LADS: Optimizing Data Transfers using Layout-Aware Data Scheduling

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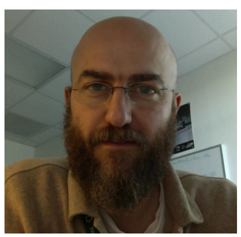

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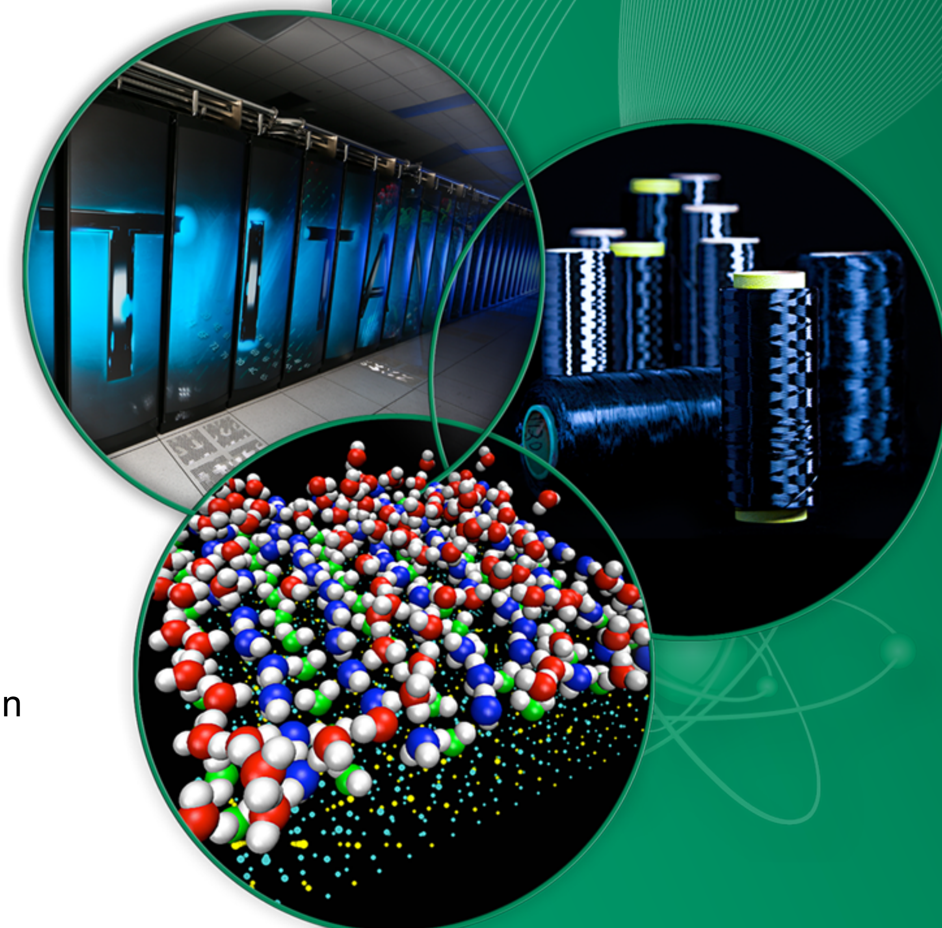
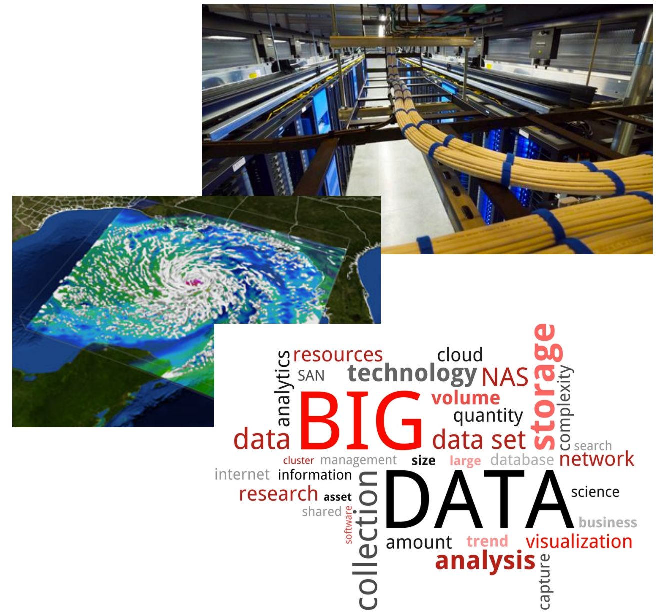


Outline

- Background
- Motivation
- LADS: Layout-Aware Data Scheduler
- Problem Definition
- Design
- Evaluation
- Conclusion

Leading Research Requires the Use of Extreme-scale Resources across DOE

- Big Data Challenges in Science Domains
- Extreme-scale Resources
  - Computational facilities – ALCF, NERSC, and OLCF
    - 1 exabyte generated per year by 2018
- Coupling data
  - Is to combine two different data sets physically stored on different institutes to use for big data analysis purpose
- Many examples of coupling data today:
  - Nuclear interaction datasets generated at NERSC needed at the OLCF for Petascale simulation
  - Climate simulations run at ALCF and OLCF validated with BER data sets at ORNL data centers



Unfortunately data-sets do not exist in isolation!

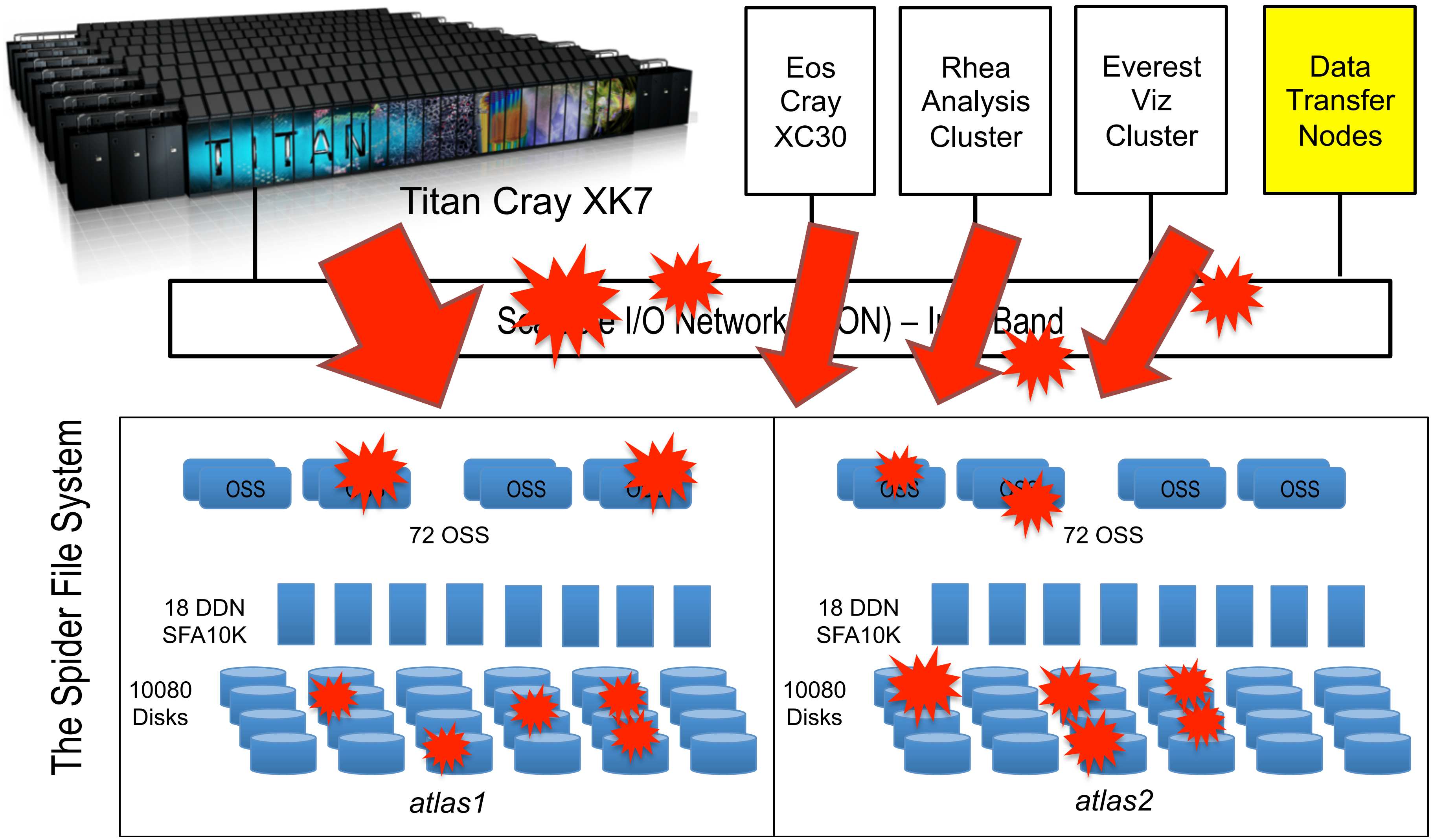
Enabling Network Technology

- DOE's Energy Science Network (Esnet)
  - Network infrastructure between many DOE facilities
- Improved data transfer rate
  - Currently at 100Gb/s, mostly likely to support 400Gb/s
  - 1Tb/s in near future

However, this network improvement only contributes the network transfer rate.

