BACHELOR THESIS Data Center Infrastructure: Network Design Concept

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BACHELOR THESIS

Data Center Infrastructure: Network Design Concept

By

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http://www.beldenvn.com/ [1]

LIST OF ABBREVIATIONS

IT	Information Technology
DC	Data Center
DCN	Data Center Network
UPS	Uninterruptible Power Supply
PDU	Power Distribution Units
CRAC	Computer Room Air Conditioning
ANSI	American National Standards Institute
NOC	Network Operations Center
TOR	Top Of Rack
MOR	Middle Of Rack
EOR	End Of Rack

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ABSTRACT

The 21st century is a booming era of digital technology; it is also the age of cloud computing where internet-based data is handled from remote places. Data is being entered, stored. Processed, deposited and backed up all at the central information infrastructure located in specific buildings that we called Information Technology rooms or data center. Data center is a place where all the information technology servers, the storage and network facilities are gathered in compliance with the art of technology, in which the equipment requires 24 /7 continuous operation. Data centers are becoming as important a part of business operations as office, retail, and industrial assets. Nowadays, there are four concerns: Big Data, Internet of things, Industry 4.0 revolution and smart-cities are all trends that will increase demand for computing power, and thus data centers, on an exponential rather than linear scale. However, we have some limitations regarding knowledge about the architecture infrastructure of a data center, especially the application and design of data center infrastructure in a typical area and domain. This thesis intends to present a comprehensive literature review that accounts for definition, basic concept design requirements, application, and infrastructure topology of data centers. Based on these observations, an important part of the report, we aim at the basic design related to the infrastructure of a small data center at USTH. The primary design is based on the best practices and international reference standards for data center infrastructure design such as Tier-3 level recommended by Uptime Institute and ANSI/TIA-942 standard. The design scale is geared towards the current use of IT equipment as well as the ability to expand in the next 5-years of USTH. We conclude the design by describing key components and challenges for future research on constructing effective and accurate data center infrastructures.

Keywords: Data center, Cloud computing, Server, Infrastructure topology, Tier level, End of row, Top of rack

I. INTRODUCTION

1.1 CONTEXT AND MOTIVATION

Data centres or Data centers are facilities that house the hardware and software that support companies, government organizations, banks, universities' information technology systems. The mission critical nature of computers in the modern business world means that data centers have additional requirements that differentiate them from a typical storage unit. These include enhanced power, cooling, connectivity and security features. Data centers are becoming as important a part of business operations as office, retail and industrial assets. This trend is being driven by several factors including the increasingly digital world, IT development and the importance enterprise IT strategy plays in business delivery. The evolution of cloud computing which provides on-demand provisioning of elastic resources with a pay-as-you-go model has transformed the Information and Communication Technology (ICT) industry. Over the last few years, large enterprises and government organizations have migrated their data and mission-critical workloads into the cloud. As we are moving towards the fifth generation of cellular communication systems (5G), Mobile Network Operators need to address the increasing demand for more bandwidth and critical latency applications. Thus, they leverage the capabilities of cloud computing and run their network elements into distributed cloud resources. The adoption of cloud computing by many industries has resulted in the establishment of humongous data centers around the world containing thousands of servers and network equipment. Data centers are large-scale physical infrastructures that provide computing resources, network and storage facilities. Cloud computing is expanding across different industries and along with it the footprint of data center facilities which host the infrastructure and run the services is growing. Since 2015 there has been 259 hyper-scale data centers around the globe, and by 2020 this number will grow to 485 as shown in [1]. These types of data centers will roughly accommodate 50% of the servers installed in all the distributed data centers worldwide. Data centers are promoted as a key enabler for the fast-growing Information Technology (IT) industry, resulting in a global market size of 152 billion US dollars by 2016 [2].

In Vietnam [3], the new Cybersecurity Law is among the strengths that would drive more demand for data centers. The law that came into effect earlier this year requires tech businesses to store Vietnamese users' data within the country and provide it to the Ministry of Public Security on request. In the International Telecommunication Union's 2018 survey Vietnam ranked 50th out of 175 countries in cybersecurity. The country's emerging and tech-savvy population is another factor. It has 64 million Internet users. The fast-growing trend in the Asia-Pacific of co-locating data centers is underpinned by the rapid pace of digitization and a surge in demand for cloud-based services across the region. And in Vietnam, currently there are 17 colocation data centers from 3 areas in Vietnam (Hanoi, HCM and Da Nang). Nowadays, with a large number of people using Internet services and smartphones; create a trend of big technology companies moving factories and transferring servers to Vietnam. Vietnam is also in the development of 5G information technology infrastructure, aiming toward smart cities. Therefore, the trend of developing the Data Center market in Vietnam is being evaluated with full potential. However, a full understanding of the infrastructure and the operation of data centers is still being limited, focused mainly within some large service providers such as Viettel IDC, CMC Telecom... Currently, there are no statistical reports or aggregate assessments about the number of Data Center, or guidelines related to the design of infrastructure and operations of the Data Center in Vietnam.

1.2 OBJECTIVES OF THE THESIS

As mentioned in section 1.1, the increase in the number and size of Data Centers in Vietnam in the coming years is very large, thus making a full understanding of the infrastructure, components (electrical, cooling, etc…), information technology infrastructure (cabling, internet connectivity…) becomes a necessity.

In this thesis, we will have an overview of the data center's network infrastructure which includes key components and international standards serve as references for data center design.

As an important part of the thesis, we cover the design of a small scale data center (20 rack cabinets), used for data storage, data processing, computation and simulation, etc.… for University of Science and Technology of Hanoi. This small scale design will serve as the basis for more detailed designs of data centers in the future.

1.3 STRUCTURE OF THE THESIS

The thesis is structured into three main parts starting with the introduction of the topic. The rest of the work is organized as follows:

Part II gives an introduction on data centers concepts, and briefly presents the architecture of data centers. It shows that main components inside a data center network (router, switches...), and the basic network topologies (tree-based) that is often considered when selecting solutions for a data center.

