NetApp Verified Architecture

NetApp and Broadcom Modern SAN Cloud-Connected Flash Solution

VMware vSphere Verified Architecture Design Edition

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Abstract

This NetApp® Verified Architecture was jointly designed and verified by NetApp and Broadcom Inc. It uses the latest Brocade, Emulex, and VMware vSphere technology solutions as well as NetApp all-flash storage. The solution sets a new standard for enterprise SAN storage and data protection that will promote superior business value.

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Foreword: Thoughts from Broadcom

NVM Express (NVMe) solutions are in the waning days of their early adopter phase. Up to this point, customers would invest cycles into test and development of applications or deploy NVMe for isolated applications to see if its performance lived up to the claims being made. Plus, the use cases and technologies where NVMe solutions could be deployed were limited.

The performance has been proven time and time again (see the Demartek validation), and we are now on the threshold of the wider adoption phase of NVMe solutions, with the hypergrowth phase just around the corner. The key is expanding the array of use cases with a wider range of commonly deployed environments. In modern data centers, it is rare to find dedicated solutions on isolated hardware deployments. The sheer physical size and total cost of that model makes it impractical. The dedicated deployment model issue was resolved well over a decade ago with virtual machines (VMs).

So why bring up the history lesson? We are seeing history repeat itself. As I mentioned before, we are entering the wider adoption phase of NVMe in production environments. With plans for VMware supporting NVMe over Fibre Channel (NVMe/FC), the complete deployment model will soon be available (hypervisor, server, Broadcom-Brocade Gen 6 FC fabrics, and NetApp® industry-leading NVMe/FC storage arrays). Customers will realize the performance benefits of NVMe/FC for their mission-critical SAN applications, in a deployment model to which they are accustomed. This document addresses virtualized workloads with VMware vSphere using NetApp FCP, but also covers NVMe/FC, which we will commence testing after VMware adds support for NVMe/FC to vSphere. After testing is completed, we will publish another edition of this document that will compare FCP and NVMe/FC, just as we've done in the previous documents in this series.

NetApp continues to lead the market in delivering superior storage solutions for mission-critical enterprise SAN applications. Broadcom is proud to partner with NetApp, a company that continues to demonstrate the highest degree of excellence in its future-forward vision and technology. This technology will take customers into the next decade of enterprise SANs.

Jim Zucchero
Global Sales Executive, NetApp team
Broadcom Inc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Executive Summary

A NetApp® Verified Architecture describes systems and solutions that are designed, tested, and documented to facilitate and to improve customer deployments. These designs incorporate a wide range of technologies and products into a portfolio of solutions that NetApp has developed to help meet your business needs.

This NetApp Verified Architecture provides a solution that modernizes your VMware vSphere SAN storage with 32Gb FC and cloud connectivity options, giving your company the fastest cloud-ready solution for mission-critical virtualized workloads.

This document discusses the following topics:

- The challenge that organizations face today with data assets and infrastructure
- The solution enabling your business to apply disruptive future technology nondisruptively
- Ten good reasons to modernize your traditional SAN infrastructure
- A world-class modern SAN verified reference architecture
- Data protection solutions recommended by NetApp for this architecture
- Financial analysis that illustrates a self-funding TCO business case for modernizing SAN infrastructure, yielding:
  - 80% to 90%+ reduction in data center floor space
  - 50% to 90%+ reduction in power and cooling
  - 50% to 80% reduction in labor costs

As mentioned in the foreword, NVMe/FC support was not available for VMware vSphere when this architecture was developed. However, an investment in the modern SAN FC-based architecture described here is future-proofed and supports an easy migration through software upgrade only; no hardware changes are required. You will be able to use FCP, iSCSI, and soon NVMe/FC in VMware installations based on NetApp ONTAP® data management software, after VMware adds NVMe support to its initiator stack. Also, any migrations from FCP to NVMe/FC or back are quite simple, because both protocols can use the same components concurrently. Thus, there is no big cutover from one infrastructure to another.

1.1 The Challenge

The challenge that organizations face today is how to rapidly and nondisruptively transform, modernize, and streamline critical data and IT services to scale and to adapt to customer and business needs. At the same time, these services must be future proof and cloud ready so that an organization can maintain a competitive edge.

Background: According to IDC, by 2020, 50% of Forbes Global 2000 companies will see most of their business depend on their ability to create digitally enhanced products, services, and experiences. Data is the lifeblood of future-thinking companies. The growth and dynamism of this avalanche of new data require modern companies to move in real time with the marketplace. However, for many, their current IT infrastructure isn't up to the task. The growing stress on the entire IT infrastructure to manage this overload of data interferes with the ability to quickly capitalize on the inherent value of the data.

1.2 The Solution

The ONTAP best-in-class SAN solution offers the following benefits:

- The solution has the best performance [1]of any enterprise storage vendor.
- ONTAP has industry-leading availability: better than six nines (31.5 seconds of downtime per year).
- The solution offers comprehensive global support and professional services.
- NetApp was the first SAN vendor to offer end-to-end 32Gb FCP support.
- The solution represents the most complete hybrid multicloud vision in the data storage industry.
- You'll be able to migrate new and existing workloads to new NVMe/FC when the operating systems or hypervisors being used announce support for NVMe/FC.

The bottom line is that migrating to ONTAP improves customer experience and application performance while offering the flexibility to migrate data and applications between FCP, iSCSI, and NVMe/FC.

As a result, CxOs now have the opportunity, and the challenge, to harness the power of data through digital transformation and modernization. They can also use the following emerging best-in-class technologies from world-class industry leaders—NetApp and Broadcom's Brocade and Emulex divisions—to:

- Rapidly deliver and monetize vital digital data services
- Accelerate the pace of innovation
- Acquire, grow, and retain market share
- Improve customer service and experience
- Maximize return on investment
- Protect and secure customers and critical data
- Increase agility and response to changing business needs

1.3 Ten Good Reasons to Modernize Your SAN with NetApp and Broadcom

This document describes a verified, unified, modern SAN solution reference architecture, designed by industry leaders Broadcom and NetApp, with best-in-the-market performance, availability, supportability, and scalability. Using this design, you will enjoy industry-leading performance, availability, and supportability by running VMware with ONTAP FCP SAN. This solution is also very flexible, because you can choose which protocol or protocols to present data with. The solution also offers the option of migrating virtualized environments from existing protocols like FCP or iSCSI to new NVMe-based protocols like NVMe/FC when supported by VMware.

NetApp and Broadcom provide an end-to-end NVMe-powered solution, from host to storage controller, that can help you realize the promise and the benefits of NVMe technology. With a system that yields the fastest [2]access, management, and utilization of critical data, you can accelerate your time to innovation and take advantage of the following benefits:

- **Digitally transform critical business applications.** Enable the next generation of your critical applications, ready for analytics, artificial intelligence (AI), and machine learning capabilities.

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[1] Storage Performance Council A800 SPC-1 Full Disclosure Report: https://spcresults.org/sites/default/files/files/full_disclosure_report/A32007_FDR_1.pdf

[2] Ibid

- **Harness the power of the hybrid cloud.** Cloud-enable your IT services to get the benefits of on-premises storage with the flexibility of public cloud.
- **Get a best-in-class solution for enterprise SAN.** Strengthen your competitive advantage by partnering with the fastest-growing flash, SAN, fabric, and host bus adapter (HBA) leaders.
- **Significantly simplify operations.** Improve IT responsiveness through simplification of SAN management while making performance predictable.
- **Modernize and get significant cost savings.** Improve shareholder value by reducing data center floor space by 80% to 90%+, power and cooling by 50% to 90%+, and labor costs by 50% to 80%.
- **Future-proof your SAN environment.** Nondisruptively adopt disruptive performance and technology advancements when you are ready.
- **Rapidly deliver core IT services.** Take advantage of an open systems solution that supports leading DevOps toolsets to vastly reduce the time to value for development.
- **Don't compromise on availability.** Get 99.9999% availability (an IDC audit of 210,000 systems showed less than 31.5 seconds of downtime per year) and enterprise-grade disaster recovery capabilities.
- **Improve the customer experience.** Accelerate performance, enable instant application cloning, and enable granular data recovery to improve the user experience.
- **Get next-generation enterprise data management.** Combine the value of industry-leading innovation with enterprise availability to deliver the next generation of your SAN environment.

1.4 The Architecture

This NetApp and Broadcom modern SAN NetApp verified reference architecture for VMware vSphere includes the following key NetApp and Broadcom technologies:

- FC Protocol
- Sixth-generation host and fabric technology operating at end-to-end 32Gb FC
- NetApp AFF all-flash arrays with the industry's ultra-low latency NVMe storage

The performance benefits accrue as you adopt these technologies. If you adopt all of them, you get game-changing performance benefits with end-to-end visibility through Brocade Fabric Vision technology. In the future, you will be able to add NVMe/FC, storage-class memory, and persistent memory so that you can realize further increased performance.

2 Program Summary

This document is part of the Modern SAN Best Practices Program, which provides test and validated design and configuration recommendations for next-generation modern FC and NVMe-powered SAN fabrics. It is part of a series that covers the deployment of popular enterprise applications.

This program is a collaboration between Broadcom's Brocade and Emulex divisions and NetApp, who jointly developed the industry's first end-to-end enterprise 32Gb FCP and NVMe architectures. The information is designed to support IT organizations that upgrade their legacy SAN architectures to next-generation NVMe-enabled fabrics to meet the low-latency, high-bandwidth requirements of modern and future enterprise apps.

This document describes the system and solution that were designed, tested, and documented to facilitate modern SAN deployments. These designs incorporate a wide range of technologies and products into a portfolio of solutions that NetApp has developed to meet your business needs. The document also describes the design choices and best practices for this shared infrastructure solution. These design considerations and recommendations are not limited to the specific components that are described in this document; they also apply to other versions of components.

The solution that is described in this document provides the following TCO benefits:

- 80% to 90%+ reduction in data center floor space
- 50% to 90%+ reduction in power and cooling
- 50% to 80% reduction in labor costs

Table 1 shows a cost-benefit analysis, and Table 2 compares legacy SAN and modern SAN that incorporates the joint solution.

Table 1) Cost-benefit analysis of the joint solution.

Value	Analysis Results
Return on investment (ROI)	93%
Net present value (NPV)	>$2 million
Payback period (months)	6 months
Cost reduction	More than $2.2 million saved over a 3-year analysis period compared to the legacy SAN storage system
Savings on power and space	$390,000
Administration cost savings	$230,000

Table 2) Comparison of legacy SAN and NetApp modern SAN.

	Legacy SAN	NetApp Modern SAN
Host connectivity	FC	FC, NVMe/FC
NVMe next-generation support	No	Yes
Unified storage	No	Yes
Staff to manage	2 FTE	½ FTE
Bandwidth	8Gb avg. (max. 16Gb FC)	32Gb
Data migrations	Required	No
Data center footprint	Large	Small

In addition, by integrating secondary storage into your SAN and flash infrastructure, your company can better protect and secure your data while reducing overall costs. Your secondary storage can be a combination of NetApp all-flash arrays for short-term recovery and either an on-premises object store or a public cloud hyperscaler for longer-term retention. For example, the on-premises object store might be the NetApp StorageGRID® storage solution, and the public cloud hyperscaler might be Amazon Web Services (AWS) or Microsoft Azure.

3 Solution Overview

3.1 NetApp and Broadcom Modern SAN Solution Benefits

The NetApp and Broadcom enterprise SAN solution comprises Brocade Gen 6 FC switches, Emulex Gen 6 FC HBAs, and NetApp AFF storage systems. It is a reference architecture, predesigned, best practice configuration that is built on FCP (FC using SCSI command sets) SAN on the latest NetApp and Broadcom technologies.

This solution delivers a baseline configuration and can also be sized and optimized to accommodate many different use cases and requirements. It supports tight integration with virtualized and cloud infrastructures and data protection, making it the logical choice for a long-term investment.

The solution delivers operational efficiency and consistency with the versatility to meet various SLAs and IT initiatives, including:

- Application rollouts or migrations
- Business continuity
- Cloud delivery models (public, private, and hybrid) and service models (infrastructure as a service [IaaS], platform as a service [PaaS], and software as a service [SaaS])
- Asset consolidation and virtualization
- Data center consolidation and footprint reduction

Broadcom and NetApp have thoroughly validated and verified this solution architecture and its many use cases. They have also created a portfolio of detailed documentation, information, presale and post-sale services, and references to assist you in transforming your data center to this shared infrastructure model. This portfolio includes, but is not limited to, the following items:

- Best practice architectural design
- Workload sizing and scaling guidance
- Implementation and deployment instructions
- Technical specifications (rules for what is and what is not a reference architecture)
- FAQs
- NetApp and Broadcom jointly validated designs that focus on various use cases

3.2 Target Audience

The target audience for this document includes the following groups:

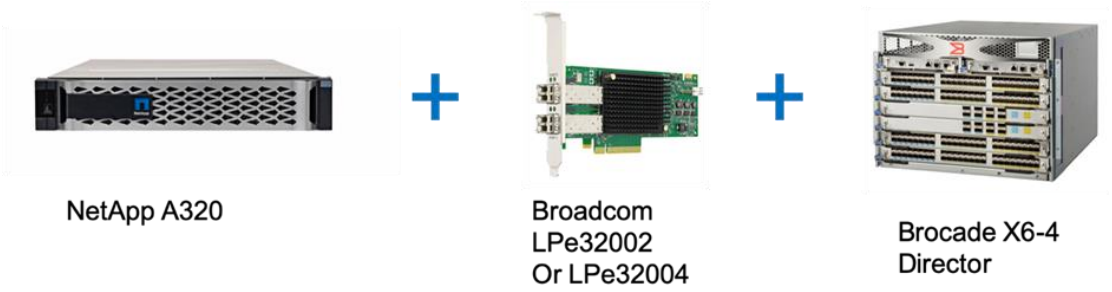
- **The CIO, CTO, and CFO,** who can benefit from the executive summary, use case examples, ROI and TCO information, and information about future strategies.
- **Business information officers,** who can learn new ways to serve line-of-business owners with benefits from modern technologies.
- **Architects, administrators, and solutions engineers** who are responsible for designing and deploying infrastructure for enterprise mission-critical applications.
- **Database administrators,** who require new data management capabilities and performance to serve evolving data requirements.
- **Application owners,** who need real-time, lower-latency data to feed current and newer generations of applications.
- **Virtualization architects and administrators,** who are responsible for designing, deploying, and managing virtualized enterprise mission-critical environments.
- **Data architects,** who require platforms that are designed to enable more real-time analytics and to serve the AI and machine learning requirements that new workloads need.
- **Cloud architects,** who must harness the power of the hybrid cloud and use core and cloud-native solutions.
- **Backup administrators,** who must protect data and apply innovations to make data protection seamless and nondisruptive to the business.
- **Service delivery managers,** who must meet SLAs and service-level objectives (SLOs) that require IT infrastructure and solutions that promote consistent and predictable results.

3.3 Solution Technology

This document focuses on virtualized workloads. We assume some numbers for typical inefficient utilization rates that we see on legacy storage. We also factor in our 2:1 to 4:1 storage efficiency and workload multitenancy benefits when consolidating multiple traditional SAN storage systems into a NetApp AFF A320 configuration.

Figure 1 shows the component families of the solution architecture. Implementation of this solution reduces the footprint, management overhead, maintenance spending, and power and cooling, and it improves service availability and performance.

Figure 1) Component families of the NetApp and Broadcom joint architecture.



Most of today's all-flash arrays are deployed on low-risk, multi-queue-capable, deep-queue-rich, and proven FC-based storage networks, with their robust scalable fabric services and credit-based flow control. Because of their reliability and deterministic performance, FC fabrics serve as the most widely implemented storage network infrastructure for mission-critical applications. Little change is required in the standards to implement NVMe/FC, so the introduction of NVMe/FC along with existing storage is easy, seamless, and noninvasive. And because NVMe/FC can use the same infrastructure components concurrently with other FC traffic, it is easy to migrate workloads at the pace that works for your organization. NVMe/FC also allows the efficient transfer of NVMe commands and structures end to end with no translations.

The world's first end-to-end enterprise NVMe/FC solution with a NetApp all-flash array and Brocade Gen 6 FC network is purpose-built for tomorrow's mission-critical workloads by employing today's infrastructure.

Innovations in storage technology are disrupting the data center industry. Faster media types and more efficient mechanisms to access those media across various well-defined infrastructures are unlocking unprecedented speeds, lower latencies, and dramatic improvements in system and application efficiency and performance. These benefits are based on three advances: NVMe, NVMe over Fabrics (NVMe-oF), and new storage-class memory (SCM). Benefits also come from persistent memory (PMEM) solutions used by NetApp MAX Data, which alters the performance and protection available to virtualized deployments across the SAN, server, and cloud.

The current testing uses available data center solutions, specifically with NVMe/FC Brocade Gen 6 (and other hardware). You can also use Gen 5 switches and other NetApp controllers, such as AFF A700s, A700, and A800 configurations. Future technologies, such as MAX Data, can be integrated with minimal disruption.

NVMe

The NVMe specification is designed to take advantage of NVMEM in all kinds of compute environments, from mobile phones to webscale service providers. It adds substantial I/O path parallelization (65,535 I/O queues, each with a queue depth of up to 64k outstanding I/Os), making communication with storage

systems massively parallel. Because of lower protocol overhead and lower-latency connectivity between servers and storage devices, this parallelization provides greater bandwidth.

Numerous queues and huge queue depths allow today's storage and servers to exploit their increasingly large number of cores and memory. This capability accelerates processing of I/O threads by spreading the processing across multiple CPU cores. This attribute is critical to bring together traditional enterprise applications with real-time analytics workloads, enabling new digital services for the modern enterprise.

