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Overview of advanced storage technologies and storage virtualization

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Overview of storage networking technologies

What will we learn?

- The concept of storage networking
- How the Fibre Channel technology provides a storage-specific, high-performance and highly reliable networked interconnection, called Storage Area Network (SAN)
- How a SAN allows both sharing physical storage and data between servers to form a clustered architecture
- High-availability, multipathing and load-balancing
- How SCSI block I/O can be implemented over Ethernet networks using iSCSI or FCoE
- The difference between SAN (block I/O) and NAS (file I/O)
- How a NAS provides an alternative way to implement a storage network

Definition of storage networking

- Term *storage networking* identifies any system in which storage devices are accessed over networked interconnection and transport technologies

- Currently, storage networking can be implemented using one of these options:

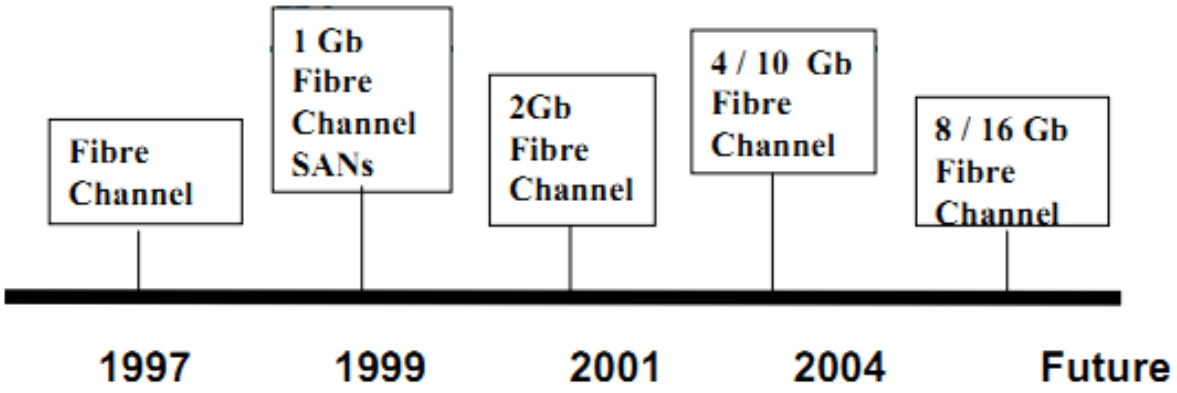
  - SCSI payload transported over storage-specific high-speed network technologies: Fibre Channel

  - SCSI payload transported over standard computer networks technologies: iSCSI, FCoE (Fibre Channel over Ethernet)

  - File-sharing protocols transported over standard computer networks technologies: NAS (Network-Attached Storage)

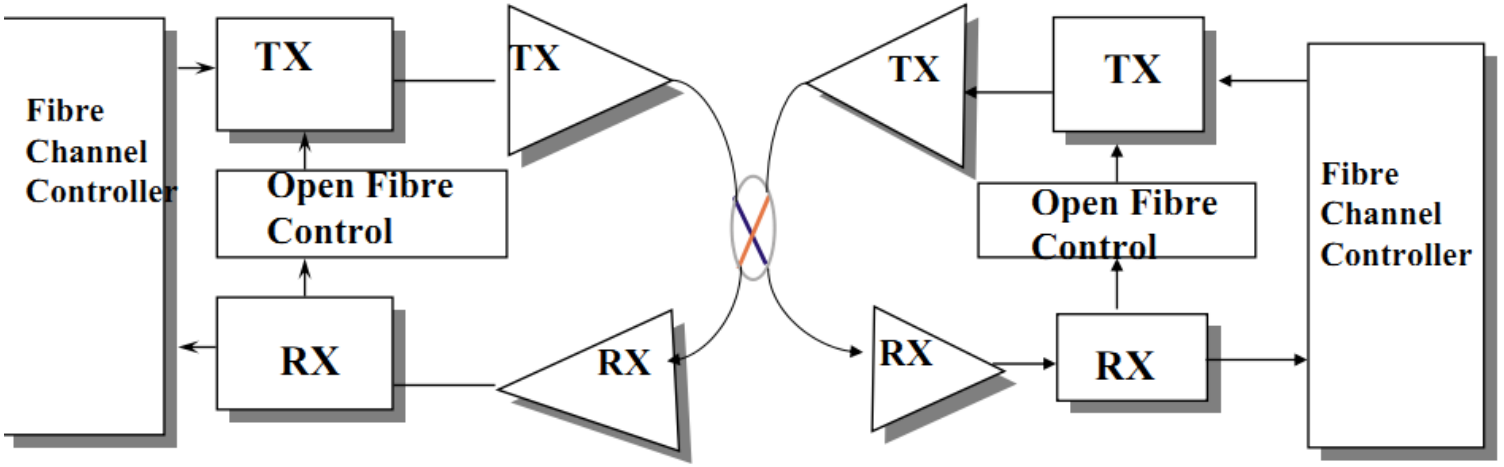
FIBRE CHANNEL

Fibre Channel Technology



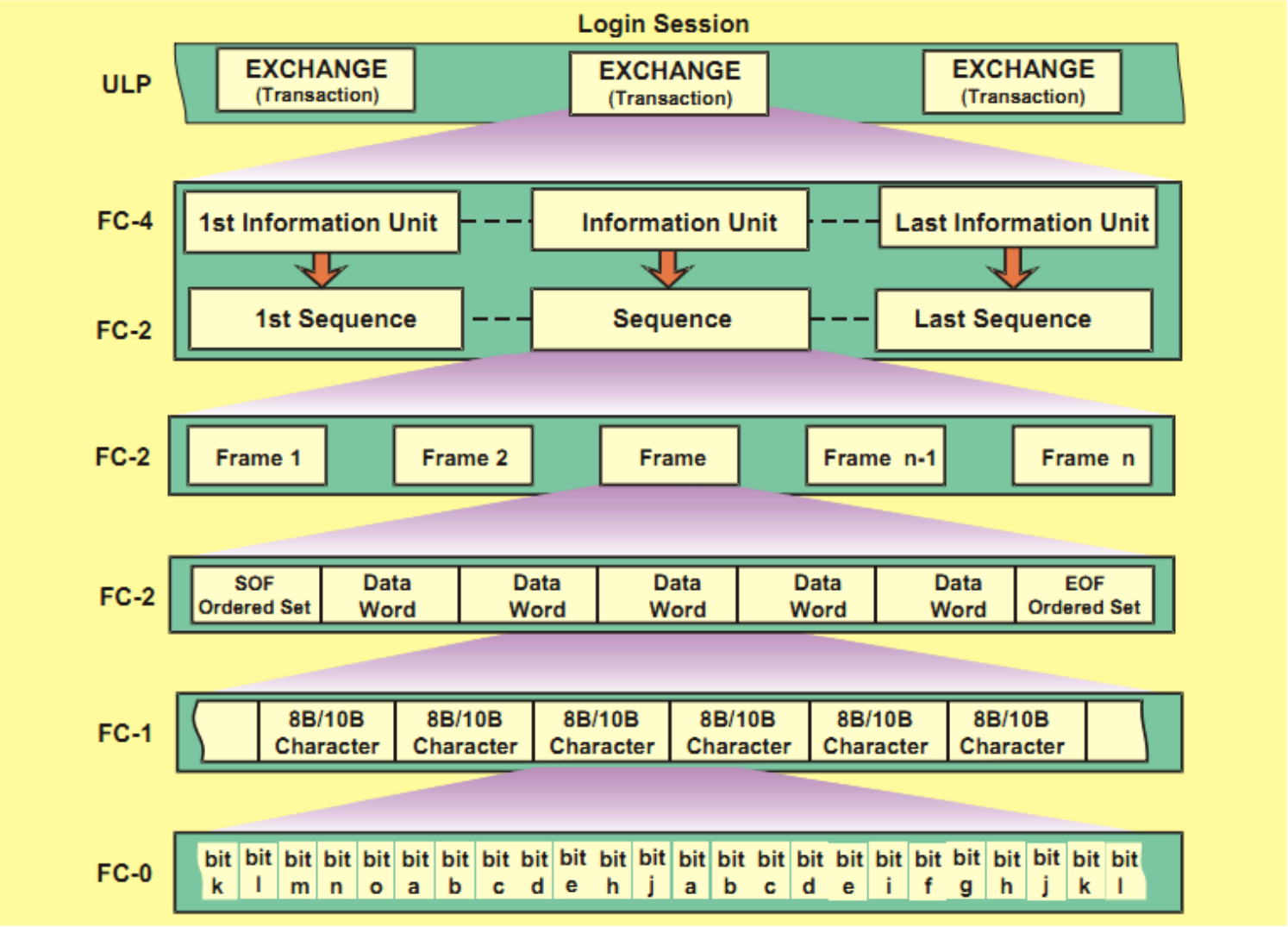
- Fibre Channel (FC) is an open standard for networked serial data transfer, which incorporates:
  - "Channel transport" characteristics of an I/O bus
  - Flexible connectivity and distance reliability of traditional networks
- Current day FC implementations allow reliable operation up to 16 Gbps per link

Fibre Channel Technology

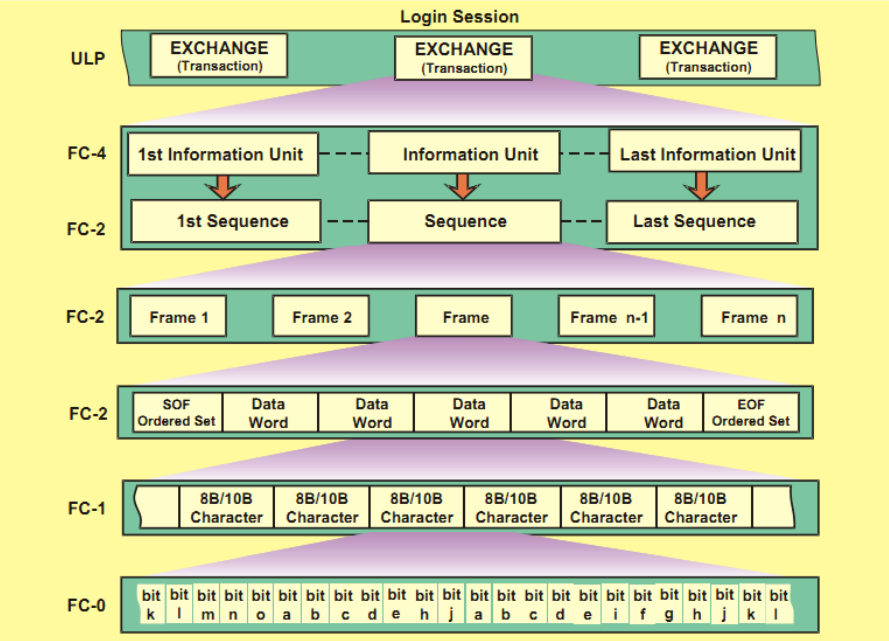


- FC uses a serial, bi-directional link
  - Transmission over optical fiber
  - Transmission over copper, using differential signaling, also standardized
    - No longer used for external interconnects
    - Possibly used by manufacturers for backplanes of FC-to-FC disk arrays
  - Use of optical fiber ensures low BER (Bit Error Rate) and high reliability for long links (tens or a few hundred meters)

FC protocol stack

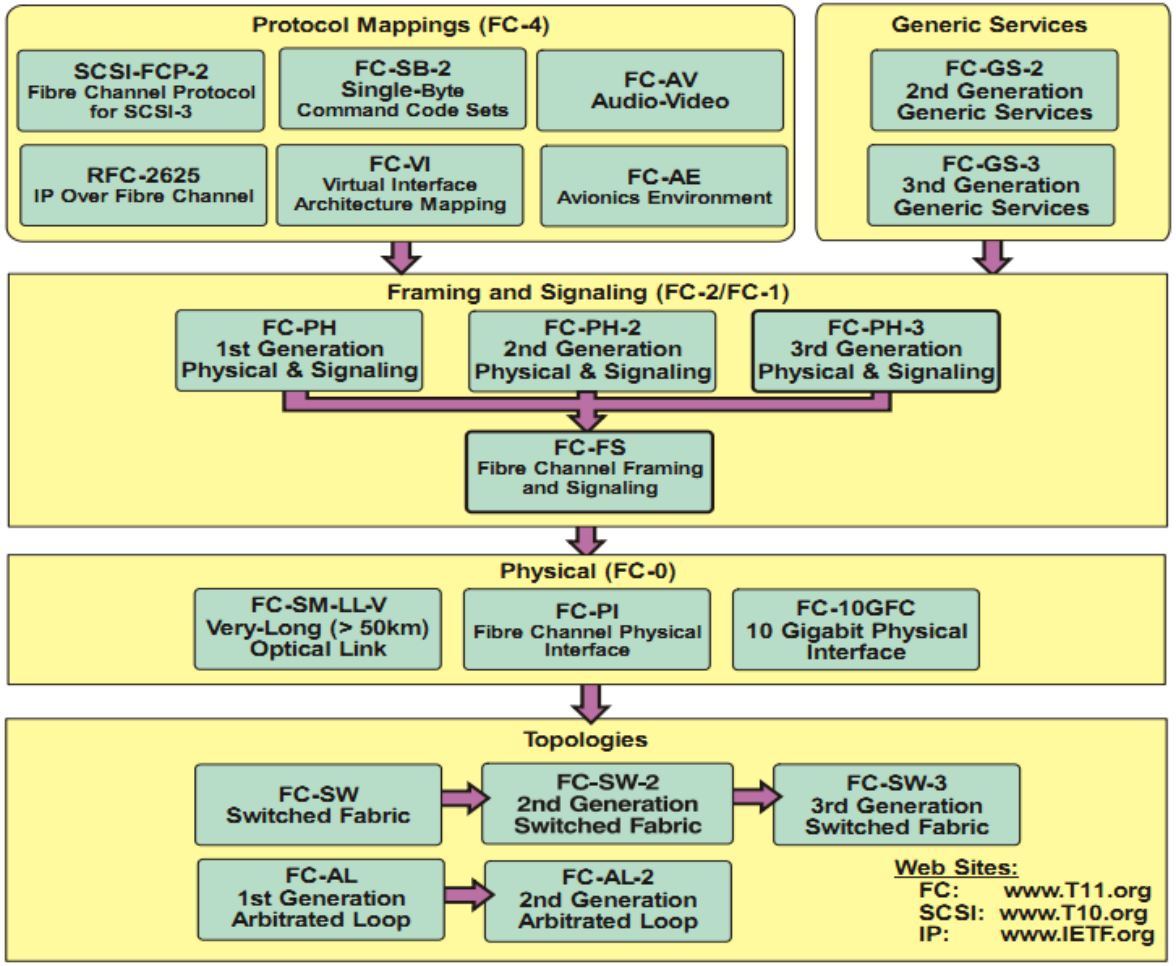


FC protocol stack



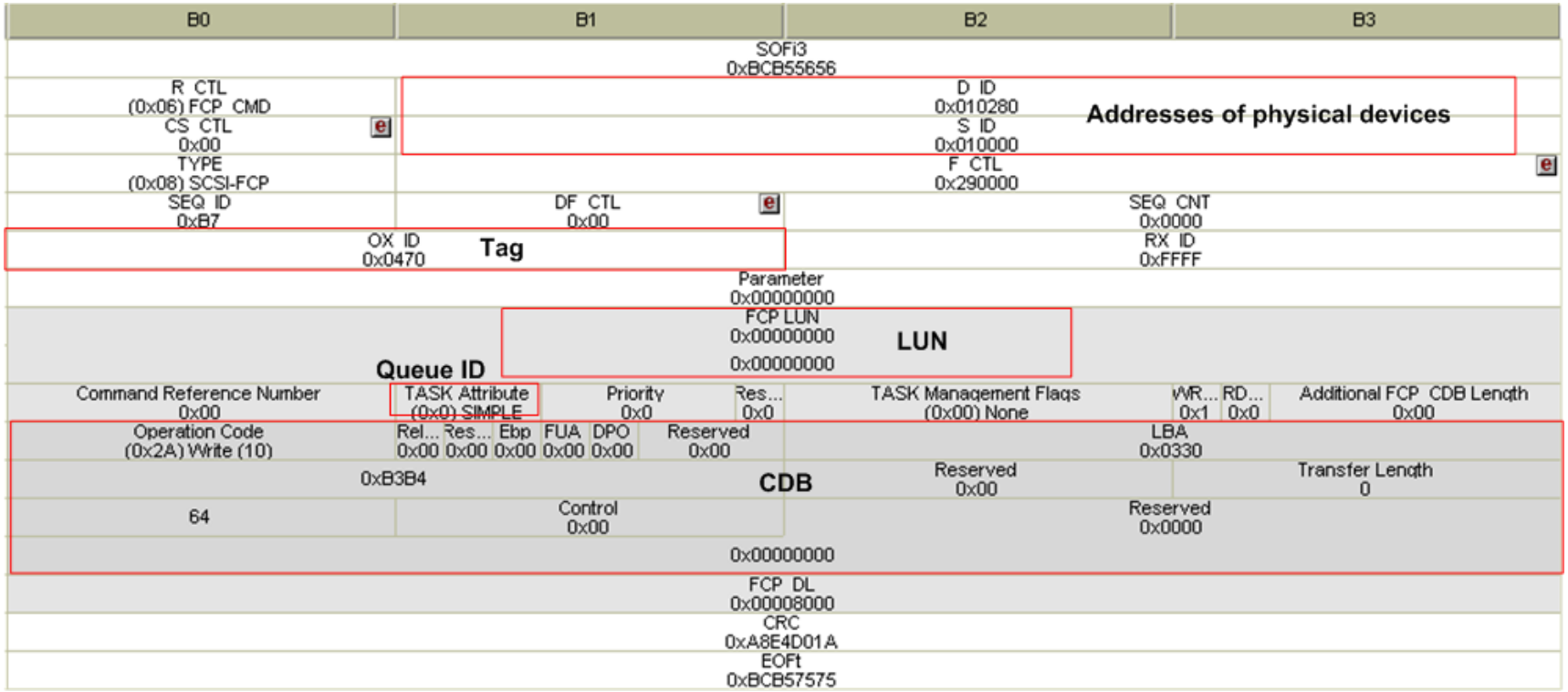
- FC standard is structured as a layered protocol stack
- FC-0 = physical level, signaling
- FC-1 and FC-2 = framing and link-level control
- FC-4 = Transport level. Carries payload edge-to-edge