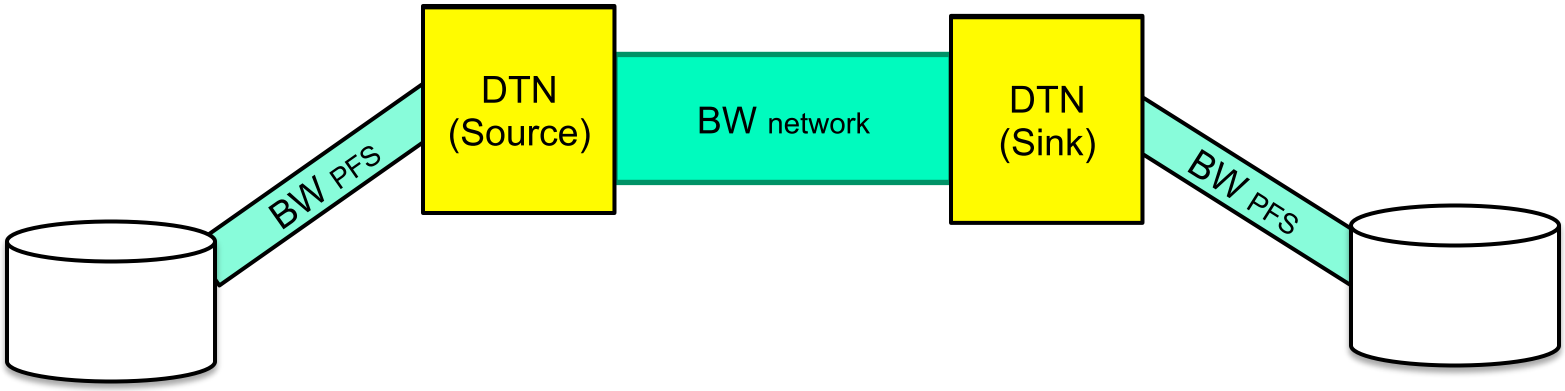
Data sets are stored at slow storage systems.

OLCF center-wide PFS and clients



The PFS can become the bottleneck for data transfers.

Problem and Challenge



$BW_{PFS} < BW_{network}$

Data transfer nodes (DTNs) are a focal point for impedance match between the **faster networks** and the relatively **slower storage systems** (PFS).

Key Question

How to improve the underutilized PFS bandwidth for big data transfers?

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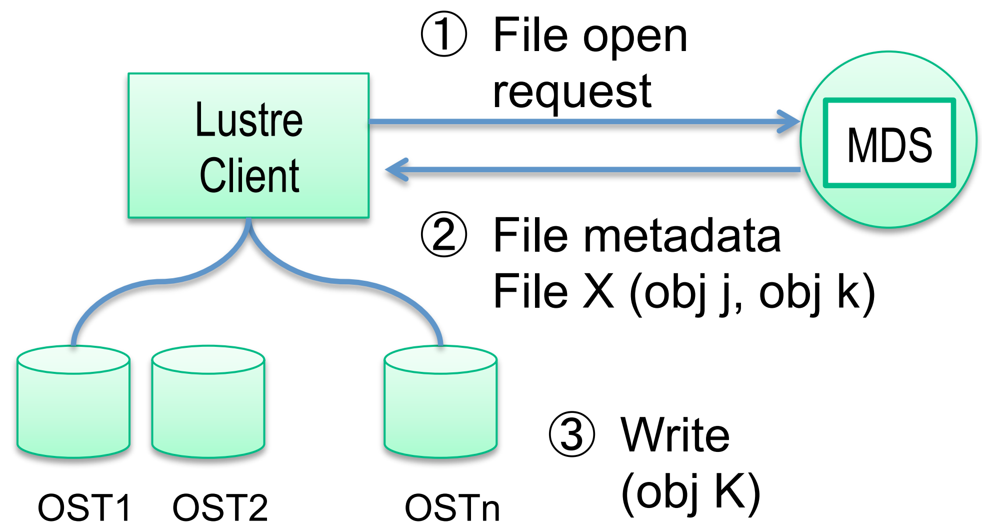
General Parallel File Systems

- Parallel File Systems
  - Lustre, IBM's GPFS, PVFS, PanFS
- Lustre
  - Two types of servers
    - MDS and OSS
  - Metadata server (MDS)
    - Holds the directory tree
    - Stores metadata about each file (except for size)
    - Once file is opened, I/O to file does not involve the MDS
  - Object storage server (OSS)
    - Manages OSTs (disk/LUN)
    - OSTs hold stripes of the file contents
      - Think RAID0
    - Maintains the locking for the file contents it is responsible for

File open and file I/O in Lustre



Observation form the PFS

PFS is viewed as a single name space.

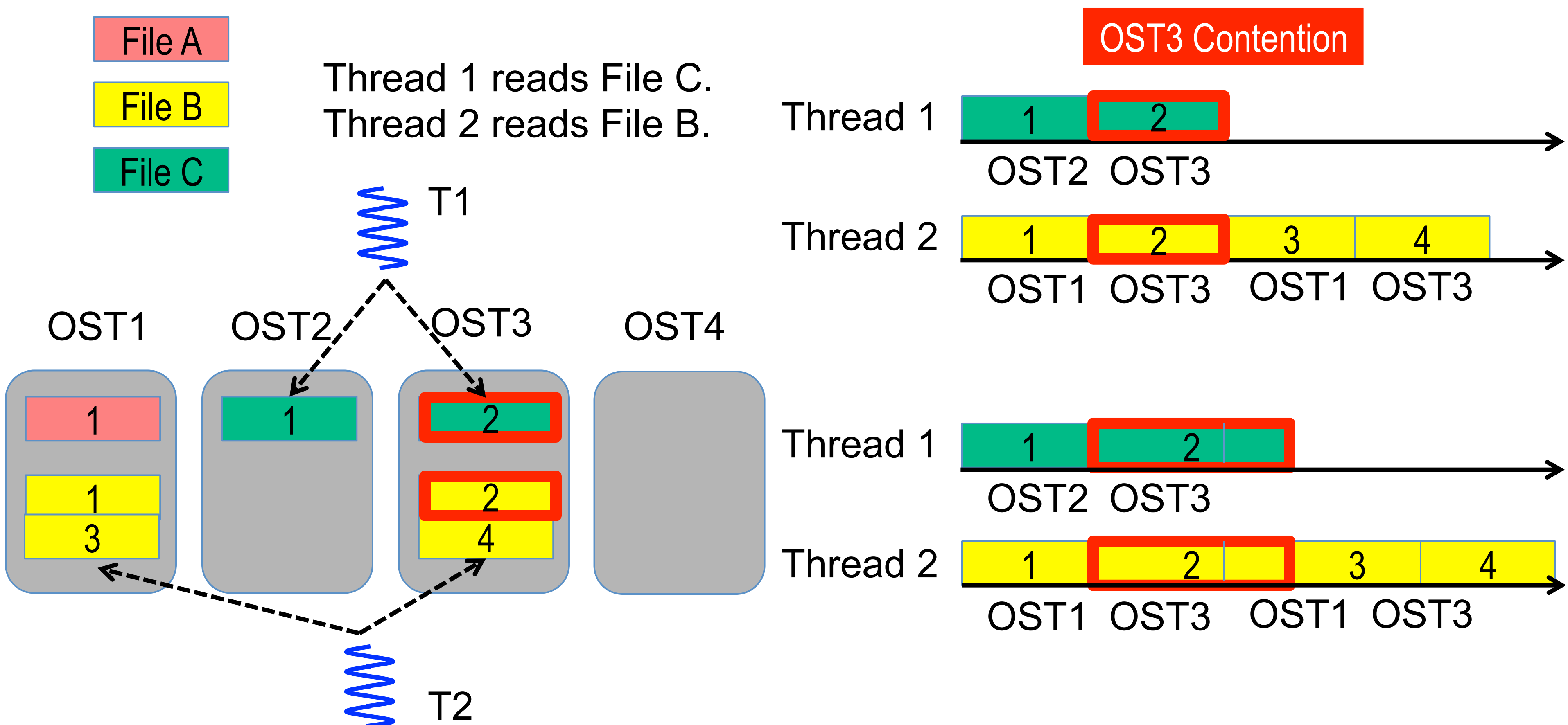
However it is not a single disk, but the arrays of multiple disks with servers.

PFS has been designed for parallel I/Os.

However, traditional data transfer tools do not fully utilize the available parallelism on the PFS for I/Os.

