Dell EMC Ready Solutions for VDI: VMware Horizon 7 on Dell EMC PowerEdge R7525 Servers
Reference Architecture Guide

Abstract
This reference architecture guide describes technical considerations and best practices for integrating VMware Horizon brokering software with Dell EMC PowerEdge R7525 servers to create virtual application and desktop environments in a VMware vSphere environment.

Dell Technologies Solutions
Notes, cautions, and warnings

**NOTE:** A NOTE indicates important information that helps you make better use of your product.

**CAUTION:** A CAUTION indicates either potential damage to hardware or loss of data and tells you how to avoid the problem.

**WARNING:** A WARNING indicates a potential for property damage, personal injury, or death.
Executive summary

Business challenge

The way that we work has fundamentally changed, with more employees working outside the office on their own schedule. The digital workspace is the way for IT to deliver the applications and data that employees need to work across any device from any place, and virtual desktop infrastructure (VDI) is a key enabling technology. Organizations on the road to IT and digital transformation are implementing VDI solutions to provide a flexible, reliable, and secure workspace for their employees.

However, finding a high-performance, scalable, and cost-effective way to use virtual desktops to meet seasonal demand spikes, provide disaster recovery (DR), and respond quickly to unexpected regional and global events or disasters is a challenge for many organizations.

Some of the particular challenges that organizations face today include:

- **Workforce empowerment**—Personal technology and work-life balance is driving newer and higher expectations. People need the same benefits at home as they have in their office—if they even have an office. They want faster, easier-to-use devices and applications that fit their specific needs. Technology itself has become a way to attract and retain the best talent, and so has become a differentiator.
- **Optimized IT resources**—Organizations that manage a large number of traditional PCs find that the task is becoming increasingly complex. With desktop virtualization, you move applications, data, and the operating system desktop to the data center. IT can centrally manage the virtual desktop and save time and money by troubleshooting remotely instead of physically visiting each PC.
- **Improved security**—Organizations require the ability to control data, recover from disasters, apply policies, comply with regulations, and monitor risk. Maintaining data and application security, as well as compliance, is the leading IT concern in organizations of all sizes. Mobile office trends and bring-your-own device initiatives mean that more devices and sensitive data are out of direct IT control, increasing the risk of data theft, viruses, malware, and ransomware attacks. In addition, traditional anti-virus solutions cannot keep up with the amount of new malware that is created daily. In addition, non-security IT specialists tend to find security and compliance complex.
- **Cost management**—Organizations must monitor and optimize the total cost of ownership (TCO) for all their workers, achieve greater utilization from infrastructure assets, and reduce energy use.

With virtual infrastructure, you can enable your workforce to be more productive whilestreamlining IT costs and management. With VDI solutions from Dell Technologies, you can streamline the design and implementation process and be assured you have a solution that is optimized for performance, density, and cost-effectiveness.

Solution overview

VDI technology works as a key workforce transformation enabler for organizations by freeing employees to work anytime and anywhere without compromising on security or a high-quality user experience. VDI also streamlines IT operations and cost management through a simplified approach to provisioning and updating user environments that can be seamlessly delivered to centrally managed thin client devices.
Dell Technologies offers several products and solutions that dramatically reduce the barriers to adopting VDI. Whether you are considering building out a new environment or expanding an existing footprint, Dell Technologies offers a predictable approach to procure, deploy, and support a virtual desktop and application environment that delivers the secure, high-performance experience that your end users expect. This solution is based on Dell EMC PowerEdge R7525 servers with 2nd Gen AMD EPYC processors, optional NVIDIA GPUs, and VMware vSAN software-defined storage. The software stack is VMware Horizon 7 VDI software in a VMware vSphere environment.

VMware Horizon 7 provides a complete end-to-end solution delivering Microsoft Windows virtual desktops to end users on a wide variety of endpoint devices. Horizon provides a complete virtual desktop delivery and management system by integrating distributed components with advanced configuration tools that simplify the creation and real-time management of the virtual desktop infrastructure. Virtual desktops are dynamically assembled on demand, providing users with pristine, yet personalized, desktops each time they log in.

**Key benefits**

VDI, in short, enables people to work anywhere, anytime, on any device, for any application. It allows organizations to transform their workforces without compromising on security or a high-quality user experience. VDI also streamlines IT operations and cost management through a simplified approach to user management. The key benefits of VDI are:

- **Access from anywhere**—Maintain access to your desktops and applications no matter where you are, allowing you to run applications or full desktops anywhere, on any device.
- **Security**—Allow users to access and interact with sensitive data without it ever crossing the corporate firewall, helping you to maintain security without sacrificing productivity.
- **High performance**—Provide workstation-level performance and beyond for critical users wherever they are, based on AMD EPYC CPUs and NVIDIA virtual GPU (vGPU) technology.

In particular for this solution, the 2nd Gen AMD EPYC line is a new type of server processor that sets a higher standard for data centers. It has achieved #1 performance in several industry benchmarks and has earned multiple world records. Its "Hardened at the Core" protection helps defend against side-channel attacks, and its secure, encrypted virtualization features help keep your data safe. The processor’s agility helps you to manage new deployments and changing workloads with the system resources you need, simply and cost-effectively.

In addition to performance, this VDI solution based on the 2nd Gen AMD EPYC provides:

- **Customer choice in VDI and data center solutions with respect to processor vendor**
- **Diversification against security weaknesses, such as side channel vulnerabilities**
- **High core count options for VDI use cases, which drives dense server configurations and high user density per host**

**Document purpose**

This reference architecture guide provides an overall architecture, configuration details, and performance testing results for designing end-to-end VDI environments with VMware Horizon 7 on Dell EMC PowerEdge R7525 servers with 2nd Gen AMD EPYC processors and VMware vSAN software-defined storage.

The document details the solution for a high-density VDI infrastructure that can be tailored to each customer’s particular needs. It describes a range of VDI-optimized configurations that can be tuned for ease of management, maximum density, and high performance. It provides design guidance and best practices for Dell Technologies server selections and specifications, including 2nd Gen AMD EPYC processor types and options for NVIDIA GPUs and vGPUs. It also provides design and configuration guidance for the vSAN software-defined storage, the physical network, the VMware vSphere and Horizon 7 software components, and the Dell client components.

**Audience**

This guide is for decision makers, managers, architects, developers, and technical administrators of IT environments who want an in-depth understanding of Ready Solutions for VDI. Ready Solutions for VDI deliver virtual desktops to users using VMware Horizon 7 VDI components with a high-performance and high-density server infrastructure.

**We value your feedback**

Dell Technologies and the authors of this document welcome your feedback on the solution and the solution documentation. Contact the Dell EMC Ready Solutions for VDI team by email or provide your comments by completing our documentation survey.

**Authors:** Dell EMC Ready Solutions for VDI team

**NOTE:** The following website provides additional documentation for VDI Ready Solutions: VDI Info Hub for Ready Solutions.
Solution architecture

This section provides an architecture overview and guidance on managing and scaling a VMware Horizon 7 environment on PowerEdge R7525 servers.

Architecture overview

Figure 1 depicts the architecture of the validated solution, including the network, compute, management, and storage layers. This architecture aligns with the VMware Horizon block/pod design. A pod is made up of a group of interconnected Horizon Connection Servers that broker connections to desktops or published applications. A pod has multiple blocks to provide scalability, and a block is a collection of one or more vSphere clusters hosting pools of desktops or applications. Each block has a dedicated vCenter Server and composer servers (if linked clones are used).

Figure 1. PowerEdge R7525 servers with VMware Horizon

The deployment option for this Dell EMC Ready Solutions for VDI solution supports all cloning techniques available from VMware: full, linked, and instant.

A vSphere cluster can have a maximum of 64 nodes and 8,000 virtual machines (VMs) per cluster (6,400 with vSAN). To expand beyond this limit, you can add clusters and balance the VMs and nodes across the new clusters.
Enterprise solution pods

The compute, management, and storage layers are converged into a block of PowerEdge servers, hosting VMware vSphere. The number of nodes that are supported for vSphere 6.7, which is 64, determines the recommended boundaries of an individual vSphere cluster.

Dell Technologies recommends that the VDI management infrastructure nodes be separated from the compute resources. In smaller environments, management and compute are in the same vSphere HA cluster. Optionally, the management node can also be used for VDI VMs with an expected reduction of 30 percent of host resources for these nodes only. The 30 percent accounts for management VM resource reservations and should be factored in when sizing. Compute hosts can be used interchangeably for Horizon Apps (hosted applications) and desktops, as required.

This reference architecture guide describes a single-site or single data center design. For multi-site or disaster recovery (DR) configurations, see the Horizon 7 Multi-Site Architecture.

Scaling the solution

VMware vSAN-based solutions provide flexibility as you scale, reducing the initial and future cost of ownership. Add additional physical and virtual servers to the server pools to scale horizontally (scaling out). Add virtual resources to the infrastructure to scale vertically (scaling up).

Scaling out

Each component of the solution architecture scales independently depending on the required number of supported users. You can add appliance nodes at any time to expand the vSAN Software Defined Storage (SDS) pool in a modular fashion. The scaling limit for vSAN is restricted by the limits of the hypervisor to 64 nodes per block.

The boundary for a Horizon block is the vCenter. The number of virtual machines a vCenter (and therefore a block) can host depends on the type of Horizon 7 VMs being used. The recommended limits for a Horizon block at the time of writing are:

- 12,000 full and instant-clone VMs
- 4,000 linked-clone VMs

For the latest sizing guidance, see VMware Configuration Maximums and VMware Horizon 7 sizing and limitations and recommendations.

VMware recommends a limit of 5,000 instant-clone VMs per block. With this limit in mind, 25 compute nodes with 200 knowledge user VMs per node would reach the maximum number of VMs for the block.

Figure 2 shows a 5,000-user Horizon block and pod supporting up to 5,000 knowledge user VMs. The VMware Horizon management infrastructure and knowledge user VMs are separated into separate vSphere clusters. Four management nodes are a suitable configuration to start with and can be scaled as appropriate.

A combined management and compute architecture could also be used, which would eliminate the need for a separate management cluster. In this configuration, each pod contains its own vCenter Server instance and VDI components.

Figure 2. 5,000-user Horizon block and pod

The following figure shows a scale-out to a 20,000-user Horizon vSAN pod with 5,000-user blocks:
Scaling up

Dell Technologies recommends a validated disk configuration for general-purpose VDI. These configurations leave drive slots available for future vertical expansion and ensure that you protect your investment as new technology transforms your organization.

**NOTE:** These configurations can accept additional or faster processors or memory than the guidance provided here.

For more information about Horizon pod/block architecture and scaling, see the VMware Workspace ONE and VMware Horizon Reference Architecture.

### Key components

This section describes the key hardware and software components of the solution.

#### Servers

PowerEdge rack servers provide the highest performance for a diverse set of workloads. They’re designed to speed deployment and improve application performance for VDI environments. As workloads and workplaces become more complex, it becomes more important than ever for businesses to have end-to-end solutions that work together seamlessly. Powerful, simplified, and automated OpenManage tools help to manage large clusters easily and effectively, while robust security is built into the servers to protect against malicious activity.

Because PowerEdge servers do not offer life cycle management and additional bundled software, Dell Technologies recommends customized deployment services and at least three years of ProSupport Plus. Add VMware Horizon 7 Advanced or Enterprise to license your PowerEdge servers for a full VDI deployment.

### PowerEdge R6515 servers

The Dell EMC PowerEdge R6515 is a 1-socket, 1U rack-based server that is designed to run complex workloads, using highly scalable memory, I/O, and network. The system is based on the 2nd Gen AMD EPYC processor (up to 64 cores), has up to 16 DIMMs, PCIe (PCIe) 4.0-enabled expansion slots, and a choice of LAN-on-Motherboard (LOM) riser technologies.
The Dell EMC PowerEdge R7525 is a 2-socket, 2U rack-based server that is designed to run complex workloads using highly scalable memory, I/O capacity, and network options. The system is based on the 2nd Gen AMD EPYC processor (up to 64 cores), has up to 32 DIMMs, PCI Express (PCIe) 4.0-enabled expansion slots, and OCP 3 Mezzanine networking options.

