Securing the Storage Infrastructure

Information Security Framework:

The basic information security framework is built to achieve four security goals: confidentiality, integrity, and availability (CIA), along with accountability. This framework incorporates all security standards, procedures, and controls, required to mitigate threats in the storage infrastructure environment.

1. **Confidentiality:**
   - Provides the required secrecy of information and ensures that only authorized users have access to data. This requires authentication of users who need to access information.
   - Data in transit (data transmitted over cables) and data at rest (data residing on a primary storage, backup media, or in the archives) can be encrypted to maintain its confidentiality.
   - In addition to restricting unauthorized users from accessing information, confidentiality also requires implementing traffic flow protection measures as part of the security protocol. These protection measures generally include hiding source and destination addresses, frequency of data being sent, and amount of data sent.
2. **Integrity:**
   - Ensures that the information is unaltered. Ensuring integrity requires detection of and protection against unauthorized alteration or deletion of information.
   - Ensuring integrity stipulates measures such as error detection and correction for both data and systems.
3. **Availability:**
   - This ensures that authorized users have reliable and timely access to systems, data, and applications residing on these systems.
   - Availability requires protection against unauthorized deletion of data and denial of service.
   - Availability also implies that sufficient resources are available to provide a service.
4. **Accountability service:**
   - Refers to accounting for all the events and operations that take place in the data center infrastructure.
   - The accountability service maintains a log of events that can be audited or traced later for the purpose of security.

Risk Triad:

Risk triad defines risk in terms of threats, assets, and vulnerabilities.

Risk arises when a threat agent (an attacker) uses an existing vulnerability to compromise the security services of an asset, for example, if a sensitive document is transmitted without any protection over an insecure channel, an attacker might get unauthorized access to the document and may violate its confidentiality and integrity. This may, in turn, result in business loss for the organization. In this scenario potential business loss is the risk, which arises because an attacker uses the vulnerability of the unprotected communication to access the document and tamper with it.

Assets, threats, and vulnerabilities are considered from the perspective of risk identification and control analysis.

Assets:

Information is one of the most important assets for any organization. Other assets include hardware, software, and other infrastructure components required to access the information.

To protect these assets, organizations must develop a set of parameters to ensure the availability of the resources to authorized users and trusted networks. These parameters apply to storage resources, network infrastructure, and organizational policies.

Security methods have two objectives.

1. To ensure that the network is easily accessible to authorized users. It should also be reliable and stable under disparate environmental conditions and volumes of usage.
2. To make it difficult for potential attackers to access and compromise the system.

The security methods should provide adequate protection against unauthorized access, viruses, worms, trojans, and other malicious software programs.

Security measures should also include options to encrypt critical data and disable unused services to minimize the number of potential security gaps. The security method must ensure that updates to the operating system and other software are installed regularly. At the same time, it must provide adequate redundancy in the form of replication and mirroring of the production data to prevent catastrophic data loss if there is an unexpected data compromise.

For the security system to function smoothly, all users are informed about the policies governing the use of the network.

The effectiveness of a storage security methodology can be measured by two key criteria.

1. The cost of implementing the system should be a fraction of the value of the protected data.
2. It should cost heavily to a potential attacker, in terms of money, effort, and time.

Threats:

Threats are the potential attacks that can be carried out on an IT infrastructure.

These attacks can be classified as **active or passive**.

- **Passive attacks** are attempts to gain unauthorized access into the system. They pose threats to confidentiality of information.
- **Active attacks** include data modification, denial of service (DoS), and repudiation attacks. They pose threats to data integrity, availability, and accountability.

In a **data modification attack**, the unauthorized user attempts to modify information for malicious purposes. A modification attack can target the data at rest or the data in transit. These attacks pose a threat to data integrity.

Denial of service (DoS) attacks prevent legitimate users from accessing resources and services. These attacks generally do not involve access to or modification of information. Instead, they pose a threat to data availability. The intentional flooding of a network or website to prevent legitimate access to authorized users is one example of a DoS attack.

Repudiation is an attack against the accountability of information. It attempts to provide false information by either impersonating someone or denying that an event or a transaction has taken place. For example, a repudiation attack may involve performing an action and eliminating any evidence that could prove the identity of the user (attacker) who performed that action. Repudiation attacks include circumventing the logging of security events or tampering with the security log to conceal the identity of the attacker.

Vulnerability:

The paths that provide access to information are often vulnerable to potential attacks.

Each of the paths may contain various access points, which provide different levels of access to the storage resources. It is important to implement adequate security controls at all the access points on an access path.

Implementing security controls at each access point of every access path is known as **defense in depth.**

Defense in depth recommends using multiple security measures to reduce the risk of security threats if one component of the protection is compromised. It is also known as a **“layered approach to security.”** Since there are multiple measures for security at different levels, defense in depth gives additional time to detect and respond to an attack. This can reduce the scope or impact of a security breach.

Attack surface, attack vector, and work factor are the three factors to consider when assessing the extent to which an environment is vulnerable to security threats.

Attack surface refers to the various entry points that an attacker can use to launch an attack. Each component of a storage network is a source of potential vulnerability. An attacker can use all the external interfaces supported by that component, such as the hardware and the management interfaces, to execute various attacks. These interfaces form the attack surface for the attacker. Even unused network services, if enabled, can become a part of the attack surface.

An attack vector is a step or a series of steps necessary to complete an attack. For example, an attacker might exploit a bug in the management interface to execute a snoop attack whereby the attacker can modify the configuration of the storage device to allow the traffic to be accessed from one more host. This redirected traffic can be used to snoop the data in transit.

Work factor refers to the amount of time and effort required to exploit an attack vector. For example, if attackers attempt to retrieve sensitive information, they consider the time and effort that would be required for executing an attack on a database. This may include determining privileged accounts, determining the database schema, and writing SQL queries. Instead, based on the work factor, they may consider a less effort-intensive way to exploit the storage array by attaching to it directly and reading from the raw disk blocks.

Having assessed the vulnerability of the environment, organizations can deploy specific control measures. Any control measures should involve all the three aspects of infrastructure: people, process, and technology, and the relationships among them.

To secure people, the first step is to establish and assure their identity. Based on their identity, selective controls can be implemented for their access to data and resources. The effectiveness of any security measure is primarily governed by processes and policies.

Finally, the technologies or controls that are deployed should ensure compliance with the processes, policies, and people for its effectiveness.

These security technologies are directed at reducing vulnerability by minimizing attack surfaces and maximizing the work factors.

These controls can be **technical** or **nontechnical**.

- **Technical controls** are usually implemented through computer systems, whereas nontechnical controls are implemented through administrative and physical controls.
- **Administrative controls** include security and personnel policies or standard procedures to direct the safe execution of various operations. Physical controls include setting up physical barriers, such as security guards, fences, or locks.

Based on the roles they play, controls are categorized as **preventive, detective, and corrective.**

- **The preventive control** attempts to prevent an attack; Preventive controls avert the vulnerabilities from being exploited and prevent an attack or reduce its impact.
- **The detective control** detects whether an attack is in progress; detective controls discover attacks and trigger preventive or corrective control
- after an attack is discovered, the corrective controls are implemented. **Corrective controls** reduce the effect of an attack.

For example, an Intrusion Detection/Intrusion Prevention System (IDS/IPS) is a detective control that determines whether an attack is underway and then attempts to stop it by terminating a network connection or invoking a firewall rule to block traffic.

Storage Security Domains:

To identify the threats that apply to a storage network, access paths to data storage can be categorized into three security domains:

1. Application access,
2. Management access, and
3. Backup, replication, and archive.

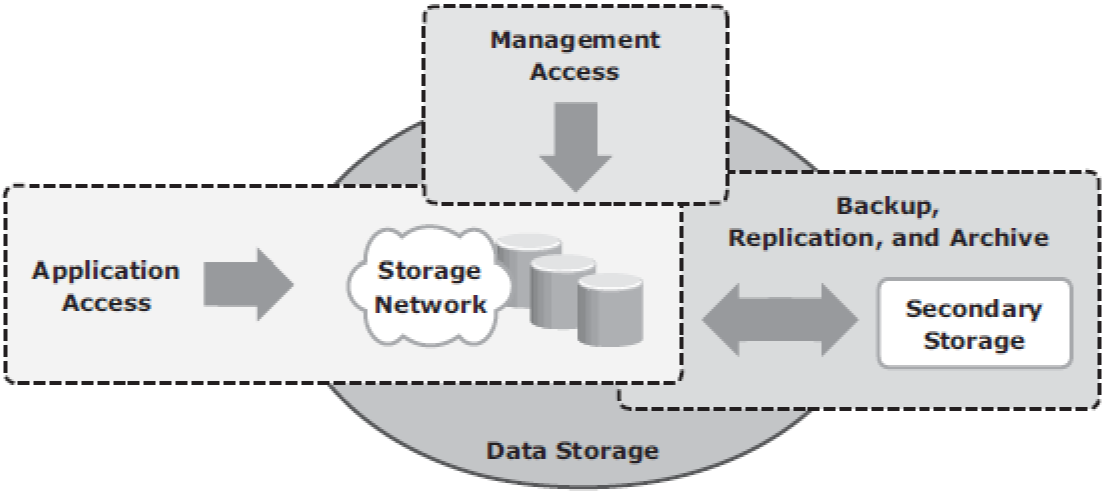


Figure 14-1: Storage security domains

The first security domain involves application access to the stored data through the storage network.

The second security domain includes management access to storage and interconnect devices and to the data residing on those devices. This domain is primarily accessed by storage administrators who configure and manage the environment.

The third domain consists of backup, replication, and archive access. Along with the access points in this domain, the backup media also needs to be secured.

Securing the Application Access Domain

The application access domain may include only those applications that access the data through the file system or a database interface.

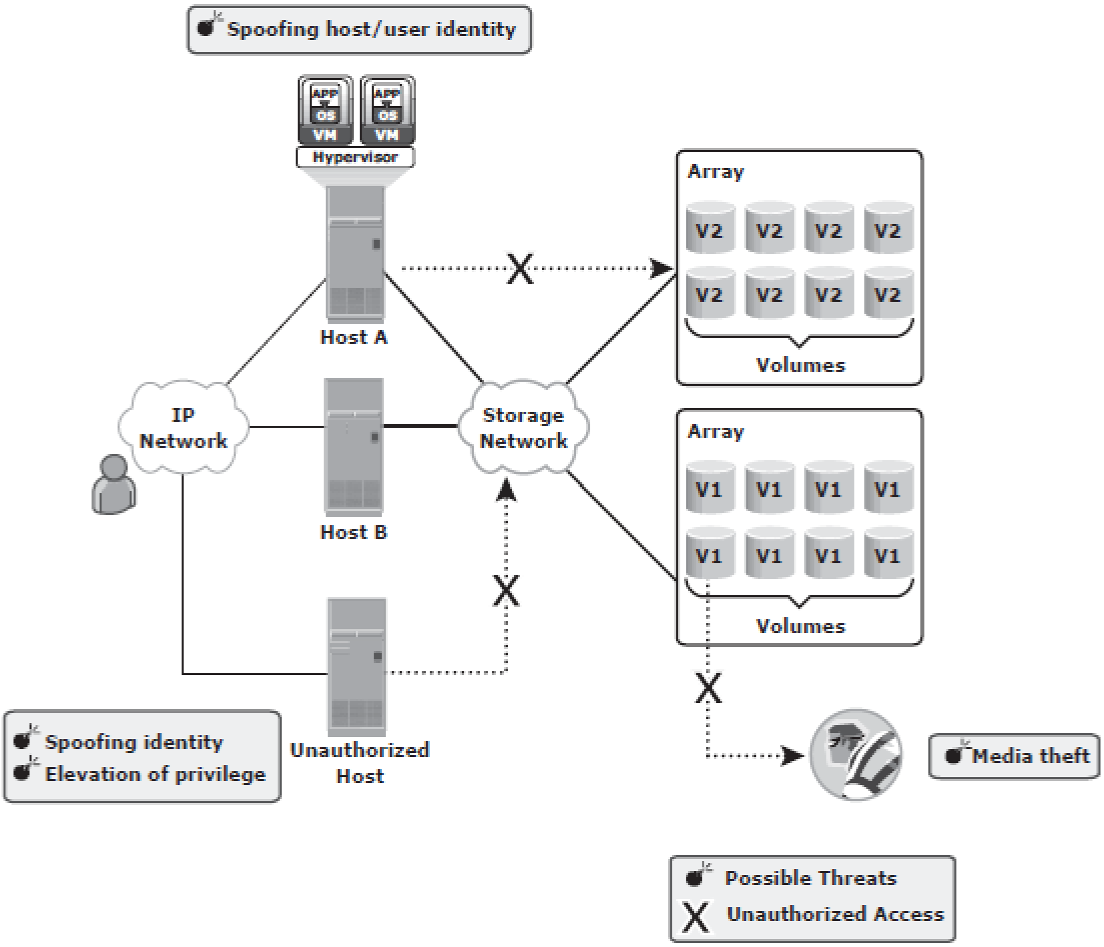


Figure 14-2: Security threats in an application access domain

Figure 14-2 shows application access in a storage networking environment. Host A can access all V1 volumes; host B can access all V2 volumes. These volumes are classified according to the access level, such as confidential, restricted, and public.

Some of the possible threats in this scenario could be host A spoofing the identity or elevating to the privileges of host B to gain access to host B's resources. Another threat could be that an unauthorized host gains access to the network; the attacker on this host may try to spoof the identity of another host and tamper with the data, snoop the network, or execute a DoS attack.

Also any form of media theft could also compromise security. These threats can pose several serious challenges to the network security; therefore, they need to be addressed.

Controlling User Access to Data:

Access control services regulate user access to data. These services mitigate the threats of spoofing host identity and elevating host privileges. Both these threats affect **data integrity** and **confidentiality.**

Access control mechanisms used in the application access domain are user and host **authentication** (technical control) and **authorization** (administrative control). These mechanisms may lie outside the boundaries of the storage network and require various systems to interconnect with other enterprise identity management and authentication systems, for example, systems that provide strong authentication and authorization to secure user identities against spoofing.

NAS devices support the creation of **access control lists** that regulate user access to specific files.

Different storage networking technologies, such as iSCSI, FC, and IP-based storage, use various authentication mechanisms, such as Challenge-Handshake Authentication Protocol (CHAP), Fibre Channel Security Protocol (FC-SP), and IPSec, respectively, to authenticate host access.

Zoning is a control mechanism on the switches that segments the network into specific paths to be used for data traffic; **LUN masking** determines which hosts can access which storage devices.

Regular auditing is required to ensure proper functioning of administrative controls. This is enabled by logging significant events on all participating devices.

Event logs should also be protected from unauthorized access because they may fail to achieve their goals if the logged content is exposed to unauthorized modifications by an attacker.