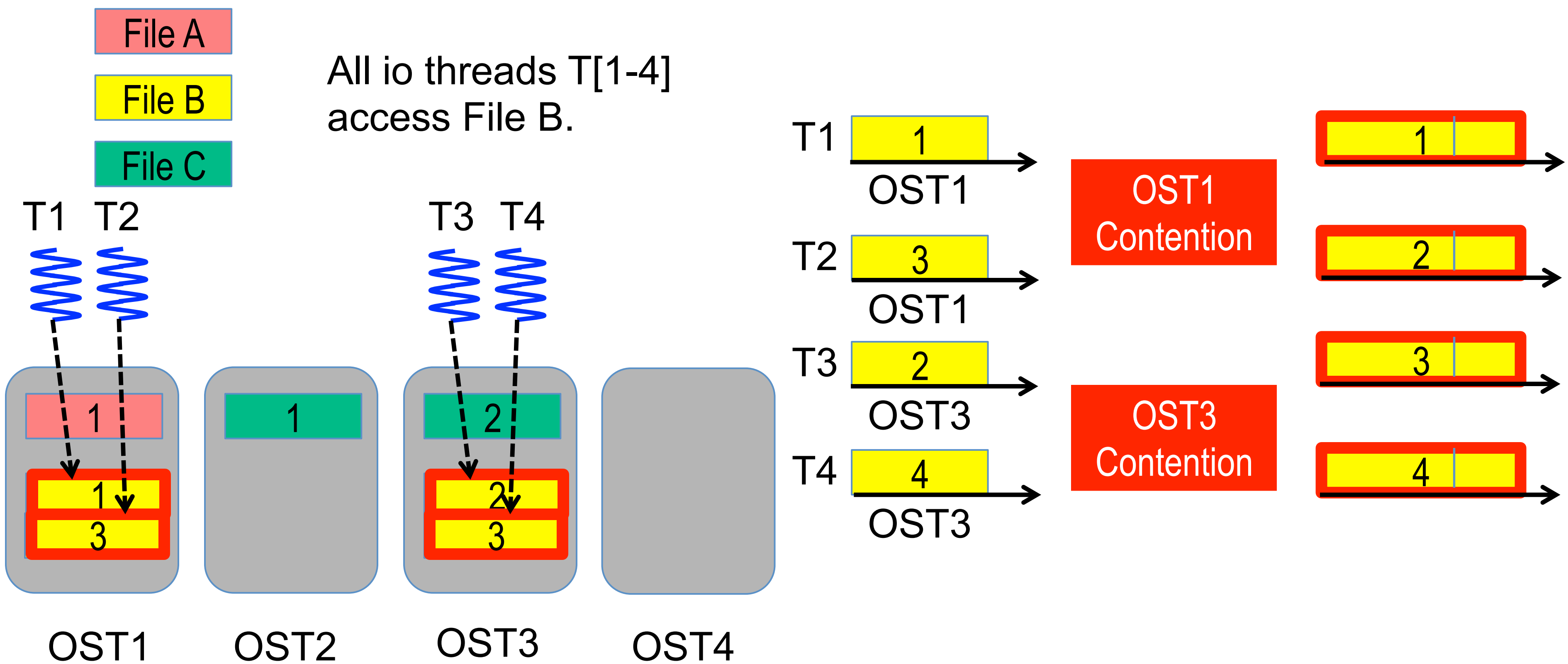
Problem(1): Traditional File Based Approach

- Ignoring file layout information
- A complete file can be assigned to each thread, and each thread works on the file until the file is read.
  - Multiple threads can interfere each other on accessing the same OST.



Problem(2): Traditional File Based Approach

- Ignoring file layout information
- Multiple threads can work on a single file.
  - The parallelism can be limited by a stripe width of a file in the PFS.



Bulk Data Movement Software

- GridFTP
  - Requires Globus Toolkit
  - Supports multiple I/O threads, but it implements a file based approach
- bbcp
  - The most popular data transfer tool for convenience reason, not for performance
  - Implements a file based approach
- RFTP [SC'11]
  - It is a file based approach, not fully utilizing underlying object layouts on the PFS
- SCP
  - A single thread secure copy tool

None of these tools are optimized for fully utilizing the parallelism on PFS for big data transfers.

Traditional file transfers tools employ a logical view of files.

On the other hand,

> LADS uses the **physical view of files**, instead of a **logical view of files**.

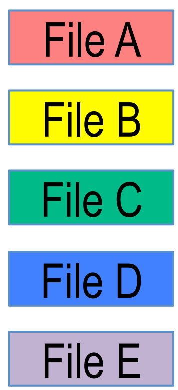
LADS can understand

- The physical layout of files in which files are composed of data objects
- The set of storage targets that hold the objects
- The topology of storage servers and targets

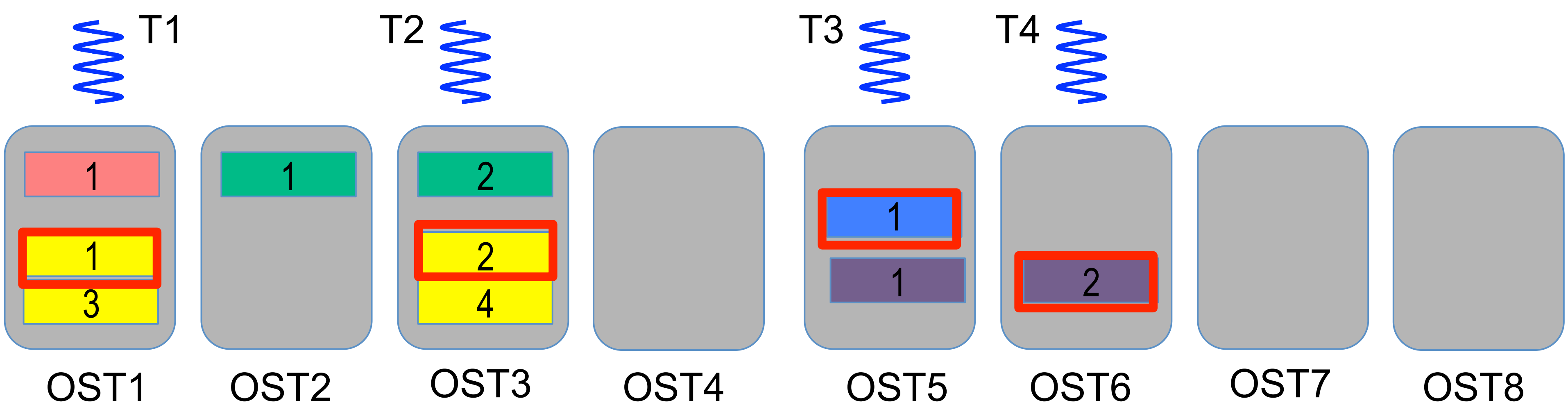
Solution: Object Based Approach

- Aware of file layout information
- A thread can work on any slice (object) on any OST.

None of I/O threads contend for OSTs.
Parallelism = 4 (# of threads)



Thread 1 reads obj 1 of File B.
Thread 2 reads obj 2 of File B.
Thread 3 reads obj 1 of File D.
Thread 4 reads obj 2 of File E.



LADS: Design Goals

Parallelism on Multi-core CPUs

Portability for Modern Network Technologies

Parallelism on PFS

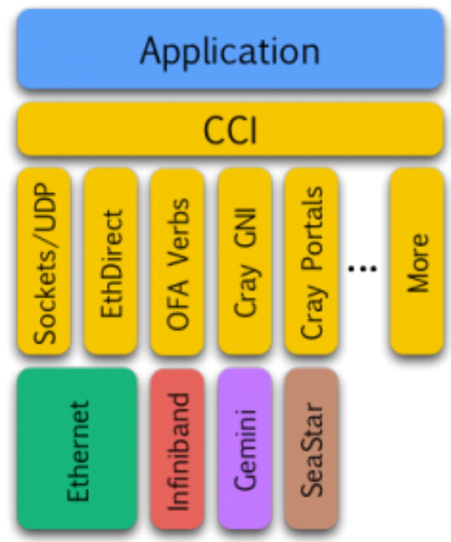
HotSpot/Congestion Avoidance

End-to-End Data Transfer Optimization

Solving the **impedance mismatch problem** between the **faster network** and **slower storage system**

Common Communication Interface

- A new generic, communication abstraction layer
  - A network **Application Programming Interface (API)** for inter-process communication



