

Reference Architecture

Developing Storage
Solutions with Intel Cloud
Edition for Lustre* and
Amazon Web Services

Developing High-Performance, Scalable, Cost-Effective Storage Solutions with Intel Cloud Edition Lustre* and Amazon Web Services

Designed specifically for high performance computing, the open source Lustre parallel file system is one of the most popular, powerful, and scalable data storage systems currently available. It is widely used in super-computing scenarios that require high performance and enormous storage capacity. Sixty percent of the largest 100 clusters in the world¹ are currently running Lustre. Amazon Web Services (AWS) is a leading provider of cloud computing infrastructure that allows scientists and engineers to solve problems that require fast computation coupled with high-bandwidth, low-latency networking.

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Intel Cloud Edition for Lustre* software provides a high-performance Lustre file system on AWS using AWS resources. It includes CentOS, Lustre, Ganglia, and Lustre Monitoring Tool (LMT). The product is delivered in the form of an Amazon Machine Image (AMI) available on the AWS Marketplace.

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A Typical HPC File System

Scale-up storage solutions and other traditional network file systems such as NFSv3 designate a single node to function as the I/O server for the storage cluster. All I/O data reads and writes go through that single node.

Figure 1 shows a typical NFS configuration. Although this system is simple to manage in a single cluster deployment, pushing all of an enterprise’s I/O through one server node creates a bottleneck for data-intensive workloads and for workloads that need a high number of threads/processes.

When scaling up an NFS-based environment, each NFS cluster must be managed individually, which adds to data bottlenecks as well as management overhead and costs.

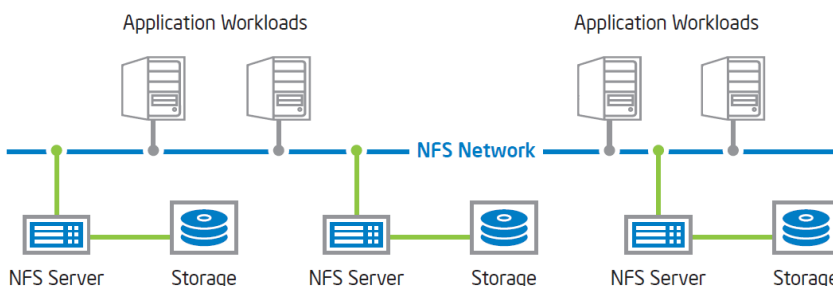


Figure 1: Typical NFS Configuration

Lustre Architecture

Lustre is a Portable Operating System Interface (POSIX) object-based file system that splits file metadata, such as the file system namespace, file ownership, and access permission, from the file data and stores each on different servers. File metadata is stored on a metadata server. File data is split into multiple objects and stored in parallel across several object storage targets (OST). Figure 2 shows a typical Lustre file system configuration. The Lustre network, a very powerful and fast abstraction layer, makes it possible for the Lustre file system to run on different heterogeneous networks. Lustre Networking (LNET) provides the communications infrastructure required by the Lustre file system. It enables highly-available cluster communication across a variety of networking technologies and supports transparent recovery during failures.

Lustre is designed to achieve maximum performance and scalability for POSIX applications that require outstanding streamed I/O. Users can create a single POSIX namespace of up to 512 petabytes (PB) and very large files up to 32 PB. Several sites with a Lustre cluster scale beyond one terabyte (TB) per second² and have metadata operation rates of 800,000 statistics per second.

