Flow control: a prerequisite for Ethernet scaling

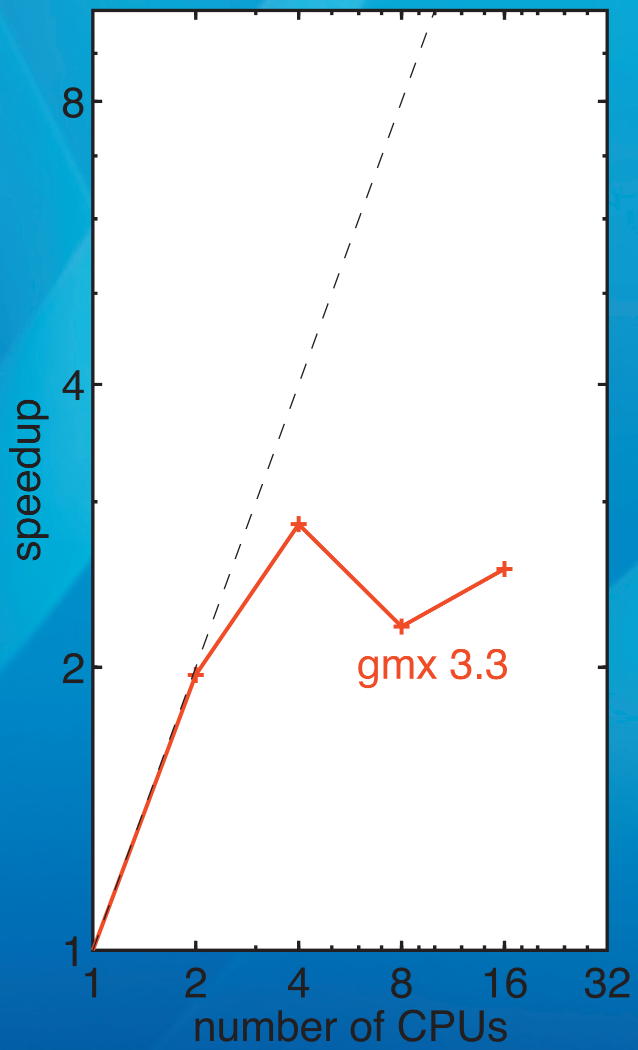
Carsten Kutzner, David van der Spoel, Erik Lindahl,
Martin Fechner, Bert L. de Groot, Helmut Grubmüller

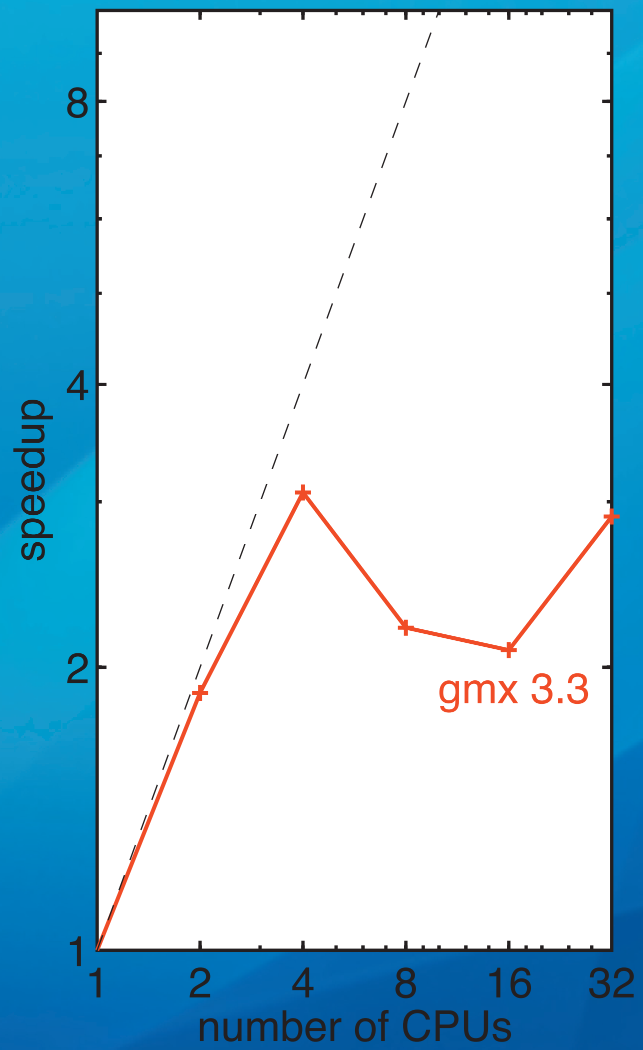
- GROMACS and network congestion
- a network stress-test with MPI_Alltoall
- IEEE 802.3x = ???
- high-level flow control / ordered communication

GROMACS 3.3 GigE speedup

Aquaporin-1 benchmark (80k atoms)

1 CPU/node



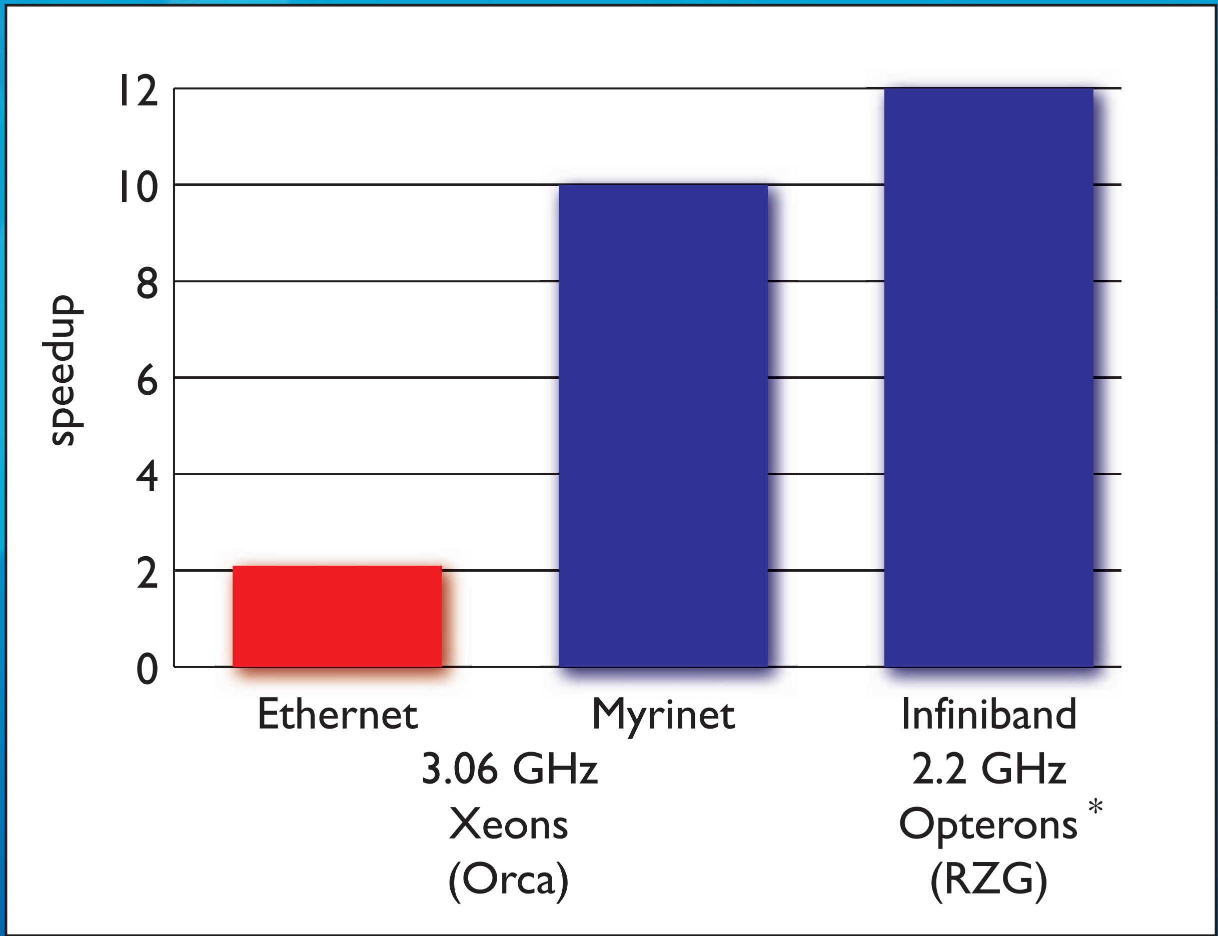


2 CPUs/node

Orca,
Coral,
Slomo,
...

GROMACS 3.3 GigE speedup

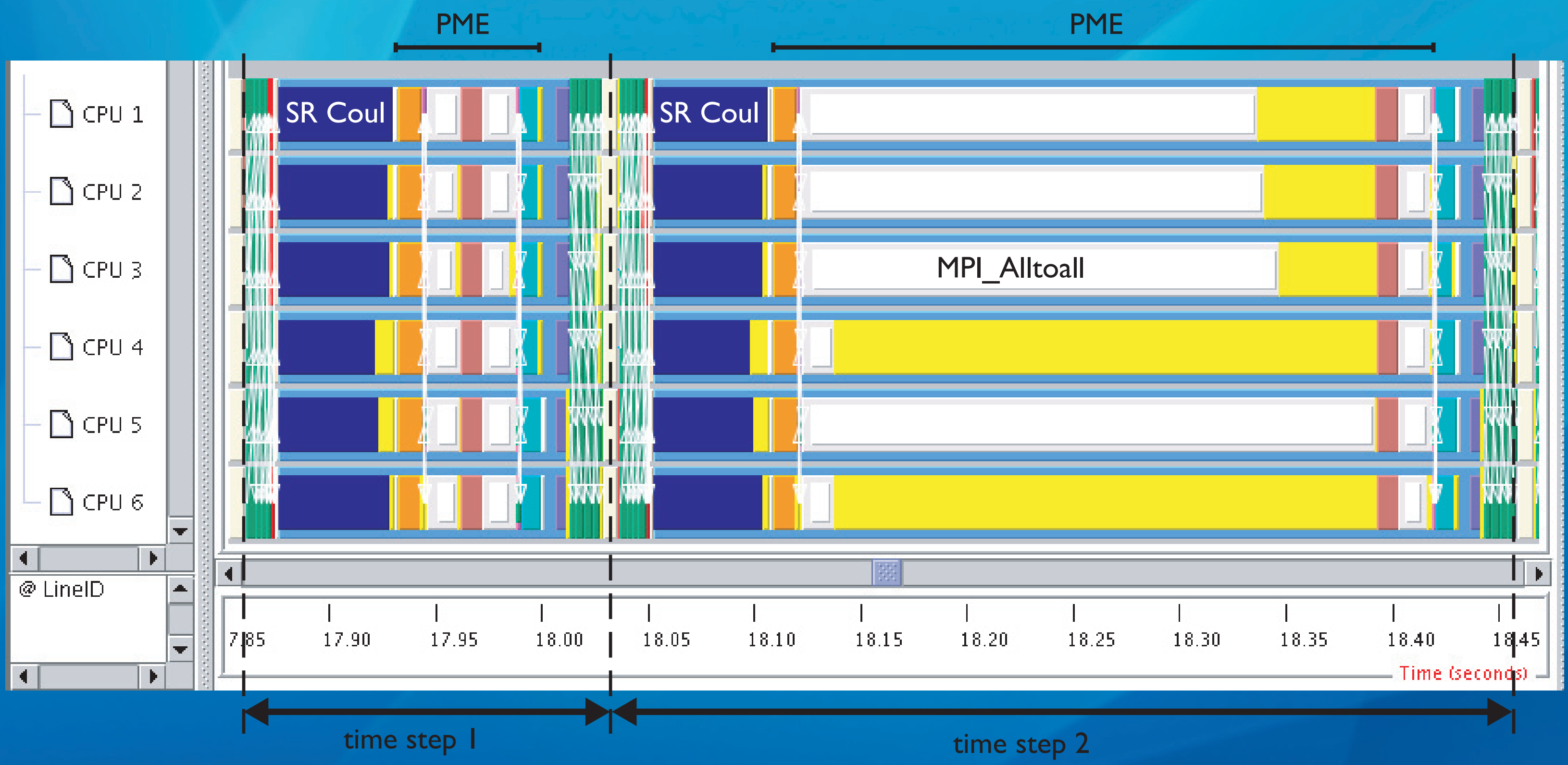
compared to other interconnects (8x2 CPUs)



* benchmark done by Renate Dohmen, RZG

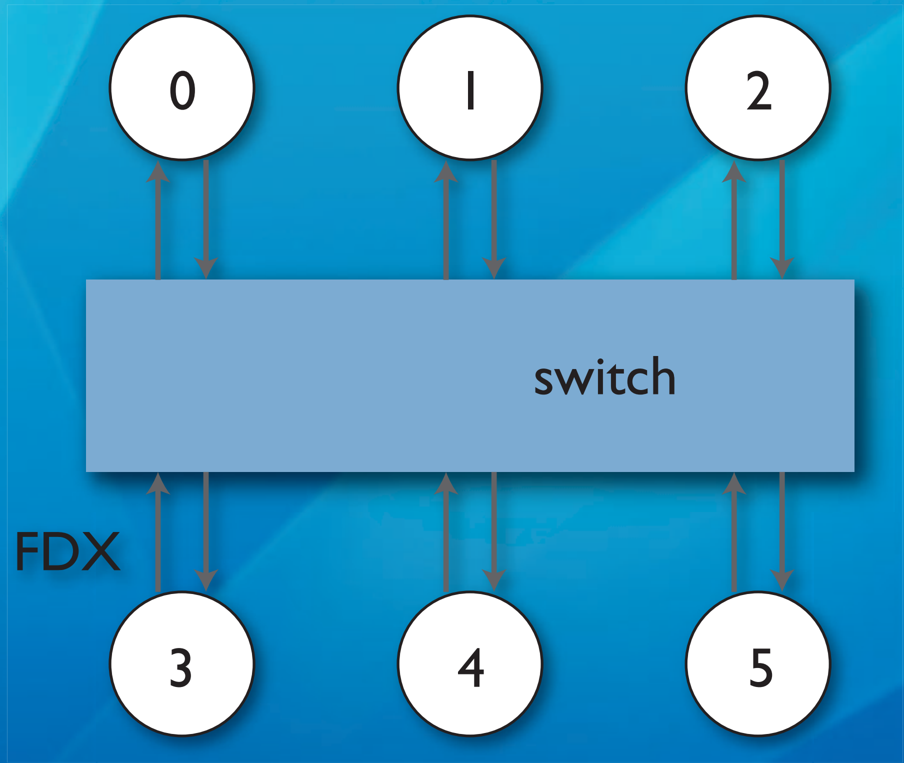
Where is the problem?

