Outline

Deadlocks

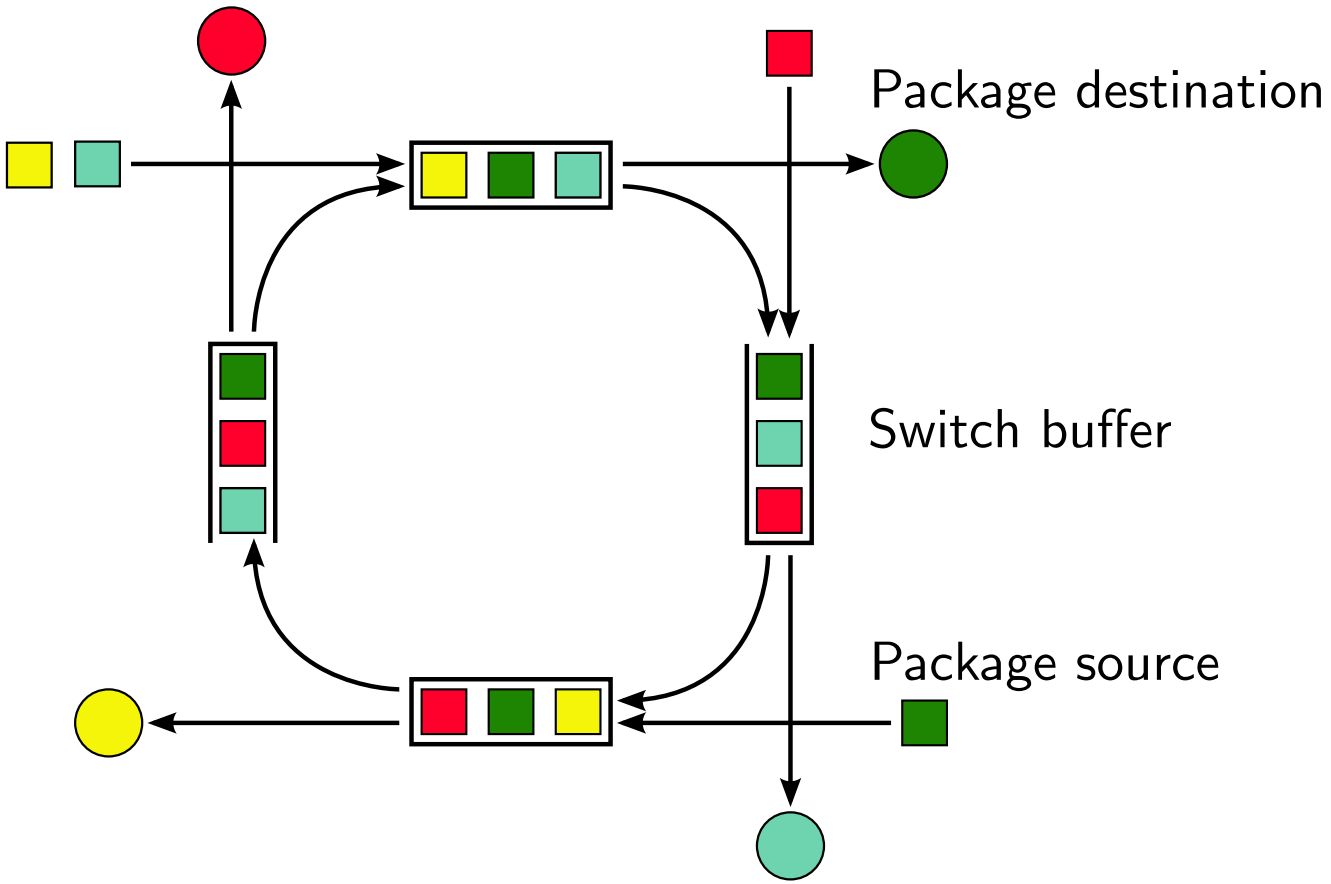
- Definition
- Deadlocks in interconnects
- Approaches for deadlock-free routing
- Theorem of Dally and Seitz
- Virtual channels and channel dependency graph

Definition

Definition Deadlock [Tanenbaum, 2007]

A set of processes is deadlocked if each process in the set is waiting for an event that only a process in the set can cause.