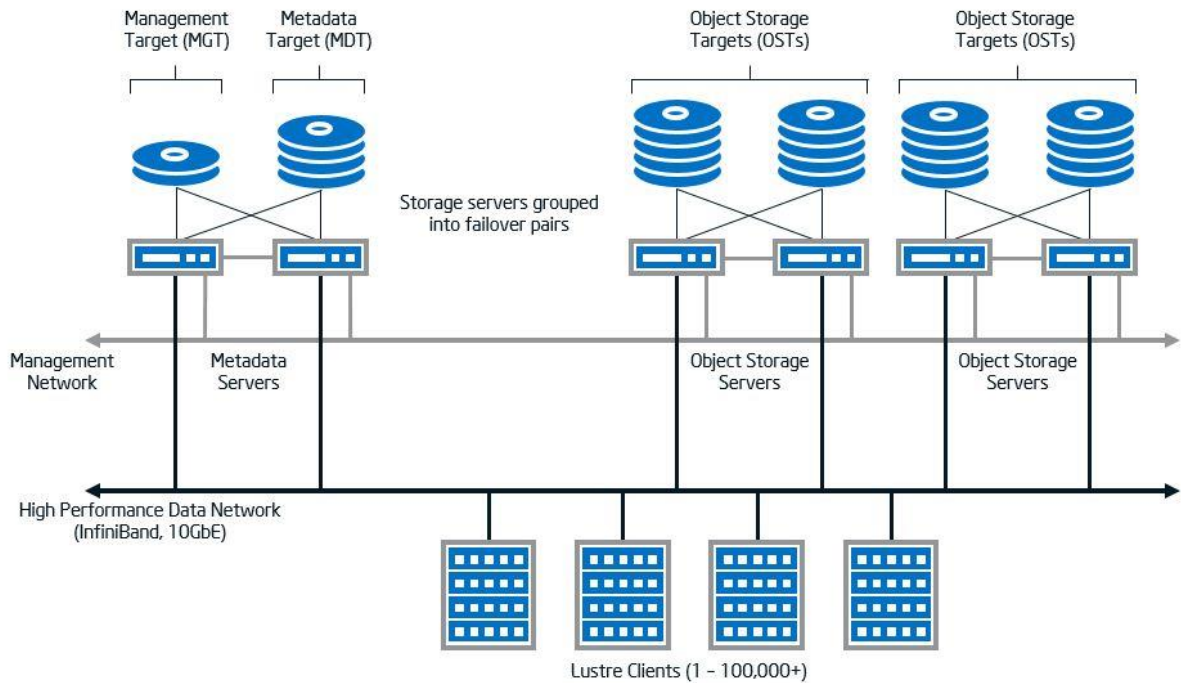


Figure 2: Typical Lustre File System Configuration

Intel Cloud Edition for Lustre*

Intel Cloud Edition for Lustre* is available through the AWS Marketplace. This product provides a high performance Lustre file system on the AWS cloud using AWS compute, storage, and I/O resources supported by Intel. Intel Cloud Edition for Lustre* is intended to be used as the working file system for High Performance Computing (HPC) or other I/O intensive workloads. It is not intended to be used as long-term storage or as an alternative to cloud storage options, such as Amazon Simple Storage Service (Amazon S3). Amazon S3 is recommended for long-term data storage on AWS; Lustre is recommended wherever a high-performance shared file system is required. With the latest edition of Intel Cloud Edition for Lustre*, Amazon S3 storage can be used to import data into the Lustre file system.

Available Versions

Intel Cloud Edition for Lustre* supports several advanced AWS capabilities.

- The Amazon Virtual Private Cloud (Amazon VPC) lets you provision a logically isolated section of the AWS cloud where you can launch AWS resources in a virtual network that you define. Amazon VPC is now the default mode of networking in AWS deployments. It allows for full control over addressing and access.
- The Lustre high-availability solution automatically configures Amazon EC2 Auto Scaling, which adds support for restarting unhealthy Amazon EC2 instances. If an instance becomes unhealthy, the preconfigured Auto Scaling feature will detect the failure and start a new instance. After the new instance is online, it will reattach the orphaned target's resource (network interface and Amazon Elastic Block Store [Amazon EBS] volumes) and restart the target.
- In some end-user environments, direct access to non-VPC network resources is not allowed. As Intel Cloud Edition for Lustre* requires access to AWS service endpoints in order to perform configuration tasks on behalf of the user, this can present a deployment challenge.

Fortunately, Intel Cloud Edition for Lustre* does support proxied access to the AWS endpoints, using a special cut-down CloudFormation template. This proxy template does not create a NAT instance to act as a gateway, and instead accepts input parameters for a HTTP proxy hostname and port. Using this information, the template is able to create a Lustre cluster without direct access to the AWS endpoints.

The following table lists the three Intel Cloud Edition for Lustre* versions and their features available on AWS.

Features	Evaluation	Self-Support	Premier Support (8x5)
Intel Support	no	no	yes
Instance Types	T2	C3, C4, M4	C3, C4, M4
IPSec Encryption	yes	yes	yes
EBS Encryption	yes	yes	yes
EBS Storage	yes	yes	yes
VPC*	yes	yes	yes
Enhanced Networking**	no	yes	yes

* Contact Intel support for information on using these features

** Enhanced Networking is only supported with C3 and C4 instances

Premier Support (8x5)

This product offering is our high-end option with support from the Lustre* experts at Intel. It includes IPSec over-the-wire encryption, EBS encryption, Enhanced Networking, and C3 and C4 compute optimized instances as well as M4.10xlarge instances. Enhanced Networking provides SRIOV, which allows a physical device to be virtualized and connected directly to a virtual machine. This provides lower latency and more consistent performance.