- delays of 0.25s in comm-intensive program parts (MPI_Alltoall, MPI_Allreduce, MPI_Bcast, consecutive MPI_Sendrecvs)



Network congestion

- If more packets arrive than a receiver can process, packets are dropped (and later retransmitted)



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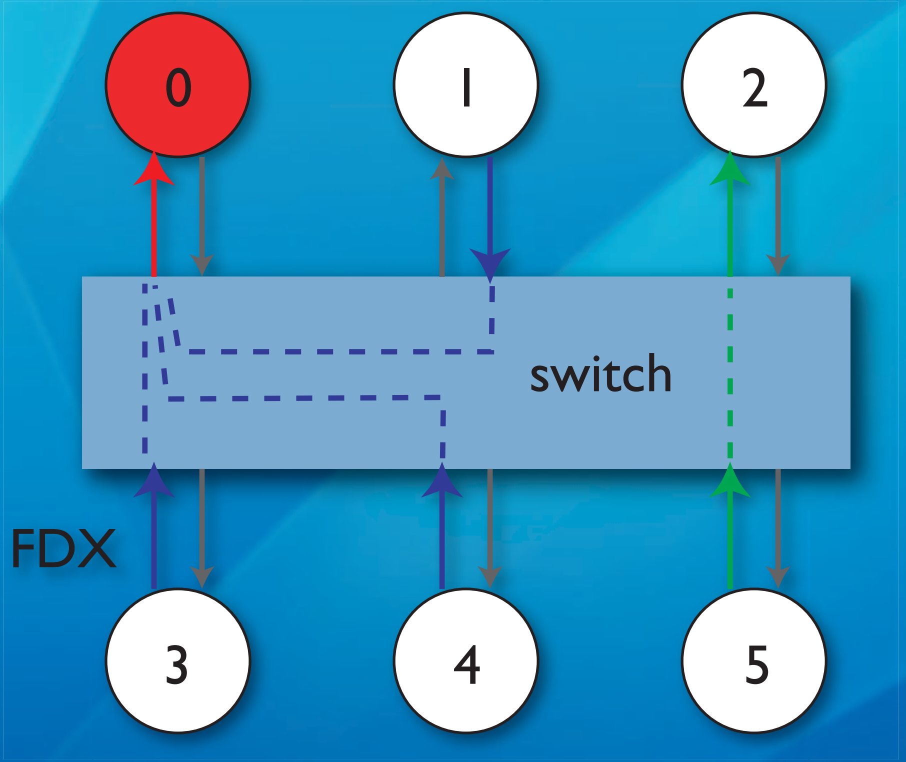
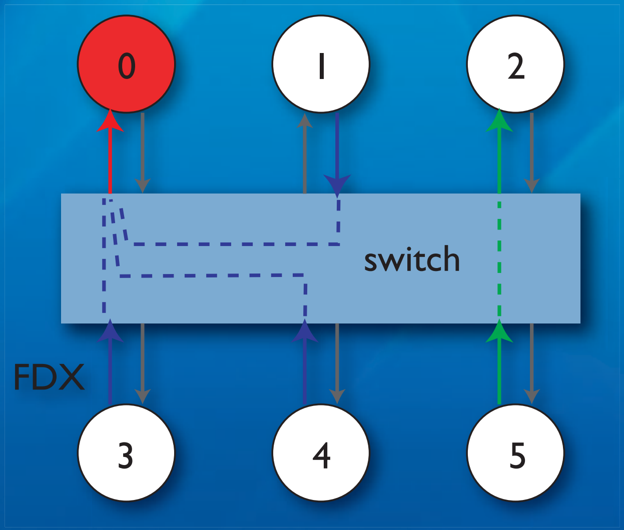


common MPI_Alltoall implementations

order of message transfers is random!

LAM:

```
/* Initiate all send/recv to/from others. */
for (i loops over processes)
{
  MPI_Recv_init(from i ...);
  MPI_Send_init(to i ...);
}
/* Start all the requests. */
MPI_Startall(...);
/* Wait for them all. */
MPI_Waitall(...);
```

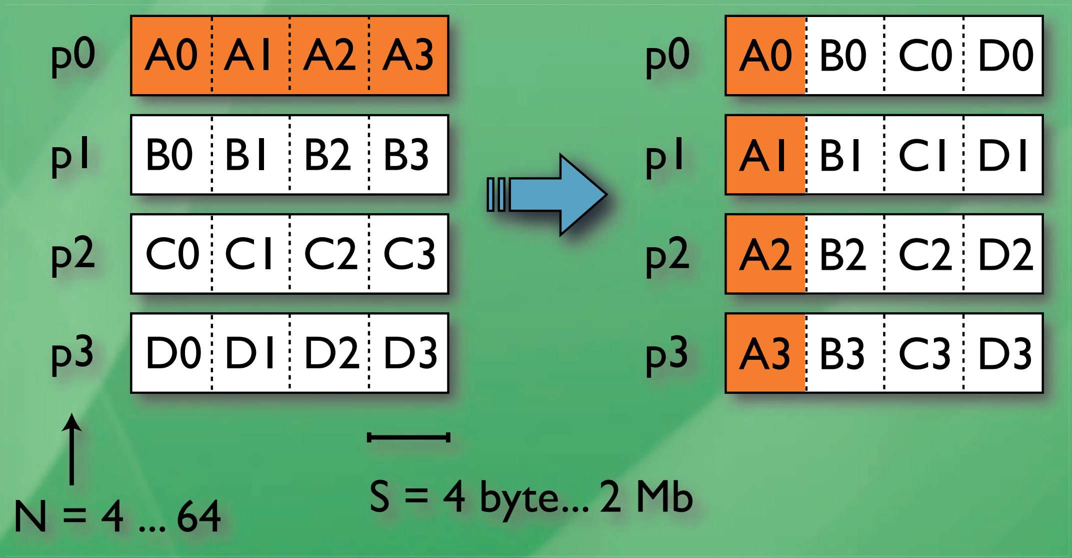


MPICH:

```
/* do the communication -- post *all* sends and re-
ceives: */
for ( i=0; i<size; i++ )
{
/* Performance fix sent in by Duncan Grove
<duncan@cs.adelaide.edu.au>. Instead of posting
irecvs and isends from rank=0 to size-1, scatter the
destinations so that messages don't all go to rank 0
first. Thanks Duncan! */
  dest = (rank+i) % size;
  MPI_Irecv(from dest)
}
for ( i=0; i<size; i++ )
{
  dest = (rank+i) % size;
  MPI_Isend(to dest)
}
/* ... then wait for *all* of them to finish: */
MPI_Waitall(...);
```

A network stress-test with MPI_Alltoall

- MPI_Alltoall, a parallel matrix transpose

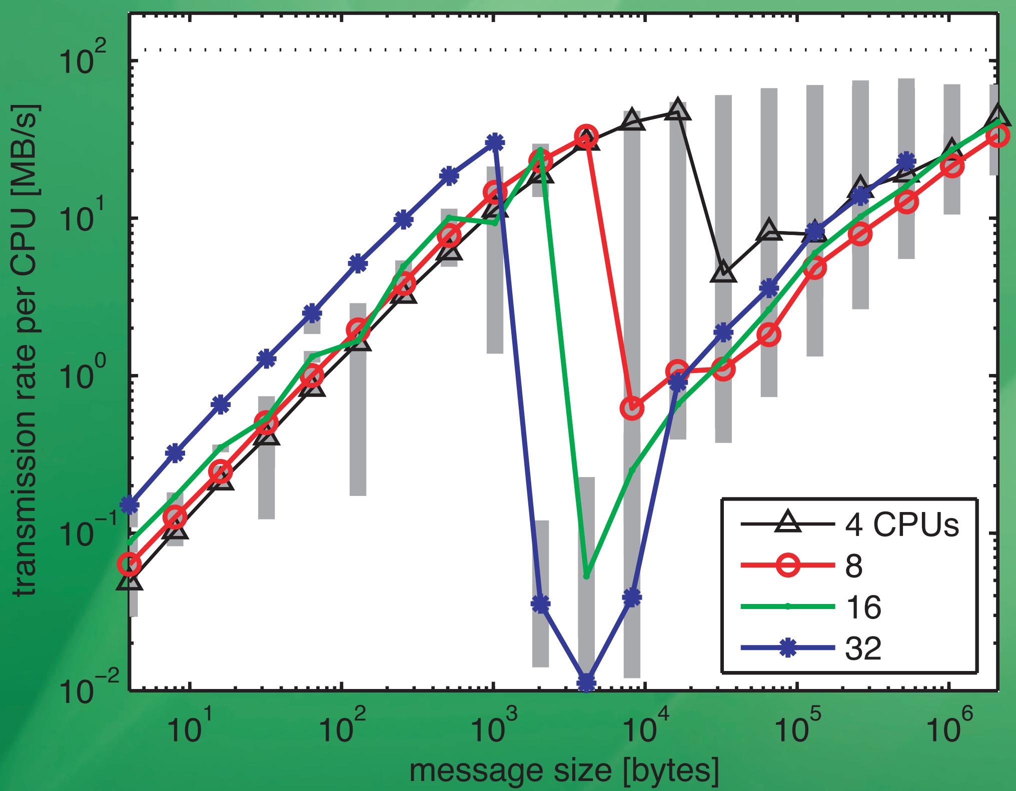


- each of N procs sends N-1 messages of size S
- N*(N-1) messages transferred in time Δt
- transmission rate T per proc: $T = (N-1)S / \Delta t$

LAM MPI_Alltoall

T averaged over 25 calls (bars: min/max)

I CPU/node



LAM MPI_Alltoall

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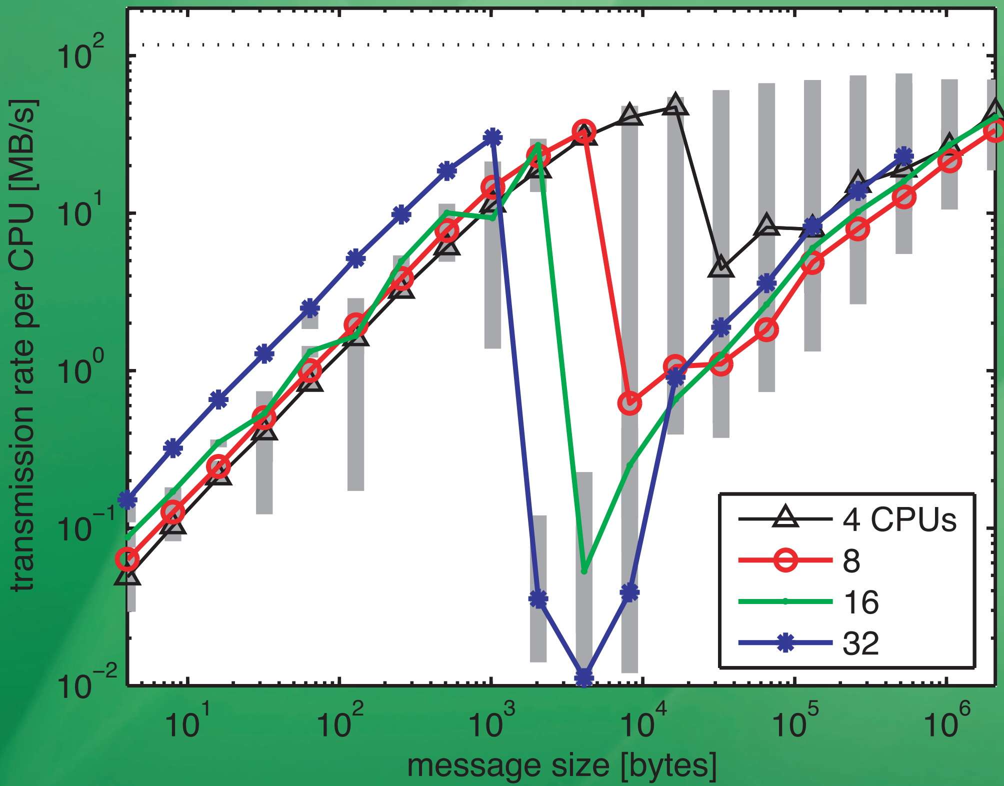
1 CPU/node



data transferred within the FFTW all-to-all:

Aquaporin-1, PME grid 90x88x80=633600 floats

CPUs	byte to each CPU
2	649440
4	173184
6	73800
8	43296
16	11808
32	2952

Guanylin, PME grid 30x30x21=18900 floats

CPUs	byte to each CPU
2	19800
4	5632
6	2200
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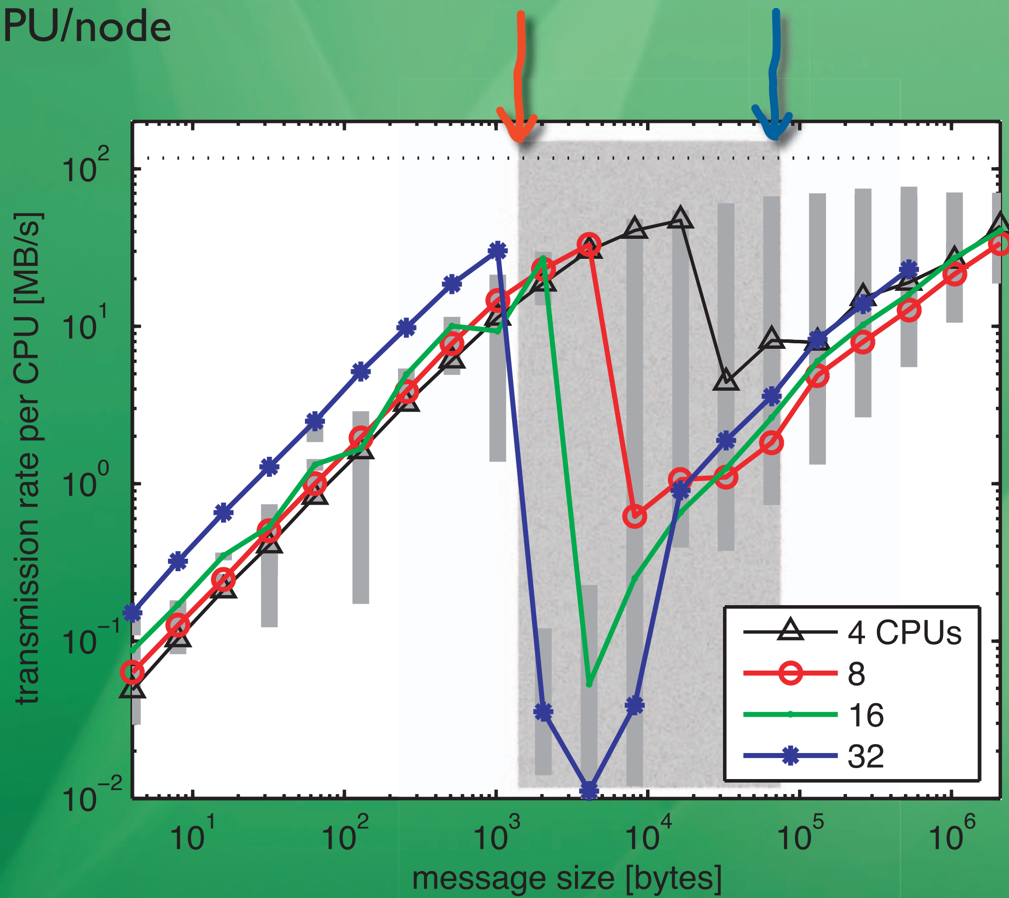

