FROM RESEARCH TO INDUSTRY

Scaling one single Lustre Filesystem up to 20K clients

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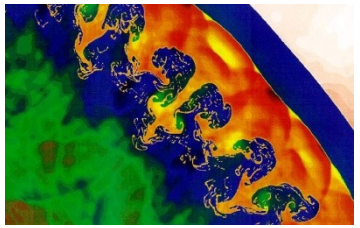
AGENDA

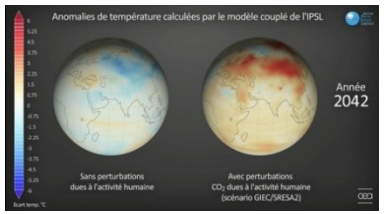
- Site update
- Context case study
- Credits and peer_credits
- CPU Partition Table
- High priority RPC nightmare

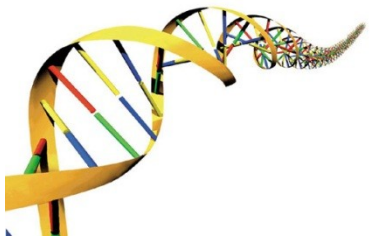
Site update

Compute centers at CEA/DAM

- **2 production compute centers:**
  - EXA: Defense application
  - TGCC: European research
    - Hosting France Génomique (storage of DNA sequencing data)
    - Hosting CCRT (for industrial companies)
    - Hosting Human Brain project
- **1 lab compute center:**
  - R&D compute nodes
  - R&D storage cluster
- **Compute power:**
  - EXA: 40 Pflops (~20K clients)
  - TGCC: 25 Pflops (~6K clients)
  - LAB: 1 Pflops (~200 clients)
- **2 production compute centers with a similar design:**
  - Nearly the same architecture, technologies, tools and system software

