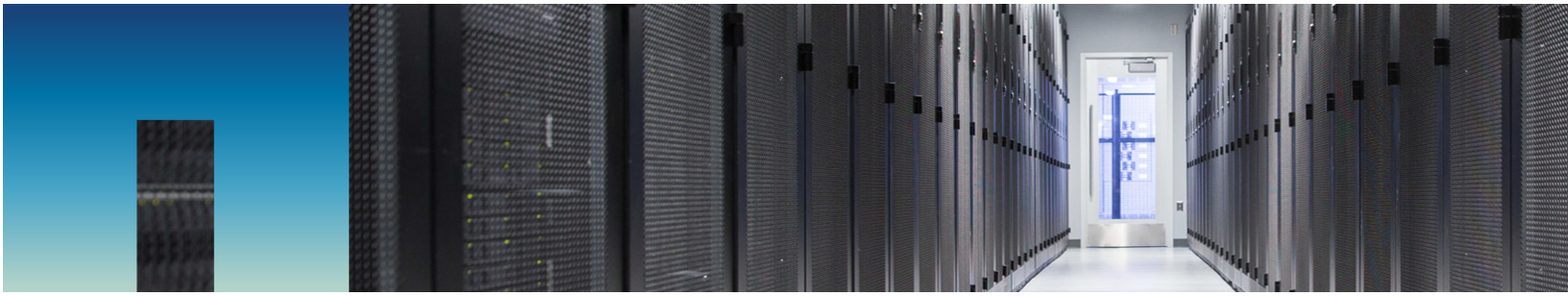

NetApp Verified Architecture

NetApp and Broadcom Modern SAN Cloud-Connected Flash Solution

Oracle and SUSE NetApp Verified Architecture Design Edition

Modernize your enterprise SAN with end-to-end NVMe over Fibre Channel, the fastest cloud-ready solution for mission-critical workloads

Contributors
Broadcom Inc.: Jim Zucchero and Naem Saafein
NetApp: Adam Fore, Andy Grimes, Danny Hohman, Darryl Clinkscales, Lee Howard, Mike Peppers, Pavan Jhamnani, Rob McDonald, Scott Lane, Stetson Webster, Steve Botkin, Steve Collins, and Vidula Aiyer

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In partnership with

BROCADE
A Broadcom Inc. Company

Abstract

This NetApp® Verified Architecture has been jointly designed and verified by NetApp and Broadcom Inc. It uses the latest Brocade, Emulex, and SUSE technology solutions along with NetApp all-flash storage, which sets a new standard for enterprise SAN storage and data protection that will drive superior business value.

NetApp®

Forward: Thoughts from Broadcom

Storage system customers face never-ending challenges to keep a competitive edge, to scale for hypergrowth opportunities, and to manage ever-increasing needs for IT services within their organizations. It's imperative that they work with and invest in the right strategic partners who will help them meet their most business-critical needs of today and tomorrow.

With its rich portfolio of products, Broadcom has the distinction of being the market leader in enterprise Fibre Channel SAN solutions. Broadcom has a rich heritage of technology leadership that it provides to enterprise OEM customers. The right OEM partners will uphold Broadcom's high standards of excellence and of meeting customer expectations.

For over 15 years, NetApp has provided FC solutions to customers as a Broadcom OEM partner. With NetApp's market leadership position in NVMe over Fibre Channel (NVMe/FC) technology, NetApp is enabling its own customers to deliver superior IT performance for their most important, 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, which will take customers into the next decade of enterprise SANs.

Jim Zucchero
Global Sales Executive, NetApp team
Broadcom Inc.

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1 Executive Summary

NetApp® Verified Architectures describe 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 the business needs of customers.

This NetApp Verified Architecture provides a solution that modernizes your enterprise SAN with end-to-end NVMe, giving your company the fastest cloud-ready solution for mission-critical workloads.

This report addresses the following:

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

1.1 The Challenge

The challenge today is how to rapidly and non-disruptively 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 the 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 new avalanche of data requires 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 good news is that, just as flash transformed enterprise storage a few years ago, a new emerging technology, NVMe, is poised to transform the enterprise again. NVMe (Non-Volatile Memory Express), an emergent storage access and transport protocol, delivers the fastest response times yet for business-critical enterprise applications. NVMe is about to provide a major speed boost for enterprise data storage systems. But this time, the transformative effect could be greater still, because NVMe isn't just a storage specification. The broader NVMe over Fabrics (NVMe-oF) protocol rearchitects the entire data path, from server to storage system, enabling superior performance and lower latency than traditional technologies can deliver.

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 these 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 10 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 a first-to-market enterprise NVMe/FC solution. 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 right now. With a system that yields the fastest access, management, and utilization of critical data, you can accelerate your time to innovation and leverage the following benefits:

1. **Digitally transform critical business applications.** Enable the next generation of your critical applications, ready for analytics, artificial intelligence (AI), and machine learning capabilities.
2. **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.
3. **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.
4. **Significantly simplify operations.** Improve IT responsiveness through simplification of SAN management while ensuring predictable performance.
5. **Modernize and get significant cost savings.** Improve shareholder value by attaining a 50% reduction in database licensing costs, 80% to 90%+ reduction in data center floor space, 50% to 90%+ reduction in power and cooling, and 50% to 80% reduction in labor costs.
6. **Future-proof your SAN environment.** Non-disruptively adopt disruptive performance and technology advancements when you are ready.
7. **Rapidly deliver core IT services.** Take advantage of an open platform that supports leading DevOps toolsets to vastly reduce the time to value for development.
8. **Don’t compromise on availability.** Get 99.9999% availability (IDC audit of 210,000 systems for a year, <5 seconds down/year) and enterprise-grade disaster recovery (DR) capabilities.
9. **Improve the customer experience.** Accelerate performance, enable instant application cloning, and enable granular data recovery to improve the user experience.
10. **Get next-generation enterprise data management.** Bring the value of industry-leading innovation together 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 includes the following key NetApp and Broadcom technologies: NVMe-oF, Oracle 12c, SUSE, and sixth-generation host and fabric technology. And the benefits accrue as you adopt these technologies. Adopt all of them and get game-changing performance benefits with end-to-end visibility through Fabric Vision technology. In the future, you will be able to add storage-class memory and persistent memory so that you can realize further increased performance.

