The Case of the Missing Supercomputer Performance

Achieving Optimal Performance on the 8,192 Processors of ASCI Q

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The Problem

ASCI Q running SAGE is not performing as well as it should

- ASCI Q
  - 8192 processors
  - Installed at Los Alamos National Laboratory (LANL)
  - 2nd fastest supercomputer (2003)
- SAGE
  - Eulerian hydrodynamics application
  - 150,000 lines of Fortran and MPI code

How the authors

I. determined that ASCI Q was not performing well
II. identified the source of the performance loss
III. improved performance
IV. remeasure the performance

- A performance model of SAGE (verified on many systems to predict performance within 10% error)
- Measured ASCI Q one half (4096 processors) at a time, the two halves are consistent
- SAGE performs significantly worse than was predicted by the model

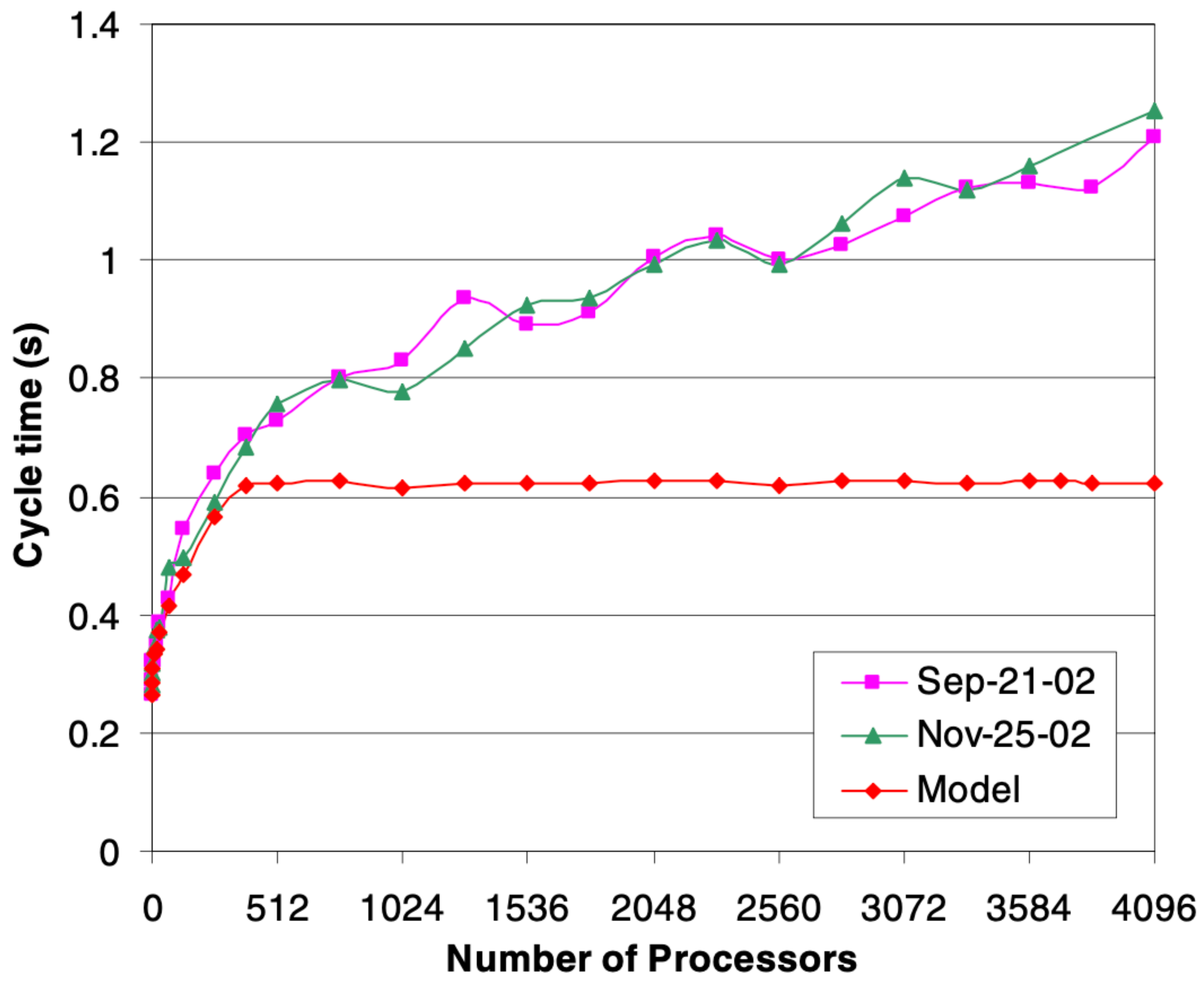


Figure 1: Expected and measured SAGE performance

- Performance of using 4 processors/node is different

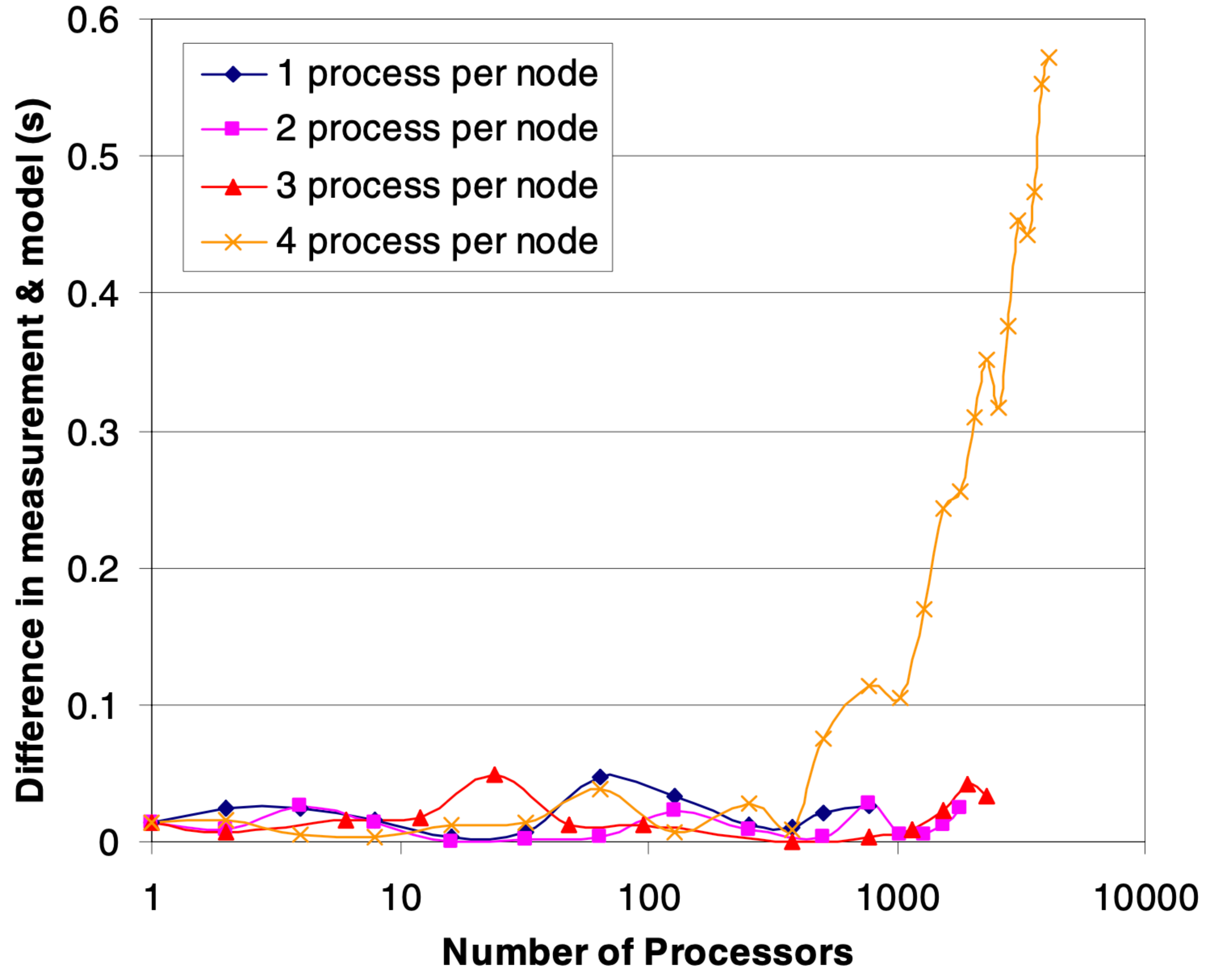


Figure 2: Difference between modeled and measured SAGE performance when using 1, 2, 3, or 4 processors per node

- > 256 nodes, using 4 processors/node is worse than using 3 processors/node
- > 512 nodes , using 4 processors/node is worse than using 2 processors/node

