Abstract

This white paper details how Dell EMC Isilon scale-out NAS storage and the Isilon OneFS operating system architecture provide high availability and data protection needed to meet the challenges organizations face as they deal with the deluge of digital content and unstructured data and the growing importance of data protection.

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Introduction

Today, organizations of all sizes across the full spectrum of the business arena are facing a similar problem: An explosion in the sheer quantity of file-based data they are generating and, by virtue, are forced to manage. This proliferation of unstructured data, often dubbed 'big data', has left traditional storage architectures unable to satisfy the demands of this growth and has necessitated the development of a new generation of storage technologies. Additionally, broader data retention requirements, regulatory compliance, tighter availability service level agreements (SLAs) with internal/external customers, and cloud and virtualization initiatives are only serving to compound this issue.

Intended Audience

This paper presents information for deploying, managing, and protecting a Dell EMC Isilon cluster. This paper does not intend to provide a comprehensive background to the Isilon OneFS architecture.

Please refer to the OneFS Technical Overview white paper for further details on the OneFS architecture.

The target audience for this white paper is anyone configuring and managing an Isilon clustered storage environment. It is assumed that the reader has an understanding and working knowledge of the OneFS components, architecture, commands and features.

More information on OneFS commands and feature configuration is available in the OneFS Administration Guide.

High availability and reliability at the petabyte scale

Once data sets grow into the petabytes realm, a whole new level of availability, management and protection challenges arise. At this magnitude, given the law of large numbers with the sheer quantity of components involved, there will almost always be one or more components in a degraded state at any point in time within the storage infrastructure. As such, guarding against single points of failure and bottlenecks becomes a critical and highly complex issue. Other challenges that quickly become apparent at the petabyte scale include the following:

- **File System Limitations**: How much capacity and how many files can a file system accommodate?
- **Disaster Recovery**: How do you duplicate the data off site and then how do you retrieve it?
- **Scalability of Tools**: How do you take snapshots of massive data sets?
- **Software Upgrades and Hardware Refresh**: How do you upgrade software and replace outdated hardware with new?
- **Performance Issues**: How long will searches and tree-walks take with large, complex datasets?
- **Backup and Restore**: How do you back up a large dataset and how long will it take to restore?

Given these challenges, the requirement for a new approach to file storage is clear. Fortunately, when done correctly, scale-out NAS can fulfill this need.

Areal density and drive rebuild times

In today’s world of large capacity disk drives, the probability that secondary device failures will occur has increased dramatically. Areal density, the amount of written information on the disk’s surface in bits per square inch, continues to outstrip Moore’s law. However, the reliability and performance of disk drives are not increasing at the same pace and this is compounded by the growing amount of time it takes to rebuild drives.

Large capacity disks such as six and eight terabyte SATA drives require much longer drive reconstruction times since each subsequent generation of disk still has the same number of heads and actuators servicing increased density platters. This significantly raises the probability of a multiple drive failure scenario.
Silent data corruption

Another threat that needs to be addressed, particularly at scale, is the looming specter of hardware induced corruption. For example, when CERN tested the data integrity of standard disk drives they discovered some alarming findings. To do this, they built a simple write and verify application which they ran across a pool of three thousand servers, each with a hardware RAID controller. After five weeks of testing, they found in excess of five hundred instances of silent data corruption spread across seventeen percent of the nodes - after having previously thought everything was fine. Under the hood, the hardware RAID controller only detected a handful of the most blatant data errors and the rest passed unnoticed.

Suffice to say, this illustrates two inherent data protection requirements: First, the need for an effective, end-to-end data verification process to be integral to a storage device in order to detect and mitigate such instances of silent data corruption. Second, the requirement for regular and reliable backups is the linchpin of a well-founded data protection plan.

Data protection continuum

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

![Data Protection Continuum](image)

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 lie the data recovery approaches in order of decreasing timeliness. These solutions typically include a form of point-in-time snapshots for fast recovery, followed by synchronous and asynchronous replication. Finally, backup to tape or a virtual tape library sits at the end of the continuum, providing insurance against large scale data loss, natural disasters and other catastrophic events.

High availability with Isilon

Dell EMC Isilon scale-out NAS storage solutions, powered by the Isilon OneFS operating system, uses a holistic approach to ensuring that data is consistent and intact - both within the file system and when exiting the cluster via a network interface. Furthermore, the Isilon clustering technology is uncompromisingly designed to simplify the management and protection of multi-petabyte datasets.

Isilon scale-out architecture

An Isilon cluster is built on a highly redundant and scalable architecture based upon the hardware premise of shared nothing. The fundamental building blocks are platform nodes of which there are anywhere from three to one hundred and forty four nodes in a cluster. Each of these platform nodes contains CPU, memory, disk and I/O controllers in an efficient 2U or 4U rack-mountable chassis. Redundant Ethernet or InfiniBand (IB) adapters provide a high speed back-end cluster interconnect—essentially a distributed system bus - and each node houses mirrored and battery-backed file system journal to protect any uncommitted writes. With the exception of the LCD control front panel, all of a node's components are standard enterprise commodity hardware.
These Isilon nodes contain a variety of storage media types and densities, including SAS and SATA hard disk drives (HDDs), solid-state drives (SSDs), and a configurable quantity of memory. This allows customers to granularly select an appropriate price, performance and protection point to accommodate the requirements of specific workflows or storage tiers.

Highly available storage client access is provided via multiple 1, 10 or 40Gb/s Ethernet interface controllers within each node, and across a variety of file and object protocols, including NFS and SMB. OneFS also provides full support for both IPv4 and IPv6 environments across the front end Ethernet network(s).

Heterogeneous Isilon clusters can be architected with a wide variety of node styles and capacities, in order to meet the needs of a varied data set and wide spectrum of workloads. These node styles encompass several hardware generations, and fall loosely into four main categories or tiers. The following table illustrates these tiers, and the associated hardware generations and models:

<table>
<thead>
<tr>
<th>Tier</th>
<th>I/O Profile</th>
<th>Drive Media</th>
<th>Gen 6 Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Performance</td>
<td>High Perf, Low Latency</td>
<td>Flash</td>
<td>F800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F810</td>
</tr>
<tr>
<td>Performance</td>
<td>Transactional I/O</td>
<td>SAS &amp; SSD</td>
<td>H600</td>
</tr>
<tr>
<td>Hybrid / Utility</td>
<td>Concurrency &amp; Streaming Throughput</td>
<td>SATA/SAS &amp; SSD</td>
<td>H5600</td>
</tr>
<tr>
<td></td>
<td>Nearline &amp; Deep Archive</td>
<td>SATA</td>
<td>H500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H400</td>
</tr>
<tr>
<td>Archive</td>
<td></td>
<td></td>
<td>A200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A2000</td>
</tr>
</tbody>
</table>

Table 1: Isilon Hardware Tiers and Node Types
Isilon OneFS architectural overview

Isilon OneFS collapses the traditional elements of the storage stack—data protection, volume manager, file system, etc.—into a single, unified software layer (see Figure 3 below). This allows for a highly extensible file system that affords unparalleled levels of protection and availability.

Built atop FreeBSD’s UNIX implementation, availability and resilience are integral to OneFS from the lowest level on up. For example, unlike BSD, OneFS provides mirrored volumes for the root and /var file systems via the Isilon Mirrored Device Driver (IMDD), stored on flash drives. OneFS also automatically saves last known good boot partitions for further resilience.

On the network side, the Isilon logical network interface (LNI) framework provides a robust, dynamic abstraction for easily combining and managing differing interfaces, enabling network resilience. Multiple network interfaces can be trunked together with Link Aggregation Control Protocol (LACP) and Link Aggregation and Link Failover (LAGG) to provide bandwidth aggregation in addition to client session failover and general network resilience.

