Storage Area Networks (SAN) in Data Center

Understanding the working and fault tolerant nature of SAN

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Audience:

This report attempts to introduce Storage Area Network in Data Centers for graduate students and IT professionals who wish to gain familiarity with this technology.

This report assumes that the readers are familiar with basic networking terminologies and functionality.

This report is also useful for business enterprise that wishes to expand their data storage and would like to get familiarity with the concept of Storage Area Networks.

This report will briefly introduce different storage technologies and storage devices. The report will also study in detail the components of SAN architecture, the design consideration of SAN and fault tolerant features of SAN.

Abstract:

Internet of things [Kevin Ashton in 2009] has now become an indispensable part of daily life. With the advent of cloud computing, Software As Service and rich media streaming to name a few, demands for enterprise storage have grown exponentially. Data has become immensely critical and need to protect and access data has far exceed the simple tape drive backup. Historically data centers were created out of servers, disk arrays and DAS storage technology with each application having its own dedicated storage device.

Along with the explosion of data and innovations in technology, networking infrastructure has also improved dramatically. Data storage solutions have also evolved significantly. Data storage could be in form of historical DAS (Directly attached data) or Network storage technologies such as NAS (Network Attached storage) or SAN (Storage Area Network). With improvements in network infrastructure, modern data centers are now more gearing towards SAN storage technology to provide data consolidation, resource sharing, data management and disaster recovery.

This report will explore all the aspect of SAN and discuss why SAN is a viable solution of data centers today.

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1. Introduction:

Today, increasingly the requirements for storage and computing data are moving away from PC-like clients to smaller devices like mobile but with the same user experience as a PC. Earlier web services were mostly related to search and information and data was left to reside in the client's machine like email, photo, video storage and application computing. However with the increasing demand to improve user experience, ease of large data storage and efficient management of resources, the shift has been towards server-side computing.

Few of benefits of server-side computing:

- Software as service has simplified application development on vendor side and like-wise improved user experience. Vendors can make changes and improvements on their server side and deploy them without having to update many of their clients with updated request via hardware and software configurations.

- Resources are shared amongst many users resulting in lower cost per average user. Management of server and storage of data becomes easier as they will be maintained under an unified entity, rather than a single laptop or server.

- Heavy computational workloads are better served by offshored massive computing centers versus their own small client servers.

- Computation, storage and retrieval of data are energy intensive and may be difficult for individual smaller enterprises to handle.

- Internet service that is the backbone of todays computing, deals with millions of user program that interact to implement features such as email, social media, texting etc. require maintaince and implementation by engineers who are no longer bounded by geographical limitations. Such large scale deployment are better served when they are housed offshore in large centers than can be accessed from any where and also can provide fault-tolerance in form of back-ups, fast data retrieval so that the user experience is not hampered.

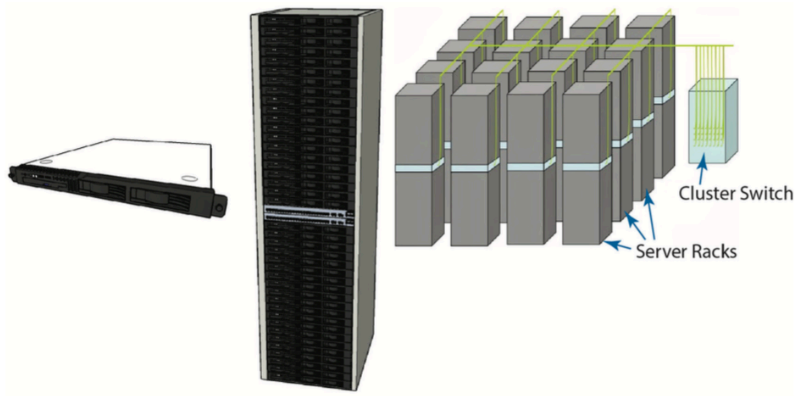

Figure 1: Typical components of warehouse-scale systems

With the rising levels of broadband Internet and increasing number of applications that interact with each other, there is a need for efficient and reliable processing and storage solution. Enterprises can no longer be impeded by data fetching delay due to traditional bottlenecked, server attached storage systems.

Need to solve this unique ever increasing zero tolerance data backup and data retrieval has given rise to a solution in form of SAN technology (Storage Area Network) an high performance, high speed subnet structure that provides direct access from enterprise servers to an offshore secondary storage system such as optical disk or RAID arrays based on fibre channel technology. Not only must the data be available and reliable it should also be secure.

2: Types of storage technologies

Data centers depend on two type of Storage technology.

