NetApp

VMware vSphere with ONTAP Best Practices

NetApp Solutions

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TR-4597: VMware vSphere for ONTAP

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NetApp ONTAP software has been a leading storage solution for VMware vSphere environments for almost two decades and continues to add innovative capabilities to simplify management while reducing costs. This document introduces the ONTAP solution for vSphere, including the latest product information and best practices, to streamline deployment, reduce risk, and simplify management.

Best practices supplement other documents such as guides and compatibility lists. They are developed based on lab testing and extensive field experience by NetApp engineers and customers. They might not be the only supported practices that work in every environment, but they are generally the simplest solutions that meet the needs of most customers.

This document is focused on capabilities in recent releases of ONTAP (9.x) running on vSphere 6.0 or later. See the section ONTAP and vSphere release-specific information for details related to specific releases.

Why ONTAP for vSphere?

There are many reasons why tens of thousands of customers have selected ONTAP as their storage solution for vSphere, such as a unified storage system supporting both SAN and NAS protocols, robust data protection capabilities using space-efficient NetApp Snapshot copies, and a wealth of tools to help you manage application data. Using a storage system separate from the hypervisor allows you to offload many functions and maximize your investment in vSphere host systems. This approach not only makes sure your host resources are focused on application workloads, but it also avoids random performance effects on applications from storage operations.

Using ONTAP together with vSphere is a great combination that lets you reduce host hardware and VMware software expenses. You can also protect your data at lower cost with consistent high performance. Because virtualized workloads are mobile, you can explore different approaches using Storage vMotion to move VMs across VMFS, NFS, or vVols datastores, all on the same storage system.

Here are key factors customers value today:

- **Unified storage.** Systems running ONTAP software are unified in several significant ways. Originally this approach referred to both NAS and SAN protocols, and ONTAP continues to be a leading platform for SAN along with its original strength in NAS. In the vSphere world, this approach could also mean a unified system for virtual desktop infrastructure (VDI) together with virtual server infrastructure (VSI). Systems running ONTAP software are typically less expensive for VSI than traditional enterprise arrays and yet have advanced storage efficiency capabilities to handle VDI in the same system. ONTAP also unifies a variety of storage media, from SSDs to SATA, and can extend that easily into the cloud. There's no need to buy one flash array for performance, a SATA array for archives, and separate systems for the cloud. ONTAP ties them all together.

- **Virtual volumes and storage policy-based management.** NetApp was an early design partner with VMware in the development of vSphere Virtual Volumes (vVols), providing architectural input and early support for vVols and VMware vSphere APIs for Storage Awareness (VASA). Not only did this approach bring granular VM storage management to VMFS, it also supported automation of storage provisioning through storage policy-based management. This approach allows storage architects to design storage pools with different capabilities that can be easily consumed by VM administrators. ONTAP leads the storage industry in vVol scale, supporting hundreds of thousands of vVols in a single cluster, whereas enterprise array and smaller flash array vendors support as few as several thousand vVols per array. NetApp is also driving the evolution of granular VM management with upcoming capabilities in support of vVols 3.0.

- **Storage efficiency.** Although NetApp was the first to deliver deduplication for production workloads, this innovation wasn't the first or last one in this area. It started with ONTAP Snapshot copies, a space-efficient data protection mechanism with no performance effect, along with FlexClone technology to instantly make read/write copies of VMs for production and backup use. NetApp went on to deliver inline capabilities, including deduplication, compression, and zero-block deduplication, to squeeze out the most storage from expensive SSDs. Most recently, ONTAP added the ability to pack smaller I/O operations and files into a disk block using compaction. The combination of these capabilities has resulted in customers seeing savings of up to 5:1 for VSI and up to 30:1 for VDI.

- **Hybrid cloud.** Whether used for on-premises private cloud, public cloud infrastructure, or a hybrid cloud that combines the best of both, ONTAP solutions help you build your data fabric to streamline and optimize data management. Start with high-performance all-flash systems, then couple them with either disk or cloud storage systems for data protection and cloud compute. Choose from Azure, AWS, IBM, or Google clouds to optimize costs and avoid lock-in. Leverage advanced support for OpenStack and container technologies as needed. NetApp also offers cloud-based backup (SnapMirror Cloud, Cloud Backup Service, and Cloud Sync) and storage tiering and archiving tools (FabricPool) for ONTAP to help reduce operating expenses and leverage the broad reach of the cloud.

- **And more.** Take advantage of the extreme performance of NetApp AFF A-Series arrays to accelerate your virtualized infrastructure while managing costs. Enjoy completely nondisruptive operations, from maintenance to upgrades to complete replacement of your storage system, using scale-out ONTAP clusters. Protect data at rest with NetApp encryption capabilities at no additional cost. Make sure performance meets business service levels through fine-grained quality of service capabilities. They are all part of the broad range of capabilities that come with ONTAP, the industry's leading enterprise data management software.

ONTAP capabilities for vSphere

Protocols

ONTAP supports all major storage protocols used for virtualization, such as iSCSI, Fibre Channel (FC), Fibre Channel over Ethernet (FCoE), or Non-Volatile Memory Express over Fibre Channel (NVMe/FC) for SAN environments, as well as NFS (v3 and v4.1), and SMB or S3 for guest connections. Customers are free to pick what works best for their environment and can combine protocols as needed on a single system (for example, augmenting general use of NFS datastores with a few iSCSI LUNs or guest shares).

Features

There are many ONTAP features that are useful for managing virtualized workloads. Some that require additional product licenses are described in the next section. Others packaged as standalone tools, some for ONTAP and others for the entire NetApp portfolio, are described after that.

Here are further details about base ONTAP features:

- **NetApp Snapshot copies.** ONTAP offers instant Snapshot copies of a VM or datastore with zero performance effect when you create or use a Snapshot copy. They can be used to create a restoration point for a VM prior to patching or for simple data protection. Note that these are different from VMware (consistency) snapshots. The easiest way to make an ONTAP Snapshot copy is to use the SnapCenter Plug-In for VMware vSphere to back up VMs and datastores.

- **Storage efficiency.** ONTAP supports inline and background deduplication and compression, zero-block deduplication, and data compaction.

- **Volume and LUN move.** Allows nondisruptive movement of volumes and LUNs supporting vSphere datastores and vVols within the ONTAP cluster to balance performance and capacity or support

nondisruptive maintenance and upgrades.

- **QoS.** QoS allows for managing performance on an individual LUN, volume, or file. This function can be used to limit an unknown or bully VM or to make sure an important VM gets sufficient performance resources.

- **NetApp Volume Encryption, NetApp Aggregate Encryption.** NetApp encryption options offer easy software-based encryption to protect data at rest.

- **FabricPool.** This feature tiers colder data automatically at the block level to a separate object store, freeing up expensive flash storage.

- **REST, Ansible.** Use ONTAP REST APIs to automate storage and data management, and Ansible modules for configuration management of your ONTAP systems.Note that some ONTAP features are not well-suited for vSphere workloads. For example, FlexGroup prior to ONTAP 9.8 did not have full cloning support and was not tested with vSphere (see the FlexGroup section for the latest on using it with vSphere). FlexCache is also not optimal for vSphere as it is designed for read-mostly workloads. Writes can be problematic when the cache is disconnected from the origin, resulting in NFS datastore errors on both sides.

ONTAP licensing

Some ONTAP features that are valuable for managing virtualized workloads require an additional license, whether available at no additional cost, in a license bundle, or a la carte. For many customers, the most cost-effective approach is with a license bundle. Here are the key licenses relevant to vSphere and how they are used:

- **FlexClone.** FlexClone enables instant, space-efficient clones of ONTAP volumes and files. This cloning is used when operations are offloaded to the storage system by VMware vSphere Storage APIs – Array Integration (VAAI), for backup verification and recovery (SnapCenter software), and for vVols cloning and Snapshot copies. Here is how they are used:

  - VAAI is supported with ONTAP for offloaded copy in support of vSphere clone and migration (Storage vMotion) operations. The FlexClone license allows for fast clones within a NetApp FlexVol volume, but, if not licensed, it still allows clones using slower block copies.

  - A FlexClone license is required for vVols functionality. It enables cloning of vVols within a single datastore or between datastores, and it enables vSphere-managed Snapshot copies of vVols, which are offloaded to the storage system.

- The storage replication adapter (SRA) is used with VMware Site Recovery Manager, and a FlexClone license is required to test recovery in both NAS and SAN environments. SRA may be used without FlexClone for discovery, recovery, and reprotection workflows.

- **SnapRestore.** SnapRestore technology enables instant recovery of a volume in place without copying data. It is required by NetApp backup and recovery tools such as SnapCenter where it is used to mount the datastore for verification and restore operations.

- **SnapMirror.** SnapMirror technology allows for simple, fast replication of data between ONTAP systems on-premises and in the cloud. SnapMirror supports the version flexibility of logical replication with the performance of block replication, sending only changed data to the secondary system. Data can be protected with mirror and/or vault policies, allowing for disaster recovery as well as long-term data retention for backup. SnapMirror supports asynchronous as well as synchronous relationships, and ONTAP 9.8 introduces transparent application failover with SnapMirror Business Continuity.

  SnapMirror is required for SRA replication with Site Recovery Manager. It is also required for SnapCenter to enable replication of Snapshot copies to a secondary storage system.