Protecting the Storage Infrastructure

Security controls for protecting the storage infrastructure address the threats of unauthorized tampering of data in transit that leads to a loss of data integrity, denial of service that compromises availability, and network snooping that may result in loss of confidentiality.

The security controls for protecting the network fall into two general categories: **network infrastructure integrity and storage network encryption.**

Controls for ensuring the infrastructure integrity include a **fabric switch function** that ensures fabric integrity. This is achieved by preventing a host from being added to the SAN fabric without proper authorization.

Storage network encryption methods include the use of IPSec for protecting IP-based storage networks, and FC-SP for protecting FC networks.

In secure storage environments, root or administrator privileges for a specific device are not granted to every user. Instead, **role-based access control (RBAC)** is deployed to assign necessary privileges to users, enabling them to perform their roles.

Management networks for storage systems should be logically separate from other enterprise networks. For example, IP network segmentation is enforced with the deployment of filters at Layer 3 by using routers and firewalls, and at Layer 2 by using VLANs and port-level security on Ethernet switches.

Finally, physical access to the device console and the cabling of FC switches must be controlled to ensure protection of the storage infrastructure.

Data Encryption:

The most important aspect of securing data is protecting data held inside the storage arrays. Threats at this level include tampering with data, which violatesdata integrity, and media theft, which compromises data availability and confi- dentiality. To protect against these threats, encrypt the data held on the storage **media or encrypt the data prior to being transferred to the disk.**

It is also critical to decide upon a method for ensuring that data deleted at the end of its life cycle has been completely erased from the disks and cannot be reconstructed for malicious purposes.

Data should be encrypted as close to its origin as possible. If it is not possible to perform encryption on the host device, an **encryption appliance can be used for encrypting data** at the point of entry into the storage network.

Encryption devices can be implemented on the fabric that encrypts data between the host and the storage media. These mechanisms can protect both the data at rest on the destination device and data in transit.

On NAS devices, adding antivirus checks and file extension controls can further enhance data integrity. In the case of CAS, use of MD5 or SHA-256 cryptographic algorithms guarantees data integrity by detecting any change in content bit patterns. In addition, the data erasure service ensures that the data has been completely overwritten by bit sequence before the disk is discarded.

An organization’s data classification policy determines whether the disk should actually be scrubbed prior to discarding it and the level of erasure needed based on regulatory requirements.

Securing the Management Access Domain

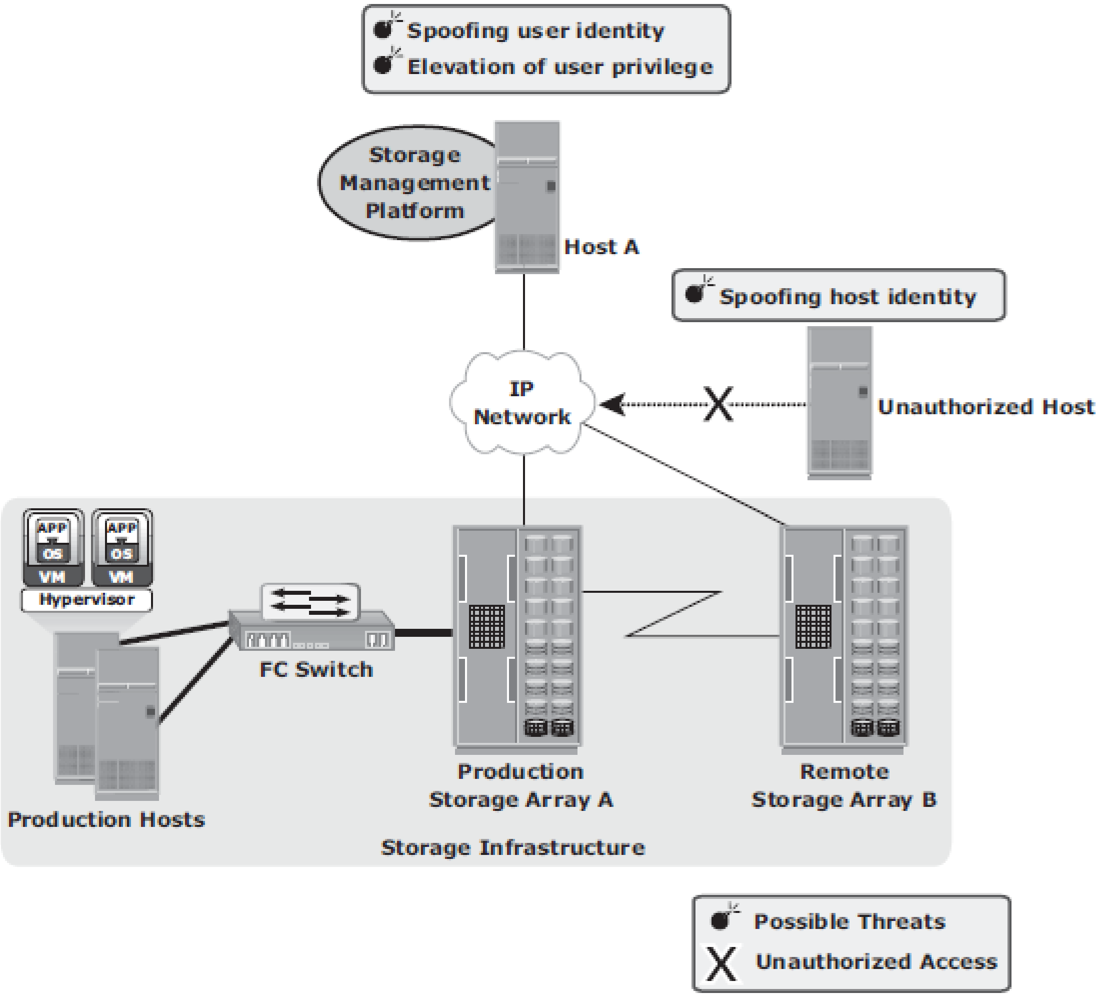


Figure 14-3: Security threats in a management access domain

Management access, whether monitoring, provisioning, or managing storage resources, is associated with every device within the storage network.

Figure 14-3 depicts a storage networking environment in which production hosts are connected to a SAN fabric and are accessing production storage array A, which is connected to remote storage array B for replication purposes. Further, this configuration has a storage management platform on Host A. A possible threat in this environment is an unauthorized host spoofing the user or host identity to manage the storage arrays or network. For example, an unauthorized host may gain management access to remote array B.

Providing management access through an external network increases the potential for an unauthorized host or switch to connect to that network. In such circumstances, implementing appropriate security measures prevents certain types of remote communication from occurring. Using secure communication channels, such as Secure Shell (SSH) or Secure Sockets Layer (SSL)/Transport Layer Security (TLS), provides effective protection against these threats.

Event log monitoring helps to identify unauthorized access and unauthorized changes to the infrastructure. Event logs should be placed outside the shared storage systems where they can be reviewed if the storage is compromised.

Controlling Administrative Access:

Controlling administrative access to storage aims to safeguard against the threats of an attacker spoofing an administrator's identity or elevating privileges to gain administrative access. Both of these threats affect the integrity of data and devices. To protect against these threats, administrative access regulation and various auditing techniques are used to enforce accountability of users and processes.

Access control should be enforced for each storage component. In some storage environments, it may be necessary to integrate storage devices with third-party authentication directories, such as Lightweight Directory Access Protocol (LDAP) or Active Directory.

If an administrative user is a necessity, the number of activities requiring administrative privileges should be minimized. Instead, it is better to assign various administrative functions by using RBAC.

Auditing logged events is a critical control measure to track the activities of an administrator. However, access to administrative log files and their content must be protected.

Deploying a reliable Network Time Protocol on each system that can be synchronized to a common time is another important requirement to ensure that activities across systems can be consistently tracked. In addition, having a **Security Information Management** (SIM) solution supports effective analysis of the event log files.

Protecting the Management Infrastructure:

Mechanisms to protect the management network infrastructure include encrypting management traffic, enforcing management access controls, and applying IP network security best practices.

Restricting network activity and access to a limited set of hosts minimizes the threat of an unauthorized device attaching to the network and gaining access to the management interfaces.

Access controls need to be enforced at the storage-array level to specify which host has management access to which array. Some storage devices and switches can restrict management access to particular hosts and limit the commands that can be issued from each host.

A separate private management network is highly recommended for management traffic.

Unused network services must be disabled on every device within the storage network. This decreases the attack surface for that device by minimizing the number of interfaces through which the device can be accessed.

Securing Backup, Replication, and Archive

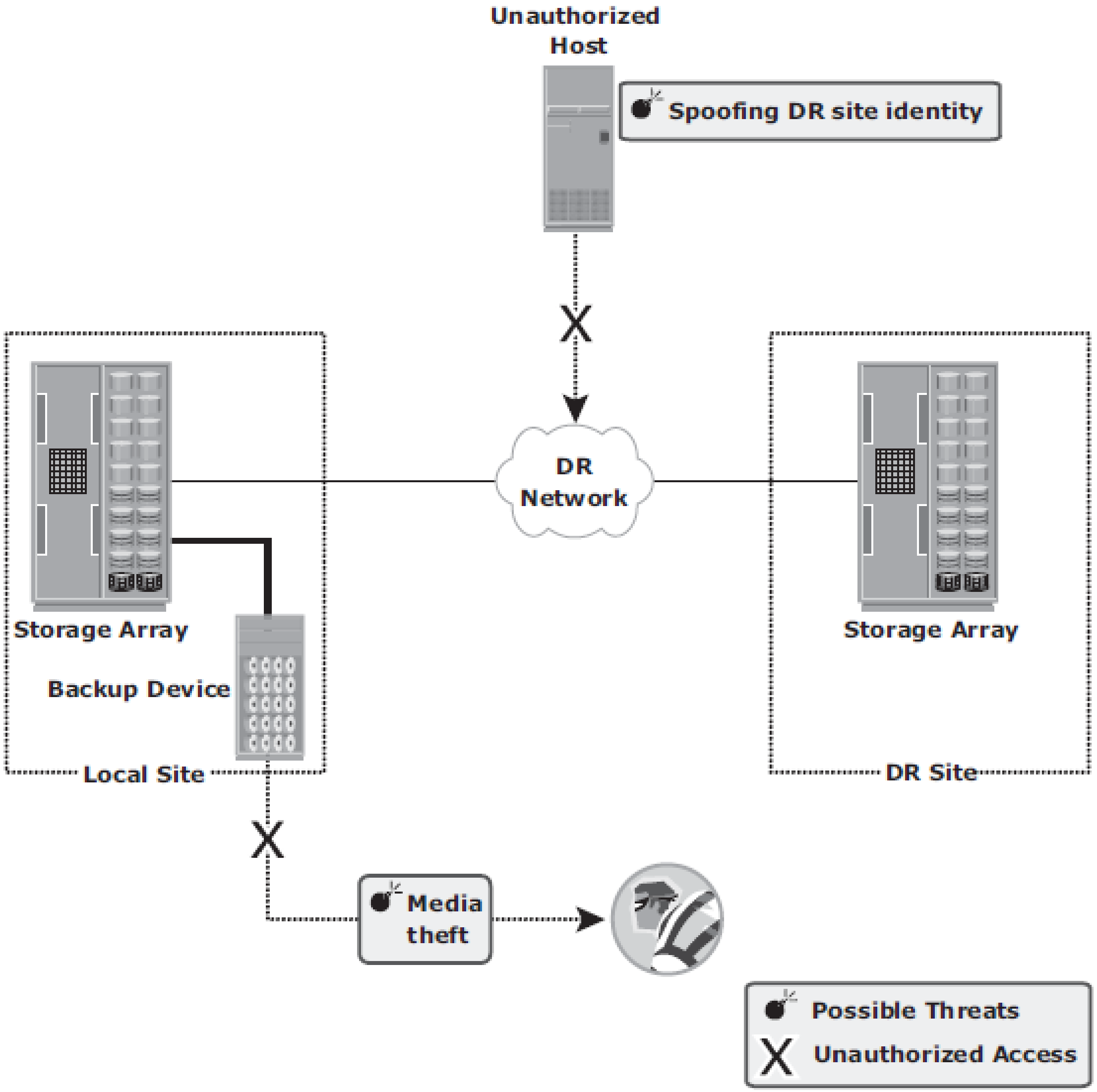


Figure 14-4: Security threats in a backup, replication, and archive environment

Securing backup is complex and is based on the backup software that accesses the storage arrays. It also depends on the configuration of the storage environments at the primary and secondary sites, especially with remote backup solutions performed directly on a remote tape device or using array-based remote replication.

Organizations must ensure that the disaster recovery (DR) site maintains the same level of security for the backed up data.

Protecting the backup, replication, and archive infrastructure requires addressing several threats, including spoofing the legitimate identity of a DR site, tampering with data, network snooping, DoS attacks, and media theft. Such threats represent potential violations of integrity, confidentiality, and availability.

Figure 14-4 illustrates a generic remote backup design whereby data on a storage array is replicated over a DR network to a secondary storage at the DR site. In a remote backup solution where the storage components are separated by a network, the threats at the transmission layer need to be countered. Otherwise, an attacker can spoof the identity of the backup server and request the host to send its data. The unauthorized host claiming to be the backup server may lead to a remote backup being performed to an unauthorized and unknown site.

In addition, attackers can use the DR network connection to tamper with data, snoop the network, and create a DoS attack against the storage devices.

The physical threat of a backup tape being lost, stolen, or misplaced, especially if the tapes contain highly confidential information, is another type of threat. Backup-to-tape applications are vulnerable to severe security implications if they do not encrypt data while backing it up.

Security Implementations in Storage Networking

FC SAN

- An FC SAN is configured as an isolated private environment with fewer nodes than an IP network.
- FC SANs impose fewer security threats.
- Today, no single comprehensive security solution is available for FC SANs.
- Fibre Channel Security Protocol (FC-SP) standards (T11 standards), align security mechanisms and algorithms between IP and FC interconnects.
- These standards describe protocols to implement security measures in a FC fabric, among fabric elements and N_Ports within the fabric.
- They also include guidelines for authenticating FC entities, setting up session keys, negotiating the parameters required to ensure frame-by-frame integrity and confidentiality, and establishing and distributing policies across an FC fabric.