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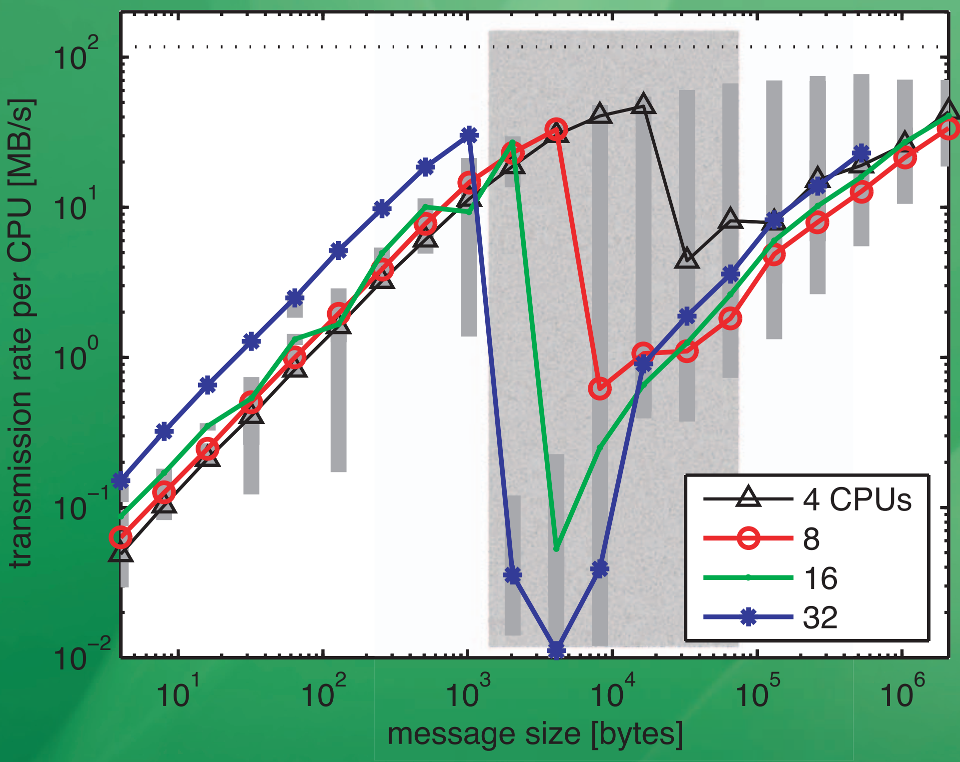
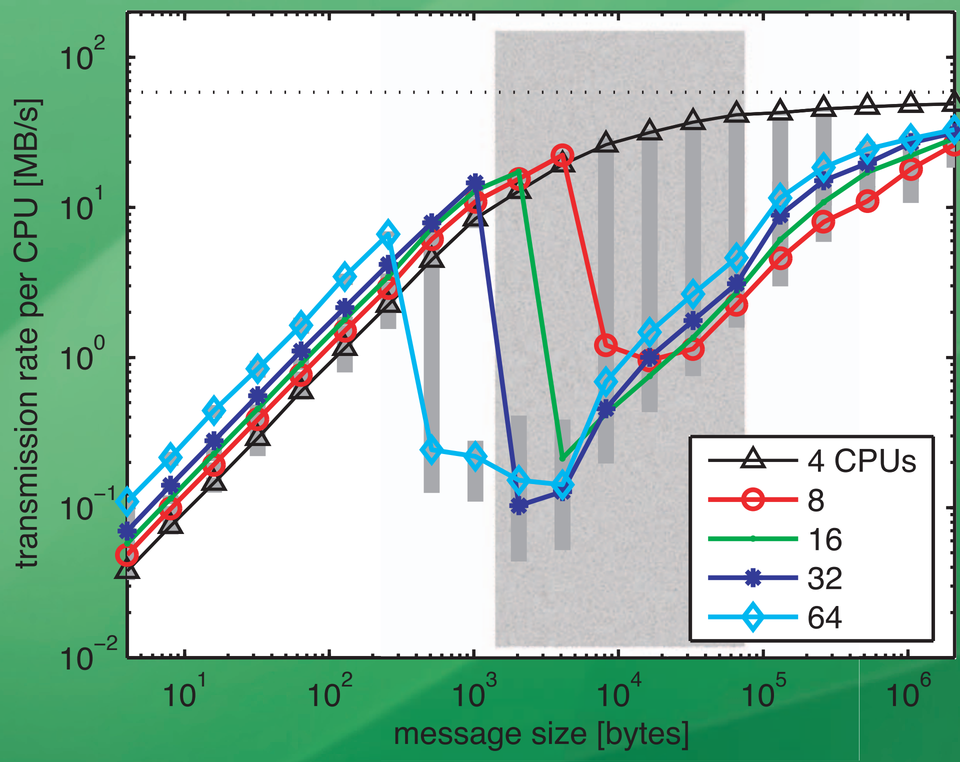
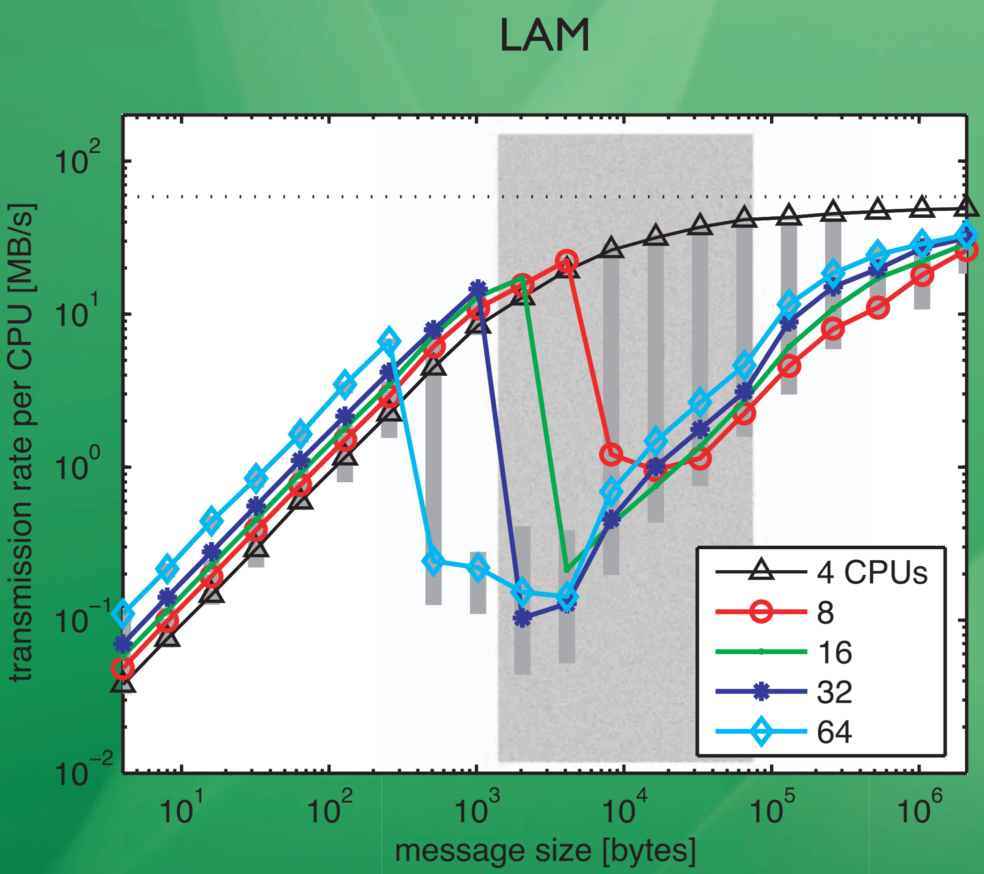
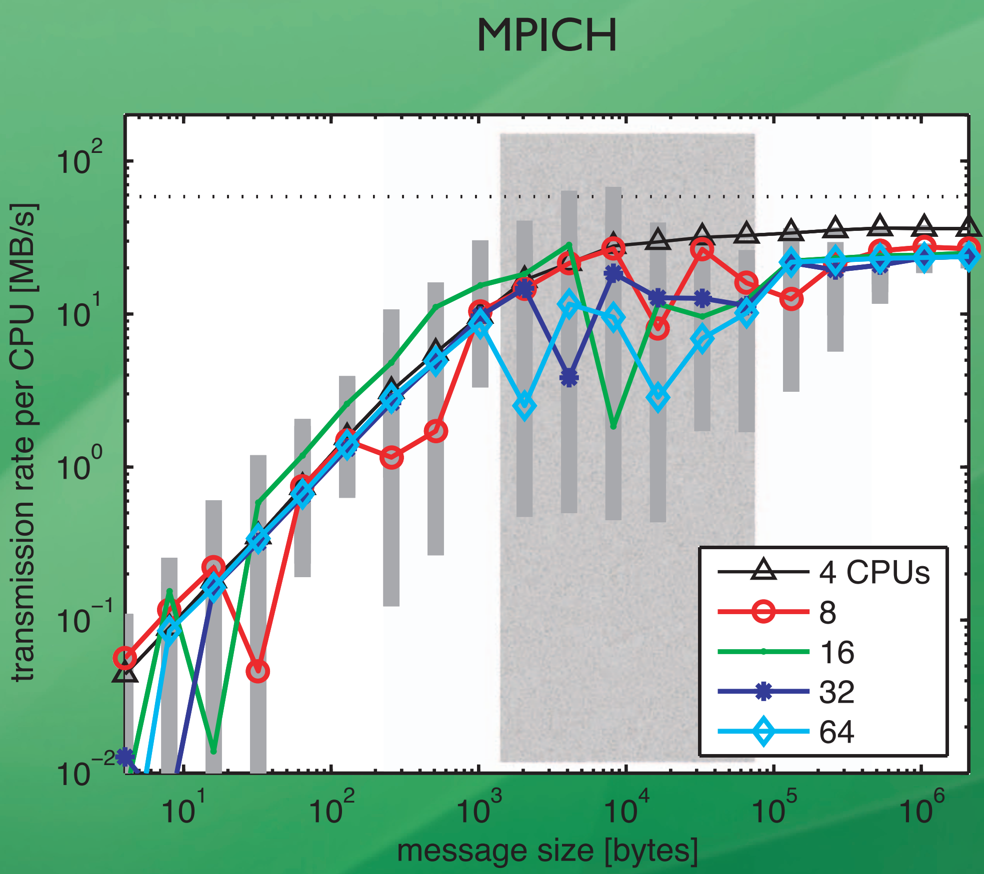


2 CPUs/node



LAM vs. MPICH (2 CPUs/node)





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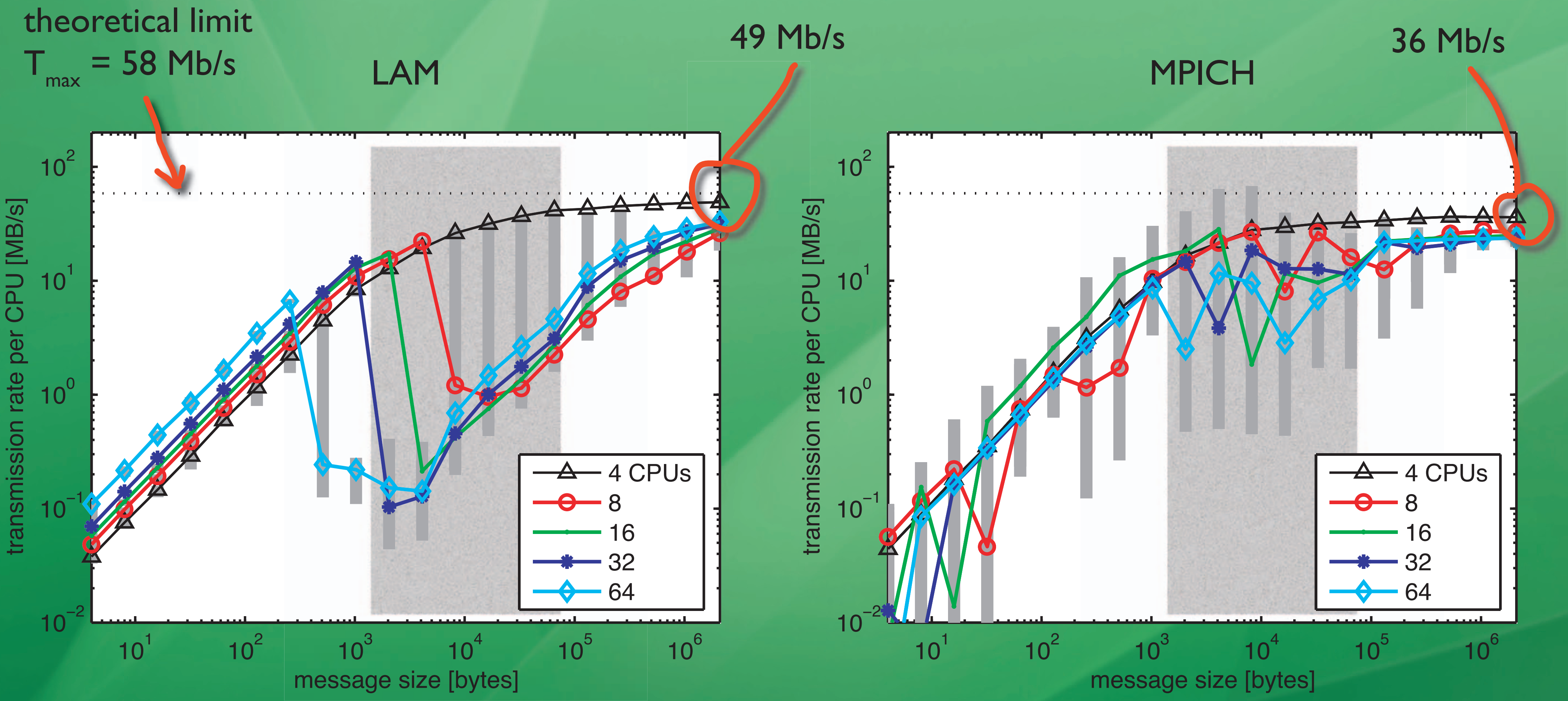
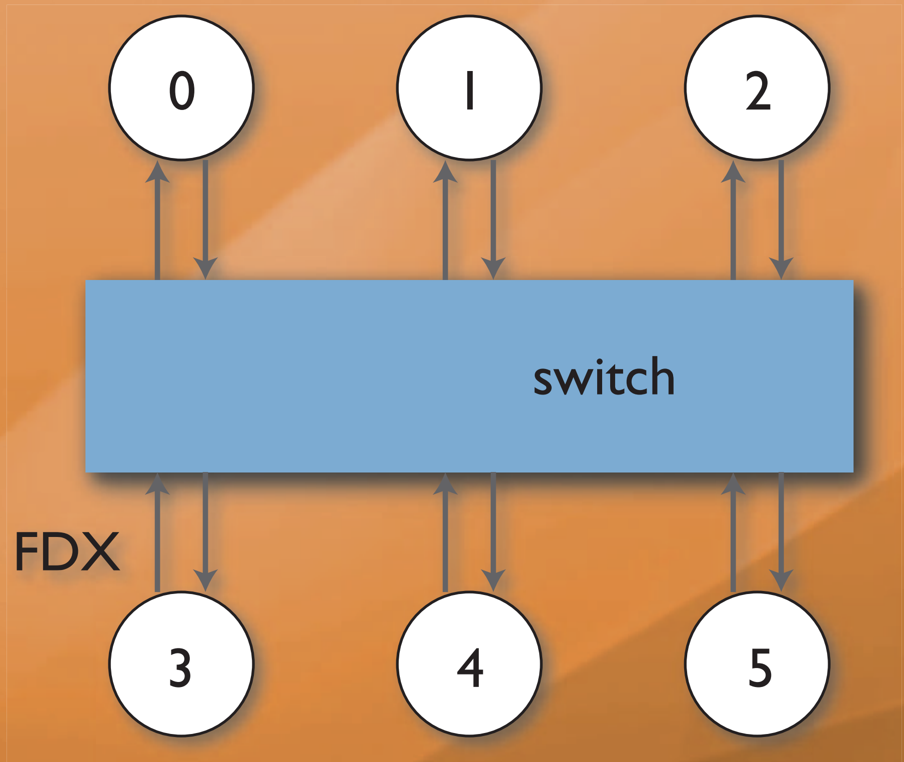


