Performance evaluation of the PVFS-2 architecture

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PDP 2007

Outline

1. Introduction
2. Overview of PVFS2
3. Performance Limitations
4. Realization with TAS
5. Results
6. Summary

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   - Motivation
   - Idea
2. Overview of PVFS2
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   - Metadata
   - Small Contiguous I/O Requests
   - Large Contiguous I/O Requests
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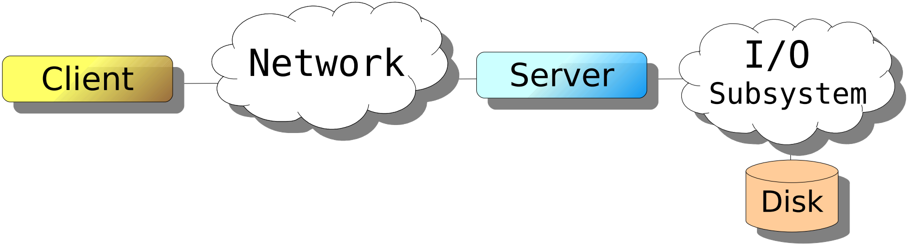
Motivation

- Performance of a parallel file system depends on capabilities of participating components
  - Network
  - I/O subsystem
  - Client and server machines
  - The parallel file system



- Performance characteristics and performance optimizations of components interfere with each other

Motivation

Example:

- Performance of the I/O subsystem depends on multiple factors:
  - Location of the file's blocks on disk and the disk's current head position
  - File system fragmentation
  - Caching strategies
  - RAID level if appropriate
  - ...
- Typically the I/O subsystem greatly limits the aggregated performance

As a consequence it is non-trivial to:

- develop meaningful benchmarks
- assess measured performance
- tune a parallel file system
- discover of performance bottlenecks (and bugs) in the architecture

It is important to reduce the complexity for these tasks!

Idea

Replace layers of a parallel file system with efficient stubs

- Upper bound for throughput of replaced layers
- Measure overhead of upper layers
- Evaluate lower layers
- Performance regression tests to show impact of modifications
- Persistency layer is a good candidate
  - replace it by a dummy which pretends to manage data correctly
  - most benchmarks can be applied
  - answer the questions:
    - Is the parallel file system able to saturate the network ?
    - Does a modification of a specific network parameter increase the throughput for a test-case ?
    - Is a bottleneck in the persistency layer ?
    - ...

Idea

- Why not run on a in-memory file system like tmpfs ?
  - Memory is limited
  - The persistency layer itself might be complex, thus locating the reason for a discovered bottleneck in the code might be not easy
  - The persistency layer may incorporate caching mechanisms
  - For analysis it might be easier to replace the handling in the layer with algorithms and data structures which have a well known complexity
  - But, tmpfs is a good candidate for comparison with original and replaced layer

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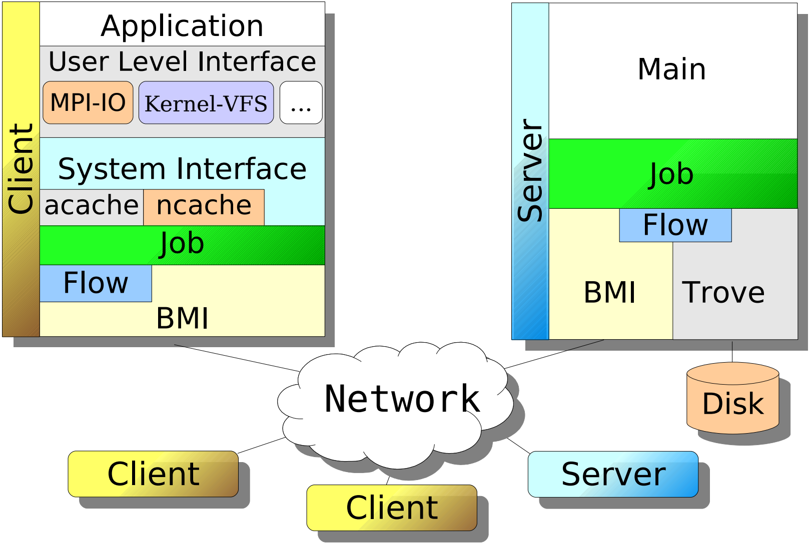
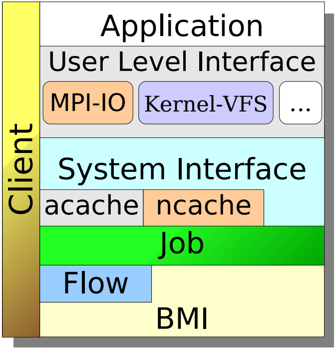
Overview of PVFS2

