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Throughput Optimization With a NUMA-aware Runtime System for Efficient Scientific Data Streaming

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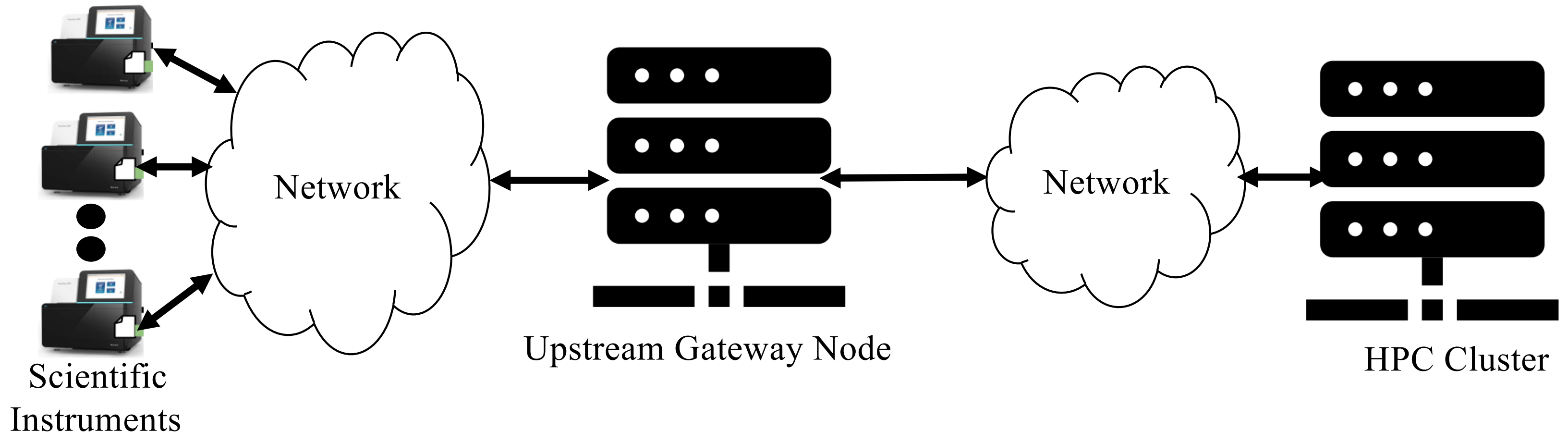
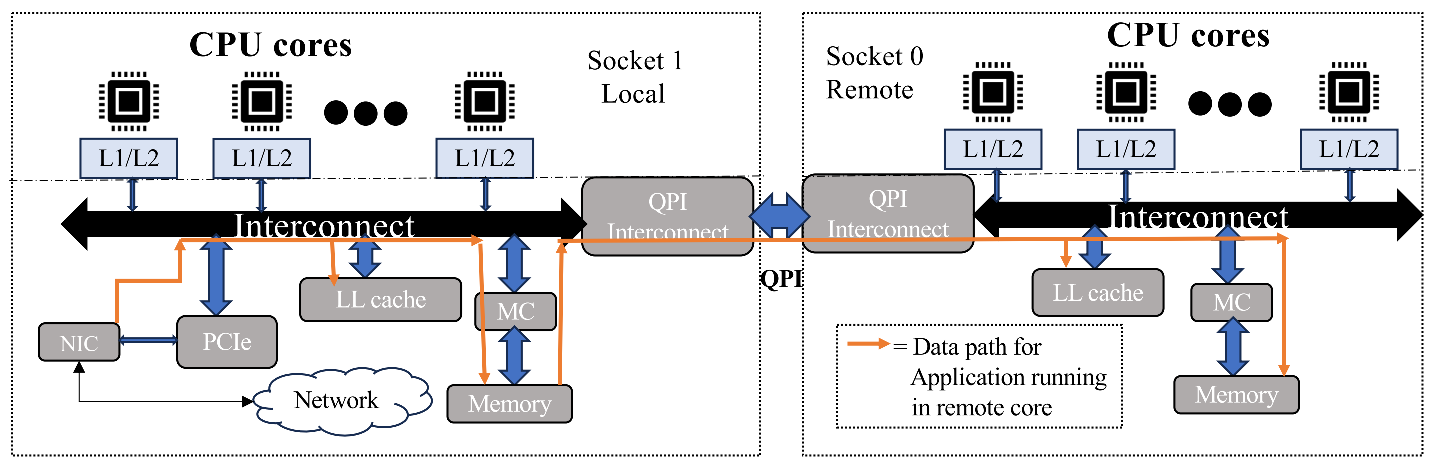
Addressing High-Speed Data Streaming in Scientific Research



