

Dell PowerScale OneFS: Best Practices

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White Paper

Abstract

This white paper describes best practices for installing, configuring, and managing a Dell PowerScale cluster.

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Executive summary

Introduction

This paper presents best practices for deploying and managing a Dell PowerScale cluster. It also offers configuration and tuning recommendations to help achieve optimal performance for different workloads. This paper does not intend to provide a comprehensive background to the OneFS architecture.

For more details about the OneFS architecture, see [OneFS Technical Overview](#).

Audience

The target audience for this white paper is anyone designing and deploying a Dell PowerScale clustered storage environment. It is assumed that the reader has an understanding and working knowledge of the OneFS components, architecture, commands, and features.

For more information about OneFS commands and feature configuration, see the [OneFS Administration Guide](#).

Revisions

Date	Part number/ revision	Description
November 2017		Updated for OneFS 8.1.1
February 2019		Updated for OneFS 8.1.3
April 2019		Updated for OneFS 8.2
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Note: For links to other documentation for this topic, see the [PowerScale Info Hub](#).

Data layout recommendations

Directory structure and layout

In general, it is more efficient to create a deep directory hierarchy that consolidates files in balanced subdirectories than it is to spread files out over a shallow subdirectory structure. Although the recommended maximum file limit per directory is one million, a best practice is to constrain the number of files in any one directory to one hundred thousand. A maximum of 100,000 directories per directory is also recommended. OneFS dynamically allocates new inodes from free file system blocks.

The key for file and directory layout always revolves around balance. The goal should be for a directory tree structure and its file contents to be as uniform as possible.

- Storing large numbers of files in a directory may affect enumeration and performance, but whether performance is affected depends on workload, workflow, applications, tolerance for latency, and other factors. To better handle storing a large number of files in a directory, use nodes that contain solid state drives (SSDs).
- Directory tree depth is limited to 509 directories and is determined by a maximum path length of 1,023 characters. However, depths greater than 275 directories may affect system performance.
- The maximum number of open files is 315,000 per node.
- Hard links are limited to a maximum of 65,535 per cluster. However, setting the number of per-file hard links to higher than 1,000 can slow down snapshot operations and file deletions. This per-file value can be configured by the `efs.ifm.max_links` syscontrol.

The OneFS protocol daemons, such as the input-output daemon (lwio), may impose additional constraints on the number of files that a node can have open. The protocol daemons typically impose such constraints because the kernel places limits on per-process memory consumption.

File count limits

OneFS dynamically allocates new inodes from free file system blocks. The maximum number of possible inodes runs into the billions and depends on the number and density of nodes in the cluster, as expressed by the following formulas:

- 4Kn drives: $((\text{number of nodes in the cluster}) * (\text{node raw TB}) * 1000^4 * .99) / (8192 * (\text{number of inode mirrors}))$
- 512n drives: $((\text{number of nodes in the cluster}) * (\text{node raw TB}) * 1000^4 * .73) / (512 * (\text{number of inode mirrors}))$

File size limits

The largest file size that OneFS currently supports is increased to 16 TB in OneFS 8.2.2 and later, up from a maximum of 4 TB in prior releases.

To support files larger than 4 TB, adequate space is required in all of a cluster's disk pools in order to avoid a potential performance impact. As such, the following hard requirements apply:

Table 1. Large file support requirements

Large file support requirement	Description
Version	A cluster must be running OneFS 8.2.2 or later in order to enable large file support.
Disk Pool	A maximum sized file (16 TB) plus protection can consume no more than 10% of any disk pool . This translates to a minimum disk pool size of 160 TB plus protection.
SyncIQ Policy	All SyncIQ remote clusters must be running OneFS 8.2.2 or later and also satisfy the restrictions for minimum disk pool size and SyncIQ policies.

After installing OneFS 8.2.2 or later on a cluster intended for large file support, the following CLI utility will verify that the cluster's disk pools and existing SyncIQ policies meet the above requirements:

```
# isi_large_file -c
```

Once the validation confirms that the cluster meets the requirements, the following CLI command is then run to enable large file support:

```
# isi_large_file -e
```

Upon successfully enabling large file support, the 'cluster full' alert threshold is automatically lowered to 85% from the OneFS default of 95%. This is to ensure that adequate space is available for large file creation, repair, and restriping. Also, any SyncIQ replication partners must also be running OneFS 8.2.2 or later, adhere to the above minimum disk pool size, and have the large file feature enabled.

Any disk pool management commands that violate the large file support requirements are not allowed. Once enabled, disk pools are periodically checked for compliance and OneFS will alert if a disk pool fails to meet the minimum size requirement.

Be aware that, once enabled, large file support cannot be disabled on a cluster. This may affect future expansion planning for the cluster and all its SyncIQ replication partners.

For more information about OneFS limits and guidelines, see the [PowerScale OneFS Technical Specifications Guide](#).

OneFS storage efficiency

A typical dataset consists of a mix of large and small files stored in a file system consisting of a hierarchical directory structure. Usually, around 30 percent of the data is active; 70 percent is inactive. Snapshots typically back up the data for short-term retention combined with a long-term DR strategy, which frequently includes replication to a secondary cluster, and disk-to-disk or disk to tape NDMP backups.

In this document, large files are considered as files that are 128 KB or larger, and small files are files less than 128 KB. This is significant because at 128 KB and above, OneFS uses erasure coding (FEC) to parity protect a file, which results in high levels of storage efficiency. Conversely, files less than 128 KB in size are essentially mirrored, so have a larger on-disk footprint. Large file efficiency using erasure coding offsets the penalty of mirroring of small files.

OneFS also provides additional storage efficiency using its native, post-process deduplication engine, SmartDedupe, as well as in-line compression and deduplication. More details are provided in [OneFS data reduction best practices](#).

Node hardware recommendations

Overview

Another key decision for cluster performance in an environment is the type and quantity of nodes deployed. Heterogeneous clusters can be architected with a wide variety of node styles and capacities, in order to meet the needs of a varied dataset and wide spectrum of workloads. These node styles encompass several hardware generations and fall loosely into four main categories or tiers.

- Extreme performance (all-flash)
- Performance
- Hybrid/Utility
- Archive

The following figure illustrates these tiers, and the associated Gen 6 hardware models:

Tier	I/O Profile	Drive Media	Nodes	
Performance	High Perf, Low Latency	Flash NVMe/SAS	F910	F900
			F710	F810
			F210	F800
				F600
				F200
Hybrid / Utility	Concurrency & Streaming Throughput	SATA/SAS & SSD	H710	H600
			H7100	H5600
			H700	H500
			H7000	H400
Archive	Nearline & Deep Archive	SATA	A310	A300
			A3100	A3000
				A300
				A3000

Figure 1. PowerScale node hardware tiers

Before OneFS 8.0, the recommendation was for a maximum cluster size of around 64 nodes based on numerous factors. These factors include balancing customer experience with the manageability of extra-large clusters, the risk profile associated with the size of the fault domain that represents for their business, and the ease and simplicity of a single cluster. However, OneFS 8 and later releases have seen considerable back-end network infrastructure enhancements. Those enhancements provide cluster stability up to the current supported maximum of 252 nodes per cluster in OneFS 8.2 and later.

Cluster pool size and limits

OneFS SmartPools allows you to define the value of the data within your workflows based on policies, and automatically aligns data to the appropriate price/performance tier over time. Data movement is seamless, and with file-level granularity and control using automated policies, manual control, or API interface, performance and layout, storage tier

alignment, and protection settings can be tuned and optimized with minimal impact to end users.

OneFS 9.5 introduced SmartPools transfer limits. The transfer limit is a configurable threshold, expressed as a percentage. If a target pool's capacity reaches or exceeds the transfer limit, the pool will be considered full and data will not be moved to that pool.

The principal benefits of transfer limits include reliability, by preventing undesirable spillover actions, and performance, by avoiding unnecessary work.

Transfer limits can be specified as a percentage per tier or per node pool, or they can be disabled. The default transfer limit in OneFS 9.5 is 90 percent. The default limit applies to any of a cluster's storage pools where a limit is not explicitly set.

OneFS data protection

Overview

A OneFS powered cluster eliminates much of the overhead that traditional storage systems consume. By not having RAID groups, OneFS evenly distributes, or stripes, data among a cluster's nodes with layout algorithms that maximize storage efficiency and performance. The system continuously reallocates data across the cluster, further maximizing space efficiency. At the same time, OneFS protects data with forward error correction, or FEC—a highly efficient method of reliably protecting data.

- With Gen6 hardware in particular, the best practice is to use the recommended “hybrid” protection level, typically 2d:1n, for cluster protection.
- The recommended protection level for a particular node pool is indicated as **Suggested** in the list of requested protection levels.

You can view the protection levels in the WebUI by going to **Data Management > Storage Pools > SmartPools** and selecting the wanted node pool or tier. For example:

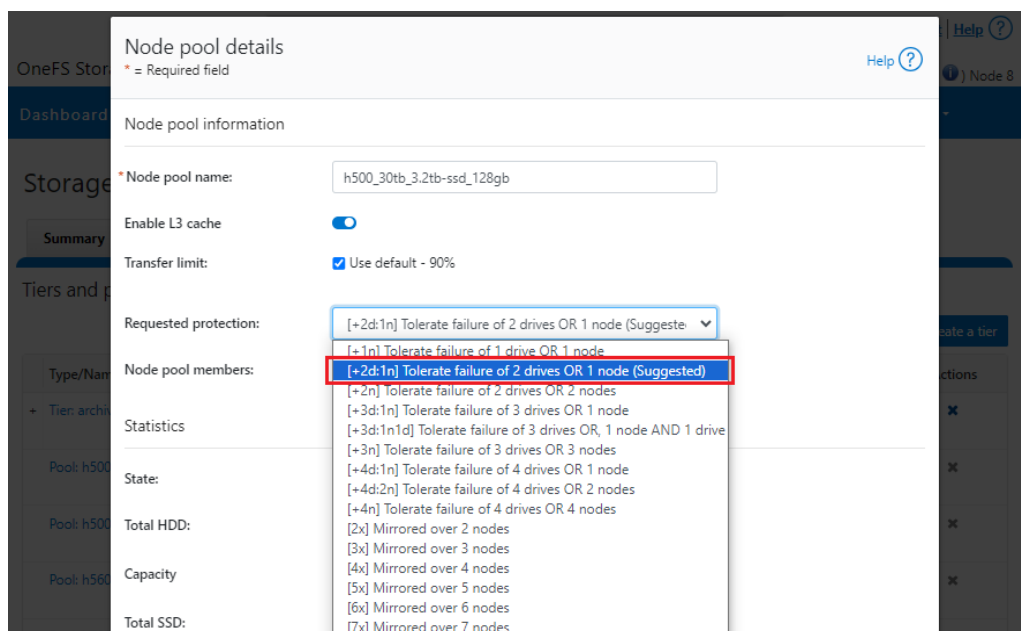


Figure 2. OneFS suggested protection level

The hybrid protection schemes are particularly useful for PowerScale Gen6 chassis and other high-density node configurations, where the probability of multiple drives failing far surpasses that of an entire node failure.

For all current Gen6 hardware configurations, the recommended protection levels are '+2d:1n' or '+3d:1n1d'.

In the unlikely event that multiple devices have simultaneously failed, such that the file is "beyond its protection level," OneFS will re-protect everything possible and report errors on the affected individual files to the cluster's logs.

OneFS also provides various mirroring options ranging from 2x to 8x, allowing from two to eight mirrors of the specified content. Metadata, for example, is mirrored at one level above FEC by default. For example, if a file is protected at +2n, its associated metadata object will be 4x mirrored.

The full range of OneFS protection levels are summarized in the following table:

Table 2. OneFS protection levels

Protection level	Description
+1n	Tolerate failure of 1 drive OR 1 node (Not Recommended)
+2d:1n	Tolerate failure of 2 drives OR 1 node
+2n	Tolerate failure of 2 drives OR 2 nodes
+3d:1n	Tolerate failure of 3 drives OR 1 node
+3d:1n1d	Tolerate failure of 3 drives OR 1 node AND 1 drive
+3n	Tolerate failure of 3 drives or 3 nodes
+4d:1n	Tolerate failure of 4 drives or 1 node
+4d:2n	Tolerate failure of 4 drives or 2 nodes
+4n	Tolerate failure of 4 nodes
2x to 8x	Mirrored over 2 to 8 nodes, depending on configuration

See the [OneFS Technical Overview](#) white paper for further details on OneFS data protection levels.

OneFS enables the protection policy to be modified in real time, while clients are attached and reading and writing data. Be aware, however, that increasing a cluster's protection level may increase the amount of space consumed by the data on the cluster.

OneFS also provides underprotection alerting for new cluster installations. If the cluster is underprotected, the cluster event logging system (CELOG) will generate alerts. The alerts warn the administrator of the protection deficiency and recommend a change to the appropriate protection level for that cluster's configuration.

Small file considerations

In practice, a OneFS powered cluster typically delivers 75 to 90 percent space efficiency for a typical dataset. Given a dataset with a wide range of file sizes, it is the large files that dominate utilization, saving as much as 20 to 30 percent of capacity over traditional storage systems. Even when small files make up more than 90 percent of a dataset by file count, they consume only 10 percent or less of the capacity. As such, the efficiencies in storing large files overshadow any inefficiencies in storing small files. Further, as a dataset increases in size, a cluster moves closer to 80 percent efficiency.

Data tiering and layout recommendations

SmartPools data tiering

SmartPools enables a multi-tier architecture to be created using high-performance nodes with SSD for performance tiers and high-capacity SATA-only nodes for the high-capacity archive tier. For example, a file pool policy could move files from the performance tier to a more cost-effective capacity-biased tier after the wanted period of inactivity.

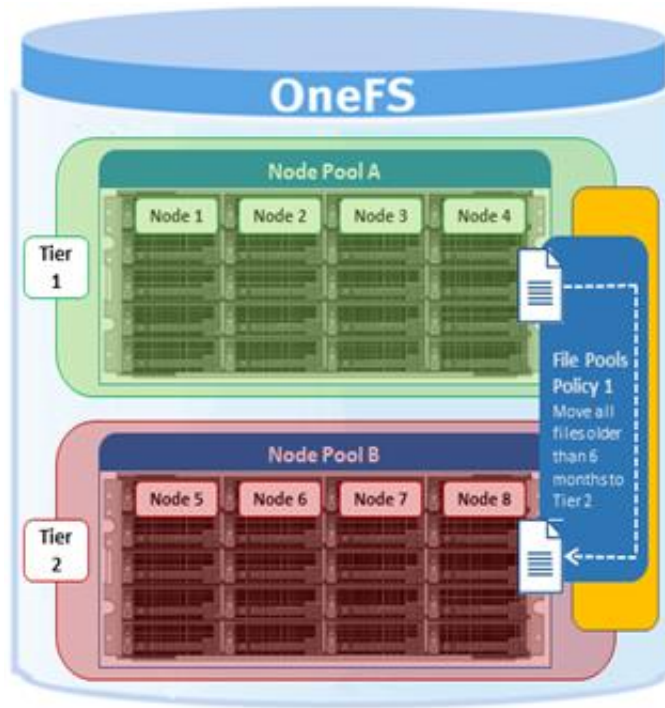


Figure 3. SmartPools tiering

The following figure shows the creation of an 'archive' file pool policy for colder data, which moves files that have not been accessed for more than 30 days to a lower storage tier.

Edit file pool policy details
* = Required field

Description

CloudPools state: **No access**

CloudPools state details: Policy has no CloudPools actions

* Policy name: Archive-30day

Description: Archive unmodified data after 30 days.

Select files to manage

Specify criteria for determining which files will be managed by this policy:

* File matching criteria

IF condition

Remove criteria: Modified is older than 1 Month

Add an "And" condition

Add an "Or" condition

Apply SmartPools actions to selected files

Storage settings

☒ Move to storage pool or tier

Storage target: a3000_240tb_6.4tb-ssd_96gb (node pool)

SSD strategy: Use SSDs for metadata read acceleration (Recommended)

Figure 4. Creating a file pool policy

For optimal cluster performance, we recommend observing the following OneFS SmartPools best practices:

- It is not recommended to tier-based on modify time (-mtime). Access time is the preferred tiering criteria, with an -atime value of 1 day.
- Ensure that cluster capacity utilization (hard drive and SSD) remains below 90% on each pool.
- If the cluster consists of more than one node type, direct the default file pool policy to write to the higher performing node pool. Data can then be classified and down-tiered as necessary.
- A file pool policy can have three 'OR' disjunctions and each term joined by an 'OR' can contain at most five 'AND's.
- The number of file pool policies should not exceed thirty. More than thirty policies may affect system performance.
- Define a performance and protection profile for each tier and configure it accordingly.
- File pool policy order precedence matters, as the policies are applied on first match basis (the first file pool policy to match the expression will be the applied policy).
- When employing a deep archiving strategy, ensure that the performance pool is optimized for all directories and metadata and the archive tier is just for cold file storage as they age out. To implement this configuration, add a 'TYPE=FILE' statement to the aging file pool policy rule or rules to only move files to the archive tier.