FC protocol stack



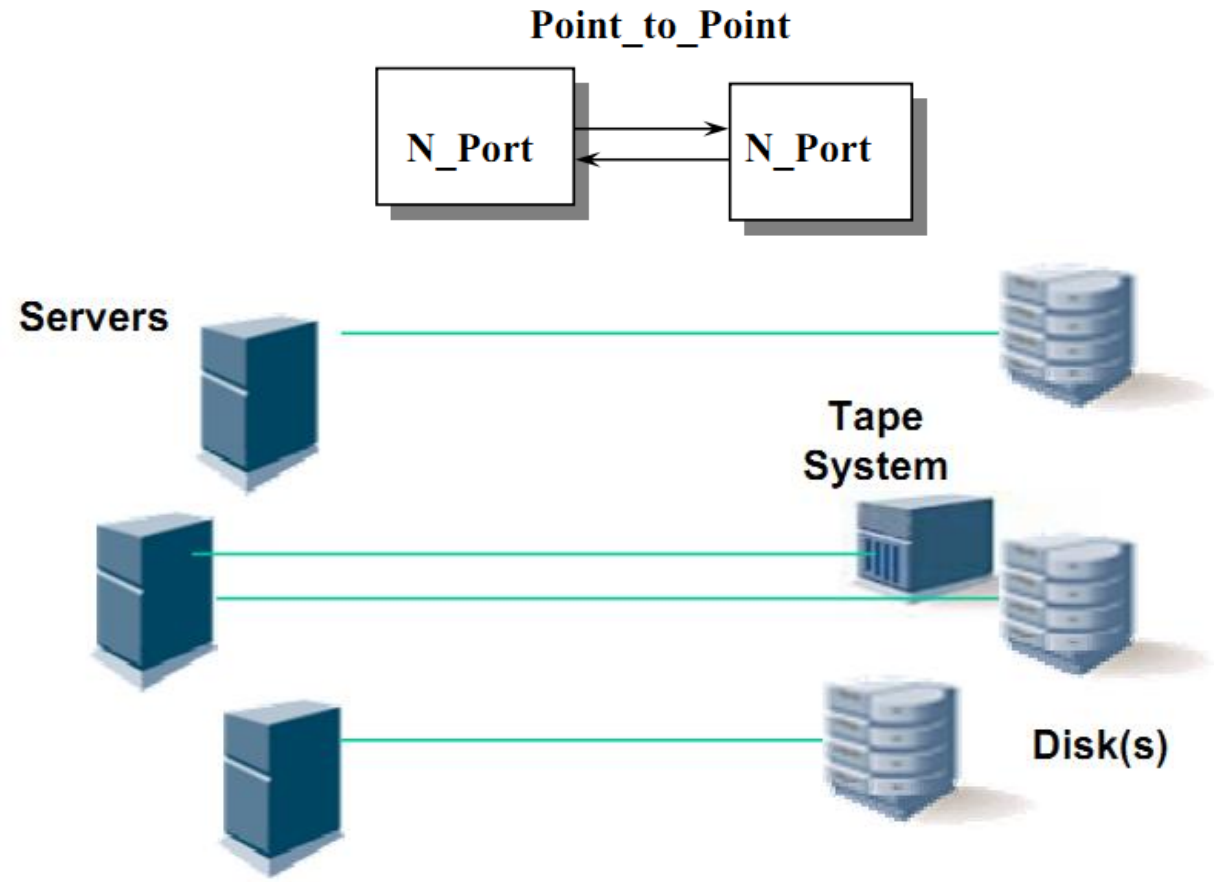
- Typical FC-4 payload is SCSI protocol (FCP)

FC protocol stack



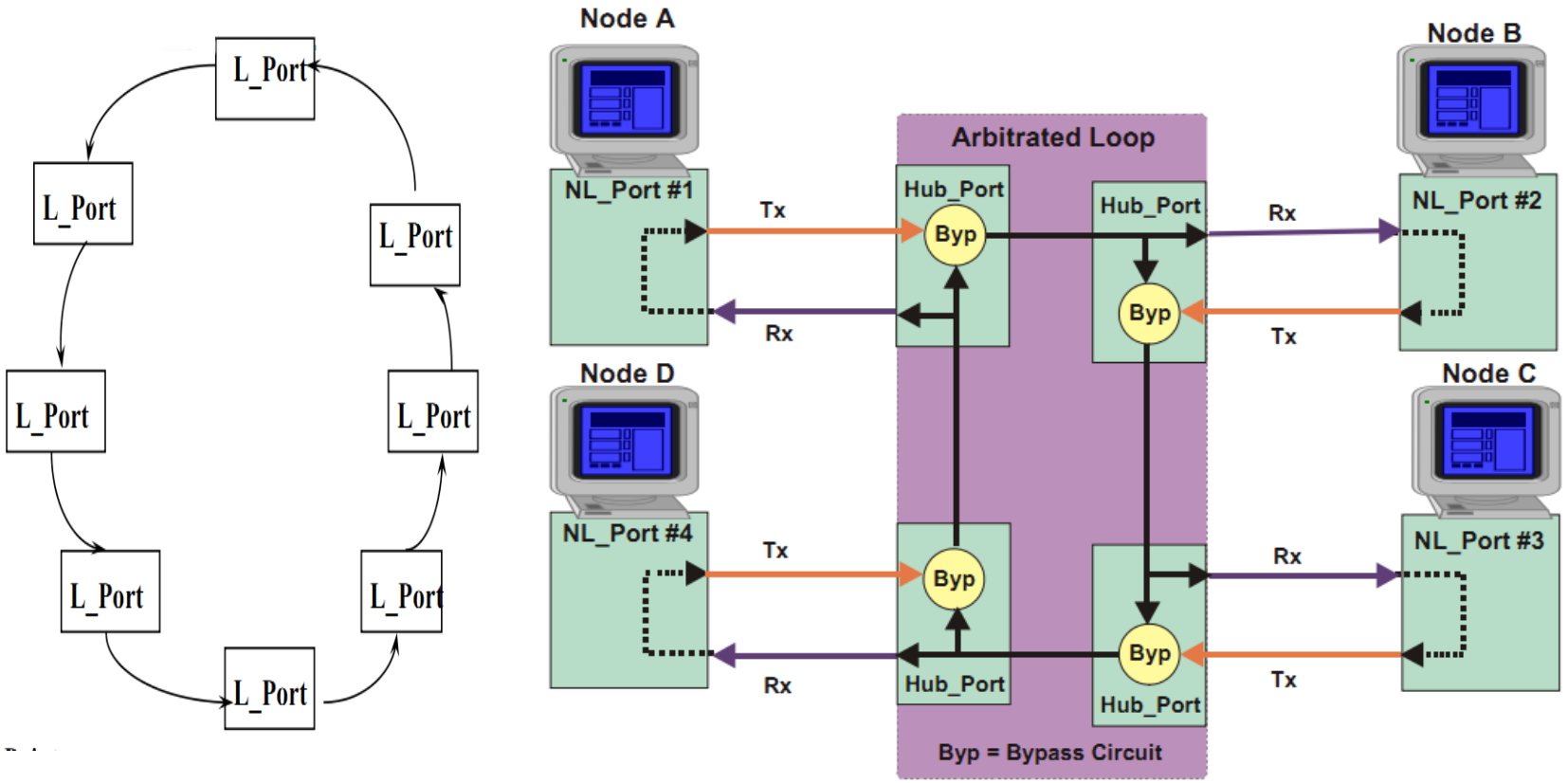
- SCSI protocol commands and responses are encapsulated within payload area of FC frame

Fibre Channel topologies



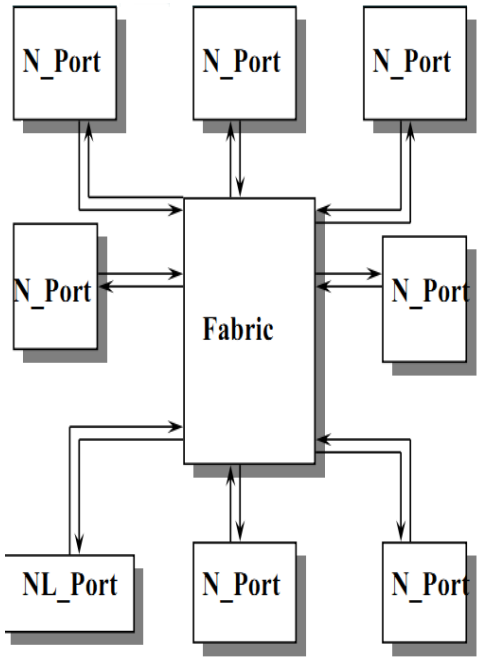
- Simplest topology for FC is DAS (Direct-Attach Storage)
  - Point-to-point interconnection between server and storage

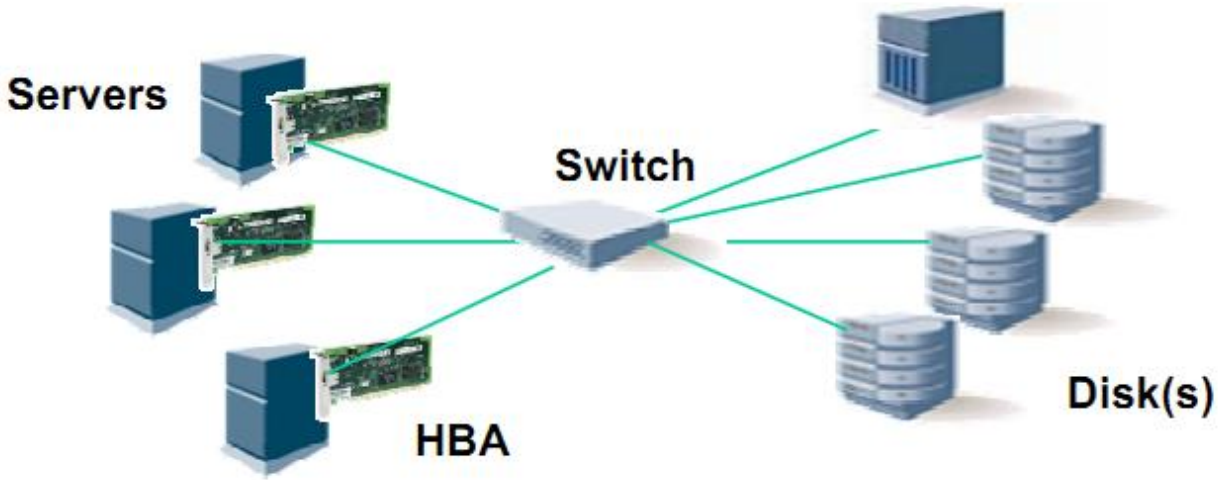
Fibre Channel topologies



- FC supports also arbitrated loop topology
  - Can use hub, but also workable just with cabling
  - Limits overall transfer speed (“bandwidth”) of system

