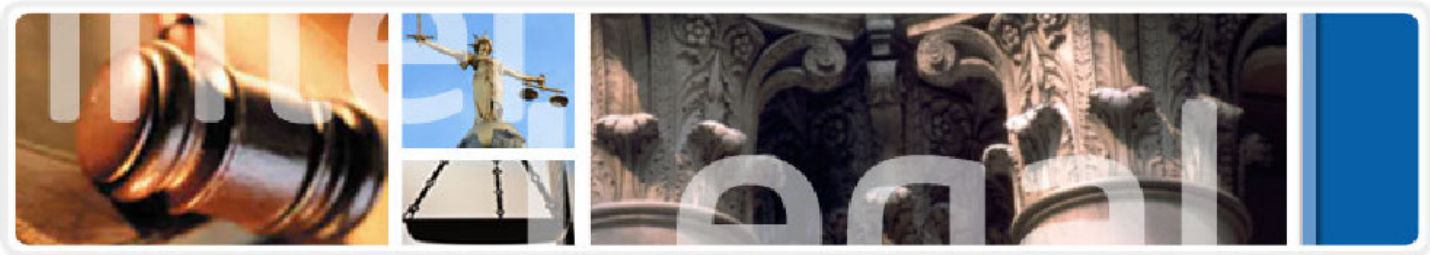
Lustre* Networking



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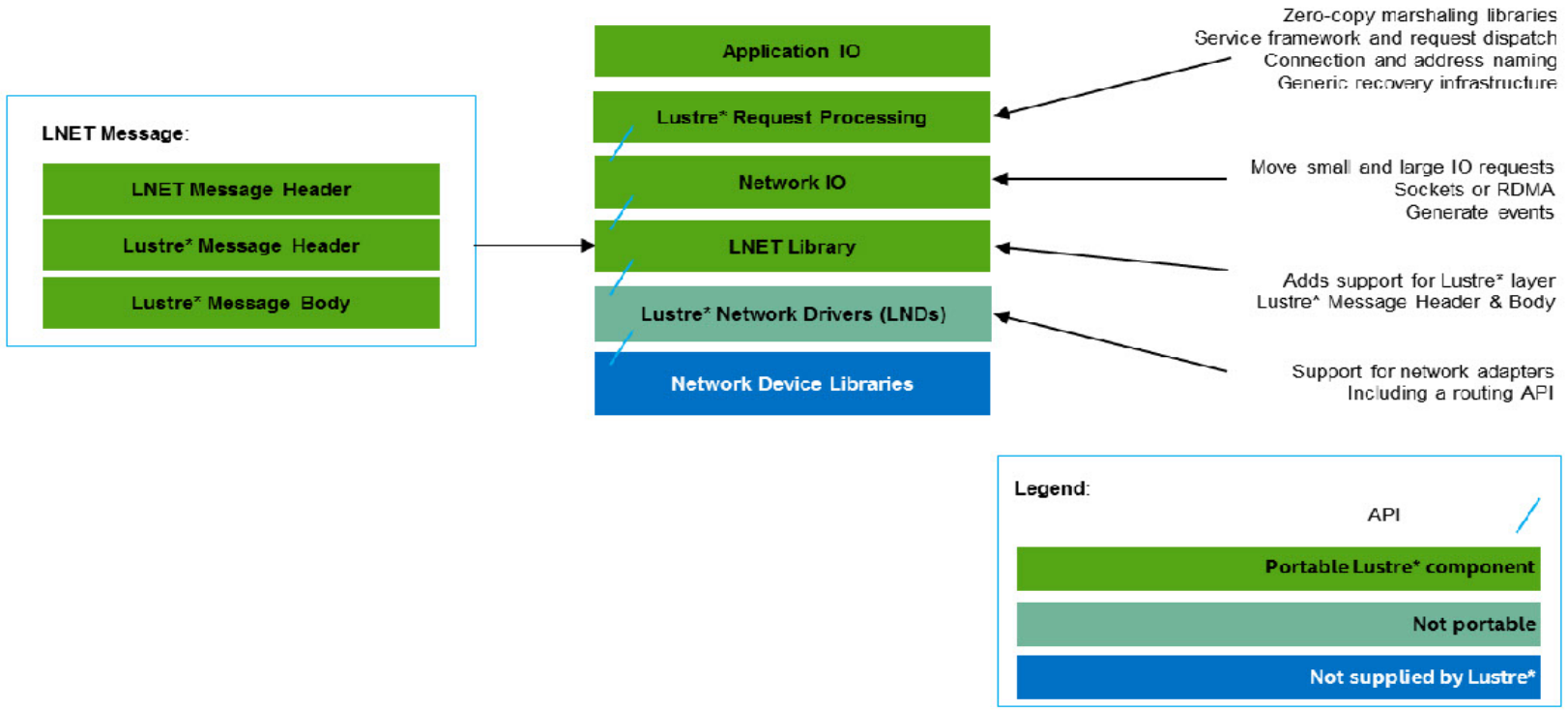
Module Overview