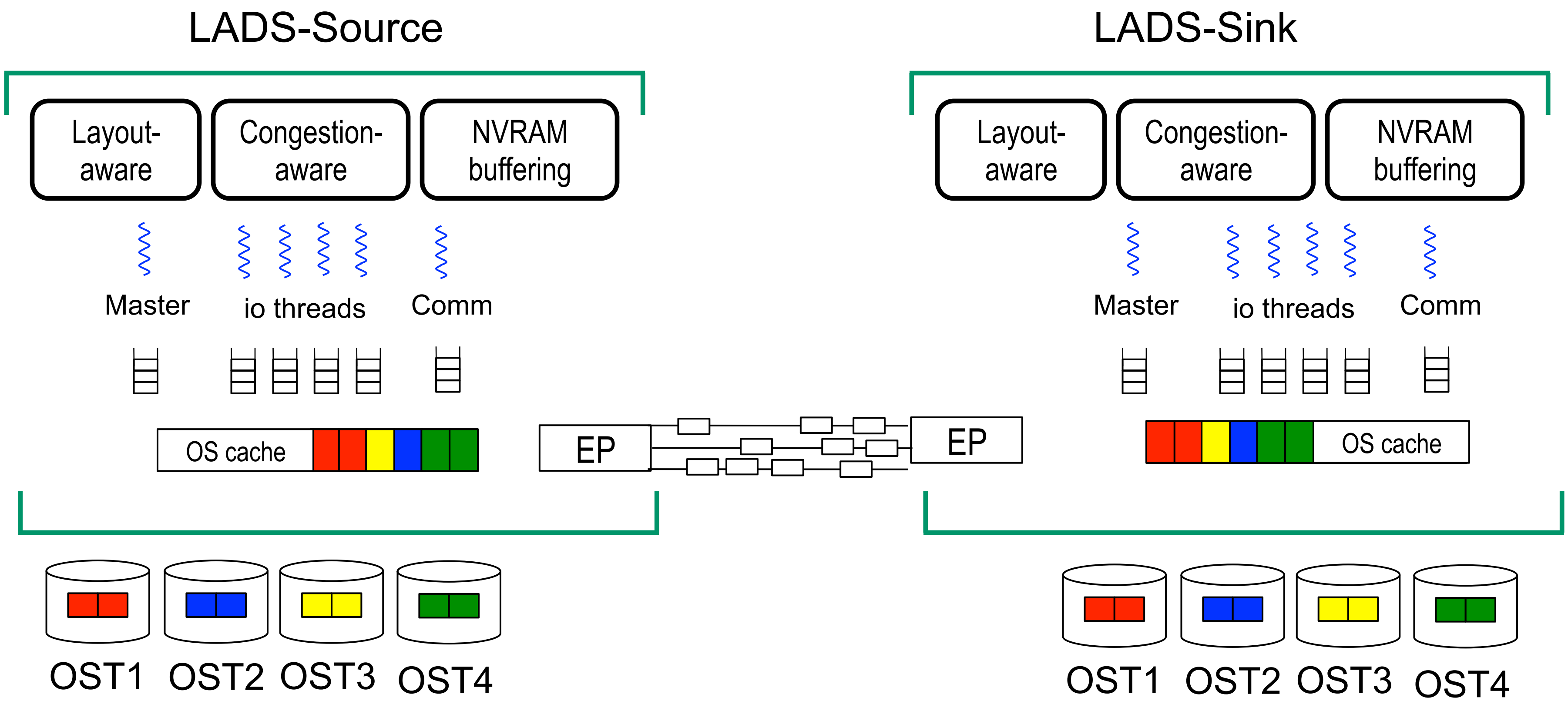
- Design goals
  - Portability, Scalability, Performance, Robustness, Simplicity

- Network solutions that CCI is currently supporting
  - Sockets (TCP, UDP), verbs (InifiBand, RoCE, iWarp), Cray uGNI, and a high-performance kernel-level Ethernet

[CCI HOTI'11] *S. Atchley, D. Dillow, G. Shipman, P. Geoffray, J. Squyres, G. Bosilca and R. Minnich, "The Common Communication Interface (CCI)"*
In the Proceedings of 19th IEEE Symposium on High Performance Interconnects (HOTI), 2011.

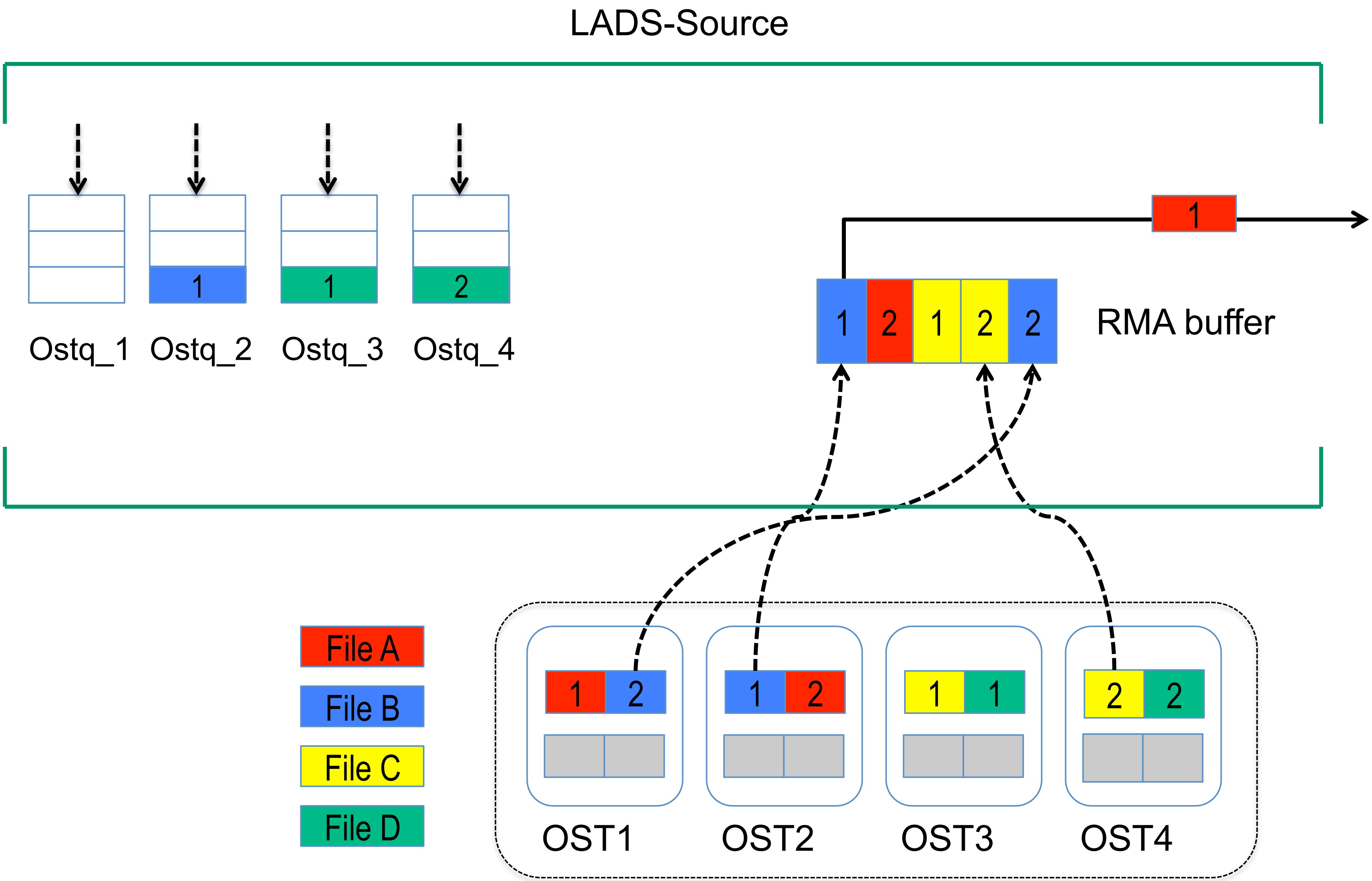
CCI Website: http://cci-forum.com`

LADS Architecture Overview



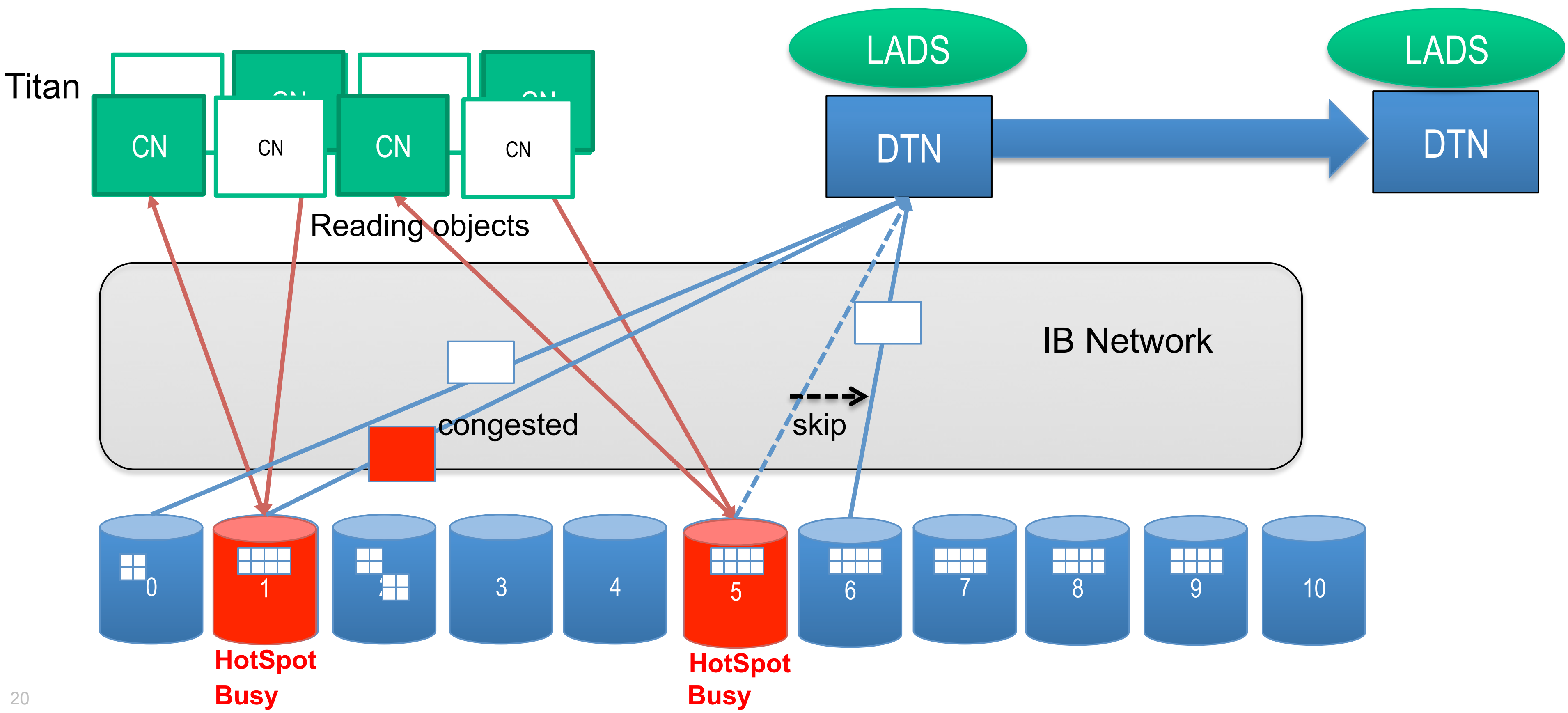
- CCI implementation
  - Construct endpoints (virtual device) and pre-register RMA buffers
- Threads Implementation
  - Queue based implementation with Master, I/O and Comm threads

