VMware Horizon View 6 VDI with Dell SC8000 All-Flash Arrays for 4,000 Persistent Desktop Users

Large-scale virtual desktop infrastructure (VDI) deployment using all-flash arrays and next-generation, mixed-use SSDs

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A Dell Reference Architecture

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Executive summary

This document provides a storage reference architecture for building large-scale, persistent-desktop VDI deployments with medium-to-heavy user workloads from a storage perspective. Designed for 4,000 users, the solution uses VMware® Horizon View™ 6 linked clones and leverages a single Dell™ SC8000 All-Flash Array (AFA) with next-generation, mixed-use SSDs.

The solution retains the end-user productivity of customized desktops while providing high performance with up to 65,000 IOPS and less than 4 ms latency. It offers extreme scalability, minimized desktop administration overhead, and a low cost per desktop. Details are provided for the storage I/O characteristics under various VDI workload scenarios like boot and login storms, as well as a common steady-state workload level of 12 IOPS/desktop.

1 Introduction

Desktop virtualization is an important strategy for organizations seeking to reduce the cost and complexity of managing an expanding variety of client desktops, laptops, and mobile devices. Virtual desktop infrastructure (VDI) offers an opportunity to not only reduce the operational expenses for desktop management and provisioning, but also to improve user mobility and data security.

A VDI deployment can place high capacity and performance demands on the storage platform. Consolidating large amounts of inexpensive standalone desktop storage into a centralized infrastructure can create tremendous capacity demands on the centrally managed shared storage used in VDI deployments. Performance demands are determined by the number of I/O operations per second (IOPS) generated by basic desktop client operations (such as system boot, logon, and logoff) and by desktop user operations. Storm events such as morning logons and afternoon logoffs by many users at the same time can cause I/O spikes that place high performance demands on the storage infrastructure. Moreover, IOPS generated per desktop can vary greatly depending on the user type. For example, knowledge workers with several demanding applications can create significantly higher IOPS per desktop than task workers performing routine operations.

To meet the capacity and performance demands of VDI, choosing the right storage platform is critical and the Dell SC8000 All-Flash Array (AFA) is an ideal choice. With its advanced storage architecture, feature set, and tight hypervisor integration, the SC8000 AFA provides an automated, self-tuning storage system capable of efficiently scaling to satisfy VDI production-level workloads. Specifically, its flash-optimized Data Progression tiers data across multiple disk tiers and RAID types, enabling a dramatic cost-per-desktop reduction in VDI deployments. These benefits are most prevalent for persistent desktops which allow user customization — such as personalized desktop wallpaper, menus, fonts, and icon placement — and enable customizations to be retained between sessions, just like with dedicated physical desktops.

A cost-effective, appropriately-sized storage platform is key to VDI deployment success, and the SC8000 AFA offers an excellent platform. When paired with VMware Horizon View 6 and VMware vSphere® hosts, it provides a solution with excellent scalability, high performance, and simplified management.

1.1 Environment

The solution presented in this paper used the following software:

- VMware Horizon View 6
- VMware ESXi™ 5.5
- VMware vSphere management
- Login VSI (for simulating real-world VDI workloads)

The hardware used to host the environment consisted of the following:

- Dell PowerEdge™ M620 blade servers for VDI workload
- Dell PowerEdge M710HD blade servers for infrastructure hosting
- Dell PowerEdge M1000e blade enclosure

- Dell Networking MXL Ethernet blade switches
- Dell Networking S5000 Top-of-Rack (ToR) switch
- Brocade® M5424 Fibre Channel (FC) blade modules
- Brocade 5100 FC ToR switches
- Dell SC8000 storage array controllers
- Dell SC220 drive expansion bays

The hardware components are fully detailed in section 3.2.

1.2 Objectives

The primary objectives of the tests conducted for this paper include:

- Determine the performance impact on the storage array during the peak VDI I/O activity such as boot and login storms
- Show the latency at the full steady-state user load of 12 IOPS per desktop

1.3 Audience

This document is intended for anyone who wishes to understand the performance characteristics of mixed-use SSD drives in a VDI solution. This could include, but is not limited to, solution architects, storage architects, customers, solutions partners, and enterprise technologists.

2 VDI storage platform considerations

When choosing a VDI storage platform, there are a few important factors to consider:

RAID tiering: Solutions from some vendors require pre-allocation and segregation of RAID levels, holding large amounts of storage captive, which can have negative cost and performance impacts. Dell SC Series arrays present a fully-virtualized storage pool, configuring and mixing RAID levels on demand across all drives to address reads and writes differently. RAID 10 is used for new writes, while blocks not being updated are converted to read only at parity RAID 5 or 6. This provides the performance benefits of RAID 10, plus the capacity benefits of RAID 5/6. RAID acts as a flexible sub-tier for Dell arrays, optimizing data placement within each drive. This maximizes performance, capacity, and administrator efficiency.

Dynamic Capacity: Dynamic Capacity technology makes the initial VDI capacity sizing an easy exercise. Virtual volumes can be created for thousands of virtual desktops without pre-allocating physical capacity. Actual storage capacity is consumed only when data is written to disk. As the virtual environment grows to accommodate more users, the system dynamically provisions storage from a centralized pool of unused capacity. With Dynamic Capacity, storage purchases can be deferred until actually required and seamlessly added to the pool without any service disruption, thereby significantly enhancing project ROI. Capacity can be grown to over 1 petabyte without downtime.

Hypervisor integration: Additional operational efficiencies are realized through integration with the hypervisor layer. Dell SC Series arrays tightly integrate with industry-leading hypervisors such as VMware vSphere, Microsoft® Hyper-V®, and Citrix® XenServer®. This integration enables optimal storage performance, lower costs, and simplified VDI deployments. As an example, the Dell Storage vSphere client plug-in reduces complexity by providing integrated storage provisioning and management. Support for VMware vStorage APIs for Array Integration (VAAI) enhances vSphere server performance by offloading storage related tasks (such as hardware-assisted locking, full copy, and block zeroing), reducing vSphere server compute overhead, network traffic, and virtual desktop deployment times.

In summary, the advanced storage architecture and feature set of the Dell SC Series, combined with its tight hypervisor integration, provides an automated, self-tuning storage system capable of efficiently scaling to VDI production-level workloads at a very low cost.