- Rapid Data Generation Rates
- Infrastructure Bottlenecks
- Need for Upgraded Upstream Processing:

- Gateway Node Functions
- Optimized System Architecture
- Scalability for Future Demands

NUMA Considerations and Performance Management



- NUMA Architecture Basics
- Memory Access in NUMA
- NIC Operation and NUMA

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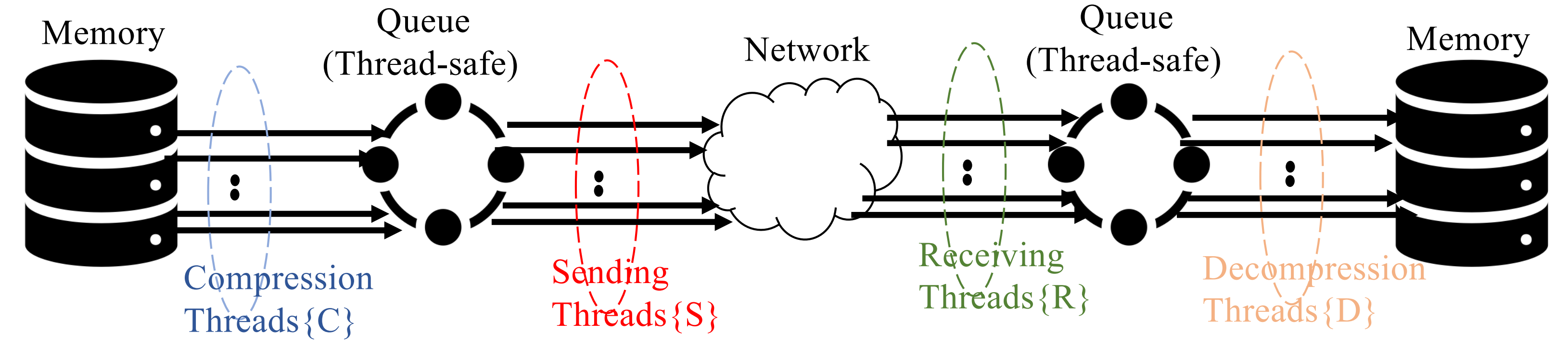
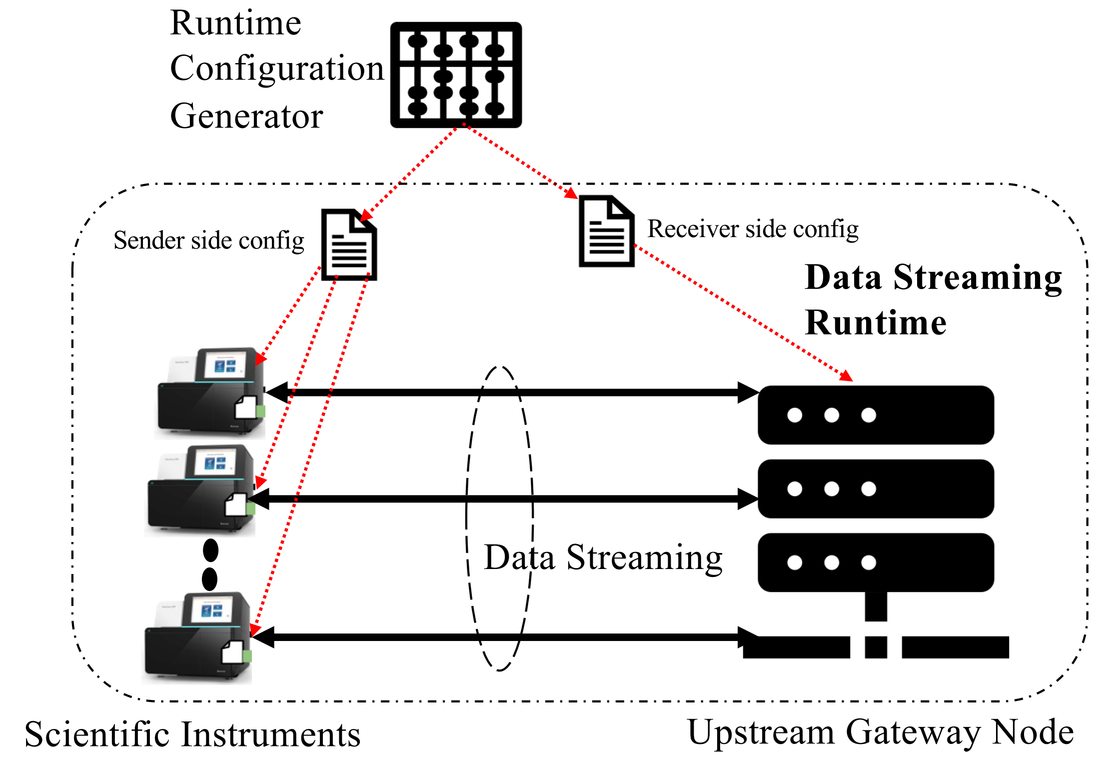
The Role and Objectives of the Runtime System