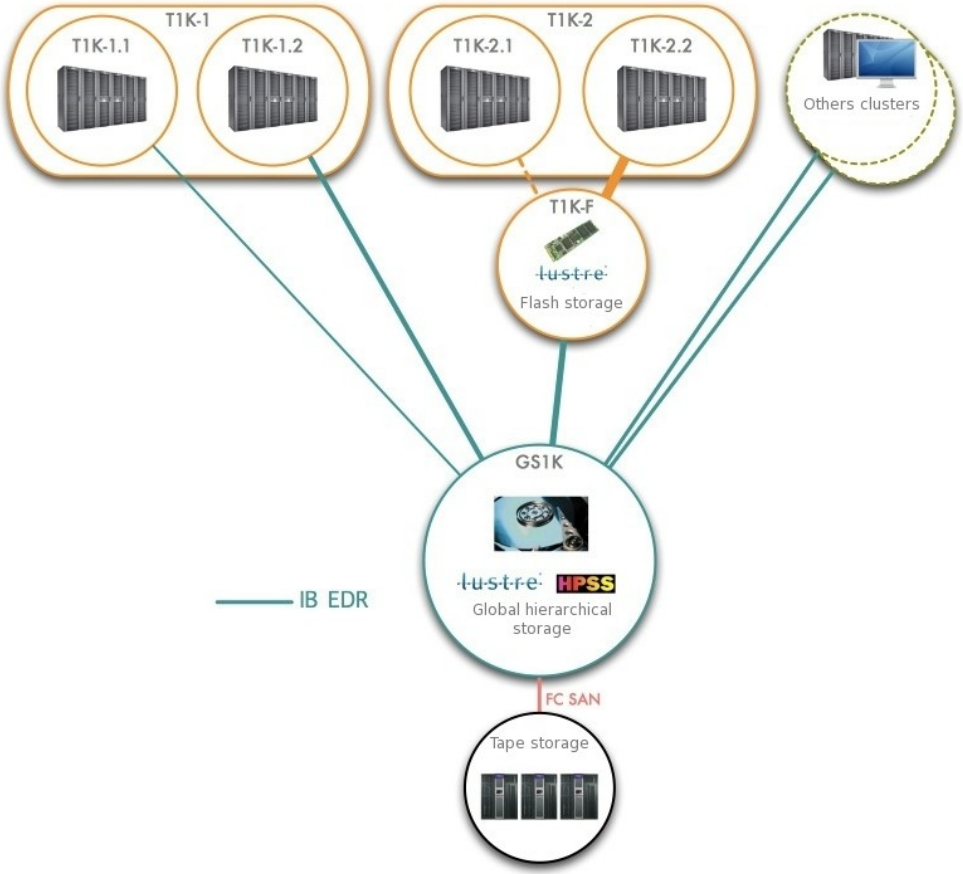






Human Brain Project

Global storage: data centric approach



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- **User interface: Lustre/HSM (Lustre 2.12.9++)**
  - Lustre 2.15 upgrade planned for Q2/Q3 2023

CEA HPC storage numbers

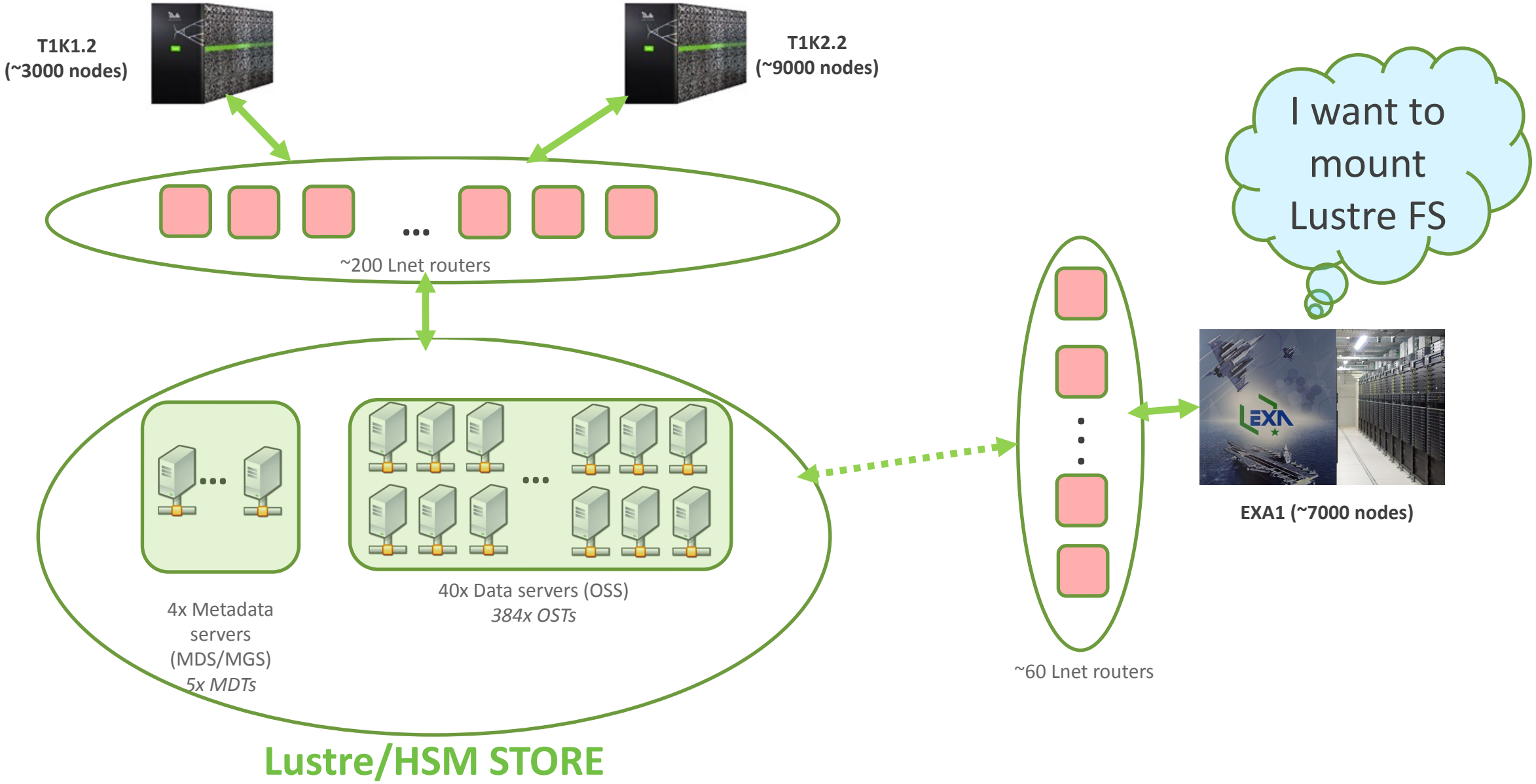
Production systems	Capacity	Throughput	IOPS
TGCC	40 PB (total: 80 PB, HSM backend)	900 GB/s	5000 K
TERA	60 PB (total: 120 PB, HSM backend)	2.5 TB/s	25000 K