NetApp technology is built for the future. With the industry's only unified data management system that supports SAN or NAS, all-flash, software-defined, hybrid, and cloud storage, it works with both existing (traditional) and emerging applications (for example, NoSQL databases and AI). These features and capabilities are all part of your data fabric powered by NetApp. NetApp systems support scaling (up and out) dynamically in seconds or minutes, instead of taking hours or days. And you can allocate applications where they run best across your data fabric, whether it's on the premises or in the cloud. Also, to maximize performance and reduce overall storage cost, NetApp FabricPool allows you to move data automatically between AFF storage solutions and cloud storage tiers.

Broadcom's Brocade and Emulex divisions are leaders in the SAN fabric space. Along with these divisions, NetApp is the first to market with an end-to-end enterprise NVMe/FC solution over a 32Gb FC fabric. With this joint solution, you can enable and accelerate this digital transformation for your enterprise—now.

Brocade G620 Gen 6 FC Switches

Broadcom's Brocade has been the leading provider of storage networking solutions worldwide for more than 20 years, supporting the mission-critical systems and business-critical applications of most large enterprises. Brocade networking solutions help organizations achieve their critical business initiatives as they transition to a world where applications and information can reside anywhere. Today, Brocade is extending its proven data center expertise across the entire network with open, application-optimized, and efficient solutions that are built for consolidation and unmatched business agility.

The sixth generation of FC is aimed at satisfying the needs of growing deployments of flash storage, hyperscale virtualization, and new high-speed data center architectures such as NVMe. Brocade G620 Gen 6 FC switches shatter application performance barriers with up to 100 million IOPS and 32Gb/128Gb FC performance to meet the demands of flash-based storage workloads. Pay-as-you-grow scalability enables organizations like yours to scale from 24 to 64 ports so that you can support your evolving storage environments. Also, Brocade X6-4 with Brocade Fabric Vision technology combines innovative hardware, software, and integrated network sensors to ensure the industry-leading operational stability and redefine application performance. It provides a modular building block for increased scalability to accommodate growth for large-scale enterprise infrastructures. It accelerates application response time by up to 71% across 32Gb links. Built for midsize networks, the 8U Brocade X6-4 has four horizontal blade slots to provide up to 192 32Gb FC device ports and 16 additional 128Gb UltraScale ICL ports. Each blade slot can be populated with two optional blades. For device connectivity, the Brocade FC32-48 FC device port blade provides 48 32Gb FC ports.

Brocade's IO Insight is the industry's first integrated network sensor tool that proactively and nonintrusively monitors real-time storage I/O health and performance statistics for both SCSI and NVMe traffic from any device port on a Gen 6 FC platform. IO Insight then applies this information within an intuitive, policy-based monitoring and alerting suite to quickly identify the root cause of problems at the storage or VM tier. This level of granularity enables quick identification of degraded application performance at the host VM and storage tiers, reducing time to resolution.

IO Insight proactively monitors individual host and storage devices to gain deeper insight into the performance of the network to maintain SLA compliance. To diagnose I/O operational issues, it also obtains total I/Os, first response time, I/O latency (exchange completion time), and outstanding I/O performance metrics for a specific host or storage device. Lastly, it enables tuning of device configurations with integrated I/O metrics to optimize storage performance. You can define preventive

actions such as administrator notifications and port fencing to avoid greater negative impact, as shown in Figure 2.

Figure 2) Configuring IO Insight end-to-end monitoring.

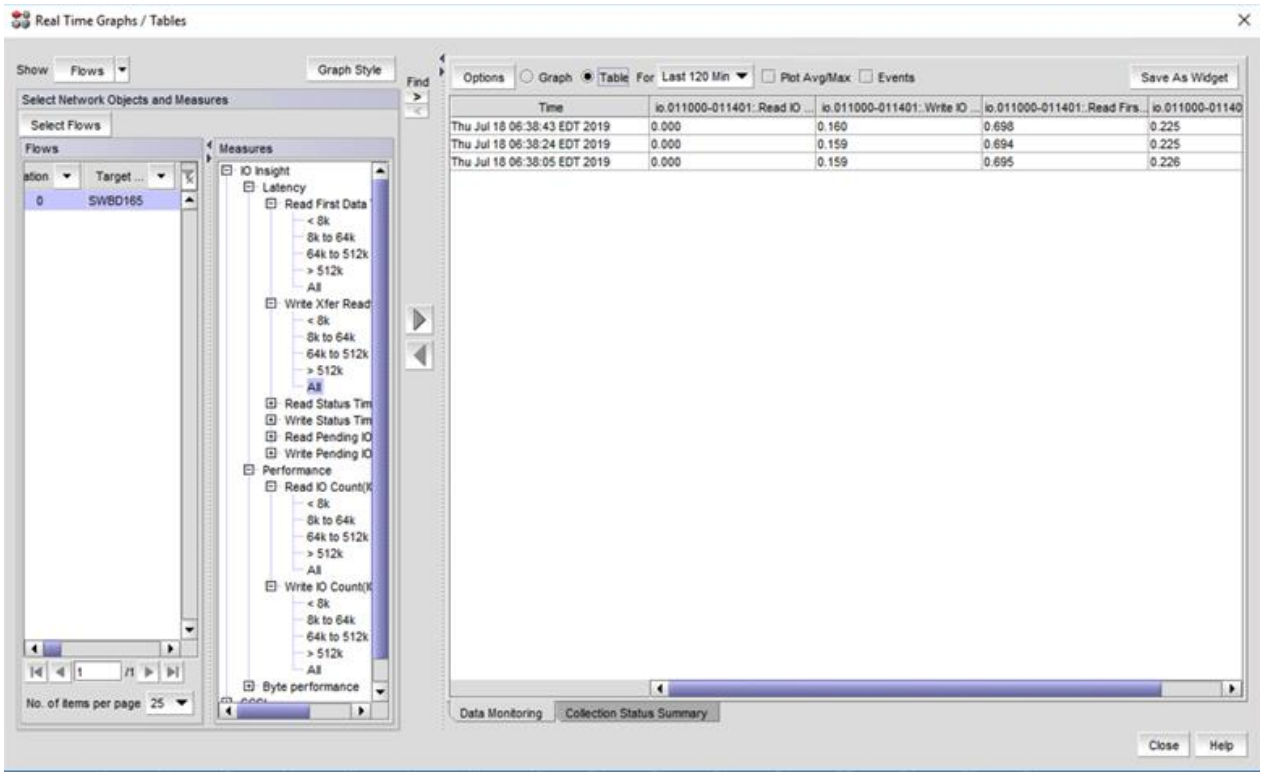


Figure 3 shows the IO Insight real-time flow control.

Figure 3) Monitoring IO Insight real-time flow control.

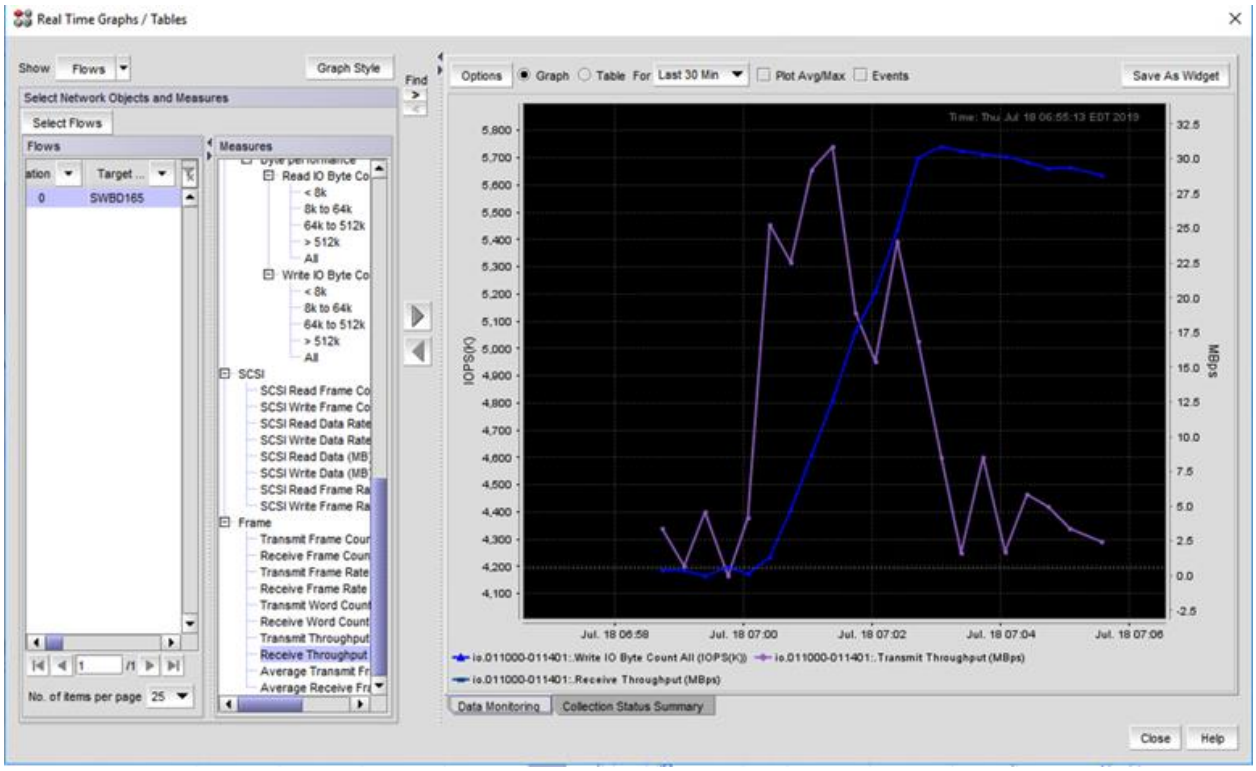
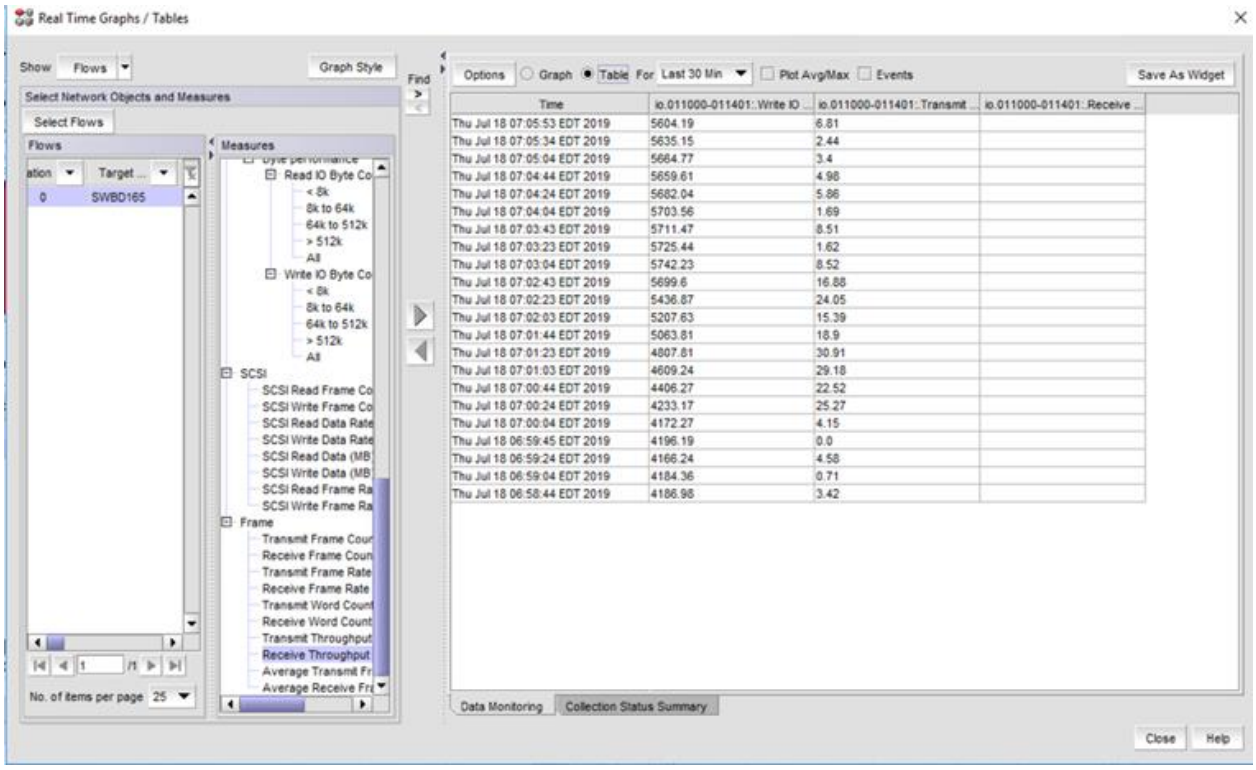


Figure 4 shows the IO Insight flow statistics.

Figure 4) IO Insight flow statistics (table view).



NetApp ONTAP data management software supports both NVMe-oF and SCSI over FC protocols concurrently. Your organization can seamlessly integrate Brocade Gen 6 FC networks with the next generation of low-latency flash storage, without disruptive replacement.

Emulex Gen 6 FC HBAs

Emulex FC HBAs by Broadcom are designed to meet the demanding performance, reliability, and management requirements of modern networked storage systems that use high-performance and low-latency solid-state drives (SSDs). The latest Emulex LPe32002 FC HBAs with dynamic multicore architecture deliver an industry-leading 1.6 million IOPS to any port that needs it, providing high performance when and where it's needed. The LPe32000 series provides 3200MBps per link and up to 12800MBps per card of throughput, low latency, and enhanced manageability. It also provides the highest reliability in the industry (10 million hours mean time between failures) to ensure maximum uptime.

The secure firmware update feature protects and ensures the authenticity of device firmware. Emulex Gen 6 FC HBAs are NVMe/FC-enabled, delivering up to 55% lower insertion latency for NVMe/FC than for SCSI over FC. And for investment protection, these FC HBAs also support both NVMe/FC and FCP (SCSI over FC protocol) concurrently.

NetApp ONTAP Tools for VMware vSphere

NetApp offers several standalone software tools that can be used with NetApp ONTAP and VMware vSphere to manage your virtualized environment. NetApp Virtual Storage Console (VSC) is a VMware vCenter plug-in that simplifies storage management and efficiency features, enhances availability, and reduces storage costs and operational overhead, whether you're 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, VSC is recommended as a best practice when you use vSphere with systems running ONTAP software. It includes both a VSC server appliance and UI extensions for vCenter.

Other ONTAP tools not used in this NetApp Verified Architecture include:

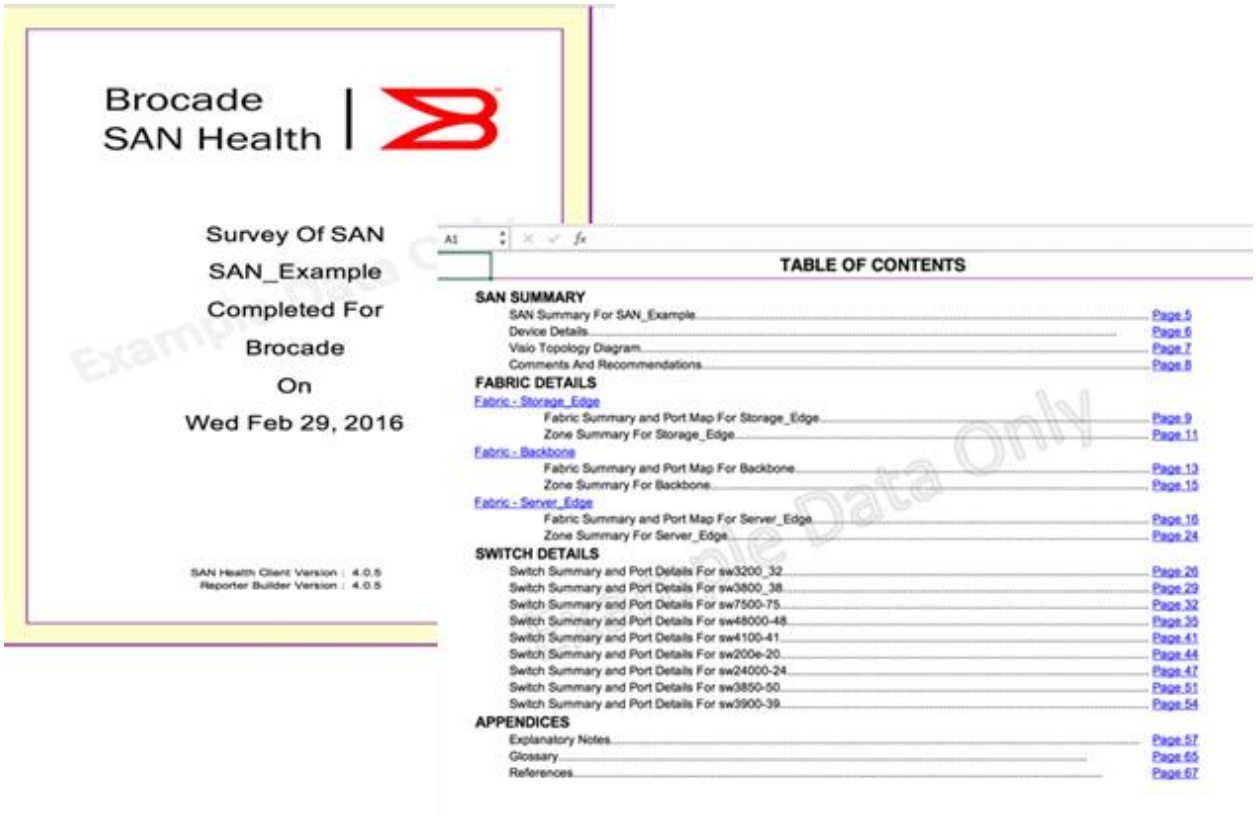
- NetApp NFS Plug-In for VMware VAAI, which enables you to use vSphere Storage APIs Array Integration (VAAI) offload features with NFS storage
- NetApp VASA Provider for ONTAP to enable VMware Virtual Volumes (VVols) support
- The VMware Storage Replication Adapter used together with VMware Site Recovery Manager to manage data replication between production and disaster recovery sites

Brocade SAN Health

Your storage architecture is critical for your business agility and success. Brocade's free SAN Health tool delivers clear insights into performance, inventory, and bottlenecks to optimize your SAN infrastructure and to align it with your business needs. This hardware-agnostic and easy-to-run tool generates personalized storage network performance and inventory reports to help you prevent issues, avoid application downtime, reduce troubleshooting time to resolution, and improve capacity planning and productivity. Figure 5 shows the components of the SAN Health tool, and Figure 6 shows how to use it.