- **SnapCenter.** SnapCenter software provides a unified, scalable platform and plug-in suite for application-consistent data protection and clone management. A SnapCenter license is included with the data

protection license bundles for AFF and FAS systems. SnapCenter Plug-in for VMware vSphere is a free product if you are using the following storage systems: FAS, AFF, Cloud Volumes ONTAP, or ONTAP Select. However, SnapRestore and FlexClone licenses are required.

- **MetroCluster.** NetApp MetroCluster is a synchronous replication solution combining high availability and disaster recovery in a campus or metropolitan area to protect against both site disasters and hardware outages. It provides solutions with transparent recovery from failure, with zero data loss (0 RPO) and fast recovery (RTO within minutes). It is used in vSphere environments as part of a vSphere Metro Storage Cluster configuration.

Virtualization tools for ONTAP

NetApp offers several standalone software tools that can be used together with ONTAP and vSphere to manage your virtualized environment. The following tools are included with the ONTAP license at no additional cost. See Figure 1 for a depiction of how these tools work together in your vSphere environment.

ONTAP tools for VMware vSphere

ONTAP tools for VMware vSphere is a set of tools for using ONTAP storage together with vSphere. The vCenter plug-in, formerly known as the Virtual Storage Console (VSC), simplifies storage management and efficiency features, enhances availability, and reduces storage costs and operational overhead, whether you are using SAN or NAS. It uses best practices for provisioning datastores and optimizes ESXi host settings for NFS and block storage environments. For all these benefits, NetApp recommends using these ONTAP tools as a best practice when using vSphere with systems running ONTAP software. It includes both a server appliance and user interface extensions for vCenter.

NFS Plug-In for VMware VAAI

The NetApp NFS Plug-In for VMware is a plug-in for ESXi hosts that allows them to use VAAI features with NFS datastores on ONTAP. It supports copy offload for clone operations, space reservation for thick virtual disk files, and Snapshot copy offload. Offloading copy operations to storage is not necessarily faster to complete, but it does offload host resources such as CPU cycles, buffers, and queues. You can use ONTAP tools for VMware vSphere to install the plug-in on ESXi hosts.

VASA Provider for ONTAP

The VASA Provider for ONTAP supports the VMware vStorage APIs for Storage Awareness (VASA) framework. It is supplied as part of ONTAP tools for VMware vSphere as a single virtual appliance for ease of deployment. VASA Provider connects vCenter Server with ONTAP to aid in provisioning and monitoring VM storage. It enables VMware Virtual Volumes (vVols) support, management of storage capability profiles and individual VM vVols performance, and alarms for monitoring capacity and compliance with the profiles.

Storage Replication Adapter

The SRA is used together with VMware Site Recovery Manager (SRM) to manage data replication between production and disaster recovery sites and test the DR replicas nondisruptively. It helps automate the tasks of discovery, recovery, and reprotection. It includes both an SRA server appliance and SRA adapters for the Windows SRM server and SRM appliance. The SRA is supplied as part of ONTAP tools for VMware vSphere.

The following figure depicts ONTAP tools for vSphere.

Best practices

vSphere datastore and protocol features

Five protocols are used to connect VMware vSphere to datastores on a system running ONTAP software:

- FC
- FCoE
- NVMe/FC
- iSCSI
- NFS

FC, FCoE, NVMe/FC, and iSCSI are block protocols that use the vSphere Virtual Machine File System (VMFS) to store VMs inside ONTAP LUNs or namespaces that are contained in an ONTAP volume. Note that, starting from vSphere 7.0, VMware no longer supports software FCoE in production environments. NFS is a file protocol that places VMs into datastores (which are simply ONTAP volumes) without the need for VMFS. SMB, iSCSI, or NFS can also be used directly from a guest OS to ONTAP.

The following tables presents vSphere supported traditional datastore features with ONTAP. This information does not apply to vVols datastores, but it does generally applies to vSphere 6.x and 7.x releases using supported ONTAP releases. You can also consult VMware Configuration Maximums for specific vSphere releases to confirm specific limits.

Capability/Feature	FC/FCoE	iSCSI	NFS
Format	VMFS or raw device mapping (RDM)	VMFS or RDM	N/A
Maximum number of datastores or LUNs	256 targets/HBA	256 targets	256 mounts Default NFS. MaxVolumes is 8. Use ONTAP tools for VMware vSphere to increase to 256.
Maximum datastore size	64TB	64TB	100TB FlexVol volume or greater with FlexGroup volume
Maximum datastore file size (for VMDKs using vSphere version 5.5 and VMFS 5 or later)	62TB	62TB	16TB 62TB is the maximum size supported by vSphere.
Optimal queue depth per LUN or file system	64	64	N/A

The following table lists supported VMware storage-related functionalities.

Capacity/Feature	FC/FCoE	iSCSI	NFS
vMotion	Yes	Yes	Yes
Storage vMotion	Yes	Yes	Yes
VMware HA	Yes	Yes	Yes
Storage Distributed Resource Scheduler (SDRS)	Yes	Yes	Yes
VMware vStorage APIs for Data Protection (VADP)–enabled backup software	Yes	Yes	Yes
Microsoft Cluster Service (MSCS) or failover clustering within a VM	Yes	Yes*	Not supported
Fault Tolerance	Yes	Yes	Yes
Site Recovery Manager	Yes	Yes	Yes
Thin-provisioned VMs (virtual disks)	Yes	Yes	Yes This setting is the default for all VMs on NFS when not using VAAI.
VMware native multipathing	Yes	Yes	N/A

*NetApp recommends using in-guest iSCSI for Microsoft clusters rather than multi- writer enabled VMDKs in a

VMFS datastore. This approach is fully supported by Microsoft and VMware, offers great flexibility with ONTAP (SnapMirror to ONTAP systems on-premises or in the cloud), is easy to configure and automate, and can be protected with SnapCenter. vSphere 7 adds a new clustered VMDK option. This is different from multi-writer enabled VMDKs but requires a datastore presented via the FC protocol, which has clustered VMDK support enabled. Other restrictions apply. See VMware's Setup for Windows Server Failover Clustering documentation for configuration guidelines.

The following table lists supported ONTAP storage management features.

Capability/Feature	FC/FCoE	iSCSI	NFS
Data deduplication	Savings in the array	Savings in the array	Savings in the datastore
Thin provisioning	Datastore or RDM	Datastore or RDM	Datastore
Resize datastore	Grow only	Grow only	Grow, autogrow, and shrink
SnapCenter plug-ins for Windows, Linux applications (in guest)	Yes	Yes	Yes
Monitoring and host configuration using ONTAP tools for VMware vSphere	Yes	Yes	Yes
Provisioning using ONTAP tools for VMware vSphere	Yes	Yes	Yes

The following table lists supported backup features.

Capability/Feature	FC/FCoE	iSCSI	NFS
ONTAP Snapshot copies	Yes	Yes	Yes
SRM supported by replicated backups	Yes	Yes	Yes
Volume SnapMirror	Yes	Yes	Yes
VMDK image access	VADP-enabled backup software	VADP-enabled backup software	VADP-enabled backup software, vSphere Client, and vSphere Web Client datastore browser
VMDK file-level access	VADP-enabled backup software, Windows only	VADP-enabled backup software, Windows only	VADP-enabled backup software and third-party applications
NDMP granularity	Datastore	Datastore	Datastore or VM

Selecting a storage protocol

Systems running ONTAP software support all major storage protocols, so customers can choose what is best for their environment, depending on existing and planned networking infrastructure and staff skills. NetApp testing has generally shown little difference between protocols running at similar line speeds, so it is best to focus on your network infrastructure and staff capabilities over raw protocol performance.

The following factors might be useful in considering a choice of protocol:

- **Current customer environment.** Although IT teams are generally skilled at managing Ethernet IP infrastructure, not all are skilled at managing an FC SAN fabric. However, using a general-purpose IP network that's not designed for storage traffic might not work well. Consider the networking infrastructure you have in place, any planned improvements, and the skills and availability of staff to manage them.

- **Ease of setup.** Beyond initial configuration of the FC fabric (additional switches and cabling, zoning, and the interoperability verification of HBA and firmware), block protocols also require creation and mapping of LUNs and discovery and formatting by the guest OS. After the NFS volumes are created and exported, they are mounted by the ESXi host and ready to use. NFS has no special hardware qualification or firmware to manage.

- **Ease of management.** With SAN protocols, if more space is needed, several steps are necessary, including growing a LUN, rescanning to discover the new size, and then growing the file system). Although growing a LUN is possible, reducing the size of a LUN is not, and recovering unused space can require additional effort. NFS allows easy sizing up or down, and this resizing can be automated by the storage system. SAN offers space reclamation through guest OS TRIM/UNMAP commands, allowing space from deleted files to be returned to the array. This type of space reclamation is more difficult with NFS datastores.

- **Storage space transparency.** Storage utilization is typically easier to see in NFS environments because thin provisioning returns savings immediately. Likewise, deduplication and cloning savings are immediately available for other VMs in the same datastore or for other storage system volumes. VM density is also typically greater in an NFS datastore, which can improve deduplication savings as well as reduce management costs by having fewer datastores to manage.

