8. Storage Interface

Special Topics in Computer Systems:
Modern Storage Systems
(IC820-01)

Instructor:

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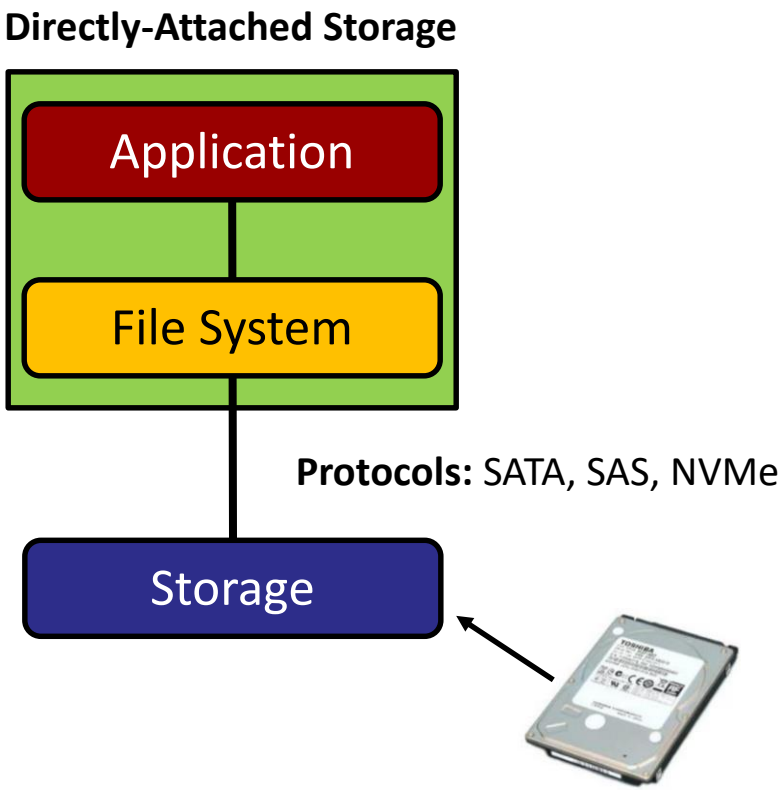
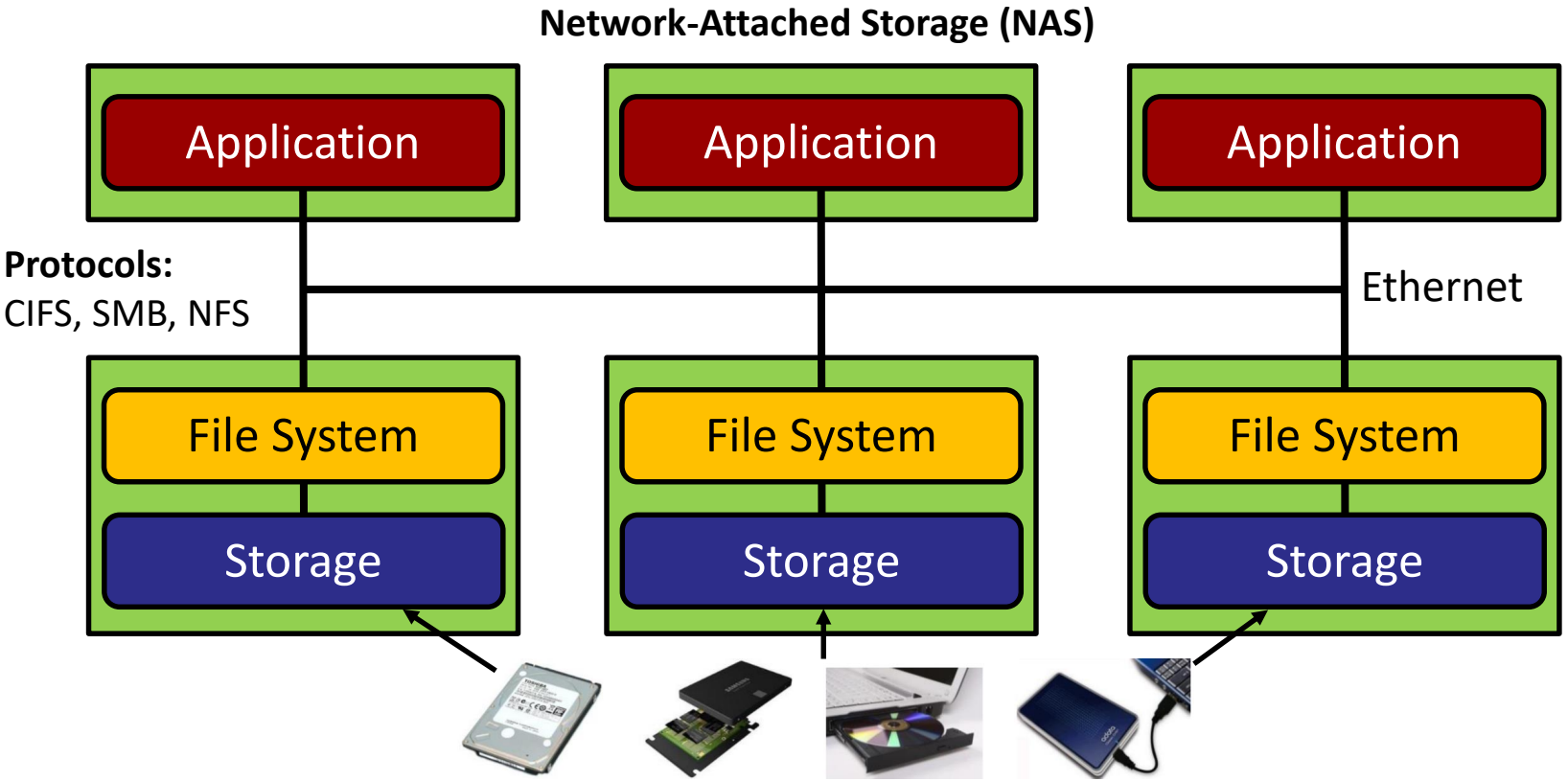
DAS, NAS, and SAN

- **Directly-Attached Storage (DAS)**
  - Direct-attached storage device
  - Generally attached/dedicated to a specific server



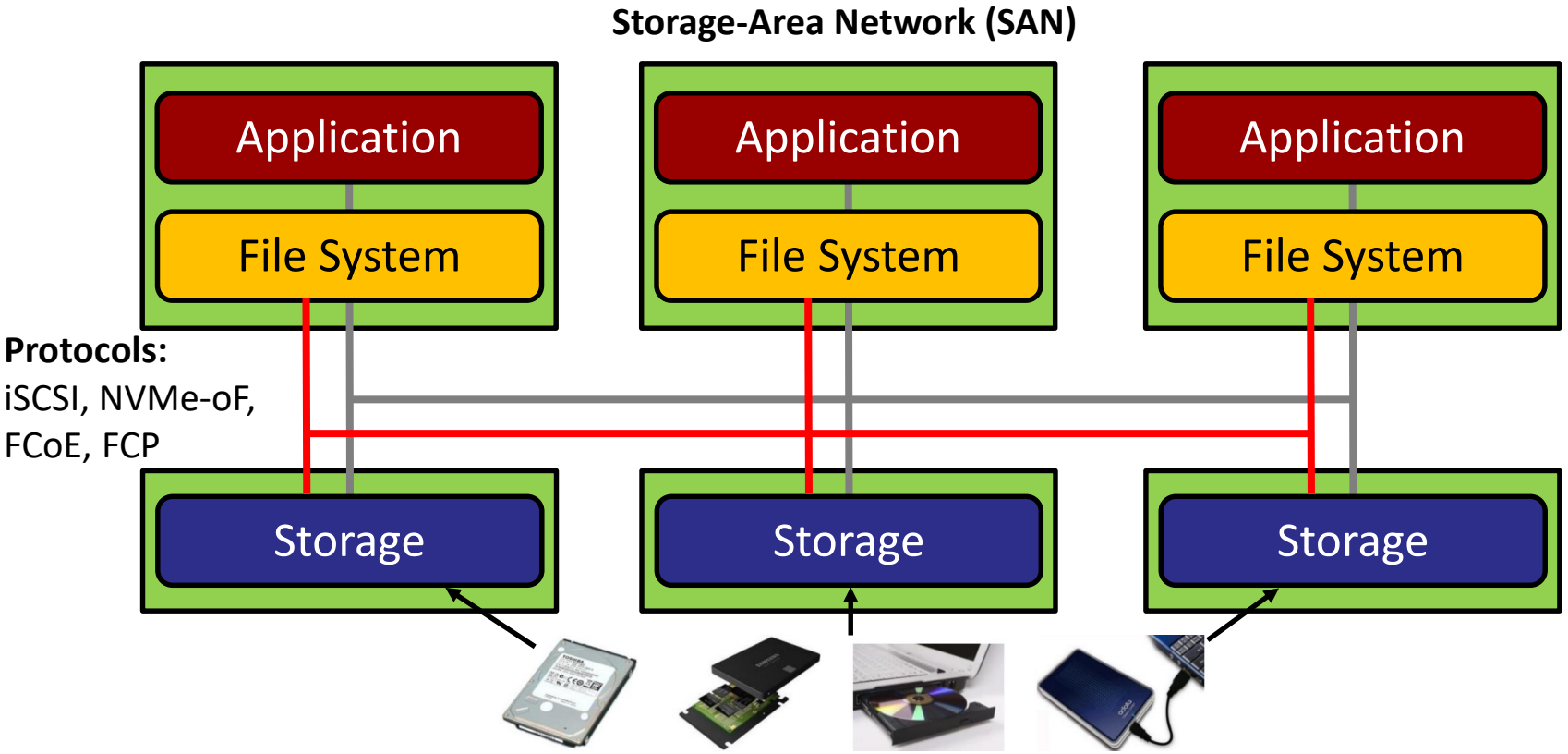
DAS, NAS, and SAN (Cont.)