To sign up for a SAN Health check or to get a copy of the NetApp branded SAN Health tool, contact your NetApp account team.

Figure 5) SAN Health report title page and table of contents.



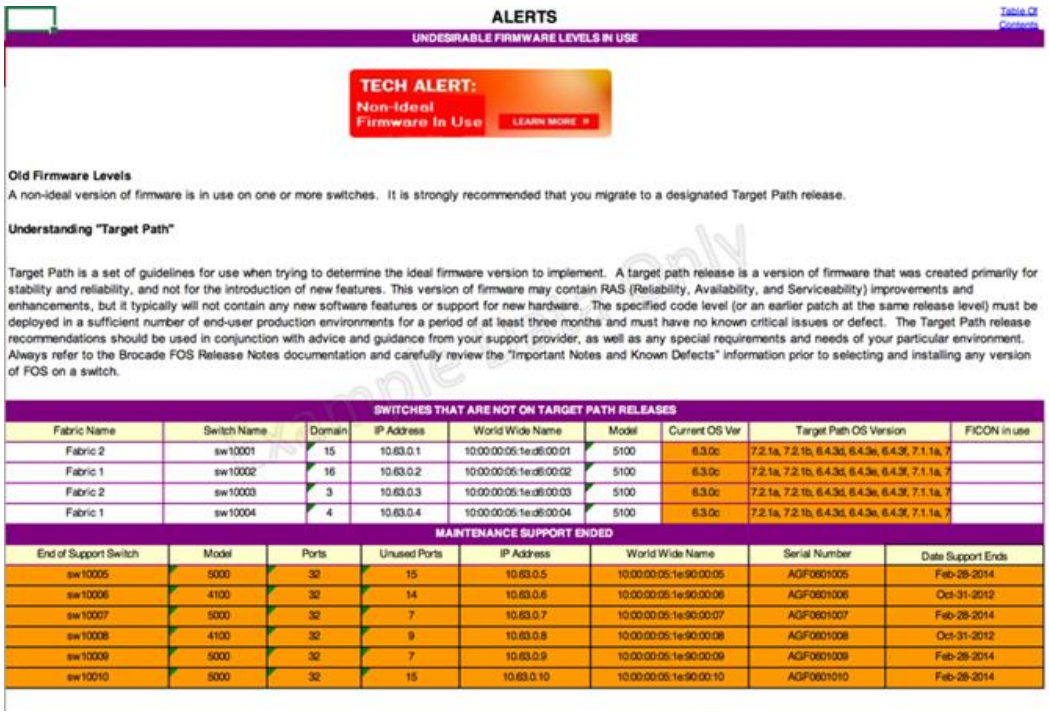
Brocade
SAN Health

Survey Of SAN
SAN_Example
Completed For
Brocade
On
Wed Feb 29, 2016

SAN Health Client Version : 4.0.5
Reporter Builder Version : 4.0.5

TABLE OF CONTENTS

Figure 6) SAN Health color-coded alerts and warnings.



ALERTS

Table Of Contents

UNDESIRABLE FIRMWARE LEVELS IN USE

TECH ALERT:
Non-Ideal Firmware In Use
LEARN MORE »

Old Firmware Levels

A non-ideal version of firmware is in use on one or more switches. It is strongly recommended that you migrate to a designated Target Path release.

Understanding "Target Path"

Target Path is a set of guidelines for use when trying to determine the ideal firmware version to implement. A target path release is a version of firmware that was created primarily for stability and reliability, and not for the introduction of new features. This version of firmware may contain RAS (Reliability, Availability, and Serviceability) improvements and enhancements, but it typically will not contain any new software features or support for new hardware. The specified code level (or an earlier patch at the same release level) must be deployed in a sufficient number of end-user production environments for a period of at least three months and must have no known critical issues or defect. The Target Path release recommendations should be used in conjunction with advice and guidance from your support provider, as well as any special requirements and needs of your particular environment. Always refer to the Brocade FOS Release Notes documentation and carefully review the "Important Notes and Known Defects" information prior to selecting and installing any version of FOS on a switch.

SWITCHES THAT ARE NOT ON TARGET PATH RELEASES

Fabric Name	Switch Name	Domain	IP Address	World Wide Name	Model	Current OS Ver	Target Path OS Version	FICON in use
Fabric 2	sw10001	15	10.63.0.1	10:00:00:05:1e:d6:00:01	5100	6.3.0c	7.2.1a, 7.2.1b, 6.4.3d, 6.4.3e, 6.4.3f, 7.1.1a, 7	
Fabric 1	sw10002	16	10.63.0.2	10:00:00:05:1e:d6:00:02	5100	6.3.0c	7.2.1a, 7.2.1b, 6.4.3d, 6.4.3e, 6.4.3f, 7.1.1a, 7	
Fabric 2	sw10003	3	10.63.0.3	10:00:00:05:1e:d6:00:03	5100	6.3.0c	7.2.1a, 7.2.1b, 6.4.3d, 6.4.3e, 6.4.3f, 7.1.1a, 7	
Fabric 1	sw10004	4	10.63.0.4	10:00:00:05:1e:d6:00:04	5100	6.3.0c	7.2.1a, 7.2.1b, 6.4.3d, 6.4.3e, 6.4.3f, 7.1.1a, 7	

MAINTENANCE SUPPORT ENDED

End of Support Switch	Model	Ports	Unused Ports	IP Address	World Wide Name	Serial Number	Date Support Ends
sw10005	5000	32	15	10.63.0.5	10:00:00:05:1e:90:00:05	AGF0601005	Feb-28-2014
sw10006	4100	32	14	10.63.0.6	10:00:00:05:1e:90:00:06	AGF0601006	Oct-31-2012
sw10007	5000	32	7	10.63.0.7	10:00:00:05:1e:90:00:07	AGF0601007	Feb-28-2014
sw10008	4100	32	9	10.63.0.8	10:00:00:05:1e:90:00:08	AGF0601008	Oct-31-2012
sw10009	5000	32	7	10.63.0.9	10:00:00:05:1e:90:00:09	AGF0601009	Feb-28-2014
sw10010	5000	32	15	10.63.0.10	10:00:00:05:1e:90:00:10	AGF0601010	Feb-28-2014

Figure 7 is a SAN Health Visio diagram that illustrates the fabric layout and useful objects.

Figure 7) SAN Health Visio fabric layout and useful objects.

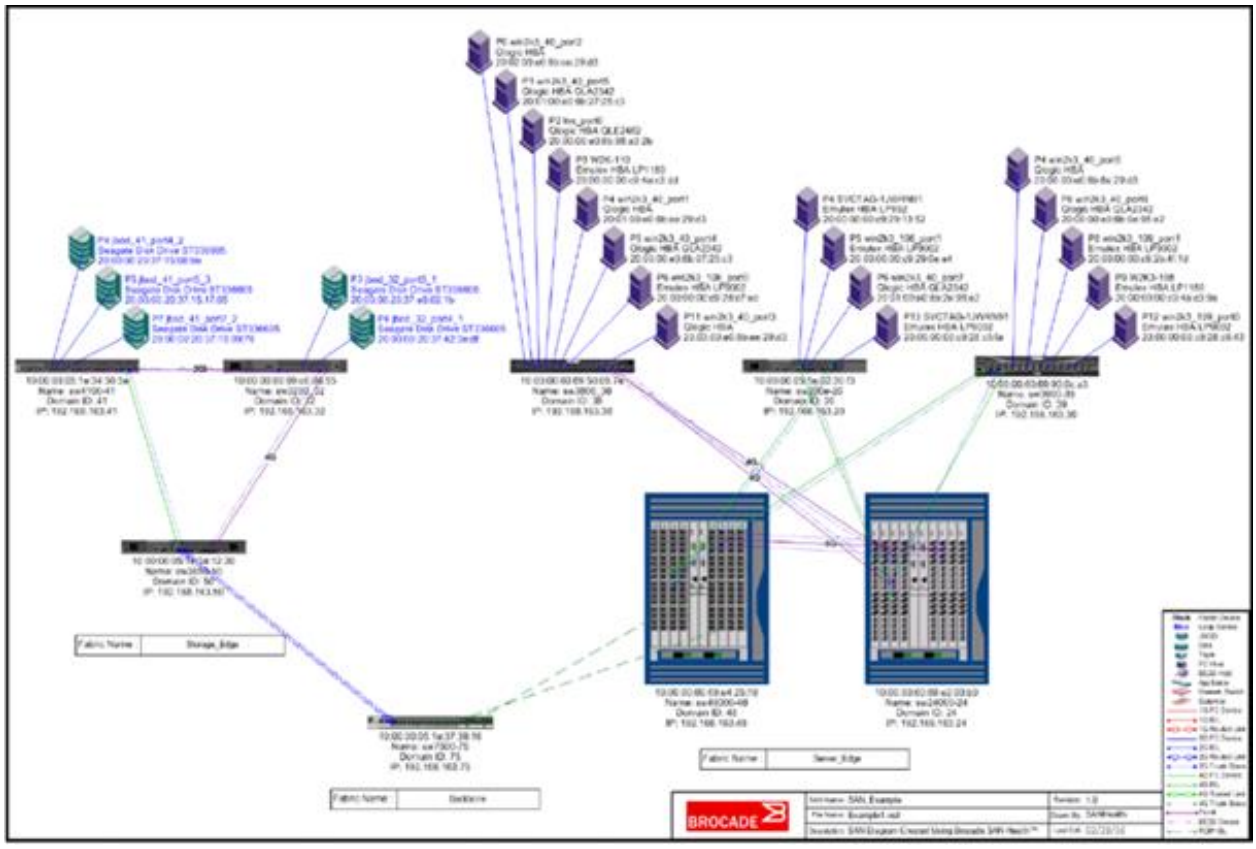
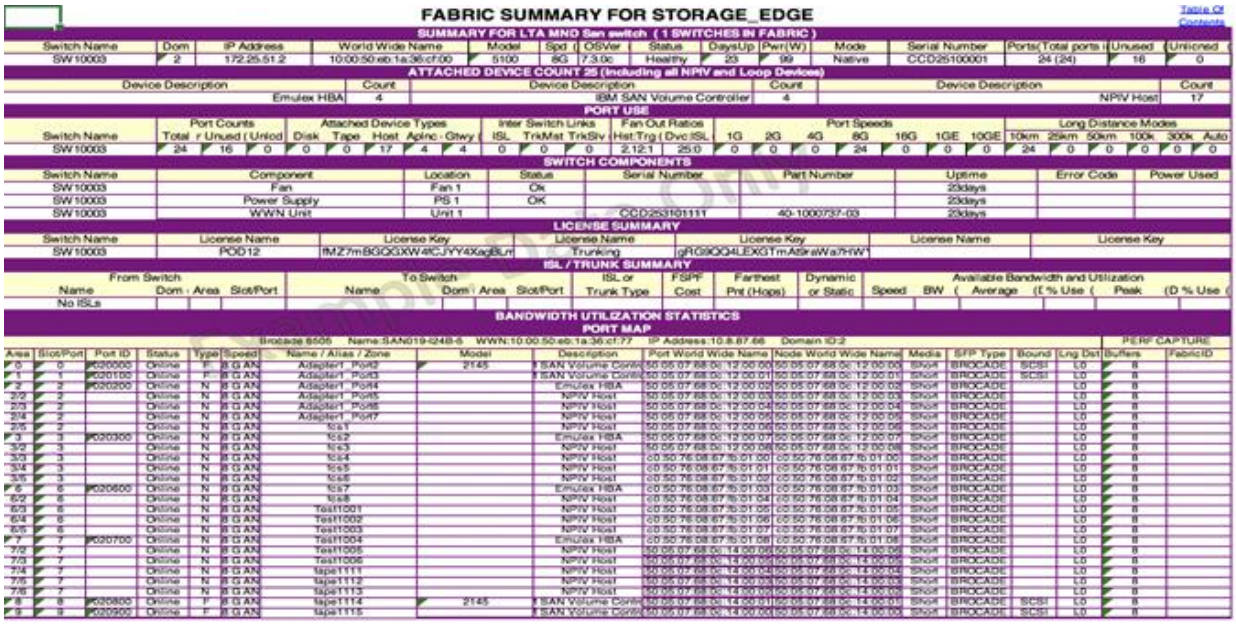


Figure 8 is a comprehensive SAN Health summary that details the current configuration and best practice, health, and configuration checks.

Figure 8) SAN Health summary.



FABRIC SUMMARY FOR STORAGE_EDGE

SUMMARY FOR LTA MND San switch (1 SWITCHES IN FABRIC)

Switch Name	Dom	IP Address	World Wide Name	Model	Spd	OSVer	Status	DaysUp	Pwr(W)	Mode	Serial Number	Ports(Total ports	Unused	Unlicned
SW10003	2	172.25.51.2	10:00:50:eb:1a:36:cf:00	5100	8G	7.3.0c	Healthy	23	99	Native	CCD25100001	24 (24)	16	0

ATTACHED DEVICE COUNT 25 (Including all NPIV and Loop Devices)

Device Description	Count	Device Description	Count	Device Description	Count
Emulex HBA	4	IBM SAN Volume Controller	4	NPIV Host	17

PORT USE

Switch Name	Port Counts Total	Unused	Unlicd	Attached Device Types Disk	Tape	Host	Aplnc	Gtwy	Inter Switch Links ISL	TrkMst	TrkSlv	Fan Out Ratios Hist Trg	Dyc ISL	Port Speeds 1G	2G	4G	8G	16G	1GE	10GE	Long Distance Modes 10km	25km	50km	100k	300k	Auto
SW10003	24	16	0	0	0	17	4	4	0	0	0	2.12:1	25:0	0	0	0	24	0	0	0	24	0	0	0	0	0

SWITCH COMPONENTS

Switch Name	Component	Location	Status	Serial Number	Part Number	Uptime	Error Code	Power Used
SW10003	Fan	Fan 1	Ok			23days		
SW10003	Power Supply	PS 1	OK			23days		
SW10003	WWN Unit	Unit 1		CCD2531011	40-1000737-03	23days		

LICENSE SUMMARY

Switch Name	License Name	License Key	License Name	License Key	License Name	License Key
SW10003	POD12	fMZ7mBGQGXW4fCJYY4XagELn	Trunking	gRG9QQ4LEXGTmAtlraWa7HW1		

ISL / TRUNK SUMMARY

From Switch Name	Dom	Area	Slot/Port	To Switch Name	Dom	Area	Slot/Port	ISL or Trunk Type	FSPF Cost	Farthest Pnt (Hops)	Dynamic or Static	Available Bandwidth and Utilization Speed	BW	Average	(E % Use	Peak	(D % Use
No ISLs																	

BANDWIDTH UTILIZATION STATISTICS

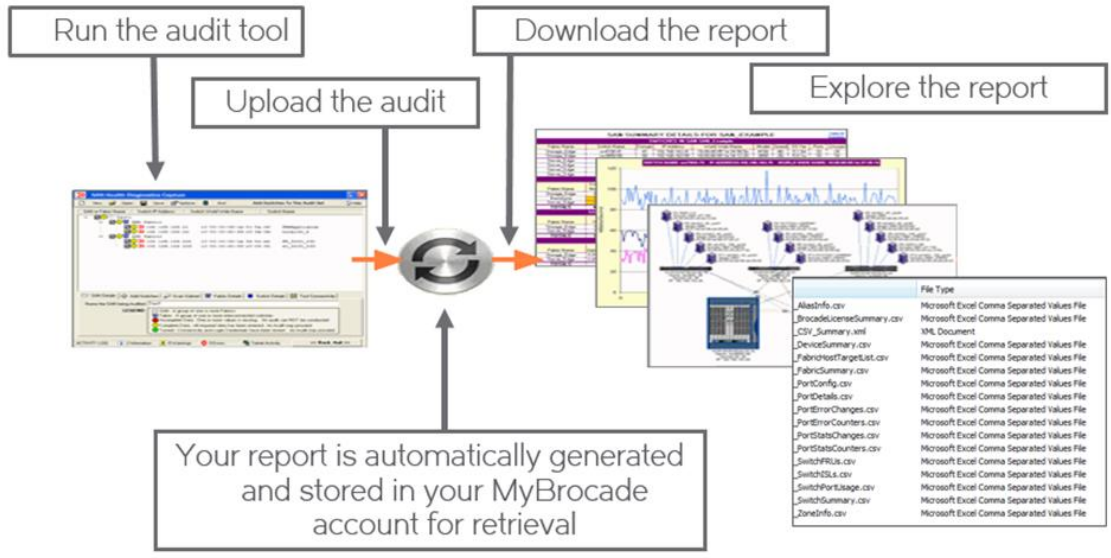
PORT MAP

Brocade 6505 Name:SAN019-6248-6 WWN:10:00:50:eb:1a:36:cf:77 IP Address:10.8.87.66 Domain ID:2