Part III presents the proposal design for a typical Data center in the University of Science and Technology of Hanoi. We propose designing a small Data Center according to TIER

– 3 standards and ANSI/TIA-942 Standard for University of Science and Technology of Hanoi. This design aims to expand in the future as the number of students in the school can increases up to 5000 students/year; racks are used for different departments in the University: Faculty of SPACE, EN, ICT…., prioritizing the storage of student records, faculty records, the need for computing resources and other important USTH databases.

II. BACKGROUND AND RELATED WORKS

2.1 WHAT IS A DATA CENTER?

2.1.1 The basic concepts of a data center.

Data Center (DC) has many definitions; all of them try to describe the functions and components of a DC. Cisco [4] describes a DC as: a physical facility that organizations use to house their critical applications and data. A data center's design is based on a network of computing and storage resources that enable the delivery of shared applications and data. The key components of a data center design include routers, switches, firewalls, storage systems, servers, and application-delivery controllers. According to [5], data centers are computer warehouses that store large amounts of data that meet the daily transaction processing needs of different businesses. They contain servers for the collection of data and network infrastructure for the utilization and storage of the data. [6] tried to give a comprehensive definition: “A data center is a physical space that is environmentally controlled with clean electrical power and network connectivity that is optimized for hosting servers. The temperature and humidity of data center environment are controlled to enable proper operation of the equipment and the facility is physically secured to prevent deliberate or accidental damage to the physical equipment. This facility will have one or more connections to the public Internet, often via redundant and physically separated cables into redundant routers. Behind the routers will be security applications, like firewalls or deep packet inspection elements, to enforce a security perimeter protecting servers in the data center. Behind the security appliances are often load balancers which distribute traffic across front end servers like web servers. Often there is one or two tiers of server behind the application front end like second tier servers implementing application or business logic and a third tier of database servers. Establishing and operating a traditional data center facility - including IP routers and infrastructure, security applications, load balancers, servers’ storage and supporting systems - requires a large capital outlay and substantial operation expenses, all to support application software that often has widely varying load so that much of the resource capacity is often underutilized”. A narrower definition given by Maurizio Portolani et al. [7]: “Data centers house critical computing resources in controlled environments and under centralized management, which enable enterprises to operate around the clock or according to their business needs. These computing resources include mainframes; web and application servers; file and print servers; messaging servers; application software and the operating systems that run them; storage subsystems; and the network infrastructure, whether IP or storage-area network (SAN). Applications range from internal financial and human resources to external e-commerce and business-to-business applications. Additionally, a number of servers support network operations and network-based applications. Network operation applications include Network Time Protocol (NTP); TN3270; FTP; Domain Name System (DNS); Dynamic Host Configuration Protocol (DHCP); Simple Network Management Protocol (SNMP); TFTP; Network File System (NFS); and network-based applications, including IP telephony, video streaming over IP, IP video conferencing, and so on". For this thesis's purpose, we can have the definition of a data center as: an infrastructure of resources that collect, store, manage and distribute a large amount of critical data base on requirements and international standards. It consists of all necessary facility elements (space, power, and cooling) as well as IT elements (server, storage, and network). A typical data center according to this deffinition will follow the topology showing key funtional area as in Figure 1.

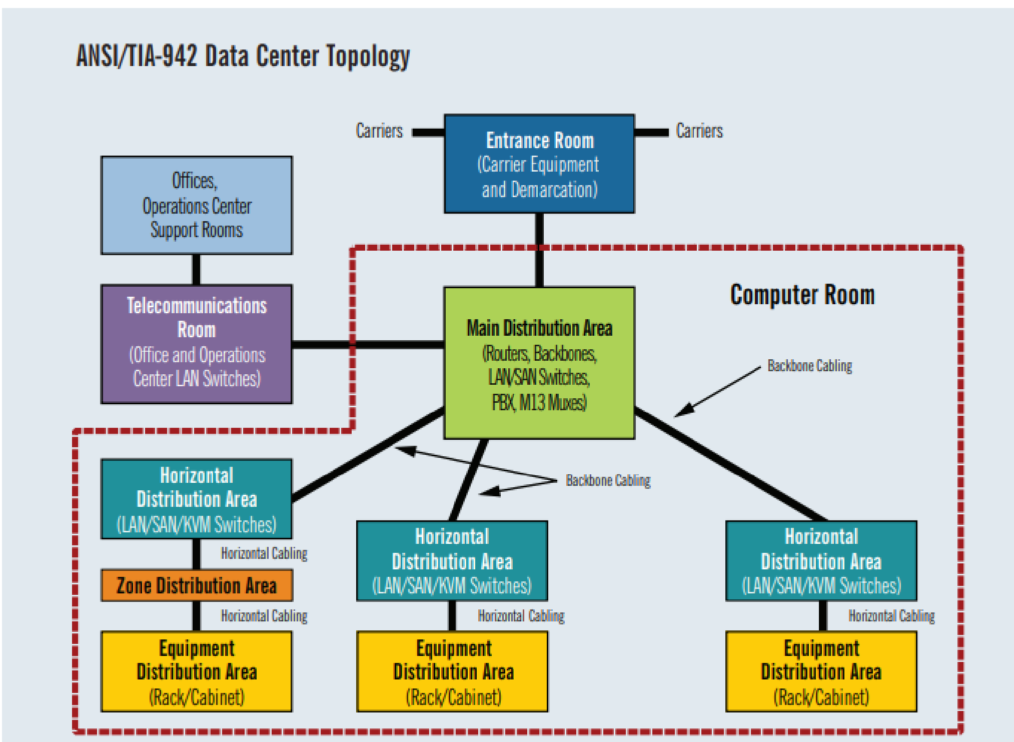


Figure 1: TIA-942 compliant data center showing key functional area[2]

[2] http://www.tia-942.org/

2.1.2 Why data centers are important.

There are many applications of the Data Center; the criticality of data centers has been fueled mainly by two aspects. First, the ever-increasing growth in the demand for data computing, processing and storage by a variety of large-scale cloud services, such as Google, Facebook and Amazon, by telecommunication operators, by banks and government organizations, resulted in the proliferation of large data centers with thousands or millions of servers, CPU. A study by International Data Corporation for EMC estimated that 1.8 trillion gigabytes (GB) or around 1.8 zettabytes (ZB), of digital information was created in 2011. The amount of data in 2012 was approximately 2.8 ZB and is expected to rise to 40 ZB by the year 2020 [8]. Second, the requirement for supporting a vast variety of applications ranging from those that run for a few seconds to those that run persistently on shared hardware platforms has promoted building large-scale computing infrastructures. As a result, data centers have been touted as one of the keys enabling technologies for the fast-growing IT industry and at the same time resulting in global data center market size is expected to reach revenues of around $174 billion by 2023 [9].