FC SAN Security Architecture:

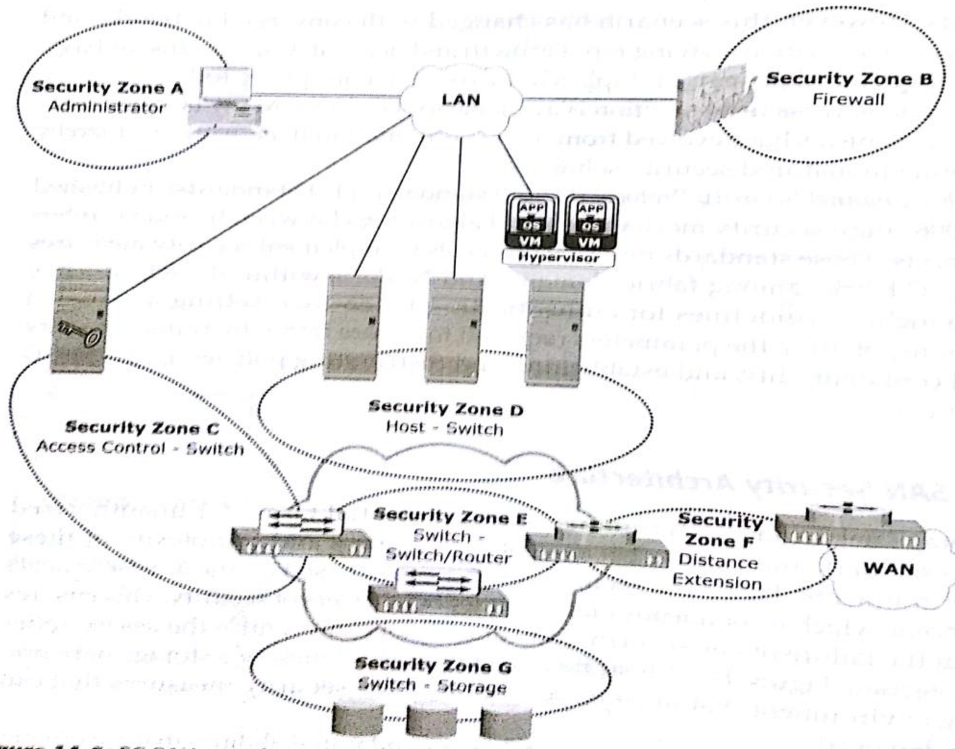
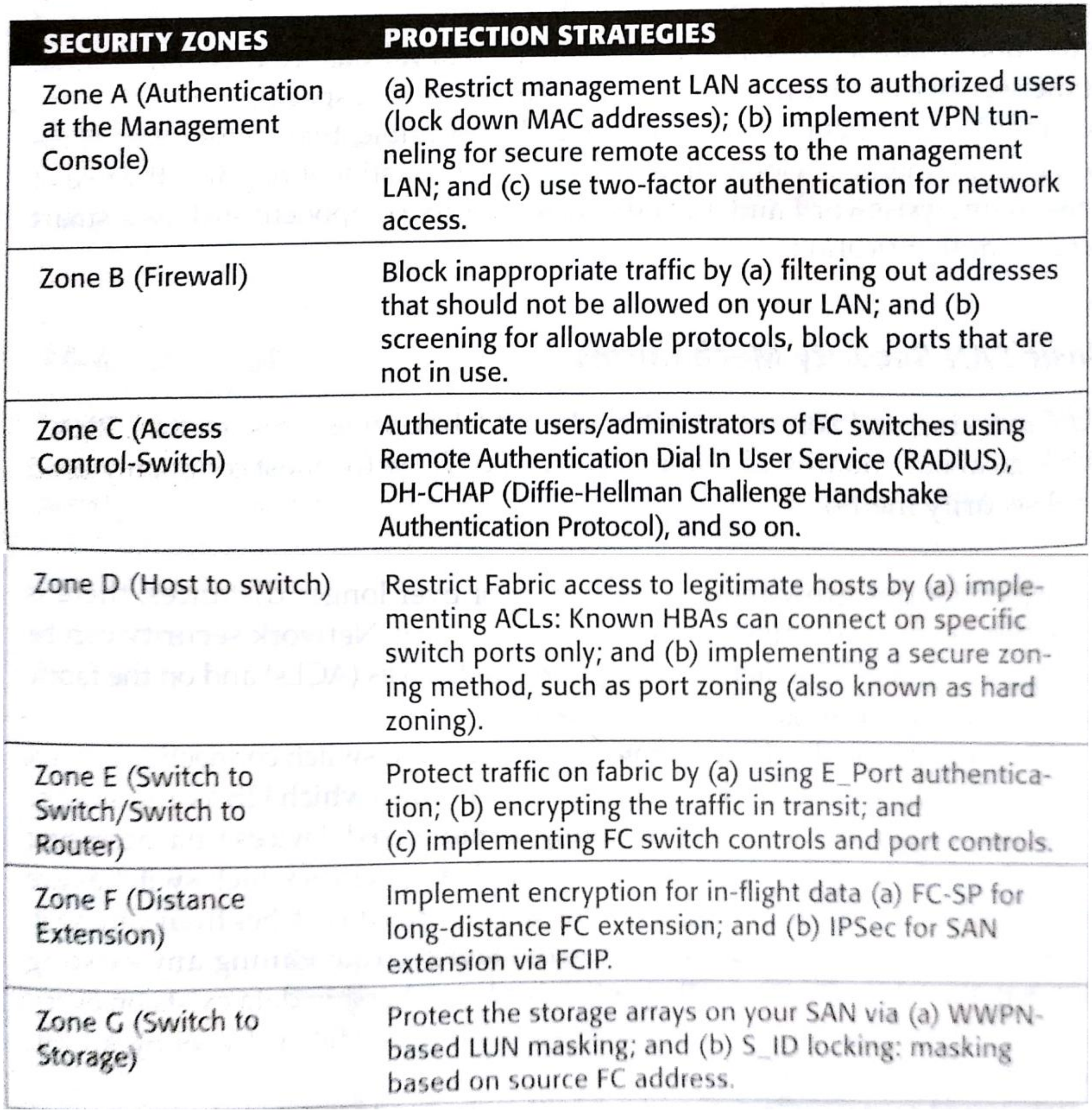


Figure 14-5: FC SAN security architecture

Figure 14-5 illustrates various levels (zones) of a storage networking environment that must be secured and the security measures that can be deployed.

Table 14-1: Security Zones and Protection Strategies



SECURITY ZONES	PROTECTION STRATEGIES
Zone A (Authentication at the Management Console)	(a) Restrict management LAN access to authorized users (lock down MAC addresses); (b) implement VPN tunneling for secure remote access to the management LAN; and (c) use two-factor authentication for network access.
Zone B (Firewall)	Block inappropriate traffic by (a) filtering out addresses that should not be allowed on your LAN; and (b) screening for allowable protocols, block ports that are not in use.
Zone C (Access Control-Switch)	Authenticate users/administrators of FC switches using Remote Authentication Dial In User Service (RADIUS), DH-CHAP (Diffie-Hellman Challenge Handshake Authentication Protocol), and so on.
Zone D (Host to switch)	Restrict Fabric access to legitimate hosts by (a) implementing ACLs: Known HBAs can connect on specific switch ports only; and (b) implementing a secure zoning method, such as port zoning (also known as hard zoning).
Zone E (Switch to Switch/Switch to Router)	Protect traffic on fabric by (a) using E_Port authentication; (b) encrypting the traffic in transit; and (c) implementing FC switch controls and port controls.
Zone F (Distance Extension)	Implement encryption for in-flight data (a) FC-SP for long-distance FC extension; and (b) IPSec for SAN extension via FCIP.
Zone G (Switch to Storage)	Protect the storage arrays on your SAN via (a) WWPN-based LUN masking; and (b) S_ID locking: masking based on source FC address.

Basic SAN Security Mechanisms:

1)*LUN Masking and Zoning:*

- **LUN masking** and **zoning** are the basic SAN security mechanisms used to protect against unauthorized access to storage.
- The standard implementations of LUN masking on storage arrays mask the LUNs presented to a frontend storage port based on the WWPNs of the source HBAs.
- WWPN zoning is the preferred choice in security-conscious environments.

2) Securing Switch Ports:

- Security mechanisms, such as **port binding, port lockdown, port lockout**, and **persistent port disable**, can be implemented on switch ports.
- Port binding limits the number of devices that can attach to a particular switch port and allows only the corresponding switch port to connect to a node for fabric access.
- Port binding mitigates but does not eliminate WWPN spoofing.
- Port lockdown and port lockout restrict a switch port's type of initialization.
- Persistent port disable prevents a switch port from being enabled even after a switch reboot.

3) *Switch-Wide and Fabric-Wide Access Control:*

- Network security can be configured on the FC switch by using **access control lists (ACLs)** and on the fabric by using **fabric binding.**
- ACLs incorporate the device connection control and switch connection control policies.
- The device connection control policy specifies which HBAs and storage ports can be a part of the fabric, preventing unauthorized devices from accessing it.
- Similarly, the switch connection control policy specifies which switches are allowed to be part of the fabric, preventing unauthorized switches from joining it.
- Fabric binding prevents an unauthorized switch from joining any existing switch in the fabric. It ensures that authorized membership data exists on every switch and any attempt to connect any switch in the fabric by using an ISL causes the fabric to segment.
- **Role-based access control** provides additional security to a SAN by preventing unauthorized activity on the fabric for management operations. It enables the security administrator to assign roles to users that explicitly specify privileges or access rights after logging into the fabric.

4) ***Logical Partitioning of a Fabric: Virtual SAN:***

Figure 14-6 depicts logical partitioning in a VSAN.

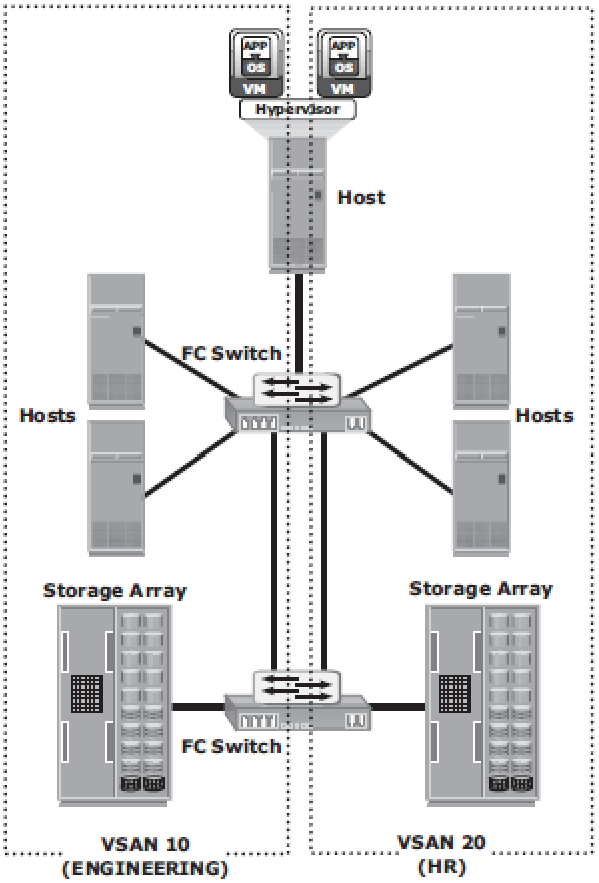


Figure 14-6: Securing SAN with VSAN

The SAN administrator can create distinct VSANs by populating each of them with switch ports. In the example, the switch ports are distributed over two VSANs: 10 and 20 — for the Engineering and HR divisions, respectively. Although they share physical switching gear with other divisions, they can be managed individually as standalone fabrics.

Zoning should be done for each VSAN to secure the entire physical SAN. Each managed VSAN can have only one active zone set at a time.

VSANs minimize the impact of fabricwide disruptive events because management and control traffic on the SAN — which may include RSCNs, zone set activation events, and more — does not traverse VSAN boundaries. Therefore, VSANs are a cost-effective alternative for building isolated physical fabrics. They contribute to information availability and security by isolating fabric events and providing authorization control within a single fabric.

NAS

NAS is open to multiple exploits, including viruses, worms, unauthorized access, snooping, and data tampering. Various security mechanisms are implemented in NAS to secure data and the storage networking infrastructure.

Permissions and ACLs form the first level of protection to NAS resources by restricting accessibility and sharing. These permissions are deployed over and above the default behaviors and attributes associated with files and folders. In addition, various other authentication and authorization mechanisms, such as Kerberos and directory services, are implemented to verify the identity of network users and define their privileges. Similarly, firewalls protect the storage infrastructure from unauthorized access and malicious attacks.

NAS File Sharing: Windows ACLs:

Windows supports two types of ACLs:

1. **discretionary access control lists (DACLs) and**
2. **system access control lists (SACLs).**

The DACL, commonly referred to as the ACL, that determines access control.

The SACL determines what accesses need to be audited if auditing is enabled.

In addition to these ACLs, Windows also supports the concept of object ownership. The owner of an object has hard-coded rights to that object, and these rights do not need to be explicitly granted in the SACL. The owner, SACL, and DACL are all statically held as attributes of each object. Windows also offers the functionality to inherit permissions, which allows the child objects existing within a parent object to automatically inherit the ACLs of the parent object.

ACLs are also applied to directory objects known as security identifiers (**SID**s). These are automatically generated by a Windows server or domain when a user or group is created, and they are abstracted from the user.

In this way, though a user may identify his login ID as “User1,” it is simply a textual representation of the true SID, which is used by the underlying operating system.

Internal processes in Windows refer to an account’s SID rather than the account’s username or group name while granting access to an object. ACLs are set by using the standard Windows Explorer GUI but can also be configured with CLI commands or other third-party tools.

NAS File Sharing: UNIX Permissions

For the UNIX operating system, a user is an abstraction that denotes a logical entity for assignment of ownership and operation privileges for the system. A user can be either a person or a system operation.

A UNIX system is only aware of the privileges of the user to perform specific operations on the system and identifies each user by a user ID (UID) and a username, regardless of whether it is a person, a system operation, or a device.

In UNIX, users can be organized into one or more groups. The concept of group serves the purpose to assign sets of privileges for a given resource and sharing them among many users that need them. For example, a group of people working on one project may need the same permissions for a set of files.

UNIX permissions specify the operations that can be performed by any ownership relation with respect to a file. In simpler terms, these permissions specify what the owner can do, what the owner group can do, and what everyone else can do with the file. For any given ownership relation, three bits are used to specify access permissions. The first bit denotes read (r) access, the second bit denotes write (w) access, and the third bit denotes execute (x) access. Because UNIX defines three ownership relations (Owner, Group, and All), a triplet (defining the access permission) is required for each ownership relationship, resulting in nine bits. Each bit can be either set or clear. When displayed, a set bit is marked by its corresponding operation letter (r, w, or x), a clear bit is denoted by a dash (-), and all are put in a row, such as rwxr-xr-x.

In this example, the owner can do anything with the file, but group owners and the rest of the world can read or execute only. When displayed, a character denoting the mode of the file may precede this nine-bit pattern. For example, if the file is a directory, it is denoted as “d”; and if it is a link, it is denoted as “l.”