- Open source
- Redevelopment of the Parallel Virtual File System
- Developed and maintained at Argonne National Lab and Clemson University
- Tightly integrated into MPI-IO (drivers available in ROMIO/MPICH-2)
- Servers can be configured to be data and/or metadata servers
- Data is typically striped over the data servers in 64 KByte chunks (RAID-0)

Architecture of PVFS2



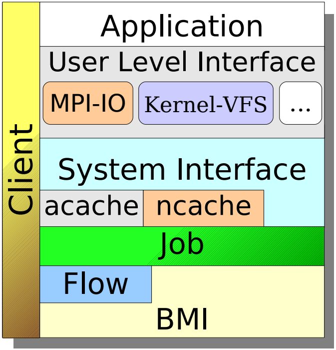
Architecture of PVFS2 - Client



Description of the layers

- User-level-interface
  - Integration into linux VFS for POSIX access
  - ROMIO module available in MPICH2
- System Interface
  - Provides API for manipulation of file system objects
  - Contains caches for directory hierarchy and object attributes
- Job
  - Thin layer, combines and controls lower layers

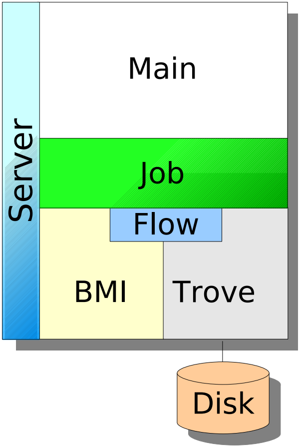
Architecture of PVFS2 - Client



Description of the layers

- Flow
  - Reliable transfer of data between two endpoints
  - Defines data flow policy e.g. parallel streams
- BMI
  - Network interface
  - TCP, Myrinet, IB, ...

Architecture of PVFS2 - Server



Description of the layers

- Main process
  - Accepts new requests
  - Starts server statemachines
- Trove
  - Persistency layer
  - Implementation uses Berkeley DB and local file system.

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Simple Model

Performance limitations

- CPU
  - Use hash tables etc. $\Rightarrow$ constant time needed per request
  - Limits the number of requests
- Input/Output subsystem
  - Access time
  - Throughput
- Network
  - Latency
  - Bandwidth > Throughput

- Estimate and compare performance with measured throughput

Performance implications of the PVFS2 architecture

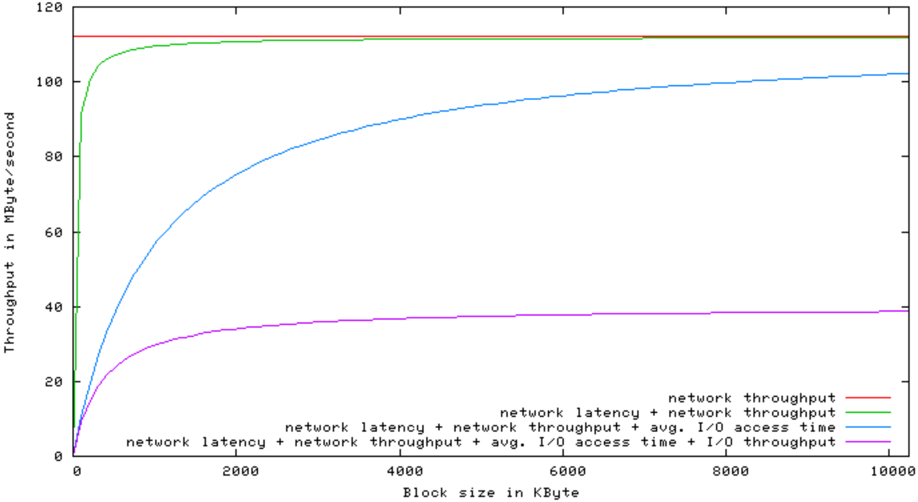
I/O

- No client side cache for data $\Rightarrow$ each I/O operation requires at least one message exchange
- Small I/O requests are transfered with initial requests (Read) or response (Writes)
- Larger I/O requests require rendezvous protocol $\Rightarrow$ extra round-trip for writes

