Interferences between Communications and Computations in Distributed HPC Systems

Alexandre DENIS, Emmanuel JEANNOT, Philippe SWARTVAGHER
Inria Bordeaux – Sud-Ouest, France

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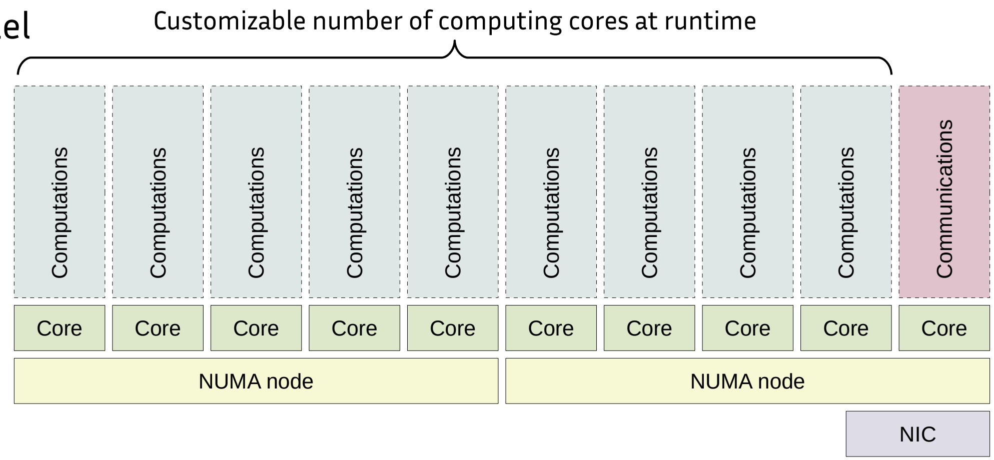
Introduction

- Communications: one of key factors for scalability
- Computations and communications in parallel: raising trend to get better performances
- Are there interferences between computations and communications ?
- Yes, communications can impact computations
  - Langguth, X. Cai, and M. Sourouri. 2018. Memory Bandwidth Contention: Communication vs Computation Tradeoffs in Supercomputers with Multicore Architectures. In 2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS). 497–506
  - T. Groves, R. E. Grant, and D. Arnold. 2016. NiMC: Characterizing and Eliminating Network-Induced Memory Contention. In 2016 IEEE International Parallel and Distributed Processing Symposium (IPDPS). 253–262.
- What about computations impacting communications ?

Context

- Distributed StarPU applications
  - Task-based runtime system for heterogeneous architectures

- Computations and communications in parallel
  - **One thread dedicated to communications**
  - Other threads perform computations
  - One thread bound per core



Origins of interferences ?

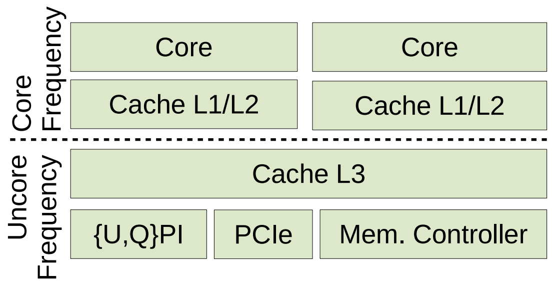
- Hypotheses:
  - Processor frequency variations
  - Memory contention
  - Runtime system