IEEE 802.3x flow control

- IEEE 802.3x[1] defines low level flow control mechanism to prevent network congestion
- flow of ... messages/data/TCP packets
- receivers may send PAUSE frames to tell source to stop sending
- reduce packet loss!



1 IEEE, 2000. Information technology–Telecommunications and information exchange between systems–Local and metropolitan area networks–Specific requirements–Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications. IEEE 802.3, New York, Annex 31B: MAC control PAUSE operation.

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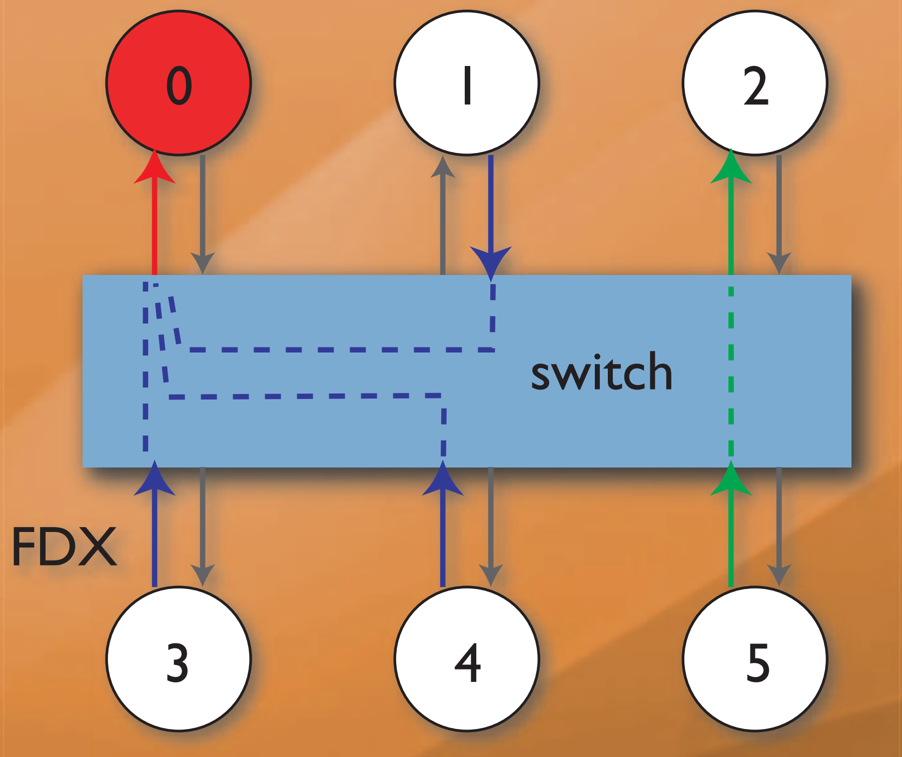

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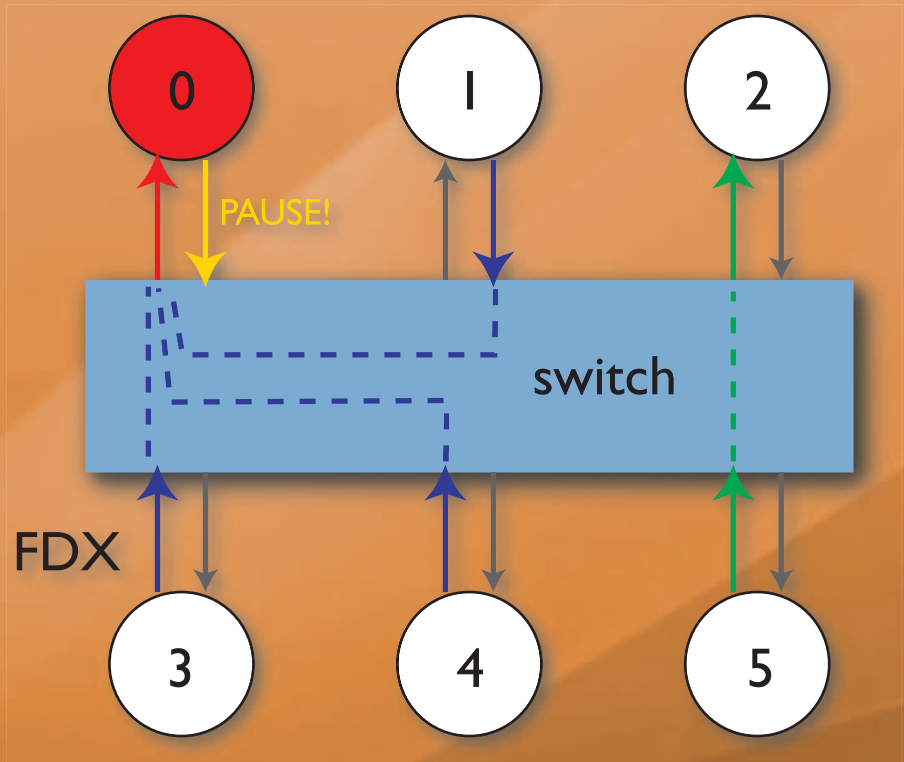

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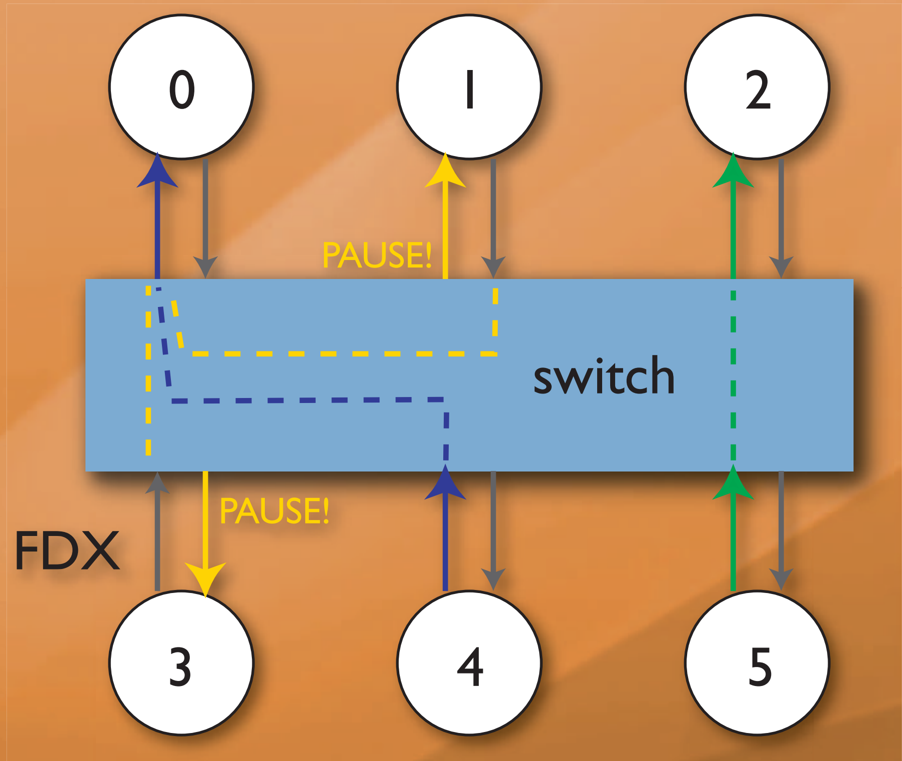

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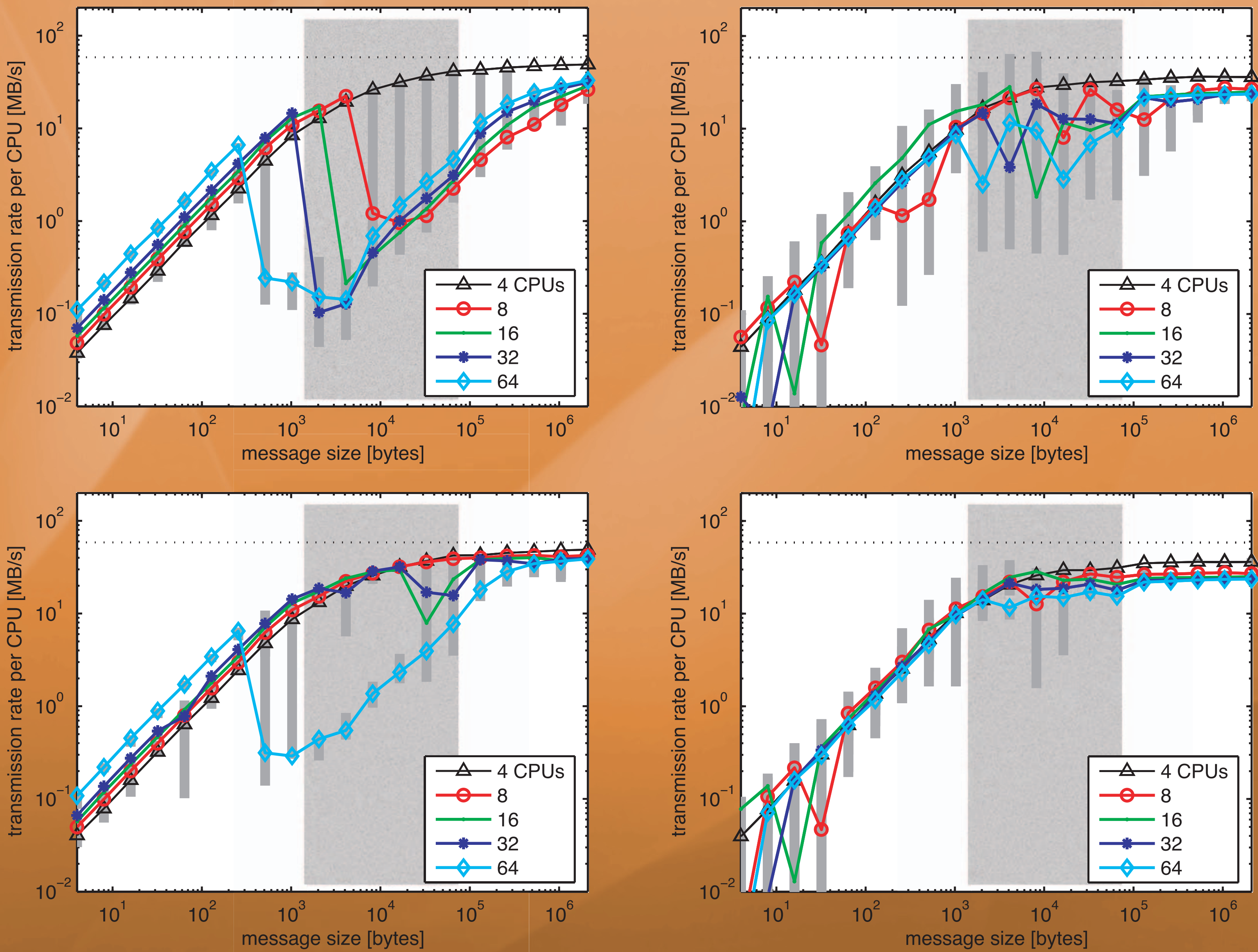
MPI_Alltoall performance (2 CPUs/node)