- Optimized Packet Processing
- Reducing Cross-Socket Traffic

Overview of the Runtime System Framework



- Runtime Configuration Generator
- Distributed Framework

Dataset and Compression-Decompression Algorithms

- **Dataset Characteristics:**
  - Utilized a synthesized 16 GB dataset reflective of real tomographic data, processed in 11.0592 MB chunks.

- **Compression-Decompression Algorithms:**
  - LZ4 algorithm selected for its speed and favorable compression ratio, achieving an average 2:1 compression.

Compression Behavior and Performance with NUMA

Goal: Maximize Resource Utilization and Minimize Network I/O

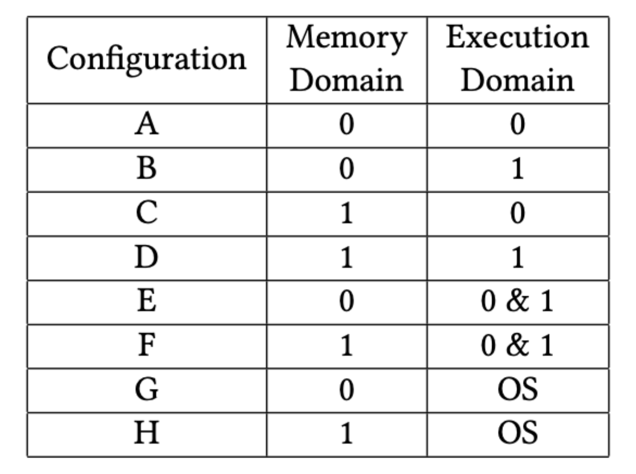
- Use available CPU cores for efficient data compression, effectively doubling the data transfer speed.