- By default, the SmartPools job runs only once per day. If you create a file pool policy to be run at a higher frequency, ensure the SmartPools job is configured to run multiple times per day.
- Enable SmartPools Virtual Hot Spares with a minimum of 10% space allocation. This allocation ensures that space is available for data reconstruction and reprotection in case a drive or node fails. It also generally helps guard against file-system-full issues.
- Avoid creating hard links to files which will cause the file to match different file pool policies
- If node pools are combined into tiers, the file pool rules should target the tiers rather than specific node pools within the tiers.
- Avoid creating tiers that combine node pools both with and without SSDs.
- The number of SmartPools tiers should not exceed five. Although you can exceed the guideline of five tiers, doing so is not recommended because it might affect system performance.
- Where possible, ensure that all nodes in a cluster have at least one SSD, including nearline and high-density nodes.
- For performance workloads, SSD metadata read-write acceleration is recommended. The metadata read acceleration helps with getattr, access, and lookup operations while the write acceleration helps reduce latencies on create, delete, setattr, mkdir operations. Ensure that sufficient SSD capacity (6-10%) is available before turning on metadata-write acceleration.
- Determine if metadata operations for a particular workload are biased towards reads, writes, or an even mix, and select the optimal SmartPools metadata strategy.
- Avoid using OneFS Filesystem Explorer or the 'isi set' command to change file attributes, such as protection level, for a group of data. Instead use SmartPools file pool policies.
- If SmartPools takes more than a day to run on OneFS 8.2 or later, or the cluster is already running the FSAnalyze job, consider scheduling the FilePolicy (and corresponding IndexUpdate job) to run daily. Also consider reducing the frequency of the SmartPools job to monthly. The following table provides a suggested job schedule when deploying FilePolicy:

Table 3. Suggested job schedule when deploying FilePolicy

Job	Schedule	Impact	Priority
FilePolicy	Every day at 22:00	LOW	6
IndexUpdate	Every six hours, every day	LOW	5
SmartPools	Monthly – Sunday at 23:00	LOW	6

- If planning on using *atime*, be sure to enable *Access Time Tracking* as early as possible. The use of a 24-hour precision is recommended to prevent performance problems.

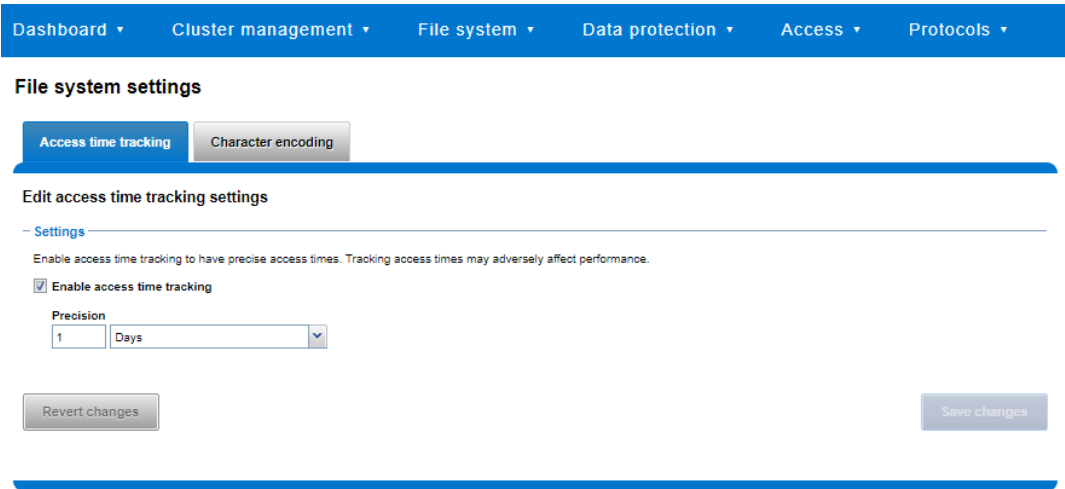


Figure 5. Access time tracking configuration

For more information about OneFS data tiering and file pool policies, see the [SmartPools white paper](#).

Data access and on-disk layout

Data access settings can be configured at the pool (or even the single file) level to optimize data access for the type of application accessing it. Data can be optimized for concurrent, streaming, or random access. Each of these settings changes how data is laid out on disk and how it is cached.

Table 4. OneFS data access settings

Data access setting	Description	On-disk layout	Caching
Concurrency	Optimizes for current load on the cluster, featuring many simultaneous clients; this setting provides the best behavior for mixed workloads	Stripes data across the minimum number of drives required to achieve the data protection setting configured for the file.	Moderate prefetching
Streaming	Optimizes for high-speed streaming of a single file, for example to enable very fast reading with a single client	Stripes data across a larger number of devices.	Aggressive prefetching
Random	Optimizes for unpredictable access to the file by performing almost no cache prefetching	Stripes data across the minimum number of drives required to achieve the data protection setting configured for the file	Little to no prefetching

As the settings indicate, the ‘Random’ access setting performs little to no read-cache prefetching to avoid wasted disk access. This works best for workload with only small files (< 128 KB) and large files with random small block accesses.

Streaming access works best for sequentially read medium to large files. This access pattern uses aggressive prefetching to improve overall read throughput, and on disk layout spreads the file across many disks to optimize access.

Concurrency (the default setting for all file data) access is the middle ground with moderate prefetching.

Concurrency is the preferred access setting for mixed workloads.

Attribute optimization of files and directories

The attributes of a particular directory or file can be viewed by running the following command and replacing data in the example with the name of a directory or file. The command's output below, which shows the properties of a directory named 'data', has been truncated to aid readability:

```
# isi get -D data ❶
POLICY    W    LEVEL PERFORMANCE COAL  ENCODING      FILE
IADDRS
default    4x/2 concurrency on ❷  N/A          ./
<1,36,268734976:512>, <1,37,67406848:512>, <2,37,269256704:512>,
<3,37,336369152:512> ct: 1459203780 rt: 0
*****
* IFS inode: [ 1,36,268734976:512, 1,37,67406848:512,
2,37,269256704:512, 3,37,336369152:512 ]
*****
* Inode Version:      6
* Dir Version:        2
* Inode Revision:     6
* Inode Mirror Count: 4
* Recovered Flag:     0
* Restripe State:     0
* Link Count:         3
* Size:               54
* Mode:               040777
* Flags:              0xe0
* Stubbed:            False
* Physical Blocks:    0
* LIN:                1:0000:0004
* Logical Size:       None
* Shadow refs:        0
* Do not dedupe:      0
* Last Modified:      1461091982.785802190
* Last Inode Change:  1461091982.785802190
* Create Time:        1459203780.720209076
* Rename Time:        0
* Write Caching:      Enabled ❸
* Parent Lin:         2
* Parent Hash:        763857
* Snapshot IDs:       None
* Last Paint ID:      47
* Domain IDs:         None
* LIN needs repair:   False
* Manually Manage:
*      Access         False
```

```

*           Protection      True
* Protection Policy:  default
* Target Protection:  4x
* Disk pools:        policy any pool group ID -> data target
x410_136tb_1.6tb-ssd_256gb:32(32), metadata target
x410_136tb_1.6tb-ssd_256gb:32(32)
* SSD Strategy:      metadata ❹
* SSD Status:        complete
* Layout drive count: 0
* Access pattern: 0
* Data Width Device List:
* Meta Width Device List:
*
* File Data (78 bytes):
*   Metatree Depth: 1
*   Dynamic Attributes (40 bytes):
      ATTRIBUTE          OFFSET  SIZE
      New file attribute    0       23
      Isilon flags v2      23       3
      Disk pool policy ID  26       5
      Last snapshot paint time 31     9
*****

* NEW FILE ATTRIBUTES ❺
* Access attributes:  active
* Write Cache:  on
* Access Pattern:  concurrency
* At_r: 0
* Protection attributes:  active
* Protection Policy:  default
* Disk pools:        policy any pool group ID
* SSD Strategy:      metadata-write
*
*****

```

Figure 6. File and directory attributes

Here is what some of these lines mean:

- ❶ OneFS command to display the file system properties of a directory or file.
- ❷ The directory's data access pattern is set to concurrency.
- ❸ Write caching (SmartCache) is turned on.
- ❹ The SSD strategy is set to metadata-read.
- ❺ Files that are added to the directory are governed by these settings, most of which can be changed by applying a file pool policy to the directory.

SSD strategies

In addition to traditional hard disk drives (HDDs), OneFS nodes can also contain a smaller quantity of flash memory-based solid state drives (SSDs), right up to all-flash nodes. There are several ways that SSDs can be used within a cluster.

OneFS SSD Strategies are configured on a per file pool basis. These strategies include:

- Metadata read acceleration: Creates a preferred mirror of file metadata on SSD and writes the rest of the metadata, plus all the actual file data, to HDDs.
- Metadata read and write acceleration: Creates all the mirrors of a file's metadata on SSD. Actual file data goes to HDDs.
- Avoid SSDs: Never uses SSDs; writes all associated file data and metadata to HDDs only. This strategy is used when there is insufficient SSD storage and you want to prioritize its utilization.
- Data on SSDs: All of a node pool's data and metadata resides on SSD.

Any node pools consisting of off all-flash F-series nodes will automatically store all data and metadata on SSD, since those nodes do not contain any traditional hard disk drives.

The following SSD strategy decision tree explains the options available:

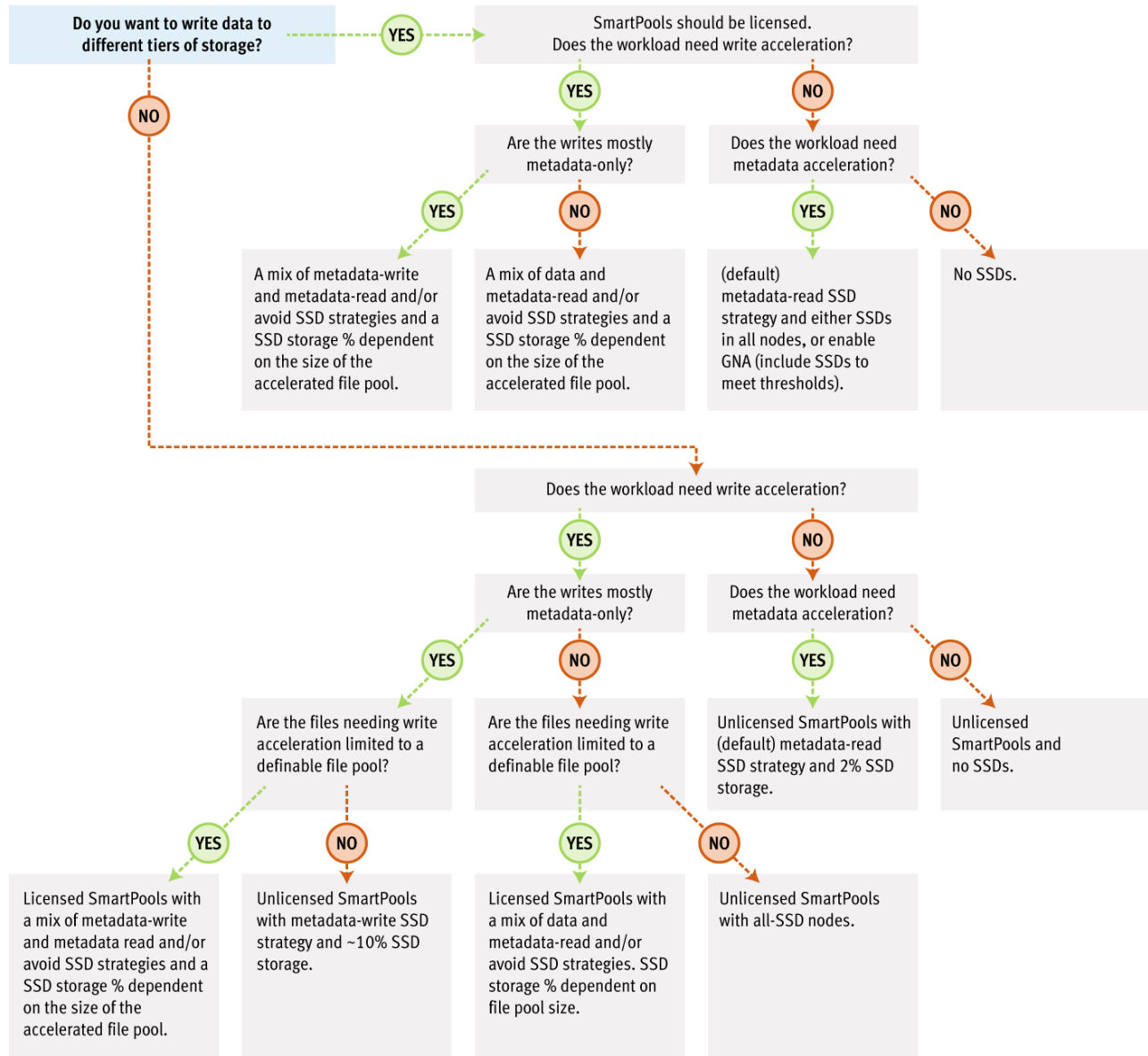


Figure 7. SSD usage decision tree

In all these cases, ensure that SSD capacity utilization remains below 90%.

If snapshots are enabled on a cluster, use the SSD Strategy "Use SSDs for metadata read/write acceleration" to enable faster snapshots deletes. The SSD metadata write strategy will require 6-10% of a pool's capacity on SSD to accommodate all the metadata mirrors.

In order to configure a particular tier to be the default for both data and metadata, the default file pool policy requires the SSD strategy to be set to **Use SSDs for data & metadata**.

For more information about data tiering and management in OneFS, see the [SmartPools white paper](#).

OneFS caching recommendations

OneFS uses up to three levels of read cache, plus an NVRAM-backed write cache, or coalescer, as shown in the following figure.

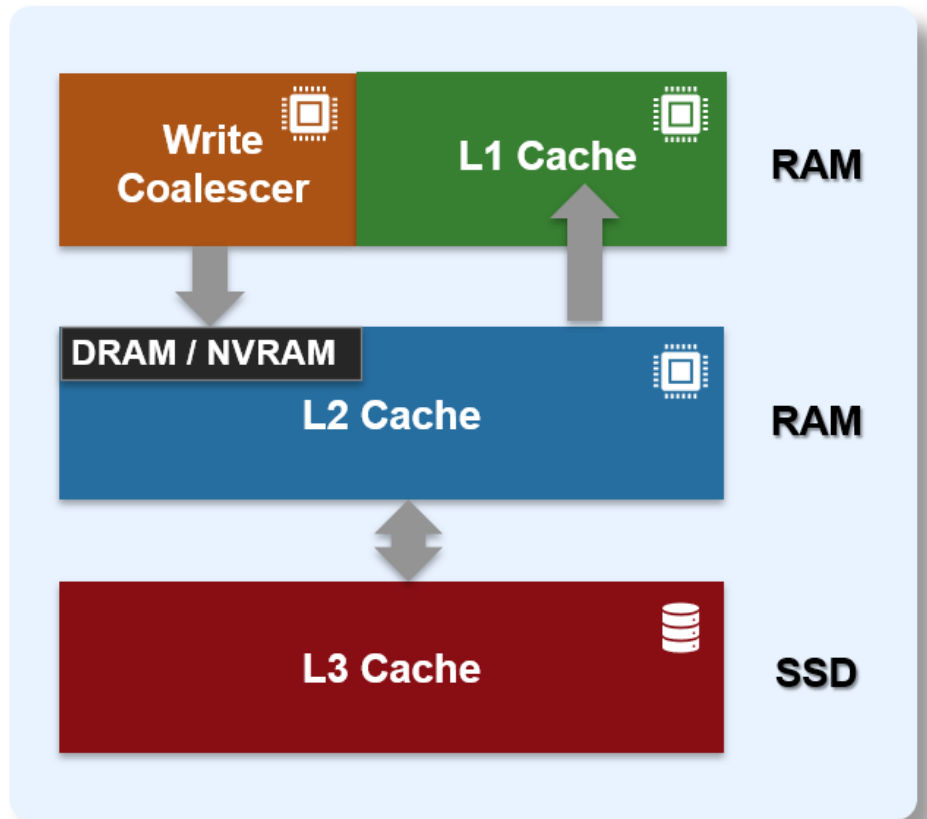


Figure 8. OneFS caching hierarchy

The first two types of read cache, level 1 (L1) and level 2 (L2), are memory (RAM) based, and analogous to the cache used in processors (CPUs). These two cache layers are present in all storage nodes.