3 Solution architecture

The overall architecture of the SC8000 AFA VDI solution is presented in Figure 1.

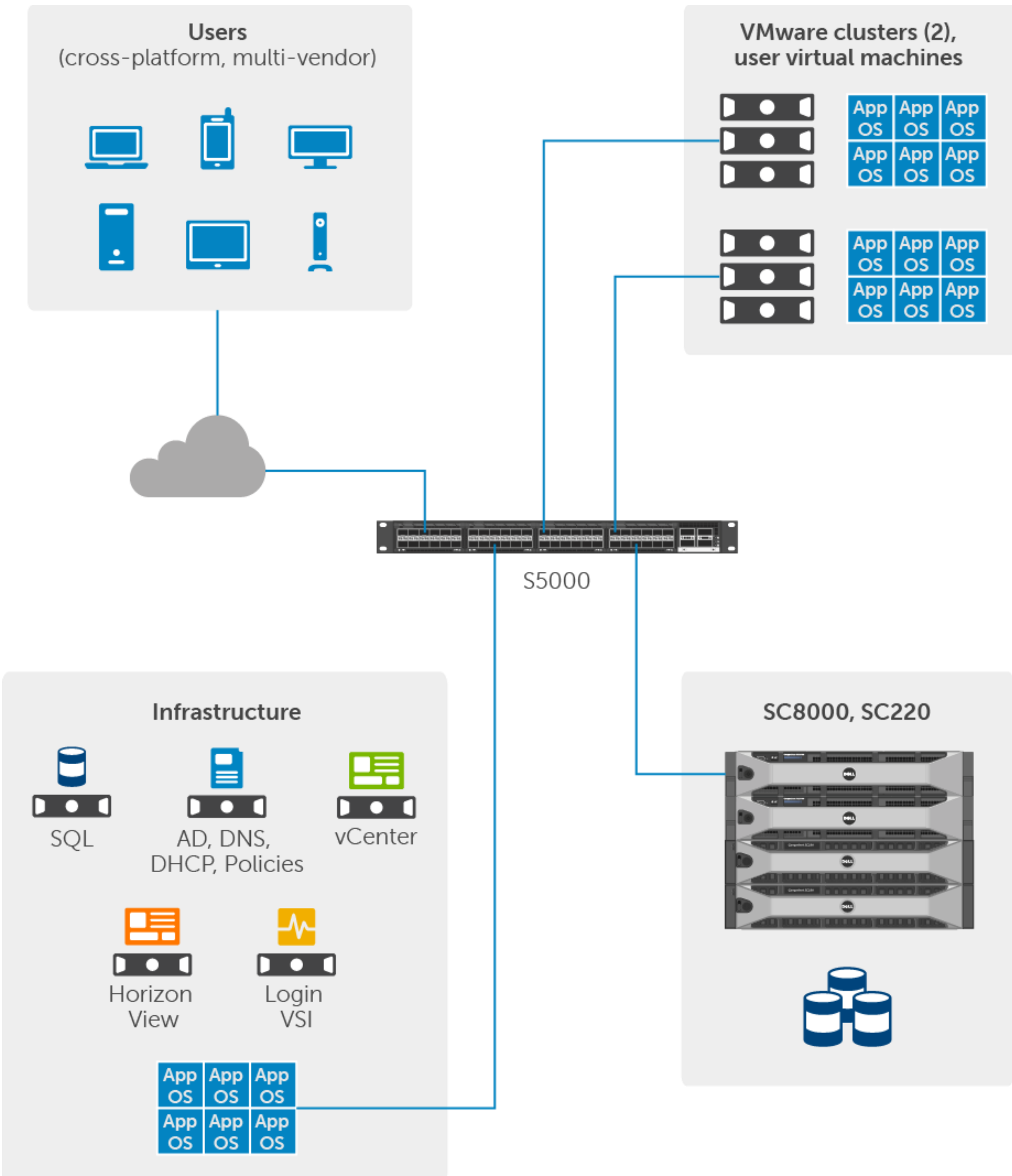

Figure 1 Solution architecture

3.1 Software

This section provides an overview of the VDI solution software components.

3.1.1 VMware Horizon View

The solution is based on Horizon View 6 which provides an end-to-end solution delivering Microsoft Windows® virtual desktops to users on a wide variety of endpoint devices. Virtual desktops are built using linked clones, providing an efficient, small-footprint solution that is highly manageable.

Horizon View uses a distributed architecture which allows scaling of components as needed. This is shown in Figure 2.

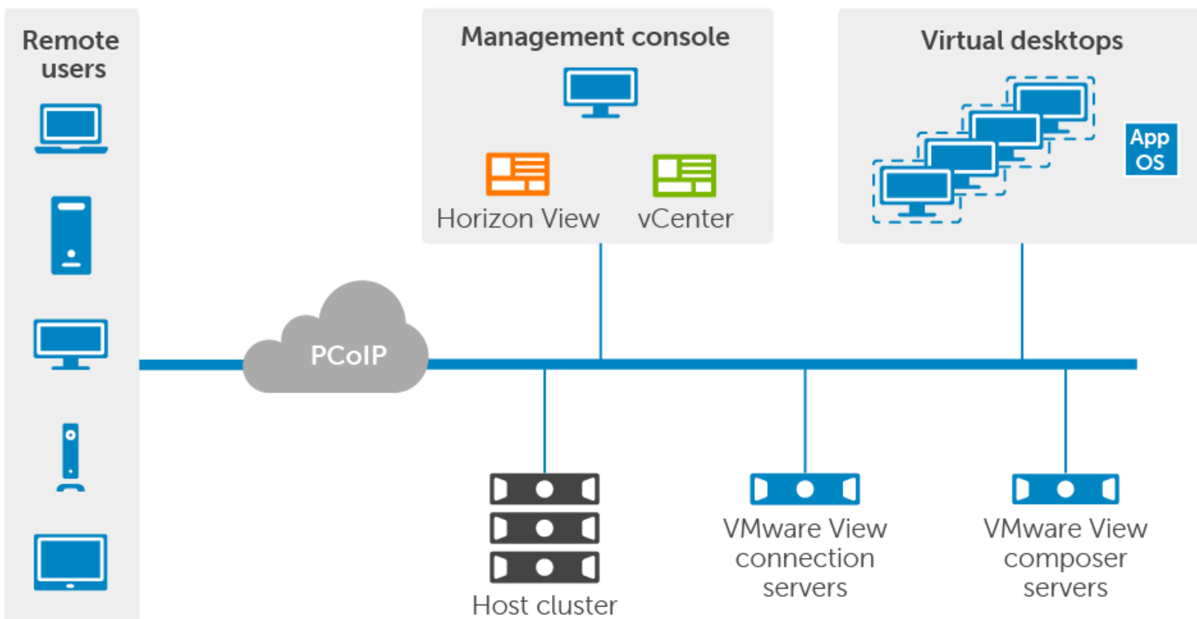

Figure 2 Logical architecture

The core Horizon View components include:

- **Connection Server:** The Connection Server is the central hub for managing connections. Users connect using either the Horizon View client or a web browser. The Connection Server then connects the user to the proper virtual desktop session based on the assignments. Users can either be assigned a static machine (in this case, for persistence) or given a random machine in a non-persistent environment.
- **Composer:** The Horizon View Composer server handle the tasks of provisioning virtual desktops to the proper pool using the correct base image. It also handles maintenance task, such as a desktop refresh or recompose.
- **VMware Horizon View agent:** Installed on user devices, the Horizon View agent provides users with quick, secure, self-service access to documents, applications, and desktops from any of the user's

devices including smartphones, tablets, and PCs. VMware Horizon provides on-demand access to Windows, web, and Software as a Service (SaaS) applications.

- **Management console:** The Horizon View management console is a web service application that can be run from any Windows server in the environment. For simplicity, the console was run from the vSphere server. The management servers used were configured using VMware vCenter™ 5.5 with a local Microsoft SQL Server® 2008 R2 instance. Each server had its own local install of SQL.

3.1.1.1 Linked clones

All 4,000 virtual machines were created in less than 3 hours using parallel environments both taking advantage of the high performance all-flash array.

The virtual machines were created using the linked clone method in Horizon View. This provides efficient use of space and simplifies management. By using linked clones, a single replica image is used for shared data resulting in a very small footprint. After cloning, the total space consumed is 7.5 TB before snapshots. This equates to less than 2 GB/VM in a persistent state before user login.

After the user profiles were created, the VMs each consumed approximately 2.4 GB of space. This includes the user customizations, page file, and changes made to customize each VM to the assigned user. Each VM runs Microsoft Office® 2013, Adobe® Reader®, and a mix of Login VSI applications.

Virtual desktops are assigned to the same user every time with desktop persistence. All changes made by a user are retained for future sessions. The changes are stored in a delta VMDK stored with the VM.

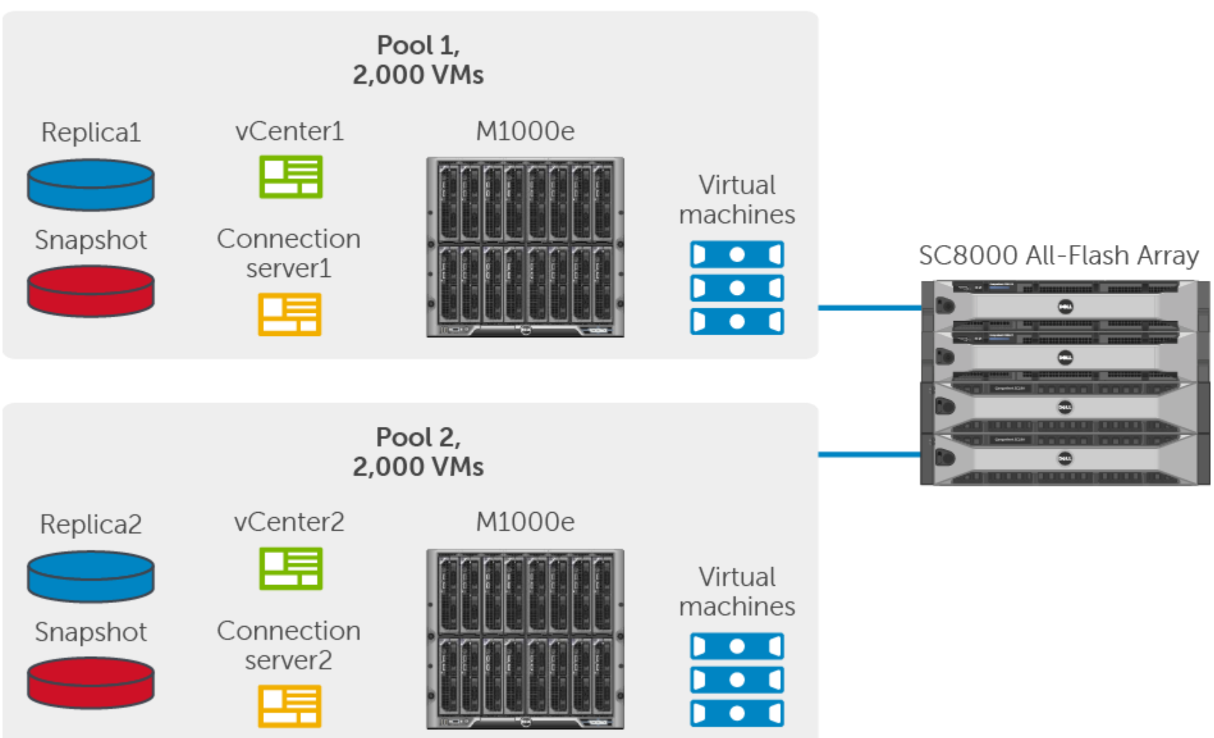

Figure 3 Virtual desktop pools

All the desktops in an automated desktop pool with dedicated user assignments are based off a master desktop template which is selected during the pool-creation process. This ensures each user gets a dedicated machine they can customize.

Horizon View also supports creating non-persistent environments to streamline support and troubleshooting. These desktops automatically revert upon user logoff.

3.1.2 VDI hypervisor platform: VMware vSphere 5.5

VMware vSphere 5.5 is the enterprise virtualization platform used for building VDI and cloud infrastructures. VMware vSphere 5.5 includes three major layers: virtualization, management, and interface. The virtualization layer includes infrastructure and application services. The management layer is central for configuring, provisioning, and managing virtualized environments. The interface layer includes the vSphere client and the vSphere web client.