2 Program Summary

This report is part of the Modern SAN Best Practices Program that provides test and validated design and configuration recommendations for next-generation NVMe-powered fabrics. This report is part of a series that will cover the deployment of popular enterprise applications.

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

This report describes the system and the 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 the business needs of customers like you. This report also describes the design choices and the best practices for this shared infrastructure platform. 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 report provides the following TCO benefits:

- 50% reduction in database licensing costs
- 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 SAN that incorporates the joint solution.

Table 1) Cost-benefit analysis of the joint NetApp and Broadcom 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	$390.00
Administration cost savings	$230.00

Table 2) Comparison of legacy SAN and NetApp and Brocade enterprise SAN.

	Legacy SAN	NetApp Brocade 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 16G 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 (for example, NetApp StorageGRID® Webscale) or a public cloud hyperscaler (for example, Amazon Web Services [AWS] or Microsoft Azure) for longer-term retention.

3 Solution Overview

3.1 NetApp and Brocade Enterprise SAN Solution Benefits

This solution comprises Brocade Gen 6 Fibre Channel Switches, Emulex Gen 6 FC HBAs, and NetApp AFF storage systems. It is a predesigned, best practice configuration that is built on SAN NVMe/FC 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 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

Brocade 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)
- Frequently asked questions (FAQs)
- NetApp and Brocade jointly validated designs that focus on various use cases

3.2 Target Audience

The target audience for this NetApp Verified Architecture report 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
- **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 leverage core and cloud-native solutions
- **Backup administrators,** who must protect data and leverage new 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

In this report, we focus on database and analytic types of workloads. This example factors in Oracle 12c savings around infrastructure and licensing, because the Oracle 12c migration forces infrastructure migration. 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 A700s configuration.

Figure 1 shows the technology components of the joint solution, and Figure 2 shows the component families of the architecture. Implementation of this solution should reduce the footprint, management overhead, maintenance spending, and power and cooling, and it should improve service availability and performance.

Figure 1) Technology components of the NetApp and Broadcom validated solution.

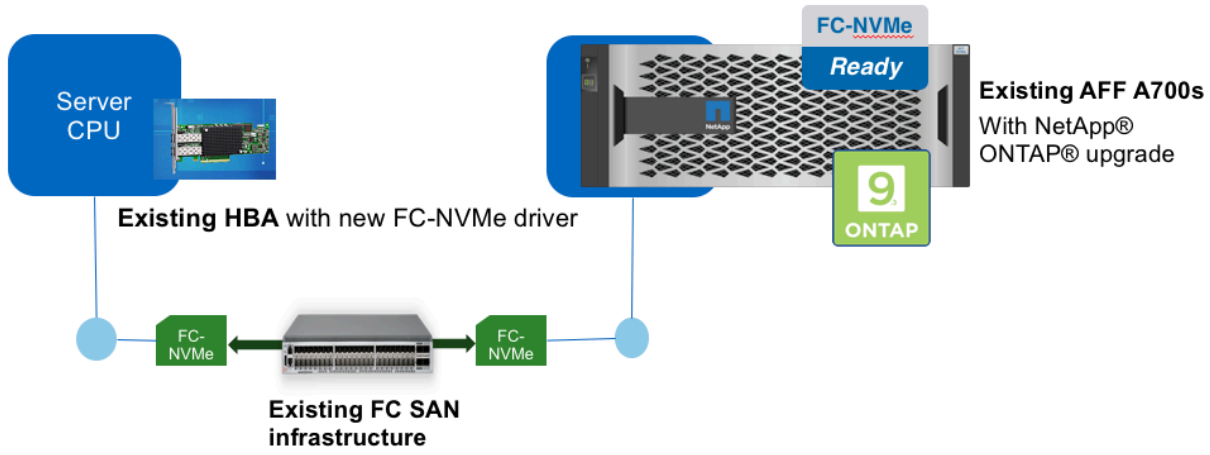
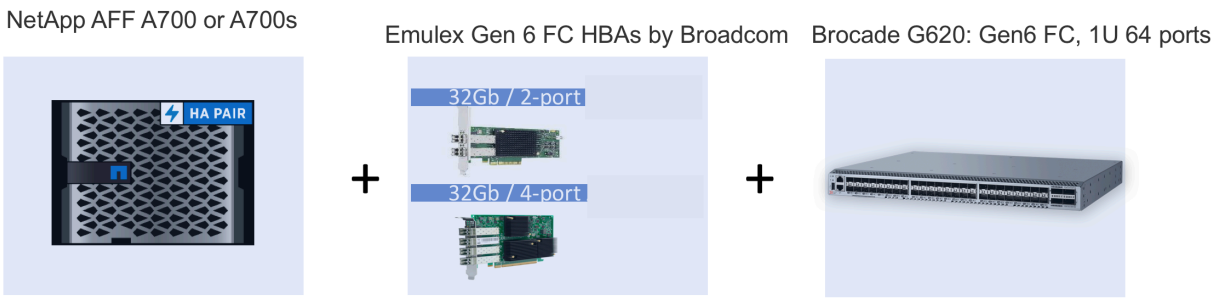


Figure 2) Component families of the NetApp and Broadcom joint architecture.



Most of today's all-flash arrays are deployed on low-risk, multiqueue-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. Because little change is required in the standards to implement NVMe/FC, 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 Fibre Channel network is purpose-built for tomorrow's mission-critical workloads by leveraging today's infrastructure.

New innovations in storage technology are disrupting the data center industry. The introduction of faster media types and more efficient mechanisms to access those media across well-defined various infrastructures is unlocking unprecedented speeds, lower latencies, and dramatic improvements in system and application efficiency and performance. These benefits are based on three advances: NVMe, NVMe-oF, and new storage-class memory (SCM).

