



NetApp HCI with Cisco ACI

NetApp Solutions

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Table of Contents

- TR-4857: NetApp HCI with Cisco ACI 1
 - Use Cases 1
 - Architecture 1
 - Design Considerations 6
 - Deploying NetApp HCI with Cisco ACI 7
 - Validation Results 20
 - Where to Find Additional Information 21

TR-4857: NetApp HCI with Cisco ACI

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Cisco Application Centric Infrastructure (Cisco ACI) is an industry-leading, secure, open, and comprehensive Software-Defined Networking (SDN) solution. Cisco ACI radically simplifies, optimizes, and accelerates infrastructure deployment and governance, and it expedites the application deployment lifecycle. Cisco ACI deployed in data centers is proven to work with NetApp HCI with full interoperability. You can manage Ethernet networks for compute, storage, and access with Cisco ACI. You can establish and manage secure network segments for server-to-server and virtual machine (VM)-to-VM communications as well as secure storage-network access through iSCSI from server-to-NetApp HCI storage. This level of endpoint-to-endpoint network security allows customers to architect and operate NetApp HCI in a more secure fashion.

[Next: Use Cases](#)

Use Cases

The NetApp HCI with Cisco ACI solution delivers exceptional value for customers with the following use cases:

- On-premises software-defined compute, storage, and networking infrastructure
- Large enterprise and service-provider environments
- Private cloud (VMware and Red Hat)
- End User Computing and Virtual Desktop Infrastructure
- Mixed-workload and mixed-storage environments

[Next: Architecture](#)

Architecture

Solution Technology

This document outlines the best practices to follow for a fully featured on-premises data center or private cloud while interoperating NetApp HCI with Cisco ACI. To demonstrate workload independence, networking best practices are extended to virtualization solutions, including VMware vSphere and Red Hat Virtualization when deployed over NetApp HCI, and to other storage solutions like NetApp ONTAP and StorageGRID. It also emphasizes the interoperability of Cisco ACI switches with different virtual switches, for example, VMware Distributed Switch (VDS), Cisco ACI Virtual Edge (AVE), Linux Bridge, or Open vSwitch.

NetApp HCI

NetApp HCI is an enterprise-scale, hyper-converged infrastructure solution that delivers compute and storage resources in an agile, scalable, easy-to-manage architecture. Running multiple enterprise-grade workloads can result in resource contention, where one workload interferes with the performance of another. NetApp HCI alleviates this concern with storage quality-of-service (QoS) limits that are available natively within NetApp Element software. Element enables the granular control of every application and volume, helps to eliminate noisy neighbors, and satisfies enterprise performance SLAs. NetApp HCI multitenancy capabilities can help eliminate many traditional performance related problems. See the following graphic for an overview of NetApp HCI.

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NetApp HCI streamlines installation through the NetApp Deployment Engine (NDE), an intuitive deployment engine that automates more than 400 inputs to fewer than 30 to get your setup running in about 45 minutes. In addition, a robust suite of APIs enables seamless integration into higher-level management, orchestration, backup, and disaster recovery tools. With the NetApp Hybrid Cloud Control management suite, you can manage, monitor, and upgrade your entire infrastructure throughout its lifecycle through a single pane of glass.

Software-Defined Architecture

NetApp HCI provides a software-defined approach for deploying and managing data and storage resources. NetApp HCI uses NetApp Element software to provide an easy-to-use GUI-based portal and REST-based API for storage automation, configuration, and management. NetApp Element software provides modular and scalable performance, with each storage node delivering guaranteed capacity and throughput to the environment.

NetApp HCI uses the NetApp Deployment Engine (NDE) to automate the configuration and deployment of physical infrastructure, including the installation and configuration of the VMware vSphere environment and the integration of the NetApp Element Plug-in for vCenter Server. The following figure depicts an overview of the process for deploying NetApp HCI.

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Performance Guarantee

A common challenge is delivering predictable performance when multiple applications are sharing the same infrastructure. An application interfering with other applications creates performance degradation. Mainstream applications have unique I/O patterns that can affect each other's performance when deployed in a shared environment. To address these issues, the NetApp HCI Quality of Service (QoS) feature allows fine-grained control of performance for every application, thereby eliminating noisy neighbors and satisfying performance SLAs. In NetApp HCI, each volume is configured with minimum, maximum, and burst IOPS values. The minimum IOPS setting guarantees performance, independent of what other applications on the system are doing. The maximum and burst values control allocation, enabling the system to deliver consistent performance to all workloads.

NetApp Element software uses the iSCSI storage protocol, a standard way to encapsulate SCSI commands on a traditional TCP/IP network. Element uses a technique called iSCSI login redirection for better performance. iSCSI login redirection is a key part of the NetApp Element software cluster. When a host login request is received, the node decides which member of the cluster should handle the traffic based on IOPS and the capacity requirements for the volume. Volumes are distributed across the NetApp Element software cluster and are redistributed if a single node is handling too much traffic for its volumes or if a new node is added. Multiple copies of a given volume are allocated across the array. In this manner, if a node failure is followed by volume redistribution, there is no effect on host connectivity beyond a logout and login with redirection to the new location. With iSCSI login redirection, a NetApp Element software cluster is a self-healing, scale-out architecture that is capable of nondisruptive upgrades and operations.

Interoperability

Previous generations of hyperconverged infrastructure typically required fixed resource ratios, limiting deployments to four-node and eight-node configurations. NetApp HCI is a disaggregated hyper-converged infrastructure that can scale compute and storage resources independently. Independent scaling prevents costly and inefficient overprovisioning and simplifies capacity and performance planning.

The architectural design choices offered enables you to confidently scale on your terms, making HCI viable for core Tier-1 data center applications and platforms. It is architected in building blocks at either the chassis or

the node level. Each chassis can hold four nodes in a mixed configuration of storage or compute nodes. NetApp HCI is available in mix-and-match, small, medium, and large storage and compute configurations.

