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# Using Monitoring Data to Improve HPC Performance via Network-Data-Driven Allocation

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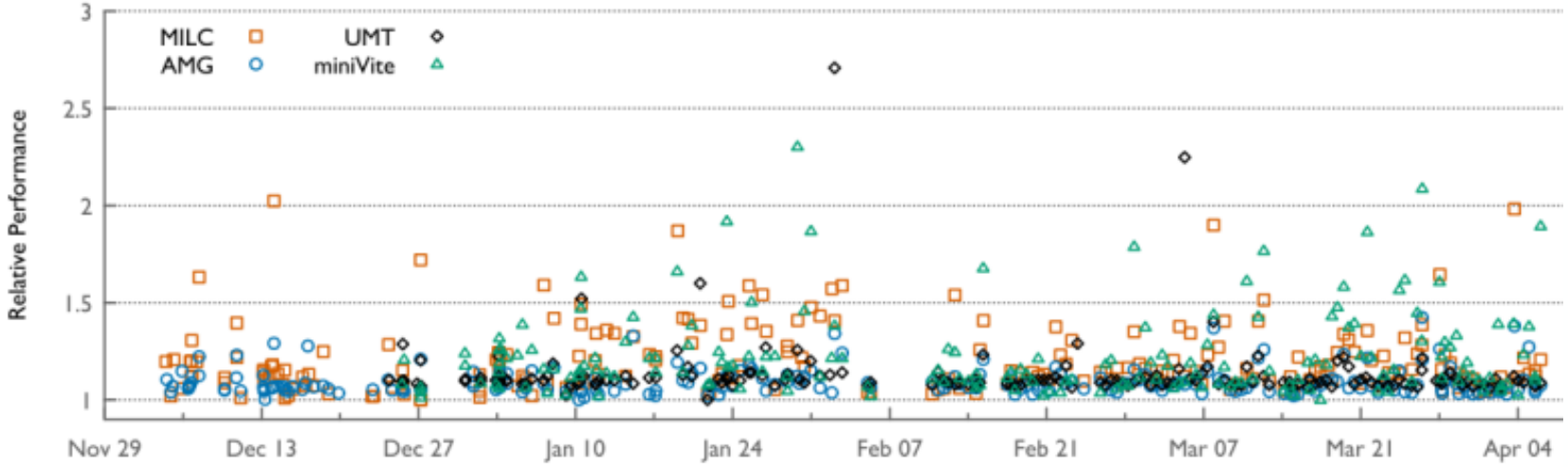
# Performance degradation happens on HPC systems

The shared interconnections in a dragonfly system

- Network contention causes HPC performance variability as high as 2x [Bhatele, SC'13], 3x [Bhatele, IPDPS'20], 7x [Chunduri, SC'17], 8x [Zhang, Cluster'20]

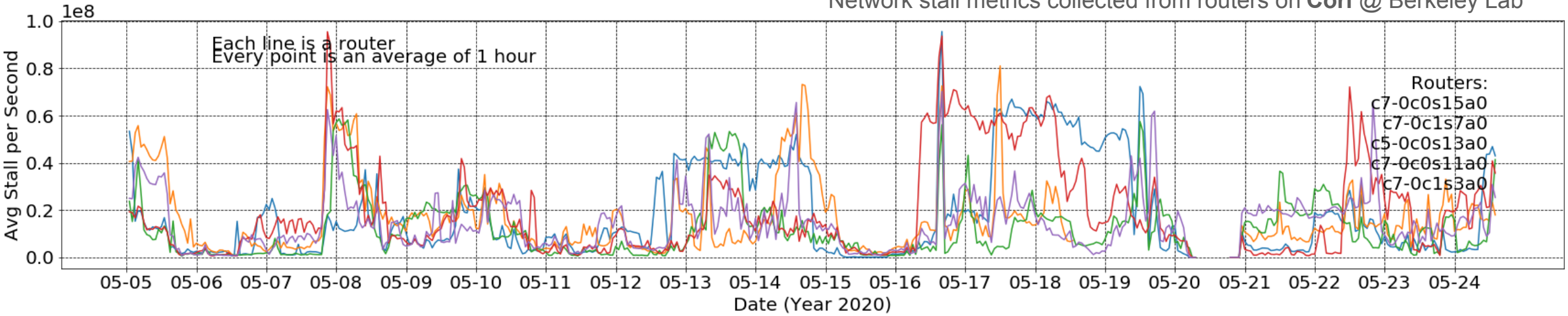
Experiments on **Cori** @ Berkeley Lab [Bhatele, IPDPS'20]



# Monitoring data are available on HPC systems

- The LDMS monitoring system [Agelastos, SC'14] has been deployed on many HPC systems, such as
  - **Cori**, 12k-node, @LBNL, USA
  - Trinity, 19k-node, @LANL, USA
  - Blue Waters, 28k-node, @NCSA, USA