Area	Slot/Port	Port ID	Status	Type	Speed	Name / Alias / Zone	Model	Description	Port World Wide Name	Node World Wide Name	Media	SFP Type	Bound	Lng Dist	PERF CAPTURE Buffers	FabricID
0	0	020000	Online	F	8 G AN	Adapter1 Port2	2145	SAN Volume Contro	50:05:07:68:0c:12:00:00	50:05:07:68:0c:12:00:00	SW/fi	BROCADE	SCSI	LO	8	
1	1	020100	Online	F	8 G AN	Adapter1 Port3		SAN Volume Contro	50:05:07:68:0c:12:00:01	50:05:07:68:0c:12:00:01	SW/fi	BROCADE	SCSI	LO	8	
2	2	020200	Online	N	8 G AN	Adapter1 Port4		Emulex HBA	50:05:07:68:0c:12:00:02	50:05:07:68:0c:12:00:02	SW/fi	BROCADE		LO	8	
2/2	2		Online	N	8 G AN	Adapter1 Port5		NPIV Host	50:05:07:68:0c:12:00:03	50:05:07:68:0c:12:00:03	SW/fi	BROCADE		LO	8	
2/3	2		Online	N	8 G AN	Adapter1 Port6		NPIV Host	50:05:07:68:0c:12:00:04	50:05:07:68:0c:12:00:04	SW/fi	BROCADE		LO	8	
2/4	2		Online	N	8 G AN	Adapter1 Port7		NPIV Host	50:05:07:68:0c:12:00:05	50:05:07:68:0c:12:00:05	SW/fi	BROCADE		LO	8	
2/5	2		Online	N	8 G AN	tes1		NPIV Host	50:05:07:68:0c:12:00:06	50:05:07:68:0c:12:00:06	SW/fi	BROCADE		LO	8	
3	3	020300	Online	N	8 G AN	tes2		Emulex HBA	50:05:07:68:0c:12:00:07	50:05:07:68:0c:12:00:07	SW/fi	BROCADE		LO	8	
3/2	3		Online	N	8 G AN	tes3		NPIV Host	50:05:07:68:0c:12:00:08	50:05:07:68:0c:12:00:08	SW/fi	BROCADE		LO	8	
3/3	3		Online	N	8 G AN	tes4		NPIV Host	c0:50:76:08:67:fb:01:00	c0:50:76:08:67:fb:01:00	SW/fi	BROCADE		LO	8	
3/4	3		Online	N	8 G AN	tes5		NPIV Host	c0:50:76:08:67:fb:01:01	c0:50:76:08:67:fb:01:01	SW/fi	BROCADE		LO	8	
3/5	3		Online	N	8 G AN	tes6		NPIV Host	c0:50:76:08:67:fb:01:02	c0:50:76:08:67:fb:01:02	SW/fi	BROCADE		LO	8	
6	6	020600	Online	N	8 G AN	tes7		Emulex HBA	c0:50:76:08:67:fb:01:03	c0:50:76:08:67:fb:01:03	SW/fi	BROCADE		LO	8	
6/2	6		Online	N	8 G AN	tes8		NPIV Host	c0:50:76:08:67:fb:01:04	c0:50:76:08:67:fb:01:04	SW/fi	BROCADE		LO	8	
6/3	6		Online	N	8 G AN	Test1001		NPIV Host	c0:50:76:08:67:fb:01:05	c0:50:76:08:67:fb:01:05	SW/fi	BROCADE		LO	8	
6/4	6		Online	N	8 G AN	Test1002		NPIV Host	c0:50:76:08:67:fb:01:06	c0:50:76:08:67:fb:01:06	SW/fi	BROCADE		LO	8	
6/5	6		Online	N	8 G AN	Test1003		NPIV Host	c0:50:76:08:67:fb:01:07	c0:50:76:08:67:fb:01:07	SW/fi	BROCADE		LO	8	
7	7	020700	Online	N	8 G AN	Test1004		Emulex HBA	c0:50:76:08:67:fb:01:08	c0:50:76:08:67:fb:01:08	SW/fi	BROCADE		LO	8	
7/2	7		Online	N	8 G AN	Test1005		NPIV Host	50:05:07:68:0c:14:00:06	50:05:07:68:0c:14:00:06	SW/fi	BROCADE		LO	8	
7/3	7		Online	N	8 G AN	Test1006		NPIV Host	50:05:07:68:0c:14:00:07	50:05:07:68:0c:14:00:07	SW/fi	BROCADE		LO	8	
7/4	7		Online	N	8 G AN	tape1111		NPIV Host	50:05:07:68:0c:14:00:04	50:05:07:68:0c:14:00:04	SW/fi	BROCADE		LO	8	
7/5	7		Online	N	8 G AN	tape1112		NPIV Host	50:05:07:68:0c:14:00:03	50:05:07:68:0c:14:00:03	SW/fi	BROCADE		LO	8	
7/6	7		Online	N	8 G AN	tape1113		NPIV Host	50:05:07:68:0c:14:00:05	50:05:07:68:0c:14:00:05	SW/fi	BROCADE		LO	8	
8	8	020800	Online	F	8 G AN	tape1114	2145	SAN Volume Contro	50:05:07:68:0c:14:00:01	50:05:07:68:0c:14:00:01	SW/fi	BROCADE	SCSI	LO	8	
9	9	020900	Online	F	8 G AN	tape1115		SAN Volume Contro	50:05:07:68:0c:14:00:00	50:05:07:68:0c:14:00:00	SW/fi	BROCADE	SCSI	LO	8	

Figure 9 shows the steps that are required to run and use SAN Health.

Figure 9) Using SAN Health.



VMware vSphere

There are many reasons why more than 50,000 customers have selected ONTAP software as their storage solution for VMware vSphere. For example, ONTAP provides a unified storage system supporting both SAN and NAS protocols, robust data protection capabilities through 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 that your host resources are focused on

application workloads, but also avoids random performance impacts to applications from storage operations.

Combining ONTAP software with VMware vSphere allows you to reduce host hardware and VMware software expenses, make sure data is protected at lower cost, and provide consistent high performance. Virtualized workloads are mobile. Therefore, you can explore different storage approaches by using VMware Storage vMotion to move VMs across VMware Virtual Machine File System (VMFS), NFS, or VVols datastores, all on the same storage system.

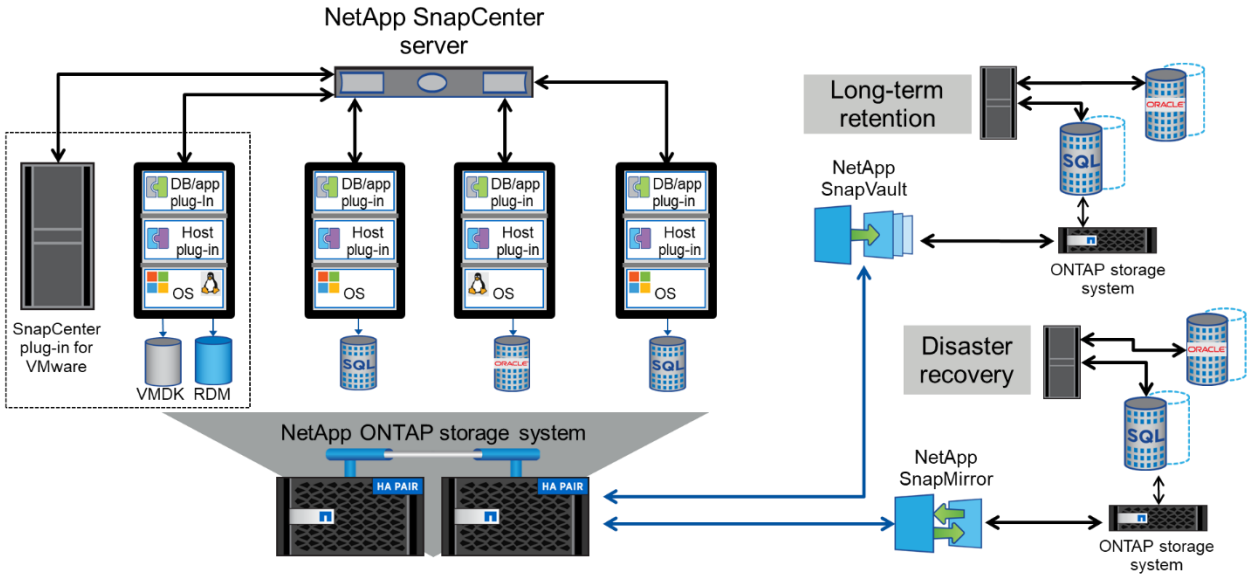
Data Protection

Backing up your VMs and quickly recovering them are among the great strengths of ONTAP for vSphere. It is easy to manage these capabilities in vCenter with VSC and NetApp SnapCenter® software. Use Snapshot copies to make quick copies of your VM or datastore without affecting performance, and then send them to a secondary system by using NetApp SnapMirror® or NetApp SnapVault® technology for longer-term, off-site data protection. This approach minimizes storage space and network bandwidth by storing only changed information.

SnapCenter provides a unified, scalable system for application-consistent data protection and clone management. This software simplifies backup, restore, and clone lifecycles through the creation of backup policies that can be applied to multiple jobs. These policies can define schedule, retention, replication, and other capabilities. They allow optional selection of VM-consistent snapshots; this approach uses the hypervisor's ability to quiesce I/O before taking a VMware snapshot. However, because of the performance impact 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 data.

These plug-ins offer extended capabilities to protect the databases in both physical and virtual environments. With vSphere, you can use these plug-ins to protect SQL Server or Oracle databases where data is stored on raw device mapping (RDM) LUNs, iSCSI LUNs directly connected to the guest OS, or Virtual Machine Disk (VMDK) files on either VMFS or NFS datastores. The plug-ins allow specification of different types of database backups, such as 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. Figure 10 is an example of a SnapCenter deployment.

Figure 10) SnapCenter deployment example.



The power of ONTAP Snapshot copies is extended further with FabricPool. This data fabric technology allows cold snapshot blocks to automatically move to a separate object storage tier to increase the number of Snapshot copies that can be maintained (up to 1,023) while reducing the cost of storage. This object tier can be in the form of a private cloud (such as NetApp StorageGRID) or a public cloud (such as AWS or Azure). The solution moves cold data to the cloud as the blocks age but is recalled automatically if the Snapshot copy is needed to recover a VM or entire datastore.

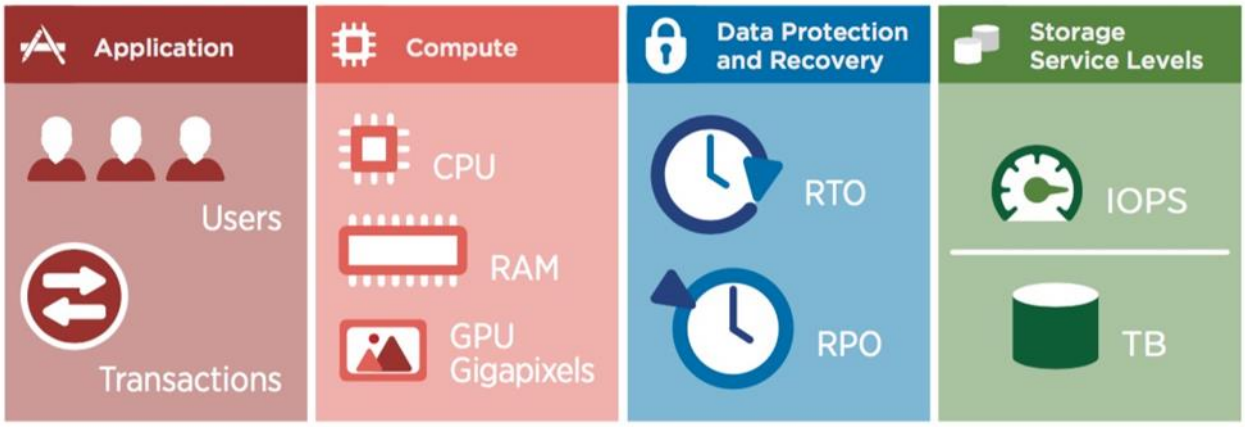
Service-Level Design and Management

Today's successful IT organizations are taking a new approach to meeting the expectations for more predictable storage costs, performance, and agility for IT services. Instead of managing assets, they are starting to manage services on a shared infrastructure and operate their IT like a service provider. Connecting technology to your business is key to a successful transition. NetApp can help you get started.

A NetApp Professional Services hybrid multicloud advisory engagement or a hybrid multicloud architecture and design engagement helps bridge the gap between technology and business. These engagements create a strategy for enabling your IT to function like a service provider. They provide key service delivery metrics and recommendations for delivering consistent storage service levels by using all-flash storage or a combination of flash and high-density disks. Figure 11 shows service consumption metrics.

For more information about how these engagements can help you build the right strategy for aligning service levels to your business needs, contact your local NetApp sales representative.

Figure 11) Service consumption metrics for IT services.



RTO = recovery time objective; RPO = recovery point objective.

Quality of service (QoS) addresses many problems simultaneously. It enables a predictable cost per gigabyte and provides a performance commitment to applications and storage consumers. Nearly every storage performance underdelivery problem is caused by an overdelivery somewhere else.

Simply overbuying infrastructure doesn't solve this problem, because any one application can consume all the available IOPS from the allocated storage resources. Without QoS, the performance cost of any volume in your system is completely random, regardless of the underlying media.

SSDs are creating a problem for shared infrastructure: The drives are faster than the components that are above them. Just a small amount of storage can overwhelm the controller resources. By basing storage resource allocations on priorities, QoS solves this problem. This approach allows architects to design storage solutions that protect workloads from each other on shared storage. Architects can also design solutions that guarantee that each workload has the resources that it needs regardless of what other

workloads in the solution are doing. These benefits in turn allow greater amounts of SSD capability to be attached to controllers without stranding storage or causing unacceptable latency.

Some organizations don't implement QoS because of the complexity and cost of managing individual settings for hundreds or thousands of volumes. Using pre-defined performance service levels simplifies the task of managing QoS settings at the volume level.

Professional Services

NetApp and its partner network have an extensive portfolio of services to facilitate successful deployment of your modern SAN environment or your cloud-connected flash storage array:

- **Storage implementation services.** Get your new storage systems up and running quickly with help from our experts.
- **Data migration services.** We have a long history of successful data migrations from other manufacturers' arrays. Take the stress and worry out of the equation by having NetApp perform the migration.
- **NetApp OnCommand® Insight services.** Quickly achieve full effectiveness and business impact of OnCommand Insight through the deep knowledge and expertise of our experts.

3.4 Use Case Summary

The use case for virtualizing enterprise applications is well known. Not only does virtualization reduce costs through physical consolidation of servers and storage, which increases asset utilization, it also provides business flexibility. New server instances can be provisioned in moments to address urgent business needs. Furthermore, automation (the software-defined data center) can be applied to enable greater consistency, reducing problems that affect availability and data security.

Yet enterprises today face new imperatives that a modern SAN approach can address simply and quickly. Here are some of the ways NetApp and Broadcom customers are adding value with ONTAP.

Table 3) ONTAP value for the virtualization use case.

Benefit	Description
Cloud	ONTAP facilitates a broad array of hybrid cloud options. These options help enterprises combine public and private clouds to add flexibility and reduce their infrastructure management overhead. You can use cloud offerings from Azure, AWS, IBM, Google, and others with integrated ONTAP offerings for data protection, cloud computing, and business continuance while avoiding provider lock-in.
Data protection	Integrated data protection using Snapshot copies and cloning will speed virtual storage provisioning, and it offers better protection of critical data than external protection systems do. SnapCenter software adds advanced application-level data protection for many enterprise applications, even when they are deployed in a VM.
Cost efficiency	Integrated storage efficiency allows ONTAP to significantly reduce storage costs over legacy SAN systems. NetApp AFF systems can run all storage efficiency capabilities in production with no performance impact—something most other SAN arrays cannot do. Because of ONTAP storage efficiency features, customers have seen savings of up to 5:1 for virtual server infrastructure and up to 30:1 for virtual desktop infrastructure. NetApp makes it simple to plan for these efficiency benefits with the most effective guarantee available.

Benefit	Description
Security	ONTAP offers a range of features to meet an organization's security needs. NetApp Volume Encryption (NVE) can be enabled quickly on any ONTAP volume and doesn't require an external key server. You can also use it to enable digital shredding of data. Or you can use NetApp Storage Encryption with self-encrypting disks for full disk encryption. Many customers use Snapshot copies to protect against malware and ransomware, and to increase protection, you can make Snapshot copies immutable by using NetApp SnapLock® software (see TR-4572 for more information).
Performance	As described throughout this document, a modern SAN solution using 32Gb FC SAN or NVMe/FC can meet the ever-faster performance requirements demanded by today's global, always-on enterprise.
Flexibility	Needs change quickly in today's organizations, and ONTAP is quick to adapt. Most of these capabilities are included with an ONTAP system at no additional charge or can be enabled with a license key. And although the focus of this NetApp Verified Architecture is SAN, the unified storage capabilities of ONTAP make it simple to add NAS protocols to support other applications and file sharing.

4 Technology Available from NetApp That Supports NVMe/FC

This section covers the minimum technology requirements for the NetApp and Broadcom NVMe/FC verified architecture.

Note: These specifications are also excellent building blocks for optimizing NetApp ONTAP modern SAN environments.

4.1 Hardware Requirements

Table 4) Hardware requirements for the joint solution.

Hardware	Components
NetApp AFF	AFF C190, A300, A320, A700, A700s, A800 high-availability (HA) pair with 32Gb FC target ports and at least 24 SAS 960GB SSDs
Switches	X6 Directors, G630, G620, and G610 Switches
FC HBAs	Emulex LPe32002-M2 32Gb FC
x86 servers	–

4.2 Software Requirements

Table 5) Software requirements for the joint solution.