Topics covered in this module include:

- LNET Overview
- Network IDentifier Configuration
- Multi-[rail, path, plane]
- Multi-rail (Bonding)
- Introduction to LNET Routing
- LNET Configuration Parameters
- Summary

LNET Overview

Lustre* Network Software Stack



Interfaces Supported by Lustre* LNDs

Lustre* has provided support for many different types of network interfaces

- Each requires a supporting Lustre* Network Driver (LND)
- Key today are InfiniBand*, Intel® Omni-Path Architecture (Intel® OPA), Cray's GNI, and Sockets

InfiniBand* - uses OFED LND

- Native RDMA using Verbs, High Performance

Intel® Omni-Path - uses OFED LND

- Intel's new 100 Gbps network - leveraging QLogic's TrueScale, InfiniBand*, and Cray's Interconnects

Cray Interconnects - uses GNI LND

Sockets - uses SOCK LND on TCP port 988

- Internet Protocol over Ethernet or InfiniBand* (IPoIB)

RDMA over Converged Ethernet (RoCE) - uses OFED LND (requires a lossless Ethernet network)

- RoCE v1 is a link-layer only protocol - v2 is both routable and priority-based

Internet Wide Area RDMA Protocol (iWARP) - uses OFED LND

- RDMA over Sockets using iWARP extensions - currently implemented over TCP (offloaded)

Lustre* Network Operations

Start or Stop LNET

```
# lctl network [up|down]
```

List the Lustre* Network IDentifiers (NID)

```
# lctl list_nids
```

Check communication

```
# lctl ping <NID>
```

- When used with o2iblnd, the ping verifies RDMA functionality

Unconfigure LNET

```
# lctl network unconfigure
```

LNET functions independent of a file system

- In the case of Lustre* routers

Lustre* Network Operations - "lnetctl"

As of Lustre* 2.7, "lnetctl" works with Dynamic LNET Configuration (DLC) to configure Nodes and Routers

- Nodes:
  - Start/Stop LNET, Add/Remove/Show Networks, Add/Remove/Show Routes
- Routers:
  - Enable/Disable Routing, Enable/Disable/Show Routes, Configure Routing Buffers, Show Routing Parameters and Statistics

Start or Stop LNET

```
# lnetctl lnet [configure|unconfigure]
```

List the Lustre* Networks and Network IDentifiers (NID)

```
# lnetctl net show [--verbose]
```

Add a New Network

```
# lnetctl net add --net <LNET> --if <INTERFACE>
```

Remove a Network

```
# lnetctl net del --net <LNET>
```

Network IDentifier Configuration

Network IDentifier Configuration

Every Lustre* network needs an LNET Network IDentifier (NID)

Configured dynamically ("lnetctl"), or in `/etc/modprobe.d/`

- Actual file name is arbitrary - suggested is "`lnet.conf`"

Without an explicit configuration

- Starting Lustre* configures and enables LNET on the first non-loopback interface

LNET works with the per-interface network configuration

- Frame size, buffer sizes, TCP settings, etc.