Network stall metrics collected from routers on **Cori** @ Berkeley Lab



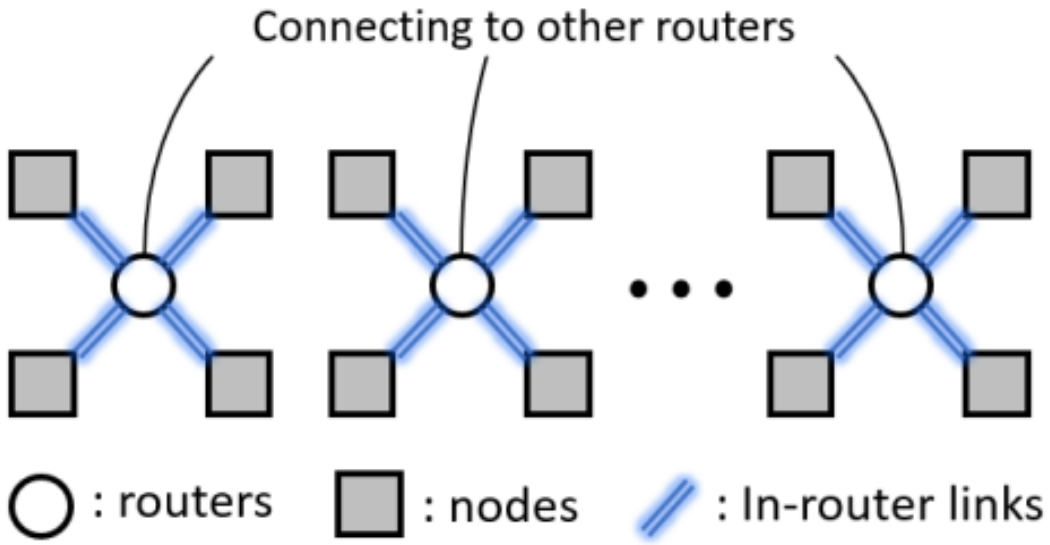
# Related work on HPC job allocation

1. Strategies based on static properties (job size, topology, etc.)
   [Jain, SC'14], [Prisacari, HPDC'14], [Jokanovic, IPDPS'15], [Wang, SC'16]
2. Strategies based on profiled job characteristics (communication graph)
   [Soryani, JoSC'13], [Michelogiannakis, CCGRID'17], [Yan, ICPP'19]
3. Strategies based on thermal and energy constraints
   [Cheng, IPDPS'14], [Cao, IPDPS'17]
4. Strategies based on other running jobs' placement (avoid interference)
   [Pollard, SC'18], [Zhang, IPDPS'18]
5. Strategies based on system performance status / resource utilization
   [Werstein, PDCAT'06], [Yang, JoSC'11], [LaCurts, IMC'13]

- Existing allocation strategies seldom consult system network monitoring data at runtime.
- As a result, these strategies cannot easily adapt to the change of network hot spots.
- Using monitoring data to collect network performance has lower overhead than active network query methods used in earlier works (e.g., LaCurts, IMC'13)

# Network-Data-Driven (NeDD) job allocation framework


- We propose the NeDD job allocation framework
  1. System Network Monitoring: quantify network traffic intensity of routers - Runtime
  2. Application Profiling: determine application's sensitivity to congestion - Offline
  3. Allocation Decision: place job onto nodes by avoiding congestion - Runtime
- Our experiments on Cori shows NeDD reduces application execution time by **11**% on average and up to **34**%

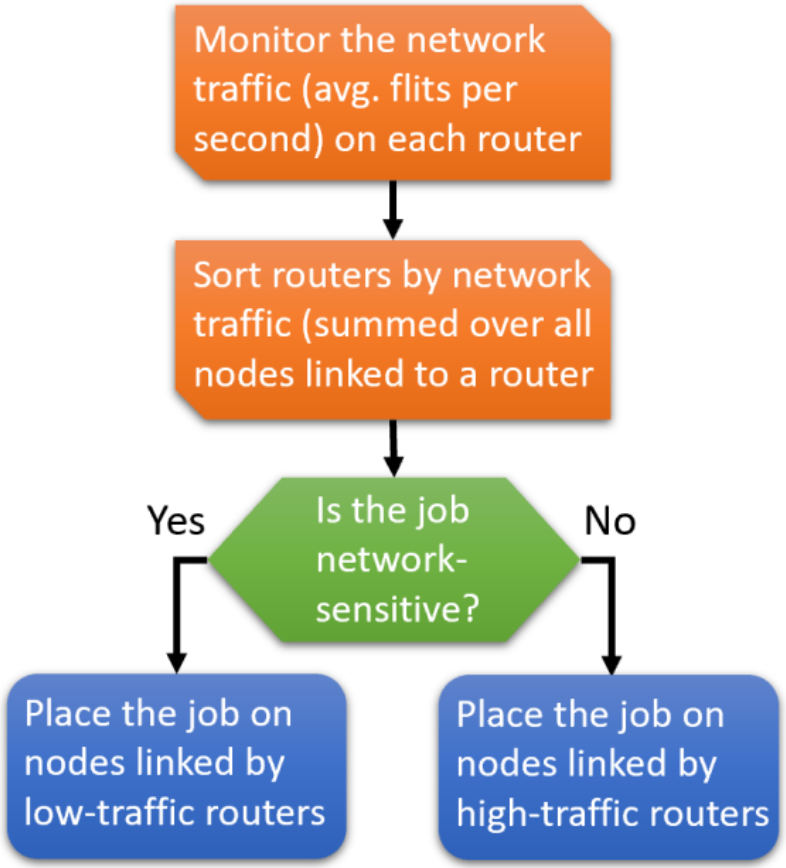




- To quantify the network traffic, we collect the flits per second metric between each node and its parent router
- Define *network traffic intensity* of a router: the total flits per second summed over all nodes directly connected to that router


TABLE I: The ratio of execution time spent on MPI operations.