Strategy: Employ Data Compression to Enhance Throughput

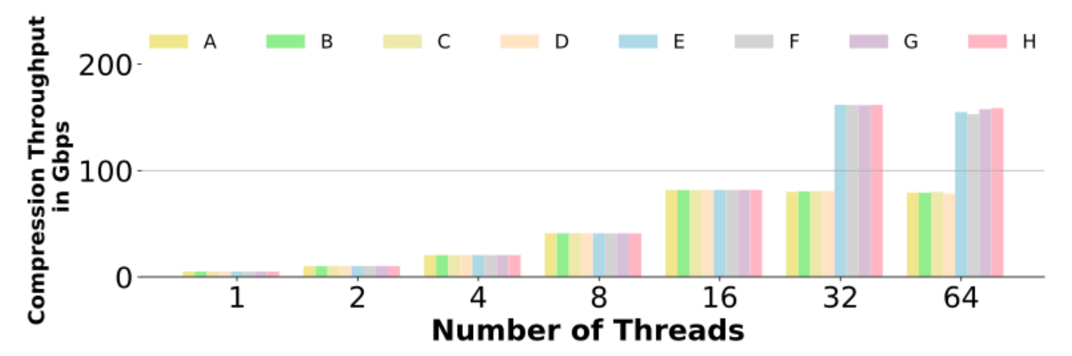
- Implement LZ4 compression algorithm for real-time data compression with a 2:1 compression ratio.

Observation: Compression Throughput and CPU Core Count

- Increased thread count improves compression speed up to the number of available CPU cores; beyond that, performance plateaus due to context switching.



Configuration	Memory Domain	Execution Domain
A	0	0
B	0	1
C	1	0
D	1	1
E	0	0 & 1
F	1	0 & 1
G	0	OS
H	1	OS



Decompression Behavior and Performance with NUMA

Goal: Analyze Decompression Speed Influencers

- Determine the impact of the number of decompression threads and their NUMA domain alignment on performance.

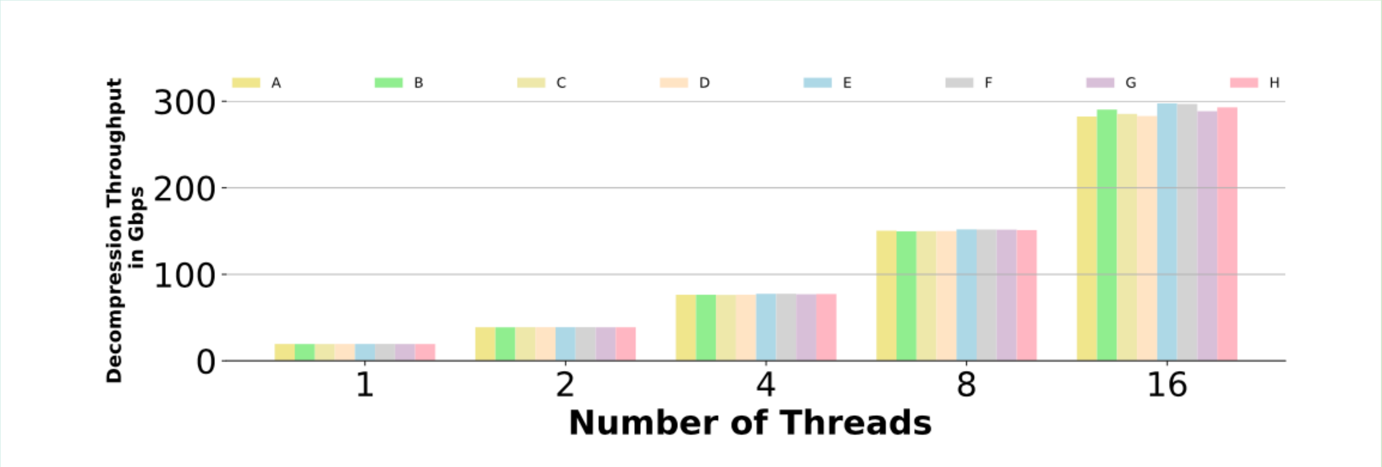
Strategy: Optimize Thread Distribution Across NUMA Domains

- Decompression speed improves with additional threads, with best performance when evenly spread across NUMA domains.

Observation: Decompression Throughput Unaffected by NUMA Domain

- Decompression performance remains consistent regardless of the NUMA domain of data storage or execution.