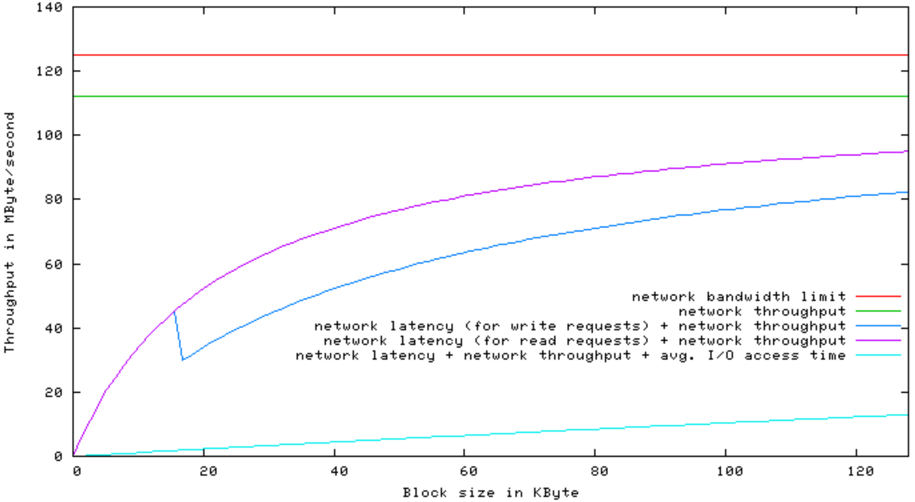
Metadata

- Read-only operations are cached for a small time frame
- Modifying operations typically consist of multiple requests mostly processed in serial e.g. creation with MPI needs 4 requests to metadata servers and one for each participating data server
- Each request requires one message exchange

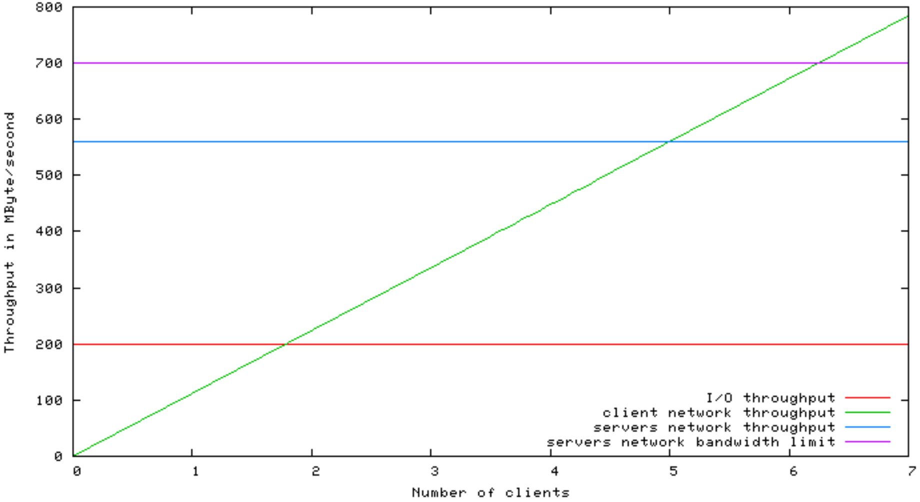
Estimated performance for small contiguous I/O requests



Estimated performance for small contiguous I/O requests



Estimated performance for large contiguous I/O requests



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Realization with TAS

- Replaces persistency layer (TROVE) with stub
- Handle metadata correctly
- Use a red-black-tree as basic data structure
- Discard data from I/O requests and signal completion
- Return immediately from requests (No sperate threads)

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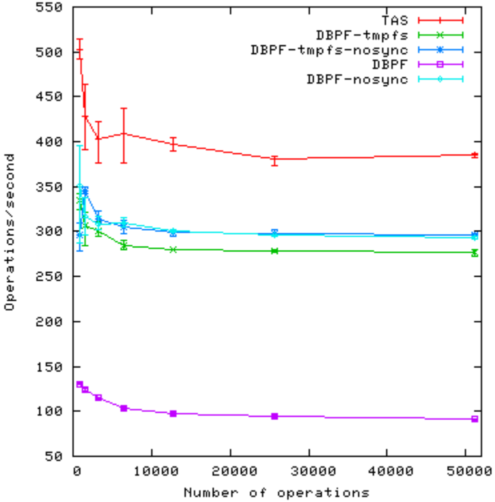
Benchmarking Program for Metadata

- MPI program
- Operates in one directory
- Each client creates a disjoint set of files with MPI_MODE_CREATE
- Runtime is measured on each process and maximum time used to calculate metadata throughput in operations/second.