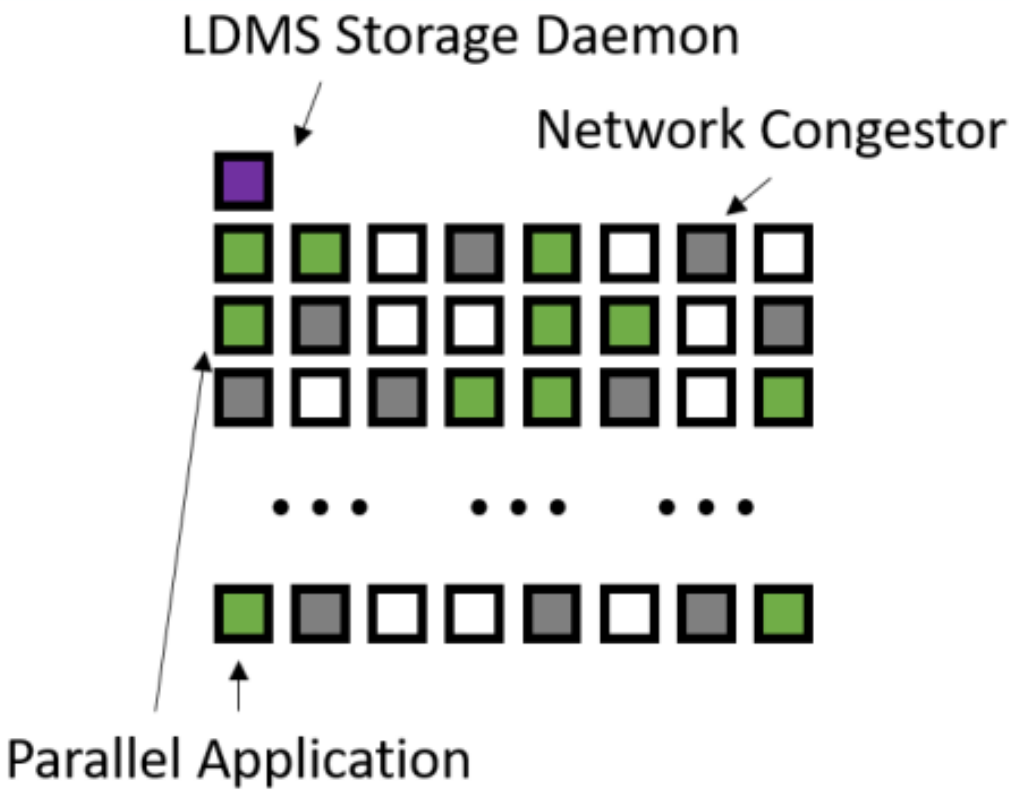
| Application | MPI Operation | MPI_Allreduce | MPI_Sendrecv/Send/Isend | MPI_Wait/Waitall | MPI_(other) |
|---|---|---|---|---|---|
| miniMD | 68.9% | 1.1% | 65.8% | 0 | 2.0% |
| LAMMPS | 51.5% | 22.4% | 10.5% | 12.7% | 5.9% |
| MILC | 48.2% | 1.9% | 7.7% | 34.0% | 4.6% |
| HACC | 49.7% | 1.4% | 0 | 41.2% | 7.1% |
| QMCPACK | 19.3% | 14.2% | 0 | <0.1% | 5.1% |
| HPCG | 11.5% | <0.1% | 4.6% | 6.4% | 0.5% |

- We characterize applications' sensitivity to network congestion based on its MPI statistics collected by the *CrayPat* tool.
  - Our previous work [Zhang, Cluster'20] shows that MPI usage statistics are good indicators of applications' sensitivity to network congestion.
- No need to run an application multiple times under different network conditions to get its sensitivity.


- Allocation Decision:
  - We place a network-sensitive job onto nodes whose parent routers have low network traffic intensity.
  - And vice versa.

# Design of experiments




- Use 201 nodes from the Cori system
  - 64 nodes for Network Congestion
  - 32 nodes for Parallel Application
  - 1 node for LDMS metric storage daemon
- Network congestor: GPCNeT [Chunduri, SC'19]
  - Run an RMA broadcast communication kernel continuously

Step 1: randomly place the network congestor

Step 2: place application following a certain allocation strategy and run

Step 3: repeat with different congestor placement

# Applications in our experiments

| Application | Description |
|---|---|
| HACC | Hardware Accelerated Cosmology Code framework |
| HPCG | High Performance Conjugate Gradient benchmark |
| LAMMPS | Large-scale Atomic/Molecular Massively Parallel Simulator |
| MILC | MIMD Lattice Computation for quantum chromodynamics |
| miniMD | Parallel Molecular Dynamics simulation |
| QMCPACK | Many-body ab initio Quantum Monte Carlo for computing electronic structures |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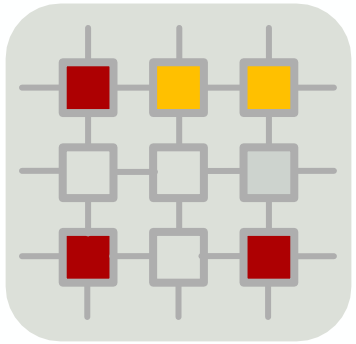
Network-sensitive