NAS File Sharing: Authentication and Authorization:

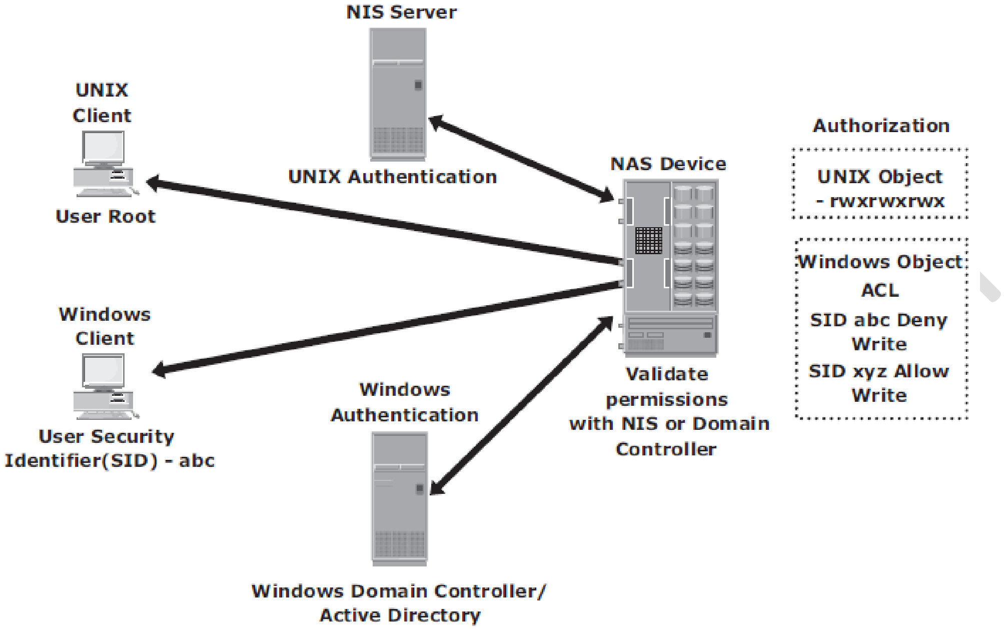


Figure 14-7: Securing user access in a NAS environment

Authentication requires verifying the identity of a network user and therefore involves a login credential lookup on a Network Information System (NIS) server in a UNIX environment. Similarly, a Windows client is authenticated by a Windows domain controller that houses the Active Directory. The Active Directory uses LDAP to access information about network objects in the directory and Kerberos for network security. NAS devices use the same authentication techniques to validate network user credentials. Figure 14-7 depicts the authentication process in a NAS environment.

Authorization defines user privileges in a network. The authorization techniques for UNIX users and Windows users are quite different. UNIX files use mode bits to define access rights granted to owners, groups, and other users, whereas Windows uses an ACL to allow or deny specific rights to a particular user for a particular file.

Complexities arise when UNIX and Windows users access and share the same data. If the NAS device supports multiple protocols, the integrity of both permission methodologies must be maintained. At the same time, validate the domain controller and NIS server connectivity and bandwidth. If multiprotocol access is required, specific vendor access policy implementations need to be considered.

Kerberos

Kerberos is a network authentication protocol, which is designed to provide strong authentication for client/server applications by using secret-key cryptography. It uses cryptography so that a client and server can prove their identity to each other across an insecure network connection. After the client and server have proven their identities, they can choose to encrypt all their communications to ensure privacy and data integrity.

In Kerberos, authentications occur between clients and servers. The client gets a **ticket** for a service and the server decrypts this ticket by using its **secret key**. Any entity, user, or host that gets a service ticket for a Kerberos service is called a **Kerberos client**.

The term Kerberos server generally refers to the **Key Distribution Center (KDC).** The KDC implements the **Authentication Service (AS)** and the **Ticket Granting Service (TGS).** The KDC has a copy of every password associated with every principal, so it is absolutely vital that the KDC remain secure. In Kerberos, users and servers for which a secret key is stored in the KDC database are known as **principals**.

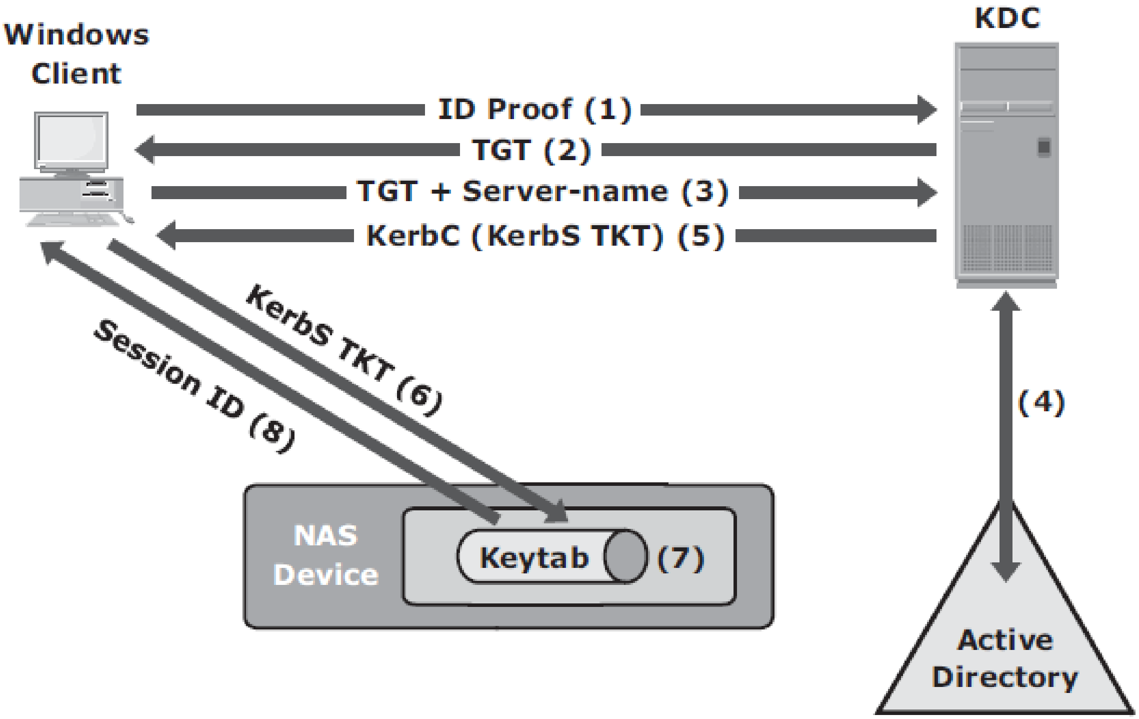


Figure 14-8: Kerberos authorization

The Kerberos authentication process shown in Figure 14-8 includes the following steps:

1. The user logs on to the workstation in the Active Directory domain (or forest) using an ID and a password. The client computer sends a request to the AS running on the KDC for a Kerberos ticket. The KDC verifies the user’s login information from Active Directory. (This step is not explicitly shown in Figure 14-8.)

2. The KDC responds with an encrypted Ticket Granting Ticket (TGT) and an encrypted session key. TGT has a limited validity period. TGT can be decrypted only by the KDC, and the client can decrypt only the session key.

3. When the client requests a service from a server, it sends a request, consisting of the previously generated TGT, encrypted with the session key and the resource information to the KDC.

4. The KDC checks the permissions in Active Directory and ensures that the user is authorized to use that service.

5. The KDC returns a service ticket to the client. This service ticket contains fields addressed to the client and to the server hosting the service.

6. The client then sends the service ticket to the server that houses the required resources.

7. The server, in this case the NAS device, decrypts the server portion of the ticket and stores the information in a keytab file. As long as the client’s Kerberos ticket is valid, this authorization process does not need to be repeated. The server automatically allows the client to access the appropriate resources.

8. A client-server session is now established. The server returns a session ID to the client, which tracks the client activity, such as file locking, as long as the session is active.

Network-Layer Firewalls:

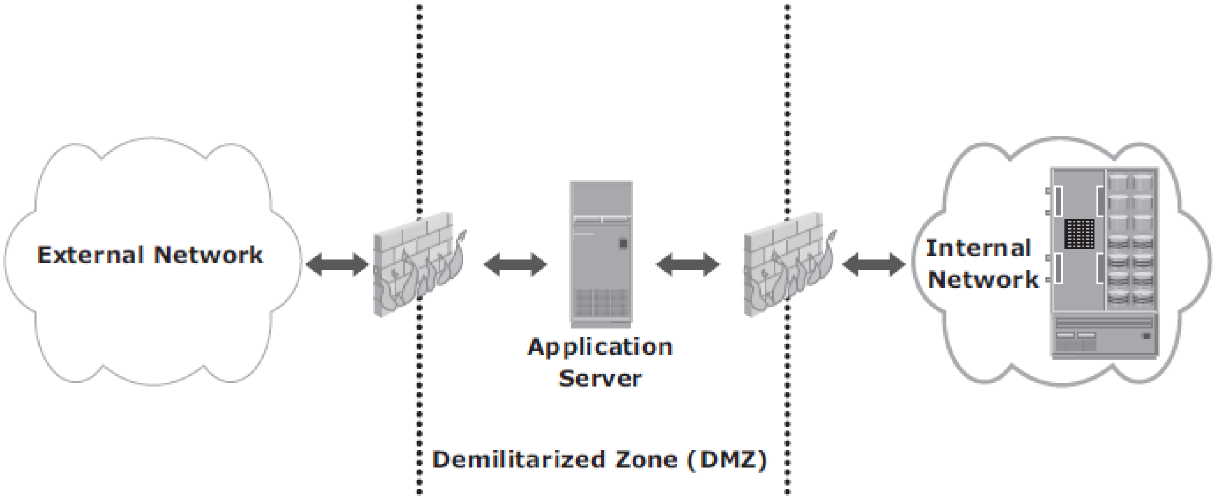


Figure 14-9: Securing a NAS environment with a network-layer firewall

Network layer firewalls are implemented in NAS environments to protect the NAS devices from various attacks initiated through the public IP network.

These network-layer firewalls can examine network packets and compare them to a set of configured security rules. Packets that are not authorized by a security rule are dropped and not allowed to continue to the destination. Rules can be established based on a source address (network or host), a destination address (network or host), a port, or a combination of those factors (source IP, destination IP, and port number). The effectiveness of a firewall depends on how robust and extensive the security rules are. A loosely defined rule set can increase the probability of a security breach.

Figure 14-9 depicts a typical firewall implementation. A demilitarized zone (DMZ) is commonly used in networking environments. A DMZ provides a means to secure internal assets while allowing Internet-based access to various resources. In a DMZ environment, servers that need to be accessed through the Internet are placed between two sets of firewalls. Application-specific ports, such as HTTP or FTP, are allowed through the firewall to the DMZ servers. However, no Internet-based traffic is allowed to penetrate the second set of firewalls and gain access to the internal network.

The servers in the DMZ may or may not be allowed to communicate with internal resources. In such a setup, the server in the DMZ is an Internet-facing web application accessing data stored on a NAS device, which may be located on the internal private network. A secure design would serve only data to internal and external applications through the DMZ.

IP SAN

Challenge-Handshake Authentication Protocol (CHAP):

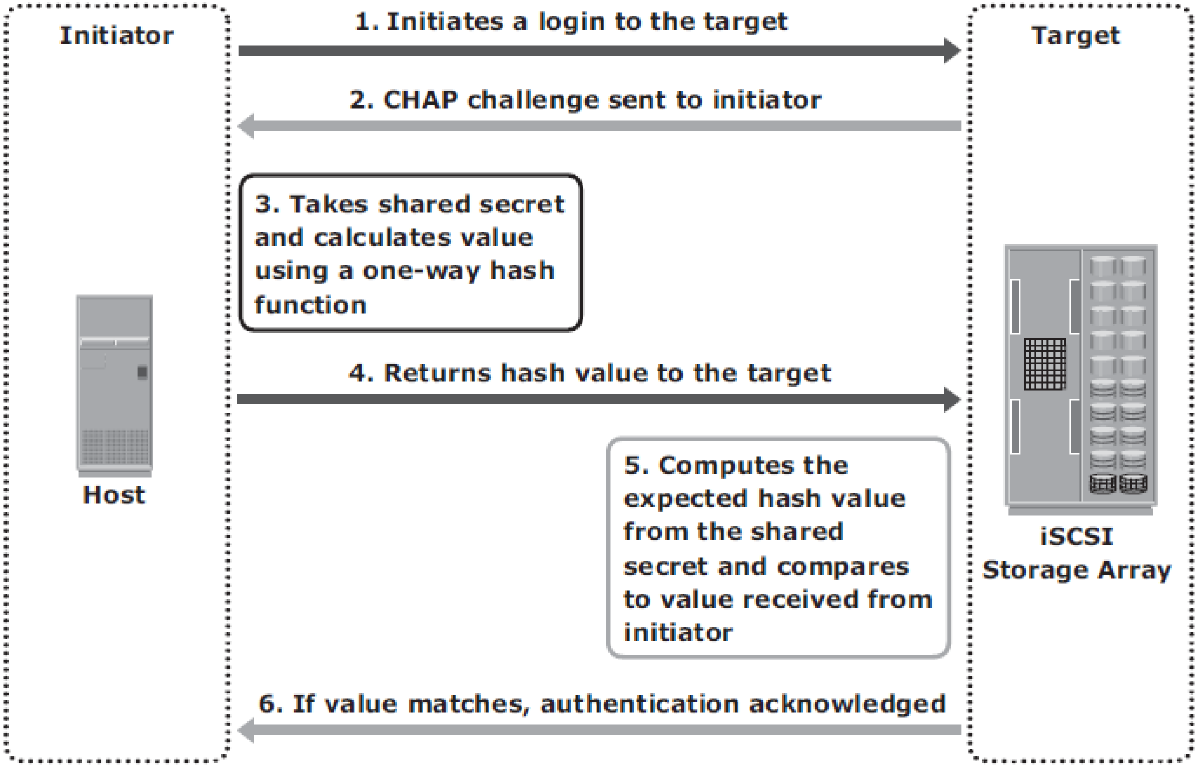

Initiator
Target
1. Initiates a login to the target
2. CHAP challenge sent to initiator
3. Takes shared secret and calculates value using a one-way hash function
4. Returns hash value to the target
5. Computes the expected hash value from the shared secret and compares to value received from initiator
6. If value matches, authentication acknowledged
Host
iSCSI Storage Array

Figure 14-10: Securing IPSAN with CHAP authentication

The Challenge-Handshake Authentication Protocol (CHAP) is a basic authentication mechanism that has been widely adopted by network devices and hosts. CHAP provides a method for initiators and targets to authenticate each other by utilizing a secret code or password. CHAP secrets are usually random secrets of 12 to 128 characters. The secret is never exchanged directly over the communication channel; rather, a one-way hash function converts it into a hash value, which is then exchanged. A hash function, using the MD5 algorithm, transforms data in such a way that the result is unique and cannot be changed back to its original form. Figure 14-10 depicts the CHAP authentication process.

If the initiator requires reverse CHAP authentication, the initiator authenticates the target by using the same procedure. The CHAP secret must be configured on the initiator and the target. A CHAP entry, composed of the name of a node an the secret associated with the node, is maintained by the target and the initiator.