Self-Support

This product offering provides the same features as the Premier Support product, but without the included support from Intel. It includes IPSec over-the-wire encryption, EBS encryption, Enhanced Networking, and C3, C4, and M4.10xlarge instances. Also includes Enhanced Networking (SRIOV), and provides lower latency and consistent performance.

Evaluation

The "Evaluation" offering is an entry level product offered on Marketplace which can be used for proof-of-concept and development testing. Support is not included with this version, so we recommend moving to a product which includes "Premier Support" once you have evaluated the product.

Support

Product versions containing **Premier Support** are supported by the Lustre* experts at Intel®. Product support includes live 8x5 PST phone & email support as well as the latest software updates, patches, and fixes to ensure a stable, flexible, and robust storage environment that leverages the benefits of cloud-based infrastructure. The Evaluation and Self-Support versions of the Intel Cloud Edition for Lustre* software does not include Support. If you would like more information on this product or are interested in adding Support please contact hpdd-cloud-lustre@intel.com for more information.

How to Create a Lustre Cluster on AWS

Intel Cloud Edition for Lustre* is designed to create a scalable, very fast parallel Lustre file system to be attached to an external cluster of compute nodes. During the creation of the Lustre cluster, a single client will be created. This is used for test purposes only. The compute cluster can be created using a variety of cluster managers. AWS has simplified this process with an easy-to-use tool called [CfnCluster](#), which is discussed later in this paper.

Step 1: Subscribe to a Product Version

Choose the version of Intel Cloud Edition for Lustre* that meets your requirements and then subscribe using the AWS Marketplace shown in Figure 4 or the [Intel web page](#) shown in Figure 5

intel
Software

Intel Cloud Edition for Lustre* software - Self Support

Sold by: Intel Corporation

Intel Cloud Edition for Lustre software is a scalable, parallel file system purpose-built for HPC. Ideally suited for dynamic, pay-as-you go applications from rapid simulation and prototyping to cloud bursting some or all of your peak HPC workloads. Intel Cloud Edition for Lustre software helps maximize storage performance and cost-effectiveness with AWS. ****IMPORTANT NOTE****: Intel Lustre is a cluster solution that **REQUIRES** multiple instances. Please be aware that the Pricing Details listed are for a single instance and may vary depending on your cluster configuration.

Customer Rating	Be the first to review this product
Latest Version	1.2
Base Operating System	Linux/Unix, CentOS 6.7
Delivery Method	64-bit Amazon Machine Image (AMI) (Learn more)
Support	See details below
AWS Services Required	EC2, EBS, DynamoDB, CloudFormation, AutoScaling

Continue You will have an opportunity to review your order before launching or being charged.

Pricing Details

For region
US East (N. Virginia)

Hourly Fees
Total hourly fees will vary by instance type and EC2 region.

Figure 4: AWS Marketplace Page for Subscribing to a Product Version



Figure 5: Intel Web Page for Global (HVM) Version

Step 2: Launch a Cloud Formation Template

After you receive confirmation email, you are ready to use the templates to create your cluster. On the Intel web page, click the link that corresponds to your product version, as shown in Figure 6.

Each version has several templates to choose from. Select a cluster configuration that meets your requirements.

Templates have been created for the following AWS regions: US East (N. Virginia), US West (Oregon, N. California), Asia Pacific (Tokyo, Singapore, Sydney), South America (Sao Paulo), EU (Ireland). Choose the template for your preferred Availability Zone.

Templates will require additional configuration parameters.