Datastore layout

ONTAP storage systems offer great flexibility in creating datastores for VMs and virtual disks. Although many ONTAP best practices are applied when using the VSC to provision datastores for vSphere (listed in the section Recommended ESXi host and other ONTAP settings), here are some additional guidelines to consider:

- Deploying vSphere with ONTAP NFS datastores results in a high-performing, easy-to-manage implementation that provides VM-to-datastore ratios that cannot be obtained with block-based storage protocols. This architecture can result in a tenfold increase in datastore density with a correlating reduction in the number of datastores. Although a larger datastore can benefit storage efficiency and provide operational benefits, consider using at least four datastores (FlexVol volumes) to store your VMs on a single ONTAP controller to get maximum performance from the hardware resources. This approach also allows you to establish datastores with different recovery policies. Some can be backed up or replicated more frequently than others, based on business needs. Multiple datastores are not required with FlexGroup volumes for performance as it scales by design.

- NetApp recommends the use of FlexVol volumes and, starting with ONTAP 9.8 FlexGroup volumes, NFS datastores. Other ONTAP storage containers such as qtrees are not generally recommended because these are not currently supported by ONTAP tools for VMware vSphere. Deploying datastores as multiple qtrees in a single volume might be useful for highly automated environments that can benefit from datastore-level quotas or VM file clones.

- A good size for a FlexVol volume datastore is around 4TB to 8TB. This size is a good balance point for performance, ease of management, and data protection. Start small (say, 4TB) and grow the datastore as needed (up to the maximum 100TB). Smaller datastores are faster to recover from backup or after a disaster and can be moved quickly across the cluster. Consider the use of ONTAP autosize to automatically grow and shrink the volume as used space changes. The ONTAP tools for VMware vSphere Datastore Provisioning Wizard use autosize by default for new datastores. Additional customization of the grow and shrink thresholds and maximum and minimum size can be done with System Manager or the command line.

- Alternately, VMFS datastores can be configured with LUNs that are accessed by FC, iSCSI, or FCoE. VMFS allows traditional LUNs to be accessed simultaneously by every ESX server in a cluster. VMFS datastores can be up to 64TB in size and consist of up to 32 2TB LUNs (VMFS 3) or a single 64TB LUN (VMFS 5). The ONTAP maximum LUN size is 16TB on most systems, and 128TB on All SAN Array systems. Therefore, a maximum size VMFS 5 datastore on most ONTAP systems can be created by using four 16TB LUNs. While there can be performance benefit for high-I/O workloads with multiple LUNs (with high-end FAS or AFF systems), this benefit is offset by added management complexity to create, manage, and protect the datastore LUNs and increased availability risk. NetApp generally recommends using a single, large LUN for each datastore and only span if there is a special need to go beyond a 16TB datastore. As with NFS, consider using multiple datastores (volumes) to maximize performance on a single ONTAP controller.

- Older guest operating systems (OSs) needed alignment with the storage system for best performance and storage efficiency. However, modern vendor-supported OSs from Microsoft and Linux distributors such as Red Hat no longer require adjustments to align the file system partition with the blocks of the underlying storage system in a virtual environment. If you are using an old OS that might require alignment, search the NetApp Support Knowledgebase for articles using "VM alignment" or request a copy of TR-3747 from a NetApp sales or partner contact.

- Avoid the use of defragmentation utilities within the guest OS, as this offers no performance benefit and affects storage efficiency and Snapshot copy space usage. Also consider turning off search indexing in the guest OS for virtual desktops.

- ONTAP has led the industry with innovative storage efficiency features, allowing you to get the most out of your usable disk space. AFF systems take this efficiency further with default inline deduplication and compression. Data is deduplicated across all volumes in an aggregate, so you no longer need to group similar operating systems and similar applications within a single datastore to maximize savings.

- In some cases, you might not even need a datastore. For the best performance and manageability, avoid using a datastore for high-I/O applications such as databases and some applications. Instead, consider guest-owned file systems such as NFS or iSCSI file systems managed by the guest or with RDMs. For specific application guidance, see NetApp technical reports for your application. For example, TR-3633: Oracle Databases on Data ONTAP has a section about virtualization with helpful details.

- First Class Disks (or Improved Virtual Disks) allow for vCenter-managed disks independent of a VM with vSphere 6.5 and later. While primarily managed by API, they can be useful with vVols, especially when managed by OpenStack or Kubernetes tools. They are supported by ONTAP as well as ONTAP tools for VMware vSphere.

Datastore and VM migration

When migrating VMs from an existing datastore on another storage system to ONTAP, here are some practices to keep in mind:

- Use Storage vMotion to move the bulk of your virtual machines to ONTAP. Not only is this approach nondisruptive to running VMs, it also allows ONTAP storage efficiency features such as inline deduplication and compression to process the data as it migrates. Consider using vCenter capabilities to select multiple VMs from the inventory list and then schedule the migration (use Ctrl key while clicking Actions) at an appropriate time.

- While you could carefully plan a migration to appropriate destination datastores, it is often simpler to migrate in bulk and then organize later as needed. If you have specific data protection needs, such as different Snapshot schedules, you might want to use this approach to guide your migration to different datastores.

- Most VMs and their storage may be migrated while running (hot), but migrating attached (not in datastore) storage such as ISOs, LUNs, or NFS volumes from another storage system might require cold migration.

- Virtual machines that need more careful migration include databases and applications that use attached storage. In general, consider the use of the application's tools to manage migration. For Oracle, consider using Oracle tools such as RMAN or ASM to migrate the database files. See TR-4534 for more information. Likewise, for SQL Server, consider using either SQL Server Management Studio or NetApp tools such as SnapManager for SQL Server or SnapCenter.

ONTAP tools for VMware vSphere

The most important best practice when using vSphere with systems running ONTAP software is to install and use the ONTAP tools for VMware vSphere plug-in (formerly known as Virtual Storage Console). This vCenter plug-in simplifies storage management, enhances availability, and reduces storage costs and operational overhead, whether using SAN or NAS. It uses best practices for provisioning datastores and optimizes ESXi host settings for multipath and HBA timeouts (these are described in Appendix B). Because it's a vCenter plug-in, it's available to all vSphere web clients that connect to the vCenter server.

The plug-in also helps you use other ONTAP tools in vSphere environments. It allows you to install the NFS Plug-In for VMware VAAI, which enables copy offload to ONTAP for VM cloning operations, space reservation for thick virtual disk files, and ONTAP Snapshot copy offload.

The plug-in is also the management interface for many functions of the VASA Provider for ONTAP, supporting storage policy-based management with vVols. After ONTAP tools for VMware vSphere is registered, use it to create storage capability profiles, map them to storage, and make sure of datastore compliance with the profiles over time. The VASA Provider also provides an interface to create and manage vVol datastores.

In general, NetApp recommends using the ONTAP tools for VMware vSphere interface within vCenter to provision traditional and vVols datastores to make sure best practices are followed.

General Networking

Configuring network settings when using vSphere with systems running ONTAP software is straightforward and similar to other network configuration. Here are some things to consider:

- Separate storage network traffic from other networks. A separate network can be achieved by using a dedicated VLAN or separate switches for storage. If the storage network shares physical paths such as uplinks, you might need QoS or additional uplink ports to make sure of sufficient bandwidth. Don't connect hosts directly to storage; use switches to have redundant paths and allow VMware HA to work without intervention.

- Jumbo frames can be used if desired and supported by your network, especially when using iSCSI. If they are used, make sure they are configured identically on all network devices, VLANs, and so on in the path between storage and the ESXi host. Otherwise, you might see performance or connection problems. The MTU must also be set identically on the ESXi virtual switch, the VMkernel port, and also on the physical ports or interface groups of each ONTAP node.

- NetApp only recommends disabling network flow control on the cluster network ports within an ONTAP cluster. NetApp makes no other recommendations for best practices for the remaining network ports used for data traffic. You should enable or disable as necessary. See TR-4182 for more background on flow control.

- When ESXi and ONTAP storage arrays are connected to Ethernet storage networks, NetApp recommends configuring the Ethernet ports to which these systems connect as Rapid Spanning Tree Protocol (RSTP) edge ports or by using the Cisco PortFast feature. NetApp recommends enabling the Spanning-Tree PortFast trunk feature in environments that use the Cisco PortFast feature and that have 802.1Q VLAN trunking enabled to either the ESXi server or the ONTAP storage arrays.

- NetApp recommends the following best practices for link aggregation:

- Use switches that support link aggregation of ports on two separate switch chassis, using a multichassis link aggregation group approach such as Cisco's Virtual PortChannel (vPC).
- Disable LACP for switch ports connected to ESXi unless using dvSwitches 5.1 or later with LACP configured.
- Use LACP to create link aggregates for ONTAP storage systems, with dynamic multimode interface groups with IP hash.
- Use IP hash teaming policy on ESXi.

The following table provides a summary of network configuration items and indicates where the settings are applied.

Item	ESXi	Switch	Node	SVM
IP address	VMkernel	No**	No**	Yes
Link aggregation	Virtual switch	Yes	Yes	No*
VLAN	VMkernel and VM port groups	Yes	Yes	No*
Flow control	NIC	Yes	Yes	No*
Spanning tree	No	Yes	No	No
MTU (for jumbo frames)	Virtual switch and VMkernel port (9000)	Yes (set to max)	Yes (9000)	No*
Failover groups	No	No	Yes (create)	Yes (select)

*SVM LIFs connect to ports, interface groups, or VLAN interfaces that have VLAN, MTU, and other settings, but the settings are not managed at the SVM level.

