Technical Report

A Continuous-Availability Solution for VMware vSphere and NetApp

Using VMware High Availability and Fault Tolerance and NetApp MetroCluster

NetApp and VMware, Inc.

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EXECUTIVE SUMMARY

This document describes various failure scenarios in a virtual infrastructure environment and the solutions to recover from these failures by deploying **VMware® High Availability (HA), VMware Fault Tolerance (FT), VMware vCenter™ Heartbeat, and NetApp® MetroCluster**. These solutions help maintain continuous availability of the computing and storage resources of the virtual infrastructure between sites, provide complete disaster recovery during loss of a site, and the ability to shift the complete operation of the environment between two sites to minimize disruption during scheduled downtime.

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1. INTRODUCTION

This technical report provides an overview and describes the end-to-end implementation details of production-class continuous-availability solutions for virtual infrastructures consisting of VMware ESX™ Servers and NetApp storage systems.

1.1 INTENDED AUDIENCE

This document is for:

- ✓ Customers and prospects looking to implement a continuous-availability solution for their virtual infrastructure consisting of VMware ESX Servers and NetApp FAS storage
- ✓ End users and management seeking information on a continuous-availability solution in a production or dev/test environment

1.2 SCOPE

What this document describes:

- ✓ End-to-end architecture overview of the continuous-availability solution for virtual infrastructure
- ✓ Detailed design and implementation guide; configuration best practices
- ✓ Reproducible test results that simulate common failure scenarios resulting from operational problems and real disasters

The scope of this document is limited to the following:

- ✓ This report does not replace any official manuals and documents from NetApp and VMware on the products used in the solution or those from any other switch vendors referenced in the report.
- ✓ This report does not discuss any performance impact and analysis from an end-user perspective during a disaster.
- ✓ This report does not replace NetApp and VMware professional services documents or services.
- ✓ This report does not discuss a regional (long-distance) disaster recovery solution. If you are looking for a regional disaster recovery solution in addition to the high-availability option discussed in this paper, contact your NetApp representative for further assistance.

1.3 ASSUMPTIONS AND PREREQUISITES

This document assumes familiarity with the following:

- ✓ Basic knowledge of VMware's virtualization technologies and products: VMware vCenter Server 2.5 and vCenter Server 4.0, VMware Infrastructure 3™, and VMware vSphere™ 4.0
- ✓ Basic knowledge of NetApp storage systems and Data ONTAP®

2 BACKGROUND

2.1 BUSINESS CHALLENGE

Economic challenges drive businesses to provide high levels of availability and business continuity while simultaneously achieving greater levels of cost savings and reduced complexity. As a result, data center infrastructure is increasingly virtualized because virtualization provides compelling economic, strategic, operational, and technical benefits. Planning a robust high-availability infrastructure solution for virtual data center environments hosting mission-critical applications is of utmost importance.

Some of the key aspects of an effective high-availability virtualized infrastructure should include:

- ✓ Operational efficiency and management simplicity
- ✓ Cost effectiveness
- ✓ Architectural simplicity
- ✓ High performance
- ✓ Resiliency and flexibility

VMware provides uniform, cost-effective failover protection against hardware and software failures within a virtualized IT environment with VMware high availability and fault tolerance.

NetApp MetroCluster is a cost-effective, synchronous replication solution for combining high availability and disaster recovery in a campus or metropolitan area to protect against both site disasters and hardware outages. MetroCluster provides automatic recovery for any single storage component failure and single-command recovery in case of major site disasters, for zero data loss and recovery within minutes rather than hours.

Combining VMware HA and FT and NetApp MetroCluster technologies offers a great value proposition. The combination provides a simple and robust continuous-availability solution for planned and unplanned downtime in virtual data center environments hosting mission-critical applications.

Each of these solutions is discussed briefly in the next section.

2.2 CONTINUOUS-AVAILABILITY SOLUTIONS FOR VIRTUAL INFRASTRUCTURE

VMWARE SOLUTION: VMWARE HA (VI3 AND VSPHERE 4)

VMware cluster technology groups VMware ESX Server hosts into a pool of shared resources for virtual machines and provides the VMware HA feature. When the HA feature is enabled on the cluster, each ESX Server maintains communication with other hosts so that if any ESX host becomes unresponsive or isolated, the HA cluster can negotiate the recovery of the virtual machines that were running on that ESX host among surviving hosts in the cluster.

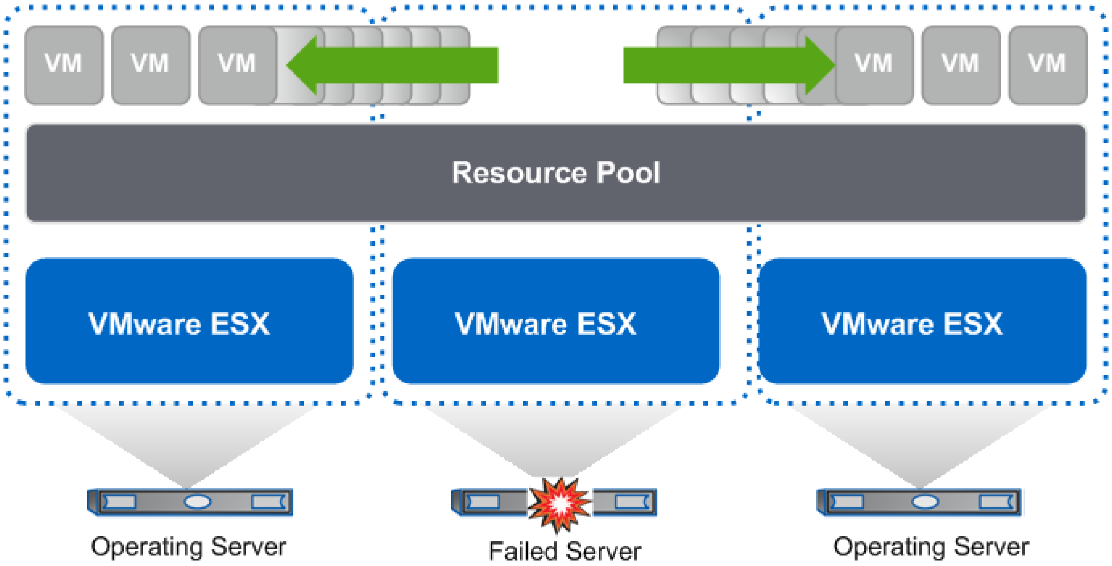


Figure 1) VMware HA architecture.

Note:

1. Setting up an HA cluster requires a vCenter Server. Once the cluster is set up, it can maintain HA without further interaction with the vCenter Server.
2. VMware's distributed resource scheduler (DRS) is out of the scope of this document. However, note that VMware DRS can be enabled simultaneously with VMware HA on the same cluster.

VMWARE SOLUTION: VMWARE FT (VSPHERE 4 ONLY)

VMware Fault Tolerance leverages the well-known encapsulation properties of virtualization by building high availability directly into the x86 hypervisor to deliver hardware-style fault tolerance to virtual machines.

VMware FT provides continuous availability for mission-critical virtual machines by creating and maintaining a secondary VM that is identical to (and able to replace) the primary VM in case of hardware failure. On enabling VMware vLockstep, the secondary VM runs in virtual lockstep with the primary VM to replicate the executions of the primary VM, thereby providing fault tolerant protection.

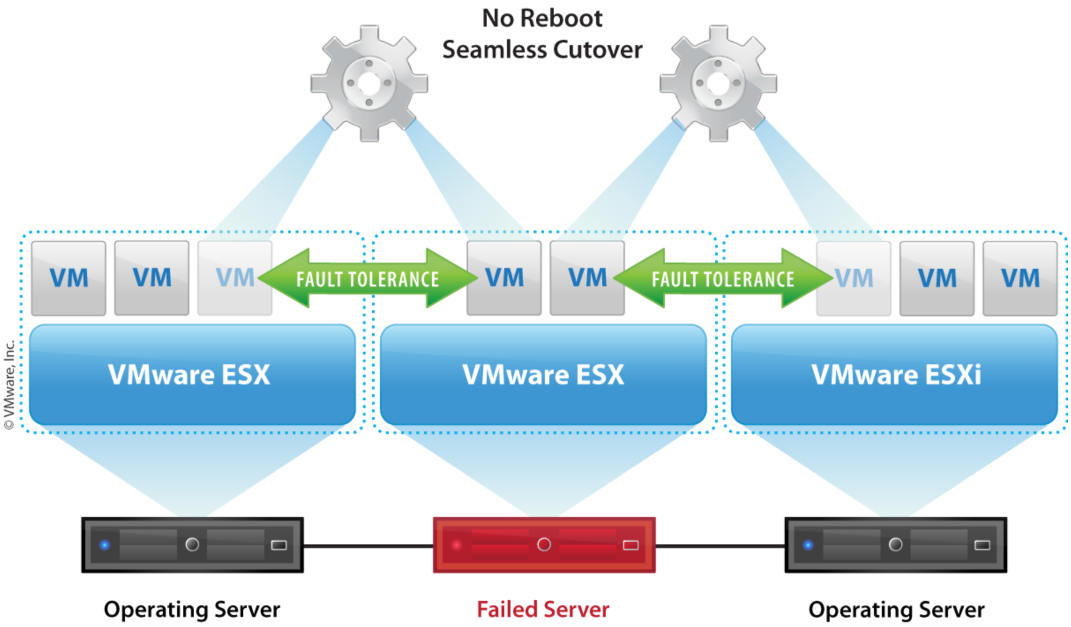


Figure 2) VMware Fault Tolerance architecture.

NETAPP SOLUTIONS: NETAPP ACTIVE-ACTIVE, SYNCMIRROR, AND METROCLUSTER

NetApp clusters, also referred to as **active-active HA pairs**, consist of two independent storage controllers that provide fault tolerance and high-availability storage for virtual environments. The cluster mechanism provides nondisruptive failover between controllers in the event of a controller failure. Redundant power supplies in each controller maintain constant power. Storage HBAs and Ethernet NICs are all configured redundantly within each controller. The failure of up to two disks in a single RAID group is accounted for by **RAID-DP**®.

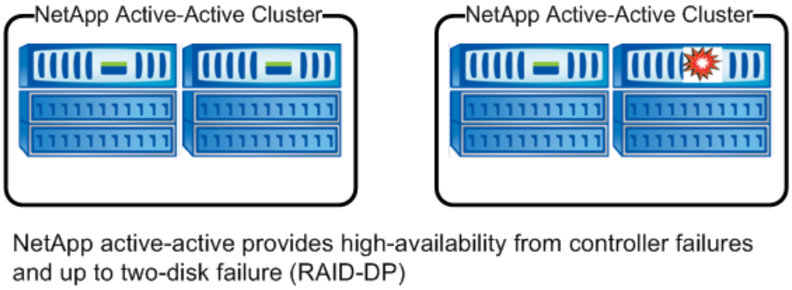
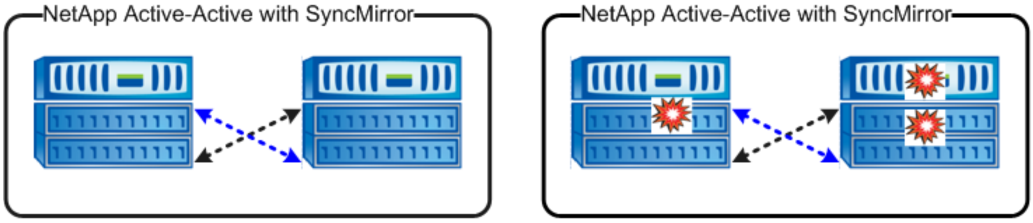


Figure 3) Active-active cluster.

The NetApp active-active HA cluster model can be enhanced by synchronously mirroring data at the RAID level using NetApp **SyncMirror**®[1]. This mirrored active-active configuration maintains two complete copies of all mirrored data. These copies are called **plexes** and are continually and synchronously updated every time Data ONTAP writes to a mirrored aggregate. When SyncMirror is

[1] See 1 and 4 in Appendix C.

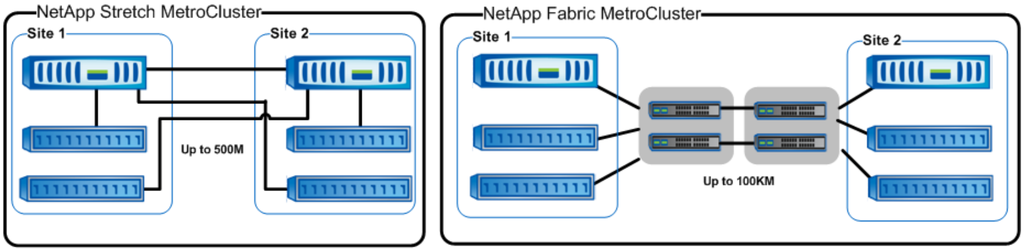
used with HA clustering, the cluster has the ability to survive the loss of complete RAID groups or shelves of disks on either side of the mirror.