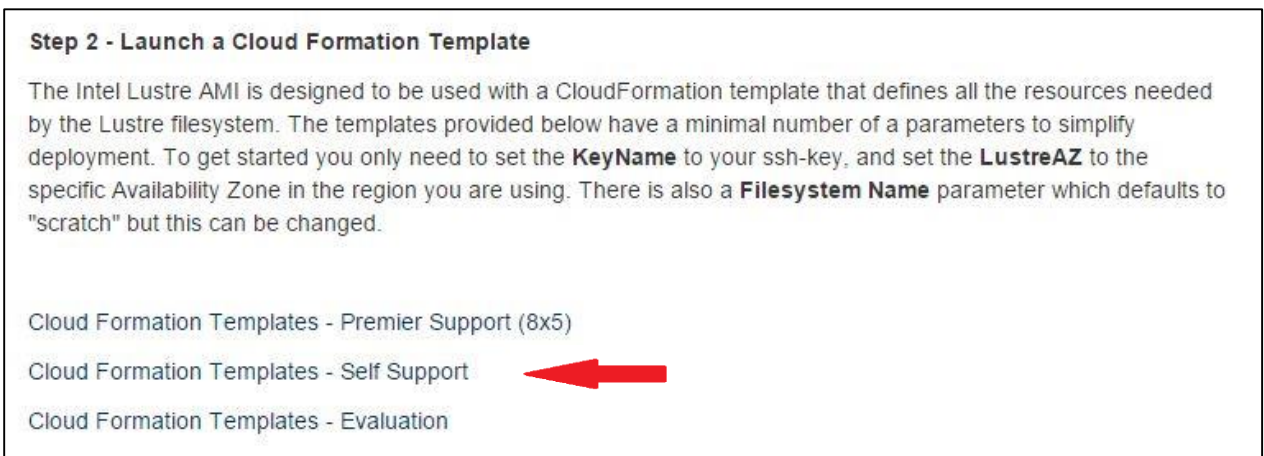


Figure 6a: Launch a Cloud Formation Template Screen

High Availability VPC Templates (v1.2)

The High Availability templates also run in a VPC, but these manage resources differently than the other templates which allows us to support HA without requiring any additional instances. In addition to creating the EBS volumes for Lustre, we also create a new Elastic Network Interface for each Lustre server, and associates that ENI with the EBS volumes used by that Lustre server. If an instance should fail, a replacement instance is launched by the autoscaler. When the new instance starts, it adopts the now orphaned network interface and the associated EBS volumes, and the failed Lustre service is resumed.

These templates create a new private subnet in an existing VPC, and also create a NAT gateway in an existing public subnet. The NAT gateway is required because the Lustre instances are using AWS services (such as DynamoDB and EC2 API) to coordinate the management of the Lustre filesystem. The gateway can also be used as an ssh host to access the Lustre subnet. There are three VPC-specific parameters:

VpcId - the ID of an existing VPC. The new Lustre subnet will be created here.

VpcPrivateCidr - an available CIDR address range that will be used for the new Lustre subnet.

VpcPublicSubnetId - an existing public subnet in **VpcId**. A NAT gateway will be created in this subnet.

Self Support

Template	Description	Launch in US East (N. Virginia)
ha	Create a highly available Lustre cluster in a VPC using C4 class instances and GP2 EBS volumes.	Launch Stack
Template	Description	Launch in Asia Pacific (Tokyo)
ha	Create a highly available Lustre cluster in a VPC using C4 class instances and GP2 EBS volumes.	Launch Stack
Template	Description	Launch in South America (Sao Paulo)
ha	Create a highly available Lustre cluster in a VPC using C4 class instances and GP2 EBS volumes.	Launch Stack




Figure 6b: Launch a Cloud Formation Template Screen

Step 3: Customize Your Cluster

You can open the template files. For example, in Figure 6b, in the Template column, you can click HA (used to deploy on the C4 instance type), modify it, and save it to a location of your choice. This gives you the flexibility to customize your cluster: to define the instance types you want to use, for example, or to include Amazon VPC settings. If you have your own modified version, select **Choose File** (shown in Figure 7), and browse to your template location. Click **Next** to continue.