NetApp HCI provides proven multiprotocol and hybrid- cloud support with enterprise grade features. It also offers easy interoperability with multiple different host virtualization technologies and storage solutions. Deploying ONTAP Select and StorageGRID as appliances expands NetApp HCI storage capabilities to include file, block, and object storage services. NetApp HCI provides an agile infrastructure platform for virtual data centers of different flavors. VMware vSphere, Red Hat Virtualization, KVM, Citrix Hypervisor, and so on are supported platforms that can use the NetApp HCI infrastructure to provide a scalable, enterprise-grade on-premises virtual environment.

For more details, see the [NetApp HCI documentation](#).

Cisco ACI

Cisco ACI is an industry leading software-defined networking solution that facilitates application agility and data center automation. Cisco ACI has a holistic architecture with a centralized policy-driven management. It implements a programmable data center Virtual Extensible LAN (VXLAN) fabric that delivers distributed networking and security for any workload, regardless of its nature (virtual, physical, container, and so on).

Cisco pioneered the introduction of intent-based networking with Cisco ACI in the data center. It combines the high- performance hardware and robust software integrated with two important SDN features—overlays and centralized control. The ACI fabric consists of Cisco Nexus 9000 series switches running in ACI mode and a cluster of at least three centrally managed Application Policy Infrastructure Controllers (APIC) servers. The following figure provides an overview of Cisco ACI.

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Policy-Driven Networking

Cisco ACI, with its policy driven model, makes network hardware stateless. The Application Policy Infrastructure Controller (APIC) acts as the central controller managing and configuring all the switches in the ACI fabric. The Cisco ACI fabric consists of Cisco Nexus 9000 series switches which are centrally configured and managed by the cluster of APICs using the declarative policy model.

Cisco ACI uses logical constructs to form a layered policy architecture to define and manage the different functions of the entire fabric, including infrastructure, authentication, security, services, applications, and diagnostics.

The following figure depicts the categorization and relation between different logical constructs in Cisco ACI.

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Tenants are logical containers with administrative boundaries that exercise domain-based access control. It is a logical policy isolation and does not equate to a real network construct.

Within the tenant, a context is a unique layer-3 forwarding policy domain. A context can be directly mapped to the Virtual Routing and Forwarding (VRF) concept of traditional networks. In fact, a context is also called VRF. Because each context is a separate layer- 3 domain, two different contexts can have overlapping IP spaces.

Within a context, a bridge domain (BD) represents a unique layer-2 forwarding construct. The bridge domain defines the unique layer-2 MAC address space and can be equated to a layer-2 flood domain or to a layer-3 gateway. A bridge domain can have zero subnets, but it must have at least one subnet if it is to perform routing for the hosts residing in the BD.

In ACI, an endpoint is anything that communicates on the network, be it a compute host, a storage device, a network entity that is not part of the ACI fabric, a VM, and so on. A group of endpoints that have the same policy requirements are categorized into an Endpoint Group (EPG). An EPG is used to configure and manage multiple endpoints together. An EPG is a member of a bridge domain. One EPG cannot be a member of multiple bridge domains, but multiple EPGs can be members of a single bridge domain.

All the endpoints that belong to the same EPG can communicate with each other. However, endpoints in different EPGs cannot communicate by default, but they can communicate if a contract exists between the two EPGs allowing that communication. Contracts can be equated to ACLs in traditional networking. However, it differs from an ACL in the way that it doesn't involve specifying specific IP addresses as source and destination and that contracts are applied to an EPG as a whole.

See the [Cisco ACI documentation](#) for more information.

Networking Advantages

Cisco ACI provides many advantages over traditional networking. Programmability and automation are critical features of a scalable data center virtualization infrastructure and the policy driven mechanism of Cisco ACI opens a lot of opportunities for providing optimal physical and virtual networking.

- **Virtual Machine Manager (VMM) Integration.** With the Cisco ACI open REST API features, integration with virtualized environments is easy. Cisco ACI supports VMM integration with multiple hypervisors and provides automated access and control over the hypervisor virtual switches to the networking constructs in ACI. VMM integration in ACI seamlessly extends the ACI policy framework to virtual workloads. In other words, VMM integration allows Cisco ACI to control the virtual switches running on virtualization hosts and to extend the ACI fabric access policies to virtual workloads. The integration also automates the hypervisor's virtual switch deployment and configuration tasks. Cisco ACI VMM integration provides the following benefits:
 - Single point of policy management for physical and virtual environments through APIC
 - Faster application deployment, with transparent instantiation of applications in virtual environments
 - Full integrated visibility into the health of the application through holistic aggregation of information across physical and virtual environments
 - Simplified networking configuration for virtual workloads because the port-group or VM NIC profiles required to attach to the VMs are created automatically. For more information on Cisco ACI VMM integration, see the [Cisco documentation](#). In addition, see the Cisco ACI [virtualization compatibility matrix](#) for version compatibility details.
- **Micro-segmentation.** Micro-segmentation in Cisco ACI allows you to classify the endpoints in existing application EPGs into microsegment (uSeg) EPGs using network-based or VM-based attributes. This helps for filtering the endpoints more granularly and apply specific dynamic policies on those endpoints. Micro-segmentation can be applied to any endpoints within the tenant. Cisco supports micro-segmentation on a variety of virtual switches - Cisco ACI Virtual Edge, VMware VDS and Microsoft vSwitch. uSeg EPGs can be configured with multiple attributes but an endpoint can be assigned to only one EPG. For more details, see the [Cisco ACI Virtualization guide](#) for the specific version.
- **Intra-EPG Isolation.** By default, all endpoints belonging to the same EPG can communicate with each other. Intra-EPG Isolation in Cisco ACI is a feature to prevent endpoints in the same EPG communicate with each other. It achieves isolation by using different VLANs for traffic from ACI leaf to hypervisor hosts and from hypervisor hosts to ACI leaf. Intra-EPG isolation can be enforced on both application EPGs and microsegment EPGs. See the specific version of the [Cisco ACI virtualization guide](#) for more information.