Though this configuration is specifically with Gen 6 (and other hardware), you can also use Gen 5 switches and other NetApp controllers, such as the AFF A300, AFF A700, and AFF A800 configurations.

NVMe

The NVMe specification is designed to leverage nonvolatile memory in all kinds of compute environments, from mobile phones to webscale service providers. It adds massive I/O path parallelization (64,000 I/O queues, each with a queue depth of up to 64,000 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.

The massive number of queues and the huge queue depths that each can support allow today's storage and servers to use the increasingly large numbers 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 platform that supports SAN or NAS, all-flash, software-defined, hybrid, and cloud storage, it supports both existing (traditional) and emerging applications (for example, NoSQL databases and AI). These features and capabilities are all part of the NetApp Data Fabric. NetApp systems support scaling (up and out) dynamically in seconds or minutes, instead of taking hours or days. And you can allocate applications to

where they run best across your Data Fabric, whether it's on the premises or in the cloud. And to maximize performance and reduce overall storage cost, NetApp FabricPool allows you to move data automatically between AFF storage solutions and cloud storage tiers.

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

Brocade G620 Gen 6 Fibre Channel 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 Fibre Channel 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 Fibre Channel 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.

Brocade's IO Insight is the industry's first integrated network sensor tool that proactively and non-intrusively 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 at the virtual machine (VM) tier.

With standards-based, end-to-end VM tagging, Brocade VM Insight seamlessly monitors VM performance throughout a storage fabric. Your administrators can quickly determine the source of VM or application performance anomalies and can provision and fine-tune the infrastructure based on VM or application requirements to meet critical SLAs and SLOs.

The NVMe/FC feature supports both NVMe-oF and SCSI over FC protocols concurrently. Your organization can seamlessly integrate Brocade Gen 6 Fibre Channel networks with the next generation of low-latency flash storage, without a disruptive rip and replace.

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 Multi-core 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, along with the highest reliability in the industry (10 million hours MTBF) 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 SCSI over Fibre Channel. And for investment protection, these FC HBAs also support both NVMe/FC and SCSI over Fibre Channel protocols concurrently.

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 3 shows the components of the SAN Health tool, and Figure 4 shows how to use it.

Figure 3) Components of Brocade's SAN Health tool.

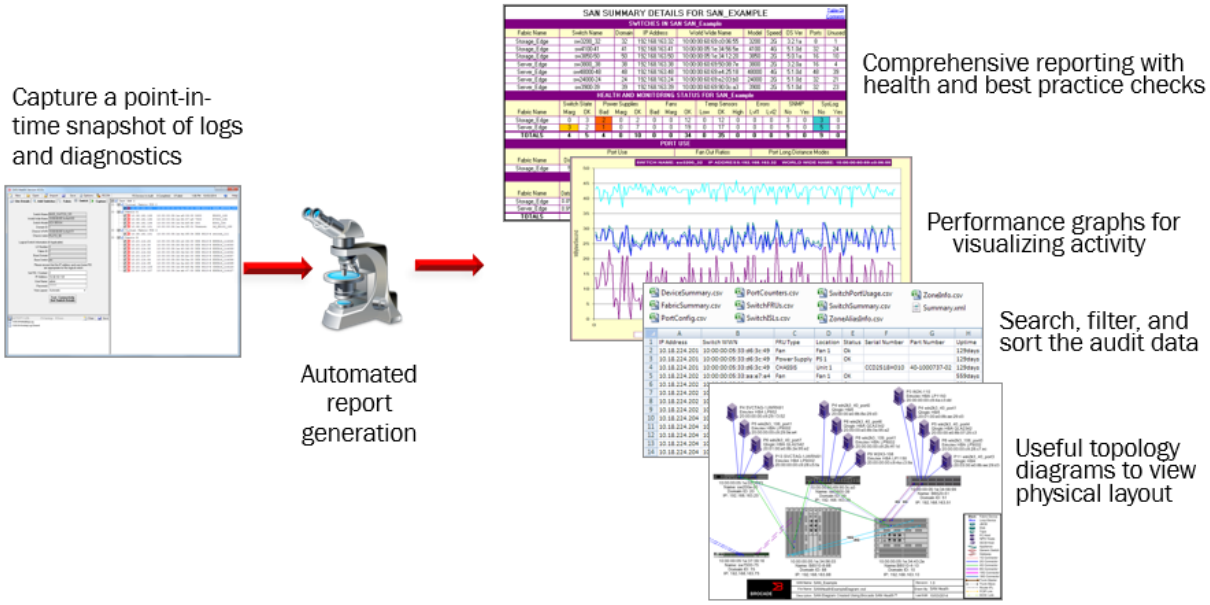
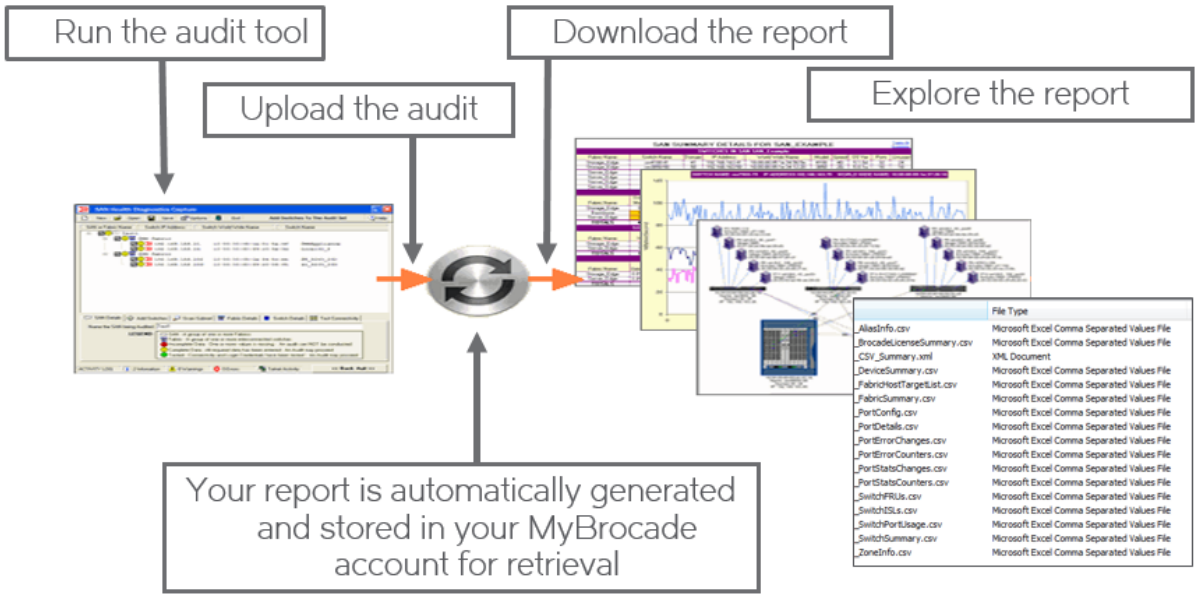