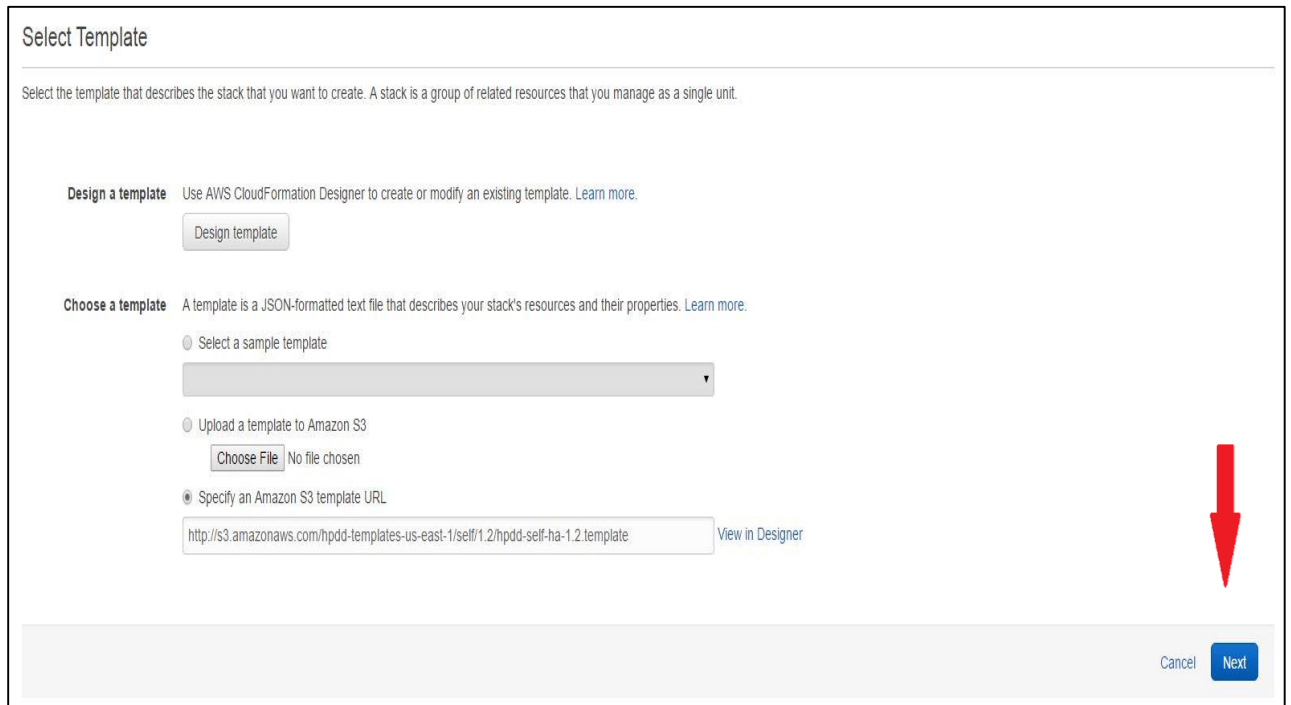


Figure 7: Select Template Screen

Figure 8 shows the parameters required to build a Lustre file system cluster using the templates available in the Self-Service version. AWS CloudFormation templates are stored on Amazon S3, and the path is filled in automatically when you press **Launch Stack** (shown in Figure 6b).

Step 4: Pass the Private Key Used for SSH Connections

Enter the name of a private key to be used for SSH connections, as shown in Figure 8. The key must be created before you use the templates. For more information, see [Amazon EC2 Key Pairs](#). At this stage, you can change a number of parameters, including the number of object storage servers. (The default is 4.)

Specify Details

Specify a stack name and parameter values. You can use or change the default parameter values, which are defined in the AWS CloudFormation template. [Learn more.](#)

Stack name

Parameters

AccessFrom	<input type="text" value="0.0.0.0/0"/>	Lockdown access to Lustre services (default is accessible for 0.0.0.0/0)
EnableCloudWatchLogs	<input type="text" value="false"/>	Enable forwarding of cluster logs to CloudWatch.
EnableEncryption	<input type="text" value="false"/>	Enable encryption of Lustre traffic over the wire and on disk.
FsName	<input type="text" value="scratch"/>	Name of the lustre filesystem.
HTTPFrom	<input type="text" value="0.0.0.0/0"/>	Lockdown access to Lustre Ganglia on MGS (default is accessible for 0.0.0.0/0)
ImportBucket	<input type="text"/>	[Optional] Bucket to import data from.
ImportDest	<input type="text"/>	[Optional] Subdirectory in Lustre filesystem to import data into. Will default to ImportPrefix, if specified.
ImportPrefix	<input type="text"/>	[Optional] Import all keys below prefix in ImportBucket. If unspecified, all keys in ImportBucket will be imported.
KeyName	<input type="text" value="lustre"/>	Name of and existing EC2 KeyPair to enable SSH access to the instance
MdsInstanceType	<input type="text" value="c4.8xlarge"/>	Instance type used for Lustre servers
NATInstanceType	<input type="text" value="m3.medium"/>	NAT Device EC2 Instance type
OssCount	<input type="text" value="4"/>	Number of OSS instances.
OssInstanceType	<input type="text" value="c4.8xlarge"/>	Instance type used for Lustre OSS servers
OstRaid	<input type="text" value="stripe"/>	Configure how storage is used by the lustre target. Stripe mode creates a single Lustre target on a RAID0 volume containing all available storage volumes. JBOD mode creates one Lustre target per available volume.
OstVolumeCount	<input type="text" value="4"/>	Number of EBS volumes to create for each OST.
OstVolumeSize	<input type="text" value="100"/>	Size of EBS volumes to use for OSTs.
PlacementGroupName	<input type="text" value="lustre"/>	Name of Placement Group to use (optional, leave blank if not required)
SSHFrom	<input type="text" value="0.0.0.0/0"/>	Lockdown SSH access to the NAT host (default can be accessed from anywhere)
VpcId	<input type="text" value="vpc-f250ce97 (172.31.0.0/16)"/>	Id of an existing VPC that contains a public subnet i.e. vpc-d54ebeb7
VpcPrivateCIDR	<input type="text" value="172.31.64.0/20"/>	CIDR for new private subnet i.e. 10.0.2.0/24
VpcPublicSubnetId	<input type="text" value="subnet-83be78a8 (172.31.48.0/20)"/>	Id of an existing public VPC subnet i.e. subnet-ae4e6ec4
WorkerCount	<input type="text" value="2"/>	Number of Worker instances.
WorkerInstanceType	<input type="text" value="c3.large"/>	Instance type used for Worker instances

Figure 8: Parameters Screen

5: Launch the Instance

To launch the instance you will need to review and acknowledge the selections at the bottom of the screen, and then click **Create**. These steps are not shown. The AWS CloudFormation stack process will begin. You can use the AWS CloudFormation console to check the creation status, as shown in Figure 9.