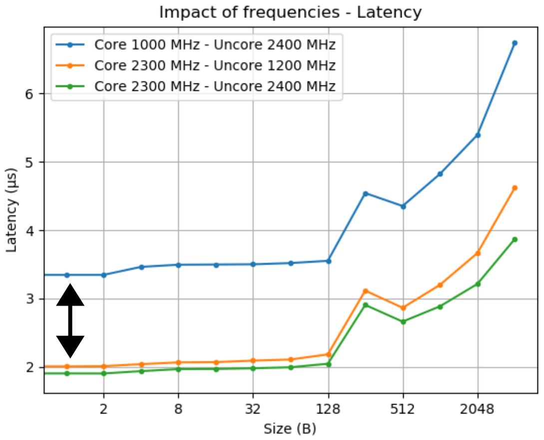
Frequency variations

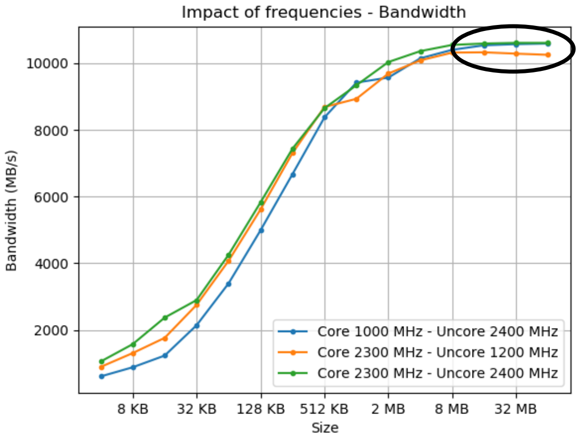
- Network performances are comprised of:
  - > Software overhead, to set up the communication
  - > Memory transfer time, to move the data between main memory and NIC
- Duration of these two steps: influenced by processor frequencies
- Dynamic frequency scaling of processors:
  - > **Change processor frequency according to workload** to avoid overheating
  - > AVX instructions (for computations) can force the core to lower its frequency

Frequency variations

- With alone communications and constant frequencies:
  - > *Core* frequency → has an impact on **network latency**
  - > *Uncore* frequency → has an impact on **network bandwidth**





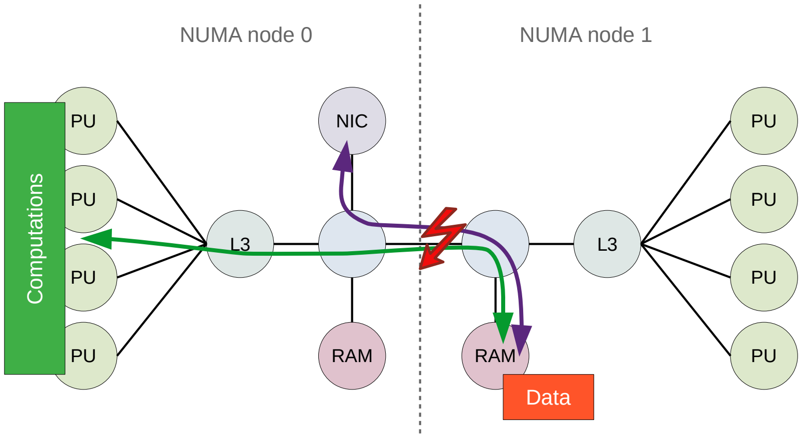


Frequency variations

- However, with computations in parallel of communications:
  - > CPU-bound computations
  - > Computing cores can change their frequency...
  - > ... but not the communicating core
    - → negligible impact on communications

Memory contention

- For computations, data move between RAM and cores
- For communications, data move between RAM and NIC
- → **Contention on memory bus** !



Experimental protocol

- **Goal**: compare performances of computations and communications alone and in parallel
  - → benchmarking program
- 3 steps:
  1) Computations alone
  2) Communications alone

  } to get their nominal performances → Compare them

  3) Computations and communications in parallel → to see the impact of one on each other → Compare them

- Computations:
  - Memory-bound: STREAM kernels:

```
COPY : for(i=0; i<ARRAY_SIZE; i++) A[i]=B[i]
TRIAD: for(i=0; i<ARRAY_SIZE; i++) C[i]=A[i]+3.14*B[i]
```

    → memory bandwidth per core (higher is better)
  - Embarrassingly parallel, independant from communications

- Communications:
  - 2 MPI processes (one per node)
  - Ping-pongs to measure network latency (with 4 B) and bandwidth (with 64 MB)