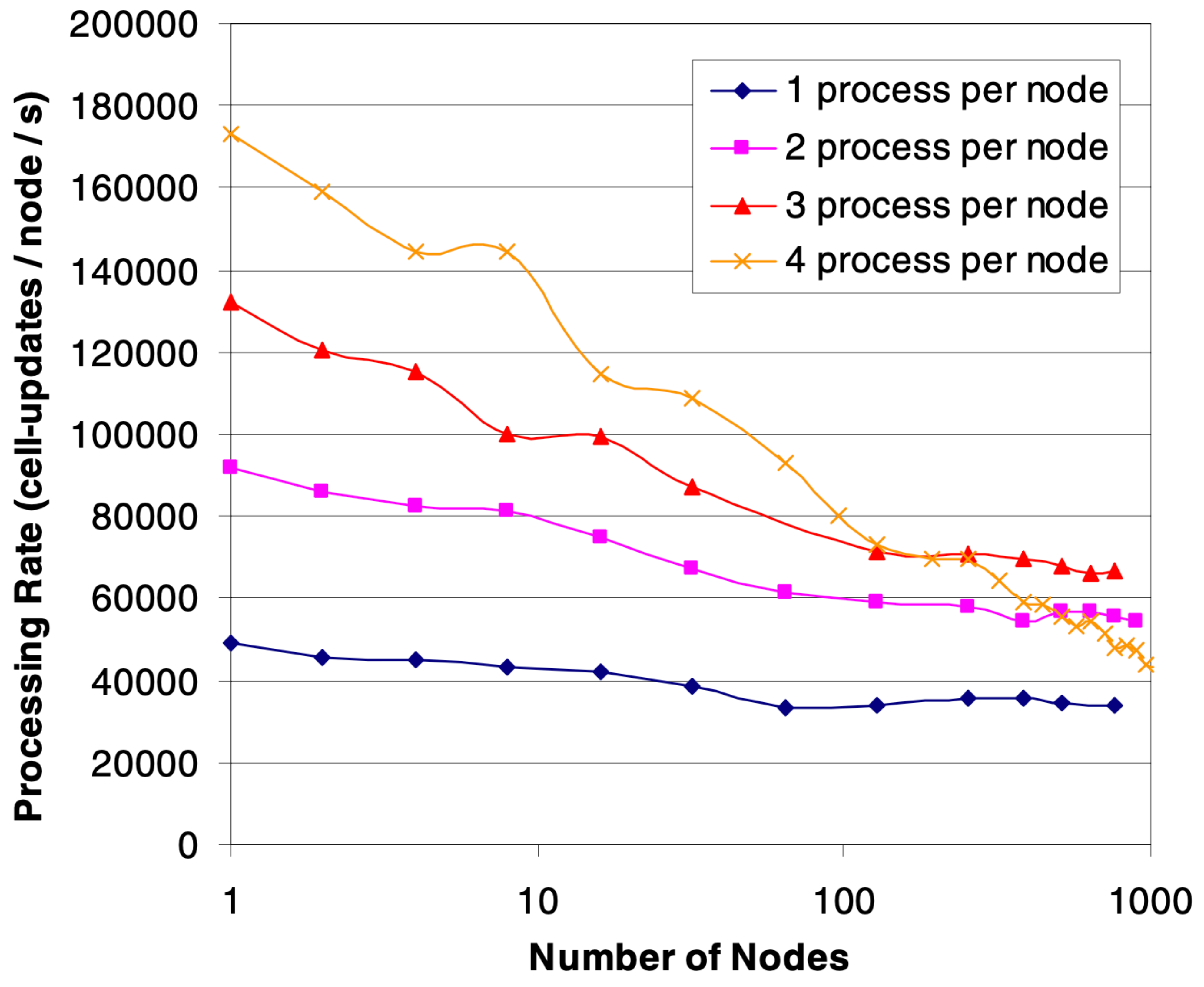
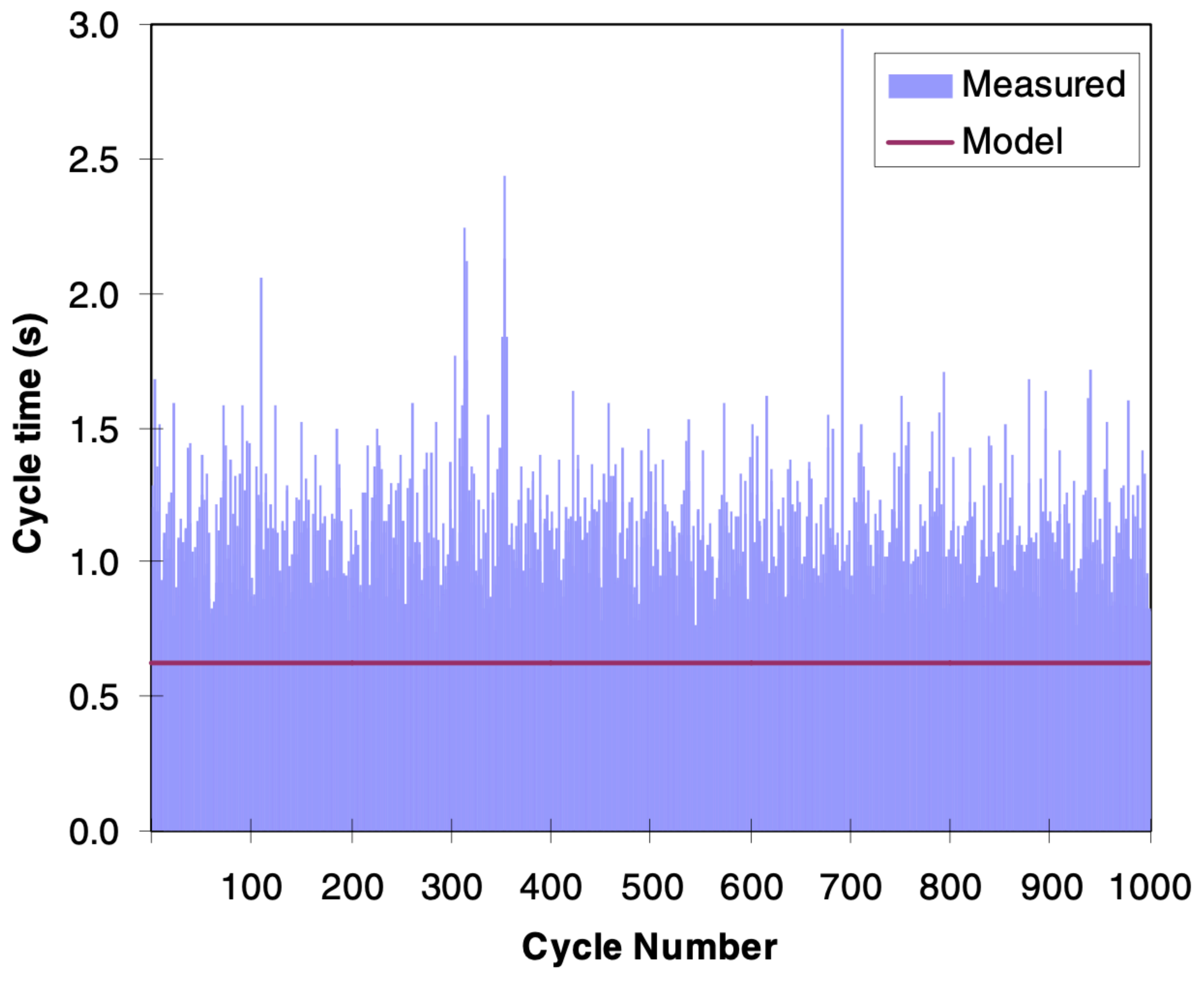
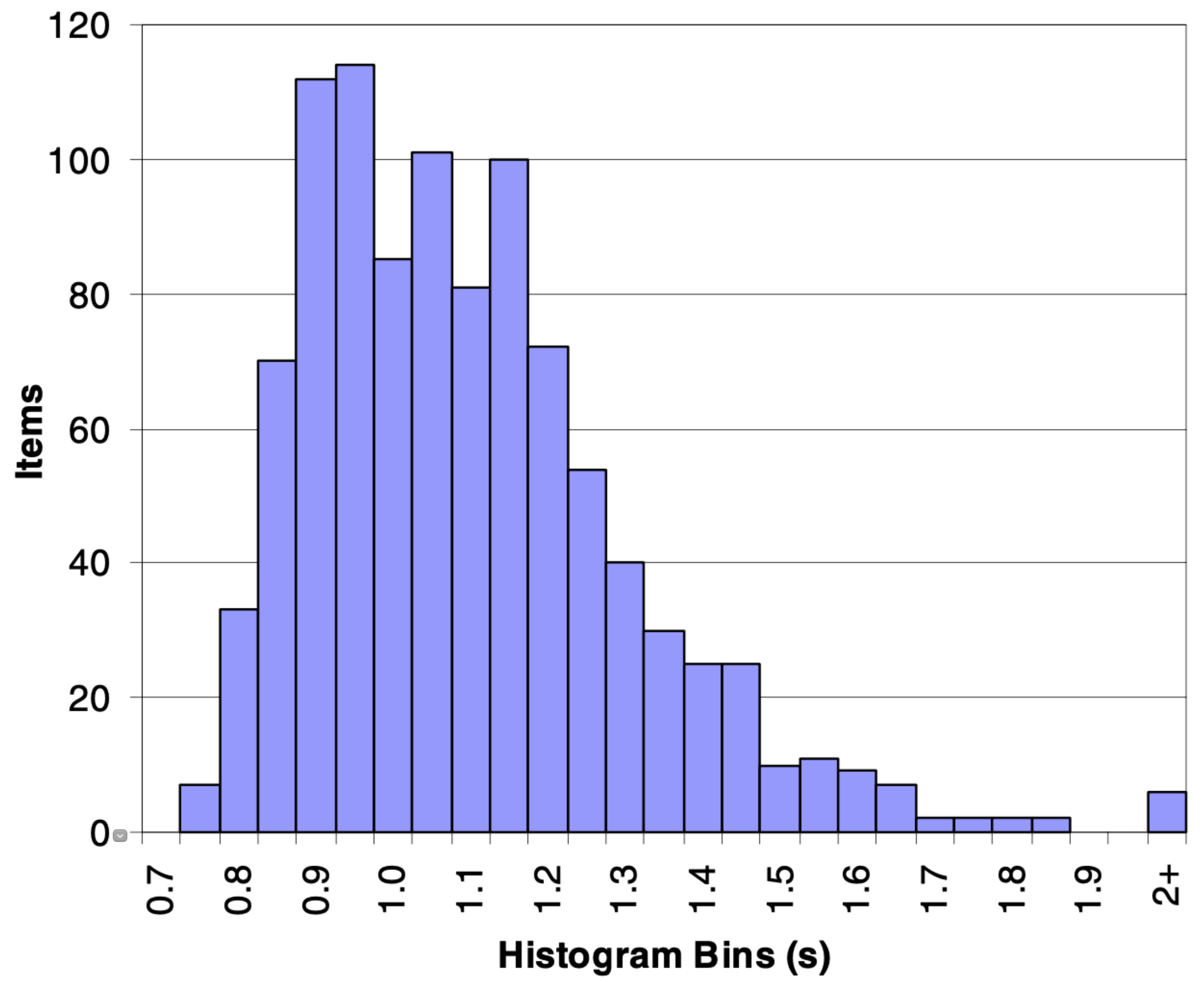


Figure 3: Effective SAGE processing rate when using 1, 2, 3, or 4 processors per node



(a) Variability



(b) Histogram

Figure 4: SAGE cycle-time measurements on 3,584 processors

- SAGE performs a constant amount of work per cycle and could be expected to take a constant amount of time to finish
- Cycle time ranges from 0.7 to 3 seconds, greater than a factor of 4 in variability

- Collective-communication operations: allreduce, reduction, account for the increase in cycle time