Within the cluster, every disk within each node is assigned both a Globally Unique Identifier (GUID) and logical drive number and is subdivided into 32MB cylinder groups comprised of 8KB blocks. Each cylinder group is responsible for tracking, via a bitmap, whether its blocks are used for data, inodes or other metadata constructs. The combination of node number, logical drive number and block offset comprise a block or inode address and fall under the control of the aptly named Block Allocation Manager (BAM).

In addition to block and inode allocation, the BAM also handles file layout and locking and abstracts the details of OneFS distributed file system from the kernel and userspace. The BAM never actually touches the disk itself, instead delegating tasks to the local and remote block manager elements respectively on the appropriate nodes. The Remote Block Manager (RBM) is essentially a Remote Procedure Call (RPC) protocol that utilizes either IP over Ethernet or the Socket Direct Protocol (SDP) over redundant Ethernet or InfiniBand for reliable, low-latency back-end cluster communication. These RBM messages—everything from cluster heartbeat pings to distributed locking control - are then processed by a node’s Local Block Manager via the Device Worker Thread (DWT) framework code.

Figure 3: OneFS Collapsed Stack Storage Architecture

Please refer to the OneFS Technical Overview white paper for further details on the OneFS architecture.

Safe writes

For write operations, where coherency is vital, the BAM first sets up a transaction. Next it uses a 2-phase commit protocol (2PC) over the RBM to guarantee the success of an atomic write operation across all participant nodes. This is managed via the BAM Safe Write (BSW) code path. The 2PC atomically updates multiple disks across the 2PC participant nodes, using their journals for transaction logging. The write path operates as follows:

1. **Client performs a transactional write.**
   - Block is written to journal; memory buffer is pinned.
   - Rollback data is maintained.

2. **Transaction commits.**
   - Journal data is pinned; memory buffer is dirty.
   - Rollback data can now be discarded.
   - Top level operation is complete.
3. **OneFS asynchronously flushes dirty buffers to disk at some point.**
   Placed into the writeback cache.
   Journal data still required and memory buffer discarded.

4. **Journal approaches full or timeout and issues disk writeback cache flush.**
   This occurs relatively infrequently.

5. **Cache flush complete.**
   Journal data discarded for writes that were returned prior to flush.

### Cluster group management

Cluster coherence and quorum is handled by OneFS Group Management Protocol (GMP). The challenge is combining the various elements—performance, coherency, client access protocols - across multiple heads. The GMP is built on several distributed algorithms and strictly adheres to Brewer’s Theorem, which states that it is impossible for a distributed computer system to simultaneously guarantee all three of the following; consistency, availability and partition tolerance. OneFS does not compromise on either consistency or availability.

Given this, a quorum group comprising more than half of a cluster's nodes must be active and responding at any given time. In the event that a node is up and responsive but not a member of the quorum group, it is forced into a read-only state.

OneFS employs this notion of a quorum to prevent “split-brain” conditions that might possibly result from a temporary cluster division. The quorum also dictates the minimum number of nodes required to support a given data protection level. For example, seven or more nodes are needed for a cluster to support a +3n configuration. This allows for a simultaneous loss of three nodes while still maintaining a quorum of four nodes, allowing the cluster to remain operational.

The group management protocol keeps track of the state of all the nodes and drives that are considered part of the cluster. Whenever devices are added or removed from the cluster, either proactively or reactively, a group change is broadcast, the group ID is incremented and any uncommitted journal write transactions are resolved.

Please refer to the Cluster Composition, Group State and Quorum white paper for further details on cluster group management.

### Concurrency and locking

OneFS employs a distributed lock manager that utilizes a proprietary hashing algorithm to orchestrate coherent locking on data across all nodes in a storage cluster. The design is such that a lock coordinator invariably ends up on a different node than the initiator and either shared or exclusive locks are granted as required. The same distributed lock manager mechanism is used to orchestrate file system structure locks as well as protocol and advisory locks across the entire cluster. OneFS also provides support for delegated locks (i.e. SMB opportunistic locks and NFSv4 delegations) and also byte-range locks.

### File layout

OneFS is a single file system providing one vast, scalable namespace—free from multiple volume concatenations or single points of failure. As such, all nodes access the same structures across the cluster using the same block addresses and all directories are inode number links emanating from the root inode.

The way data is laid out across the nodes and their respective disks in a cluster is fundamental to OneFS functionality. As mentioned previously, OneFS uses an 8KB block size, and sixteen of these blocks are combined to create a 128KB stripe unit. Files are striped across nodes allowing files to use the resources (spindles and cache) of up to twenty nodes, based on per-file policies.

The layout decisions are made by the BAM on the node that initiated a particular write operation using the 2PC described above. The BAM Safe Write (BSW) code takes the cluster group information from GMP and the desired protection policy for the file and makes an informed decision on where best to write the data blocks to ensure the file is properly protected. To do this, the BSW generates a write plan, which comprises all the steps required to safely write the new data blocks across the protection group. Once complete, the BSW will then execute this write plan and guarantee its successful completion.
All files, inodes and other metadata structures (B-trees, etc.) within OneFS are either mirrored up to eight times or erasure code protected, with the data spread across the various disk cylinder groups of multiple nodes. Erasure code protection uses an N+M scheme with N representing the number of nodes—the stripe width—and M the number of error correcting code (ECC) blocks. This is described in more detail within the 'Flexible Protection' chapter below.

OneFS will not write files at less than the desired protection level, although the BAM will attempt to use an equivalent mirrored layout if there is an insufficient stripe width to support a particular forward error correction (FEC) protection level.

Flexible protection

OneFS is designed to withstand multiple simultaneous component failures (currently four) while still affording unfettered access to the entire file system and dataset. Data protection is implemented at the file system level and, as such, is not dependent on any hardware RAID controllers. This provides many benefits, including the ability to add new data protection schemes as market conditions or hardware attributes and characteristics evolve. Since protection is applied at the file-level, a OneFS software upgrade is all that’s required in order to make new protection and performance schemes available.

OneFS employs the popular Reed-Solomon erasure coding algorithm for its protection calculations. Protection is applied at the file-level, enabling the cluster to recover data quickly and efficiently. Inodes, directories and other metadata are protected at the same or higher level as the data blocks they reference. Since all data, metadata and FEC blocks are striped across multiple nodes, there is no requirement for dedicated parity drives. This both guards against single points of failure and bottlenecks and allows file reconstruction to be a highly parallelized process. Today, OneFS provides +1n through +4n protection levels, providing protection against up to four simultaneous component failures respectively. A single failure can be as little as an individual disk or, at the other end of the spectrum, an entire node.

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

Note: The Isilon 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 all New Generation hardware configurations, the recommended protection level is ‘+2d:1n’.

The hybrid protection schemes are particularly useful for Isilon New Generation chassis and other high density node configurations, where the probability of multiple drives failing far surpasses that of an entire node failure. 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 individual files affected to the cluster’s logs.

OneFS also provides a variety of 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 +1n, its associated metadata object will be 3x mirrored.

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

<table>
<thead>
<tr>
<th>Protection Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1n</td>
<td>Tolerate failure of 1 drive OR 1 node</td>
</tr>
<tr>
<td>+2d:1n</td>
<td>Tolerate failure of 2 drives OR 1 node</td>
</tr>
<tr>
<td>+2n</td>
<td>Tolerate failure of 2 drives OR 2 nodes</td>
</tr>
<tr>
<td>+3d:1n</td>
<td>Tolerate failure of 3 drives OR 1 node</td>
</tr>
<tr>
<td>+3d:1n1d</td>
<td>Tolerate failure of 3 drives OR 1 node AND 1 drive</td>
</tr>
<tr>
<td>+3n</td>
<td>Tolerate failure of 3 drives or 3 nodes</td>
</tr>
</tbody>
</table>
Table 2: OneFS FEC Protection Levels

<table>
<thead>
<tr>
<th>Protection Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+4d:1n</td>
<td>Tolerate failure of 4 drives or 1 node</td>
</tr>
<tr>
<td>+4d:2n</td>
<td>Tolerate failure of 4 drives or 2 nodes</td>
</tr>
<tr>
<td>+4n</td>
<td>Tolerate failure of 4 nodes</td>
</tr>
<tr>
<td>2x to 8x</td>
<td>Mirrored over 2 to 8 nodes, depending on configuration</td>
</tr>
</tbody>
</table>

Striped, distributed metadata coupled with continuous auto-balancing affords OneFS truly linear performance characteristics, regardless of fullness of file system. Both metadata and file data are spread across the entire cluster keeping the cluster balanced at all times.

