Tentative Schedule

- **Data Center Networking (2 lessons)**
- **SDN/NFV (2 lessons)**
- **Content Delivery Networks (1 lesson)**
- **Visit to INESC TEC's Data Center (last lesson)**

Goal

- Recent networking topics
  - Virtualization, Data Center Networking, Software Defined Networking, Network Function Virtualization, Content Delivery Networks
- Breadth First approach – cover multiple topics
- Topics of interest to industry

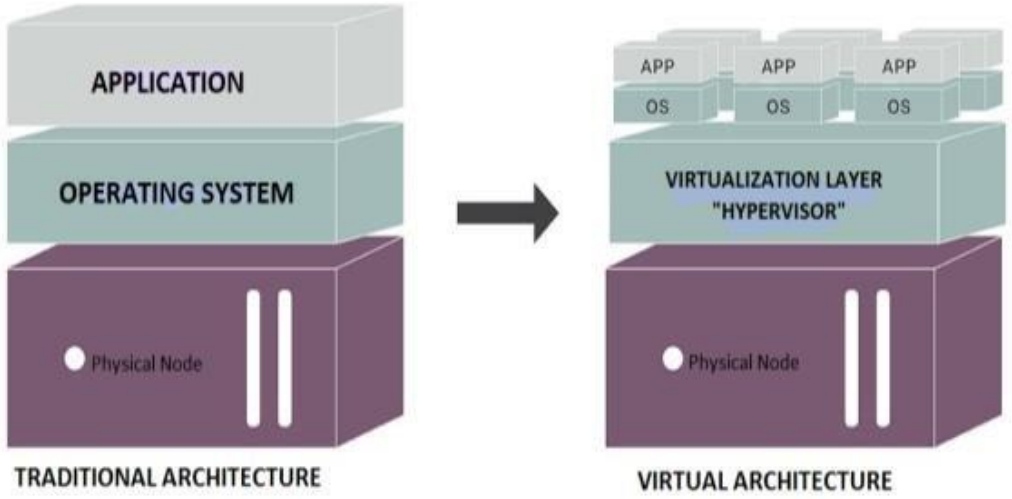
What You Will Learn – Data Center Networking

- How are data center networks different from those in homes/offices?
- What are the standards for data center layout?
- How have Ethernet and other protocols been changed to accommodate data centers?
- How and why connect multiple data centers on a single Ethernet?

Source: https://www.datacenters.com/news/future-data-centers-distributed-grid-or-cloud-computing [Accessed: 7th May 2021]

What You Will Learn – Virtualization

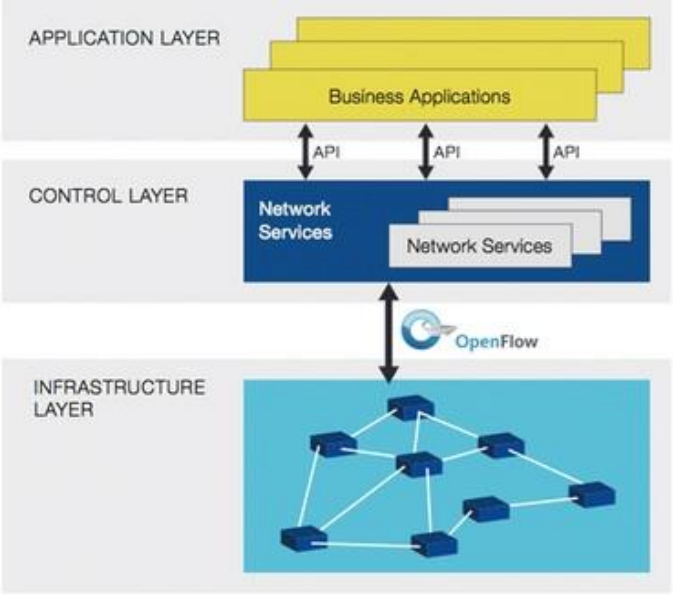
- Why virtualize?
- How are servers virtualized?
- How is storage virtualized?
- What networking components are virtualized and how?
- What are the new networking standards related to virtualization?



Source: R. Kamla, T. Yahiya, N. Mustafa, "An Implementation of Software Routing for Building a Private Cloud", International Journal of Computer Network and Information Security 10(3), doi: 10.5815/ijcnis.2018.03.01.

What You Will Learn – Software Defined Networking

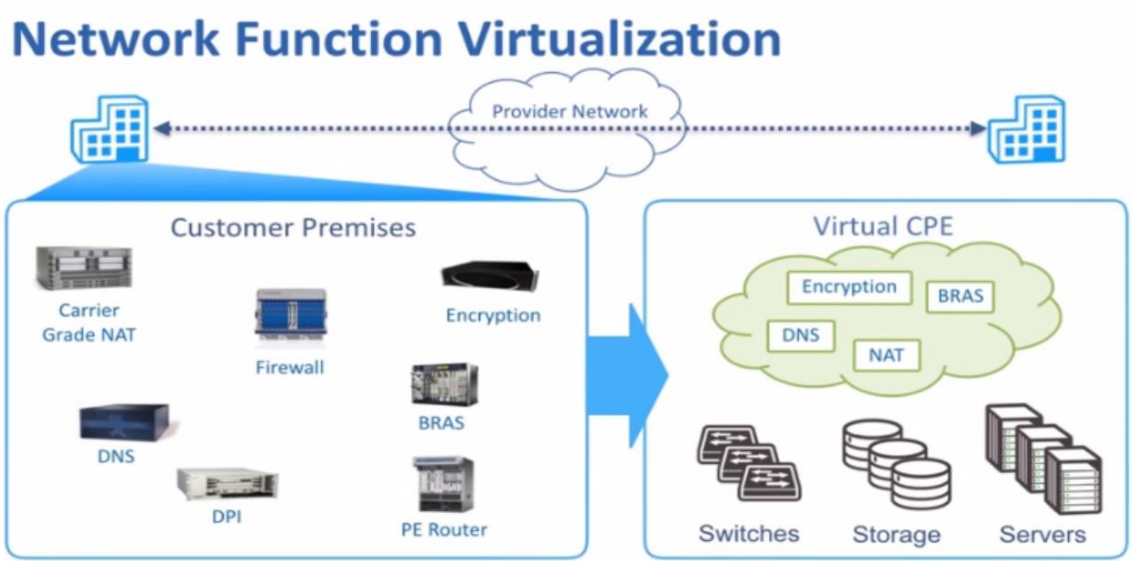
- What is software defined networking?
- Why is the industry running to adopt this new technology so fast?
- What new facilities are enabled by SDN?
- What is the difference between SDN and OpenFlow?
- What are the different flavors of SDN?



Source: https://www.sdxcentral.com/networking/sdn/definitions/what-the-definition-of-software-defined-networking-sdn [Accessed: 7th May 2021]

What You Will Learn – Network Function Virtualization

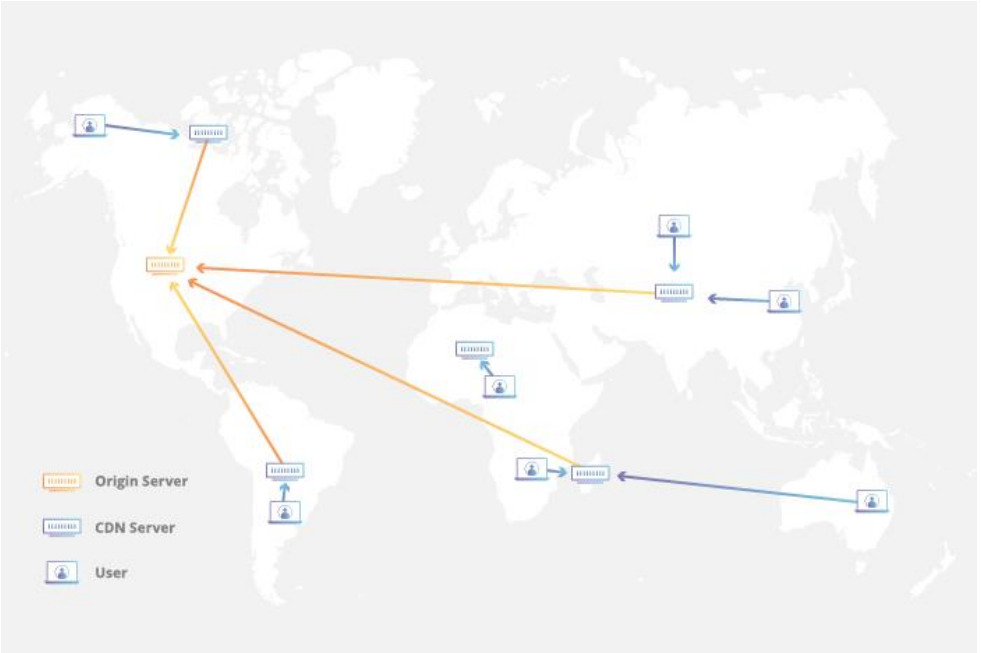
- What is NFV?
- NFV and SDN Relationship
- Concepts, Architecture, Requirements, Use cases



Source: https://www.ciena.com/insights/videos/video-intro-to-NFV-prx.html [Accessed: 7th May 2021]

What You Will Learn – Content Delivery Networks

- How content is delivered over the Internet?
- What is the networking architecture involved?
- What kind of infrastructure is deployed worlwide?
- What are the major stakeholders?