Throughout the solution, all VMware and Microsoft best practices and prerequisites for core services are adhered to (for example, NTP, DNS, and Microsoft Active Directory®). The vCenter 5.5 servers used in the solution are Windows Server 2008 R2 physical servers. SQL Server is a core component of the Windows version of vCenter and is hosted on the same server residing in the management tier. This was done to accelerate VM task speed during testing. In a production environment, the vCenter server would typically be a Windows VM or VMware appliance.

3.2 Hardware

This section details the hardware used in the VDI solution. Note that the goal of this document was to determine the performance (including testing boot storms, login storms, and steady states) of the SC8000 All-Flash Array running a 480 GB mixed-use SSD configuration for the Horizon-View-based, persistent-desktop VDI deployments. Therefore, sufficient headroom was left in the other components to ensure none of the other components in the VDI stack would cause bottlenecks.

3.2.1 Storage

The storage used to host the virtual desktops included an SC8000 array with dual controllers running Storage Center Operating System (SCOS) 6.6. All 16 front-end ports were 8 Gb FC, and all 4 back-end ports were 6 Gb serial-attached SCSI (SAS). The array used two enclosures of SSDs. The mixed-use drives were 480 GB drives composed of 46 active drives with two hot spares. The use of a mixed-use drive type was chosen to highlight the performance of the next-generation drive and demonstrate how it can improve the cost and capacity of the array. Table 1 summarizes the storage hardware configuration.

Table 1 Storage hardware components

Storage role	Type	Quantity	Description
Controllers: VDI workload	SC8000	2	System Center Operating System (SCOS) 6.4.1

Storage role	Type	Quantity	Description
Enclosures	SC220	2	24 bay, 2.5-inch disk drive enclosure
Ports	FC, 8 Gbps SAS, 6 Gbps	16 4	Front-end host connectivity Back-end drive connectivity
Drives	480 GB	48	46 active with 2 hot spares

The volumes created to host the virtual desktops took advantage of thin provisioning technology for efficient capacity allocation. Table 2 details the volume layout on the SC8000 AFA hosting the virtual desktops.

Table 2 Volumes for hosting virtual desktops

Name	Type	Quantity	Size	Description
VDI volumes	VMFS	12	2 TB	Each thin provisioned volume stores 333 virtual machines

For each persistent desktop VM, the deltas for each VM were stored on the same datastore as the virtual machine hard disk. Dell thin provisioning technology was leveraged, and repeated testing over a long period of time showed low actual capacity utilization consistently. However, if additional capacity is needed, additional drives can be added to the solution. The existing solution provides ample room for growth, and no additional storage is anticipated for the current user configuration. Only 9.5 TB of data were written to disk, with 15 TB available for data storage with the existing RAID protection. Dell flash-optimized Data Progression moves data automatically across RAID types depending on the data access patterns and usage.

The SC8000 AFA hosting the virtual desktops had volume caching turned off. With the high-performance drives of the SC8000 All-Flash Array, caching is not required. For SC Series arrays utilizing HDDs, caching should be enabled to ensure consistent performance. The caching should only be turned off for SC Series AFA solutions.

In addition to the array hosting the virtual desktops, a second storage array hosted the storage needed for infrastructure. This storage array used a combination of SSDs and HDDs. The role of this infrastructure storage is purely to provide storage for domain controllers, SQL servers, VMware vCenter, and related server roles and Login VSI launchers (for VDI desktop load generation). In an actual deployment, this array could be part of the existing storage platform or could be combined with the VDI storage array, depending on actual requirements. The separation was to provide I/O isolation to show the actual VDI load was independent of the infrastructure load.

All storage hardware was configured to Dell best practices with vSphere 5.x. For more information on these best practices, see the document, Dell Compellent Best Practices with VMware vSphere 5.x.

3.2.2 Hosting environment

The virtual desktop hosting environment ran VMware ESXi. All hosts were blade-chassis based, providing full hardware remote control and power management, as well as simplifying hardware updates, switch management, and standardizing hardware from a replacement perspective. Chassis-based servers also simplify cluster management, with a chassis-based networking backplane providing high-performance, redundant connectivity. Figure 4 shows the physical networking diagram.