Context case study

Case study

- Jump to past (Q4 2021)
- EXA1 (new supercomputers) Lustre mount request :)
- New Atos BXI internal network (specific LND)
- 60 LNET routers (no multirail)
- Add 7K clients to existing Lustre filesystems
- Lustre/HSM case study

Case study


T1K1.2
(~3000 nodes)
T1K2.2
(~9000 nodes)
~200 Lnet routers
4x Metadata servers (MDS/MGS)
5x MDTs
40x Data servers (OSS)
384x OSTs
Lustre/HSM STORE
~60 Lnet routers
I want to mount Lustre FS
EXA1 (~7000 nodes)

Case study

- **~20K Lustre clients**
- **3 supercomputers mounted (many) same Lustre FS**
- **Heterogeneous routers configuration (BXI_V1, BXI_V2, ConnectIB, ConnectX-4, ConnectX-6)**
- **All Lustre servers are Virtual Machines (limited ressources)**
- **HA configured (7 failover nids on Lustre targets)**

What we know:

- **Follow best practices Lustre scales well around 10K clients (**thanks to Lustre community and users feedback**)**
- **Cray had some issues with many large supercomputers**
  - https://cug.org/proceedings/attendee_program_cug2012/includes/files/pap166.pdf
- **BXI_V2 pretty young: issues on large scale (fixed now)**

Baby storm is here

- **Give us a try to mount FS:**
  - Unable to mount all nodes (7K) at same time (+12K already mounted)
  - Targets disconnection on already mounted clients
- **Successfully mounted (step of max 500 parallel mounts)**
  - Not very hopefully
  - Not pretty robust for future…

Analysis highly “recommended”, first issues seen:

- Lnet credits starvation on routers/servers
- Memory usage increases (50% of total memory)
- Many “small” RPC on MDS/MGS node (~**180000** RPC/s)