Deadlocks in interconnects



Approaches for deadlock-free routing

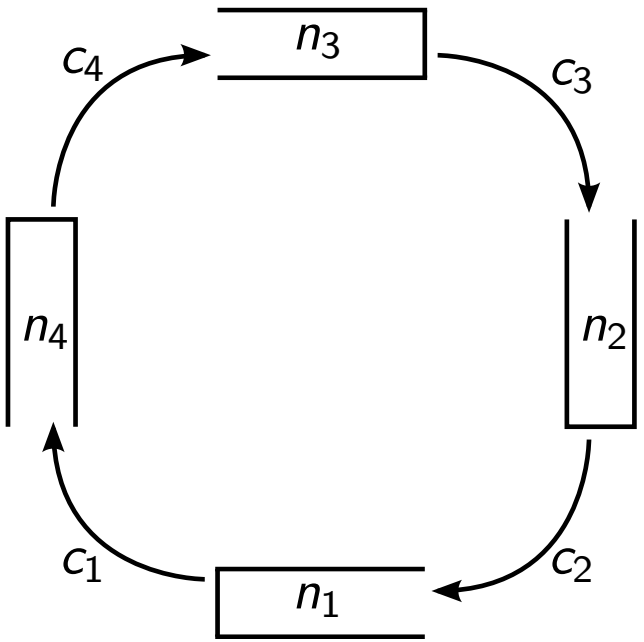
- Package life-time (only to break the deadlock, if they occur)
- Controller principle
- Up*/Down* routing
- Virtual channels
  - "Deadlock-Free Message Routing in Multiprocessor Interconnection Networks" [Dally and Seitz, 1987]
  - Each link will be split into multiple virtual channels
  - Channel dependency graph

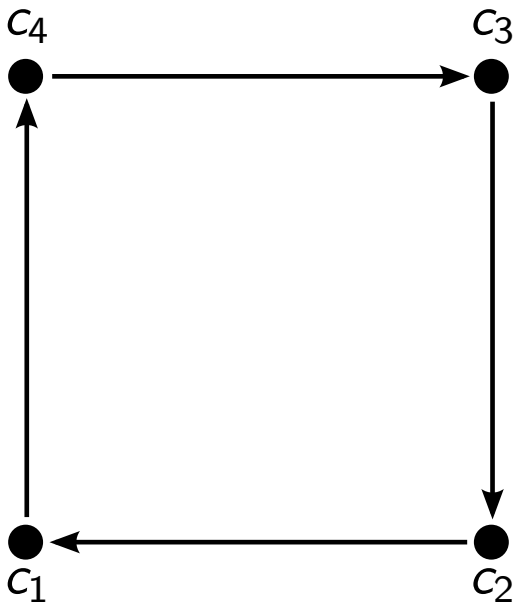
Theorem of Dally and Seitz

Theorem of Dally and Seitz

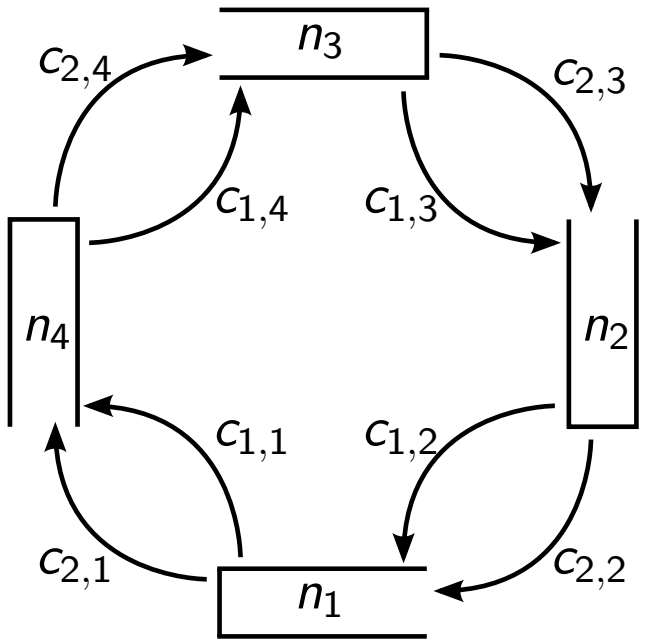
A routing algorithm for a interconnect is deadlock-free, iff there are no cycles in the corresponding channel dependency graph.