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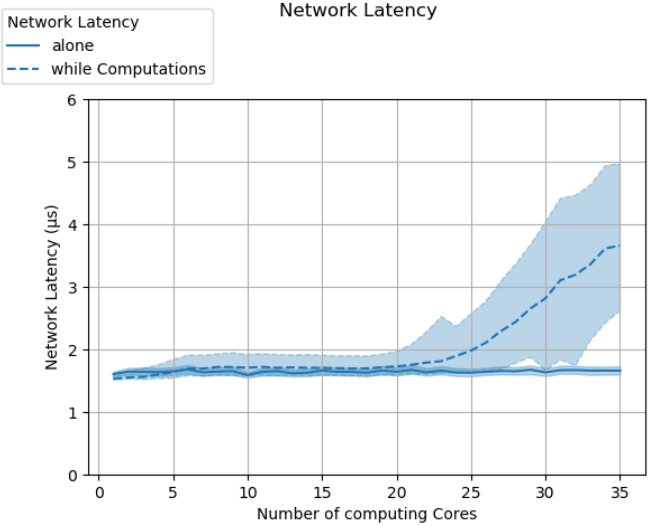
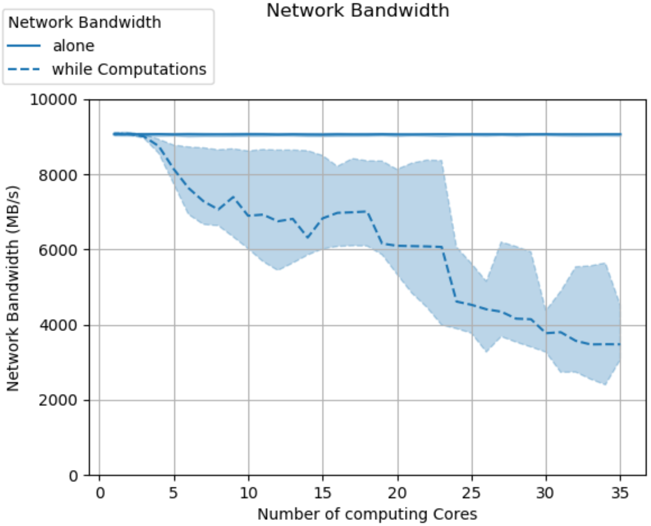
Impacts of memory contention on communications