Lustre layers blockdiagram

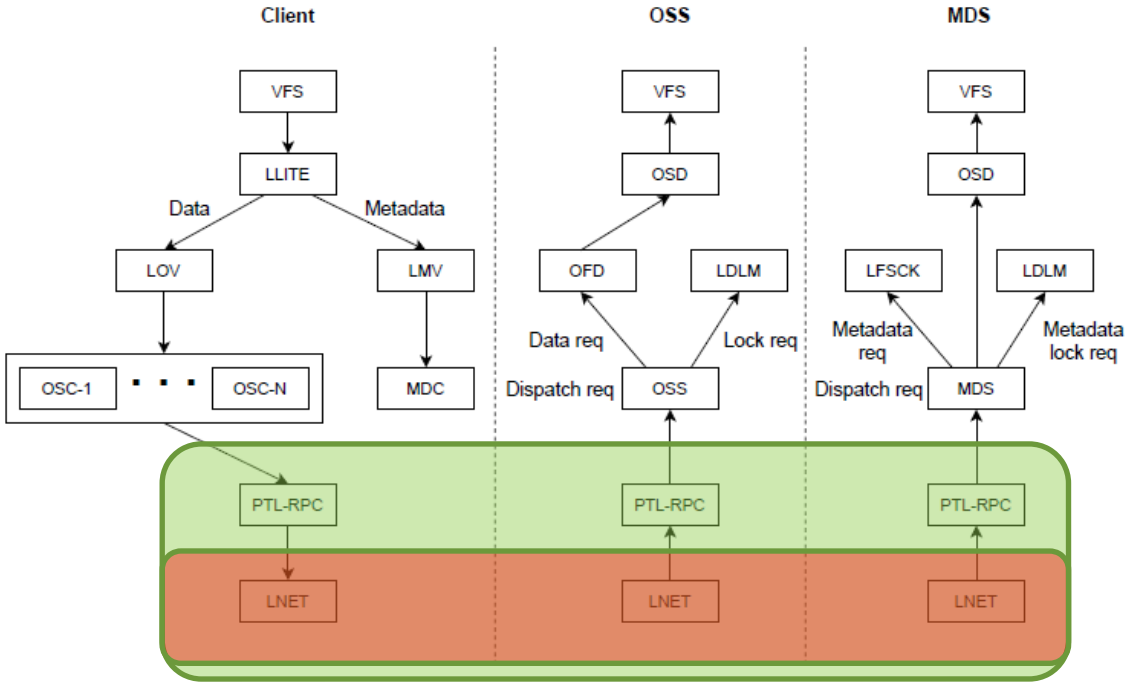
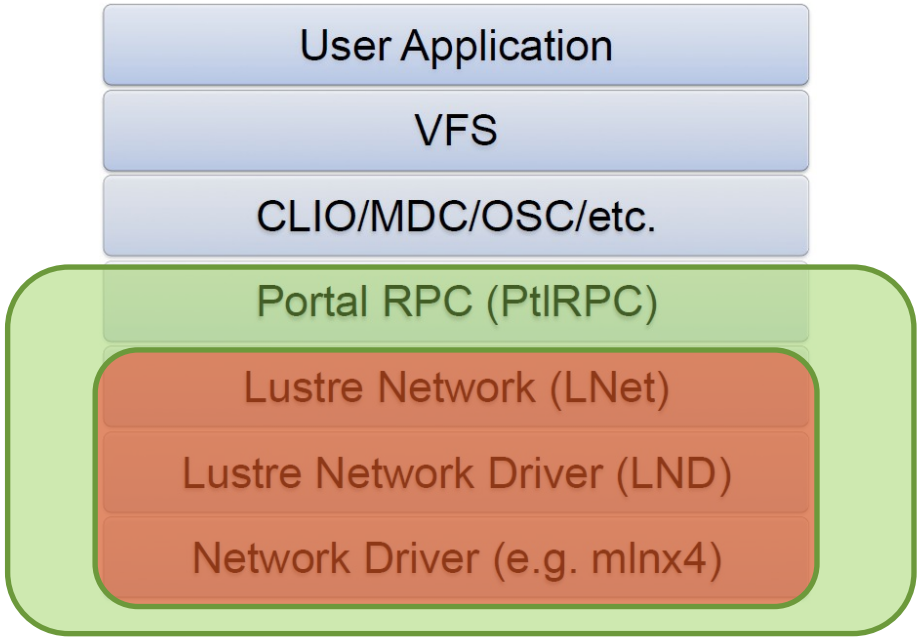


Figure 4. Basic view of Lustre software stack

Extracted from excellent ORNL Lustre Internals Papers
https://info.ornl.gov/sites/publications/Files/Pub166872.pdf



Extracted from LAD'15 Chris Horn talk

Point to point communication

End to end communication

Credits and peer credits

Credits and peer_credits

- **First analysis :**
  - Not enough resources on server side to absorb client activity
  - Seen by monitoring lnet interface credits (peer_credits starvation)

```
# cat /sys/kernel/debug/lnet/peers
nid                      refs state  last   max   rtr   min    tx   min queue
192.168.7.4@o2ib10          1    up    66     8     8     8     8     6 0
192.168.6.61@o2ib10         1    up   154     8     8     8     8   -13489 2300
192.168.3.20@o2ib10         1    up   149     8     8     8     8     4 0
192.168.7.38@o2ib10         1    up   187     8     8     8     8     2 0
```