Architectural Diagram

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This diagram represents the physical architecture of NetApp HCI with Cisco ACI that was designed for this solution. Two leaf switches connected via spines and managed by a cluster of three APICs forms the ACI fabric. The leaf switches are connected to upstream routers for external connectivity. Three pairs of NetApp HCI compute nodes (each pair dedicated for a hypervisor) are configured with a two-cable option. Four storage nodes were configured with four-cable option to form the Element cluster. A pair of AFF A200 nodes are used to provide the ONTAP capabilities to the system.

Hardware and Software Requirements

Compute

The following tables list the hardware and software compute resources utilized in the solution. The components that are used in any implementation of the solution might vary based on customer requirements.

Hardware	Model	Quantity
NetApp HCI compute nodes	NetApp H410C	6

Software	Purpose	Version
VMware ESXi	Virtualization	6.7
VMware vCenter Server Appliance	Virtualization management	6.7
Red Hat Enterprise Linux	Operating system	7.7
KVM	Virtualization	1.5.3-167
Red Hat Virtualization	Virtualization	4.3.9

Storage

The following tables list the hardware and software storage resources used in this solution. The components that are used in any particular implementation of the solution might vary based on customer requirements.

Hardware	Model	Quantity
NetApp HCI storage nodes	NetApp H410S	4
AFF	A200	2

Software	Purpose	Version
NetApp HCI	Infrastructure	1.8
NetApp Element	Storage	12.0
ONTAP	Storage	9.7P6
ONTAP Select	Storage	9.7
Storage Grid	Storage	11.3

Networking

The following tables list the hardware and software network resources used in this solution. The components that are used in any particular implementation of the solution might vary based on customer requirements.

Hardware	Model	Quantity
Cisco UCS server	UCS C-220 M3	3
Cisco Nexus	N9K-C9336-PQ	2
Cisco Nexus	N9K-C9396-PX	2

Software	Purpose	Version
Cisco APIC	Network Management	3.2(9h)
Cisco Nexus ACI-mode Switch	Network	13.2(9h)
Cisco AVE	Network	1.2.9
Open vSwitch (OVS)	Network	2.9.2
VMware Virtual Distributed Switch	Network	6.6

[Next: Design Considerations](#)

Design Considerations

Network Design

The minimum configuration of a Cisco ACI fabric consists of two leaf switches and two spine switches with a cluster at least three APICs managing and controlling the whole fabric. All the workloads connect to leaf switches. Spine switches are the backbone of the network and are responsible for interconnecting all leaf switches. No two leaf switches can be interconnected. Each leaf switch is connected to each of the spine switches in a full-mesh topology.

With this two-tier spine-and-leaf architecture, no matter which leaf switch the server is connected to, it's traffic always crosses the same number of devices to get to another server attached to the fabric (unless the other server is located on the same leaf). This approach keeps latency at a predictable level.

Compute Design

The minimum number of compute nodes required for a highly available infrastructure using NetApp HCI is two. NetApp HCI provides two options for cabling: two-cable and six-cable. NetApp HCI H410C compute nodes are available with two 1GbE ports (ports A and B) and four 10/25GbE ports (ports C, D, E, and F) on board. For a two-cable option, ports D and E are used for connectivity to uplink switches, and, for a six-cable option, all ports from A to F are used. Each node also has an additional out-of-band management port that supports Intelligent Platform Management Interface (IPMI) functionality. This solution utilizes the two-cable option for compute nodes.

For VMware deployments, NetApp HCI comes with an automated deployment tool called the NetApp Deployment Engine (NDE). For non-VMware deployments, manual installation of hypervisors or operating systems is required on the compute nodes.

Storage Design

NetApp HCI uses four-cable option for storage nodes. NetApp HCI H410S storage nodes are available with two 1GbE ports (ports A and B) and two 10/25GbE ports (ports C and D) on board. The two 1GbE ports are bundled as Bond1G (active/passive mode) used for management traffic and the two 10/25GbE ports are bundled as Bond10G (LACP active mode) used for storage data traffic.

For non-VMware deployments, the minimum configuration of NetApp HCI storage cluster is four nodes. For NetApp HCI versions earlier than 1.8 with VMware deployments, the minimum configuration is four storage nodes. However, for HCI version 1.8 with VMware deployments, the minimum configuration for NetApp HCI storage cluster is two nodes. For more information on NetApp HCI two-node storage cluster, see the documentation [here](#).

Next: [VMware vSphere: NetApp HCI with Cisco ACI](#)

Deploying NetApp HCI with Cisco ACI

VMware vSphere: NetApp HCI with Cisco ACI

VMware vSphere is an industry-leading virtualization platform that provides a way to build a resilient and reliable virtual infrastructure. vSphere contains virtualization, management, and interface layers. The two core components of VMware vSphere are ESXi server and the vCenter Server. VMware ESXi is hypervisor software installed on a physical machine that facilitates hosting of VMs and virtual appliances. vCenter Server is the service through which you manage multiple ESXi hosts connected in a network and pool host resources. For more information on VMware vSphere, see the documentation [here](#).

Workflow

The following workflow was used to up the virtual environment. Each of these steps might involve several individual tasks.

1. Install and configure Nexus 9000 switches in ACI mode and APIC software on the UCS C-series server. See the Install and Upgrade [documentation](#) for detailed steps.
2. Configure and setup ACI fabric by referring to the [documentation](#).
3. Configure the tenants, application profiles, bridge domains, and EPGs required for NetApp HCI nodes. NetApp recommends using one BD to one EPG framework, except for iSCSI. See the documentation [here](#) for more details. The minimum set of EPGs required are in-band management, iSCSI, iSCSI-A, iSCSI-B, VM motion, VM-data network, and native.



iSCSI multipathing requires two iSCSI EPGs: iSCSI-A and iSCSI-B, each with one active uplink.



NetApp mNode requires an iSCSI EPG with both uplinks active.

4. Create the VLAN pool, physical domain, and AEP based on the requirements. Create the switch and interface profiles for individual ports. Then attach the physical domain and configure the static paths to the EPGs. See the [configuration guide](#) for more details.

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Use an access port policy group for interfaces connecting to NetApp HCI compute nodes, and use vPC policy group for interfaces to NetApp HCI storage nodes.