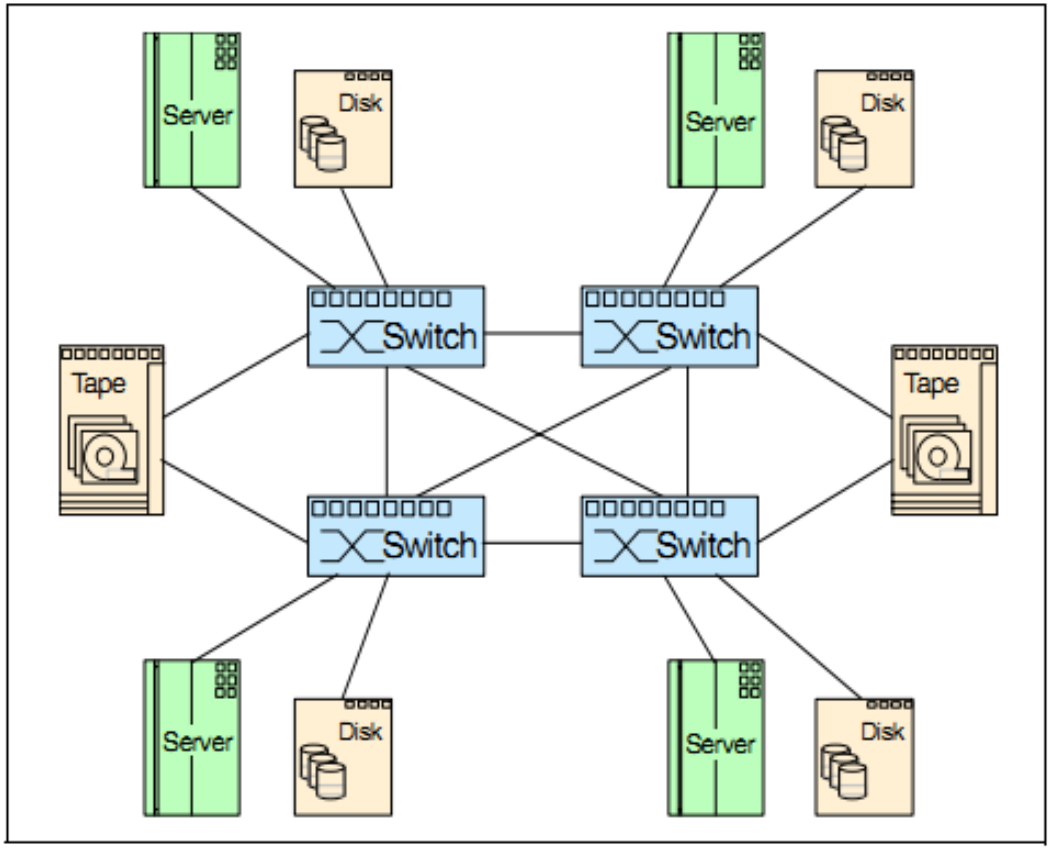
Fibre Channel topologies





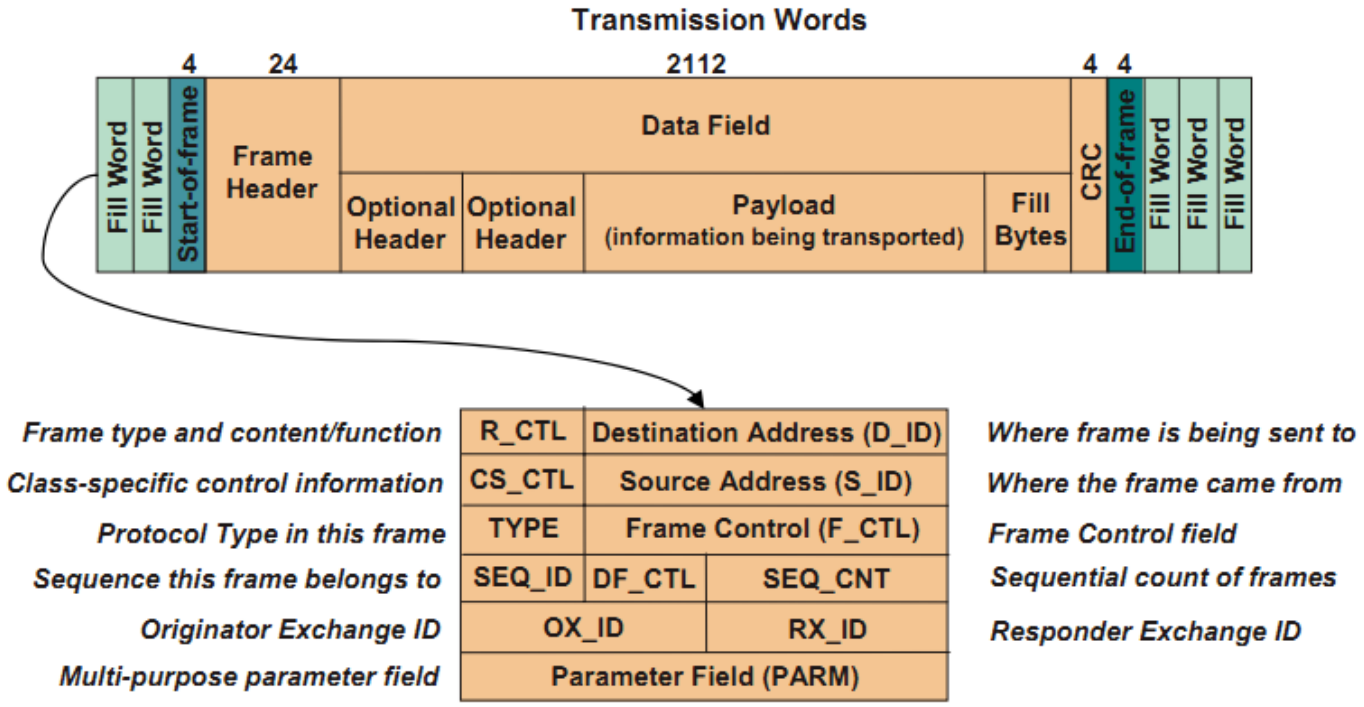
- Most versatile topology is *Fabric*
  - Truly meshed network, using a fabric switch
  - Devices connected by point-to-point links to switch
  - Switch moves data between links
    - While aggregated bandwidth of switch holds, links can work at maximum speed

Fibre Channel topologies



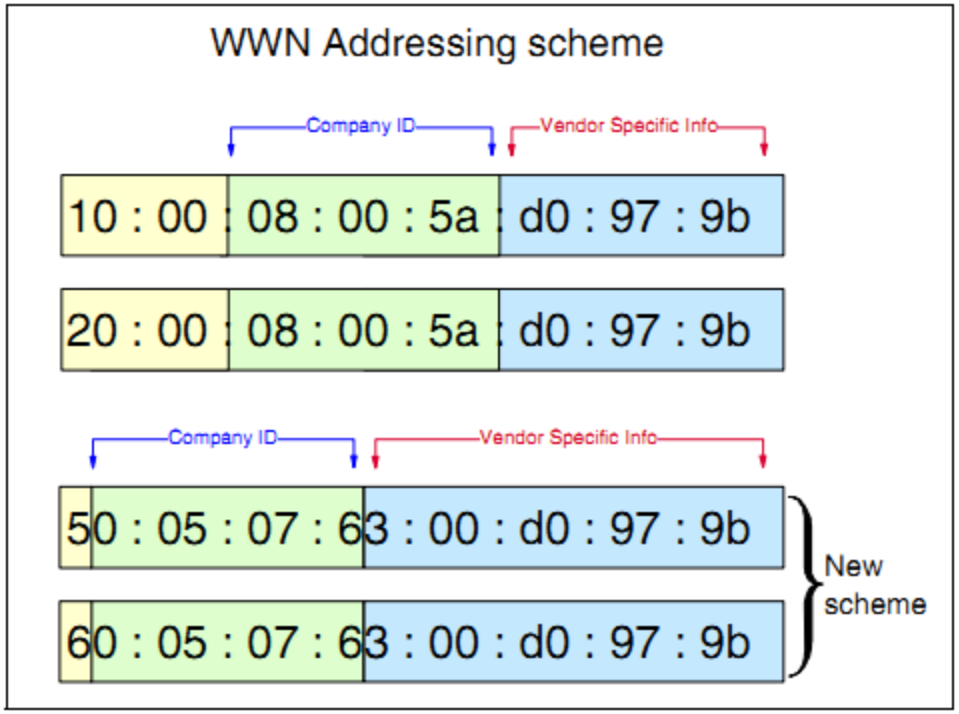
- FC switches can be interconnected to form a complex, switched fabric
  - Known as *meshed topology*

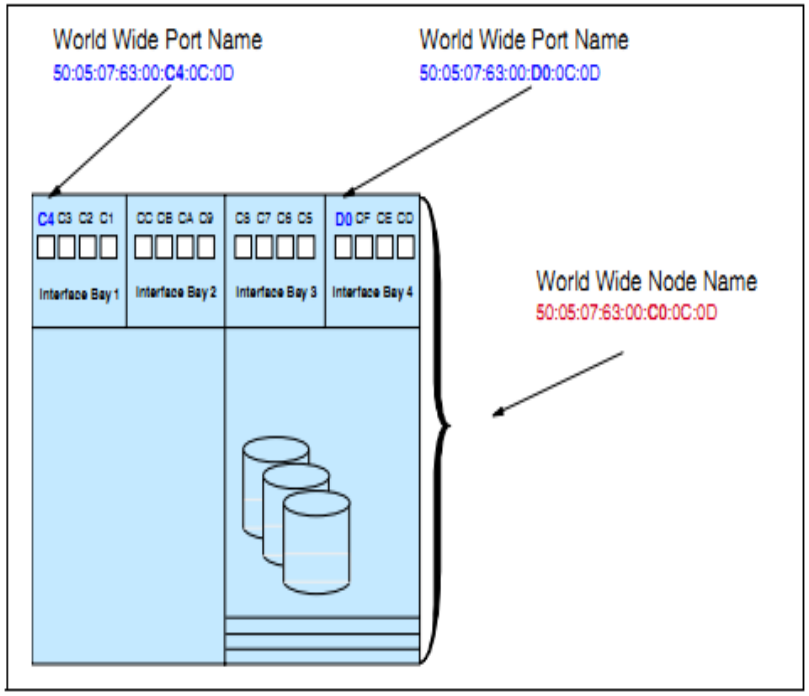
FC addressing



- FC frame requires unambiguous addressing for reliable travel through fabric
  - Frame uses 24-bit address for destination (D_ID) and source (S_ID)
  - Address must uniquely identify each FC port of each FC device

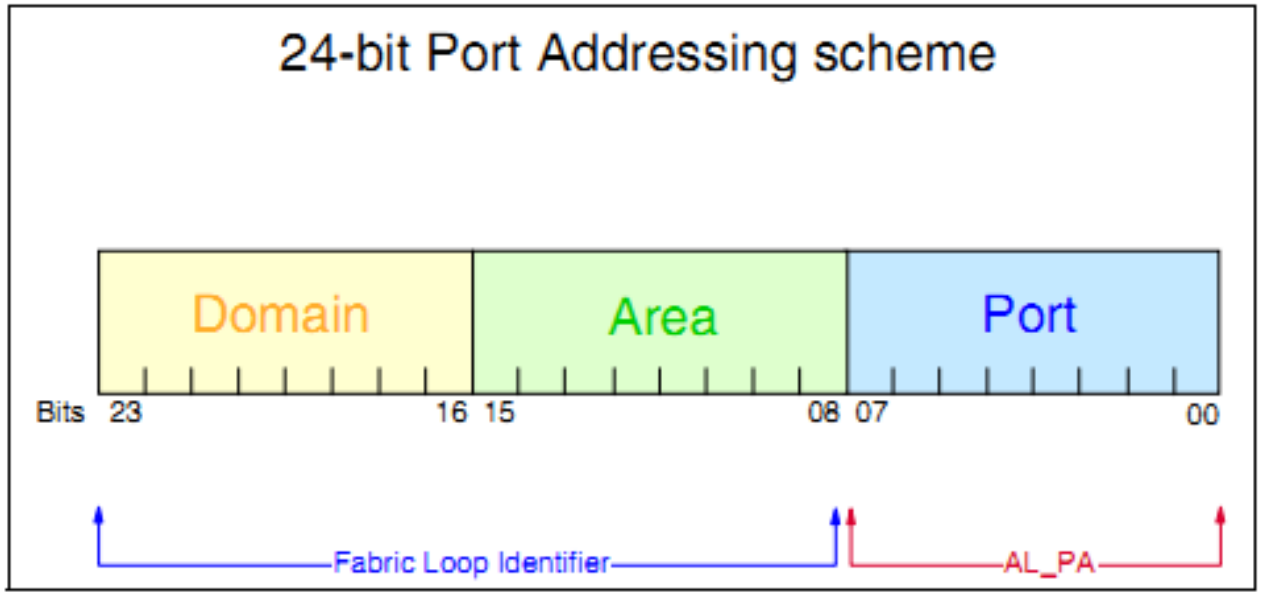
FC Addressing





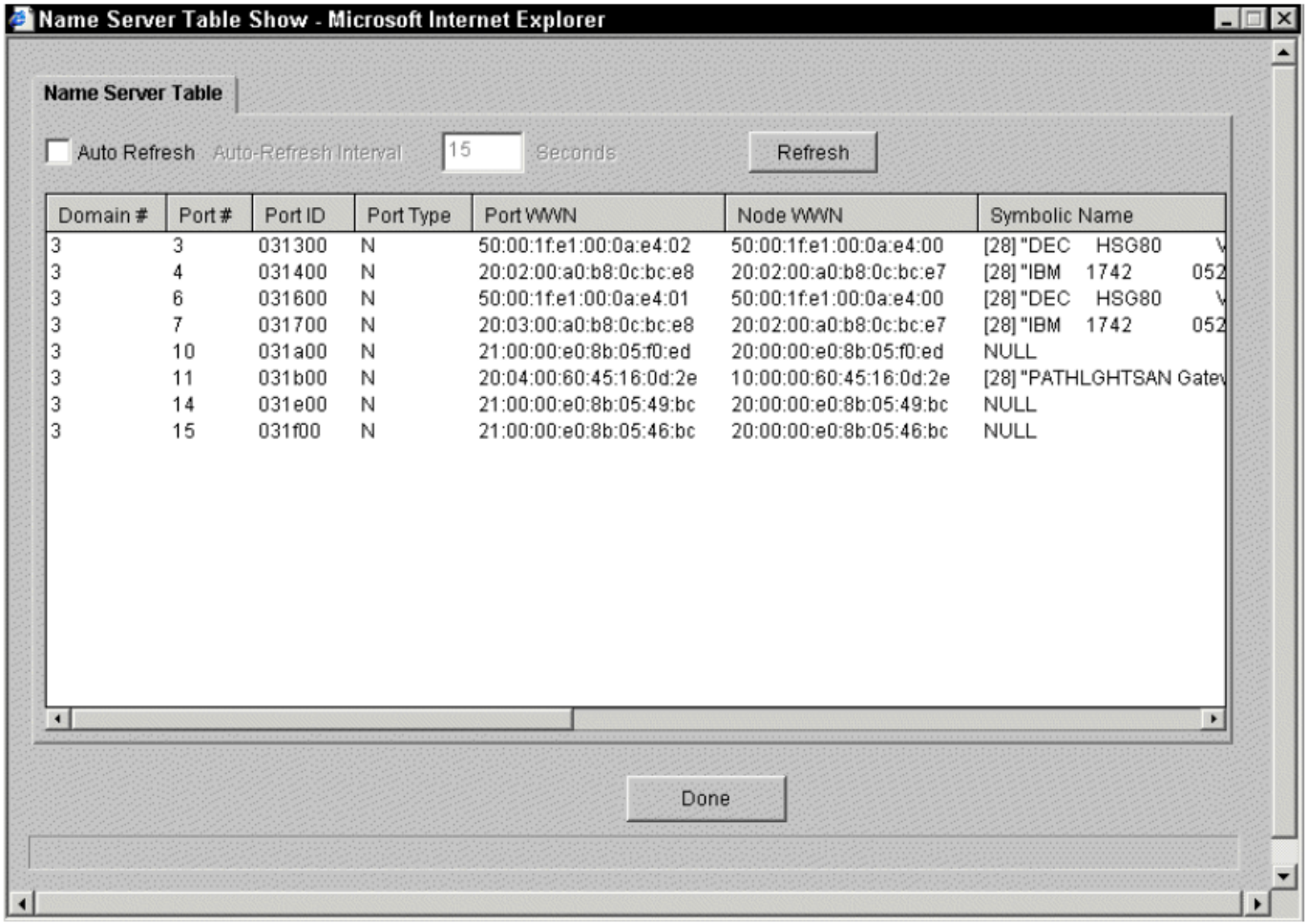
- Each FC device has a world-wide unique identifier, called World Wide Name (WWN)
  - Identifies maker and model, along with individual device
- Device can have also a unique identifier for each port (WWPN)

FC Addressing



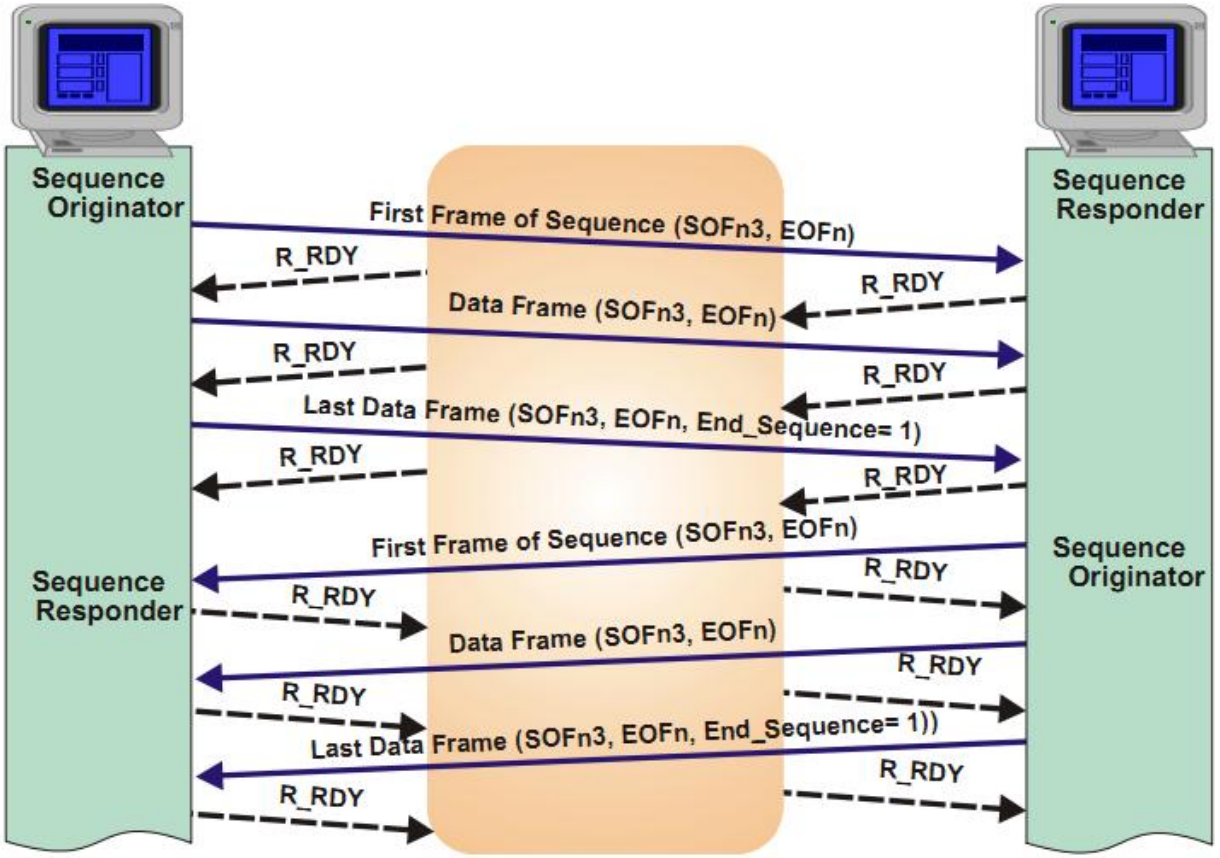
- Switch assigns an unique 24-bit address to each WWN or WWPN that joins the fabric (FLOGI)