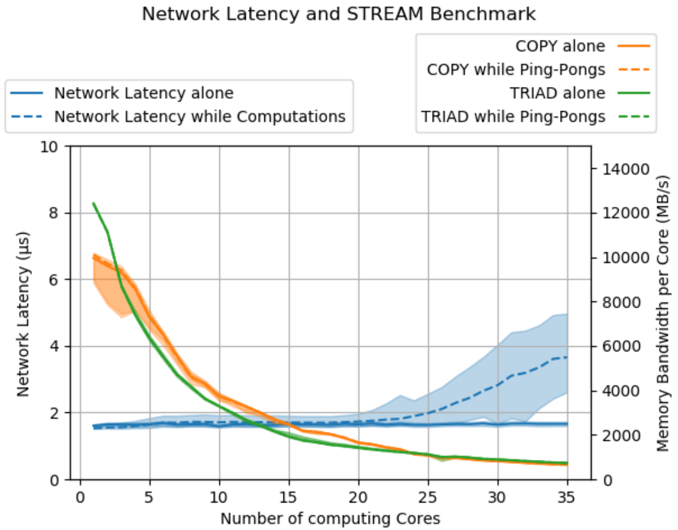
Network Latency Benchmark: **4 B**



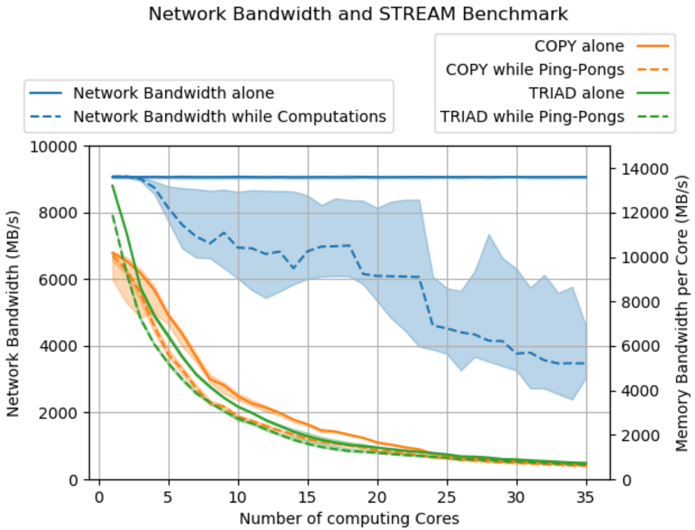
Network Bandwidth Benchmark: **64 MB**

- Network latency impacted from 23 computing cores
- Network bandwidth impacted from 3 computing cores