Network-insensitive

- We determine network intensiveness by looking at time spent on MPI operations

# Job allocation strategies compared

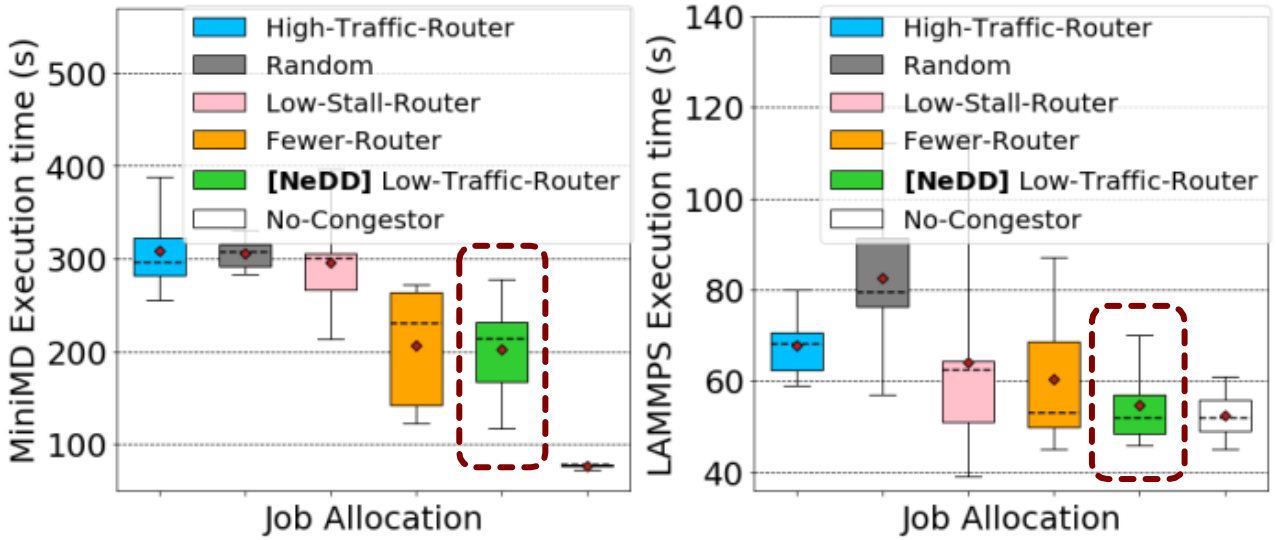


- Low-Traffic-Router places a job on nodes whose parent routers have low network traffic intensity.
  - This is **NeDD's** strategy for network-sensitive applications.
- High-Traffic-Router prioritizes routers with high network traffic intensity.
  - This is **NeDD's** strategy for network-insensitive applications.
- Random strategy places a job randomly.
- Low-Stall-Router strategy prioritizes routers with low Ntile network stalls (i.e., network stall count summed over all Ntiles in a router).
- Fewer-Router places a job into fewer routers by prioritizing routers connected to more idle nodes.

# Experiment results – single job

- For network-sensitive apps, NeDD reduces job execution time by up to 34% when compared with the Random allocation strategy.
- For network-insensitive apps, the performance degradation of NeDD is small.

network-sensitive apps




Red point: mean
Dashed line: median

# Experiment results – single job

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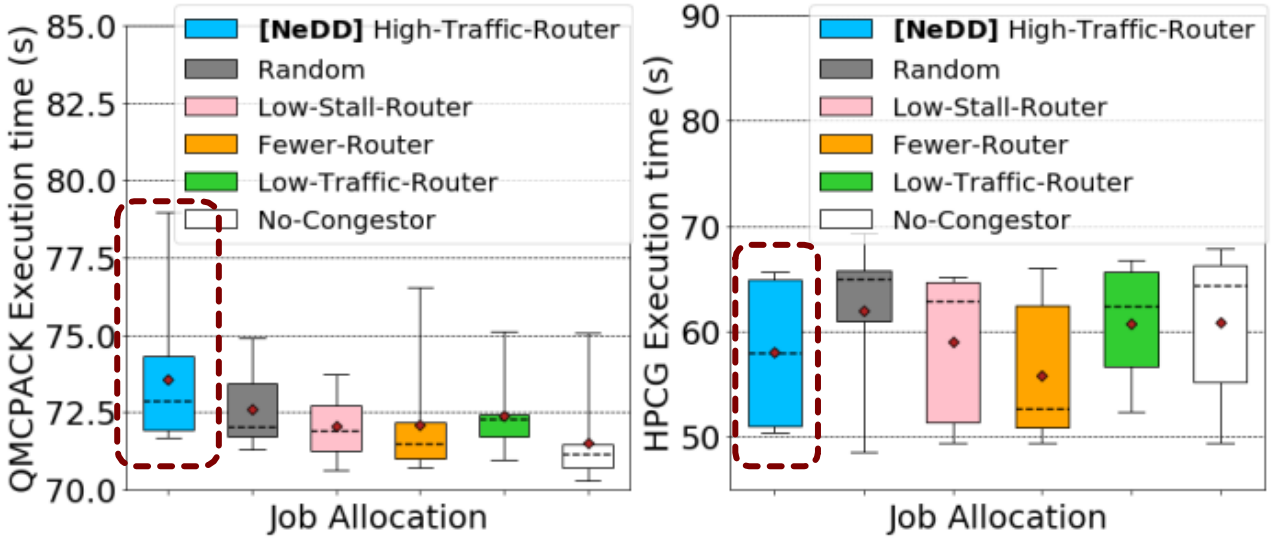
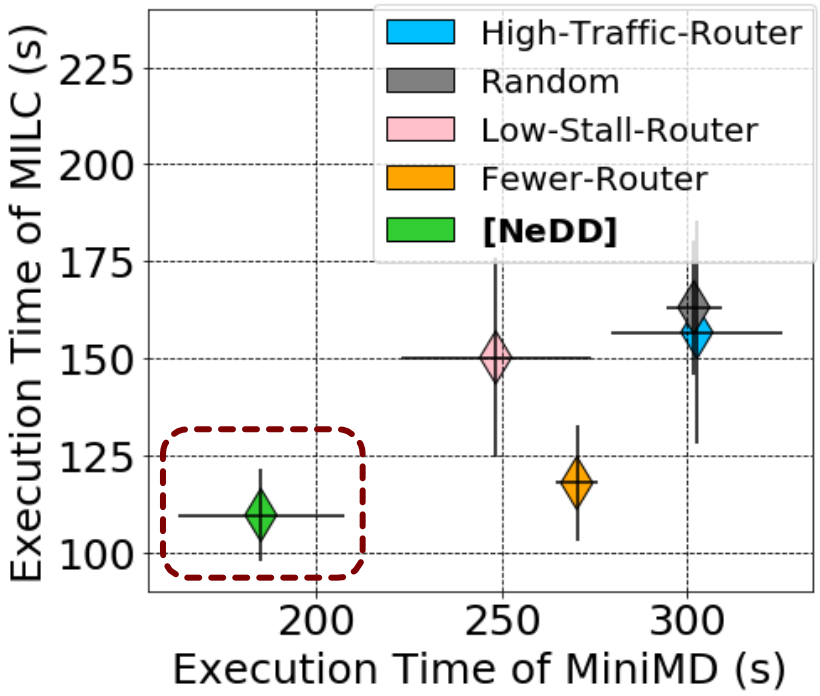
network-insensitive apps