Please refer to the OneFS Technical Overview white paper for further details on OneFS data protection levels.

Failure domains and resource pools

Data tiering and management in OneFS is handled by Isilon SmartPools software. From a data protection point of view, SmartPools facilitates the subdivision of large numbers of high-capacity, homogeneous nodes into smaller, more Mean Time to Data Loss (MTTDL)-friendly disk pools. For example, an 80-node A2000 cluster would typically run at +3d:1n1d protection level. However, partitioning it into four, twenty node pools would allow each pool to run at +2d:1n, thereby lowering the protection overhead and improving data utilization without any net increase in management overhead.
**Automatic partitioning**

In keeping with the goal of storage management simplicity, OneFS will automatically calculate and partition the cluster into pools of disks or ‘node pools’ which are optimized for both MTTDL and efficient space utilization. This means that protection level decisions, such as the 80-node cluster example above, are not left to the customer—unless desired.

With Automatic Provisioning, every set of equivalent node hardware is automatically divided into node pools comprising up to forty nodes and six drives per node. These node pools are protected by default at +2d:1n, and multiple pools can then be combined into logical tiers and managed using Isilon SmartPools file pool policies. By subdividing a node’s disks into multiple, separately protected pools, nodes are significantly more resilient to multiple disk failures than previously possible.

![SmartPools Automatic Provisioning](image)

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More information is available in the SmartPools white paper.

The new generation of Isilon hardware uses a modular and dense architecture in which four nodes are contained in a single 4RU chassis. This new design enhances the concept of disk pools, node pools, and ‘neighborhoods’ and adds another level of resilience to the OneFS failure domain concept. Each new generation Isilon chassis contains four compute modules (one per node), and five drive containers, or sleds, per node.

![New Generation Isilon Chassis Front View Showing Drive Sleds](image)
Each sled is a tray which slides into the front of the chassis and contains between three and six drives, depending on the configuration of a particular chassis. Disk Pools are the smallest unit within the Storage Pools hierarchy. OneFS provisioning works on the premise of dividing similar nodes’ drives into sets, or disk pools, with each pool representing a separate failure domain. These disk pools are protected by default at +2d:1n (or the ability to withstand two disks or one entire node failure).

Disk pools are laid out across all five sleds in each New Generation node. For example, a node with three drives per sled will have the following disk pool configuration:

![Figure 7: New Generation Disk Pools](image)

Node Pools are groups of Disk Pools, spread across similar Isilon storage nodes (compatibility classes). Multiple groups of different node types can work together in a single, heterogeneous cluster. For example, an Isilon cluster can include one Node Pool of Isilon F800 All-Flash storage nodes for I/Ops-intensive applications, one Node Pool of Isilon Hybrid storage nodes, primarily used for high-concurrent and sequential workloads, and one Node Pool of Isilon Archive storage nodes, primarily used for nearline and/or deep archive workloads.

This allows OneFS to present a single storage resource pool comprising multiple drive media types – SSD, high speed SAS, large capacity SATA, etc. – providing a range of different performance, protection and capacity characteristics. This heterogeneous storage pool in turn can support a diverse range of applications and workload requirements with a single, unified point of management. It also facilitates the mixing of older and newer hardware, allowing for simple investment protection even across product generations, and seamless hardware refreshes.

Each Node Pool only contains disk pools from the same type of storage nodes and a disk pool may belong to exactly one node pool. For example, Isilon F800 all-flash nodes with 1.6TB SSD drives would be in one node pool, whereas Isilon A2000 archive nodes with 10 TB SATA Drives would be in another. Today, a minimum of 4 nodes (one chassis) are required per Node Pool for New Generation hardware, or three previous generation nodes per Node Pool.

OneFS ‘neighborhoods’ are fault domains within a node pool, and their purpose is to improve reliability in general, and guard against data unavailability from the accidental removal of drive sleds. Prior to the Isilon New Generation platform, OneFS had an ideal size of 20 nodes per node pool, and a maximum size of 39 nodes. On the addition of the 40th node, the nodes would split into two neighborhoods of twenty nodes.
With Isilon New Generation hardware, the ideal size of a neighborhood changes from 20 to 10 nodes. This will protect against simultaneous node-pair journal failures and full chassis failures. As such, when a 38 node New Generation cluster is expanded to 40 nodes, the two existing neighborhoods (20 and 18 nodes respectively) will be split into four 10-node neighborhoods:

![Isilon Node Pools Example](image)

**Figure 8: Isilon Node Pools Example**

Overall, a New Generation cluster will have a reliability of at least one order of magnitude greater than previous generation clusters of a similar capacity as a direct result of the following enhancements:

- Mirrored Journals
- Smaller Neighborhoods
- Mirrored Boot Drives

**Manual node pool management**

Once a node pool has been automatically provisioned, additional manual node pools can be created. When complete, the constituent nodes can then be manually reassigned across these node pools, as desired. Manual node pools require a minimum of three nodes in each pool (four for New Generation hardware) and are considered an advanced cluster configuration, since they can have a significant impact on cluster performance.

**Virtual hot spares**

SmartPools also provides a virtual hot spare option, if desired. This functionality allows space to be reserved in a disk pool, equivalent to up to four full drives. This virtual hot spare pool can be immediately utilized for data re-protection in the event of a drive failure.
From a data availability and management point of view, SmartPools also applies storage tiering concepts to disk pools, allowing the storage and movement of data according to rich file policies or attributes. As such, SmartPools facilitates the automated alignment of data with the appropriate class of storage according to its business value, performance profile, and availability requirements. An Isilon cluster can thereby provide multiple storage pools, each supporting a range of availability SLAs within a single, highly scalable and easily managed file system. This resource pool model aligns beautifully with the current IT trend of private and hybrid cloud initiatives.

More information is available in the SmartPools white paper.

**OneFS Fault tolerance**

**File system journal**

Each Isilon node has a battery backed and mirrored file system journal. Each journal is used by OneFS as stable storage, and guards write transactions against sudden power loss or other catastrophic events. The journal protects the consistency of the file system, and, as such, OneFS is therefore fully journaled.

**Proactive device failure**

OneFS will proactively remove, or SmartFail, any drive that reaches a particular threshold of detected Error Correction Code (ECC) errors, and automatically reconstruct the data from that drive and locate it elsewhere on the cluster. Both SmartFail and the subsequent repair process are fully automated and hence require no administrator intervention.

**Isilon data integrity**

Isilon “ISI” Data Integrity (IDI) is the OneFS process that protects file system structures against corruption via 32-bit CRC checksums. All Isilon blocks, both for file and metadata, utilize checksum verification. Metadata checksums are housed in the metadata blocks themselves, whereas file data checksums are stored as metadata, thereby providing referential integrity. All checksums are recomputed by the initiator, the node servicing a particular read, on every request.

In the event that the recomputed checksum does not match the stored checksum, OneFS will generate a system alert, log the event, retrieve and return the corresponding error correcting code (ECC) block to the client and attempt to repair the suspect data block.

**Protocol checksums**

In addition to blocks and metadata, OneFS also provides checksum verification for Remote Block Management (RBM) protocol data. As mentioned above, the RBM is a unicast, RPC-based protocol developed by Isilon for use over the back-end cluster interconnect. Checksums on the RBM protocol are in addition to the hardware checksums provided at the network layer, and are used to detect and isolate machines with certain faulty hardware components and exhibiting other failure states.