Source: https://www.cloudflare.com/learning/cdn/what-is-a-cdn [Accessed: 7th May 2021]

What You Will Learn – (Virtual) visit to INESC TEC's DC

- How does a real data center look like?
- How is virtualization and networking done in practice?

Reference Books

- Annabel Z. Dodd, “The Essential Guide to Telecommunications”, 5th Edition, Prentice Hall, 2012, ISBN: 978-0-13-705891-4
- G. Santana, “Data Center Virtualization Fundamentals”, Cisco Press, 2014, ISBN:1587143240
- A. Sánchez-Monge, K. Szarkowicz, “MPLS in the SDN Era”, 1st Edition, O’Reilly, 2016, ISBN: 978-1491905456
- L. Krattiger, S. Kapadia, D. Jansen, “Building Data Centers with VXLAN BGP EVPN”, 1st Edition, Cisco Press, 2017, ISBN: 978-1-58714-467-7
- D. Robinson, “Content Delivery Networks: Fundamentals, Design, and Evolution”, 1st Edition, Wiley, 2017, ISBN: 9781119249870

Data Center Networking

- **Storage and Server Virtualization**
- **Data Center Network Architectures**
- **Virtual Private Networks in Data Centers**

Storage and Server Virtualization

Overview

- Why Virtualize?
- Server Virtualization Concepts
- Storage Virtualization
- Open Virtualization Format (OVF)

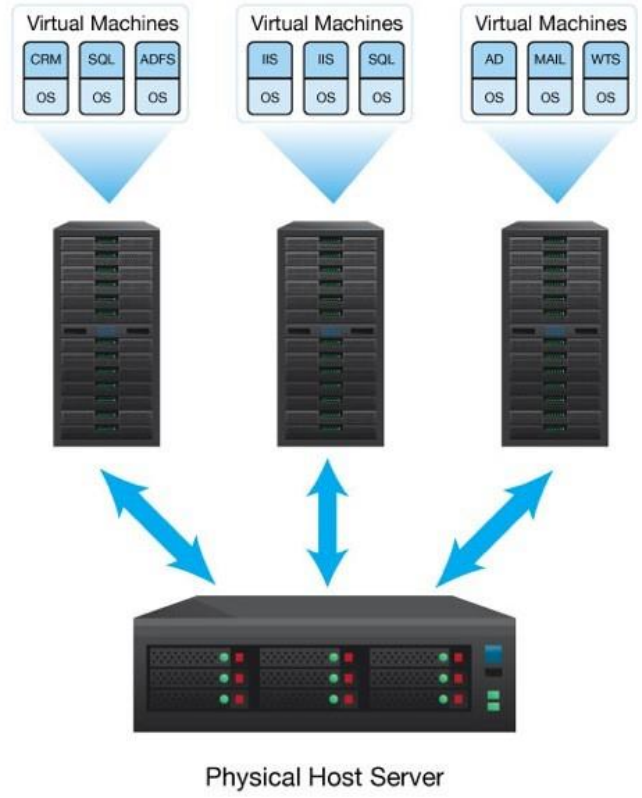
Virtualization

"*Virtualization means that applications can use a resource without any concern for where it resides, what the technical interface is, how it has been implemented, which platform it uses, and how much of it is available.*"

by Rick F. Van der Lans in *Data Virtualization for Business Intelligence Systems*

Virtualization

- The term virtual refers to **entities such as networks or servers that provide the functions of the physical devices they are emulating**
- Server virtualization refers to **single servers performing the functions of multiple servers**
- To illustrate, **multiple *virtual machines* can exist within a single server**, with each virtual machine performing the functions of a single server
- A virtual machine is software with the functionality of a computer



Reasons to Virtualize

1. **Sharing**: Break up a large resource

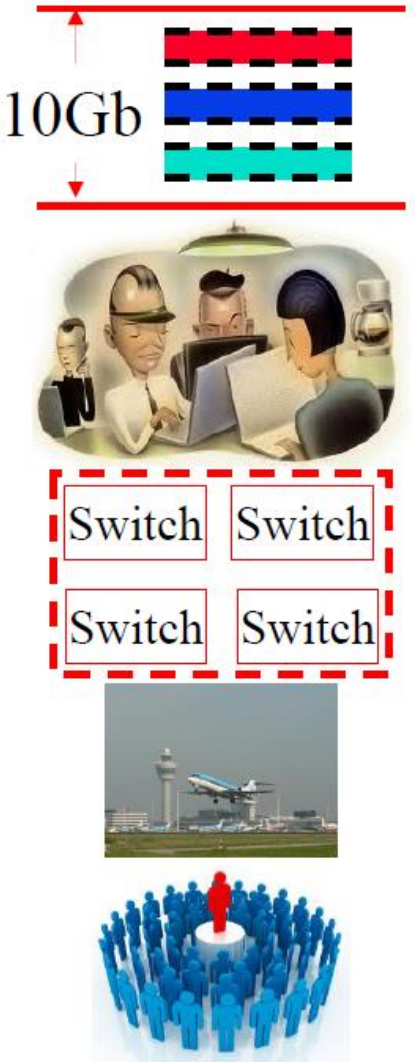
   Large Capacity or high-speed – e.g., servers, physical link

2. **Isolation**: Protection from other tenants – e.g., Virtual Private Network

3. **Aggregating**: Combine many resources in to one, e.g., storage

4. **Dynamics**: Fast allocation, Change/Mobility, load balancing, e.g., virtual machines

5. **Ease of Management** → Easy distribution, deployment, testing



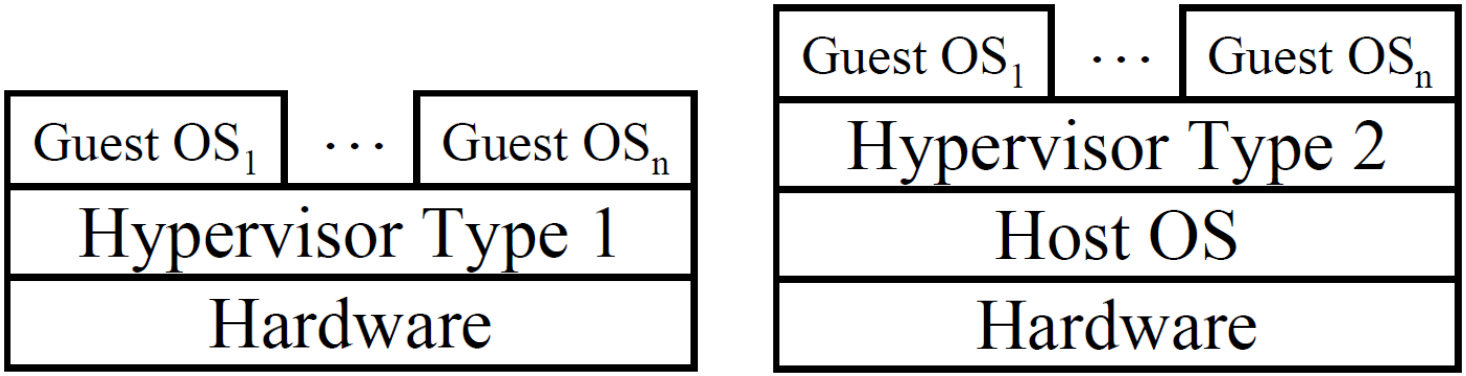
Advantages of Virtualization

- **Minimize hardware costs** (CapEx)
  - Multiple virtual servers on one physical hardware
- **Easily move VMs** to other data centers
  - Provide disaster recovery. Hardware maintenance
  - Follow the sun (active users), follow the moon (cheap power)
- **Consolidate idle workloads** (usage is bursty and asynchronous)
  - Increase device utilization
- **Conserve power**
  - Free up unused physical resources
- **Easier automation** (Lower OpEx)
  - Simplified provisioning/administration of hardware and software
- **Scalability and Flexibility** → Multiple operating systems

Virtualization in Computing

- **Storage**
  - Virtual Memory
  - Virtual Disks, Cloud storage
- **Computing**
  - Virtual Server → Virtual Datacenter
  - Virtual Machine → Cloud
- **Networking** (plumbing of computing)
  - Virtual Channels, Virtual LANs, Virtual Private Networks