Figure 4) Steps required to run and to use SAN Health.

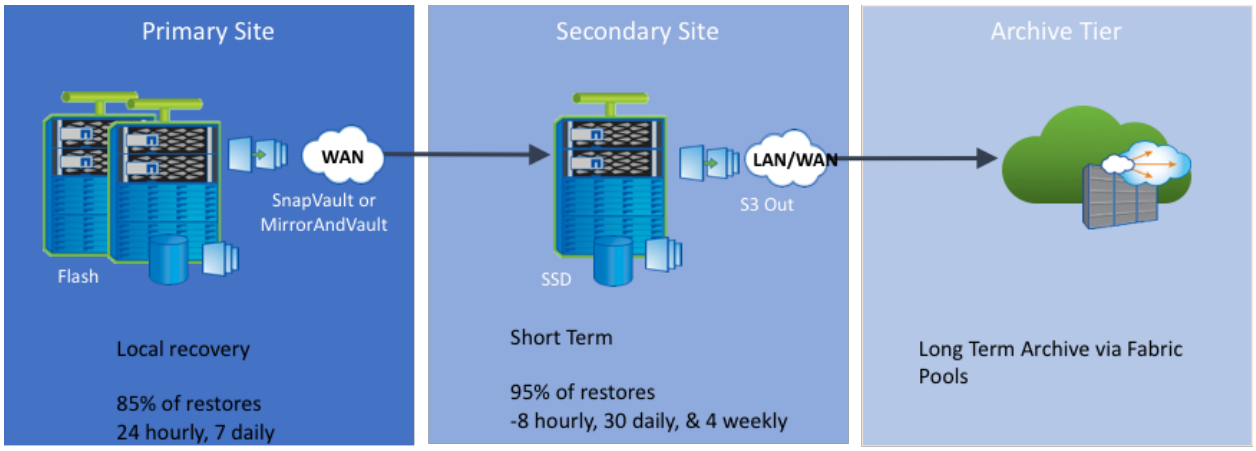


Data Protection

By using NetApp Snapshot™ technology, primary NetApp ONTAP systems provide immediate retention for a short period (usually 15 to 30 days). Daily, data is vaulted by using NetApp SnapVault® technology or is mirrored by using NetApp SnapMirror® technology to a secondary AFF ONTAP system for short-term (off-primary-site) retention. With traditional storage, this process takes weeks.

By using FabricPool technology, ONTAP automatically moves data (through policy management) over Amazon S3 to a third tier (labeled “Archive Tier” in Figure 5) for a longer-term retention (months to years). This third tier can be in the form of a private cloud (for example, StorageGRID Webscale) or a public cloud (AWS or Azure). The solution is automated, providing end-to-end data management.

Figure 5) NetApp data protection components.



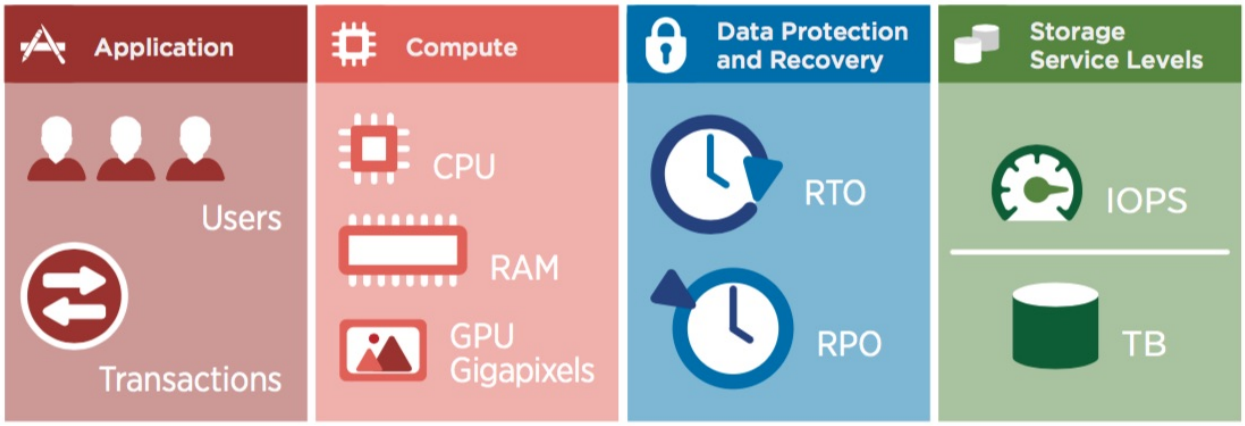
Service-Level Design and Management

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. They are moving from managing assets to managing services on a shared infrastructure and are operating their IT like a service provider does. Connecting technology to your business is key to a successful transition. NetApp can help you get started.