5. Create and assign contracts for tightly-controlled access between workloads. For more information on configuring the contracts, see the guide [here](#).
6. Install and configure NetApp HCI using NDE. NDE configures all the required parameters, including VDS port groups for networking, and also installs the mNode VM. See the [deployment guide](#) for more information.
7. Though VMM integration of Cisco ACI with VMware VDS is optional, using the VMM integration feature is a best practice. When not using VMM integration, an NDE-installed VDS can be used for networking with physical domain attachment on Cisco ACI.
8. If you are using VMM integration, NDE-installed VDS cannot be fully managed by ACI and can be added as read-only VMM domain. To avoid that scenario and make efficient use of Cisco ACI's VMM networking feature, create a new VMware VMM domain in ACI with a new VMware vSphere Distributed Switch (vDS) and an explicit dynamic VLAN pool. The VMM domain created can integrate with any supported virtual switch.
 - a. **Integrate with VDS.** If you wish to integrate ACI with VDS, select the virtual switch type to be VMware Distributed Switch. Consider the configuration best practices noted in the following table. See the [configuration guide](#) for more details.

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- b. **Integrate with Cisco AVE.** If you are integrating Cisco AVE with Cisco ACI, select the virtual switch type to be Cisco AVE. Cisco AVE requires a unique VLAN pool of type Internal for communicating between internal and external port groups. Follow the configuration best practices noted in this table. See the [installation guide](#) to install and configure Cisco AVE.

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9. Attach the VMM domain to the EPGs using Pre-Provision Resolution Immediacy. Then migrate all the VMNICs, VMkernel ports, and VNICs from the NDE-created VDS to ACI-created VDS or AVE and so on. Configure the uplink failover and teaming policy for iSCSI-A and iSCSI-B to have one active uplink each. VMs can now attach their VMNICs to ACI-created port groups to access network resources. The port groups on VDS that are managed by Cisco ACI are in the format of `<tenant-name>|<application-profile-name>|<epg-name>`.



Pre-Provision Resolution Immediacy is required to ensure the port policies are downloaded to the leaf switch even before the VMM controller is attached to the virtual switch.

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10. If you intend to use micro-segmentation, then create micro-segment (uSeg) EPGs attaching to the right BD. Create attributes in VMware vSphere and attach them to the required VMs. Ensure the VMM domain has Enable Tag Collection enabled. Configure the uSeg EPGs with the corresponding attribute and attach the VMM domain to it. This provides more granular control of communication on the endpoint VMs.

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The networking functionality for VMware vSphere on NetApp HCI in this solution is provided either using VMware VDS or Cisco AVE.

VMware VDS

VMware vSphere Distributed Switch (VDS) is a virtual switch that connects to multiple ESXi hosts in the cluster or set of clusters allowing virtual machines to maintain consistent network configuration as they migrate across multiple hosts. VDS also provides for centralized management of network configurations in a vSphere environment. For more details, see the [VDS documentation](#).

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The following table outlines the necessary parameters and best practices for configuring and integrating Cisco ACI with VMware VDS.

Resource	Configuration Considerations	Best Practices
Endpoint groups	<ul style="list-style-type: none">• Separate EPG for native VLANs• Static binding of interfaces to HCI storage and compute nodes in native VLAN EPG uses 802.1P mode. This is required for node discovery to run NDE.• Separate EPGs for iSCSI, iSCSI-A, and iSCSI-B with a common BD• iSCSI-A and iSCSI-B are for iSCSI multipathing and are used for VMkernel ports on ESXi hosts• Physical domain to be attached to iSCSI EPG before running NDE• VMM domain to be attached to iSCSI, iSCSI-A, and iSCSI-B EPGs	<ul style="list-style-type: none">• Contracts between EPGs to be well defined. Allow only required ports for communication.• Use unique native VLAN for NDE node discovery• For EPGs corresponding to port-groups being attached to VMkernel ports, VMM domain to be attached with Pre-Provision for Resolution Immediacy

Resource	Configuration Considerations	Best Practices
Interface policy	<ul style="list-style-type: none"> • A common leaf access port policy group for all ESXi hosts • One vPC policy group per NetApp HCI storage node • LLDP enabled, CDP disabled 	<ul style="list-style-type: none"> • Separate VLAN pool for VMM domain with dynamic allocation turned on • Recommended to use vPC with LACP Active port-channel policy for interfaces towards NetApp HCI storage nodes • Recommended to use individual interfaces for compute nodes, no LACP.
VMM Integration	<ul style="list-style-type: none"> • Local switching preference • Access mode is Read Write. 	<ul style="list-style-type: none"> • MAC-Pinning-Physical-NIC-Load for vSwitch policy • LLDP for discovery policy • Enable Tag collection if micro-segmentation is used
VDS	<ul style="list-style-type: none"> • Both uplinks active for iSCSI port-group • One uplink each for iSCSI-A and iSCSI-B 	<ul style="list-style-type: none"> • Load balancing method for all port-groups to be 'Route based on physical NIC load' • iSCSI VMkernel port migration to be done one at a time from NDE deployed VDS to ACI integrated VDS
Easy Scale	<ul style="list-style-type: none"> • Run NDE scale by attaching the same leaf access port policy group for ESXi hosts to be added • One vPC policy group per NetApp HCI storage node • Individual interfaces (for ESXi hosts) and vPCs (for storage nodes) should be attached to native, in-band management, iSCSI, VM motion EPGs for successful NDE scale • LLDP enabled, CDP disabled 	<ul style="list-style-type: none"> • Recommended to use vPC with LACP Active port-channel policy for interfaces towards NetApp HCI storage nodes • Recommended to use individual interfaces for compute nodes, no LACP.



For traffic load-balancing, port channels with vPCs can be used on Cisco ACI along with LAGs on VDS with LACP in active mode. However, using LACP can affect storage performance when compared to iSCSI multipathing.

Cisco AVE

Cisco ACI Virtual Edge (AVE) is a virtual switch offering by Cisco that extends the Cisco ACI policy model to

virtual infrastructure. It is a hypervisor- independent distributed network service that sits on top of the native virtual switch of the hypervisor. It leverages the underlying virtual switch using a VM-based solution to provide network visibility into the virtual environments. For more details on Cisco AVE, see the [documentation](#). The following figure depicts the internal networking of Cisco AVE on an ESXi host (as tested).