Configuration	Memory Domain	Execution Domain
A	0	0
B	0	1
C	1	0
D	1	1
E	0	0 & 1
F	1	0 & 1
G	0	OS
H	1	OS

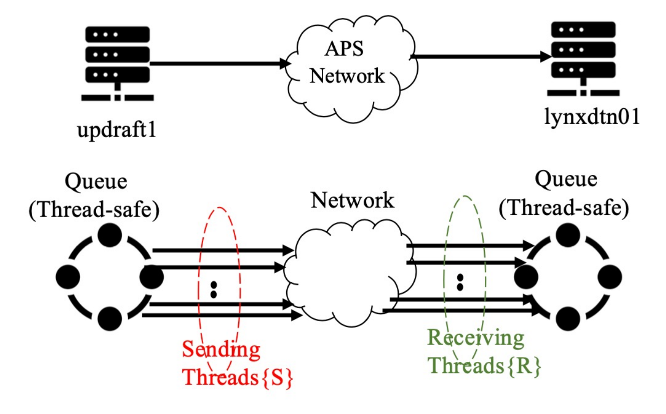


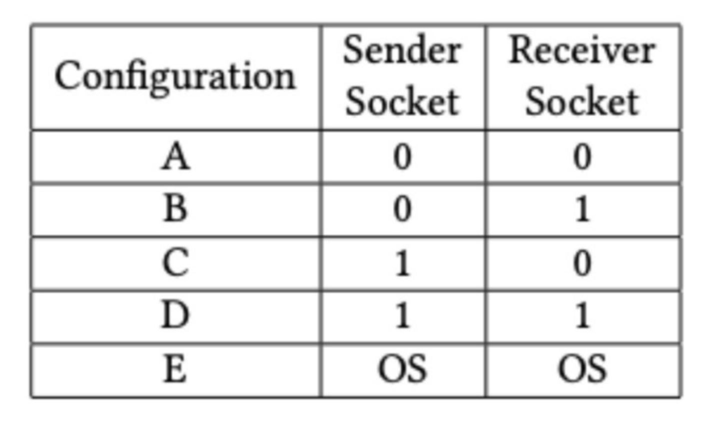
Sending and Receiving Threads Performance with NUMA

- **Goal: Understand Thread Influence on Network Throughput**
  - Examine the effect of the number and location of sending and receiving threads on network throughput.

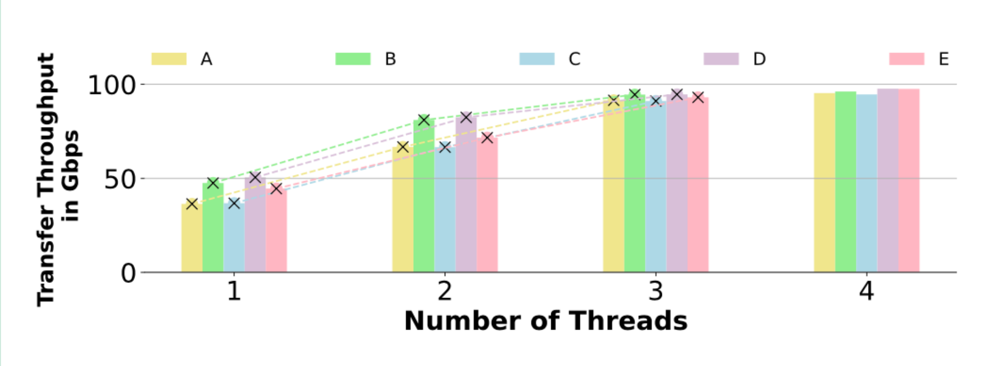
- **Strategy: Symmetrical Thread Arrangement Across NUMA Domains**
  - Deploy an equal number of sending and receiving threads, creating a balanced TCP streaming environment.

- **Observation: Receiving Thread Location Impacts Throughput**
  - Placing receiving threads in the same NUMA domain as the NIC significantly boosts throughput, especially for smaller thread counts.