LAM

MPICH

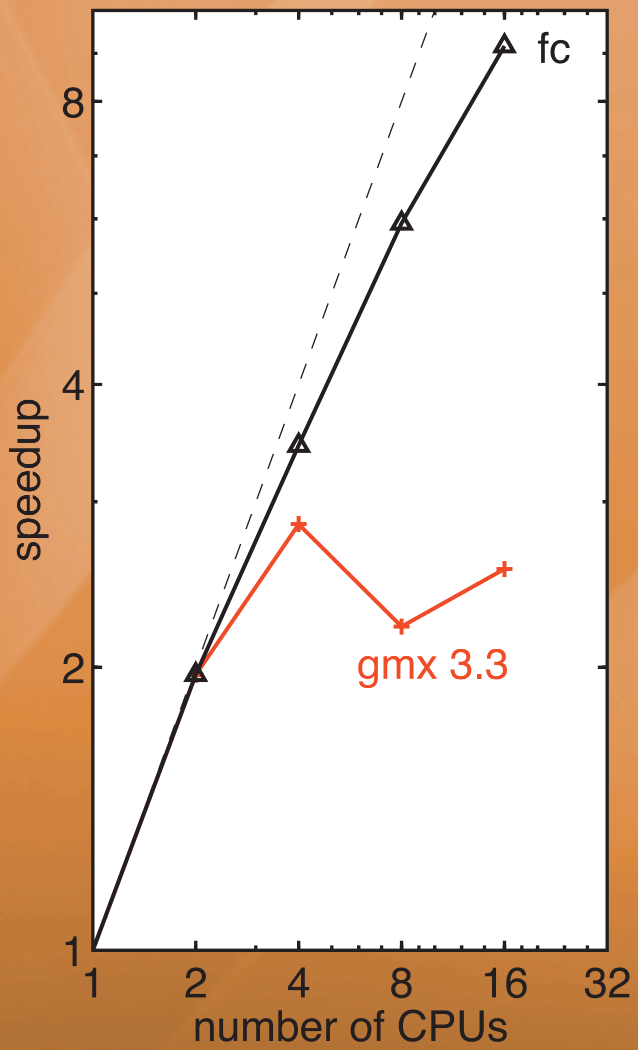
no flow control

with IEEE 802.3x flow control

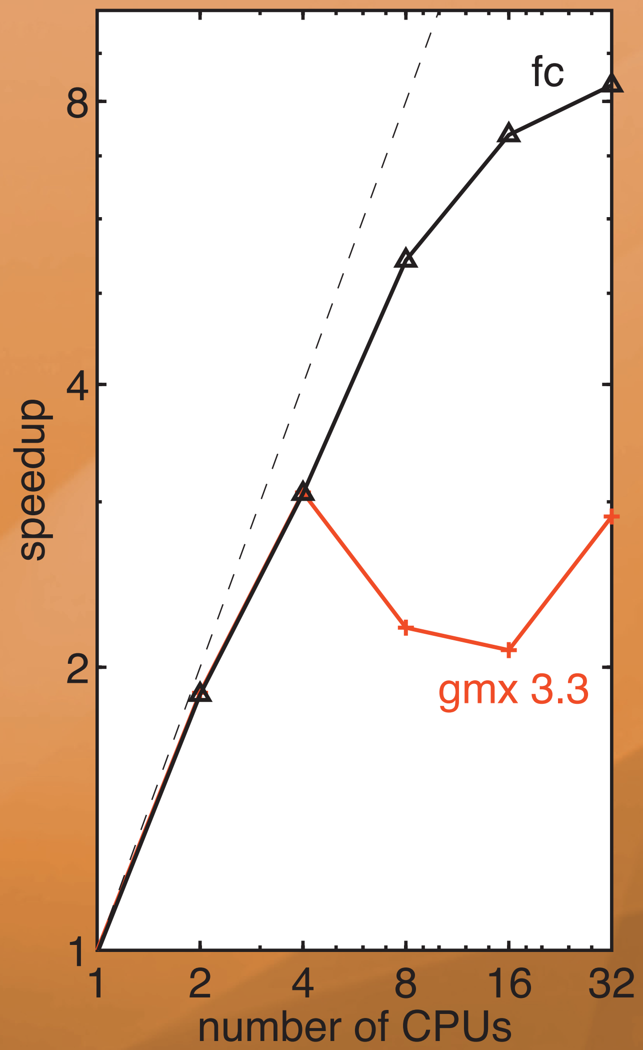


GROMACS 3.3 GigE speedup

1 CPU/node



2 CPUs/node



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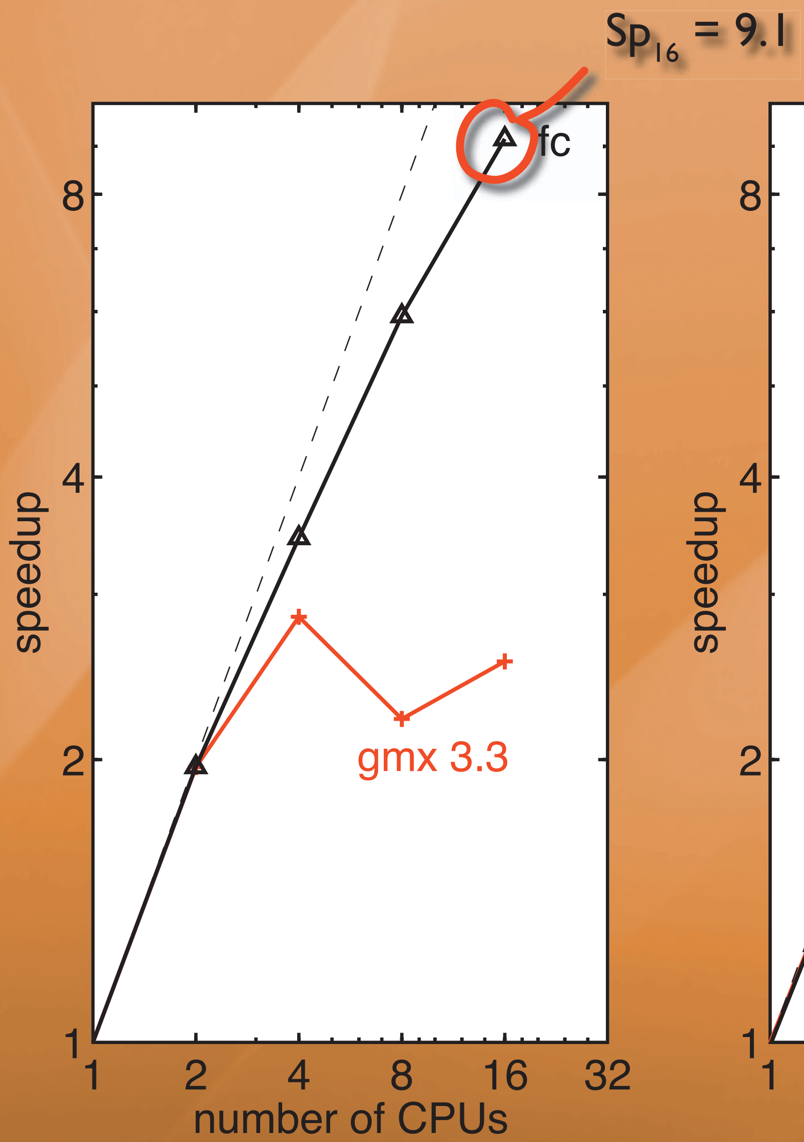
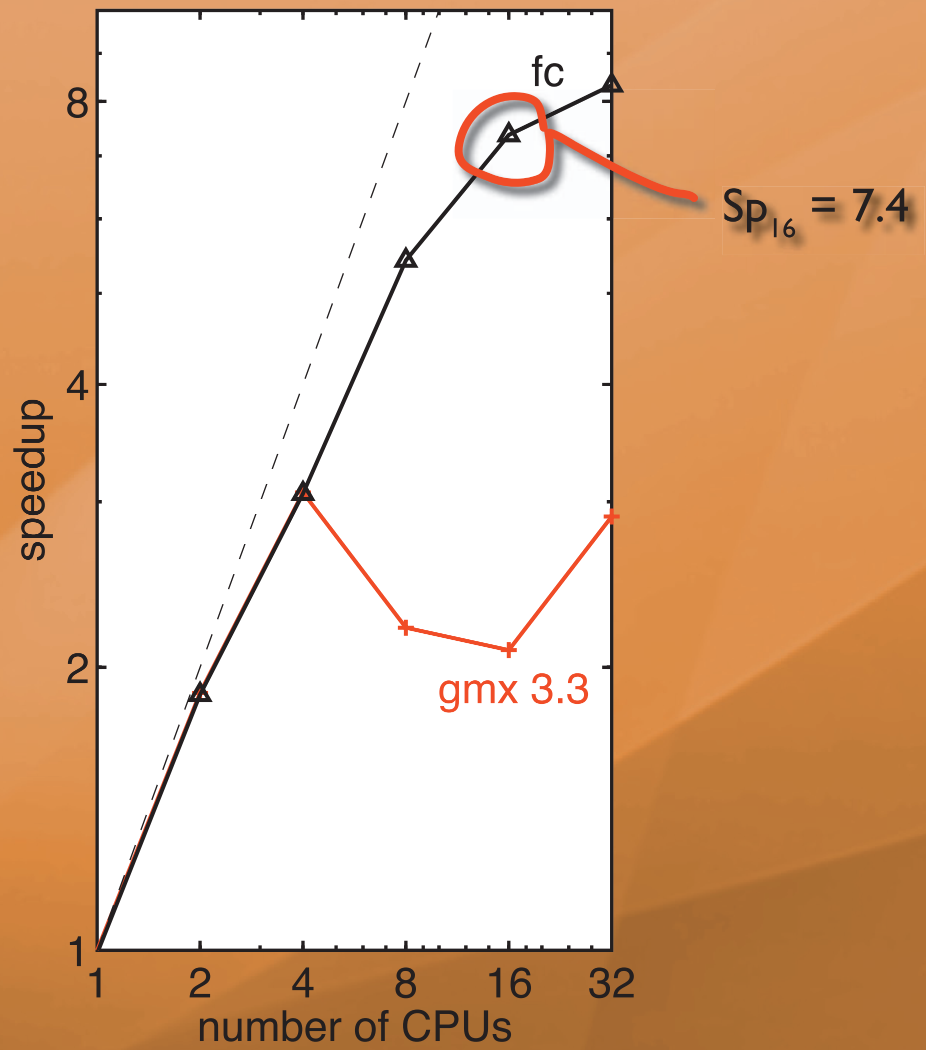
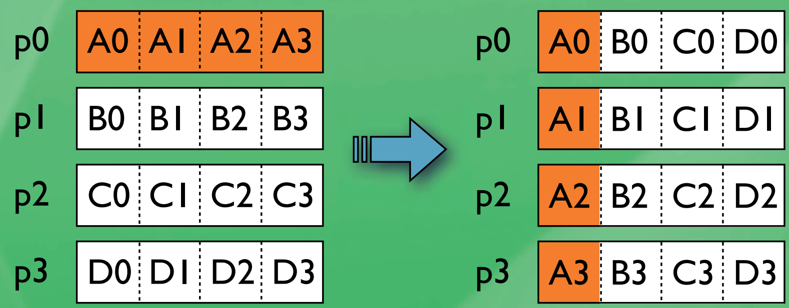




High-level flow control

- low-level flow control does not guarantee good performance for 16+ CPUs

- implement own all-to-all



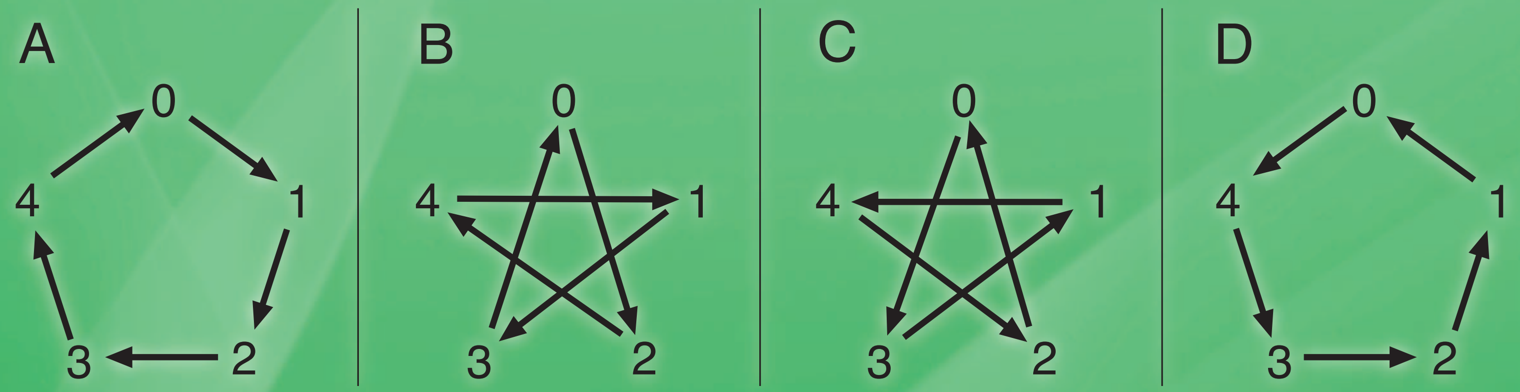
- idea:
  arrange communication in separated phases, each free of congestion

- experimental MPI prototype: CC-MPI[2]

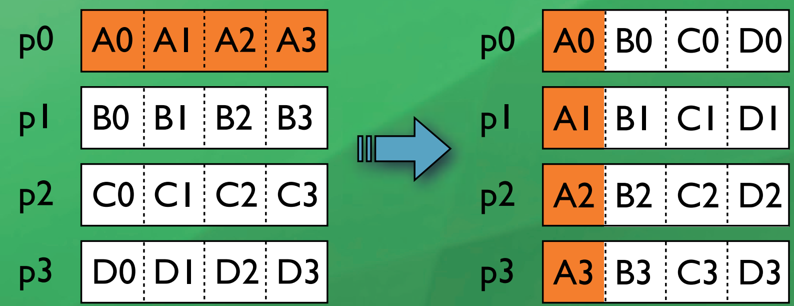
2 Karwande et al., 2005, An MPI prototype for compiled communication on Ethernet switched clusters, J Parallel Distrib Comput 65

High-level flow control

ordered all-to-all for single-CPU nodes



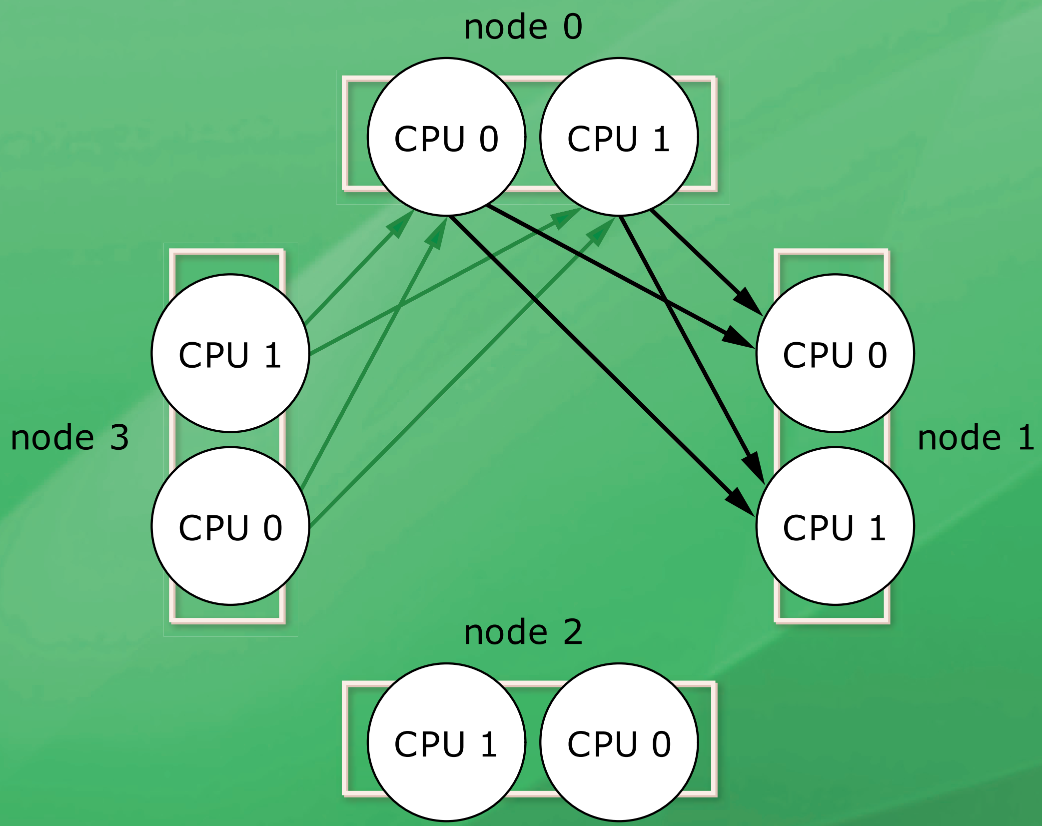

```
for (i=0; i<ncpu; i++)   /* loop over all CPUs */
{
   /* send to destination CPU
      while receiving from source CPU: */
   dest = (cpuid+i) % ncpu;
   source = (ncpu+cpuid-i) % ncpu;
   MPI_Sendrecv(send to dest, recv from source);
   /* separate the communication phases: */
   if (i<ncpu-1)
      MPI_Barrier(comm);
}
```