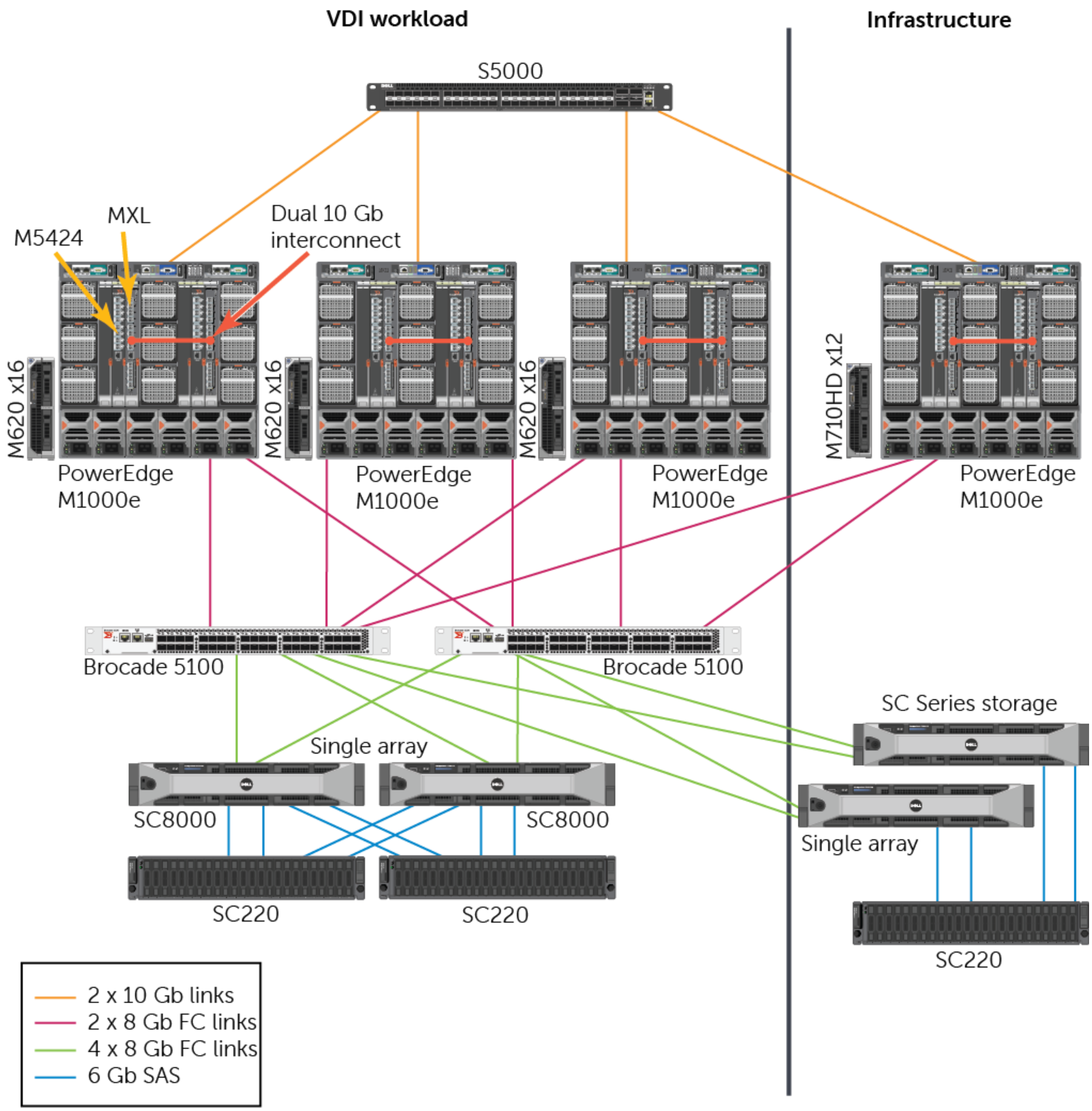

Figure 4 Physical connectivity

Table 3 Host and desktop virtual machine configuration

Component	Description
Server	M620, 320 GB RAM, 2x8 core Intel® Xeon® Processor E5-2680 @ 2.7 GHz
Operating system	VMware ESXi 5.5
FC	Qlogic® QME2572 HBA, Brocade M5424 IO module
Network	Dell Networking MXL 40Gb/10Gb
Virtual desktop hardware	2vCPUs, 3 GB RAM, VMXNET3, 30 GB cache disk

Table 4 Infrastructure virtual machine configuration

Component	Description
Operating system	Windows Server 2008 R2
vNIC Driver version	VMXNET3
Applications	Active Directory Domain Controllers, DNS, DHCP, vSphere servers, Enterprise Manager server, Liquidware Labs™ Stratusphere™ UX, Microsoft SQL, Login VSI

Table 5 Persistence configuration

Component	Description
VMware Horizon View	6.0

3.2.3 Networking

Table 6 Network switches

Component	Description
ToR switch	Dell Networking S5000
Quantity	1
Firmware	9.0
Applications	ToR switch, VLAN management, VLAN routing

Table 7 Infrastructure blade chassis network switches

Component	Description
Chassis switch	Dell Networking MXL 10 Gb Ethernet
Quantity	2
Firmware	9.0
Application	Chassis-based switching for launcher hosts and PVS

Table 8 Workload blade chassis network switches

Component	Description
Chassis switch	Dell Networking MXL
Quantity	6 (2 per blade chassis)
Firmware	8.3.16
Applications	Chassis-based switching, server connectivity

Table 9 Blade chassis FC switches

Component	Description
Chassis switch	Brocade 5424
Quantity	6 (2 per blade chassis)
Firmware	7.1.0.a
Applications	Chassis-based switching, storage connectivity

Table 10 ToR FC switches

Component	Description
FC switch	Brocade 5100
Quantity	2
Firmware	7.1.0a
Applications	FC fabric, chassis, and storage connectivity

4 Test methodology

This section outlines the testing process, criteria, tools, and monitoring methods used in this document. The criteria defined here can be used to compare a custom configuration or desired architecture.

4.1 Test objectives

The primary objectives of the tests include:

- Determine the performance impact on the storage array during the peak VDI I/O activity such as boot and login storms
- Show the latency at the full steady state user load of 12 IOPS per desktop

The goal of these tests were to help create a storage architecture reference point for building large-scale persistent-desktop VDI deployments with medium-to-heavy workloads from a storage perspective.

4.2 Test tools

For this document, Login VSI was used to generate a standardized workload.

PowerCLI was used to accelerate the virtual machine boot rate. For the purposes of this test, a script was used to connect to each host and turn the VMs on with a 1 second delay between each Start-VM command. This allowed all VMs to be powered on in 10 minutes.

Since the workload needed to be generated across a large number of machines in a consistent manner, Login VSI was used to control the login rate for the workstations. By testing varying rates of machines that log in per minute, the maximum login rate per minute that the environment can handle was determined.

4.2.1 Load generation

The load generation was done using Login VSI with the configuration in Table 11.

Table 11 Load generation configuration

Workload	Login VSI
Power user	12 IOPS

The Login VSI medium workload is designed to run on two vCPUs per desktop VM in Login VSI 4.0 and has the following characteristics:

- Once a session has been started, the workload will repeat (loop) every 48 minutes.
- The loop is divided in 4 segments, and each consecutive Login VSI user logon will start at different segments. This ensures that all elements in the workload are equally used throughout the test.
- During each loop, the response time is measured every 3–4 minutes.
- The medium workload opens up to 5 applications simultaneously.

- The keyboard type rate is 160 ms for each character.
- Approximately 2 minutes of idle time is included to simulate real-world users.

In every loop, each user will open and use:

- Microsoft Outlook® to browse messages.
- Microsoft Internet Explorer® to browse different webpages; a YouTube-style video (480p movie trailer) is opened three times in every loop.
- Microsoft Word to measure response time in one instance; in another instance to review and edit a document.
- Doro PDF Printer and Acrobat Reader to print the Word document and review in PDF.
- Microsoft Excel® to open a very large randomized worksheet.
- Microsoft PowerPoint® to review and edit a presentation.
- FreeMind, a Java-based mindmapping application.