**These devices have IP addresses of their own for management, but these addresses are not used in the context of ESXi storage networking.

SAN (FC, FCoE, NVMe/FC, iSCSI), RDM

In vSphere, there are three ways to use block storage LUNs:

- With VMFS datastores
- With raw device mapping (RDM)
- As a LUN accessed and controlled by a software initiator from a VM guest OS

VMFS is a high-performance clustered file system that provides datastores that are shared storage pools. VMFS datastores can be configured with LUNs that are accessed using FC, iSCSI, FCoE, or NVMe namespaces accessed by the NVMe/FC protocol. VMFS allows traditional LUNs to be accessed simultaneously by every ESX server in a cluster. The ONTAP maximum LUN size is generally 16TB; therefore, a maximum-size VMFS 5 datastore of 64TB (see the first table in this section) is created by using four 16TB LUNs (All SAN Array systems support the maximum VMFS LUN size of 64TB). Because the ONTAP LUN architecture does not have small individual queue depths, VMFS datastores in ONTAP can scale to a greater degree than with traditional array architectures in a relatively simple manner.

vSphere includes built-in support for multiple paths to storage devices, referred to as native multipathing (NMP). NMP can detect the type of storage for supported storage systems and automatically configures the

NMP stack to support the capabilities of the storage system in use.

Both NMP and NetApp ONTAP support Asymmetric Logical Unit Access (ALUA) to negotiate optimized and nonoptimized paths. In ONTAP, an ALUA-optimized path follows a direct data path, using a target port on the node that hosts the LUN being accessed. ALUA is turned on by default in both vSphere and ONTAP. The NMP recognizes the ONTAP cluster as ALUA, and it uses the ALUA storage array type plug-in (`VMW_SATP_ALUA`) and selects the round robin path selection plug-in (`VMW_PSP_RR`).

ESXi 6 supports up to 256 LUNs and up to 1,024 total paths to LUNs. Any LUNs or paths beyond these limits are not seen by ESXi. Assuming the maximum number of LUNs, the path limit allows four paths per LUN. In a larger ONTAP cluster, it is possible to reach the path limit before the LUN limit. To address this limitation, ONTAP supports selective LUN map (SLM) in release 8.3 and later.

SLM limits the nodes that advertise paths to a given LUN. It is a NetApp best practice to have at least one LIF per node per SVM and to use SLM to limit the paths advertised to the node hosting the LUN and its HA partner. Although other paths exist, they aren't advertised by default. It is possible to modify the paths advertised with the add and remove reporting node arguments within SLM. Note that LUNs created in releases prior to 8.3 advertise all paths and need to be modified to only advertise the paths to the hosting HA pair. For more information about SLM, review section 5.9 of TR-4080. The previous method of portsets can also be used to further reduce the available paths for a LUN. Portsets help by reducing the number of visible paths through which initiators in an igroup can see LUNs.

- SLM is enabled by default. Unless you are using portsets, no additional configuration is required.

- For LUNs created prior to Data ONTAP 8.3, manually apply SLM by running the `lun mapping remove-reporting-nodes` command to remove the LUN reporting nodes and restrict LUN access to the LUN-owning node and its HA partner.

Block protocols (iSCSI, FC, and FCoE) access LUNs by using LUN IDs and serial numbers, along with unique names. FC and FCoE use worldwide names (WWNNs and WWPNs), and iSCSI uses iSCSI qualified names (IQNs). The path to LUNs inside the storage is meaningless to the block protocols and is not presented anywhere in the protocol. Therefore, a volume that contains only LUNs does not need to be internally mounted at all, and a junction path is not needed for volumes that contain LUNs used in datastores. The NVMe subsystem in ONTAP works similarly.

Other best practices to consider:

- Make sure that a logical interface (LIF) is created for each SVM on each node in the ONTAP cluster for maximum availability and mobility. ONTAP SAN best practice is to use two physical ports and LIFs per node, one for each fabric. ALUA is used to parse paths and identify active optimized (direct) paths versus active nonoptimized paths. ALUA is used for FC, FCoE, and iSCSI.

- For iSCSI networks, use multiple VMkernel network interfaces on different network subnets with NIC teaming when multiple virtual switches are present. You can also use multiple physical NICs connected to multiple physical switches to provide HA and increased throughput. The following figure provides an example of multipath connectivity. In ONTAP, configure either a single-mode interface group for failover with two or more links that are connected to two or more switches, or use LACP or other link-aggregation technology with multimode interface groups to provide HA and the benefits of link aggregation.

- If the Challenge-Handshake Authentication Protocol (CHAP) is used in ESXi for target authentication, it must also be configured in ONTAP using the CLI (`vserver iscsi security create`) or with System Manager (edit Initiator Security under Storage > SVMs > SVM Settings > Protocols > iSCSI).

- Use ONTAP tools for VMware vSphere to create and manage LUNs and igroups. The plug-in automatically determines the WWPNs of servers and creates appropriate igroups. It also configures LUNs according to best practices and maps them to the correct igroups.

- Use RDMs with care because they can be more difficult to manage, and they also use paths, which are limited as described earlier. ONTAP LUNs support both physical and virtual compatibility mode RDMs.

- For more on using NVMe/FC with vSphere 7.0, see this ONTAP NVMe/FC Host Configuration guide and TR-4684.The following figure depicts multipath connectivity from a vSphere host to an ONTAP LUN.

NFS

vSphere allows customers to use enterprise-class NFS arrays to provide concurrent access to datastores to all the nodes in an ESXi cluster. As mentioned in the datastore section, there are some ease of use and storage efficiency visibility benefits when using NFS with vSphere.

The following best practices are recommended when using ONTAP NFS with vSphere:

- Use a single logical interface (LIF) for each SVM on each node in the ONTAP cluster. Past recommendations of a LIF per datastore are no longer necessary. While direct access (LIF and datastore on same node) is best, don't worry about indirect access because the performance effect is generally minimal (microseconds).

- VMware has supported NFSv3 since VMware Infrastructure 3. vSphere 6.0 added support for NFSv4.1, which enables some advanced capabilities such as Kerberos security. Where NFSv3 uses client-side locking, NFSv4.1 uses server-side locking. Although an ONTAP volume can be exported through both protocols, ESXi can only mount through one protocol. This single protocol mount does not preclude other ESXi hosts from mounting the same datastore through a different version. Make sure to specify the protocol version to use when mounting so that all hosts use the same version and, therefore, the same locking style. Do not mix NFS versions across hosts. If possible, use host profiles to check compliancy.

  ◦ Because there is no automatic datastore conversion between NFSv3 and NFSv4.1, create a new NFSv4.1 datastore and use Storage vMotion to migrate VMs to the new datastore.

  ◦ Please refer to the NFS v4.1 Interoperability table notes in the NetApp Interoperability Matrix tool for specific ESXi patch levels required for support.

- NFS export policies are used to control access by vSphere hosts. You can use one policy with multiple volumes (datastores). With NFSv3, ESXi uses the sys (UNIX) security style and requires the root mount option to execute VMs. In ONTAP, this option is referred to as superuser, and when the superuser option is used, it is not necessary to specify the anonymous user ID. Note that export policy rules with different values for `-anon` and `-allow-suid` can cause SVM discovery problems with the ONTAP tools. Here's a sample policy:

  ◦ Access Protocol: nfs3
  ◦ Client Match Spec: 192.168.42.21

- RO Access Rule: sys
- RW Access Rule: sys
- Anonymous UID:
- Superuser: sys

- If the NetApp NFS Plug-In for VMware VAAI is used, the protocol should be set as `nfs` when the export policy rule is created or modified. The NFSv4 protocol is required for VAAI copy offload to work, and specifying the protocol as `nfs` automatically includes both the NFSv3 and the NFSv4 versions.

- NFS datastore volumes are junctioned from the root volume of the SVM; therefore, ESXi must also have access to the root volume to navigate and mount datastore volumes. The export policy for the root volume, and for any other volumes in which the datastore volume's junction is nested, must include a rule or rules for the ESXi servers granting them read-only access. Here's a sample policy for the root volume, also using the VAAI plug-in:
  - Access Protocol. nfs (which includes both nfs3 and nfs4)
  - Client Match Spec. 192.168.42.21
  - RO Access Rule. sys
  - RW Access Rule. never (best security for root volume)
  - Anonymous UID.
  - Superuser. sys (also required for root volume with VAAI)

- Use ONTAP tools for VMware vSphere (the most important best practice):
  - Use ONTAP tools for VMware vSphere to provision datastores because it simplifies management of export policies automatically.
  - When creating datastores for VMware clusters with the plug- in, select the cluster rather than a single ESX server. This choice triggers it to automatically mount the datastore to all hosts in the cluster.
  - Use the plug- in mount function to apply existing datastores to new servers.
  - When not using ONTAP tools for VMware vSphere, use a single export policy for all servers or for each cluster of servers where additional access control is needed.