The same steps are executed in a two-way CHAP authentication scenario. After these steps are completed, the initiator authenticates the target. If both authentication steps succeed, then data access is allowed. CHAP is often used because it is a fairly simple protocol to implement and can be implemented across a number of disparate systems.

iSNS discovery domains:

iSNS discovery domains function in the same way as FC zones. Discovery domains provide functional groupings of devices in an IP-SAN. For devices to communicate with one another, they must be configured in the same discovery domain. State change notifications (SCNs) inform the iSNS server when devices are added to or removed from a discovery domain. Figure 14-11 depicts the discovery domains in iSNS.

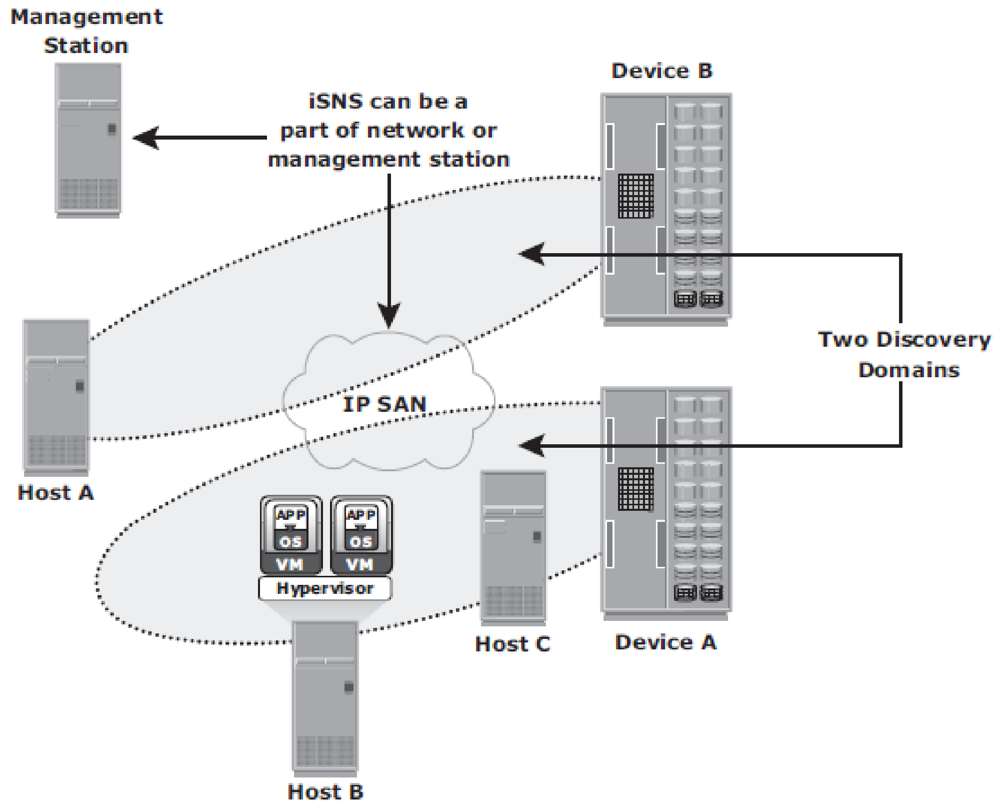


Figure 14-11: Securing IPSAN with iSNS discovery domains

Securing Storage Infrastructure in Virtualized and Cloud Environments:

Security Concerns:

Organizations are rapidly adopting virtualization and cloud computing, however they have some security concerns. These key security concerns are **multitenancy, velocity of attack, information assurance, and data privacy.**

Multitenancy, **by virtue of virtualization, enables multiple independent tenants to be serviced using the same set of storage resources.** In spite of the benefits offered by multitenancy, it is still a key security concern for users and service providers. Colocation of multiple VMs in a single server and sharing the same resources increase the attack surface. It may happen that business critical data of one tenant is accessed by other competing tenants who run applications using the same resources.

Velocity-of-attack refers to a situation in which any existing security threat in the cloud spreads more rapidly and has a larger impact than that in the traditional data center environments. Information assurance for users ensures confidentiality, integrity, and availability of data in the cloud. Also the cloud user needs assurance that all the users operating on the cloud are genuine and access the data only with legitimate rights and scope.

Data privacy is also a major concern in a virtualized and cloud environment. A CSP needs to ensure that Personally Identifiable Information (PII) about its clients is legally protected from any unauthorized disclosure.

Security Measures:

Security measures can be implemented at the compute, network, and storage levels. These security measures implemented at three layers mitigate the risks in virtualized and cloud environments.

Security at the Compute Level:

- Securing a compute infrastructure includes enforcing the security of the physical server, hypervisor, VM, and guest OS (OS running within a virtual machine).
- Physical server security involves implementing user authentication and authorization mechanisms. These mechanisms identify users and provide access privileges on the server.

- To minimize the attack surface on the server, unused hardware components, such as NICs, USB ports, or drives, should be removed or disabled.
- A hypervisor is a single point of security failure for all the VMs running on it. Rootkits and malware installed on a hypervisor make detection difficult for the antivirus software installed on the guest OS.
- To protect against attacks, security-critical hypervisor updates should be installed regularly. Further, the hypervisor management system must also be protected.
- Access to the management system should be restricted to authorized administrators. Furthermore, there must be a separate firewall installed between the management system and the rest of the network.
- **VM isolation and hardening** are some of the common security mechanisms to effectively safeguard a VM from an attack.
- **VM isolation** helps to prevent a compromised guest OS from impacting other guest OSs. VM isolation is implemented at the hypervisor level.
- **Hardening** is a process to change the default configuration to achieve greater security.
- Apart from the measures to secure a hypervisor and VMs, virtualized and cloud environments also require further measures on the guest OS and application levels.

<u>Security at the Network Level:</u>

The key security measures that minimize vulnerabilities at the network layer are firewall, intrusion detection, demilitarized zone (DMZ), and encryption of data-in-flight.

- A **firewall** protects networks from unauthorized access while permitting only legitimate communications. In a virtualized and cloud environment, a firewall can also protect hypervisors and VMs. For example, if remote administration is enabled on a hypervisor, access to all the remote administration interfaces should be restricted by a firewall.
- A firewall also secures VM-to-VM traffic. This firewall service can be provided using a **Virtual Firewall (VF).** A VF is a firewall service running entirely on the hypervisor. A VF provides packet filtering and monitoring of the VM-to-VM traffic. A VF gives visibility and control over the VM traffic and enforces policies at the VM level.
- Intrusion Detection (ID) is the process to detect events that can compromise the confidentiality, integrity, or availability of a resource.
- An **ID System (IDS)** automatically analyzes events to check whether an event or a sequence of events match a known pattern for anomalous activity, or whether it is (statistically) different from most of the other events in the system. It generates an alert if an irregularity is detected.

- **DMZ and data encryption** are also deployed as security measures in the virtualized and cloud environments.

Security at the Storage Level:

Major threats to storage systems in virtualized and cloud environments arise due to compromises at compute, network, and physical security levels. This is because access to storage systems is through compute and network infrastructure. Therefore, adequate security measures should be in place at the compute and network levels to ensure storage security.

Common security mechanisms that protect storage include the following:

- Access control methods to regulate which users and processes access the data on the storage systems
- Zoning and LUN masking
- Encryption of data-at-rest (on the storage system) and data-in-transit. Data encryption should also include encrypting backups and storing encryption keys separately from the data.
- Data shredding that removes the traces of the deleted data

Apart from these mechanisms, isolation of different types of traffic using VSANs further enhances the security of storage systems. In the case of storage utilized by hypervisors, additional security steps are required to protect the storage. Storage for hypervisors using clustered file systems supporting multiple VMs may require separate LUNs for VM components and VM data.

Monitoring the Storage Infrastructure

Monitoring Parameters:

Storage infrastructure components should be monitored for **accessibility, capacity, performance, and security.**

Accessibility refers to the availability of a component to perform its desired operation during a specified time period. Monitoring the accessibility of hardware components (for example, a port, an HBA, or a disk drive) or software component (for example, a database) involves checking their availability status by reviewing the alerts generated from the system. For example, a port failure might result in a chain of availability alerts.

A storage infrastructure uses redundant components to avoid a single point of failure. Failure of a component might cause an outage that affects application availability, or it might cause performance degradation even though accessibility is not compromised. Continuously monitoring for expected accessibility of each component and reporting any deviation helps the administrator to identify failing components and plan corrective action to maintain SLA requirements.

Capacity refers to the amount of storage infrastructure resources available. Examples of capacity monitoring include examining the free space available on a file system or a RAID group, the mailbox quota allocated to users, or the numbers of ports available on a switch. Inadequate capacity leads to degraded performance or even application/service unavailability.

Capacity monitoring ensures uninterrupted data availability and scalability by averting outages before they occur. For example, if 90 percent of the ports are utilized in a particular SAN fabric, this could indicate that a new switch might be required if more arrays and servers need to be installed on the same fabric.

Capacity monitoring usually leverages analytical tools to perform trend analysis. These trends help to understand future resource requirements and provide an estimation on the time line to deploy them.

Performance monitoring evaluates how efficiently different storage infrastructure components are performing and helps to identify bottlenecks. Performance monitoring measures and analyzes behavior in terms of response time or the ability to perform at a certain predefined level. It also deals with the utilization of resources, which affects the way resources behave and respond.

Performance measurement is a complex task that involves assessing various components on several interrelated parameters. The number of I/Os performed by a disk, application response time, network utilization, and server-CPU utilization are examples of performance parameters that are monitored.

Monitoring a storage infrastructure for security helps to track and prevent unauthorized access, whether accidental or malicious. **Security monitoring helps to track unauthorized configuration changes to storage infrastructure resources.** For example, security monitoring tracks and reports the initial zoning configuration performed and all the subsequent changes. Security monitoring also detects unavailability of information to authorized users due to a security breach. Physical security of a storage infrastructure can also be continuously monitored using badge readers, biometric scans, or video cameras.

Components Monitored:

Hosts:

The accessibility of a host depends on the availability status of the hardware components and the software processes running on it. For example, a host's NIC failure might cause inaccessibility of the host to its user. Server clustering is a mechanism that provides high availability if a server failure occurs.

Monitoring the file system capacity utilization of a host is important to ensure that sufficient storage capacity is available to the applications. Running out of file system space disrupts application availability.

Monitoring helps estimate the file system's growth rate and predict when it will reach 100 percent. Accordingly, the administrator can extend (manually or automatically) the file system's space proactively to prevent application outage. Use of virtual provisioning technology enables efficient management of storage capacity requirements but is highly dependent on capacity monitoring.

Host performance monitoring mainly involves a status check on the utilization of various server resources, such as CPU and memory. For example, if a server running an application is experiencing 80 percent of CPU utilization continuously, it indicates that the server may be running out of processing power, which can lead to degraded performance and slower response time.

Administrators can take several actions to correct the problem, such as upgrading or adding more processors and shifting the workload to different servers. In a virtualized environment, additional CPU and memory may be allocated to VMs dynamically from the pool, if available, to meet performance requirements.

Security monitoring on servers involves tracking of login failures and execution of unauthorized applications or software processes. Proactive measures against unauthorized access to the servers are based on the threat identified. For example, an administrator can block user access if multiple login failures are logged.

Storage Network:

Storage networks need to be monitored to ensure uninterrupted communication between the server and the storage array. Uninterrupted access to data over the storage network depends on the accessibility of the physical and logical components of the storage network. The physical components of a storage network include switches, ports, and cables. The logical components include constructs, such as zones. Any failure in the physical or logical components causes data unavailability. For example, errors in zoning, such as specifying the wrong WWN of a port, result in failure to access that port, which potentially prevents access from a host to its storage.

Capacity monitoring in a storage network involves monitoring the number of available ports in the fabric, the utilization of the inter-switch links, or individual ports, and each interconnect device in the fabric. Capacity monitoring provides all the required inputs for future planning and optimization of fabric resources.

Monitoring the performance of the storage network enables assessing individual component performance and helps to identify network bottlenecks. For example, monitoring port performance involves measuring the receive or transmit link utilization metrics, which indicates how busy the switch port is. Heavily used ports can cause queuing of I/Os on the server, which results in poor performance.

For IP networks, monitoring the performance includes monitoring network latency, packet loss, bandwidth utilization for I/O, network errors, packet retransmission rates, and collisions.

Storage network security monitoring provides information about any unauthorized change to the configuration of the fabric — for example, changes to the zone policies that can affect data security. Login failures and unauthorized access to switches for performing administrative changes should be logged and monitored continuously.

<u>Storage:</u>

The accessibility of the storage array should be monitored for its hardware components and various processes. Storage arrays are typically configured with redundant components, and therefore individual component failure does not usually affect their accessibility. However, failure of any process in the storage array might disrupt or compromise business operations. For example, the failure of a replication task affects disaster recovery capabilities. Some storage arrays provide the capability to send messages to the vendor's support center if hardware or process failures occur, referred to as a call home.

Capacity monitoring of a storage array enables the administrator to respond to storage needs preemptively based on capacity utilization and consumption trends. Information about unconfigured and unallocated storage space enables the administrator to decide whether a new server can be allocated storage capacity from the storage array.

A storage array can be monitored using a number of performance metrics, such as utilization rates of the various storage array components, I/O response time, and cache utilization. For example, an over utilized storage array component might lead to performance degradation.

A storage array is usually a shared resource, which may be exposed to security threats. **Monitoring security helps to track unauthorized configuration of the storage array and ensures that only authorized users are allowed to access it.**

Accessibility Monitoring Example:

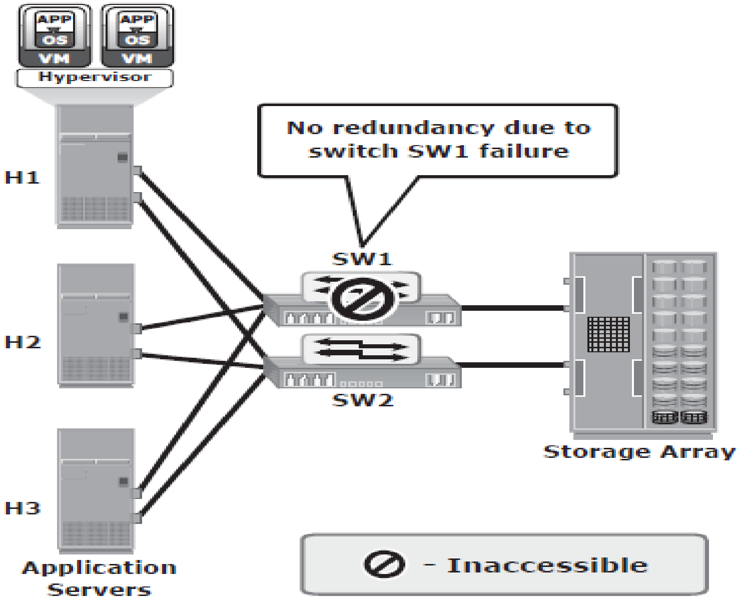


Figure 15-1: Switch failure in a storage infrastructure

Failure of any component might affect the accessibility of one or more components due to their interconnections and dependencies. Consider an implementation in a storage infrastructure with three servers: H1, H2, and H3.