- DAS – Directly attached storage, where every application has its own dedicated storage medium
- Network Storage technology – Access to data stored in storage medium is provided through IP network. They are consist of:
    - NAS: Network attached storage – Connection between host servers and storage device is through LAN
    - SAN: Storage area network – A special dedicated network independent of LAN/WAN provides connection between server host and storage devices

2.1: Directly attached storage (DAS)

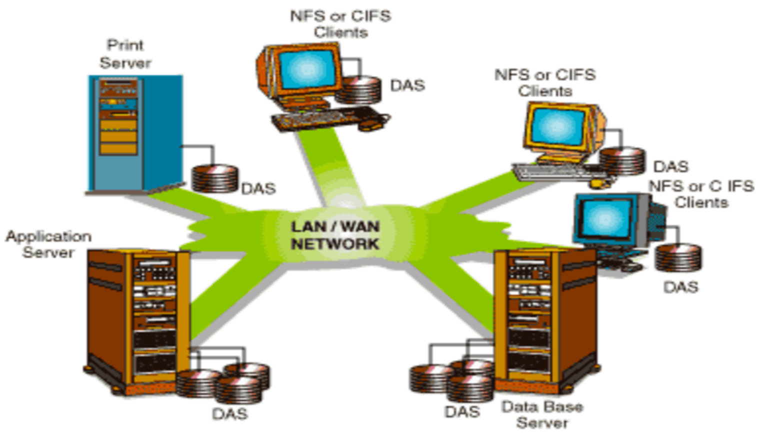

Figure 2: Direct attached Storage (DAS) topology

Historically, data storage in computing world was limited to storage centralized around a mainframe. With the development and affordability of personal computers data storage transitioned from centralized to decentralized distributed storage. A centralized mainframe that provided centralized processing and storage solution gave way to server with thick clients or work computer that performed their own processing. However as the computation increased so did the demand to store large volumes of data increased and this resulted in greater demand for servers to store and process data away from central main frame.

The primary solution was to increase the data storage limit of servers and workstations by attaching secondary storage in form of disks or other physical storage medium directly attached to the computation system called (DAS) Directly Attached Storage. DAS is a dedicated storage device that is connected to server or work area with a dedicated cable. Depending on the nature of the data stored, the disk may be protected with different levels of RAID.

DAS has its own advantages. It is easily accessible and does not have to rely on network traffic and in process eliminates the need have complex network communication protocols. However the traditional method of directly attached storage system in spite of its direct connection to data device has shown server limitations in terms of scalability and reliability. More storage devices have to be attached to address the increase in data storage, but that gives rise to data storage islands and communication issues between them. In past DAS was primary method to address data storage but with increase in speed and efficiency of network, network storage technologies have been adopted by enterprises.

2.2: Network Storage Technologies:

Network storage technology is about making access to data stored at some physical storage medium available to client via a reliable network. The evolution of data storage and means to access data has evolved through various phases driven by the changing ways in which technology has changed over the years and also by the exponential increase in need to store, retrieve and transfer data in an efficient and flawless manner. The improvements in network technology; speed and data transfer rates have made data centers a feasible option.

There are two major groups of network storage technologies: NAS (Network Attached Storage) and (SAN) Storage area network.

2.2 A: Network Attached Storage (NAS)

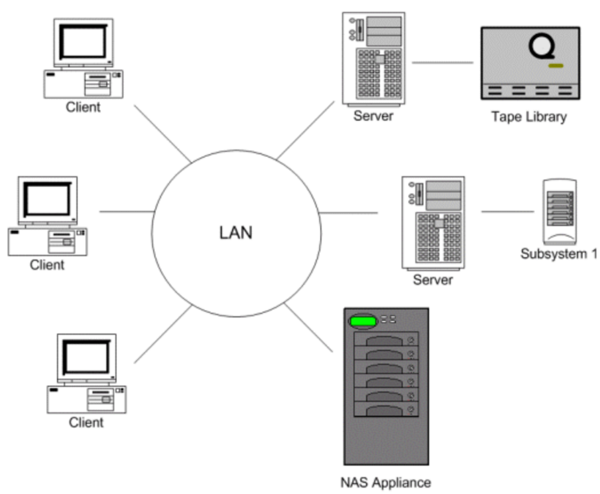

Figure 3: Network Attached Storage (NAS) topology

NAS uses data storage methodology that provides connection to data between servers or clients and special storage device via LAN (Local Area Network).
These devices are accessed by clients either via servers or directly without a middleware through the device's assigned IP Address. This facilitates an environment that enables many servers that run on different operating systems to store and retrieve their data centrally. This also enables efficient management and scalability. Storage capacity can be increased externally without eating into enterprise space. Fault tolerance can be achieved by using RAID and unlike DAS if a server fails, the work is not halted. Multiple computers can share same storage space that minimizes overhead, easy to install and managed through web interface.