4.2.2 Monitoring tool

Performance and latency measuring were done with Dell Enterprise Manager. This tool provided consolidated performance data across the entire environment from a single console.

4.3 Test phases

The VDI environment has multiple types of load, each with a distinct profile. This poses a challenge from a sizing and cost perspective because the need to support high boot loads needs to be balanced against the overall cost of the solution.

4.3.1 Boot storm

The boot storm was the phase of the test where all of the virtual machines were turned on in rapid succession. The boot storm was measured from the time the first machine was turned on until the time the last machine was available for login.

In this test scenario, the boot time was reduced by using PowerCLI on both vCenter servers to manage power state for each of the VMs. This results in a 10 minute window to power on all machines and have them reach the login screen. This is a very acceptable boot time for 4,000 virtual machines. If a faster boot time is required, the drive count could be increased. This boot time is the fastest this drive configuration can achieve.

4.3.2 Login storm

The login storm phase was designed to test the storage array performance when all 4,000 users were logged into the virtual machines. A high login rate was used to generate substantial I/O load during this login storm phase. Since the workload starts as soon as the machine is logged in, there is only a small difference in I/O from login to steady-state load. The time to login all 4,000 VMs was 15 minutes.

4.3.3 Steady state

The steady-state performance was one of the primary focus areas of this test. The goal was to achieve the lowest possible latency during the steady-state phase of the test with 4,000 users. The majority usage of a VDI solution is providing users with centrally managed workstations, so the most important criteria for this solution is providing the best possible user experience.

4.4 Test criteria

There were several test criteria that needed to be monitored during the testing to show the performance of the system under load.

4.4.1 Storage throughput and latency

The goal for this test was to maintain under 5 ms of volume latency. This is to highlight the performance characteristics of SSDs and Dell flash-optimized storage.

4.5 Test configuration

The virtual machines are configured in 2 pools, with a Connection and Composer server per pool. Each pool contains 2,000 virtual machines. By using a CSV mapping file, a single instance of Login VSI can control the entire set of virtual machines.

Table 12 Testing details

Item	Count	Description
Machine pools	2	Logical collections of machines for management purposes; each pool uses a single configuration, replicated to each storage resource
Connection servers	2	Connection broker, collection management
Virtual machines	4,000	The virtual machines being tested
VM datastores	12	The volumes for virtual machine storage and virtual machine disk cache
VM workload hosts	56	ESXi hosts
VM infrastructure hosts	16	ESXi hosts, used to run the Login VSI launchers, which initiate RDP sessions
Login VSI launchers	200	The machines initiating the remote connections to the virtual machines

Table 13 Login VSI configuration

Configuration option	Setting
Launchers	200
Connection	VMware Horizon Client
User count	4,000
Workload	Medium
Run time	4 hours

4.6 Test results

The following sections detail the test results in each of the test phases.

4.6.1 Boot storm

The boot storm phase of the tests is the least-common scenario. The boot storm only happens if the entire system is restarted, such as if it is taken down for maintenance, or if a power failure or other catastrophic error occurs.

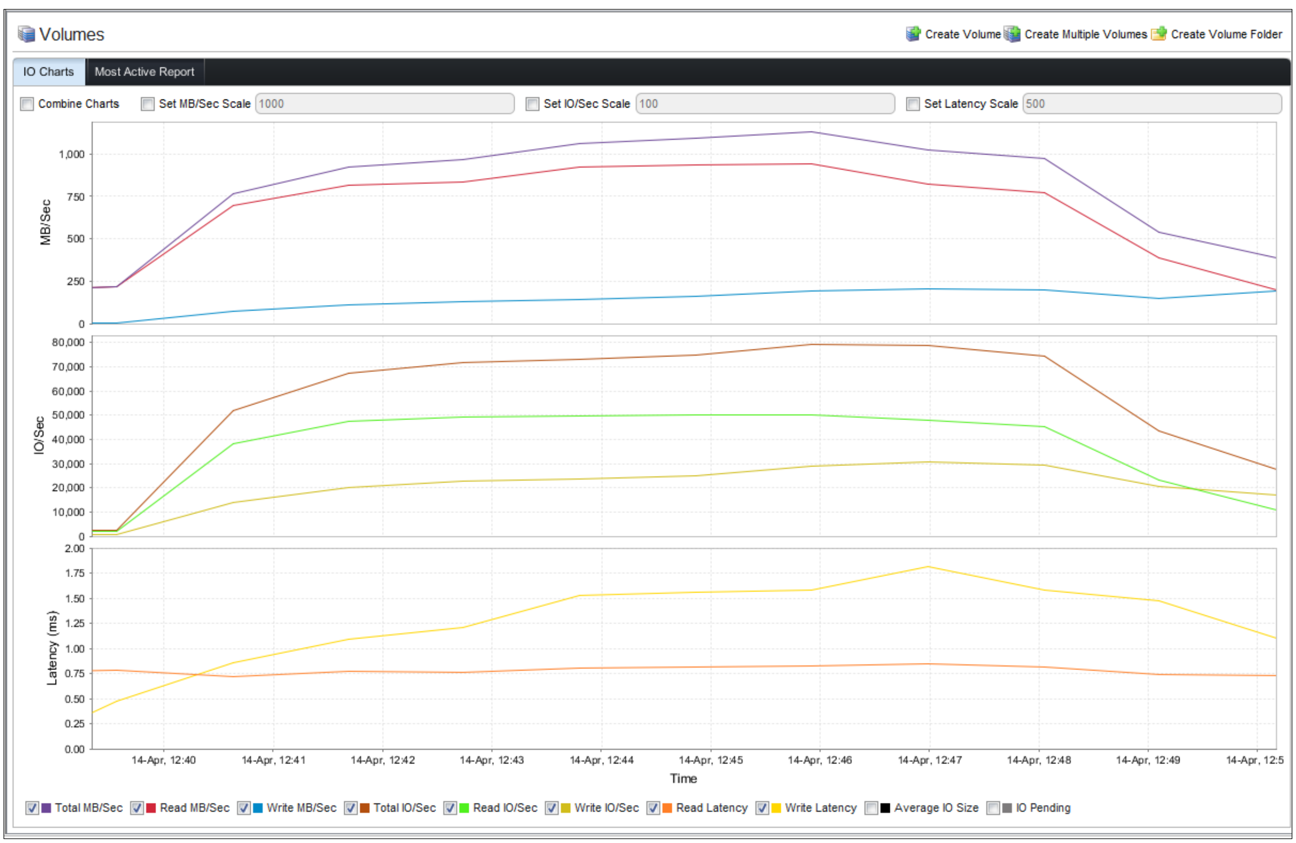

Figure 5 Boot storm I/O

The boot storm had a read to write ratio of 2 to 1 with average block size of 14 KB. The maximum I/O achieved was approximately 80,000 IOPS at less than 1.8 ms average latency. This test resulted in a boot time of less than 10 minutes for all 4,000 virtual machines from power-on to the login screen. Multiple vCenter servers were required to achieve this level of performance.