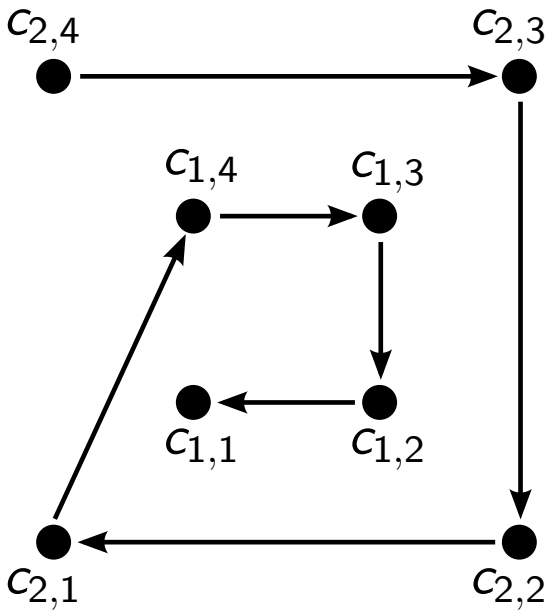
Virtual channels and channel dependency graph



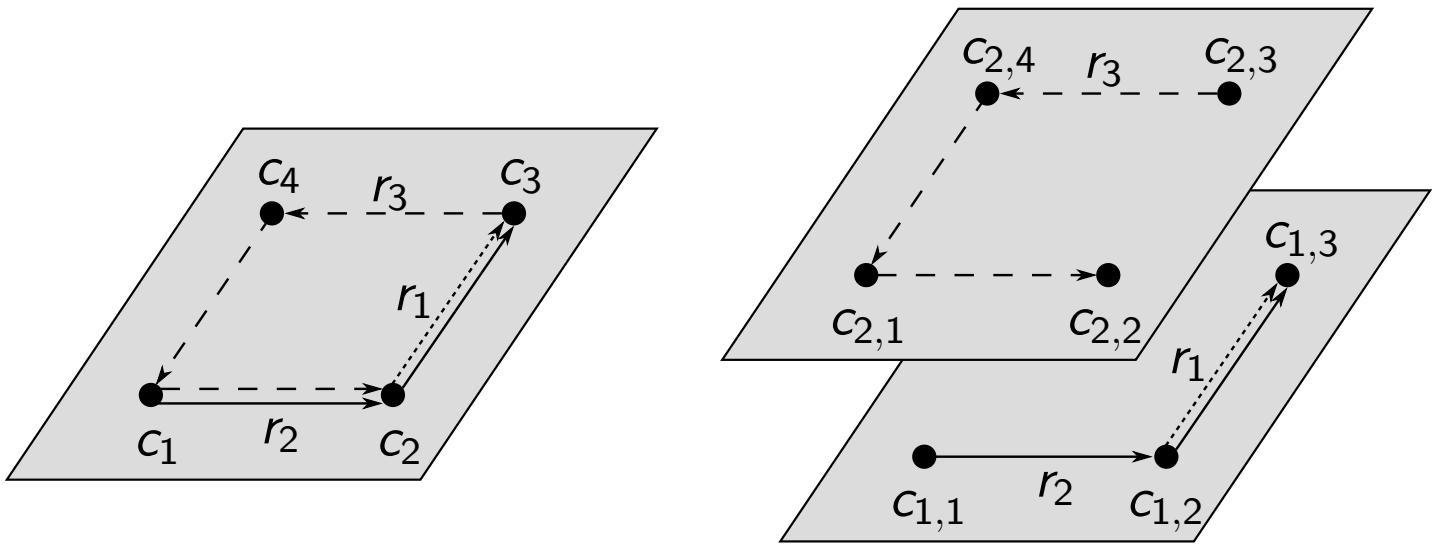


Virtual channels and channel dependency graph





Virtual channels and channel dependency graph



Outline

Deadlock-free SSSP routing algorithm

- DFSSSP routing algorithm
- How to identify the "weakest" edge?

DFSSSP routing algorithm

Algorithm 1 DFSSSP routing algorithm

```
/* Phase 1: Identification of all network components */
Scan(...)
/* Phase 2: Calculate paths */
SSSP(...)
/* Phase 3: Assign paths to virtual layers */
RemoveDeadlocks(...)
/* Phase 4: Balancing of all virtual layers */
Balancing(...)
```

DFSSSP routing algorithm

Algorithm 2 Remove deadlocks from the channel dependency graph (Phase 3)

Input: Linear forwarding tables
Output: Assign each path to a virtual layer

```
/* Initialization of layer 1 */
for all PortPairs(source, destination) do
    Update CDG[1] with the source-destination path
end for
/* Search cycles in the channel dependency graph */
for i = 1, ..., max − 1 do
    repeat
        Search for cycle in CDG[i]
        Identify "weakest" edge of the cycle
        Move port pairs or paths on this edge to CDG[i + 1]
    until no cycle found in CDG[i]
end for
Search for cycle in CDG[max]
```

How to identify the "weakest" edge?

... to minimize the number of needed virtual layers.