Important:

After the AWS CloudFormation stack process is complete, Amazon EC2 resources will be running; Lustre resources will have automatically started; the Lustre file system might be mounted by Lustre clients; and billing for the use of newly created resources will have begun.

Name	Instance ID	Instance Type	Availability Zone	Instance State	Status Checks	Alarm Status	Public DNS	Public IP	Key Name
mgs00	i-754bcdd4	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
NATDevice	i-514ccae0	m3.medium	us-east-1a	running	2/2 checks...	None	ec2-54-172-135-255.co...	54.172.135.255	lustre
mgs	i-254bcd94	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss02	i-634bcdd2	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss03	i-624bcdd3	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss01	i-6d4bcddc	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss00	i-6c4bcddd	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
client00	i-bc4bcd0d	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
client01	i-bf4bcd0e	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre

Figure 9: AWS CloudFormation Console

Using CfnCluster to Build an HPC Compute Cluster Using a Lustre File System on AWS

Intel Cloud Edition for Lustre* is designed to create storage nodes, but not compute nodes. Fortunately, [CfnCluster](#) can be used to create HPC compute nodes tailored to Message Passing Interface (MPI)-based applications in AWS. It does not matter what the cluster is used for and can easily be extended to support different frameworks. The command line interface (CLI) is stateless and all operations are performed using AWS CloudFormation or other AWS services. The CfnCluster tool includes a Lustre client. Be sure to verify the availability of a compatible Lustre client in distinct Amazon Machine Images (AMI).

Install CfnCluster and Edit the Config File

To install CfnCluster, follow [these instructions](#).

Before you can use CfnCluster, you must edit the config file, which is divided into several sections. This is where you can customize your cluster with details, such as Amazon EC2 instance types (the default is t2.micro) and the initial number of compute nodes to create (the default is 2).

In the VPC Settings section shown below, type the settings used in Step 4. Otherwise, you will not be able to connect the Lustre file system and Lustre clients available on CfnCluster. For more information about the high-level network configurations CfnCluster supports, see [Network Configurations](#).

At a minimum, you will need to update the following sections of the config file:

```
[aws]
# This is the AWS credentials section (required).
# These settings apply to all clusters
# replace these with your AWS keys
# If not defined, boto will attempt to use a) environment
# or b) EC2 IAM role.
aws_access_key_id = ``enter your key``
aws_secret_access_key = ``enter your key``

[cluster default]
# Name of an existing EC2 KeyPair to enable SSH access to the
instances.
key_name = bill (Replace with your key name)

## VPC Settings
[vpc public]
# ID of the VPC you want to provision cluster into.
vpc_id = vpc-f250ce97 (Replace with your vpc id)
# ID of the Subnet you want to provision the Master server into
master_subnet_id = subnet-83be78a8 (replace with your subnet id)
```

Important:

After you have updated the parameters in the config file, follow the installation instructions to create the cluster. After the cluster is created, Amazon Elastic Compute Cloud (Amazon EC2) resources will be running and billing will have begun.

Name	Instance ID	Instance Type	Availability Zone	Instance State	Status Checks	Alarm Status	Public DNS	Public IP	Key Name
mgs00	i-754bcd4	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
Compute	i-3b69ef8a	c4.8xlarge	us-east-1a	running	Initializing	None	ec2-52-90-57-244.com...	52.90.57.244	lustre
Compute	i-3a69ef8b	c4.8xlarge	us-east-1a	running	Initializing	None	ec2-52-90-111-75.com...	52.90.111.75	lustre
Master	i-a36fe912	c4.8xlarge	us-east-1a	running	2/2 checks...	None	ec2-52-70-86-49.comp...	52.70.86.49	lustre
NATDevice	i-514ccae0	m3.medium	us-east-1a	running	2/2 checks...	None	ec2-54-172-135-255.co...	54.172.135.255	lustre
mgs	i-254bcd94	c4.xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss02	i-634bcd2	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss03	i-624bcd3	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss01	i-6d4bcd4	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
oss00	i-6c4bcd5	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
client00	i-bc4bcd6	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre
client01	i-bf4bcd7	c4.8xlarge	us-east-1a	running	2/2 checks...	None			lustre

Figure 10: AWS CloudFormation Console Showing Monitoring Enabled

You can use the Amazon EC2 Management console to obtain the public IP address of your master server and the private IP address for the mgt instance shown in Figure 9 and Figure 10.