SyncMirror with NetApp active-active cluster provides high availability from complete RAID groups and disk shelves failure in addition to controllers.

Figure 4) NetApp SyncMirror.

NetApp MetroCluster builds on the NetApp cluster model by providing the capability to place the nodes of the clusters at geographically dispersed locations. Similar to the mirrored active-active configuration, MetroCluster also maintains two complete copies of all mirrored data. These copies are called **plexes** and are continually and synchronously updated each time Data ONTAP writes data to the disks.



MetroCluster enables placement of two nodes of the cluster in geographically dispersed locations.
Provides high availability with campus and metro distance level protection.

Figure 5) NetApp active-active SyncMirror and MetroCluster.

MetroCluster supports distances of up to 100 kilometers.

For distances **less than 500 meters,** the cluster interconnects, controllers, and disk shelves are all directly connected. This is referred to as a **stretch MetroCluster** configuration.

For distances over **500 meters**, MetroCluster uses redundant Fibre Channel switches and interswitch links (ISL) between the sites. This configuration is referred to as a **fabric MetroCluster** configuration. In this case, the controllers and the storage are connected through the ISLs.

Note: The above figures are simplified representations and do not indicate the redundant connection between each component.

DIFFERENT TIERS OF PROTECTION WITH VMWARE VI3 WITH NETAPP STORAGE

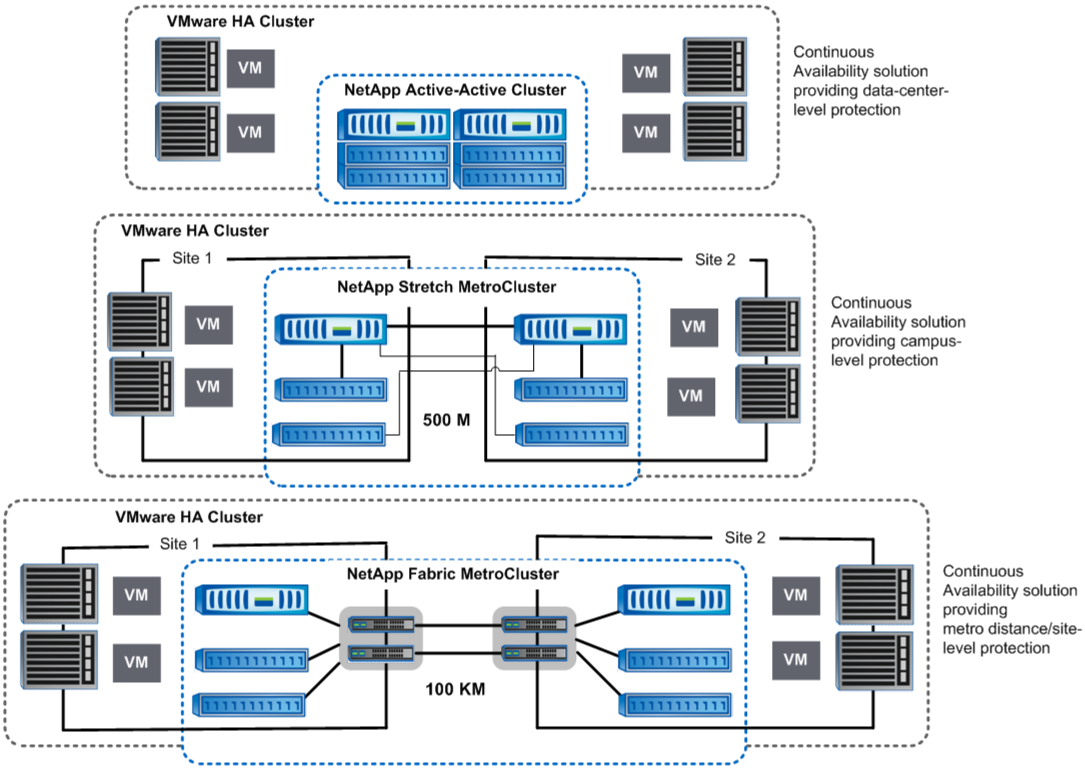


Figure 6) VMware VI3 with NetApp storage.

DIFFERENT TIERS OF PROTECTION WITH VMWARE VSPHERE 4.0 WITH NETAPP STORAGE

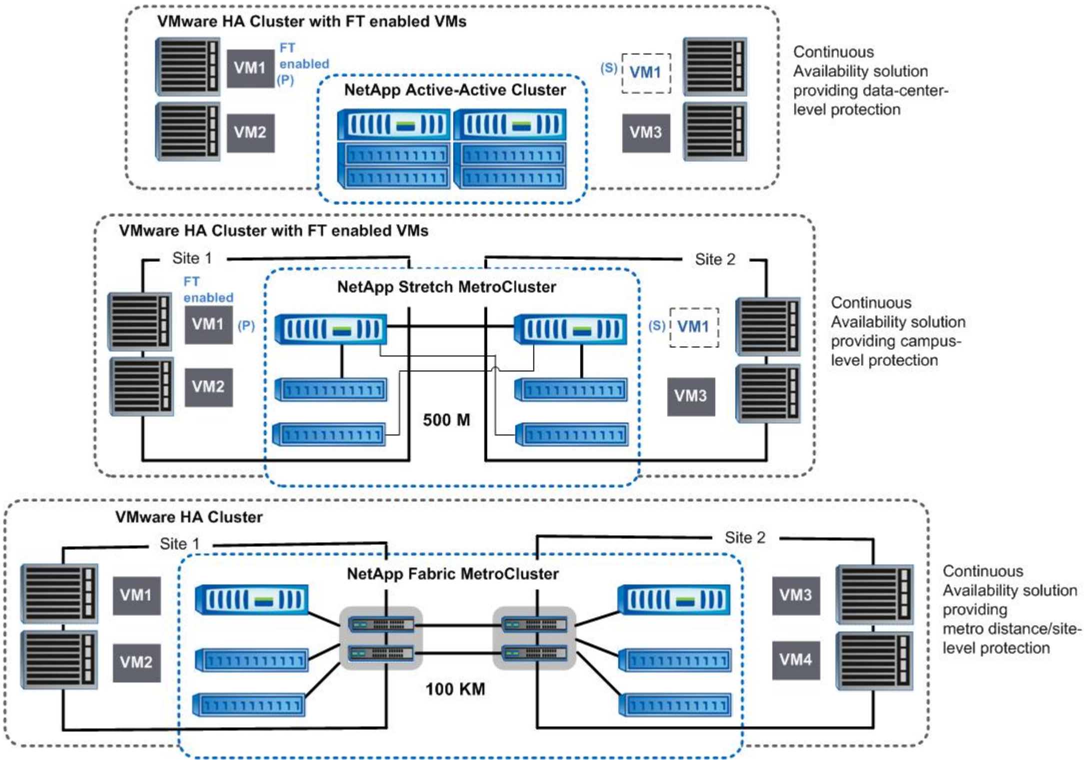


Figure 7) VMware vSphere 4.0 with NetApp storage.

Table 1 summarizes various scenarios for this continuous-availability solution.

Table 1) Continuous-availability-solution scenarios.

#	Tier of Protection	VMware Component		NetApp Component	Scope of Protection
		VI 3	vSphere 4		
1	Data-center-level protection	VMware HA	• VMware HA • VMware FT • vCenter Heartbeat	NetApp active-active cluster (with or without SyncMirror)	Complete protection against common server and storage failures, including but not limited to failure of: • Physical ESX Server • Power supplies • Disk drives • Disk shelves • Cables • Storage controllers and so on
2	Cross-campus-level protection	VMware HA	• VMware HA • VMware FT • vCenter Heartbeat	NetApp stretch MetroCluster	VMware HA cluster nodes and the NetApp FAS controllers located at different buildings within the same site (up to 500 m). Can handle building-level disasters in addition to protections provided in tier 1.
3	Metro (site-level) distance protection	VMware HA	• VMware HA • vCenter Heartbeat	NetApp fabric MetroCluster	VMware HA cluster nodes and the NetApp FAS controllers located at different regional sites (up to 100 km). Can handle site-level disasters in addition to protections provided in tier 1.
4	Regional protection	Outside of the scope of this report			

3 ARCHITECTURE OVERVIEW OF THE HIGH-AVAILABILITY SOLUTION

3.1 HIGH-LEVEL TOPOLOGY DIAGRAM

Figures 8 through 11 illustrate the architecture of a campus-distance-level (up to 500 meters) and metro-distance-level (up to 100 km) HA solution for virtual infrastructure made up of VMware ESX Servers, vCenter Server, and NetApp storage. As described previously, continuous availability of the virtual infrastructure is provided through seamless integration of two technologies working in two different layers:

- VMware HA and FT technology for high availability at the server level
- NetApp MetroCluster technology for high availability at the storage level:
  - Stretch MetroCluster setup, for campus-distance-level protection
  - Fabric MetroCluster setup, for metro-distance-level protection

Each site in this high-availability solution is “active” with VMware ESX Servers running Windows® and Linux® VMs. In the test setup, there are three ESX Servers in each site, each running two VMs (one Windows and the other Linux).

VMware ESX Servers in each site can access NetApp storage at the back-end MetroCluster setup using FC, NFS, or iSCSI protocols. The unified storage architecture of NetApp FAS systems provides the flexibility to use any protocol.

Note: A fabric MetroCluster configuration requires a separate front-end SAN to use FC data stores in VMware ESX Servers in addition to the back-end fabric.

TOPOLOGY DIAGRAM OF THE SOLUTION FOR VMWARE VIRTUAL INFRASTRUCTURE 3 (VI3)

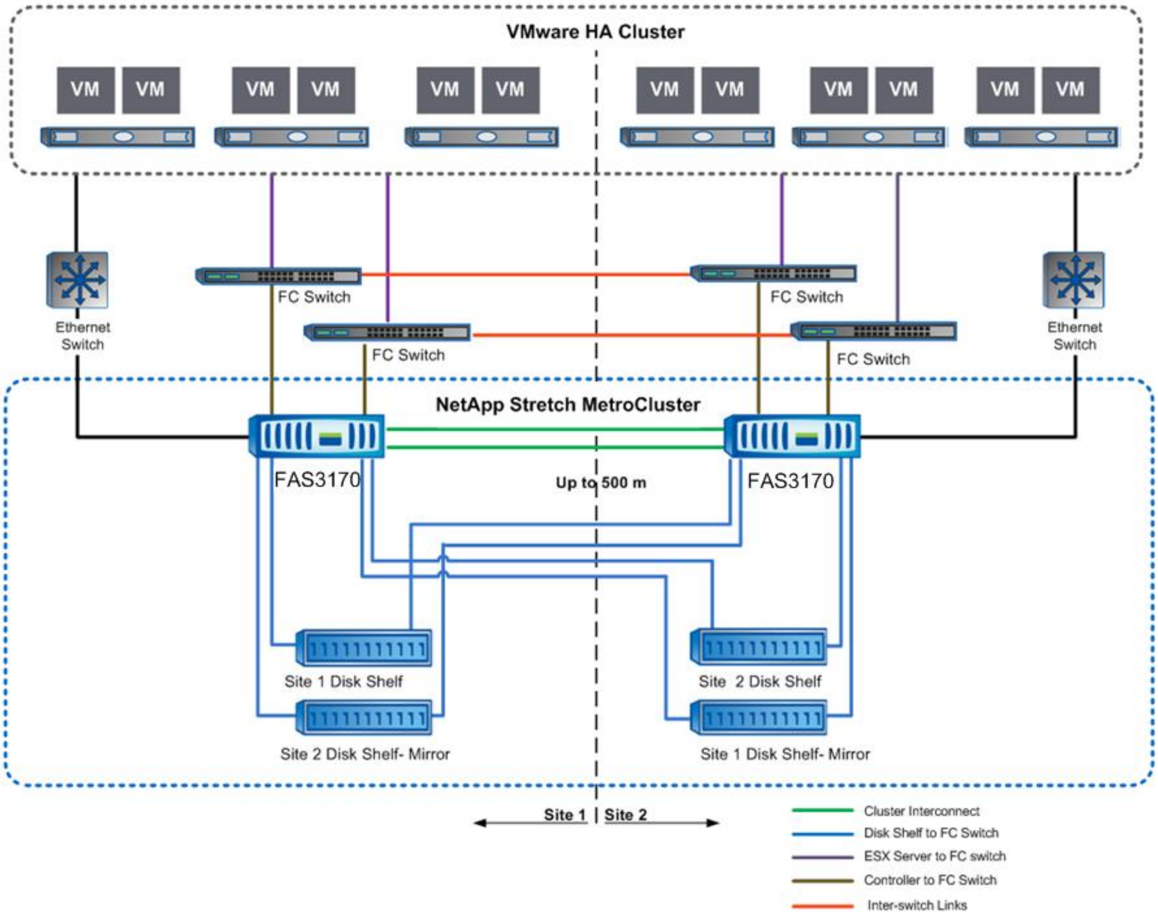


Figure 8) VMware HA and NetApp stretch MetroCluster solution in VMware VI3.