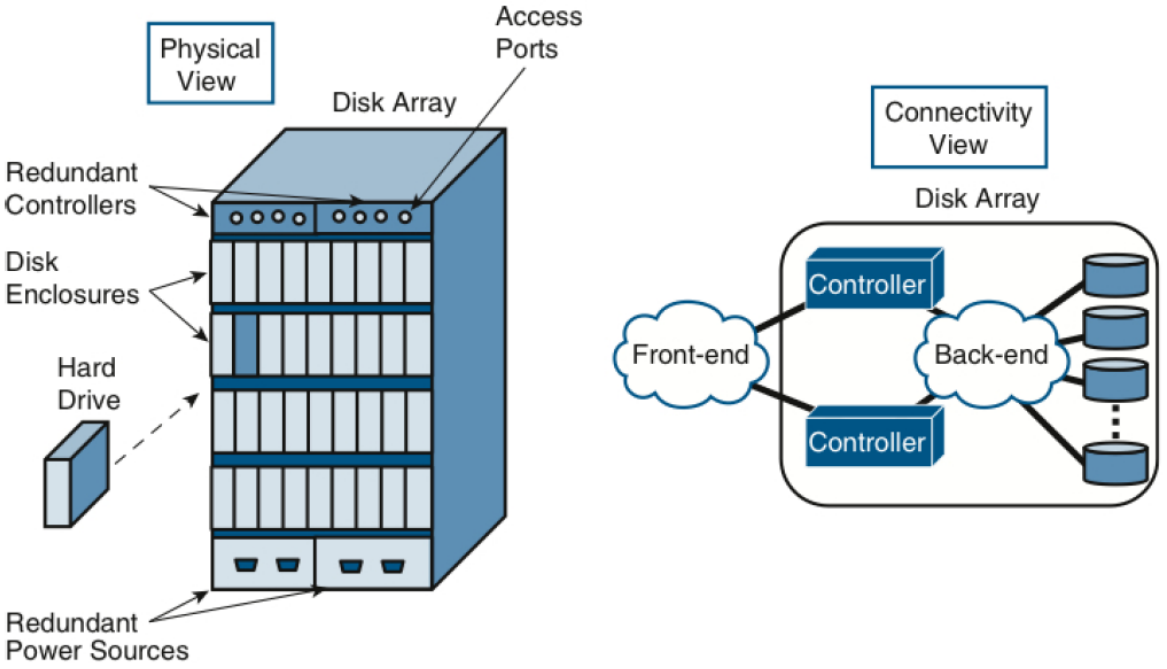
Server Virtualization Concepts



- **Host OS**: Runs on the bare metal (directly on the host's hardware)
- **Guest OS**: Runs on the host OS – e.g., Windows 7 on Windows 10
- **Hypervisor**: Software to support multiple virtual machines
  - Type 1: Runs on bare metal – e.g., VMware ESXi
  - Type 2: Runs on a host OS (guest OS runs as a process on the host)
    e.g., VMware Player, VirtualBox
  - Type 3: Can be categorized as both 1 and 2 – e.g., Linux KVM

Disk Arrays (aka Storage Arrays)

- In data centers, all disks are external to the server
  - Data accessible by other servers in case of a server failure
- JBODs (Just a bunch of disks) → difficult to manage, no redundancy
- Disk Arrays → easy to manage pool of disks with redundancy (RAID)



Source: G. Santana, "Data Center Virtualization Fundamentals", Cisco Press, 2014, ISBN:1587143240

Data Access Methods

- Three ways for applications to access data:
  - **Block Access** → fixed number of bytes (block-size), e.g., 1 sector, 4 sectors, 16 sectors
  - **File Access** → set of bytes with name, creation date, and other meta data
  - **Record Access** → used for highly structured data in databases. Each record has a particular format and set of fields (accessed using e.g., SQL)
- **Storage systems** provide **block access**
  - logical volume manager in the OS provides other "virtual" views, e.g., file or record

Benefits of Storage Virtualization

- **Distance**: Remote storage devices appear local → Much larger distances
- **Spread**: Data is spread over multiple physical disks to improve reliability and performance → Greater performance
- **File System**: Windows, Linux, and UNIX all use the same storage device → Increased disk utilization
- **Higher availability** → multiple access path, redundant storage
- **Disaster recovery** capability
- **Virtual Interface**: A SCSI[1] disk connected to a computer with no SCSI interface
- Continuous **on-line backup**

[1] Small Computer System Interface

Benefits of Storage Virtualization (Cont.)

- **Easier testing**
- **Size**
  - Multiple smaller volume appear as single large volume
  - Increased scalability
- Allows **thin provisioning**
  - Appears as if there is bigger disk than physical

Open Virtualization Format (OVF)

- Standard for packaging and distributing a virtual appliance consisting of one or more virtual machines (VMs)
  - Facilitates the mobility of VMs
- Independent of hypervisor or processor architecture
- ISO/IEC standard (ISO 17203)
- OVF package consists of several files in a directory
  - An XML file with extension .ovf or a compliant format, e.g., .vmdk in the directory contains all the meta data required to run the package, e.g., hardware requirements, descriptions, security certificates, etc.
- VMware, Microsoft, Oracle, Citrix, IBM and many others support OVF
- Other popular formats
  - Virtual Hard Disk (Microsoft), Virtual Machine Disk (VMware)

Summary

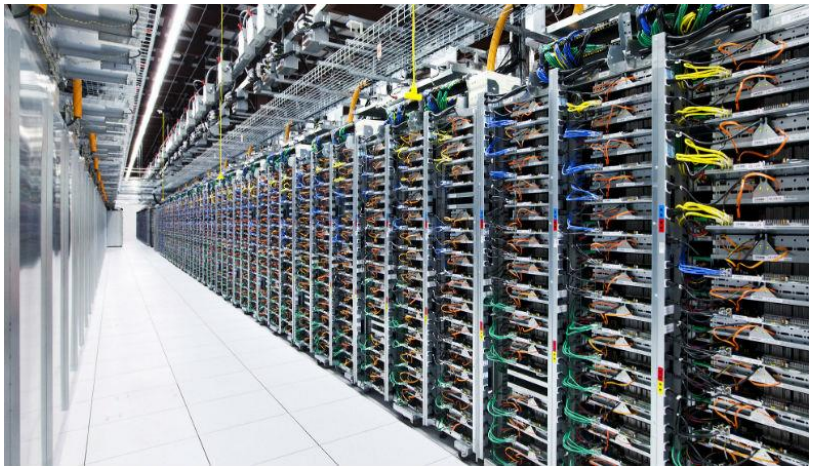
- Virtualization allows computation to be done **anywhere**, **anytime** on **any infrastructure**
  - Easy and efficient resource scheduling and management
- Servers, storage, and network all need to be virtualized
- Hypervisors
  - Type 1 run on bare metal
  - Type 2 require a host OS
- OVF is standard format for virtual images

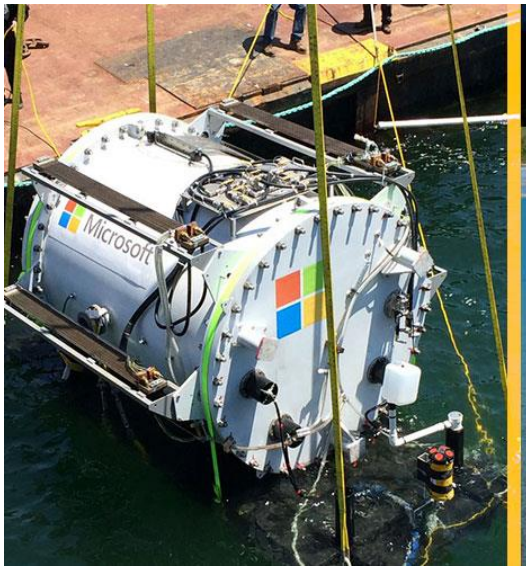
Data Center Network Architectures

Overview

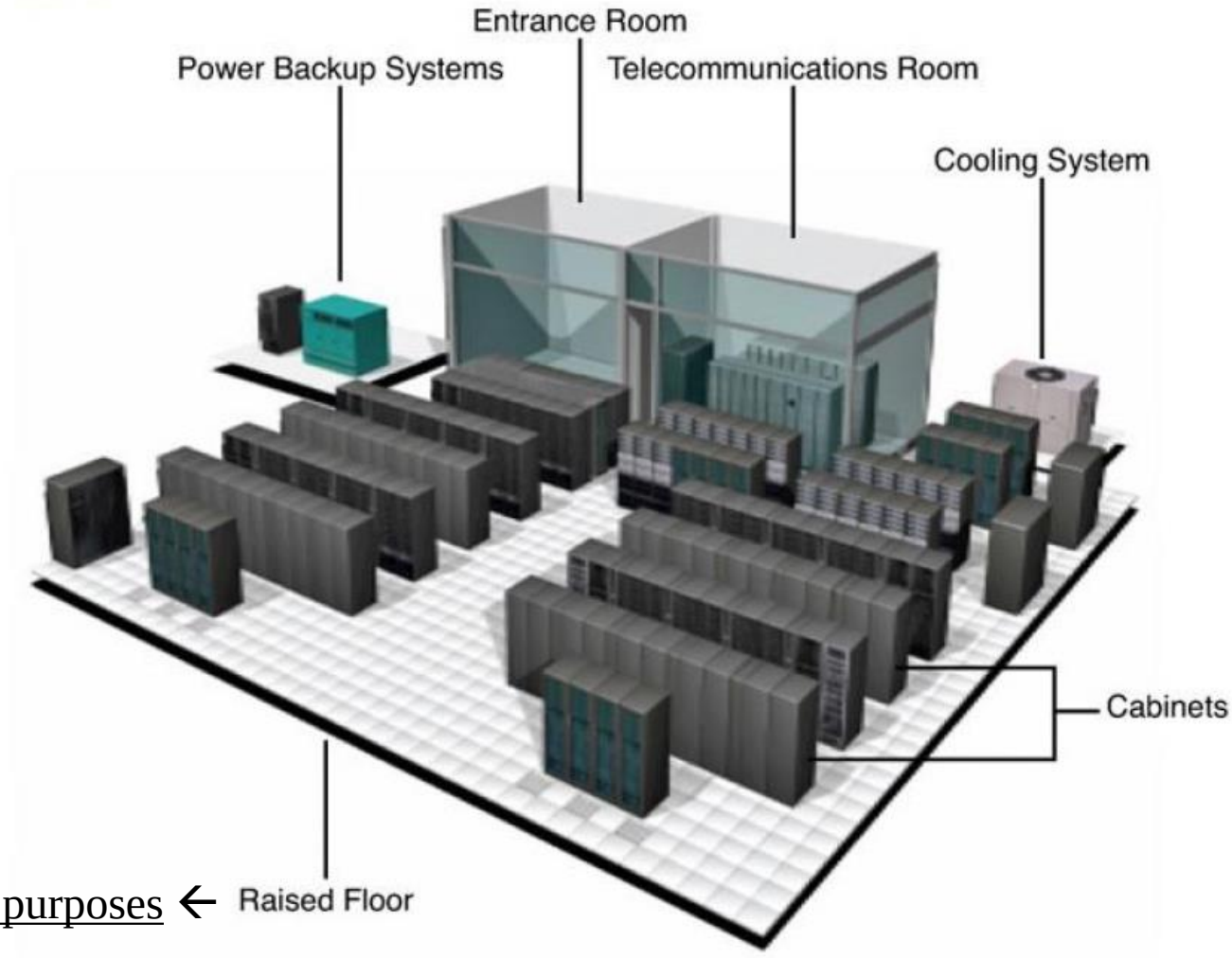
1. Data Center Physical Layout
2. Data Center Network Cabling
3. ToR vs. EoR Switches
4. Data Center Network Architectures