- **Network-Attached Storage (NAS)**
  - Connected to a server via a network
  - Can be shared or dedicated



DAS, NAS, and SAN (Cont.)

- **Storage-Area Network (SAN)**
  - Connected to a server via a storage network
  - Can be shared or dedicated



Outline

- **Directly-Attached Storage (DAS)**
- **Network-Attached Storage (NAS)**
- **Storage-Area Network (SAN)**

Storage Interface

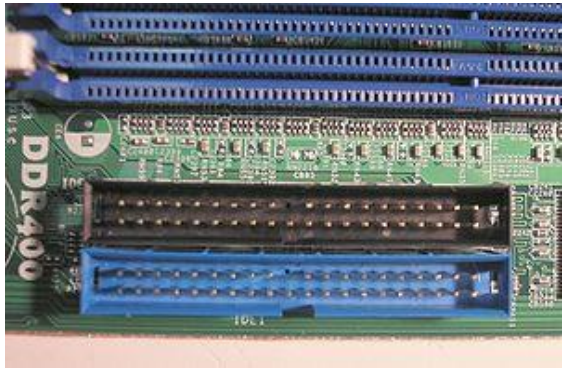
- **Hard drives and SSDs use four major interfaces to communicate with the host system**
  - PATA: Parallel Advanced Technology Attachment
  - SATA: Serial Advanced Technology Attachment
  - SAS: Serial-Attached SCSI
  - NVMe: NVMe over peripheral component interconnect express
  - DIMM: The memory channel

Parallel ATA

- **A direct connection to the 16-bit ISA bus introduced with the IBM PC/AT**
  - Use the Integrated Drive Electronics (IDE) protocol
  - With a 16-bit bus, two bytes are transmitted per bus transaction
  - Double-edge clocking mechanism for DMA transfers

100 MB/s =
25 MHz strobe x **2** (double data rate clocking) x **16 bits** per edge / 8 bits per byte

- **Provide up to the maximum throughput of 133 MB/s**
  - No further development



Motherboard sockets

IDE Cable

Serial ATA

- **The proactive evolution of the ATA interface from a parallel bus to a serial bus architecture**
  - Overcome the electrical constraints that are increasing the difficulty of continued speed enhancements of the parallel communication
  - Use either the IDE or Intel's Advanced Host Controller Interface (AHCI) protocol

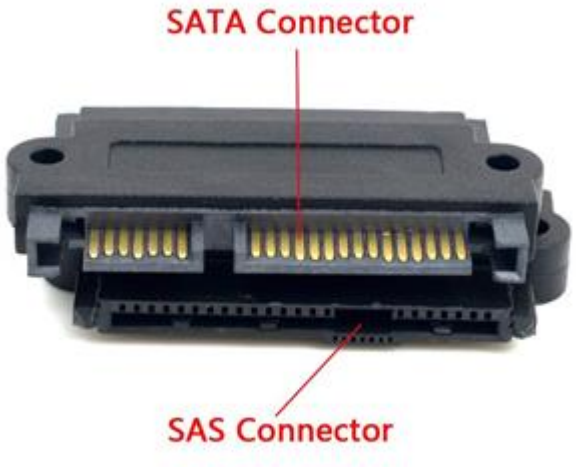
150 MB/s =
1500 MHz clock x **1 bit** per clock x 8b/10b encoding / 8 bits per byte

- **SATA 3.0 provides up to 600 MB/s throughput**

SATA Cable and Connector

Serial-Attached SCSI

- **Based on Small Computing System Interface (SCSI) by a floppy disk maker**
  - Improved to support a parallel bus later
- **Higher performance with full duplex**
  - The link can transfer data to and from the device simultaneously
- **High reliability and scalability**
  - High-Availability (HA): two ports for failover, error recovery, and error correction
  - A large number of disks: up to 255
  - But, need a special controller (e.g., HBA)
- **SAS 3.0 provides up to 1.2 GB/s throughput**



PCIe/NVMe

- **For nonvolatile memory attached to a computer over the high-speed PCIe bus (which is devised to support graphics)**
- **Provide much greater storage bandwidth than SATA and SAS**
  - Support multiple lanes (e.g., 1x, 2x, 4x, 8x, 16x): 1 GB/s per lane (PCIe 3.0)
  - Support multiple queues for better performance
    - 65,535 command queues (c.f., a single queue in AHCI)
    - 65,535 outstanding commands (c.f., 32 in AHCI)
  - Support full duplex

NVMe SSD with M.2 form factor

DIMM

- **The fastest interface to the CPU, outperforming the NVMe/PCIe interface**
  - Storage media is seen as byte-addressable memory
  - No interrupt interrupts and deterministic latency

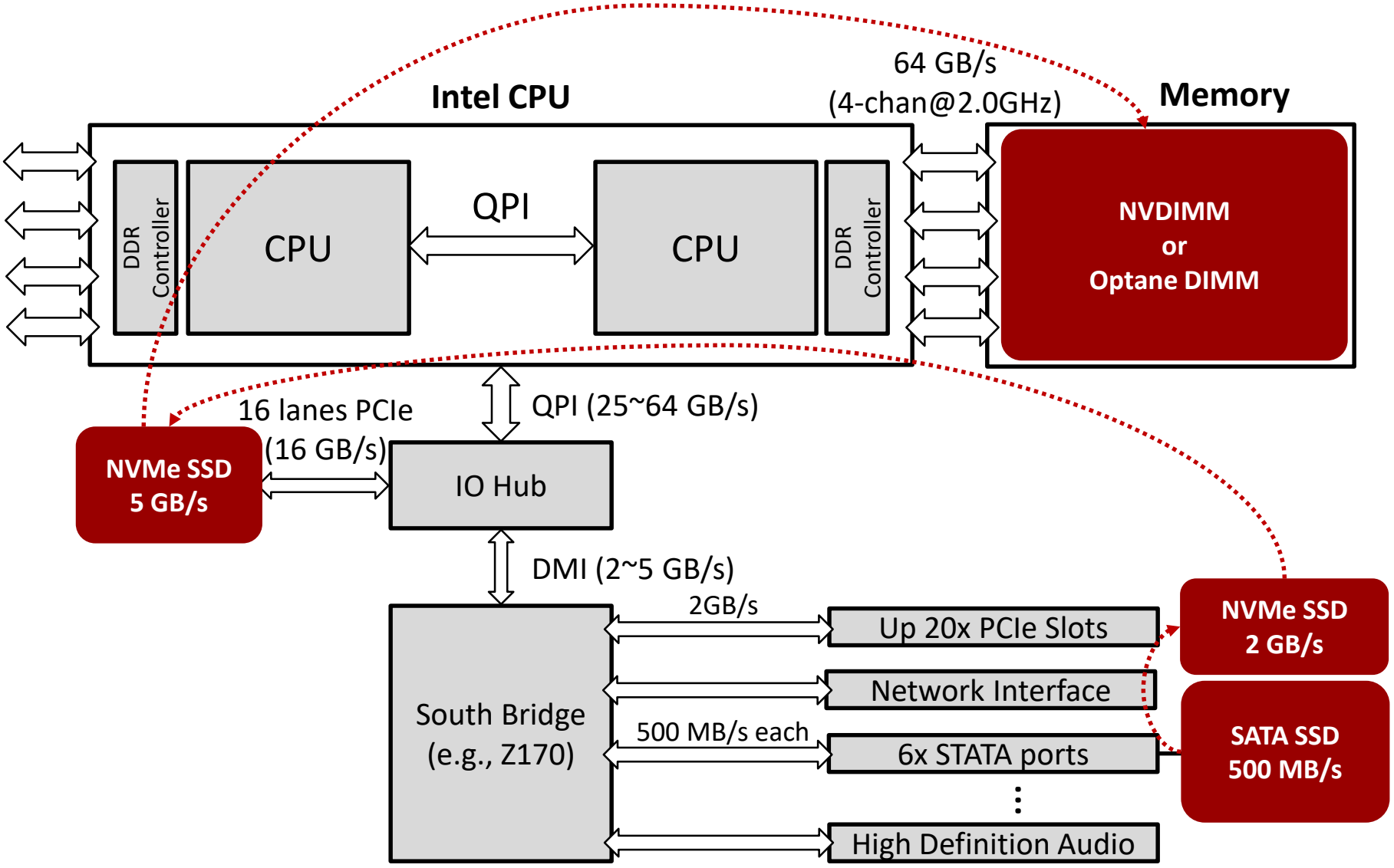
- **Products available in market**
  - **NVDIMM-N:**
    - Standard DRAM with the addition of NAND flash that stores DRAM's data in event of power failure
  - **NVDIMM-F:**
    - Connect multiple SSDs to the DRAM bus
  - **Optane DIMM: (Introduced in 2019)**
    - Based on Intel's 3D-Xpoint memory

Summary

Interface	Mnemonic Meaning	Transfer Speed	Characteristics
SATA	Serial ATA	0.6 GB/s	Low cost
SAS	Serial Attached SCSI	1.2 GB/s	Supports multiple ports Error detection/correction
NVMe	Nonvolatile memory express over PCIe	1 GB/s per lane (3.0) 2 GB/s per lane (4.0)	Up to 16 lanes High command queue support
DIMM	Nonvolatile memory on memory channel	Up to 1 GB/s over 64-bit bus	Very low latency No interrupt Deterministic

- NVMe is becoming a standard interface both for desktop or server systems based on its high performance
- Optane DIMM will be alternative that will replace costly DRAM and slow SSD cache