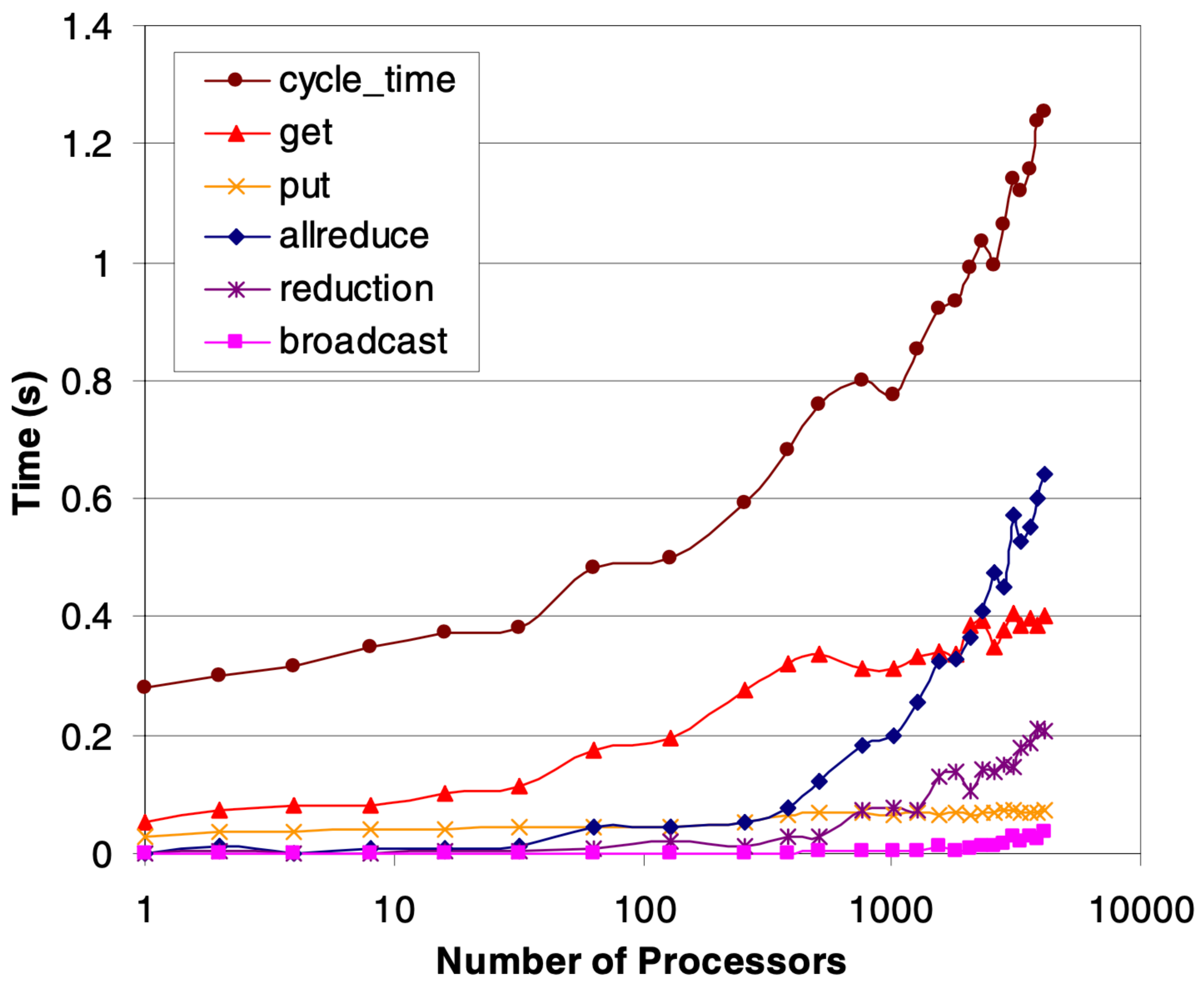


Figure 5: Profile of SAGE's cycle time
Using 4 processors per node

- <=3 processors / node, latency < 300 us

- A problem arises when using all 4 processors within a node, latency > 3ms

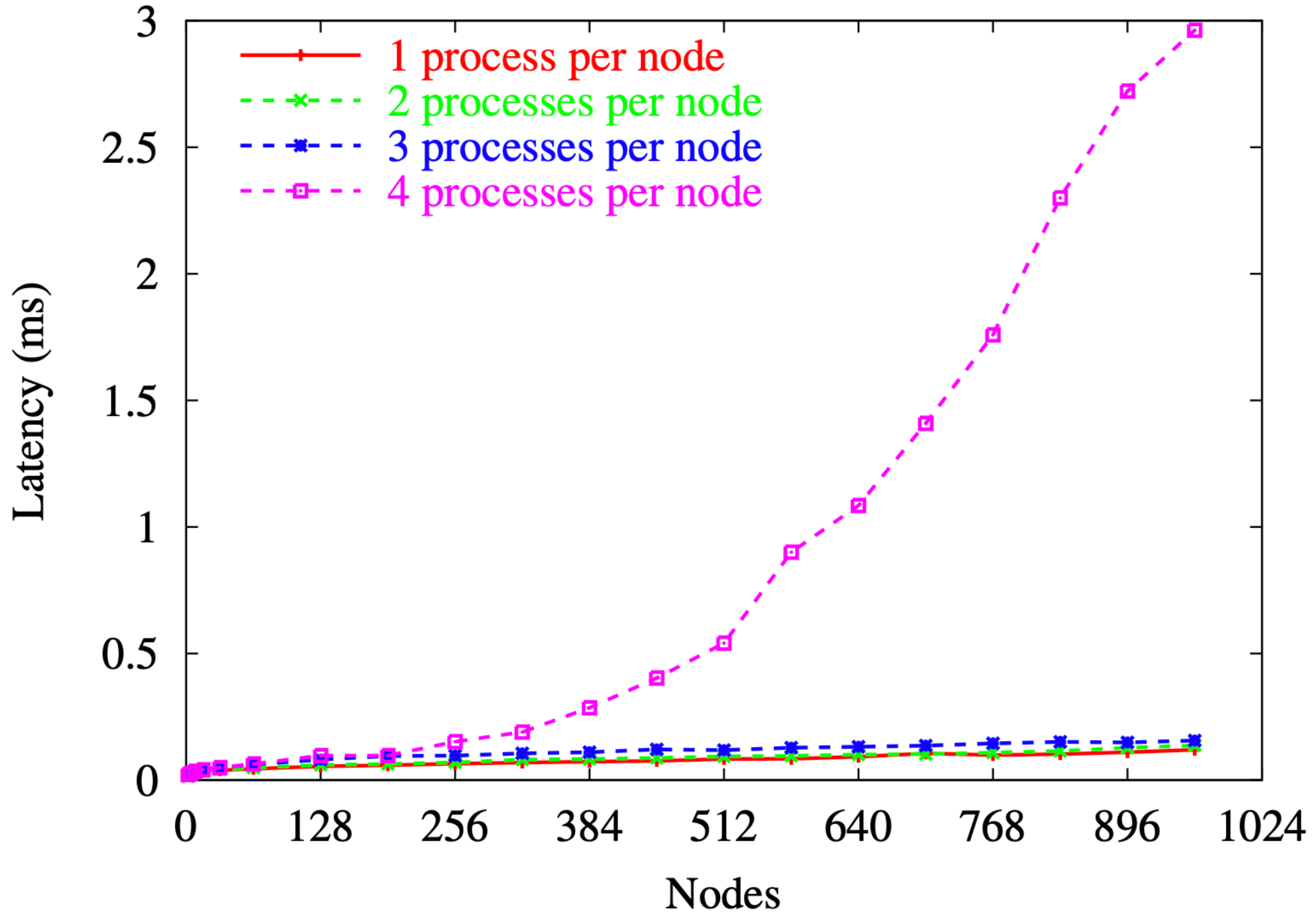


Figure 6: allreduce latency as a function of the number of nodes and processes per node

- Synthetic parallel benchmark, alternatively computes for 0, 1, or 5ms then performs either an allreduce or a barrier
- Ideal: grow logarithmically with increasing number of nodes, insensitive to computational granularity
- Actual: grow linearly with number of nodes, and increase with computational granularity

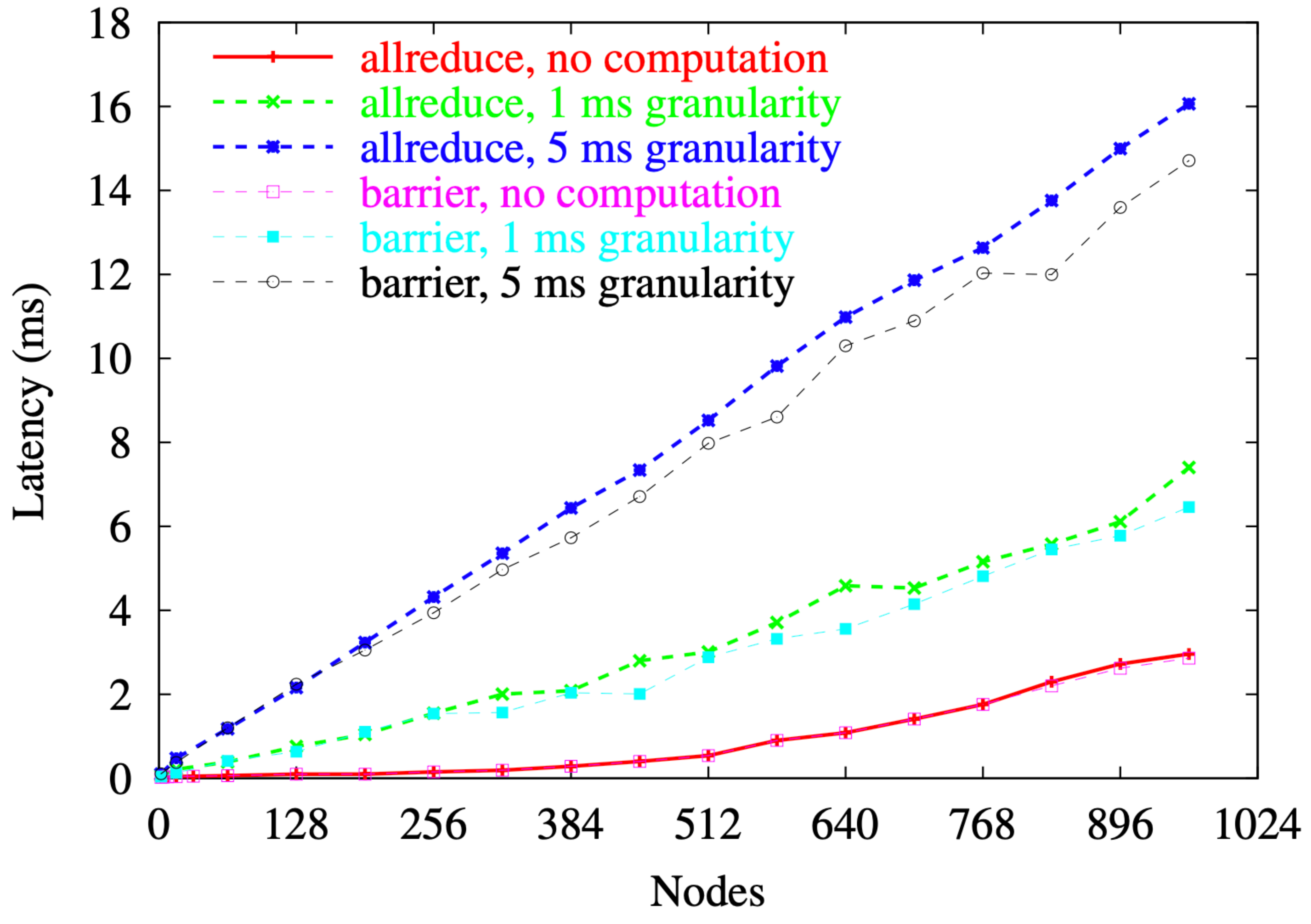


Figure 7: allreduce and barrier latency with varying amounts of intervening computation