All the servers are configured with two HBAs, each connected to the production storage array through two switches, SW1 and SW2, as shown in Figure 15-1. All the servers share two storage ports on the storage array and multipathing software is installed on all the servers.

If one of the switches (SW1) fails, the multipathing software initiates a path failover, and all the servers continue to access data through the other switch, SW2. However, due to the absence of a redundant switch, a second switch failure could result in inaccessibility of the array.

Monitoring for accessibility enables detecting the switch failure and helps an administrator to take corrective action before another failure occurs. In most cases, the administrator receives symptom alerts for a failing component and can initiate actions before the component fails.

Capacity Monitoring Example:

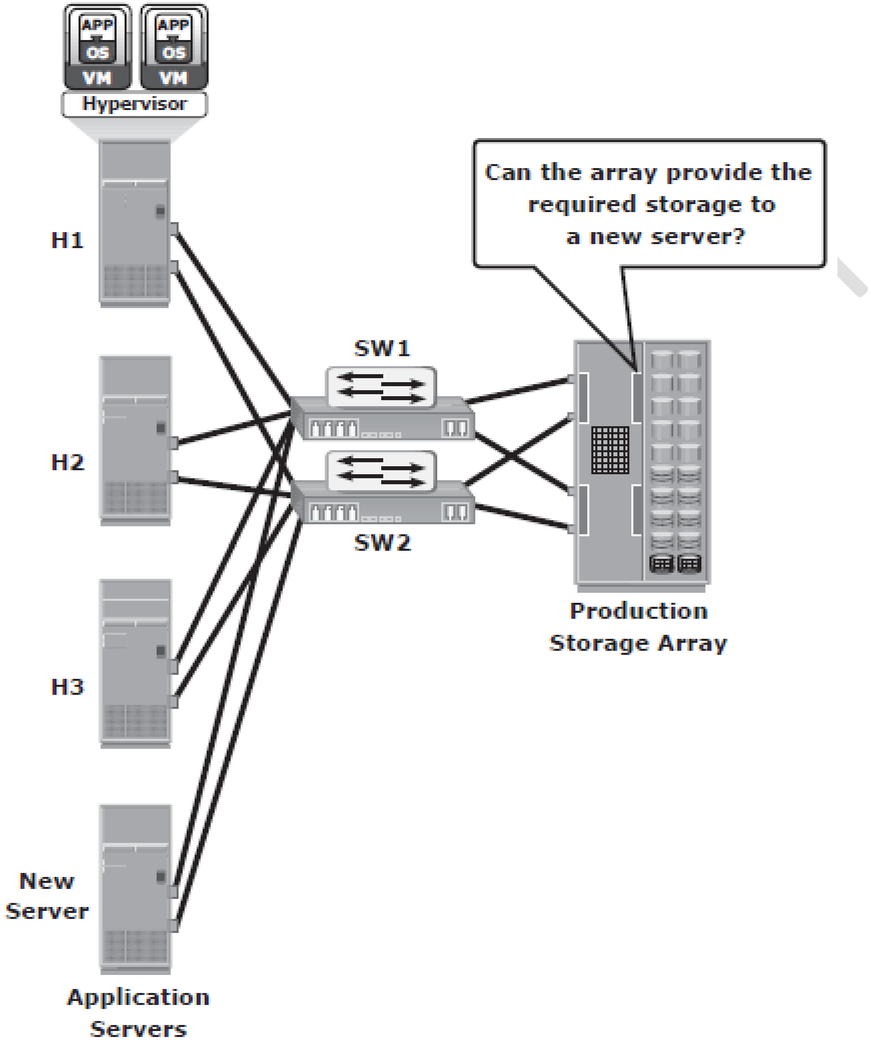


Figure 15-2: Monitoring storage array capacity

In the scenario shown in Figure 15-2, servers H1, H2, and H3 are connected to the production array through two switches, SW1 and SW2. Each of the servers is allocated storage on the storage array. When a new server is deployed in this configuration, the applications on the new server need to be given storage capacity from the production storage array.

Monitoring the available capacity (configurable and unallocated) on the array helps to proactively decide whether the array can provide the required storage to the new server. Also, monitoring the available number of ports on SW1 and SW2 helps to decide whether the new server can be connected to the switches.

The following example illustrates the importance of monitoring the file system capacity on file servers. Figure 15-3 (a) illustrates the environment of a file system when full and that results in application outage when no capacity monitoring is implemented.

Monitoring can be configured to issue a message when thresholds are reached on the file system capacity. For example, when the file system reaches 66 percent of its capacity, a warning message is issued, and a critical message is issued when the file system reaches 80 percent of its capacity (see Figure 15-3 [b]). This enables the administrator to take action to extend the file system before it runs out of capacity. Proactively monitoring the file system can prevent application outages caused due to lack of file system space.

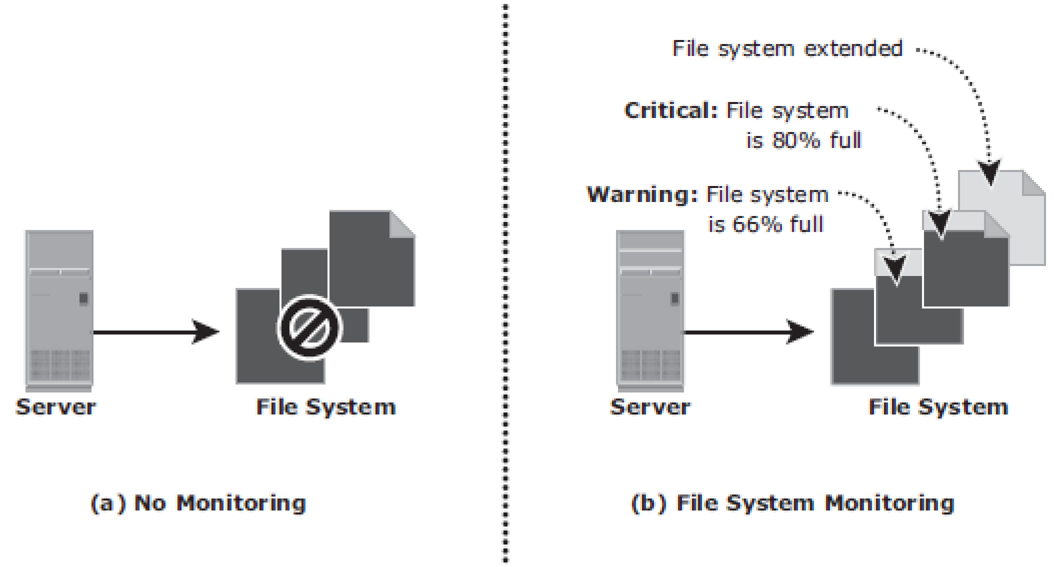

File system extended
Critical: File system is 80% full
Warning: File system is 66% full
Server
File System
Server
File System
(a) No Monitoring
(b) File System Monitoring

Figure 15-3: Monitoring server file system space

Performance Monitoring Example:

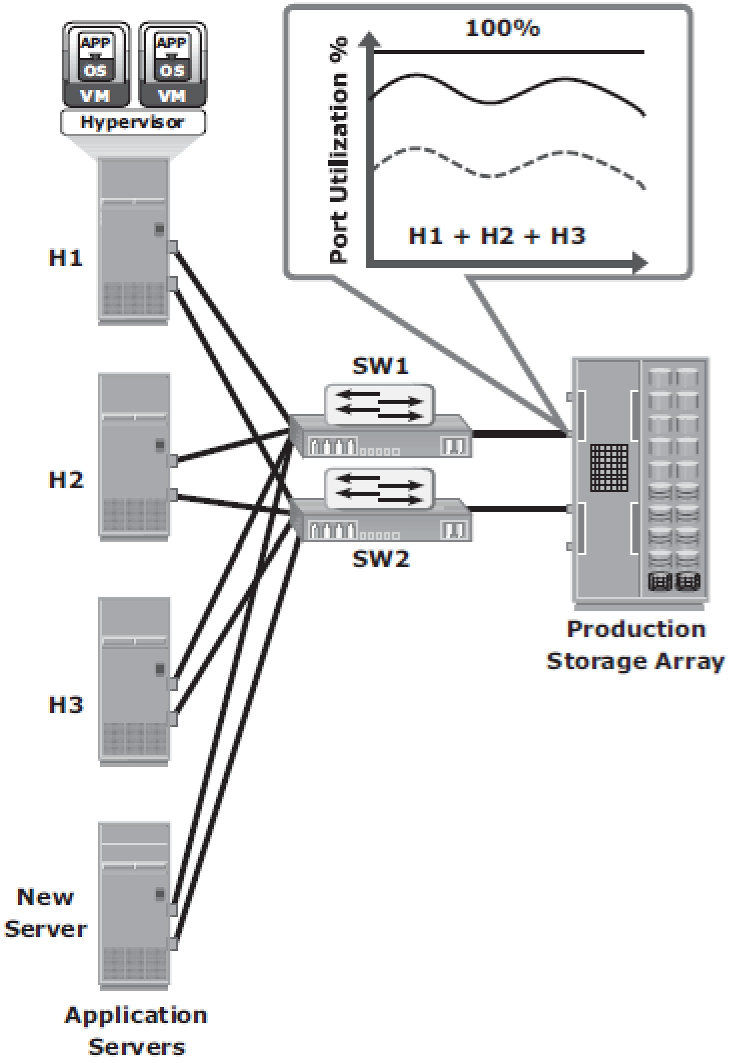


Figure 15-4: Monitoring array port utilization

The example shown in Figure 15-4 illustrates the importance of monitoring performance on storage arrays. In this example, servers H1, H2, and H3 (with two HBAs each) are connected to the storage array through switch SW1 and SW2. The three servers share the same storage ports on the storage array to access LUNs. A new server running an application with a high work load must be deployed to share the same storage port as H1, H2, and H3.

Monitoring array port utilization ensures that the new server does not adversely affect the performance of the other servers. In this example, utilization of the shared storage port is shown by the solid and dotted lines in the graph. If the port utilization prior to deploying the new server is close to 100 percent, then deploying the new server is not recommended because it might impact the performance of the other servers. However, if the utilization of the port prior to deploying the new server is closer to the dotted line, then there is room to add a new server.

Security Monitoring Example:

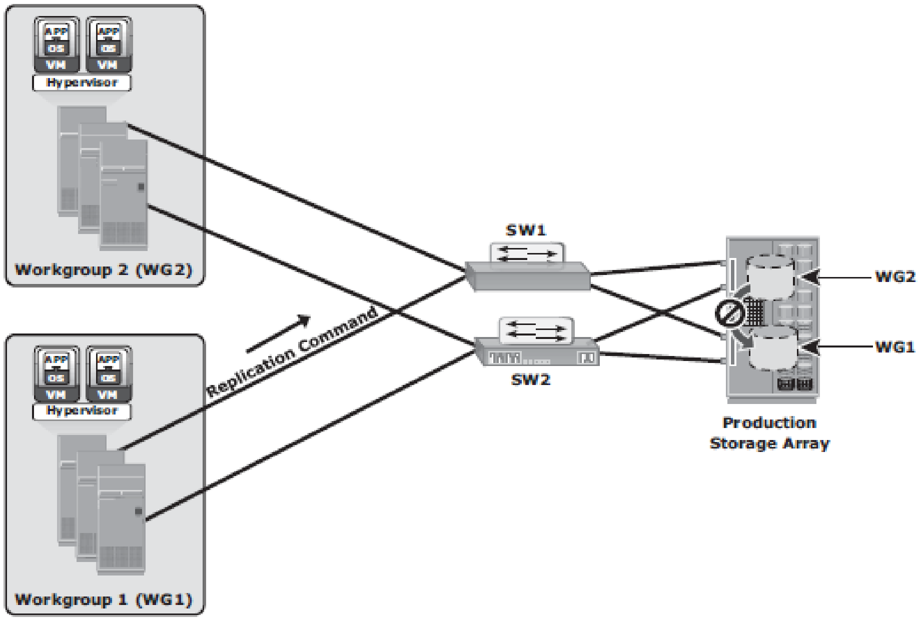


Figure 15-6: Monitoring security in a storage array

The example shown in Figure 15-6 illustrates the importance of monitoring security in a storage array.In this example, the storage array is shared between two workgroups, WG1 and WG2. The data of WG1 should not be accessible to WG2 and vice versa. A user from WG1 might try to make a local replica of the data that belongs to WG2. If this action is not monitored or recorded, it is difficult to track such a violation of information security. Conversely, if this action is monitored, a warning message can be sent to prompt a corrective action or at least enable discovery as part of regular auditing operations.

An example of host security monitoring is tracking of login attempts at the host. The login is authorized if the login ID and password entered are correct; or the login attempt fails. These login failures might be accidental (mistyping) or a deliberate attempt to access a server. Many servers usually allow a fixed number of successive login failures, prohibiting any additional attempts after these login failures. In a monitored environment, the login information is recorded in a system log file, and three successive login failures trigger a message, warning of a possible security threat.

Alerts:

Alerting of events is an integral part of monitoring. Alerting keeps administrators informed about the status of various components and processes — for example, conditions such as failure of power, disks, memory, or switches, which can impact the availability of services and require immediate administrative attention. Other conditions, such as a file system reaching a capacity threshold or a soft media error on disks, are considered warning signs and may also require administrative attention.

Monitoring tools enable administrators to assign different severity levels based on the impact of the alerted condition. Whenever a condition with a particular severity level occurs, an alert is sent to the administrator, a script is triggered, or an incident ticket is opened to initiate a corrective action.

Alert classifications can range from information alerts to fatal alerts.

Information alerts provide useful information but do not require any intervention by the administrator. The creation of a zone or LUN is an example of an information alert. Warning alerts require administrative attention so that the alerted condition is contained and does not affect accessibility. For example, if an alert indicates that the number of soft media errors on a disk is approaching a predefined threshold value, the administrator can decide whether the disk needs to be replaced.

Fatal alerts require immediate attention because the condition might affect overall performance, security, or availability. For example, if a disk fails, the administrator must ensure that it is replaced quickly.

Continuous monitoring, with automated alerting, enables administrators to respond to failures quickly and proactively. Alerting provides information that helps administrators prioritize their response to events.

Storage Infrastructure Management Activities:

1) Availability Management:

A critical task in availability management is establishing a proper guideline based on defined service levels to ensure availability. **Availability management involves all availability-related issues for components or services to ensure that service levels are met.**

A key activity in availability management is to provision redundancy at all levels, including components, data, or even sites.