Table 1: Some typical Data Center – Top 5 biggest in the world 2019 [10]

N°	Data Center Company	Facility Location	Area
1	**Range International Information Group**	Langfang, China	6,300,000 Sq. Ft
2	**Switch SuperNAP**	Nevada, USA	3,500,000 million Sq. Ft
3	**DuPont Fabros Technology**	Virginia, USA	1,600,000 million Sq. Ft
4	**Utah Data Centre**	Utah, USA	1,500,000 million Sq. Ft
5	**Microsoft Data Centre**	Iowa, USA	1,200,000 Sq. Ft

Data centers are designed to support business applications and research activities that includes: (1) Email and file sharing, which need to store for a long time; (2) Customer relationship management is managing all company’s relationships and interactions with customers and potential customers. Customer data is uploaded and stored in a DC that allows companies to access their customer data anytime, anywhere; (3) Big data, artificial intelligence, and machine learning which requires storing, processing a large amount of data in a short time; (4) Virtual desktops, communication, and collaboration services.

2.2 DATA CENTER CLASSIFICATION AND INFRASTRUCTURE COMPONENTS

2.2.1 Data Center classification

Data centers in general can be classified in the following ways: owner and service provision purpose; classified according to the number of cabinet racks (or the number of IT equipment); classified according to the rating standards Uptime institute...

Two major types of data center ownership are enterprise and colocation. Enterprise data centers are built and owned by large technology companies (such as Amazon, Facebook, Google, Microsoft, Yahoo, as well as government agencies, financial institutions, insurance companies, retailers, and other companies across all industries). Enterprise data centers support web-related services for their organizations, partners, and customers. Colocation data centers are usually built, owned, and managed by data center service providers in order such as Coresite, CyrusOne, Digital Realty Trust, DuPont Fabros, and QTS. These data center service providers do not use the services themselves but rather lease the space to one or multiple tenants [11].

The Data Center Institute classifies data centers into six size groups (Table 2), measuring by space or number of racks [11, 12]. Uptime Institute created a standard Tier Classification System (Table 3) that has four tiers to consistently evaluate the infrastructure performance or uptime of data centers [13].

Table 2: Data center size classifications by rack number and location space

Size	Number of racks	Computer space (m^2)
Mini - data center	1-10	2.6-26
Small - data center	11-200	28.6- 520
Medium - data center	201-800	522.6-2080
Large - data center	801-3,000	2082.6-7800
Massive- data center	3,001-9,000	7802.6-23400
Mega - data center	More than 9,000	More than 23,400

Table 3: Data center Infrastructure classification Tiers

Tier	Description	Up-time	Down-time Per Year
Tier 1 - Basic Capacity	Data centers provide dedicated site infrastructure to support IT beyond an office setting, including a dedicated space for IT systems, an uninterruptible power supply, dedicated cooling equipment that does not shut down at the end of normal office hours, and an engine generator to protect IT functions from extended power outages.	99.671%	28.8 Hours
Tier 2 - Redundant Capacity Components	Data centers include redundant critical power and cooling components to provide select maintenance opportunities and an increased margin of safety against IT process disruptions that would result from site infrastructure equipment failures. The redundant components include power and cooling equipment.	99.749%	22 Hours
Tier 3 - Concurrently Maintainable	Data centers have no shutdowns for equipment replacement and maintenance. A redundant delivery path for power and cooling is added to the redundant critical components of Tier II so that each component needed to support the IT processing environment can be shut down and maintained without impacting the IT operation.	99.982%	1.6 Hours
Fault Tolerance	Site infrastructure builds on Tier III, adding the concept of Fault Tolerance to the site infrastructure topology. Fault Tolerance means that when individual equipment failures or distribution path interruptions occur, the effects of the events are stopped short of the IT operations.	99.995%	26.3 Minutes

2.2.2 Data Center main components

The hardware components can be put in two categories: information technology infrastructure (server, calbing…systems) and physical infrastructure (mechanical and electrical equipment) [14] The mechanical and electrical systems (M&E) can make up more than 60% of the total developmental cost of a new data center and is thus a major cost component. M&E systems include electrical substations, chillers, backup generators; uninterrupted power supplies (UPS) and computer room air-conditioning (CRAC) units. Table 4 shows the list of the main components inside a DC. In this thesis, we will focus on IT facilities and network component.