High-level flow control

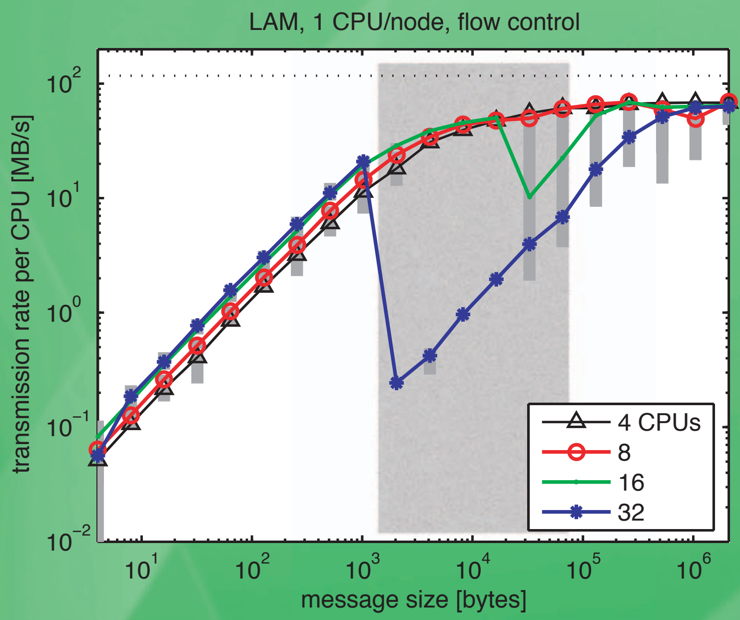
ordered all-to-all for multi-CPU nodes

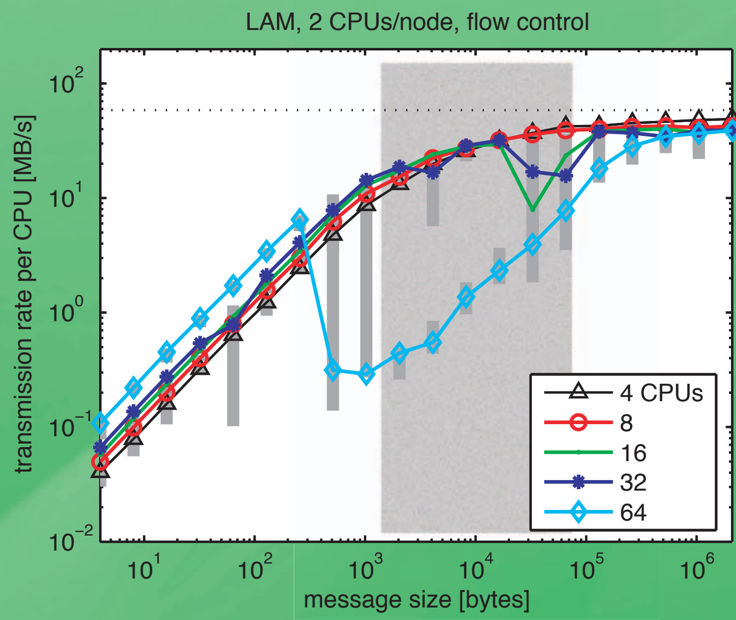
```
/* loop over all nodes */
for (i=0; i<nnodes; i++)
{
   /* send to destination node
      while receiving from source node: */
    destnode = (nodeid+i) % nnodes;
    sourcenode = (nnodes+nodeid-i) % nnodes;
    /* loop over CPUs on a node: */
    for (j=0; j < cpus_per_node; j++)
    {
       /* source and destination CPU: */
       destcpu  =destnode*cpus_per_node + j;
       sourcecpu=sourcenode*cpus_per_node+j;
       MPI_Irecv(from sourcecpu ...);
       MPI_Isend(to destcpu ...);
    }
    /* wait for communication to finish: */
    MPI_Waitall(...);
    MPI_Waitall(...);
    /* separate the communication phases: */
    if (i<nnodes-1)
       MPI_Barrier(...);
}
```



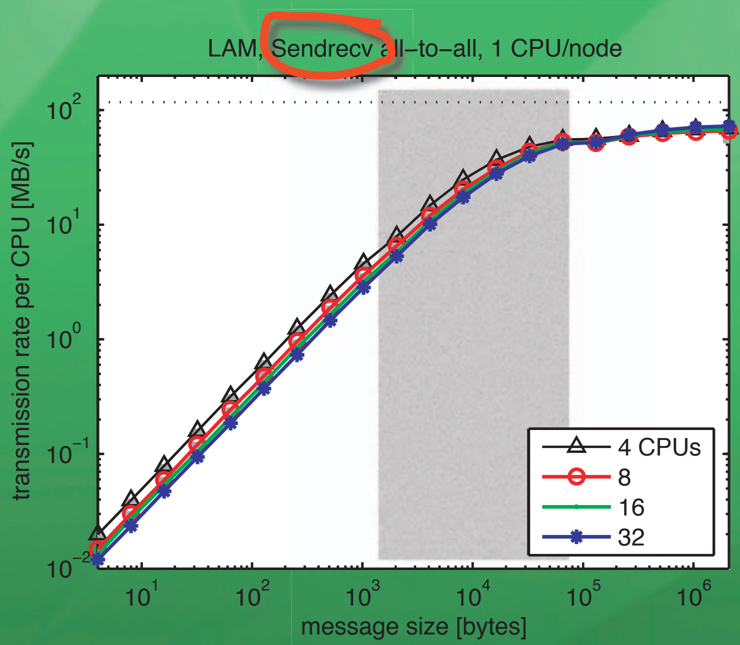
High- vs. low level flow control – LAM

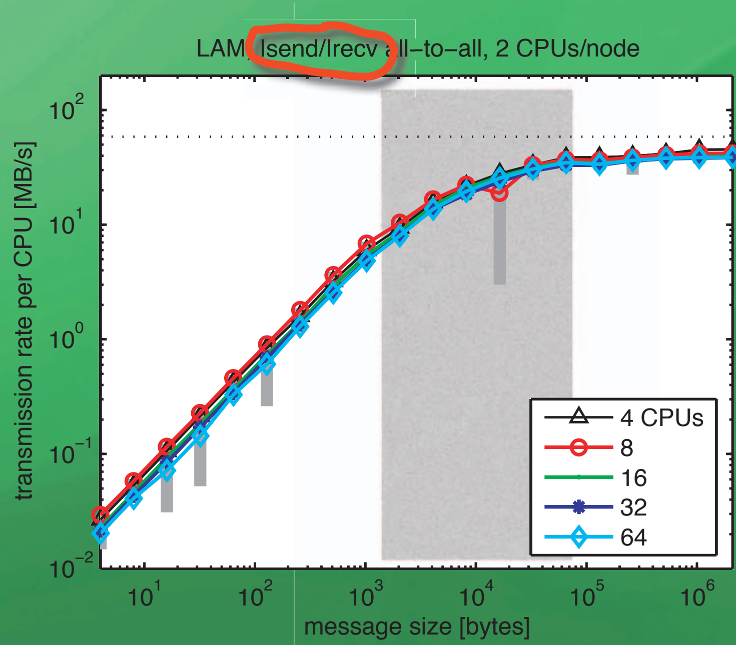
with
IEEE 802.3x
flow control





with
high-level
flow control





High- vs. low level flow control – LAM

with
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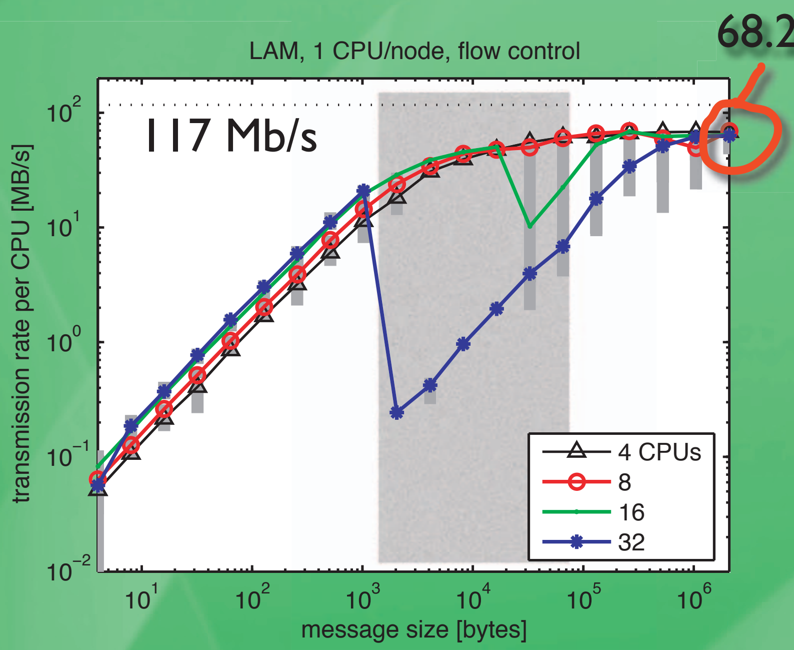

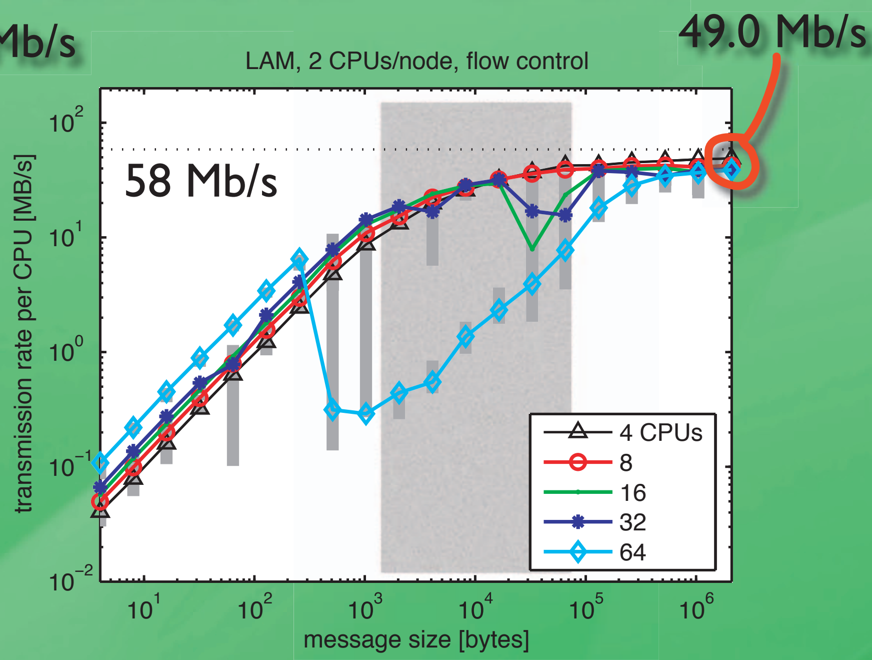

with
high-level
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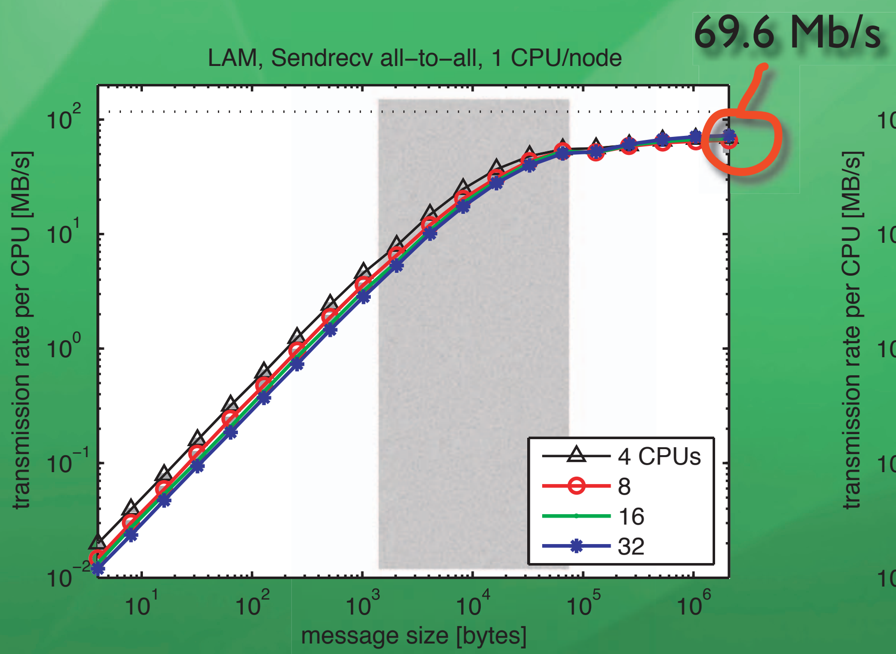