Data Centers





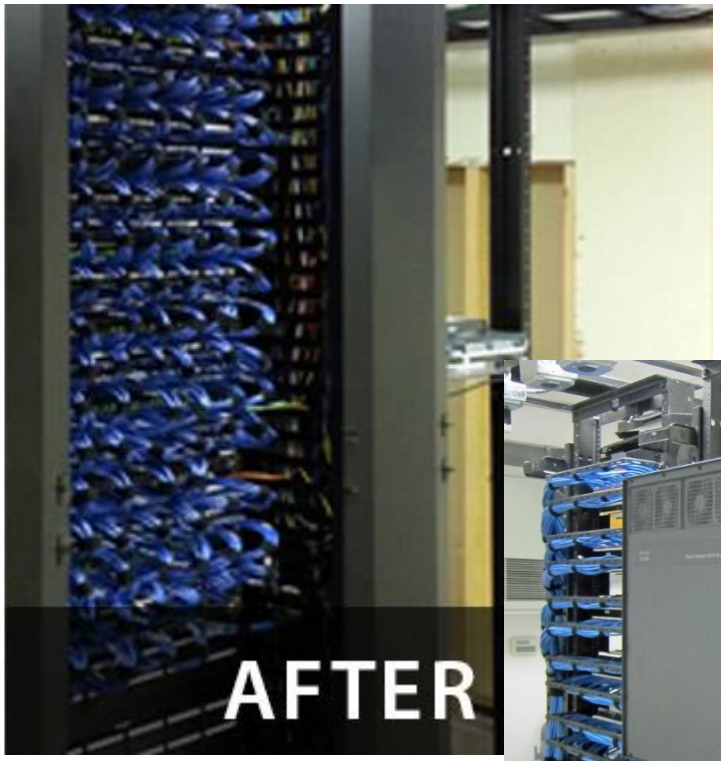
Data Center Physical Layout



For cooling purposes ← Raised Floor

Source: G. Santana, “Data Center Virtualization Fundamentals”, Cisco Press, 2014, ISBN:1587143240

Structured Cabling



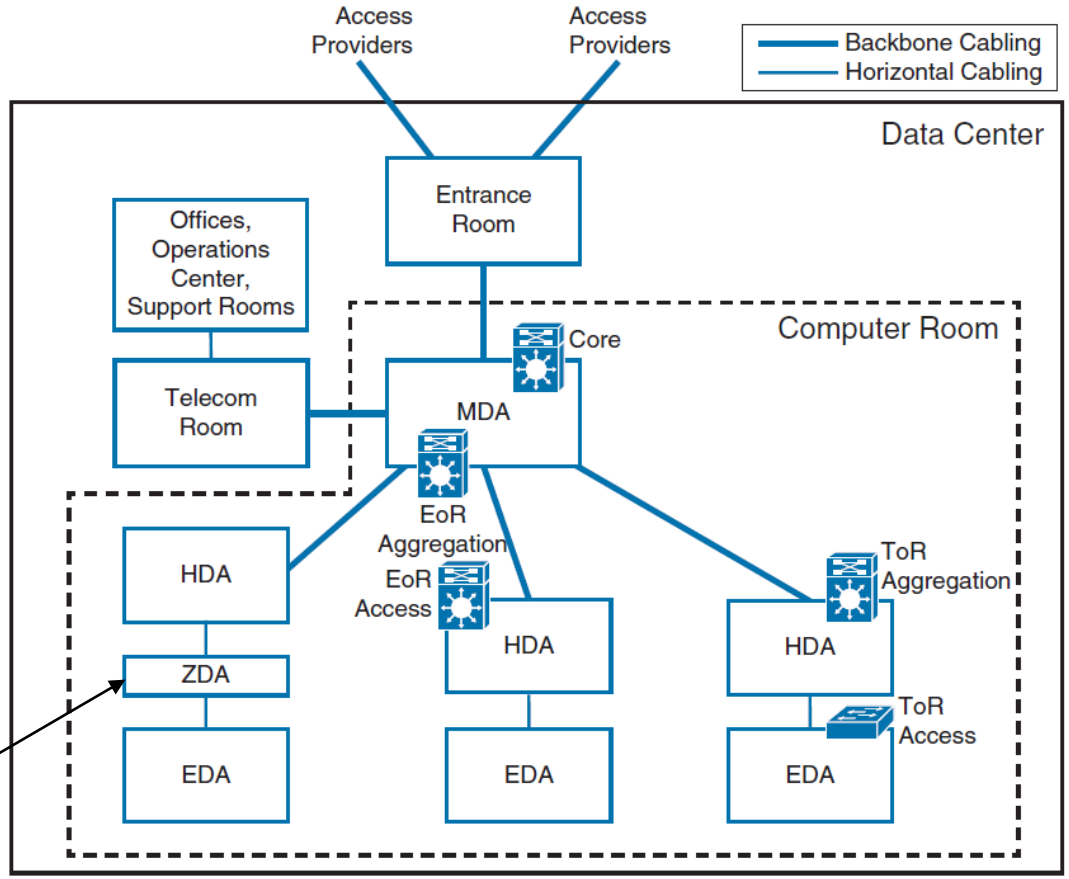
ANSI/TIA-942 Standard

78% of data center owners adopting it

- Telecommunications Infrastructure Standard for Data Centers

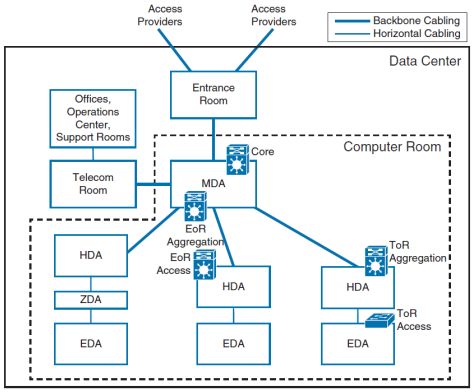
- Main Distribution Area (MDA)
- Horizontal Distribution Area (HDA)
- Zone Distribution Area (ZDA)
- Equipment Distribution Area (EDA)