- Improved performance of allreduce 7x better
- SAGE spends 51% of time in allreduce, should lead to 78% performance gain in SAGE
- Actual: only marginal improvement
- Eliminates MPI implementation and network as source of performance loss
- Hypothesis: periodic system activities were interfering with application execution, causing performance variability (“noise”)

- A simple benchmark of running synthetic computation for 1000 seconds in the absence of noise
- Slowed down experienced by each process is low, < 2.5%
- Contradicts the “noise” hypothesis

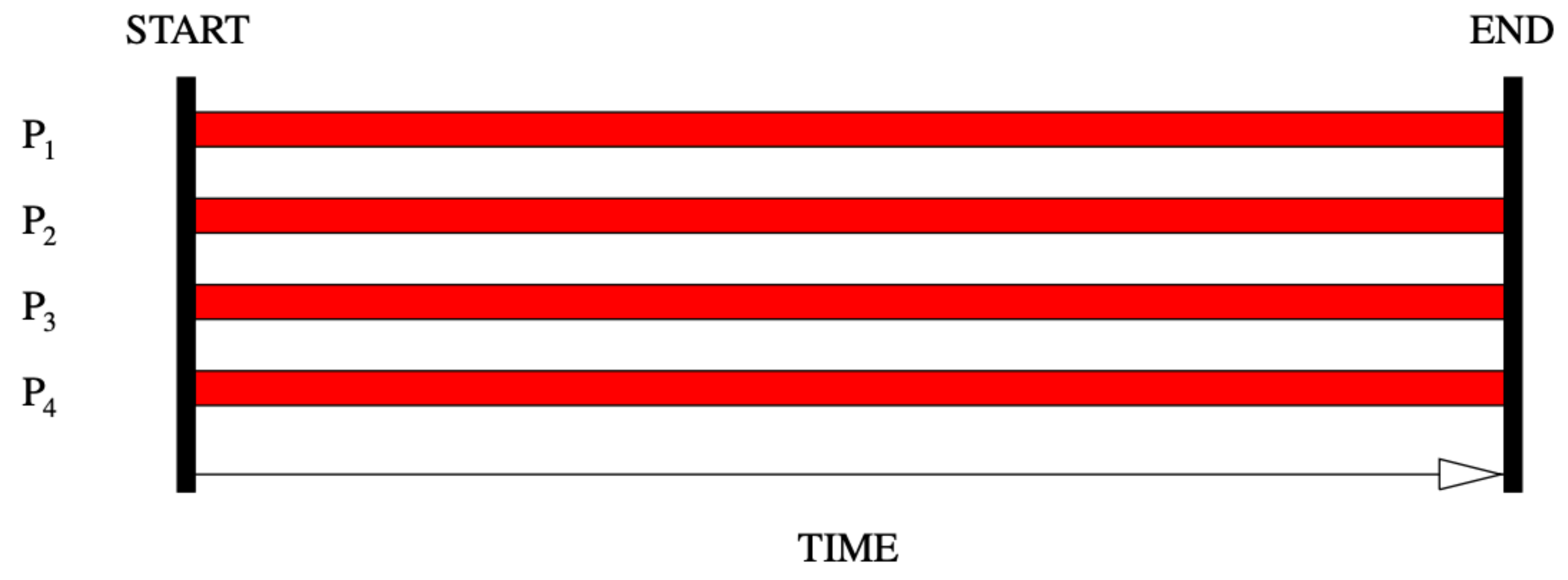


Figure 8: Performance-variability microbenchmark

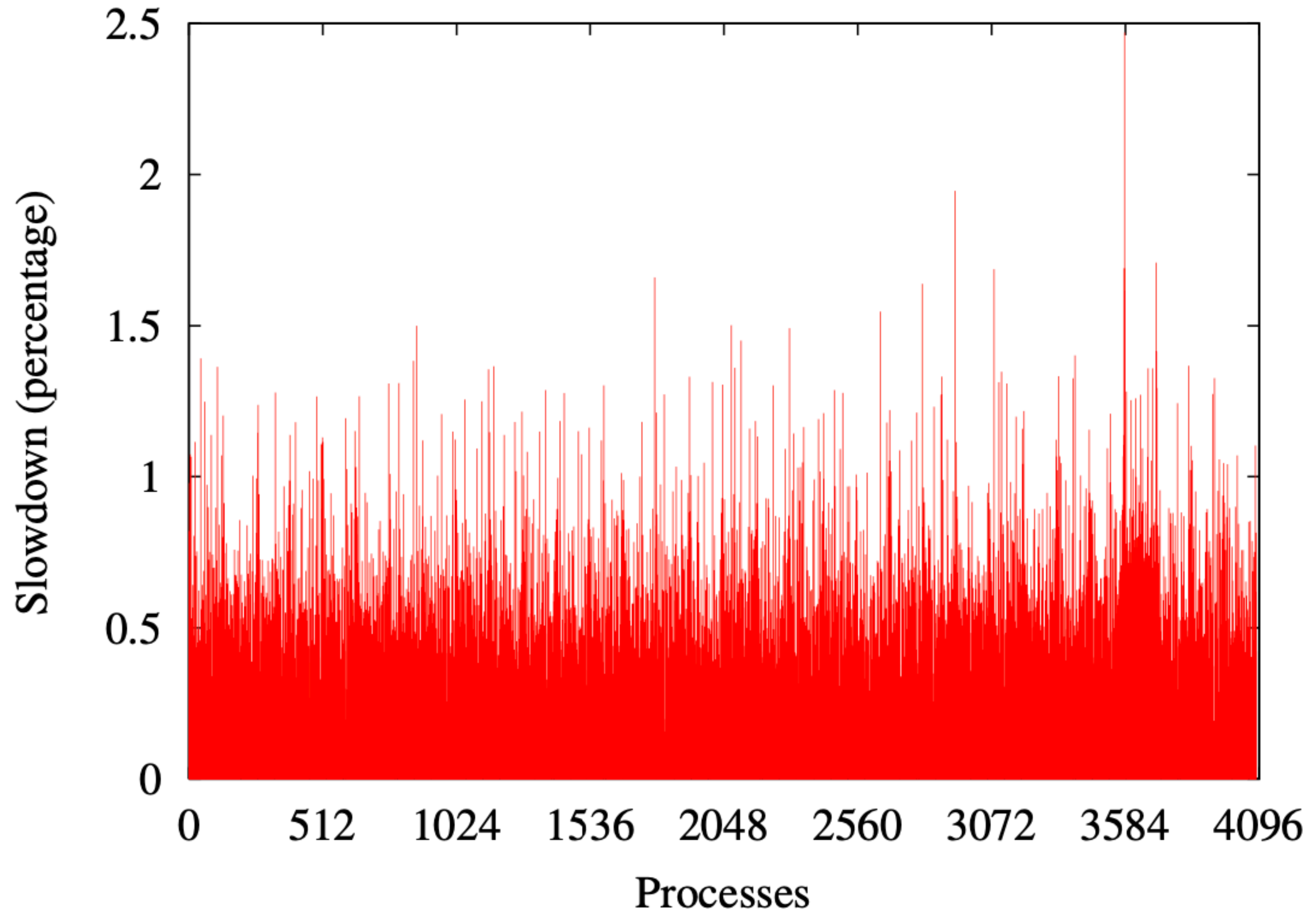


Figure 9: Results of the performance-variability microbenchmark

- A new benchmark of running 1 million iterations of synthetic computation, each iteration precisely 1ms in the absence of noise, total 1000 seconds
- Result is the same as previous benchmark
- Aggregate the four processor measurements taken on each node
- Found regular pattern of noise: every 32 nodes contain some nodes that are noisier