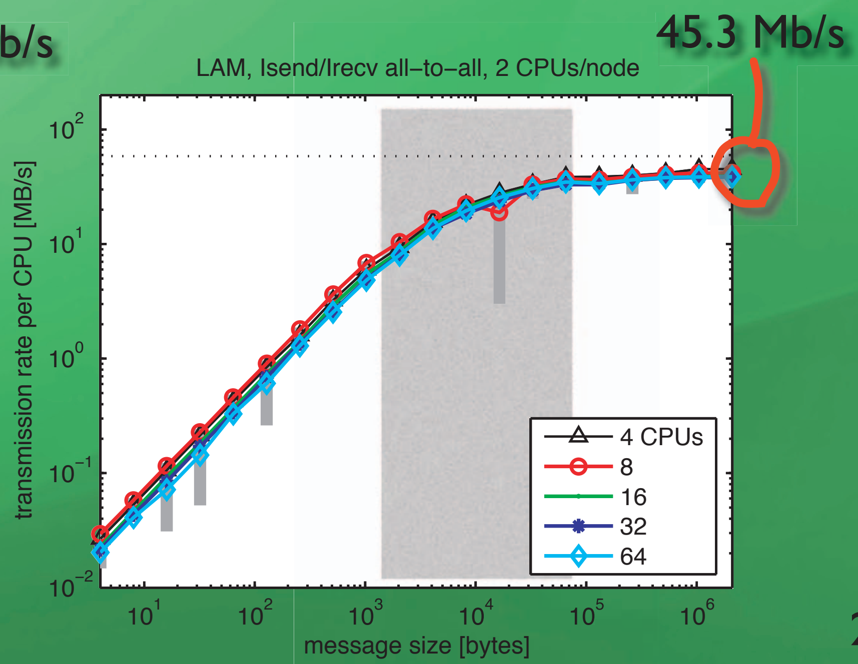

High- vs. low level flow control – MPICH

with
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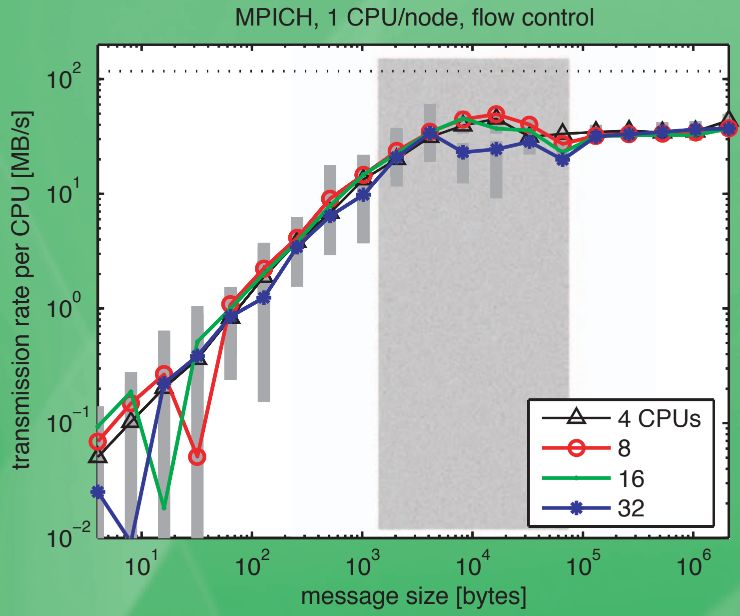

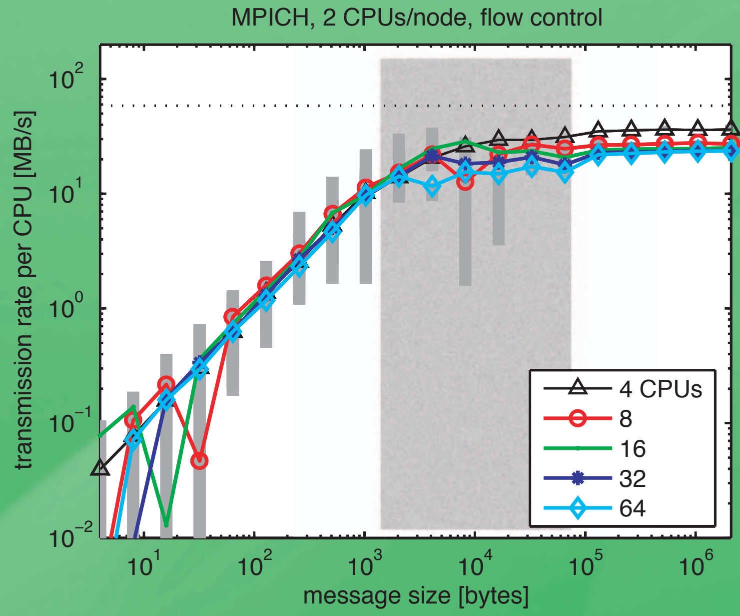

with
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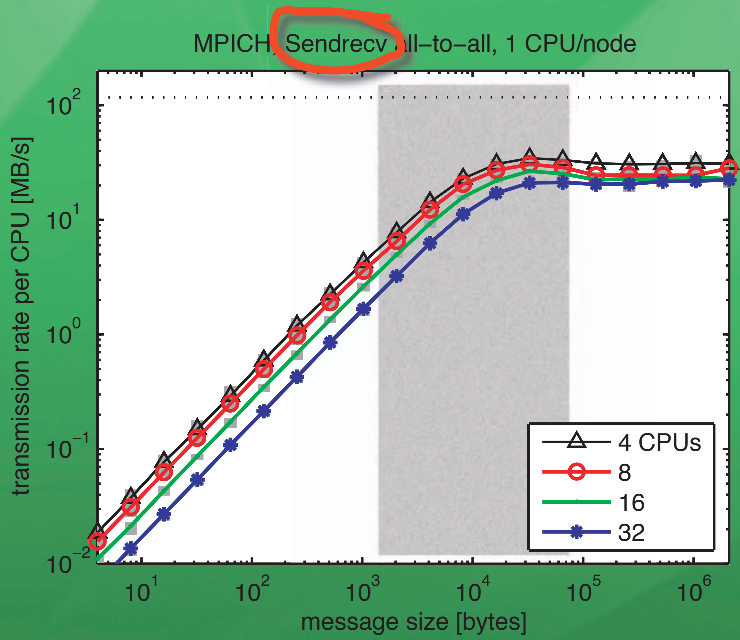

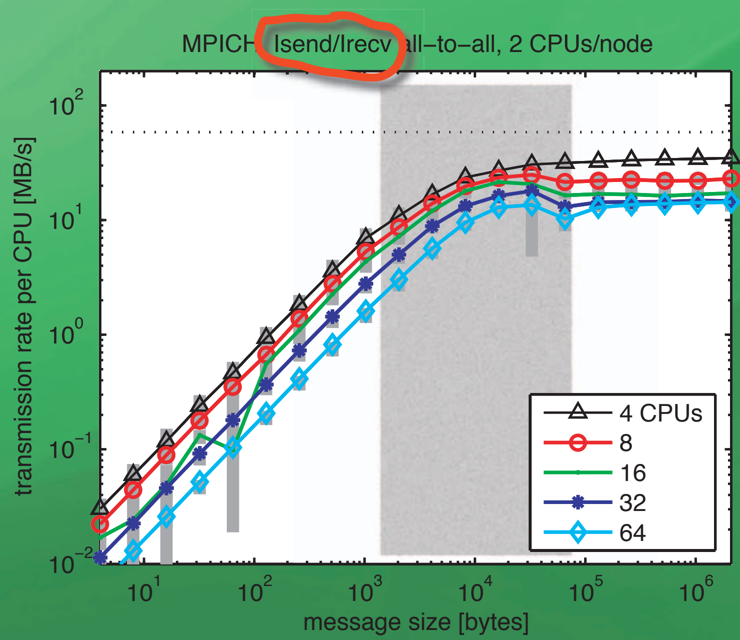

High- vs. low level flow control – MPICH

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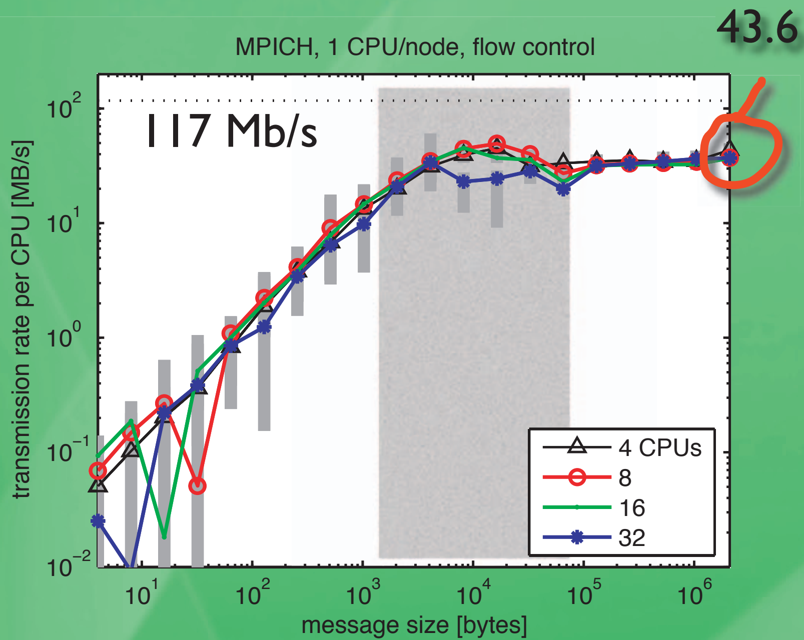

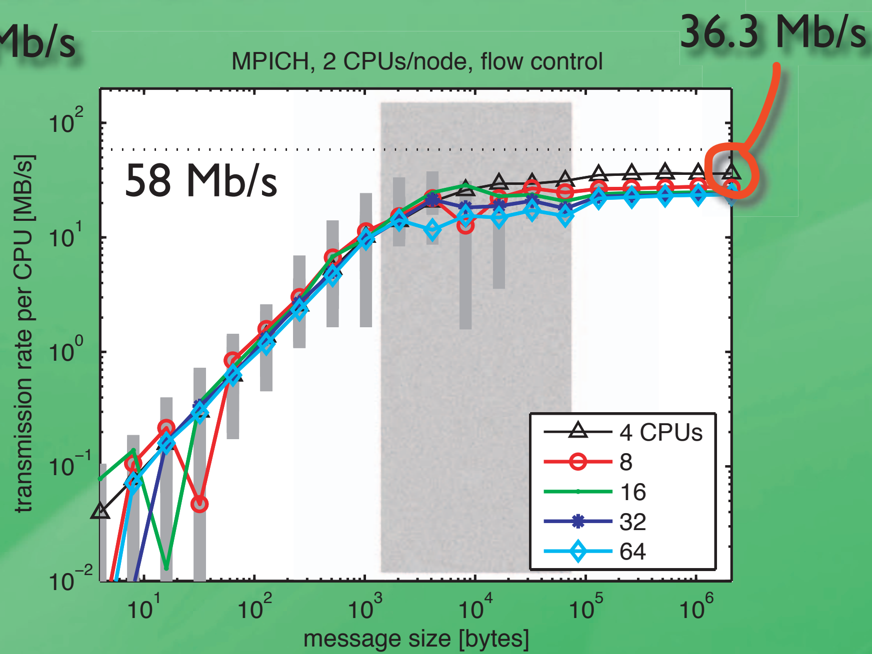

with
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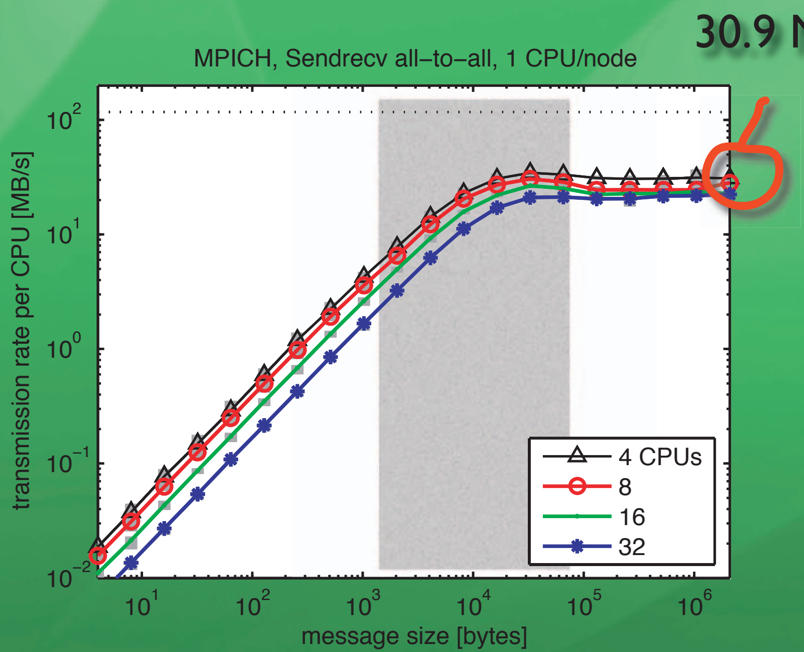
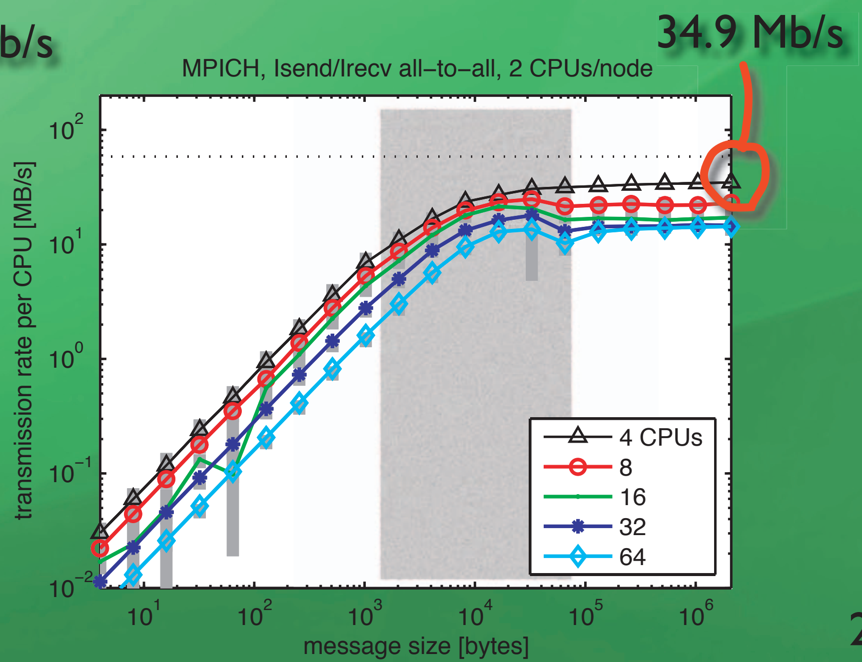