FC Addressing



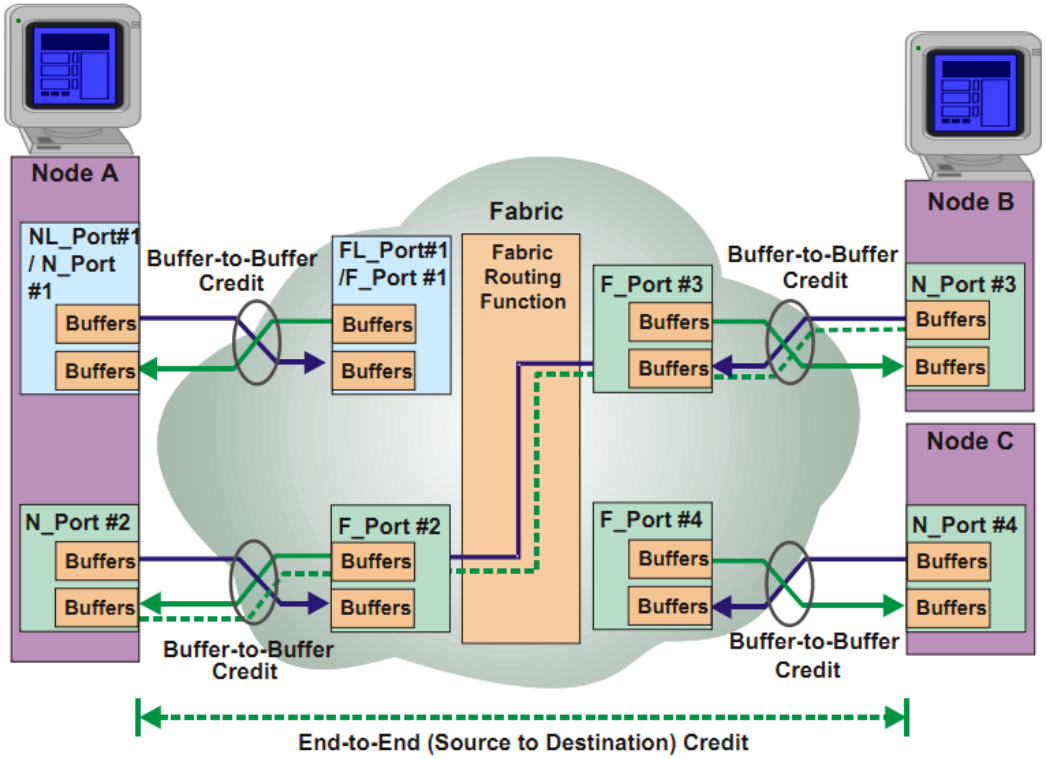
- Switch maintains in RAM translation table between WWN/WWPN and fabric address

FC flow control



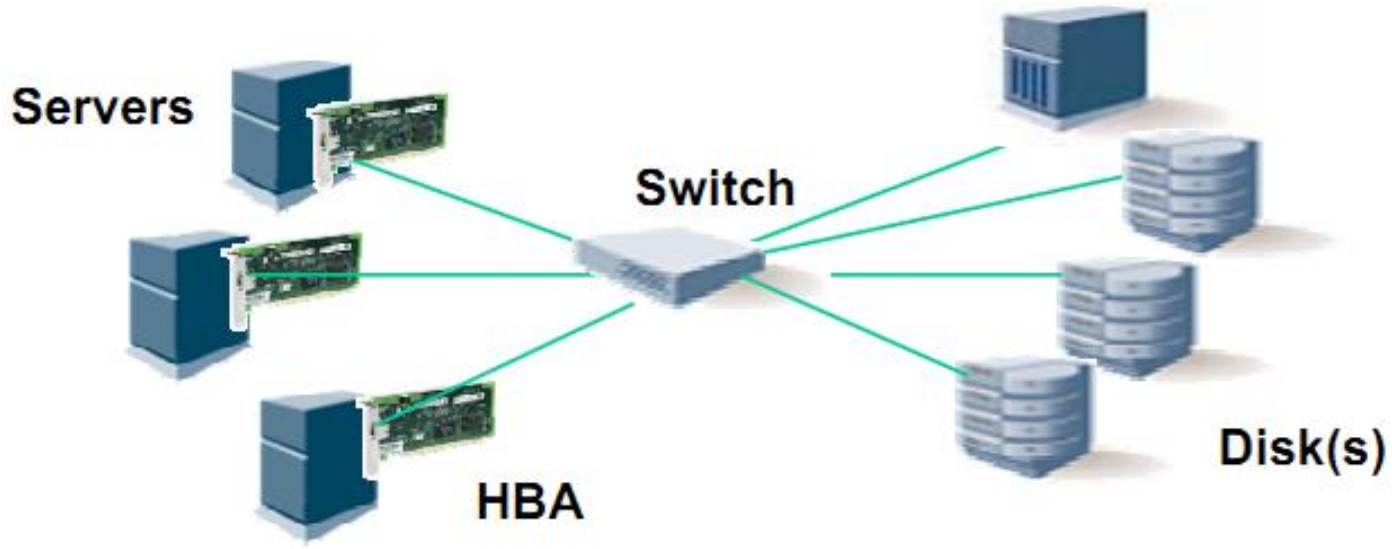
- Usually FC works in *Class3* service (connectionless communication with no end-to-end ACKs)
  - Link layer DO acknowledge every frame
  - Obviously, same kind of flow control is required

FC flow control



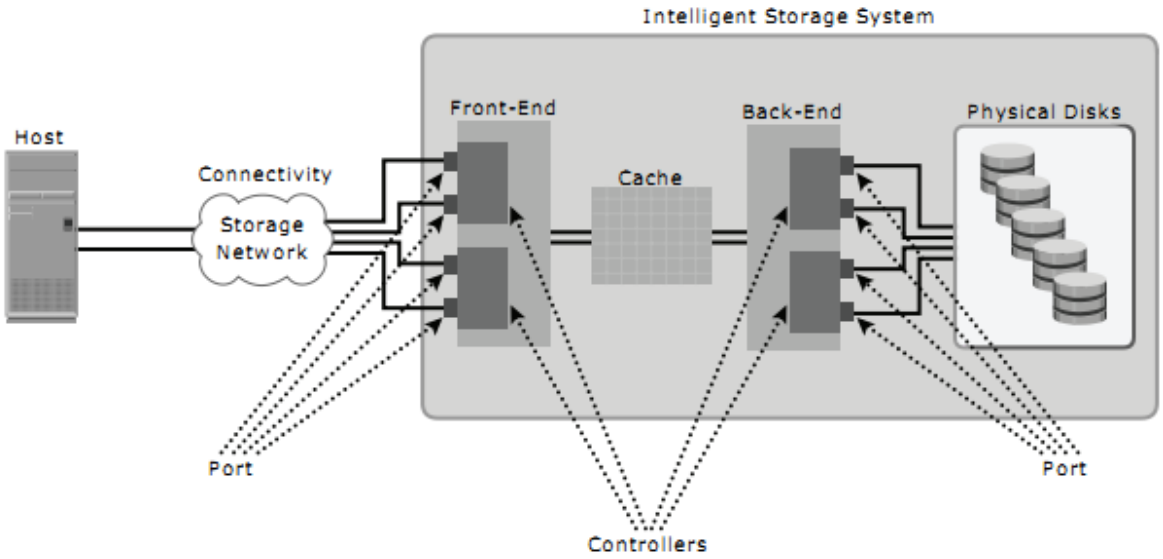
- FC uses link-level flow control, called *Buffer-to-Buffer* credits
  - Essentially, fancy name for a sliding window flow-control protocol
- FC Buffer credits ensure that fabric congestion does not result in packet loss
  - I/O timeouts due to packet loss are nasty

Storage Area Network (SAN)



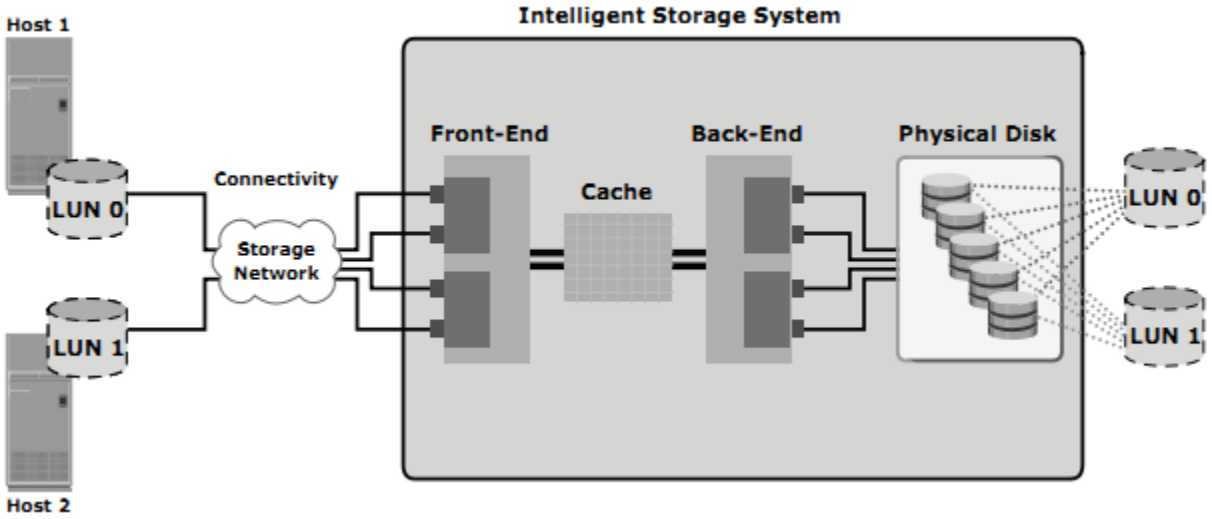
- A Storage Area Network carries data between servers and storage devices through a FC fabric, implemented by one or more FC switches

Storage Area Network (SAN)



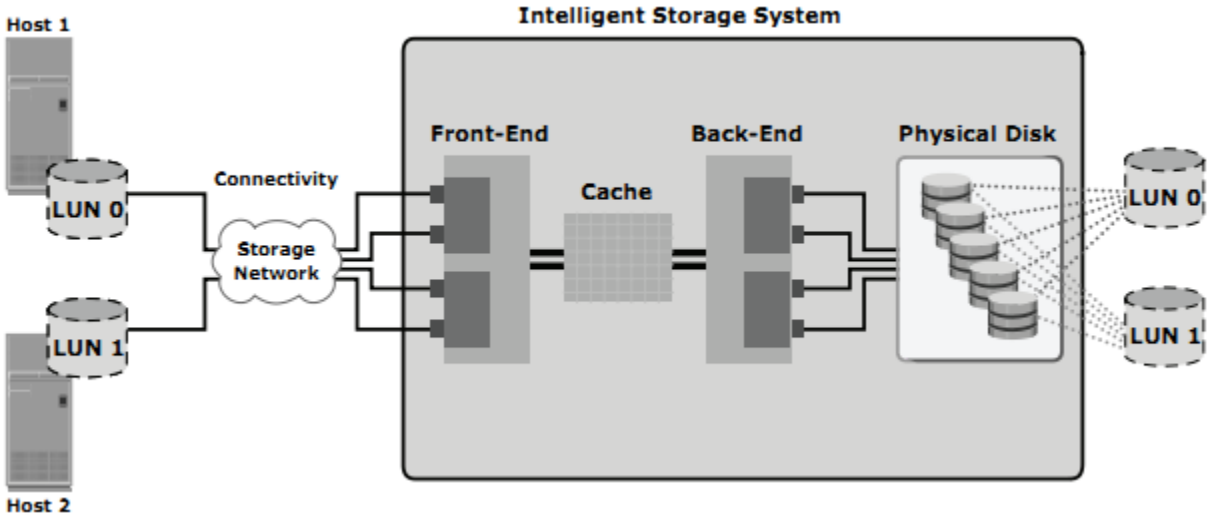
- Front-end controller of smart storage offers FC interface
  - Encapsulates and de-encapsulates SCSI payload onto/from FC frames
  - Allows flexibility for choosing performance/cost of physical storage
  - FC-to-FC: FC front-end, FC backend to physical disks
    - Maximum performance, maximum cost
  - FC-to-SAS: FC front-end, SAS backend: medium performance and cost
  - FC-to-SATA: SATA backend, lower performance and reliability, low cost

Shared physical storage with SANs



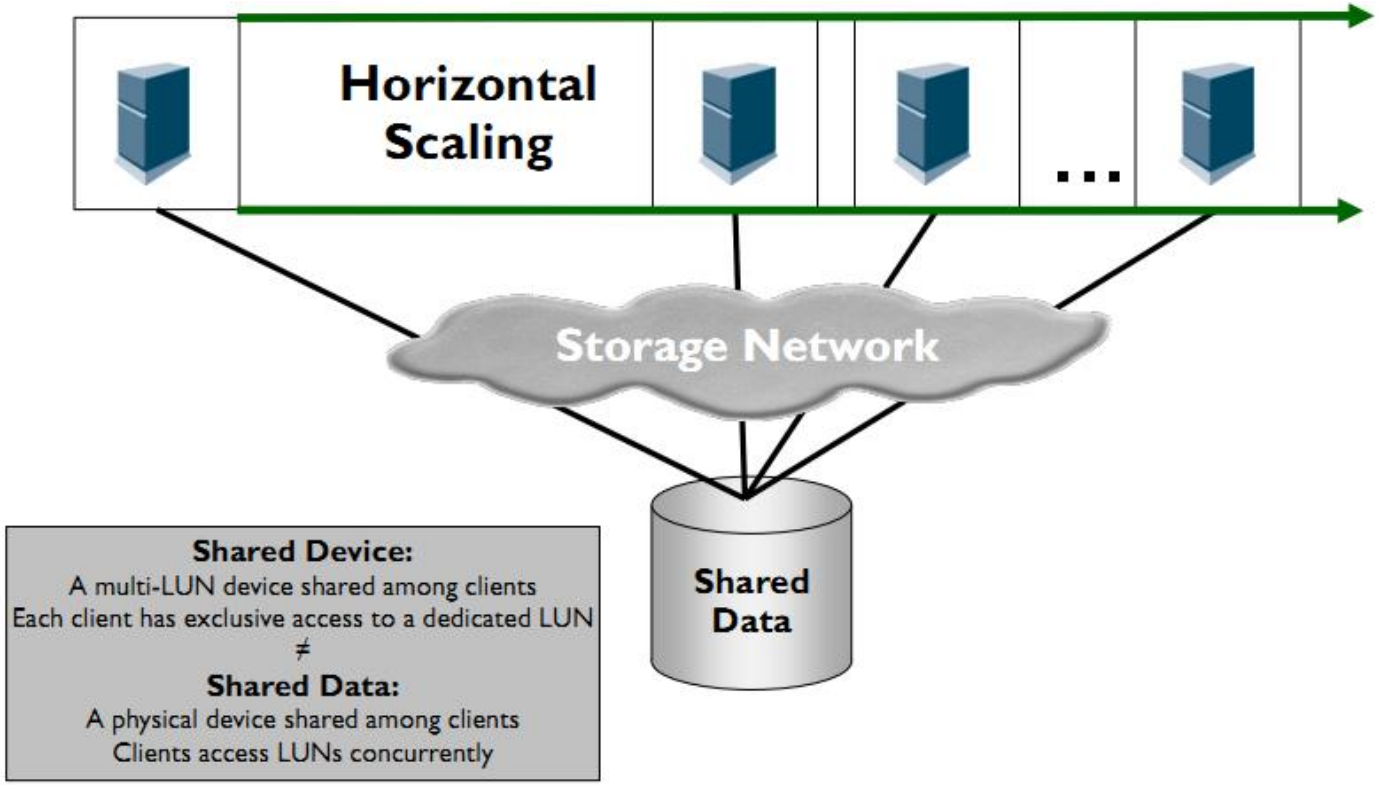
- Front-end controller hides physical disks to servers
  - Storage organized as separate LUNs
- Controller uses unique WWN identification to perform LUN-Mapping
  - Configuration of which server can see which LUN