Multiple LNETs can exist on one physical network

- e.g. Both o2ib1000 and o2ib1001 on ib0
- May be useful with fine-grained routing, or some types of load balancing

NID Configuration (cont)

Two configuration options: "`networks`" or "`ip2nets`"

- Mutually exclusive – use either "`networks`" or "`ip2nets`"

Option networks

- Simpler format to read and write
- Configures LNET on a specific Linux interface
- May include multiple LNET configurations

Option ip2nets

- More complex to read and write
- Supports deploying the same "`lnet.conf`" to nodes with different network interfaces
- LNETs are configured by matching their interface(s) and/or IP address(es)

LNET Multi-plane Example Using Networks

Server has 3 Ethernet ports and 1 IB port

- The first Ethernet interface (eth0) is for management - it will not be used by Lustre*
- The remaining ports, eth1, eth2 and ib0, will all be configured to use LNET

```
options lnet networks="tcp1(eth1),tcp2(eth2),o2ib0(ib0)"
```

- `networks` options are parsed in the order shown above

In the above configuration:

- `tcp1` will run over `eth1`
- `tcp2` will run over `eth2`
- `o2ib0` will run over `ib0` (and will sometimes show as "`o2ib`" – minus the numerical suffix)
- Lustre* will not configure `eth0` with an LNET NID

LNET Multi-plane Example Using ip2nets

Servers

- Server1: eth0 IP address: 192.168.0.2; ib0 IP over InfiniBand* (IPoIB) address: 132.6.1.2
- Server2: eth0 IP address: 192.168.0.4; ib0 IP over InfiniBand* (IPoIB) address: 132.6.1.4

Clients

- Ethernet/TCP clients: All have IP addresses 192.168.0.5-255
- InfiniBand* clients: All have IP over InfiniBand* (IPoIB) addresses 132.6.[2-3].2, .4, .6, .8

Configuration (semicolon between entries)

```
options lnet ip2nets="tcp1(eth0) 192.168.0.[2,4]; \
  tcp1 192.168.0.*; o2ib1 132.6.[1-3].[2-8/2]"
```

- Nodes use the first matching rule for particular network types
- Nodes with multiple matches on different interfaces support multiple LNETs
- [1-3] matches the addresses 1, 2, and 3
- [2-8/2] matches the addresses 2, 4, 6, 8

LNET Multi-plane Example - with Comments

Setup

- MDS – `10.10.120.[3,4] (eth1)`
- OSS – `10.10.[1-8].[1-253] (ib0)`
- OSS – `10.20.[1-8].[1-254/2] (ib0)`
- Clients – `10.30.x.x` (any interface)
- Remote clients use – `eth1`
- Routers – Not shown

```
options lnet ip2nets="\
  tcp1(eth1) 10.10.120.[3,4]          # MDS group; \
  o2ib1(ib0) 10.10.[1-8].[1-254]      # 1st OSS group;   \
  o2ib2(ib0) 10.20.[1-8].[1-254/2]    # 2nd OSS group;  \
  tcp2       10.30.x.x                # 10.30.0.0 clients; \
  tcp3(eth1)                          # Remote clients"
```

Multi-[rail, path, plane]

Network Connections - Multi-rail

Multi-rail (a.k.a “Bonding”)

- Multiple connections between end points, using the same network ID
  - Imagine: Train tracks, working together to transfer data
  - Example: Ethernet Bonding in Linux
- Ethernet bonding in Linux is fully supported by LNET
  - LNET uses the underlying bonding technology
- InfiniBand* bonding is not as clear cut
  - LNET over IPoIB (sockets) fully supports multi-rail (using sock LND)
  - OFED InfiniBand* does not support multi-rail for RDMA
  - LNET over RDMA-IB supports interface failover (using o2ib LND)
- Next unit will cover bonding in more detail

Network Connections - Multi-path

Multi-path

- Multiple connections providing different routes to the same end point
  - Example: A node with:
    - Two adapters with different network IDs, and
    - The adapters are connected to different switches in the fabric
- Not supported by Lustre* between nodes
- Lustre* determines one (1) NID to reach a destination, and it sticks with it
- Lustre* servers do use multi-path to storage controllers

Network Connections - Multi-plane

Multi-plane (a.k.a. “Dual-Homed”)

- Having separate connections to 2+ networks
  - Each network connection requires a unique network identifier
  - Often referred to as “dual-homed”, or “multi-homed”
- Supported by Lustre* via LNET
  - Nodes have routing table entries for each LNET Network
- Works with commonly used network protocols
  - InfiniBand*, Ethernet, etc.
  - Heterogeneous networks

Multi-plane (cont)

A use case for a multi-plane configuration

- Additional bandwidth gained by using additional networks
- Supporting multiple compute clusters
- Connected nodes are relegated into separate groups
  - Remember, LNET always uses the same local NID to communicate with a peer