Red point: mean
Dashed line: median

# Experiment results – two jobs

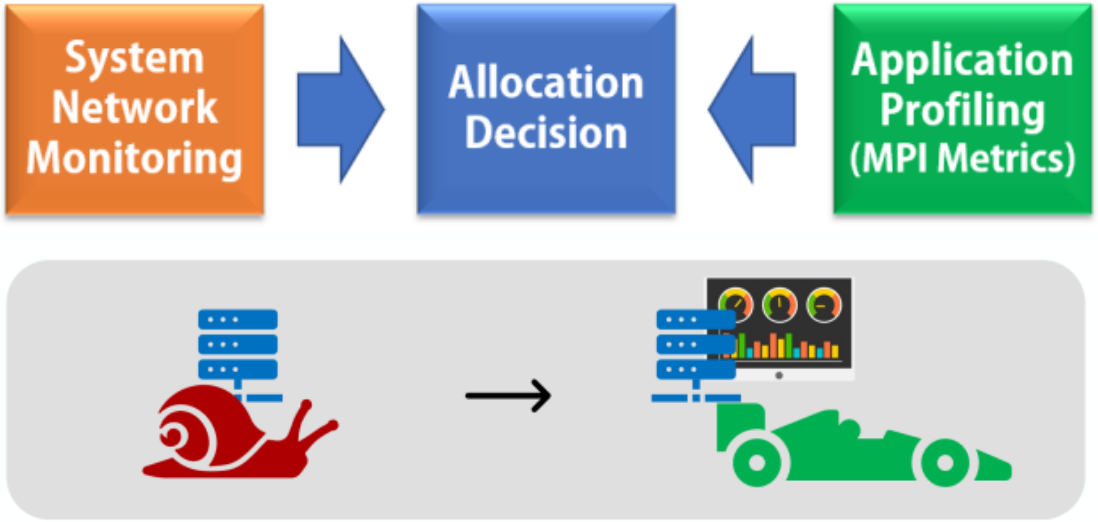



- In this experiments, the congestor is first placed, then two jobs (miniMD and MILC) are placed following a certain allocation strategy, and two jobs start simultaneously.
- X-/Y-axis represents miniMD/MILC's average execution time.
- NeDD allocation strategy improves the performance of both jobs.

# Thank you

Using Monitoring Data to Improve HPC Performance via Network-Data-Driven Allocation

- We demonstrate system monitoring data could be used in job allocation to improve HPC performance.
- NeDD allocation framework could reduce job execution time by up to 34%.