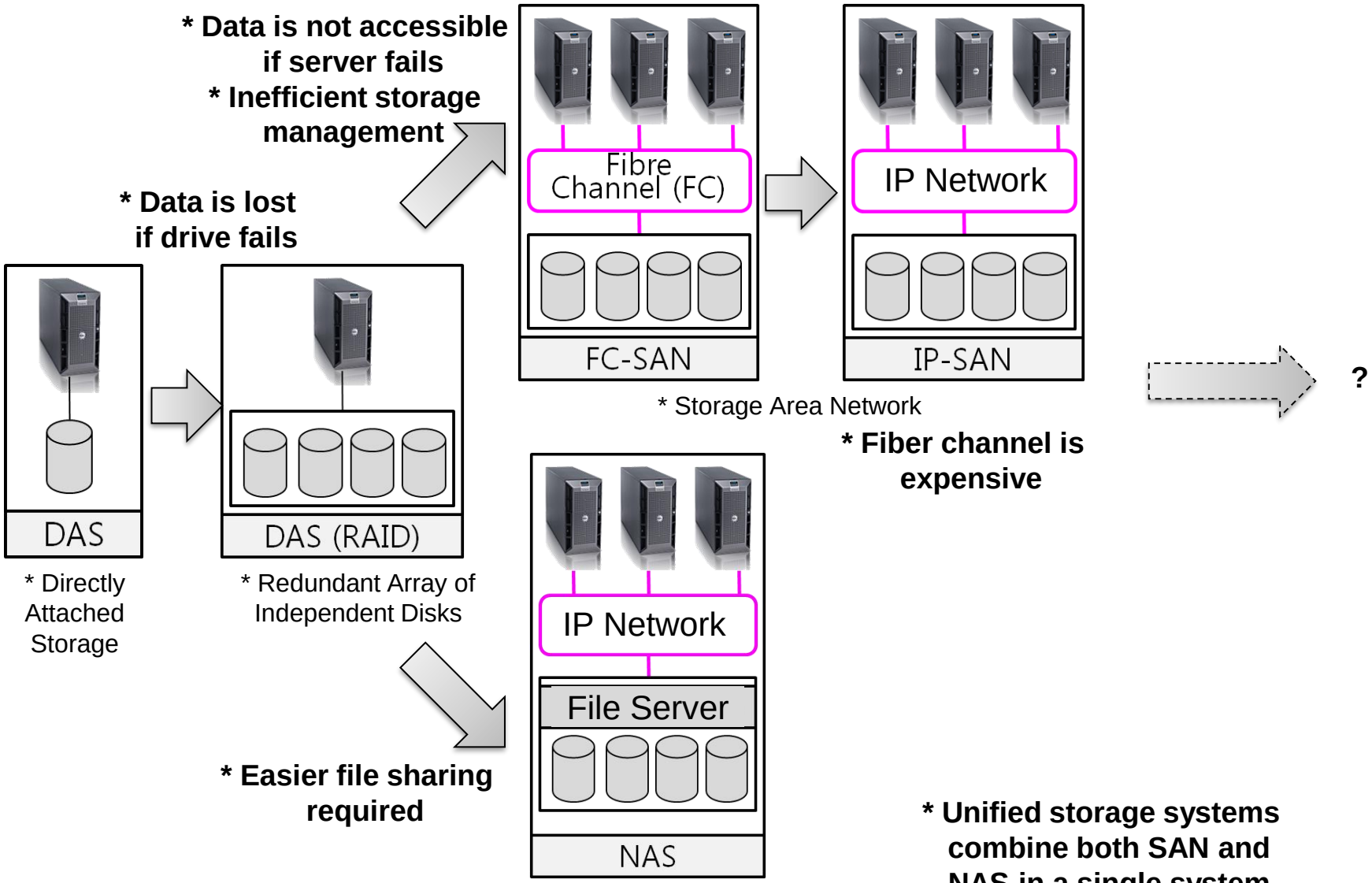
Storage Bandwidth Hierarchy



Outline

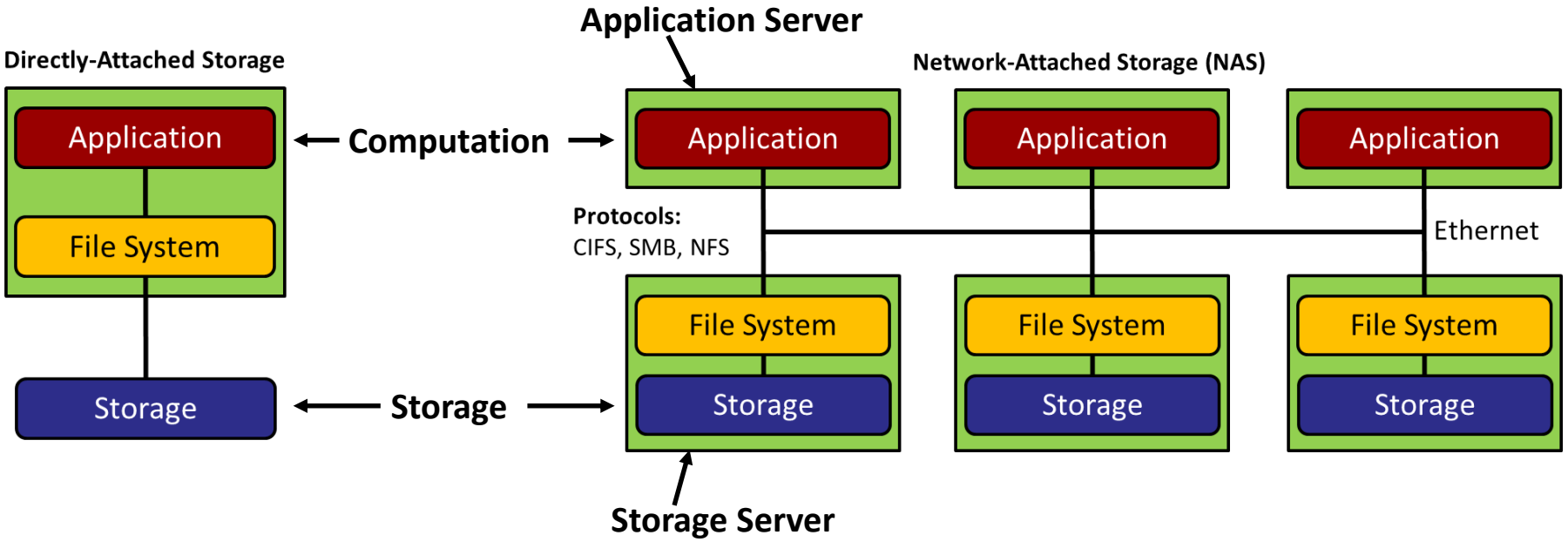
- Directly-Attached Storage (DAS)
- **Network-Attached Storage (NAS)**
- Storage-Area Network (SAN)

Evolution of Storage System



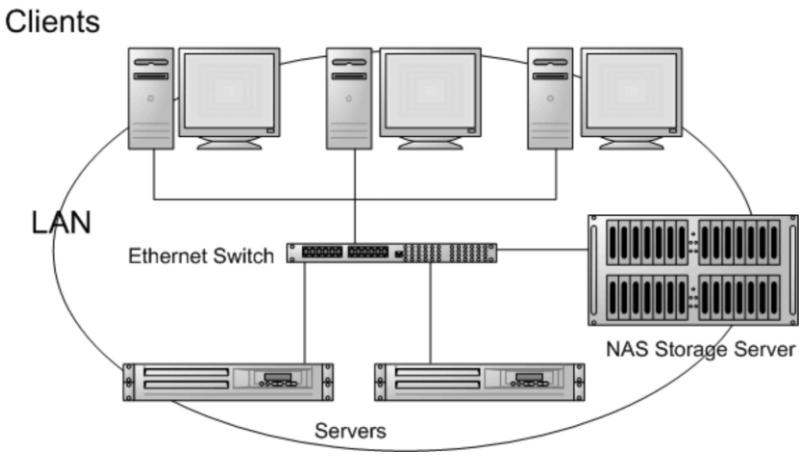
Computation & Storage Separation

- **Computation and storage are often separated in large scale systems**
  - ***Scalability***: add new application or storage servers depending on client's needs
  - ***Better management***: automatically back up user data
  - ***Availability*** / ***Reliability***: failure of a single server does not affect other servers
  - ***Sharing***: easy to share user contents
  - ***Cost***: thin provisioning, deduplication, and compression