An optional third tier of read cache, called SmartFlash or Level 3 cache (L3), is also configurable on nodes that contain solid state drives (SSDs). SmartFlash (L3 cache) is an eviction cache that is populated by L2 cache blocks as they are aged out from memory.

L3 cache best practices

If you are using L3 cache, we recommend the following best practices:

- Use a small number (ideally no more than two) of large capacity SSDs rather than multiple small SSDs.
- Use the appropriate capacity of SSDs that will fit your working dataset. The `isi_cache_stats` utility can help to determine that on existing clusters. A useful general rule is to size L3 SSD capacity per node according to the following formula:

$$\text{L2 capacity} + \text{L3 capacity} \geq 150\% \text{ of working set size.}$$
- While L3 cache can potentially use up to a 2:1 hard drive to SSD ratio per node, use at most 2-3 SSDs for L3 per node.

- Repeated random read workloads will typically benefit most from L3 cache through latency improvements.
- Although not recommended, both L3 cache and Global Namespace Acceleration (GNA) are supported within the same cluster.
- The same procedure is used for replacing failed L3 cache SSDs as for other storage drives. However, L3 cache SSDs do not require FlexProtect or AutoBalance to run post replacement, so it is typically a much faster process.
- For a legacy node pool using a SmartPools metadata-write strategy, do not convert to L3 cache unless:
 - The SSDs are seriously underutilized.
 - The SSDs in the pool are oversubscribed and spilling over to hard disk.
 - Your primary concern is SSD longevity.

L3 cache considerations

When deploying L3 cache, the following considerations should be kept in mind:

- All the SSDs within a node pool can either be used for L3 cache, or for SmartPools data strategies (metadata-ro, metadata-rw, data) – but not mixed L3/SmartPools usage.
- L3 cache is not applicable for nodes containing 16 or more SSDs, and all SSD node pools are not eligible for L3 cache enablement.
- Enabling L3 cache on an existing node pool with SSDs takes some time. The data and metadata on the SSDs have to be evacuated to other drives before the SSDs can be formatted for caching. Conversely, disabling L3 cache is a very fast operation because no data has to be moved and drive reformatting can begin right away.
- If you are concerned about metadata being evicted from L3, you can deploy more SSDs per node to accommodate a large working set. Alternatively, you can disable L3 and stick with traditional SmartPools metadata acceleration (either metadata read-only or read/write) for the particular node pool.
- It is possible to have GNA and L3 in the same cluster (different node pools), although some manual setup is required including a SmartPools policy to avoid SSD storage on L3 node pool. Note that L3 node pool hard drive space does count towards GNA limits
- All the SSDs in an L3 cache node pool must be the same size.
- If an L3 cache SSD fails, OneFS does not need to run FlexProtect or AutoBalance jobs, like with a regular file system SSD. However, after the failed SSD is replaced, some time will be needed before the cache is repopulated.
- All new node pools containing SSD will have L3 cache enabled by default.
- Existing node pools with SSD will not be modified to use L3 cache on upgrade.
- SSDs displace HDDs. More SSDs and fewer hard drive spindles can impact streaming and concurrency performance towards total capacity.

- The L3 cache is intentionally avoided for streaming reads during data prefetch operation. The streaming requests are kept to the spinning disks (HDDs), while the SSDs are used for the random I/O.
- L3 cache node pool hard drive space does not count in GNA SSD percentage calculations.
- In L3 cache, metadata is preferentially cached over data blocks.
- When a node reboots, there is no automatic flushing of L2 blocks to L3 cache.
- Unlike HDDs and SSDs that are used for storage, when an SSD used for L3 cache fails, the drive state should immediately change to REPLACE without a FlexProtect job running. An SSD used for L3 cache contains only cache data that does not have to be protected by FlexProtect. After the drive state changes to REPLACE, you can pull and replace the failed SSD.
- Although there is no percentage completion reporting shown when converting node pools to use L3 cache, you can estimate it by tracking SSD space usage throughout the job run. The Job impact policy of the FlexprotectPlus or SmartPools job, responsible for the L3 conversion, can also be reprioritized to run faster or slower.
- InsightIQ reports current and historical L3 cache statistics.
- For L3 cache, the isi_cache_stats prefetch statistics will always read zero because it is purely an eviction cache and does not use data or metadata prefetch.
- L3 cache has a metadata only mode (as opposed to data and metadata) to support high-density archive storage nodes.

For more information, see the [OneFS SmartFlash](#) white paper.

Network recommendations

Introduction

There are two separate network infrastructures associated with a Dell PowerScale cluster.

External front-end network

Clients connect to the cluster using Ethernet connections (10, 25, 40 or 100 GbE) that are available on all nodes. . Plus OneFS 9.10 introduces support for InfiniBand front-end connectivity on the all-flash F910 and F710 platforms. Because each node provides its own network interfaces, the amount of aggregate bandwidth available to the cluster scales linearly with performance and capacity. The cluster supports standard network communication protocols to a customer network, including NFS, SMB, HTTP, FTP, HDFS, and S3 object, plus full IPv4 and IPv6 support.

Note: Full IPv6 support is available in OneFS 9.8 and later releases, with the addition of IPv6-aware Source-based routing (SBR).

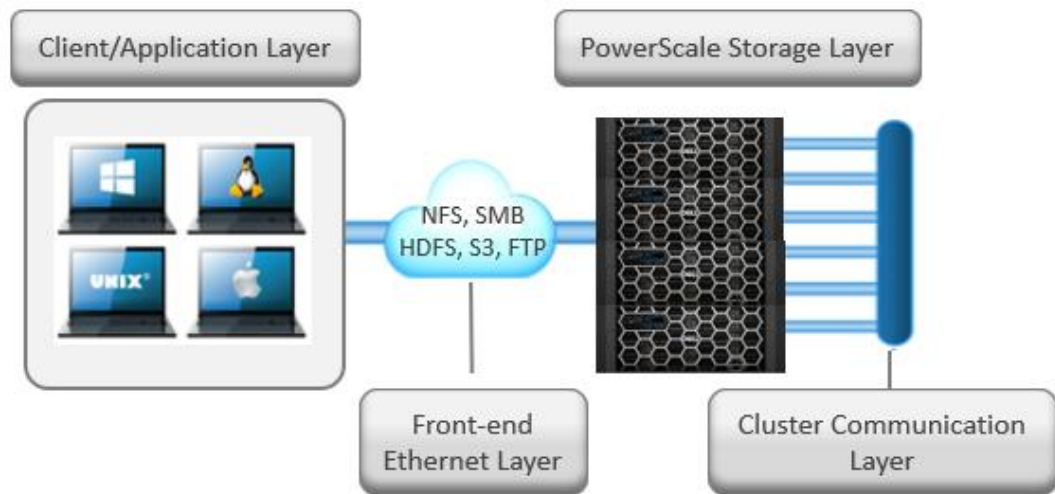


Figure 9. Cluster networking architectural overview

Front-end connectivity considerations

For most workflows, the recommendation is to configure at least one front-end 25, 40, or 100 GbE connection per node to support the high levels of network utilization that take place. Archive nodes and cold data workloads can sometimes be fine with 10 Gb Ethernet connections per node.

A best practice is to bind multiple IP addresses to each node interface in a SmartConnect subnet pool. Generally, optimal balancing and failover are achieved when the number of addresses allocated to the subnet pool equals $N * (N - 1)$, where N equals the number of node interfaces in the pool. For example, if a pool is configured with a total of five node interfaces, the optimal IP address allocation would total 20 IP addresses ($5 * (5 - 1) = 20$) to allocate four IP addresses to each node interface in the pool. For larger-scaled clusters, there is a practical number of IP addresses that is a good compromise between $N * (N - 1)$ approach and a single IP per node approach. Example: for a 35-node cluster, 34 IPs per node may not be necessary, depending on workflow.

Assigning each workload or data store to a unique IP address enables OneFS SmartConnect to move each workload to one of the other interfaces. This minimizes the additional work that a remaining node in the SmartConnect pool must absorb and ensuring that the workload is evenly distributed across all the other nodes in the pool.

For a SmartConnect pool with four-node interfaces, using the $N * (N - 1)$ model will result in three unique IP addresses being allocated to each node. A failure on one node interface will cause each of that interface's three IP addresses to fail over to a different node in the pool. This ensuring that each of the three active interfaces remaining in the pool receives one IP address from the failed node interface. If client connections to that node were evenly balanced across its three IP addresses, SmartConnect distributes the workloads to the remaining pool members evenly.

For more information, see the [Dell PowerScale: Network Design Considerations](#) white paper.

Optimal network settings

Jumbo frames, where the maximum transmission unit (MTU) is set to 9000 bytes, yield slightly better throughput performance with slightly less CPU usage than standard frames,

where the MTU is set to 1500 bytes. For example, jumbo frames can provide about 5 percent better throughput and about 1 percent less CPU usage.

For more information, see the [Dell PowerScale: Network Design Considerations](#) white paper.

Network isolation

OneFS optimizes storage performance by designating zones to support specific workloads or subsets of clients. Different network traffic types can be isolated on separate subnets using SmartConnect pools.

For large clusters, partitioning the cluster's networking resources and allocating bandwidth to each workload minimizes the likelihood that heavy traffic from one workload will affect network throughput for another. SyncIQ replication and NDMP backup traffic, in particular, can benefit from its own set of interfaces, separate from user and client I/O load.

Many customers as a best practice create separate SmartConnect subnets for the following traffic isolation:

- Workflow separation.
- SyncIQ Replication.
- NDMP backup on target cluster.
- Service Subnet for cluster administration and management traffic.
- Different node types and performance profiles.

OneFS includes a 'Groupnets' networking object as part of the support for multitenancy. Groupnets sit above subnets and pools and allow separate Access Zones to contain distinct DNS settings.

Network configuration

External network Internal network DNS cache Settings				
External network				Add a groupnet
Networks	Detail	Type	Description	Actions
groupnet0	DNS servers: 10.231.252.14, 10.231.252.15	Default	Initial groupnet	View/Edit More ▾
subnet0	NET 10.224.126.0/23	IPv4	Initial subnet	View/Edit More ▾
pool0	IP ranges: 10.224.127.1 - 10.224.127.10		Initial 25gige-1 pool	View/Edit More ▾
rule0	Node type: any, Interface: 25gige-1		Initial 25gige-1 provisioning rule	View/Edit More ▾

Figure 10. OneFS network object hierarchy

Connection-balancing and failover policies

By default, OneFS SmartConnect balances connections among nodes by using a round-robin policy and a separate IP pool for each subnet. A SmartConnect license adds advanced balancing policies to evenly distribute CPU usage, client connections, or throughput. It also lets you define IP address pools to support multiple DNS zones in a subnet.

Table 5. Example of usage scenarios and recommended balancing options

Load-balancing policy	General of other	Few clients with extensive usage	Many persistent NFS and SMB connections	Many transitory connections (HTTP, FTP, S3)	NFS automounts or UNC paths
Round Robin	✓	✓	✓	✓	✓
Connection Count *	✓	✓		✓	✓
CPU Utilization *					
Network Throughput *					

* Metrics are gathered every 5 seconds for CPU utilization and every 10 seconds for Connection Count and Network Throughput. In cases where many connections are created at the same time, these metrics may not be accurate, creating an imbalance across nodes.

A 'round robin' load balancing strategy is the recommendation for both client connection balancing and IP failover.

Dynamic failover

SmartConnect supports IP failover to provide continuous access to data when hardware or a network path fails. Dynamic failover is recommended for high availability workloads on SmartConnect subnets that handle traffic from NFS clients.

For optimal network performance, observe the following SmartConnect best practices:

- Do not mix interface types (40 Gb, 10 Gb, 1 Gb) in the same SmartConnect Pool
- Do not mix node types with different performance profiles (for example, H700 and A300 interfaces).
- Use the 'round-robin' SmartConnect Client Connection Balancing and IP-failover policies.

SmartConnect pool sizing

To evenly distribute connections and optimize performance, the recommendation is to size SmartConnect for the expected number of connections and for the anticipated overall throughput likely to be generated. The sizing factors for a pool include:

- The total number of active client connections expected to use the pool's bandwidth at any time.
- Expected aggregate throughput that the pool needs to deliver.
- The minimum performance and throughput requirements in case an interface fails.

Because OneFS is a single volume, fully distributed file system, a client can access all the files and associated metadata that are stored on the cluster, regardless of the type of node a client connects to or the node pool on which the data resides. For example, data stored for performance reasons on a pool of all-flash nodes can be mounted and accessed by connecting to an archive node in the same cluster. The different types of platform nodes, however, deliver different levels of performance.

To avoid unnecessary network latency under most circumstances, the recommendation is to configure SmartConnect subnets such that client connections are to the same physical pool of nodes on which the data resides. In other words, if a workload's data lives on a

pool of F-series nodes for performance reasons, the clients that work with that data should mount the cluster through a pool that includes the same F-series nodes that host the data.

SmartConnect considerations

Keep in mind the following networking and name server considerations:

- Minimize disruption by suspending nodes in preparation for planned maintenance and resuming them after maintenance is complete
- Leverage the groupnet feature to enhance multitenancy and DNS delegation, where desirable.
- Ensure traffic flows through the right interface by tracing routes. Leverage OneFS Source-Based Routing (SBR) feature to keep traffic on wanted paths.
- If you have firewalls, ensure that the appropriate ports are open. For example, for the DNS service, if you open UDP port 53, ensure that TCP port 53 is also open.
- The client never sends a DNS request directly to the cluster. Instead, the site nameservers handle DNS requests from clients and route the requests appropriately.
- In order to successfully distribute IP addresses, the OneFS SmartConnect DNS delegation server answers DNS queries with a time-to-live (TTL) of 0 so that the answer is not cached. Certain DNS servers (particularly Windows DNS Servers) will fix the value to one second. If many clients request an address within the same second, all of them receive the same address. If you encounter this problem, you might have to use a different DNS server, such as BIND.
- Certain clients perform DNS caching and might not connect to the node with the lowest load if they make multiple connections within the lifetime of the cached address.
- The site DNS servers must be able to communicate with the node that is currently hosting the SmartConnect service. That node is the node with the lowest logical node number (LNN) with an active interface in the subnet that contains the SSIP address. This behavior cannot be modified.
- Connection policies other than round robin are sampled every 10 seconds. The CPU policy is sampled every 5 seconds. If multiple requests are received during the same sampling interval, SmartConnect will attempt to balance these connections by estimating or measuring the additional load.

For more information, see the [OneFS SmartConnect](#) white paper.

Protocol recommendations

NFS considerations

NFSv3 is the ubiquitous protocol for clients accessing storage due to the maturity of the protocol version, ease of implementation, and wide availability of client and server stacks.

There are some useful configuration settings to keep in mind when using a OneFS powered cluster with NFS clients in a performance-oriented environment.

Client NFS mount settings

For NFS3 and NFS4, the maximum read and write sizes (rsize and wsize) are 1 MB. When you mount NFS exports from a cluster, a larger read and write size for remote procedure calls can improve throughput. The default read size in OneFS is 128 KB. An NFS client uses the largest supported size by default. Setting the value too small on a client overrides the default value and can undermine performance.

For performance workloads, the recommendation is to avoid explicitly setting NFS rsize or wsize parameters on NFS clients when mounting a cluster's NFS exports directly, or using the automounter. Instead, for NFSv3 clients, use the following mount parameters:

```
mount -vers=3,rw,tcp,hard,intr,retry=2,retrans=5,timeo=600
```

For NFS clients that support it, the READDIRPLUS call can improve performance by 'prefetching' file handle, attribute information, and directory entries, plus information to allow the client to request additional directory entries in a subsequent readdirplus transaction. This ability relieves the client from having to query the server for that information separately for each entry.

For an environment with a high file count, the readdirplus prefetch can be configured to a value higher than the default value of 10. For a low file count environment, you can experiment with setting it lower than the default.

Another recommendation for performance NFS workflows is to use asynchronous (async) mounts from the client. Conversely, using sync as a client mount option makes all write operations synchronous, usually resulting in poor write performance. Sync mounts should be used only when a client program relies on synchronous writes without specifying them.

Optimal thread count

The number of threads used by the OneFS NFS server is dynamically allocated and auto-tuned, and is dependent on the amount of available RAM.