4.6.2 Login storm

The login storm phase is a much more common scenario. This scenario occurs every time the workday starts and is a more important test. The following charts show the performance during the login phase.

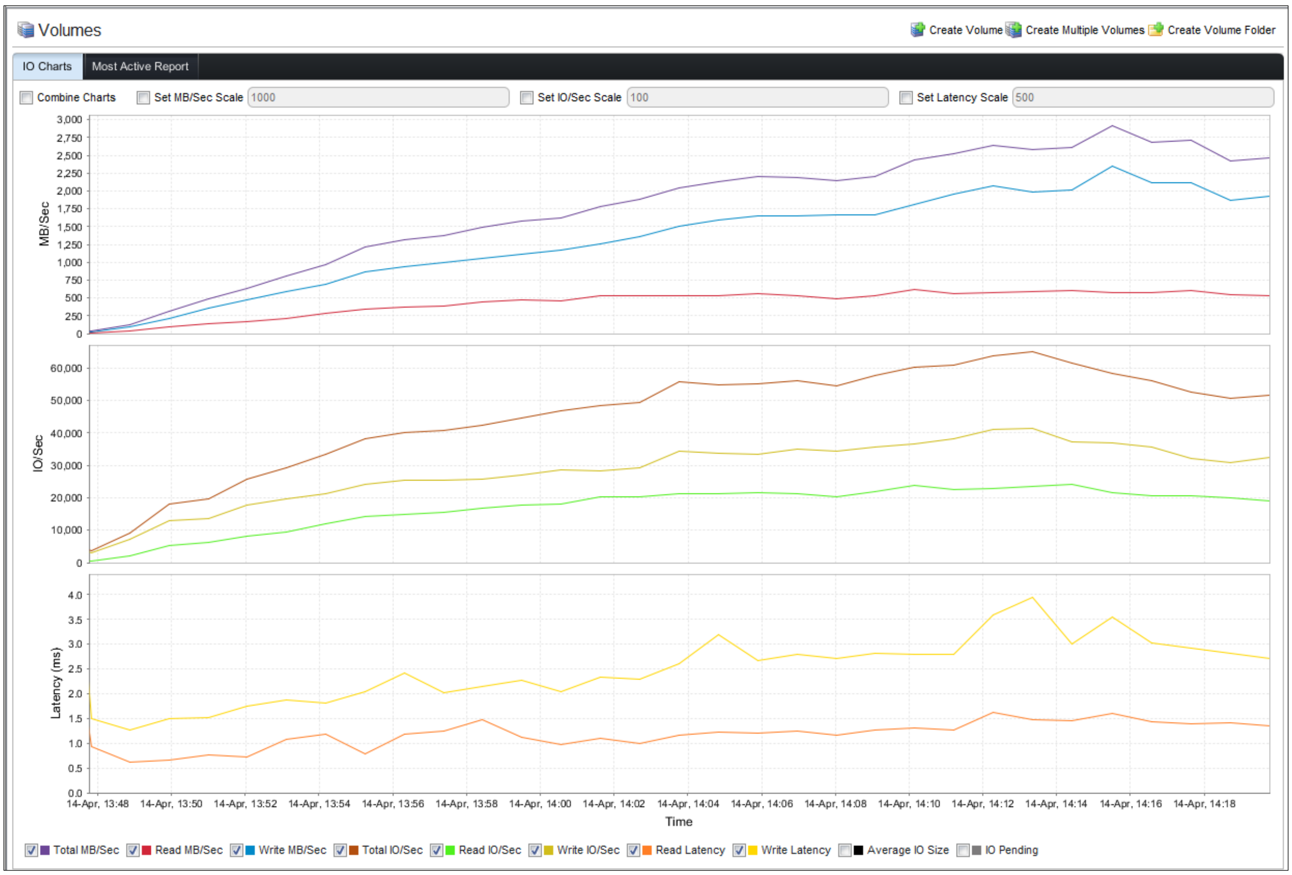

Figure 6 Login storm I/O

The login storm chart shows the entire login-to-steady-state transition and highlights the maximum I/O achieved during this test. During the login storm, all 4,000 users were logged in within 15 minutes and the maximum I/O was 65,000 IOPS with less than 4 ms average latency. The login storm had a write-to-read ratio of 3 to 2 with average block size of 41 KB. Even with this aggressive login rate, the SC8000 AFA delivered excellent performance. There is one very brief spike above 3.5 ms in the write latency at the end of the login phase where the steady-state transition occurred. However, average latency was less than 3.5 ms throughout the login storm including the single write latency spike. This shows that users should experience very good performance upon login.

4.6.3 Steady state

The steady-state phase is the most important phase of the test cycle. The majority of the system time will be spent in steady-state, and the performance during this phase of the test is the most critical because it determines the user experience. The steady state load had a write-to-read ratio of 1.6 to 1 with an average block size of 48 KB. Figure 7 shows the performance during the steady-state phase of the test. The two SC8000 controllers with 48 SSDs within two SC220 enclosures consistently delivered 48,000 IOPS for the 4,000-user persistent-desktop VDI environment. The average write latency during this test was just 2.5 ms. This equates to an excellent user experience during the steady-state phase.