Software	Version
NetApp ONTAP	9.1 or later
Brocade Fabric OS (FOS)	8.1.0a or later
Emulex firmware	FV11.4.204.25 DV11.4.354.0

Software	Version
VMware	vSphere 6.0 or later

4.3 Technology Used During Testing

This section covers the technology used in our lab for this NetApp and Broadcom verified architecture.

Table 6) Hardware used for the joint solution.

Hardware	Quantity
NetApp AFF A320 HA pair with four 32Gb FC target ports and 24 SAS 960GB SSDs	1
Switches Brocade X6-4 256 32Gb FC ports director	1
FC HBAs Emulex LPe32002-M2 32Gb FC	10
x86 servers Fujitsu RX2540 M2	10

Table 7) Software used for the joint solution.

Software	Version
NetApp ONTAP	9.6 RC1
Brocade FOS	8.2.1b
Emulex firmware	FV11.4.204.25 DV11.4.354.0
VMware	ESXi 6.7.0. 10302608

4.3 Testbed Design

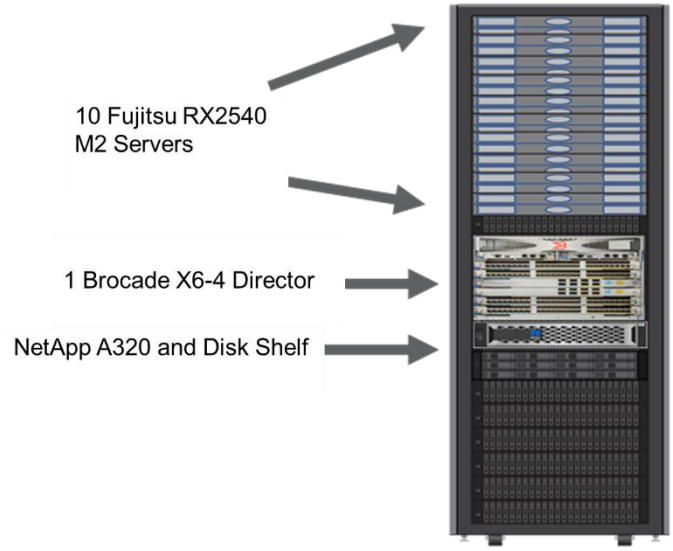
This section provides details for the tested configurations as well as an overview of the hardware that was used for the performance results.

Figure 12 shows that our solution was deployed with a Brocade X6-4 32Gb FCP director. Each storage node had four ports connected to the FCP switch. Each server had two ports connected to the switch. At no point in the testing did the network connectivity create a bottleneck.

For Ethernet connectivity, each of the 10 hosts had both 1Gb and 10Gb links for management, vMotion, and other provisioning traffic.

Each of the 10 ESXi hosts had two FCP ports that were connected to the Brocade director. Each AFF A320 node had four FCP target ports that were also connected to the same director, for eight total connected target ports. For FCP, we configured the Brocade director with port zoning to map port 1 of each ESXi host to the first port of each of the AFF A320 storage nodes. Similarly, we mapped port 2 of each ESXi host to the second of each of the AFF A320 storage nodes.

Figure 12) NetApp and Broadcom validated architecture testbed layout.



4.4 Workload Design

To verify this architecture, we used an industry-standard VM tiling benchmark to present load across multiple hosts. In the next edition of this document, we will use this benchmark to compare performance between 32Gb FC and 32Gb NVMe/FC protocols.

5 Solution Verification

NetApp studied the performance of an AFF A320 storage system. The following subsections describe the test methodology that we used to verify the architecture while we ran a suite of synthetic workloads.

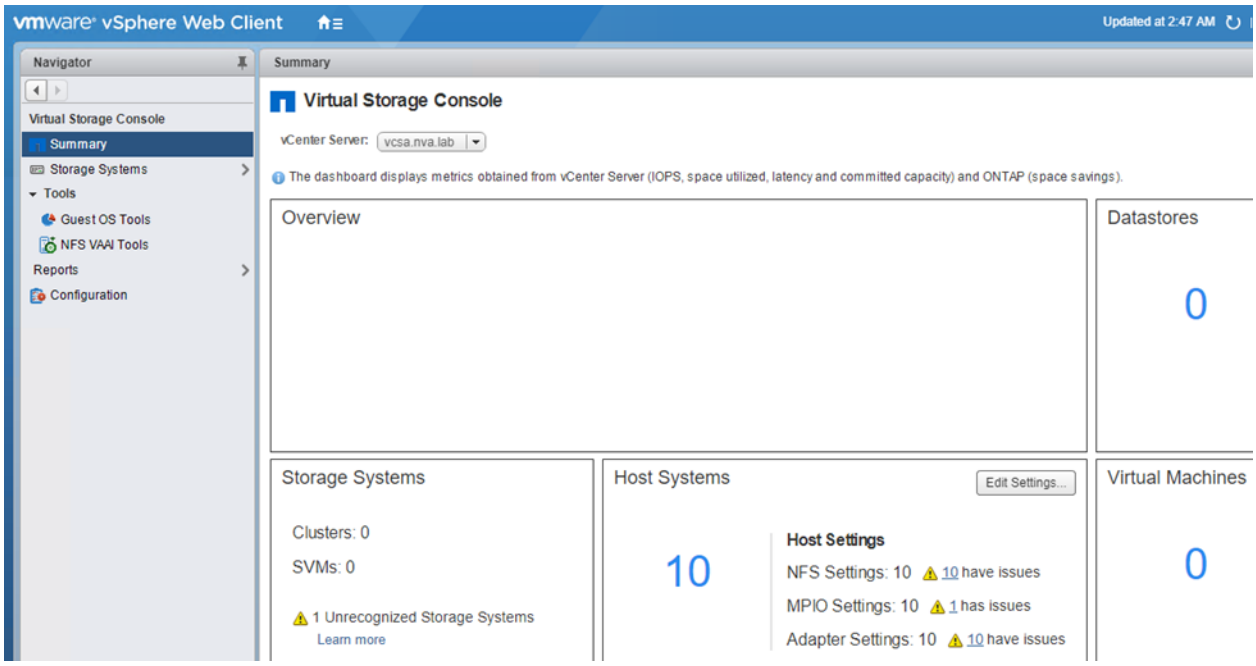
5.1 Test Methodology

The following test methodology was used to verify the architecture:

- VMware ESXi 6.7 was installed on 10 hosts.
- The NetApp AFF A320 storage system contained two nodes, with a single disk aggregate on each node.
- FCP was configured by using a single NetApp ONTAP storage virtual machine (SVM).
- VSC was used to configure host settings to best practices.

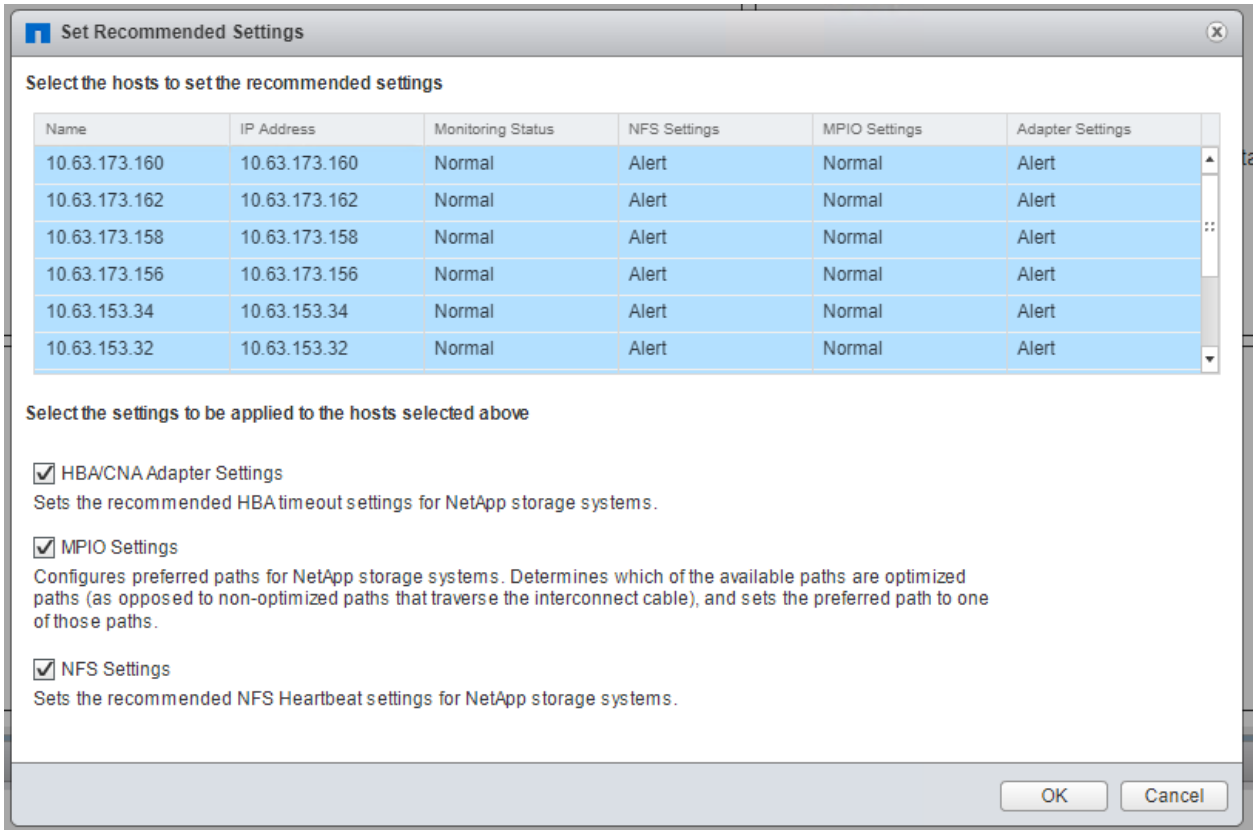
Figure 13 shows the VSC dashboard reporting issues on some hosts.

Figure 13) VSC dashboard host settings.



Selecting Edit Settings allows you to review and update host settings, as shown in Figure 14.

Figure 14) Specifying host settings with VSC.



An ONTAP best practice for VMware vSphere is to use a single LUN for each datastore, with a recommended size of 4TB to 8TB. This size is a good balance point for performance, ease of management, and data protection (using either tape backup or remote replication). Datastores were provisioned through VSC by using:

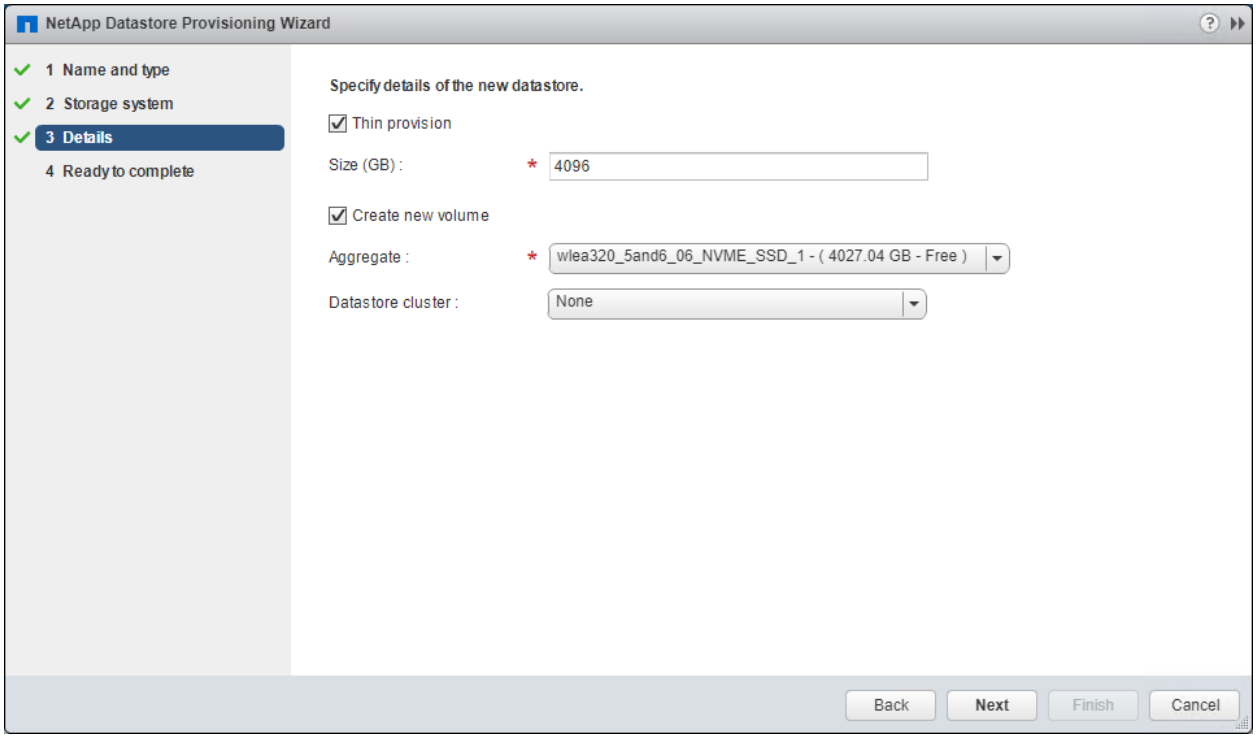
- Thin provisioning (NetApp FlexVol® volumes, LUNs, and VM files)
- FlexVol volume autosize (VSC default)
- All storage efficiency features including inline zero-block deduplication, inline adaptive compression, inline and background (auto) volume and aggregate deduplication, and inline data compaction (AFF default)

  Note: Snapshot copies were configured separately for datastore protection. VSC does not schedule or reserve space for Snapshot copies.

Because ONTAP systems are designed for multiple workloads and tenants, best performance is obtained when at least four FlexVol volumes are used per node. For this test, we used 10 hosts with 8 ONTAP datastores, so the number of FlexVol volumes was not a concern. IT teams evaluating ONTAP systems for vSphere should keep this configuration in mind. It might be simpler to configure a single datastore with a single LUN for a proof-of-concept (POC) evaluation; however, this configuration doesn't represent a normal VMware vSphere storage environment and does not deliver the best performance from an ONTAP system. Likewise, performance is best tested with multiple VMs. Testing storage performance by running a storage benchmark tool in a single VM does not represent typical virtualization workloads.

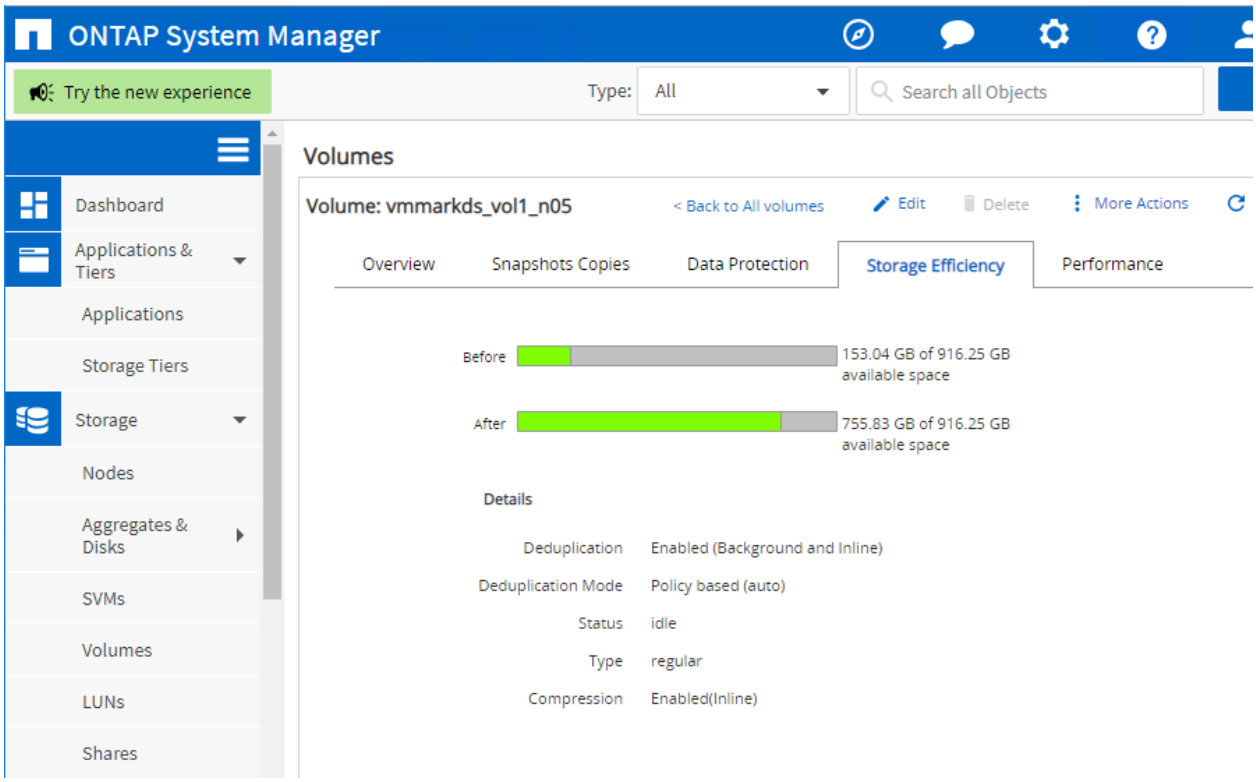
Figure 15 shows the simple VSC dialog box used to provision a new datastore. For this test, VMFS6 was used with a 4TB datastore.

Figure 15) Datastore provisioning wizard.



ONTAP systems support a graphical interface, ONTAP System Manager, which can be used to confirm the storage efficiency and other volume best practices as previously described and as shown in Figure 16.