Configuration	Sender Socket	Receiver Socket
A	0	0
B	0	1
C	1	0
D	1	1
E	OS	OS

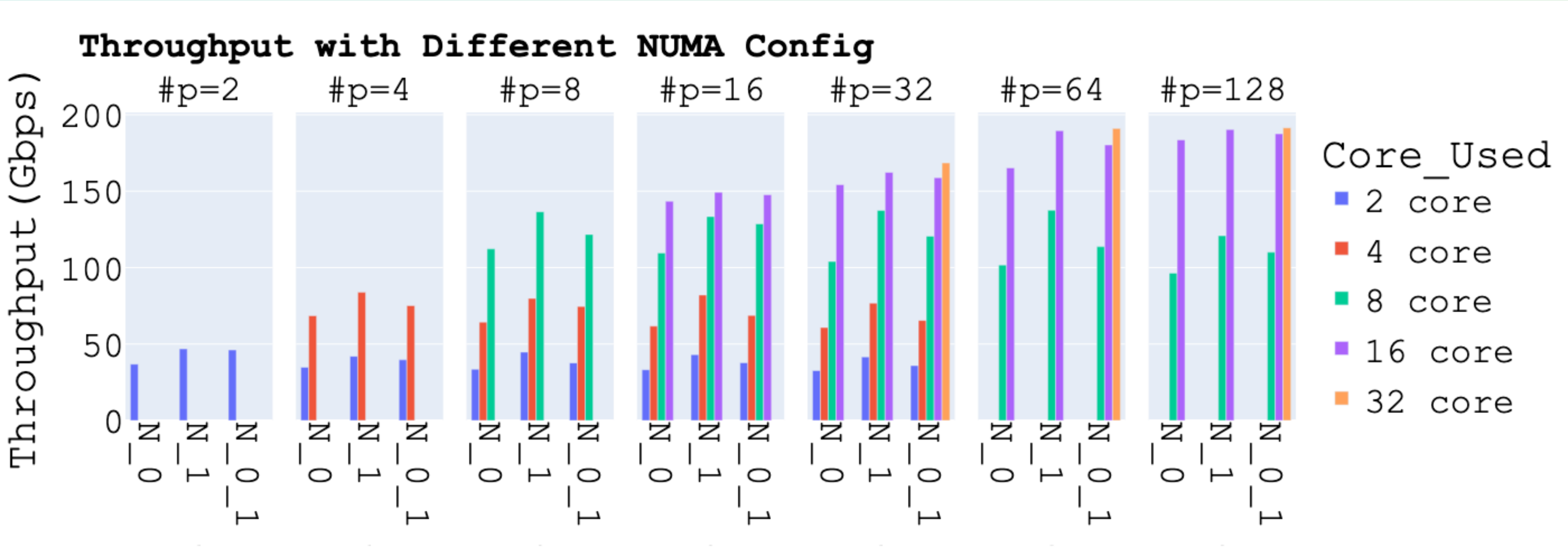


Network Performance and NUMA

Goal of the Experiment : Investigate network transfer throughput and core affinity on data streaming between facilities with high-bandwidth connections.

Strategic Use of NUMA: Utilize NUMA-aware strategies to improve throughput by assigning tasks to cores that have local memory access to the NIC.

Observations from the Experiment:



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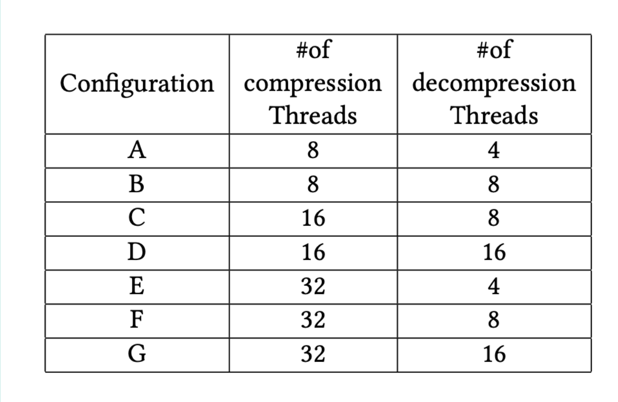
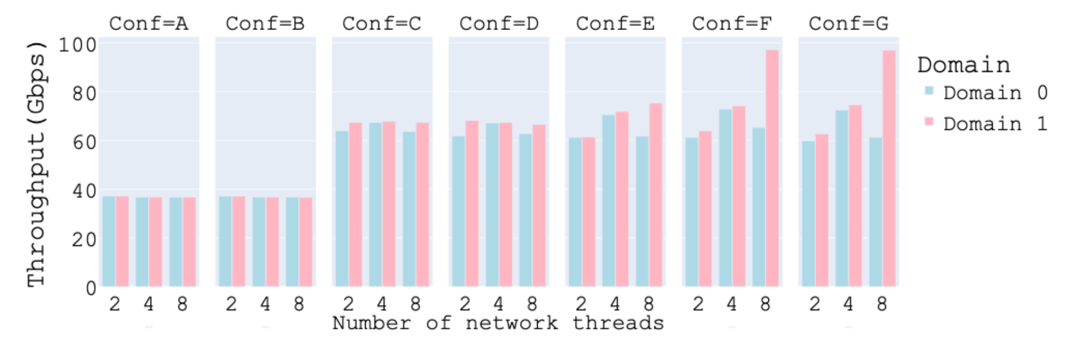
Single Stream Evaluation in Runtime System

- **Goal: Assess Runtime System Efficiency with a Single Data Stream**
    - Evaluate system performance across various configurations for compression, decompression, and transmission-reception threads.

- **Strategy: Diverse Thread Configuration Experiments**
    - Use two interconnected machines capable of 100 Gbps transfers to test different combinations of thread counts and execution domains.



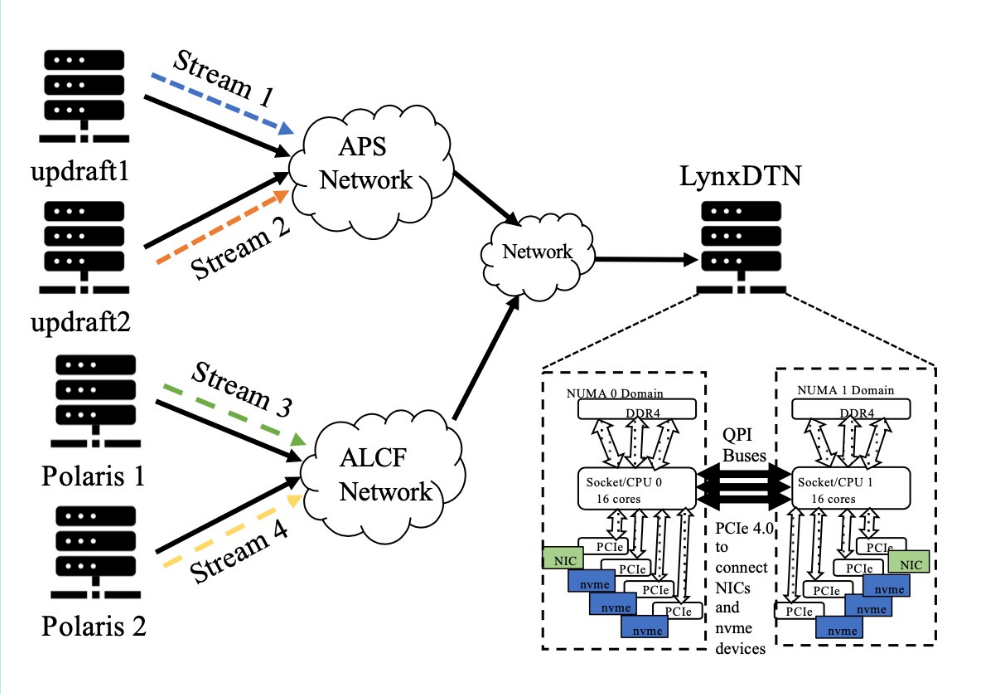
Configuration	#of compression Threads	#of decompression Threads
A	8	4
B	8	8
C	16	8
D	16	16
E	32	4
F	32	8
G	32	16



- **Observation: Bottlenecks and Throughput Efficiency**
    - Throughput varies with the number of compression threads; end-to-end performance peaks with receiver threads in NUMA domain 1, achieving 97 Gbps in optimal settings.