Optional



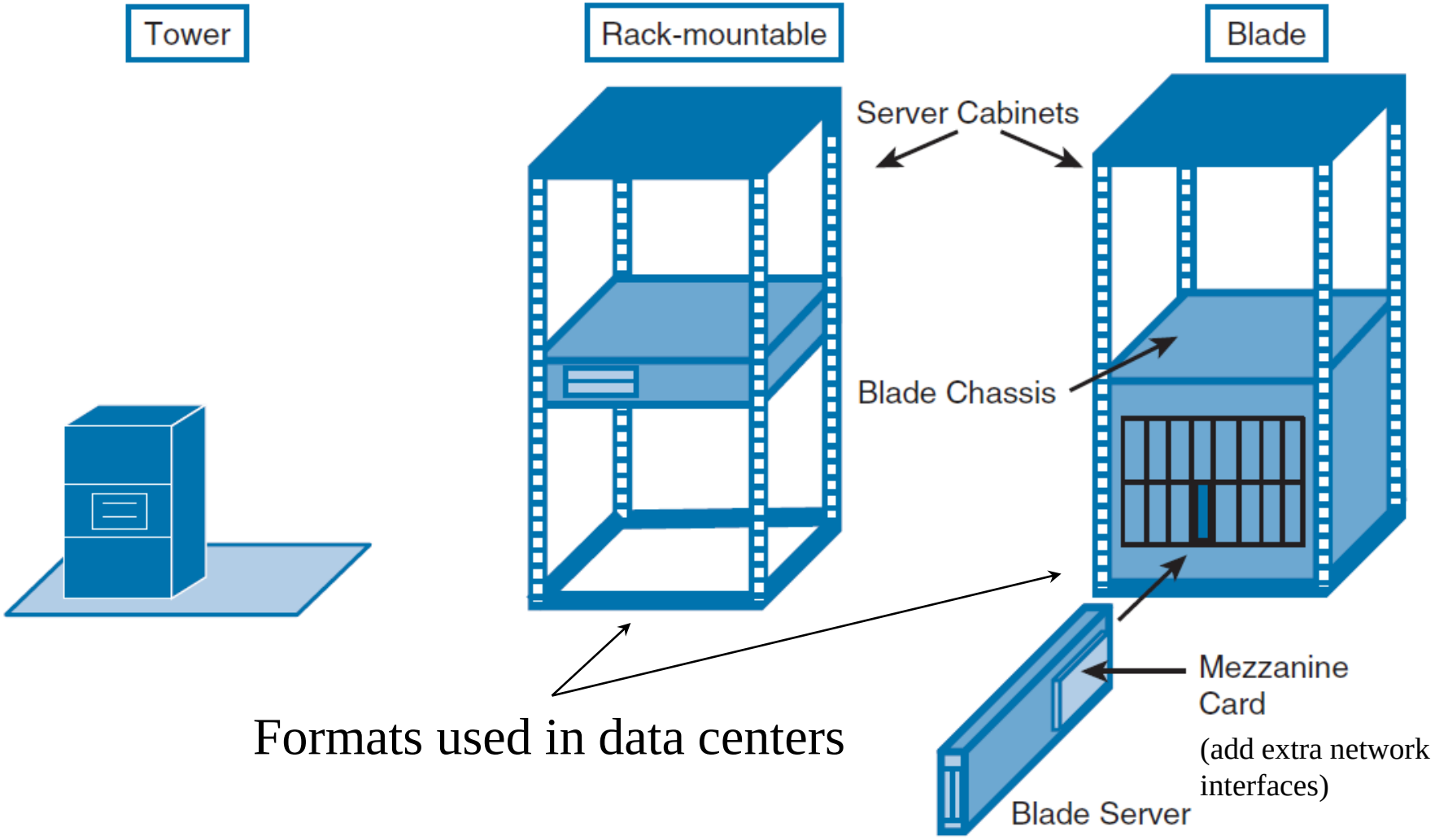
Source: G. Santana, “Data Center Virtualization Fundamentals”, Cisco Press, 2014, ISBN:1587143240

ANSI/TIA-942 Standard



- **Computer Room**: Data processing equipment (Servers)
- **Entrance Room**: Data Center to external cabling
- **Cross-Connect**: Enables termination of cables
- **Main Distribution Area (MDA)**: Main cross connect. Central Point of Structured Cabling. Core network devices.
- **Horizontal Distribution Area (HDA)**: Connections to active equipment.
- **Equipment Distribution Area (EDA)**: Active Servers+Switches. Alternate hot and cold aisle
- **Zone Distribution Area (ZDA)**: Optionally between HDA and EDA
- **Backbone Cabling**: Connections between MDA, HDA, and Entrance room

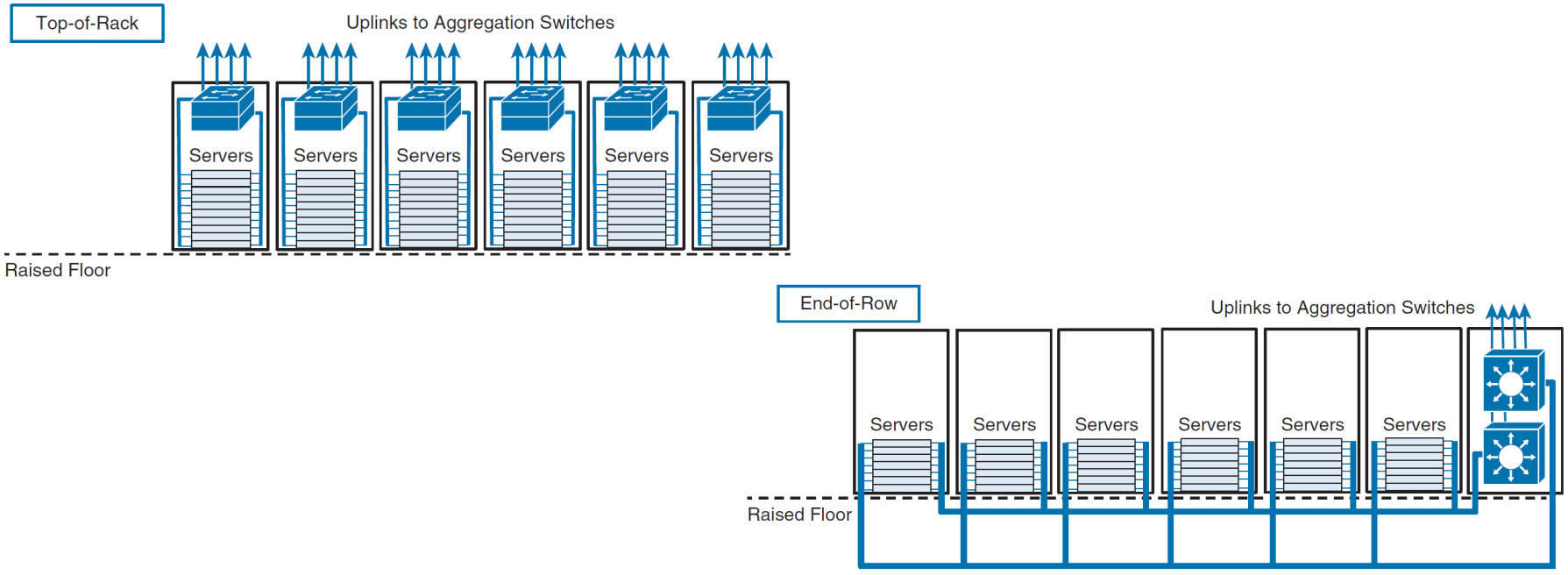
Server Formats



Source: G. Santana, “Data Center Virtualization Fundamentals”, Cisco Press, 2014, ISBN:1587143240

Server Connection Models

- The *Top-of-Rack (ToR)* and *End-of-Row (EoR)* designs represent **how access switches and servers are connected to each other**
- Both of them have a **direct impact over a major part of the entire data center cabling system**

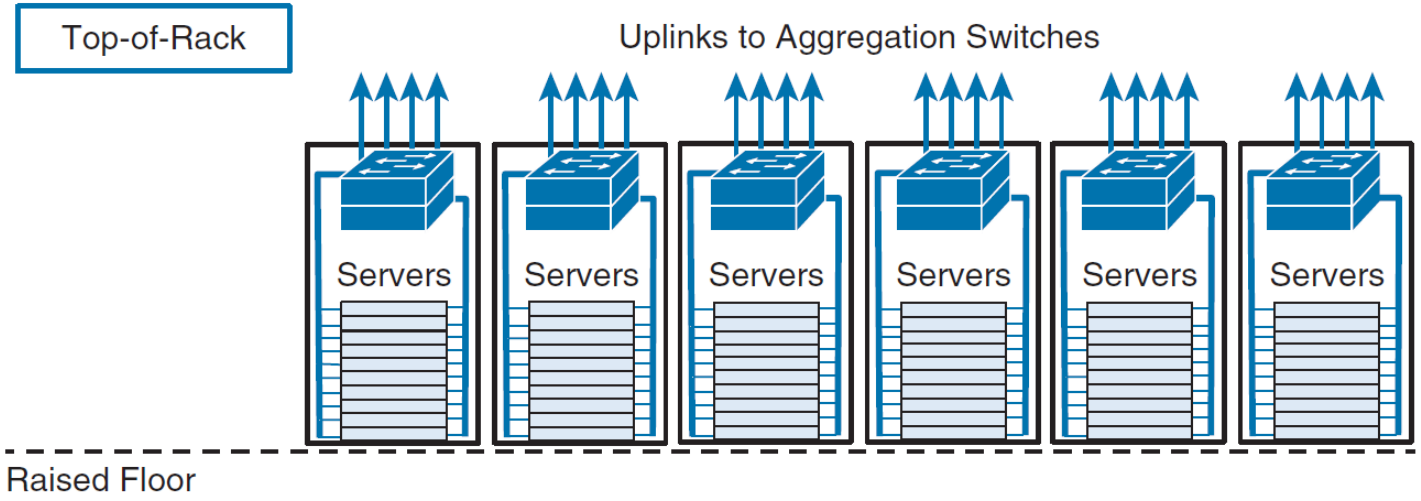


Source: G. Santana, “Data Center Virtualization Fundamentals”, Cisco Press, 2014, ISBN:1587143240