Figure 16) ONTAP System Manager view of volume storage efficiency.



To gain even greater storage efficiency, while also taking advantage of the power of ONTAP integrated data protection, we used NetApp FabricPool to offload cold blocks used by historical Snapshot copies. FabricPool enables automated tiering of inactive (cold) data to low-cost object storage tiers, whether in off-premises public clouds, such as Amazon S3 and Microsoft Azure Blob Storage, or on-premises private clouds such as NetApp StorageGRID. We selected from the available object storage types, as shown in Figure 17, and then configured access to an Amazon S3 bucket in Figure 18.

Figure 17) Selecting an object store provider for the cloud tier.

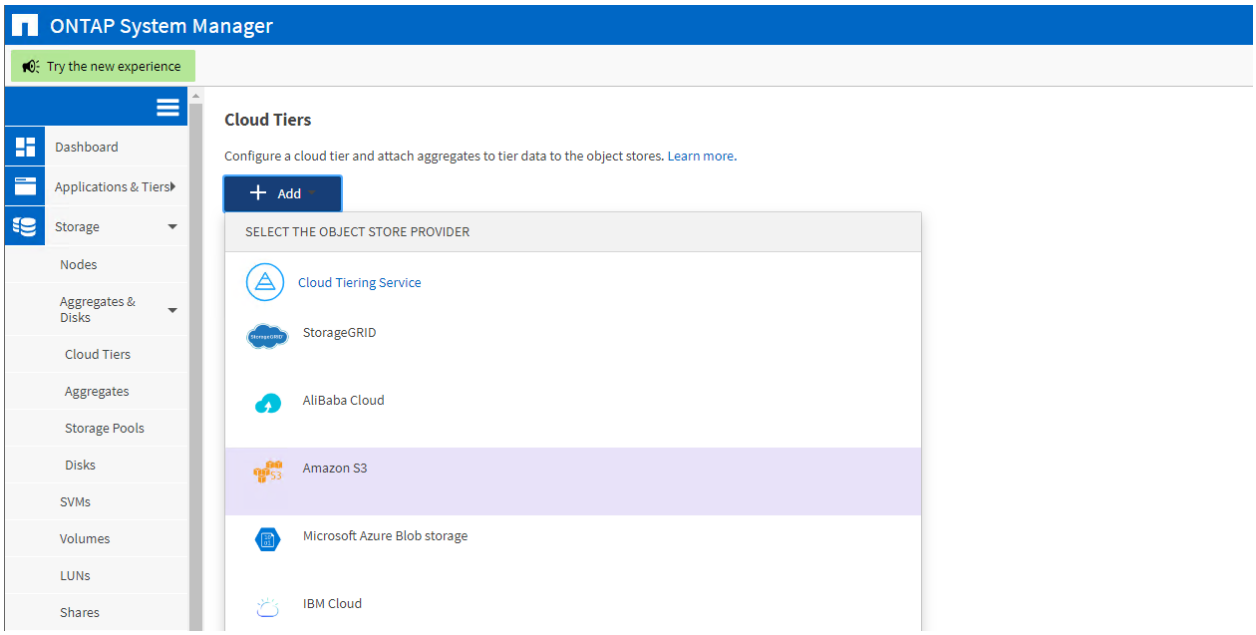
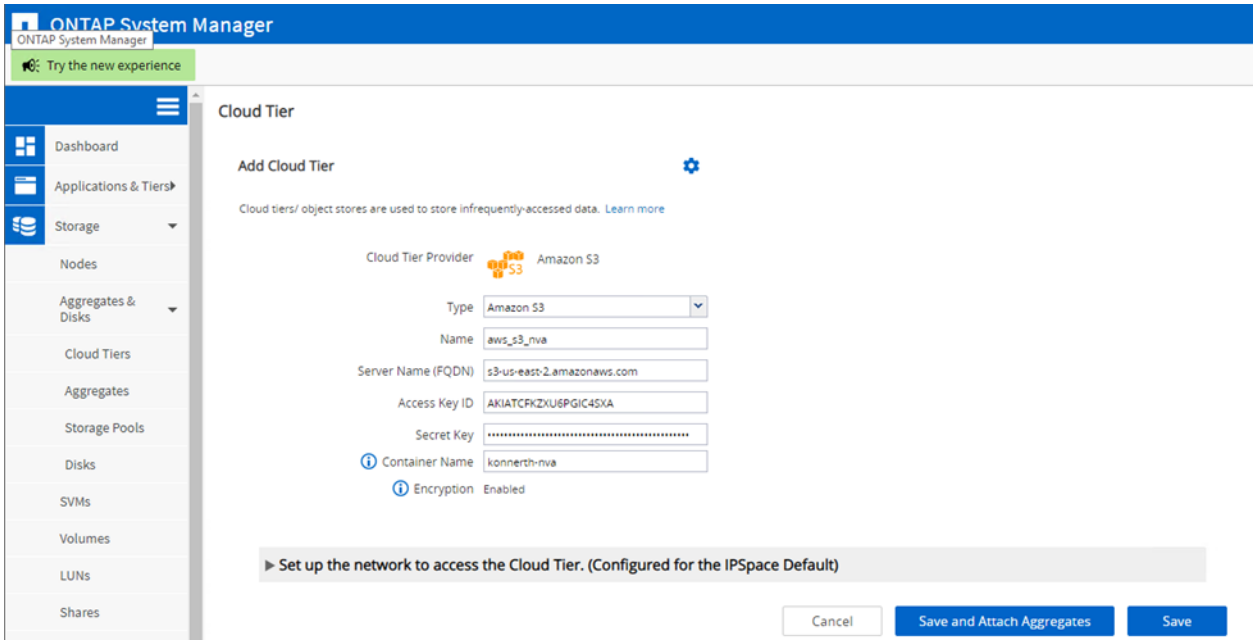


Figure 18) Adding the Amazon S3 cloud tier.



We then attached the cloud object storage to an ONTAP disk aggregate. To begin tiering, we set the tiering policy at the individual workload or volume level. In this example, FlexVol volumes were the vSphere datastores, so we changed the tiering policies for the datastore volumes to `snapshot-only`. We carried out these tasks from one screen in ONTAP System Manager, as shown in Figure 19. After we configured SnapCenter, we used Snapshot copies to protect the datastores. When the aggregate reached a specified level of fullness (the default is 50%) and the Snapshot copies reached a certain age (the default is 2 days), FabricPool began to tier blocks from eligible Snapshot copies to the cloud. Figure

20 shows how the 2.5TB of cold Snapshot copy data was moved to the cloud tier, freeing up space on the flash performance tier for active data. Figure 21 shows the SnapCenter dashboard after protection was configured for the datastores and VMs in the test environment.

Figure 19) Attaching an aggregate and specifying the volume tiering policy.

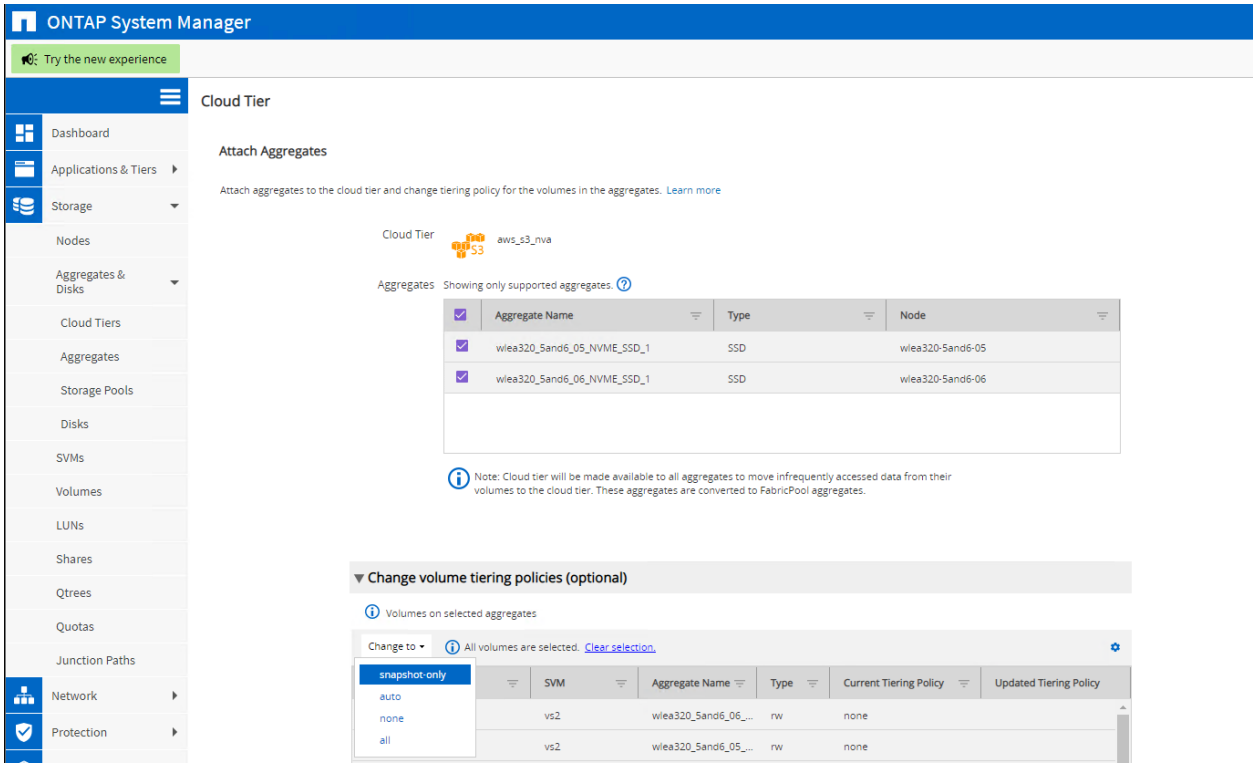


Figure 20) Monitoring performance and cloud tier space usage.

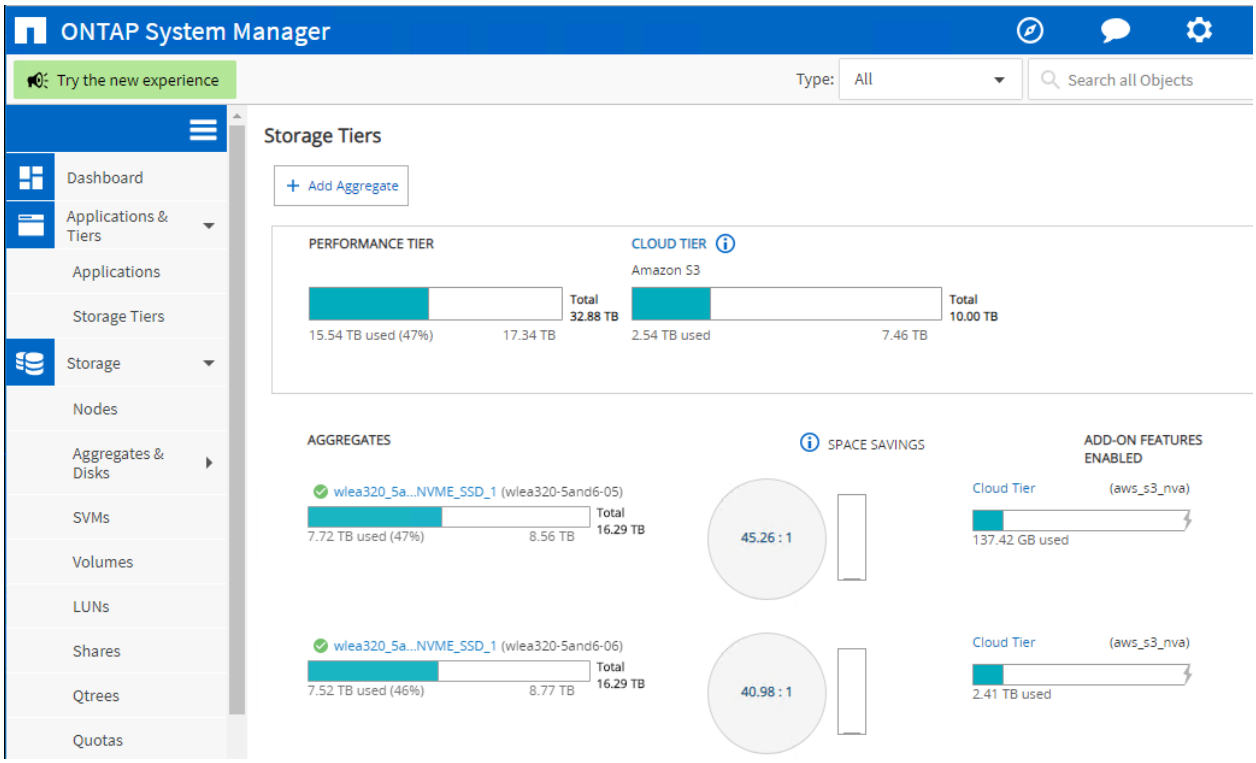
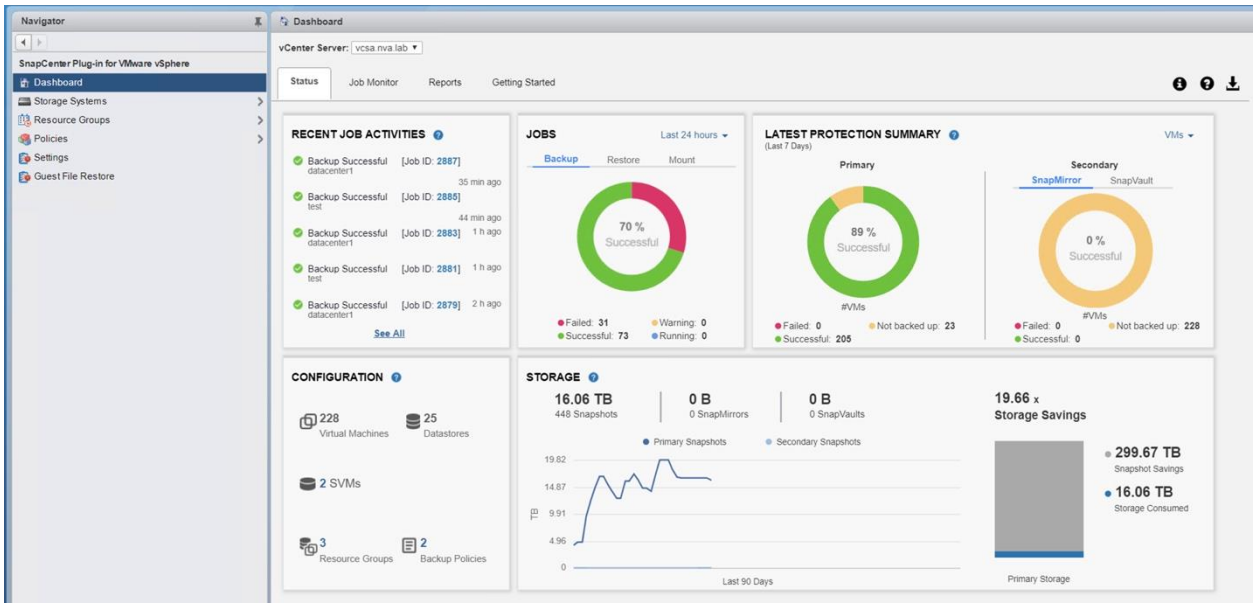


Figure 21) SnapCenter dashboard.



5.2 Test Results

To demonstrate performance management and the simplicity of deploying ONTAP 9.6 with VMware vCenter 6.7, we emulated a mixed workload environment by using several different workload generating tools and software. This work was in line with standard server virtualization infrastructure benchmarks and workload generators, such as VMware VMmark 3 and SpecVirt. These mixed workloads included

infrastructure operations such as vMotion across storage and compute hosts as well as application workloads on managed VMs.

To emulate multiple tenant applications, we deployed a mixed workload featuring a suite of applications and workloads. To generate these workloads, we ran VMmark 3 as a workload generator. We did not perform conforming runs. These results make no claim to a VMmark tile score or other result. We also used VDbench as an additional workload to emulate noisy neighbor behavior and add another steady-state workload. The workloads under test included:

- DVD Store 3 (ds3) on PostgreSQL 9.3
- MongoDB 3.0.14
- Web servers running NGINX 1.12.0
- Other common web server application elements
- VDbench

In addition to these application workloads, VMmark 3 also conducted the following standard infrastructure operations as part of the workload under test:

- Storage vMotion
- Compute vMotion
- VM snapshots

We then used a mixture of features available through the integrated suite of ONTAP tools, which made it simple and convenient to deploy and manage VMware datastores through the vCenter console and to manage storage directly through ONTAP System Manager.

We focused on two main cases: the simplicity and advantage of throughput floors (QoS Min) to protect key applications and the simplicity and performance-neutral impact of NVE to offer additional security in a multitenant environment. To highlight these cases, we started with a stable system that had controlled latency and emulated multiple tenants running. Next, we protected key workloads by using throughput floors, which showed no impact in latency. Next, we added extreme workload to several tenants, emulating runaway processes, and we showed the value of throughput floors in protecting key workloads against unanticipated application behavior. Finally, we returned to a steady-state workload and enabled NVE against all our tenants to demonstrate how it enhances security with minimal impact to system performance.

Additional information about the workload is available in Appendix A.

Steady-State Workload

The steady-state workload captured a steady state of eight tenant workloads, each consisting of a mixture of real applications and a steady-state workload from VDbench. In this workload, there was a consistent steady latency typical of AFF deployments that support a heterogeneous environment. Depending on background workload, there were occasional latency shifts, but overall, there was consistent low latency. This workload also had constant Storage vMotion activity that created occasional bursts of IO. Four concurrent Storage vMotion operations were triggered by VMmark at set intervals; they account for the variation in traffic at regular intervals.