The R7525 is a highly adaptable and powerful platform capable of handling a variety of demanding workloads while also providing flexibility. This server is the ideal AMD EPYC-based platform for hosting the VDI compute components.
Dell EMC Ready Solutions for VDI-optimized configurations

For graphics-intensive desktop deployments, we recommend the VDI-optimized 2U servers that support GPU hardware.

The R7525 can be configured with or without GPUs. Dell Technologies also offers similar configurations in a 1U/1 node appliance, although fewer graphics configurations are available on these platforms.

We have designated common configurations as Management-Optimized, Density-Optimized, and Virtual Workstation. These designations are outlined in the following table and are referenced throughout the document.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Platform</th>
<th>CPU</th>
<th>RAM</th>
<th>Disk</th>
<th>GPU (optional)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management-Optimized</td>
<td>R6515</td>
<td>1 x AMD EPYC 7402P (24 core @ 2.8 GHz)</td>
<td>256 GB (8 x 32 GB @ 3,200 MHz)</td>
<td>4 TB + (capacity)</td>
<td>None</td>
<td>Offers density and value to provide a dedicated environment to deploy virtualized management infrastructure</td>
</tr>
<tr>
<td>Density-Optimized</td>
<td>R7525</td>
<td>2 x AMD EPYC 7502 (32 core @ 2.5 GHz)</td>
<td>1024 GB (16 x 64 GB @ 3,200 MHz)</td>
<td>8 TB + (capacity)</td>
<td>Up to 3 x FLDW Up to 6 x full length single width</td>
<td>Offers an abundance of high-performance features and tiered capacity that maximizes user density</td>
</tr>
</tbody>
</table>
Table 1. Common configurations (continued)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Platform</th>
<th>CPU</th>
<th>RAM</th>
<th>Disk (optional)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Workstation</td>
<td>R7525</td>
<td>2 x AMD EPYC 7302 (16 core @ 3.0 GHz)</td>
<td>512 GB (16 x 32 GB @ 3,200 MHz)</td>
<td>Up to 3 x FLDW Up to 6 x full length single width</td>
<td>Offers an abundance of high-performance features that deliver remote workstation-class performance</td>
</tr>
</tbody>
</table>

VMware vSAN software-defined storage

vSAN is available in hybrid or all-flash configurations.

After vSAN is enabled on a cluster, all disk devices that are presented to the hosts are pooled together to create a shared data store that is accessible by all hosts in the VMware vSAN cluster. VMs can then be created with storage policies assigned to them. The storage policy dictates availability, performance, and available capacity.

vSAN provides the following configuration options:

- Hybrid configuration—Uses flash-based devices for the cache tier and magnetic disks for the capacity tier. Hybrid configurations are ideal for clients looking for higher volume in the capacity tier. The performance of SSD and magnetic spinning disks is comparable in VDI applications if sufficient magnetic spinning disks are used.

- All-flash configuration—Uses flash for both the cache tier and capacity tier to deliver enterprise performance and a resilient storage platform. In this configuration, the cache tier is fully dedicated to writes, allowing all reads to come directly from the capacity tier. This model allows the cache device to protect the endurance of the capacity tier. All-flash configured solutions enable data deduplication features to extend the capacity tier.

NVIDIA Virtual GPU

NVIDIA vGPU brings the full benefit of NVIDIA hardware-accelerated graphics to virtualized solutions. This technology provides exceptional graphics performance for virtual desktops and virtual workstations when sharing a GPU among multiple users.

Figure 10. NVIDIA vGPUs in a virtualized solution

NVIDIA vGPU is the industry’s most advanced technology for sharing or aggregating true GPU hardware acceleration between multiple virtual desktops without compromising the graphics experience.

NVIDIA vGPU offers four software variants to enable graphics for different virtualization techniques:

- GRID Virtual Applications (GRID vApps)—Designed to deliver graphics accelerated applications using RDSH
- GRID Virtual PC (GRID vPC)—Designed to provide full virtual desktops with dual 4K monitor support
- Quadro Virtual DataCenter Workstation (Quadro vDWS)—Designed to provide workstation-grade performance in a virtual environment with support for quad 4K monitors
Virtual Compute Server (vComputeServer)—Designed to accelerate compute-intensive workloads, such as artificial intelligence (AI), deep learning (DL), and data science run in a virtual machine.

Dell EMC Ready Solutions for VDI can be configured with the following NVIDIA GPUs for an optimum user experience that is hosted from your data center:

- NVIDIA M10 (Maxwell)—Recommended for virtual applications or virtual PC environments. Each card is equipped with 32 GB of video buffer with a maximum available buffer per user of 8 GB. Dell Technologies recommends hosting a maximum of 32 Windows 10 users per card. A maximum of 3 cards are possible but consider sizing with a maximum of 2 cards per node. Systems should also be configured with less than 1 TB of memory when using the M10.
- NVIDIA T4 Tensor Core GPU (Turing)—NVIDIA’s newest architecture is available in the T4 GPU, which is considered the universal GPU for data center workflows. Add up to six GPU cards into each R7525 system to enable up 96 GB of video buffer. For modernized data centers, use this card in off-peak hours to perform your inferencing workloads.
- NVIDIA Quadro RTX 6000 and Quadro RTX 8000 (Turing)—Brings the most significant advancement in computer graphics in over a decade to professional visualization workflows. Designers and artists can now wield the power of hardware-accelerated ray tracing, deep learning, and advanced shading to dramatically boost productivity and create content faster than ever before.

Mixed GPU deployments

As a best practice, ensure that members of a VMware vSAN-based cluster are identical or as homogeneous as possible in terms of hardware, software, and firmware. This practice is primarily to reduce operational complexity and maintenance requirements. When deploying NVIDIA vGPU and the associated NVIDIA GPUs in a PowerEdge environment, a mixed GPU environment may be necessary or beneficial for several reasons, including:

- Usage patterns and workloads that are better matched to different physical GPU types must be addressed.
- A newer generation of NVIDIA GPUs that adds greater value to the overall solution has been released.
- A previously deployed cluster has GPUs that have reached their end-of-life, and the cluster must be expanded to accommodate a growth in the user base.

If a mixed GPU configuration is unavoidable, consider the following information when planning and designing within a VMware Horizon VDI environment:

- Mixed physical GPUs are not supported within a single node. A single compute node can only contain a single physical GPU type.
- Each NVIDIA GPU model has its own set of NVIDIA vGPU profiles that are unique to that card model.
- Each chosen vGPU profile needs an associated VMware Horizon gold image. These gold images add an administrative overhead because they must be either maintained separately or copied from a single parent gold image and the vGPU configurations that are applied to each subsequent related vGPU-enabled gold image.
- Separate VMware Horizon desktop pools must be created and maintained for each related vGPU profile.
- VMware Horizon intelligently picks the appropriate hosts to deploy the NVIDIA vGPU pool to the correlated NVIDIA graphics cards within a vSphere cluster.

Physical network components

Ready Solutions for VDI solutions allow for flexibility in networking selections. VDI validations have been successfully performed with the following hardware, although several other choices are available:

- Dell EMC Networking S4048 (10 GbE ToR switch)—The S4048 switch optimizes your network for virtualization with a high-density, ultra-low-latency ToR switch that features 48 x 10 GbE SFP+ and 6 x 40 GbE ports (or 72 x 10 GbE ports in breakout mode) and up to 720 Gbps performance. The S4048-ON also supports Open Network Install Environment (ONIE) for zero-touch installation of alternate network operating systems.
- Dell EMC Networking S5248F (25 GbE ToR switch)—The S5248F switch provides optimum flexibility and cost-effectiveness for demanding compute and storage traffic environments. This ToR switch features 48 x 25 GbE SFP28 ports, 4 x 100 GbE QSFP28 ports and 2 x 100 GbE QSF28-DD ports. The S5248F-ON also supports ONIE for zero-touch installation of network operating systems.
Networking

Designed for true linear scaling, PowerEdge servers use a leaf-spine network architecture, which consists of two network tiers: an L2 Leaf and an L3 Spine that is based on 40 GbE and non-blocking switches. This architecture maintains consistent performance without any throughput reduction.

VMware vSphere

VMware vSphere provides a powerful, flexible, and secure foundation for business agility that accelerates the digital transformation to cloud computing and promotes success in the digital economy.

vSphere provides the following benefits for VDI applications:

- Improved appliance management—The vCenter Server Appliance Management interface provides CPU and memory statistics, network and database statistics, disk space usage, and health data. These features reduce reliance on a command-line interface for simple monitoring and operational tasks.
- VMware vCenter Server native high availability—This solution for vCenter Server Appliance consists of active, passive, and witness nodes that are cloned from the existing vCenter Server instance. The vCenter HA cluster can be enabled, disabled, or destroyed at any time. Maintenance mode prevents planned maintenance from causing an unwanted failover. The vCenter Server database uses Native PostgreSQL synchronous replication, while key data outside the database uses a separate asynchronous file system replication.
- Backup and restore—Native backup and restore for the vCenter Server Appliance enables users to back up vCenter Server and Platform Services Controller appliances directly from the VAMI or API. The backup consists of a set of files that is streamed to a selected storage device using the SCP, HTTP(S), or FTP(S) protocols. This backup fully supports VCSA instances with both embedded and external Platform Services Controller instances.
- VMware vSphere HA support for NVIDIA vGPU-configured VMs—vSphere HA protects VMs with the NVIDIA vGPU shared pass-through device. In the event of a failure, vSphere HA tries to restart the VMs on another host that has an identical NVIDIA vGPU profile. If no available healthy host meets this criterion, the VM fails to power on.
- VMware vSAN Enterprise Edition—Includes all-flash, space-efficiency features (deduplication, compression, and erasure coding), software-defined, data-at-rest encryption, and stretched clusters for cost-efficient performance and greater hardware choice.
- VMware Log Insight—Provides log management, actionable dashboards, and refined analytics, which enable deep operational visibility and faster troubleshooting.

**NOTE:** vSphere Enterprise Edition (or vSphere Desktop) is required to support NVIDIA graphics cards.

VMware Horizon

The architecture that this guide describes is based on VMware Horizon 7, which provides a complete end-to-end solution delivering Microsoft Windows virtual desktops to users on a wide variety of endpoint devices. Virtual desktops are dynamically assembled on demand, providing users with pristine, yet personalized, desktops each time they log in.

VMware Horizon 7 provides a complete virtual desktop delivery system by integrating several distributed components with advanced configuration tools that simplify the creation and real-time management of the virtual desktop infrastructure.

For more information, see Horizon Resources and Horizon License FAQ.

The core Horizon components include:

- Horizon Connection Server (HCS)—Installed on servers in the data center. The Horizon Connection Server brokers client connections, authenticates users, enrolls users by mapping them to desktops and/or pools, establishes secure connections from clients to desktops, supports single sign-on, and sets and applies policies.
- Horizon Administrator—Provides administrator functions such as deployment and management of Horizon desktops and pools, setting and controlling user authentication, and more.
- Horizon Agent—Installed on all VMs, physical machines, and Terminal Service servers that are used as a source for Horizon desktops. On VMs, the agent is used to communicate with the Horizon client to provide services such as USB redirection, printer support, and more.
- Horizon Client—Installed on endpoints for creating connections to Horizon desktops that can be run from tablets, Windows, Linux, or Mac PCs or laptops, thin clients, and other devices.
- Unified Access Gateway—Provides a way to securely deliver connections that require a higher level of security to access, such as remote connections from the internet.
- Horizon Portal—Provides access to links for downloading full Horizon clients. Enable the HTML access feature to run a Horizon desktop inside a supported browser.
- vCenter Server—Provides centralized management and configuration to the entire virtual desktop and host infrastructure. It facilitates configuration, provisioning, and management services.
Horizon clone technology

VMware Horizon 7 offers the following methods for cloning desktops:

- Full clones—Full clones are typically used in environments where dedicated resources are assigned to specific users. Full clones are typically not ideal for large-scale VDI deployments because full copies have no connection to the original VM. Updates must be performed on each VM with this approach. Additionally, space efficiency technologies must be enabled at the storage layers that may impact user density and performance.

- Instant clones—Instant clones are available only with Horizon 7 Enterprise licenses. This technology can provision a VM the instant a user requests one. The result is a far easier approach to operating system updates and patch management, because the VM is created near to the time of login. You can use the combination of JMP features such as App Volumes and Dynamic Environment Manager to emulate persistence.