Server Connection Models – ToR

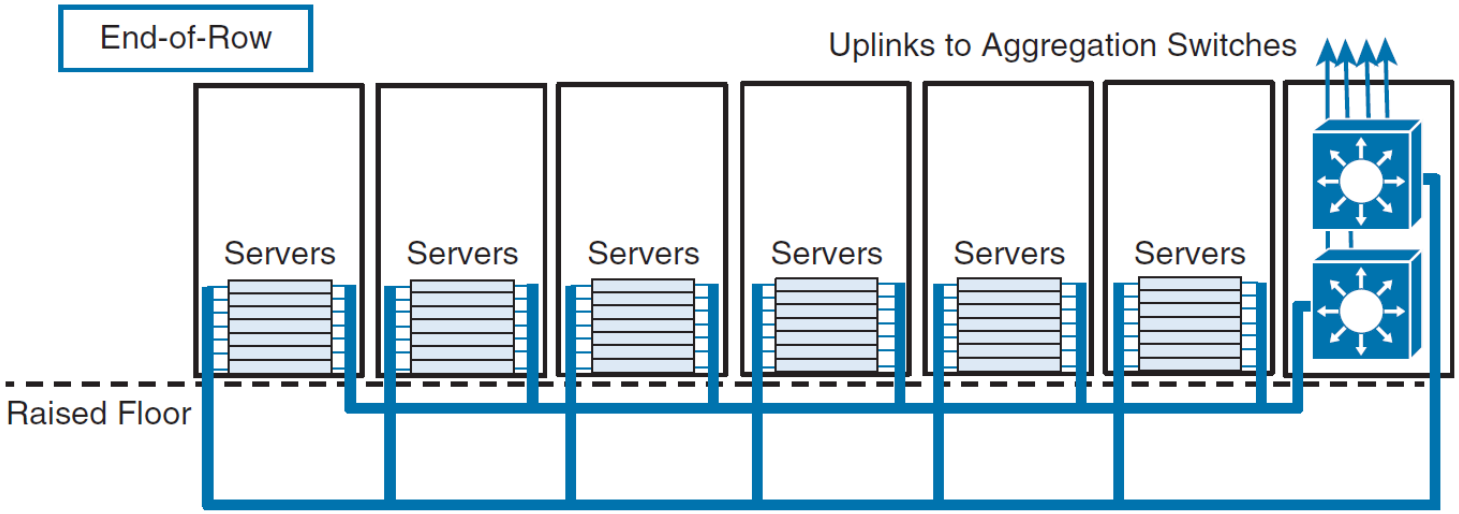
- Design based on intra-rack cabling between servers and smaller switches installed on the same racks as the servers

- While **reducing the amount of cabling** and **optimize the space used by network equipment**, they offer the network team the **challenge to manage a higher number of devices** (two per server rack, as shown in the Figure)

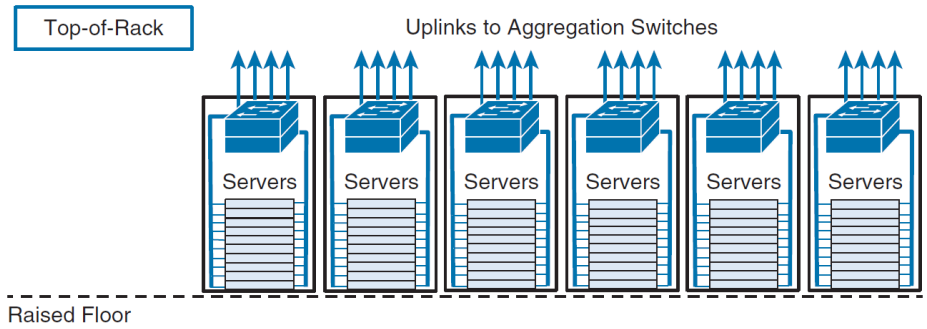


Server Connection Models – EoR

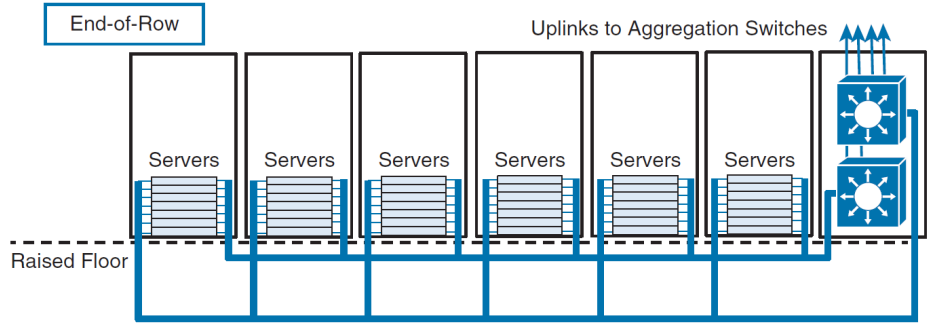
- Design based on inter-rack cabling between servers and high-density switches installed on the same row as the server racks
- While **reducing the number of network devices** and **optimize port utilization on the network devices**, EoR flexibility taxes data centers with a **great quantity of *horizontal cabling* running under the raised floor or on aerial trays** (as illustrated in the Figure)



ToR vs. EoR Switches



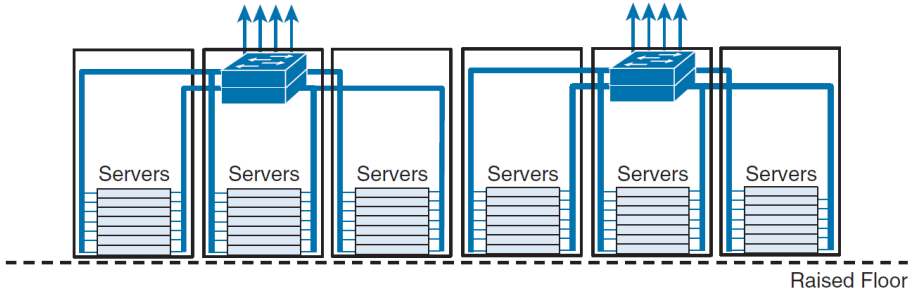
- ToR
  - + Easier cabling
  - + Per-cabinet upgrade of connection technologies (1 to 10 Gbit/s Ethernet)
  - - High management effort on multiple switches
  - - If rack is not fully populated ⇒ unused ToR ports



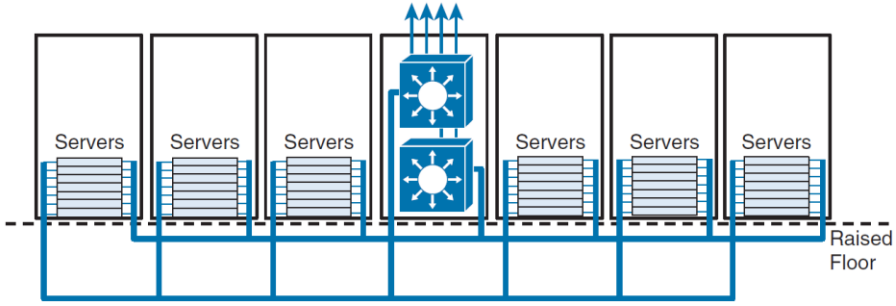
- EoR
  - + Servers can be placed in any rack
  - + Ports can easily be added, upgraded
  - - Longer cables and cabling sprawl
  - - Upgrade may be more difficult (new connectivity technologies)

Server Connection Models – Which one is better?

- The answer is: “It depends.”
- Along the last decades, none of the access models was clearly defined as the “best”
- The best design choice leans on the number of servers per rack, the data rate for the connections, the budget, and the operational complexity
- Also, additional approaches can be considered …