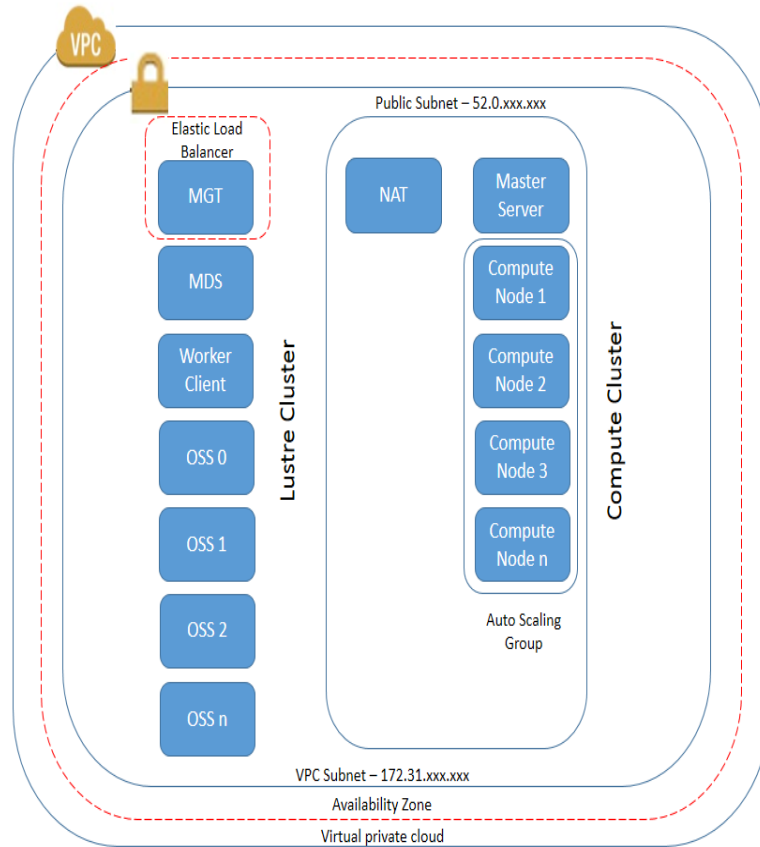


Figure 11: Resulting Client Cluster and Lustre Cluster Model

Mount the Lustre File System

Using an SSH connection, connect to the master server, and then mount the Lustre file system on all of the compute nodes.

The Lustre client is already available on all of the compute nodes, so you can run the following command as root:

```
# mount -t lustre <Private IP of MGT>@tcp0:/scratch /mnt/lustrefs
```

To simplify the administration of all the compute nodes, use `pdsh` as `ec2-user`:

```
$ pdsh -g clients sudo -u root mount -t lustre <Private IP of MGT>@tcp0:/scratch /mnt/lustrefs
```

Open MPI libraries are also included in the `CfnCluster` software stack. MPI-based applications can be easily rebuilt to run in this environment.

To measure the I/O performance of the cluster, we compiled IOR (<https://github.com/chaos/ior>)

version 2.10 with the MPI libraries.

Instance Type and Performance Measurements

To establish a baseline for I/O performance of the file system, we created an example Lustre file system using four c4.8x large instances as object storage servers and four c4.8x large client compute instances.

We used IOR, a parallel file system test developed by the Scalable/IO Project (SIOP) at LLNL (<https://computing.llnl.gov/?set=code&page=sio>). This program performs parallel writes and reads to and from a file using MPI-IO and reports the throughput rates. MPI is used for process synchronization.

We ran IOR using 144 threads across 2 nodes with xfersize of 1 MiB block size for each thread of 4 GiB and an aggregate file size of 576 GiB, which resulted in:

- Max Write: 2023.97 MiB/sec (2122.29 MB/sec)*
- Max Read: 1520.97 MiB/sec (1594.86 MB/sec)*

LMT or the Lustre Monitoring Tool (<https://github.com/chaos/lmt>) is installed with Intel Cloud Edition for Lustre. Ltop is a part of LMT and is a command line utility which gathers I/O statistics from Lustre filesystem servers. We used LTOP to record the filesystem activity during the IOR experiment:



Figure 12: Lustre filesystem I/O performance

Figure 13 shows the testing results. The same parameters as used in Steps 3 and 4 were then used to show the effects of scaling the Lustre file system by increasing the number of Amazon EC2 object storage server instances.