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The following table lists the necessary parameters and best practices for configuring and integrating Cisco ACI with Cisco AVE on VMware ESXi. Cisco AVE is currently only supported with VMware vSphere.

Resource	Configuration Considerations	Best Practices
Endpoint Groups	<ul style="list-style-type: none"> • Separate EPG for native VLANs • Static binding of interfaces towards HCI storage and compute nodes in native VLAN EPG uses 802.1P mode. This is required for node discovery to run NDE. • Separate EPGs for iSCSI, iSCSI-A and iSCSI-B with a common BD • iSCSI-A and iSCSI-B are for iSCSI multipathing and are used for VMkernel ports on ESXi hosts • Physical domain to be attached to iSCSI EPG before running NDE • VMM domain is attached to iSCSI, iSCSI-A, and iSCSI-B EPGs 	<ul style="list-style-type: none"> • Separate VLAN pool for VMM domain with dynamic allocation turned on • Contracts between EPGs to be well defined. Allow only required ports for communication. • Use unique native VLAN for NDE node discovery • Use native switching mode in VMM domain for EPGs that correspond to port groups being attached to host's VMkernel adapters • Use AVE switching mode in VMM domain for EPGs corresponding to port groups carrying user VM traffic • For EPGs corresponding to port-groups being attached to VMkernel ports, VMM domain is attached with Pre-Provision for Resolution Immediacy
Interface Policy	<ul style="list-style-type: none"> • One vPC policy group per NetApp HCI storage node • LLDP enabled, CDP disabled • Before running NDE, for NDE discovery: <ul style="list-style-type: none"> ◦ Leaf Access port policy group for all ESXi hosts • After running NDE, for Cisco AVE: <ul style="list-style-type: none"> ◦ One vPC policy group per ESXi host 	<ul style="list-style-type: none"> • NetApp recommends using vPCs to ESXi hosts for Cisco AVE • Use static mode on port-channel policy for vPCs to ESXi • Use Layer-4 SRC port load balancing hashing method for port-channel policy • NetApp recommends using vPC with LACP active port-channel policy for interfaces to NetApp HCI storage nodes

Resource	Configuration Considerations	Best Practices
VMM Integration	<ul style="list-style-type: none"> • Create a new VLAN range [or Encap Block] with role Internal and Dynamic allocation' attached to the VLAN pool intended for VMM domain • Create a pool of multicast addresses (one address per EPG) • Reserve another multicast address different from the pool of multicast addresses intended for AVE fabric-wide multicast address • Local switching preference • Access mode to be Read Write mode 	<ul style="list-style-type: none"> • Static mode on for vSwitch policy • Ensure that vSwitch port-channel policy and interface policy group's port-channel policy are using the same mode • LLDP for discovery policy • Enable Tag collection if using micro-segmentation • Recommended option for Default Encap mode is VXLAN
VDS	<ul style="list-style-type: none"> • Both uplinks active for iSCSI port-group • One uplink each for iSCSI-A and iSCSI-B 	<ul style="list-style-type: none"> • iSCSI VMkernel port migration is done one at a time from NDE deployed VDS to ACI integrated VDS • Load balancing method for all port-groups to be Route based on IP hash
Cisco AVE	<ul style="list-style-type: none"> • Run NDE with access port interface policy groups towards ESXi hosts. Individual interfaces towards ESXi hosts should be attached to native, in-band management, iSCSI, VM motion EPGs for successful NDE run. • Once the environment is up, place the host in maintenance mode, migrate interface policy group to vPC with static mode on, assign vPC to all required EPGs and remove the host from maintenance mode. Repeat the same process for all hosts. • Run the AVE installation process to install AVE control VM on all hosts 	<ul style="list-style-type: none"> • Use local datastore on the hosts for installing AVE control VM. Each host should have one AVE control VM installed on it • Use network protocol profile on the in-band management VLAN if DHCP is not available on that network

Resource	Configuration Considerations	Best Practices
Easy Scale	<ul style="list-style-type: none"> • Run NDE scale with access port interface policy group for ESXi hosts to be added. Individual interfaces should be attached to native, in-band management, iSCSI, VM motion EPGs for successful NDE run. • Once the ESXi host is added to the vSphere cluster, place the host in maintenance mode and migrate the interface policy group to vPC with static mode on. Then attach the vPC to required EPGs. • Run AVE installation process on the new host for installing AVE control VM on that host • One vPC policy group per NetApp HCI storage node to be added to the cluster • LLDP enabled, CDP disabled 	<ul style="list-style-type: none"> • Use local datastore on the host for installing AVE control VM • Use network protocol profile on the in-band management VLAN if DHCP is not available on that network • Recommended to use vPC with LACP Active port-channel policy for interfaces towards NetApp HCI storage nodes



For traffic load balancing, port channel with vPCs can be used on Cisco ACI along with LAGs on ESXi hosts with LACP in active mode. However, using LACP can affect storage performance when compared to iSCSI multipathing.

[Next: Red Hat Virtualization: NetApp HCI with Cisco ACI](#)

Red Hat Virtualization: NetApp HCI with Cisco ACI

Red Hat Virtualization (RHV) is an enterprise virtual data center platform that runs on Red Hat Enterprise Linux using the KVM hypervisor. The key components of RHV include Red Hat Virtualization Hosts (RHV-H) and the Red Hat Virtualization Manager (RHV-M). RHV-M provides centralized, enterprise-grade management for the physical and logical resources within the virtualized RHV environment. RHV-H is a minimal, light-weight operating system based on Red Hat Enterprise Linux that is optimized for the ease of setting up physical servers as RHV hypervisors. For more information on RHV, see the documentation [here](#). The following figure provides an overview of RHV.