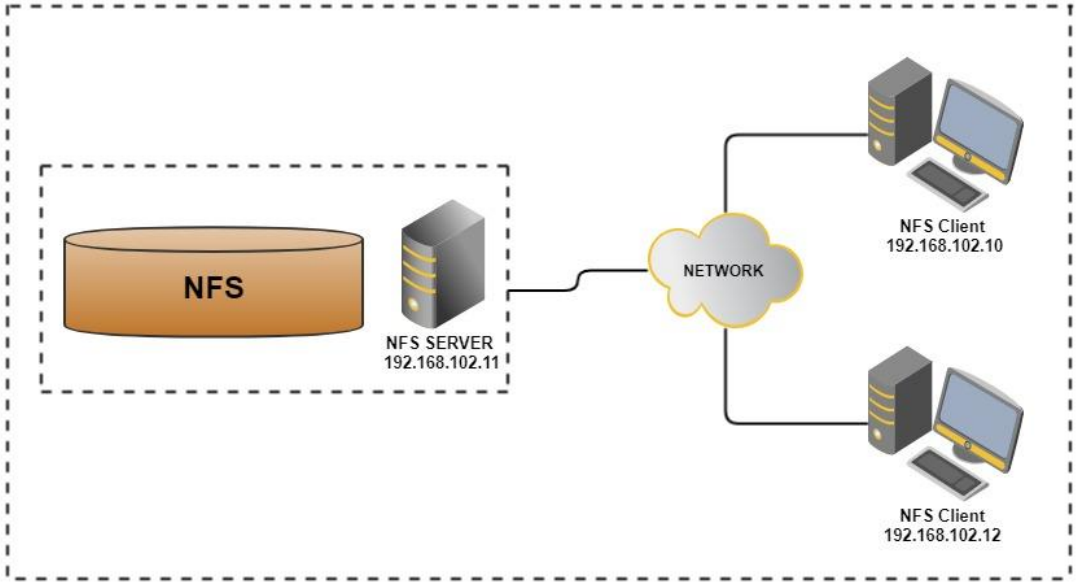
NAS Detail

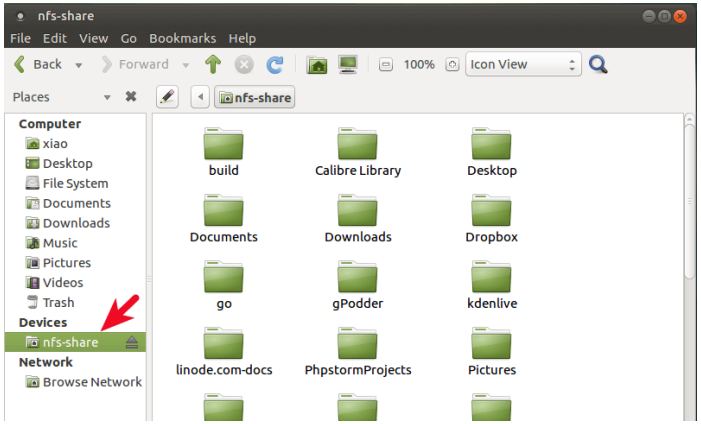
- **Provides file-level access to storage**
  - Ethernet connectivity through TCP/IP
  - NFS (Network File System)
  - CIFS (Common Internet File System)
  - SMB (Server Message Block)
- ***Networked file system* allows for concurrent access to data**
- **Several layers between data request and receipt**



NFS*

- A distributed file system protocol developed by Sun Microsystems in 1984
- Allow a user on a client computer to access files over a computer network much like local storage is accessed
- The NFS is an open standard defined in a Request for Comments (RFC), allowing anyone to implement the protocol



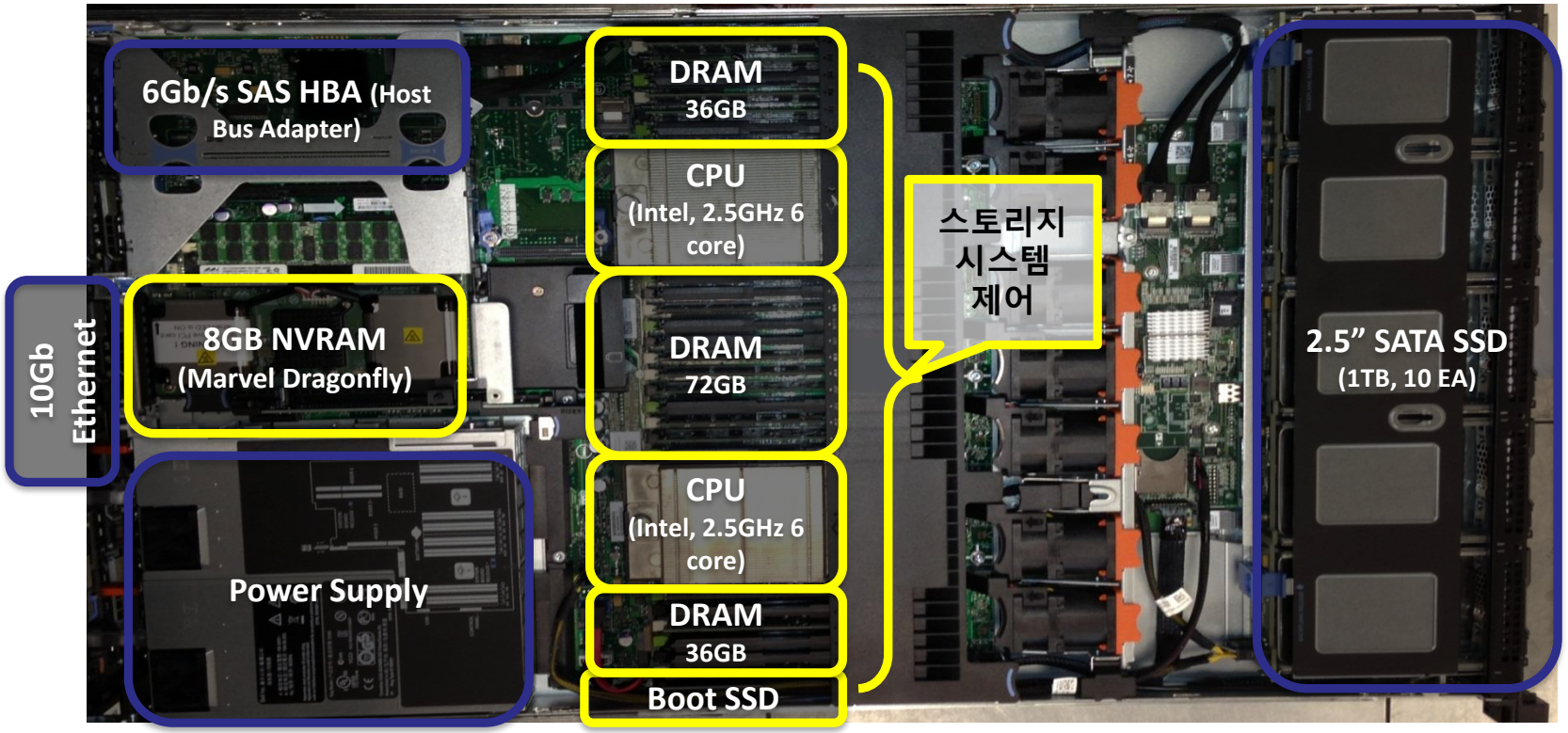


* Design and Implementation of the Sun Network Filesystem, USENIX ATC '85

Enterprise NAS Server

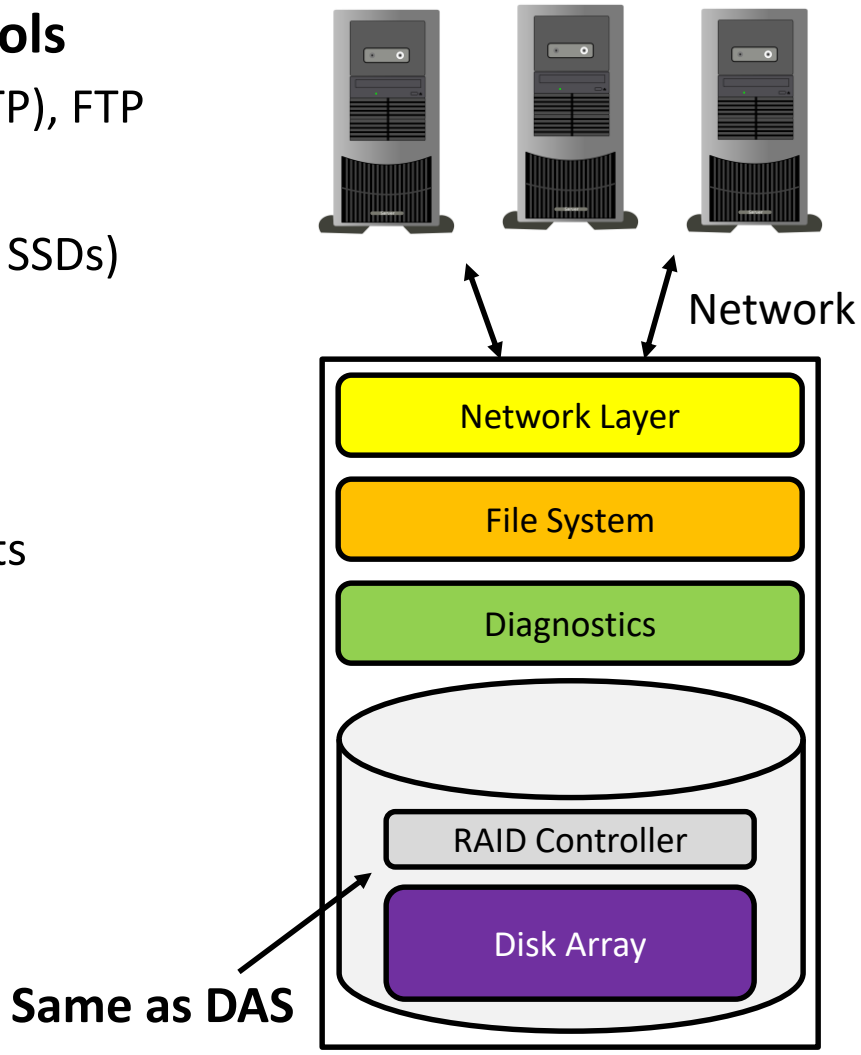
- Responsible for servicing user requests over the network
- Hardware specification is similar to high-end enterprise servers
- Perform *lots of jobs* internally

[Solidfire HW Architecture]