LADS: Transferring Data at Source



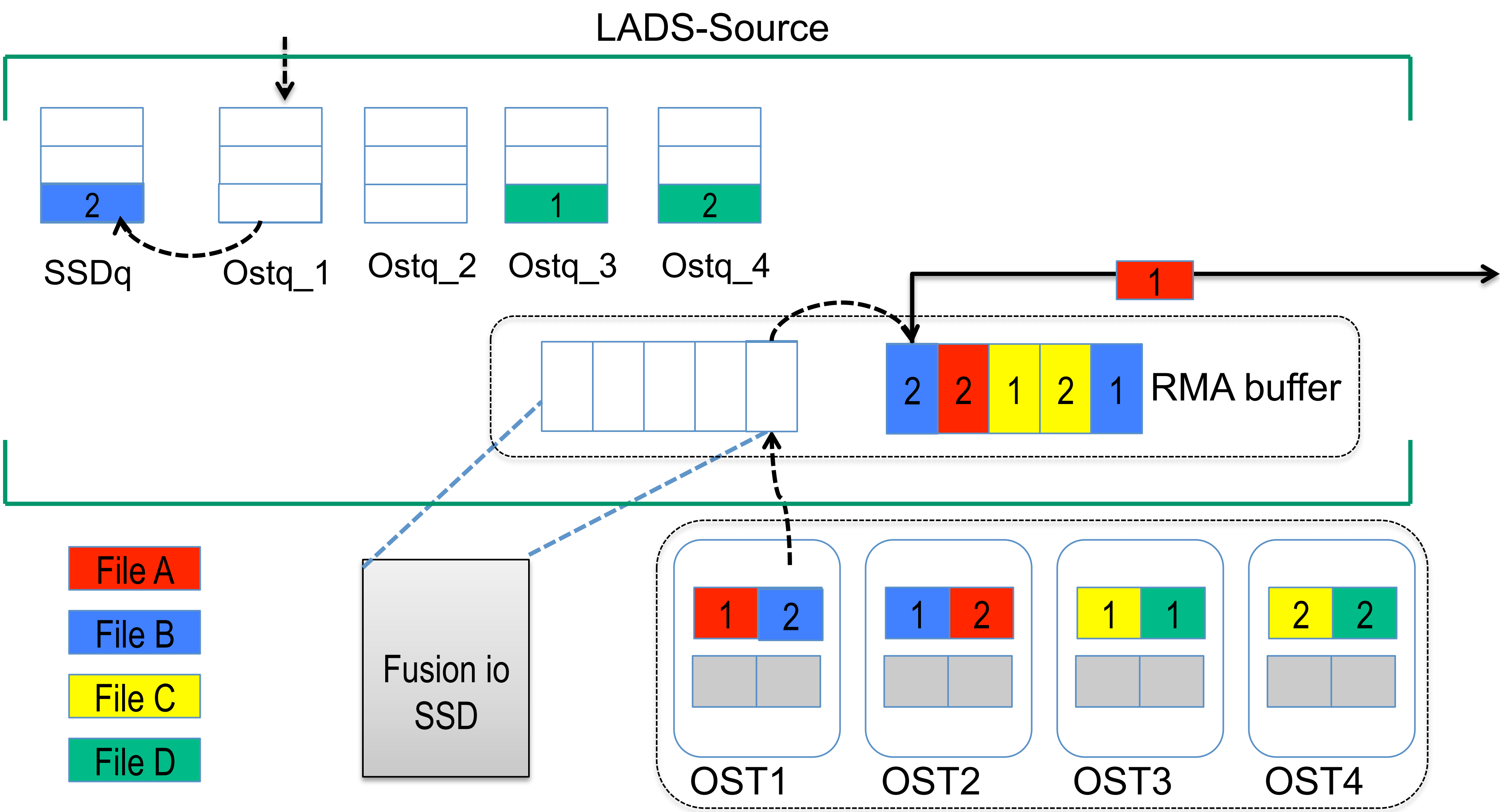
LADS: Congestion-Aware Algorithm

- Minimizing impact of intermittent congestion on storage servers
- Implemented a threshold-based reactive algorithm using
  - a preset value (object reading or writing time) for determining congested server
  - the number of skips on the congested servers

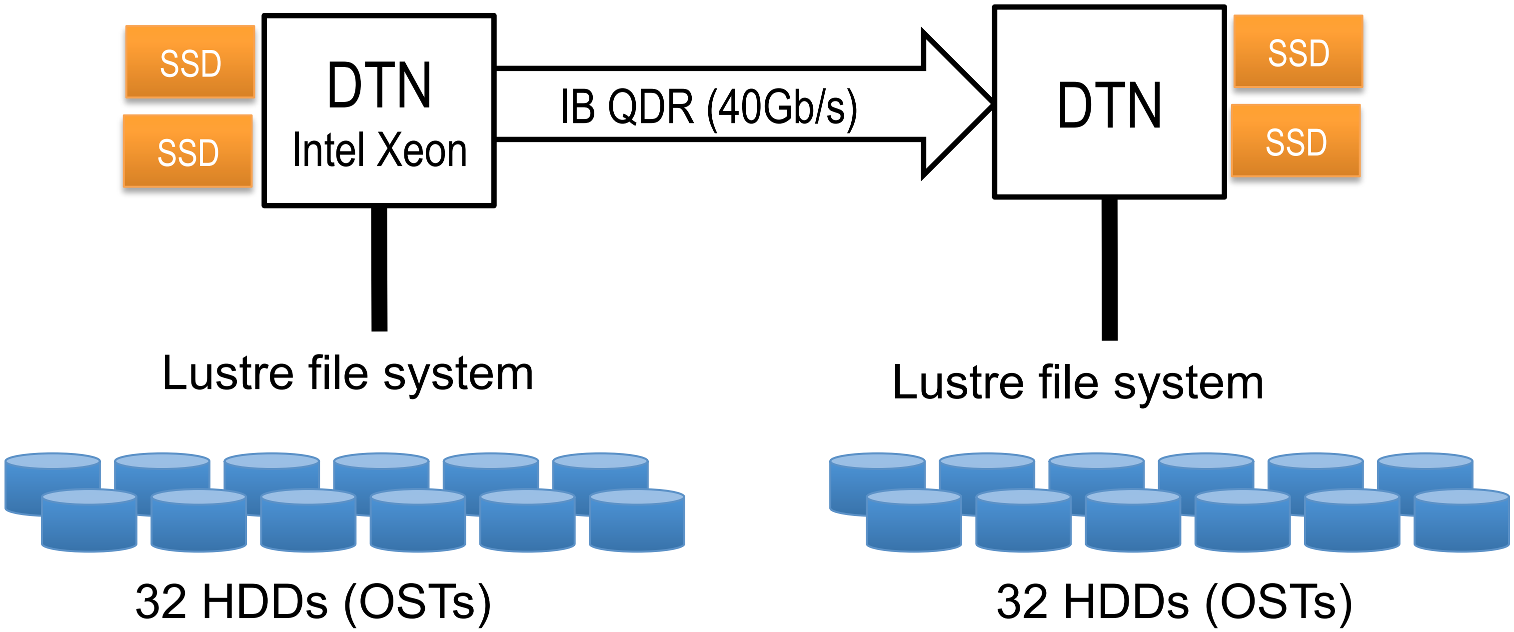


LADS: Source-based Buffering on NVM

- Source's RMA buffer full
  - The RMA buffer at source can be full if the sink is experiencing wide-spread congestion.