2.2 B: Storage Area Network (SAN)

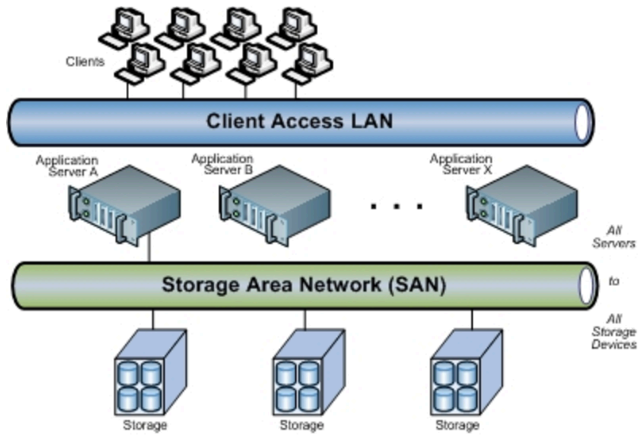

Figure 4: Storage Attached Network (SAN) topology

SAN on the other hand has a special dedicated network (according to Wikipedia) that is different from LAN or WAN, having its own specialized protocol and hardware. SAN components consist of independent communication infrastructure that provides high efficiency physical connection to transfer data between computer system and storage elements.

Since SAN enables transfer of data directly between client computer system and the storage device, it can prevent server bottlenecks. Separation of server control from data increases data transfer, flexibility and performance. User can directly access storage device, thereby increasing application performance. SAN architecture is independent of LAN/WAN and this increases LAN/WAN bandwidth as backup operation of accessing/storing data is moved to SAN network.

In addition to improved network performance and increased data availability, other benefits include resource sharing, efficient use of disk, reduce physical storage requirements, security, fault-tolerance and reduced processor.

With the wide acceptance of SANs and merging of the storage and existing IP Protocols (LANs/MANs/WANs), data centers can see benefits in form of storage consolidation, mirroring, backup, and ease of management [4]

3. Requirements of SAN in data center infrastructure [2]

For modern data center to adopt SAN it must be able to provide the following:

- **Scalability**: Provide infrastructure for business to expand services without having to worry about changing demands for storage resources
- **System simplification**: Provide easy to implement infrastructure with minimum maintaince overhead and greater return on investment
- **Flexible and heterogeneous Connectivity**: Storage environment performance should be independent of client's OS platforms and should have minimum configuration overheads
- **Security**: Data access and storage should not become corrupted or overlaid by other applications or systems
- **Encryptions**: Sensitive and high secure data must be read and accessed only for authorized systems
- **Hypervisors**: Should support environment for cloud computing.
- **Speed**: Infrastructure should be able to manage high network flow and I/O intensive requirements of the industry
- **Availability**: Refers to both media failure protection and safe data migration without halting any application process. Efficient back-up and recover mechanism in from of:
    - **Server-less back-up**: Ability to back up without using computer processor of client's server
    - **Synchronous copy**: Before the application goes to next phase, the data is stored at multiple places. This capability ensures that your data is at two or more places before your application goes to the next step.
    - **Asynchronous copy:** Before the application goes to next phase, the data is stored at multiple places but within a short time. The disk subsystem controls the flow of data

4. SAN Components:

SAN components consists of:

- Host Components
- Fabric components
- Storage Components

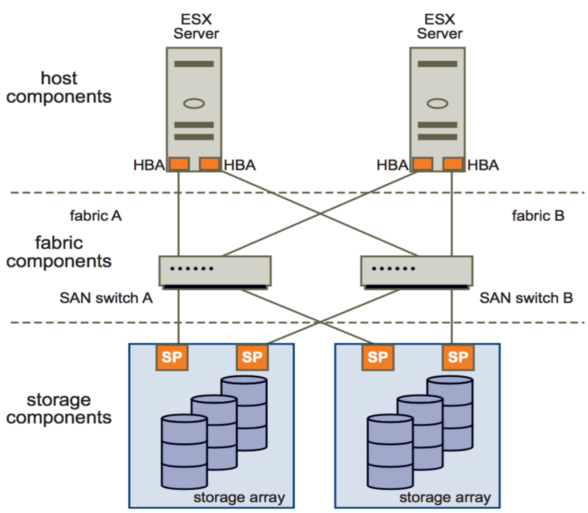

Figure 5: SAN components layers

4.1 Host Components

❖ **HBA** (Host Bus Adapter)

HBA allows host server to connect to SAN storage components via FC. HBA card is the only part of SAN that's inside each host server and connects via PCI Express (PCIe) slot of server

HBA is responsible for connecting each individual server either directly via directly attached connection or to a group of storage devices using variety of storage networking technologies. HBA or host adapter card provides the necessary interface between internal bus of the host server and the external storage devices via a fabric. Since HBA resides inside the host server, it can facilitate high-availability, SAN management and administration, data recovery and load balancing.