NFS connection count

As a conservative best practice, active NFS v3 or v4 connections should be kept under 1,000, where possible. Although no maximum limit for NFS connections has been established, the number of available TCP sockets can limit the number of NFS connections. The number of connections that a node can process depends on the ratio of active-to-idle connections as well as the resources available to process the sessions. Monitoring the number of NFS connections to each node helps prevent overloading a node with connections.

NFS recommendations

The recommended limit for NFS exports per cluster is 40,000. To maximize performance, configure NFS exports for asynchronous commit.

For larger NFS environments consider the following:

- Use 100, 40, or 25 GbE whenever available.
- Consider aggregating client interfaces using LACP (unless using NFS nconnect).
- Where possible, use Jumbo frames (MTU 9000) to increase network payload.

- Use SmartConnect load-balancing, typically with a round-robin balancing policy.
- Optimize mount point organization.
- Consider using NFS netgroups for large, complex NFS environments.
- For high-throughput workloads, OneFS 9.10 supports 200Gb Ethernet or Infiniband front-end networks on both the F910 and F710 platforms.

NFS over RDMA

OneFS 9.2 and later versions include Remote Direct Memory Access support for applications and clients with NFS over RDMA. OneFS 9.2 and later versions allow substantially higher throughput performance, especially for single connection and read-intensive workloads, while also reducing both cluster and client CPU utilization. OneFS 9.2 and later versions support NFSv3 over RDMA by the ROCEv2 network protocol (also known as Routable RoCE or RRoCE). New OneFS CLI and WebUI configuration options have been added, including global enablement, and IP pool configuration, filtering and verification of RoCEv2 capable network interfaces.

NFS over RDMA is also available on all PowerScale nodes that contain Mellanox ConnectX network adapters on the front end with either 25, 40, or 100 GbE connectivity. The 'isi network interfaces list' CLI command can be used to easily identify which of a cluster's NICs support RDMA.

On the other side, the NFS clients will also need RoCEv2 capable NICs and drivers, and to be running RoCEv2.

Key considerations when using NFS over RDMA include:

- The MTU should match on both the OneFS cluster and NFSv3 client.
- IP failover will not work from an interface that supports ROCEv2 to one that does not. Therefore, if you are testing on a cluster where not all NICs support RoCE, and you are configuring failover, you are advised to create a separate RDMA IP pool.
- It is also recommended to place a router, or L3 Switch, between the OneFS cluster nodes and the RDMA clients, since the Linux NFS over RDMA stack tends not to handle Gratuitous ARP very gracefully.
- Priority flow control should be enabled on all the switch ports.

For more information, see the [OneFS NFS Design Considerations and Best Practices](#) white paper.

SMB considerations

Server Message Block (SMB), also known as Common Internet File System, is Microsoft's application-layer network protocol for Windows file sharing. While SMB1 is rarely used these days, OneFS also supports SMB2 and SMB3, including features such as continuous availability (CA) for transparent failover, encryption, and multichannel for increased application throughput.

Best practices for the SMB protocol on OneFS include:

- The recommendation is to use either SMB2 or SMB3 Windows clients. Where possible, avoid using SMB1.

- Create no more than 80,000 SMB shares per cluster and keep share names below 80 characters.
- For SMB 2 & 3, do not exceed 3,000 active sessions and 27,000 idle connections per node. For SMB1, the recommended limit is 1000 connections per node.
- SMB read and write performance improvements can often be achieved by setting the data-access pattern to Streaming.
- An access zone can authenticate users with only one Active Directory domain. Although you can add more than one of the other directory services to a zone, a best practice is to limit each zone to no more than one of each of the directory services. User mapping rules apply only in the access zone in which you created them.
- As a best practice, if you create access zones, make sure that the directory paths for each zone under /ifs do not overlap. Instead, you should designate separate directory trees for each zone.
- In general, a best practice is to use Microsoft Active Directory with Windows Services for UNIX and RFC 2307 attributes to manage Linux, UNIX, and Windows systems. In some versions of Microsoft Windows, Windows Services for UNIX is also known as Identity Management for UNIX (IDMU). Integrating UNIX and Linux systems with Active Directory centralizes identity management and eases interoperability. Make sure your domain controllers are running Windows Server 2003 R2 or later.
- Where possible, a best practice is to authenticate all users with Kerberos because it is a highly secure protocol. If you are authenticating users with Kerberos, ensure that both the cluster and clients use either Active Directory or the same NTP server as their time source.
- In an environment with two or more identity management systems, the simplest configurations name users consistently so that each UNIX user corresponds to a similarly named Windows user. Before assigning a UID and GID, OneFS searches its other authentication providers, such as LDAP, for other identities with the same name. If OneFS finds a match, the mapping service by default selects the associated UID and group memberships. Naming users consistently also allows user mapping rules with wildcards to match names and map them without explicitly specifying each pair of accounts.
- The native identity option is likely to be the best for a network with UNIX and Windows systems. In native mode, OneFS favors setting the UID as the on-disk identity because doing so improves NFS performance. OneFS stores only one type of identifier—either a UID and a GID or a SID—on disk at a time. As a best practice, if you change the on-disk identity, you should run the repair permissions job; see the [OneFS Administration Guide](#).

SMB3 Multichannel

SMB3 Multichannel allows storage devices to use multiple network connections simultaneously and dramatically increase throughput to clients and is enabled by default on OneFS. The SMB client will automatically detect, negotiate, and use multiple network connections if a proper configuration is identified.

On the client side, use Windows 2012 or Windows 8 or later, with at least one of the following 10, 25, 40, or 100 Gb Ethernet network configurations:

- Multiple network adapters
- One or more network adapters that support RSS (Receive Side Scaling)
- One of more network adapters configured with NIC Teaming

Additionally:

- Use a high-performance nonblocking Ethernet switch.
- Avoid configuring LACP.
- If using SMB multichannel, it will automatically detect the IP addresses of both 10GbE/40GbE interfaces on the client and load balance across each of the two interfaces on the dual-ported NIC.
- SMB multichannel only works between a client and a single PowerScale node. It cannot share the load between PowerScale nodes. With SMB multichannel, Windows client connections to PowerScale node have integrated failover, and all throughput is load-balanced between NICs.
- No manual configuration is required on either the Windows client or PowerScale cluster to enable SMB multichannel.
- Each cluster interface is given its own static IP address in the same subnet – do not bond the Ethernet connections using LACP.
- Configure the client's NIC driver as follows:
 - “Max Number of RSS Queues” set to the physical core count for client's CPU
 - “Receive Side Scaling” set to “Enabled”
 - “Receive Buffers” set to 4096
 - “Transmit Buffers” set to 16384
- If using Windows Server 2012, make sure the “Enable Virtual Machine Queues” setting under “Virtualization” is set to disabled.
- Windows 8 clients may need the “interrupt moderation rate” in the NIC driver set to “disabled” in order to achieve optimal performance.
- SMB continuous availability can only be enabled during share creation. However, users can still update timeout, lockout, and write integrity settings when creating or modifying a share.
- SMB continuous availability is not enabled by default. An existing share needs to be re-created in order to enable CA.

For more information, see the [Dell PowerScale: Solution Design and Considerations for SMB Environments](#) white paper.

New cluster best practices

When initializing a new cluster, the OneFS installation process creates three directories under the clustered file system root, /ifs:

- /ifs/data
- /ifs/home
- /ifs.ifsvar

Consider the following guidelines for directories under /ifs.

- Avoid modifying permissions on /ifs.ifsvar (mode 755). Do not use directory for general storage.
- Avoid modifying /ifs/data/Isilon_Support, which is created the first time the isi_gather_info command is run to collect cluster logs.
- Create hidden shares for /ifs and set ACLs appropriately.

In OneFS 9.0 and later, /ifs.ifsvar is hidden from view in the CLI, utilities, scripts, protocols, and recursive tools. Anything that attempts to access .ifsvar by full or relative path will still succeed. This feature works by omitting /ifs.ifsvar when listing this one directory. It only effects the .ifsvar directory and does not prevent protocols from accessing /ifs.ifsvar. Prior to OneFS 9.0, /ifs.ifsvar is hidden from view, but not from tools, scripts, or protocols.

Proper directory layout is critical to a successful OneFS disaster recovery plan.

When planning a cluster's initial directory structure, consider multitenancy, availability, and disaster recovery requirements.

- During a failover event, NFS clients require their exported paths to remain the same to enable accessing the data. The mount entry for any NFS connection must have a consistent mount point so that during failover, you do not have to manually edit the file system table (fstab) or automount entries on all connected clients.
- OneFS balances a cluster's connections among all the nodes that service external (front-end) connections. Regularly monitor cluster connections (for example, with InsightIQ). If the number of connections frequently approaches the maximum number the node can support, consider adding another node.
- SmartConnect balances incoming network connections across all the configured network interfaces in a SmartConnect Zone or pool with one of several load-balancing policies. The most common of these policies is round robin, which is effective for most workflows. However, understand whether your front-end connections are being evenly distributed, either in count or bandwidth. Monitor front-end connection distribution.
- Regularly monitor cluster usage with InsightIQ, the OneFS WebUI dashboard, or the command-line interface (CLI). When disk space usage reaches 90 percent, Dell strongly recommends adding additional capacity.
- Many cluster configuration settings are global and have cluster-wide effects. Before changing cluster-wide configuration settings, ensure that you fully understand the global settings and their implications. For information about global cluster configuration settings, see the OneFS Administration Guide

- Confirm that remote support functions work correctly through Secure Remote Services or internal email/SNMP notifications. Note that OneFS 9.1 and beyond only support ESRSv3. Clusters running ESRSv2 will be automatically transitioned to v3 on upgrade to OneFS 9.1 or later.
- OneFS 9.5 and later provides integration with Dell Technologies Connectivity Services (formerly known as SupportAssist), the next-generation remote connectivity system for transmitting events, logs, and telemetry from a PowerScale cluster to Dell Support. Connectivity Services provides a full replacement for ESRS, as well as enabling Dell Support to perform remote diagnosis and remediation of cluster issues. Intended for all customers who can send telemetry off-cluster to Dell over the Internet, Connectivity Services integrates ESE into PowerScale OneFS, along with a suite of daemons to allow its use on a distributed system.
- OneFS provides a recommended protection level based on cluster configuration. This suggested protection level strikes the best balance between data protection and storage efficiency. Follow its recommendations.
- Recommend disabling client DNS caching, where possible. To handle client requests properly, SmartConnect requires that clients use the latest DNS entries. If clients cache SmartConnect DNS information, they might connect to incorrect SmartConnect zone names. In this situation, SmartConnect might not appear to be functioning properly.
- Use LACP on interfaces that carry clients when LACP can be configured across two separate switches to provide switch redundancy.
- Use consistent Ethernet MTU sizes across your network. For example, if using jumbo frames, ensure MTU 9000 is enabled uniformly across the network infrastructure to prevent packet fragmentation or dropped data.
- If round-robin is used as the SmartConnect load balancing strategy with only a small number of high-throughput clients (fewer than 10), the distribution of SMB/NFS connections could result in overloading a few nodes while starving others.

Data availability and protection recommendations

Availability and recovery objectives

A solid business continuity plan is at the core of every effective data protection strategy. An explicitly defined and routinely tested plan is essential to minimize the potential impact to the workflow when a failure or natural disaster occurs

Among the primary approaches to data protection are fault tolerance, redundancy, snapshots, replication (local and/or geographically separate), and backups to nearline storage, VTL, or tape.

Some of these methods are biased towards cost efficiency but have a higher risk associated with them, and others represent a higher cost but also offer an increased level of protection. Two ways to measure cost against risk from a data protection point of view are:

- **Recovery Time Objective (RTO):** RTO is the allotted amount of time within a Service Level Agreement (SLA) to recover data. For example, an RTO of four hours means data must be restored and made available within four hours of an outage.
- **Recovery Point Objective (RPO):** RPO is the acceptable amount of data loss that can be tolerated per an SLA. With an RPO of 30 minutes, 30 minutes is the maximum amount of time that can elapse since the last backup or snapshot was taken.

The availability and protection of data can be illustrated in terms of a continuum:

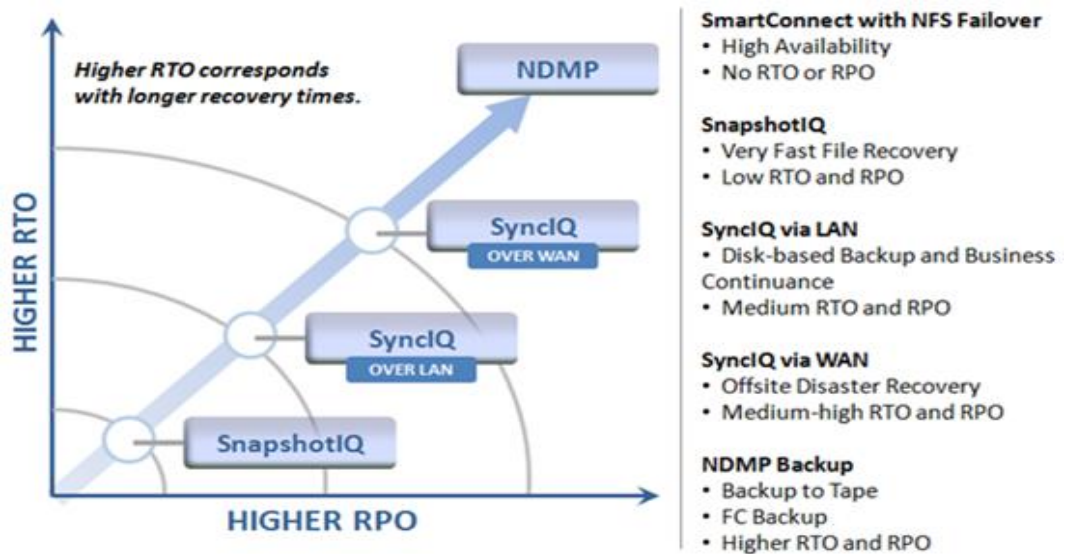


Figure 11. OneFS data protection technology alignment with protection continuum

At the beginning of the continuum sits high availability. This requirement is usually satisfied by redundancy and fault tolerant designs. The goal here is continuous availability and the avoidance of downtime by the use of redundant components and services. Further along the continuum are the data recovery approaches in order of decreasing timeliness: SnapshotIQ for fast recovery, followed by SyncIQ, and finally traditional backup, providing insurance against large-scale data loss, natural disasters, and other catastrophic events.

- Snapshots are frequently used to back up the data for short-term retention and to satisfy low recovery objective SLAs.
- Replication of data from the primary cluster to a target DR cluster, ideally at a geographically separate location, is strongly recommended.
- NDMP backup to tape or VTL (virtual tape library) typically satisfies longer term high recovery objective SLAs and any regulatory compliance requirements.

For more information, see the [High Availability and Data Protection with Dell PowerScale Scale-out NAS](#) white paper.

Snapshot considerations

Snapshots always carry a trade-off between cluster resource consumption (CPU, memory, disk) and the benefit of increased data availability, protection, and recovery.

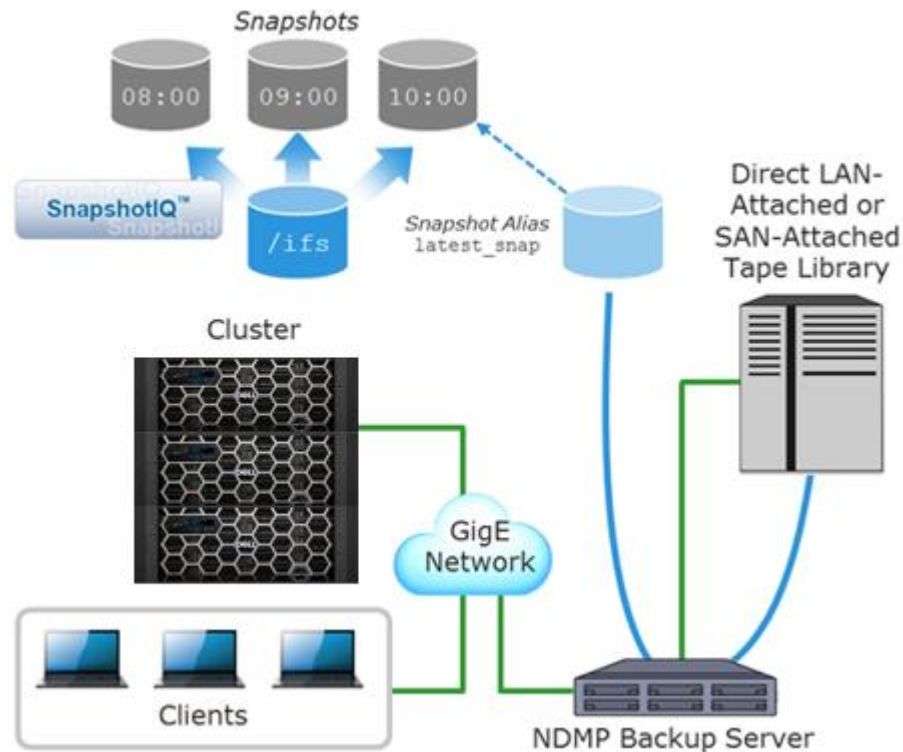


Figure 12. SnapshotIQ integration with NDMP backups

OneFS SnapshotIQ creates snapshots at the directory-level instead of the volume-level, thereby providing improved granularity.