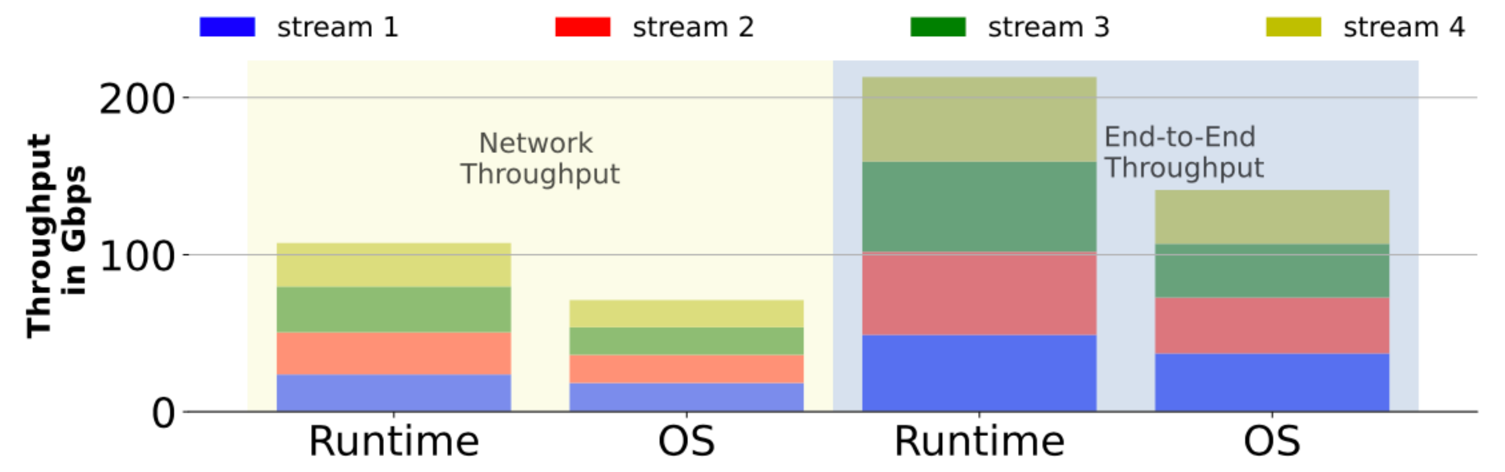
Multi Stream Evaluation in Runtime System

- **Goal: Compare Runtime System and OS-Determined Thread Placement**
  - Test the runtime system's effectiveness against an OS-controlled thread execution location strategy.
- **Strategy: Multi-Source Data Stream Generation and Reception**
  - Generate four concurrent data streams across machines with varying architectures, assessing combined and individual network and end-to-end throughput.



Multi Stream Evaluation in Runtime System

- **Observation: Runtime System Superiority in Throughput**
  - The runtime system, leveraging detailed architectural knowledge, significantly outperforms the OS's autonomous thread placement, achieving 105.41 Gbps network and 212.95 Gbps end-to-end performance.



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Conclusion - Optimizing Data Streaming with NUMA-Aware Runtime System

- Comprehensive System Evaluation
- NUMA Optimization Proven Effective
- Multi-Stream Performance Superiority
- Single Stream Insights
- Empirical Evidence of Efficiency
- Future-Proofing Data Transmission

Future directions

- **Towards Dynamic Pinning:**
  - Current system utilizes static CPU pinning which, while effective, does not adapt to fluctuating workloads in multi-user environments.

The project's GitHub repository : https://github.com/H-jamil/ha4hpdt.git.

Questions:

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