Device driver supplied by the vendor allow HBA card to be recognized by vendor specific operating system that is installed at the kernel mode. This vendor driver device is responsible for performing protocol translation and reliable communication at the physical and data link level. In order to achieve high availability addition of 2 or more HBA devices can allow increased level of redundancy at the hardware level.

4.2 Fabric components

In SAN topology a server gains access to storage device via a network connection through one or more fibre hubs or switches.

❖ **Fibre Hub:**

Hubs are used as a communication method in FC-Al implementation.

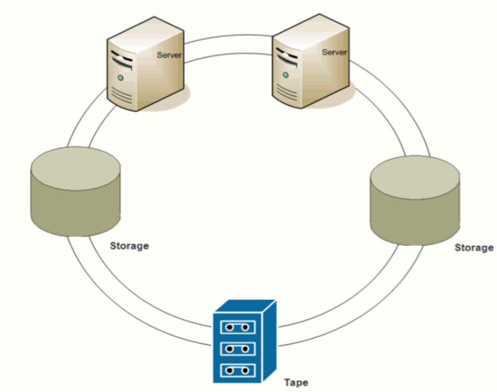

Figure 6: FC-AL Loop

In FC-AL implementation Hub's are responsible for physically connecting node in a logical loop. They facilitate high-speed data transfer between computer system and storage device. All the devices share same bandwidth and data travels through all the connecting points/nodes. Initially Hub was the preferred mode of data transfer in SAN, but with the availability of low cost and high performance fibre switches Hubs are rarely part of SAN design

❖ **Fibre Switch:**

A fibre switch is more intelligent than a hub and can retain in its memory the routing path, thereby can directly route data from one port to another physically connected port in the network. The fibre switch provides high performance by high port capacity, fault tolerance and high throughput.

Fibre switch functionality is similar to a traditional switch in a LAN/WAN network. They provide increased bandwidth along with scalable performance through a number of interconnected storage devices that can be increased on demand. Fibre switch can vary in number of ports and the media they can support. Multiple switches can be connected to form a fabric as shown in Figure 7, to sustain a large number of servers and storage system.

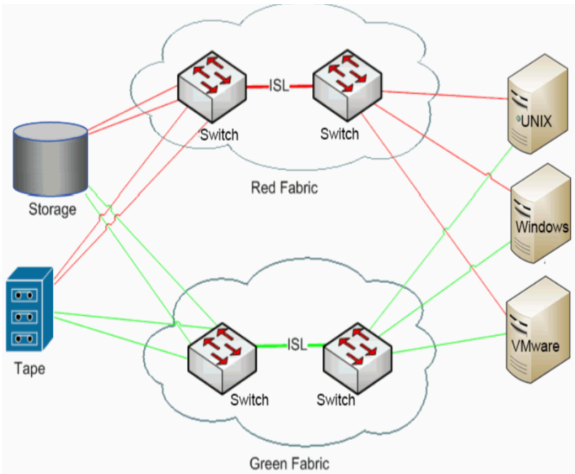

Figure 7: Fibre Switch in SAN design

By connecting multiple switches to form a fabric, fault tolerance of the system is improved. On failure of red fabric the data can be accessed and stored through the green fabric.

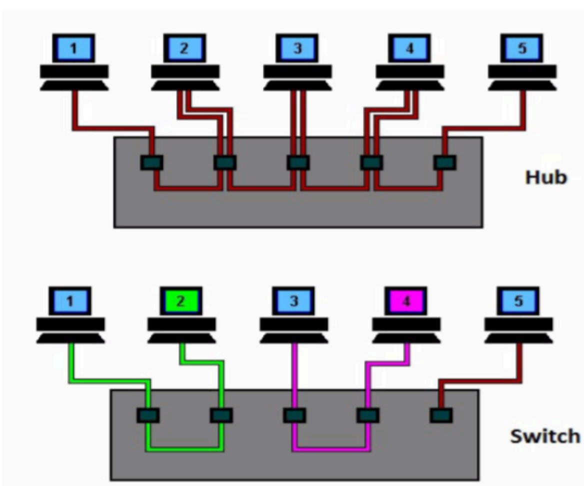

Figure 8: Figure shows the difference between Hub and a Switch. In Hub all the machines are interconnected and media can only be used by on one machine at a time. In switched network, media can be accessed by more than one machine at a time.