A NetApp Service Design Workshop or hybrid cloud–focused Cloud Service Design Workshop helps bridge the gap between technology and business. It creates a strategy for enabling your IT to function like a service provider and to operate under a delivery model that offers predictable storage costs, application performance, and business agility. The workshop provides key service delivery metrics and recommendations for delivering consistent storage service levels by using all flash or a combination of flash and high-density disks. Figure 6 shows service consumption metrics.

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

Figure 6) 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 under delivery problem is caused by an over delivery 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 managing storage resource allocations based 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 QoS settings for hundreds or thousands of volumes. By translating service-level policies into the QoS settings for individual volumes, adaptive QoS automates the task of dynamically managing QoS 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.
- **OnCommand Insight Services.** Quickly achieve full effectiveness and business impact of NetApp OnCommand® Insight through the deep knowledge and expertise of our experts.

3.4 Use-Case Summary

Bringing together data from core enterprise applications and data from Internet of Things (IoT), video, social media, and more, opens new frontiers when analytics, AI, and machine learning are applied to the

combination. Following is just a sample of the many ways that this modern SAN solution can provide tangible business value to your organization.

Life sciences and healthcare companies can now apply knowledge from clinical trial and patient research results in real time. They can use this knowledge to help shape new, more effective tests; to improve patient safety; and to reduce time to market for new medicines, treatments, and therapies. They can ingest, infer, and derive actionable insights from social listening on the side effects of drugs and treatments on the market today. These transformations in the drug development process alone can deliver significantly enhanced quality of patient care.

Financial institutions must protect customer interests and experience—their personal information and their transactions—which is of increasing urgency in this time of skyrocketing cyberthreats. Risks from outside the organization and from within it are key factors. These firms must analyze mountains of internal data and transactions, coupled with digital communications, market feeds, IoT and mobile banking data, and so on. And they have the task of leveraging analytics and machine learning to correlate multiple data sources so that they can rapidly identify fraud or external and internal suspicious actions.

These tools enable them not only to identify industry and market patterns, but also to recognize transactional patterns that indicate fraud. Staying ahead of these high-risk situations can help preserve the company reputation and brand and can help avoid costs that can be in the millions of dollars. And the ability of this infrastructure to enable organizations to rapidly recover from security-related incidents yields significant business value.

The retail industry is undergoing significant transformation and disruption, affecting commerce that's conducted in brick-and-mortar stores and through global and digital outlets. Retailers can take advantage of the data in traditional core IT services, the cloud, IoT, and predictive analytics when it's applied to customer preferences, market trends, and competitive data. With this data, retailers can grow their business and customer loyalty by bringing new products to market faster, by managing supply-chain logistics, and by staying ahead of competition.

These use cases are just a few examples in which bringing together analytics, AI, and IoT along with core enterprise data can enable new business outcomes. Enterprise SAN architectures must evolve to support these new types of use cases. They must provide real high-speed access to large amounts of data and must make the transport of various datasets between on-premises and internal and external clouds of your choice easy.

This joint solution also provides data protection that applies to the following use cases:

- All traditional SAN and any NetApp ONTAP systems that serve primary data over SAN fabrics
- Disaster recovery requirements with failover capabilities from site to site
- Long-term archiving
- NDMP tape replacement for backup
- High-performance database platforms and data protection
- Public and private cloud adoption
- Need to provide short- and long-term retention for data protection

4 Technology Requirements

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

4.1 Hardware Requirements

Table 3) Hardware requirements for the joint solution.

Hardware	Quantity
NetApp AFF A700s high-availability (HA) pair with four 32Gb FC target ports and 24 SAS 960GB SSDs	1
Switches Brocade G620 48-port 32Gb FC switch	2
Fibre Channel HBAs Emulex LPe32002-M2 32Gb FC	4
Fujitsu PRIMERGY RX300 S8, 2 Intel Xeon E5-2630 v2, 2.6GHz, 6c/12t with 256GB RAM (16 x 16GB)	4

4.2 Software Requirements

Table 4) Software requirements for the joint solution.

Software	Version
NetApp ONTAP—AFF A700s storage	9.4
Brocade Fabric OS (FOS)—Brocade G620 switches	8.1.0a
Emulex Firmware— FC HBAs	FV11.4.204.25 DV11.4.354.0
SLES—Fujitsu PRIMERGY RX300 S8 servers	12SP3 4.4.126-7.ge7986b5-default
BIOS—Fujitsu PRIMERGY RX300 S8 servers	V4.6.5.4 R1.3.0 for D2939-B1x

4.3 Network Design

This section provides the network connectivity details for the tested configurations.

