Lustre SMP Scaling Improvements

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Agenda

- Where we started from
- Why we need this project
- The problems
- What we can improve
- Current status
Where we started from

- Initial goal of this project
  - Soft lockup of LNet on client side
    - RDMA Portal can have very long buffer list (hundreds even thousands of match-entries on the list, need to compare one by one)
- Survey on low-end 4-core machines
  - LNet has one single global spinlock to protect everything
  - Lockmeter shows extremely high contention on the global lock while running insanity network test (lnet_selftest)
    - 40+% UTIL (fraction of time that the lock was held during the report interval)
    - 60% CON (fraction of lock requests that found the lock was busy when it was requested)
  - RPC rate is not good enough - it’s CPU bound!
Why we need this project

• With more powerful CPU, is metadata performance improving?
  • Unfortunately… 😞

• Metadata performance is not disk bound
  • We have tested with ramdisk
  • Profiles show that performance is CPU-bound on scaling tests, especially on metadata stack

• Stability of Lustre
  • Not all soft lockup is a real BUG, it’s probably just bad implementation

• I/O performance on NUMA systems
Why we need this project

Our objectives

• Make metadata performance faster
  • Unlock potential of higher IOPS from Flash/SSD

• Better I/O performance on NUMA systems

• Take advantage of rate of innovation in commodity microprocessor technology so our Lustre storage products can keep pace

• Less pressure on CMD 😊
The problems
LNet is the clue

• No heavy operation by LNet itself after we resolve the long ME-list (Match Entry) issue
  • List (search/change) operations, assignments, simple calculations

• Splitting the global lock by logic-path and making some cacheline optimizations…
  • 4 cores: better performance, Lockmeter: 4% UTIL, 15% CON
  • 8+ cores: barely better. It’s still a disaster while running insanity network test like Inet_selftest
The problems

Overhead of synchronization (1 of 2)

- Memory speeds can’t catch up with CPU speeds
- Synchronization requires consistent view of data across CPUs, so synchronization is much much slower than normal instructions because of memory latency
- Huge amount of data traffic for synchronizations
- We tried to make critical section faster, but critical section efficiency is bad
  - Ta (lock acquisition), Tc (Critical section), Tr (lock release)
  - Efficiency = Tc / (Ta + Tc + Tr)
The problems

Overhead of synchronization (2 of 2)
The problems

All globals are hurting us

- Global locks are everywhere
  - Simple, but really bad
- Global stats, global refcount
  - Huge amount of data traffic between CPUs
- Few people care about cacheline conflicts
  - A simple code sample

```c
struct foobar {
    spinlock_t    locka;
    Int           a;
    Spinlock_t    lockb;
    Int           b;
};
```
The problems
Non-CPU affinity threads pool

- Most LND threads and ptlrpc service threads are not CPU affinity
  - Threads are scheduled by different CPUs, all data need to be taken to local cache of CPUs again and again

- Global waitq
  - Contention on waitq (sleep / wakeup)
  - Round robin wakeup, refresh cache again and again
The problems
Hash tables & Misc

• We are not careful enough about our hash tables
  • The two biggest hash tables are not well-hashed
    • Object hash
    • LdIm hash
  • We have a hash table implementation for general purposes which is used everywhere, however…
    • Not good enough, a lot of unnecessary addref / decref, they are expensive atomic operations most of the time
    • Soft lockup
• Misc
  • Over-protected logic
  • LASSERT on very expensive conditions
What we can improve
libcfs infrastructure (1 of 2)

• CPU abstraction
  • CPU-node of libcfs can be (1-N) physical core, or NUMA node

• New interfaces for NUMA allocator
  • Local memory for each node, not only for MDT stack, also helpful for OST stack

• New interfaces for per-CPU data allocator

• New interfaces for cacheline aligned allocator

• LIFO wait-queue
  • Instead of FIFO wait-queue
What we can improve
libcfs infrastructure (2 of 2)

- Scalable local-global lock
  - Very fast local change
  - Slow global change
- A better implementation of cfs_hash
  - More flexible APIs
  - Different refcount modes and more efficient find-add
  - Much less addref/decref
  - Much SMP safer rehash & iteration
What we can improve

Restructured LNet & LND

• Each CPU has its local entry for LNet
• Each CPU has its own buffers (ME & MD list)
  • Requests are received on local buffer
  • Lazy portal is more important now
• EQ (Event Queue) improvements
  • EQ callback can happen concurrently on different CPUs
  • EQ has per-CPU refcount
• CPU affinity LND threads
  • Connections are hashed by NIDs
  • Each CPU has its own peer table
  • Completion vector of OFED
What we can improve

ptlrpc service

• Per-CPU service data
  • Locks, request buffer, request queue, reply state, AT…
  • More grained locks
    • Although they are local to each CPU, we still have cross CPU data access sometimes

• CPU affinity service threads pool
  • Local waitq for each CPU, otherwise all threads are serialized by the global waitq
  • LIFO wait queue can help to reduce active threads

• Cacheline optimization is always important
What we can improve
Ptlrpc performance

**echo getattr**

<table>
<thead>
<tr>
<th>Threads</th>
<th>1 client</th>
<th>2 clients</th>
<th>4 clients</th>
<th>8 clients</th>
<th>16 clients</th>
<th>32 clients</th>
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**Total # of threads**

**echo get attr**

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</table>

**Total # of threads**
What we can improve

Hash tables and overprotected data

• Better hash for objects and Idlm resources
  • 1 million files tests, max search depth dropped from hundreds to less than 50
  • It not only reduces overhead of searching, also avoids cache pollution
    • One cache miss means hundreds of cycles on most processors
• Over-protected data
  • We protect the same data at different levels of stack
  • MDT takes 2 locks on create/unlink where as one would be enough (survey still under way)
What we can improve

Everywhere

• Lazy update to globals
• Big reference count
• Per-CPU stats
• Code level improvement everywhere
  • Unnecessary lock dance
  • Wrong lock type
  • Redundant memset in our allocators
What we can improve

File stat (1-128 clients, 1 thread/client, 4K files/thread)

[Graphs showing performance comparison between current and patched versions in private and shared directories.]
What we can improve
opencreate / removal
(1-128 clients, 1 thread/client, 4K files/thread)
Current status

- Implementation almost complete
- Initial tests show good result
- Need more survey on backend filesystem
- Metadata performance testing on Hyperion is underway
- BULL is helping us to test NUMIOA performance
- Changes are targeted for the Lustre 2 code branch
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