- Linked clones—Linked clones require fewer storage resources than full clones. This technology is appropriate for many VDI use cases. Differences between the master VM and the clone are maintained in a delta file. While updates can be rolled out effectively, multiple VM rebuilds are required to correctly deploy a patch at the operating system level. Operating system updates are rolled out to the master images and then the desktop pool is pointed to the new snapshot with the updates. A Horizon Composer instance is required with linked clones to manage the recompose functions of the pool.

**NOTE:** Horizon Composer must be installed on a VM running the Windows Server operating system.

For more information, see the VMware Horizon 7 Instant-Clone Desktops and RDSH Servers White Paper.

Client components

Users can use a variety of client components to access the virtual desktops. The following table lists the client components that Dell Technologies recommends:

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Recommended use</th>
<th>More information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude laptops and 2-and-1s</td>
<td>Biggest screens in a smaller footprint with a wide array of ports to connect peripherals and enjoy speakerphone experience</td>
<td>Mobility and space saving devices</td>
<td><a href="http://www.delltechnologies.com/Latitude">www.delltechnologies.com/Latitude</a></td>
</tr>
<tr>
<td></td>
<td>More responsive apps with Dell Optimizer and intelligent audio for better conference experience</td>
<td>Latitude portfolio allows users to be productive and stay connected with versatile, space-saving mobile solutions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Better connectivity including 4G LTE, Wi-Fi 6, and eSIM. 5G design on the Latitude 9510. Smart antenna design on select products for better connections</td>
<td>Offers a modern portfolio built to prioritize customer experience and keep employees productive wherever they work with a selection of laptops, 2-in-1s, and ecosystem products.</td>
<td></td>
</tr>
<tr>
<td>OptiPlex business desktops and All-in-Ones</td>
<td>Intel 9th Gen core processors. Achieve 2x system responsiveness with Intel Optane Memory. Flexible expansion options, including rich CPU, SSD, and PCIe NVMe Many innovative form factors with versatile mounting options, including the industry’s only zero-footprint modular desktop hidden in plain sight, and space-saving AIOs Rich interaction with display technology, including 4k UHD AIO and matching multi-monitor support.</td>
<td>The ultimate modular solution</td>
<td><a href="http://www.delltechnologies.com/OptiPlex">www.delltechnologies.com/OptiPlex</a></td>
</tr>
<tr>
<td></td>
<td>The most complete workstation portfolio with towers, racks and mobile form factors.</td>
<td>OptiPlex desktops and All-in-Ones are ideal for desk-centric and remote workers in fixed environments who require varying degrees of performance and expandability.</td>
<td></td>
</tr>
<tr>
<td>Precision workstations</td>
<td>World’s most powerful workstations for the most demanding applications, scalable storage, and RAID options Smallest, most intelligent, and highest-performing mobile workstation portfolio</td>
<td>High-end graphics and extreme performance</td>
<td><a href="http://www.delltechnologies.com/Precision">www.delltechnologies.com/Precision</a></td>
</tr>
</tbody>
</table>
Table 2. Recommended client components (continued)

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Recommended use</th>
<th>More information</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rack workstations delivering shared or dedicated resources</td>
<td>Precision workstations designed to run processor- and graphic-intensive applications and activities with mission-critical reliability such as analytics, simulations or modeling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ensures peace of mind with ISV certified, reliable performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyse thin clients</td>
<td>The most secure thin client OS with no sensitive data or personal information exposed on the local device.</td>
<td>Security and manageability. Wyse thin clients are optimized to access virtualized desktops and/or cloud applications and deliver high quality client computing experiences and enterprise-class security, while streamlining management through centralized control.</td>
<td><a href="http://www.delltechnologies.com/wyse">www.delltechnologies.com/wyse</a></td>
</tr>
<tr>
<td></td>
<td>Dedicated to corporate use, prevents unauthorized software and viruses</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optimizes management and efficiency by delivering a controlled access to centralized data, applications, and resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High quality user experiences with desktop, All-in-One, and mobile form factors and a comprehensive ecosystem</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Login VSI performance testing

Testing process

To ensure the optimal combination of end-user experience (EUE) and cost-per-user, we conducted performance analysis and characterization (PAAC) testing on this solution using the Login VSI load-generation tool. Login VSI is a carefully designed, holistic methodology that monitors both hardware resource utilization parameters and EUE during load-testing.

We tested each user load against four runs: a pilot run to validate that the infrastructure was functioning and valid data could be captured, and three subsequent runs to enable data correlation. During testing, while the environment was under load, we logged in to a session and completed tasks that correspond to the user workload. While this test is subjective, it helps to provide a better understanding of the EUE in the desktop sessions, particularly under high load. It also helps to ensure reliable data gathering.

- **Compute host servers**—VMware vCenter (for VMware vSphere-based solutions) or Microsoft Performance Monitor (for Microsoft Hyper-V-based solutions) gathers key data (CPU, memory, disk, and network usage) from each of the compute hosts during each test run. This data is exported to .csv files for single hosts, and then consolidated to show data from all hosts. While the report does not include specific performance metrics for the management host servers, these servers are monitored during testing to ensure that they are performing at an expected level with no bottlenecks.

- **Hardware resources**—Resource contention, which occurs when hardware resources have been exhausted, can cause poor EUE. We monitored the relevant resource utilization parameters and applied relatively conservative thresholds. Thresholds are carefully selected to deliver an optimal combination of good EUE and cost-per user while also providing burst capacity for seasonal or intermittent spikes in usage. The following table shows the resource utilization parameters and thresholds:

Table 3. Resource utilization parameters and thresholds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pass/fail threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical host CPU utilization</td>
<td>85%a</td>
</tr>
<tr>
<td>Physical host CPU readiness</td>
<td>10%</td>
</tr>
<tr>
<td>Physical host memory utilization</td>
<td>85%</td>
</tr>
<tr>
<td>Network throughput</td>
<td>85%</td>
</tr>
<tr>
<td>Storage I/O latency</td>
<td>20 milliseconds (ms)</td>
</tr>
<tr>
<td>LoginVSI Failed Session</td>
<td>2%</td>
</tr>
</tbody>
</table>
Table 3. Resource utilization parameters and thresholds (continued)

a. The Ready Solutions for VDI team recommends that average CPU utilization not exceed 85% in a production environment. A 5% margin of error was allocated for this validation effort. Therefore, CPU utilization sometimes exceeds our recommended percentage. Because of the nature of Login VSI testing, these exceptions are reasonable for determining our sizing guidance.

- GPU resources—vSphere Client monitoring collects data about the GPU resource use from a script that is run on VMware ESXi 6.7 and later hosts. The script runs for the duration of the test and contains NVIDIA System Management Interface commands. The commands query each GPU and log the GPU processor, temperature, and memory use to a .csv file. Alternately, VMware vSphere 6.7 and newer has GPU metrics that are built directly into the vSphere Client and API.

Load generation

Login VSI from Login VSI, Inc. is the industry-standard tool for testing VDI environments and Remote Desktop Session Host (RDSH) environments.

Login VSI installs a standard collection of desktop application software (for example, Microsoft Office and Adobe Acrobat Reader) on each VDI desktop. It then uses launcher systems to connect a specified number of users to available desktops within the environment. When the user is connected, a login script starts the workload, configures the user environment, and starts the test script. Each launcher system can launch connections to several VDI desktops (target machines). A centralized management console configures and manages the launchers and the Login VSI environment.

In addition, we used the following login and boot paradigm:

- Users were logged in within a login timeframe of one hour, except when testing low-density solutions such as GPU/graphic-based configurations, in which users were logged in every 10 to 15 seconds.
- All desktops were started before users logged in.
- All desktops ran an industry-standard anti-virus solution. Windows 10 machines used Windows Defender.

Profiles and workloads

Machine profiles and user workloads determine the density numbers that the solution can support. Each profile and workload is bound by specific metrics and capabilities, with two targeted at graphics-intensive use cases. The profiles and workloads are defined as follows:

- Profile—The configuration of the virtual desktop, the number of vCPUs, and the amount of RAM that is configured on the desktop and available to the user.
- Workload—The set of applications used.

We load-tested two profiles by using a workload that is representative of the profile. The following table describes each use case:

Table 4. Profiles and workloads

<table>
<thead>
<tr>
<th>Profile name/workload</th>
<th>Workload description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Worker</td>
<td>The least intensive of the standard workloads. This workload primarily runs Microsoft Excel and Microsoft Internet Explorer, with some minimal Microsoft Word activity, as well as Microsoft Outlook, Adobe Acrobat, and copy and zip actions. The applications are started and stopped infrequently, which results in lower CPU, memory, and disk I/O usage.</td>
</tr>
<tr>
<td>Knowledge Worker</td>
<td>Designed for virtual machines with 2 vCPUs. This workload includes the following activities:</td>
</tr>
<tr>
<td></td>
<td>• Outlook—Browse messages.</td>
</tr>
<tr>
<td></td>
<td>• Internet Explorer—Browse websites and open a YouTube style video (480p movie trailer) three times in every loop.</td>
</tr>
<tr>
<td></td>
<td>• Microsoft Word—Start one instance to measure response time and another to review and edit a document.</td>
</tr>
<tr>
<td></td>
<td>• Doro PDF Printer and Adobe Acrobat Reader—Print a Word document and export it to PDF.</td>
</tr>
<tr>
<td></td>
<td>• Microsoft Excel—Open a large randomized sheet.</td>
</tr>
<tr>
<td></td>
<td>• Microsoft PowerPoint—Review and edit a presentation.</td>
</tr>
<tr>
<td></td>
<td>• FreeMind—Run a Java-based mind-mapping application.</td>
</tr>
<tr>
<td></td>
<td>• Other—Perform various copy and zip actions.</td>
</tr>
<tr>
<td>Power Worker</td>
<td>The most intensive of the standard workloads. The following activities are performed with this workload:</td>
</tr>
<tr>
<td></td>
<td>• Begin by opening four instances of Internet Explorer and two instances of Adobe Acrobat Reader, which remain open throughout the workload.</td>
</tr>
</tbody>
</table>
Table 4. Profiles and workloads (continued)

<table>
<thead>
<tr>
<th>Profile name/workload</th>
<th>Workload description</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Perform more PDF printer actions than in the other workloads.</td>
<td></td>
</tr>
<tr>
<td>• Watch a 720p and a 1080p video.</td>
<td></td>
</tr>
<tr>
<td>• Reduce the idle time to two minutes.</td>
<td></td>
</tr>
<tr>
<td>• Perform various copy and zip actions.</td>
<td></td>
</tr>
</tbody>
</table>

Graphics performance configuration/multimedia

A workload that is designed to heavily stress the CPU when using software graphics acceleration. GPU-accelerated computing offloads the most compute-intensive sections of an application to the GPU while the CPU processes the remaining code. This modified workload uses the following applications for its GPU/CPU-intensive operations:

- Adobe Acrobat
- Google Chrome
- Google Earth
- Microsoft Excel
- HTML5 3D spinning balls
- Internet Explorer
- MP3
- Microsoft Outlook
- Microsoft PowerPoint
- Microsoft Word
- Streaming video

Test configurations

The following section summarizes the test configurations that we used.

Desktop VM test configurations

The following table summarizes the compute VM configurations for the profiles and workloads that we tested:

Table 5. Compute VM configurations

<table>
<thead>
<tr>
<th>User profile</th>
<th>vCPUs</th>
<th>ESXi configured memory</th>
<th>ESXi reserved memory</th>
<th>Screen resolution</th>
<th>Operating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Worker⁴</td>
<td>2</td>
<td>3 GB</td>
<td>1.5 GB</td>
<td>1280 x 720</td>
<td>Windows 10 Enterprise 64-bit</td>
</tr>
<tr>
<td>Knowledge Worker</td>
<td>2</td>
<td>4 GB</td>
<td>2 GB</td>
<td>1920 x 1080</td>
<td>Windows 10 Enterprise 64-bit</td>
</tr>
<tr>
<td>Power Worker</td>
<td>4</td>
<td>8 GB</td>
<td>4 GB</td>
<td>1920 x 1080</td>
<td>Windows 10 Enterprise 64-bit</td>
</tr>
<tr>
<td>Multimedia</td>
<td>4</td>
<td>8 GB</td>
<td>8 GB</td>
<td>1920 x 1080</td>
<td>Windows 10 Enterprise 64-bit</td>
</tr>
</tbody>
</table>

⁴ Dell Technologies has validated the LoginVSI Task Worker workload with two vCPUs assigned per VM, although LoginVSI lists the typical VM vCPU profile for this workload as being a single vCPU. Dell Technologies diverges from this definition to deliver virtual desktops with great user experience. Increasing the vCPU count to 2 in the vCPU profile that is associated with the Task Worker workload does have a minor impact on densities but generates improved user experience in return.