There is no requirement for reserved space for snapshots in OneFS. Snapshots can use as much or little of the available file system space as desirable.

Snapshots can either be manually taken on-demand or automated with a snapshot schedule.

Snapshot scheduling allows cluster administrators to automatically generate snapshots according to a predefined itinerary. OneFS snapshot schedules can be configured at daily, weekly, monthly, or yearly intervals, with single or multiple job frequency per schedule, and down to a per-minute granularity. Similarly, automatic snapshot deletion can be configured per defined schedule at an hourly through yearly range.

- An ordered deletion schedule is simple to configure but retains a larger number of snapshots and is recommended for datasets with a lower rate of change.
- For more active data, an unordered deletion schedule can prove more effective. The configuration and monitoring overhead is slightly higher, but fewer snapshots are retained.

The following table provides a suggested snapshot schedule for both ordered and unordered deletion configurations.

Table 6. Snapshot schedule recommendations

Definition type	Snapshot frequency	Snapshot time	Snapshot expiration	Max retained snapshots
Ordered deletion (for mostly static data)	Every four hours	Start at 12:00AM End at 11:59AM	1 month	180
Unordered deletion (for frequently modified data)	Every other hour	Start at 12:00AM End at 11:59AM	1 day	27
	Every day	At 12:00AM	1 week	
	Every week	Saturday at 12:00AM	1 month	
	Every month	First Saturday of month at 12:00AM	3 months	

For optimal cluster performance, we recommend observing the following SnapshotIQ best practices.

- Use an ordered snapshot deletion strategy where viable.
- Configure the cluster to take fewer snapshots, and for the snapshots to expire more quickly, so that less space will be consumed by old snapshots. Take only as many snapshots as you need and keep them active for only as long as you need them.
- Using SmartPools, snapshots can physically reside on a different disk tier than the original data. The recommendation, however, is to keep snapshots on the same tier on which they were taken.
- The default snapshot limit is 20,000 per cluster. We recommend limiting snapshot creation to 1,024 per directory.
- Limit snapshot depth to a maximum of 275 directories.
- Avoid creating snapshots of directories that are already referenced by other snapshots.
- It is recommended that you do not create more than 1000 hard links per file in a snapshot to avoid performance degradation.
- Creating snapshots of directories higher on a directory tree will increase the amount of time it takes to modify the data referenced by the snapshot and require more cluster resources to manage the snapshot and the directory.
- Avoid taking snapshots at /ifs level. Taking snapshots at a parent dataset level is recommended, enabling faster snapshot deletions and avoiding management complexities. In particular, avoid taking nested snapshots, redundant snapshots, or overly scoped snapshots. For example, if you schedule snapshots of /ifs/data and /ifs/data/foo and /ifs/data/foo/bar, consider taking snapshots of only the intermediate or most granularly scoped part (/ifs/data/foo or /ifs/data/foo/bar).
- If you intend on reverting snapshots for a directory, it is recommended that you create SnapRevert domains for those directories while the directories are empty. Creating a domain for a directory that contains less data takes less time.

- Delete snapshots in order, beginning with the oldest. Where possible, avoid deleting snapshots from the middle of a time range. Newer snapshots are mostly pointers to older snapshots and deleting them will not free up much space. Deleting the oldest snapshot ensures you will actually free up the space. You can determine snapshot order (if not by name or date) by using the `isi snapshots list` command. The snapshot IDs (first column) are non-conserved, serial values.
- Configure the SSD Strategy to “Use SSDs for metadata read/write acceleration” for faster snapshots deletes.
- Quotas can be used to calculate a file and directory count that includes snapshot revisions, provided the quota is configured to include snaps in its accounting using the “--snaps=true” configuration option.
- SnapshotDelete will only run if the cluster is in a fully available state, (no drives or nodes are down).
- A snapshot schedule cannot span multiple days: To generate snapshots from 5:00 PM Monday to 5:00 AM Tuesday, create one schedule that generates snapshots from 5:00 PM to 11:59 PM on Monday, and another schedule that generates snapshots from 12:00 AM to 5:00 AM on Tuesday.
- If a directory is moved, you cannot revert any snapshots of that directory that were taken before its move.
- Do not delete SyncIQ snapshots (snapshots with names that start with SIQ), unless the only remaining snapshots on the cluster are SyncIQ snapshots, and the only way to free up space is to delete those SyncIQ snapshots.

Writable snapshots, first available in OneFS 9.3, provide the ability to create fast, simple, lightweight copies of datasets. They provide a modifiable view of a regular snapshot, presented at a target directory and accessible by clients across the full range of supported NAS protocols. This allows disaster recovery procedures to be routinely tested on identical, space-efficient, temporary copies of production data.

For more information, see the [Data Protection with Dell PowerScale SnapshotIQ](#) white paper.

Replication considerations

OneFS SyncIQ delivers high-performance, asynchronous replication of unstructured data to address a broad range of recovery point objectives (RPO) and recovery time objectives (RTO). This enables customers to make an optimal tradeoff between infrastructure cost and potential for data loss if a disaster occurs. SyncIQ does not impose a hard limit on the size of a replicated file system so will scale linearly with an organization’s data growth up into the multiple petabyte ranges.

SyncIQ is easily optimized for either LAN or WAN connectivity to replicate over short or long distances, providing protection from both site-specific and regional disasters. Additionally, SyncIQ uses a highly parallel, policy-based replication architecture designed to leverage the performance and efficiency of clustered storage. As such, aggregate throughput scales with capacity and allows a consistent RPO over expanding datasets.

A secondary cluster synchronized with the primary production cluster can afford a substantially improved RTO and RPO than tape backup. Both implementations have their distinct advantages. And SyncIQ performance is easily tuned to optimize either for network

bandwidth efficiency across a WAN or for LAN speed synchronization. Synchronization policies may be configured at the file level, directory level, or entire file-system-level and can either be scheduled to run at regular intervals or performed manually.

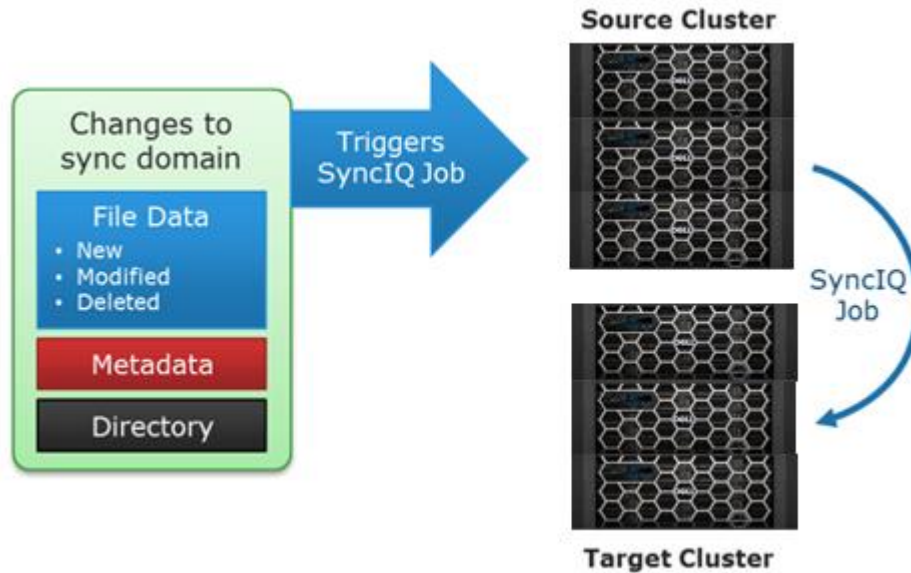


Figure 13. SyncIQ change-based replication

OneFS queues any additional jobs until a job execution slot becomes available, and jobs that are queued can be easily canceled. SyncIQ policies also have a priority setting to allow favored policies to preempt others. In addition to chronological scheduling, replication policies can also be configured to start whenever the source is modified (change based replication). If preferred, a delay period can be added to defer the start of a change-based policy.

Bear in mind the following SyncIQ recommendations:

- Highly recommend implementing Superna Eyeglass for failover/failback.
- The recommended limit of running SyncIQ policies is 1000 policies and 50 concurrent jobs per cluster (for a cluster with 4 or more nodes).
- While the maximum number of workers per node per policy is eight, the default and recommended number of workers per node is three.
- The recommended limit of workers per replication policy is 40.
- Recommend having the target cluster running the same or a later version of OneFS as the source cluster.
- After creating a policy and before running the policy for the first time, use the policy assessment option to see how long it takes to scan the source cluster dataset with default settings.
- Increase workers per node in cases where network utilization is low. This can help overcome network latency by having more workers generate I/O on the wire. If adding more workers per node does not improve network utilization, avoid adding more workers because of diminishing returns and worker scheduling overhead.

- Increase workers per node in datasets with many small files to push more files in parallel. As more workers are employed, more CPU is consumed, due to other cluster operations.
- Consider using SmartConnect pools to constrain replication to a dedicated set of cluster network interfaces, and to avoid contention with other workflows accessing the cluster through these nodes.
- Use SyncIQ network throttling to control how much network bandwidth SyncIQ can consume.
- Avoid full dataset replications where possible. Changing any of the following parameters will trigger a full baseline sync of the policy:
 - Source path or paths: root path, include and exclude paths
 - Source file selection criteria: type, time, and regular expressions
- With a policy of type Sync, modifying file attributes comparison options and values causes a re-sync and deletion of any nonmatching files from the target next time the job runs. This does not apply to policies of type Copy.
- Specifying file criteria in a SyncIQ policy will slow down a copy of sync job.
- Full baseline replication takes much longer than incremental synchronizations, so to optimize performance, avoid triggering full synchronizations unless necessary. Changing any of the following parameters will trigger a baseline sync of the policy:
 - Source path or paths: root path, include and exclude paths
 - Source file selection criteria: type, time, and regular expressions
 - Remember that “target aware synchronizations” are much more CPU-intensive than regular baseline replication. However, they potentially generate far less network traffic if both source and target datasets are already seeded with similar data.
 - Setting a target cluster password is useful for security and to verify that the source cluster is replicating to the correct target. The target cluster password is different from a cluster’s root password. Do not specify a target password unless you create the required password file on the target cluster.
- If a cluster is running OneFS 8.2 or later, use SyncIQ encryption to protect any replication sessions that traverse WAN or other insecure or untrusted network segments.

For more information, see the [PowerScale SyncIQ](#) white paper.

Data management recommendations

Quota best practices

OneFS SmartQuotas tracks disk usage with reports and allows for the enforcement of storage limits with alerts and hard boundaries. SmartQuotas consists of two types of capacity quota:

- Accounting Quotas: Monitor and report on the amount of storage consumed, but do not take any action.

- **Enforcement Quotas:** Restrict how much storage that a user, group, or directory can use and send notifications.

OneFS SmartQuotas can have one of four enforcement types:

- **Hard:** A limit that cannot be exceeded.
- **Soft:** A limit that can be exceeded until a grace period has expired.
- **Advisory:** An informal limit that can be exceeded.
- **None:** No enforcement. Quota is accounting only.

All three quota types have both a limit, or threshold, and a grace period. A hard quota has a zero-time grace period, an advisory quota has an infinite grace period, and a soft quota has a configurable grace period.

Even when a hard quota limit is reached, there are certain instances where operations are not blocked. These include administrative control by root (UID 0), system maintenance activities, and the ability of a blocked user to free up space.

Storage Quotas

Use storage quotas to configure, monitor, and enforce usage limits on your Isilon cluster.

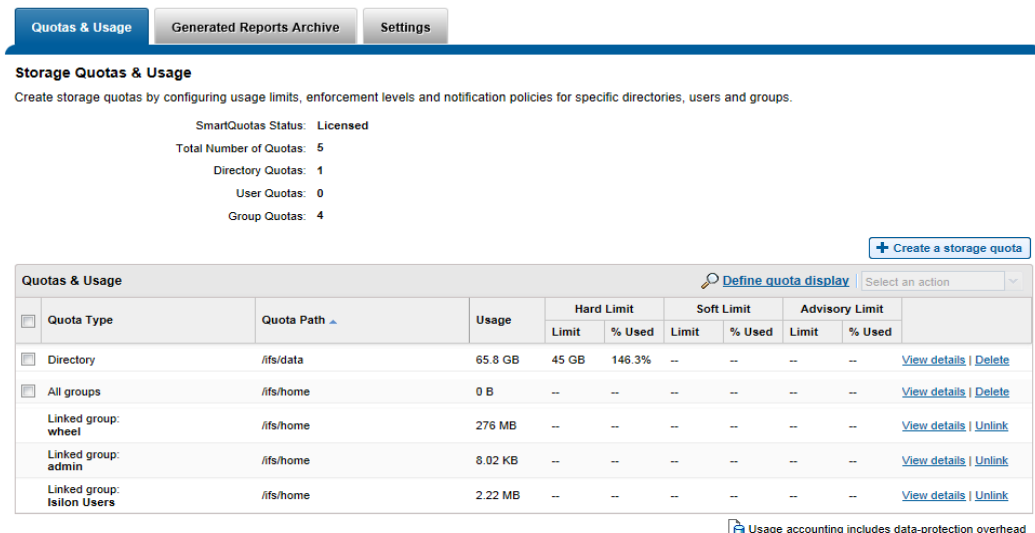


Figure 14. SmartQuotas usage overview

SmartQuotas best practices include:

- Avoid creating quotas on the root directory of the default OneFS share (/ifs). A root-level quota may result in performance degradation.
- Where possible, observe the best practice of a maximum number of 500,000 quotas per cluster in OneFS 8.2 and later, and 20,000 quotas per cluster in prior releases.
- Limit quota depth to a maximum of 275 directories.
- Governing a single directory with overlapping quotas can also degrade performance.
- Directory quotas can also be used to alert of and constrain runaway jobs, preventing them from consuming massive amounts of storage space.
- Enforcement quotas are not recommended for snapshot-tracking quota domains.

- Before using quota data for analysis or other purposes, verify that no QuotaScan jobs are running.
- Rather than editing the quota email notification templates directly, copy them to another directory to edit and deploy them.
- If quota reports are not in the default directory, you can run the 'isi quota settings reports view' command to find the directory where they are stored.
- Use the 'isi quota quotas notifications disable' command to disable all notifications for a quota.

Quota considerations

Quota considerations include:

- The maximum tested quota limit is 400,000 (although the file system has no hard-coded limit on quotas). However, when listing a large number of quotas, only a partial list may be returned.
- With CloudPools data, the quota is calculated based on the size of the data local to the cluster. For example, for a 100MB file tiered to a cloud provider, SmartQuotas would calculate just the size of the local stub file (8K).
- SmartQuotas reports the logical capacity of the files, whether they are deduplicated or not.
- The QuotaScan job runs after the creation of a quota, but not after a change. However, it does run on a schedule and incorporates any changes then.
- If two quotas are created on the same directory – for example an accounting quota without Snapshots and a hard quota with Snapshots - the quota without Snapshot data overrules the limit from the quota with Snapshot data.
- SmartQuotas also provide a low impact way to provide directory file count reports.
- Configuration changes for linked quotas must be made on the parent quota that the linked quota is inheriting from. Changes to the parent quota are propagated to all children. To override configuration from the parent quota, you must unlink the quota first.
- If a quota type uses the accounting-only option, enforcement limits cannot be used for that quota.
- Cloned and deduplicated files are treated as ordinary files by quotas. If the quota includes data protection overhead, the data protection overhead for shared data is not included in the usage calculation.
- Moving quota directories across quota domains is not supported.
- You can edit or delete a quota report only when the quota is not linked to a default quota.
- A quota can only be unlinked when it is linked to a default quota. Configuration changes for linked quotas must be made on the parent (default) quota that the linked quota is inheriting from. Changes to the parent quota are propagated to all children. If you want to override configuration from the parent quota, you must first unlink the quota.