**Dynamic sector repair**

OneFS includes a Dynamic Sector Repair (DSR) feature whereby bad disk sectors can be forced by the file system to be rewritten elsewhere. When OneFS fails to read a block during normal operation, DSR is invoked to reconstruct the missing data and write it to either a different location on the drive or to another drive on the node. This is done to ensure that subsequent reads of the block do not fail. DSR is fully automated and completely transparent to the end-user. Disk sector errors and Cyclic Redundancy Check (CRC) mismatches use almost the same mechanism as the drive rebuild process.

**MediaScan**

MediaScan’s role within OneFS is to check disk sectors and deploy the above DSR mechanism in order to force disk drives to fix any sector ECC errors they may encounter. Implemented as one of the phases of the OneFS job engine, MediaScan is run automatically based on a predefined schedule. Designed as a low-impact, background process, MediaScan is fully distributed and can thereby leverage the benefits of Isilon’s unique parallel architecture.
IntegrityScan

IntegrityScan, another component of the OneFS job engine, is responsible for examining the entire file system for inconsistencies. It does this by systematically reading every block and verifying its associated checksum. Unlike traditional ‘fsck’ style file system integrity checking tools, IntegrityScan is designed to run while the cluster is fully operational, thereby removing the need for any downtime. In the event that IntegrityScan detects a checksum mismatch, a system alert is generated and written to the syslog and OneFS automatically attempts to repair the suspect block.

The IntegrityScan phase is run manually if the integrity of the file system is ever in doubt. Although this process may take several days to complete, the file system is online and completely available during this time. Additionally, like all phases of the OneFS job engine, IntegrityScan can be prioritized, paused or stopped, depending on the impact to cluster operations.

Further information is available in the OneFS Job Engine white paper.

Fault isolation

Because OneFS protects its data at the file-level, any inconsistencies or data loss is isolated to the unavailable or failing device—the rest of the file system remains intact and available.

For example, an 8-node node, H500 cluster, protected at +2n:1d, sustains three simultaneous drive failures—one in each of three nodes. Even in this degraded state, I/O errors would only occur on the very small subset of data housed on all three of these drives. The remainder of the data striped across the other two hundred and thirty-seven drives would be totally unaffected. Contrast this behavior with a traditional RAID6 system, where losing more than two drives in a RAID-set will render it unusable and necessitate a full restore from backups.

Similarly, in the unlikely event that a portion of the file system does become corrupt (whether as a result of a software or firmware bug, etc.) or a media error occurs where a section of the disk has failed, only the portion of the file system associated with this area on disk will be affected. All healthy areas will still be available and protected.

As mentioned above, referential checksums of both data and meta-data are used to catch silent data corruption (data corruption not associated with hardware failures). The checksums for file data blocks are stored as metadata, outside the actual blocks they reference, and thus provide referential integrity.

Accelerated drive rebuilds

The time that it takes a storage system to rebuild data from a failed disk drive is crucial to the data reliability of that system. With the advent of multi-terabyte drives, and the creation of increasingly larger single volumes and file systems, typical recovery times for large, multi-terabyte SATA drive failures are becoming multiple days or even weeks. During this MTTDL period, storage systems are vulnerable to additional drive failures and the resulting data loss and downtime.

Since OneFS is built upon a highly distributed architecture, it’s able to leverage the CPU, memory and spindles from multiple nodes to reconstruct data from failed drives in a highly parallel and efficient manner. Because Isilon is not bound by the speed of any particular drive, OneFS is able to recover from drive failures extremely quickly and this efficiency grows relative to cluster size. As such, a failed drive within an Isilon cluster will be rebuilt an order of magnitude faster than hardware RAID-based storage devices. Additionally, OneFS has no requirement for dedicated ‘hot-spare’ drives.

Automatic drive firmware updates

Isilon clusters support automatic drive firmware updates for new and replacement drives, as part of the non-disruptive firmware update process. Firmware updates are delivered via drive support packages, which both simplify and streamline the management of existing and new drives across the cluster. This ensures that drive firmware is up to date and mitigates the likelihood of failures due to known drive issues. As such, automatic drive firmware updates are an important component of Isilon’s high availability and non-disruptive operations strategy. Drive and node firmware can be applied as either a rolling upgrade or via a full cluster reboot.

Prior to OneFS 8.2, node firmware updates had to be installed one node at a time, which was a time consuming operation especially in large clusters. Node firmware updates can now be choreographed across a cluster by providing a list of nodes to be simultaneously updated. The upgrade helper tool can be used to select a desired combination of nodes that can be updated simultaneously and an explicit list of nodes that should not be updated together (for example, nodes in a node-pair).
**Rolling upgrade**

A rolling upgrade individually upgrades and restarts each node in the cluster sequentially. During a rolling upgrade, the cluster remains online and continues serving data to clients with no interruption in service. Prior to OneFS 8.0, a rolling upgrade can only be performed within a OneFS code version family and not between OneFS major code version revisions. From OneFS 8.0 onwards, every new release will be rolling-upgradable from the prior version.

**Non-disruptive Upgrades**

Non-disruptive upgrades (NDUs) allow a cluster administrator to upgrade the storage OS while their end users continue to access data without error or interruption. Updating the operating system on an Isilon cluster is a simple matter of a rolling upgrade. During this process, one node at a time is upgraded to the new code, and the active NFS and SMB3 clients attached to it are automatically migrated to other nodes in the cluster. Partial upgrade is also permitted, whereby a subset of cluster nodes can be upgraded. The subset of nodes may also be grown during the upgrade. Additionally, OneFS 8.2 enables an upgrade to be paused and resumed, allowing customers to span upgrades of large clusters over multiple smaller Maintenance Windows.

**Roll Back Capable**

OneFS 8.0 introduced support for upgrade rollback. This feature provides the ability to return a cluster with an uncommitted upgrade to its previous version of OneFS.

![Figure 9: OneFS Non-Disruptive Upgrade States](image)

**Performing the upgrade**

As part of an upgrade, OneFS automatically runs a pre-install verification check. This verifies that the configuration in your current installation of OneFS is compatible with the version of OneFS that is intended for the upgrade. When an unsupported configuration is found, the upgrade is stopped and instructions on troubleshooting the issue are displayed. Proactively running the pre-installation upgrade check before starting an upgrade helps to avoid any interruption due to incompatible configuration.
Isilon data protection

To effectively protect a file system that is hundreds of terabytes or petabytes in size requires an extensive use of multiple data availability and data protection technologies. As mentioned above, the demand for storage is continuing to grow exponentially and all predictions suggest it will continue to expand at a very aggressive rate for the foreseeable future.

In tandem with this trend, the demand for ways to protect and manage that storage also increases. Today, several strategies for data protection are available and in use. As mentioned earlier, if data protection is perceived as a continuum, at the beginning lies high availability. Without high availability technologies such as drive, network and power redundancy, data loss and its subsequent recovery would be considerably more prevalent.

Historically, data protection was always synonymous with tape backup. However, over the past decade, several technologies like replication, synchronization and snapshots, in addition to disk based backup (such as nearline storage and VTL), have become mainstream and established their place within the data protection realm. Snapshots offer rapid, user-driven restores without the need for administrative assistance, while synchronization and replication provide valuable tools for business continuance and offsite disaster recovery.

High availability and data protection strategies

At the core of every effective data protection strategy lies a solid business continuance plan. All enterprises need an explicitly defined and routinely tested plan to minimize the potential impact to the workflow when a failure occurs or in the event of a natural disaster.

There are a number ways to address data protection and most enterprises adopt a combination of these methods, to varying degrees.

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 versus 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, this is the maximum amount of time that can elapse since the last backup or snapshot was taken.