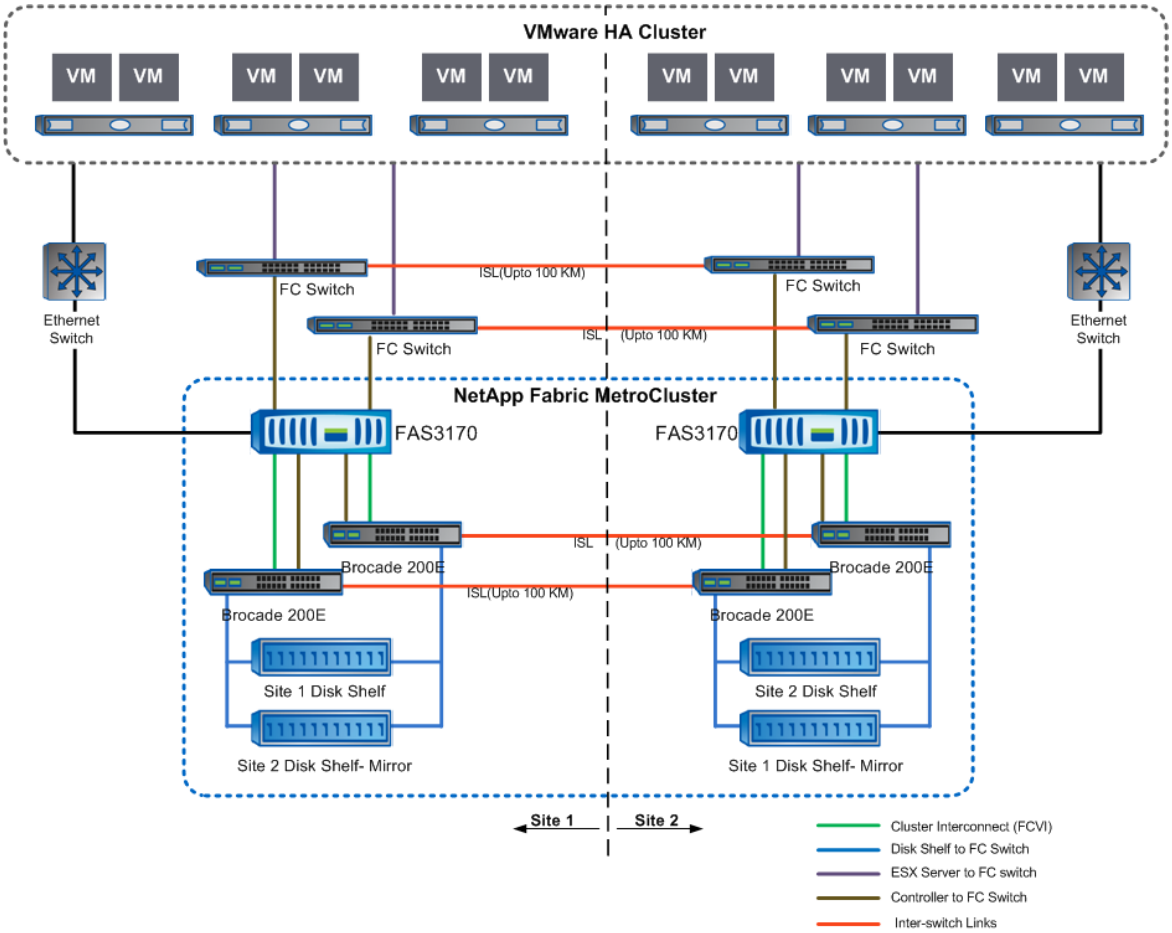


Figure 9) VMware HA and NetApp fabric MetroCluster solution in VMware VI3.

TOPOLOGY DIAGRAM OF THE SOLUTION FOR VMWARE VSPHERE 4

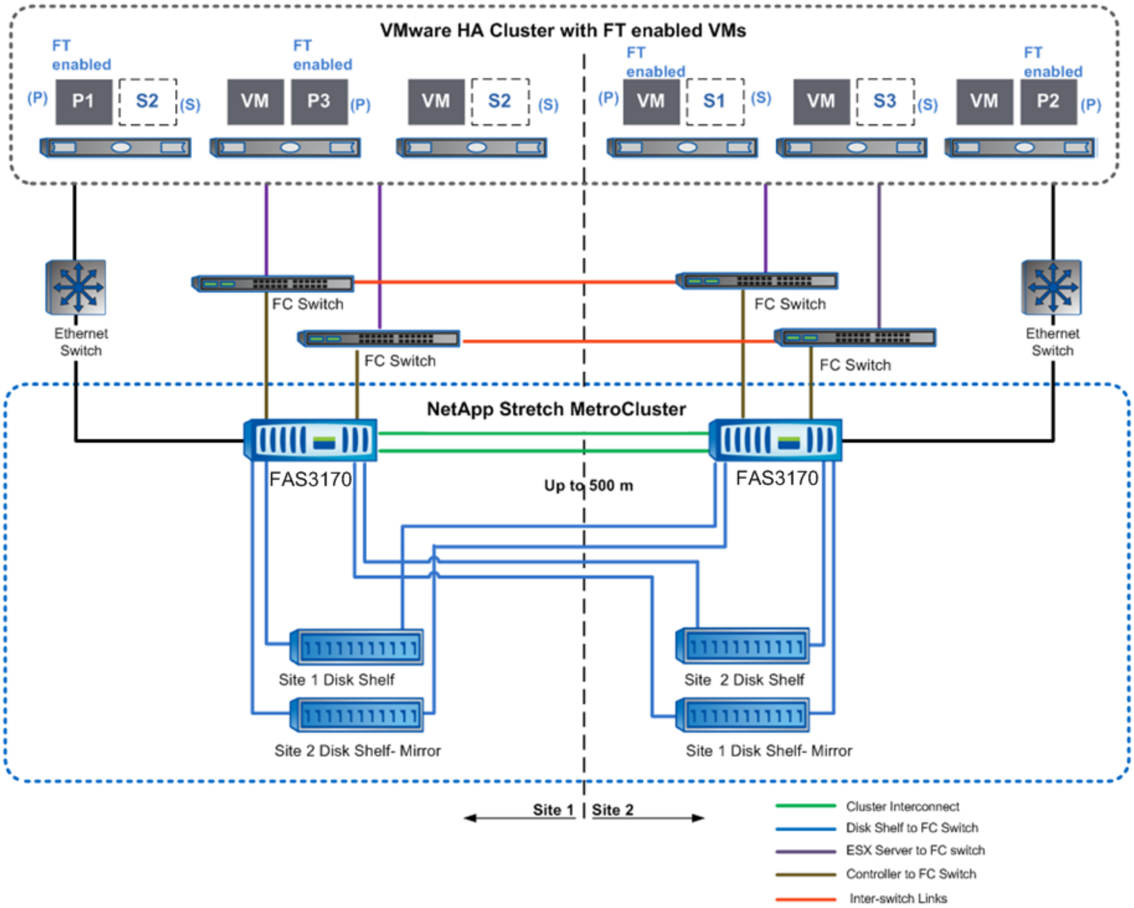


Figure 10) VMware HA and FT and NetApp stretch MetroCluster solution in VMware vSphere 4.

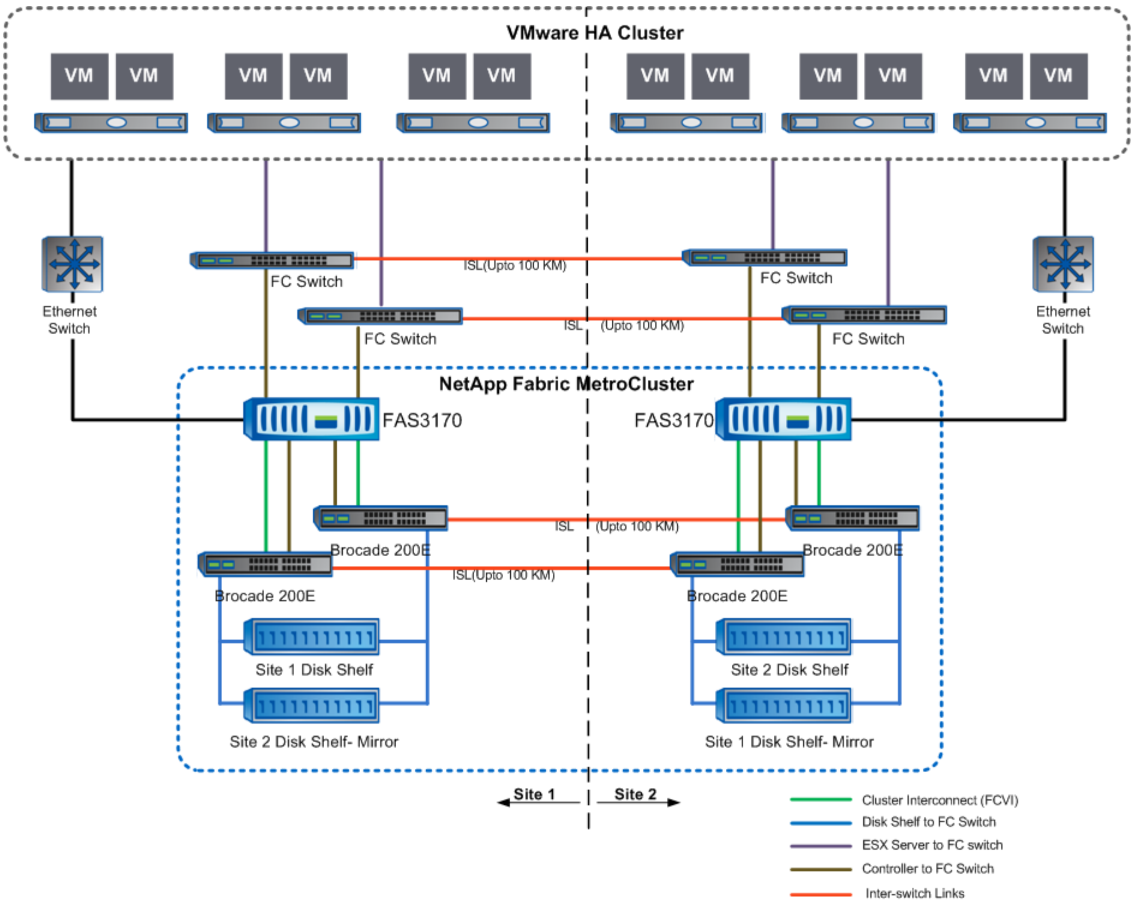


Figure 11) VMware HA and NetApp fabric MetroCluster solution in VMware vSphere 4.

3.2 DEPLOYMENT DETAILS

MATERIAL LIST FOR HIGH-AVAILABILITY SETUP

Table 2) Material list for VMware VI3 and NetApp MetroCluster setup.

Infrastructure Component	Vendor	Quantity	Details
Server	Any		As per VMware Compatibility Guide
Storage	NetApp		NetApp storage systems—fabric and stretch MetroCluster config, RAID-DP For the currently supported matrix, see NetApp support site.
Switch (fabric MetroCluster only, not required for stretch MetroCluster)	Brocade	Four	Brocade Switch Model 200E 16P, Full Fabric, 4GB SWL SFPs For currently supported matrix, see NetApp support site.
Switch (front-end SAN)	Brocade	Four	Brocade Switch Model 3800
Network Adapter	Broadcom	Two per server	Broadcom NetXtreme II BCM 5708 1000Base-T
HBA	QLogic	Two per server	QLogic QLA 2432 A minimum of 2 HBAs are required in a production environment.
Software	NetApp		Data ONTAP 7.2.4 or higher See section 4.2 and the VMware KB article VMware VI3 Support with NetApp MetroCluster.
	NetApp		cluster_remote
	NetApp		syncMirror_local
	VMware		VMware ESX Server 3.5 U3 or later
	VMware		VMware vCenter Server 2.5U4 or later

Table 3) Material list for VMware vSphere 4 and NetApp MetroCluster setup.