Impacts of memory contention on communications & computations



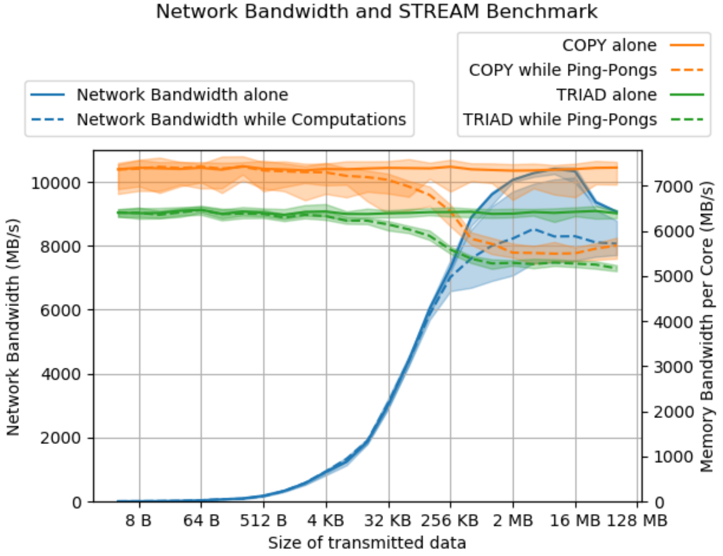
Network Latency Benchmark: **4 B**



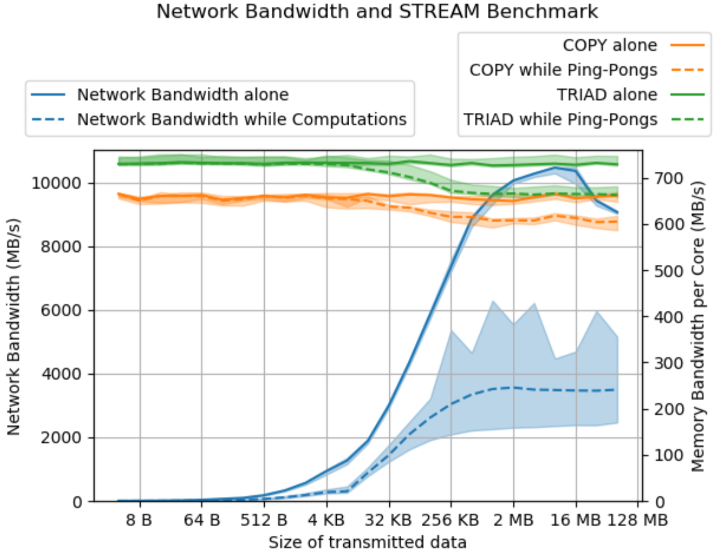
Network Bandwidth Benchmark: **64 MB**

- Computations impacted by ping-pongs to measure network bandwidth

Impacts of message size



With **5** computing cores

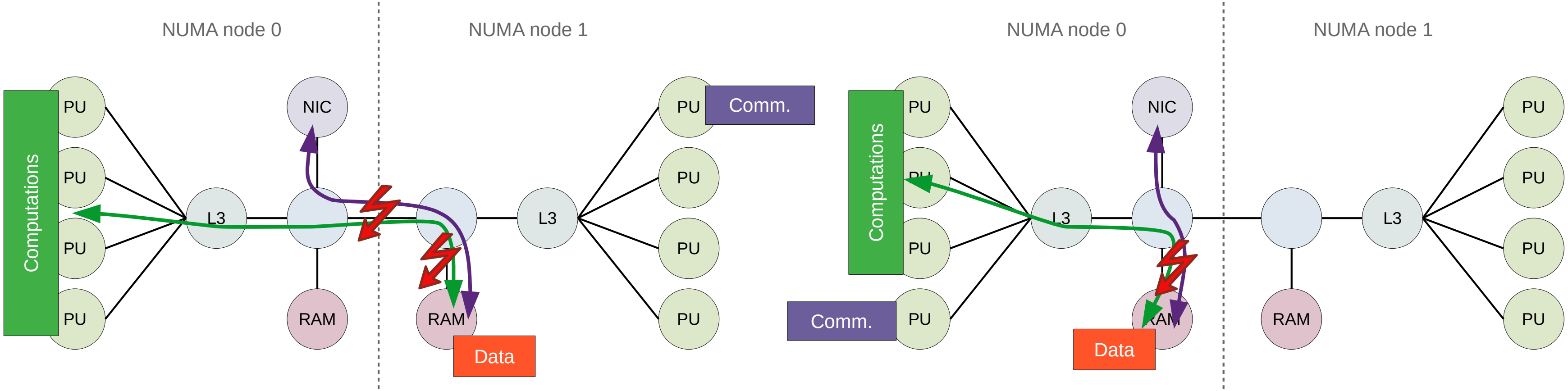


With **35** computing cores

- Large number of computing cores impacts a **wide range of message sizes**
- Large message sizes can disturb even a small number of computing cores

Impacts of placements

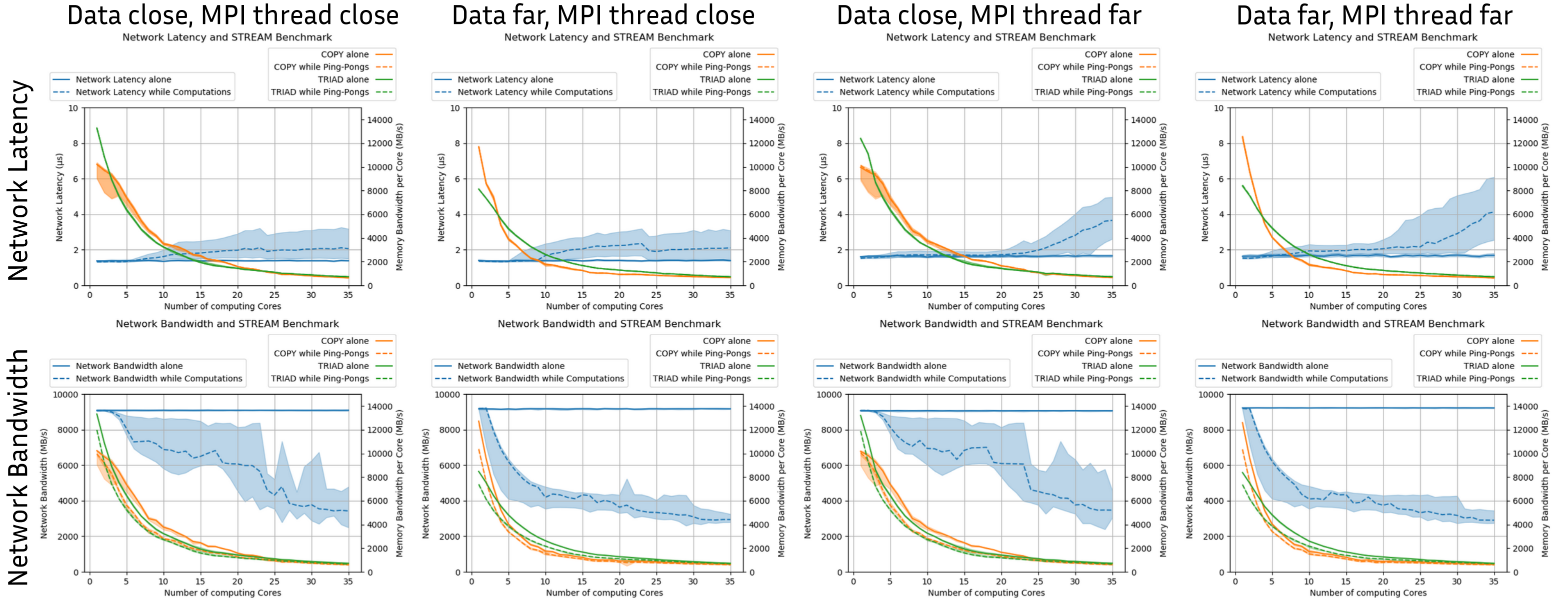
- **Placement** of data and communication thread **regarding the NIC**
  - > Change the path taken by the data and thus change the memory contention