Shared physical storage with SANs



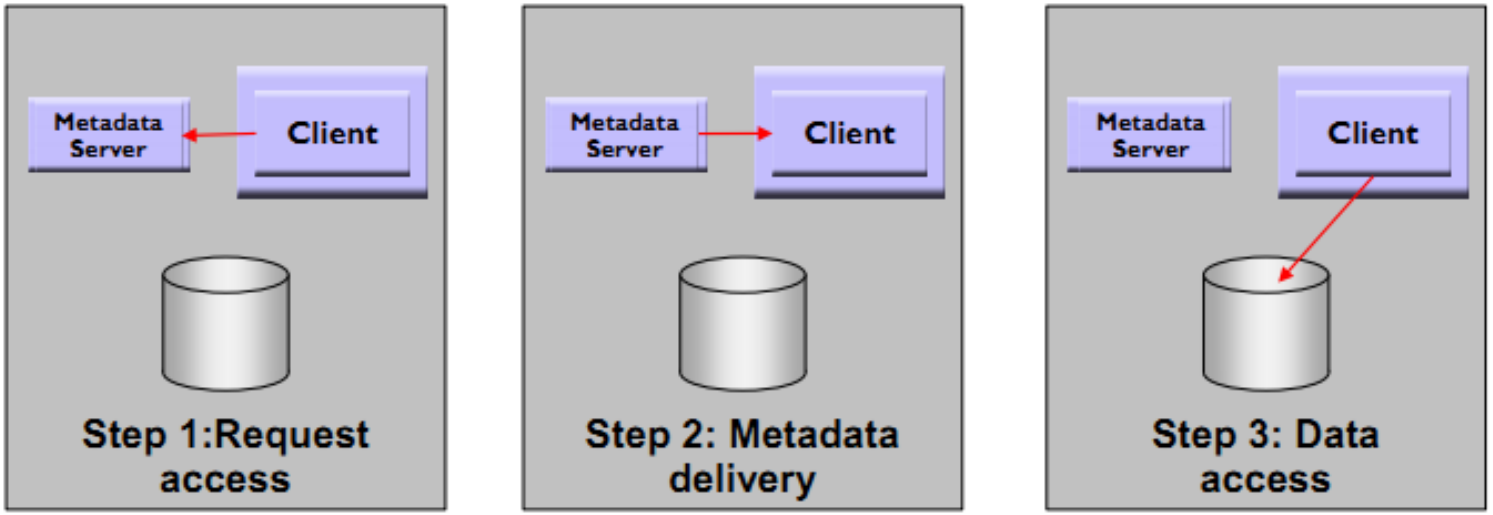
- In simplest configuration, each server will be shown a single LUN
  - No two servers share same LUN
    - Avoids coherency problems in filesystems
  - Reduces costs by centralizing physical storage array

Sharing data with SANs



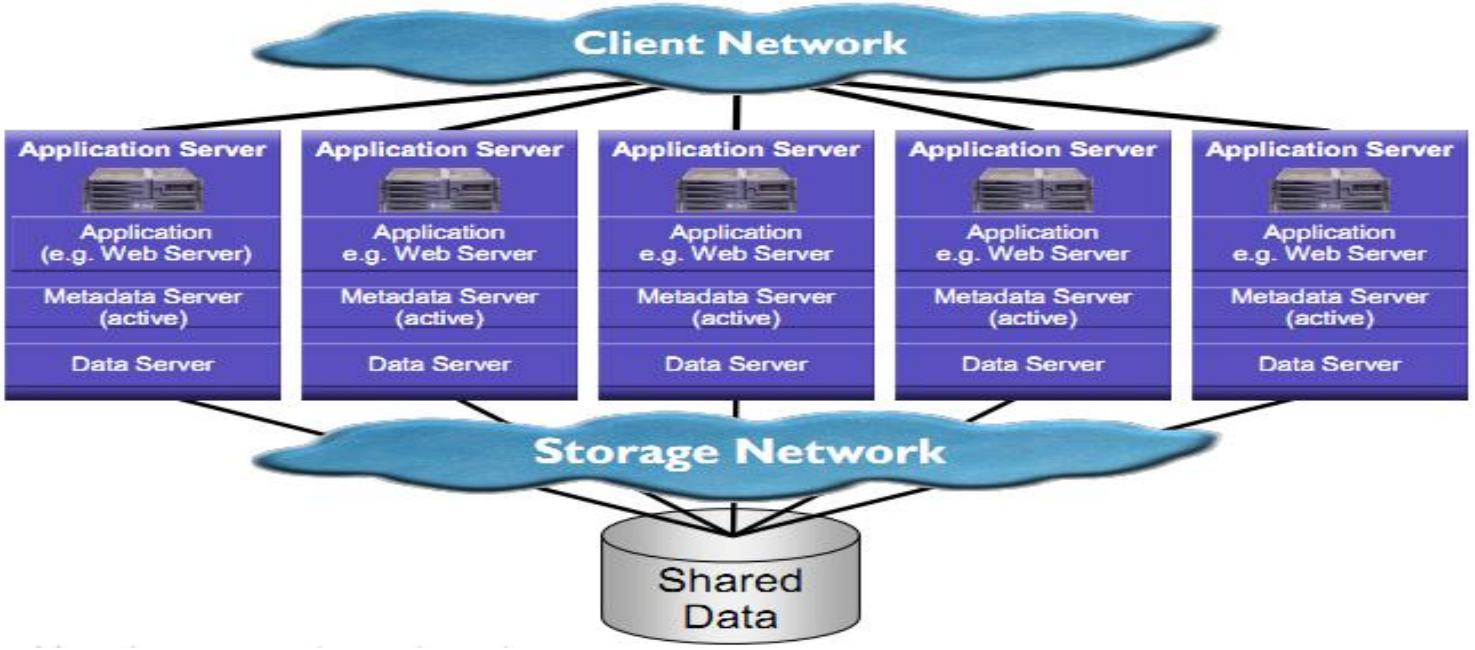
- SANs allow also sharing data between servers
- Front-end controller allows concurrent access to same SCSI LUN from several servers
- Problem: access MUST be coordinated at the filesystem level, or coherency problems will arise soon

Sharing data with SANs



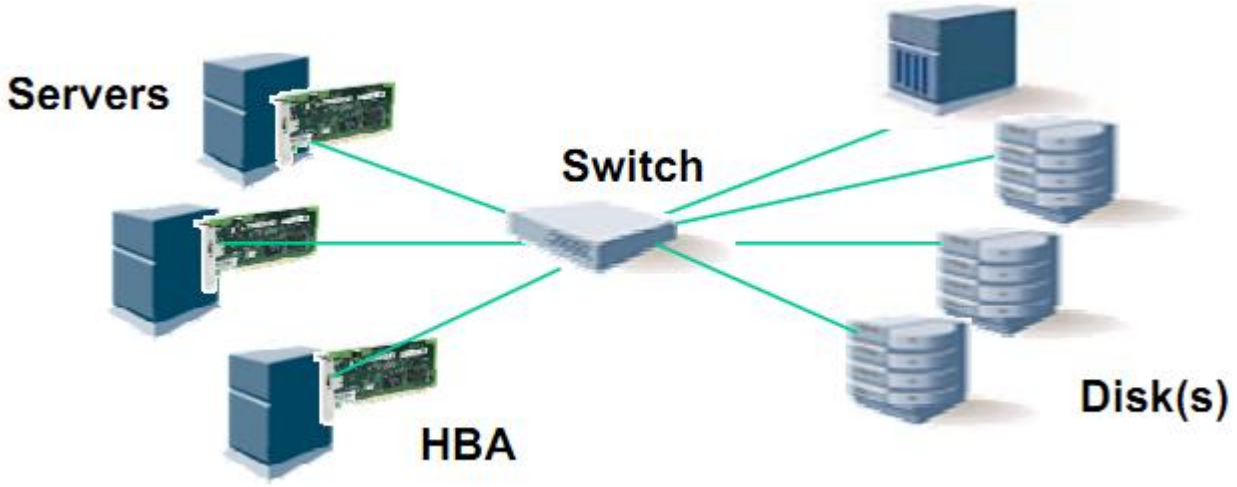
- Solution: clustered file-system
  - Metadata server keeps database with mapping of filesystem contents to SCSI blocks (LBAs)
  - Servers (clients) must request ticket to metadata server before access to data (read or write)
  - Metadata server returns permission and block metadata while maintaining system-wide coherency
  - Client can then do physical access to block device

Sharing data with SANs



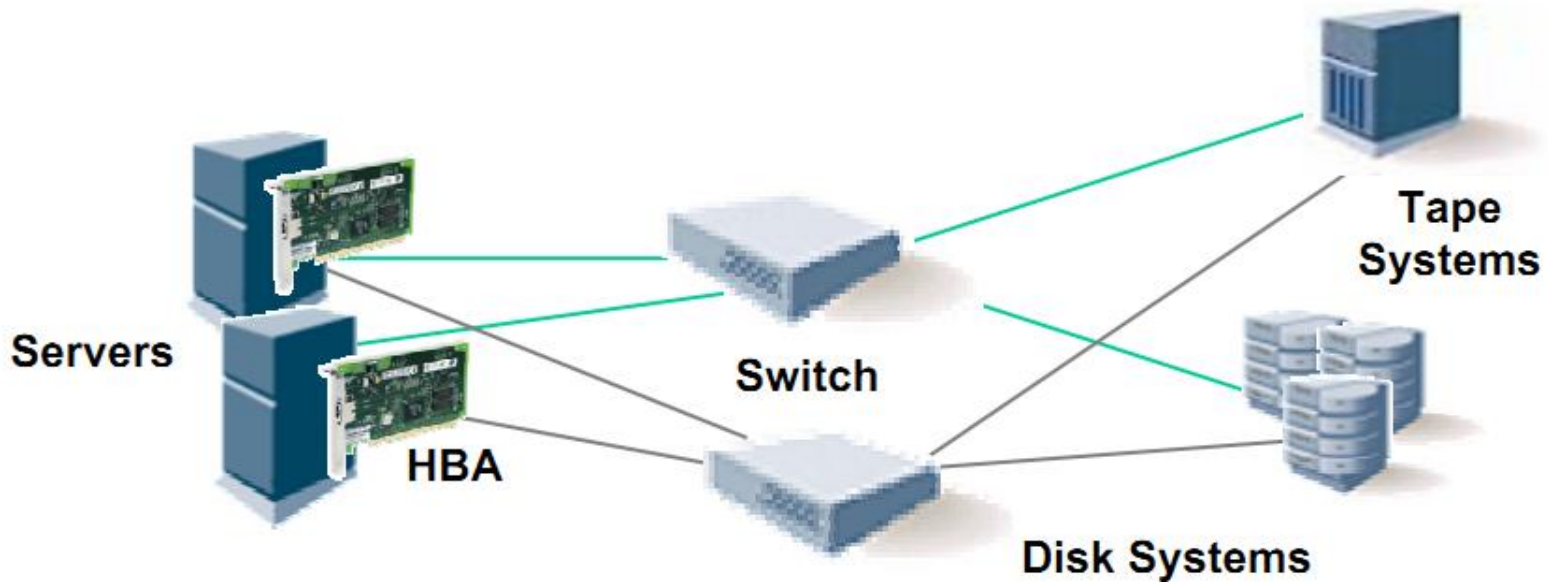
- Metadata server and clients all must have physical, SCSI-level access to shared storage
  - SAN connectivity makes this possible
- In production environment, two metadata servers
  - Active-passive: simpler, no High Availability (downtime to switch server)
  - Active-active: more complex, allows High Availability and load balancing

High Availability and Multipathing



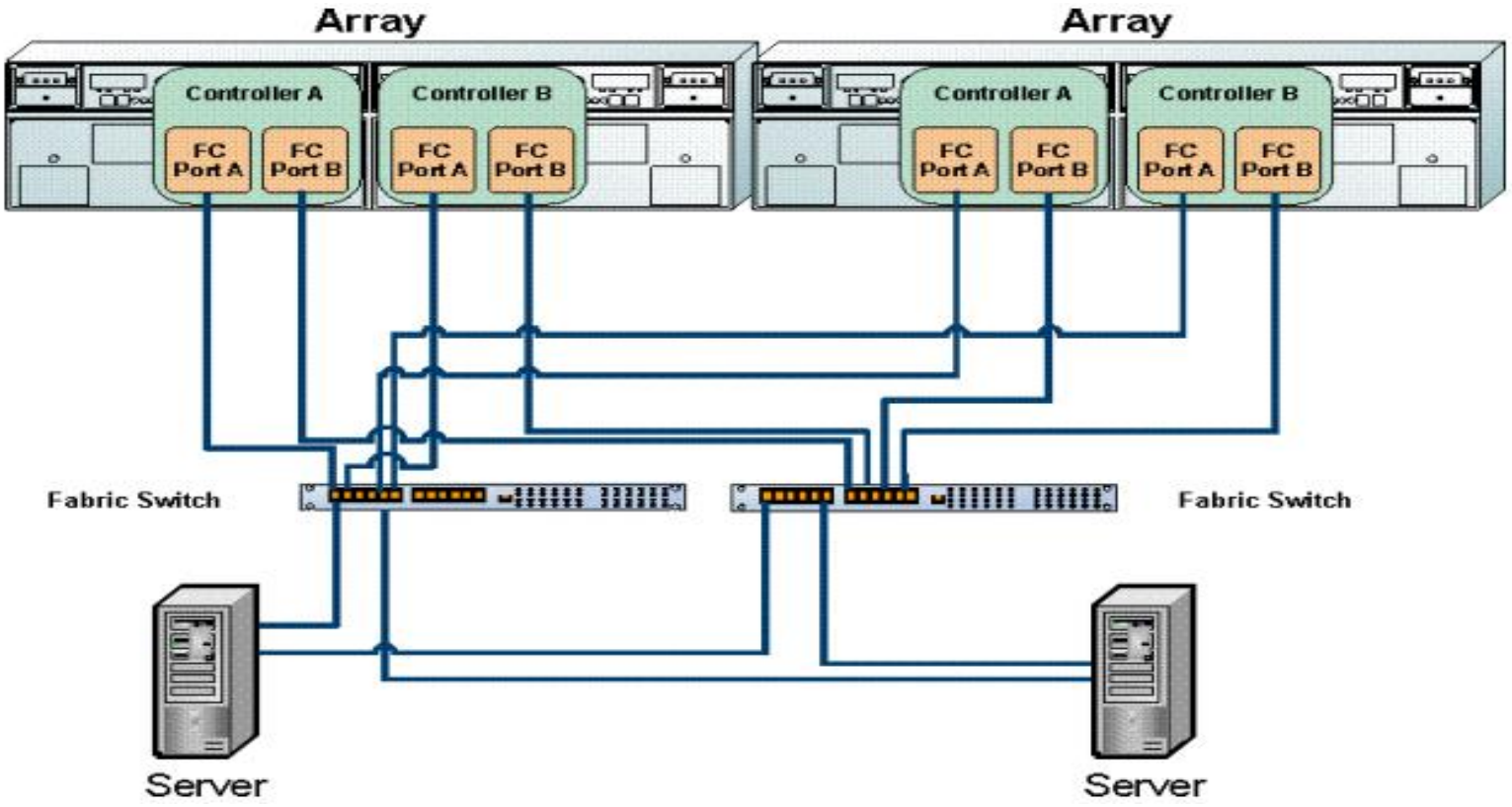
- Problem with SAN of figure: lots of single points of failure
  - Only one FC switch
  - Only one FC link between devices and switch
- Additional problem: congestion if all I/O transactions target the same LUN (link)