Infrastructure Component	Vendor	Quantity	Details
Server	Any		As per VMware FT Compatibility Guide, hosts must have FT-compatible processors. Also see the VMware KB article on FT-compatible processor.
Storage	NetApp		NetApp storage systems—fabric and stretch MetroCluster config, RAID-DP. For currently supported matrix, see NetApp support site.
Switch (fabric MetroCluster only, not required for stretch MetroCluster)	Brocade	Four	Brocade Switch Model 200E 16P, Full Fabric, 4GB SWL SFPs For currently supported matrix, see the NetApp support site.
Switch (front-end SAN)	Brocade	Four	Brocade Switch Model 3800
Network Adapter	Broadcom	Two per server	Broadcom NetXtreme II BCM 5708 1000Base-T See VMware Fault Tolerance recommendations and Considerations on VMware vSphere 4.
HBA	QLogic	Two per server	QLogic QLA 2432 A minimum of two HBAs are required in a production environment.
Software	NetApp		Data ONTAP 7.2.4 or higher
	NetApp		cluster_remote

	NetApp		syncMirror_local
	VMware		VMware vSphere ESX Server 4.0 or later
	VMware		VMware vSphere vCenter Server 4.0 or later

LOW-LEVEL CONNECTION DIAGRAM OF NETAPP STRETCH METROCLUSTER SETUP

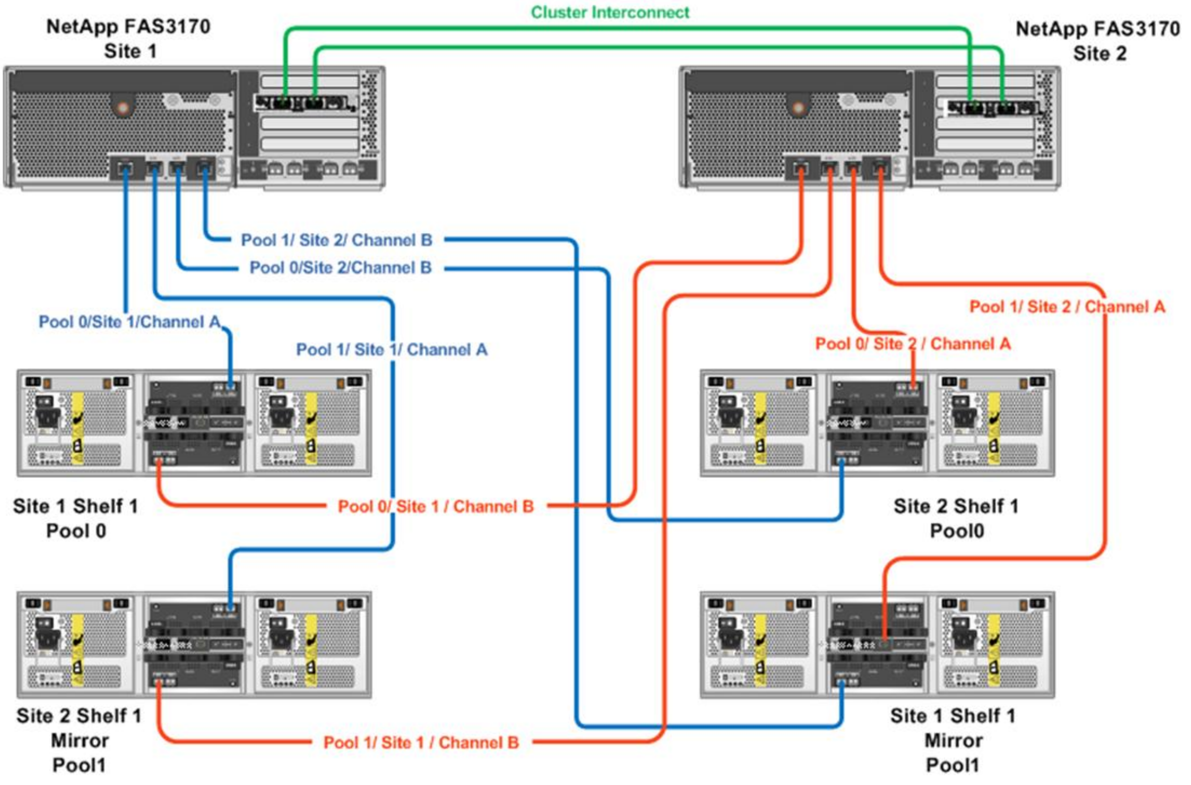


Figure 12) Stretch MetroCluster connection diagram.

LOW-LEVEL DIAGRAM OF NETAPP FABRIC METROCLUSTER SETUP

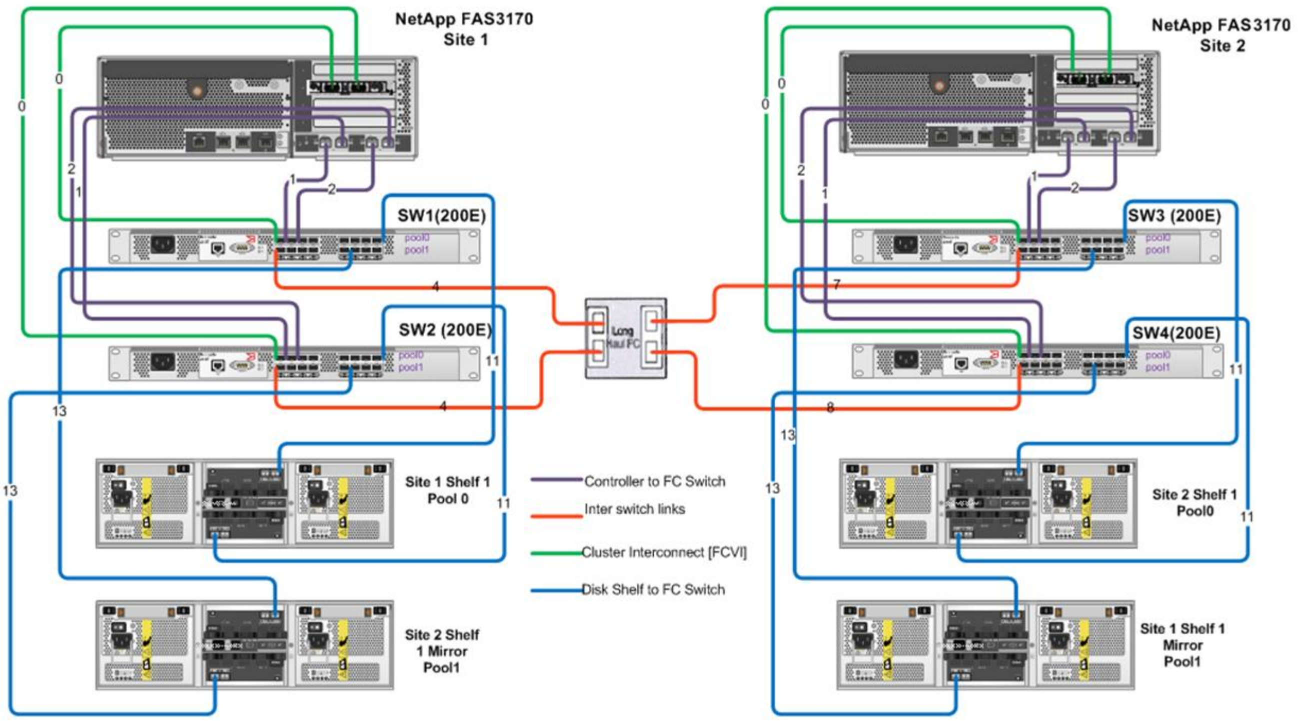


Figure 13) Fabric MetroCluster connection diagram.

BROCADE SWITCH CONNECTION DETAILS AND CONFIGURATION TABLES

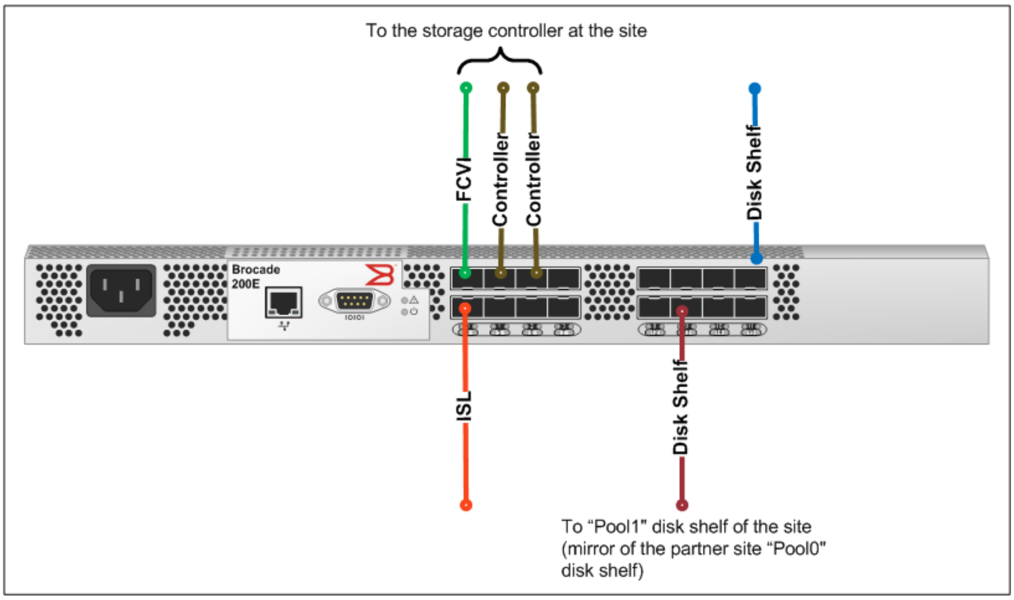


Figure 14) Brocade switch connection details in fabric MetroCluster setup.

For connection details on the Brocade switch in a MetroCluster setup, see Appendix B.

4 SETUP AND CONFIGURATION OF THE CONTINUOUS-AVAILABILITY SOLUTION

4.1 NETAPP STORAGE CONFIGURATION

BEST PRACTICE: Set the Data ONTAP configuration option `cf.takeover.change_fsid` to `OFF`. This option is supported on Data ONTAP version 7.2.4 and higher.

- In the event of complete storage controller and/or all disk shelves failure (storage controller and associated local disk shelves), a manual failover of the MetroCluster should be performed. If the `change_fsid` option is set to `OFF` on a NetApp FAS storage controller running Data ONTAP version 7.2.4 or higher, after performing a manual MetroCluster failover, the UUIDs of the mirrored LUNs are retained and additional steps in the ESX Server side are not required to detect the VMFS volumes. Once the VMFS volumes are detected, the VMs can be manually powered on.
- On NetApp FAS storage controllers running Data ONTAP older than 7.2.4, after performing a manual MetroCluster failover, the mirrored LUNs do not maintain the same LUN UUID as the original LUNs because this option is not available. When these LUNs house the VMFS-3 file system, the volumes are detected by ESX Server 3.x as being on Snapshot™ LUNs. Similarly, if a RAW LUN that is mapped as an RDM (Raw Device Mapping) is replicated or mirrored through MetroCluster, the metadata entry for the RDM must be recreated to map to the replicated or mirrored LUN. To make sure the ESX hosts have access to the VMFS volumes on the mirrored LUNs, see VMware KB 1001783.

```
Localnode*>
Localnode*> options cf.takeover.change_fsid
cf.takeover.change_fsid        on
Localnode*>
Localnode*> options cf.takeover.change_fsid off
Localnode*>
Localnode*> options cf.takeover.change_fsid
cf.takeover.change_fsid        off
Localnode*>
Localnode*> _
```

Figure 15) Set the cf.takeover.change_fsid configuration to OFF.

✓ The FAS controllers should be licensed with the following features:

- `cluster, cluster_remote, syncmirror_local`
- `iscsi, fcp, nfs`

✓ MetroCluster setup with software-based disk ownership for the NetApp FAS controllers with the Brocade switches is performed in accordance with the guidelines provided by:

- Data ONTAP 7.3 Active-Active Configuration Guide (part number: 210-04192_A0): http://now.netapp.com/NOW/knowledge/docs/ontap/rel7311/pdfs/ontap/aaconfig.pdf
- Brocade 200E Switch Configuration Guide
- MetroCluster Design and Implementation Guide: http://media.netapp.com/documents/tr-3548.pdf

✓ In the FAS controllers on both sites, flexible volumes are created inside the same aggregate corresponding to two types of ESX data stores: VMFS (FC and iSCSI) and NFS.