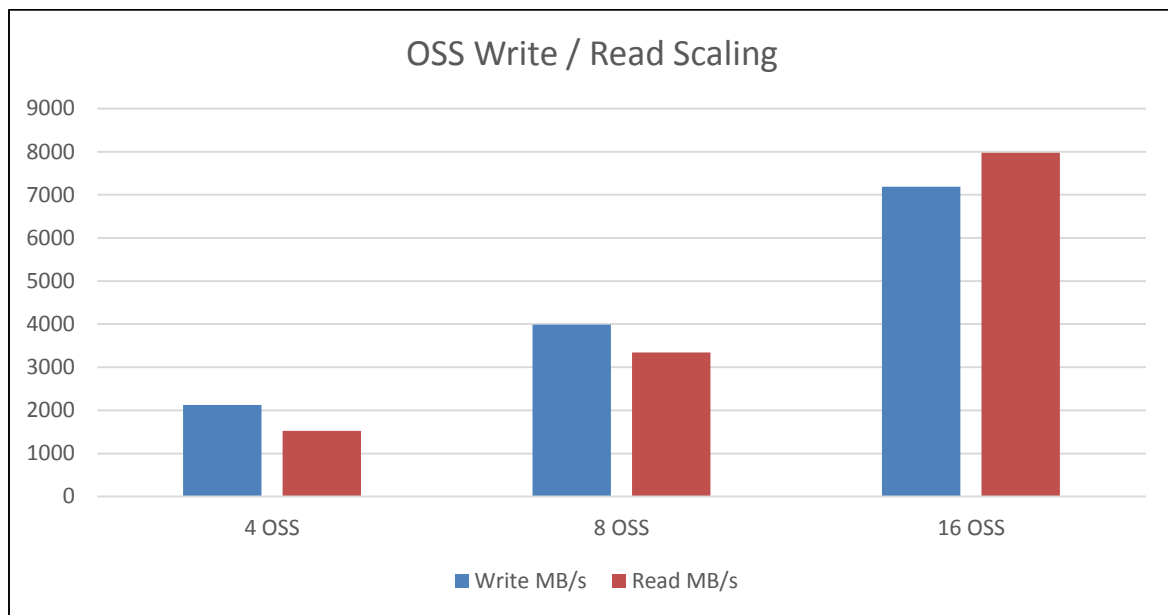


Figure 13: Testing Results

As the number of object storage server Amazon EC2 instances in the cluster increased, both read and write performance increased at a near-linear rate.

Summary

The Intel Lustre solution is a fast, scalable storage platform positioned to accelerate application performance, even with complex workloads. Intel Cloud Edition for Lustre* software is an ideal foundation for dynamic AWS-based workloads that require fast, scalable, and cost-effective storage. Using the resources and templates described in this document, you can innovate on your problem, not your infrastructure.

For more information

Amazon Web Services Instance Types:

<http://aws.amazon.com/ec2/>

Intel Cloud Edition for Lustre:

<https://wiki.hpdd.intel.com/display/PUB/HPDD+Wiki+Front+Page>

CfnCluster Getting Started:

http://cfncluster.readthedocs.org/en/latest/getting_started.html

Configuring CfnCluster

http://cfncluster.readthedocs.org/en/latest/getting_started.html#configuring-cfncluster

Network Configurations Supported by CfnCluster:

<http://cfncluster.readthedocs.org/en/latest/networking.html>

IOR HPC Benchmark Source:

<https://github.com/chaos/ior>

¹ www.top500.org

² http://zfsonlinux.org/docs/LUG12_ZFS_Lustre_for_Sequoia.pdf, results in presentation by LLNL at Lustre User Group 2012, April 23, 2012

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Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products.

Tests document performance of components on a particular test, in specific systems. Differences in hardware, software, or configuration will affect actual performance. Consult other sources of information to evaluate performance as you consider your purchase.

Test and System Configurations: All tests were performed by Intel using cfncluster Version 22 to create the compute stack. Version 1.2 of the Intel Cloud Edition / Lustre Self Support was used to create the Lustre Stack. For more complete information about performance and benchmark results, visit <http://www.intel.com/performance>.

The products described may contain design defects or errors known as errata which may cause the product to deviate from published specifications. Current characterized errata are available on request

For more information on performance tests and on the performance of Intel products, reference www.intel.com/procs/perf/limits.htm and any Intel source materials such as [performance briefs](#) or white papers.

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