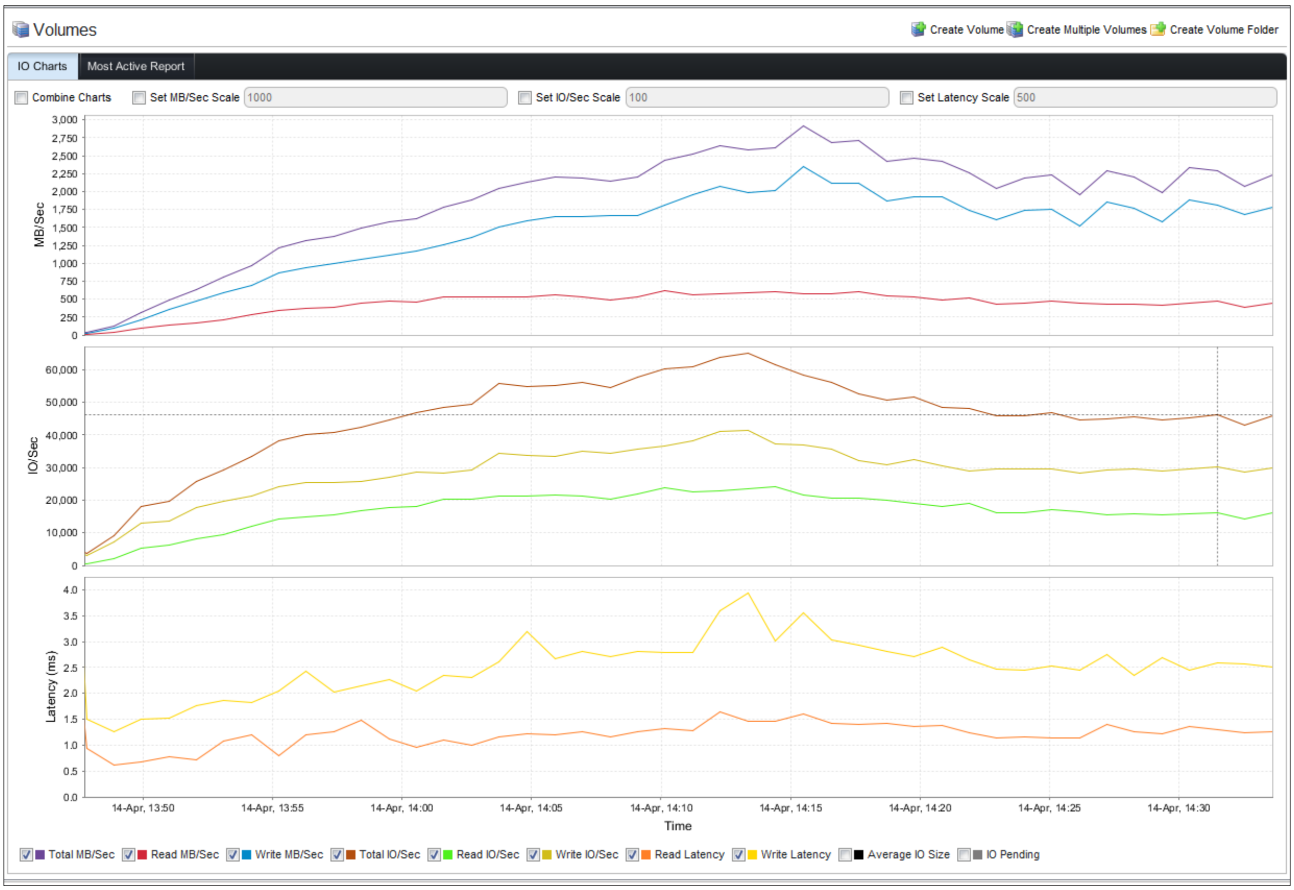

Figure 7 Steady-state I/O

5 Conclusion

The paper demonstrates how a 4,000-user persistent-desktop Horizon View VDI environment can be deployed with a single Dell SC8000 AFA comprising two controllers and two enclosures of SSDs. The storage I/O characteristics under various VDI workload scenarios (boot storm, login storm, and steady state) demonstrate the effectiveness of the SC8000 AFA as a storage building block for desktop virtualization deployments.

The testing of the next-generation 480 GB mixed-use SSD drives show they can handle medium VDI workloads very cost effectively. For example, they delivered 80,000 IOPS with less than 2 ms latency at boot storm and 48,000 IOPS with less than 2.5 ms latency at 12 IOPS/desktop for this 4,000 user deployment.

With the ability to support a large number of desktops with a small footprint, the Dell SC8000 AFA and the next-generation 480 GB drive can help organizations limited by cost-per-desktop start their VDI deployment plans much sooner. With its superb performance, advanced storage architecture, feature set including flash-optimized Data Progression, and tight hypervisor integration, the SC8000 AFA provides an excellent platform for VDI infrastructure.

A Appendix

A.1 Horizon View

Table 14 Horizon Connection server configurations

Component	Description
Horizon View	6.0.1
Application	Virtual machine assignment management, web interface, connection broker
Servers	12 cores, 144 GB RAM
Storage	40 GB SAN data volume

A.2 VMware ESXi Hypervisor

Table 15 VMware ESXi server configuration

Component	Description
ESXi	5.5
Application	End-user virtual machine host
Server	2x8 core processor, 320 GB RAM
Storage	200 GB SSD local boot volume, SAN-based VMFS volumes

A.3 VMware vCenter

Table 16 VMware vCenter configuration

Component	Description
VMware vCenter	5.5
Application	Hypervisor management, centralized management

A.4 Login VSI

Table 17 Login VSI details

Component	Description
Login VSI	4.1.3
Application	Load-generation test harness; controls all virtual machine sessions used for load generation

B Additional resources

B.1 Technical support and resources

For Copilot support of Dell SC Series products:

- Global online support
- Email: support@compellent.com (non-emergency business hours)
- Phone: 866-EZ-STORE (866-397-8673) (United States only)

The Dell Compellent Portal is an online portal for existing customers. A valid portal account is required to access the Knowledge Center. Once login to the portal, go to “Knowledge center”.

Dell TechCenter is an online technical community for IT professionals and is a great resource to discover and learn about a wide range of technologies such as storage, servers, networking, software, and cloud management.

B.2 VMware support

For VMware support, see the following resources:

- VMware.com
- Education and training
- Online documentation
- VMware communities