Hardware configuration

The following table shows the hardware configuration that we used in the testing:
Table 6. Hardware configuration

<table>
<thead>
<tr>
<th>Enterprise platform</th>
<th>CPU</th>
<th>Memory</th>
<th>HBA</th>
<th>Disk</th>
<th>Network</th>
<th>GPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dell EMC PowerEdge R7525</td>
<td>2 x AMD EPYC 7502 (32 core @ 2.5 GHz)</td>
<td>1024 GB (16 x 64 GB @ 3200 MHz)</td>
<td>Dell HBA345</td>
<td>2 x 800 GB WI SAS SSD (cache) 4 x 1.92 TB MU SAS SSD (capacity)</td>
<td>Mellanox ConnectX-5 25Gbe Dual port SFP28</td>
<td>6 x NVIDIA T4</td>
</tr>
</tbody>
</table>

BIOS, firmware, and software versions

The following table shows the BIOS, firmware, and software versions that we used in the testing:

Table 7. BIOS, firmware, and software versions

<table>
<thead>
<tr>
<th>Hypervisor</th>
<th>Hypervisor version</th>
<th>Hypervisor build</th>
<th>BIOS</th>
<th>NVIDIA vGPU version</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESXi</td>
<td>6.7 Update 3</td>
<td>15160138</td>
<td>1.2.11</td>
<td>10.1</td>
</tr>
</tbody>
</table>

PAAC gold image version

The following table shows the PAAC gold image version that we used in the testing:

Table 8. PAAC gold image version

<table>
<thead>
<tr>
<th>Guest OS</th>
<th>Microsoft Office</th>
<th>VMware Tools</th>
<th>VMware Horizon Agent</th>
<th>Display protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows 10 version 1909</td>
<td>Office 2019 version 1808</td>
<td>11.0.5 + appinfo disabled</td>
<td>7.10.1</td>
<td>Blast</td>
</tr>
</tbody>
</table>

Summary of test results and analysis

We used the Login VSI test suite to simulate the user experience for several profile types under the typical workload for that type. The following table summarizes the test results for the compute hosts using the various workloads and configurations:

Table 9. Test results summary

<table>
<thead>
<tr>
<th>Server configuration</th>
<th>Login VSI workload</th>
<th>User density per host</th>
<th>Remote display protocol</th>
<th>Average CPU usage</th>
<th>Average memory consumed</th>
<th>Average active memory</th>
<th>Average IOPS per user</th>
<th>Average net Mbps per user</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density Optimized</td>
<td>Knowledge Worker</td>
<td>207</td>
<td>BLAST</td>
<td>85%</td>
<td>651 GB</td>
<td>225 GB</td>
<td>7.18</td>
<td>5.37</td>
</tr>
<tr>
<td>Density Optimized</td>
<td>Power Worker</td>
<td>158</td>
<td>BLAST</td>
<td>84%</td>
<td>965 GB</td>
<td>277 GB</td>
<td>9.25</td>
<td>6.6</td>
</tr>
<tr>
<td>Density Optimized + 6 x T4</td>
<td>Power Worker (Virtual PC: T4-1B)</td>
<td>96</td>
<td>BLAST</td>
<td>82% (GPU 23%)</td>
<td>846 GB</td>
<td>776 GB</td>
<td>12.9</td>
<td>4.6</td>
</tr>
</tbody>
</table>

The table headings are defined as follows:

- User density per host—The number of users per compute host that successfully completed the workload test within the acceptable resource limits for the host. For clusters, this number reflects the average of the density that is achieved for all compute hosts in the cluster.
- Average CPU usage—The average CPU usage over the steady-state period. For clusters, this number represents the combined average CPU usage of all compute hosts.
- Average active memory—For ESXi hosts, the amount of memory that is actively used, as estimated by the VMkernel based on recently touched memory pages. For clusters, this is the average amount of guest physical memory that is actively used across all compute hosts over the steady-state period.
- Average IOPS per user—IOPS calculated from the average disk IOPS over the steady state period divided by the number of users.
Knowledge Worker, 207 users per host, ESXi 6.7, Horizon 7.10

We ran the following tests for this workload:

**CPU usage**

Each compute host was populated with 207 virtual machines for a total of 621. With all user virtual machines powered on before starting the test, the CPU usage was approximately 6 percent.

The following figure shows the performance data for 207 user sessions per host. The CPU reaches a steady state average of 85 percent during the test cycle when all users are logged in.

![CPU usage percentage](image)

**Figure 11. CPU usage percentage**

CPU core utilization had a steady state average of 72 percent and peaked at 78 percent, indicating that there was still headroom for extra CPU cycles per core.
The CPU readiness percentage was low throughout testing, indicating that the VMs had no significant delays in scheduling CPU time. The Readiness Steady State average was 1.75 percent while the peak was 2.1 percent and remained below the threshold of 10 percent.
Memory

In regard to memory consumption for the cluster, out of a total of 1,024 GB of available memory per node, memory usage was not an issue. The compute hosts reached a maximum memory consumption of 669 GB with active memory usage reaching a max of 418 GB. There was no ballooning or swapping at any point during the test.

Figure 14. Consumed memory (GB)

Figure 15. Active memory (GB)
Network usage

Network bandwidth was not an issue on this test that ran with a steady state peak of approximately 1,362 Mbps. The busiest period for network traffic was just after all user logins had completed. The host reached a peak of 1,704 Mbps during the deletion and re-creation of the instant clones. The steady state average was 1,113 Mbps.

![Network usage graph](image)

Figure 16. Network usage (Mbps)

IOPS

The following figure displays the disk IOPS figure for the vSAN datastore. The graph clearly displays the initial logging in of the desktops, the steady state and logging out phases, and finally the re-creation of the desktops after testing was complete.

The cluster reached a maximum total (read + write) of 18,376 disk IOPS (read + write) during the instant clone re-creation period after testing and a steady state average of 4,461 disk IOPS (read + write). The steady state peak was 6,978 disk IOPS (read + write).
Figure 17. Cluster disk IOPS

Disk I/O latency

Disk I/O latency was not an issue during the Login VSI testing period of this test run. The maximum latency reached on the vSAN datastore was approximately 1.13 ms (read + write) during steady state. This was well below the 20 ms threshold that is regarded as becoming potentially troublesome. The average latency during steady state was 1.07 ms (read + write).

Figure 18. Cluster latency (ms)
User experience

The Login VSI Max user experience score shown below for this test was not reached, indicating that there was no deterioration in user experience at the number of users tested.

![User experience summary](image)

**Figure 19. User experience summary**

**Analysis**

- 1,024 GB of memory installed on each node is more than sufficient for the number of desktops tested.
- The feature of instant clones where the virtual machines are deleted and re-created after the users log out leads to the highest workload on each host, higher than at any point during the actual test period itself. The CPU reaches the same maximum levels at it did during testing and memory, network, and datastore metrics all surpass the levels seen during the actual test period.
- The VMware Horizon Blast Extreme remote display protocol was used during testing with the dynamic encoder enabled.
- The data collection interval was 1 minute for any non-vSAN datastore metrics. All vSAN metrics data collection intervals were 5 minutes.

**Power Worker, 158 users per host, ESXi 6.7, Horizon 7.10**

We ran the following tests for this workload:

**CPU usage**

Each compute host was populated with 158 virtual machines for a total of 474. With all user virtual machines powered on before starting the test, the CPU usage was approximately 8 percent.

The following figure shows the performance data for 158 user sessions per host. The CPU reached a steady state average of 84 percent during the test cycle when all users were logged in.
Figure 20. CPU usage percentage

CPU core utilization had a steady state average of 73 percent and peaked at 78 percent, indicating that there is still headroom for extra CPU cycles per core.

Figure 21. CPU core utilization percentage
CPU readiness is defined as the percentage of time that the virtual machine was ready, but could not get scheduled to run on the physical CPU. The CPU readiness percentage was low throughout testing, indicating that the VM had no significant delays in scheduling CPU time. The readiness steady state average was 2.3 percent while the peak was 3.1 percent and remained below the threshold of 10 percent.

![Figure 22. CPU readiness percentage](image)

**Memory**

In regard to memory consumption for the cluster, out of a total of 1,024 GB of available memory, memory usage was not an issue. The host reached a maximum memory consumption of 997 GB with active memory usage reaching a max of 652 GB. There was no ballooning or swapping at any point during the test.
Network usage

Network bandwidth was not an issue on this test run with a steady state peak of approximately 1,181 Mbps. The busiest period for network traffic was just after all user logins had completed. The host reached a peak of 1,697 Mbps during the deletion and re-creation of the instant clones. The steady state average was 1,049 Mbps.
IOPS

The following figure shows the disk IOPS figure for the vSAN datastore. The graph clearly displays the initial logins of the desktops, the steady state and logging out phases, and finally the re-creation of the desktops after testing was complete. The datastore reached a maximum of 18,614 disk IOPS during the instant clone re-creation period after testing and a steady state average of 4,837 disk IOPS. The steady state peak was 9,869 disk IOPS.
Disk I/O latency

Disk I/O latency was not an issue during the Login VSI testing period of this test run. The maximum latency reached on the vSAN datastore was approximately 1.15 ms (read + write), this was during steady state. This was well below the 20 ms threshold regarded as becoming potentially troublesome. The average latency during steady state was 1.10 ms (read + write).

![Cluster latency (ms)](image)

User experience

The Login VSI Max user experience score shown below for this test was not reached, indicating that there was no deterioration in user experience at the number of users tested.

![User experience summary](image)
Analysis

- 1,024 GB of memory installed on each node is more than sufficient for the number of desktops tested.
- The feature of instant clones where the virtual machines are deleted and re-created after the users log out leads to the highest workload on each host, higher than at any point during the actual test period itself. The CPU reaches the same maximum levels at it did during testing and memory, network, and datastore metrics all surpass the levels that were seen during the actual test period.
- The VMware Horizon Blast Extreme remote display protocol was used during testing with the dynamic encoder enabled.
- The data collection interval was 1 minute for any non-vSAN datastore metrics. All vSAN metrics data collection intervals were 5 minutes.

Power Worker, 96 vGPU users per host, ESXi 6.7, Horizon 7.10

We ran the following tests for this workload:

CPU usage

The GPU-enabled compute host was populated with 96 vGPU-enabled virtual machines with the NVIDIA T4-1B vGPU profile. With all user virtual machines powered on before starting the test, the CPU usage was approximately 18 percent on the GPU-enabled Compute host.

The following figure shows the performance data for 96 user sessions. The CPU reached a steady state average of 82 percent during the test cycle when all users were logged in. CPU Core Utilization had a steady state average of 72 percent. CPU readiness only increased during the Logoff/Re-create clones phase, indicating a heavy load on the CPU at the time. In steady state it averaged 3.8 percent which was within tolerance. The spike in CPU readiness during the logging out phase appears to be correlated with the re-creation of the virtual machines. This seems to be related to the simultaneous creation of the Instant Clone VMs and Shared PCI vGPU devices assigned to these VMs.

**NOTE:** This graph displays all three CPU metrics that were shown on separate graphs in the previous tests.

![CPU usage percentage](png)

The spike in CPU readiness appears to be correlated with the re-creation of the virtual machines. This seems to be related to the simultaneous creation of the Instant Clone VMs and Shared PCI vGPU devices assigned to these VMs.
GPU usage

The following figure shows the performance of the six NVIDIA T4 GPU cards installed in the vGPU VM host. The GPUs' usage never went above 35 percent during the test run and the steady state average usage was 23 percent.