One placement configuration

Another placement configuration

Impacts of placements

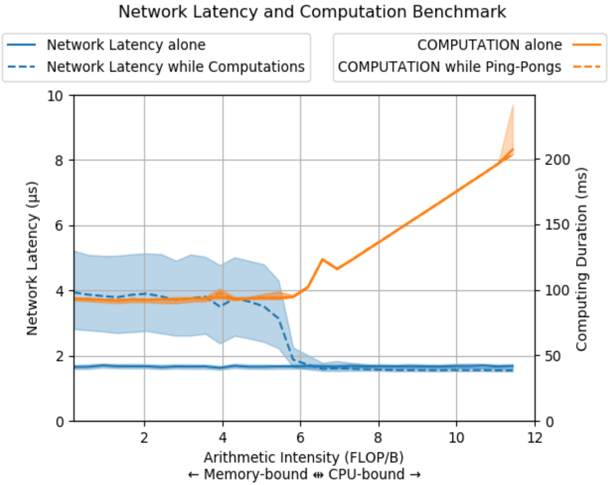


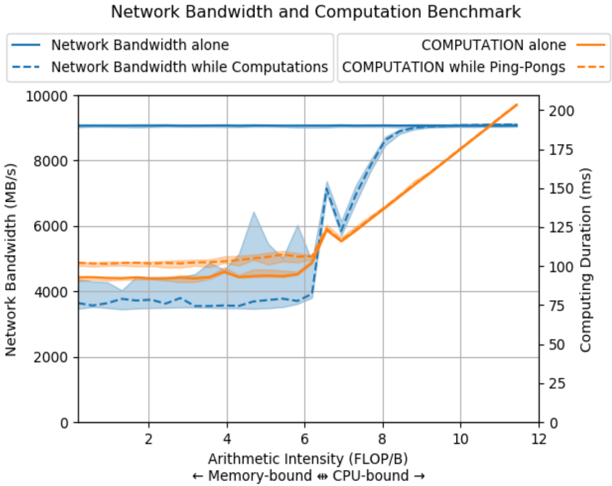
- Communication thread far from the NIC: network latency is more impacted by contention
- Data far from the NIC: network bandwidth is more impacted by contention
- STREAM always more impacted with network bandwidth benchmark in parallel

Impacts of arithmetic intensity

- *Arithmetic intensity*: number of flops per byte of moved data
- → `TRIAD` with tunable arithmetic intensity

```
for (i = 0; i < ARRAY_SIZE; i++)
    for (c = 0; c < cursor; c++)
        C[i] = A[i] + 3.14 * B[i]
```