Configuration example - Multi-plane InfiniBand*

- Servers each have two IB interfaces - ib0 and ib1
- Clients each have one IB interface - ib0
- Clients attach to only one of the server interfaces
- Using a "/17" network

```
option lnet ip2nets="\
     o2ib0(ib0) 10.10.[0-127].*   # subnet 1: servers + clients;\
     o2ib1(ib1) 10.10.[128-255].* # subnet 2: servers;\
     o2ib1(ib0) 10.10.[128-255].* # subnet 2: clients"
```

Multi-rail (Bonding)

Multi-rail ("Bonding")

Switch from Multi-rail terminology to the more familiar term of bonding

Not all protocols support bonding equally

- Bonding works well for Ethernet and IPoIB, as it did for ELAN and others
  - Much better bonding support in Ethernet vs IPoIB
- Bonding for RDMA data transfers is not supported by the OFED stack
  - LNET provides limited bonding support for RDMA over IB

Ethernet bonding in Linux

- Linux provides a very good bonding driver
- Provides fault tolerance and load balancing
- Supports seven (7) different bonding modes
- Lustre* supports the use of Linux bonded interfaces

Multi-rail ("Bonding") (cont)

Ethernet bonding (cont)

Creating a bonded Ethernet interface using Linux bonding techniques

```
alias bond0 bonding
options bond0 mode=balance-alb miimon=1000
  (other options exist as well)
```

For reference, this means:

- Use interface `bond0`
- Use Active Load Balancing (ALB) - mode 6
  - Has certain requirements of the Ethernet driver
- Use "`miimon=1000`" (ms) for link detection
  - Must support Media Independent Interface (MII) checking/setting

Configuring the bonded interface into LNET:

```
options lnet networks=tcp1(bond0)
```

Bonding - LNET over InfiniBand*

The `o2ib` LND provides limited support for LNET bonding over InfiniBand*

Active-passive configuration only

- If active interface fails, other interface becomes active
- Used in situations where high availability is required
- No aggregation of IO

Configure bond using InfiniBand* LND

```
options lnet networks=o2ib0(bond0)
```

Enable failover bonding using this LNET option

```
options ko2iblnd dev_failover=1
```

Multi-Rail LNET (over InfiniBand*) design

- See wiki.lustre.org/Projects

Introduction to LNET Routing

LNET Routing

The Lustre* Network protocol is a routable protocol

- Routing across a WAN
- Routing within a Data Center
  - Connect different LNET types - InfiniBand* with Ethernet or Aries/Gemini (Cray)
  - Fine Grained Routing (FGR) - router preferences, to avoid ISLs

Components

- Lustre* end-nodes
  - Lustre* clients and servers
  - Configured with routes to remote LNETs
- Lustre* routers
  - Multi-plane nodes
  - Run LNET protocol only, via Lustre* client software
  - Forward traffic between LNETs
  - Deploy multiple routers for both performance and high-availability

LNET Routing - End Nodes

End nodes have static routes defined

- Route to destination LNET via router on local LNET

Routing decision is based on destination NID

- If destination NID is on a local LNET, send direct to NID
- If destination NID is on a remote LNET, find the best route

Best route is based on hop count *(excluding FGR)*

- If one router has the shortest hops to the destination, that route is used
- If multiple routers have the same hop count to the destination, those routers are used in a round robin manner

LNET Routing - End Nodes (cont)

End nodes monitor routers

- All Lustre* nodes always monitor peers via LND
  - Cannot be disabled
  - LND detects when a peer is down - will not send to a down node
- End nodes can also monitor routers at the LNET layer

LNET monitoring of a router is performed by the Router Checker

- Though disabled by default, enabling certain LNET parameters enables the Router Checker
  - live_router_check_interval, dead_router_check_interval
- Router Checker issues an LNET_GET to the router
  - Receives a list of router NIDs and their state
  - If the route to the destination is not available, that route will be marked down
  - If any NID is down and avoid_asym_router_failure=1, router will be marked down
  - If the “dead check” is enabled, end node will detect when the router is up again

LNET Routing - Routers

Lustre* routers are basically multi-planed Lustre* clients

- Their routing tables contain the interfaces they know about, and possibly static routes to remote networks for WAN configurations
- The routers buffer incoming messages and relay them out another interface
- They have an interface specific LND with necessary customizations
- Though there will be multiple LND layers, one for each interface, there will be only one LNET thread

The LNET layer is a single kernel thread, so LNET, and thus LNET routing, is logically a single queue