For example, when a server is deployed to support a critical business function, it requires high availability. This is generally accomplished by deploying two or more HBAs, multipathing software, and server clustering. The server must be connected to the storage array using at least two independent fabrics and switches that have built-in redundancy. In addition, the storage arrays should have built-in redundancy for various components and should support local and remote replication.

2) Capacity Management:

The goal of capacity management is to ensure adequate availability of resources based on their service level requirements. Capacity management also involves optimization of capacity based on the cost and future needs.

Capacity management provides capacity analysis that compares allocated storage to forecasted storage on a regular basis. It also provides trend analysis based on the rate of consumption, which must be rationalized against storage acquisition and deployment timetables.

Storage provisioning is an example of capacity management. It involves activities, such as creating RAID sets and LUNs, and allocating them to the host. Enforcing capacity quotas for users is another example of capacity management. Provisioning a fixed amount of user quotas restricts users from exceeding the allocated capacity.

Technologies, such as data deduplication and compression, have reduced the amount of data to be backed up and thereby reduced the amount of storage capacity to be managed.

3) Performance Management:

Performance management ensures the optimal operational efficiency of all components.

Performance analysis is an important activity that helps to identify the performance of storage infrastructure components. This analysis provides information on whether a component meets expected performance levels.

Several performance management activities need to be performed when deploying a new application or server in the existing storage infrastructure. Every component must be validated for adequate performance capabilities as defined by the service levels. For example, to optimize the expected performance levels, activities on the server, such as the volume configuration, database design or application layout, configuration of multiple HBAs, and intelligent multipathing software, must be fine-tuned.

The performance management tasks on a SAN include designing and implementing sufficient ISLs in a multiswitch fabric with adequate bandwidth to support the required performance levels. The storage array configuration tasks include selecting the appropriate RAID type, LUN layout, front-end ports, back-end ports, and cache configuration, when considering the end-to-end performance.

4) <u>Security Management:</u>

The key objective of the security management activity is to ensure confidentiality, integrity, and availability of information in both virtualized and nonvirtualized environments.

Security management prevents unauthorized access and configuration of storage infrastructure components. For example, while deploying an application or a server, the security management tasks include managing the user accounts and access policies that authorize users to perform role-based activities. The security management tasks in a SAN environment include configuration of zoning to restrict an unauthorized HBA from accessing specific storage array ports. Similarly, the security management task on a storage array includes LUN masking that restricts a host’s access to intended LUNs only.

5) <u>Reporting:</u>

Reporting on a storage infrastructure involves keeping track and gathering information from various components and processes. This information is compiled to generate reports for trend analysis, capacity planning, chargeback, and performance.

Capacity planning reports contain current and historic information about the utilization of storage, file systems, database table space, ports, and so on. Configuration and asset management reports include details about device allocation, local or remote replicas, and fabric configuration.

This report also lists all the equipment, with details, such as their purchase date, lease status, and maintenance records.

Chargeback reports contain information about the allocation or utilization of storage infrastructure components by various departments or user groups.

Performance reports provide details about the performance of various storage infrastructure components.

Storage Infrastructure Management in a Virtualized Environment:

Storage virtualization has enabled **dynamic migration of data and extension of storage volumes**. Due to dynamic extension, storage volumes can be expanded non-disruptively to meet both capacity and performance requirements. Because virtualization breaks the bond between the storage volumes presented to the host and its physical storage, data can be migrated both within and across data centers without any downtime. This has made the administrator’s tasks easier while reconfiguring the physical environment.

Virtual storage provisioning is another tool that has changed the infrastructure management cost and complexity scenario. In conventional provisioning, storage capacity is provisioned upfront in anticipation of future growth. Because growth is uneven, some users or applications find themselves running out of capacity, whereas others have excess capacity that remains underutilized. Use of virtual provisioning can address this challenge and make capacity management less challenging. In virtual provisioning, storage is allocated from the shared pool to hosts on-demand. This improves the storage capacity utilization, and thereby reduces capacity management complexities.

Virtualization has also contributed to network management efficiency. **VSANs and VLANs** made the administrator’s job easier by isolating different networks logically using management tools rather than physically separating them.

Disparate virtual networks can be created on a single physical network, and reconfiguration of nodes can be done quickly without any physical changes. It has also addressed some of the security issues that might exist in a conventional environment.

On the host side, compute virtualization has made host deployment, reconfiguration, and migration easier than physical environment**. Compute, application, and memory virtualization have not only improved provisioning, but also contributed to the high availability of resources.**

Storage Management Examples:

Example 1: Storage Allocation to a New Server/Host:

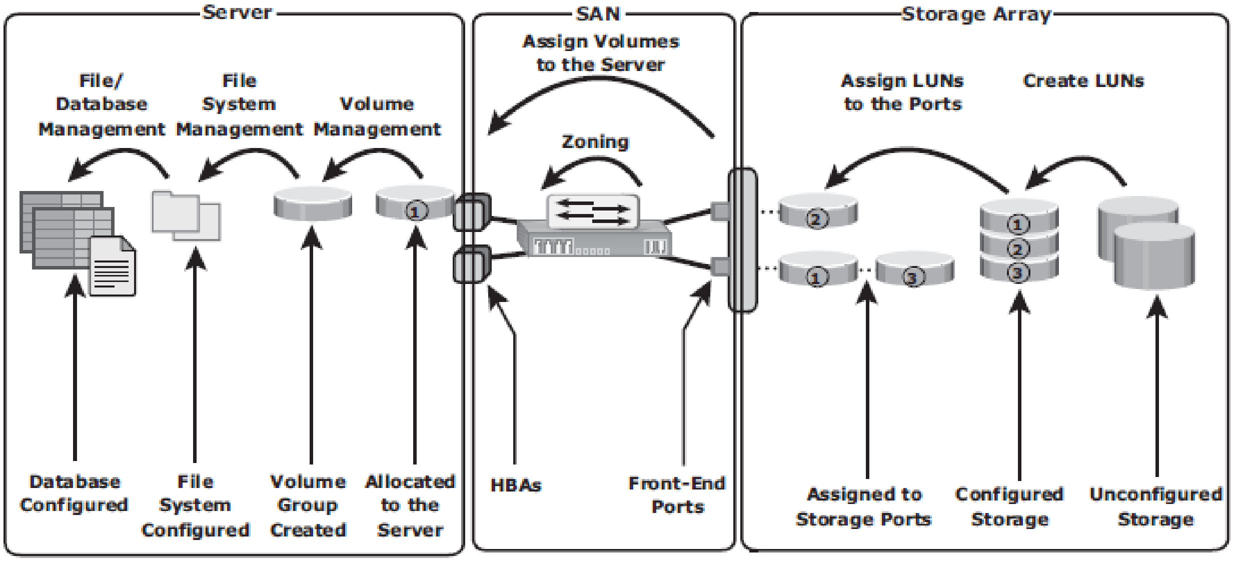


Figure 15-7: Storage allocation tasks

Consider the deployment of a new RDBMS server to the existing nonvirtualized storage infrastructure. As a part of storage management activities, first, the administrator needs to install and configure the HBAs and device drivers on the server before it is physically connected to the SAN.

As the next step, the administrator needs to perform zoning on the SAN switches to allow the new server access to the storage array ports via its HBAs.

Further, the administrator needs to configure LUNs on the array and assign these LUNs to the storage array front-end ports.

The server then discovers the LUNs assigned to it by either a bus rescan process or sometimes through a server reboot, depending upon the operating system installed.

A volume manager may be used to configure the logical volumes and file systems on the host. The number of logical volumes or file systems to be created depends on how a database or an application is expected to use the storage.

The administrator's task also includes installation of a database or an application on the logical volumes or file systems that were created.

The last step is to make the database or application capable of using the new file system space. Figure 15-7 illustrates the activities performed on a server, a SAN, and a storage array for the allocation of storage to a new server.

Example 2: File System Space Management:

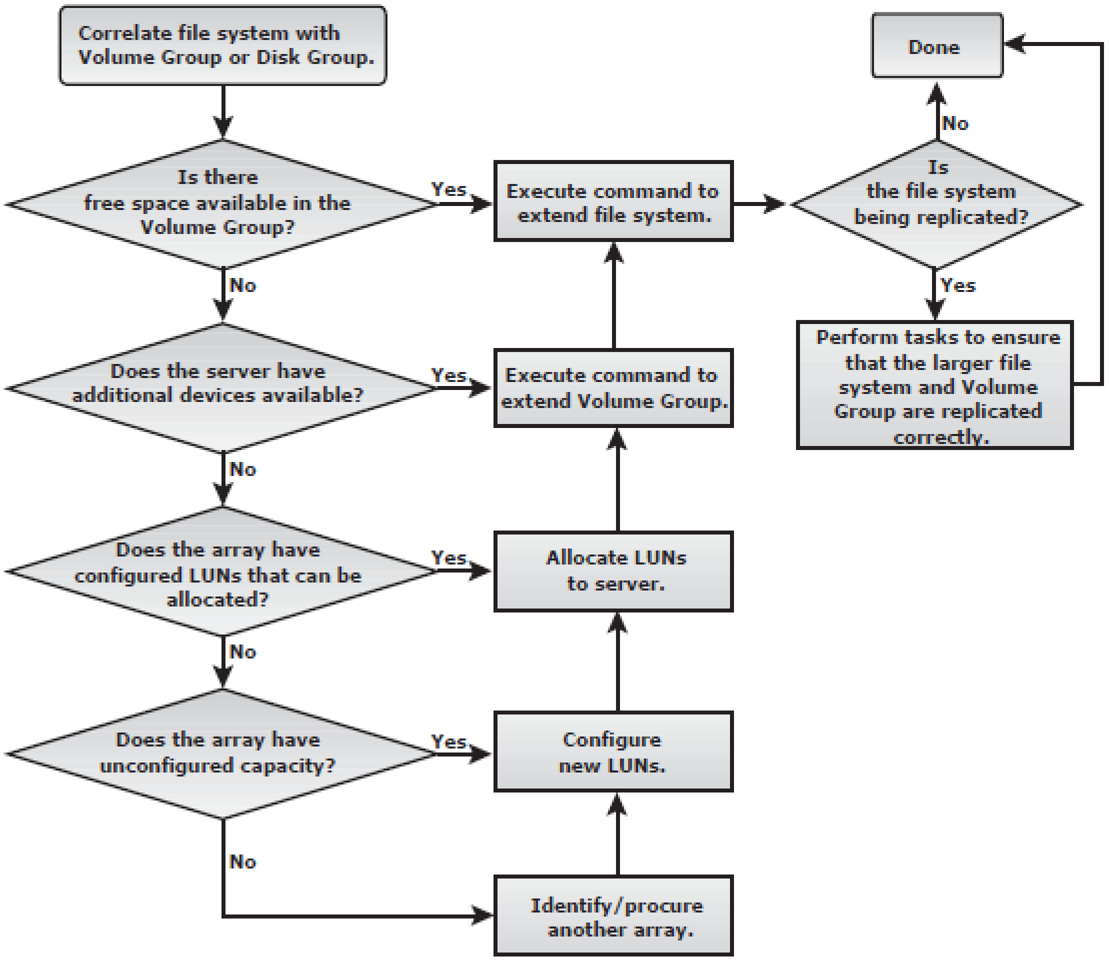
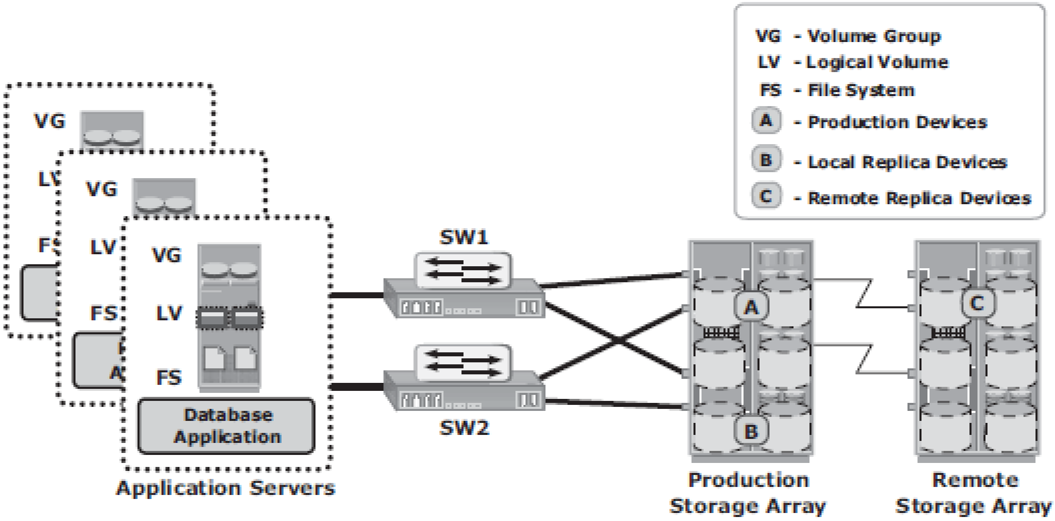

Correlate file system with Volume Group or Disk Group.
Is there free space available in the Volume Group?
Yes
No
Execute command to extend file system.
Is the file system being replicated?
No
Done
Yes
Perform tasks to ensure that the larger file system and Volume Group are replicated correctly.
Does the server have additional devices available?
Yes
No
Execute command to extend Volume Group.
Does the array have configured LUNs that can be allocated?
Yes
No
Allocate LUNs to server.
Does the array have unconfigured capacity?
Yes
No
Configure new LUNs.
Identify/procure another array.

Figure 15-8: Extending a file system

The dynamic extension of file systems or a logical volume depends on the operating system or the logical volume manager (LVM) in use.

Figure 15-8 shows the steps and considerations for the extension of file systems in the flow chart.

Example 3: Chargeback Report:



Application	Storage (GB)	Production Storage Raw (GB)	Local Replica Storage Raw (GB)	Remote Replica Storage Raw (GB)	Total Storage Raw (GB)	Chargeback Cost $ 5/Raw (GB)
Payroll_1	100	200	100	125	425	$ 2125
Engineering_1	200	250	200	250	700	$ 3500

Figure 15-9: Chargeback report

Chargeback reports are used by data center administrators to ensure that storage consumers are well aware of the costs of the services that they have requested Figure 15-9 shows a configuration deployed in a storage infrastructure. Three servers with two HBAs each connect to a storage array via two switches, SW1 and SW2.

Individual departmental applications run on each of the servers. Array replication technology is used to create local and remote replicas. The production device is represented as A, the local replica device as B, and the remote replica device as C.

A report documenting the exact amount of storage resources used by each application is created using a chargeback analysis for each department. If the unit for billing is based on the amount of raw storage (usable capacity plus protection provided) configured for an application used by a department, the exact amount of raw space configured must be reported for each application. Figure 15-9 shows a sample report. The report shows the information for two applications, Payroll_1 and Engineering_1.