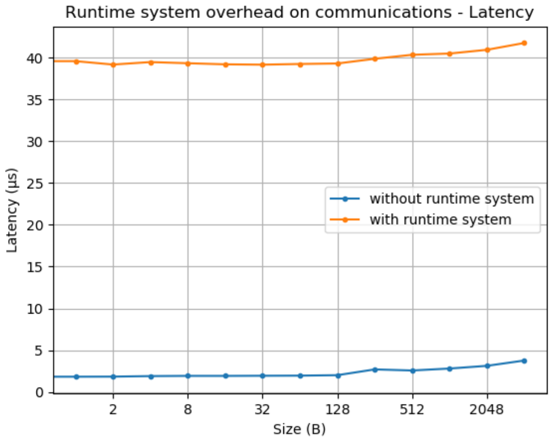


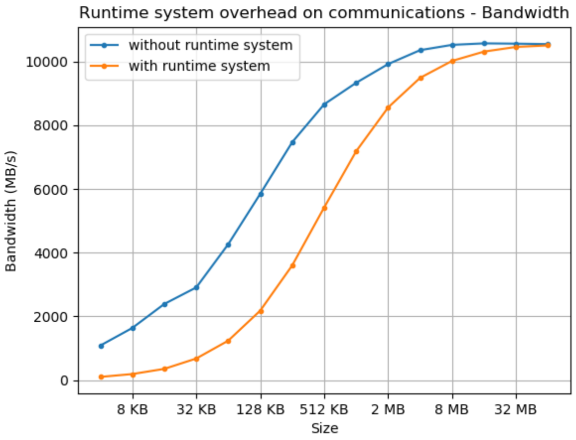


- **Computations more CPU-bound → less trafic on memory bus → less contention**

Impact of a runtime system

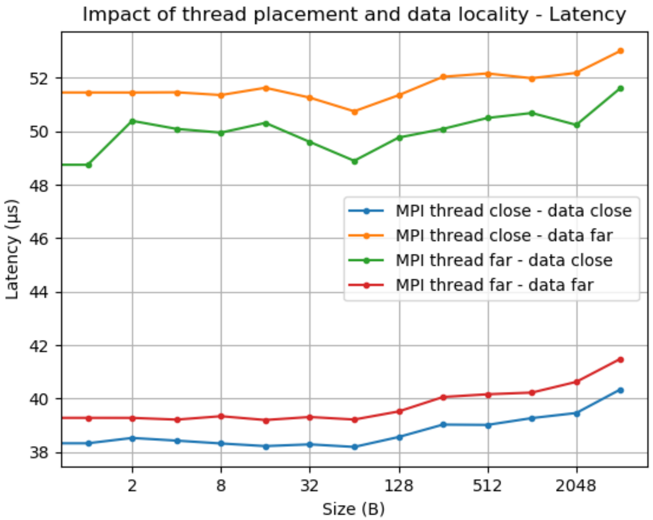
- Runtime system: **StarPU**
  - > Distributed task-based runtime system
  - > Abstracts network communications
- StarPU's overhead on lonely communications:
  - > Without runtime system: `MPI_Send()` / `MPI_Recv()`
  - > With runtime system: `starpu_mpi_send()` / `starpu_mpi_recv()`