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Starting with Cisco APIC release 3.1, Cisco ACI supports VMM integration with Red Hat Virtualization environments. The RHV VMM domain in Cisco APIC is connected to RHV-M and directly associated with a data center object. All the RHV-H clusters under this data center are considered part of the VMM domain. Cisco ACI automatically creates logical networks in RHV-M when the EPGs are attached to the RHV VMM domain in ACI. RHV hosts that are part of a Red Hat VMM domain can use Linux bridge or Open vSwitch as its virtual switch. This integration simplifies and automates networking configuration on RHV-M, saving a lot of manual work for system and network administrators.

Workflow

The following workflow is used to set up the virtual environment. Each of these steps might involve several individual tasks.

1. Install and configure Nexus 9000 switches in ACI mode and APIC software on the UCS C-series server. Refer to the Install and Upgrade [documentation](#) for detailed steps.
2. Configure and setup the ACI fabric by referring to the [documentation](#).
3. Configure tenants, application profiles, bridge domains, and EPGs required for NetApp HCI nodes. NetApp recommends using one BD to one EPG framework, except for iSCSI. See the documentation [here](#) for more details. The minimum set of EPGs required are in-band management, iSCSI, VM motion, VM-data network, and native.
4. Create the VLAN pool, physical domain, and AEP based on the requirements. Create the switch and interface profiles and policies for vPCs and individual ports. Then attach the physical domain and configure the static paths to the EPGs. see the [configuration guide](#) for more details. This table lists best practices for integrating ACI with Linux bridge on RHV.

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Use a vPC policy group for interfaces connecting to NetApp HCI storage and compute nodes.

5. Create and assign contracts for tightly controlled access between workloads. For more information on configuring the contracts, see the guide [here](#).
6. Install and configure the NetApp HCI Element cluster. Do not use NDE for this install; rather, install a standalone Element cluster on the HCI storage nodes. Then configure the required volumes for installation of RHV. Install RHV on NetApp HCI. Refer to [RHV on NetApp HCI NVA](#) for more details.
7. RHV installation creates a default management network called ovirtmgmt. Though VMM integration of Cisco ACI with RHV is optional, leveraging VMM integration is preferred. Do not create other logical networks manually. To use Cisco ACI VMM integration, create a Red Hat VMM domain and attach the VMM domain to all the required EPGs, using Pre- Provision Resolution Immediacy. This process automatically creates corresponding logical networks and vNIC profiles. The vNIC profiles can be directly used to attach to hosts and VMs for their communication. The networks that are managed by Cisco ACI are in the format `<tenant-name>|<application-profile-name>|<epg-name>` tagged with a label of format `aci_<rhv-vmm-domain-name>`. See [Cisco's whitepaper](#) for creating and configuring a VMM domain for RHV. Also, see this table for best practices when integrating RHV on NetApp HCI with Cisco ACI.



Except for ovirtmgmt, all other logical networks can be managed by Cisco ACI.

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The networking functionality for RHVH hosts in this solution is provided by Linux bridge.

Linux Bridge

Linux Bridge is a default virtual switch on all Linux distributions that is usually used with KVM/QEMU-based hypervisors. It is designated to forward traffic between networks based on MAC addresses and thus is regarded as a layer-2 virtual switch. For more information, see the documentation [here](#). The following figure

depicts the internal networking of Linux Bridge on RHV-H (as tested).

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The following table outlines the necessary parameters and best practices for configuring and integrating Cisco ACI with Linux Bridge on RHV hosts.

Resource	Configuration considerations	Best Practices
Endpoint groups	<ul style="list-style-type: none"> • Separate EPG for native VLAN • Static binding of interfaces towards HCI storage and compute nodes in native VLAN EPG to be on 802.1P mode • Static binding of vPCs required on In-band management EPG and iSCSI EPG before RHV installation 	<ul style="list-style-type: none"> • Separate VLAN pool for VMM domain with dynamic allocation turned on • Contracts between EPGs to be well defined. Allow only required ports for communication. • Use unique native VLAN for discovery during Element cluster formation • For EPGs corresponding to port-groups being attached to VMkernel ports, VMM domain to be attached with 'Pre-Provision' for Resolution Immediacy
Interface policy	<ul style="list-style-type: none"> • One vPC policy group per RHV-H host • One vPC policy group per NetApp HCI storage node • LLDP enabled, CDP disabled 	<ul style="list-style-type: none"> • Recommended to use vPC towards RHV-H hosts • Use 'LACP Active' for the port-channel policy • Use only 'Graceful Convergence' and 'Symmetric Hashing' control bits for port-channel policy Use 'Layer4 Src-port' load balancing hashing method for port-channel policy Recommended to use vPC with LACP Active port-channel policy for interfaces towards NetApp HCI storage nodes
VMM Integration	<ul style="list-style-type: none"> • Do not migrate host management logical interfaces from ovirtmgmt to any other logical network 	<ul style="list-style-type: none"> • iSCSI host logical interface to be migrated to iSCSI logical network managed by ACI VMM integration



Except for the ovirtmgmt logical network, it is possible to create all other infrastructure logical networks on Cisco APIC and map them to the VMM domain. 'ovirtmgmt' logical network uses the static path binding on the In-band management EPG attached with the physical domain.

KVM on RHEL: NetApp HCI with Cisco ACI

KVM (for Kernel-based Virtual Machine) is an open-source full virtualization solution for Linux on x86 hardware such as Intel VT or AMD-V. In other words, KVM lets you turn a Linux machine into a hypervisor that allows the host to run multiple, isolated VMs.

KVM converts any Linux machine into a type-1 (bare-metal) hypervisor. KVM can be implemented on any Linux distribution, but implementing KVM on a supported Linux distribution—like Red Hat Enterprise Linux—expands KVM's capabilities. You can swap resources among guests, share common libraries, and optimize system performance.

Workflow

The following high-level workflow was used to set up the virtual environment. Each of these steps might involve several individual tasks.