The Isilon high availability and data protection suite

**Data Protection**—described in detail earlier, at the heart of OneFS is FlexProtect. This unique, software based data protection scheme allows differing levels of protection to be applied in real time down to a per-file granularity, for the entire file system, or at any level in between.

**Redundancy**— as we have seen, Isilon’s clustered architecture is designed from the ground-up to support the following availability goals:

- No single point of failure
- Unparalleled levels of data protection in the industry
- Tolerance for multi-failure scenarios
- Fully distributed single file system
- Pro-active failure detection and pre-emptive, fast drive rebuilds
- Flexible data protection
- Fully journalled file system
- High transient availability
- Non-disruptive upgrades and operations

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The following diagram illustrates how the core components of the Isilon data protection portfolio align with the notion of an availability and protection continuum and associated recovery objectives.

**Figure 10: Isilon Data Protection technology alignment with protection continuum**

Connection load balancing and failover

**SmartConnect**

As mentioned previously, at the leading edge of the data protection continuum lies high availability. This not only includes disk, CPU, and power redundancy, but also network resilience. Isilon SmartConnect software contributes to data availability by supporting dynamic NFS failover and failback for Linux and UNIX clients and SMB3 continuous availability for Windows clients. This ensures that when a node failure occurs, or preventative maintenance is performed, all in-flight reads and writes are handed off to another node in the cluster to finish its operation without any user or application interruption.

During failover, clients are evenly redistributed across all remaining nodes in the cluster, ensuring minimal performance impact. If a node is brought down for any reason, including a failure, the virtual IP addresses on that node is seamlessly migrated to another node in the cluster. When the offline node is brought back online, SmartConnect automatically rebalances the NFS and SMB3 clients across the entire cluster to ensure maximum storage and performance utilization. For periodic system maintenance and software updates, this functionality allows for per-node rolling upgrades affording full-availability throughout the duration of the maintenance window.

To further increase the protection and security of in-flight data, OneFS supports encryption for the SMBv3 protocol version. This can be configured on a per-share, zone, or cluster-wide basis. Only operating systems that support SMB3 encryption can work with encrypted shares. These operating systems can also work with unencrypted shares if the cluster is configured to allow non-encrypted connections. Other operating systems can access non-encrypted shares only if the cluster is configured to allow non-encrypted connections.

OneFS 8.2 also introduces HDFS transparent data encryption TDE for Apache, Cloudera and Hortonworks Hadoop stacks. Encryption is performed on the client side and can use an external key management server. Data written to and read from these HDFS encryption zones can only be accessed over the HDFS protocol.
Snapshots

SnapshotIQ

Next along the high availability and data protection continuum are snapshots. The RTO of a snapshot can be very small and the RPO is also highly flexible with the use of rich policies and schedules. Isilon SnapshotIQ software can take read-only, point-in-time copies of any directory or subdirectory within OneFS.

OneFS Snapshots are highly scalable and typically take less than one second to create. They create little performance overhead, regardless of the level of activity of the file system, the size of the file system, or the size of the directory being copied. Also, only the changed blocks of a file are stored when updating the snapshots, thereby ensuring highly-efficient snapshot storage utilization. User access to the available snapshots is via a /.snapshot hidden directory under each file system directory.

Isilon SnapshotIQ can also create unlimited snapshots on a cluster. This provides a substantial benefit over the majority of other snapshot implementations because the snapshot intervals can be far more granular and hence offer improved RPO time frames.
SnapshotIQ architecture

SnapshotIQ has several fundamental differences as compared to most snapshot implementations. The most significant of these are, first, that OneFS snapshots are per-directory based. This is in contrast to the traditional approach, where snapshots are taken at a file system or volume boundary. Second, since OneFS manages and protects data at the file-level, there is no inherent, block-level indirection layer for snapshots to use. Instead, OneFS takes copies of files, or pieces of files (logical blocks and inodes) in what’s termed a logical snapshot process.

The process of taking a snapshot in OneFS is relatively instantaneous. However, there is a small amount of snapshot preparation work that has to occur. First, the coalescer is paused and any existing write caches flushed in order for the file system to be quiesced for a short period of time. Next, a marker is placed at the top-level directory inode for a particular snapshot and a unique snapshot ID is assigned. Once this has occurred, the coalescer resumes and writes continue as normal. Therefore, the moment a snapshot is taken, it essentially consumes zero space until file creates, delete, modifies and truncates start occurring in the structure underneath the marked top-level directory.

Any changes to a dataset are then recorded in the pertinent snapshot inodes, which contain only referral (‘ditto’) records, until any of the logical blocks they reference are altered or another snapshot is taken. In order to reconstruct data from a particular snapshot, OneFS will iterate though all of the more recent versions snapshot tracking files (STFs) until it reaches HEAD (current version). In so doing, it will systematically find all the changes and ‘paint’ the point-in-time view of that dataset.

OneFS uses both Copy on Write (CoW) and Redirect on Write (RoW) strategies for its differential snapshots and utilizes the most appropriate method for any given situation. Both have advantages and disadvantages and OneFS dynamically picks which flavor to use in order to maximize performance and keep overhead to a minimum. Typically, CoW is most prevalent, and is primarily used for small changes, inodes and directories. RoW, on the other hand, is adopted for more substantial changes such as deletes and large sequential writes.

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. A snapshot reserve can be configured if preferred, although this will be an accounting reservation rather than a hard limit. Additionally, when using Isilon SmartPools, snapshots can be stored on a different disk tier than the one the original data resides on. For example, the snapshots taken on a performance aligned tier can be physically housed on a more cost effective archive tier.
Snapshot Change Tracking

Snapshot schedules

Snapshot scheduling are configured at a daily, weekly, monthly or yearly interval, with single or multiple job frequency per schedule, down to a per-minute granularity. And automatic deletion can be configured per defined schedule at an hourly through yearly range.

Snapshot deletes

When snapshots are manually deleted, OneFS will mark the appropriate snapshot IDs and queue a job engine job to affect their removal. The SnapshotDelete job is queued immediately but the job engine will typically wait a minute or so to actually start running it. During this interval, the snapshot will be marked as ‘delete pending’.

A similar procedure occurs with expired snapshots. Here, the snapshot daemon is responsible for checking expiration of snapshots and marking them for deletion. The daemon performs the check every 10-seconds. The job is then queued to delete a snapshot completely and then it is up to the job engine to schedule it. The job might run immediately (after a min or so of wait) if the job engine determines that the job is runnable and there are no other jobs with higher priority running at the moment. For SnapshotDelete, it is only run if the group is in a pristine state, i.e., no drives/nodes are down.

The most efficient method for deleting multiple snapshots simultaneously is to process older through newer, and SnapshotIQ will automatically attempt to orchestrate deletes in this manner. A SnapshotDelete job engine schedule can also be defined so snapshot deletes only occur during desired times.

In summary, SnapshotIQ affords the following benefits:
• Snapshots are created 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.
• Integration with Windows Volume Snapshot Manager allows Windows clients a method to restore from “Previous Versions”
• Snapshots are easily managed using flexible policies and schedules.
• Using SmartPools, snapshots can physically reside on a different disk tier than the original data.
• Up to 1,024 snapshots can be created per directory.
• The default snapshot limit is 20,000 per cluster.

Snapshot restore
For simple, efficient snapshot restoration, SnapshotIQ provides SnapRevert functionality. Using the Job Engine for scheduling, a SnapRevert job automates the restoration of an entire snapshot to its top level directory. This is invaluable for quickly and efficiently reverting to a previous, known-good recovery point, for example in the event of virus or malware outbreak. Additionally, individual files, rather than entire snapshots, can also be restored in place using FileRevert functionality. This can help drastically simplify virtual machine management and recovery.

Further information is available in the OneFS SnapshotIQ white paper.