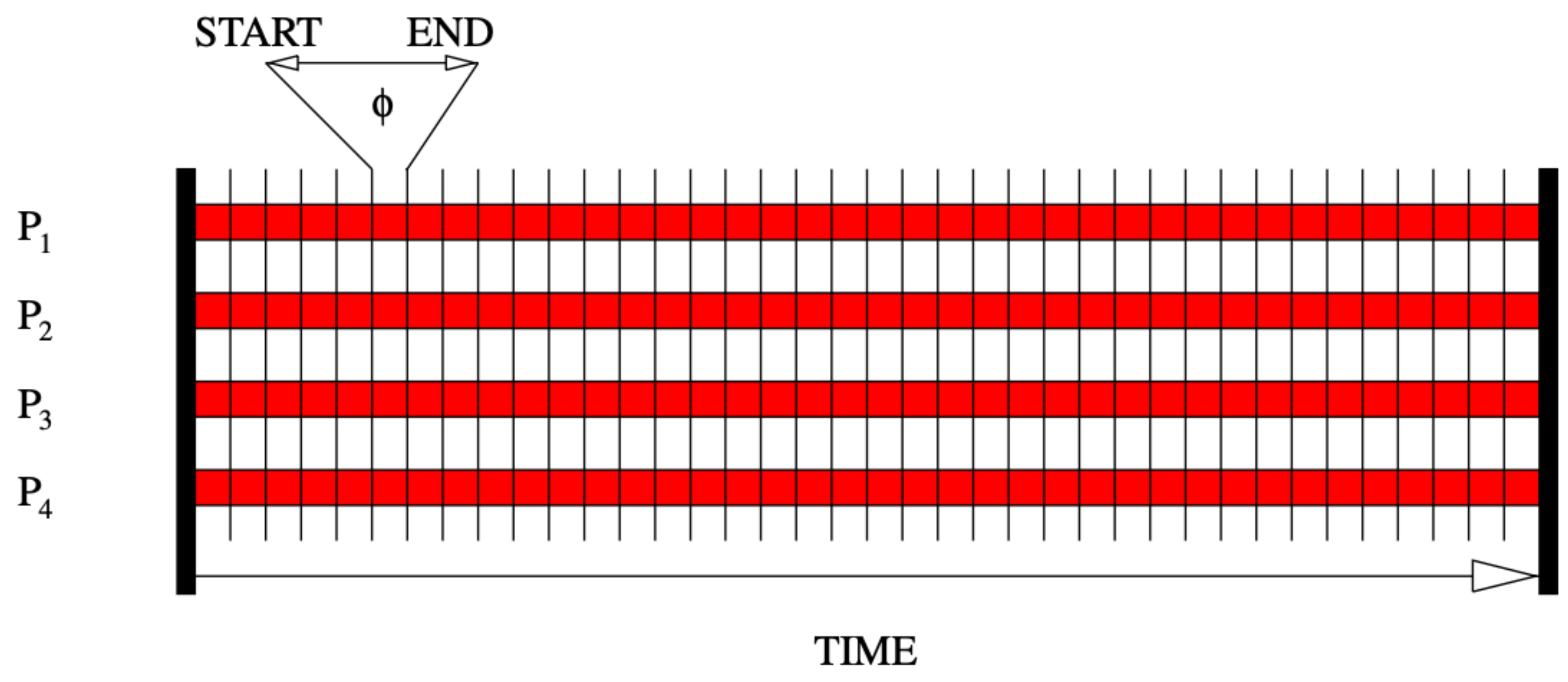


Figure 10: Performance-variability of the new microbenchmark

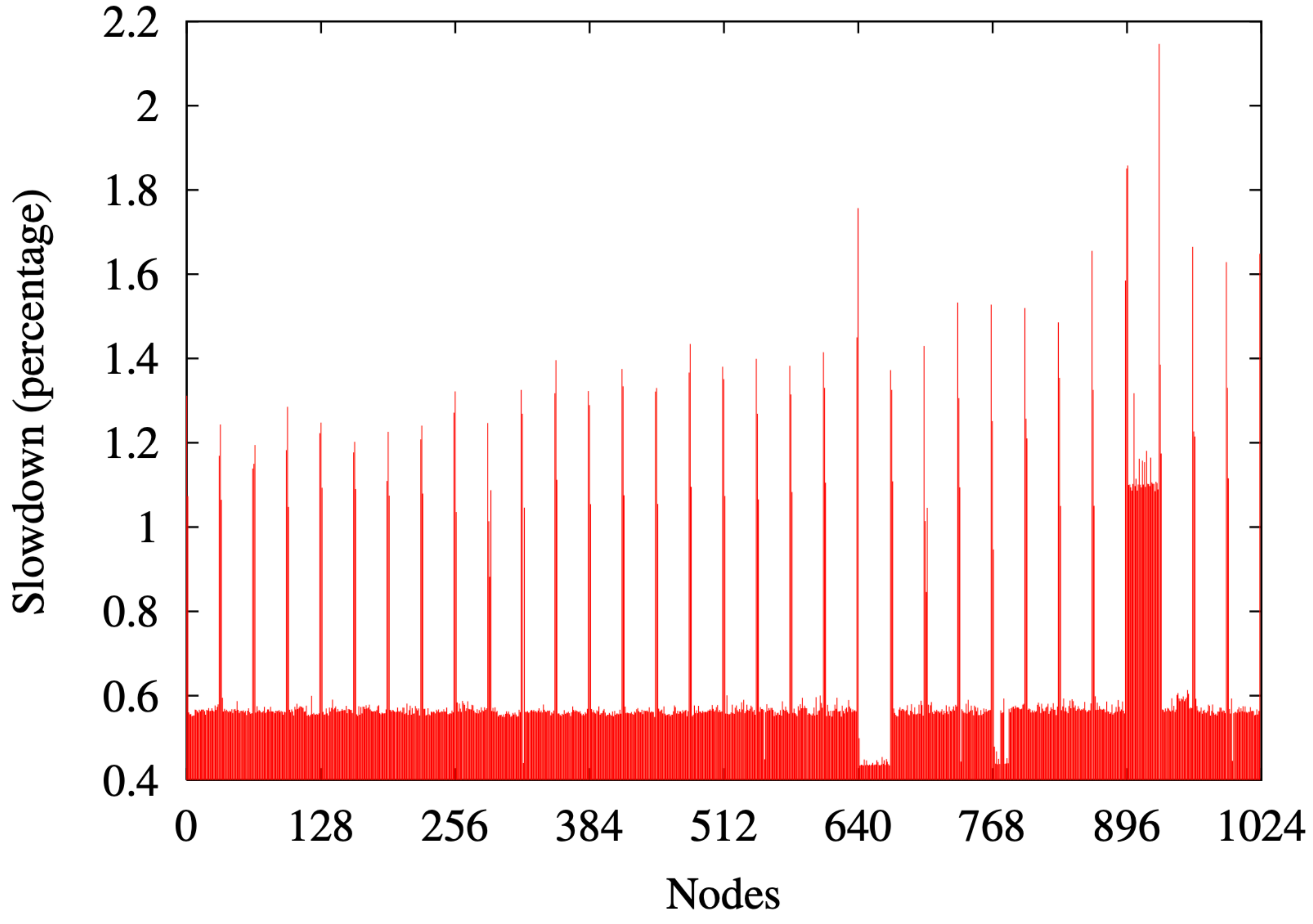


Figure 11: Results of the performance-variability microbenchmark analyzed on a per-node basis

- All nodes suffer a moderate amount of noise

- Node 0 (cluster manager), node 1 (the quorum node), node 31 (the RMS cluster monitor) suffer more

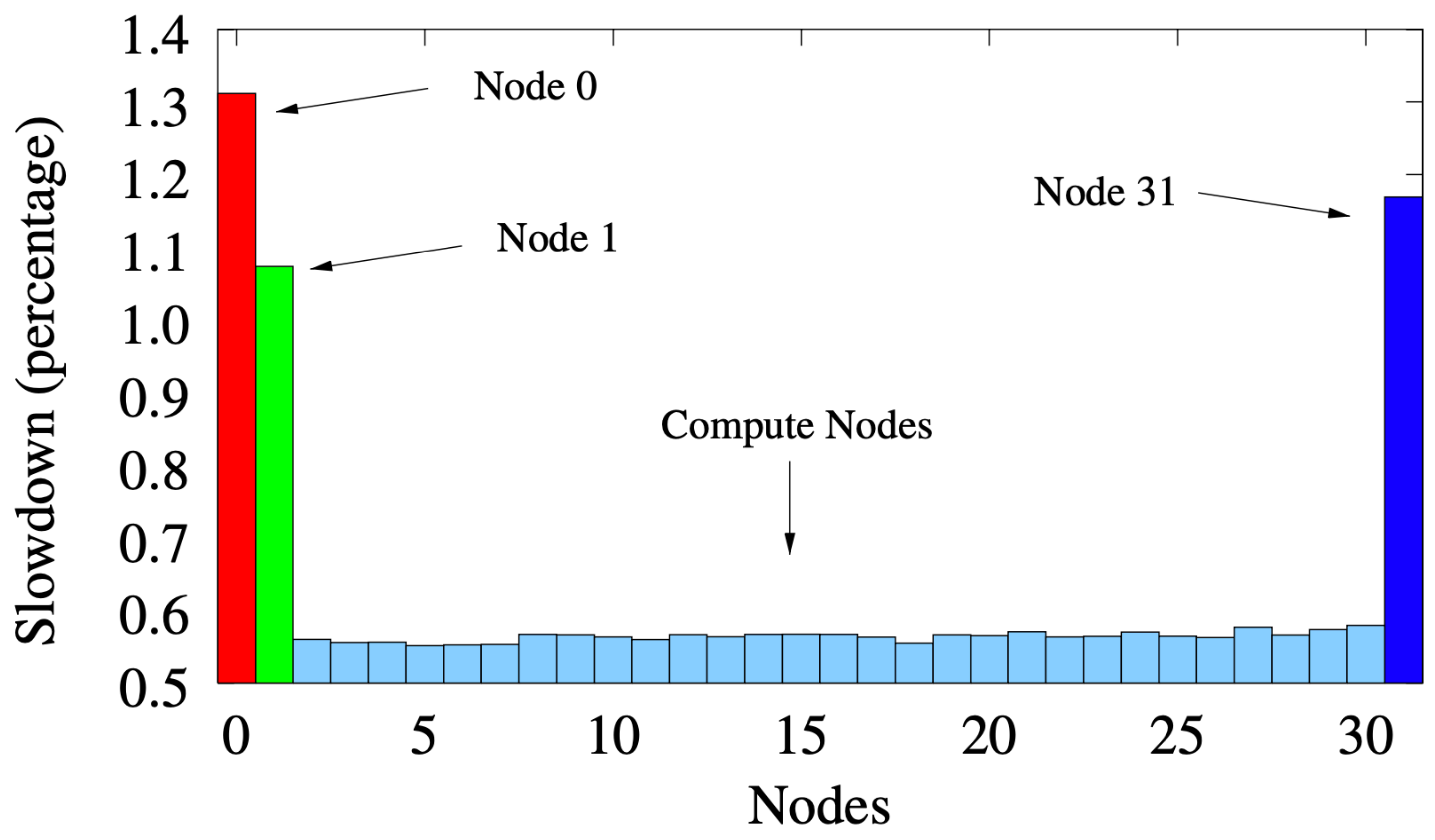
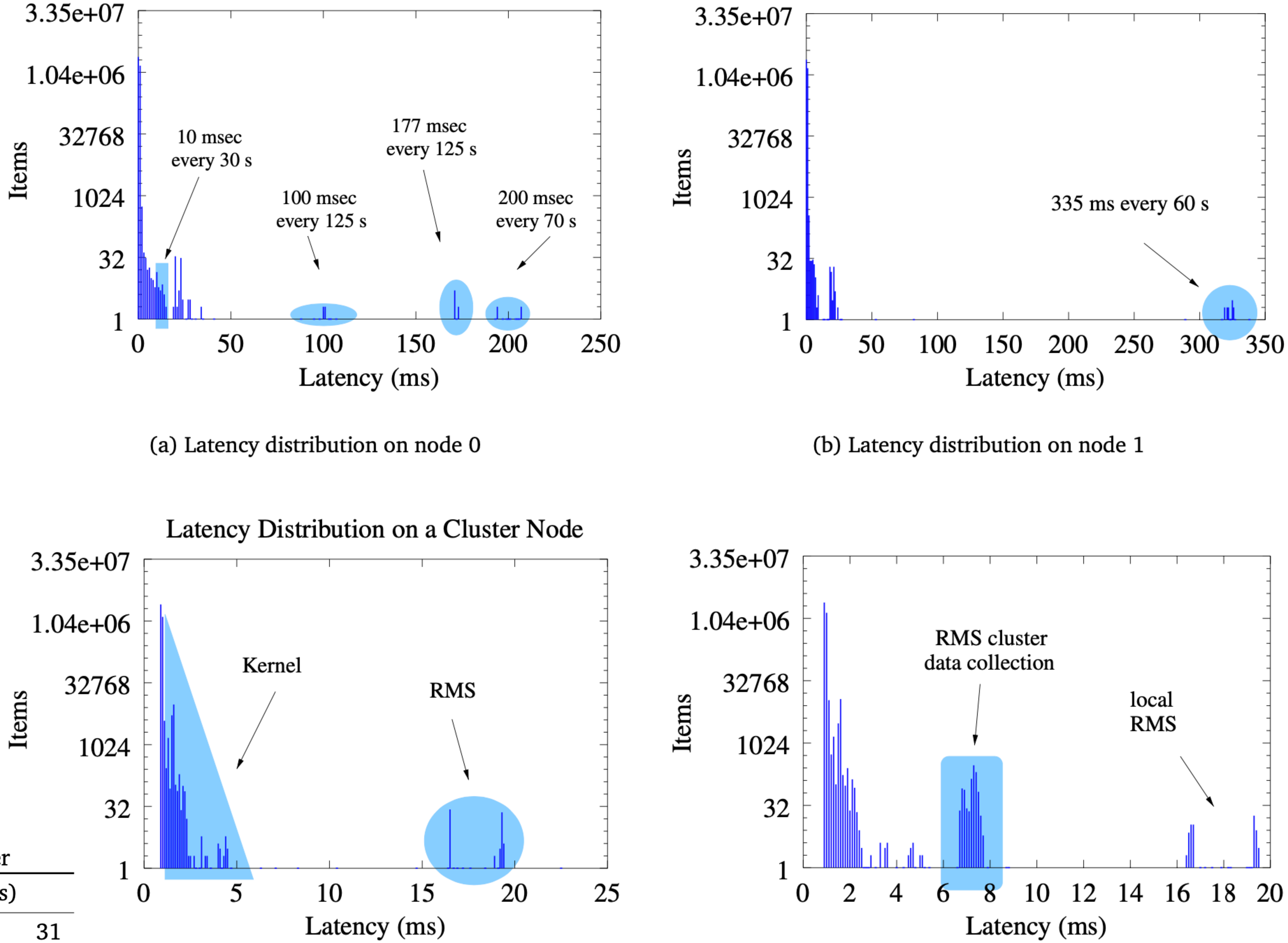