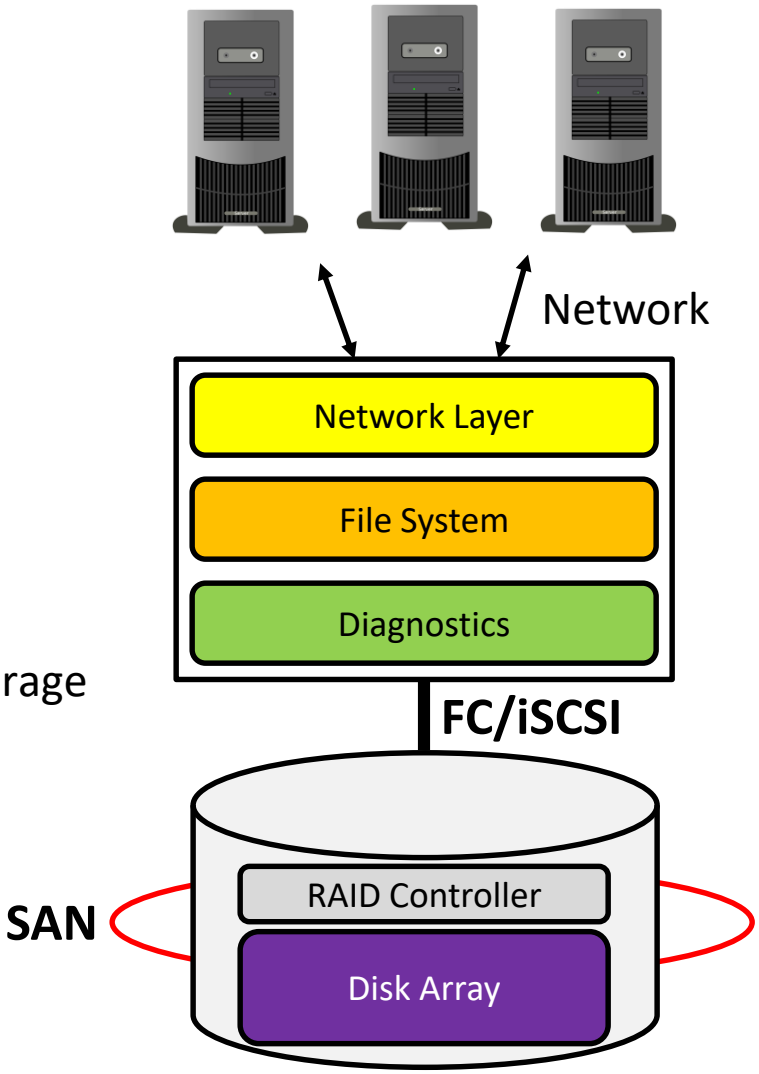
Enterprise NAS Server Features

- **Support various file-sharing protocols**
  - Windows (CIFS), UNIX (NFS), Web (HTTP), FTP
- **Disk management**
  - Manage many disks (32 ~ 250 HDDs or SSDs)
- **Scales from GBs to TBs**
  - Scale up & scale out
- **Fault tolerant**
  - Dual, redundant, hot-swap components
- **Data protection**
  - RAID, Backup to disks & tape
- **Management software**
  - Manage & setup from remote location
- **Diagnostic software**
  - Predictive failure analysis and alters



NAS Gateway

- **Offers benefits and characteristics of NAS**
  - Connect to IP networks
  - Performs as a file server
  - Heterogeneous file sharing
  - Data protection
  - Clustering and failover features
- **NAS gateway is a NAS appliance with one exception**
  - Supports direct attachment to Fibre Channel storage or connection to a storage device across SAN
  - Do not have integrated disks for data storage



Outline

- Directly-Attached Storage (DAS)
- Network-Attached Storage (NAS)
- **Storage-Area Network (SAN)**

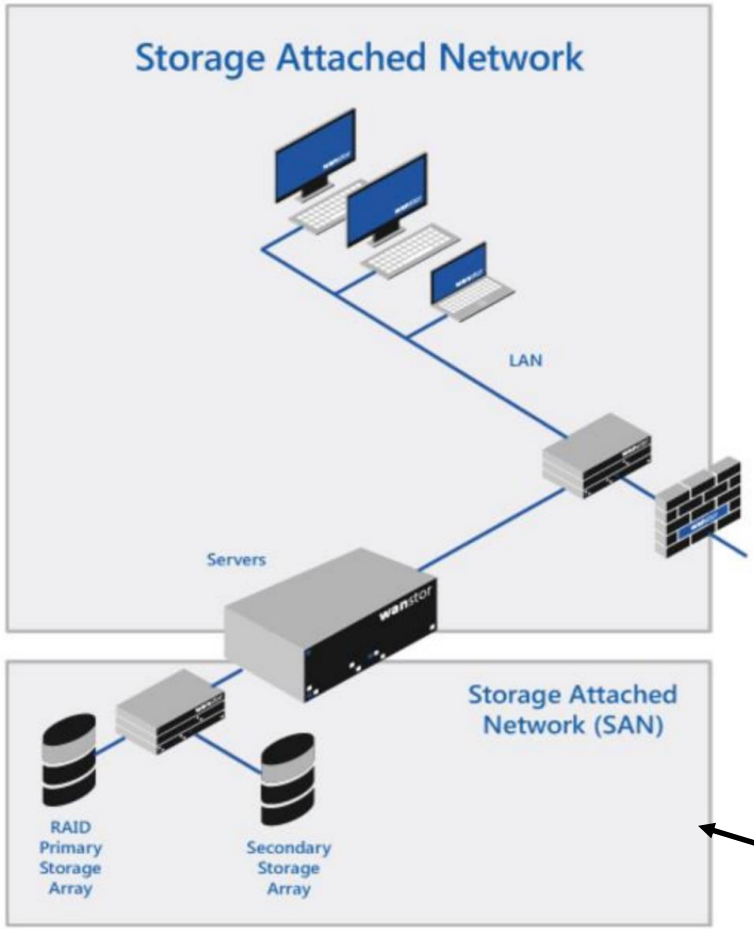
SAN Detail

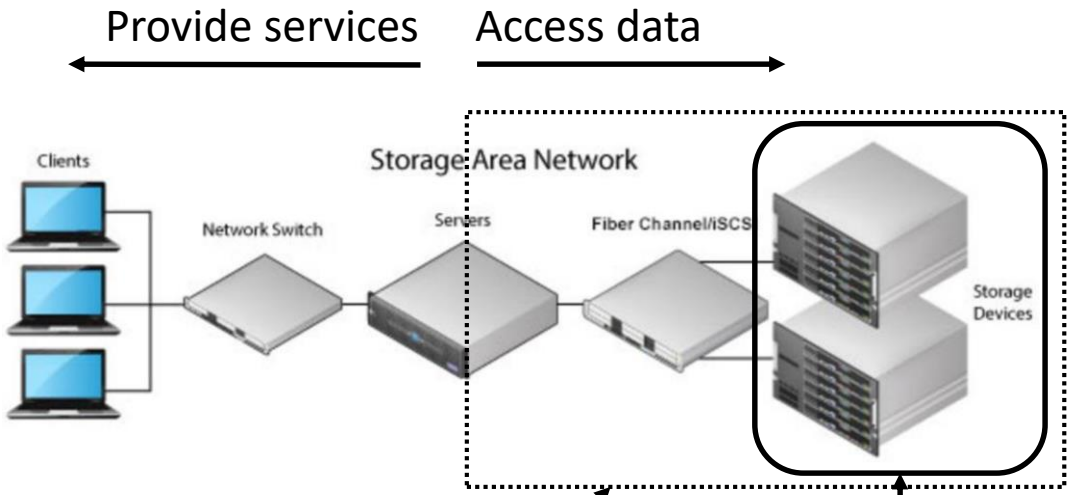
- **SAN storage devices are connected over the network to servers**
- **Provides *block-level storage* that can be accessed by the applications running on any networked servers**

- **Differences between SAN and NAS**
  - While SANs provide block-level storage for servers, a NAS device provides file-level storage for end users
  - OS sees a SAN as a disk, while they see a NAS device as a file server

  → Latest storage boxes support ether NAS, SAN, or both, depending on configuration

SAN Architecture



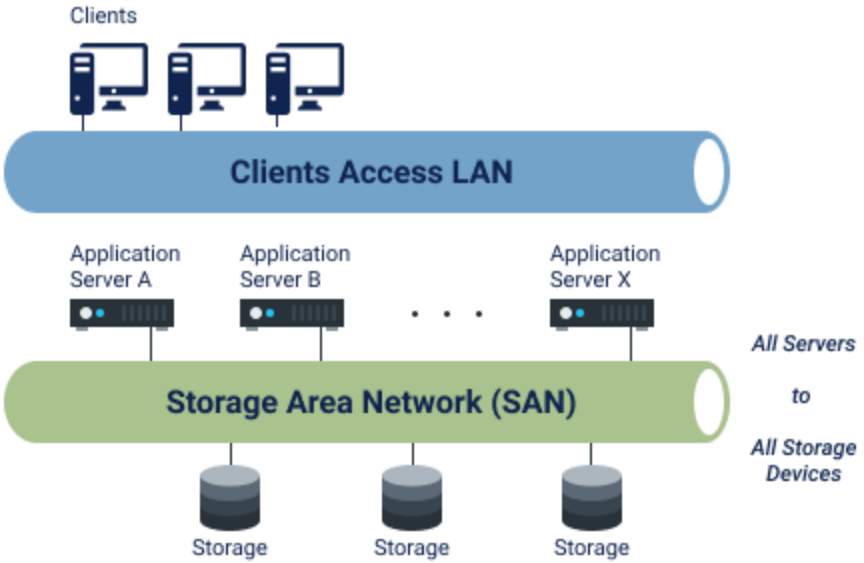


Separate storage network

Almost the same as storage servers in NAS (x86 CPU + HDDs or SSDs)

Fibre Channel

- **Fibre Channel (FC) stands for a set of protocols, technologies and services used to build a "classic" SAN network**
  - Fibre Channel Protocol (FCP) - data transfer protocol that lets through SCSI commands.
  - Fibre optic infrastructure - used to transmit data to and/or from FC devices.
  - Name Service - acts as a database for connected devices. It is quite similar to a domain name system (DNS).
  - Set of flow control service



Fibre Channel (Cont.)