1. Install and configure Nexus 9000 switches in ACI mode, and install and configure APIC software on a UCS C-series server. See the Install and Upgrade [documentation](#) for detailed steps.
2. Configure and set up the ACI fabric by referring to the [documentation](#).
3. Configure the tenants, application profiles, bridge domains, and EPGs required for NetApp HCI nodes. NetApp recommends using a one-BD-to-one-EPG framework except for iSCSI. See the [documentation here](#) for more details. The minimum set of EPGs required are in-band management, iSCSI, VM Motion, VM-data network, and native.
4. Create the VLAN pool, physical domain, and AEP based on the requirements. Create the switch and interface profiles and policies for vPCs and individual ports. Then attach the physical domain and configure the static paths to the EPGs. See the [configuration guide](#) for more details. Also see this table [<link>](#) for best practices for integrating ACI with Open vSwitch on the RHEL–KVM hypervisor.



Use a vPC policy group for interfaces connecting to NetApp HCI storage and compute nodes.

5. Create and assign contracts for tightly-controlled access between workloads. For more details on configuring the contracts, see the guide [here](#).
6. Install and configure a NetApp HCI Element cluster. Do not use NDE for this installation; rather, install a standalone Element cluster on HCI storage nodes. Then configure the required volumes for the installation of RHEL. Install RHEL, KVM, and Open vSwitch on the NetApp HCI compute nodes. Configure storage pools on the hypervisor using Element volumes for a shared storage service for hosts and VMs. For more details on installation and configuration of KVM on RHEL, see the [Red Hat documentation](#). See the [OVS documentation](#) for details on configuring Open vSwitch.
7. RHEL KVM hypervisor's Open vSwitch cannot be VMM integrated with Cisco ACI. Physical domain and static paths must be configured on all required EPGs to allow the required VLANs on the interfaces connecting the ACI leaf switches and RHEL hosts. Also configure the corresponding OVS bridges on RHEL hosts and configure VMs to use those bridges. The networking functionality for the RHEL KVM hosts in this solution is achieved using Open vSwitch virtual switch.

Open vSwitch

Open vSwitch is an open-source, enterprise-grade virtual switch platform. It uses virtual network bridges and flow rules to forward packets between hosts. Programming flow rules work differently in OVS than in the

standard Linux Bridge. The OVS plugin does not use VLANs to tag traffic. Instead, it programs flow rules on the virtual switches that dictate how traffic should be manipulated before forwarded to the exit interface. Flow rules determine how inbound and outbound traffic should be treated. The following figure depicts the internal networking of Open vSwitch on an RHEL-based KVM host.

[Error: Missing Graphic Image]

The following table outlines the necessary parameters and best practices for configuring Cisco ACI and Open vSwitch on RHEL based KVM hosts.

Resource	Configuration Considerations	Best Practices
Endpoint groups	<ul style="list-style-type: none"> • Separate EPG for native VLAN • Static binding of interfaces towards HCI storage and compute nodes in native VLAN EPG to be on 802.1P mode • Static binding of vPCs required on in-band management EPG and iSCSI EPG before KVM installation 	<ul style="list-style-type: none"> • Separate VLAN pool for physical domain with static allocation turned on • Contracts between EPGs to be well defined. Allow only required ports for communication. • Use unique native VLAN for discovery during Element cluster formation
Interface Policy	<ul style="list-style-type: none"> • One vPC policy group per RHEL host • One vPC policy group per NetApp HCI storage node • LLDP enabled, CDP disabled 	<ul style="list-style-type: none"> • NetApp recommends using vPC towards RHV-H hosts • Use LACP Active for the port-channel policy • Use only Graceful Convergence and Symmetric Hashing control bits for port-channel policy • Use Layer4 Src-Port load-balancing hashing method for port-channel policy • NetApp recommends using vPC with LACP Active port-channel policy for interfaces towards NetApp HCI storage nodes

[Next: ONTAP on AFF: NetApp HCI and Cisco ACI](#)

ONTAP on AFF: NetApp HCI and Cisco ACI

NetApp AFF is a robust storage platform that provides low-latency performance, integrated data protection, multiprotocol support, and nondisruptive operations. Powered by NetApp ONTAP data management software, NetApp AFF ensures nondisruptive operations, from maintenance to upgrades to complete replacement of your storage system.

NetApp ONTAP is a powerful storage operating system with capabilities like inline compression, nondisruptive hardware upgrades, and cross-storage import. A NetApp ONTAP cluster provides a unified storage system with simultaneous data access and management of Network File System (NFS), Common Internet File System (CIFS), iSCSI, Fibre Channel (FC), Fibre Channel over Ethernet (FCoE), and NVMe/FC protocols. ONTAP provides robust data protection capabilities, such as NetApp MetroCluster, SnapLock, Snapshot copies, SnapVault, SnapMirror, SyncMirror technologies and more. For more information, see the [ONTAP documentation](#).

To extend the capabilities of storage to file services and add many more data protection abilities, ONTAP can be used in conjunction with NetApp HCI. If NetApp ONTAP already exists in your environment, you can easily integrate it with NetApp HCI and Cisco ACI.

Workflow

The following high-level workflow was used to set up the environment. Each of these steps might involve several individual tasks.

1. Create a separate bridge domain and EPG on ACI for NFS and/or other protocols with the corresponding subnets. You can use the same HCI-related iSCSI EPGs.
2. Make sure you have proper contracts in place to allow inter-EPG communication for only the required ports.
3. Configure the interface policy group and selector for interfaces towards AFF controllers. Create a vPC policy group with the LACP Active mode for port-channel policy.

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4. Attach both a physical and VMM domain to the EPGs created. Attach the vPC policy as static paths and, in the case of the Cisco AVE virtual switch, use Native switching mode when you attach the VMM domain.

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5. Install and configure an ONTAP cluster on the AFF controllers. Then create and configure NFS and/or iSCSI volumes/LUNs. See the [AFF and ONTAP documentation](#) for more information.
6. Create a VMkernel adapter (in the case of VMware ESXi) or a logical interface (in the case of RHV-H and RHEL-KVM hosts) attaching the NFS (or other protocols) port group or logical network.
7. Create additional datastores, storage domains, or storage pools on hypervisors (VMware, RHV, or KVM) using AFF storage.