Figure 12: Slowdown per node within each 32-node cluster



(a) Latency distribution on node 0

(b) Latency distribution on node 1

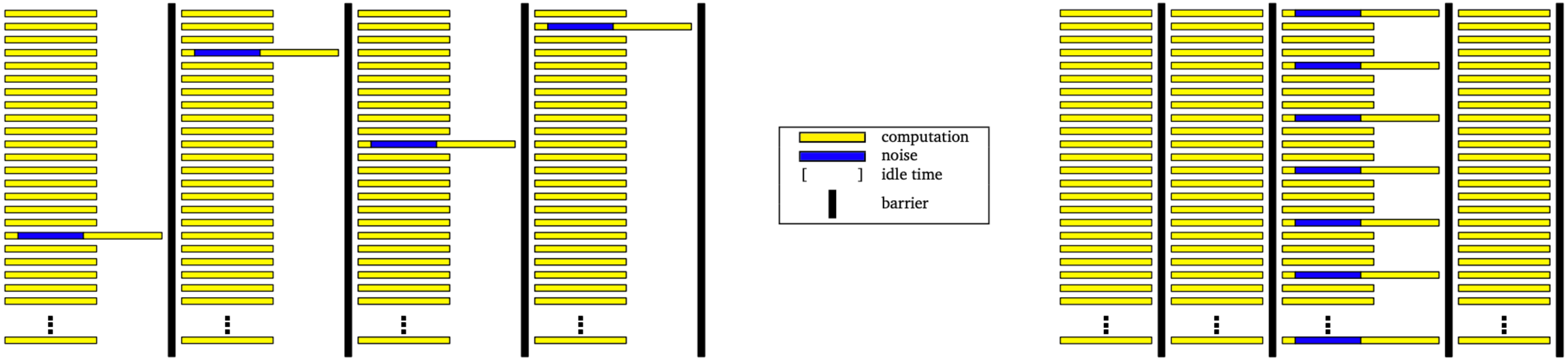
(c) Latency distribution on nodes 2–30

(d) Latency distribution on node 31

Figure 13: Identification of the events that cause the different types of noise

TABLE 2: Summary of noise on each 32-node cluster

Source of noise	Duration (ms)	Location (nodes) 0	1	2–30	31
Kernel	0–3	✔	✔	✔	✔
RMS dæmons	5–18	✔	✔	✔	✔
TruCluster dæmons	>18	✔	✔		



(a) Uncoordinated noise

(b) Coscheduled noise

Figure 14: Illustration of the impact of noise on synchronized computation

- A delay in a single process slows down the whole application
- Not possible or cost effective to remove daemons or kernel threads
- Solution: coschedule the activities, pay penalty only once

- Developed a simulator, taking account into all events
- Each event: <F, L, E, P>
- Frequency F, average duration L, the distribution E, the placement (set of nodes) P
- Remove noise on either node 0, 1 or 31, only 15% improvement
- Remove all three nodes, 35%
- Remove kernel noise: significant improvement
- More performance is lost to short but frequent noise on all nodes than to long but less frequent noise on just a few nodes

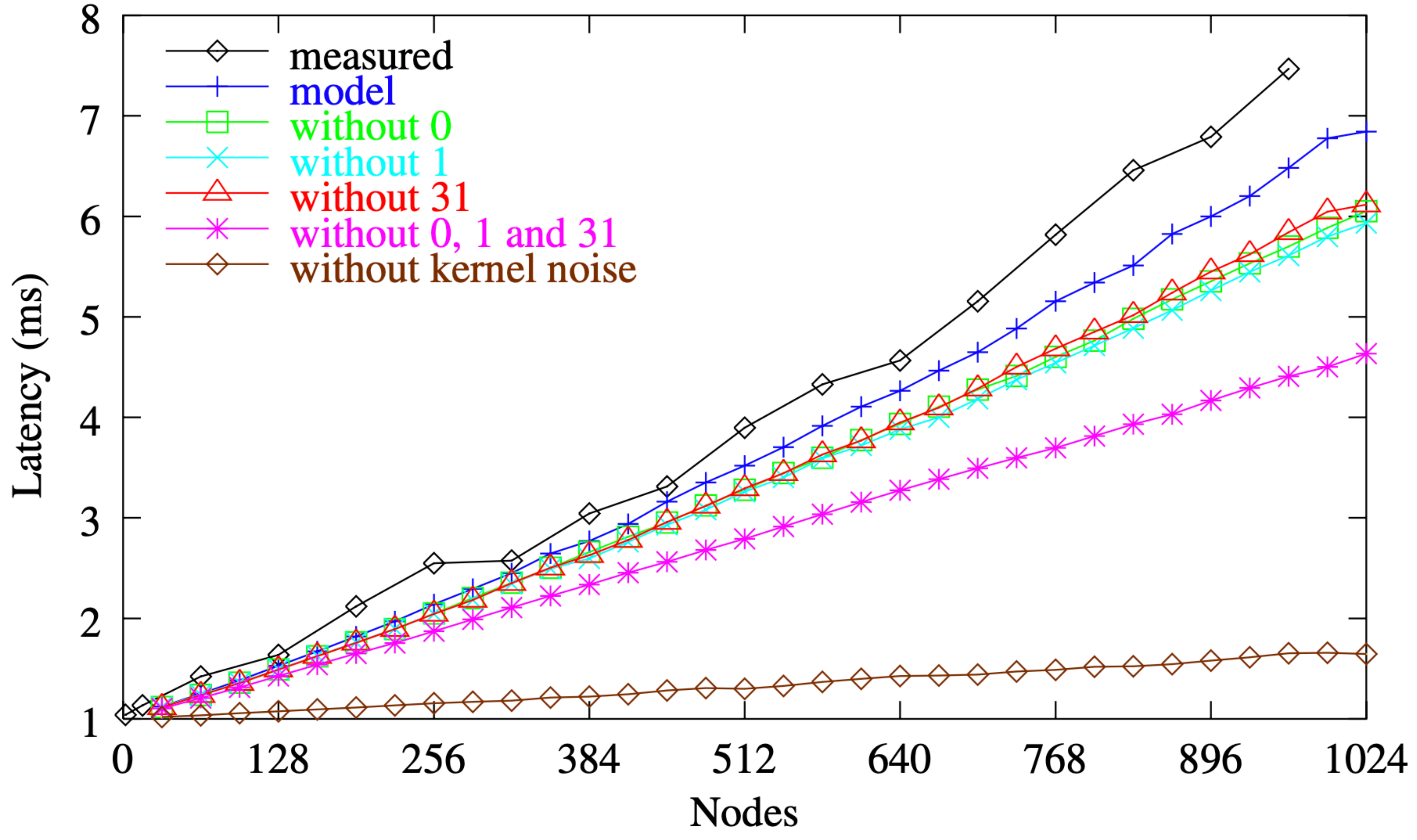


Figure 15: Simulated vs. experimental data with progressive exclusion of various sources of noise in the system

- The authors undertook some optimizations on ASCI Q
- Removed about ten daemons from all nodes
- Decreased the frequency of RMS monitoring by a factor of 2 on each node (30 -> 60 seconds)
- Moved several TruCluster daemons from node 1 and 2 to node 0 on each cluster
- Expected speed improvement is a factor of 2.2

- 3 different computational granularity - 0, 1, 5ms (length of computation between two barriers)
- Only shows performance improvement of micro benchmark
- Will this improve performance of SAGE?