Abstract formulation: "acyclic path partitioning" problem (APP)

- Split a set of paths into subsets which produces acyclic channel dependency graphs.
- Shown to be NP-complete
- Proof based on an polynomial transformation from graph k-colorability problem into APP

APP is NP-complete $\Rightarrow$ use heuristic to identify the "weakest" edge

- Edge with most paths in the cycle
- Random edge of the cycle
- **Edge with smallest number of paths**

Outline

Simulations and measurements

- Simulations with IBSim
  - Real existing topologies
- Measurements on a real system – Deimos
  - PC-Farm Deimos
  - Netgauge
  - BenchIT
  - NAS parallel benchmarks

Real existing topologies

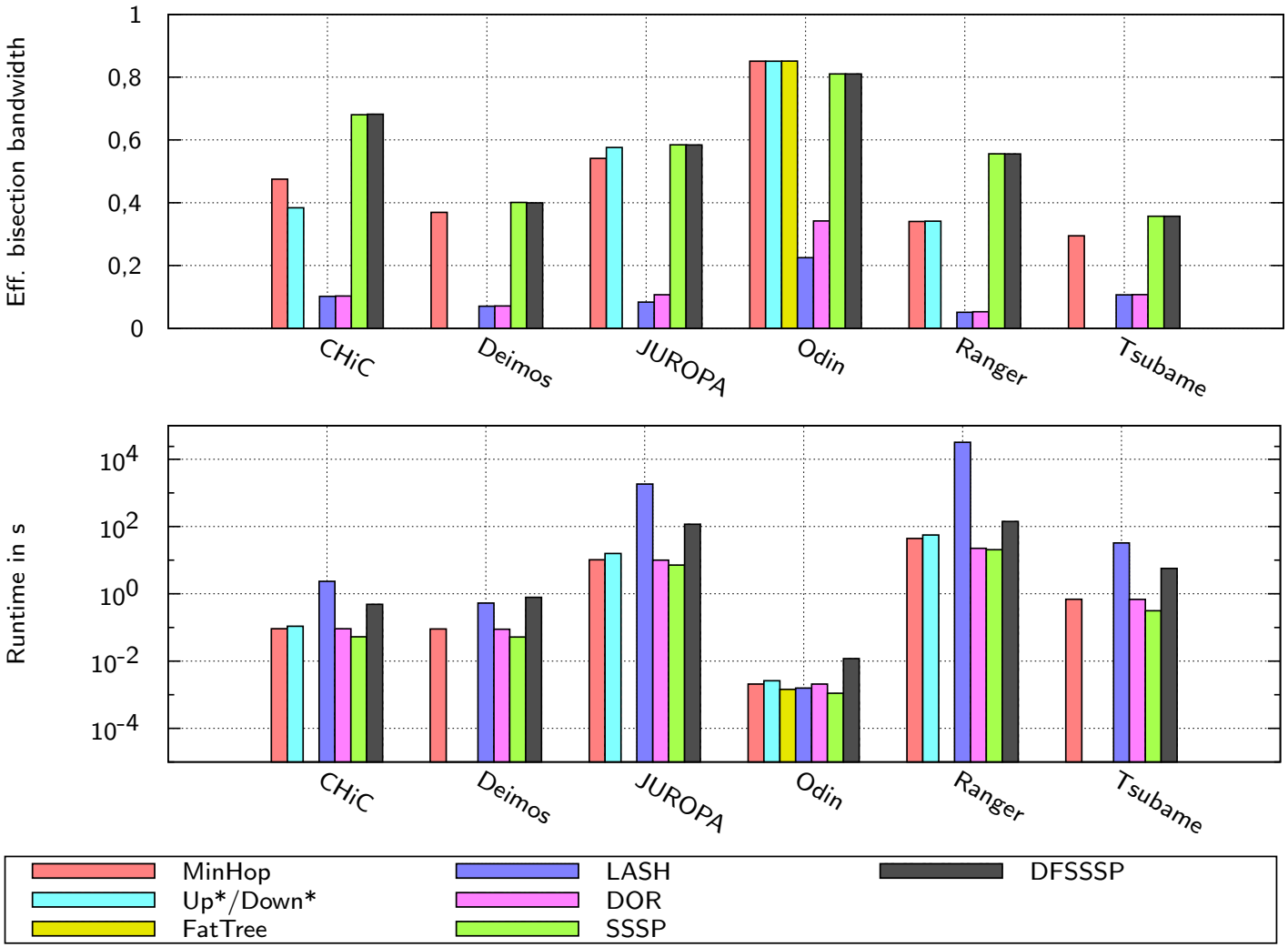


Figure: Simulation with IBSim and ORCS [Schneider et al., 2009]

Measurements on a real system – Deimos

HPC-system operated by ZIH

- Linux Networx PC-Farm (13.9 TFlop/s)
- 726 compute nodes connected by 108 IB switches
- 2,6 GHz AMD Opteron X85 dual core
- 1, 2 or 4 processors per node
- 2 GByte RAM per core