File clones
OneFS File Clones provides a rapid, efficient method for provisioning multiple read/write copies of files. Common blocks are shared between the original file and clone, providing space efficiency and offering similar performance and protection levels across both. This mechanism is ideal for the rapid provisioning and protection of virtual machine files and is integrated with VMware's linked cloning and block and file storage APIs. This utilizes the OneFS shadow store metadata structure, which is able to reference physical blocks, references to physical blocks, and nested references to physical blocks.

Figure 14: File Clones
SmartDedupe

Shadow stores also provide the basis for Isilon SmartDedupe software. 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 means that initial file write or modify performance is not impacted, since no additional computation is required in the write path.

![Figure 15: Isilon Storage Efficiency with SmartDedupe](image)

When SmartDedupe runs for the first time, it scans the data set and selectively samples blocks from it, creating the fingerprint index. The index is scanned for duplicates and, when a match is found, a byte-by-byte comparison of the blocks is performed to verify that they are absolutely identical and to ensure there are no hash collisions. Then, if they are determined to be identical, duplicate blocks are removed from the actual files and replaced with pointers to the shadow stores.

Further information is available in the OneFS SmartDedupe white paper.

Small File Storage Efficiency

Another principle consumer of shadow stores is OneFS Small File Storage Efficiency. Introduced in OneFS 8.0.1, this feature maximizes the space utilization of a cluster by decreasing the amount of physical storage required to house the small files that often comprise an archive dataset, such as found in healthcare PACS workflows.

Efficiency is achieved by scanning the on-disk data for small files, which are protected by full copy mirrors, and packing them in shadow stores. These shadow stores are then parity protected, rather than mirrored, and typically provide storage efficiency of 80% or greater.
Small File Storage Efficiency trades a small read latency performance penalty for improved storage utilization. The archived files obviously remain writable, but when containerized files with shadow references are deleted, truncated or overwritten it can leave unreferenced blocks in shadow stores. These blocks are later freed and can result in holes which reduces the storage efficiency.

The actual efficiency loss depends on the protection level layout used by the shadow store. Smaller protection group sizes are more susceptible, as are containerized files, since all the blocks in containers have at most one referring file and the packed sizes (file size) are small.

In OneFS 8.2, a deframenter is added to reduce the fragmentation of files as a result of overwrites and deletes. This shadow store defragmenter is integrated into the ShadowStoreDelete job. The defragmentation process works by dividing each containerized file into logical chunks (~32MB each) and assess each chunk for fragmentation.

If the storage efficiency of a fragmented chunk is below target, that chunk is processed by evacuating the data to another location. The default target efficiency is 90% of the maximum storage efficiency available with the protection level used by the shadow store. Larger protection group sizes can tolerate a higher level of fragmentation before the storage efficiency drops below this threshold.

In-line Data Reduction

Isilon in-line data reduction is introduced in the OneFS 8.2.1 release exclusively on the F810 all-flash platform. The OneFS architecture is comprised of the following principle 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 comprises 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 dedupe, and then compression. This order allows each phase to reduce the scope of work each subsequent phase.

![Diagram: In-line data reduction workflow.](image)

**Figure 17: In-line data reduction workflow.**

The F810 includes a compression off-load capability, with each node in an F810 chassis containing a Mellanox Innova-2 Flex Adapter. This means that compression and decompression are transparently performed by the Mellanox adapter with minimal latency, thereby avoiding 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 128KB, with each chunk comprising sixteen 8KB data blocks. This is optimal since it is also the same size that OneFS uses for its data protection stripe units, providing simplicity and efficiency, by avoiding the overhead of additional chunk packing.

![Diagram: Compression chunks and OneFS transparent overlay.](image)

**Figure 18: Compression chunks and OneFS transparent overlay.**

Consider the diagram above. After compression, this chunk is reduced from sixteen to six 8KB blocks in size. This means that this chunk is now physically 48KB 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 128KB in size, regardless of its actual physical size.

Efficiency savings must be at least 8KB (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 16KB that yields 8KB (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 de-compress or recompress data to change protection levels, perform recovered writes, or otherwise shift protection-group boundaries.

**Replication**

**SyncIQ**

While snapshots provide an ideal solution for infrequent or smaller-scale data loss occurrences, when it comes to catastrophic failures or natural disasters, a second, geographically separate copy of a dataset is clearly beneficial. Here, a solution is required that is significantly faster and less error-prone than a recovery from tape, yet still protects the data from localized failure.
Isilon SyncIQ software 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 and includes policy level bandwidth control and reservation. This allows replication over both short and long distances, while meeting consistent SLAs and providing protection from both site-specific and regional disasters. Additionally, SyncIQ utilizes 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 data sets.

There are two basic implementations of SyncIQ:

- The first is utilizing SyncIQ to replicate to a local target cluster within a datacenter. The primary use case in this scenario is disk backup and business continuance.
- The second implementation uses SyncIQ to replicate to a remote target cluster, typically located in a geographically separate datacenter across a WAN link. Here, replication is typically utilized for offsite disaster recovery purposes.

In either case, a secondary cluster synchronized with the primary production cluster can afford a substantially improved RTO and RPO than tape backup and 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-, directory- or entire file system-level and can either be scheduled to run at regular intervals or executed manually.

SyncIQ supports up to one thousand defined policies, of which up to fifty may run concurrently. 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.

To ensure the security of replicated data in-flight, OneFS 8.2 introduces SyncIQ encryption. X.509 Transport Layer Security (TLS) certificates used by the nodes in the replicating clusters are managed via the SyncIQ certificate store. SyncIQ encryption can be configured either per-policy or globally.
SyncIQ linear restore

Leveraging OneFS SnapshotIQ infrastructure, the Linear Restore functionality of SyncIQ is able to detect and restore (commit) consistent, point in time, block-level changes between cluster replication sets, with a minimal impact on operations and a granular RPO. This ‘change set’ information is stored in a mirrored database on both source and target clusters and is updated during each incremental replication job, enabling rapid failover and failback RTOs.

![SNAPSHOT CHANGES](image)

**Figure 20: The SyncIQ Linear Restore Change Commit Mechanism**

SyncIQ replica protection

All writes outside of the synchronization process itself are disabled on any directory that is a target for a specific SyncIQ job. However, if the association is broken between a target and a source, the target may then return to a writable state. Subsequent resolution of a broken association will force a full resynchronization to occur at the next job run. As such, restricted writes prevent modification, creation, deletion, linking or movement of any files within the target path of a SyncIQ job. Therefore, replicated disaster recovery (DR) data is protected within and by its SyncIQ container or restricted-writer domain, until a conscious decision is made to bring it into a writeable state.

SyncIQ failover and failback

In the event that a primary cluster becomes unavailable, SyncIQ provides the ability to failover to a mirrored, DR cluster. During such a scenario, the administrator makes the decision to redirect client I/O to the mirror and initiates SyncIQ failover on the DR cluster. Users will continue to read and write to the DR cluster while the primary cluster is repaired.
Once the primary cluster becomes available again, the administrator may decide to revert client I/O back to it. To achieve this, the administrator initiates a SyncIQ failback prep process which synchronizes any incremental changes made to the DR cluster back to the primary.

Failback is divided into three distinct phases:

1. First, the prep phase readies the primary to receive changes from the DR cluster by setting up a restricted writer domain and then restoring the last known good snapshot.
2. Next, upon successful completion of failback prep, a final failback differential sync is performed.
3. Lastly, the administrator commits the failback, which restores the primary cluster back to its role as the source and relegates the DR cluster back to a target again.

In addition to the obvious unplanned failover and failback, SyncIQ also supports controlled, proactive cluster failover and failback. This provides two major benefits:

- The ability to validate and test DR procedures and requirements
- Performing planned cluster maintenance.

![Figure 21: SyncIQ Automated Data Failover and Failback](image)

**Note:** In OneFS 8.0.1 and later, SyncIQ data failover and failback is fully supported for both enterprise and compliance SmartLock WORM datasets.