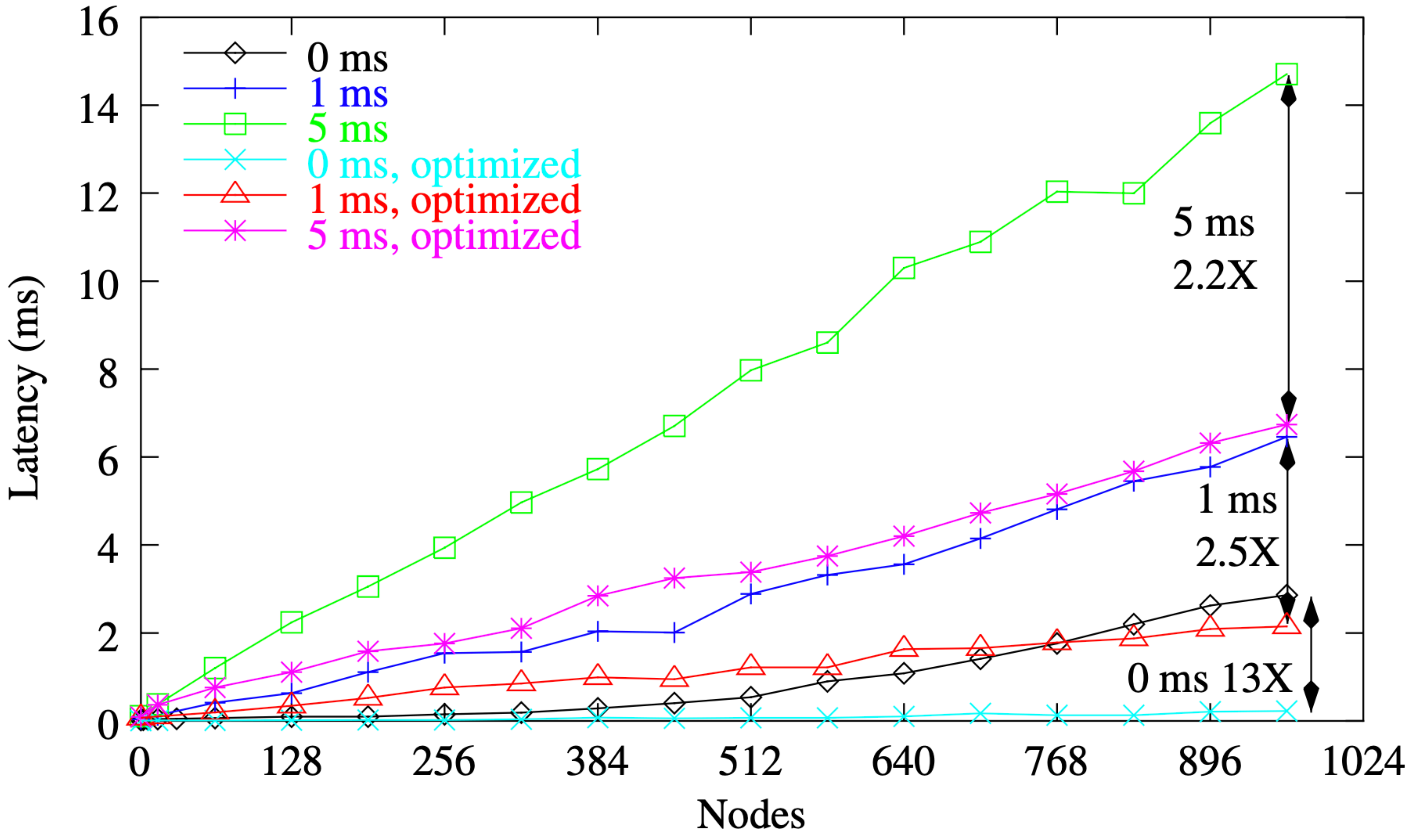


Figure 16: Performance improvements obtained on the barrier-synchronization microbenchmark for different computational granularities

- Jan-27-03 and May-01-03 are measured after noise removal
- May-01-03 (min) is min cycle time of over 50 cycles
- There is room for further improvement: remove one processor from node 0 and node 31, run system tasks

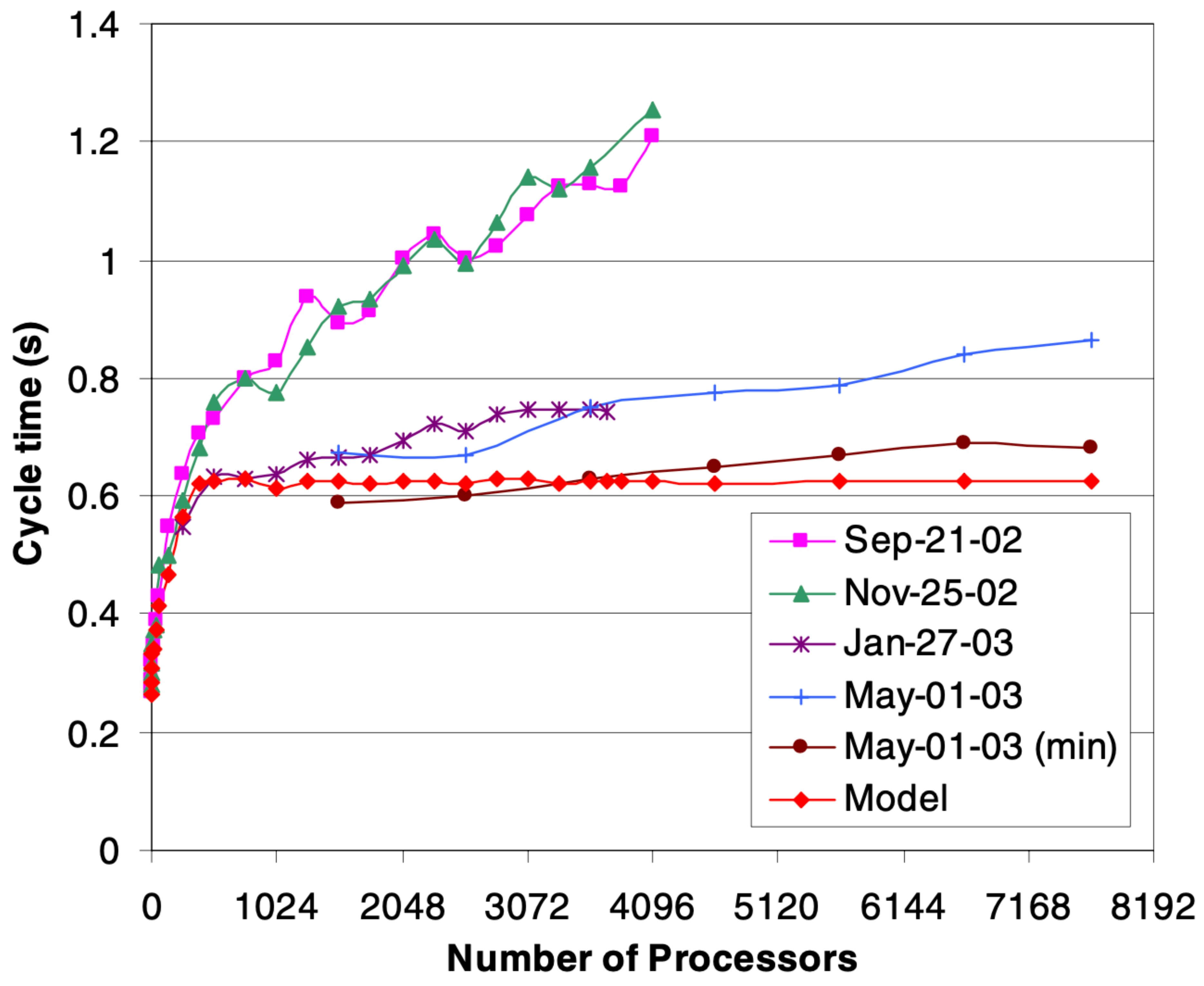
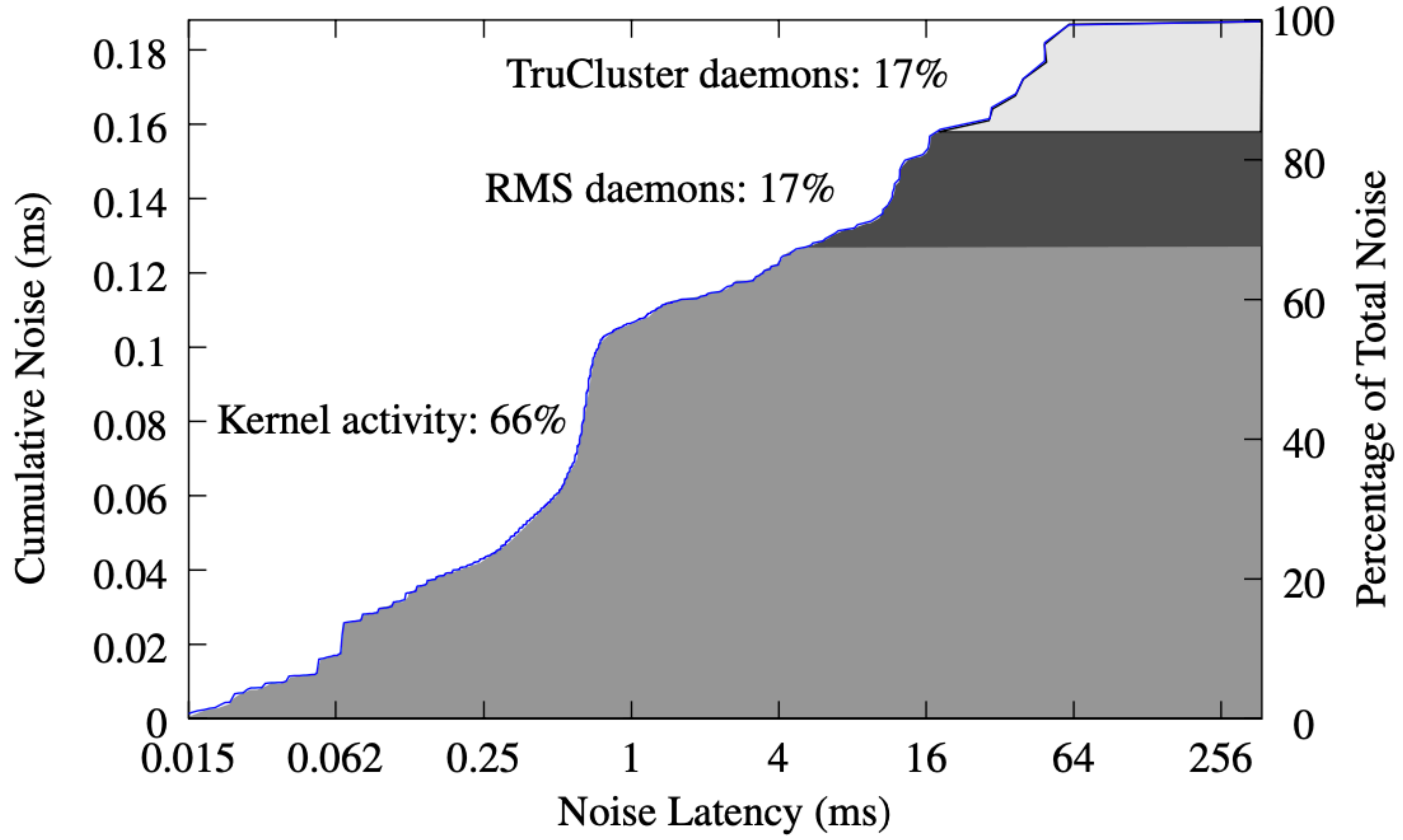