Figure 22 illustrates a single-node throughput during a steady-state test captured during ramp-up, steady state, and completion. The total cluster throughput on the system was twice what was measured here.

Figure 22) Single-node throughput during a steady-state test.

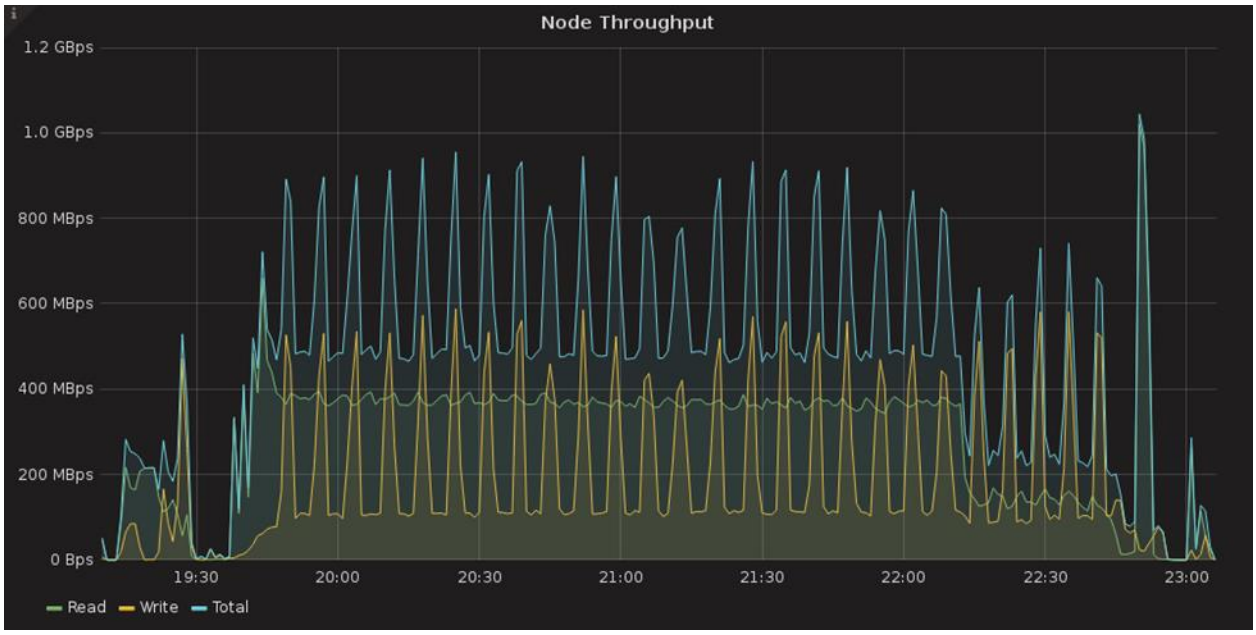


Figure 23 illustrates single-node IOPS reflecting the distribution of I/O across the cluster.

Figure 23) Single-node IOPS reflecting distribution of I/O across the cluster.

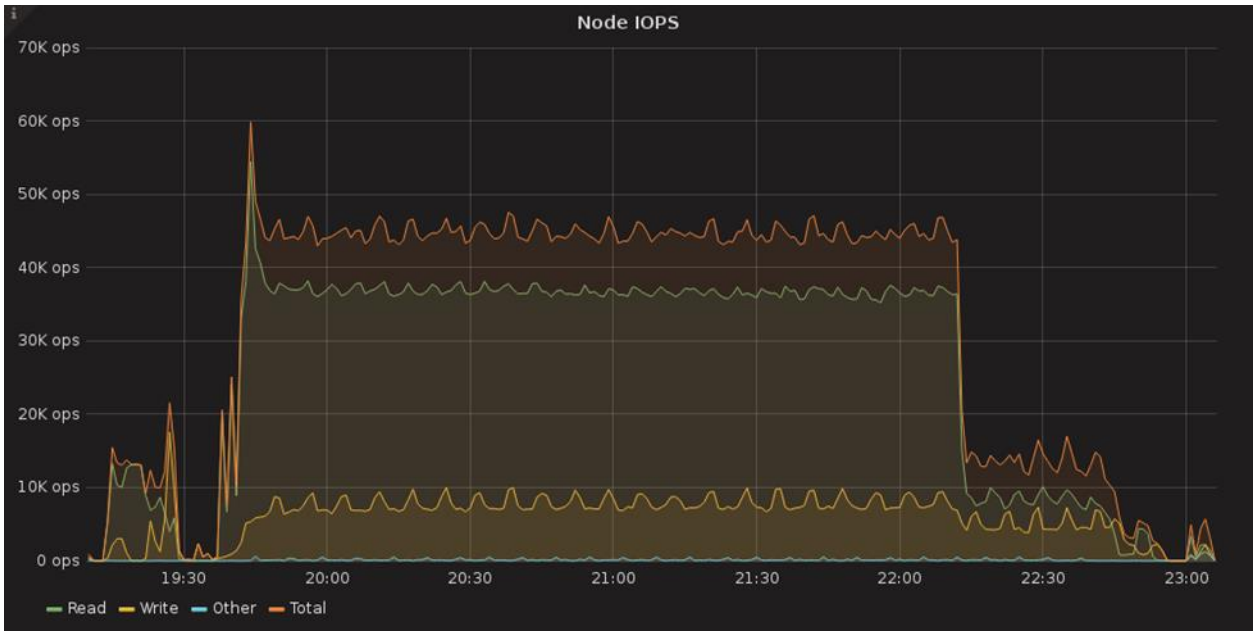
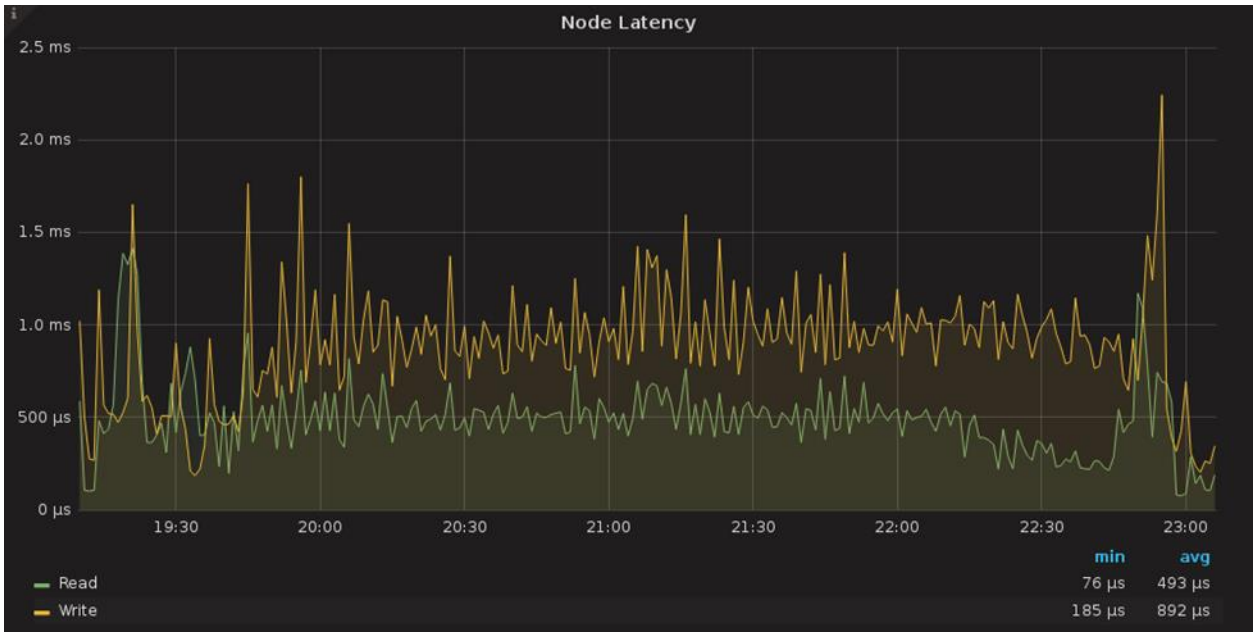


Figure 24 illustrates latency measured on a single node in the cluster. Latencies were virtually identical across nodes throughout the test. The ONTAP system provided consistent low latency throughout the baseline test.

Note: These statistics reflect the round-trip time (RTT) that begins when an FCP operation first arrives to ONTAP and ends when an acknowledgment is received from the client after completion of the FCP operation. This RTT is an accurate reflection of storage latency at the hypervisor layer.

Figure 24) Latency measured on a single node in the cluster.



Noisy Neighbor Workload

A noisy neighbor workload used VDbench to generate abnormal traffic on six of the eight tenants. This workload increased concurrency to 1,024 and pushed VDbench to maximum IOPS available during this concurrency. Here, our tenants with normal workloads saw increased variance in latency over the course of the test. Latency spikes above 1ms were common, and response times generally were worse and varied more greatly. This condition is potentially common in a test/development environment that resides alongside a production environment. A bad change in the test/development environment creates an unanticipated workload that has an impact on the production workload, leading to unhappy clients and applications.

Figure 25 illustrates the IOPS of a normal tenant during noisy neighbor conditions. The IOPS were consistent throughout the test for this tenant.

Figure 25) IOPS of a normal tenant during noisy neighbor conditions.

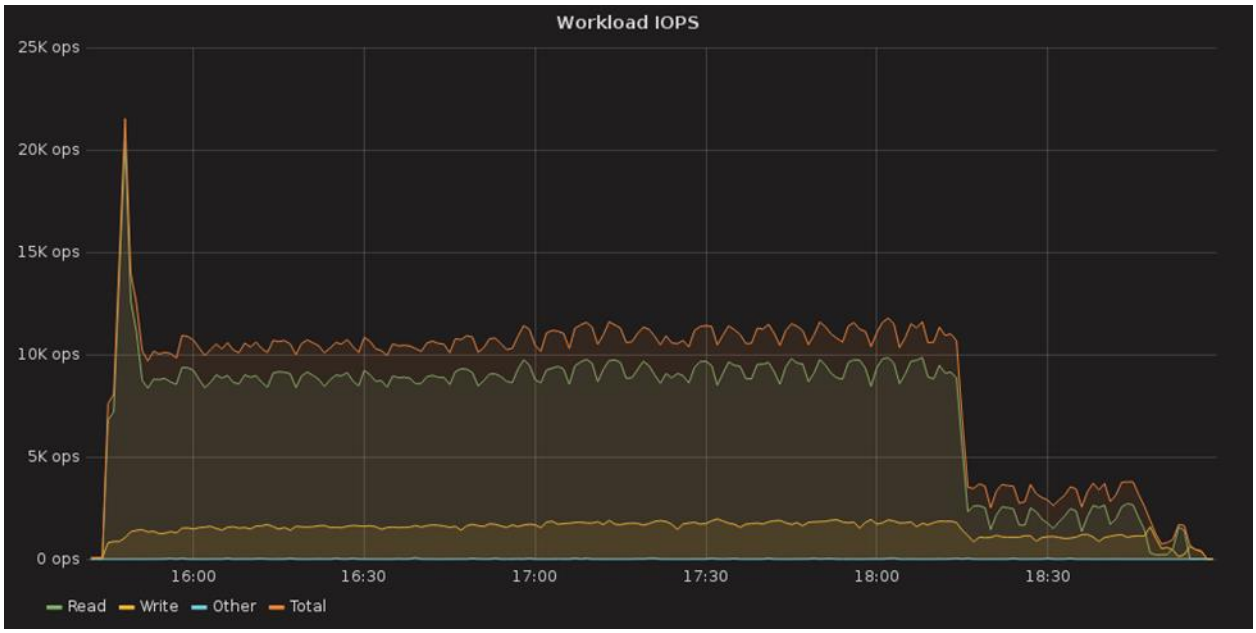
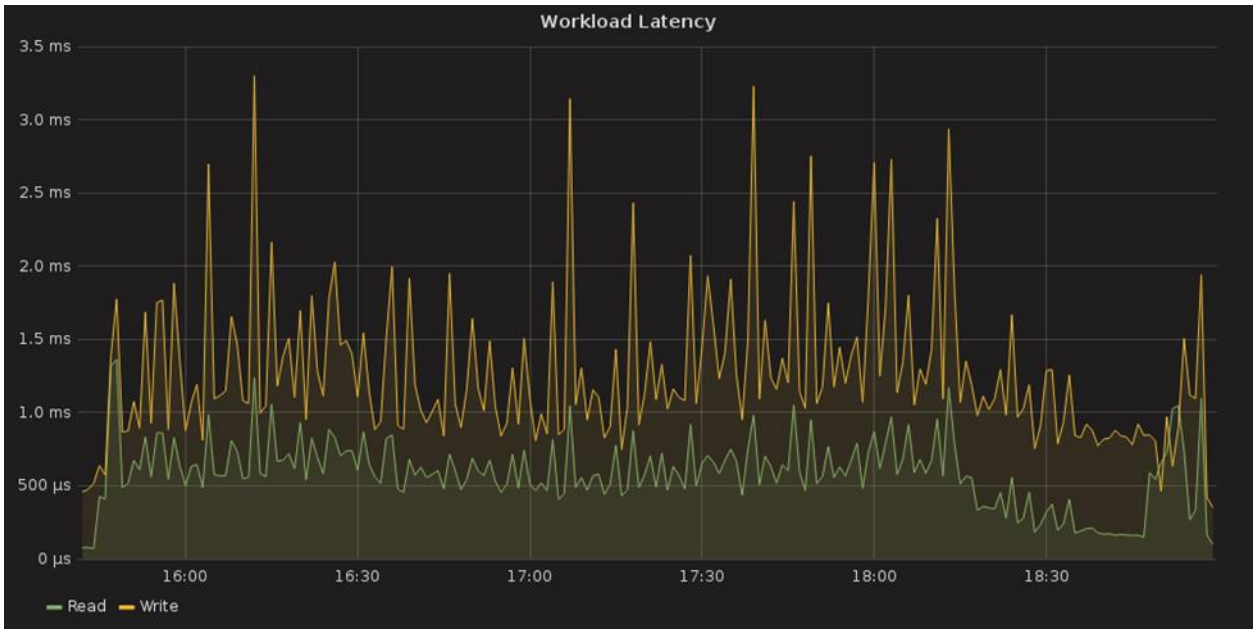


Figure 26 shows how the workload latency is less stable. With noisy neighbor nodes presenting inconsistent and high-throughput traffic, there is less stability in the tenant with good behavior. There are frequent latency spikes and a latency curve that is less consistent overall.

Figure 26) Workload latency was less stable.



Mitigating Noisy Neighbors with Throughput Floors (QoS Min)

In this scenario, we repeated our noisy neighbor workload with an additional protection in place. We applied throughput floors to our tenant LUNs to protect key baseline workloads. The process involved two steps easily completed in System Manager. The performance results showed that our simulated "production" datastores had vastly improved latency with significantly less variance than the unprotected

test. Latencies consistently stayed below 1ms and latency variance was much lower. Throughput floors allow administrators to protect baseline workloads in multitenant environments and reduce the risk to normal workloads posed by other co-resident tenants.

Figure 27 shows the same tenant IOPS with a throughput floor in place to protect the tenant workload. The application workload was unaffected by the throughput floor.

Figure 27) IOPS with a throughput floor in place to protect the tenant workload.