- **Adjust credits/peer_credits:** read Chris Horn LAD'15 talk again :)
  - **Credits = Throttling mechanism** (a "TCP congestion window" like)
  - **Notice:** peer_credits != credits
  - **Credits:** Amount of credits per interface (o2ib10 here) for all CPT (CPU Partition Table)
  - **Peer_credits**: Max "inflight" lnet messages allowed for a peer

Credits and Credits computation

Peer_credits:

- Fine tuning in Lnet routing configuration (router is the closest/direct hop)
- Max value 255 (LND/Network driver compatibility ie max_send_wr supported), default 8
- CEA values
  - Servers: 42 (CX Firmware + MOFED 4.7.3 limitation due to ConnectIB interfaces)
  - Clients: 42 **except for BXI LND (32)**
  - Routers: 42 (IB LND), 32 (BXI LND)

Credits:

- Default: 256
- **Rule of thumb (CEA)**: credits=$((peer_credits*max_peer_seen))
- CEA credits servers=$((42*260))=10920
- Notice: value is divided per CPT (min value: 64 per CPT)

Credits computation for routers

- **No computation needed (**of course yes!**)**

- **Monitoring router buffer credits needed :**
  - Relevant only on routers
  - Give credit live consumption per CPT
  - for each type of RPC
    - 0 : ack and control packets
    - 1 : <= 4kb size RPC (ping and others)
    - 256 : >4Kb RPC (I/O)
  - count : credits left
  - credits : total available buffer credits
  - min column : low water mark (negative value indicates credits starvation)

```
# cat /sys/kernel/debug/lnet/buffers
pages count credits     min
    0  1024    1024    1021
    0  1024    1024    1020
    1  8192    8192    8059
    1  8192    8192    8036
  256   512     512     507
  256   512     512     507
```

Credits tuning results

- Parallel 7K clients successfully
- Seems few disconnection on some part of 7K nodes
- Few credits starvation, lower water mark < 3 digits (no queue)
- Others clusters are fine

Still work to do

- **A big job which breaks 2K nodes**
  - **generating BXI interconnect instability**
  - **some clients were able to partially communicate, some others fully hang**

- **Lustre level:** catastrophic effect
  - OOM on routers and servers
  - Others supercomputers are stuck
- **Lnet storm messages:** up to 7 800 000 RPC/s from routers to servers
- How can we handle this? (we hadn't the BXI fix at this time!)

CPU Partition Table

Handle 7 800 000 RPC/s?

- **lnet_selftest** is our best friend
- Seen a limitation on IB per servers/routers to ~180 000 RPC/s
- Non optimal CPU load distribution (pool of 4 CPUs closed to 90%, some others pools to 30%, …), Hashing function per peers (LU-14676)
- Goal: add more CPU Partition Table to have a better distribution from routers (avoid NID overlap per CPU)
- CPU server configuration: 12 cores, 1 NUMA node

```
# cat /etc/modprobe.d/libcfs.conf
option libcfs cpu_pattern="0[1] 1[2] 2[3] 3[4]
4[5] 5[6] 6[7] 7[8] 8[9] 9[10] 10[11]"
```

Handle 7 800 000 RPC/s!

- **Result:** big boost to **1 800 000 RPC/s** per server
- Still many RPC/s on MDS/MGS node during storm (Interconnect hang)
  - Move MGS outside MDS on a Virtual Machine
  - Useful to raw monitor MGS traffic and of course MDS traffic
- CPT live configuration:

```
lnetctl net show -v
cat /sys/kernel/debug/lnet/cpu_partition_table
```

- **Notice:** these tunings increase significantly performance, the tradeoff is the memory usage

High priority RPC nightmare

High priority RPC nightmare

- Configuration was pretty stable but:
  - Still massive small RPC (High priority) rates in case of network failure
  - No OOM except with one bad user workload
- How can we handle this?
  - Understand the storm HP RPC rates on reconnection
  - User workload analysis
- Storm HP RPC rates:
  - Only obd_ping RPCs seen
  - Obd_ping gives health status of Lustre servers and clients in both ways
  - Obd_ping are sent every “obd_timeout/4” (“keepalive” like)
  - On hp rpc timeout, clients immediately resend an obd_ping (no more credits on routers/servers for example…)
  - On large configuration (clients+lustre targets), **Lnet flooding occurs**

High priority RPC nightmare

- OOM on bad user workload
  - After profiling, workload ~= an IOR (FPP) from 1000 nodes (128000 processes) with a striping to -1 (here 384) on each file. A bit huge…
  - OOM root cause comes from ost_io services.