Figure 17: SAGE performance: expected and measured after noise removal

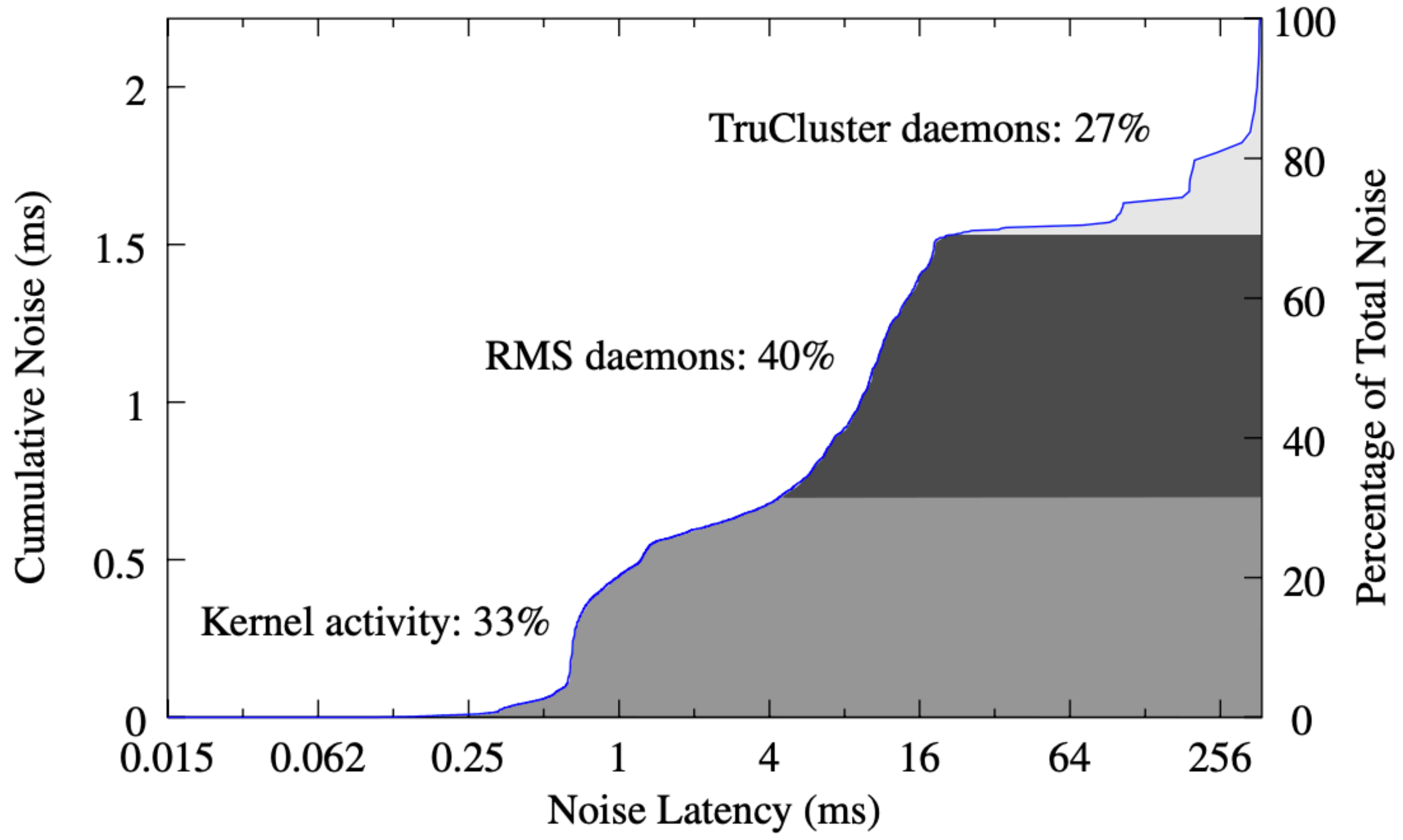
TABLE 3: SAGE effective performance after noise removal

Configuration	Usable processors	Cycle time	Processing rate (10^6 cell updates/sec.)	Improvement factor
Unoptimized system	8,192	1.60	69.1	—*N/A*—
3 processes/node	6,144	0.64	129.3	1.87
Without node 0	7,936	0.87	123.1	1.78
Without nodes 0 and 31	7,680	0.86	120.6	1.75
Without nodes 0 and 31 (best observed)	7,680	0.68	152.5	2.21
Model	8,192	0.63	178.4	2.58

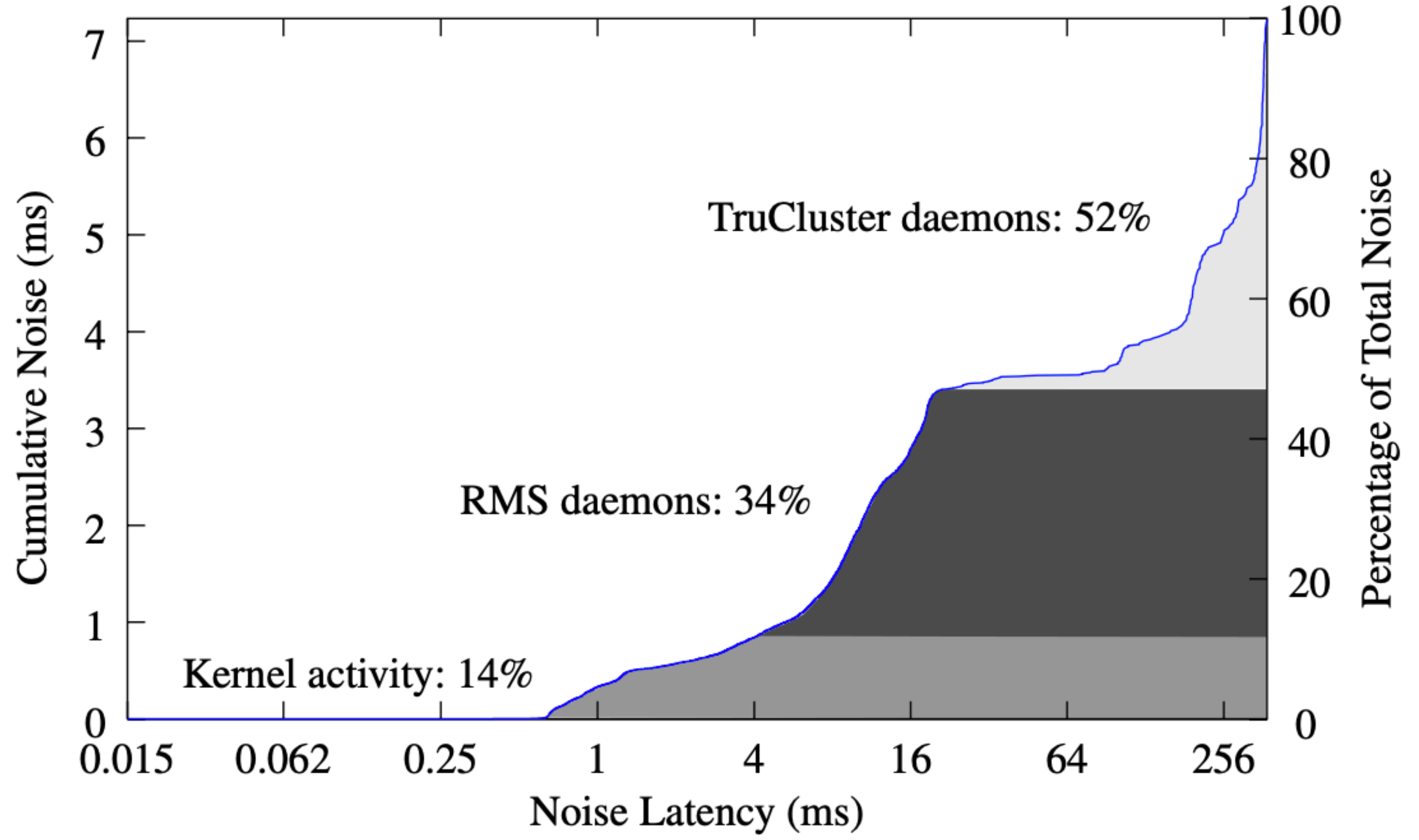
- Categorize the relative impact of each of the three primary sources of noise
- The computational granularity of the application “enter in resonance” with noise of a similar harmonic frequency and duration



(a) No intervening computation



(b) 1 ms of intervening computation



(c) 5 ms of intervening computation

Figure 18: Cumulative noise distribution for barrier synchronizations with different computational granularities

- X axis: duration of an individual occurrence of system noise
- Y axis: cumulative amount of barrier performance lost to noise
- 0 - 3ms: kernel activity, 5 - 18ms: RMS daemons, >18ms TruCluster daemons