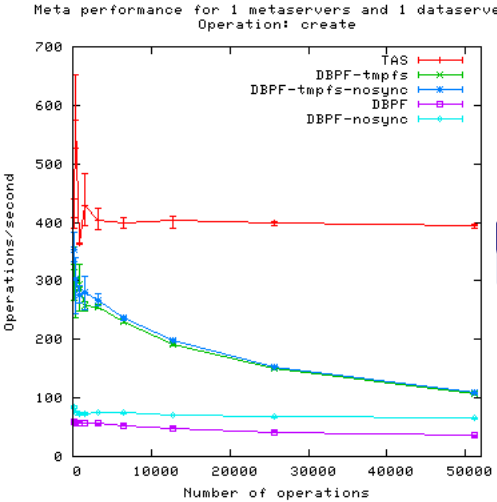
One data server, one metadata server, one client



Notes

- Data is from July 06.
- DBPF is the current persistency implementation
- DBPF normally synchronizes modifications to disk, thus mainly limited by disk latency (and throughput)
- Nosync refers to a variant where metadata synchronization with the I/O subsystem is omitted

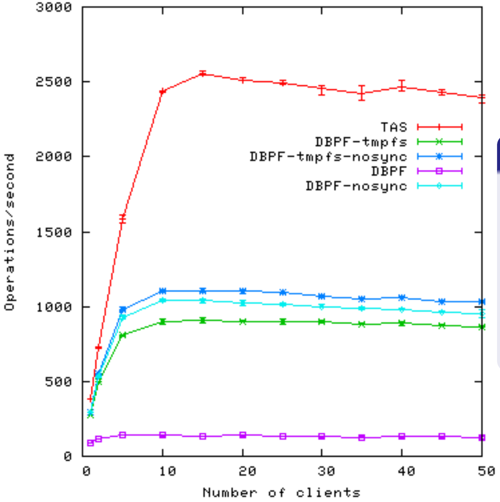
One data server, one metadata server, one client



Notes

- Data is from December 05.

One data server, one metadata server



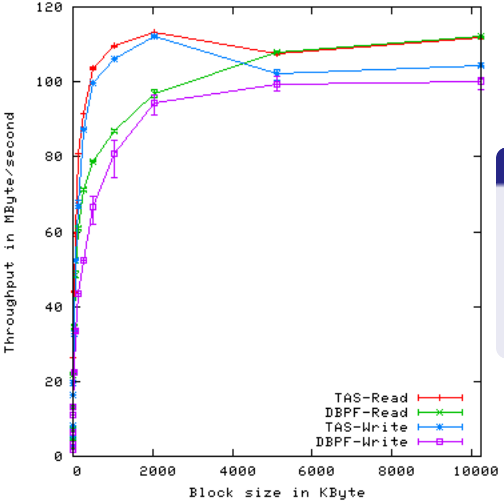
Notes

- Multiple clients creating a total of 51200 files
- DBPF tmpfs and nosync results are close together like expected

Benchmarking Program for I/O Throughput

- MPI program (mpi-io-test)
- Operates on one file
- Each client
  - opens the file individually
  - writes a number of blocks of the same size with MPI_File_write
  - opens the file again
  - reads the data in chunks back
- The processes synchronize between two I/O operations
- Time is measured for each I/O operation and maximum taken for calculation

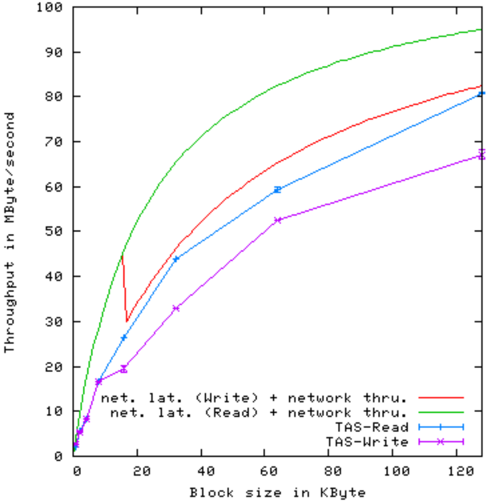
1 Client, 1 Data servers



Notes

- Total file size: 100 MByte
- Should be cached well by OS
- TAS forms a upper bound
- Close to network bandwidth