**Continuous replication mode**

Complementary to the manual and scheduled replication policies, SyncIQ also offers a continuous mode, or replicate on change, option. When the "Whenever the source is modified" policy configuration option is selected, SyncIQ will continuously monitor the replication data set (sync domain) and automatically replicate and changes to the target cluster. Events that trigger replication include file additions, modifications and deletions, directory path, and metadata changes. Additionally, include and exclude rules can also be applied to the policy, providing a further level of administrative control.
Archiving and data security

As we have seen, Isilon SyncIQ software (described above) enables the simple creation of a secure remote archive.

SmartPools

Isilon SmartPools software enables the segregation of data according to its business value, aligning it with the appropriate class of storage and levels of performance and protection. Data movement is seamless, and with file-level granularity and control via automated policies, manual control, or API interface, you can tune performance and layout, storage tier alignment, and protection settings – all with minimal impact to end-users.
SmartPools facilitates the creation and management of a dedicated local archive pool within a cluster for data retention and high availability purposes.

CloudPools

Isilon CloudPools software provides a cloud storage tiering capability which is built on the SmartPools data management framework. CloudPools enables data to be stored in a cold or frozen data tier or archive, thereby taking advantage of lower-cost, off-premise storage.

File pool policies define which old or unused data on a cluster should be archived to the cloud. The supported cloud storage options include Amazon S3, Microsoft Azure, Google Cloud, Dell EMC ECS, Virtustream, and Isilon to Isilon via the OneFS RAN (RESTful access to namespace API). CloudPools automatically optimizes and protects the transfer of data to cloud storage with the use of both encryption and compression.

Although file data is moved to remote storage, the files remain visible in the OneFS file system. CloudPools accomplishes this by retaining a local SmartLink (or stub) file, which is a pointer to the location of data in the cloud. CloudPools is also integrated with the other OneFS storage management and protection services including SnapshotIQ, SyncIQ replication, SmartQuotas, NDMP backup, etc.

SmartLock

OneFS utilizes Isilon SmartLock software to provide immutable storage for data. Based on a write once, read many (WORM) locking capability, SmartLock ensures tamper-proof archiving of critical data sets for disaster recovery and regulatory compliance purposes. Configured at the directory-level, SmartLock delivers simple to manage secure data containers that remain locked for a configurable duration or indefinitely. Additionally, SmartLock satisfies the regulatory compliance demands of stringent data retention policies, including SEC 17a-4.
Data Encryption at Rest

Isilon also provides a solution for the security of data at rest. This involves dedicated storage nodes containing self-encrypting drives (SEDs), in combination with an encryption key management system embedded within OneFS. Data is encrypted on disk using the AES-256 cipher, and each SED has a unique data encryption key (DEK) which is used to encrypt and decrypt data as it's read from and written to disk. OneFS automatically generates an authentication key (AK) that wraps and secures the DEK. This means that the data on any SED which is removed from its source node cannot be unlocked and read, thereby guarding against the data security risks of physical drive theft.

The Isilon Data Encryption at Rest solution also allows SED drives to be securely wiped before being re-purposed or retired, via cryptographic erasure. Cryptographic erasure involves ‘shredding’ the encryption keys to wipe data, and can be done in a matter of seconds. To achieve this, OneFS irreversibly overwrites the vendor-provided password, or MSID, on each drive, resulting in all the on-disk data being scrambled.

Isilon encryption of data at rest satisfies a number of industries’ regulatory compliance requirements, including U.S. Federal FIPS 140-2 Level 2 and PCI-DSS v2.0 section 3.4.

Audit

Isilon Audit can detect potential sources of data loss, fraud, inappropriate entitlements, access attempts that should not occur, and a range of other anomalies that are indicators of risk. This can be especially useful when the audit associates data access with specific user identities.

In the interests of data security, OneFS provides ‘chain of custody’ auditing by logging specific activity on the cluster. This includes OneFS configuration changes plus NFS, SMB, and HDFS client protocol activity, which are required for organizational IT security compliance, as mandated by regulatory bodies like HiPAA, SOX, FISMA, MPAA, etc.

OneFS auditing uses Dell EMC’s Common Event Enabler (CEE) to provide compatibility with external, 3rd party audit applications like Varonis DatAdvantage. With OneFS 8.0.1 and later, a cluster can write audit events across up to five CEE servers per node in a parallel, load-balanced configuration. This allows Isilon to deliver an end to end, enterprise grade audit solution.

OneFS Hardening

Isilon 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.

File Filtering

OneFS file filtering can be used across NFS and SMB clients to allow or disallow writes to an export, share, or access zone. This feature prevents certain types of file extensions to be blocked, for files which might cause security problems, productivity disruptions, throughput issues or storage clutter. Configuration can be either via a blacklist, which blocks explicit file extensions, or a white list, which explicitly allows writes of only certain file types.

Nearline, VTL and tape backup

At the trailing end of the protection continuum lies traditional backup and restore—whether to tape or disk. This is the bastion of any data protection strategy and usually forms the crux of a ‘data insurance policy’. With high RPO and RTOs, often involving a retrieval of tapes from secure, offsite storage, tape backup is typically the mechanism of last resort for data recovery in the face of a disaster.

Backup Accelerator

Isilon provides the ability to perform large-scale backup and restore functions across massive, single-volume data sets—while leveraging an enterprise’s existing, SAN-based tape and VTL infrastructure. This is enabled by the Isilon A100 Backup Accelerator (BA) node, which features a quad-port 4GB/s Fibre Channel card, quad-core processors, and 8GB of RAM.
A single Isilon A100 Backup Accelerator can concurrently stream backups at 480MB/s, or 1.7TB/hour, across its four Fibre Channel ports. Additionally, as data grows, multiple Backup Accelerator nodes can be added to a single cluster to support a wide range of RPO/RTO windows, throughput requirements and backup devices.

OneFS 8.2 also introduces support for a combination 10Gb Ethernet and Fibre Channel PCI card, which allows Gen 6 nodes with an ethernet backend to perform 2-way NDMP by directly connecting to SAN attached tape library or VTL.

Backup from snapshots

In addition to the benefits provided by SnapshotIQ in terms of user recovery of lost or corrupted files, it also offers a powerful way to perform backups while minimizing the impact on the file system.

Initiating backups from snapshots affords several substantial benefits. The most significant of these is that the file system does not need to be quiesced, since the backup is taken directly from the read-only snapshot. This eliminates lock contention issues around open files and allows users full access to data throughout the duration of the backup job.

SnapshotIQ also automatically creates an alias which points to the latest version of each snapshot on the cluster, which facilitates the backup process by allowing the backup to always refer to that alias. Since a snapshot is, by definition, a point-in-time (PIT) copy, by backing up from a snapshot, the consistency of the file system or sub-directory is maintained.

This process can be further streamlined by using the Network Data Management Protocol (NDMP) snapshot capability to create a snapshot as part of the backup job, then delete it upon successful completion of the backup.

Parallel streams

Isilon’s distributed architecture allows backups to be spread across multiple network streams from the cluster, which can significantly improve performance. This is achieved by dividing the root file system into several paths based on the number of nodes in the cluster and the structure of sub-directories under the file system root. For example, if the file system on a four-node cluster can be segregated logically among four sub-directories, each of these sub-directories can be backed up as a separate stream, one served from each node.

Figure 24: Backup Using SnapshotIQ
OneFS also includes multi-stream NDMP backup. In this case, a backup job can be configured against a top level directory, and a separate NDMP stream will be used to back up each subdirectory in parallel. This drastically increases the throughput of backups and simplicity of configuration, thereby allowing fast job completion and the ability to define tighter recovery objectives. Parallel NDMP is supported by both Dell EMC Networker and Commvault Simpana DMAs.