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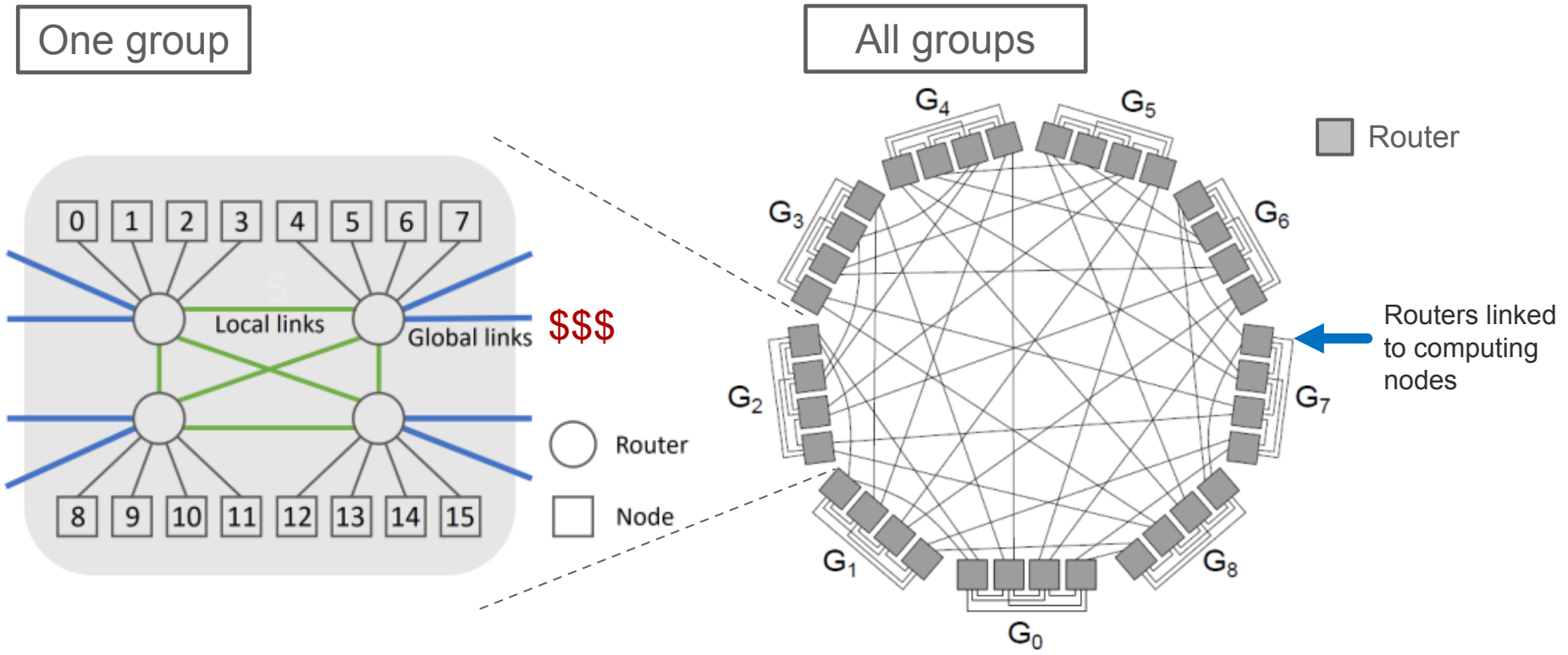
# BACK UP

# Dragonfly network topology

[Kim, SIGARCH'08]




## Advantages

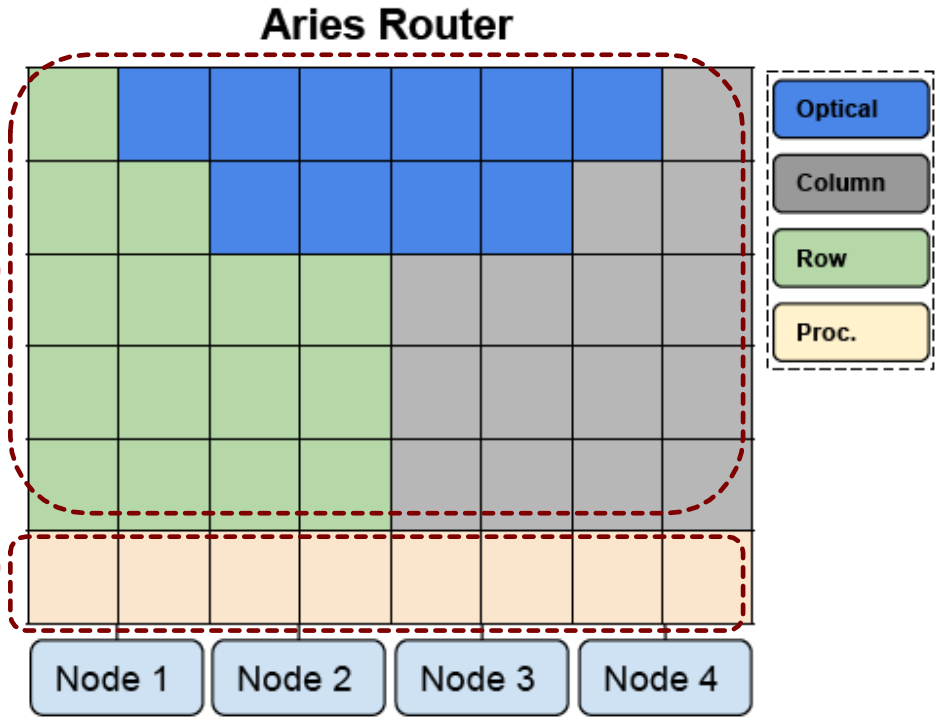
- Constant network diameter
- Employs both electrical & optical network connections

## Implemented in

- Cray Cascade system [Faanes, SC'12]
- IBM PERCS architecture [Chakaravarthy, HiPC'12]