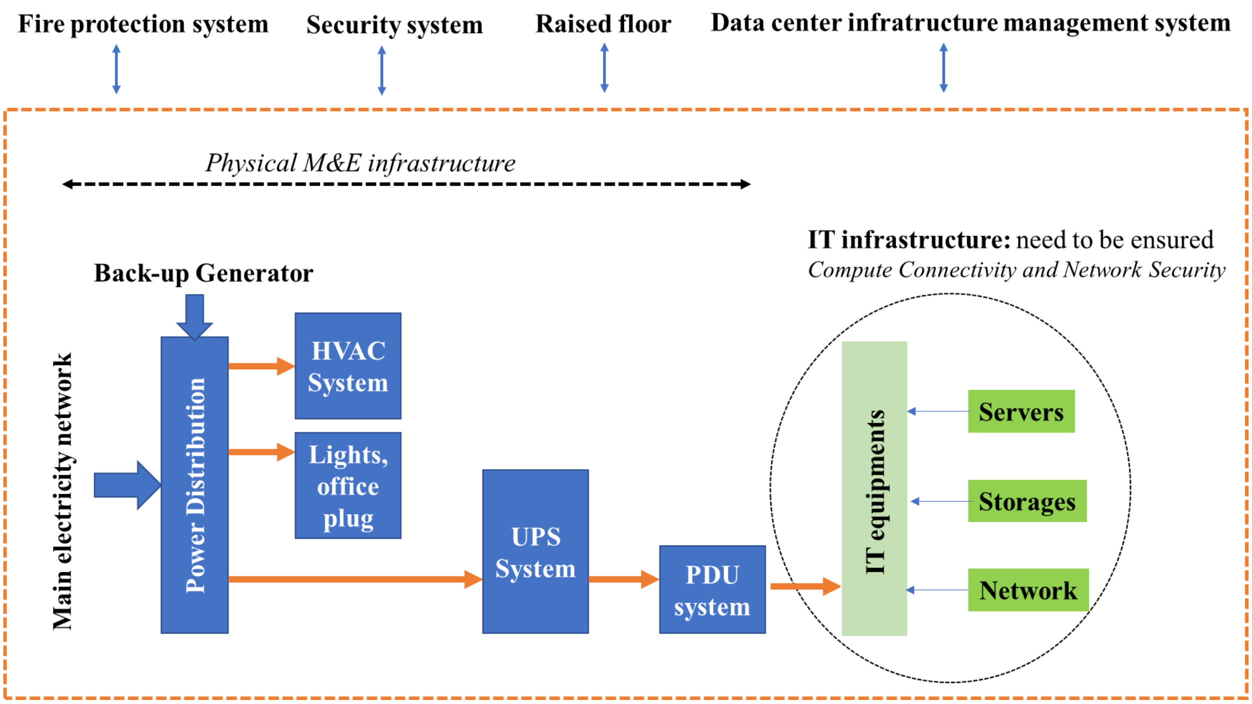


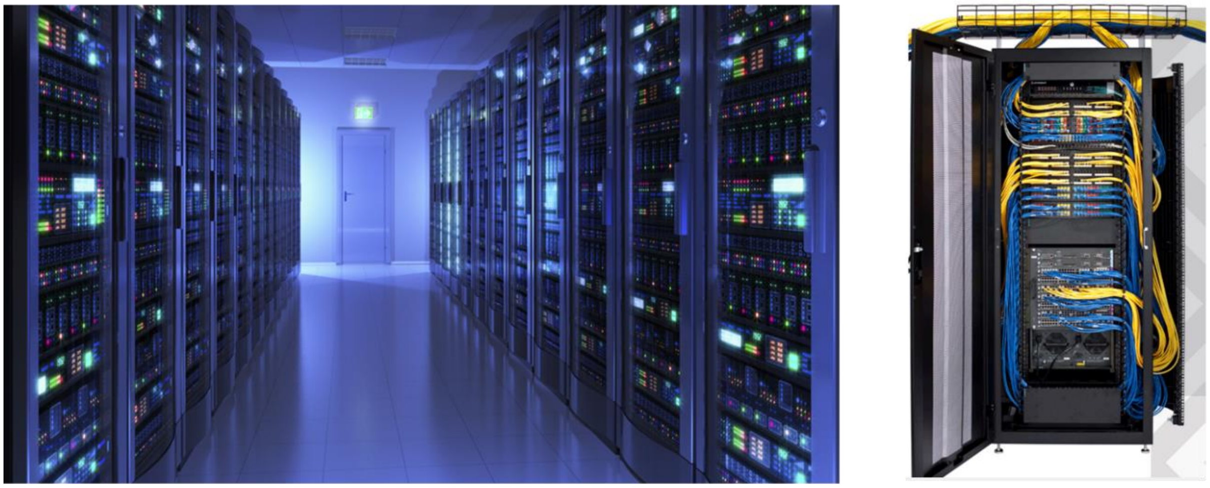
Figure 2: Critical infrastructure of a data center

Table 4: Data center components

Items	Components	Description
Hardware		
IT facilities	Server Racks	For housing server devices
	Network Racks	For network device (router, switch, firewall…)
	Storage Racks	For data storage
	Cabling systems	For communication inside a DC
Energy facilities	Electrical network	To supply the power
	Generator (GEN)	To guarantee a reliable power supply
	Uninterruptible power supply (UPS) and Battery storage	To guarantee a reliable power supply
	Main distribution & power distribution unit (PDU), rack, and server levels)	To supply the power to racks, equipment…
Mechanical facilities	Heating, ventilation and air conditioning - HVAC	To provide the total cooling capacity, and distributed air to the IT equipment.
	Chiller system	Outdoor heat exchange or transport
Other facilities	Raised floor	For cabling
	Fire protection	International standard for data center (NFPA 75 and NFPA 76)
	Security system	Surveillance camera

2.2.2.1 The IT racks

A typical rack cabinet's components can be seen in figure 3 and figure 4:



a) Rack cabinet rows **a) Inside of the Rack cabinet**

Figure 3: Explored view of a typical rack

A data center rack is a type of physical steel and electronic encloses that are designed to house servers, networking devices, cables and other data center computing equipment. This physical structure provides equipment placement and orchestration within a data center facility. Each rack is generally prefabricated with slots for connecting electrical, networking and Internet cables. Data center racks are created using a systematic design, and are classified based on their capacity - the amount of IT equipment they can hold. It can be defined as two types of power space for a rack in Data Center [15, 16]. The standard width of most IT equipment and the standard frame or enclosure for mounting multiple equipment module is 19 inches wide, including edges or ears that protrude on each side which allow the module to be fastened to the rack frame with screws [17]. The current 19-inch rack standard was established by the Electronic Industry Alliance (EIA). The specific standards are the EIA-310-D, Cabinet, racks, panels and associated equipment standard, and the equivalent IEC 60297-3-100, Mechanical structures for electronic equipment – dimensions of mechanical structures of the 19 inches series - Part 3-100: Basic dimensions of front panels, sub-racks, chassis, racks and cabinets [18].The unit for standard rack height and vertical mounting grid is often specified in ”U”, one U is equals to 1.75 inches. The most common IT rack dimensions for a DC have been 24 inches wide (exterior), 42 inches deep, and 42U tall with the mounting frame width of 19 inches [18, 19].