- Solution:
  - Tell user not to retry, not a persistent solution.
  - How to fix both issues (OOM + obd_ping burst)?

Solution thanks to adaptive timeout

- Obd_ping storm comes from network issues (Lnet credits starvation or lack of ressources on the path)

- For RPC timeout, Lustre relies on Adaptive timeout. Best practices often talk about at_max, not often at_min:
  - From Lustre manual “The at_min parameter is the minimum processing time that a server will report”
  - “0” means pretty fast when all is fine on Lnet network and Lustre servers/routers/clients
  - In case of “target” failure, this value is used by clients to send HP RPC to the target => flooding occurs

At_min

- We can help Lustre to not retry before Lnet message timeout
- Have to rely on your lnet configuration:

```
# lnetctl global show
global:
    numa_range: 0
    max_intf: 200
    discovery: 0
    retry_count: 0
    transaction_timeout: 50
    health_sensitivity: 0
    recovery_interval: 1
```

- Here, no retry_count, a recommendation is to have:
  - at_min=((retry_count + 1) * transaction_timeout+”piece of processing time”)
- CEA value: at_min=55

Summary

Summary

- Simulating a 80K parallel mounts clients: take 30s, credits starvation occurs, clients wait Lnet transaction timeout before to retry
- On production, 20K clients mount successful
- No more OOM in case of bad user workload or network instability
- BXI_V2 fixed now (no more full internal interconnect hang)
- No call to “ptlrpc_grow_req_bufs” function
- TBF QoS in use to limit bad user workload

- Large stable Lustre filesystem “relies” on:
  - Lnet credits tuning
  - CPT configuration adapted to your hardware
  - Adaptive timeout well tuned (obd_timeout, at_min, at_max)

Questions?

QoS Deep Dive related

OOM root cause

- Need a quick reproducer of OOM (outside production servers), how to?
  - mount 20 times the same test Lustre Filesystem on 1000 nodes (goal: simulating 20K exports on servers)
  - Forge bad Lnet routes (to add noise on Lnet routing). Reverse Lnet network on routers.
  - monitor obd_ping, “ptlrpc_grow_req_bufs” function
    - `routerstat`
    - `lctl dk set_param=+malloc`
- Events seen:
  - massive High Priority RPC occurs during reconnection (due to credits + cpt tunings), obd_ping > 200 000 RPC/s
  - requested buffers (rqbds) are allocated and grow up to OOM

Workaround in place

- Issue: requested buffers is the PTLRPC entry point from upper Lustre services:
  - Only low level (dangerous) tuning available
  - Trial method is an acceptable way to find upper values (not an easy task to simulate the worst case scenario on your FS, take idea from users workload)

```
# lctl get_param *.*.*.req_buffers_max
ldlm.services.ldlm_canceld.req_buffers_max=0
ldlm.services.ldlm_cbd.req_buffers_max=0
mds.MDS.mdt.req_buffers_max=0
mds.MDS.mdt_fld.req_buffers_max=0
mds.MDS.mdt_io.req_buffers_max=0
mds.MDS.mdt_out.req_buffers_max=0
mds.MDS.mdt_readpage.req_buffers_max=0
mds.MDS.mdt_seqm.req_buffers_max=0
mds.MDS.mdt_seqs.req_buffers_max=0
mds.MDS.mdt_setattr.req_buffers_max=0
mgs.MGS.mgs.req_buffers_max=0
```

- Setup custom req_buffers_max values for mdt,oss services