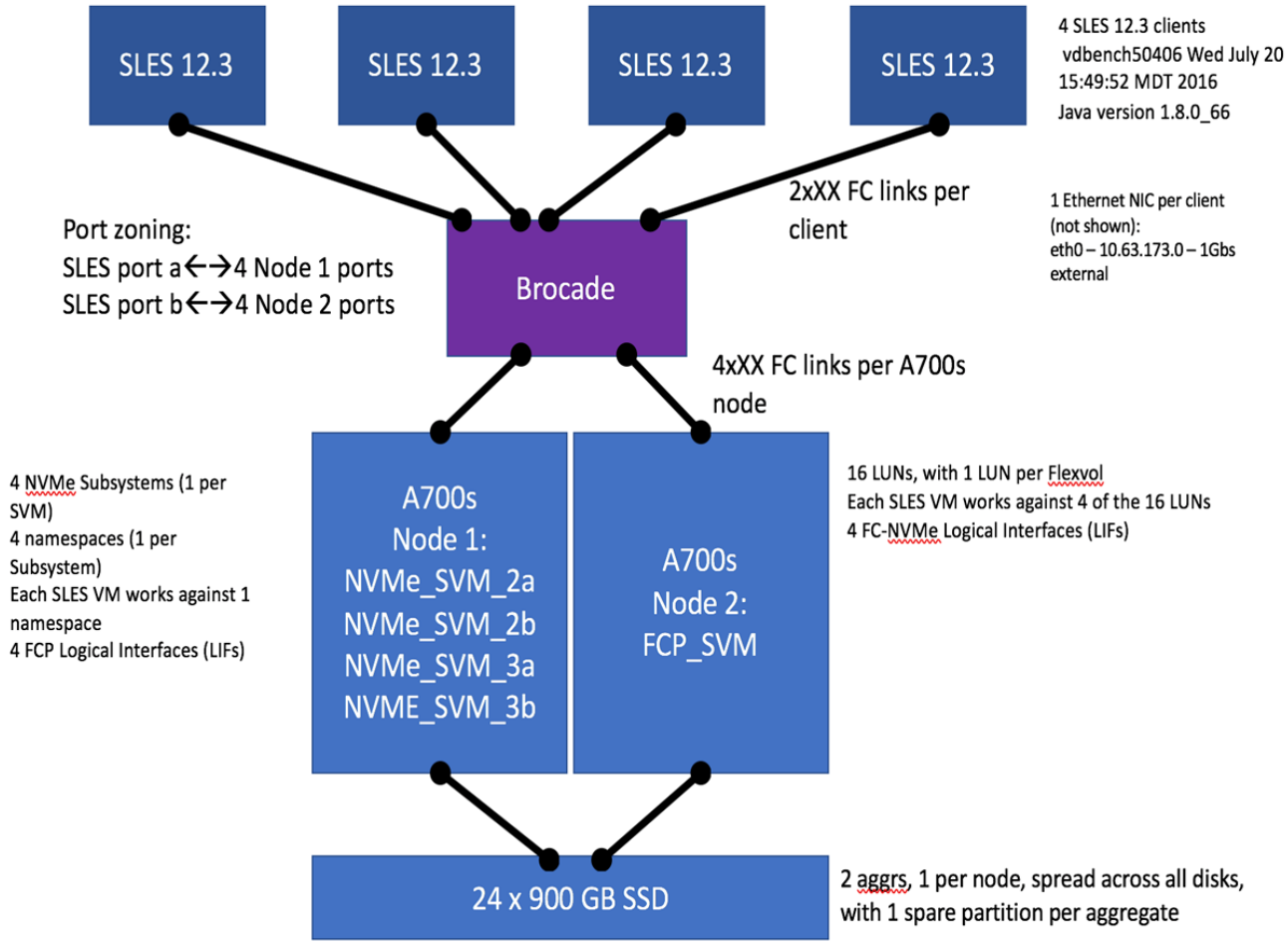
The network diagram in Figure 7 shows that the Fibre Channel Protocol (FCP) SAN was deployed with a Brocade G620 32Gb FCP switch. Each storage node had four ports connected to the FCP switch. Each server had two ports connected to the switch. At no point in the testing did the network connectivity create a bottleneck.

For Ethernet connectivity, each of the four hosts had a 1Gbps link for external access and to manage VDBench coordination between nodes.

We used one group per server to contain the FCP initiators. We then used the “latency-performance” tuned profile to manage the SUSE hosts. We manually modified the FCP Device Mapper Multipathing (DM-Multipath) devices to use the “deadline” scheduler.

Each of the four SUSE servers had two FCP ports that were connected to the Brocade switch. Each AFF A700s node had four FCP target ports that were also connected to the same switch, for eight total connected target ports. We configured the Brocade switch with port zoning to map port 1 of each SUSE host to all four ports of the AFF A700s storage node 1. Similarly, we mapped port 2 of each SUSE host to all four ports of the AFF A700s storage node 2.

Figure 7) NetApp and Broadcom validated architecture testbed layout.



4.4 Workload Design

We used VDBench 5.04.06 and Java 1.8.0_66-b17 to drive different IOPS mixes against FCP and NVMe/FC storage. Those mixes included an emulation of workloads to use profiles that mimic the storage load of an Oracle 12c database that runs an 80/20 select/update mix. We included other synthetic I/O patterns to give a general indication of the difference in performance between FCP and NVMe/FC.

Note: We took care in these test steps to simulate real database and customer workloads, but we acknowledge that workloads vary across databases. In addition, these test results were obtained in a closed lab environment with no competing workloads on the same infrastructure. In a typical shared-storage infrastructure, other workloads share resources. Your results might vary from the results that are found in this report.

During our testing, only one protocol and workload were active at a given time. This approach allowed us to reuse the same SUSE hosts for each of the two protocols, resulting in comparable performance measurements between the NVMe/FC and FCP accessible containers. We created one aggregate in ONTAP on each of the two storage nodes, named `NVMe_aggr` and `FCP_aggr`, respectively. Each aggregate consumed 23 of the 24 SAS-attached SSDs, leaving 1 SSD spare for each data aggregate.

The `NVMe_aggr` contained four 512GB namespaces. Each 512GB namespace was mapped to a single SUSE host to drive I/O. Each namespace was contained in its own NetApp FlexVol volume. Each namespace was associated with its own subsystem.

The `FCP_aggr` contained 16 LUNs, each contained within its own FlexVol volume. The total container size was the same as for the NVMe namespaces. Each LUN was mapped to each of the four SUSE hosts to receive I/O traffic evenly.

We used the VDBench load-generation tool to generate workload mixes against an AFF A700s storage target. VDBench is an open-source workload generator that's provided by Oracle and that can be found at http://www.oracle.com/technetwork/server-storage/vdbench-downloads-1901681.html. VDBench generates a variety of I/O mixes, ranging from small random I/Os, to large sequential I/Os, to mixed workloads that are designed to emulate real application traffic.

We first conducted an initial write phase to populate the thin-provisioned LUNs and namespaces. This phase writes through each LUN or namespace exactly one time with nonzero data. This step confirms that we are not reading uninitialized portions of a LUN or namespace that can be satisfied from the AFF A700s without due processing.