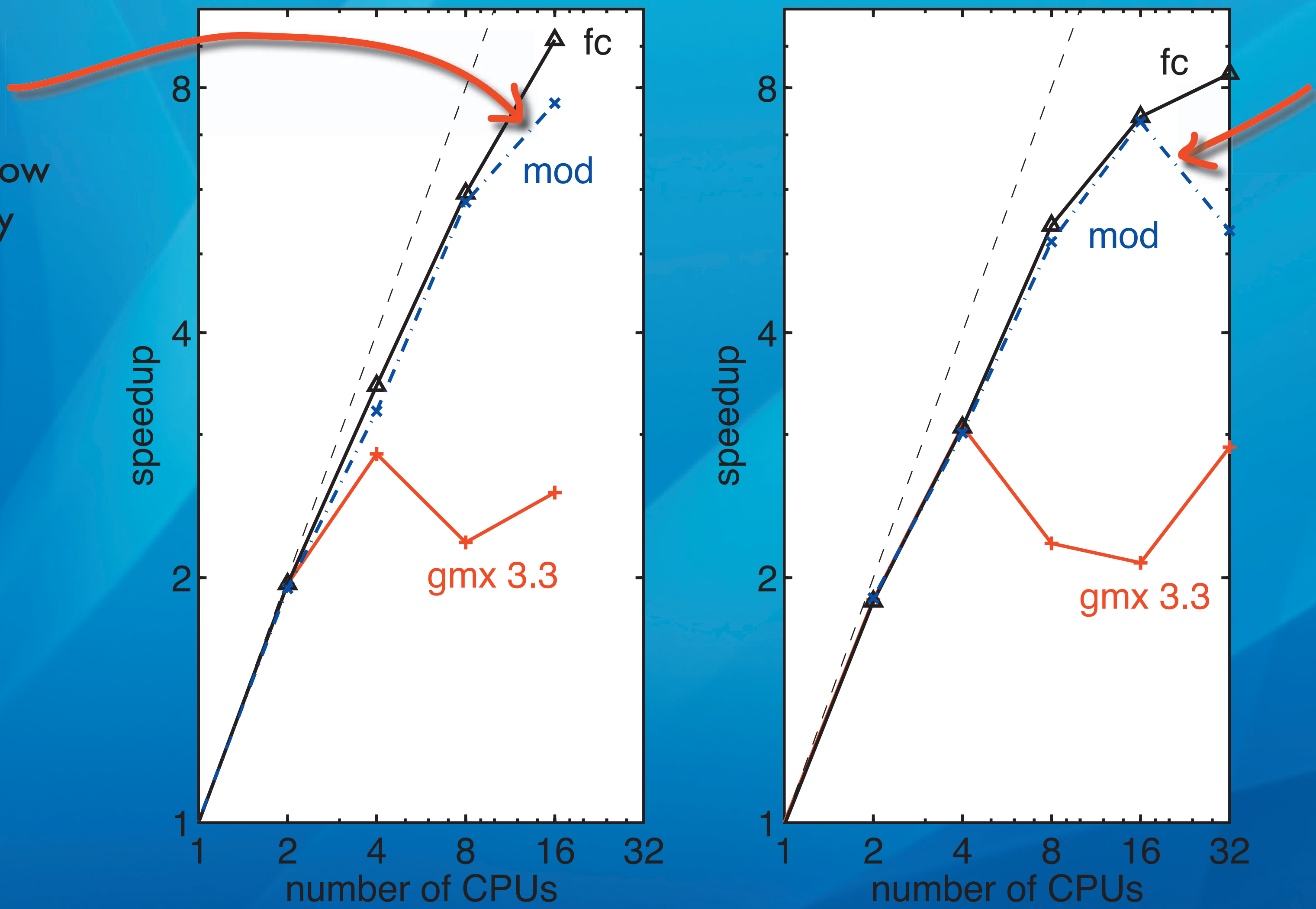
GROMACS 3.3 GigE speedup

MPI_Alltoall vs. ordered all-to-alls

1 CPU/node

2 CPUs/node

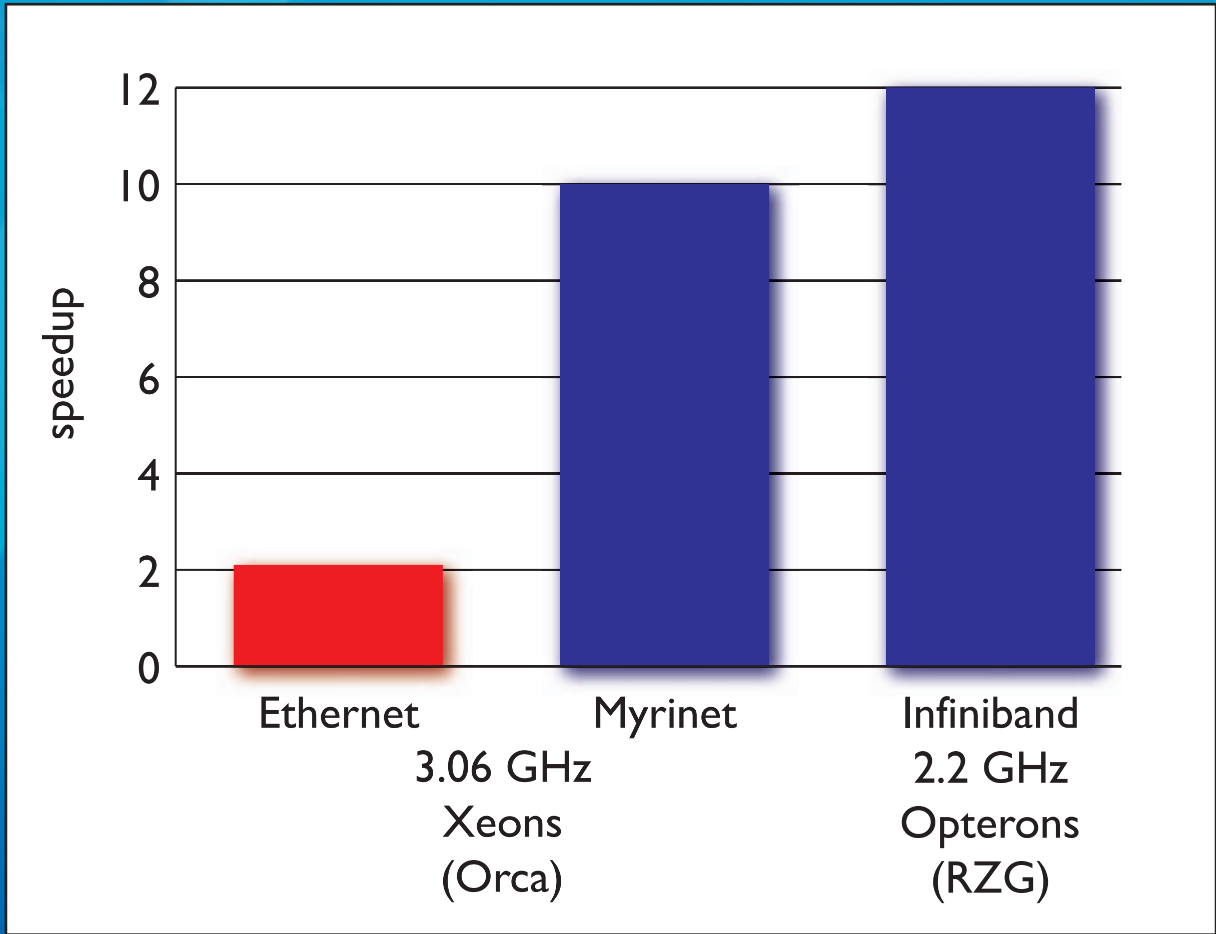
Sendrecv-scheme, high-level flow control only



Isend/Irecv scheme, high-level flow control only

GROMACS 3.3 GigE speedup

compared to other interconnects (8x2 CPUs)



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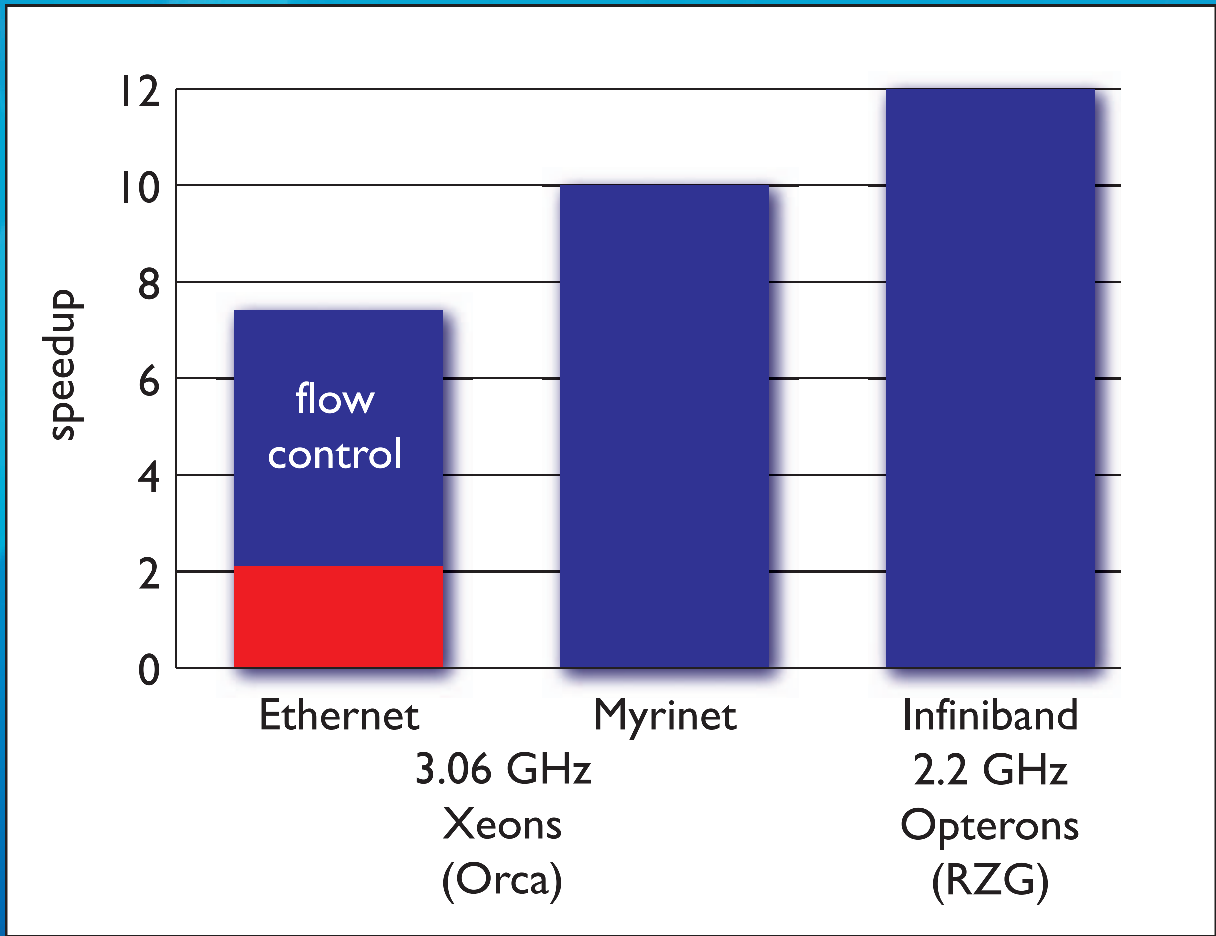

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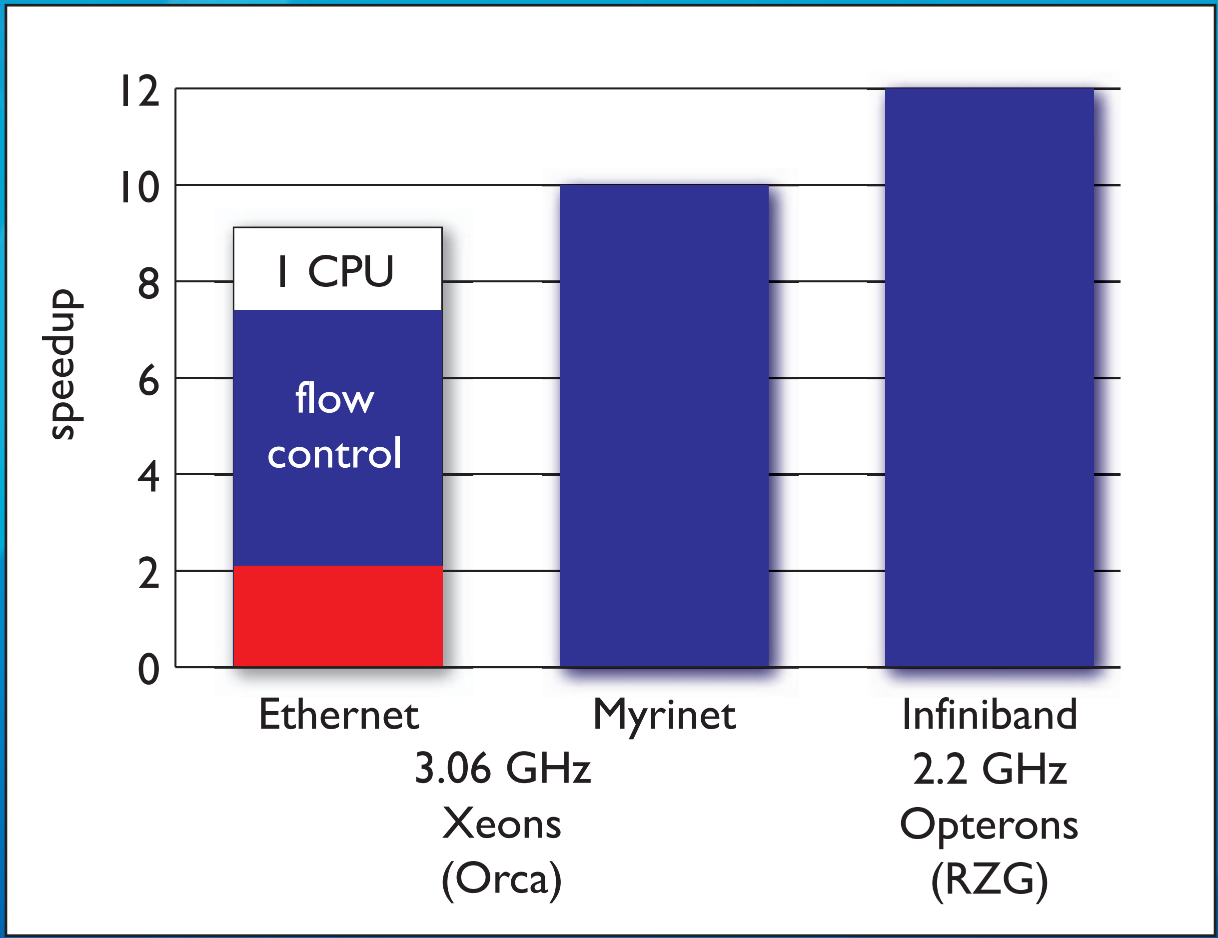

Conclusions

- when running GROMACS on >2 Ethernet-connected nodes, flow control is needed to avoid network congestion
- implemented a congestion-free all-to-all for multi-CPU nodes
- highest network throughput probably for combination of high+low level flow control
- findings can be applied to other parallel applications that need all-to-all communication

Outlook

- MPICH1-1.2.6 → MPICH2-1.0.2
- LAM-7.1.1 → OpenMPI-1.0rc1

- allocation technique for PME/PP splitting on multi-CPU nodes