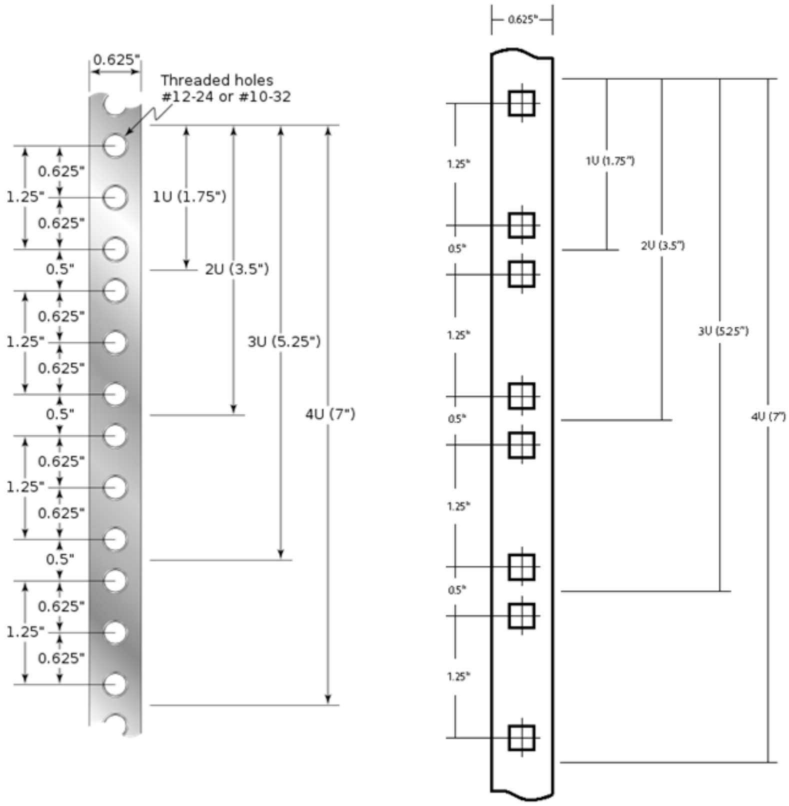


Figure 4: Rack's holes for mounting [17]

2.2.2.2 Servers and Storage system

a) Severs

Server is where the critical data inside a DC is accessed, managed, and processed. They provide the computing power needed to execute user applications, operating systems, file transfer services, computational services for large scientific workflows, and communications. Servers are vital to organizations and businesses since a down server can jeopardize them severely. They need to be available 24/7 with almost no down time. Usually, data center's servers are dived into two major types: (1) rack mounted/ rack servers, and (2) blade servers.

A rack-mounted server or standard racked server or simply a rack server is the standard server box that can be fit into a standardized 19-inch-wide rack. The height of a rack server can vary from 1 rack unit (RU), to 2 RU, 4 RU, or even 8 RU (one RU 5 1.75 inches 5 44.45mm) (Figure 5). In general, high-end servers are powerful and costly [20]. They are mounted parallel to the ground.

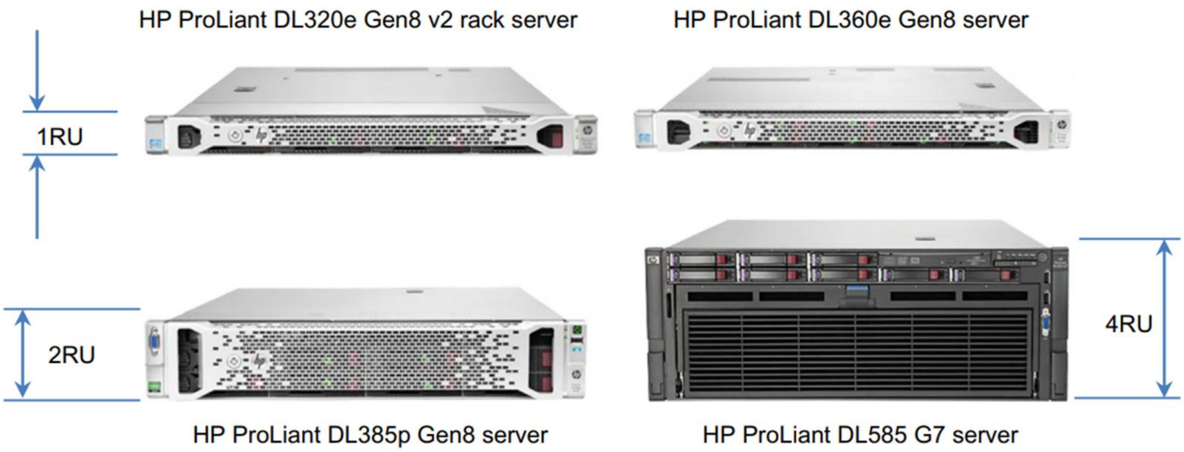


Figure 5: Racks severs and their size [20]

Blade servers on the other hand have the vertical mounting arrangement approach on the majority when compared with rack servers. They are more compact and have a higher density therefore more suitable and very efficient for large scale or warehouse type data centers [20]. On the downside, due to high physical density of the internal components and insufficient space for the air flow, cooling is difficult and more expensive in blade servers compared to rack servers [21].

Figure 6: Blade servers and their power consumption [20]

b) Storage system

With the never ending and ever rising amount of data that need to be stored, storage demand has the expansion of 50-70% per year. YouTube video uploading statistics show that 100 hours of videos are uploaded to the website every minute (Youtube, n.d.). Similarly, Facebook data shows that their system processes 2.5 billion pieces of content (over 500 terabytes of data) on daily basis [21]. Currently Hard Disk Drives (HDD) and Solid State Drives (SSD) are two prominent storage hardware components inside a DC with HDD is the most popular and cost-effective solution. When it comes to business data storage systems, the major options are direct-attached storage (DAS), network-attached storage (NAS) and storage area networks (SANs).