Storage Infrastructure Management Challenges:

Monitoring and managing today's complex storage infrastructure is challenging. This is **due to the heterogeneity of storage arrays, networks, servers, databases, and applications in the environment.** For example, heterogeneous storage arrays vary in their capacity, performance, protection, and architectures.

Each of the components in a data center typically comes with vendor-specific tools for management. **An environment with multiple tools makes understanding the overall status of the environment challenging because the tools maynot be interoperable.** Ideally, management tools should correlate information from all components in one place. Such tools provide an end-to-end view of the environment, and a quicker root cause analysis for faster resolution to alerts.

Information Lifecycle Management:

Information Lifecycle Management (ILM) is a proactive strategy that enables an IT organization to effectively manage information throughout its life cycle based on predefined business policies.

From data creation to data deletion, ILM aligns the business requirements and processes with service levels in an automated fashion. This allows an IT organization to optimize the storage infrastructure for maximum return on investment. Implementing an ILM strategy has the following key benefits that directly address the challenges of information management:

- **Lower Total Cost of Ownership (TCO):** By aligning the infrastructure and management costs with information value. As a result, resources are not wasted, and complexity is not introduced by managing low-value data at the expense of high-value data.
- **Simplified management:** By integrating process steps and interfaces with individual tools and by increasing automation
- **Maintaining compliance:** By knowing what data needs to be protected for what length of time
- **Optimized utilization:** By deploying storage tiering

For example, in a sales order application, the value of the information (customer data) changes from the time the order is placed until the time that the warranty becomes void (see Figure 15-11). The value of the information is highest when a company receives a new sales order and processes it to deliver the product. After the order fulfillment, the customer data does not need to be available for real-time access. The company can transfer this data to less expensive secondary storage with lower performance until a warranty claim or another event triggers its need. After the warranty becomes void, the company can dispose of the information.

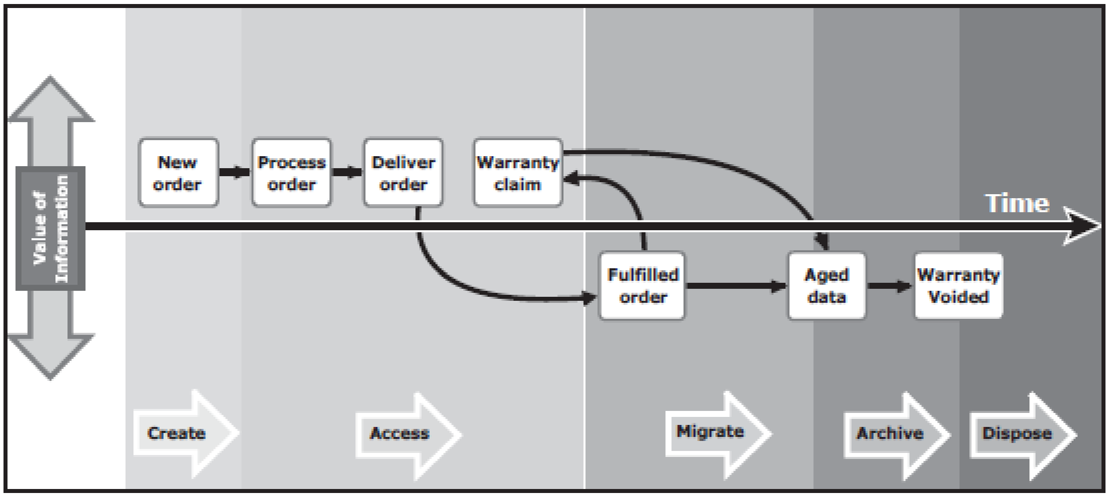


Figure 15-11: Changing value of sales order information

The following are the key challenges that exist in today's data centers:

- **Exploding digital universe:** The rate of information growth is increasing exponentially. Creating copies of data to ensure high availability and repurposing has contributed to the multifold increase of information growth.
- **Increasing dependency on information:** The strategic use of information plays an important role in determining the success of a business and provides competitive advantages in the marketplace.
- **Changing value of information:** Information that is valuable today might become less important tomorrow. The value of information often changes over time.

Storage Tiering:

Storage tiering is a technique of establishing a hierarchy of different storage types (tiers). This enables storing the right data to the right tier, based on service level requirements, at a minimal cost.

Each tier has different levels of protection, performance, and cost. For example, high performance solidstate drives (SSDs) or FC drives can be configured as tier 1 storage to keep frequently accessed data, and low cost SATA drives as tier 2 storage to keep the less frequently accessed data. Keeping frequently used data in SSD or FC improves application performance. Moving less-frequently accessed data to SATA can free up storage capacity in high performance drives and reduce the cost of storage. This movement of data happens based on defined tiering policies.

The tiering policy might be based on parameters, such as file type, size, frequency of access, and so on. For example, if a policy states “Move the files that are not accessed for the last 30 days to the lower tier,” then all the files matching this condition are moved to the lower tier.

Storage tiering can be implemented as a manual or an automated process.

Manual storage tiering is the traditional method where the storage administrator monitors the storage workloads periodically and moves the data between the tiers. Manual storage tiering is complex and time-consuming.

Automated storage tiering automates the storage tiering process, in which data movement between the tiers is performed nondisruptively. In automated storage tiering, the application workload is proactively monitored; the active data is automatically moved to a higher performance tier and the inactive data to a higher capacity, lower performance tier.

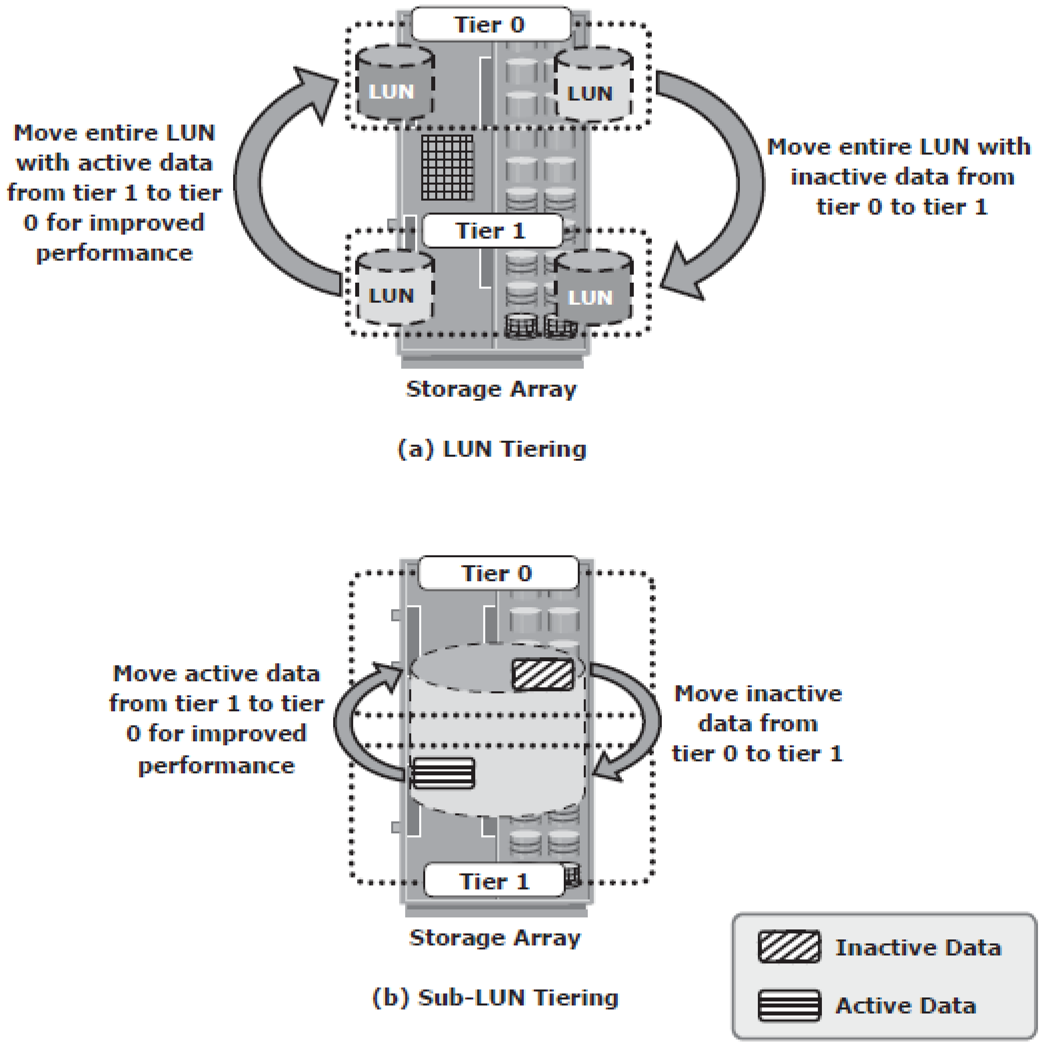
Data movements between various tiers can happen **within (intra-array) or between (inter-array) storage arrays.**

1) Intra-Array Storage Tiering

The process of storage tiering within a storage array is called intra-array storage tiering.

It enables the efficient use of SSD, FC, and SATA drives within an array and provides performance and cost optimization. The goal is to keep the SSDs busy by storing the most frequently accessed data on them, while moving out the less frequently accessed data to the SATA drives.

Data movements executed between tiers can be performed at the LUN level or at the sub-LUN level. The performance can be further improved by implementing tiered cache.


Tier 0
LUN
LUN
Move entire LUN with active data from tier 1 to tier 0 for improved performance
Move entire LUN with inactive data from tier 0 to tier 1
Tier 1
LUN
LUN
Storage Array
Tier 0
Move active data from tier 1 to tier 0 for improved performance
Move inactive data from tier 0 to tier 1
Tier 1
Storage Array
Inactive Data
Active Data

(a) LUN Tiering

(b) Sub-LUN Tiering

Figure 15-12: Implementation of intra-array storage tiering

Traditionally, storage tiering is operated at the LUN level that moves an entire LUN from one tier of storage to another (see Figure 15-12 [a]). This movement includes both active and inactive data in that LUN. This method does not give effective cost and performance benefits. Today, storage tiering can be implemented at the sub-LUN level (see Figure 15-12 [b]).

In sub-LUN level tiering, a LUN is broken down into smaller segments and tiered at that level. Movement of data with much finer granularity, for example 8 MB, greatly enhances the value proposition of automated storage tiering. Tiering at the sub-LUN level effectively moves active data to faster drives and less active data to slower drives.

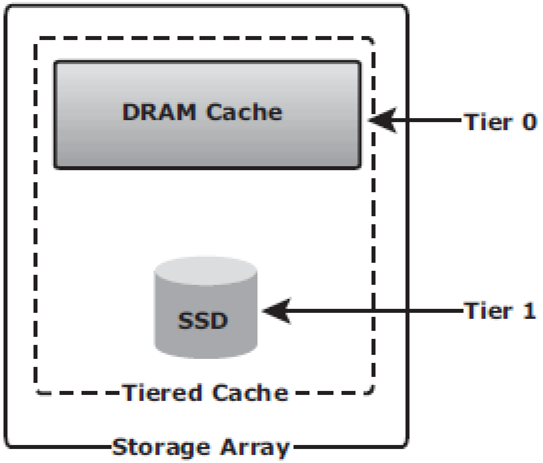


Figure 15-13: Cache tiering

Tiering is also be implemented at the cache level, as shown in Figure 15-13. A large cache in a storage array improves performance by retaining a large amount of frequently accessed data in a cache, so most reads are served directly from the cache. However, configuring a large cache in the storage array involves more cost.

An alternative way to increase the size of the cache is by utilizing the SSDs on the storage array. In cache tiering, SSDs are used as a large capacity secondary cache to enable tiering between DRAM (primary cache) and SSDs (secondary cache). Server flash-caching is another tier of cache in which a flash-cache card is installed in the server to further enhance the application's performance.

2) Inter-Array Storage Tiering:

The process of storage tiering between storage arrays is called inter-array storage tiering. Inter-array storage tiering automates the identification of active or inactive data to relocate them to different performance or capacity tiers between the arrays.

Figure 15-14 illustrates an example of a two-tiered storage environment. This environment optimizes the primary storage for performance and the secondary storage for capacity and cost.

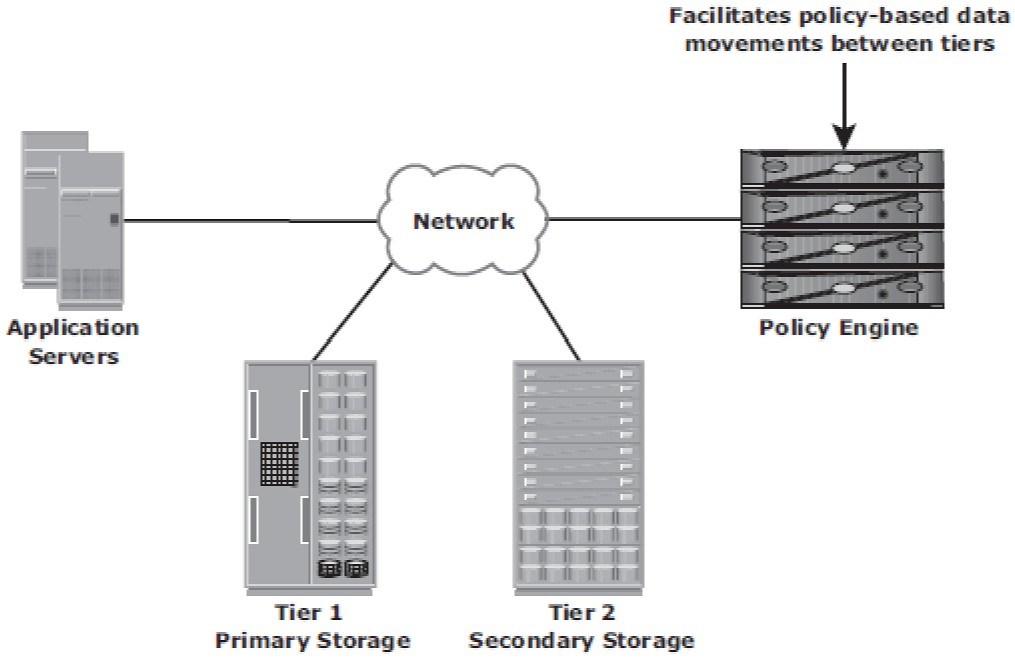


Figure 15-14: Implementation of inter-array storage tiering

The policy engine, which can be software or hardware where policies are configured, facilitates moving inactive or infrequently accessed data from the primary to the secondary storage. Some prevalent reasons to tier data across arrays is archival or to meet compliance requirements. As an example, the policy engine might be configured to relocate all the files in the primary storage that have not been accessed in one month and archive those files to the secondary storage.

For each archived file, the policy engine creates a small space-saving stub file in the primary storage that points to the data on the secondary storage. When a user tries to access the file at its original location on the primary storage, the user is transparently provided with the actual file from the secondary storage.