- Because of that there must be some significant buffering and queuing, both in the LNET layer as well as the LNDs

Next - Routing buffers at the LNET layer

LNET Routing - Routers (cont)

LNET Routers have three (3) types of buffers

- **Tiny buffers**
  - Used for transfers that have no payload - ACK, etc.
  - Zero-byte payloads
  - Default/minimum amount is 512
- **Small buffers**
  - Used for transfers that have a small payload
  - Single page (4096 bytes) payload
  - Default/minimum amount is 4096
- **Large buffers**
  - Used for large transfers
  - 1 MB - Lustre*'s magic number
  - Default/minimum amount is 256

LNET Routing Configuration

Example configuration using the LNET networks option:

- Servers are on o2ib1010 – 10.10.0.0/16
- Clients are on tcp168 – 192.168.0.0/16
- Routers are on both o2ib1010 – 10.10.0.1-5 and tcp168 – 192.168.0.1-5

Servers:

```
options lnet networks="o2ib1010(ib0)" routes="tcp168 10.10.0.[1-5]@o2ib1010" \
live_router_check_interval="45" dead_router_check_interval="180"
```

Clients:

```
options lnet networks="tcp168(eth0)" routes="o2ib1010 192.168.0.[1-5]@tcp168" \
live_router_check_interval="45" dead_router_check_interval="180"
```

Routers:

```
options lnet networks="o2ib1010(ib0), tcp168(eth0)" "forwarding=enabled"
options ko2iblnd peer_buffer_credits="12"
options ksocklnd peer_buffer_credits="8"
```

LNET Routing Configuration - Results

```
[client]#  lnetctl net show --verbose
net:
    - net: lo (not shown here...)
    - net: tcp168
      nid: 192.168.10.111@tcp168
      status: up
      interfaces:
          0: eth0
      tunables:
          peer_timeout: 180
          peer_credits: 8
          peer_buffer_credits: 0
          credits: 256
```

LNET Configuration Parameters

Network Configuration Parameters

Lustre* networking contains many, many, many configuration parameters

- Two types of Lustre* modules - and then there are the Linux modules…
- Lustre* modules: LNET (lnet.ko) and LND (ksocklnd.ko, ko2iblnd.ko, kgnilnd.ko, etc.)
- Some parameters apply to LNET, others apply to the LND
- To determine available parameters for an LND, run:

```
$ modinfo /lib/modules/…/kernel/net/lustre/[LND module]
```

Module parameters have default values

- Sometimes hard-coded (see: o2iblnd_modparams.c)
- Other times derived
  - LNET peer_buffer_credits derived from LND peer_buffer_credits
  - LND concurrent_sends based on LND peer_credits and LND map_on_demand

What do all the parameters do? Which should be focused on?

- The most significant ones, of course…

Configuration Parameters - LND

LNET's credit system

- Rate limiting is done on SENDING information
- LNET uses a credit system to limit overloading of nodes
- Cannot send anything to a peer without approval - or "credits"

Credits, Peer Credits, Peer Credits Hi-Water, and Peer Buffer Credits

- "credits" - number of outstanding sends on a specific network interface
- "peer_credits" - number of outstanding sends to one (1) peer
- "peer_credits_hiw" - number at which credit returns are eagerly requested
- "peer_buffer_credits" - number of outstanding sends from an end node

Monitor Credits

```
/proc/sys/lnet/nis
/proc/sys/lnet/peers
```

Configuration Parameters - LNET

Mostly Routing Parameters

```
config_on_load                  - configure LNET at module load
routes                          - define routes through routers

forwarding                      - route LNET traffic: enabled|disabled
auto_down                       - mark router state up/down: 0|1
check_routers_before_use        - force a check: 0|1 (req's d_r_c_i)
dead_router_check_interval      - check if down: secs
live_router_check_interval      - check if up: secs
router_ping_timeout             - router checker timeout: secs
avoid_asm_router_failure        - down router if any route down: 0|1

peer_buffer_credits             - router buffer credits, per peer
large|small|tiny_router_buffers - buffers in each group: num
```

Summary

Module Summary

LNET Overview

NID Configuration

Multi-[rail, path, plane] Configuration

Multi-rail (Bonding)

Introduction to LNET Routing

LNET Configuration Parameters

Congratulations! You have completed:

Lustre* Networking