- **"FC SAN" implies a storage network built up of dedicated hardware adapters and switches, connected using fiber optics**
  - As the network is developed for high-loaded storage devices, it uses a strong cyclic redundancy check (CRC) – data is not corrupted when transmitted
  - Fewer retransmissions compared to TCP/IP and connection retries due to loss of data
  - More isolated compared to TCP/IP-based networks – lower security risks
  - Support 8Gbps, 16Gbps, and 32Gbps

- **Disadvantage**
  - Expensive – FC requires buying special network switches and storage adapters

iSCSI

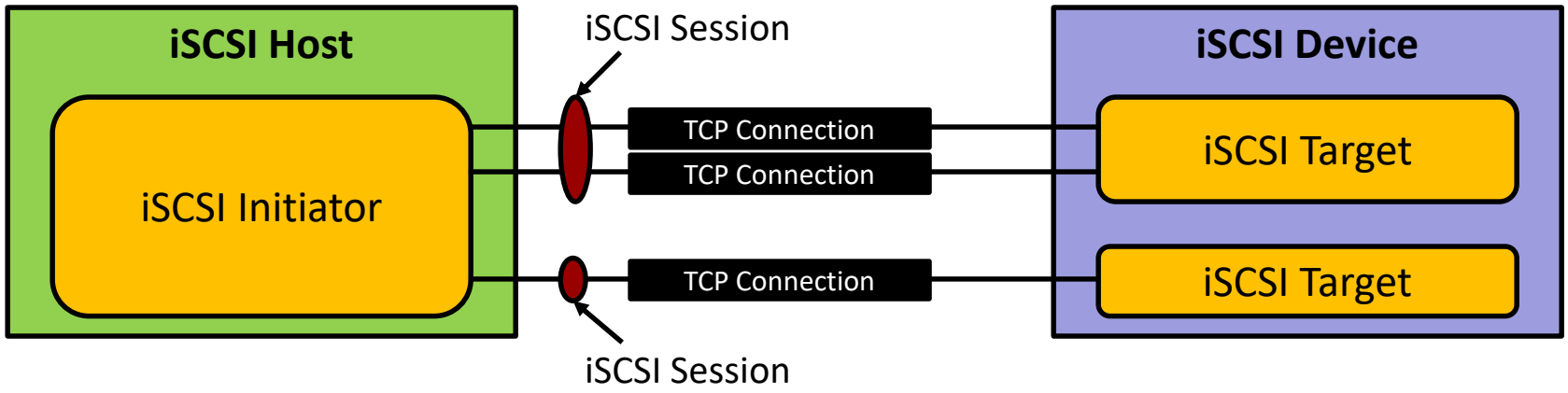
- **The basic concept of iSCSI is simply putting SCSI commands inside of a typical TCP/IP channel**
  - Just install ***iSCSI Target/Initiator*** software onto your ***storage server*** and its ***clients***

- **Ethernet and TCP/IP are widely deployed and dominant**
  - Well understood technology; Low acquisition cost; Unlimited distance
  - A scalable technology with 10/100/1000/10000 Mbps
  - Allow the creation of a single physical network using familiar standards
    - VLAN may be used for separating storage traffic from intranet traffic
  - Bring interoperability & Ethernet economics to storage

iSCSI (Cont.)

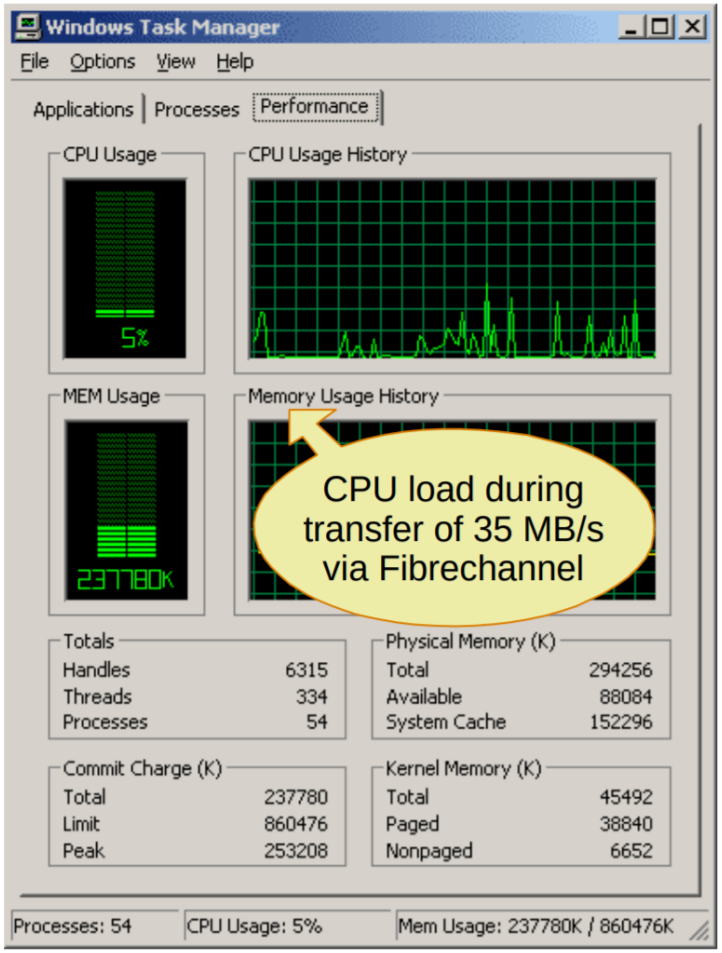
- **TCP/IP over Ethernet are designed for common usage**
- **No strong data flow controls or built-in storage discovery services**
  - IP addresses of iSCSI storage and clients, frame sizes, LUN visibility, etc
  - Optimize the network for large data block transfers to get relatively high performance
  - Hardware-accelerated network adapters to offload iSCSI processing from a host server or client

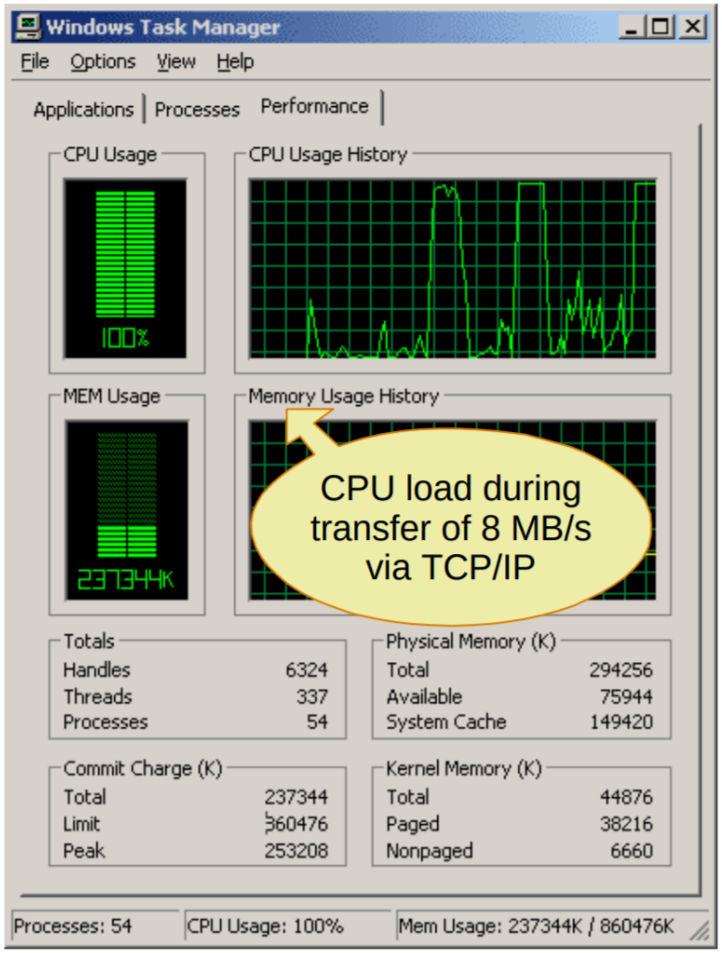
iSCSI Connectivity



- **Initiators and targets can be implemented in H/W or S/W**
- **Session between initiator and target**
  - One or more TCP connections per session
  - Login phase begins each connection
- **Services (e.g., authentication, security) negotiated during login**
- **TCP protocol provides**
  - Delivery of SCSI commands in order
  - Recovery from lost connections

CPU Load


Windows Task Manager
File Options View Help
Applications Processes Performance
CPU Usage
5%
CPU Usage History
MEM Usage
237780K
Memory Usage History
CPU load during transfer of 35 MB/s via Fibrechannel
Totals
Handles 6315
Threads 334
Processes 54
Physical Memory (K)
Total 294256
Available 88084
System Cache 152296
Commit Charge (K)
Total 237780
Limit 860476
Peak 253208
Kernel Memory (K)
Total 45492
Paged 38840
Nonpaged 6652
Processes: 54
CPU Usage: 5%
Mem Usage: 237780K / 860476K