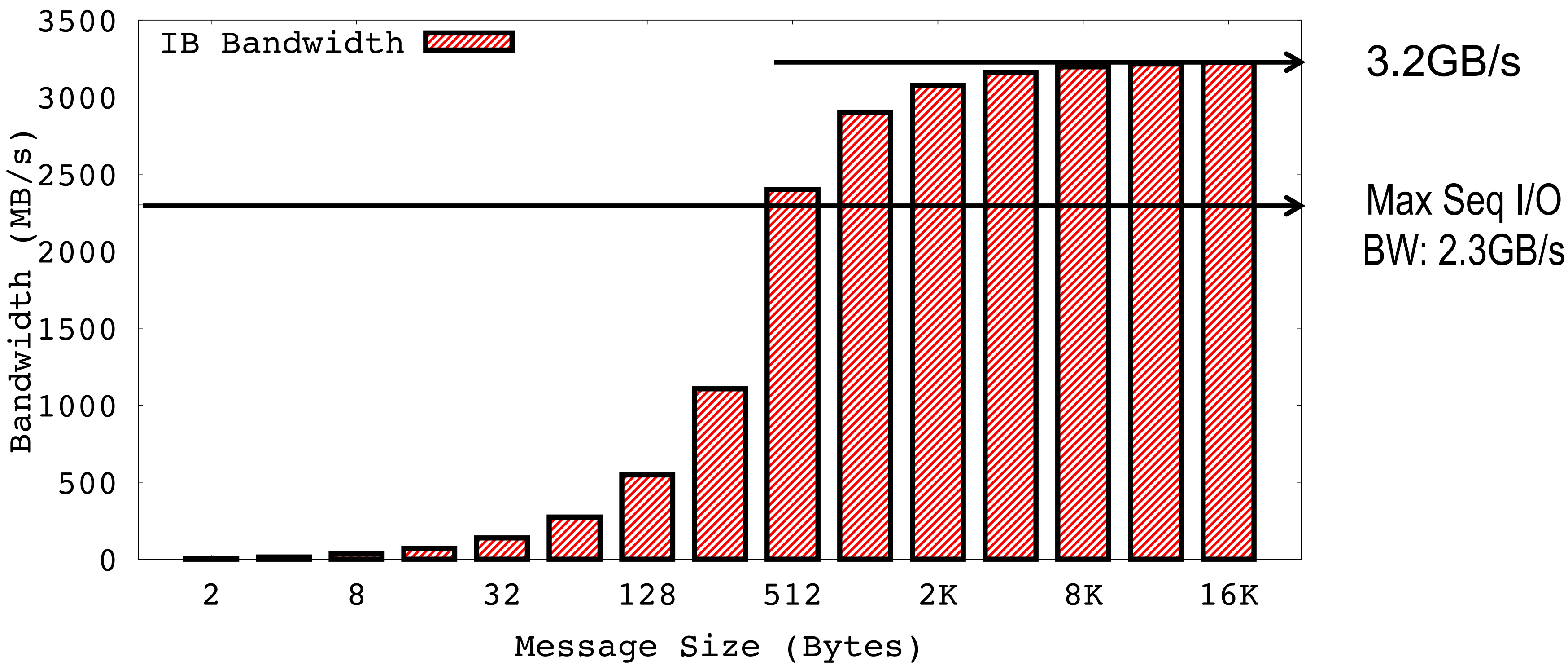


Test-bed Configuration



Validation of Test-bed

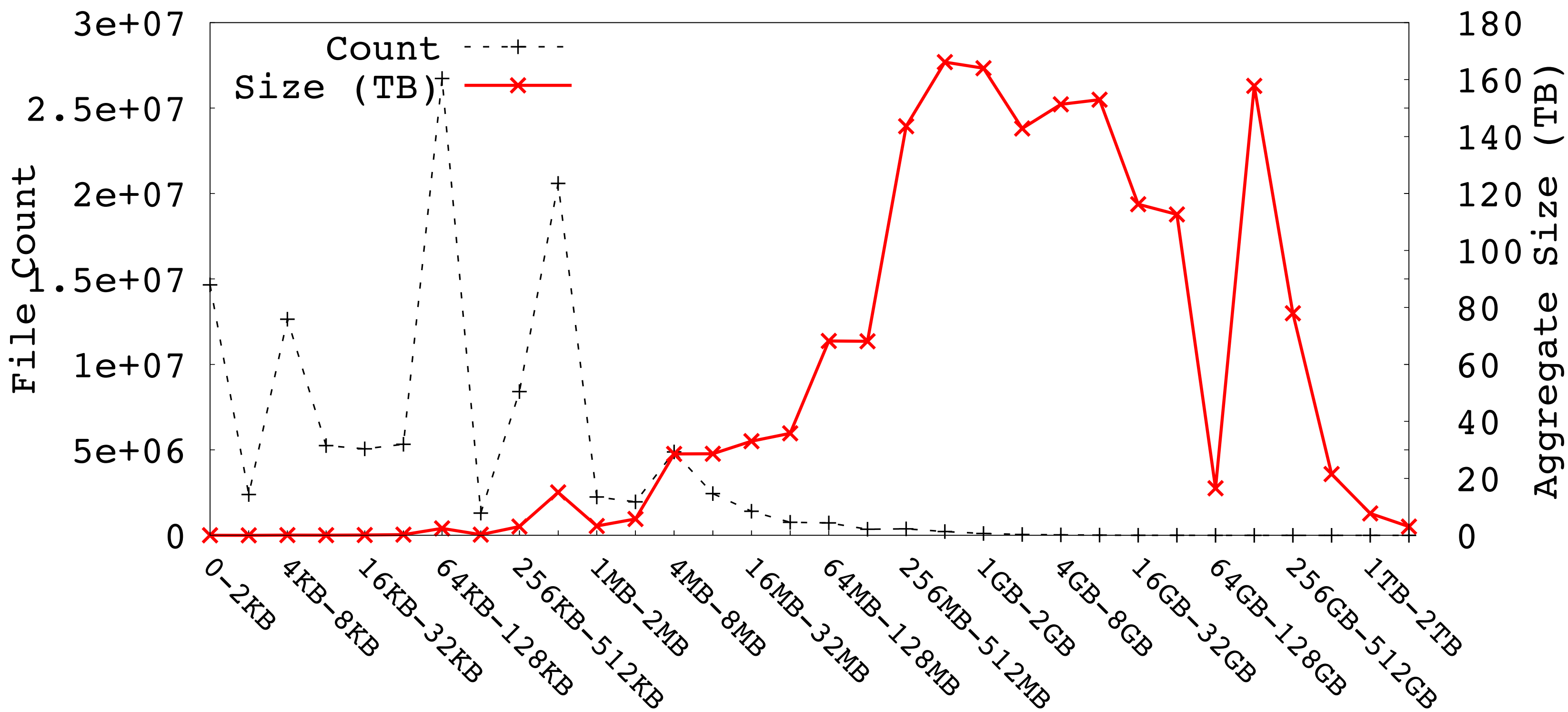
- Comparing IB bandwidth vs. Storage bandwidth



The storage server bandwidth is not over-provisioned with respect to network bandwidth.

Workloads

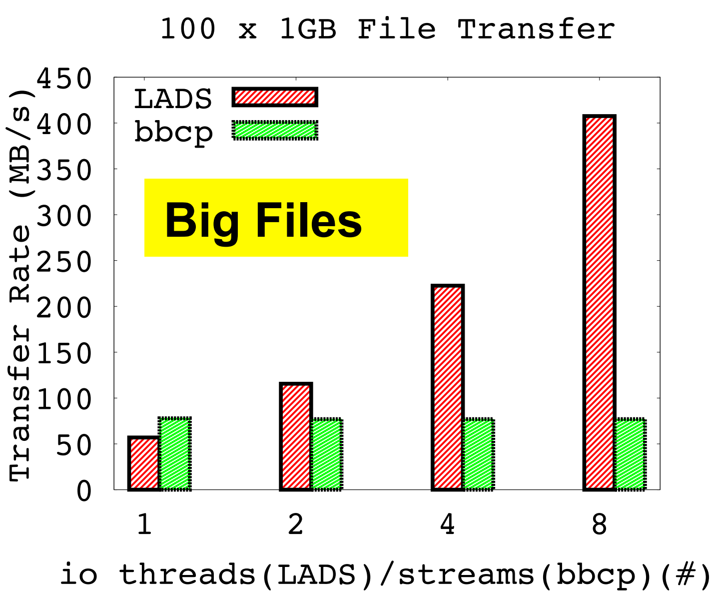
- File size distribution for a snapshot taken from the Spider-I file system

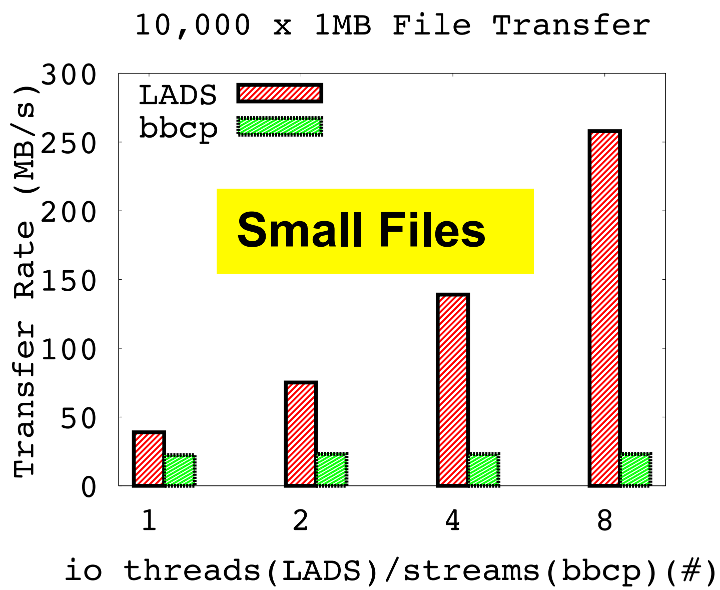


- 85% of the files are less than 1MB and less than 15% of the files are greater than 1MB.
- The larger files occupy most of the file system space.