Figure 16 depicts the physical and logical storage configuration of a NetApp MetroCluster setup as viewed from any of the sites.

BEST PRACTICE: See NetApp and VMware Virtual Infrastructure 3 Best Practices and NetApp and VMware vSphere 4 Best Practices for best practices related to creating aggregates, NFS, and VMFS data stores on NetApp FAS systems for VMware VI 3 and vSphere 4, respectively**.**

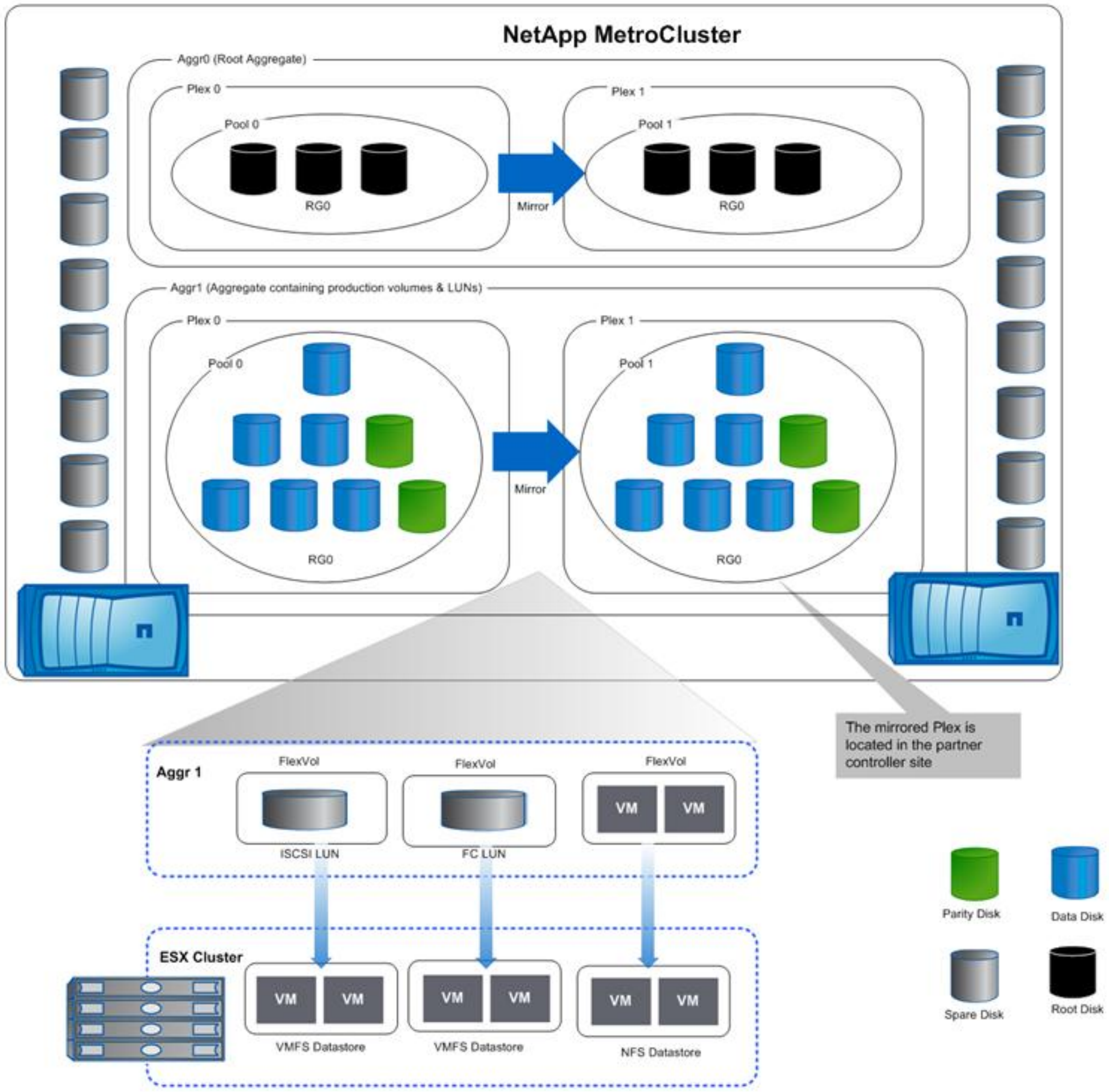


Figure 16) Physical and logical storage configuration of NetApp FAS controllers in MetroCluster setup.

4.2 VMWARE VNETWORK DISTRIBUTED SWITCH CONFIGURATION (FOR VSPHERE 4)

VMware vSphere introduces a number of new features and capabilities to virtual networking through VMware vNetwork. The most important enhancement to VMware vNetwork is the VMware vNetwork Distributed Switch (vDS). The VMware **vNetwork Distributed Switch** provides a centralized point of control for cluster-level networking and moves beyond per-host network configurations in virtual environments to simplify and enhance virtual machine networking:

- Simplified provisioning and administration of virtual networking across many hosts and clusters through a centralized interface
- Simplified end-to-end physical and virtual network management through third-party virtual switch extensions for the Cisco Nexus 1000V virtual switch
- Enhanced provisioning and traffic management capabilities through private VLAN support and bidirectional virtual machine rate limiting
- Enhanced security and monitoring for virtual machines migrated via VMware VMotion™ through maintenance and migration of the port run-time state.

In VMware VI3 and prior releases, virtual networks were constructed using virtual switches or vSwitches on each individual ESX hosts. In addition to continuing support for the vSwitch (known as the **Standard**

Switch in VMware vSphere 4), VMware vSphere 4 introduces an additional choice for VMware virtual networking using the vNetwork Distributed Switch.

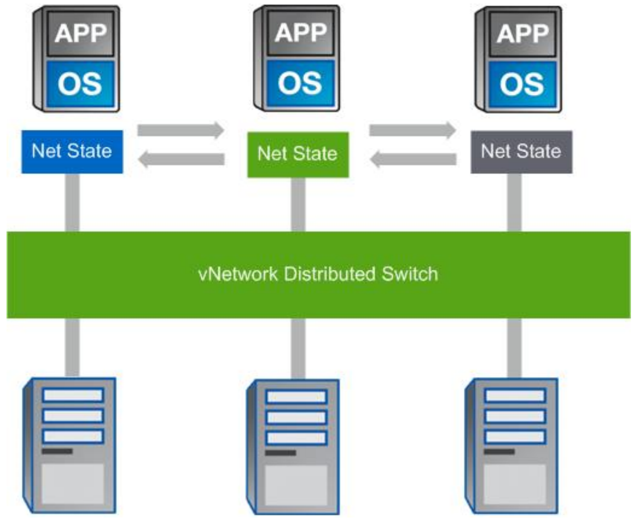


Figure 17) vNetwork Distributed Switch in a VMware vSphere environment.

The vNetwork Distributed Switch eases the management burden of per-host virtual switch configuration management by treating the network as an aggregated resource. Individual and host-level virtual switches are abstracted into a single large vNetwork Distributed Switch that spans multiple hosts at the data center level. Port Groups become Distributed Virtual Port Groups (DV Port Groups) that span multiple hosts and provide configuration consistency for VMs and virtual ports necessary for functions like VMotion.

For details on vDS, see vNetwork Distributed Switching—Concept, Design & Deployment.

NETWORKING RECOMMENDATIONS FOR VMWARE VSPHERE FT WITH NETAPP METROCLUSTER

- Use the vNetwork Distributed Switch to avoid inconsistencies in vSwitch settings. VMware vSwitch settings on hosts using the same VLAN for VMware FT logging should be uniform to make these hosts available for placement of secondary VMs.
- At a minimum, use 1GbE NICs for a VMware FT logging network. Use 10GbE NICs for increased bandwidth of FT logging traffic.
- Networking latency between ESX hosts should be within the submillisecond latency recommended for the FT logging network. Use `vmkping` to measure latency.

For details on VMware Fault Tolerance recommendations and considerations on VMware vSphere 4, see VMware Fault Tolerance Recommendations and Considerations on VMware vSphere 4.

4.3 VMWARE HA CLUSTER CONFIGURATION

BEST PRACTICE: When adding ESX hosts to a VMware HA cluster, the first five hosts added are considered primary hosts. The remaining hosts added are considered secondary hosts. Primary HA nodes hold node-state information, which is synchronized between primary nodes and from the secondary nodes. To make sure that each site contains more than one primary HA node, the first five nodes added to the HA cluster should be added one at a time, alternating between sites. The sixth node and all remaining nodes can then be added in one operation.

VMware ESX hosts and NetApp FAS controller network ports are connected to the same subnet that is shared between site 1 and site 2. The VMware ESX host's FC HBA should be connected to the same fabric that is shared between site 1 and site 2.

4.4 VMWARE FT CLUSTER CONFIGURATION (FOR VSPHERE 4)

To enable VMware Fault Tolerance in the VMware HA cluster, do the following:

- Enable host certificate checking (if upgrading from a previous version of virtual infrastructure).
- Configure networking for each host.
- Create the VMware HA cluster, add hosts, and check compliance.

VMware Fault Tolerance can be turned on from the vCenter Server (the minimum permission requirement is an account having cluster administrator permissions):

1. Select the Hosts & Clusters view.
2. Right-click a virtual machine and select Fault Tolerance > 'Turn On' Fault Tolerance.
3. The specified virtual machine is designated as a Primary VM and a Secondary VM is established on another host. The Primary VM is now fault tolerant.

To know more about the installation and configuration of vSphere Availability (HA and FT), see [vSphere Availability Guide.]

4.5 SETUP AND CONFIGURATION OPTIONS FOR THE VCENTER SERVER

OPTION 1 (FOR BOTH VMWARE VI3 AND VSPHERE 4)

In this setup, the VMware vCenter Server runs inside a virtual machine (non-FT) in the HA cluster.

Another way of designing the vCenter Server is to place it in a physical MSCS cluster with an MSCS cluster node in each site. If the storage housing the vCenter MSCS instance is at the failed site, it is necessary to perform the NetApp CFOD recovery. First recover the MSCS and start vCenter; then continue with the recovery process.

For details on the deployment of vCenter Server with MSCS cluster, see www.vmware.com/pdf/VC_MSCS.pdf.

OPTION 2—BEST PRACTICE: VMWARE VCENTER HEARTBEAT (ONLY FOR VSPHERE 4)

Because the VMware vCenter Server is used to manage many tier-1 applications, it renders itself as a tier-1 application. Therefore, it becomes very important for the VMware vCenter Server to be highly available. This is where VMware vCenter Server Heartbeat steps in.

VMware vCenter Server Heartbeat delivers high availability for the VMware vCenter Server management platform, for consistent operation of the VMware vSphere environment. Architecturally, vCenter Server Heartbeat is implemented on active-passive vCenter Server clones running on physical or virtual machines. In addition to server and network hardware, vCenter Server Heartbeat monitors the actual vCenter Server instance, its back-end database, and the underlying operating system. In case of failure, the passive node takes over and the vCenter Server Heartbeat software restarts the vCenter service. Failover can occur on both LANs and WANs. To know more about the installation and configuration of VMware vCenter Server Heartbeat, see VMware vCenter Server Heartbeat.

- vCenter Server Heartbeat protects VMware vCenter Server availability by monitoring all components of VMware vCenter Server, including VMware License Server and other plug-ins
- Minimizes downtime of critical functions such as VMware VMotion and VMware DRS
- Protects VMware vCenter Server performance, alerts, and events information, keeping it up to date even if the VMware vCenter Server experiences an outage
- Provides automatic failover and failback of VMware vCenter Server
- Enables administrators to schedule maintenance windows and maintain availability by initiating a manual switchover to the standby server
- Protects and recovers the VMware vCenter Server database
- Protects critical configuration, inventory, and other information stored in the VMware vCenter Server database, even if the database is installed on a separate server

Figure 18 illustrates the vCenter Server Heartbeat configuration used for this solution. The primary and the secondary vCenter Server VMs are deployed on separate ESX servers in separate sites and use separate data stores from the local NetApp storage controller in the MetroCluster configuration. The vCenter Server Heartbeat channel is configured over the LAN across the sites.