![GPU usage percentage](image)

**Figure 30. GPU usage percentage**

Memory

In regard to memory consumption for the cluster, out of a total of 1,024 GB of available memory, memory usage was not an issue. As all memory was reserved for the vGPU-enabled VMs, there was no variation in memory usage until the Logoff/Re-create Clones phase of the test. The host had a maximum memory consumption of 847 GB with active memory usage reaching a maximum of 777 GB. There was no ballooning or swapping at any point during the test.
Network usage

Network bandwidth was not an issue on this test run with a steady state peak of approximately 555 Mbps. The busiest period for network traffic was during the Logoff/Re-create Clones phase, with the host reaching a peak of 759 Mbps during this phase. The steady state average was 442 Mbps.
IOPS

The following figure shows the disk IOPS figure for the vSAN datastore. The graph clearly displays the initial logins of the desktops, the steady state and logging out phases, and finally the re-creation of the desktops after testing was complete. The datastore reached a maximum of 7,111 disk IOPS (read + write) during the instant clone re-creation period after testing and a steady state average of 1,235 (read + write) disk IOPS. The steady state peak was 4,355 (read + write) disk IOPS.

Figure 34. Cluster disk IOPS
Cluster latency

Disk I/O latency was not an issue during the Login VSI testing period of this test run. The maximum latency reached on the vSAN datastore was approximately 0.79 ms during steady state. This was well below the 20 ms threshold that is regarded as becoming potentially troublesome. The average latency during steady state was 0.75 ms.

Figure 35. Cluster latency (ms)

User experience

The Login VSI Max user experience score shown below for this test was not reached, indicating that there was no deterioration in user experience at the number of users tested.

Figure 36. User experience summary
Analysis

- 1,024 GB of memory installed on each node is more than sufficient for the number of desktops tested.
- The feature of instant clones where the virtual machines are deleted and re-created after the users log out leads to the highest workload on each host, higher than at any point during the actual test period itself. The CPU reached the same maximum levels at it did during testing and memory, network, and datastore metrics all surpassed the levels seen during the actual test period.
- The VMware Horizon Blast Extreme remote display protocol was used during testing with the dynamic encoder enabled.
- The data collection interval was 1 minute for any non-vSAN datastore metrics. All vSAN metrics data collection intervals were 5 minutes.

NVIDIA nVector graphics performance testing

We performed this testing on a VMware Horizon virtual desktop environment hosted on a single Dell EMC PowerEdge R7525 server that was equipped with 2nd Gen AMD EPYC processors and six NVIDIA T4 GPUs. We used the NVIDIA nVector performance assessment and benchmarking tool for this testing.

Configurations

We tested the following three configurations using the NVIDIA nVector tool:

- **GPU configuration**—We used a PowerEdge R7525 host with AMD EPYC 7502 32-core processors and six NVIDIA T4 GPUs. We enabled 96 VMs with NVIDIA T4-1B vGPU profiles and used the nVector Knowledge Worker workload.
- **Non-GPU configuration**—We used a PowerEdge R7525 host with AMD EPYC 7502 32-core processors. We performed this test on 96 virtual machines without enabling vGPUs and used the nVector Knowledge Worker workload.
- **Virtual Workstation configuration**—We used a PowerEdge R7525 host with AMD EPYC 7502 32-core processors and six NVIDIA T4 GPUs. We enabled 24 virtual workstations with NVIDIA Quadro vDWS T4-4Q vGPU profiles and used the nVector SPECviewperf 13 workload. We used this workload to generate benchmarks for workstations running professional graphics applications.

Testing process

NVIDIA nVector is a performance testing tool from NVIDIA for benchmarking VDI workloads. The nVector tool creates a load on the system by simulating a workload that matches a typical VDI environment. The tool assesses the experience at the endpoint device rather than the response time of the virtual desktop.

The nVector tool captures the performance metrics that quantify user experience, including image quality, frame rate, and user latency, from the endpoints. These metrics, when combined with resource utilization information from the servers under test, enable IT teams to assess their VDI graphics-accelerated environment needs.

We tested multiple runs for each user load scenario to eliminate single-test bias. We used a pilot run to validate that the solution was functioning as expected and we validated that testing data was being captured. We then tested subsequent runs to provide data that confirmed that the results we obtained were consistent.

To confirm true EUE experience, we logged into a VDI session and completed several tasks that are typical of a normal user workload. This small incremental load on the system did not significantly impact our ability to provide reproducible results. While the assessment undoubtedly is subjective, it helps to provide a better understanding of the end-user experience under high load. It also helps to assess the reliability of the overall testing data.

Load generation

The nVector tool runs the simulated workflow of a typical VDI workload at a predesignated scale. This part of the test requires performance monitoring to measure resource utilization. Acting as an execution engine, nVector orchestrates the necessary stages that are involved in measuring EUE for a predefined number of VDI instances. The following stages are involved in measuring EUE:

1. Provision VDI instances with predefined settings like vCPU, vRAM, and frame buffer, and provision an equal number of virtual machines that act as virtual thin clients.
2. Establish remote connections to VDI desktops using the virtual clients.
3. Measure resource utilization stats on the server, as well as on the guest operating system of the VDI desktop.
4. Run the designated workload on all the VDI instances.
5. Collect and analyze performance data and end-user experience measurements.
6. Generate a report that reflects the trade-off between end-user experience and user density (scale).

The following figure shows the stages in the NVIDIA benchmarking tool's measurement of user experience:
We collected host performance metrics and EUE metrics for the tests involving the nVector Knowledge Worker workload. For the nVector SPECviewperf13 workload test (workstation configuration), we collected host performance metrics and SPEC benchmark scores. The nVector end-user experience metrics were not collected for the SPECviewperf13 workload.

Profiles and workloads

The combination of virtual desktop profiles and simulated user workloads determines the total number of users (density) that the VDI solution can support. This testing focused on the NVIDIA nVector Knowledge Worker workload and the nVector SPECviewperf13 workloads. Specific metrics and capabilities define each virtual desktop profile and user workload. It is important to understand these terms in the context of this document.

- **Profile**: The configuration of the virtual desktop, specifically the number of vCPUs and the amount of RAM configured on the desktop that is available to the user.
- **Workload**: The set of applications used in the Performance Analysis and Characterization (PAAC) testing of the Dell VDI solution (for example, Microsoft Office applications, PDF Reader, Google Chrome, and so on).

We carried out load-testing on each profile using an appropriate workload that was representative of the relevant use case. The following table summarizes the profile to workload mapping used:

**Table 10. Profile to workload mapping**

<table>
<thead>
<tr>
<th>Profile name</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Worker</td>
<td>nVector Knowledge Worker</td>
</tr>
<tr>
<td>Custom Graphics</td>
<td>nVector SPECviewperf13</td>
</tr>
</tbody>
</table>

The following sections of this guide look in detail at the nVector Knowledge Worker and SPECviewperf13 nVector workloads used in this PAAC testing.

**nVector Knowledge Worker workload**

The nVector Knowledge Worker workload contains a mix of typical office applications, including some multimedia usage. This workload is representative of what a typical office worker does during the working day. The activities performed include:
- Working on Excel files
- Scrolling through PDFs
- Opening and working on Word documents
- Opening and presenting a PowerPoint presentation
- Opening and viewing web pages and web videos using Google Chrome
- Opening and closing applications and saving or copying content

**nVector SPECviewperf 13 workload**

The SPECviewperf 13 benchmark is the worldwide standard for measuring graphics performance based on professional applications. The benchmark measures the 3D graphics performance of systems running under the OpenGL and Direct X application programming interfaces (APIs).

The benchmark’s workloads, called viewsets, represent graphics content and behavior from actual applications. The SPECviewperf 13 workload uses a series of viewsets taken from independent software vendor (ISV) applications to characterize the graphics performance of a physical or virtual workstation. For our testing, we ran three iterations of the following viewsets:

- 3ds Max (3dsmax-06)
- CATIA (catia-05)
- Creo (creo-02)
- Energy (energy-02)
- Maya (maya-05)
- Medical (medical-02)
- Showcase (showcase-02)
- Siemens NX (snx-03)
- Solidworks (sw-04)

For more information about SPECviewperf 13 viewsets, see the SPEC website.

**Resource monitoring**

We used VMware vCenter to gather key host utilization metrics, including CPU, GPU, memory, disk, and network usage from the compute host during each test run. This data was exported to .csv files for each host and then consolidated for reporting.

Resource over-utilization can cause poor EUE. We monitored the relevant resource utilization parameters and compared them to relatively conservative thresholds. The thresholds were selected based on industry best practices and our experience to provide an optimal trade-off between good EUE and cost-per-user while also allowing sufficient burst capacity for seasonal or intermittent spikes in demand. The following table shows the pass/fail threshold for host utilization metrics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pass/fail threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical host CPU utilization</td>
<td>85%</td>
</tr>
<tr>
<td>Physical host memory utilization</td>
<td>85%</td>
</tr>
<tr>
<td>Network throughput</td>
<td>85%</td>
</tr>
<tr>
<td>Physical host CPU readiness</td>
<td>10%</td>
</tr>
</tbody>
</table>

**Measuring the end-user experience**

This section explains the EUE metrics measured by the nVector tool. These metrics include image quality, frame rate, and end-user latency.

**Metric 1: Image quality**—NVIDIA nVector uses a lightweight agent on the VDI desktop and the client to measure image quality. These agents take multiple screen captures on the VDI desktop and on the thin client to compare later. The structural similarity (SSIM) of the screen capture taken on the client is computed by comparing it to the one taken on the VDI desktop. When the two images are similar, the heatmap will reflect more colors above the spectrum with an SSIM value closer to 1.0, as shown on the right-hand side in Figure 38. As the images become less similar, the heatmap reflects more colors down the spectrum with a value of less than 1.0. More than a hundred pairs of images across an entire set of user sessions are obtained. The average SSIM index of all pairs of images is computed to provide the overall remote session quality for all users.
Metric 2: Frame rate—Frame rate is a common measure of user experience and defines how smooth the experience is. It measures the rate at which frames are delivered on the screen of the endpoint device. For the duration of the workload, NVIDIA nVector collects data on the frames per second (FPS) sent to the display device on the end client. This data is collected from thousands of samples, and the value of the 90th percentile is taken for reporting. A larger FPS indicates a more fluid user experience.

Metric 3: End-user latency—The end-user latency metric defines the level of response of a remote desktop or application. It measures the duration of any lag that an end user experiences when interacting with a remote desktop or application.

### Hardware and software components

This section describes the hardware and software components that we used to validate the solution.