We designed our VDBench workloads to highlight a range of use cases. These use cases provided a general overview of performance and demonstrate the performance differences between FCP and NVMe/FC in ONTAP 9.4:

1. **Synthetic "4-corners" testing**—16 JAVA VMs, 128 threads for FCP, 512 threads for NVMe/FC:
    a. Large sequential reads (64K)
    b. Large sequential writes (64K)
    c. Moderate sequential reads (32K)
    d. Moderate sequential writes (32K)
    e. Small random reads (4K)
    f. Small random writes (4K)
    g. Mixed random reads and writes (4K)
2. **Emulated Oracle OLTP workload**—16 Java VMs, 100 threads:
    a. 80/20 8K read/write mix
    b. 90/10 8K read/write mix
    c. 80/20 8K read/write mix with a separate stream of 64K sequential writes that emulate redo logging

5 Solution Verification

NetApp studied the performance of an AFF A700s storage system to determine its peak sustained throughput, IOPS, and read latency over the FC and NVMe/FC protocols. The following subsections describe the test methodology that we used to measure the performance of these two protocols while we ran a suite of synthetic workloads and present the results of the tests.

5.1 Test Methodology

In our study, we configured four servers that ran SUSE Enterprise Linux 12.3 with Broadcom LPe32002 FC HBAs to a single AFF A700s two-node HA storage cluster through a Brocade G620 network switch.

The AFF A700s storage cluster in our testbed contained two storage nodes. For the purposes of this test, one storage node was used to host the storage for NVMe/FC containers and one storage node was used for the FCP containers. We created one storage virtual machine (SVM) in ONTAP to host FCP-related storage objects, and we created multiple SVMs to host NVMe/FC-related objects.

5.2 Test Results

NVMe/FC delivered up to 58% higher IOPS compared with SCSI over FCP by using the same hardware configuration and workloads. This result means that you can run many more workloads on the same hardware by simply upgrading your software to NVMe-capable versions in the client OS, in the fabric firmware, and in the ONTAP version for NetApp storage. Tests also showed up to 30% reduction in latency. This lower latency means a better response time for client I/O requests, again with only a simple software upgrade.

In our tests, we observed up to **58% higher IOPS** for NVMe/FC compared with FCP **on the same hardware.** We also observed a minimum difference of 11% to 34% lower latency with NVMe/FC, depending on the test run. In addition:

- **NVMe/FC is easy to adopt.** All the performance gains that we observed were made possible by a simple software upgrade.
- **NVMe/FC protects your investment.** The benefits that we observed were with existing hardware that supports 32Gb FC.
- **NVMe/FC promotes data center consolidation.** With increased IOPS density, your system can complete more work in the same hardware footprint. Also, because NVMe/FC often reduces processor and memory loads on initiators, if you adopt NVMe/FC, your organization might be able to reduce the number of servers that you need for your workloads. This reduction translates to fewer servers and lower software licensing, footprint, and power and cooling costs.

IOPS Benefits

A more efficient fabric protocol can deliver higher IOPS. In our tests, we observed up to a 58% increase in IOPS by simply moving over to the NVMe/FC fabric from the traditional FCP (FC-SCSI) fabric.

Latency Benefits

NVMe/FC has lower latency than traditional FCP (FC-SCSI) does. We observed a minimum difference of 11% to 34% lower latency for these tests.

Better Performance with Existing Hardware

These benefits can be achieved by simply applying a software upgrade for the FC HBAs. By moving to NVMe/FC with the same storage hardware, you can attain dramatic increases in performance.

NVMe/FC Benefits—FC HBAs

NVMe/FC brings native parallelism and efficiency to block storage that FCP (FC-SCSI) cannot. In separate testing over at least the past year, Broadcom (Emulex division) has observed performance improvements of up to 2 times with NVMe/FC over FC-SCSI.

NVMe/FC Benefits—FC Switches

Brocade Gen 6 Fibre Channel fabrics transport both NVMe and FCP (FC-SCSI) traffic concurrently with the same high bandwidth and low latency. Overall, the NVMe performance benefits are in the end nodes—initiators and targets. NVMe/FC provides the same proven security that the traditional FCP has provided for many years. FC provides full fabric services for NVMe/FC and FCP (FC-SCSI), such as discovery and zoning. Also, NVMe/FC is the first enterprise NVMe-oF transport that meets the same high bar as SCSI over FC with full-matrix testing as an enabler and as essential for enterprise-level support.

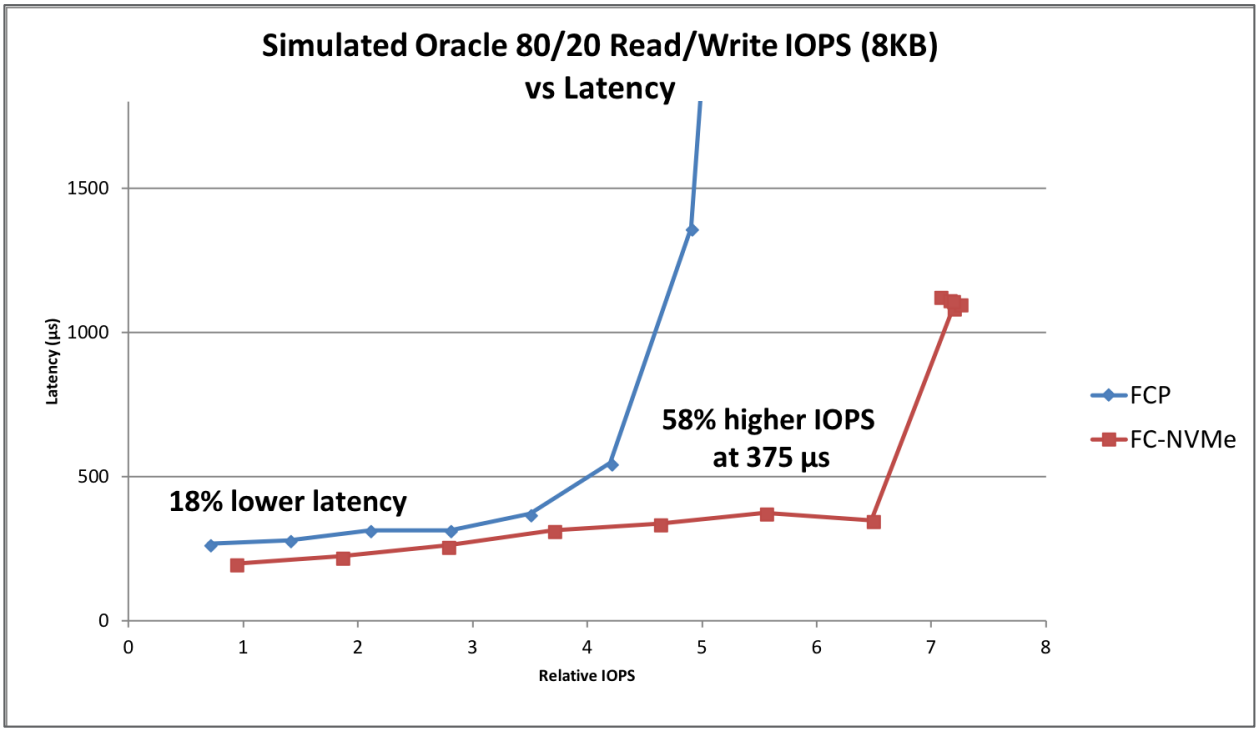
A combination of NetApp SnapVault and SnapMirror is a certified option that has been available for over a decade. Valid testing of this functionality has been performed with all systems that run ONTAP. The following tests for FabricPool were carried out:

- Backup and DR from a non FabricPool aggregate to a FabricPool aggregate with autotiering
- Backup and DR from a FabricPool aggregate to another FabricPool aggregate (auto to backup)
- Tier inactive snapshot copy–only data for a volume in FabricPool aggregate
- Backup and DR from a non FabricPool aggregate to a FabricPool aggregate (Snapshot copy only to auto)
- Backup and DR from a non FabricPool aggregate to a FabricPool aggregate (Snapshot copy only to backup)
- Archiving of a volume by using vol move
- Full volume restore from a backup or DR Snapshot copy
- Single file Snapshot copy restore from a local Snapshot copy
- Full volume restore from a local Snapshot copy

Note: This testing was for protocol performance comparison. It is not a benchmark of a storage system or any other individual component in the solution stack.

For the simulated Oracle workload with 80/20 read/write at 8KB (typical OLTP database I/O), NVMe/FC achieved **58% higher IOPS** at 375µs latency. Latency was at least 18% lower for NVMe/FC. See Figure 8.

Figure 8) Simulated Oracle 80/20 read/write IOPS (8KB) versus latency.



6 Future Disruptive Innovation

For the past few years, the IT industry has undergone a rapid chain of innovation that has resulted in substantial disruption in traditional IT delivery models and that has rendered many legacy hardware vendors obsolete. Most architectures are unable to evolve with the changes, resulting in successive waves of disruption, rearchitecture, and migration for customers that they can no longer afford.

At NetApp, we have pioneered the concept of nondisruptive operations (NDO) migrations and online transitions between generations of technology with heterogeneously scalable IT infrastructure. NetApp

has focused on innovation in software and on the ability for 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 our architectures of today and help you integrate them without forklift upgrades or disruptive migrations.

Key technology initiatives that are driving change include:

- HDDs replaced by flash
- Hardware appliances augmented or replaced by software-defined storage (SDS)
- NVMe-based media attached for flash
- NVMe-based host attachment
- Storage-class memory (SCM, also known as PMEM)
- Cloud-based IT infrastructure
- Hyper converged 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 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 our data platform. These offerings give us a superior ability to future-proof your architecture.

As we have discussed in this report, 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 report, we presented the NetApp and Broadcom modern enterprise SAN verified architecture. This solution is the optimal infrastructure approach for you to leverage best-in-class, end-to-end, modern SAN and NVMe technologies to deliver business-critical IT services today while preparing 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 for you to implement within your current operational processes and procedures. One of our main objectives is to enable organizations like yours to quickly and to non-disruptively 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 within current operational frameworks.
- Align with organizational objectives to consolidate and streamline infrastructure and operations.

In this NetApp Verified Architecture, the first in a series, tests on an Oracle workload represent the benefits of a modern SAN architecture that is suited for multiple use cases and for critical SAN-based workloads. These benefits apply to the Oracle workload that was presented in this report, and they also apply to SQL Server, SAP HANA, and similar workloads.

With the flexibility and scalability of this NetApp Verified Architecture, your organization can start with a framework to modernize and to right-size your infrastructure and can ultimately grow with and adapt to evolving business requirements.

During the solution testing of this NetApp Verified Architecture, the response times from the solution for Oracle were a breakthrough. Our combined NetApp and Broadcom NVMe-enabled AFF A700s platform performed exceptionally well, demonstrating greater than 50% higher IOPS at much lower latency—on the very same hardware—than by using traditional FC SAN design. These results demonstrated that, based on the Oracle workload, the modern NVMe NetApp and Broadcom SAN solution can support more workloads, with faster response times, while meeting all the requirements of traditional SAN infrastructures.

With these benefits, your system can serve existing workloads while streamlining infrastructure, reducing operational costs, and preparing for new workloads in the future.

8 Where to Find Additional Information

To learn more about the information that's described in this document, see the following documents and websites:

- Leading the Future of Flash with NVMe
  www.netapp.com/us/info/nvme.aspx
- NetApp AFF A-Series All-Flash Arrays
  https://www.netapp.com/us/products/storage-systems/all-flash-array/aff-a-series.aspx
- SAN Solutions
  https://www.netapp.com/us/products/storage-systems/storage-area-network.aspx
- NVMe over Fibre Channel for Dummies
  https://www.netapp.com/us/forms/campaign/nvme-for-dummies-ebook-lp.aspx
- NetApp SAN Health Program
  https://fieldportal.netapp.com/content/704155
- White Paper: New Frontiers in Solid-State Storage
  http://www.netapp.com/us/media/wp-7248.pdf

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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