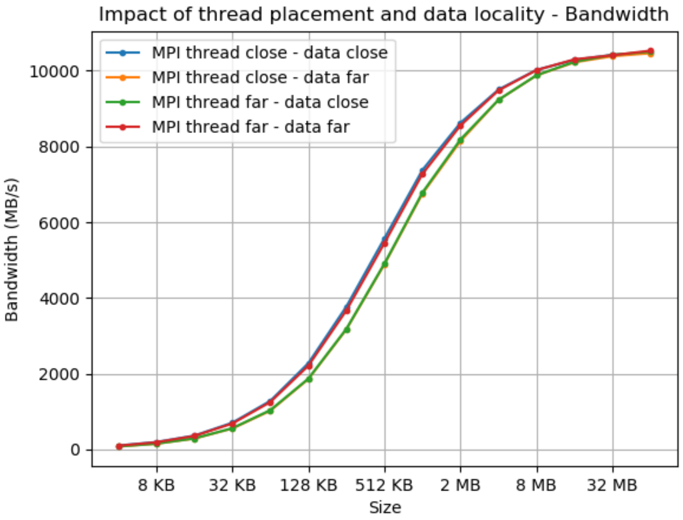




Impacts of placements with StarPU

- One thread dedicated to communication progression

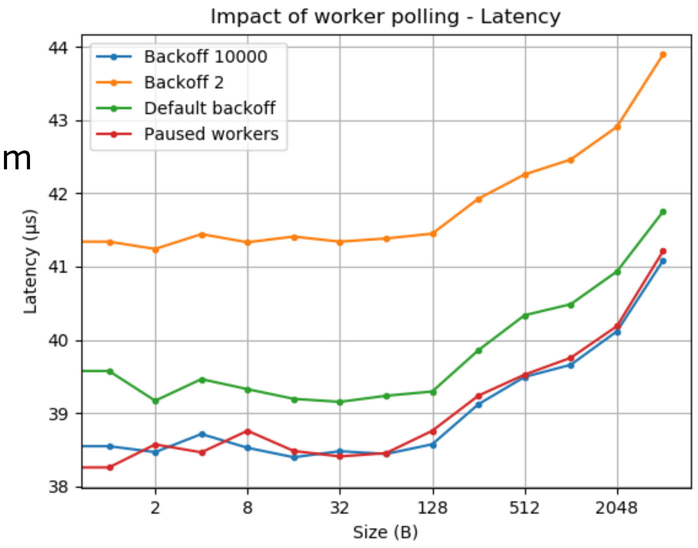




- Data to communicate has to be on **the same NUMA node** as the core running the communication thread.

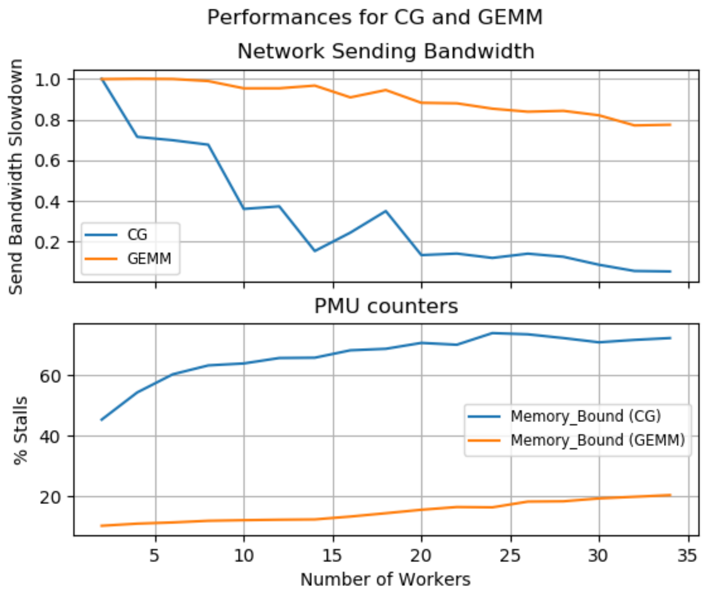
Impact of worker polling

- Each StarPU worker gets the next task to execute from a list
  - To be reactive enough: active wait by **polling**
  - Wait for few `nops` between each peek
  - Number of `nops` defined by an **exponential backoff** algorithm
- One parameter for this algorithm:
  - High value: workers poll rarely
  - Low value: workers poll frequently
- **Frequently polling workers impact communication latency**



Use-cases: computational kernels

- Computational kernels:
  - > Dense conjugate gradient (CG)
  - > Dense general matrix-matrix multiplication (GEMM)
  - > On top of StarPU
- Metrics:
  - > Impact on network performance
  - > Number of stalled cycles → lost cycles waiting for memory
- CG is **more memory-bound** than GEMM:
  - > CG has more stalls
  - > CG has a **network bandwidth more impacted**



Conclusion

- Computations and communications in parallel to get better performances in distributed HPC applications
- Side-by-side computations and communications
  - > Can disturb computations
  - > Can **highly impact communications**
- Main factor of interferences: **memory contention**, influenced by placement, message size, arithmetic intensity, runtime system overhead
- Behaviours also observed with real-world computational kernels
- Future work:
  - > Model these interactions
  - > Take into account these interactions in runtime systems to minimize them
  - > Same study with GPUs

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