High Availability and Multipathing



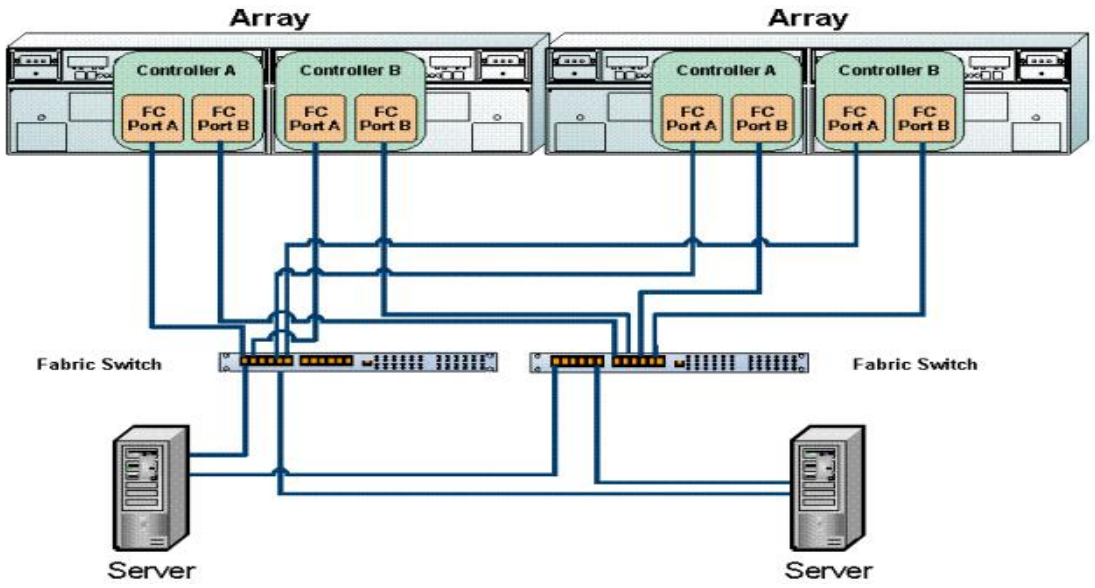
- Reliability of system improves introducing redundancy for all FC components
- System provides failover capability

Multipathing



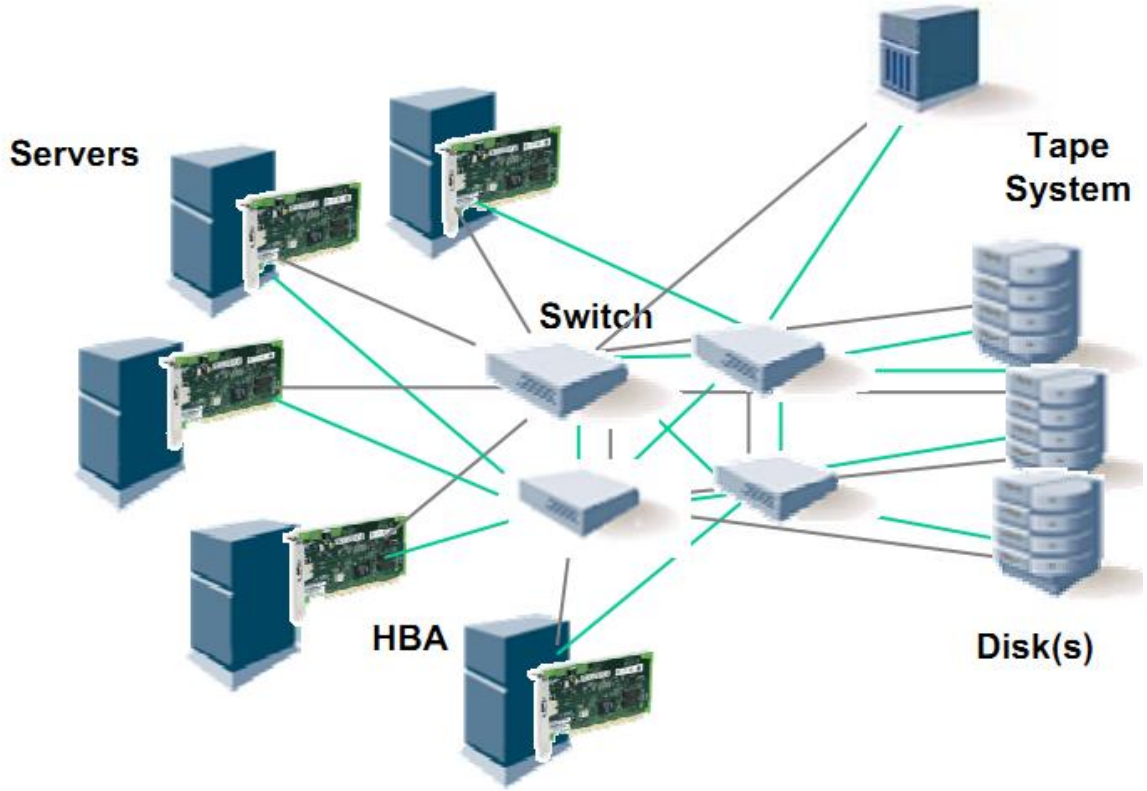
- System provides also multipathing
  - There are at least two different paths through FC fabric between any initiator and any target (LUN)

Multipathing



- Managing multipathing requires multipath-capable FC HBA device driver in servers
  - Driver uses unique SCSI-level identifiers to avoid duplicating LUNs at filesystem level.
  - Manages active-passive or active-active link status
  - If active-active, can also manage load-balancing
    - SCSI traffic split between paths to help reduce congestion

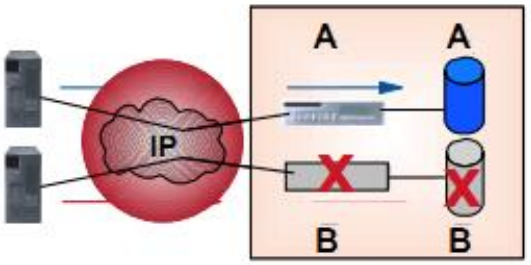
Multipathing and load-balance



- Fabric can be also scaled-out to improve redundancy and load-balancing
  - Avoids running in degraded state due to bandwidth loss if a switch fails
  - Trunking between switches provide necessary cross-over paths

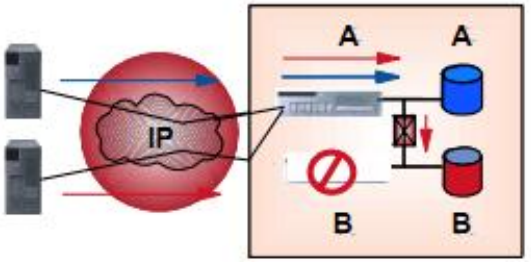
Clustering architectures

- **Shared Null**
  - No failover
  - No clustering
  - No load balancing



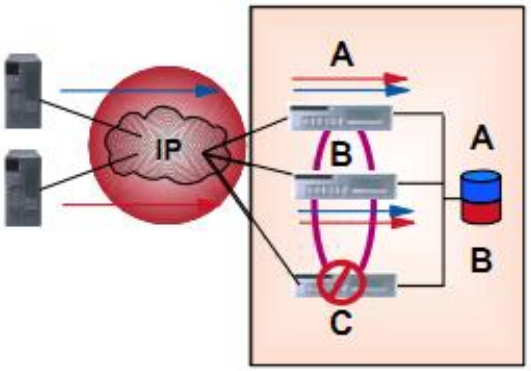
Each node accesses storage separately

- **Shared Nothing**
  - Clustered failover
  - No load balancing



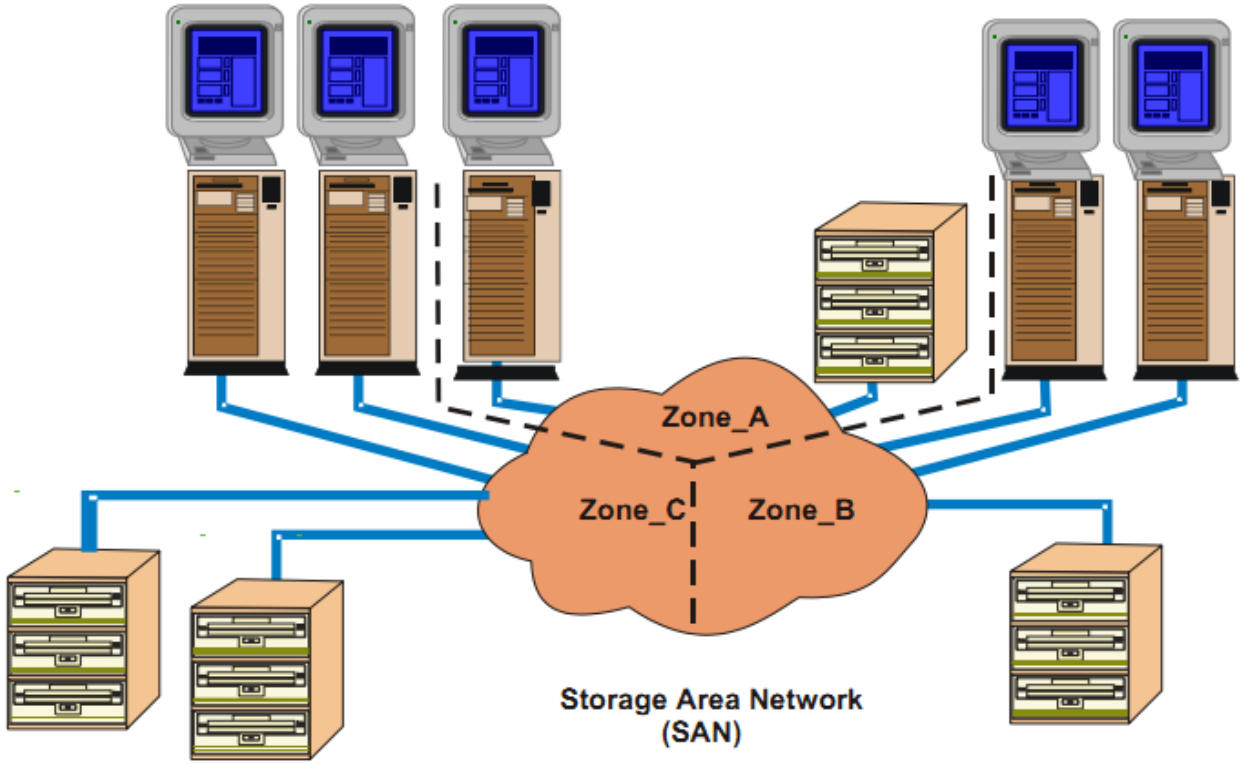
Any node can read or write to any piece of data...
NOT Concurrently

- **Shared Everything**
  - Clustering and immediate failover
  - Load balancing
  - Multinode access to large file systems



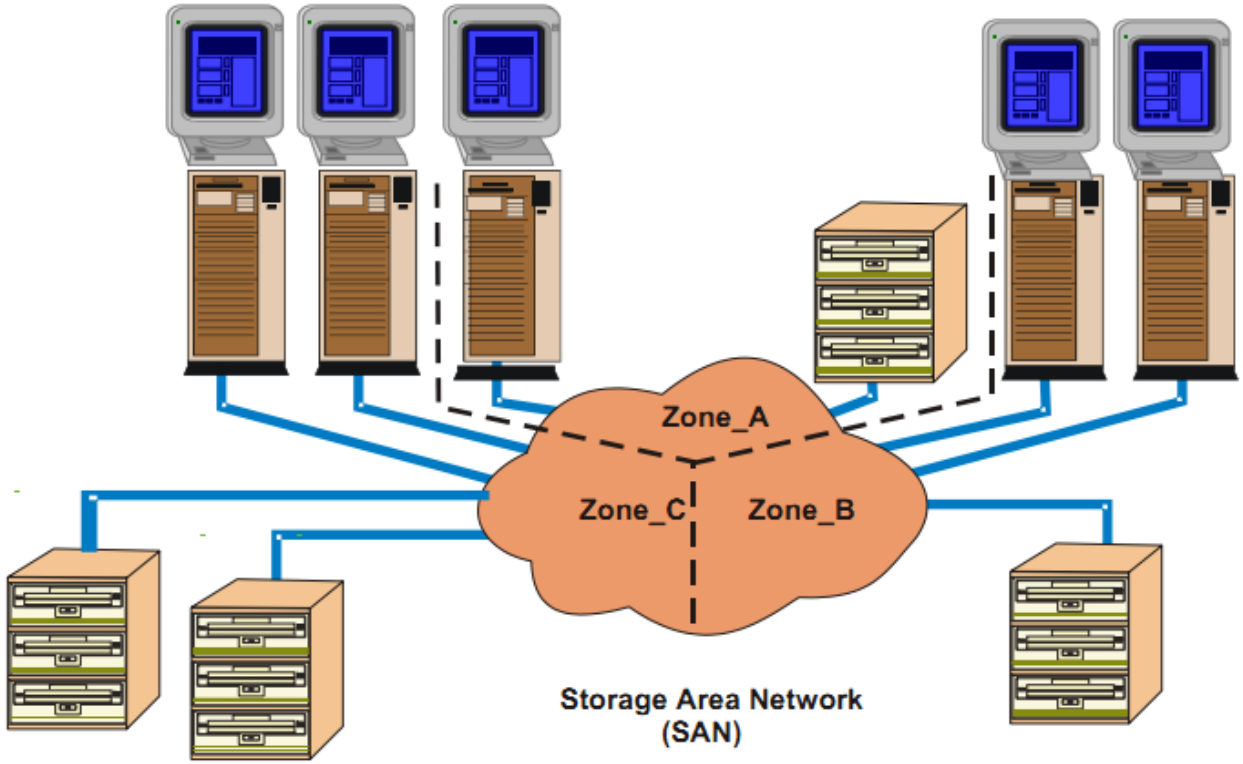
Any node can read or write to any piece of data...
CONCURRENTLY

Zoning



- SAN allows also FC access control = *zoning*
  - Done within the FC switch
  - FC traffic can be allowed or disallowed between given pairs of WWNs
  - Effective way to hide selected targets to selected initiators

Zoning



- Do not confuse with LUN-Mapping
  - Zoning: done at switch, disallows FC traffic between WWNs
  - LUN-Mapping: done at the storage controller, disallows SCSI traffic between a given LUN and a given initiator (identified by its WWN)