NDMP

OneFS facilitates performant backup and restore functionality via its support of the ubiquitous Network Data Management Protocol (NDMP). NDMP is an open-standard protocol that provides interoperability with leading data-backup products and Isilon supports both NDMP versions 3 and 4. OneFS also provides support for both direct NDMP (referred to as 2-way NDMP), and remote NDMP (referred to as 3-way NDMP) topologies.

The OneFS NDMP module includes the following functionality:

- Full and incremental backups and restores using NDMP
- Direct Access Restore/Directory Direct Access Restore (DAR/DDAR), single-file restores, and three-way backups
- Restore-to-arbitrary systems
- Seamless integration with access control lists (ACLs), alternate data streams and resource forks
- Selective File Recovery
- Replicate then backup
- Multi-stream NDMP backup

While some backup software vendors may support backing up OneFS over SMB and NFS, the advantages of using NDMP include:

- Increased performance
- Retention of file attributes and security and access controls
- Backups utilize automatically generated snapshots for point-in-time consistency.
- Redirector automatically distributes 2-way NDMP local backup or restore operations to nodes with less load.
- Throttler manages CPU usage of backup, ensuring that NDMP operations do not overwhelm any nodes.
- Extensive support by backup software vendors
- Integration with CloudPools, allowing backup of Smartlinked files as regular files or stubs (with or without data).

Direct NDMP model

This is the most efficient model and results in the fastest transfer rates. Here, the data management application (DMA) uses NDMP over the Ethernet front-end network to communicate with the Isilon cluster. On instruction, the cluster, which is also the NDMP tape server, begins backing up data to one or more tape devices which are attached to it via Fibre Channel.

The DMA, a separate server, controls the tape library’s media management. File History, the information about files and directories, is transferred from the cluster via NDMP to the DMA, where it is maintained in a catalog.

Direct NDMP is the fastest and most efficient model for backups with OneFS and requires a pool of Gen6 nodes with Fibre Channel connectors to be present within a cluster.
Remote NDMP model

In the remote NDMP scenario, there are no fibre channel connectors present in the Isilon cluster. Instead, the DMA uses NDMP over the LAN to instruct the cluster to start backing up data to the tape server - either connected via Ethernet or directly attached to the DMA host. In this model, the DMA also acts as the Backup/Media Server.

During the backup, file history is transferred from the cluster via NDMP over the LAN to the backup server, where it is maintained in a catalog. In some cases, the backup application and the tape server software both reside on the same physical machine.

OneFS remote NDMP backup also includes intelligent IP selection functionality. This enables backup applications like Avamar and Commvault to select the most desirable interfaces and preferred network for NDMP traffic.

Incremental backup

Isilon OneFS accommodates the range of full, incremental and token-based backups. In standard DR nomenclature, Level 0 indicates a full backup, and levels 1-9 are incrementals. Any level specified as 1-9 will back up all the files that have been modified since the previous lower level backup.
Token-based incremental backups are also supported. These are achieved by configuring the data management application (DMA) to maintain a timestamp database and to pass the reference time token on to the cluster for use during each incremental backup. This method does not rely on level based incremental backups, as described above, at all.

**Direct access recovery**

OneFS provides full supports for Direct Access Recovery (DAR). Direct Access Recovery allows the NDMP server to go directly to the location of a file within an archive and quickly recover that file. As such, it eliminates the need to scan through vast quantities of data typically spread across multiple tapes in an archive set, in order to recover a single file. This capability uses the offset information that is contained in the file history data passed to the DMA at backup time.

**Directory DAR**

Isilon OneFS NDMP also supports Directory DAR (DDAR), an extension of DAR. DDAR allows the NDMP server to go directly to the location of a directory within an archive and quickly recover all files/directories contained within the directory tree hierarchy. Clearly, both DAR and DDAR provide an improved RTO for smaller scale data recovery from tape.

OneFS NDMP offers Selective File Recovery—the ability to recovering a subset of files within a backup archive. Also supported is the ability to restore to alternate path locations.

**Certified backup applications**

Isilon OneFS is certified with a wide range of leading enterprise backup applications, including:

- Symantec NetBackup and Backup Exec
- Dell EMC Avamar and Networker
- IBM Tivoli Storage Manager
- CommVault Simpana
- Quest NetVault
- ASG Time Navigator

OneFS is also certified to work with the Dell EMC Cloud Tiering Appliance to simplify data migration and with Dell EMC DataDomain appliance products for deduplicated backup and archiving.

† OneFS 8.2 includes sparse file support when using Isilon as a back target with Commvault Simpana V11 SP10 or later, providing considerable space efficiency improvements.

▷ Further information is available in the [OneFS Backup and Recovery](#) guide.

**Summary**

Organizations of all sizes around the globe are dealing with a deluge of digital content and unstructured data that is driving massive increases in storage needs. As these enterprise datasets continue to expand to unprecedented sizes, data protection has never been more crucial. A new approach is needed to meet the availability, protection and performance requirements of this era of ‘big data’.

Isilon enables organizations to linearly scale capacity and performance within a single file system—one which is both simple to manage and highly available and redundant, as we have seen. Built on commodity hardware and powered by the revolutionary OneFS distributed file system, Isilon scale-out NAS solutions deliver the following key tenets:

- Unparalleled levels of data protection
- No single point of failure
- Fully distributed single file system
- Industry leading tolerance for multi-failure scenarios
- Pro-active failure detection and pre-emptive, fast drive rebuilds
- Flexible, file-level data protection
- Fully journalled file system
- Extreme transient availability

**Isilon acronyms glossary**

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>BAM</td>
<td>Block Allocation Manager</td>
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<tr>
<td>BAT</td>
<td>Block Allocation Type</td>
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<tr>
<td>BH</td>
<td>Block History</td>
</tr>
<tr>
<td>BSD</td>
<td>Berkeley Software Distribution UNIX</td>
</tr>
<tr>
<td>BSW</td>
<td>BAM Safe Write</td>
</tr>
<tr>
<td>CIFS</td>
<td>Common Internet File System</td>
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<tr>
<td>CoW</td>
<td>Copy on Write Snapshot</td>
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<tr>
<td>DFM</td>
<td>Directory Format Manager</td>
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<tr>
<td>DSR</td>
<td>Dynamic Sector Repair</td>
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<tr>
<td>DWT</td>
<td>Device Worker Thread</td>
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<tr>
<td>FEC</td>
<td>Forward Error Correction</td>
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<td>IDI</td>
<td>Isilon Data Integrity</td>
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<td>IFM</td>
<td>Inode Format Manager</td>
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<tr>
<td>IMDD</td>
<td>Isilon Mirrored Device Driver</td>
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<tr>
<td>LACP</td>
<td>Link Aggregation Control Protocol</td>
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<tr>
<td>LAGG</td>
<td>Link Aggregation</td>
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<td>LBM</td>
<td>Local Block Manager</td>
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<tr>
<td>LIN</td>
<td>Logical Inode</td>
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<tr>
<td>MDS</td>
<td>Mirrored Data Structure</td>
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<tr>
<td>NFS</td>
<td>Network File System</td>
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<tr>
<td>PIT</td>
<td>Point in Time Snapshot</td>
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<tr>
<td>POSIX</td>
<td>Portable Operating System Interface for UNIX</td>
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<td>RBM</td>
<td>Remote Block Manager</td>
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<td>RoW</td>
<td>Redirect on Write Snapshot</td>
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<tr>
<td>SDP</td>
<td>Sockets Direct Protocol</td>
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<tr>
<td>SMB</td>
<td>Server Message Block</td>
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<td>TXN</td>
<td>Transaction Code</td>
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<td>VFS</td>
<td>Virtual File System</td>
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<tr>
<td>VOPs</td>
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Version history

Author: Nick Trimbee

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TAKE THE NEXT STEP

Contact your Dell EMC sales representative or authorized reseller to learn more about how Isilon scale-out NAS storage solutions can benefit your organization.

Shop Dell EMC Isilon to compare features and get more information.

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