Next: [ONTAP Select with VMware vSphere: NetApp HCI and Cisco ACI](#)

ONTAP Select with VMware vSphere: NetApp HCI and Cisco ACI

NetApp ONTAP Select is the NetApp solution for software-defined storage (SDS), bringing enterprise-class storage management features to the software-defined data center. ONTAP Select extends ONTAP functionality to extreme edge use cases including IoT and tactical servers as a software-defined storage appliance that acts as a full storage system. It can run as a simple VM on top of a virtual environment to provide a flexible and scalable storage solution.

Running ONTAP as software on top of another software application allows you to leverage much of the qualification work done by the hypervisor. This capability is critical for helping us to rapidly expand our list of

supported platforms. Also, positioning ONTAP as a virtual machine (VM) allows customers to plug into existing management and orchestration frameworks, which allows rapid provisioning and end-to-end automation from deployment to sunsetting. The following figure provides an overview of a four-node ONTAP Select instance.

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Deploying ONTAP Select in the environment to use the storage offered by NetApp HCI extends the capabilities of NetApp Element.

Workflow

The following workflow was used to set up the environment. In this solution, we deployed a two-node ONTAP Select cluster. Each of these steps might involve several individual tasks.

1. Create an L2 BD and EPG for the OTS cluster's internal communication and attach the VMM domain to the EPG in the Native switching mode (in case of a Cisco AVE virtual switch) with Pre-Provision Resolution Immediacy.

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2. Verify that you have a VMware vSphere license.
3. Create a datastore that hosts OTS.
4. Deploy and configure ONTAP Select according to the [ONTAP Select documentation](#).

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5. Create additional datastores using ONTAP Select to make use of additional capabilities.

[Next: StorageGRID with VMware vSphere: NetApp HCI and Cisco ACI](#)

StorageGRID with VMware vSphere: NetApp HCI and Cisco ACI

StorageGRID is a robust software-defined, object-based storage platform that stores and manages unstructured data with a tiered approach along with intelligent policy-driven management. It allows you to manage data while optimizing durability, protection, and performance. StorageGRID can also be deployed as hardware or as an appliance on top of a virtual environment that decouples storage management software from the underlying hardware. StorageGRID opens a new realm of supported storage platforms, increasing flexibility and scalability. StorageGRID platform services are also the foundation for realizing the promise of the hybrid cloud, letting you tier and replicate data to public or other S3-compatible clouds. See the [StorageGRID](#) documentation for more details. The following figure provides an overview of StorageGRID nodes.

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Workflow

The following workflow was used to set up the environment. Each of these steps might involve several individual tasks.

1. Create an L2 BD and EPG for the grid network used for internal communication between the nodes in the StorageGRID system. However, if your network design for StorageGRID consists of multiple grid networks,

then create an L3 BD instead of an L2 BD. Attach the VMM domain to the EPG with the Native switching mode (in the case of a Cisco AVE virtual switch) and with Pre-Provision Resolution Immediacy. The corresponding port group is used for the grid network on StorageGRID nodes.

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2. Create a datastore to host the StorageGRID nodes.
3. Deploy and configure StorageGRID. For more details on installation and configuration, see the [StorageGRID documentation](#). If the environment already has ONTAP or ONTAP Select, then you can use the NetApp Fabric Pool feature. Fabric Pool is an automated storage tiering feature in which active data resides on local high-performance solid-state drives (SSDs) and inactive data is tiered to low-cost object storage. It was first made available in NetApp ONTAP 9.2. For more information on Fabric Pool, see the documentation [here](#).

[Next: Validation Results](#)

Validation Results

We used the iPerf tool for testing network throughput, and the baseline expectation was that the test systems should achieve throughput within 10% of the maximum line rate. Test results for different virtual switches is indicated in the following table.

For storage IOPS subsystem measurement, we used the IOmeter tool. The baseline expectation was that the test systems should achieve read/write throughput within 10% of the maximum. Test results for different hypervisors is indicated in the following table.

We considered the following scenarios for the network line rate and storage IOPS testing:

VMware

- VMs on a NetApp HCI datastore (with and without micro-segmentation)
- VMs on a NetApp ONTAP datastore
- VMs on a NetApp ONTAP Select datastore

Red Hat Virtualization

- VMs on a NetApp HCI datastore
- VMs on a NetApp ONTAP datastore

KVM (RHEL)

- VMs on a NetApp HCI datastore

Miscellaneous

- One VM on RHV with a NetApp HCI datastore and one VM on VMware vSphere with a NetApp ONTAP datastore.

Hypervisor	Virtual Switch	iPerf	IOmeter	Micro-segmentation
VMware	VDS	Pass	Pass	Pass
RHV	Linux Bridge	Pass	Pass	N/A
RHEL-KVM	Open vSwitch	Pass	Pass	N/A

[Next: Where to Find Additional Information](#)

Where to Find Additional Information

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

- NetApp HCI Documentation

<https://www.netapp.com/us/documentation/hci.aspx>

- Cisco ACI Documentation

<https://www.cisco.com/c/en/us/solutions/data-center-virtualization/application-centric-infrastructure/index.html>

- Cisco Nexus 9000 Series Switches

<http://www.cisco.com/c/en/us/products/switches/nexus-9000-series-switches/index.html>

- NetApp AFF A-series

<http://www.netapp.com/us/products/storage-systems/all-flash-array/aff-a-series.aspx>

- ONTAP Documentation

<https://docs.netapp.com/ontap-9/index.jsp>

- ONTAP Select Documentation

<https://docs.netapp.com/us-en/ontap-select/>

- StorageGRID Documentation

<https://docs.netapp.com/sgws-113/index.jsp>

- Red Hat Virtualization

https://access.redhat.com/documentation/en-us/red_hat_virtualization/4.3/

- VMware vSphere

<https://docs.vmware.com/en/VMware-vSphere/index.html>

- VMware vCenter Server

<http://www.vmware.com/products/vcenter-server/overview.html>

- NetApp Interoperability Matrix Tool

<http://now.netapp.com/matrix>

- Cisco ACI Virtualization Compatibility Matrix

<https://www.cisco.com/c/dam/en/us/td/docs/Website/datacenter/aci/virtualization/matrix/virtmatrix.html>

- VMware Compatibility Guide

<http://www.vmware.com/resources/compatibility>

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