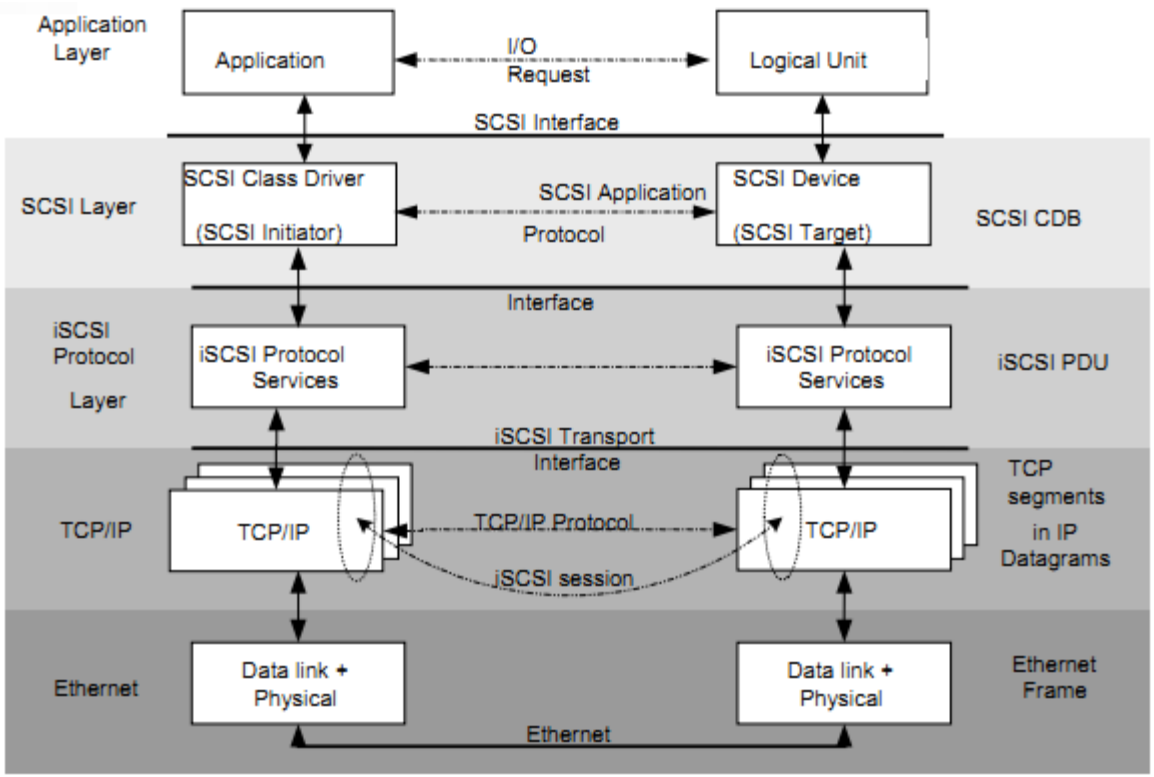
IP Storage Protocol: iSCSI

iSCSI

- iSCSI = Internet SCSI

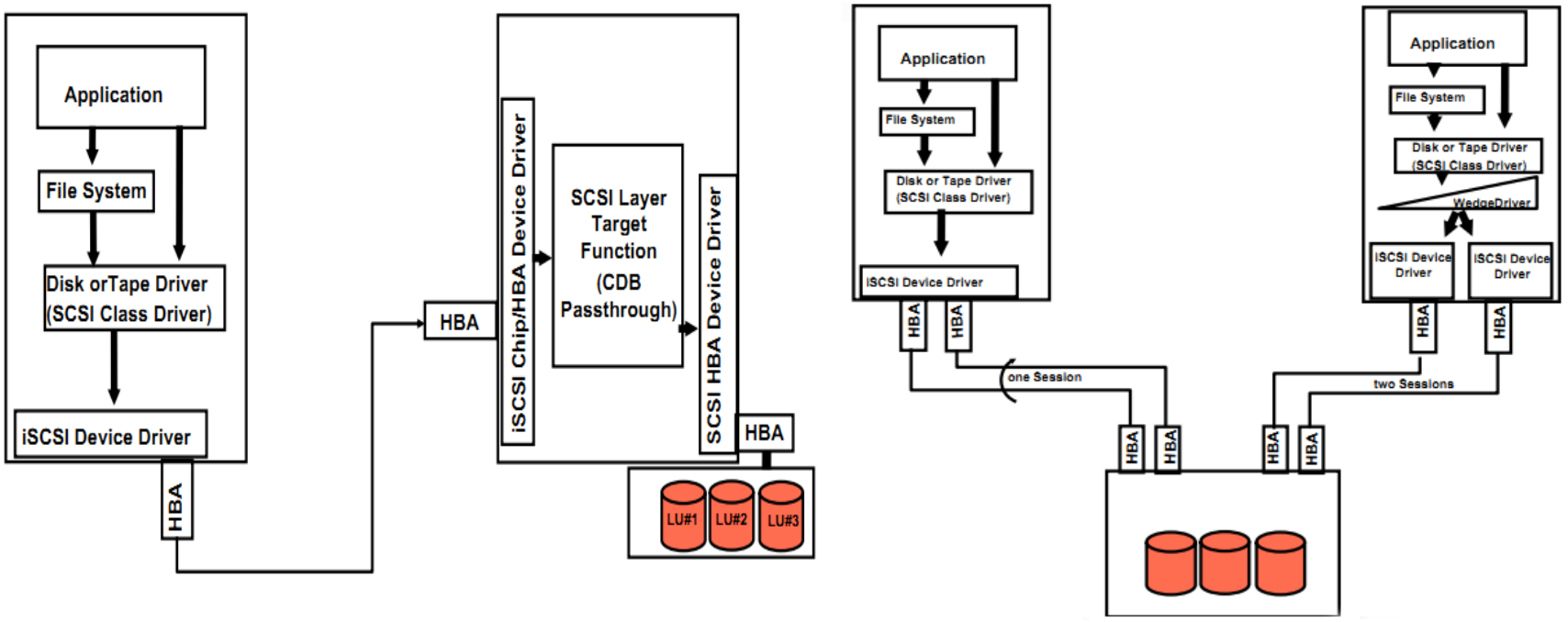
- SCSI payload is encapsulated and transported over TCP/IP network

iSCSI



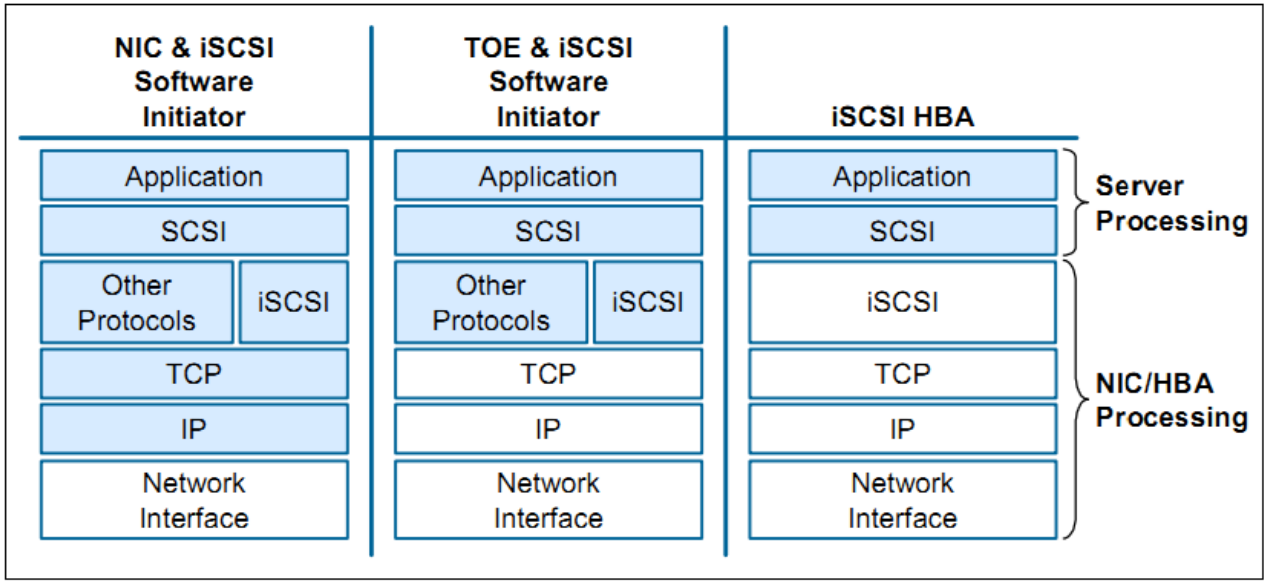
- iSCSI layers a SCSI transport layer and a SCSI protocol layer over the TCP/IP stack
  - TCP provides reliable data transport and delivery
  - IP provides routing between networks
    - Routing over FC is complex and expensive

iSCSI



- iSCSI requires use of iSCSI device driver over network HBA
  - If multiple HBAs, or multiport network HBA, iSCSI allows link aggregation for improved bandwidth or reliability
  - Multipathing also works fine with iSCSI

iSCSI performance

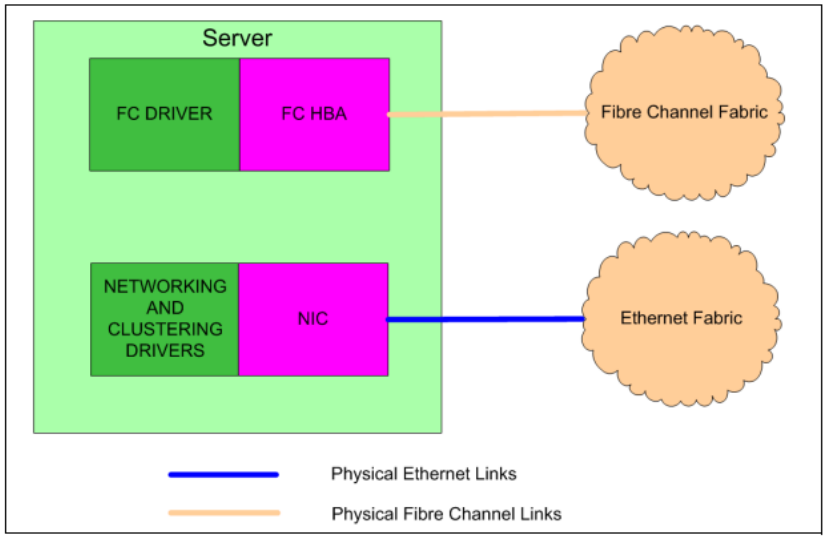


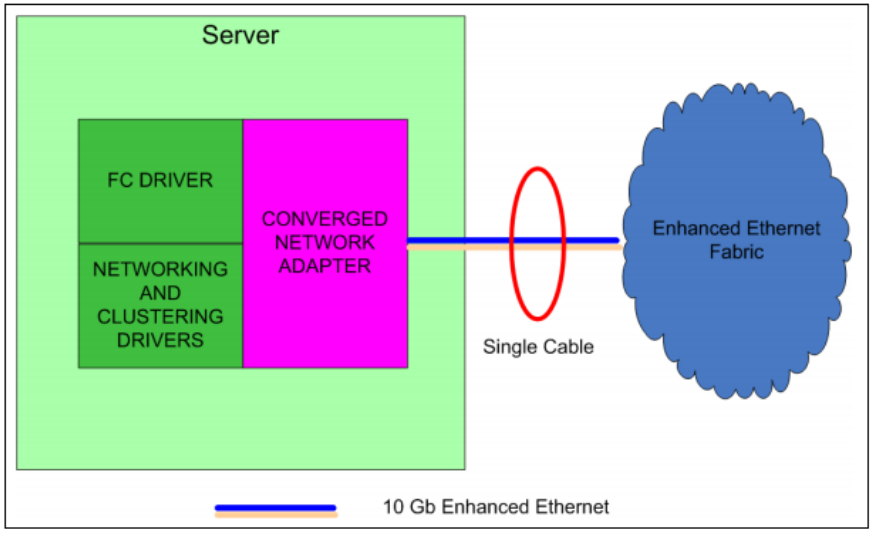
- iSCSI provides a flexible way to give SCSI access between initiators and targets
  - Quite useful for virtualization, as network traffic is much easier to virtualize than FC
- TCP processing overheads must however be carefully watched
  - TCP checksums and iSCSI protocol management can require a noticeable amount of host processing power
  - Hardware processing in iSCSI HBAs improves performance, but at a cost

Converged networking with FCoE

(Fibre Channel over Ethernet)

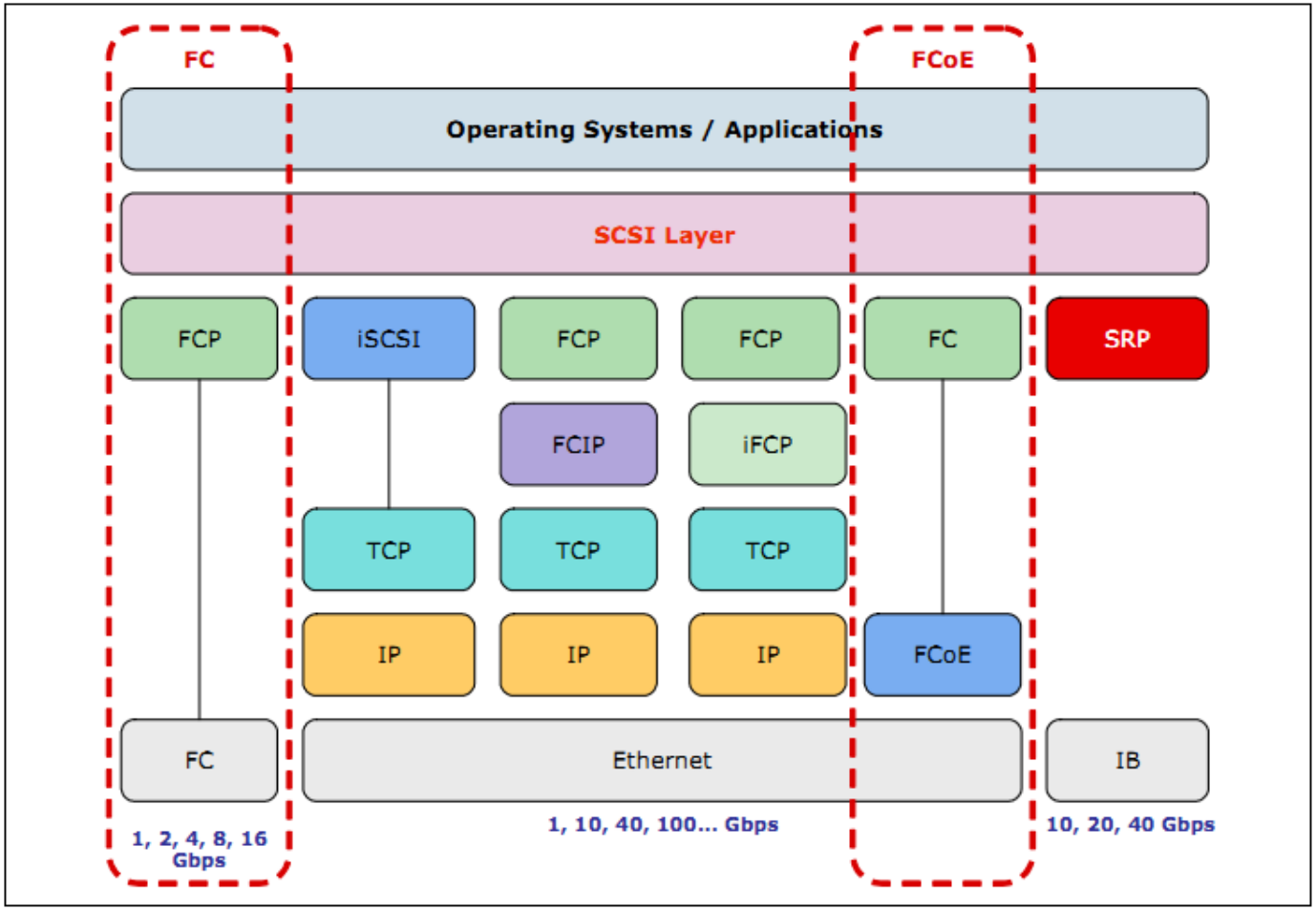
Converged networks





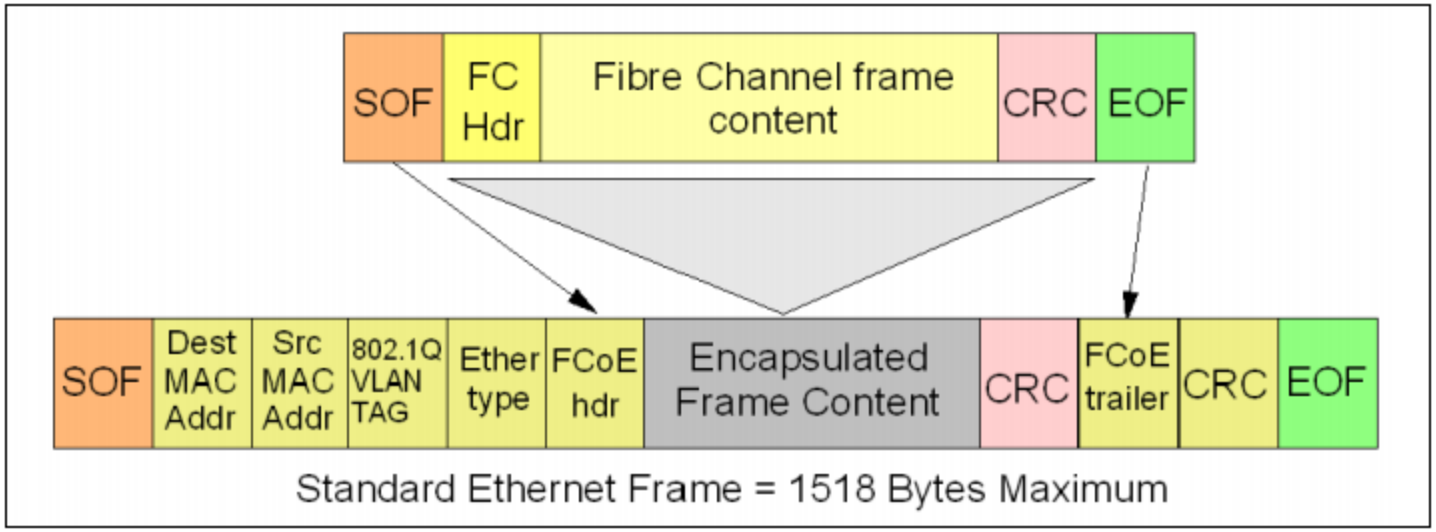
- Traditionally, datacenter required separate storage and Ethernet networks
  - Require higher hardware costs
  - Require two different sets of skills
    - Thus, two sysadms (or a very good single one), and twice personnel expenses
- With appearance of 10 Gbps Ethernet, suddenly converging both networks becomes interesting
  - Convergence requires SCSI payload being encapsulated within network protocols
  - iSCSI is, thus, one form of convergence