- Although ONTAP offers a flexible volume namespace structure to arrange volumes in a tree using junctions, this approach has no value for vSphere. It creates a directory for each VM at the root of the datastore, regardless of the namespace hierarchy of the storage. Thus, the best practice is to simply mount the junction path for volumes for vSphere at the root volume of the SVM, which is how ONTAP tools for VMware vSphere provisions datastores. Not having nested junction paths also means that no volume is dependent on any volume other than the root volume and that taking a volume offline or destroying it, even intentionally, does not affect the path to other volumes.

- A block size of 4K is fine for NTFS partitions on NFS datastores. The following figure depicts connectivity from a vSphere host to an ONTAP NFS datastore.

The following table lists NFS versions and supported features.

vSphere Features	NFSv3	NFSv4.1
vMotion and Storage vMotion	Yes	Yes
High availability	Yes	Yes
Fault tolerance	Yes	Yes
DRS	Yes	Yes
Host profiles	Yes	Yes
Storage DRS	Yes	No
Storage I/O control	Yes	No
SRM	Yes	No
Virtual volumes	Yes	No
Hardware acceleration (VAAI)	Yes	Yes (vSphere 6.5 and later, NetApp VAAI Plug-in 1.1.2)
Kerberos authentication	No	Yes (enhanced with vSphere 6.5 and later to support AES, krb5i)
Multipathing support	No	No (ESXi 6.5 and later supports through session trunking; ONTAP supports through pNFS)

FlexGroup

ONTAP 9.8 adds support for FlexGroup datastores in vSphere, along with the ONTAP tools for VMware vSphere 9.8 release. FlexGroup simplifies the creation of large datastores and automatically creates a number of constituent volumes to get maximum performance from an ONTAP system. Use FlexGroup with vSphere for a single, scalable vSphere datastore with the power of a full ONTAP cluster.

In addition to extensive system testing with vSphere workloads, ONTAP 9.8 also adds a new copy offload mechanism for FlexGroup datastores. This uses an improved copy engine to copy files between constituents in the background while allowing access on both source and destination. Multiple copies use instantly available, space-efficient file clones within a constituent when needed based on scale.

ONTAP 9.8 also adds new file-based performance metrics (IOPS, throughput, and latency) for FlexGroup files,

and these metrics can be viewed in the ONTAP tools for VMware vSphere dashboard and VM reports. The ONTAP tools for VMware vSphere plug-in also allows you to set Quality of Service (QoS) rules using a combination of maximum and/or minimum IOPS. These can be set across all VMs in a datastore or individually for specific VMs.

Here are some additional best practices that NetApp has developed:

- Use FlexGroup provisioning defaults. While ONTAP tools for VMware vSphere is recommended because it creates and mounts the FlexGroup within vSphere, ONTAP System Manager or the command line might be used for special needs. Even then, use the defaults such as the number of constituent members per node because this is what has been tested with vSphere.

- When sizing a FlexGroup datastore, keep in mind that the FlexGroup consists of multiple smaller FlexVol volumes that create a larger namespace. As such, size the datastore to be at least 8x the size of your largest virtual machine. For example, if you have a 6TB VM in your environment, size the FlexGroup datastore no smaller than 48TB.

- Allow FlexGroup to manage datastore space. Autosize and Elastic Sizing have been tested with vSphere datastores. Should the datastore get close to full capacity, use ONTAP tools for VMware vSphere or another tool to resize the FlexGroup volume. FlexGroup keeps capacity and inodes balanced across constituents, prioritizing files within a folder (VM) to the same constituent if capacity allows.

- VMware and NetApp do not currently support a common multipath networking approach. For NFSv4.1, NetApp supports pNFS, whereas VMware supports session trunking. NFSv3 does not support multiple physical paths to a volume. For FlexGroup with ONTAP 9.8, our recommended best practice is to let ONTAP tools for VMware vSphere make the single mount, because the effect of indirect access is typically minimal (microseconds). It's possible to use round-robin DNS to distribute ESXi hosts across LIFs on different nodes in the FlexGroup, but this would require the FlexGroup to be created and mounted without ONTAP tools for VMware vSphere. Then the performance management features would not be available.

- FlexGroup vSphere datastore support has been tested up to 1500 VMs with the 9.8 release.

- Use the NFS Plug-In for VMware VAAI for copy offload. Note that while cloning is enhanced within a FlexGroup datastore, ONTAP does not provide significant performance advantages versus ESXi host copy when copying VMs between FlexVol and/or FlexGroup volumes.

- Use ONTAP tools for VMware vSphere 9.8 to monitor performance of FlexGroup VMs using ONTAP metrics (dashboard and VM reports), and to manage QoS on individual VMs. These metrics are not currently available through ONTAP commands or APIs.

- QoS (max/min IOPS) can be set on individual VMs or on all VMs in a datastore at that time. Setting QoS on all VMs replaces any separate per-VM settings. Settings do not extend to new or migrated VMs in the future; either set QoS on the new VMs or re-apply QoS to all VMs in the datastore.

- SnapCenter Plug-In for VMware vSphere release 4.4 supports backup and recovery of VMs in a FlexGroup datastore on the primary storage system. While SnapMirror may be used manually to replicate a FlexGroup to a secondary system, SCV 4.4 does not manage the secondary copies.

Other capabilities for vSphere

Data protection

Backing up your VMs and quickly recovering them are among the great strengths of ONTAP for vSphere, and it is easy to manage this ability inside vCenter with the SnapCenter Plug-In for VMware vSphere. Use Snapshot copies to make quick copies of your VM or datastore without affecting performance, and then send them to a secondary system using SnapMirror for longer-term off-site data protection. This approach minimizes storage space and network bandwidth by only storing changed information.

SnapCenter allows you to create backup policies that can be applied to multiple jobs. These policies can define schedule, retention, replication, and other capabilities. They continue to allow optional selection of VM-consistent snapshots, which leverages the hypervisor's ability to quiesce I/O before taking a VMware snapshot. However, due to the performance effect of VMware snapshots, they are generally not recommended unless you need the guest file system to be quiesced. Instead, use ONTAP Snapshot copies for general protection, and use application tools such as SnapCenter plug-ins to protect transactional data such as SQL Server or Oracle. These Snapshot copies are different from VMware (consistency) snapshots and are suitable for longer term protection. VMware snapshots are only recommended for short term use due to performance and other effects.

These plug-ins offer extended capabilities to protect the databases in both physical and virtual environments. With vSphere, you can use them to protect SQL Server or Oracle databases where data is stored on RDM LUNs, iSCSI LUNs directly connected to the guest OS, or VMDK files on either VMFS or NFS datastores. The plug-ins allow specification of different types of database backups, supporting online or offline backup, and protecting database files along with log files. In addition to backup and recovery, the plug-ins also support cloning of databases for development or test purposes.

The following figure depicts an example of SnapCenter deployment.

For enhanced disaster recovery capabilities, consider using the NetApp SRA for ONTAP with VMware Site Recovery Manager. In addition to support for the replication of datastores to a DR site, it also enables nondisruptive testing in the DR environment by cloning the replicated datastores. Recovery from a disaster and reprotecting production after the outage has been resolved are also made easy by automation built into SRA.

Finally, for the highest level of data protection, consider a VMware vSphere Metro Storage Cluster (vMSC) configuration using NetApp MetroCluster. vMSC is a VMware-certified solution that combines synchronous replication with array-based clustering, giving the same benefits of a high-availability cluster but distributed across separate sites to protect against site disaster. NetApp MetroCluster offers cost-effective configurations for synchronous replication with transparent recovery from any single storage component failure as well as single-command recovery in the event of a site disaster. vMSC is described in greater detail in TR-4128.

Space reclamation

Space can be reclaimed for other uses when VMs are deleted from a datastore. When using NFS datastores,

space is reclaimed immediately when a VM is deleted (of course, this approach only makes sense when the volume is thin provisioned, that is, the volume guarantee is set to none). However, when files are deleted within the VM guest OS, space is not automatically reclaimed with an NFS datastore. For LUN-based VMFS datastores, ESXi as well as the guest OS can issue VAAI UNMAP primitives to the storage (again, when using thin provisioning) to reclaim space. Depending on the release, this support is either manual or automatic.

In vSphere 5.5 and later, the `vmkfstools -y` command is replaced by the `esxcli storage vmfs unmap` command, which specifies the number of free blocks (see VMware KB 2057513 for more info). In vSphere 6.5 and later when using VMFS 6, space should be automatically reclaimed asynchronously (see Storage Space Reclamation in the vSphere documentation), but can also be run manually if needed. This automatic UNMAP is supported by ONTAP, and ONTAP tools for VMware vSphere sets it to low priority.

VM and datastore cloning

Cloning a storage object allows you to quickly create copies for further use, such as provisioning additional VMs, backup/recovery operations, and so on. In vSphere, you can clone a VM, virtual disk, vVol, or datastore. After being cloned, the object can be further customized, often through an automated process. vSphere supports both full copy clones, as well as linked clones, where it tracks changes separately from the original object.

Linked clones are great for saving space, but they increase the amount of I/O that vSphere handles for the VM, affecting performance of that VM and perhaps the host overall. That's why NetApp customers often use storage system-based clones to get the best of both worlds: efficient use of storage and increased performance.

The following figure depicts ONTAP cloning.