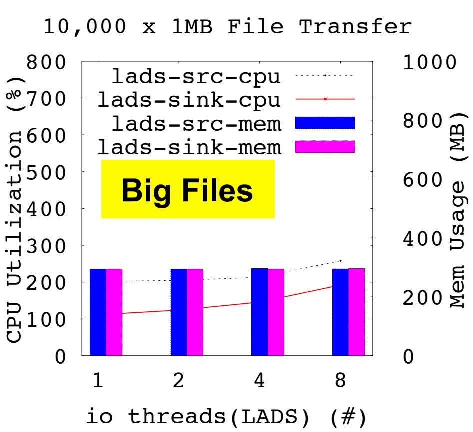
Comparison of LADS and bbcp

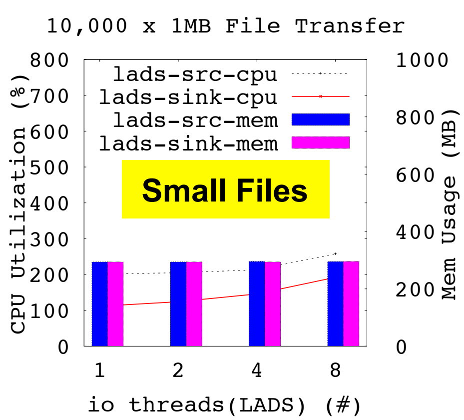
- Performance





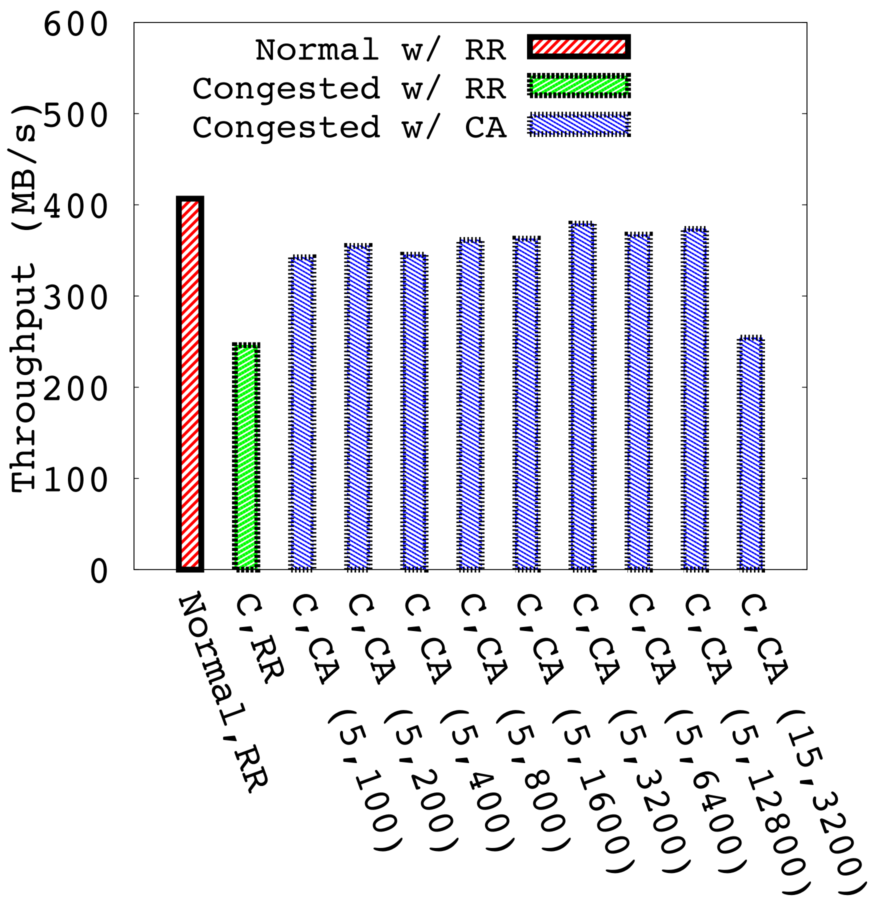
- Resource Utilization



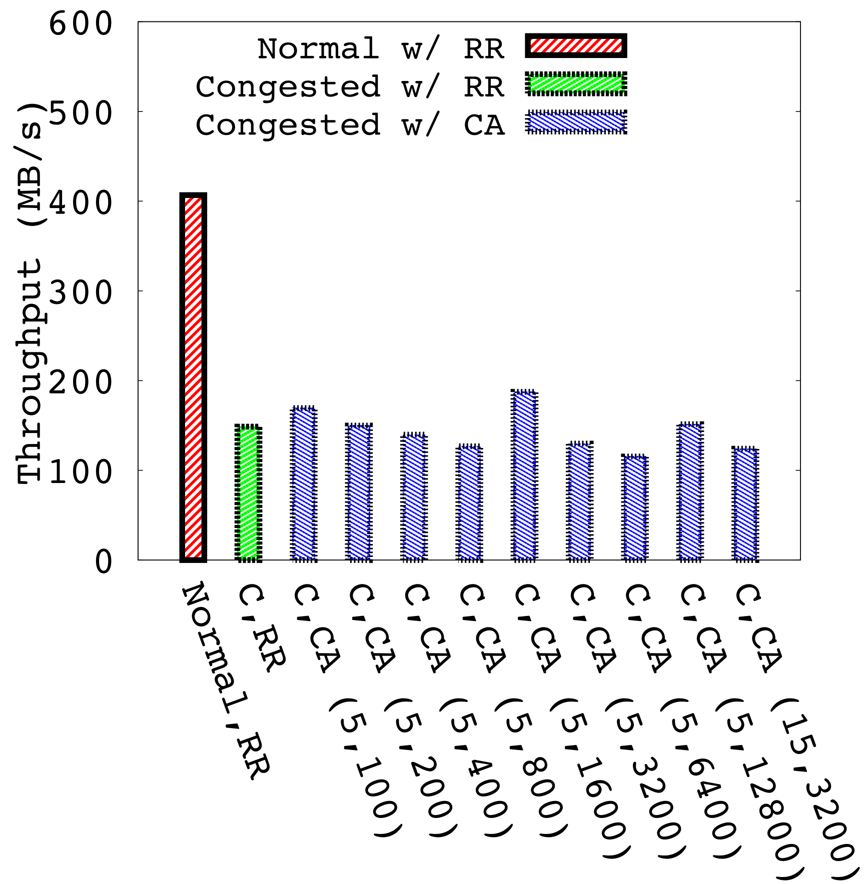


LADS with Storage in Contention

- Evaluation of storage congestion-aware algorithm in LADS



(a) Source storage congested



(b) Sink storage congested

More Experiments - Summary

- Effectiveness of the use of flash buffering at source
  - Throughputs increases as the available memory for communication at the source increases.
  - Doubling the size of DRAM is very expensive and the same throughput could be achieved using flash memory cheaper than DRAM.
- Evaluation between DTNs at ORNL
  - For this experiment, both LADS and bbcp uses Sockets (LADS uses a CCI setup to use its TCP transport).
  - LADS shows 6.8 times higher data transfer rate than bbcp.
  - bbcp shows slightly higher in throughput than LADS for a single thread.
  - In bbcp, I/O parallelism is limited to a stripe width of a file in Lustre (which is four in our evaluation).