### Host hardware configuration

The following table shows the server hardware configuration:

<table>
<thead>
<tr>
<th>Enterprise platform</th>
<th>CPU</th>
<th>GPU</th>
<th>Memory</th>
<th>HBA</th>
<th>HD configuration</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dell EMC PowerEdge R7525</td>
<td>2 x AMD EPYC 7502 (32-Core, 2.5 GHz)</td>
<td>6 x NVIDIA T4 GPUs</td>
<td>1024 GB @ 3200 MT/s (16 x 64 GB DDR4)</td>
<td>Dell HBA345</td>
<td>BOSS S1 Card, 256 GB for Hypervisor 2 x 800 GB SAS SSD (cache)</td>
<td>Mellanox ConnectX-5 25 GbE Dual port SFP28</td>
</tr>
</tbody>
</table>
Table 12. Hardware configuration

<table>
<thead>
<tr>
<th>Enterprise platform</th>
<th>CPU</th>
<th>GPU</th>
<th>Memory</th>
<th>HBA</th>
<th>HD configuration</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 x 1.92 TB SAS SSD (capacity)</td>
<td></td>
</tr>
</tbody>
</table>

Software components and versions

The following table shows the software component version details:

Table 13. Software component versions

<table>
<thead>
<tr>
<th>Hypervisor</th>
<th>Hypervisor version</th>
<th>BIOS</th>
<th>Windows 10 desktop version</th>
<th>Windows 10 endpoint version</th>
<th>NVIDIA GRID version</th>
<th>Horizon agent version</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESXi</td>
<td>6.7.0 - 15160138</td>
<td>1.2.11</td>
<td>1909 - 18363,778</td>
<td>1607 - 14593,36,30</td>
<td>10.1 - 442,06</td>
<td>7.12</td>
</tr>
</tbody>
</table>

VM configurations

The following table shows the configuration of the VDI virtual desktops:

Table 14. VM profile configuration

<table>
<thead>
<tr>
<th>Test configuration</th>
<th>nVector workload</th>
<th>GPU profile</th>
<th>vCPUs</th>
<th>ESXi memory configured</th>
<th>ESXi memory reservation</th>
<th>Screen resolution</th>
<th>Operating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU</td>
<td>Knowledge Worker</td>
<td>T4-1B</td>
<td>4</td>
<td>8 GB</td>
<td>8 GB</td>
<td>1920 X 1080</td>
<td>Windows 10</td>
</tr>
<tr>
<td>Non-GPU</td>
<td>Knowledge Worker</td>
<td>N/A</td>
<td>4</td>
<td>8 GB</td>
<td>8 GB</td>
<td>1920 X 1080</td>
<td>Windows 10</td>
</tr>
<tr>
<td>Workstation</td>
<td>SPECviewperf 13 Workload</td>
<td>T4-4Q</td>
<td>4</td>
<td>32 GB</td>
<td>32 GB</td>
<td>1920 X 1080</td>
<td>Windows 10</td>
</tr>
</tbody>
</table>

Summary and analysis of test results

GPU and non-GPU comparison

This section compares GPU and non-GPU test results performed with the NVIDIA nVector Knowledge Worker workload. For the GPU test, we used a single-node R7525 compute host with six NVIDIA T4 GPUs. We enabled 96 virtual machines with an NVIDIA T4-1B vGPU profile. For the non-GPU test, we performed testing on a R7525 compute host hosting 96 virtual machines without enabling vGPU profiles. The server was part of a three-node, VMware vSAN software-defined storage cluster. Both tests were performed on VMware Horizon 7 linked-clone virtual desktops. The Horizon Blast Extreme protocol was used as the remote display protocol with H.264 hardware encoding.

Our objective in performing these tests and comparing the results was to identify whether the GPUs improve the performance and EUE of a VDI virtual desktop running the NVIDIA nVector Knowledge Worker workload. Table 15 compares the utilization metrics gathered from vCenter for both tests while Table 16 compares the end-user experience metrics generated by the nVector tool.

The key findings from the result comparison were:

- With GPUs, the CPU utilization reduced by 20 percent. Reduced CPU utilization in the GPU test compared to the non-GPU test indicates that some of the tasks carried out by the CPU were offloaded to the GPU, improving the overall compute performance of the system.
- Both tests produced almost the same image quality. However, with GPUs enabled, the FPS increased by 25 percent and the end-user latency decreased by nearly 9 percent.
- Improved EUE metrics from the GPU test indicate that the EUE was better when GPUs were enabled.

The following table gives a summary of the average host utilization metrics:
Table 15. Average host utilization metrics summary

<table>
<thead>
<tr>
<th>Test configuration</th>
<th>Workload</th>
<th>Density per host</th>
<th>Average CPU usage</th>
<th>Average GPU usage</th>
<th>CPU readiness</th>
<th>CPU core utilization</th>
<th>Average active memory</th>
<th>Average memory consumed</th>
<th>Average net Mbps per user</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU</td>
<td>nVector Knowledge worker</td>
<td>96</td>
<td>72%</td>
<td>15%</td>
<td>3.6%</td>
<td>62%</td>
<td>769 GB</td>
<td>842 GB</td>
<td>3.67</td>
</tr>
<tr>
<td>Non-GPU</td>
<td>nVector Knowledge worker</td>
<td>96</td>
<td>92%</td>
<td>N/A</td>
<td>3.4%</td>
<td>75%</td>
<td>116 GB</td>
<td>831 GB</td>
<td>2.65</td>
</tr>
</tbody>
</table>

The following table gives a summary of the NVIDIA nVector end-user experience metrics:

Table 16. NVIDIA nVector end-user experience metrics summary

<table>
<thead>
<tr>
<th>Test configuration</th>
<th>GPU profile</th>
<th>Workload</th>
<th>Density per host</th>
<th>End-user latency</th>
<th>Frame rate</th>
<th>Image quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU</td>
<td>NVIDIA T4-1B</td>
<td>nVector Knowledge worker</td>
<td>96</td>
<td>104 ms</td>
<td>20</td>
<td>0.993</td>
</tr>
<tr>
<td>Non-GPU</td>
<td>N/A</td>
<td>nVector Knowledge worker</td>
<td>96</td>
<td>115 ms</td>
<td>16</td>
<td>0.998</td>
</tr>
</tbody>
</table>

For details of the host performance metrics, including CPU, GPU, memory and network usage, collected from vCenter, and the EUE metrics such as image quality, frame rate, and end-user latency measured from endpoints by the nVector tool, see Appendix B and Appendix C.

SPECviewperf13—Virtual Workstation test summary

This section summarizes the SPEC benchmark scores obtained from the nine SPECviewperf13 viewsets that we ran. A higher SPEC score indicates a greater speed for the simulated graphics application running in the virtual workstation.

We used a single-node R7525 compute host with six NVIDIA T4 GPUs for this virtual workstation configuration test. We enabled 24 virtual machines with an NVIDIA Quadro DWS T4-4Q vGPU profile. The server was part of a three-node, VMware vSAN software-defined storage cluster. The tests were performed on VMware Horizon 7 linked-clone virtual desktops. The Horizon Blast Extreme protocol was used as the remote protocol with H.264 hardware encoding.

The objective of this testing was to obtain the SPEC benchmark scores for nine SPECviewperf viewsets: 3dsmax, Catia, Creo, Maya, Energy, Medical, Showcase, snx, and sw. The SPECviewperf tool measures the FPS at which the GPU can render scenes across a wide variety of applications and usage models. Each viewset represents an application or a usage model, and each composite score is based on a weighted geometric mean of many different scenes and rendering modes.

Figure 39 shows the SPEC scores from the nine SPECviewperf13 viewsets that we ran. The SPECviewperf13 viewsets were run on all of the 24 virtual workstations, which ran concurrently on the host. The graph shows the average SPEC score value received from those 24 virtual workstations. Larger scores indicate a greater speed for the application. We ran three iterations for each SPECviewperf13 viewset. SPEC scores from our tests indicate an excellent graphics performance for professional graphics applications tested in the virtual workstations.

You can compare SPEC benchmark scores from our performance testing with other published scores on the SPEC website.

For details of the CPU and GPU host performance metrics recorded for each of the nine viewset tests that we ran, see Appendix D.

The following figure gives a summary of the SPEC scores:
The following table shows the SPECviewperf 13 FPS scores:

Table 17. SPECviewperf 13 FPS scores

<table>
<thead>
<tr>
<th>Viewset</th>
<th>FPS score</th>
<th>Minimum score</th>
<th>Maximum score</th>
<th>Maximum/minimum</th>
<th>Score StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>3dsmax-06</td>
<td>51.68</td>
<td>49.43</td>
<td>55.79</td>
<td>1.13</td>
<td>7.60</td>
</tr>
<tr>
<td>catia-05</td>
<td>58.12</td>
<td>57.13</td>
<td>58.85</td>
<td>1.03</td>
<td>4.77</td>
</tr>
<tr>
<td>creo-02</td>
<td>46.77</td>
<td>46.77</td>
<td>46.77</td>
<td>1.00</td>
<td>2.97</td>
</tr>
<tr>
<td>energy-02</td>
<td>11.26</td>
<td>10.32</td>
<td>13.09</td>
<td>1.27</td>
<td>2.56</td>
</tr>
<tr>
<td>maya-05</td>
<td>72.44</td>
<td>68.58</td>
<td>78.38</td>
<td>1.14</td>
<td>7.98</td>
</tr>
<tr>
<td>medical-02</td>
<td>22.46</td>
<td>22.09</td>
<td>22.73</td>
<td>1.03</td>
<td>1.20</td>
</tr>
<tr>
<td>showcase-02</td>
<td>27.39</td>
<td>26.63</td>
<td>28.83</td>
<td>1.08</td>
<td>3.67</td>
</tr>
<tr>
<td>snx-03</td>
<td>80.85</td>
<td>78.08</td>
<td>83.14</td>
<td>1.06</td>
<td>7.90</td>
</tr>
<tr>
<td>sw-04</td>
<td>55.83</td>
<td>55.33</td>
<td>56.63</td>
<td>1.02</td>
<td>3.80</td>
</tr>
</tbody>
</table>

NOTE: You can find the results and raw data for the SPECviewperf 13 benchmark testing here: https://dell.app.box.com. See the SPEC website for details of these viewsets.

Design guidance and enhancements

Design guidance

This section provides recommendations and guidelines for designing your VDI environment.

Platform configurations

With several options to choose from, consider these basic differences:
• The Density-Optimized configurations provide a good balance of performance and scalability for a variety of general-purpose VDI workloads.
• The Virtual Workstation configurations provide the highest levels of performance for more specialized VDI workloads leading to use with ISV and high-end computing workloads.

CPU

User density and graphics considerations:
• Dell EMC Ready Solutions for VDI validation test results suggest that you can use CPU oversubscription to effectively size VDI user density. To use a CPU configuration other than those that have been validated, consider the following guidance to achieve comparable results for architectures with 2nd Gen AMD EPYC processors:
  ○ Knowledge workers—3.25 users per core. For example, 52 knowledge users with dual eight-core processors
  ○ Power workers—2.5 users per core. For example, 40 power users with dual eight-core processors
• AMD and Intel CPUs are not vMotion compatible within the same VMware vSphere Cluster. If using a mixed CPU vendor environment, ensure that CPUs from the same vendor are in the same cluster. For more information, see VMware EVC and CPU Compatibility FAQ (1005764).
• For graphics configurations consider the following information:
  ○ For high-end graphics configurations with NVIDIA Quadro vDWS graphics enabled, consider choosing higher clock speeds over higher core counts. Many applications that benefit from high-end graphics are engineered with single-threaded CPU components. Higher clock speeds benefit users more in these workloads.
  ○ For NVIDIA GRID vPC configurations, consider higher core counts over faster clock speeds to reduce oversubscription.
  ○ Most graphics configurations do not experience high CPU oversubscription because vGPU resources are likely to be the resource constraint in the appliance.
• VMware has released and updated its per-CPU licensing model, which requires a license on a per-CPU basis for up to 32 physical cores. This reference architecture recommends using processors with fewer than 32 cores to avoid additional licensing requirements. See Update to VMware’s per-CPU Pricing Model for additional information.

Memory

Best practices for memory allocation and configuration include:
• Do not overcommit memory when sizing, because memory is often not the constraining resource. Overcommitting memory increases the possibility of performance degradation if contention for memory resources occurs (for example, swapping and ballooning of memory). Overcommitted memory can also impact storage performance when swap-files are created.
• Populate memory in units of eight per CPU to yield the highest performance. Dell EMC PowerEdge servers using 2nd Gen AMD EPYC processors have eight memory channels per CPU, which are controlled by eight internal memory controllers, each handling one memory channel with up to two memory DIMMs. To ensure that your environment has the optimal memory configuration, use a balanced configuration where each CPU supports a maximum of 16 DIMMs (or 24 DIMMs for a dual-CPU server). The most effective configuration is 16 DIMMS (8 per processor) with 2nd Gen AMD EPYC processors. For more information, see the Balanced Memory with 2nd Gen AMD EPYC Processors for PowerEdge Servers White Paper.

NVIDIA vGPU considerations

Best practices for sizing and configuring solutions requiring graphics accelerators include:
• GRID vPC licenses support up to 2 GB of video buffer and up to 4 x 5K monitors to cover most traditional VDI users. Maximum node density for graphics-accelerated use can typically be calculated as the available video buffer per node divided by the video buffer size.
• The addition of GPU cards does not necessarily reduce CPU utilization. Instead, it enhances the user experience and offloads specific operations that are best performed by the GPU.
• Dell Technologies recommends using the BLAST protocol for vGPU-enabled desktops. NVIDIA GPUs are equipped with encoders that support BLAST.
• Virtual workstations are typically configured with at least 2 GB video buffer.
• For solutions that use NVIDIA M10 GPU cards in a solution, Dell Technologies recommends a maximum memory capacity of less than 1 TB, due to limitations in the Maxwell architecture. Newer NVIDIA GPU architectures do not have the same limitation.