Measurements on a real system – Deimos

Measurement environment and used benchmarks

- Exclusive access
- One MPI process per node (for measurements with ≤ 512 cores)
- Same number of MPI processes $\Longrightarrow$ same compute nodes used
- Eff. bisection bandwidth with Netgauge [Hoefler et al., 2007]
- Runtime and bandwidths of pure MPI communication measured with micro-benchmarks (BenchIT [Juckeland et al., 2004])
- Performance gain for application benchmarks of NASA (NAS Parallel Benchmarks [Bailey et al., 1995])

Netgauge

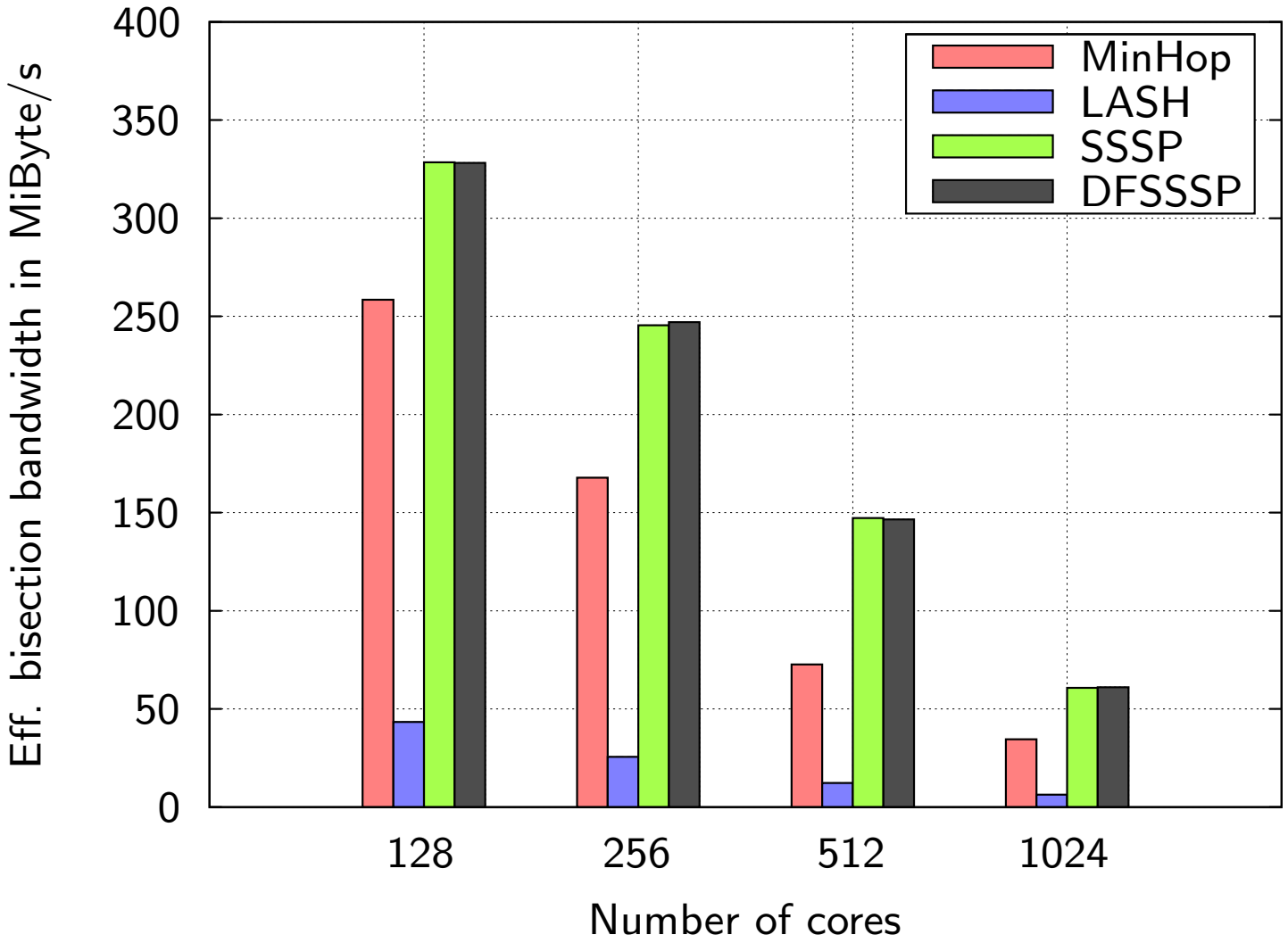


Figure: Approximation with 1000 random bisections

BenchIT

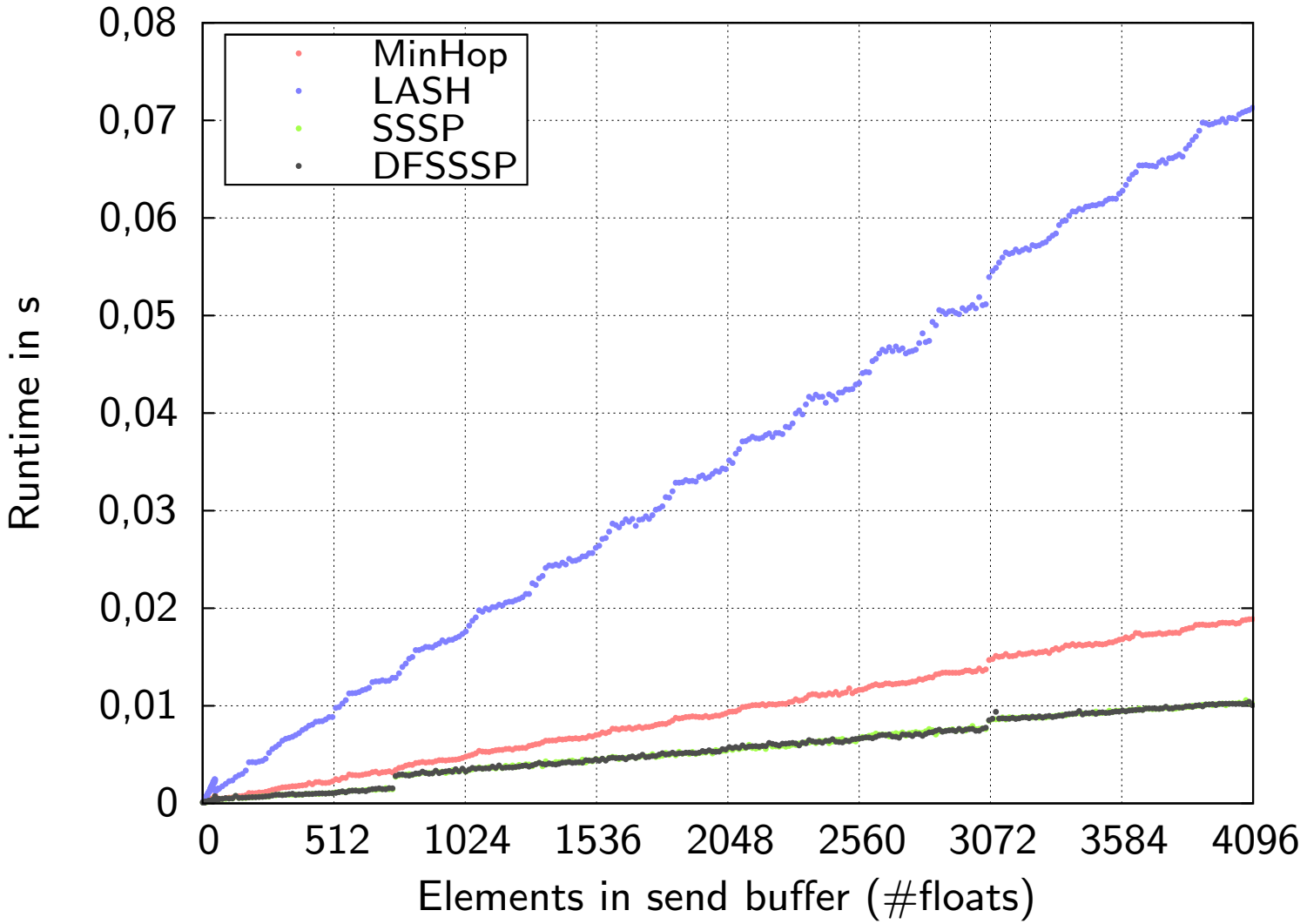


Figure: Collective *N*-to-*N* MPI operation on 128 nodes

NAS parallel benchmarks

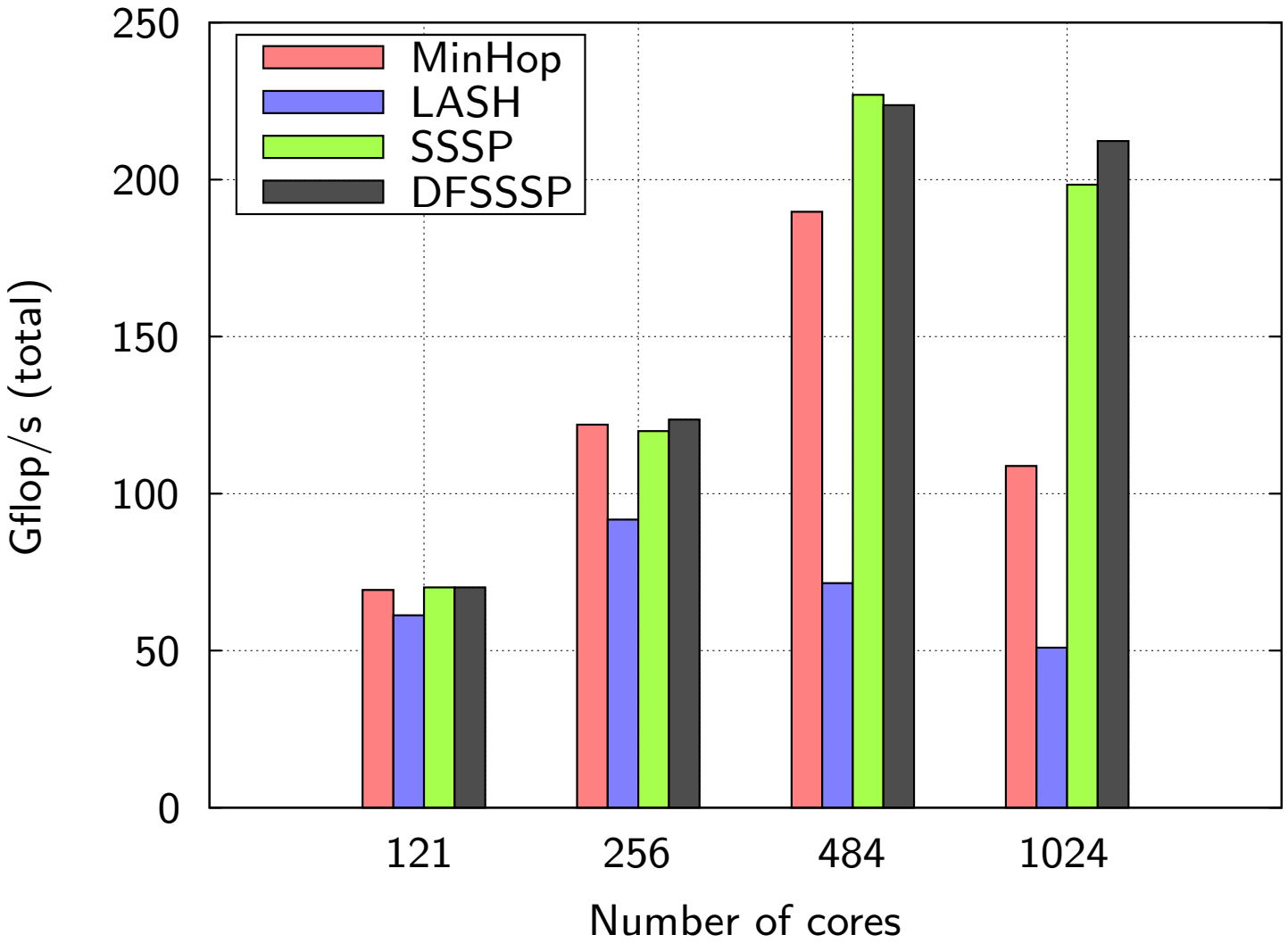


Figure: BT, class C – equation system solver

Conclusion

- Developed deadlock-free SSSP routing for arbitrary network topologies
- DF-/SSSP routing algorithm integrated in OpenSM
  - Patch available: http://unixer.de/research/dfsssp/
- Not limited to InfiniBand; usable for all interconnects which support virtual channels
- Modeled the "acyclic path partition" problem; proofed NP-completeness
- Doubled the eff. bisection bandwidth of Deimos for 512 nodes
- Performance gain (communication bound) for application benchmarks up to 95%

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Backup – Complexity analysis

Time complexity

The time complexity for the DFSSSP routing algorithm is

$$O(\,|N|^2 \cdot (\log|N| + \nabla) + |N| \cdot |C| + \nabla \cdot (|C| + |E|)\,)$$