Threads (#)	1	2	4	8
LADS	58.71	116.30	228.38	407.02
bbcp	59.91	58.46	57.85	59.49

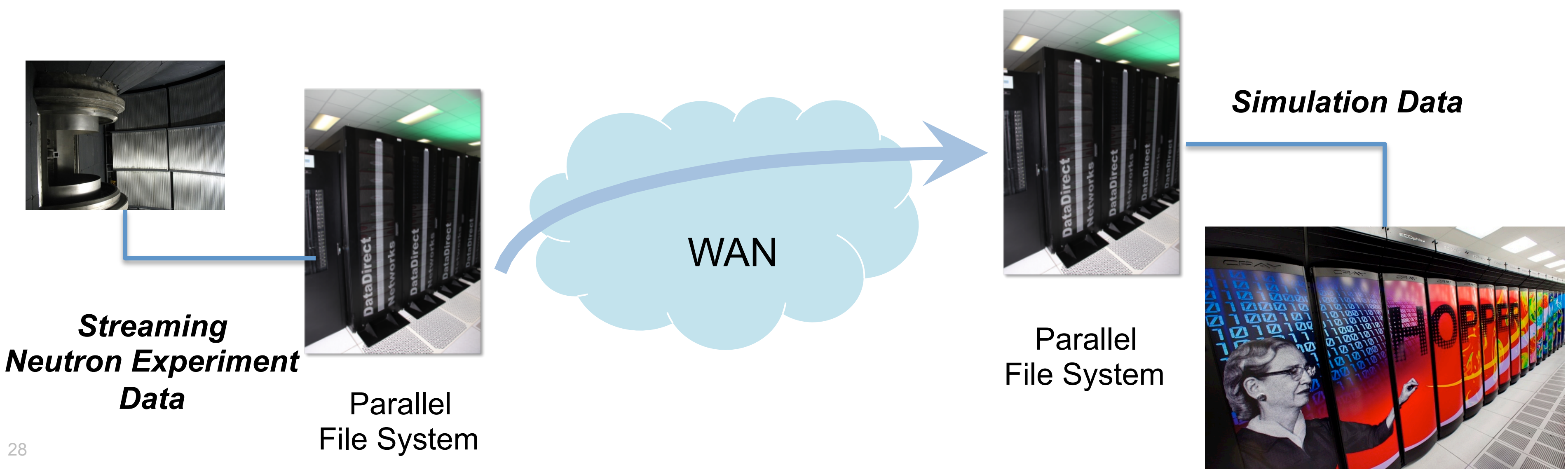
Throughput comparison (MB/s)

Summary

I. We identified multiple bottlenecks that exist along the end-to-end data transfer from source and sink host systems.

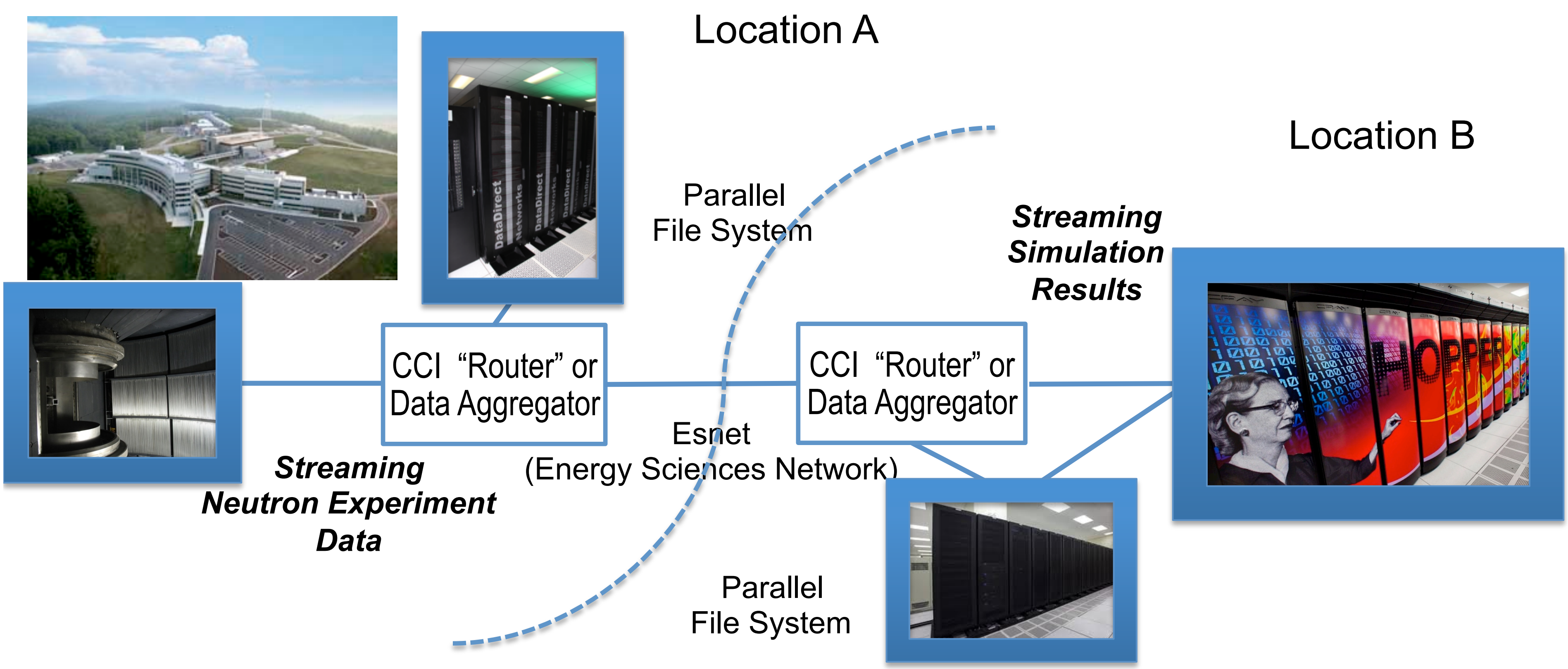
II. We developed LADS to demonstrate techniques that can alleviate some end-to-end bottlenecks while at the same time, negatively impact the use of the PFS by other resources.

III. We investigated three I/O optimization techniques: I/O slicing, layout-aware and congestion-aware I/O scheduling, and source-side SSD buffering.



Our Vision

- *An optimized end-to-end virtual path from any source to any sink*



A variety of data sources and sinks must be supported to transition from traditional data movement to streaming experiment/simulation data

Questions?

Contact info

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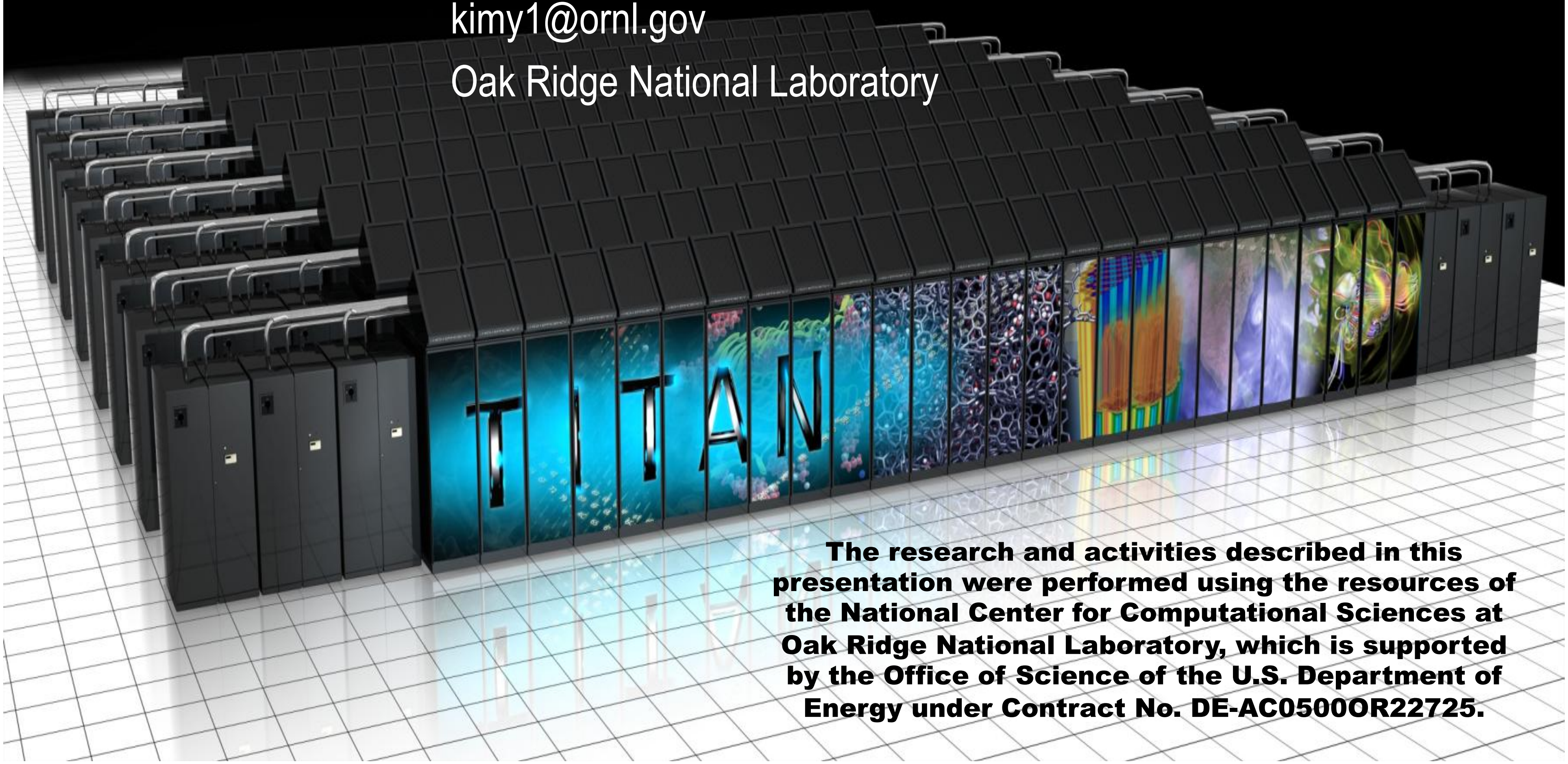

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