Template
(Not running)

Clone01

Clone02

APP

OS

APP

OS

APP

OS

0 A
1 B
2 C

0 A
1 B
2 C

0 A
1 B
2 D

Base VMDK

Cloned VMDK

Cloned VMDK

Inode

Inode

Inode

0 A   1 B   2 C   2 D

NetApp FlexVol Volume

Cloning can be offloaded to systems running ONTAP software through several mechanisms, typically at the VM, vVol, or datastore level. These include the following:

- vVols using the NetApp vSphere APIs for Storage Awareness (VASA) Provider. ONTAP clones are used to support vVol Snapshot copies managed by vCenter that are space-efficient with minimal I/O effect to create and delete them. VMs can also be cloned using vCenter, and these are also offloaded to ONTAP, whether within a single datastore/volume or between datastores/volumes.

- vSphere cloning and migration using vSphere APIs – Array Integration (VAAI). VM cloning operations can be offloaded to ONTAP in both SAN and NAS environments (NetApp supplies an ESXi plug-in to enable VAAI for NFS). vSphere only offloads operations on cold (powered off) VMs in a NAS datastore, whereas operations on hot VMs (cloning and storage vMotion) are also offloaded for SAN. ONTAP uses the most efficient approach based on source, destination, and installed product licenses. This capability is also used by VMware Horizon View.

- SRA (used with VMware Site Recovery Manager). Here, clones are used to test recovery of the DR replica nondisruptively.
- Backup and recovery using NetApp tools such as SnapCenter. VM clones are used to verify backup operations as well as to mount a VM backup so that individual files can be copied.

ONTAP offloaded cloning can be invoked by VMware, NetApp, and third-party tools. Clones that are offloaded to ONTAP have several advantages. They are space-efficient in most cases, needing storage only for changes to the object; there is no additional performance effect to read and write them, and in some cases performance is improved by sharing blocks in high-speed caches. They also offload CPU cycles and network I/O from the ESXi server. Copy offload within a traditional datastore using a FlexVol volume can be fast and efficient with FlexClone licensed, but copies between FlexVol volumes might be slower. If you maintain VM templates as a source of clones, consider placing them within the datastore volume (use folders or content libraries to organize them) for fast, space efficient clones.

You can also clone a volume or LUN directly within ONTAP to clone a datastore. With NFS datastores, FlexClone technology can clone an entire volume, and the clone can be exported from ONTAP and mounted by ESXi as another datastore. For VMFS datastores, ONTAP can clone a LUN within a volume or a whole volume, including one or more LUNs within it. A LUN containing a VMFS must be mapped to an ESXi initiator group (igroup) and then resignatured by ESXi to be mounted and used as a regular datastore. For some temporary use cases, a cloned VMFS can be mounted without resignaturing. After a datastore is cloned, VMs inside it can be registered, reconfigured, and customized as if they were individually cloned VMs.

In some cases, additional licensed features can be used to enhance cloning, such as SnapRestore for backup or FlexClone. These licenses are often included in license bundles at no additional cost. A FlexClone license is required for vVol cloning operations as well as to support managed Snapshot copies of a vVol (which are offloaded from the hypervisor to ONTAP). A FlexClone license can also improve certain VAAI-based clones when used within a datastore/volume (creates instant, space-efficient copies instead of block copies). It is also used by the SRA when testing recovery of a DR replica, and SnapCenter for clone operations and to browse backup copies to restore individual files.

Storage efficiency and thin provisioning

NetApp has led the industry with storage-efficiency innovation such as the first deduplication for primary workloads, and inline data compaction, which enhances compression and stores small files and I/O efficiently. ONTAP supports both inline and background deduplication, as well as inline and background compression.

The following figure depicts the combined effect of ONTAP storage efficiency features.

Storage Cost (y-axis) vs **Storage Capacity** (x-axis)

- Data growth
- NetApp® RAID-TEC™ and RAID DP® technologies
- NetApp Snapshot® technology
- Thin provisioning
- Cloning
- Inline deduplication
- Inline adaptive compression
- Inline data compaction

Here are recommendations on using ONTAP storage efficiency in a vSphere environment:

- The amount of data deduplication savings realized is based on the commonality of the data. With ONTAP 9.1 and earlier, data deduplication operated at the volume level, but with aggregate deduplication in ONTAP 9.2 and later, data is deduplicated across all volumes in an aggregate on AFF systems. You no longer need to group similar operating systems and similar applications within a single datastore to maximize savings.

- To realize the benefits of deduplication in a block environment, the LUNs must be thin provisioned. Although the LUN is still seen by the VM administrator as taking the provisioned capacity, the deduplication savings are returned to the volume to be used for other needs. NetApp recommends deploying these LUNs in FlexVol volumes that are also thin provisioned (ONTAP tools for VMware vSphere size the volume about 5% larger than the LUN).

- Thin provisioning is also recommended (and is the default) for NFS FlexVol volumes. In an NFS environment, deduplication savings are immediately visible to both storage and VM administrators with thin-provisioned volumes.

- Thin provisioning applies to the VMs as well, where NetApp generally recommends thin-provisioned VMDKs rather than thick. When using thin provisioning, make sure you monitor available space with ONTAP tools for VMware vSphere, ONTAP, or other available tools to avoid out-of-space problems.

- Note that there is no performance penalty when using thin provisioning with ONTAP systems; data is written to available space so that write performance and read performance are maximized. Despite this fact, some products such as Microsoft failover clustering or other low-latency applications might require guaranteed or fixed provisioning, and it is wise to follow these requirements to avoid support problems.

- For maximum deduplication savings, consider scheduling background deduplication on hard disk-based systems or automatic background deduplication on AFF systems. However, the scheduled processes use system resources when running, so ideally they should be scheduled during less active times (such as weekends) or run more frequently to reduce the amount of changed data to be processed. Automatic background deduplication on AFF systems has much less effect on foreground activities. Background compression (for hard disk–based systems) also consumes resources, so it should only be considered for secondary workloads with limited performance requirements.

- NetApp AFF systems primarily use inline storage efficiency capabilities. When data is moved to them using NetApp tools that use block replication such as the 7-Mode Transition Tool, SnapMirror, or Volume Move, it can be useful to run compression and compaction scanners to maximize efficiency savings. Review this NetApp Support KB article for additional details.

- Snapshot copies might lock blocks that could be reduced by compression or deduplication. When using scheduled background efficiency or one-time scanners, make sure that they run and complete before the next Snapshot copy is taken. Review your Snapshot copies and retention to make sure you only retain needed Snapshot copies, especially before a background or scanner job is run.

The following table provide storage efficiency guidelines for virtualized workloads on different types of ONTAP storage:

Workload	Storage efficiency guidelines		
	AFF	Flash Pool	Hard Disk Drives
VDI and SVI	For primary and secondary workloads, use: • Adaptive inline compression • Inline deduplication • Background deduplication • Inline data compaction	For primary and secondary workloads, use: • Adaptive inline compression • Inline deduplication • Background deduplication • Inline data compaction	For primary workloads, use: • Background deduplication For secondary workloads, use: • Adaptive inline compression • Adaptive background compression • Inline deduplication • Background deduplication • Inline data compaction

Quality of service (QoS)

Systems running ONTAP software can use the ONTAP storage QoS feature to limit throughput in MBps and/or I/Os per second (IOPS) for different storage objects such as files, LUNs, volumes, or entire SVMs.

Throughput limits are useful in controlling unknown or test workloads before deployment to make sure they don't affect other workloads. They can also be used to constrain a bully workload after it is identified. Minimum levels of service based on IOPS are also supported to provide consistent performance for SAN objects in ONTAP 9.2 and for NAS objects in ONTAP 9.3.

With an NFS datastore, a QoS policy can be applied to the entire FlexVol volume or individual VMDK files within it. With VMFS datastores using ONTAP LUNs, the QoS policies can be applied to the FlexVol volume that contains the LUNs or individual LUNs, but not individual VMDK files because ONTAP has no awareness of the VMFS file system. When using vVols, minimum and/or maximum QoS can be set on individual VMs using the storage capability profile and VM storage policy.

The QoS maximum throughput limit on an object can be set in MBps and/or IOPS. If both are used, the first limit reached is enforced by ONTAP. A workload can contain multiple objects, and a QoS policy can be applied to one or more workloads. When a policy is applied to multiple workloads, the workloads share the total limit of the policy. Nested objects are not supported (for example, files within a volume cannot each have their own policy). QoS minimums can only be set in IOPS.

The following tools are currently available for managing ONTAP QoS policies and applying them to objects:

- ONTAP CLI
- ONTAP System Manager
- OnCommand Workflow Automation
- Active IQ Unified Manager
- NetApp PowerShell Toolkit for ONTAP
- ONTAP tools for VMware vSphere VASA Provider

To assign a QoS policy to a VMDK on NFS, note the following guidelines:

- The policy must be applied to the `vmname- flat.vmdk` that contains the actual virtual disk image, not the `vmname.vmdk` (virtual disk descriptor file) or `vmname.vmx` (VM descriptor file).

- Do not apply policies to other VM files such as virtual swap files (`vmname.vswp`).

- When using the vSphere web client to find file paths (Datastore > Files), be aware that it combines the information of the `- flat.vmdk` and `. vmdk` and simply shows one file with the name of the `. vmdk` but the size of the `- flat.vmdk`. Add `-flat` into the file name to get the correct path.