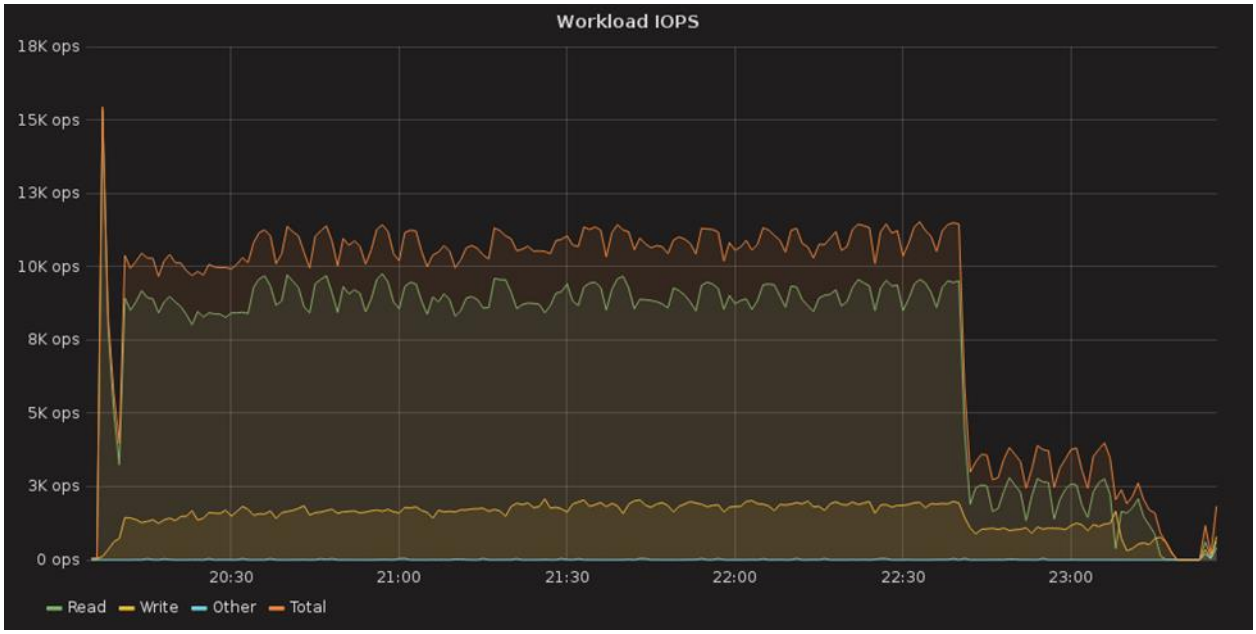
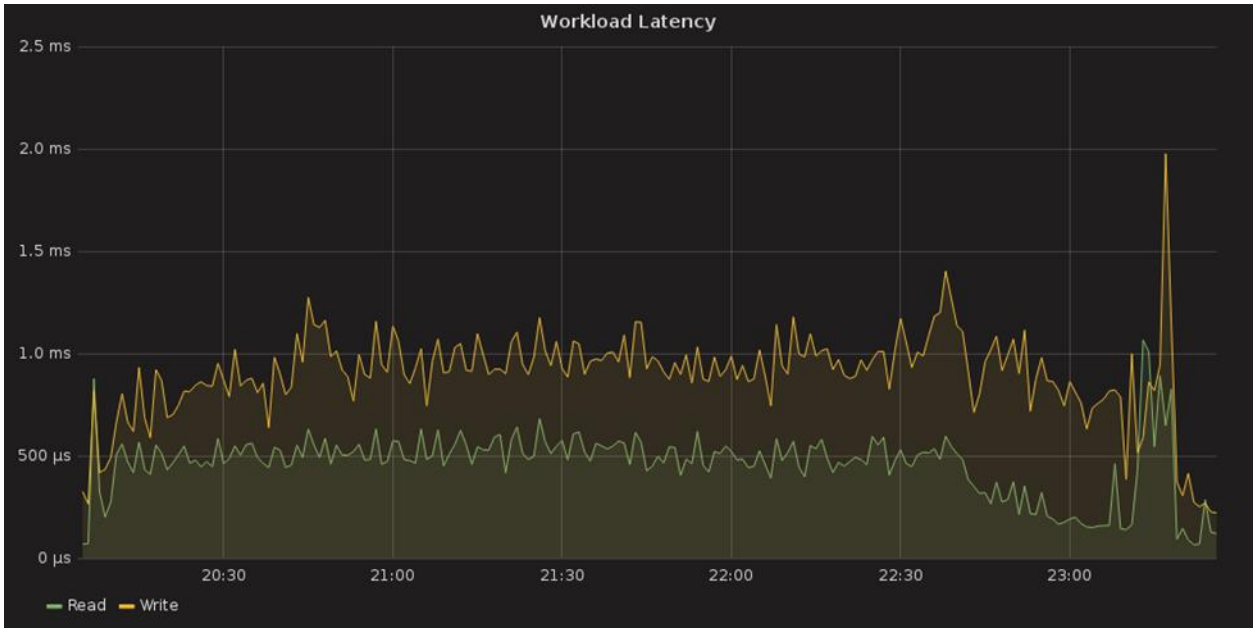


Figure 28 shows how a good-behavior tenant demonstrated considerably improved latency under the noisy neighbor conditions. Latency spikes were reduced or eliminated, baseline latency was improved, and application performance was unimpacted despite the changes in conditions.

Figure 28) A good-behavior tenant with improved latency under the noisy neighbor conditions.



NetApp Volume Encryption

With NVE, we returned to a steady-state workload. Underlying this workload, we enabled NVE on the underlying volumes that hosted the datastore LUNs. Enabling volume encryption is a simple process to start volume conversion. We completed volume encryption with our test datastores (each ~2TB in capacity including Snapshot copy space) in under 3 hours. Traffic was uninterrupted during the conversion activity. We then reran our steady-state workload. Here, results showed that performance was virtually unchanged compared with our unencrypted tests.

There are many benefits to NVE in a multitenant environment. Data residing on disk is protected from physical theft and access. Data is also protected if a system is physically moved in transit. Encryption is also possible for individual SVMs in ONTAP, which allows segregation of private keys to allow tenants to control the keys to their data.

Figure 29 shows how the workload throughput for the NVE test was unchanged compared to the baseline workload throughput shown in Figure 30.

Figure 29) Workload throughput for the NVE test was unchanged.

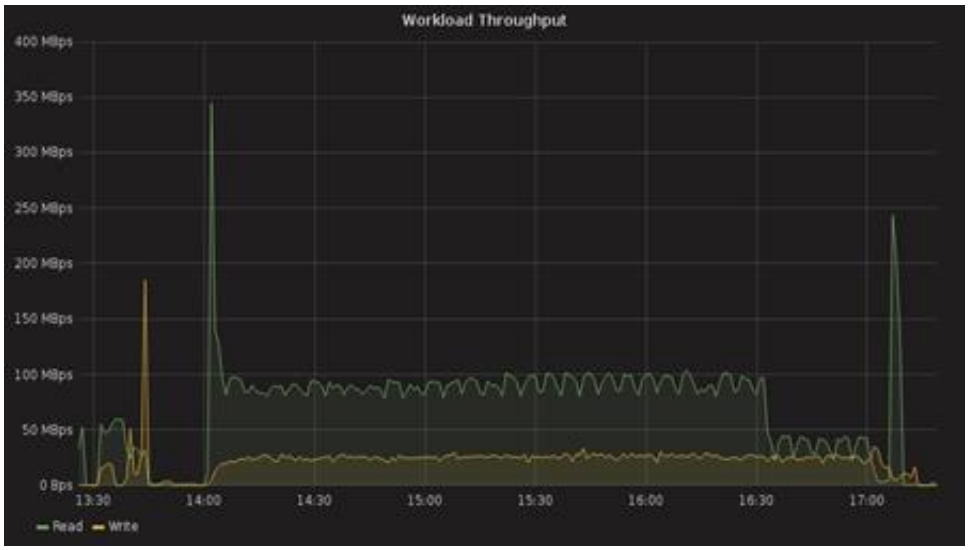


Figure 30) Baseline workload throughput.

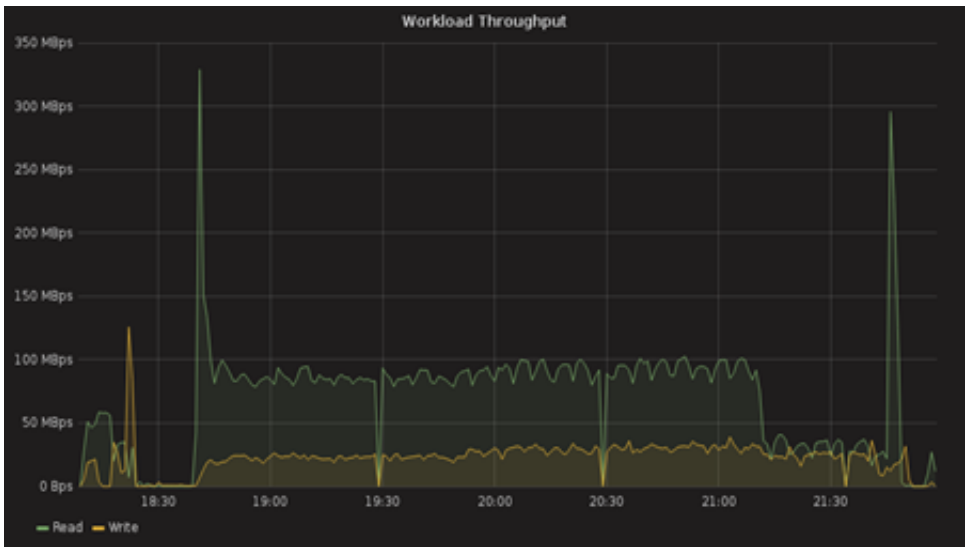
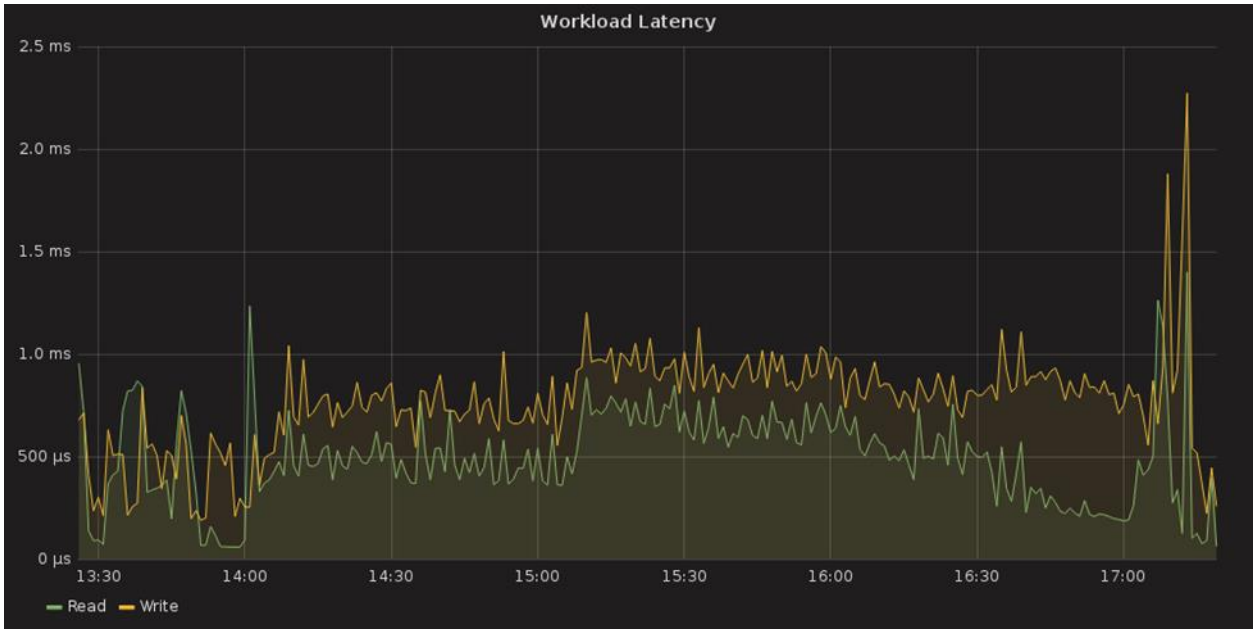


Figure 31 shows how workload latency was low and consistent with the initial steady-state workload. Workloads can capture the benefit and protection of NVE without sacrificing performance or requiring complex administrative changes.

Figure 31) Low, consistent workload latency with the initial steady-state workload.



5.3 Test Conclusion

The AFF A320 storage array and ONTAP 9.6 software provide unparalleled value in protecting critical workloads in a virtualized environment. The system's features can enable safe sharing of resources so that a system administration generalist can confidently deploy and protect mission-critical applications.

The AFF A320 can support many co-resident applications in VMware environments and offers the simplicity and tooling required to efficiently administer these environments.

Performance is the minimum competitive requirement in an all-flash world, and AFF provides value beyond this minimum. Easy-to-use tools are available to monitor, troubleshoot, and resolve performance issues easily and without extensive training.

The partnership between NetApp and Broadcom offers another opportunity to reduce reliance on complex storage, fabric, and application administration and get simplified views into each layer of a cluster deployment.

6 Future Disruptive Innovation

Over the last few years, the IT industry has undergone rapid innovation, which has caused substantial disruption to traditional IT delivery models and rendered many legacy hardware vendors obsolete. Most architectures are unable to evolve with the changes, resulting in successive waves of disruption, rearchitecture, forklift upgrades, and migration that customers can no longer afford from either an inefficiency or financial perspective.

NetApp pioneered the concept of nondisruptive operations (NDO) migrations and online transitions between generations of technology with heterogeneously scalable IT infrastructure. NetApp focused on innovation in software and on enabling you to add infrastructure as you grow, with connections between each generation of technology. The following is just a short list of recent disruptions. NetApp stands ready

to take these innovations into today's architectures and help you integrate them without forklift upgrades or disruptive migrations.

Key technology initiatives that are stimulating change include:

- HDDs replaced by flash
- Hardware appliances augmented or replaced by software-defined storage (SDS)
- NVMe-based media attached for flash
- NVMe-oF, the front-end NVMe protocol over FC, Ethernet, and other physical media
- Storage-class memory (SCM, also known as PMEM and NetApp MAX Data)
- Cloud-based IT infrastructure
- Hyperconverged infrastructure
- AI, deep learning computing

As these initiatives come into the market, NetApp continues to support the evolution and revolution of IT with an agile software-defined approach. We support initiatives such as the Internet of Things (IoT), DevOps, hybrid cloud, and in-memory database server technologies, beyond what other vendors can comfortably discuss. We recently announced partnerships with three major hyperscalers for the NetApp cloud-connected flash array; our edge-to-core-to-cloud data pipeline; and the ability to mix SDS, hardware, and cloud instances of ONTAP. These offerings give us a superior ability to future-proof your architecture.

As we have discussed in this document, with a simple software upgrade to the NVMe/FC protocol, you can easily future-proof your infrastructure with an investment in NetApp.

7 Conclusion

In this document, we presented the NetApp and Broadcom modern enterprise SAN verified architecture. It's the optimal infrastructure for using best-in-class, end-to-end, modern SAN and later NVMe technologies to deliver business-critical IT services today while you prepare for the future. As we have already seen, that future will include serving high-performance database, analytics, AI and machine learning, and IoT requirements.

NetApp and Broadcom have created an architecture framework that is both future-ready and usable today and that is easy to implement in your current operational processes and procedures. One of our main objectives is to enable organizations like yours to quickly and nondisruptively streamline and modernize their traditional SAN infrastructure and the IT services that rely on it. To meet this objective, these modern platforms must:

- Be high performing to provide more real-time analysis and availability of critical data
- Adopt modern future-facing and disruptive technologies in a nondisruptive manner
- Provide agility, flexibility, and high scalability
- Fit in current operational frameworks
- Align with organizational objectives to consolidate and streamline infrastructure and operations

In this NetApp Verified Architecture, tests on a virtualized environment represent the benefits of a modern SAN architecture that is suited for multiple use cases and critical SAN-based workloads. These benefits apply to most virtualized environments running VMware vSphere on a SAN.

With the flexibility and scalability of this architecture, your organization can start with a framework to modernize and to rightsize your infrastructure and can ultimately grow with and adapt to evolving business requirements. With these benefits, your system can serve existing workloads while streamlining infrastructure, reducing operational costs, and preparing for new workloads in the future.

Appendix A: VDbench Parameter Files

VDbench Steady-State Parameter File

```
hd=default,jvms=6,shell=ssh
hd=slave01,system=localhost
sd=default,size=100g
sd=sd1-1,host=slave01,lun=/dev/sdb,openflags=o_direct
wd=Read90Rand100_8k,sd=sd*,rdpct=90,seekpct=100,xfersize=8k
rd=default,iorate=8000,warmup=30,elapsed=9000,threads=1024
rd=R50Ra1008k,wd=Read90Rand100_8k,sd=sd*
```

VDbench Noisy Neighbor Parameter File

```
hd=default,jvms=6,shell=ssh
hd=slave01,system=localhost
sd=default,size=100g
sd=sd1-1,host=slave01,lun=/dev/sdb,openflags=o_direct
wd=Read90Rand100_8k,sd=sd*,rdpct=90,seekpct=100,xfersize=8k
rd=default,iorate=80000,warmup=30,elapsed=9000,threads=1024
rd=R50Ra1008k,wd=Read90Rand100_8k,sd=sd*
```

Where to Find Additional Information

- To learn more about the information that is described in this document, review the following documents and websites:
- An Industry First: All-Flash NVMe over Fibre Channel (blog)
  https://blog.netapp.com/leading-the-industry-with-nvme-over-fibre-channel
- An Update on the Plexistor Acquisition: Introducing NetApp Memory Accelerated Data (blog)
  https://blog.netapp.com/an-update-on-the-plexistor-acquisition-introducing-netapp-memory-accelerated-data/
- When You're Implementing NVMe over Fabrics, the Fabric Really Matters (blog)
  https://blog.netapp.com/nvme-over-fabric/
- NetApp SnapCenter data sheet
  https://www.netapp.com/us/media/ds-3700.pdf
- NetApp SAN Health Program
  https://www.netapp.com/us/forms/campaign/amer-us-fy19q3-sss-san-san-health-check-inquiry-form.aspx?ref_source=smc&cid=27476
- NetApp NVMe: Leading the Future of Flash
  www.netapp.com/us/info/nvme.aspx
- NVMe over Fibre Channel for Dummies
  https://www.netapp.com/us/forms/campaign/nvme-for-dummies-ebook-lp.aspx
- SAN Solutions product page
  https://www.netapp.com/us/products/storage-systems/storage-area-network.aspx
- TR-4080: Best Practices for Modern SAN (ONTAP 9)
  https://www.netapp.com/us/media/tr-4080.pdf
- TR-4597: VMware vSphere with ONTAP
  https://www.netapp.com/us/media/tr-4597.pdf
- TR-4684: Implementing and Configuring Modern SANs with NVMe/FC
  https://www.netapp.com/us/media/tr-4684.pdf
- New Frontiers in Solid-State Storage white paper
  http://www.netapp.com/us/media/wp-7248.pdf

- Broadcom Fibre Channel networking products
  https://www.broadcom.com/products/fibre-channel-networking/directors/x6-directors
  https://www.broadcom.com/products/fibre-channel-networking/switches/
- Brocade and NetApp partner documents
  https://www.broadcom.com/company/oem-partners/fibre-channel-networking/netapp
- VMware VMmark
  https://www.vmware.com/products/vmmark.html
- Oracle VDbench
  https://www.oracle.com/technetwork/server-storage/vdbench-downloads-1901681.html

Version History

Version	Date	Document Version History
Version 1.0	August 2019	Initial release.

Refer to the Interoperability Matrix Tool (IMT) on the NetApp Support site to validate that the exact product and feature versions described in this document are supported for your specific environment. The NetApp IMT defines the product components and versions that can be used to construct configurations that are supported by NetApp. Specific results depend on each customer's installation in accordance with published specifications.

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