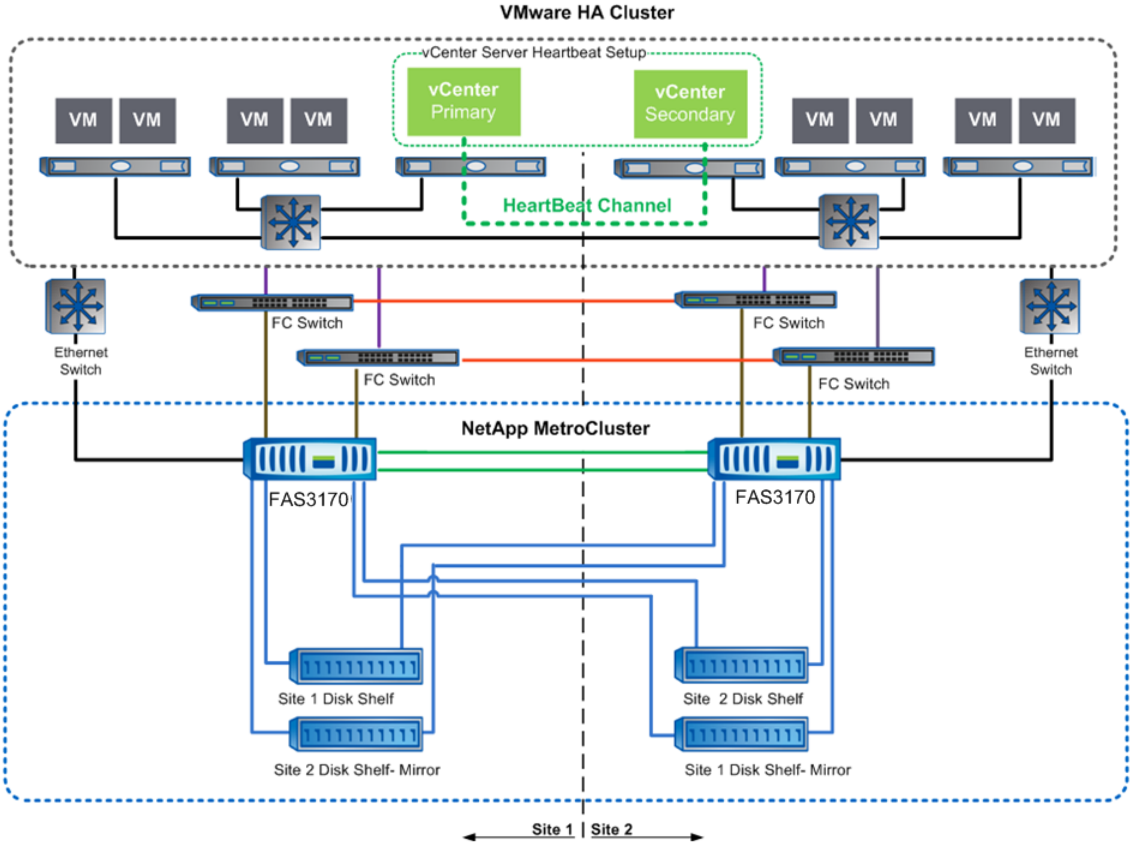


Figure 18) Center server heartbeat deployment.

5 CONTINUOUS-AVAILABILITY SOLUTION TESTS IN DIFFERENT FAILURE SCENARIOS

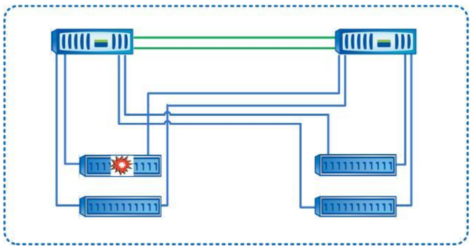
Note: The tests below are executed for continuous availability with both stretch and fabric MetroCluster setups for VMware VI3 as well as vSphere 4 environments unless otherwise specifically stated.

✓ The terms “Site 1,” “Local Site,” and “Failed Site” can be used interchangeably.
✓ The terms “Site 2” and “Remote Site” can be used interchangeably.
✓ Refer to figures in the High-Level Topology Diagram section for the component’s name, location, and connectivity.

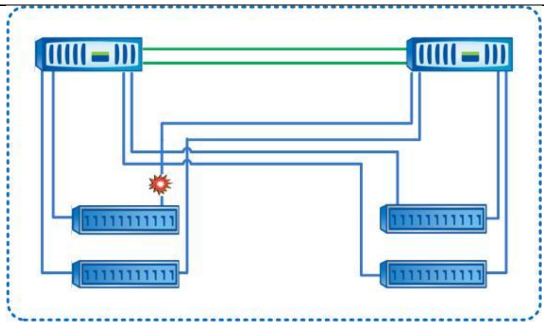
5.1 FAILURES WITHIN A DATA CENTER

OPERATIONAL SCENARIO 1: COMPLETE LOSS OF POWER TO DISK SHELF

Tests Performed	1. Power off one disk shelf. 2. Observe the result. 3. Power it back on.
Expected Results	• Relevant disks go offline; plex is broken. • No disruption to data availability for hosts containing FT and non-FT (only HA) VMs. • No change detected in the ESX Server level and FT and non-FT VMs run without any interruption. • When power is returned to the shelf, the disks are detected. A resync of the plexes occurs without any manual action.

Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 2: LOSS OF ONE LINK IN ONE DISK LOOP

Tests Performed	1. Disconnect the fiber cable on one of the disk shelves. 2. Observe the results. 3. Reconnect the fiber.	
Expected Results	• No disruption to data availability on hosts containing FT and non-FT (only HA) VMs. • The controller displays the message that some disks are connected to only one switch. • No change detected in the ESX Server level and VMs run without any interruption. • When the fiber is reconnected, the controller displays the messages that disks are now connected to two switches.	
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 3: FAILURE AND FAILBACK OF STORAGE CONTROLLER

Tests Performed	Power off one of the controllers by turning off both power supplies to simulate controller failure.
Expected Results	• No disruption in data availability to the FT or non-FT VMs. • A momentary delay from the host perspective occurs while the data store (ISCSI/NFS/FC) connection is rebuilt because of the change of processing from one controller to the other. • No interruptions in the VMs running on ESX Servers.
Actual Results	The partner controller reported the outage and began automatic takeover. There is a momentary pause in disk activity. After the takeover completed, the controller resumed normal activity. For details on how ESX hosts respond to controller failure, see the section "What happens to an ESX host in the event of a single storage component failure" in [VMware KB 1001783]().

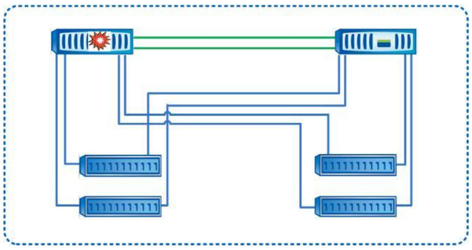
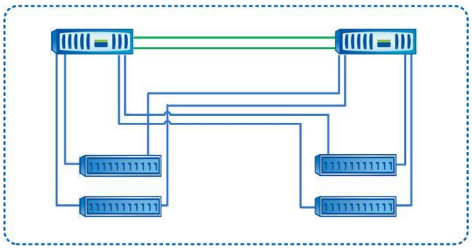
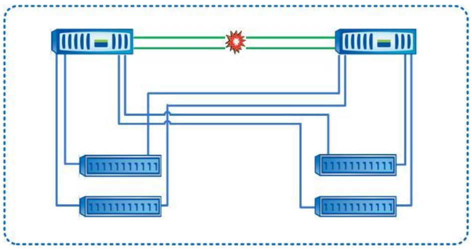
MetroCluster Behavior	Performs an automatic takeover of the powered-off node by its partner	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

Figure 19) Disk throughput.

Tests Performed	1. Power on the storage controller that was powered off during the last test (controller failback). 2. Execute the `cf giveback` command on the other storage controller to cause the failback to occur.

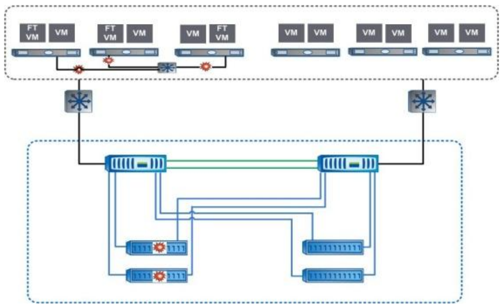
Expected Results	• No disruption to data availability to the FT and non-FT VMs. • There is a momentary drop in disk activity as indicated in the graph above. A slight delay from the host perspective occurs while the data store (ISCSI/NFS/FC) connection is rebuilt because of the change of processing from one controller to the other. • No interruptions occur in the VMs running on the ESX Servers.	
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected. For details on how ESX hosts respond to controller failback, see the section "What happens to an ESX host in the event of a single storage component failure?" in [VMware KB 1001783]().	
MetroCluster Behavior	Controller in failed site reclaims its original role prior to failure; there is no disruption to storage access to either site.	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 4: MIRRORED STORAGE NETWORK ISOLATION

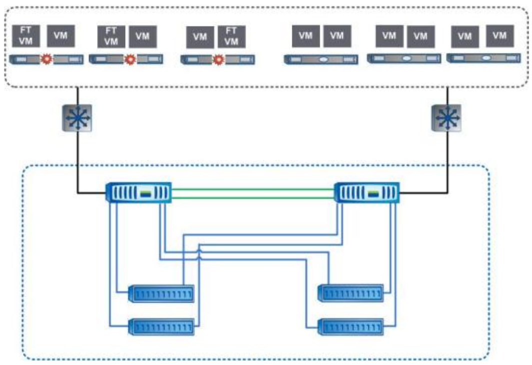
Tests Performed	Disconnect the cluster interconnect (CI) cables between the two storage controllers.	
Expected Results	• No disruption to data availability for host containing FT and non-FT VMs. • cf status on both the controllers will display VIA Interconnect is down <link 0 down, link 1 down>	
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event. Administrator receives the VIA interconnect down alert.	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 5: TOTAL NETWORK ISOLATION, INCLUDING ALL ESX HOSTS (FT AND NON-FT ENABLED) AND LOSS OF HARD DRIVE

Tests Performed	1. Disconnect the physical network cable connectivity between the ESX Server and the physical switch in one site. 2. Power off all disk shelves at site 1.
Expected Results	• No disruption to data availability on the host containing FT and non-FT VMs. • Relevant disks go offline and the plex is broken. • The secondary FT VM comes online and acts as a primary FT VM and a secondary FT VM is created in the HA cluster. • Non-FT-enabled VMs are migrated to other ESX Servers in the cluster and boot up. • When power is returned to the shelf, the disks are detected and an automatic resync of the plexes occurs. • The secondary vCenter Server of the vCenter Server Heartbeat configuration becomes active.

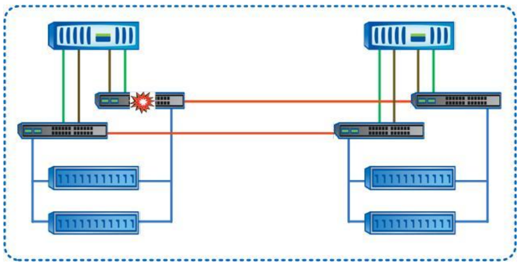
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	When the plex is broken, the other site serves all data from the surviving disk shelves.	
VMware HA Behavior	VMs previously running in the failed hosts are automatically powered on in the surviving nodes.	
VMware FT Behavior	Protects the VM (primary) by making the secondary VM as primary, and then calls HA to create a secondary copy on another node.	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 6: TOTAL ESX HOST FAILURE AT ONE SITE

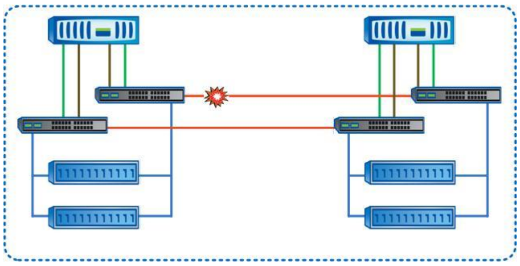
Tests Performed	Power off all ESX hosts at site 1.	
Expected Results	• No disruption to data availability for the surviving ESX hosts containing FT and non-FT VMs. • The secondary FT VMs come online and act as primary FT VMs, and one more secondary FT VM is created in the HA cluster. • Non-FT HA-enabled VMs migrate to other ESX servers in the cluster and boot up.	
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event	
VMware HA Behavior	VMs previously running in the failed hosts are automatically powered on in the surviving nodes.	
VMware FT Behavior	Protects VM (primary) by making the secondary VM as primary and then creating a secondary copy on another node.	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 7: LOSS OF ONE BROCADE FABRIC INTERCONNECT SWITCH (APPLICABLE ONLY FOR HA SOLUTIONS WITH FABRIC METROCLUSTER SETUP)

Tests Performed	1. Power off one of the Fibre Channel switches in site 1. 2. Observe the results. 3. Power it back on.
Expected Results	• There is no disruption to data availability. • The controller displays the message that some disks are connected to only one switch and that one of the cluster interconnects is down. • No change is detected in the ESX Server level and VMs run without any interruption. • When power is restored and the switch completes its boot process, the controller displays messages to indicate that the disks are now connected to two switches

	and that the second cluster interconnect is again active.	
Actual Results	Actual results were in line with the expected behavior and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

OPERATIONAL SCENARIO 8: LOSS OF ONE ISL BETWEEN THE BROCADE FABRIC INTERCONNECT SWITCHES (APPLICABLE ONLY FOR HA SOLUTIONS WITH FABRIC METROCLUSTER SETUP)

Tests Performed	Remove the ISL fiber cable between the Brocade fabric interconnect switches.	
Expected Results	• There is no disruption to data availability. • The controller displays the message that some disks are connected to only one switch and that one of the cluster interconnects is down. • No change is detected in the ESX Server level, and VMs run without any interruption. • When ISL is reconnected, the controller displays messages to indicate that the disks are now connected to two switches and that the second cluster interconnect is again active.	
Actual Results	Actual results were in line with the expected behavior, and the tests passed as expected.	
MetroCluster Behavior	No MetroCluster event	
VMware HA Behavior	No HA event	
VMware FT Behavior	No FT event	
Impact to Data Availability	None	

5.2 FAILURES THAT AFFECT AN ENTIRE DATA CENTER

OPERATIONAL SCENARIO 9: LOSS OF AN ENTIRE SITE

In case of a complete site-level disaster, all physical components of the VMware HA and FT and NetApp MetroCluster solution such as VMware ESX Servers, NetApp storage controllers, and associated disk shelves can become unavailable simultaneously. In such circumstances, a manual failover of the NetApp MetroCluster needs to be performed.