Cori @ NERSC
Edison @ NERSC
Trinity @ LANL
Shaheen II @ KAUST
… …

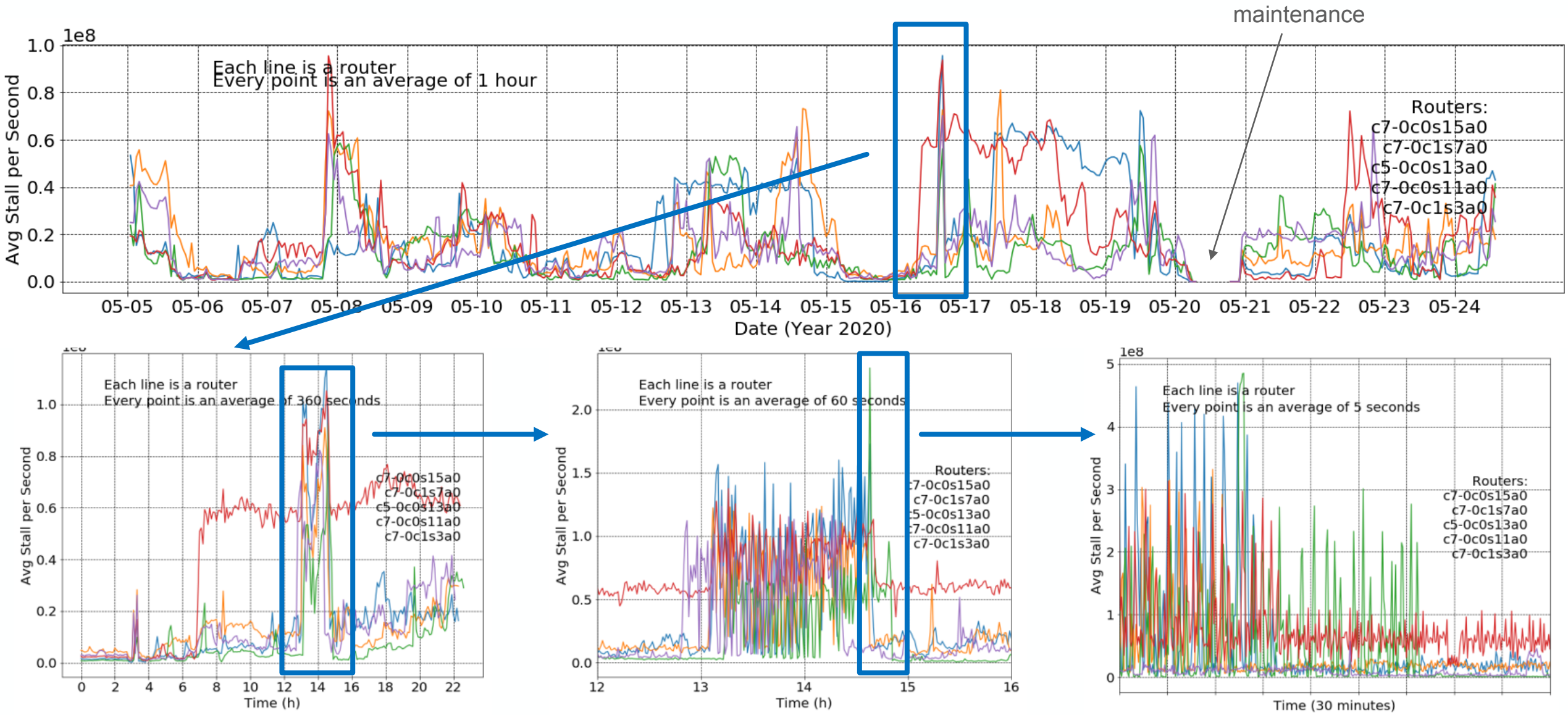
# Aries router counters



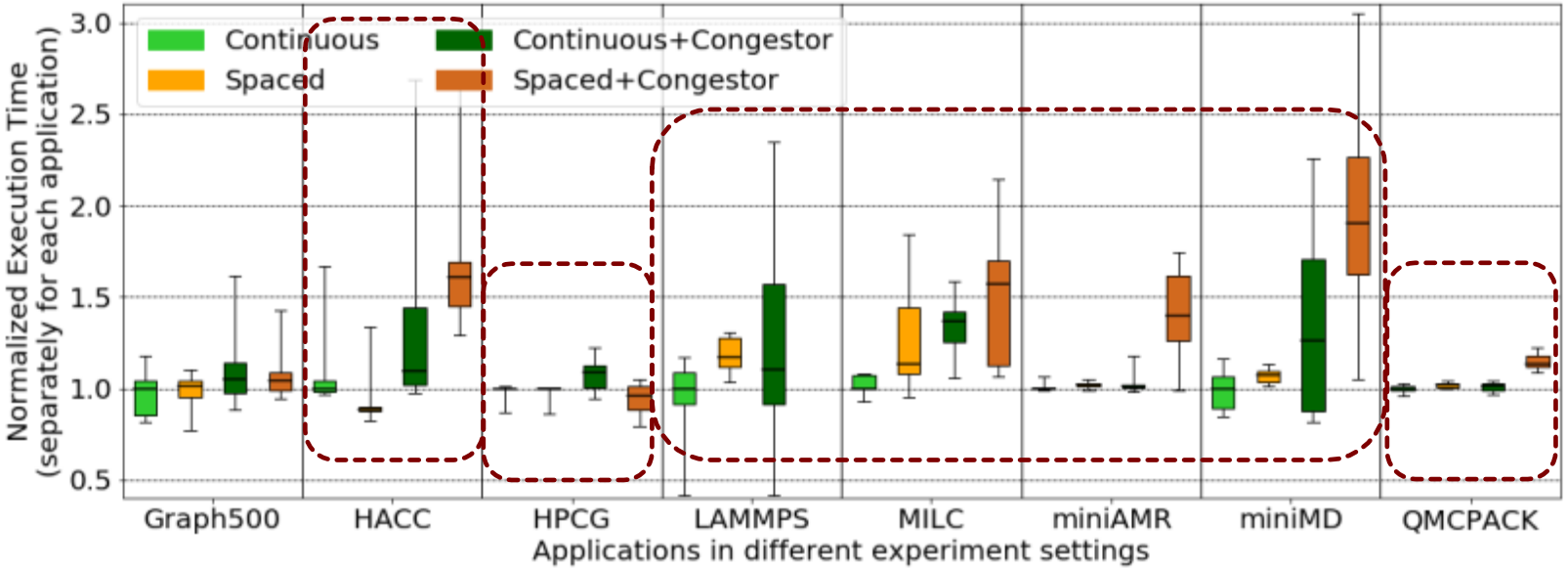

| Abbreviation | Full counter name |
|---|---|
| N_STALL_$r$_$c$ | AR_RTR_$r$_$c$_INQ_PRF_ROWBUS_STALL_CNT |
| N_FLIT_$r$_$c$_$v$ | AR_RTR_$r$_$c$_INQ_PRF_INCOMING_FLIT_VC$v$ |
| P_REQ_STALL_$n$ | AR_NL_PRF_REQ_PTILES_TO_NIC_$n$_STALLED |
| P_REQ_FLIT_$n$ | AR_NL_PRF_REQ_PTILES_TO_NIC_$n$_FLITS |
| P_RSP_STALL_$n$ | AR_NL_PRF_RSP_PTILES_TO_NIC_$n$_STALLED |
| P_RSP_FLIT_$n$ | AR_NL_PRF_RSP_PTILES_TO_NIC_$n$_FLITS |

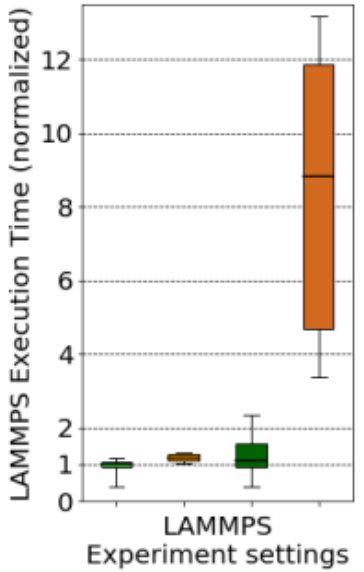
# Analyze network stall-per-second on Cori

Network congestion sometimes stays in the system for hours/days.



# Relation with MPI profiles

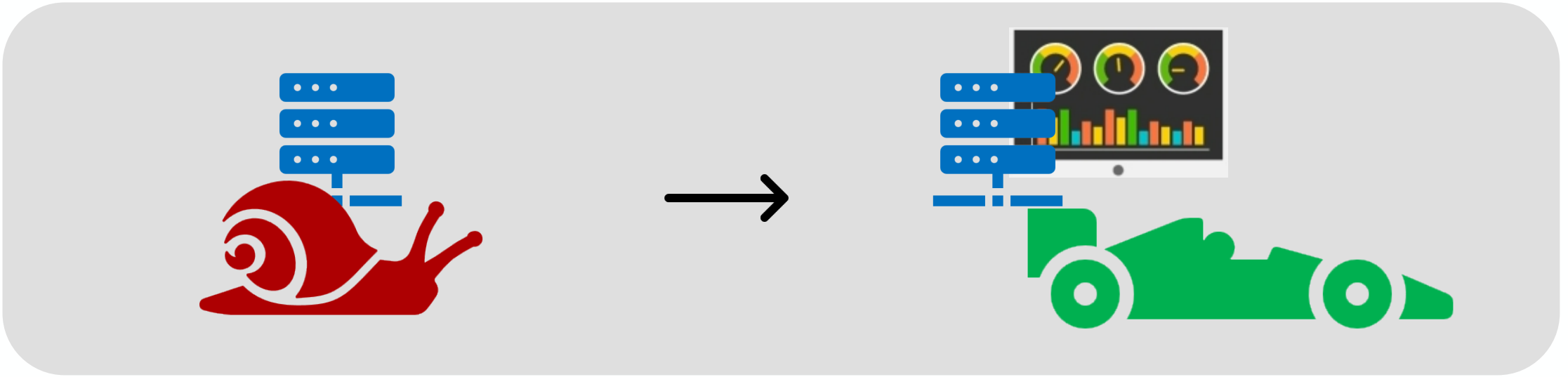