- Disabling all quota notifications also disables all system notification behavior. Use the `--clear` options to remove specific quota notification rules and fall back to the system default.
- Quota containers compartmentalize `/ifs`, so that a directory with a container will appear as its own separate 'file system slice'. For example, to configure a directory quota with a 4TB container on `/ifs/data/container1`, you could use the following CLI command:

```
# isi quota quotas create /ifs/data/container1 directory --  
hard-threshold 4T --container true
```

Within OneFS, quota data is maintained in Quota Accounting Blocks (QABs). Each QAB contains many Quota Accounting records, which need to be updated whenever a particular user adds or removes data from a file system on which quotas are enabled. If many clients are accessing the file system simultaneously, these blocks can become highly contended and a potential bottleneck.

To address this issue, quota accounts have a mechanism to avoid hot spots on the nodes storing QABs. Quota Account Constituents (QACs) help parallelize the quota accounting by including additional QAB mirrors on other nodes.

The following `sysctl` increases the number of quota accounting constituents, which allows for better scalability and reduces latencies on create/delete flurries when quotas are used.

Using this parameter, the internally calculated QAC count for each quota is multiplied by the specified value. If a workflow experiences write performance issues, and it has many writes to files or directories governed by a single quota, increasing the QAC ratio (`efs.quota.reorganize.qac_ratio`) might improve write performance.

The QAC ratio can be changed to value 8 from the default value of 1 by running the following OneFS CLI command:

```
# isi_sysctl_cluster efs.quota.reorganize.qac_ratio=8
```

For more information, see the [Storage Quota Management and Provisioning with Dell PowerScale SmartQuotas](#) white paper.

OneFS data reduction best practices

Overview

The OneFS data reduction portfolio consists of an array of several features, including compression, deduplication, and small file efficiency. While these components all co-exist, they are not universally supported across the full hardware platform portfolio. The following table indicates which features are available on each PowerScale hardware platform:

Table 7. PowerScale platform features

	F900	F810	F600	F200	H700	H7000	H600	H5600	H500	H400	A300	A3000	A200	A2000
Inline compression	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✓	✗	✗
Inline dedupe	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✓	✗	✗
SmartDedupe	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SFSE packing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Data inlining	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The following decision tree can assist with identifying the available and appropriate data reduction features for particular cluster configurations and datasets:

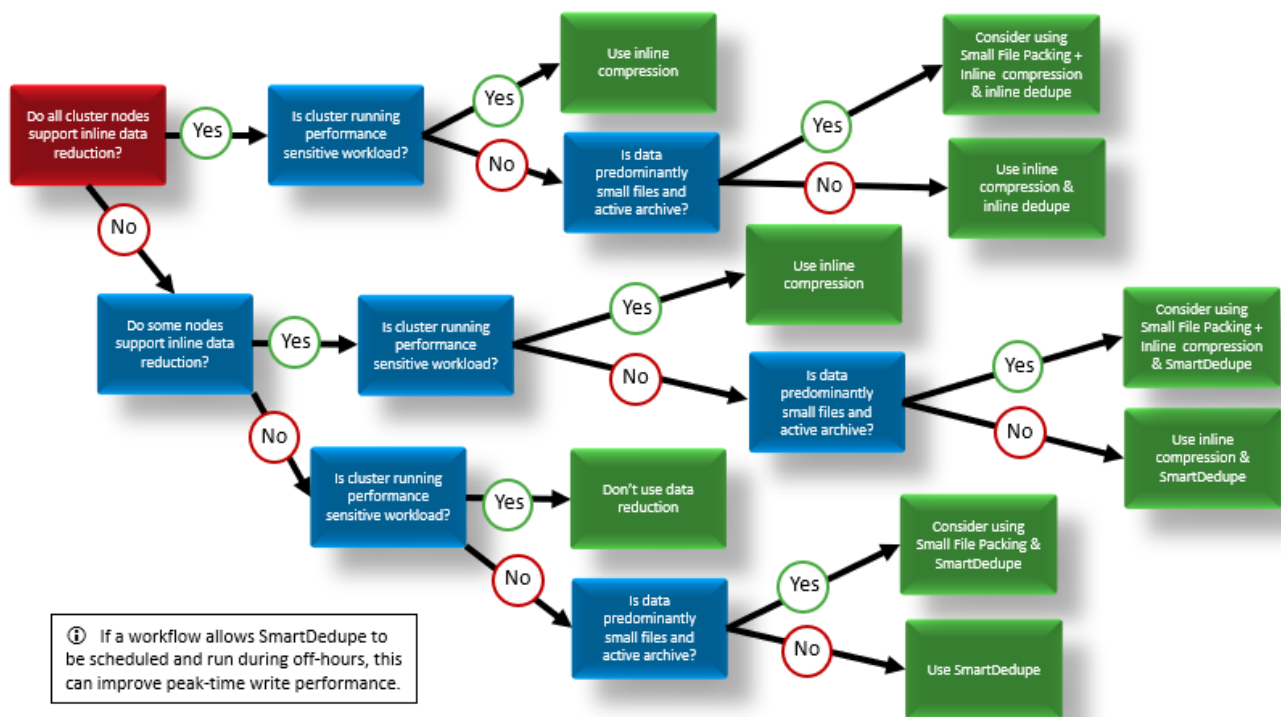


Figure 15. OneFS data reduction and storage efficiency decision tree

SmartDedupe best practices

OneFS SmartDedupe maximizes the storage efficiency of a cluster by decreasing the amount of physical storage required to house an organization's data. Efficiency is achieved by scanning the on-disk data for identical blocks and then eliminating the duplicates. This approach is commonly referred to as post-process, or asynchronous, deduplication.

After duplicate blocks are discovered, SmartDedupe moves a single copy of those blocks to a special set of files known as shadow stores. During this process, duplicate blocks are removed from the actual files and replaced with pointers to the shadow stores.

Deduplication

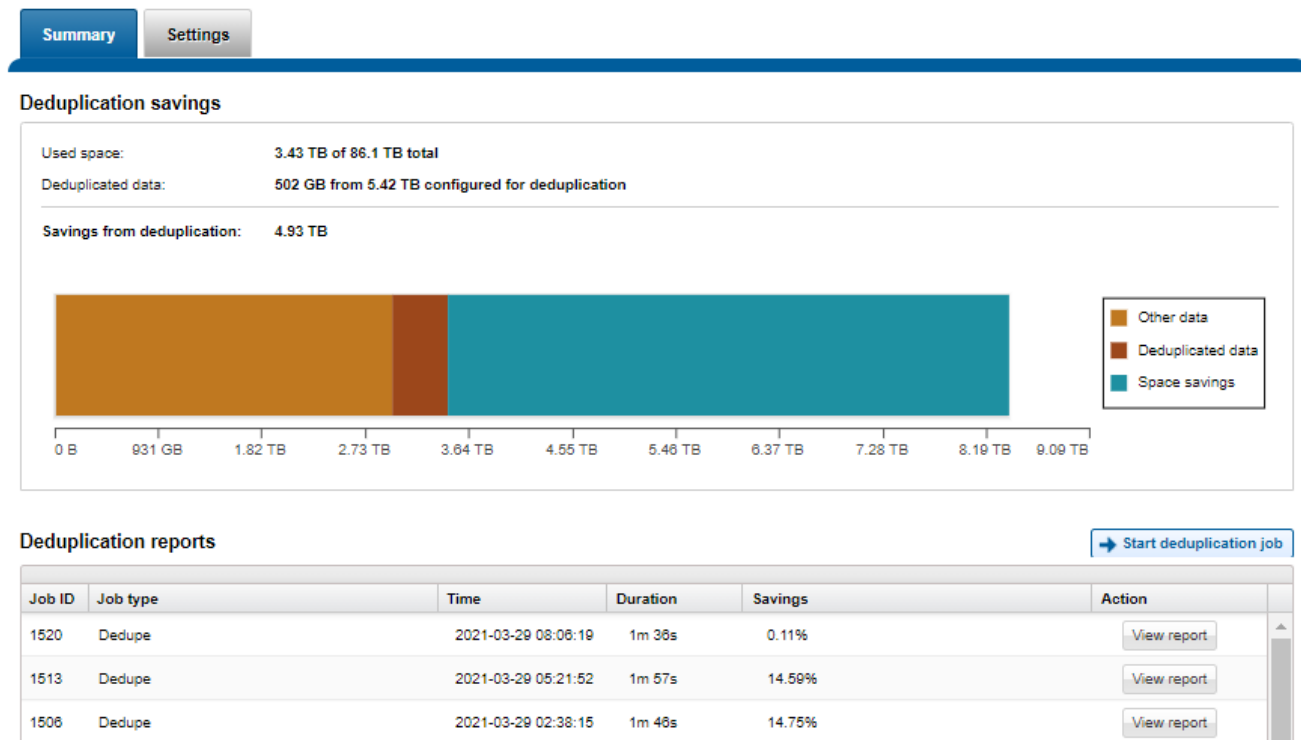


Figure 16. SmartDedupe capacity savings

For optimal cluster performance, we recommend the following SmartDedupe best practices. Some of this information is discussed elsewhere in this paper.

- Deduplication is typically applied to datasets with a lower rate of change – for example, file shares, home directories, and archive data.
- Enable SmartDedupe to run at subdirectory levels below /ifs.
- Avoid adding more than ten subdirectory paths to the SmartDedupe configuration policy,
- SmartDedupe is ideal for home directories, departmental file shares, and warm and cold archive datasets.
- Run SmartDedupe against a smaller sample dataset first to evaluate performance impact against space efficiency.
- Schedule deduplication to run during the cluster's low usage hours—overnight or weekends. By default, the SmartDedupe job runs automatically.
- After the initial deduplication job has completed, schedule incremental deduplication jobs to run every two weeks or so, depending on the size and rate of change of the dataset.
- Always run SmartDedupe with the default 'low' impact Job Engine policy.
- Run the deduplication assessment job on a single root directory at a time. If multiple directory paths are assessed in the same job, you will not be able to determine which directory should be deduplicated.

- When replicating deduplicated data, to avoid running out of space on target, verify that the logical data size (the amount of storage space saved plus the actual storage space consumed) does not exceed the total available space on the target cluster.

Bear in mind that deduplication is not free. There is always trade-off between cluster resource consumption (CPU, memory, disk), and the benefit of increased space efficiency.

SmartDedupe considerations

SmartDedupe considerations include:

- SmartDedupe will not share blocks across files with different protection policies applied.
- OneFS metadata, including the deduplication index, is not deduplicated.
- SmartDedupe will not attempt to deduplicate files smaller than 32 KB in size.
- Dedupe job performance will typically improve significantly on the second and subsequent job runs after the initial index and the bulk of the shadow stores have already been created.
- SmartDedupe will not deduplicate the data stored in a snapshot. However, snapshots can certainly be created of deduplicated data.
- If deduplication is enabled on a cluster that already has a significant amount of data stored in snapshots, it will take time before deduplication affects the snapshot data. Newly created snapshots will contain deduplicated data, but older snapshots will not.
- SmartDedupe deduplicates common blocks within the same file, resulting in even better data efficiency.

For more information, see the [OneFS SmartDedupe](#) white paper.

In-line data reduction best practices

OneFS in-line data reduction is available exclusively on the PowerScale F910, F900, F810, F710, F600, F210, F200, H700/7000, H5600, and A300/3000 platforms. The OneFS architecture has the following principal components:

- Data Reduction Platform
- Compression Engine and Chunk Map
- Zero block removal phase
- Deduplication In-memory Index and Shadow Store Infrastructure
- Data Reduction Alerting and Reporting Framework
- Data Reduction Control Path

The in-line data reduction write path consists of three main phases:

- Zero Block Removal
- In-line Deduplication
- In-line Compression

If both in-line compression and deduplication are enabled on a cluster, zero block removal is performed first, followed by deduplication, and then compression. This order allows each phase to reduce the scope of work each subsequent phase.



Figure 17. In-line data reduction workflow

OneFS provides software-based compression for the F910, F900, F710, F600, F210, F200, and H5600 platform, as fallback in the event of an F810 hardware failure, and in a mixed cluster for use in nodes without a hardware offload capability. Both hardware and software compression implementations are DEFLATE compatible.

The F810 platform includes a compression offload capability, with each node in an F810 chassis containing a Mellanox Innova-2 Flex Adapter. Thus, the Mellanox adapter transparently performs compression and decompression with minimal latency, and avoids the need for consuming a node's expensive CPU and memory resources.

The OneFS hardware compression engine uses zlib, with a software implementation of igzip as fallback in the event of a compression hardware failure. OneFS employs a compression chunk size of 128 KB, with each chunk consisting of sixteen 8 KB data blocks. This chunk size is optimal because it is the same size that OneFS uses for its data protection stripe units, providing simplicity and efficiency, by avoiding the overhead of additional chunk packing.

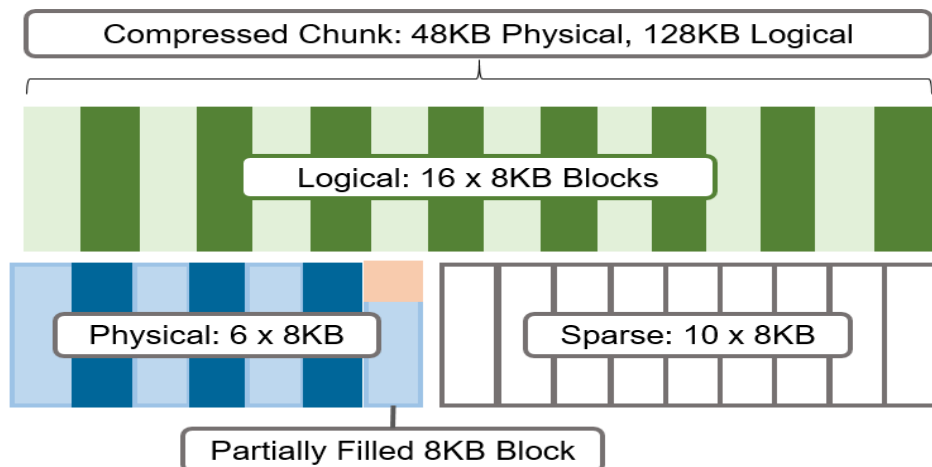


Figure 18. Compression chunks and OneFS transparent overlay

Consider the preceding diagram. After compression, this chunk is reduced from sixteen to six 8 KB blocks in size, which means that this chunk is now physically 48 KB in size. OneFS provides a transparent logical overlay to the physical attributes. This overlay describes whether the backing data is compressed or not and which blocks in the chunk are physical or sparse, such that file system consumers are unaffected by compression. As such, the compressed chunk is logically represented as 128 KB in size, regardless of its actual physical size.

Efficiency savings must be at least 8 KB (one block) in order for compression to occur, otherwise that chunk or file will be passed over and remain in its original, uncompressed state. For example, a file of 16 KB that yields 8 KB (one block) of savings would be compressed. Once a file has been compressed, it is then FEC protected.

Compression chunks will never cross node pools. This avoids the need to decompress or recompress data to change protection levels, perform recovered writes, or otherwise shift protection-group boundaries.

For optimal cluster performance, we recommend the following in-line compression best practices. Some of this information is provided elsewhere in this paper.

- In-line data reduction is for F910, F900, F810, F710, F600, F210, F200, and H5600 installations only. Legacy Isilon F800 nodes cannot be upgraded or converted to F810 nodes.
- Run the assessment tool on a subset of the data to be compressed/deduplicated.
- When replicating compressed and/or deduplicated data, to avoid running out of space on target, verify that the logical data size (the amount of storage space saved plus the actual storage space consumed) does not exceed the total available space on the target cluster.
- In general, additional capacity savings may not warrant the overhead of running SmartDedupe on node pools with in-line deduplication enabled.
- Data reduction can be disabled on a cluster if the overhead of compression and deduplication is considered too high and/or performance is impacted.
- The software data reduction fall back option is less performant, more resource intensive, and less efficient (lower compression ratio) than hardware data reduction. Consider removing F810 nodes with failing offload hardware from the node pool.
- Run the deduplication assessment job on a single root directory at a time. If multiple directory paths are assessed in the same job, you will not be able to determine which directory should be deduplicated.

In-line data reduction considerations

In-line data reduction is supported with the following caveats:

- OneFS 8.2.1 will support 4 to 252 F810 nodes, or 36 chassis, per cluster.
- OneFS 8.2.2 will support 4 to 252 H5600 or F810 nodes per cluster.
- OneFS 9.0 will support 3 to 252 F600 or F200 nodes, or 4 to 252 H5600 or F810 nodes per cluster.
- OneFS 9.2 will support 3 to 252 F900, F600, or F200 nodes, or 4 to 252 H5600 or F810 nodes per cluster.
- OneFS 9.2.1 and later will support 3 to 252 F900, F600, or F200s, or 4 to 252 F810, H700/7000, H5600, or A300/3000 nodes per cluster.
- OneFS 9.7 and later will support 3 to 252 F900, F710, F600, F210, or F200s, or 4 to 252 F810, H700/7000, H5600, or A300/3000 nodes per cluster.
- OneFS 9.8 and later will support 3 to 252 F910, F900, F710, F600, F210, or F200s, or 4 to 252 F810, H700/7000, H5600, or A300/3000 nodes per cluster.