Sizing considerations

Consider the following general best practices when sizing your deployment:
• User density—if concurrency is a concern, be sure to calculate how many users will be using the environment at the peak of utilization. For example, if only 80 percent are using the environment at any time, the environment need support only that number of users (plus a failure capacity).
• Disaster recovery—For DR, Dell Technologies recommends implementing a dual/multisite solution. The goal is to keep the customer’s environment online and, if there is an outage, to perform an environment recovery with minimum disruption to the business.

• Management and compute clusters—For small environments, using a combined management and compute cluster may be appropriate. For environments deployed at a larger scale, we recommend using separate management and compute layers. When creating a management cluster for a large-scale deployment, consider using R6515 servers to reduce the data center footprint. With a more flexible platform that accommodates a wider variety of VDI application workloads, R7525 servers are preferred for compute clusters.

• Network isolation—This design illustrates a two-NIC configuration per appliance with all the traffic separated logically using VLAN. When designing for larger-scale deployments, consider physically separating the host management and VDI traffic from the vSAN traffic for traffic isolation and to improve network performance and scalability.

• FTT—Dell Technologies recommends sizing storage with NumberOfFailuresToTolerate (FTT) set to 1, which means that you must double the amount of total storage to accommodate the mirroring of each VMDK. Depending on the scale of the environment, it may make sense to increase the FTT to 2. Consider the design of your VDI deployment to determine if the extra availability will outweigh the capacity overhead of increasing FTT.

• Slack space—Dell Technologies recommends adding an additional 30 percent of slack space to prevent automatic rebalancing of storage, which impacts performance. Automatic balancing occurs when the storage reaches 80 percent of the full threshold. Therefore, 70 percent is recommended to reserve a 10 percent buffer.

• All-flash compared with hybrid:
  ○ Hybrid and all-flash configurations have similar performance results. Because hybrid uses spinning drives, consider the durability of the disks.
  ○ Only all-flash configurations offer deduplication and compression for vSAN. Dell Technologies recommends all-flash configurations for simplified data management.
  ○ All-flash configurations need considerably less storage capacity than hybrid configurations to produce similar FTT, as shown in the following table:

<table>
<thead>
<tr>
<th>VM size</th>
<th>FTM</th>
<th>FTT</th>
<th>Overheard</th>
<th>Configuration</th>
<th>Capacity required</th>
<th>Hosts required</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 GB</td>
<td>RAID-1 (mirrored)</td>
<td>1</td>
<td>2 x</td>
<td>Hybrid</td>
<td>100 GB</td>
<td>3</td>
</tr>
<tr>
<td>50 GB</td>
<td>RAID-5 (3+1) (erasure coding)</td>
<td>1</td>
<td>1.33 x</td>
<td>All-flash</td>
<td>66.5 GB</td>
<td>4</td>
</tr>
<tr>
<td>50 GB</td>
<td>RAID-1 (mirrored)</td>
<td>2</td>
<td>3 x</td>
<td>Hybrid</td>
<td>150 GB</td>
<td>4</td>
</tr>
<tr>
<td>50 GB</td>
<td>RAID-6 (4+2) (erasure coding)</td>
<td>2</td>
<td>1.5 x</td>
<td>All-flash</td>
<td>75 GB</td>
<td>6</td>
</tr>
</tbody>
</table>

**NOTE:** For more information about multi-site design considerations for Horizon, see the VMware Workspace ONE and VMware Horizon Reference Architecture.

**Display protocol**

VMware Horizon 7.10 and newer versions support a new dynamic encoder called the Switch encoder when using the BLAST display protocol. Dell Technologies has validated this new capability and recommends enabling it. The new feature provides the capability for the display protocol to dynamically and seamlessly switch to the best codec based on user workload patterns. When using an NVIDIA vGPU, this feature is disabled and the NVENC H.264 hardware encoders are used to offload the encoding of the display protocol from the CPU. This feature can be enabled by using the registry or through the Dynamic Environment Manager. For more information on how to enable the Switch encoder, see the Horizon 7.10 release notes.

**Recommended BIOS settings**

The default BIOS settings, with some minor adjustments, were found to work well and to improve the LoginVSI baseline scores. The system behaved in a more predictable manner as it was scaled up with users with the following changes:

1. **System Profile Settings > System Profile**
   a. Set to "Performance"
2. **Processor Settings > NUMA Nodes per Socket**
   a. Set to "4"
3. **Processor Settings > x2APIC Mode**
   a. Set to "Enabled"

Additional performance improvements may vary depending on the VDI application workload. For more information, see the VMware Tuning Guide for AMD EPYC 7002 Series Processors.

**Design assessment**

Before deployment, assess your environment to validate design considerations and ensure that you are designing your architecture to meet or exceed the performance of your current environment. Dell Technologies Professional Services offers an assessment service for all VDI needs.

**Design enhancements**

This section provides guidance on data protection and file workloads.

**Data protection guidance**

The growth of VDI adoption has resulted in an elevation of the strategic importance of organizational VDI environments: users who are critical to business success are increasingly using VDI for their day-to-day productivity tasks. Consequently, the importance of protecting the VDI environment and the business value of its data has also grown as customers seek to ensure that their VDI environments meet corporate availability, recovery time objective (RTO), and recovery point objective (RPO) requirements.

For information about data protection of a VMware Horizon environment, see the Data Protection for a VMware Horizon VDI Environment using Dell EMC Data Protection Suite Operations Guide. Dell Technologies provides several data protection solutions for different data protection requirements.

**Dell EMC Avamar Virtual Edition**

Dell EMC Avamar Virtual Edition (AVE) is a data protection solution that delivers software-only data protection for virtualized environments and is therefore ideal for the VDI use case. AVE is a fully featured data protection solution that is deployed as a virtual appliance and supports advanced functionality such as backup in the cloud (including VMware Cloud on AWS), change block tracking for fast backup and recovery, and integration with multiple VMware interfaces, such as the vRealize Automation Data Protection Extension. For additional information, see Dell EMC Avamar Virtual Edition Data Protection Software.

**Data Domain Virtual Edition**

Dell EMC Data Domain Virtual Edition (DDVE) is a data protection storage solution that runs as a virtual appliance on a customer's choice of hardware or on a variety of public cloud options, including VMware Cloud on AWS. For on-premises deployments, DDVE is deployed as a virtual appliance on the relevant hardware platform. DDVE has a single point of management with Dell EMC Data Domain Management Center and scales up to 96 TB per instance. One of the key features of the DD storage protection solution is DD Boost, which provides advanced integration with data protection applications such as AVE to enable client-side deduplication, thus accelerating backup. For additional information, see Dell EMC Data Domain Virtual Edition.

The process for protecting a VMware Horizon VDI environment using AVE and DDVE is outlined in the Data Protection for a VMware Horizon VDI Environment using Dell EMC Data Protection Suite Operations Guide.

**Other Dell Technologies data protection products**

Dell Technologies provides few other data protection products for specific use cases. Products include a range of appliances that reduce data protection complexity. These scalable, preconfigured solutions combine data protection storage with software, search, and analytics. For additional information, see Dell EMC Data Protection and Management.

**File workload guidance**

The increased growth in the amount of data that is stored in file shares and user home directories across IT environments in recent years has resulted in an increased focus on the need to better manage this unstructured data. As a result, many organizations are choosing to deploy dedicated file workload solutions with capabilities such as cloud file tiering and single file system namespaces across their IT infrastructure, including for file workloads in a VDI environment.

Dell Technologies provides a number of solutions for different types of file workloads.

The architectures that are shown in the following figures show VDI management and compute environments sharing a vSphere HA cluster. This architecture is universally applicable across SDS environments that require access to dedicated file storage. It is also acceptable to configure these management and compute environments in separate HA clusters (see the Architecture overview). In this...
scenario, each compute cluster and its associated management cluster should share a single file storage system, for example Unity or Isilon.

**Dell EMC Unity storage**

Dell EMC Unity storage is simple, unified all-flash and hybrid storage with hybrid cloud capabilities.

Dell EMC Unity is ideal for general-purpose NAS/SAN mixed workload consolidation, smaller file workloads (including small to midsized VDI environments), and transactional databases.

The following figure shows an example of a 5,000-user VDI deployment using Dell EMC Unity storage for file shares:

![Site A - 5,000 User Pod](image)

**Figure 40. 5,000-user pod on Dell EMC Unity**

When you are deploying Dell EMC Unity in a VDI environment, Dell Technologies recommends that you deploy a separate Dell EMC Unity storage system with a vSphere HA cluster or block. This structure provides the greatest scalability, resiliency, and flexibility when deploying and maintaining file services for the overall user pod. As unstructured data storage needs grow over time, the capacity of each Dell EMC Unity storage system can be scaled up independently with minimal user impact. You have the choice to deploy alternative architectures to the one suggested here, but you should carefully consider the tradeoffs.

For guidance about selecting an appropriate Dell EMC Unity storage solution for your file workload requirements, see Dell EMC Unity XT All-Flash Unified Storage.

**Dell EMC Isilon file storage**

Dell EMC Isilon storage is the industry’s number one scale-out NAS solution for any file workload.

The Isilon system is ideal for a wide range of file workloads (including large-scale enterprise VDI environments requiring a single file system namespace), high-performance computing (HPC), archiving, and infrastructure consolidation.

The following figure shows an example of a 20,000-user VDI deployment using Dell EMC Isilon scale-out storage with a single namespace:
When you are deploying Isilon in a VDI environment, Dell Technologies recommends that you deploy a separate Isilon storage system with a vSphere HA cluster or block. This structure provides the greatest scalability, resiliency, and flexibility for deploying and maintaining file services for the overall user pod. As unstructured data-storage needs grow over time, you can scale up the capacity of each Isilon storage system independently with minimal user impact. In addition to scaling up each Isilon chassis, you can also scale out an Isilon system by using the Dell EMC OneFS operating system. Thus, multiple Isilon systems can provide a single volume and namespace that all user pods in a data center can access.

As shown in the previous figure, you can scale out the system as the VDI environment grows. You can deploy alternative architectures to the one suggested here, but first carefully consider the tradeoffs.

For guidance about selecting an appropriate Isilon storage solution for your file workload requirements, see Dell EMC Isilon Scale-Out Network Attached Storage.

Data center infrastructure

Enterprise equipment requires power to operate, racks to enable streamlined management, and cooling to maintain reliable operations. Careful selection of the infrastructure solutions that provide these capabilities is vital to ensure uptime, scalability, energy efficiency, and ease of management. Dell Technologies provides a wide range of data center infrastructure solutions:

- Dell EMC Netshelter SX racks—Deploy server, storage, and networking equipment and other IT hardware while optimizing power, cooling, cabling, and systems management.
- Dell EMC Keyboard Video Mouse (KVM) and Keyboard Monitor Mouse (KMM) solutions—Manage 8 to 1,024 local and remote servers running various operating systems across the enterprise.
- Dell EMC Smart-UPS—Deliver reliable power and protect IT equipment, including servers, storage, networking, point-of-sale, and medical equipment.
- APC Rack Power Distribution Units (PDUs)—Provides reliable power distribution that is designed to increase manageability and efficiency in your data center.

Conclusion

This reference architecture guide provides design, sizing, and performance information for deploying an end-to-end solution for VMware Horizon 7 on PowerEdge servers based on 2nd Gen AMD EPYC processors.

The architecture and configurations that are presented include choices of optimization strategies, such as for ease of management, high density, or high performance. The 2nd Gen AMD EPYC processors provide performance, density, and agility. The NVIDIA vGPU options provide even more accelerated performance for high-power workstation applications. Extensive performance testing results and guidance have been provided, with analysis and characterization testing against various workloads, and for user profiles that include knowledge workers, power workers, and high-performance-graphics workers.

Dell Technologies offers comprehensive, flexible, and efficient VDI solutions that are designed and optimized for your organization’s needs. These VDI solutions are easy to plan, deploy, and run. Dell EMC Ready Solutions for VDI offer several key benefits to customers, including:

- Rapid deployment and scaling
- Access from anywhere
- Hardened security
- High performance
- Predictable cost of ownership
With VDI solutions from Dell Technologies, you can streamline the design and implementation process, and be assured you have a solution that is optimized for performance, density, and cost-effectiveness.