One way to simulate a real-world site disaster in the lab is to interrupt the components of the lab setup in the order given so that the partner site component is unable to automatically detect any failure.

To simulate a site 1 disaster, do the following:

Step #	Description
1	Disconnect both Cluster Interconnect (CI) cables at site 1 (in the case of a stretch MetroCluster). Or Disconnect both ISLs at site 1 (in the case of a fabric MetroCluster).
2	Remove the power from all disk shelves in site 1.
3	Remove power from all ESX Servers in site 1.
4	Remove power from the NetApp storage controller in site 1.

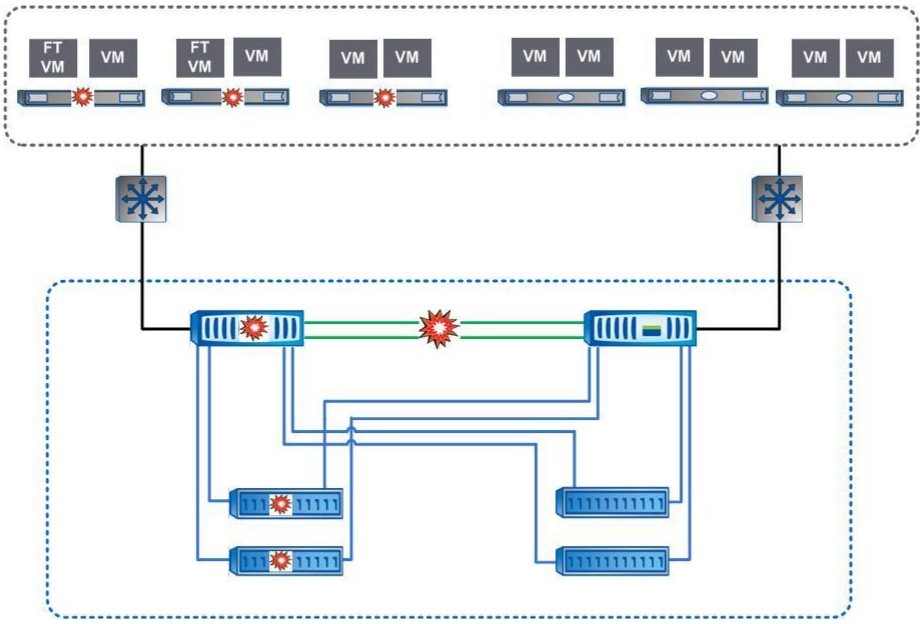


Figure 20) Loss of an entire site.

Figure 21 illustrates the recovery process involved in a complete site loss scenario.

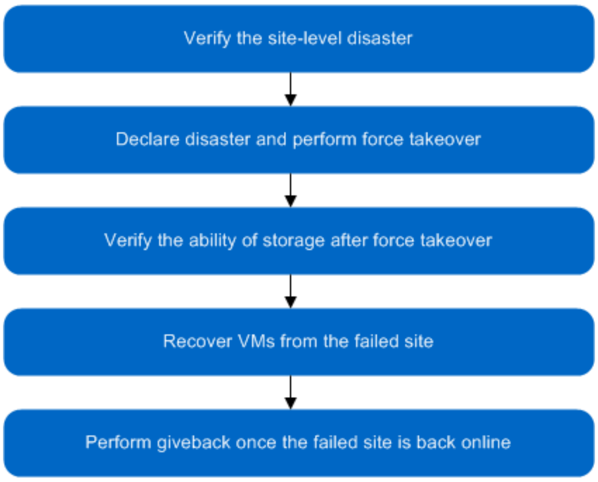


Figure 21) Recovery after loss of an entire site.

Step 1: Verify the site-level disaster

If the VMware vCenter Server is still available after a site-level disaster, it displays the unavailability of resources from the failed site. Depending on (a) the location of the VMware vCenter Server in the lab setup, which is running as a virtual machine inside the VMware HA cluster, and (b) whether the vCenter Server Heartbeat has been configured or not, the following observations can be made regarding its availability after a site-level disaster:

Table 4) vCenter Server implemented as a VM inside the HA cluster without vCenter Heartbeat.

Location of vCenter Server	Data Store	Observation	Recovery Steps
Any ESX Server in site 2	From NetApp FAS controller in site 2	vCenter Server will be up and running	N/A
Any ESX Server in site 2	From NetApp FAS controller in site 1	vCenter Server will not be available	vCenter can be powered on after the manual force takeover in step 2 below
Any ESX Server in site 1	From NetApp FAS controller in site 1	vCenter Server will not be available	vCenter can be powered on in the site 2 ESX Server after the manual force takeover described in step 2 below
Any ESX Server in site 1	From NetApp FAS controller in site 2	vCenter Server will be available after it is powered on by VMware HA service on any ESX Server cluster node in site 2	Automatic power on

Table 5) vCenter Server as a VM inside the HA cluster WITH vCenter Heartbeat (vSphere only).

Location of vCenter Server	Data Store	Observation	Recovery Steps
Any ESX Server in site 1 with vCenter Heartbeat implemented	Primary vCenter Server uses controller in site 1 and secondary vCenter Server uses controller in site 2	vCenter Server will be up and running	N/A
Any ESX Server in site 2 with vCenter Heartbeat implemented	Primary vCenter Server uses controller in site 2 and secondary vCenter Server uses controller in site 1	vCenter Server will be up and running	N/A

Optional: If the vCenter Server is available after the disaster (that is, if vCenter Heartbeat is implemented with the primary and secondary vCenter using controllers from respective sites or if the vCenter Server and its underlying storage are not on the failed site), the vCenter Server shows the unavailability of the VMs and resources in the failed site.

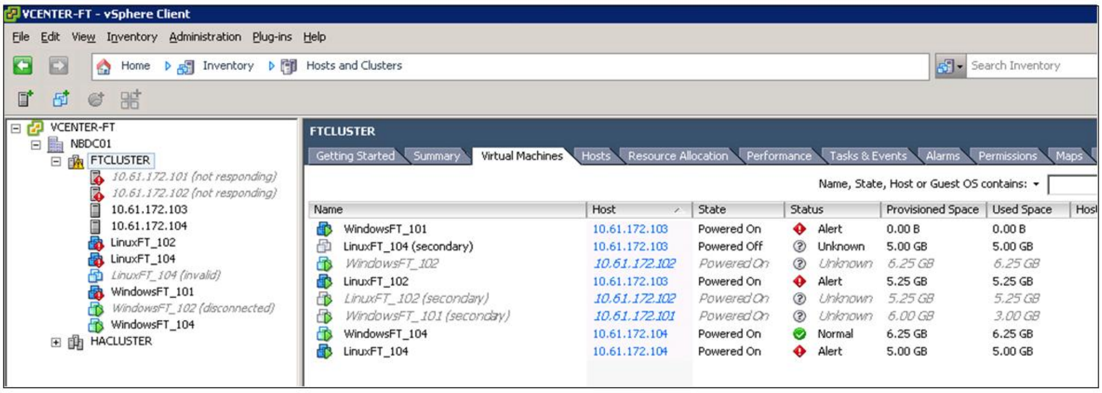


Figure 22) VM status.

The storage controller in the surviving site (site 2) shows that its partner node is down. As mentioned previously, during an entire site failure an automated cluster takeover will not be initiated by the surviving storage controller node.

```
chakotay> cf status
opaka may be down, takeover disabled because of reason (partner mailbox disks not accessible or invalid)
chakotay has disabled takeover by opaka (unsynchronized log)
VIA Interconnect is down (link 0 down, link 1 down).
```

Step 2: Declare disaster and perform force takeover

Declare a site disaster and perform a manual takeover at the surviving site (site 2) by issuing the following command in the NetApp storage controller of site 2:

`cf forcetakeover -d`

```
chakotay>
chakotay> cf forcetakeover -d
Following the command, mirrored volumes will be split and
Clients of the partner filer may experience data loss because of disaster.
Prior to issuing this command, the partner filer should be powered off.
If the cluster partner is operational or if it becomes operational at any time
while this filer is running in takeover mode, your filesystems may be destroyed.
Do you wish to continue [y/n] ??
```

Step 3: Verify availability of storage after force takeover

After executing the `cf forcetakeover` command, all LUNs and NFS exports of the failed node will be automatically available.

```
chakotay(takeover)> cf status
chakotay has taken over opaka.
chakotay(takeover)> lun show
        /vol/vsphereftiscsi_1/lunone      51g (54760833024)    (r/w, online, mapped)
chakotay(takeover)> partner
Login to partner shell: opaka
opaka/chakotay> Tue Feb  2 06:41:56 GMT [chakotay (takeover): cf.partner.login:notice]: Login to partner shell: opaka
Tue Feb  2 06:41:58 GMT [chakotay (takeover): HTTPPool03:warning]: HTTP XML Authentication failed from 10.61.175.223.

opaka/chakotay> lun show
        /vol/vsphereftiscsi/lunone      51g (54760833024)    (r/w, online, mapped)
```

Step 4: Automatic power on of virtual machines in remote site

Note: In this specific test scenario, the disaster is planned with immediate declaration; therefore, the active storage in the failed site is made available almost immediately to the ESX Server hosts in the surviving site. In real site disaster scenarios, the declaration may not be immediate. Therefore, the virtual machines may need to be manually powered on in the surviving site after storage is made available through the forced takeover.

- ✓ Takeover is successful and the virtual machines are automatically powered on in the surviving ESX Server on the remote site.
- ✓ If the vCenter Server is down, it will now boot in a surviving ESX Server and can be accessed.

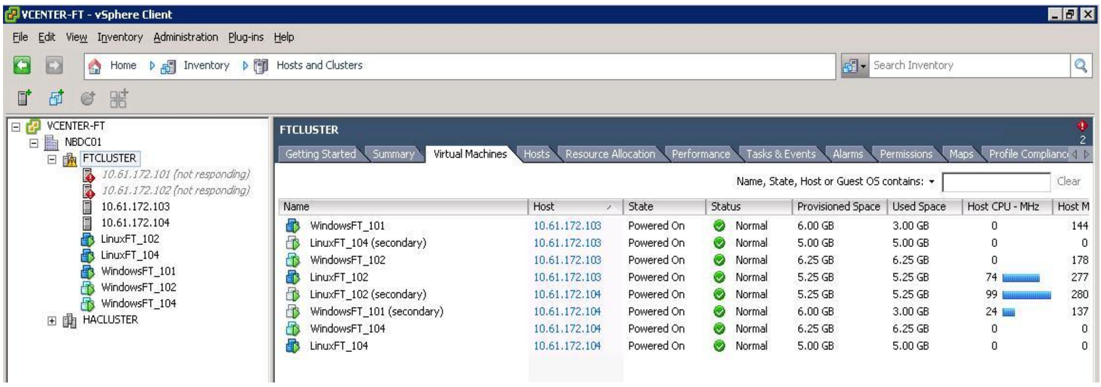


Figure 23) VM status.

✓ From this point, all VMs in the ESX Servers at the failed site get powered on and start running normally. For FT-enabled VMs, both primary and secondary are created on two separate nodes in the surviving site and the VMs restart. Similarly the HA-enabled (non-FT) VMs restart on the available cluster nodes of the surviving site.