FCoE



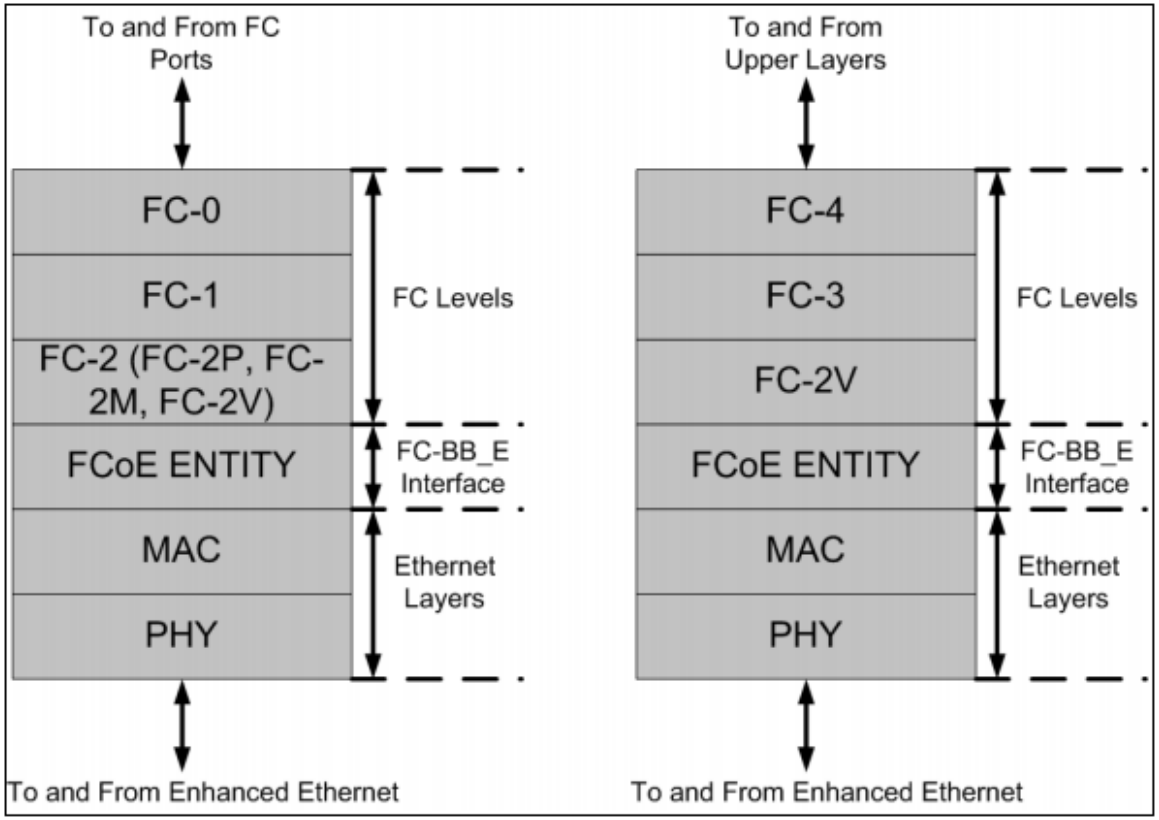
- FCoE = Fibre Channel over Ethernet
- FC with SCSI payload is directly encapsulated over Ethernet

FCoE



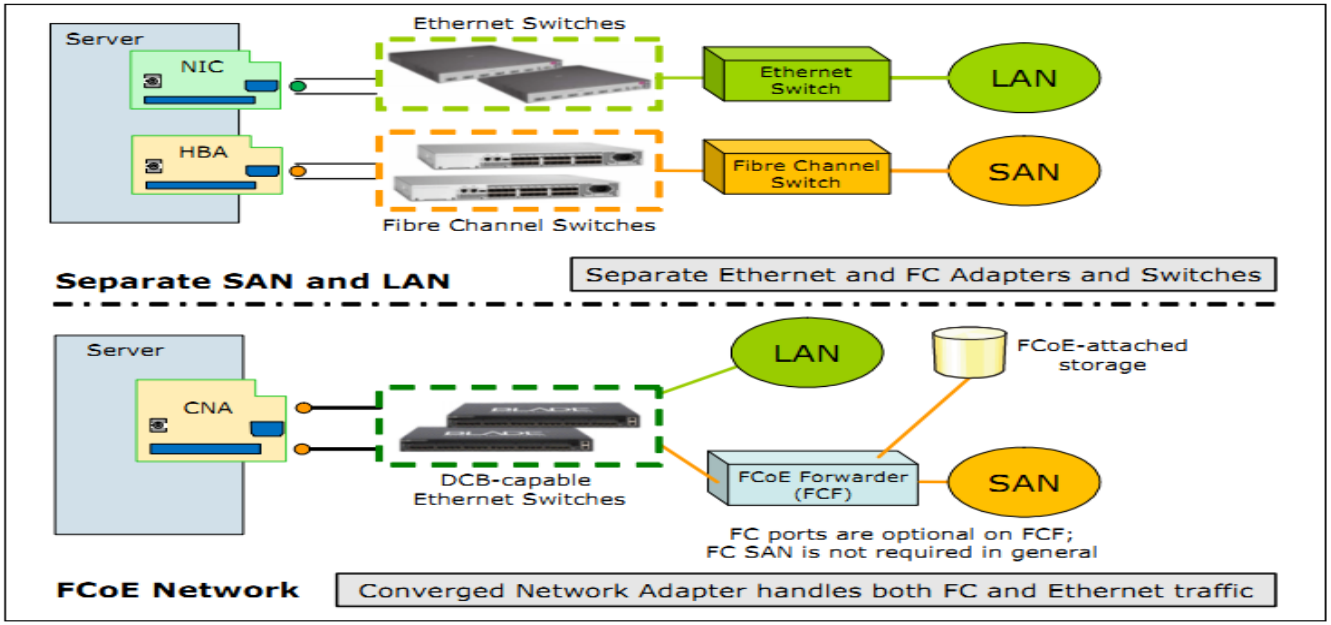
- FCoE frame is encapsulated within payload of Ethernet frame
  - Jumbo frames (payload > 1500 bytes) must be used to avoid fragmentation
  - Note that encapsulated FC frame includes also full FC headers

FCoE



- AS full FC headers are encapsulated, it is straightforward to extract FC frame and forward it to a FC SAN
  - No checksums need to be recalculated, so it is very fast

Shortcomings of FCoE



- Ethernet is connectionless, unconfirmed protocol
  - Congestion-triggered frame loss can create a real mess on FCoE performance
- FCoE assumes lossless Ethernet will be used
  - May require use of DCB (Data Center Bridging) capable switches
    - Improved link-level flow control and management controls to avoid loss of critical frames due to congestion
  - DCB does not come cheap

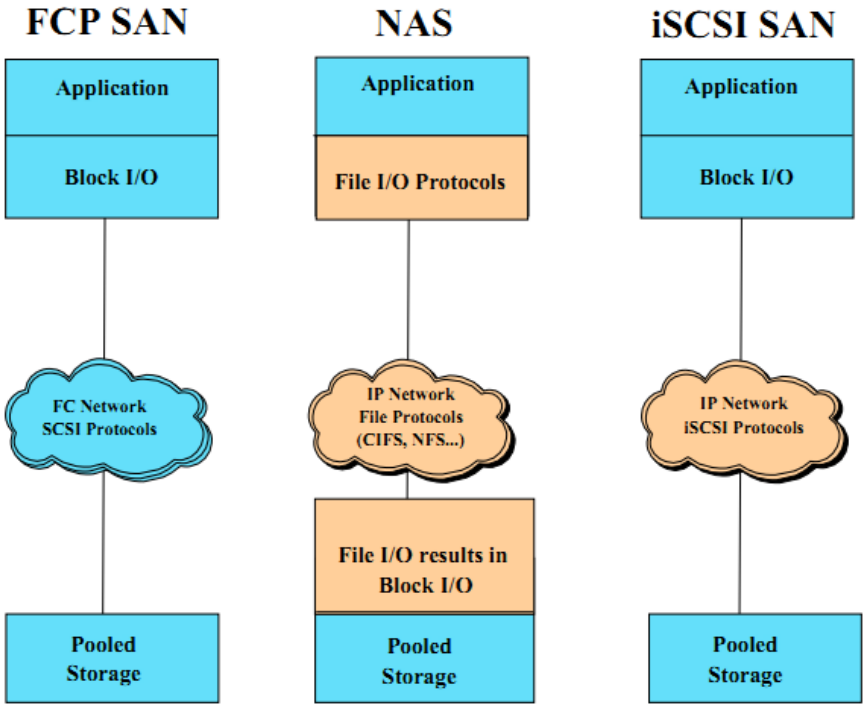
NAS: Network-Attached Storage

Network Attached Storage

- NAS is other way to access storage devices from servers using IP networks
  - NAS = high-performance storage appliance directly attached to IP networks, providing *File Serving* to clients and servers in an heterogeneous environment

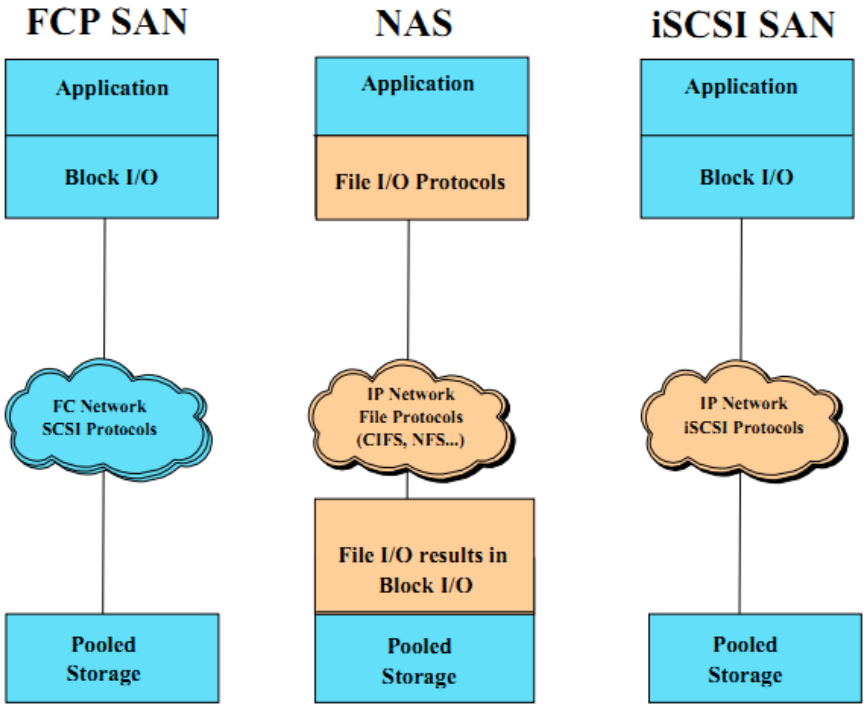
- NAS ≠ SAN
  - Same letters, totally different concepts

Block I/O vs File I/O



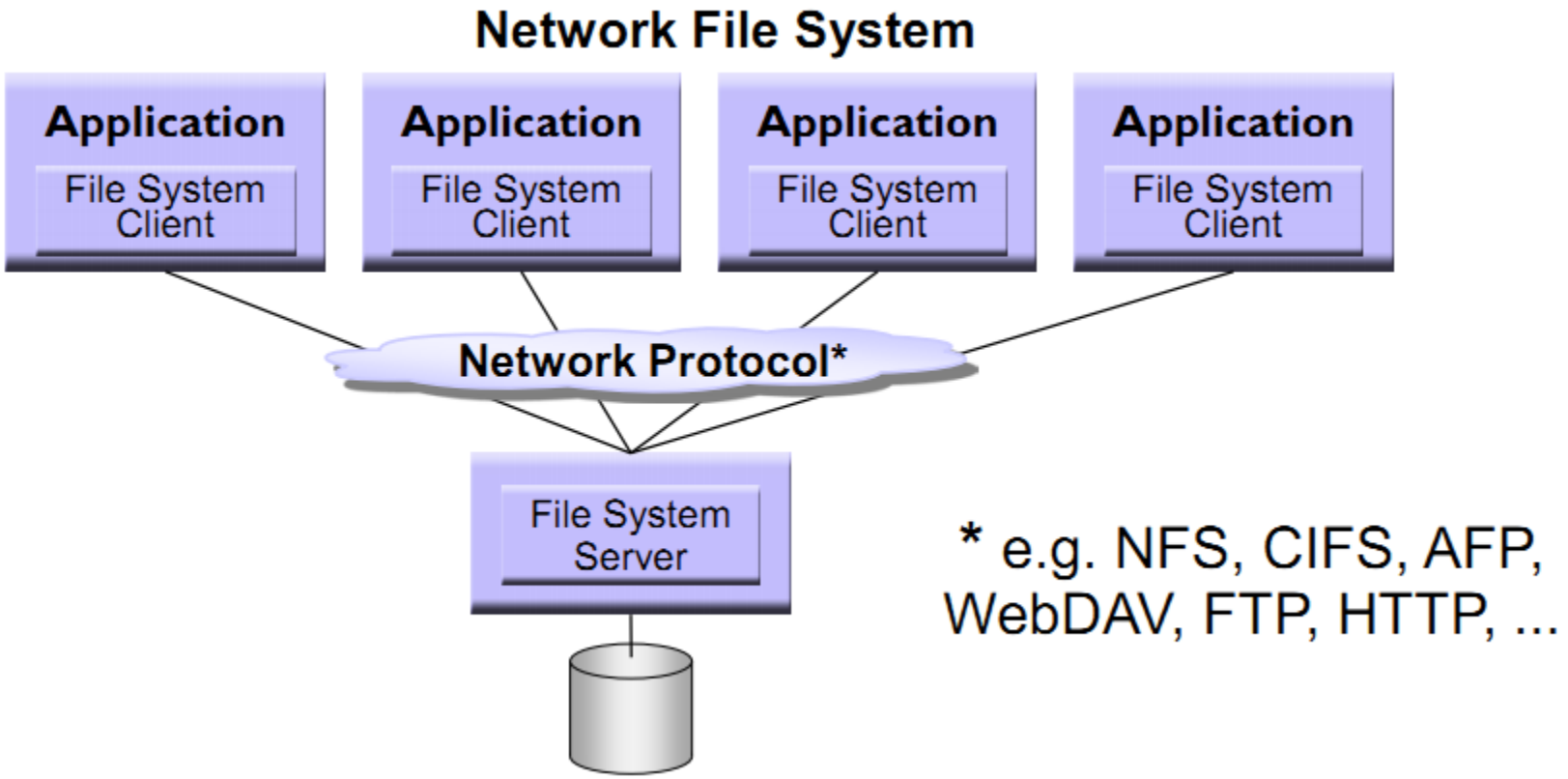
- SAN (FCP), iSCSI, FCoE are all block I/O protocols
  - SCSI payload carried over networked protocol
  - Device addressed as LBAs
    - Data directly written or read on addressed storage block, regardless of file

Block I/O vs File I/O



- NAS appliance requires use of file-sharing protocol
  - Access provided by file-sharing server, and to byte offsets (seeks) within file
  - Block storage of file is not visible to client application

Block I/O vs File I/O



- Client application accesses data through network file system
  - File system redirector transforms file access OS system calls into filesharing protocol system call
  - Redirection is transparent for client application

Block I/O vs File I/O

- NAS server (NAS appliance or NAS Gateway) transforms file I/O to block I/O
  - File sharing protocol call delivers filename and byte offset requested
  - File system in NAS server provides mapping to requested LBAs
  - Block I/O to requested LBAs is then performed on storage

Typical NAS protocols

- NFS:
  - Typical for Linux / Unix environments
  - Transported over UDP or TCP
    - UDP = potentially horrible reliability problems
    - TCP = higher overload
- CIFS (aka SMB)
  - Typical for Windows sharing
    - Can be provided by Linux server using Samba
  - Large protocol stack = large overhead
    - SMB -> NetBIOS -> TCP -> IP -> Ethernet
  - SMB 2.0 slow for bulk transfers
  - SMB 3.0 seems better (?)

NAS & iSAN

- Same gateway can support both iSCSI and NAS
  - Server manages coherent access to data from both file I/O and block I/O
- Co-existence of NAS and iSCSI very valuable for storage virtualization
  - More flexibility to choose how storage will be accessed from virtual machines

What's next?

- We have already seen how the SCSI interface hides the physical implementation of storage, showing to the server just an abstract representation of its contents

- However, the physical implementation details of a storage device are critical to understand the performance (or lack of), timing and latencies of its I/O transactions

- So, we will see now the internals of both magnetic and solid state disk drives