- **Director Class Fibre Channel Switch:**

These are high-end switches with high port count and high fault-tolerance. The architecture of these switches is modular and by adding line cards the number of ports can be increased. These witches always contain redundant component to provide high-availability at hardware level.

- **Data Routers:**

They are the intelligent bridge that connects SCSI's and fabric channel devices such as switches over the SAN fabric. Host servers also use data routers to connect to SCSI disk or tape library.

- **SAN Cables:**

SAN cables are usually fiber cables but for short distance copper cables are used over Ethernet. Fiber optic cables are used for longer distance because of their resistance to external interference and signaling disturbance. Fiber optics are more expensive but the cost is justified by the benefits of high performance of these cables.

4.3 Storage Components:

Data is stored in tape device or disk arrays or both.

- **Disk Array:**

They are collection of disk where the host rarely has direct access to individual drives. Storage arrays or disk arrays uses RAID technology to group a set of hard drive disks. RAID uses independent disk to increase fault tolerance and redundancy.

To be fault-tolerant data needs to be copied every time a change is made and manual way is not only unrealistic but also time consuming. Raid controller is responsible for synchronous writes and reads from the disk.

RAID's come in many format. RAID 1 or mirrored disk does writes twice for every read and write. It makes an exact copy of the data. It is very slow and only half capacity can be used but is high fault tolerant to disk failure. RAID 5 on the other hand uses parity to recover lost data. It consists of dividing user data in to N-1 parts (N is the number of disk used to build the RAID) and calculating parity bits. With the parity bits spread across disk, RAID 5 can rebuild user data in case of disk failure. RAID-5 requires minimum of 3 disks but spare disk can be added making it a RAID-5+Spare.

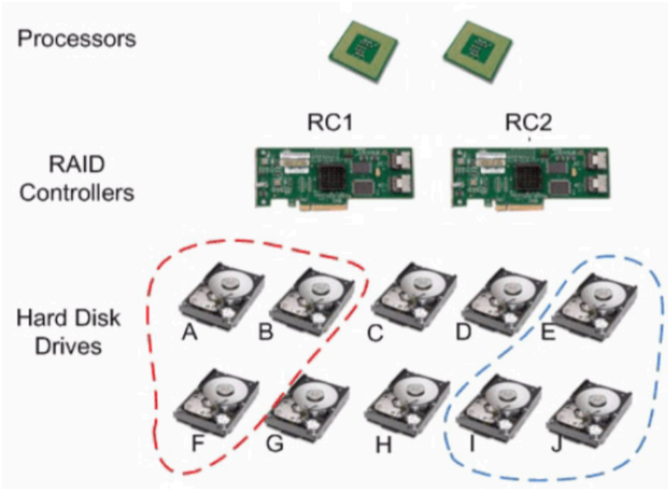

Figure 9: RAID Controller with disk pools

- **Tape Devices:**

Tape storage provides San with backup features. Smaller SANs use high capacity tapes that varies in size, data transfer rates and storage capacity. It could exist as a single tape or a group in form of tape libraries. For larger sized SANs with critical backup requirements, SAN is designed with one or more tape

5: Building Blocks of SAN: (According to VMware SAN Conceptual and Design Basics technical note [5])

HBA on the host server side is called the initiator and is responsible for initiating connection with one of the many switches in the fabric mesh.

Role of the HBA's are as follows:

1. To interact with storage devices on SAN, the host sends a block based access request.
2. HBA installed in host server provides the necessary connectivity. HBA directly interacts with fiber optics and unlike traditional Ethernet FC does not use TCP/IP protocol for transmission.
3. To transmit data into format acceptable to FC channel, HBA encapsulates SCSI requests in to FC packets as per the FC protocol.
4. Since FC is unlike Ethernet, traditional TCP/IP protocols do not apply and the requests are packed in accordance with special FC protocols.
5. HBA after conversion of data format accepted by the FC transmits the data request to SAN.
6. HBA has a sending port that connects to receiving port on the SAN switch part of the fabric. San switch then transmits the data directly to storage processor which in turn send it the to relevant storage device.