References

The documentation in this section provides additional information.

Dell Technologies documentation

The following links provide additional information from Dell Technologies. Access to these documents depends on your login credentials. If you do not have access to a document, contact your Dell Technologies representative. Also see the VDI Info Hub for a complete list of VDI resources.

- Dell Technologies Virtual Desktop Infrastructure
- PowerEdge R7525 documentation
- PowerEdge R6515 documentation
- Balanced Memory with 2nd Gen AMD EPYC Processors for PowerEdge Servers White Paper
- Storage technical documents and videos

VMware documentation

The following links provide additional information from VMware:

- VMware vSphere documentation
- VMware Horizon 7 documentation
- VMware Compatibility Guide
- Best Practices for Published Applications and Desktops in VMware Horizon Apps and VMware Horizon 7
- VMware Workspace ONE and VMware Horizon Reference Architecture

NVIDIA documentation

The following link provides additional information from NVIDIA:

- NVIDIA Virtual GPU Software Quick Start Guide

AMD documentation

The following link provides additional information from AMD:

- VMware vSphere Tuning Guide for AMD EPYC 7002 Series Processors

Appendix A: Definition of performance metrics

Table 19. Definition of performance metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU usage</td>
<td>The average CPU percentage usage over the steady state period.</td>
</tr>
<tr>
<td>CPU core utilization</td>
<td>The CPU utilization percentage of the corresponding core. A core is utilized if one or both of its logical CPUs are used. This figure is averaged across all cores.</td>
</tr>
<tr>
<td>CPU readiness</td>
<td>The percentage of time that the virtual machine was ready but could not get a scheduled run on the physical CPU.</td>
</tr>
<tr>
<td>GPU usage</td>
<td>The combined average GPU usage of all six installed T4 GPUs over the steady state period. Shown in Table 15 as “Average GPU usage.”</td>
</tr>
</tbody>
</table>
Table 19. Definition of performance metrics (continued)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed memory</td>
<td>The amount of host physical memory consumed by a virtual machine, host, or cluster. The &quot;Average memory consumed&quot; column in Table 15 represents the average consumed memory of the host over the steady state period.</td>
</tr>
<tr>
<td>Active memory</td>
<td>The amount of memory that is actively used, as estimated by the VM kernel based on recently touched memory pages. The &quot;Average active memory&quot; column in Table 15 is the average amount of guest &quot;physical&quot; memory actively used by the host over the steady state period.</td>
</tr>
<tr>
<td>Network usage</td>
<td>Network usage per user (the &quot;Average net Mbps per user&quot; column in Table 15) is the average over the steady state period divided by the number of users on a host in megabits per second.</td>
</tr>
<tr>
<td>End-user latency</td>
<td>Measures how responsive the remote session feels for the user or how interactive the session is, in other words the amount of lag.</td>
</tr>
<tr>
<td>Frame rate</td>
<td>Measures the number of frames sent to the end user in a given amount of time (per second).</td>
</tr>
<tr>
<td>Image quality</td>
<td>Measures how much the image was impacted and manipulated by the remote protocol. The SSIM metric is the structural similarity of screenshots taken from the VDI desktop and the endpoint (thin client).</td>
</tr>
</tbody>
</table>

Appendix B: nVector Knowledge Worker, 96 users, GPU test

We performed this test with a single GPU-enabled R7525 server acting as the compute host. The compute host was equipped with six NVIDIA T4 GPUs for graphic acceleration. We configured 96 vGPU-enabled virtual machines on the host with the NVIDIA GRID vPC T4-1B profile. We performed the testing with the NVIDIA nVector Knowledge Worker workload. The tests were performed on VMware Horizon 7 linked-clone desktops, and we used the VMware Horizon Blast Extreme display protocol with H.264 hardware encoding.

CPU usage

The following graph shows the percentage of CPU usage, core utilization, and readiness. CPU usage and core utilization increased during the login phase. An average CPU utilization of 72 percent was recorded during the steady state phase of this testing, which was below the 85 percent threshold we set for CPU utilization. The CPU readiness reached a peak of 8.6 percent and CPU usage spiked to almost 100 percent near the end of the test period. This was a one-time spike and it did not affect the performance of the system.
The following graph shows the performance of the six NVIDIA T4 GPUs during the testing. The average GPU utilization across the six GPUs was around 15 percent.

**GPU usage**

The following graph shows the performance of the six NVIDIA T4 GPUs during the testing. The average GPU utilization across the six GPUs was around 15 percent.
**Memory usage**

The following graph shows that the consumed and active memory usage remained constant during the testing. The average consumed memory and average active memory recorded were 769 GB and 842 GB, respectively. Memory was not a bottleneck during the testing, and the configured memory of 1,024 GB was sufficient for this workload.

![Figure 44. Memory performance](image)

**Network usage**

The following graph shows the network usage recorded during the testing. The peak network usage was around 991 Mbps. Network bandwidth was not an issue. With two 25 GbE network interface controllers (NICs) configured as uplink in an active/active team, network bandwidth usage was well below the 85 percent threshold set for network throughput.
The image quality testing takes screenshots of the endpoint and the virtual desktop, and then makes comparisons to show how the display protocol is performing. As shown in the following figure, the image quality SSIM was 0.993. An SSIM value close to 1 indicates that the image quality was excellent and was not degraded by the remoting protocol.

Frame rate

Frame rate measures the smoothness of the virtual desktop session experienced at the endpoint. It measures the rate at which frames are delivered on the screen of the endpoint device (FPS). An average FPS of 20 was recorded during this testing.
End-user latency

The end-user latency metric indicates how responsive the VDI session is at the user’s endpoint. The average end-user latency measured by the nVector Lite tool during the test was 104 ms. This low latency figure indicates that the remote session was very responsive.

Appendix C: nVector Knowledge Worker, 96 users, non-GPU test

We performed this test on a R7525 compute host with 96 virtual machines. We used the NVIDIA nVector Knowledge Worker workload and used VMware Horizon 7 linked clones to provision the virtual desktops. The Blast Extreme remote display protocol was used with H.264 hardware encoding.
CPU usage

The following graph shows the percentage of CPU usage, core utilization, and readiness. As shown in the following graph, CPU usage and core utilization increased during login. We noted that the CPU usage was significantly higher than when the same 96-user test was carried out using GPUs. CPU usage reached 100 percent on several occasions during this testing. We recorded an average CPU usage of 92 percent during the steady state phase, which was above the 85 percent threshold that we set for CPU utilization.

Better CPU performance in the GPU test compared to this non-GPU test indicates that the GPUs improve the performance of the system while running the nVector Knowledge Worker workload. The GPUs perform some of the tasks otherwise carried out by the CPUs, thereby improving the overall performance of the system.

![CPU performance graph](image)

Figure 48. CPU performance

Memory usage

The following graph shows memory usage during the test. Memory usage remained constant. The average consumed memory and the average active memory recorded were 831 GB and 116 GB, respectively.
Network usage

The following graph shows the network usage recorded during the testing. The peak network usage was around 409 Mbps. Network bandwidth was not an issue. With two 25 GbE NICs configured as an uplink in an active/active team, network bandwidth usage was well under the 85 percent threshold set for network throughput.
**Image quality—SSIM**

The image quality testing takes screenshots on the endpoint and the virtual desktop and then makes comparisons of how the display protocol is performing. As shown in the following figure, the image quality SSIM value was 0.998. This shows that the image quality was excellent and was not degraded by the remoting protocol. The image quality in both the GPU and non-GPU tests was almost equal.

![Image quality—SSIM](image1)

**Frame rate**

Frame rate measures the smoothness of the virtual desktop session experienced at the endpoint by measuring the rate at which frames are delivered on the screen of the endpoint device (FPS). An average FPS of 16 was recorded during this testing.

![Frame rate—displayed FPS](image2)
End-user latency

The end-user latency metric indicates how responsive the VDI session is at the user’s endpoint. The average end-user latency measured by the nVector Lite tool during the test was 115 ms. This low latency figure indicates that the remote session was very responsive.

Appendix D: nVector SPECviewperf13 workload, 24 users test

We used a single-node R7525 compute host with six NVIDIA T4 GPUs for this virtual workstation configuration test. We enabled 24 virtual machines with an NVIDIA Quadro DWS T4-4Q vGPU profile. The tests were performed on VMware Horizon 7 linked-clone virtual desktops, and we used the VMware Horizon Blast Extreme protocol as the remote display protocol with H.264 hardware encoding.

This section shows the CPU and GPU performance utilization graphs obtained during the nVector SPEC benchmark tests. We performed benchmark tests on nine SPECviewperf viewsets: 3dsmax, Catia, Creo, Maya, Energy, Medical, Showcase, snx, and sw. Analyzing these graphs gives a better understanding of the performance of the system during the test.

SPECviewperf13 viewsets are designed to put stress on the GPUs and generate benchmark scores. You can see that the GPU is stressed to the maximum in most of the GPU performance graphs from our testing. It is also important to monitor the performance of the CPU to see if it is a bottleneck during the testing. We configured the nVector tool to run three iterations for each viewset, and each of the CPU and GPU performance graphs includes data from those three iterations.

SPECviewperf 13—3ds Max

The following graphs show the CPU and GPU performance during testing with the SPECviewperf 3ds Max viewset. The graphs show that the GPU was stressed to the maximum. The peak CPU usage was below 80 percent in three test iterations, as shown in Figure 54. You can find the SPECviewperf 3dsmax viewset details on the SPEC website.
The following graphs show the CPU and GPU performance during testing with the SPECviewperf Catia viewset. The graphs show that the GPU was stressed to the maximum. The CPU usage was consistently above 90 percent during all three test iterations of this viewset. You can find the SPECviewperf Catia viewset details on the SPEC website.
The following graphs show the CPU and GPU performance during testing with the SPECviewperf Creo viewset. A peak GPU utilization of 70 percent was recorded. This viewset was less GPU-intensive. A peak CPU usage of 83 percent was recorded. You can find the SPECviewperf Creo viewset details on the SPEC website.
The following graphs show the CPU and GPU performance during testing with the SPECviewperf Energy viewset. The GPUs were stressed to their maximum in each iteration of the test while the peak CPU usage was below 70 percent in each iteration. You can find the SPECviewperf Energy viewset details on the SPEC website.
The following graphs show the CPU and GPU performance during testing with the SPECviewperf Maya viewset. The GPUs were stressed to their maximum in each iteration of the test. A peak CPU usage of 81 percent was recorded in the third iteration of the test. You can find the SPECviewperf Maya viewset details on the SPEC website.
Figure 62. CPU performance—Maya

Figure 63. GPU performance—Maya
The following graphs show the CPU and GPU performance during testing with the SPECviewperf Medical viewset. The GPUs were stressed to their maximum in each iteration of the test. A peak CPU usage of 68 percent was recorded in the first iteration of the test. You can find the SPECviewperf Medical viewset details on the SPEC website.

Figure 64. CPU performance—Medical

Figure 65. GPU performance—Medical
SPECviewperf 13—Showcase

The following graphs show the CPU and GPU performance during testing with the SPECviewperf Showcase viewset. The GPUs were stressed to their maximum in each iteration of the test. The peak CPU usage was around 50 percent during each iteration. You can find the SPECviewperf Showcase viewset details on the SPEC website.

Figure 66. CPU performance—Showcase

Figure 67. GPU performance—Showcase
SPECviewperf 13—Siemens NX (snx)

The following graphs show the CPU and GPU performance during testing with the SPECviewperf snx viewset. The GPUs were stressed to their maximum in each iteration of the test. The peak CPU usage was around 90 percent during each iteration. You can find the SPECviewperf snx viewset details on the SPEC website.

Figure 68. CPU performance—snx

Figure 69. GPU performance—snx
SPECviewperf 13—Solidworks (sw)

The following graphs show the CPU and GPU performance during testing with the SPECviewperf sw viewset. A peak GPU utilization of 95 percent was recorded during first iteration of the test. The peak CPU usage was approximately 90 percent during each iteration. You can find the SPECviewperf sw viewset details on the SPEC website.

Figure 70. CPU performance—sw

Figure 71. GPU performance—sw