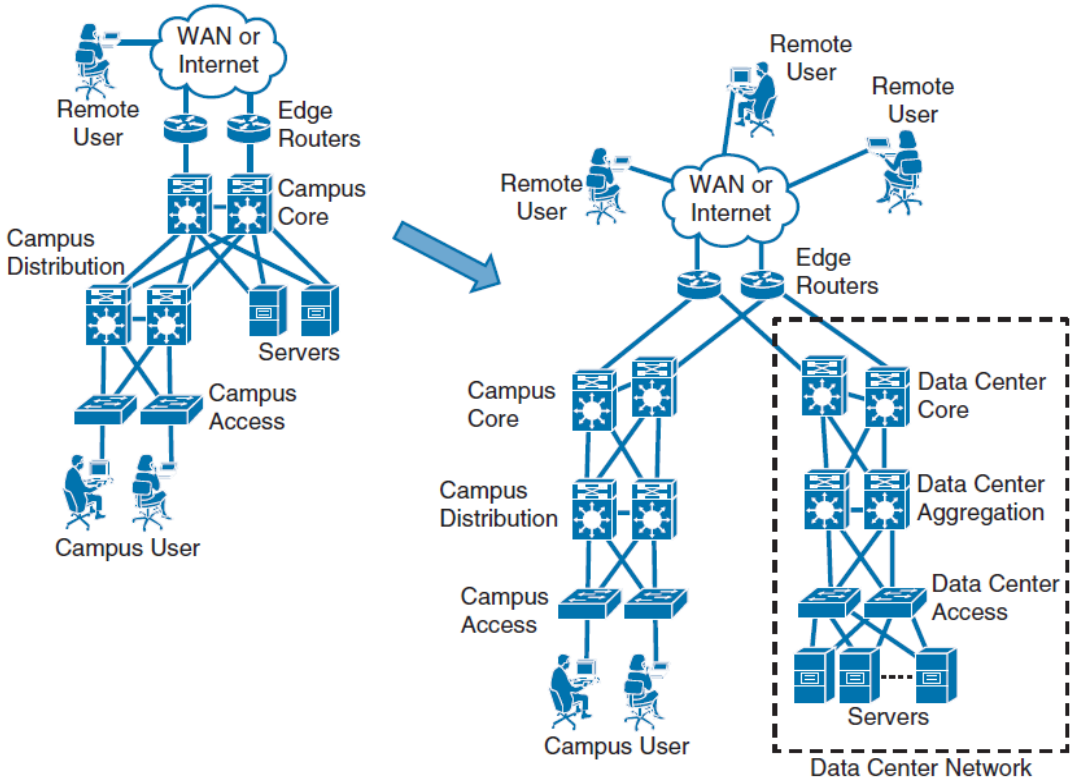
Top-of-Many-Racks



Middle-of-Row

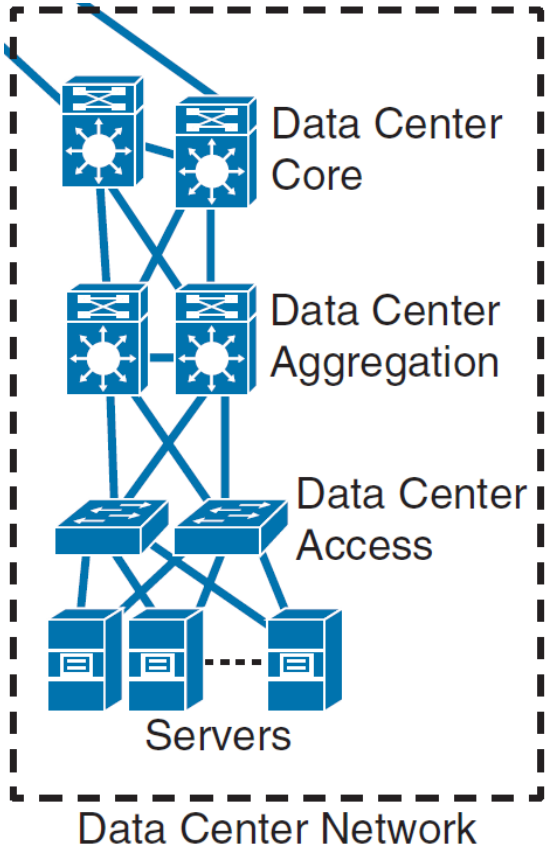
Data Center Network – Hierarchical Architecture

- Data center networks can be considered specialized evolution from campus networks
  - until late 1990s, it was common to find companies whose servers were connected to the same network structure that provided connectivity to local end users



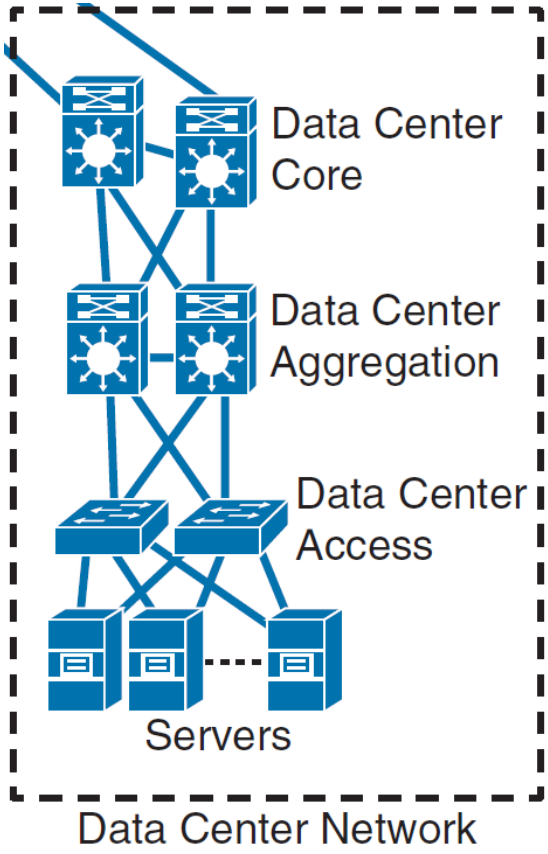
Data Center Network – Hierarchical Architecture

- Each server connected to 2 access switches with 1 Gbps
  - 10 Gbps becoming common
- Access switches connect to 2 aggregation L3 switches
  - Switches that implement routing functions
- Aggregation switches connect to 2 core L3 switches
- Core L3 switches connect to edge routers
- Core layer forwards data center ingress and egress traffic



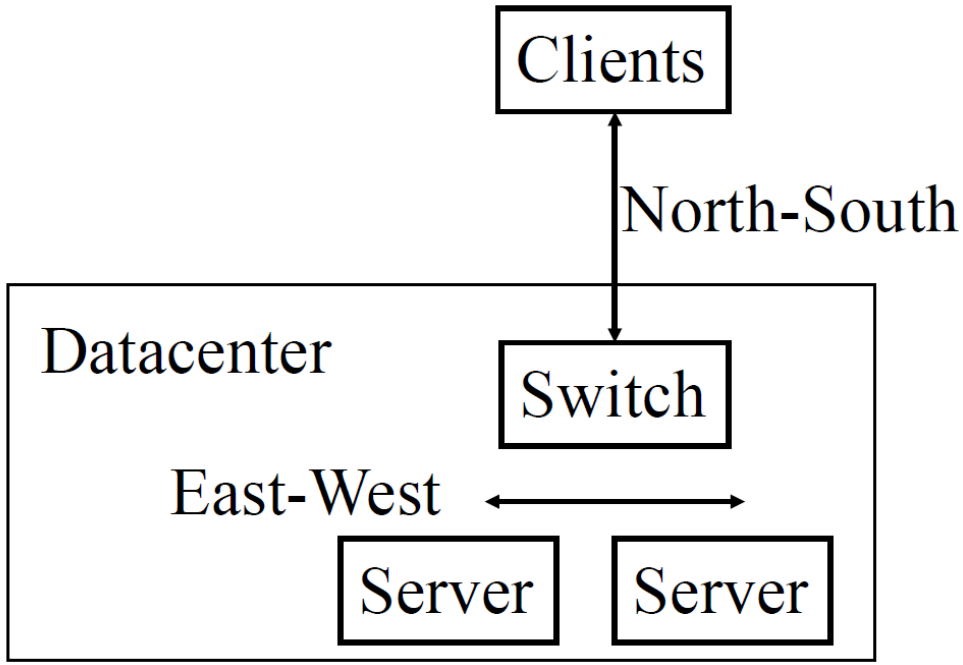
Data Center Network – Hierarchical Architecture

- Aggregation layer forwards server-to-server traffic in the data center
- Access Layer
  - Provide high number of ports for connectivity
  - Low Latency
- All switches below each pair of aggregation switches form a single Layer-2 domain
- Each Layer 2 domain typically limited to a few hundred servers to limit broadcast
- Most traffic is internal to the data center

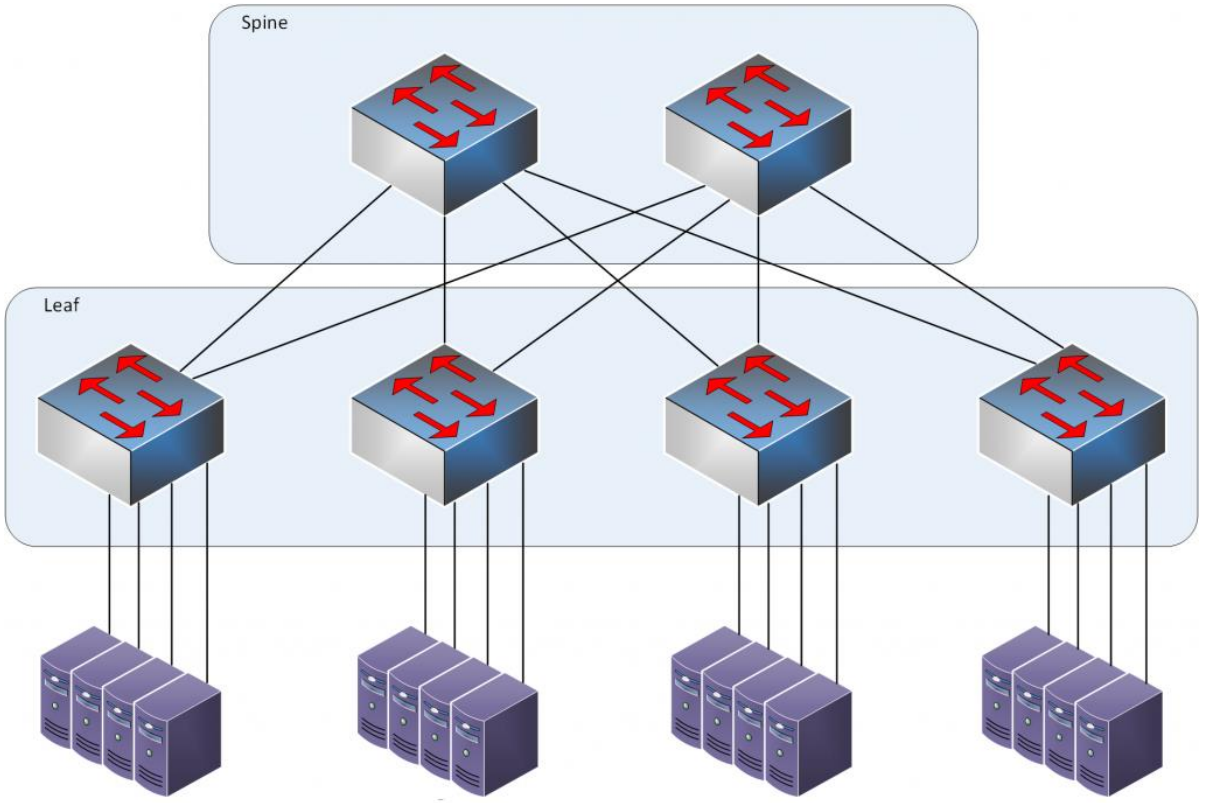


Data Center Networks – North-South vs. East-West Traffic

- Previously, most of the traffic was North-South
  - Between servers in the data center and clients outside
- Trend now is towards traffic between servers → e.g., CDNs
  - East-West traffic
  - Requires flatter network
  - Leaf-Spine Topology