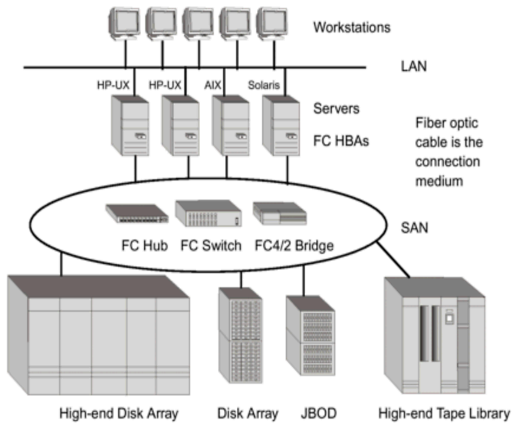

Figure 10: Interaction of SAN components

❖ **SAN Ports:**

Each of the nodes in San is made up of hosts, servers and storage devices. Each of host is connected to SAN storage device via fabric channel switch through one or more ports.

Ports are identified in two ways:

- **WWPN**: World Wide Port Number – A global identifier for the port, which allows application to connect to devices. FC switch discover WWPN of the component and then assign designated port address to that component
- **Port_Id** or port address: Inside SAN each port of FC has a unique port address that serves as its identifier. This enables routing from one port to another in SAN. FC switch assign port ID when a device logs in and is valid as long as the device is logged on.

❖ **Multi-Path and Path failover:** In FC route is described as staring from HBA installed in host server through ports in switches in fabric and finally terminating at a specific LUN part of storage device.

LUN is described as a single unit of storage device. A RAID group can have one or more LUNs accessed by one or more servers on a SAN. A host can be given a single path to access LUN or can have more than one access path called multi-pathing. In a single path if any of the components fail, the path fails. In multi-path if one of the paths fails the server can detect other working path. The process path failure identification is called path failover

❖ **A/A disk array and A/P Disk Array:**

- In A/A or **active/active disk array** all the path to LUNs are active and allows access to LUNS via all storage processors without performance degradation. All paths are active all the time.

- In A/P or **active/passive disk array**, only one storage processor is actively servicing an active LUN while the other acts as a path for data back up. In event of failure, this secondary path can act as the primary path fro accessing LUN.

❖ **Zoning:**

Access control and maintenance of SAN is achieved through zoning. By zoning SAN, the routers or switches can maintain a list of which HBA's can connect to which zone in SAN. Zoning helps segregate SANS and device within a zone have no idea about devices outside their zone. Traffic management also becomes easier as zones are restricted. Switches provide zoning in larger SANs and each zone has its own configuration and security measures.

Zoning usually seen in SAN in data center are done for the following reasons:

- Zoning results in segregation of SANs and therefore can be defined for security and isolation by providing minimum access to devices outside the zone.
- Shared services can be obtained by zoning. SANs are fault-tolerant because they allow back up of data. Separate zones could be set up for back up of data. These zones interact with SAN wide network and can facilitate only back-up services for the host servers with the SAN. This connection is independent of path servers use to access data
- Multiple storage arrays of SANs can be zoned and each of those zones can be managed separately from each other with no conflict or concern for data breach between users.

❖ **LUN Masking:**

A LUN is a unique identifier given to storage devices or logical group of storage devices so that they can be accessed easily by individual host's SCSI or fibre channel protocol. SAN provides fault tolerance by set of RAID technology, however the host server cannot directly access those RAID groups. Instead by assigning LUN's RAID's functionality can be presented to host as an individual entity. By masking LUN, host gets only selective storage presentation (Host only knows to which group to access but not individual RAID). Masking gives access control and portioning depending upon the requirements.

LUN masking can be done at server level or at the storage processor level. The administrator can then zone the SAN and configure the LUNs so that each group of host servers can see only LUNs that are designated for that group.

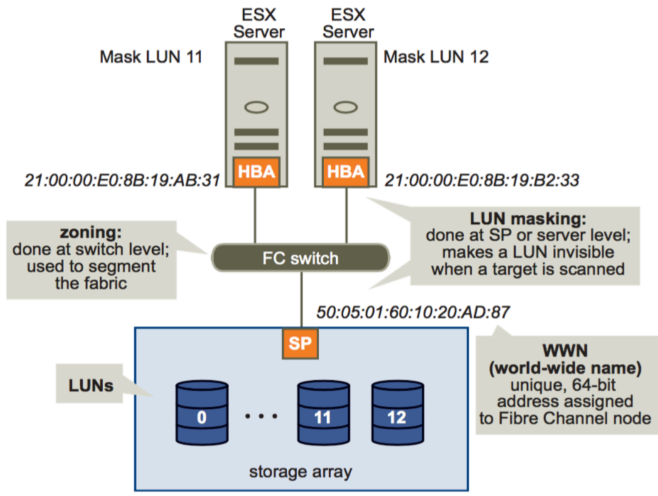

Figure 11: Connection between Host servers and LUNs

6: Bringing SAN together:

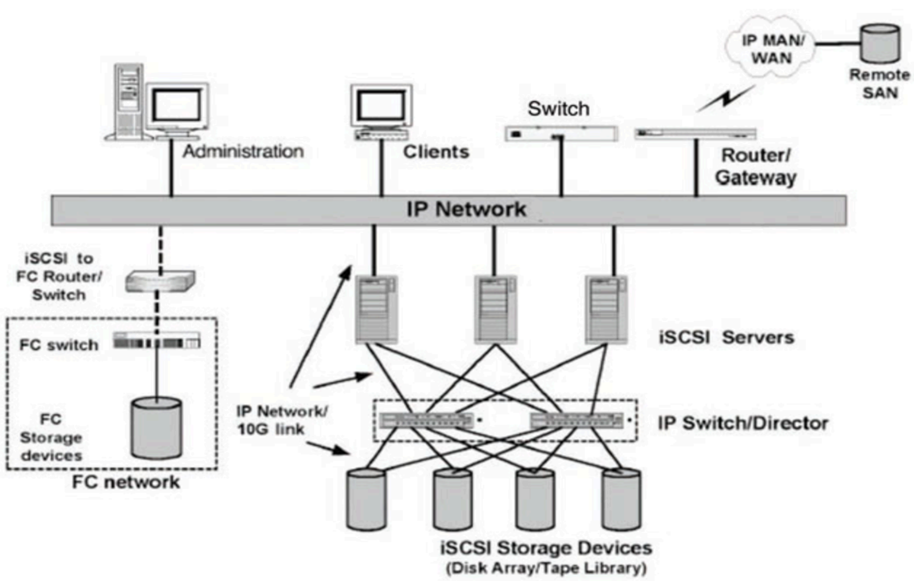

Figure 12: Configuration of SAN

iSCSI protocol is responsible for providing connection between storage device and IP Networking. iSCSI uses Ethernet to manage and store data in SCSI SAN. Historically the problem with SCSI attached devices were the distance between the storage device and the host servers. With the improvements in networking technology iSCSI is no longer bounded by distance limitations. From 1 Gigabits to 10 Gigabits, Ethernet are constantly increasing along with it the storage transport speed.

SAN over IP:

Two IP storage technologies that support SAN are FCoE (Fibre Channel over Ethernet) and SCSI over IP (iSCSI).

Fibre channel and Fibre Channel over Ethernet:

FC is a standard communication protocol technology within SAN. It provides connection within and between datacenters. FC is a high-speed serial interface that connects servers to their storage device. Each device is given their own unique identifier. Speeds that FC can handle range from 1 Gb/s to 32 Gb/s with 8-16 Gb/s being the current norm. Speed and media are the deciding factor in transmission distance. Similarly in FCoE the packets are processed and the length and distance vary according to speed affected by Ethernet network.

FC Topology:

Supports three different connection topologies: Point to Pointy, arbitrated loop (FC-Al) and switch fabric. (Components discussed in section 4.2). Switches allow zoning in SAN by creating a mesh of fabric islands. Fabric islands area connected via switches and can connect geographically separated and diverse FC fabric. FC fabric can reach long distance and consist of different topologies like ring, cascade, but may require special connection for shared data or disaster recovery.

FCoE topology:

Fibre channel is independent of the Ethernet IP network. Packets are encapsulated to pass through a single channel over Ethernet and FC Channel. This protocol allows greater distance than FC topology and is not impeded by geographical limitations. Connection to various fabric mesh are made via Ethernet bridges and routers. For fault tolerance FCoE has special protocol to connect to island FC SAN over IP infrastructure.

FC Channel SAN Connectivity:

Connection between server and storage device occurs due to connectivity protocol between different components of SAN.
(Components are discussed in detail in section 4).

Components that make up a San are:

- Interconnect Device: Switches and Directors
- HBA's: Installed in host servers, routers and bridges
- Storage device: Tape libraries, Disk Array, RAID
- Servers: Host servers
- Physical Media: Can be coax, twisted or fiber optics. Fiber optics are currently preferred
- LUNs: Single disk array or group of LUNs.