- List Bullet 1
- Data reduction savings depend heavily on factors like the data, cluster composition, and protection level.
- Compressed and deduplicated data does not exit the file system compressed or deduplicated in any shape or form.
- Decompression is substantially less expensive than compression.
- In-line data reduction is exclusive to the PowerScale F910, F900, F810, F710, F600, F210, F200, H700/7000, H5600, and A300/3000 nodes and does not require a software license. In-line data reduction will be automatically disabled on any other node pools.
- In OneFS 9.3 and earlier, in-line compression is automatically enabled on supporting nodes, whereas in-line deduplication is disabled. The following command-line syntax will activate in-line deduplication on a compression cluster:

```
'isi dedupe inline settings modify --mode enabled'
```
- In-line deduplication is enabled by default for new clusters running OneFS 9.4. For earlier OneFS releases, in-line deduplication is disabled by default.
- There is no compatibility or equivalency between F800 and F810 nodes: They cannot share the same node pool and the F800 nodes will not be able to store compressed data.
- There is no OneFS WebUI support for data reduction. Configuration and management are through the CLI only.
- Partial writes to compression chunks may require reading the entire compression chunk first and decompressing it. This is true even if most of the compression chunk is being written.
- Modifications to compression chunks may require rewriting the entire compression chunk even if only a single logical block is changed.
- Some workloads will have data access patterns that exacerbate the above issues and have the potential to cause more writes than if compression was not used.
- Data integrity failures with compressed data will likely mean that corruption does not just affect a single block but instead the entire compression chunk.
- If SmartPools is used on a mixed cluster containing compression nodes, data will only be compressed and/or in-line deduplicated when it physically resides on the compression node pool or pools. If data is tiered to non-compression node pools, it will be uncompressed on the compression nodes before it is moved, so full uncompressed capacity will be required on the compressed pool.
- Post-process SmartDedupe can run in concert with compression and in-line deduplication. It is supported but not widely used. The SmartDedupe job will have to decompress data first to perform deduplication, which is an additional resource expense.
- In-line compression on the F810 uses a dedicated backend network card, so F810 nodes will not support two-way NDMP back end through a Gen6 back-end Ethernet or Fibre Channel controller.

- Even though compressed files are unintelligible when stored on disk, this typically does not satisfy encryption requirements. However, PowerScale nodes are available with self-encrypting drives (SED) for secure data-at-rest compliance.
- As discussed earlier, in-line compression is not free. There is always a trade-off between cluster resource consumption (CPU, memory, disk), the potential for data fragmentation and the benefit of increased space efficiency.
- Since compression extends the capacity of a cluster, it also has the effect of reducing the per-TB compute resource ratio (CPU, memory, I/O).
- Depending on an application's I/O profile and the effect of In-line data reduction on the data layout, read and write performance and overall space savings can vary considerably.
- OneFS metadata structures (inodes, b-trees) are not compressed.
- Since compression trades cluster performance for storage capacity savings, compression may not be ideally suited for heavily accessed data, or high-performance workloads.
- SmartFlash (L3) caching is not applicable to F-series nodes since they contain exclusively SSD flash media anyway.
- If a heterogeneous cluster contains PowerScale F910, F900, F810, F710, F600, F210, F200, H700/7000, H5600, or A300/3000 chassis plus other nodes that do not support in-line data reduction, data will be uncompressed as it moves between pools. A non-compression node on the cluster can be an initiator for compressed writes to a compression pool and will perform compression in software. However, this may generate significant overhead for lower powered Archive class nodes.
- In-line deduplication will not permit block sharing across different hardware types or node pools to reduce the risk of performance asymmetry.
- In-line deduplication will not share blocks across files with different protection policies applied.
- OneFS metadata is not deduplicated.
- In-line deduplication will not deduplicate the data stored in a snapshot.
- There is no in-line deduplication of CloudPools files.
- In-line deduplication can deduplicate common blocks within the same file and a sequence of consecutive blocks to a single block in a shadow store, resulting in even better data efficiency.

For more information, see the [in-line data reduction](#) white paper.

Data immutability recommendations

SmartLock offers advanced data immutability and security capabilities, such as the protection of directories and files from deletion in a WORM state, the ability to disable privileged delete, and overall security. It is available in two different modes: Compliance and Enterprise. The administrative restrictions of Compliance mode have the potential to affect both compliance data as well as enterprise data. Consider the following guidelines and suggested best practices:

- Use SmartLock in Compliance mode only if your organization is legally obligated to do so under SEC rule 17-a4(f). As the Compliance mode installation or upgrade involves careful planning and preparation, it is recommended to be done with the assistance of Dell Support.
- Enterprise mode offers more than adequate security requirements for most users, in most situations. Moreover, the 'superuser' account remains available in Enterprise mode. Therefore, it is more administrator friendly compared to Compliance mode. Following are the best practices that need to be performed before putting an existing cluster in Compliance mode.
- Test and validate all workflows using a proof-of-concept Compliance mode cluster.
- Verify that the cluster time is correct before putting the cluster in Compliance mode.
- Avoid using 'run-as-root' on SMB shares. If you have previously configured SMB shares to 'run-as-root' then change the settings for those shares to specify access permissions to either 'Full-Control', 'Read-Write' or 'Read' before putting the cluster in Compliance mode.
- Use Role based access control (RBAC) for cluster access to perform file management and administrative operations. Enable RBAC, grant appropriate privileges, and then log in through the RBAC-enabled account to the command-line interface (CLI). 'compadmin' represents a regular data user in the context of the CLI.
- For any data migrations from a non-Compliance mode cluster to a cluster that you intend to put in Compliance mode, first verify that current ownership and access permissions are valid and appropriate on both clusters to allow data migration.
- Review the permissions and ownership of any files that exclusively permit the root account to manage or write data to them. Once an upgrade to Compliance mode is complete, if the existing OneFS configuration limits relevant POSIX access permissions to specific directories or files in any way, writing data or changing ownership of these objects will be blocked.
- If any root-owned workflow or datafiles exist, all ownership or permission changes should be performed before upgrading to Compliance mode. You should not change the ownership of any system files. The Compliance mode conversion process automates all required ownership changes to system files. Avoid changing the ownership of any files outside of /ifs, as no user data should reside outside of /ifs. As a best practice, change the ownership of files under /ifs that are owned by 'root' to the 'compadmin' account before upgrading to Compliance mode.
- In Compliance mode, the default POSIX permissions permit the compadmin account to write data. However, the following directories should not be modified

unless the default permissions for these directories have been changed: `/ifs/.ifsvar` and `/ifs/.snapshot`

- Verify the available disaster recovery options on Compliance mode clusters in relation to SyncIQ.
- If NDMP is being used for backups, the NDMP backups of SmartLock Compliance data are not considered to be compliant with the SEC regulation 17-a4f.

For more information, see the [SmartLock](#) white paper.

OneFS security hardening

OneFS provides a hardened profile that can be enabled for sites that are looking for additional security or need to comply with the US Department of Defense's Security Technical Implementation Guide (STIG). This profile can be enabled or disabled on a cluster as required but does require a zero-cost license to activate.

OneFS 9.5 introduces several additional security enhancements that satisfy Defense Information Systems Agency (DISA) and other federal and corporate security mandates and requirements, including:

- Multifactor authentication (MFA) through access cards (CAC and PIV), single sign-on (SSO) through SAML for the WebUI, and PKI-based authentication
- FIPS 140-2 data-in-flight encryption for major protocols, FIPS 140-2 data at rest through SEDs, SEDs master key rekey, and TLS 1.2 support
- Introduction of a host-based firewall, permitting restriction of the management interface to a dedicated subnet and hosts to specified IP pools
- IPV6-only network support for the USGv6R1 standard

Permissions, authentication, and access control recommendations

Access Zones provide secure, isolated storage pools for specific departments within an organization, allowing consolidation of storage resources without compromising security.

A minimum of two AD, LDAP or NIS servers provides redundancy and helps avoid access control lookups being a bottleneck. For larger environments, scaling the number of domain servers may be required.

The best practices for Access Zones include:

- The number of access zones should not exceed 50. The number of local users and groups per cluster should not exceed 25,000 for each. While possible, creating a larger number of local groups and/or users may affect system performance.
- Separate corporate tenants with Access Zones, up to a maximum of 50 zones.
- Use the system access zone for cluster management.
- Constrain different protocols (for example, NFS, SMB) to separate access zones.

- If you create access zones, ensure that the directory paths for each zone under /ifs do not overlap. Instead, you should designate separate directory trees for each zone.
- As part of SmartConnect's support for multitenancy, Groupnet objects sit above subnets and pools and allow separate Access Zones to contain distinct DNS settings.

For more information about identity management, authentication, and access control in combined NFS and SMB environments, see the [OneFS Multiprotocol Security Guide](#).

Job Engine recommendations

Introduction

In a clustered architecture, there are cluster jobs that are responsible for taking care of the health and maintenance of the cluster itself—these jobs are all managed by the OneFS Job Engine. The Job Engine runs across the entire cluster and reduces a task into smaller work items. It then allocates these items to multiple worker threads on each node. Jobs are typically run as background tasks across the cluster, using spare or especially reserved capacity and resources. The jobs themselves can be categorized into three primary classes, as described in [File system maintenance jobs](#), [Feature support jobs](#), and [User action jobs](#).

File system maintenance jobs

File system maintenance jobs perform background file system maintenance and typically require access to all nodes. These jobs are required to run in default configurations, and often in degraded cluster conditions. Examples include file system protection and drive rebuilds.

Feature support jobs

Feature support jobs perform work that facilitates some extended storage management function, and typically only run when the feature has been configured. Examples include deduplication and anti-virus scanning.

User action jobs

Storage administrators run user action jobs directly to accomplish some data management goal. Examples include parallel tree deletes and permissions maintenance.

The Job Engine allows up to three jobs to be run simultaneously. This concurrent job process is governed by the following criteria:

- Job priority.
- Exclusion sets—These jobs cannot run together (FlexProtect and AutoBalance).
- Cluster health—Most jobs cannot run when the cluster is in a degraded state.

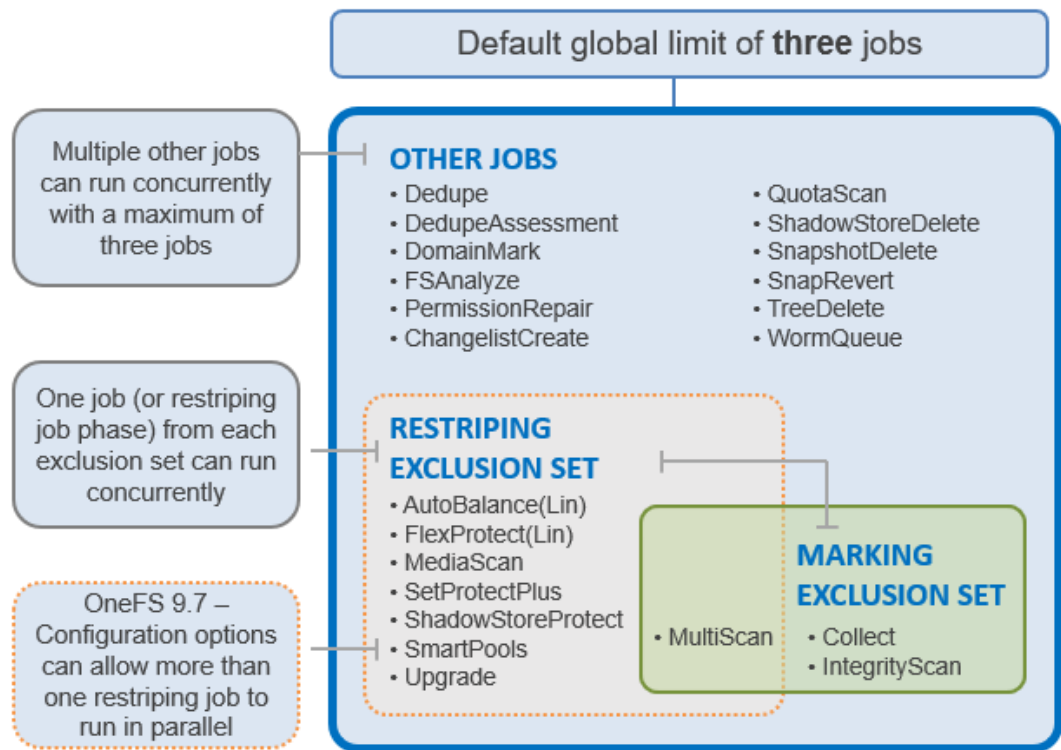


Figure 19. Job Engine exclusion sets

The default, global limit of three jobs does not include jobs for striping or marking; one job from each of those categories can also run concurrently.

For optimal cluster performance, we recommend observing the following Job Engine best practices.

- Schedule jobs to run during the cluster's low usage hours—overnight, weekends.
- Where possible, use the default priority, impact, and scheduling settings for each job.
- To complement the four default impact profiles, create additional profiles such as "daytime_medium", "after_hours_medium", "weekend_medium", to fit specific environment needs.
- Ensure the cluster, including any individual node pools, is less than 90% full, so performance is not impacted and that there is always space to reprotect data in the event of drive failures. Also enable virtual hot spare (VHS) to reserve space in case you need to smartfail devices.
- Configure and pay attention to alerts. Set up event notification rules so that you will be notified when the cluster begins to reach capacity thresholds. Make sure to enter a current email address to ensure you receive the notifications.
- It is recommended not to disable the snapshot delete job. In addition to preventing unused disk space from being freed, disabling the snapshot delete job can cause performance degradation.

- Delete snapshots in order, beginning with the oldest. Do not delete snapshots from the middle of a time range. Newer snapshots are mostly pointers to older snapshots, and they look larger than they really are.
- If you need to delete snapshots and there are down or smartfailed devices on the cluster, or the cluster is in an otherwise “degraded protection” state, contact Dell Technical Support for assistance.
- Only run the FSAnalyze job if you are using InsightIQ and/or require file system analytics. FSAnalyze creates data for InsightIQ file system analytics tools, providing details about data properties and space usage within /ifs. Unlike SmartQuotas, FSAnalyze only updates its views when the FSAnalyze job runs. Because FSAnalyze is a relatively low-priority job, higher-priority jobs can sometimes preempt it, so it can take a long time to gather all the data.
- Schedule deduplication jobs to run every 10 days or so, depending on the size of the dataset.
- SmartDedupe will automatically run with a “low-impact” Job Engine policy. However, this policy can be manually reconfigured.
- In a heterogeneous cluster, tune job priorities and impact policies to the level of the lowest performance tier.
- Before running a major (non-rolling) OneFS upgrade, allow active jobs to complete, where possible, and cancel out any outstanding running jobs.
- Before running TreeDelete, ensure there are no quotas policies set on any directories under the root level of the data for deletion. TreeDelete cannot delete a directory if a quota has been applied to it.
- If FlexProtect is running, allow it to finish completely before powering down any nodes or the entire cluster. While shutting down the cluster during restripe will not hurt anything directly, it does increase the risk of a second device failure before FlexProtect finishes reprotecting data.
- When using metadata read or metadata write acceleration, always run a job with the *LIN suffix where possible. For example, favor the FlexProtectLIN job, rather than the regular FlexProtect job.
- TreeDelete can delete a directory to which a quota has been applied using the ‘--delete-quota’ flag. For example: #isi job start TreeDelete --paths=/ifs/quota --delete quota
- Avoid data movement as much as possible during daily operations. SmartPools data placement requires resources which can contend with client IO. With a mixed node cluster where data tiering is required, the recommendation is to schedule the SmartPools job to run during off-hours (nights and/or weekends) when the client activity is at its lowest.

Job Engine considerations

For optimal cluster performance, bear in mind the following OneFS Job Engine considerations:

- When reconfiguring the default priority, schedule, and impact profile for a job, consider the following questions:
 - What resources am I impacting?