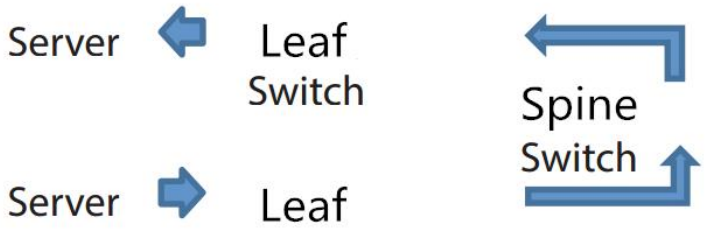


Data Center Networks – Leaf-Spine Architecture



Spine

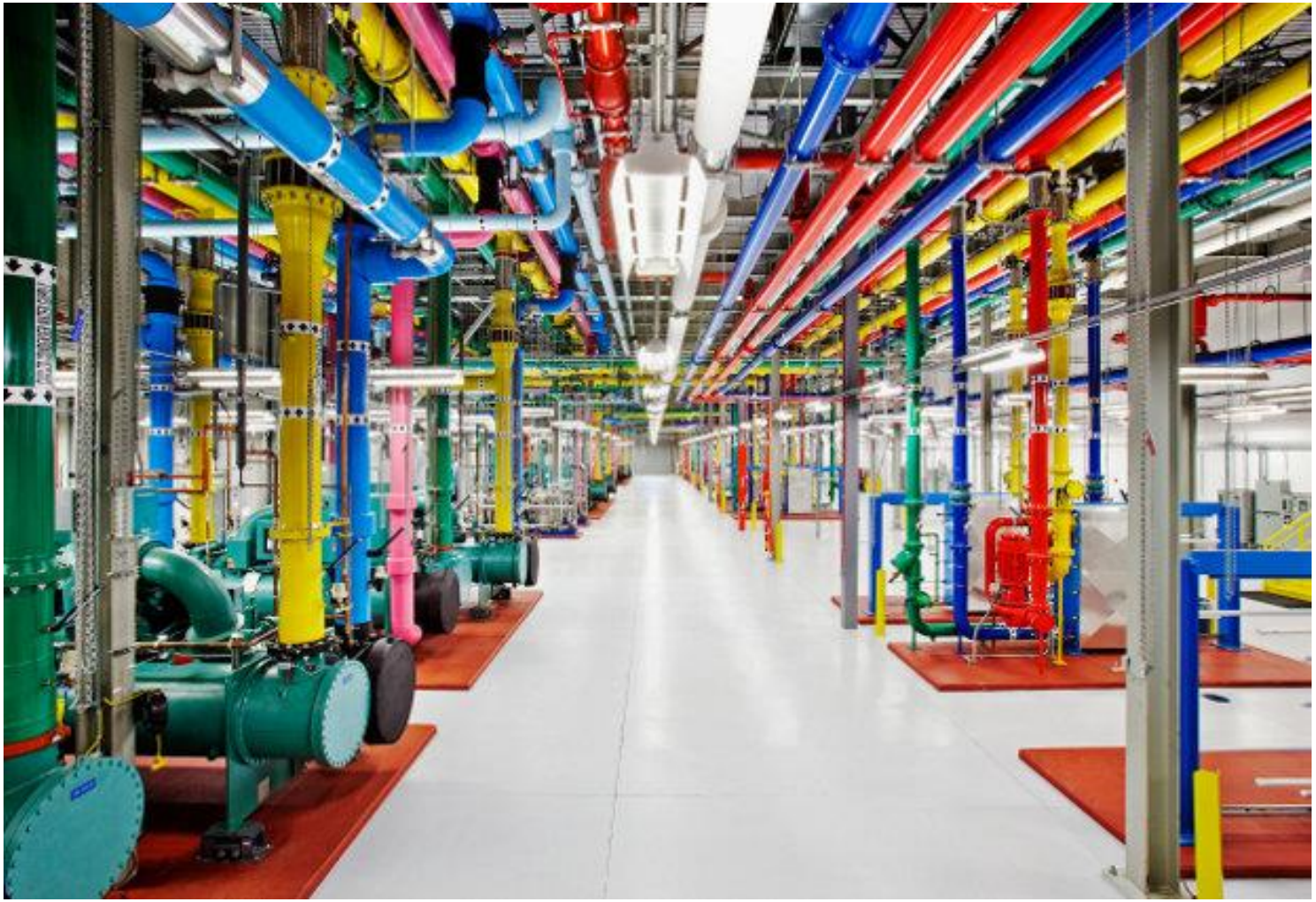
Leaf



Improve performance, reliability, and scalability

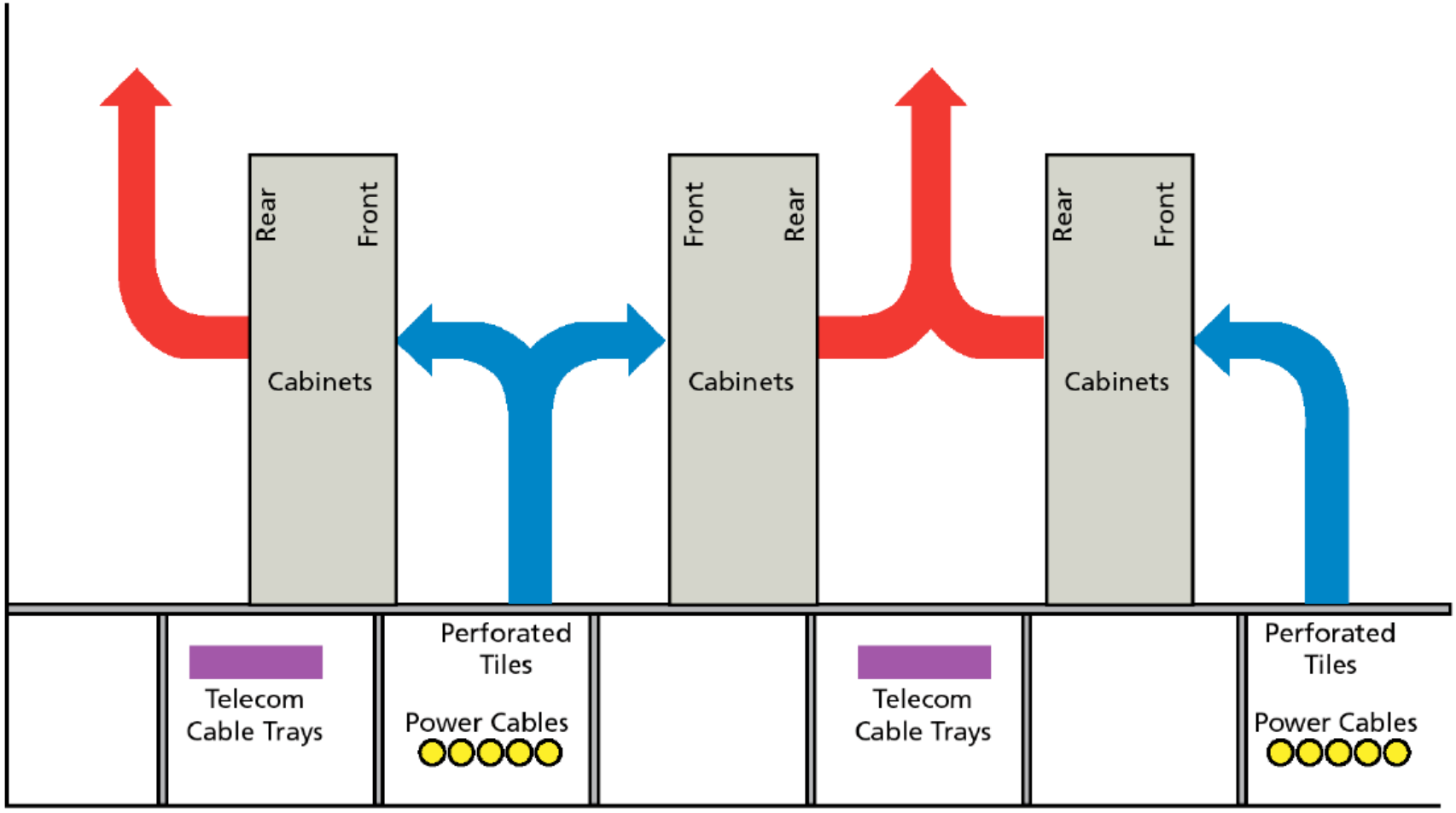
Video: https://youtu.be/x1F-RCW9fqo

Cooling Plant



Source: http://english.netmassimo.com/2012/10/18/a-visit-to-google-data-centers [Accessed: 7th May 2021]

Cooling System



Source: ADC, TIA-942 – Data Center Standards Overview, Whitepaper, 2006.

Summary

- Hierarchical Architecture
  - Three tiers: Access, Aggregation, Core
- Leaf-Spine Architecture
  - Improve performance and reliability
- Need large L2 domains
  - How to scale to tens or hundreds of thousands of servers?
  - We will discuss this in the next lesson