2.2.2.3 Network Devices in data center

By following OSI or TCP/IP protocol stack model, it is quite easy to understand the function of each type of network hardware device in a DC topology (Figure 7 and Table 5). Normally data is generated, encoded and compress in layer 6 and 7, authentication and authorization to access a server is perform in layer 5, in layer 4 data is for segmentation – divide data into segments and then send those segments across multiple networks in layer 3 in form of packets. When the packets arrive at the destined network, packets are transmitted between devices inside a LAN in layer 2 after forming into frames then go across the cable as BITs (Table 5, Figure 7 and 8).

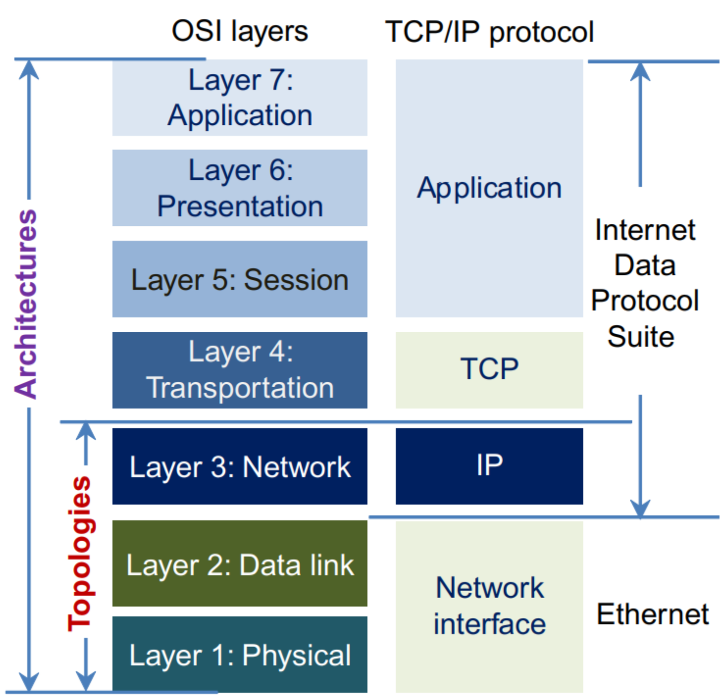


Figure 7: OSI model compare with TCP/IP model

Table 5: OSI Model depicting its seven layers with example objects in each layer, as well as their data units and function [22]

Layer	Data Unit	Function	Example
7. Application	Data	High-level APIs, including resource sharing, remote file access, directory services and virtual terminals	HTTP, FTP, SMTP
6. Presentation		Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption	ASCII, EBCDIC, JPEG
5. Session		Managing communication sessions, ie continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes	RPC, PAP
4. Transport	Segments	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing	TCP, UDP
3. Network	Packet/ Datagram	Structuring and managing a multi-node network, including addressing, routing and traffic control	IPv4, IPv6, IPsec, AppleTalk
2. Data Link	Bit/Frame	Reliable transmission of data frames between two nodes connected by a physical layer	IEEE 802.3/802.2
1. Physical	Bit	Transmission and reception of raw bit streams over a physical medium	Fiber, Copper twisted wires

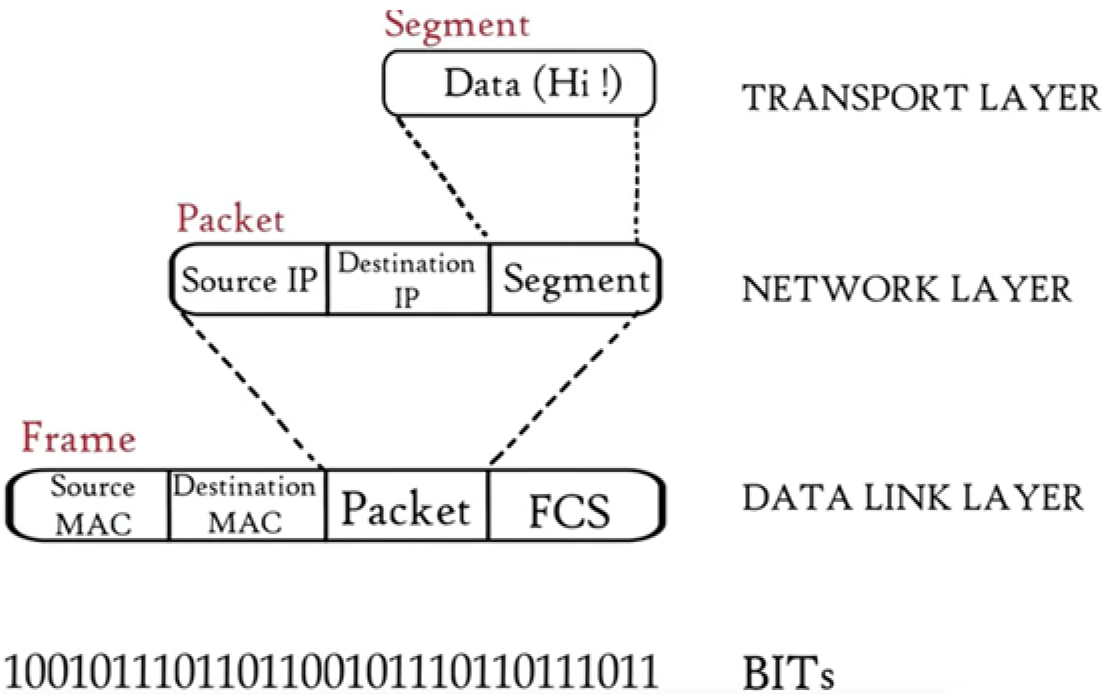


Figure 8: Protocol data unit in layer 4 to layer 1

a) Router

A router is the first line into a network and to resolve the layer 3 communication issues, a network router is required. The router joins different types of networks (LAN/WAN). The way a router directs network traffic is based on packet IPs (logical addresses) rather than MAC (physical addresses). It reads all incoming data packet logical addresses and then based on its own routing table to forward these incoming data packets to their destinations. Routers are like small computers that are designed and configured specifically for routing purpose. A typical router has a CPU, RAM, I/O interfaces, and an operating system (OS). For example, Cisco routers have an OS named the Internetwork Operating System (IOS) [20, 23]. These hardware and software are the two basic components of a router: the forwarding engine and routing engine (Figure 9).