SAN fabric switches are local with each fabric mesh and have lower to medium port compared to directors. Each port has a port-Id and HBA's connect to FC network via cabling system to the IP protocol. Server with adapter card/HBA initiates connection over fabric to one or more ports called target ports on the storage system. Target ports on the storage system identify storage device or LUNs. Every port in FC has a unique 64-bit WWN. Zones are created grouping WWN's. Each zone should at least include one HBA and one target port. Each zone has alias that can be applied to a group of WWN's and allow easy management and identification of zones.

7: Fault Tolerant features of SAN:

San should provide fast and reliable response time that should be consistent across applications, even if the application requirements demand response during peak periods for both process I/O and network bandwidth. An efficient San provides resources that are capable of handling fluctuations in service demands. The SAN should consider I/O performance, bandwidth allocation, storage capacity and disk arrays when designing for fault tolerant system.

Fault Tolerance can be achieved considering the following:

- **Configuration of Storage Array**:

Each RAID level provides application with specific level of I/O performance, capacity and redundancy. Based on requirements RAID groups are assigned LUNs. RAID group may consist of a single LUN or a group of LUNs. If a particular RAID group cannot provide the required amount of efficiency and performance, SAN should be scalable by allowing addition of LUNs. Storage array should also allow for load balancing so that no single LUN or group of LUNs is over worked. Additional LUNs could also be allocated to accommodate peak period.

- **High Availability at hardware level:**

Redundancy is built at all levels, so that the system does not have a single point failure. Redundant hardware components like HBAs, SAN switch, target ports are all required to prevent single point failure. Redundancy is how system provides fault tolerance at hardware level. Redundant I/O path from host server to storage device must be dynamically switched in event of a single point of failure. Redundant path at that point of time becomes the dominant path. Failure could also occur in the IP path from fabric switch to LUNs. If a switch fails the entire connection from server to storage device fails. In such an event redundant secondary fabric can provide the alternate route.

- **Data storage protection at storage device level:**

Data unavailability is not only unacceptable but also expensive. Along with high availability data storage device needs to be protected. Primary approach is Mirroring. Designated secondary non-addressable LUNs provide mirroring of data. These LUNs store all write operation and is an exact copy of the primary LUNs. This method though extremely effective, is time and space consuming. RAID5 or RAID 5+ Spare provide an alternative to mirroring. They provide data recovery through parity bits stored across the RAID.

- **Duplication of SAN environment:**

Fault tolerance can also be achieved through duplication of SAN environment to provide disaster recovery for extremely high availability requirement. The duplicate environments could be at a physically different location than the primary San. Both environments could share processing workload or could be functionally separate with secondary SAN providing exclusive disaster relief.

8. Conclusion:

SAN landscape is continuously evolving to handle the ever-changing needs of the data storage requirements. The benefits of these systems are many and there is no one sure fit for today's modern data center. Historically FC in native form was more predominant but with increasing bandwidth and reliability of Ethernet, FCoE is also gaining popularity. Storage solutions are evolving along with developments network and data centers infrastructure. Improvements in form of data deduplication, thin provisioning and dynamic tiering, are all changing the way data centers store data.

Data deduplication is a process in which before writing to disk, the data in disk is checked for repetition before creating a new entry. This saves enormous volumes of disk space as it prevents duplicate data from being written to the disk.

Thin provisioning creates and additional layer of virtualization by allocating storage as it gets written by the system. Use of storage is as and when required, without allocating a dedicated resource to a system. By doing this unused disk space can be allocated to another system requiring it thereby creating useful sharing of recourses. This would require efficient management of resources in order to maintain data segregation and security. This will also enable dynamic provisioning of resources.

Modern SAN technology is evolving into energy efficient technology by resorting to spin-down of individual disk or group of disk that is not being accessed. By further resorting to RAID-5 or RAID-5+Spare, energy can be saved by reducing the processing cost involved in mirroring of data.

SAN is also migrating towards multiplatform protocol storage, integrating wide choices of protocols such as CIFS, NFS, iSCSI or FC making data centers more adaptable to multiple platform hosts.

Fault-Tolerant feature of SAN (discussed in section 7) is an important feature in making it a viable and reliable solution for modern data centers. SANs thereby enable e-commerce and enterprises to provide scalable service all around the clock.

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Acronyms

FC-Al - Fibre Channel Arbitrated loop
SCSI - Small Computer System Interface
iSCCS - Internet Small Computer System Interface
RAID - Redundant Array of Independent Disk
PCIe - Peripheral Component Interconnect Express
CIFS - Common Internet File System
NFS - Network File System