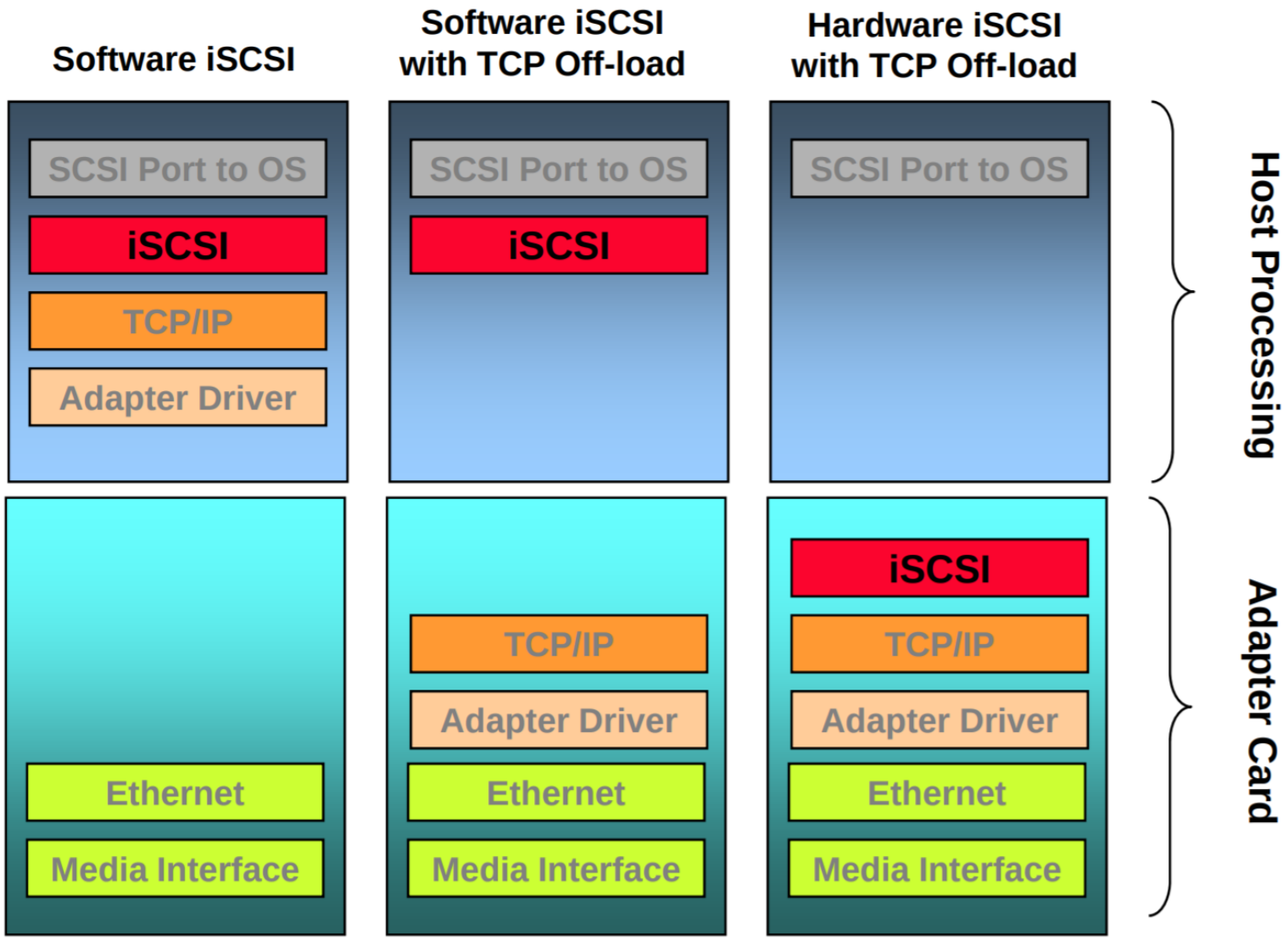

Windows Task Manager
File Options View Help
Applications Processes Performance
CPU Usage
100%
CPU Usage History
MEM Usage
237344K
Memory Usage History
CPU load during transfer of 8 MB/s via TCP/IP
Totals
Handles 6324
Threads 337
Processes 54
Physical Memory (K)
Total 294256
Available 75944
System Cache 149420
Commit Charge (K)
Total 237344
Limit 860476
Peak 253208
Kernel Memory (K)
Total 44876
Paged 38216
Nonpaged 6660
Processes: 54
CPU Usage: 100%
Mem Usage: 237344K / 860476K

TCP/IP Overhead

- **Every TCP/IP connection that is part of an iSCSI session has processing overhead**
  - Connection setup / teardown
  - TCP state machine:
    - Acknowledge, timeout, and retransmission
    - Window management
    - Congestion control
  - Checksum calculation
  - TCP segmentation

- ***TCP/IP Offload Engine*** **(TOE) helps at GbE NICs!**
  - 1 GbE links will not require full integrated TOEs
    - Increasing CPU performance might be sufficient
  - For higher than 10 GbE, TOE is necessary!

iSCSI & TOE Adapters



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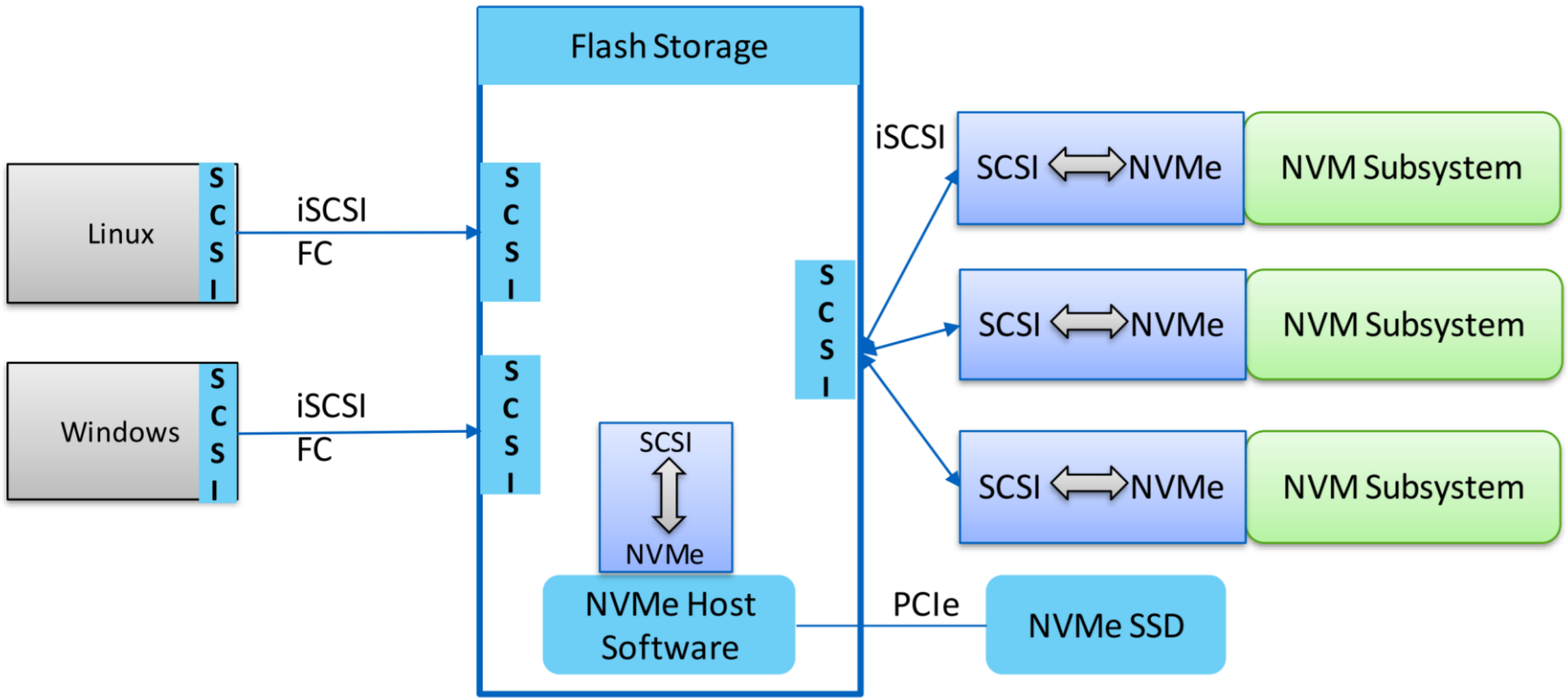
- Directly-Attached Storage (DAS)
- Network-Attached Storage (NAS)
- **Storage-Area Network (SAN)**
  - **NVMe-over-Fabric (NVMe-oF)**

NVMe-oF

- **NVMe-OF is a communication protocol that allows one computer to access NVMe devices attached to another computer**
  - Contrary to the standard NVMe protocol where NVMe devices are connected directly to PCIe bus
- **Combined with remote direct-memory access (RDMA)**
  - One computer can access another computer's memory as if that memory actually resided within the first computer
  - Don't need to go through the OS's I/O stack – run at speeds closer to the speed of memory
- **Implemented over Ethernet or InfiniBand**
- ***NVMe-oF will replace iSCSI in the future!***