This completes the takeover process for site-level disasters.

Step 5: Perform giveback once the failed site is back online

1. Power on all disk shelves connected to the storage controller of site 1.
2. Reconnect the cluster interconnect between sites so that the storage controller in site 2 can see the disk shelves from site 1. After connection, the disk shelves from either side automatically begin to resync.
3. All ESX Servers in site 1 are now powered on. When the ESX Servers are online, power on the storage controller in site 1.
4. Use the `cf status` command to verify that a giveback is possible and verify that all mirror resynchronization is complete before proceeding with the `cf giveback` command.

```
chakotay(takeover)>
chakotay(takeover)> cf status
chakotay has taken over opaka.
opaka is ready for giveback.
chakotay(takeover)>
chakotay(takeover)> cf giveback
chakotay(takeover)>
chakotay> Wed Dec 16 03:26:14 GMT [chakotay (takeover): cf.misc.operatorGiveback:info]: Cluster monitor: giveback initia
ted by operator
```

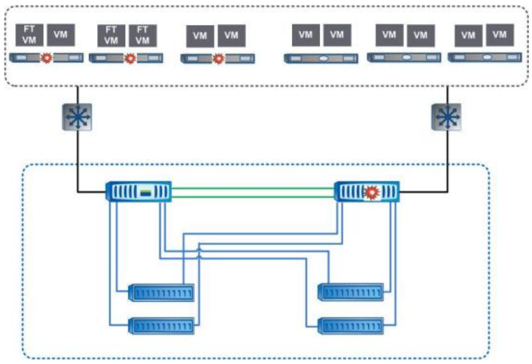
5. If necessary, perform manual migration of virtual machines from the surviving site to the restored failed site with their respective ESX Servers.

This completes the giveback process.

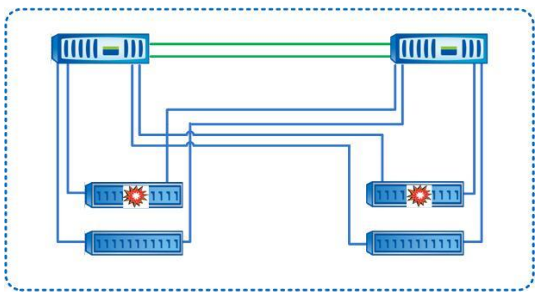
5.3 COMBINATION TESTS (FAILURES THAT AFFECT BOTH SITES)

OPERATIONAL SCENARIO 10-1: COMBINATION TEST (ESX HOST SERVER AND CONTROLLER FAILURE ACROSS SITES)

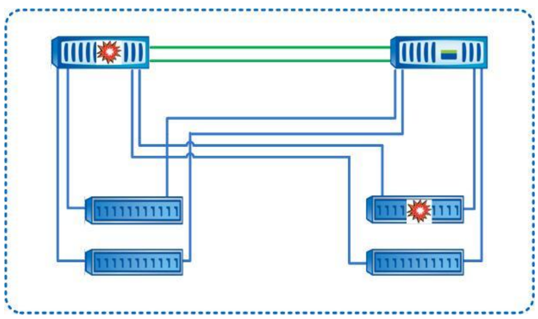
Tests Performed	1. Power off all ESX hosts at site 1. 2. Power off the storage controller at site 2.
Expected Results	• Controller at site 1 automatically takes over the powered-off controller. • There is no disruption to data availability for surviving hosts containing the FT and non-FT VMs. • The secondary FT VMs come online and start acting as primary FT VMs and new secondary FT VMs are created in the surviving FT-enabled HA cluster nodes. • Non-FT HA-enabled VMs are migrated to other ESX Servers in the cluster and restart.

<table>
<tr><td>Actual Results</td><td colspan="2">Actual results were in line with the expected behavior, and the tests passed as expected.</td></tr>
<tr><td>MetroCluster Behavior</td><td>Partner controller in site 1 performs an automatic takeover.</td><td rowspan="4"></td></tr>
<tr><td>VMware HA Behavior</td><td>VMs previously running in the failed hosts are automatically powered on in the surviving nodes.</td></tr>
<tr><td>VMware FT Behavior</td><td>Protects VM (primary) by making the secondary VM primary and then creating a secondary copy on another node</td></tr>
<tr><td>Impact to Data Availability</td><td>None</td></tr>
</table>

OPERATIONAL SCENARIO 10-2: COMBINATION TEST (DISK SHELVES FAILURE IN BOTH SITES)

<table>
<tr><td>Tests Performed</td><td colspan="2">1. Power off disk pool 0 in site 1.
2. Power off disk pool 0 in site 2.</td></tr>
<tr><td>Expected Results</td><td colspan="2">VMs should not detect any changes and continue to operate normally.</td></tr>
<tr><td>Actual Results</td><td colspan="2">Actual results were in line with the expected behavior, and the tests passed as expected.</td></tr>
<tr><td>MetroCluster Behavior</td><td>No MetroCluster event. Data is served from the mirrored copy.</td><td rowspan="4"></td></tr>
<tr><td>VMware HA Behavior</td><td>No HA event</td></tr>
<tr><td>VMware FT Behavior</td><td>No FT event</td></tr>
<tr><td>Impact to Data Availability</td><td>None</td></tr>
</table>

OPERATIONAL SCENARIO 10-3: COMBINATION TEST (CONTROLLLER AND DISK SHELF FAILURE

<table>
<tr><td>Tests Performed</td><td colspan="2">1. Power off storage controller in site 1.
2. Power off disk pool 0 in site 2.</td></tr>
<tr><td>Expected Results</td><td colspan="2">VMs should not detect any changes and should continue to operate normally.</td></tr>
<tr><td>Actual Results</td><td colspan="2">Actual results were in line with the expected behavior, and the tests passed as expected.</td></tr>
<tr><td>MetroCluster Behavior</td><td>Surviving storage controller performs automatic takeover.</td><td rowspan="4"></td></tr>
<tr><td>VMware HA Behavior</td><td>No HA event</td></tr>
<tr><td>VMware FT Behavior</td><td>No FT event</td></tr>
<tr><td>Impact to Data Availability</td><td>None</td></tr>
</table>

6 SUMMARY

Figure 24) Summary of failure scenarios and the impact on data availability.

#	Failure Scenario	Data Availability Impact
1	Complete loss of power to disk shelf	None
2	Loss of one link in one disk loop	None
3	Failure and failback of storage controller	None
4	Loss of mirrored storage or network isolation	None
5	Total network isolation, including all ESX hosts (FT or non-FT enabled) and loss of hard drive	Applications or data in the non-FT VMs running on the ESX Servers before they were powered off will be available after they automatically come up in the surviving nodes of the VMware HA cluster. FT-enabled VMs will run uninterrupted.
6	Loss of all ESX Servers in one site	Applications or data in the non-FT VMs running on the ESX Servers before they were powered off will be available after they automatically come up in the surviving nodes of the VMware HA cluster. FT-enabled VMs will run uninterrupted.
7	Loss of one Brocade Fabric Interconnect switch (applicable for continuous availability solution with fabric MetroCluster only)	None
8	Loss of one ISL between the Brocade Fabric Interconnect switches (applicable for continuous-availability solution with fabric MetroCluster only)	None
9	Loss of an entire site	Applications or data in the VMs (both FT enabled and non-FT) and running in the failed site will be available after executing the `force takeover` command from the surviving site.
10-1	Loss of all ESX Servers in one site and loss of storage controller in the other site	None
10-2	Loss of disk pool 0 in both sites	None
10-3	Loss of storage controller in one site and loss of disk pool 0 in the other	None

VMware HA, FT, and NetApp MetroCluster technologies can work in synergy to provide a simple and robust continuous-availability solution for planned and unplanned downtime in virtual data center environments.

Planned site and component failovers, at both the server and storage level, can be triggered without disrupting the environment, thus allowing scheduled maintenance without any downtime. Similarly this solution delivers complete protection against unplanned server and storage failures, including failure of the physical ESX Server, NetApp storage controller, power supplies, disk drives, disk shelves, cables, and so on.

This paper is not intended to be a definitive implementation or solutions guide for continuous-availability solutions in VMware vSphere 4 and Virtual Infrastructure 3 (VI3) with NetApp storage. Many factors related to specific customer environments are not addressed in this document. Contact NetApp Support to speak with one of our virtualization solutions experts for any deployment requirement.

7 APPENDIX A: BROCADE SWITCH CONNECTION DETAILS FOR FABRIC METROCLUSTER (SOFTWARE-BASED DISK OWNERSHIP)

Figure 25) Brocade switch connection details for fabric MetroCluster.

Switch Name	SITE1-SW1		
Port	Bank/Pool	Connected To	Purpose
0	1/0	SITE1 FCVI	Cluster interconnect
1	1/0	On-board HBA - 0a	
2	1/0	On-board HBA – 0c	
3	1/0		
4	1/1	ISL	Interswitch link
5	1/1		
6	1/1		
7	1/1		
8	2/0		
9	2/0		
10	2/0		
11	2/0	Site 1 Shelf 1 Pool 0	Disk HBA for bank 2 shelves
12	2/1		
13	2/1	Site 2 Shelf 1 Mirror Pool 1	Disk HBA for bank 2 shelves
14	2/1		
15	2/1		
Switch Name	SITE1-SW2		
Port	Bank/Pool	Connected To	Purpose
0	1/0	SITE1 FCVI	Cluster interconnect
1	1/0	On-board HBA -0b	
2	1/0	On-board HBA -0d	
3	1/0		
4	1/1	ISL	Interswitch link
5	1/1		
6	1/1		
7	1/1		
8	2/0		
9	2/0		
10	2/0		
11	2/0	Site 1 Shelf 1 Pool 0	Disk HBA for bank 2 shelves
12	2/1		
13	2/1	Site 2 Shelf 1 Mirror Pool 1	Disk HBA for bank 2 shelves
14	2/1		
15	2/1		
Switch Name	SITE2-SW3		
Port	Bank/Pool	Connected To	Purpose
0	1/0	SITE2 FCVI	Cluster interconnect
1	1/0	On-board HBA 0a	
2	1/0	On-board HBA 0b	
3	1/0		
4	1/1	ISL	Interswitch link
5	1/1		
6	1/1		
7	1/1		
8	2/0		
9	2/0		
10	2/0		
11	2/0	Site 2 Shelf 1 Pool 0	Disk HBA for bank 2 shelves

12	2/1		
13	2/1	Site 1 Shelf 1 Mirror Pool 1	Disk HBA for bank 2 shelves
14	2/1		
15	2/1		

Switch Name	SITE2-SW4		
Port	**Bank/Pool**	**Connected To**	**Purpose**
0	1/0	SITE2 FCVI	Cluster Interconnect
1	1/0	On-board 0b	
2	1/0	On-board 0d	
3	1/0		
4	1/1	ISL	Interswitch link
5	1/1		
6	1/1		
7	1/1		
8	2/0		
9	2/0		
10	2/0		
11	2/0	Site 2 Shelf 1 Pool 0	Disk HBA for bank 2 shelves
12	2/1		
13	2/1	Site 1 Shelf 1 Mirror Pool 1	Disk HBA for bank 2 shelves
14	2/1		
15	2/1		

8 APPENDIX B: MATERIALS USED IN THE LAB SETUP

Figure 26) Lab setup.

Infrastructure Component	Vendor	Quantity	Details
Server	IBM	1	IBM x3550 server
		5	IBM x3650 server
			Intel® Xeon™ Processor (Intel-VT), CPU: 74 GHz total in the cluster Memory: 52GB total in the cluster
Storage	NetApp		FAS3170: Fabric MetroCluster config, RAID-DP
Switch (MetroCluster)	Brocade	4	Brocade Switch Model 200E 16P, Full Fabric, 4GB SWL SFPs For currently supported matrix, see the NetApp support site.
Switch (front-end SAN)	Brocade	4	Brocade Switch Model 3800
Network adapter	Broadcom	Two per server	Broadcom NetXtreme II BCM 5708 1000Base-T
HBA	QLogic	One per server[2]	QLogic QLA 2432
Software	NetApp		Data ONTAP 7.3.3
	NetApp		cluster_remote
	NetApp		syncMirror_local
	VMware		VMware ESX Server v3.5 U3
	VMware		VMware vCenter Server 2.5U4
Virtual machines			Two VMs per ESX host configured for functional tests (one VM running Windows 2003 SP1 EE and another running RHEL 5 U2)

[2] Note that a production environment requires a minimum of two HBAs.

9 APPENDIX C: REFERENCES

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