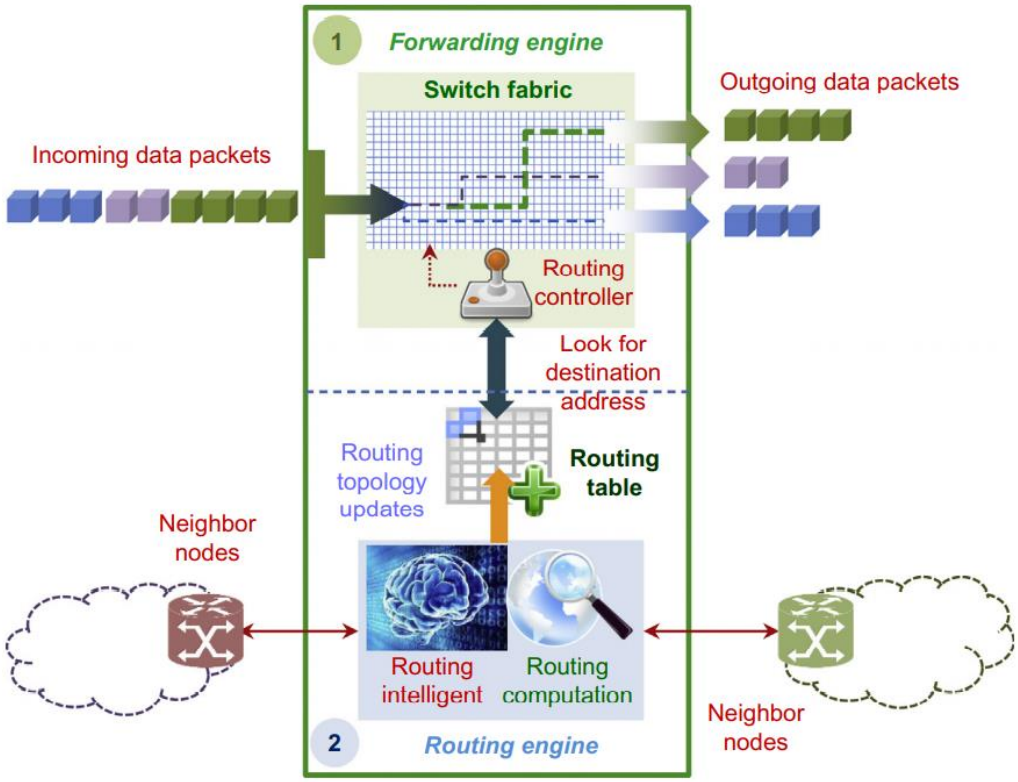


Figure 9: A typical network router architecture.

The task of forwarding engine and routing engine according to [20] are:

- ✓ Interface with different types of network, such as wireline and wireless, and accept incoming data packets from different network sources (forwarding engine).
- ✓ Examine the destination IP (routing engine).
- ✓ Find the best possible path to the packet's destination (routing engine).
- ✓ Forward the data stream or packet to the destination node (forwarding engine).
- ✓ If the primary path is blocked or down, find an alternative path if it is available and retransmit data packets to the destination node (both routing and forwarding engines).

Routers can be classified into three types (figure 10): interior, exterior, and border (or gateway). An interior router connects many autonomous LANs across location despite the geography. The exterior connect to the Internet as a backbone. The border or gateway router is the network device that connects interior and exterior routers. Interior or border (gateway) routers are those to be in a data center.

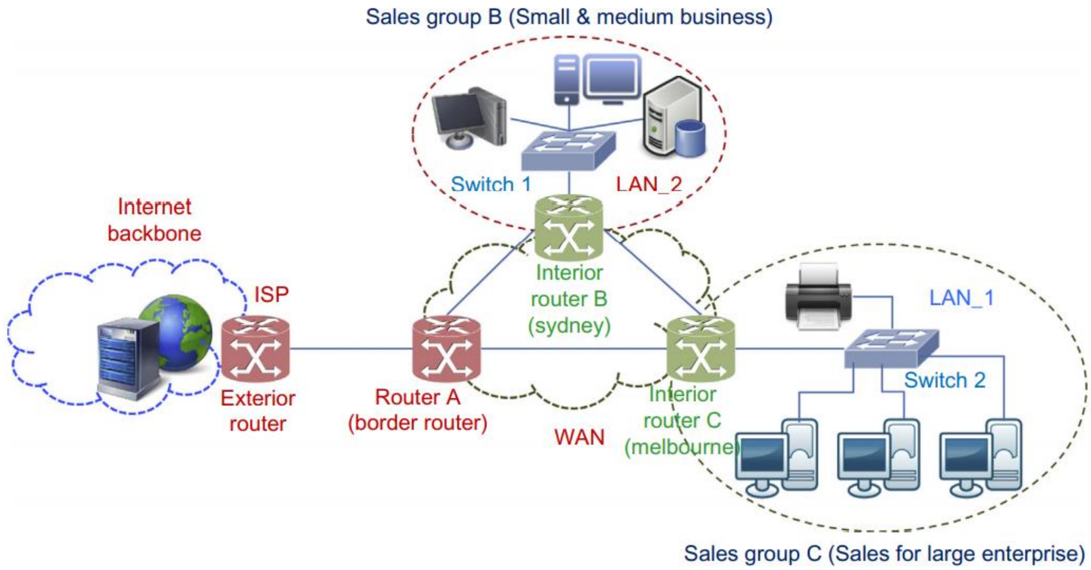


Figure 10: Router types based on network size

b) Switch

If the router is what connect LAN/WAN in layer 3 then the switch is a component that allow layer 2 communication and forms LAN/WAN. The switch joins all computer devices together to share information and resources. In a fully switched network, switching allows the network to maintain full-duplex Ethernet. Before that, data could be transmitted in only one direction at a time or half-duplex. With a fully switched network, each node communicates only with the switch, not directly with other nodes. Information can travel from devices to switch and from switch to devices simultaneously provided that the switches can permit data to be sent and received concurrently [24, 20]. The switch handle data transfer by dealing with MAC or physical address inside the NIC (Network Interface Card) of the device it connected to (Figure 11). When a device is connected to the switch, the switch will remember the MAC address of that device and which port did the device use to connect and put it in the MAC table. Data travel in frame through the switch contain the MAC address of both source and destination; the switch compares the MAC address of the destination with the MAC table and then forward the frame to the port that matches.