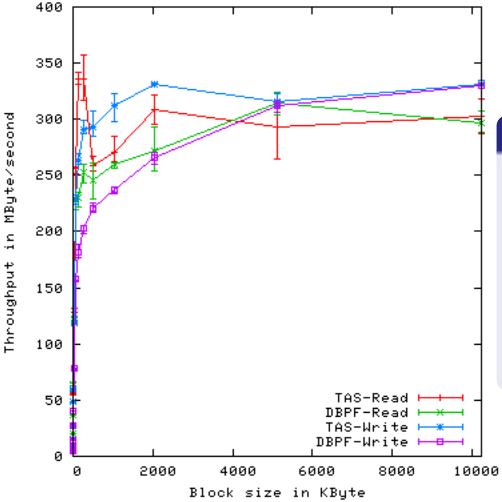
1 Clients, 1 Data server



Notes

- Estimated performance limits asymptoticly close to measured performance
- Drop due to handshake can be seen for write
- Caching strategies could boost throughput

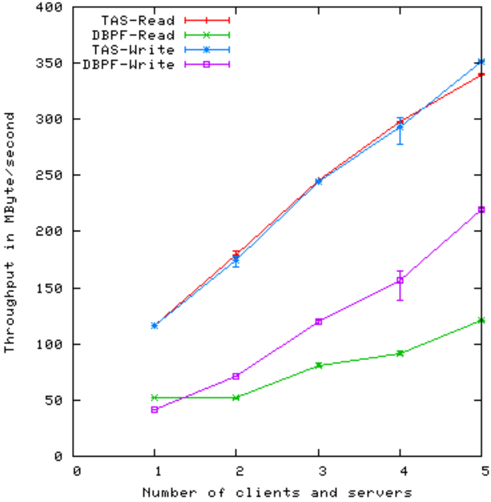
5 Clients, 5 Data servers



Notes

- TAS write performance > read performance
- Can be seen for DBPF with 10 MByte blocks
- About 3 times performance of 1 Client and 1 Data server

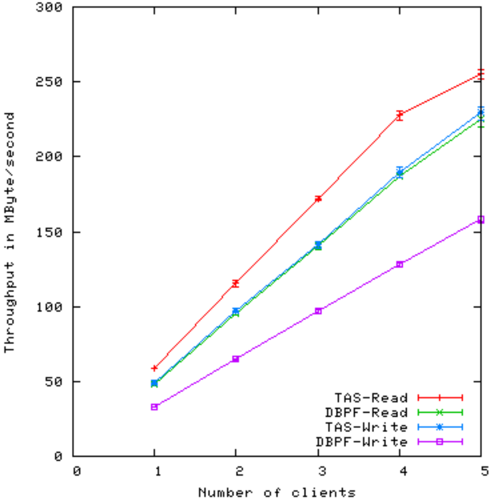
Variable number of clients and data servers



Notes

- 12800 MByte accessed in 10 MByte chunks
- Disjoint clients and servers
- Does not scale linear, network technology (Ethernet, star topology) ?
- I/O throughput does not scale for reads

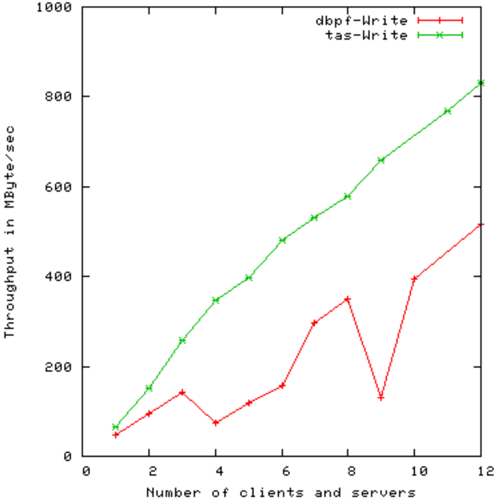
Variable number of clients and data servers



Notes

- Disjoint clients and servers
- 100 MByte accessed in 64 KByte chunks
- Good caching behavior expected
- Performance scales linear

Chiba 150 MByte per client



Notes

- Dual PIII 500 MHz, 512 MByte memory, Myrinet 2000
- Effective throughput measured between two nodes: 90 Mbytes
- Chiba hardware is old, hardware problems with myrinet interconnection, high packet loss
- Only qualitative analysis

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Summary

- A performance reference is useful for comparison and evaluation
- Analysis stubs can be used to evaluate performance
- Method allows to reduce complexity of analysis
- Regression tests with analysis stubs reveal performance differences more detailed