To assign a QoS policy to a LUN, including VMFS and RDM, the ONTAP SVM (displayed as Vserver), LUN path, and serial number can be obtained from the Storage Systems menu on the ONTAP tools for VMware vSphere home page. Select the storage system (SVM), and then Related Objects > SAN. Use this approach when specifying QoS using one of the ONTAP tools.

Maximum and minimum QoS can be easily assigned to a vVol-based VM with ONTAP tools for VMware vSphere or Virtual Storage Console 7.1 and later. When creating the storage capability profile for the vVol container, specify a max and/or min IOPS value under the performance capability and then reference this SCP with the VM's storage policy. Use this policy when creating the VM or apply the policy to an existing VM.

FlexGroup datastores offer enhanced QoS capabilities when using ONTAP tools for VMware vSphere 9.8 and later. You can easily set QoS on all VMs in a datastore or on specific VMs. See the FlexGroup section of this report for more information.

ONTAP QoS and VMware SIOC

ONTAP QoS and VMware vSphere Storage I/O Control (SIOC) are complementary technologies that vSphere and storage administrators can use together to manage performance of vSphere VMs hosted on systems running ONTAP software. Each tool has its own strengths, as shown in the following table. Because of the different scopes of VMware vCenter and ONTAP, some objects can be seen and managed by one system and not the other.

Property	ONTAP QoS	VMware SIOC
When active	Policy is always active	Active when contention exists (datastore latency over threshold)
Type of units	IOPS, MBps	IOPS, shares
vCenter or application scope	Multiple vCenter environments, other hypervisors and applications	Single vCenter server
Set QoS on VM?	VMDK on NFS only	VMDK on NFS or VMFS
Set QoS on LUN (RDM)?	Yes	No

Property	ONTAP QoS	VMware SIOC
Set QoS on LUN (VMFS)?	Yes	No
Set QoS on volume (NFS datastore)?	Yes	No
Set QoS on SVM (tenant)?	Yes	No
Policy-based approach?	Yes; can be shared by all workloads in the policy or applied in full to each workload in the policy.	Yes, with vSphere 6.5 and later.
License required	Included with ONTAP	Enterprise Plus

VMware Storage Distributed Resource Scheduler

VMware Storage Distributed Resource Scheduler (SDRS) is a vSphere feature that places VMs on storage based on the current I/O latency and space usage. It then moves the VM or VMDKs nondisruptively between the datastores in a datastore cluster (also referred to as a pod), selecting the best datastore in which to place the VM or VMDKs in the datastore cluster. A datastore cluster is a collection of similar datastores that are aggregated into a single unit of consumption from the vSphere administrator's perspective.

When using SDRS with the NetApp ONTAP tools for VMware vSphere, you must first create a datastore with the plug-in, use vCenter to create the datastore cluster, and then add the datastore to it. After the datastore cluster is created, additional datastores can be added to the datastore cluster directly from the provisioning wizard on the Details page.

Other ONTAP best practices for SDRS include the following:

- All datastores in the cluster should use the same type of storage (such as SAS, SATA, or SSD), be either all VMFS or NFS datastores, and have the same replication and protection settings.

- Consider using SDRS in default (manual) mode. This approach allows you to review the recommendations and decide whether to apply them or not. Be aware of these effects of VMDK migrations:

  - When SDRS moves VMDKs between datastores, any space savings from ONTAP cloning or deduplication are lost. You can rerun deduplication to regain these savings.

  - After SDRS moves VMDKs, NetApp recommends recreating the Snapshot copies at the source datastore because space is otherwise locked by the VM that was moved.

  - Moving VMDKs between datastores on the same aggregate has little benefit, and SDRS does not have visibility into other workloads that might share the aggregate.

Storage policy-based management and vVols

VMware vSphere APIs for Storage Awareness (VASA) make it easy for a storage administrator to configure datastores with well-defined capabilities and let the VM administrator use those whenever needed to provision VMs without having to interact with each other. It's worth taking a look at this approach to see how it can streamline your virtualization storage operations and avoid a lot of trivial work.

Prior to VASA, VM administrators could define VM storage policies, but they had to work with the storage administrator to identify appropriate datastores, often by using documentation or naming conventions. With VASA, the storage administrator can define a range of storage capabilities, including performance, tiering, encryption, and replication. A set of capabilities for a volume or a set of volumes is called a storage capability profile (SCP).

The SCP supports minimum and/or maximum QoS for a VM's data vVols. Minimum QoS is supported only on AFF systems. ONTAP tools for VMware vSphere includes a dashboard that displays VM granular performance and logical capacity for vVols on ONTAP systems.

The following figure depicts ONTAP tools for VMware vSphere 9.8 vVols dashboard.

After the storage capability profile is defined, it can be used to provision VMs using the storage policy that identifies its requirements. The mapping between the VM storage policy and the datastore storage capability profile allows vCenter to display a list of compatible datastores for selection. This approach is known as storage policy-based management.

VASA provides the technology to query storage and return a set of storage capabilities to vCenter. VASA vendor providers supply the translation between the storage system APIs and constructs and the VMware APIs that are understood by vCenter. NetApp's VASA Provider for ONTAP is offered as part of the ONTAP tools for VMware vSphere appliance VM, and the vCenter plug-in provides the interface to provision and manage vVol datastores, as well as the ability to define storage capability profiles (SCPs).

ONTAP supports both VMFS and NFS vVol datastores. Using vVols with SAN datastores brings some of the benefits of NFS such as VM-level granularity. Here are some best practices to consider, and you can find additional information in TR-4400:

- A vVol datastore can consist of multiple FlexVol volumes on multiple cluster nodes. The simplest approach is a single datastore, even when the volumes have different capabilities. SPBM makes sure that a compatible volume is used for the VM. However, the volumes must all be part of a single ONTAP SVM and accessed using a single protocol. One LIF per node for each protocol is sufficient. Avoid using multiple ONTAP releases within a single vVol datastore because the storage capabilities might vary across releases.

- Use the ONTAP tools for VMware vSphere plug-in to create and manage vVol datastores. In addition to managing the datastore and its profile, it automatically creates a protocol endpoint to access the vVols if needed. If LUNs are used, note that LUN PEs are mapped using LUN IDs 300 and higher. Verify that the ESXi host advanced system setting `Disk.MaxLUN` allows a LUN ID number that is higher than 300 (the default is 1,024). Do this step by selecting the ESXi host in vCenter, then the Configure tab, and find `Disk.MaxLUN` in the list of Advanced System Settings.

- Do not install or migrate VASA Provider, vCenter Server (appliance or Windows based), or ONTAP tools for VMware vSphere itself onto a vVols datastore, because they are then mutually dependent, limiting your ability to manage them in the event of a power outage or other data center disruption.

- Back up the VASA Provider VM regularly. At a minimum, create hourly Snapshot copies of the traditional datastore that contains VASA Provider. For more about protecting and recovering the VASA Provider, see this KB article.

The following figure shows vVols components.

Cloud migration and backup

Another ONTAP strength is broad support for the hybrid cloud, merging systems in your on-premises private cloud with public cloud capabilities. Here are some NetApp cloud solutions that can be used in conjunction with vSphere:

- **Cloud Volumes.** NetApp Cloud Volumes Service for AWS or GCP and Azure NetApp Files for ANF provide high-performance, multi-protocol managed storage services in the leading public cloud environments. They can be used directly by VMware Cloud VM guests.

- **Cloud Volumes ONTAP.** NetApp Cloud Volumes ONTAP data management software delivers control, protection, flexibility, and efficiency to your data on your choice of cloud. Cloud Volumes ONTAP is cloud-

native data management software built on NetApp ONTAP storage software. Use together with Cloud Manager to deploy and manage Cloud Volumes ONTAP instances together with your on-premises ONTAP systems. Take advantage of advanced NAS and iSCSI SAN capabilities together with unified data management, including snapshot copies and SnapMirror replication.

- **Cloud Services.** Use Cloud Backup Service or SnapMirror Cloud to protect data from on-premises systems using public cloud storage. Cloud Sync helps migrate and keep your data in sync across NAS, object stores, and Cloud Volumes Service storage.

- **FabricPool.** FabricPool offers quick and easy tiering for ONTAP data. Cold blocks in Snapshot copies can be migrated to an object store in either public clouds or a private StorageGRID object store and are automatically recalled when the ONTAP data is accessed again. Or use the object tier as a third level of protection for data that is already managed by SnapVault. This approach can allow you to store more Snapshot copies of your VMs on primary and/or secondary ONTAP storage systems.

- **ONTAP Select.** Use NetApp software-defined storage to extend your private cloud across the Internet to remote facilities and offices, where you can use ONTAP Select to support block and file services as well as the same vSphere data management capabilities you have in your enterprise data center.

When designing your VM-based applications, consider future cloud mobility. For example, rather than placing application and data files together use a separate LUN or NFS export for the data. This allows you to migrate the VM and data separately to cloud services.

Encryption for vSphere data

Today, there are increasing demands to protect data at rest through encryption. Although the initial focus was on financial and healthcare information, there is growing interest in protecting all information, whether it's stored in files, databases, or other data types.