- What would I be gaining or losing if I reprioritized this job?
- What are my impact options and their respective benefits and drawbacks?
- How long will the job run and what other jobs will it contend with?
- SyncIQ, the OneFS replication product, does not use Job Engine. However, it has both influenced, and been strongly influenced by, the Job Engine design. SyncIQ also terms its operations "jobs," and its processes and terminology bear some similarity to Job Engine. The Job Engine impact management framework is aware of the resources consumed by SyncIQ, in addition to client load, and will throttle jobs accordingly.
- A job with a name suffixed by 'Lin', for example FlexProtectLin, indicates that this job will scan an SSD-based copy of the LIN tree metadata, rather than access the hard drives themselves. This can significantly improve job performance, depending on the specific workflow.
- When more than three jobs with the same priority level and no exclusion set restrictions are scheduled to run simultaneously, the three jobs with the lowest job ID value will run. The remainder will be paused.
- There is only one 'mark cookie' available for marking jobs. So, if marking job A is interrupted by another marking job B, job A will automatically be cancelled when it resumes after the completion of B.
- For mixed node (heterogeneous) clusters that do not have a license for SmartPools data tiering module, the SetProtectPlus job will run instead, and apply the default file policy. SetProtectPlus will be automatically disabled if a valid SmartPools license key is added to the cluster.
- By default, FlexProtect is the only job allowed to run if a cluster is in degraded mode. Other jobs will automatically be paused and will not resume until FlexProtect has completed and the cluster is healthy again.
- Restriping jobs only block each other when the current phase might perform restriping. This is most evident with MultiScan, whose final phase only sweeps rather than restripes. Similarly, MediaScan, which rarely ever restripes, is can usually run to completion more often without contending with other restriping jobs.
- MediaScan restripes in phases 3 and 5 of the job, and only if there are disk errors (ECCs) which require data reprotection. If MediaScan reaches its third phase with ECCs, it will pause until AutoBalanceLin is no longer running. If MediaScan's priority were in the range 1-3, it would cause AutoBalanceLin to pause instead.
- If two jobs happen to reach their restriping phases simultaneously and the jobs have different priorities, the higher priority job (priority value closer to "1") will continue to run, and the other will pause. If the two jobs have the same priority, the job that is already in its restriping phase will continue to run, and the job newly entering its restriping phase will pause.
- During MediaScan's verify and repair phases, attempts to re-read bad sectors can occasionally cause drives to stall briefly while trying to correct the error. This interruption is typically brief and limited.

For more information, see the [PowerScale OneFS Job Engine](#) white paper.

Cluster management recommendations

Cluster configuration and administration

There are three access methods for configuring and administering a OneFS powered cluster:

- Command-line interface (CLI) - either by SSH or serial console.
- Web interface (WebUI)
- RESTful platform API (PAPI)

OneFS 9.0 and later provide Intelligent Platform Management Interface (IPMI) support for Isilon Gen6 and PowerScale platforms. This functionality allows out-of-band console access and remote node power control over a dedicated Ethernet management port and is configured and managed using the 'isi ipmi' CLI command set.

While the Web Interface is the most intuitive, menu driven, and simple to use cluster administration method, it is also the most limited in terms of scope. The CLI has a more comprehensive set of administrative commands than the WebUI, making it a popular choice for OneFS power users.

However, where possible, use scripts to automate management of the cluster through the platform API. Using scripts also avoids challenges with the CLI and WebUI in parsing large numbers of configuration policies—for example, tens of thousands of NFS exports.

Cluster capacity management

When a cluster or any of its node pools becomes more than 95% full, OneFS can experience slower performance and possible workflow interruptions in degraded mode and high-transaction or write latency sensitive operations. Furthermore, when a large cluster approaches full capacity (over 98% full), the following issues can occur:

- Performance degradation in some cases
- Workflow disruptions - failed file operations and inability to write data.
- Inability to make configuration changes or run commands to delete data and free up space
- Increased disk and node rebuild times.

To ensure that a cluster or its constituent pools do not run out of space:

- Add new nodes to existing clusters or pools
- Replace smaller-capacity nodes with larger-capacity nodes
- Create more clusters.

When deciding to add new nodes to an existing large cluster or pool, contact your sales team to order the nodes well in advance of the cluster or pool running short on space. The recommendation is to start planning for additional capacity when the cluster or pool reaches 75% full. This will allow sufficient time to receive and install the new hardware, while still maintaining sufficient free space.

The following table presents a suggested timeline for cluster capacity planning:

Table 8. Capacity planning timeline

Used capacity	Action
75%	Plan additional node purchases.
80%	Receive delivery of the new hardware.
85%	Rack and install the new node or nodes.

If an organization's data availability and protection SLA varies across different data categories (for example, home directories, file services), ensure that any snapshot, replication, and backup schedules are configured accordingly to meet the required availability and recovery objectives, and fit within the overall capacity plan.

Consider configuring a separate accounting quota for /ifs/home and /ifs/data directories (or wherever data and home directories are provisioned) to monitor aggregate disk space usage and issue administrative alerts as necessary to avoid running low on overall capacity.

For optimal performance in any size cluster, the recommendation is to maintain 10% free space in each pool of a cluster.

To better protect smaller clusters (containing 3 to 7 nodes) we recommend that you maintain 15 to 20% free space. A full smartfail of a node in smaller clusters may require more than one node's worth of space. Maintaining 15 to 20% free space can allow the cluster to continue to operate while Dell helps with recovery plans.

Plan for contingencies: having a fully updated backup of your data can limit the risk of data loss if a node fails.

Maintaining appropriate protection levels

Ensure that your cluster and pools are protected at the appropriate level. Every time you add nodes, re-evaluate protection levels. OneFS includes a 'suggested protection' function that calculates a recommended protection level based on cluster configuration, and alerts you if the cluster falls below this suggested level.

OneFS supports several protection schemes. These include the ubiquitous +2d:1n, which protects against two drive failures or one node failure.

The best practice is to use the recommended protection level for a particular cluster configuration. This recommended level of protection is clearly marked as 'suggested' in the OneFS WebUI storage pools configuration pages and is typically configured by default. For current hardware configurations, the recommended protection level is generally '+2d:1n', '+3d:1n1d', or '+4n:2d' depending on the cluster size.

Figure 20. OneFS suggested protection level

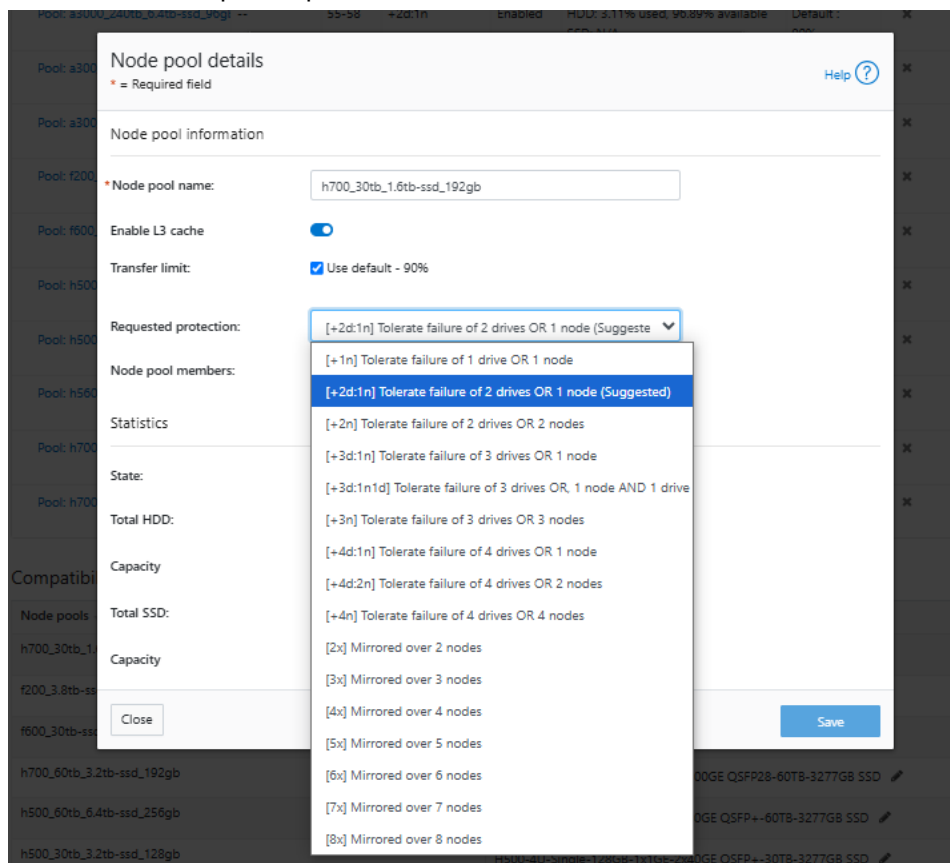
Monitoring cluster capacity

To monitor cluster capacity:

Configure alerts. Set up event notification rules so that you will be notified when the cluster begins to reach capacity thresholds. Make sure to enter a current email address in order to receive the notifications.

Monitor alerts. The cluster sends notifications when any of its node pools have reached 90 percent and 97 percent capacity. On some clusters, 5 percent (or even 1 percent) capacity remaining might mean that a lot of space is still available, so you might be inclined to ignore these notifications. However, it is best to pay attention to the alerts, closely monitor the cluster, and have a plan in place to take action when necessary.

Monitor ingest rate. It is very important to understand the rate at which data is coming into the cluster or pool. Options to do this include:



- SNMP
- SmartQuotas
- FSAnalyze

Use SmartQuotas to monitor and enforce administrator-defined storage limits.

SmartQuotas manages storage use, monitors disk storage, and issues alerts when disk storage limits are exceeded. Although it does not provide the same detail of the file

system that FSAnalyze does, SmartQuotas maintains a real-time view of space utilization so that you can quickly obtain the information you need.

Run FSAnalyze jobs. FSAnalyze is a job-engine job that the system runs to create data for InsightIQ file system analytics tools. FSAnalyze provides details about data properties and space usage within the /ifs directory. Unlike SmartQuotas, FSAnalyze updates its views only when the FSAnalyze job runs. Since FSAnalyze is a fairly low-priority job, higher-priority jobs can sometimes preempt it, so it can take a long time to gather all the data. An InsightIQ license is required to run an FSAnalyze job.

Managing data

Regularly archive data that is rarely accessed and delete any unused and unwanted data. Ensure that pools do not become too full by setting up file pool policies to move data to other tiers and pools.

Provisioning additional capacity

To ensure that your cluster or pools do not run out of space, you can create more clusters, replace smaller-capacity nodes with larger-capacity nodes, or add new nodes to existing clusters or pools. If you decide to add new nodes to an existing cluster or pool, contact your sales representative to order the nodes long before the cluster or pool runs out of space. Dell recommends that you begin the ordering process when the cluster or pool reaches 80% used capacity. This will allow enough time to receive and install the new equipment and still maintain enough free space.

Managing snapshots

Sometimes a cluster has many old snapshots that take up a lot of space. Reasons for this include inefficient deletion schedules, degraded cluster preventing job execution, and expired SnapshotIQ license.

Ensuring all nodes are supported and compatible

Each version of OneFS supports only certain nodes. See the “OneFS and node compatibility” section of the Supportability and Compatibility Guide for a list of which nodes are compatible with each version of OneFS. When upgrading OneFS, make sure that the new version supports your existing nodes. If it does not, you might need to replace the nodes.

Space and performance are optimized when all nodes in a pool are compatible. When you add new nodes to a cluster, OneFS automatically provisions nodes into pools with other nodes of compatible type, hard drive capacity, SSD capacity, and RAM. Occasionally, however, the system might put a node into an unexpected location. If you believe that a node has been placed into a pool incorrectly, contact Dell Technical Support for assistance. Different versions of OneFS have different rules regarding what makes nodes compatible.

Enabling Virtual Hot Spare

The purpose of Virtual Hot Spare (VHS) is to keep space in reserve in case you need to smartfail drives when the cluster gets close to capacity. Enabling VHS will not give you more free space, but it will help protect your data in the event that space becomes scarce. VHS is enabled by default. Dell strongly recommends that you do not disable VHS unless directed by a Support engineer. If you disable VHS in order to free some space, the space

you just freed will probably fill up again quickly with new writes. At that point, if a drive were to fail, you might not have enough space to smartfail the drive and reprotect its data, potentially leading to data loss. If VHS is disabled and you upgrade OneFS, VHS will remain disabled. If VHS is disabled on your cluster, first check to make sure the cluster has enough free space to safely enable VHS, and then enable it.

Enabling Spillover

Spillover allows data that is being sent to a full pool to be diverted to an alternate pool. Spillover is enabled by default on clusters that have more than one pool. If you have a SmartPools license on the cluster, you can disable Spillover. However, it is recommended that you keep Spillover enabled. If a pool is full and Spillover is disabled, you might get a “no space available” error but still have a large amount of space left on the cluster.

The screenshot shows the 'SmartPools Settings' tab in the OneFS management console. The 'Local Storage Settings' section is expanded. The following settings are visible:

- ☒ Increase directory protection to a higher requested protection than its contents
- ☐ Enable global namespace acceleration
- ☒ Use SSDs as L3 Cache by default for new node pools
- Virtual Hot Spare (VHS)**
 - ☒ Subtract the space reserved for the virtual hot spare when calculating available free space
 - ☒ Deny data writes to reserved disk space
 - VHS Space Reserved**
 - At least virtual drive(s)
 - At least % of total storage
- ☒ Enable global spillover
 - Spillover Data Target:

Figure 21. OneFS SmartPools VHS and Spillover configuration

Confirm that:

- There are no cluster issues.
- OneFS configuration is as expected.

In summary, best practices on planning and managing capacity on a cluster include the following:

- Maintain sufficient free space.
- Plan for contingencies.
- Manage your data:
 - Maintain appropriate protection levels.
 - Monitor cluster capacity and data ingest rate.

- Consider configuring a separate accounting quota for /ifs/home and /ifs/data directories (or wherever data and home directories are provisioned) to monitor aggregate disk space usage and issue administrative alerts as necessary to avoid running low on overall capacity.
- Ensure that any snapshot, replication, and backup schedules meet the required availability and recovery objectives and fit within the overall capacity.
- Manage snapshots.
- Use InsightIQ, ClusterIQ, and MetadataIQ for usage forecasting, file system analytics, and cluster health verification.

Best practices checklist

For optimal cluster performance, we recommend observing the following best practices. This information might be discussed elsewhere in this paper.

- Define, implement, and regularly test a data protection strategy and business continuity plan.
- Maintain sufficient free space and pay attention to data ingest rate.
- Ensure that cluster capacity utilization (hard drive and SSD) remains below 90%.
- For OneFS 9.2.1 and later, the recommendation is that each node in a PowerScale cluster has a minimum of 64 GB of RAM.
- If SmartPools is licensed, ensure that spillover is enabled (default setting).
- Manage your data: Archive infrequently accessed data and delete unused data.
- Maintain appropriate data protection levels.
- Periodically check the data protection level as the cluster grows.
- Record your original settings before making any configuration changes to OneFS or its data services.
- Monitor cluster capacity and data ingest rate.
- Ensure that all the data services that you want are licensed and configured.
- Observe NFS and SMB connection limits.
- Many cluster configuration settings are global and have cluster-wide effects. If you consider changing cluster-wide configuration settings, be sure that you fully understand the global settings and their implications.
- Manage snapshot creation and deletion schedules.
- Set up SmartConnect for load balancing and use Round Robin as the balancing policy.
- Recommend turning off client DNS caching, where possible. To handle client requests properly, SmartConnect requires that clients use the latest DNS entries.
- Ensure that Virtual Hot Spare and SmartPools spillover both remain enabled (the default).
- Ensure the SmartPools job only runs during off-hours.

Summary

- If using SmartPools tiering, reconfigure the Storage Target field from “anywhere” to a specific tier or node pool to direct ingest to a performance node pool or tier.
- Add cluster to an InsightIQ monitoring instance
- Deploy a lab cluster environment to test and validate any new cluster configurations before making changes that affect the production environment.
- Confirm that remote support functions work correctly through Dell Technologies Connectivity Services or Secure Remote Services and internal email/SNMP notifications.
- Upgrade OneFS to a newer release at least once a year using the nondisruptive ‘rolling-upgrade’ option.
- Configure and pay attention to cluster events and alerts.
- Regularly run and monitor OneFS Healthchecks.

Summary

Dell PowerScale overcomes the problems that undermine traditional NAS systems by combining the three traditional layers of storage architecture—file system, volume manager, and data protection—into a scale-out NAS cluster with a distributed file system. The Dell PowerScale architecture eliminates controller bottlenecks to reduce wall-clock runtimes for concurrent jobs. PowerScale accelerates metadata operations, improves storage efficiency to lower capital expenditures, centralizes management to reduce operating expenses, and delivers strategic advantages to increase competitiveness in a global market.