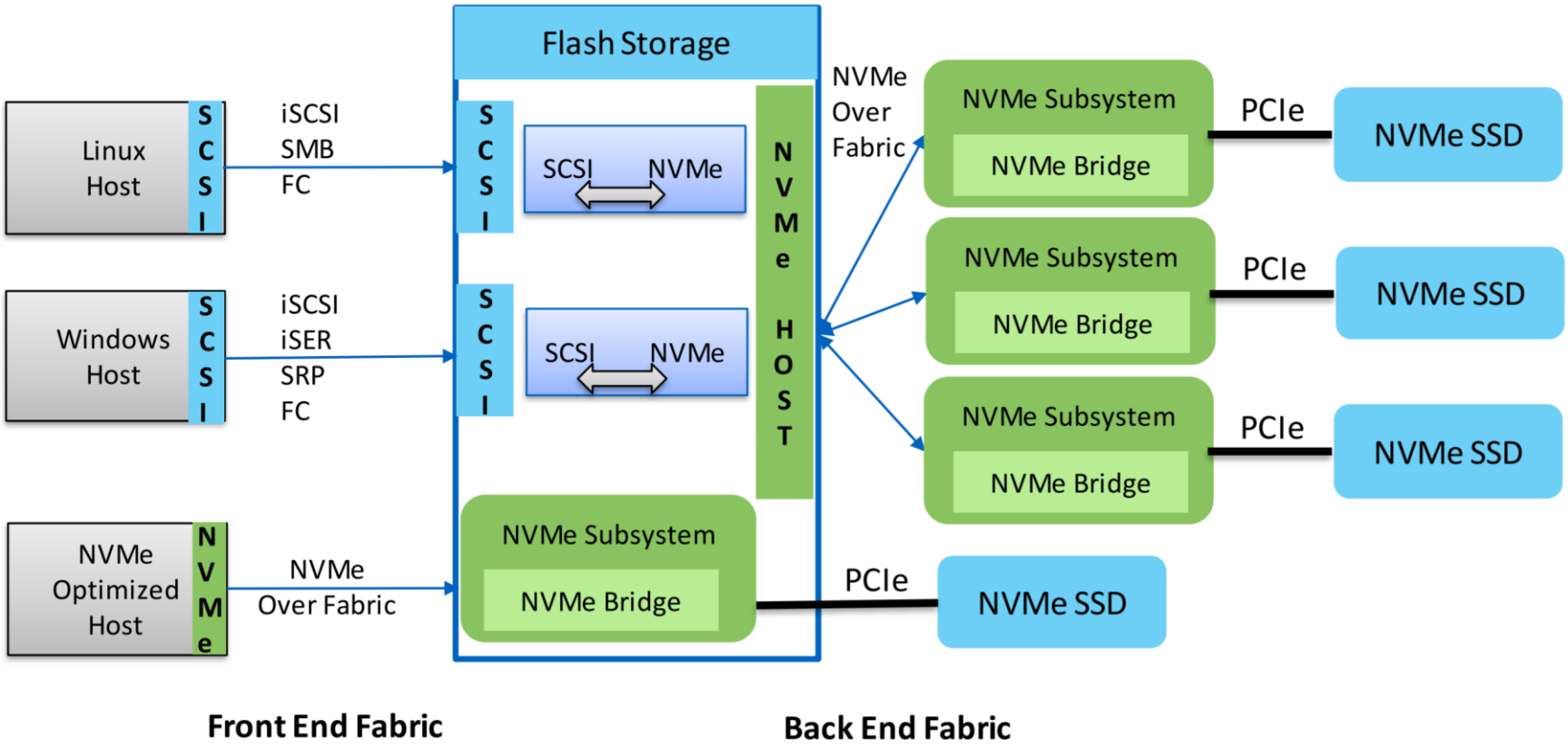
Why NVMe-oF?

- **Protocol conversion bridge is required to access the data over network which increases I/O latency**



Why NVMe-oF? (Cont.)

- NVMe-oF removes a burden on converting iSCSI comds to NVME cmds
- Enable us to take advantage of unique features of NVMe devices like multiple-queue architectures for fast storage

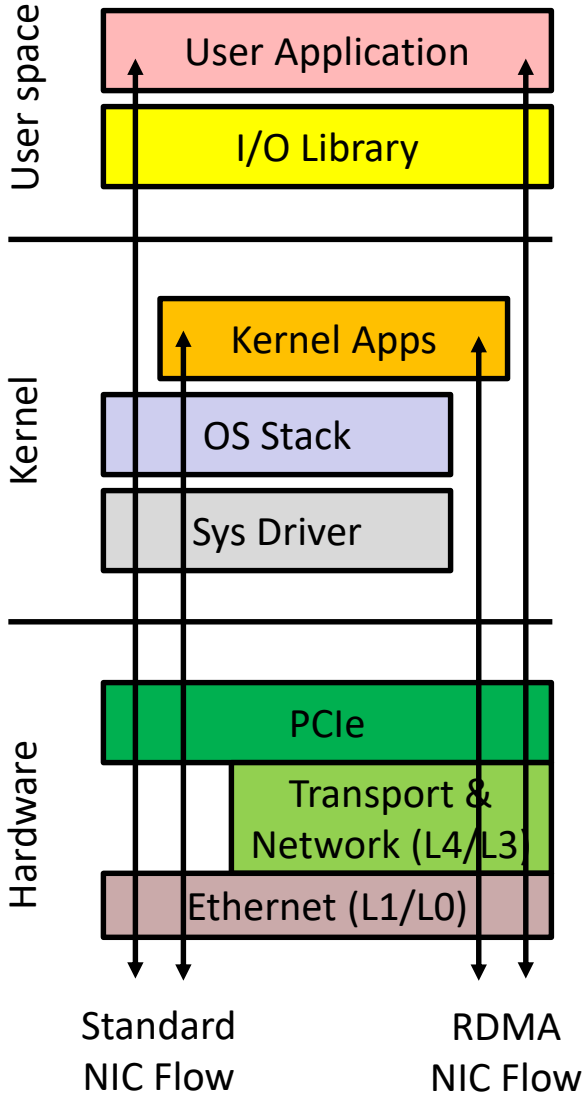


What is RDMA?

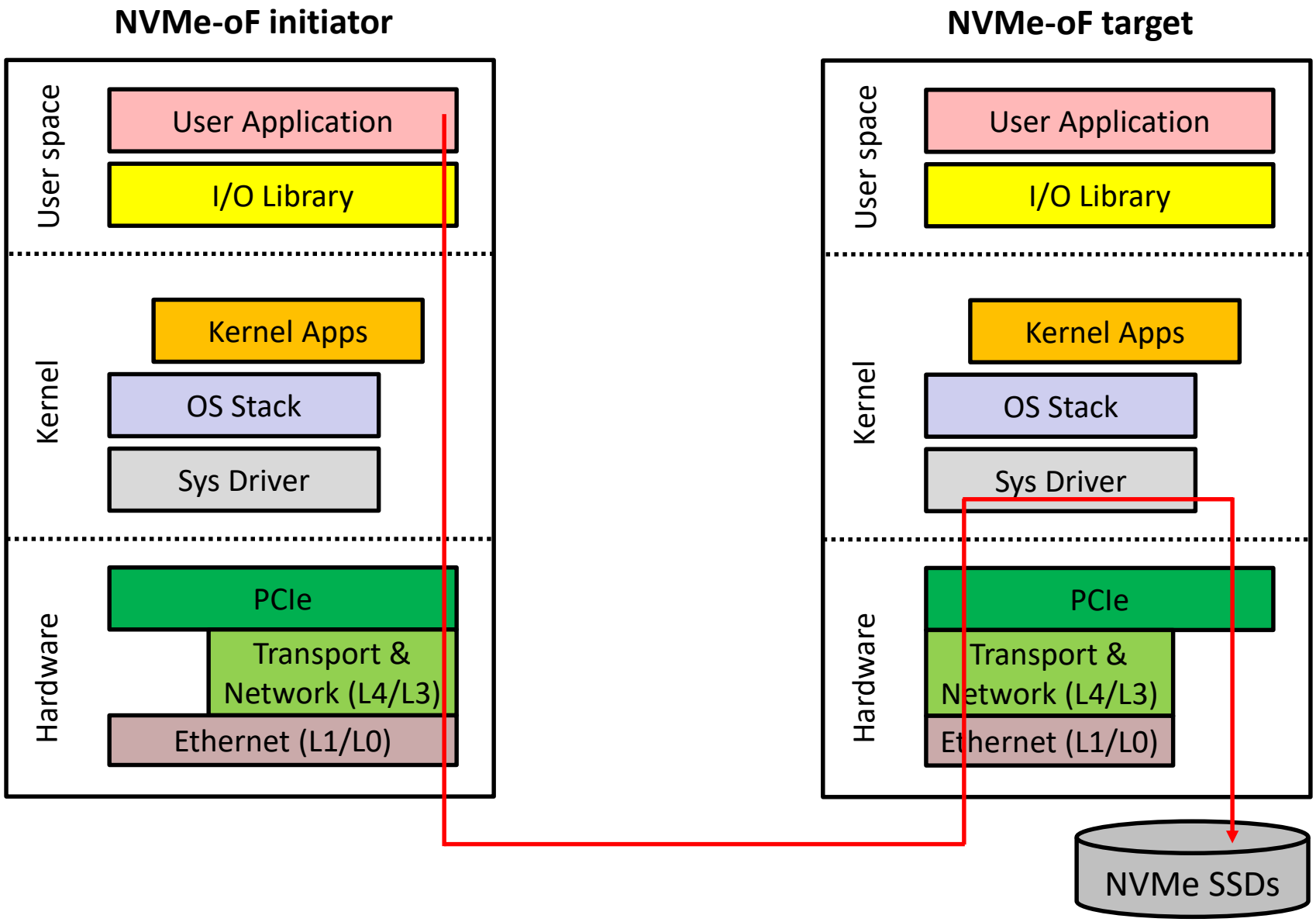
- **RDMA is a host-offload, host-bypass technology that allows an application (including storage) to make data transfers directly to/from another application's memory space**
- **The RDMA-capable Ethernet NICs (RNICs) – not the host – manage reliable connections between source and destination**
- **Applications communicate with the RDMA NIC using dedicated Queue Pairs (QPs) and Completion Queues (CQs)**
  - Suitable for the NVMe architecture

Benefits of RDMA

- **Bypass of system SW stack components that processes network traffic**
  - For user applications, RDMA bypasses the kernel altogether
  - For kernel applications, RDMA bypasses the OS stack and the system drivers
- **Direct data placement of data from one machine (real or virtual) to another machine – without copies**
- **Increased bandwidth while lowering latency, jitter, and CPU utilization**
- **Great for networked storage!**



How NVMe-oF w/ RDMA Works?



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