| Application | MPI Operation | MPI_Allreduce | MPI_Sendrecv (or Send, Isend) | MPI_Bcast | MPI_Test (or Testany) | MPI_Wait (or Waitall) | MPI_Barrier | MPI_(other) |
|---|---|---|---|---|---|---|---|---|
| Graph500 | 31.4% | 2.3% | 2.6% | 0.2% | 21.3% | <0.1% | 4.4% | 0.6% |
| HACC | 67.1% | <0.1% | 0.2% | 0 | 0 | 66.2% | 0 | 0.7% |
| HPCG | 3.7% | 0.2% | 2.1% | 0 | 0 | 1.2% | 0 | 0.2% |
| LAMMPS | 47.3% | 25.4% | 8.6% | <0.1% | 0 | 12.2% | <0.1% | 1.1% |
| MILC | 61.9% | 1.9% | 0.6% | <0.1% | 0 | 58.5% | <0.1% | 0.9% |
| miniAMR | 26.8% | 9.2% | 0.5% | <0.1% | 0 | 14.2% | 0 | 2.9% |
| miniMD | 83.4% | 0.5% | 82.5% | 0 | 0 | 0 | 0.2% | 0.2% |
| QMCPACK | 6.0% | 5.4% | <0.1% | <0.1% | <0.1% | <0.1% | 0.5% | 0.1% |

Profiled by CrayPat

- HACC, LAMMPS, MILC, miniAMR, miniMD are high in MPI operation time
- LAMMPS and miniAMR are high in MPI collective operations
- HPCG and QMCPACK are low in MPI operation



Improve HPC performance using monitoring data