Memory complexity

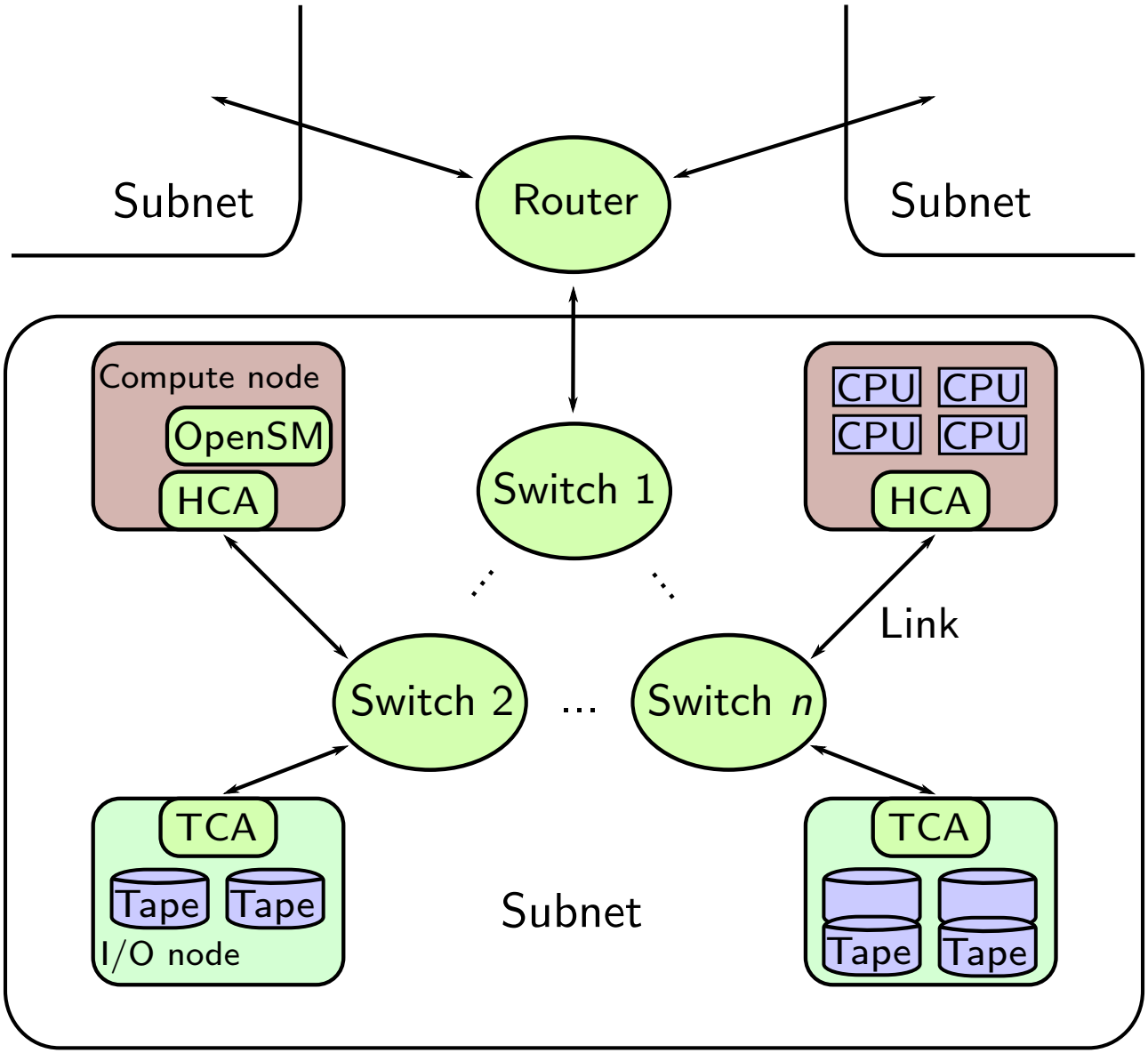
The memory complexity for DFSSSP is

$$O(\,\nabla \cdot d(I) \cdot |N|^2 + \nabla \cdot (|C| + |E|) + |N|\,)$$

Variables:

- N – nodes in the network
- C – channels/links
- E – edges in the channel dependency graph
- ∇ – minimal number of needed virtual layer
- $d(I)$ – diameter of network I

Backup – InfiniBand subnet



Backup – Metrics for interconnects

- Significant properties
  - Low latency
  - High bandwidth for package transfer
  - Absence of deadlocks in the routing
- Established metrics to rate the interconnect
  - Latency
  - Bandwidth
  - Bisection bandwidth
  - Effective bandwidth
  - Effective bisection bandwidth

Backup – SSSP algorithm

Algorithm 3 SSSP routing algorithm (Phase 2)

Input: Context of DFSSSP routing
Output: Linear Forwarding Tabellen
  / N-to-N, multi-graph Dijkstra algorithm */*
  for all Port $\in$ Subnet **do**
    Dijkstra(...) for this port as source
    Update all linear forwarding tables
    Increase edge wights
  end for