Systems running ONTAP software make it easy to protect any data with at-rest encryption. NetApp Storage Encryption (NSE) uses self-encrypting disk drives with ONTAP to protect SAN and NAS data. NetApp also offers NetApp Volume Encryption and NetApp Aggregate Encryption as a simple, software-based approach to encrypt volumes on any disk drives. This software encryption doesn't require special disk drives or external key managers and is available to ONTAP customers at no additional cost. You can upgrade and start using it without any disruption to your clients or applications, and they are validated to the FIPS 140-2 level 1 standard, including the onboard key manager.

There are several approaches for protecting the data of virtualized applications running on VMware vSphere. One approach is to protect the data with software inside the VM at the guest OS level. Newer hypervisors such as vSphere 6.5 now support encryption at the VM level as another alternative. However, NetApp software encryption is simple and easy and has these benefits:

- **No effect on the virtual server CPU.** Some virtual server environments need every available CPU cycle for their applications, yet tests have shown up to 5x CPU resources are needed with hypervisor-level encryption. Even if the encryption software supports Intel's AES-NI instruction set to offload encryption workload (as NetApp software encryption does), this approach might not be feasible due to the requirement for new CPUs that are not compatible with older servers.

- **Onboard key manager included.** NetApp software encryption includes an onboard key manager at no additional cost, which makes it easy to get started without high-availability key management servers that are complex to purchase and use.

- **No effect on storage efficiency.** Storage efficiency techniques such as deduplication and compression are widely used today and are key to using flash disk media cost-effectively. However, encrypted data cannot typically be deduplicated or compressed. NetApp hardware and storage encryption operate at a lower level and allow full use of industry-leading NetApp storage efficiency features, unlike other approaches.

- **Easy datastore granular encryption.** With NetApp Volume Encryption, each volume gets its own AES 256-bit key. If you need to change it, you can do so with a single command. This approach is great if you have multiple tenants or need to prove independent encryption for different departments or apps. This encryption is managed at the datastore level, which is a lot easier than managing individual VMs.

It's simple to get started with software encryption. After the license is installed, simply configure the onboard key manager by specifying a passphrase and then either create a new volume or do a storage-side volume move to enable encryption. NetApp is working to add more integrated support for encryption capabilities in future releases of its VMware tools.

Active IQ Unified Manager

Active IQ Unified Manager provides visibility into the VMs in your virtual infrastructure and enables monitoring and troubleshooting storage and performance issues in your virtual environment.

A typical virtual infrastructure deployment on ONTAP has various components that are spread across compute, network, and storage layers. Any performance lag in a VM application might occur due to a combination of latencies faced by the various components at the respective layers.

The following screenshot shows the Active IQ Unified Manager Virtual Machines view.

Unified Manager presents the underlying sub-system of a virtual environment in a topological view for determining whether a latency issue has occurred in the compute node, network, or storage. The view also highlights the specific object that causes the performance lag for taking remedial steps and addressing the underlying issue.

The following screenshot shows the AIQUM expanded topology.

ONTAP and vSphere release-specific information

This section provides guidance on capabilities supported by specific releases of ONTAP and vSphere. NetApp recommends confirming a specific combination of releases with the NetApp Interoperability Matrix.

ONTAP releases

At the time of publication, NetApp provides full support for these release families:

- ONTAP 9.5
- ONTAP 9.6
- ONTAP 9.7
- ONTAP 9.8

vSphere and ESXi support

NetApp ONTAP has broad support for vSphere ESXi hosts. The four major release families just described (9.5, 9.6, 9.7, and 9.8) are fully supported as data storage platforms for recent vSphere releases, including 6.0, 6.5, and 7.0 (including updates for these releases). NFS v3 interoperability is broadly defined, and NetApp supports any client, including hypervisors, that is compliant with the NFS v3 standard. NFSv4.1 support is limited to vSphere 6.0 through 7.0.

For SAN environments, NetApp conducts extensive testing of SAN components. In general, NetApp supports standard X86-64 rack servers and Cisco UCS servers together with standard Ethernet adapters for iSCSI connections. FC, FCoE, and NVMe/FC environments have more specifically defined support due to the HBA firmware and drivers needed.

Always check the NetApp Interoperability Matrix to confirm support for a specific hardware and software configuration.

NFS Plug-In for VMware VAAI

This plug-in for ESXi hosts helps by offloading operations to ONTAP using VAAI. The latest release, 1.1.2, includes support for NFSv4.1 datastores, including Kerberos (krb5 and krb5i) support. It is supported with ESXi 6.0, 6.5, and 7.0 together with ONTAP 9.5-9.8.

VASA Provider

NetApp's VASA Provider supports vVol provisioning and management (see section 3.7). Recent VASA Provider releases support ESXi 6.0, 6.5, and 7.0 together with ONTAP 9.5-9.8.

ONTAP tools for VMware vSphere

ONTAP tools for VMware vSphere is key for managing ONTAP storage together with vSphere (using it is a best practice). The latest release, 9.8, is supported with vSphere 6.5 and 7.0 together with ONTAP 9.5-9.8.

Recommended ESXi host and other ONTAP settings

NetApp has developed a set of ESXi host multipathing and HBA timeout settings for proper behavior with ONTAP based on NetApp testing. These are easily set using ONTAP tools for VMware vSphere. From the Summary dashboard, click Edit Settings in the Host Systems portlet or right-click the host in vCenter, then navigate to ONTAP tools > Set Recommended Values. Here are the currently recommended host settings with the 9.8 release.

Host Setting	NetApp Recommended Value	Reboot Required
ESXi Advanced Configuration		
VMFS3.HardwareAcceleratedLocking	Leave as set (VMware default is 1)	No
VMFS3.EnableBlockDelete	Leave as set (VMware default is 0, but this is not needed for VMFS6). For more information, see VMware KB 2007427	No
NFS Settings		
Net.TcpipHeapSize	vSphere 6.0 or later, set to 32. All other NFS configurations, set to 30	Yes
Net.TcpipHeapMax	Set to 512MB for most vSphere 6.X releases. Set to 1024MB for 6.5U3, 6.7U3, and 7.0 or later.	Yes
NFS.MaxVolumes	vSphere 6.0 or later, set to 256 All other NFS configurations, set to 64.	No
NFS41.MaxVolumes	vSphere 6.0 or later, set to 256.	No
NFS.MaxQueueDepth[1]	vSphere 6.0 or later, set to 128	No
NFS.HeartbeatMaxFailures	Set to 10 for all NFS configurations	No
NFS.HeartbeatFrequency	Set to 12 for all NFS configurations	No
NFS.HeartbeatTimeout	Set to 5 for all NFS configurations.	No

SunRPC.MaxConnPerIP	vSphere 7.0 or later, set to 128.	No
FC/FCoE Settings		
Path selection policy	Set to RR (round robin) when FC paths with ALUA are used. Set to FIXED for all other configurations. Setting this value to RR helps provide load balancing across all active/optimized paths. The value FIXED is for older, non-ALUA configurations and helps prevent proxy I/O. In other words, it helps keep I/O from going to the other node of a high-availability (HA) pair in an environment that has Data ONTAP operating in 7-Mode	No
Disk.QFullSampleSize	Set to 32 for all configurations. Setting this value helps prevent I/O errors.	No
Disk.QFullThreshold	Set to 8 for all configurations. Setting this value helps prevent I/O errors.	No
Emulex FC HBA timeouts	Use the default value.	No
QLogic FC HBA timeouts	Use the default value.	No
iSCSI Settings		
Path selection policy	Set to RR (round robin) for all iSCSI paths. Setting this value to RR helps provide load balancing across all active/optimized paths.	No
Disk.QFullSampleSize	Set to 32 for all configurations. Setting this value helps prevent I/O errors	No
Disk.QFullThreshold	Set to 8 for all configurations. Setting this value helps prevent I/O errors.	No

> ⓘ 1 - NFS advanced configuration option MaxQueueDepth may not work as intended when using VMware vSphere ESXi 7.0.1 and VMware vSphere ESXi 7.0.2. Please reference VMware KB 86331 for more information.

ONTAP tools also specify certain default settings when creating ONTAP FlexVol volumes and LUNs:

ONTAP Tool	Default Setting
Snapshot reserve (-percent-snapshot-space)	0
Fractional reserve (-fractional-reserve)	0
Access time update (-atime-update)	False
Minimum readahead (-min-readahead)	False
Scheduled Snapshot copies	None
Storage efficiency	Enabled
Volume guarantee	None (thin provisioned)

Volume Autosize	grow_shrink
LUN space reservation	Disabled
LUN space allocation	Enabled

Other host multipath configuration considerations

While not currently configured by available ONTAP tools, NetApp suggests considering these configuration options:

- In high-performance environments or when testing performance with a single LUN datastore, consider changing the load balance setting of the round-robin (VMW_PSP_RR) path selection policy (PSP) from the default IOPS setting of 1000 to a value of 1. See VMware KB 2069356 for more info.

- In vSphere 6.7 Update 1, VMware introduced a new latency load balance mechanism for the Round Robin PSP. The new option considers I/O bandwidth and path latency when selecting the optimal path for I/O. You might benefit from using it in environments with non-equivalent path connectivity, such as cases where there are more network hops on one path than another, or when using a NetApp All SAN Array system. See Path Selection Plug-Ins and Policies for more information.

Where to find additional information

To learn more about the information that is described in this document, review the following documents and/or websites:

- VMware Product Documentation
  https://www.vmware.com/support/pubs/

- NetApp Product Documentation
  https://docs.netapp.com

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