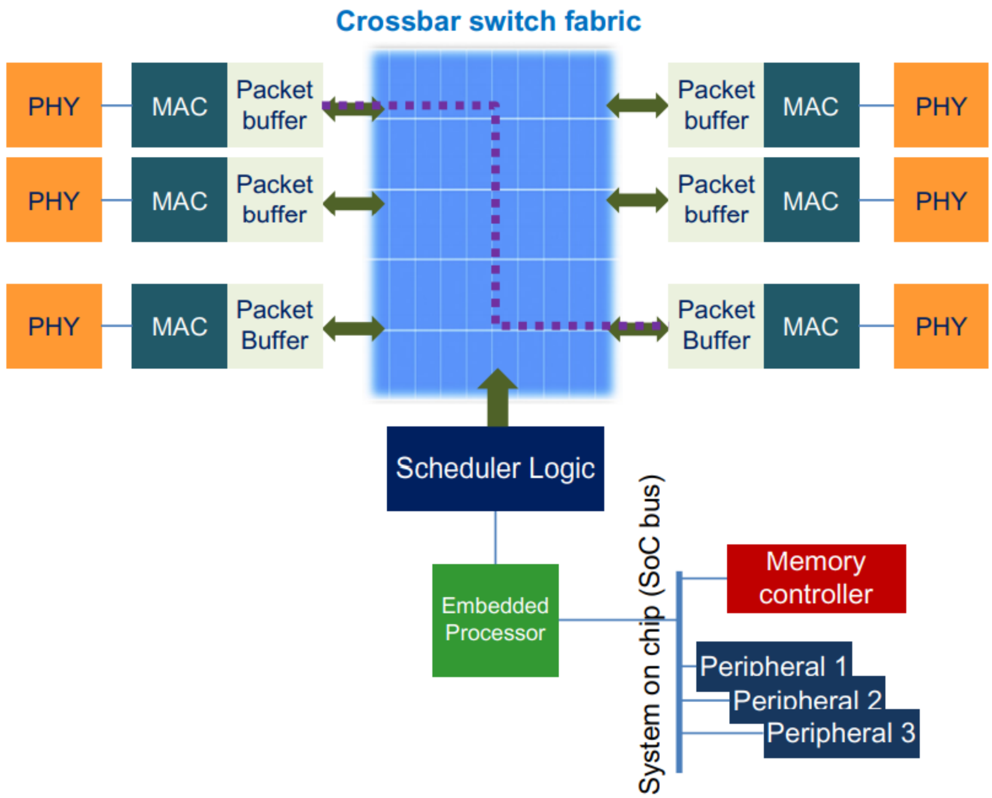


Figure 11: A typical switch functional block diagram

c) Firewall and load balancer

A firewall is a network security device that monitors incoming and outgoing network traffic and decides whether to allow or block specific traffic based on a defined set of security rules. It acts like a barrier between your LAN and incoming traffic from external sources (such as the internet) in order to block malicious traffic like viruses and hackers. A firewall can either be hardware, software, or both [25,26].Physical placement of firewall devices in the data center network infrastructure is one of the most important decisions network and security architects have to make. There are primarily two options for firewall placement [27]:

- ✓ Physically inline (in the traffic path between the core and the server).
- ✓ Logically in-line with one arm of the firewall physically connected to the network core

Load balancers manage the network flow between the servers and endpoint devices. It distributes network traffic across multiple servers and makes sure not a single server handles too many requests. By spreading the work evenly, application responsiveness is improved. The load balancer helps servers transfer data efficiently, optimizes application delivery resources and prevents server overloads. If a server is out of order, the load balancer redirects traffic to the remaining available servers. When a new server appears in the server group, the load balancer will begin sending requests to it automatically [28, 29]. Like firewall, load balancers are typically deployed in either inline or one-arm.

d) Cable and raise floor

Network cables are used to connect and transfer data and information between computers, routers, switches and storage area networks. These cables are essentially the carrier or media through which data flows. Copper and optic fibers are two common solutions for cable in data center. While optic fiber cable is better than copper cable in many aspects, due to high initial and operational cost, most data center is using a mix of copper and fiber optic cable.

Table 6: Overview of Data Center Cabling Types [30]

Communication Standard	Application	Cable Type	Connector Type
10/100Mbps (100Base-TX)	Ethernet	Cat 5e, Cat 6, Cat 6a, Cat7, Cat 7a	RJ45
1000Mbps (Gigabit or 1000Base-T)	Gigabit Ethernet	Cat 5e, Cat 6, Cat 6a, Cat7, Cat 7a	RJ45
10Gbps (10GBase-T)	10Gig Ethernet	Cat 6, Cat 6a, Cat7, Cat 7a	RJ45, GG45, TERA
40 or 100Gbps	40 or 100Gig Ethernet	Cat 7a	GG45, TERA
Fiber Channel	High Speed Ethernet	Twinaxial or Fiber	Infiniband, QSFP, SFP+, 10G - CX4, LC, SC, ST
Fiber Optic	High-Speed Ethernet	Multimode (High-bandwidth, Short Distance) Single Mode (High-speed, Long Distance)	LC, SC, ST, FDDI, MTP, MTRJ, FC, etc.

Raised floor ensures high load support, easy to access, maintenance of underfloor equipment, cleaning, and safety. Flexible module for a cold air distribution system for cooling IT equipment, to tracks, conduits, or supports for data cabling, a location for power cabling, a copper ground grid for grounding of equipment, a location to run chilled water or other utility piping. According to [31], the raised floor was developed and implemented as a system intended to provide the following functions:

- ✓ A cold air distribution system for cooling IT equipment
- ✓ Tracks, conduits, or supports for data cabling
- ✓ A location for power cabling
- ✓ A copper ground grid for grounding of equipment
- ✓ A location to run chilled water or other utility piping

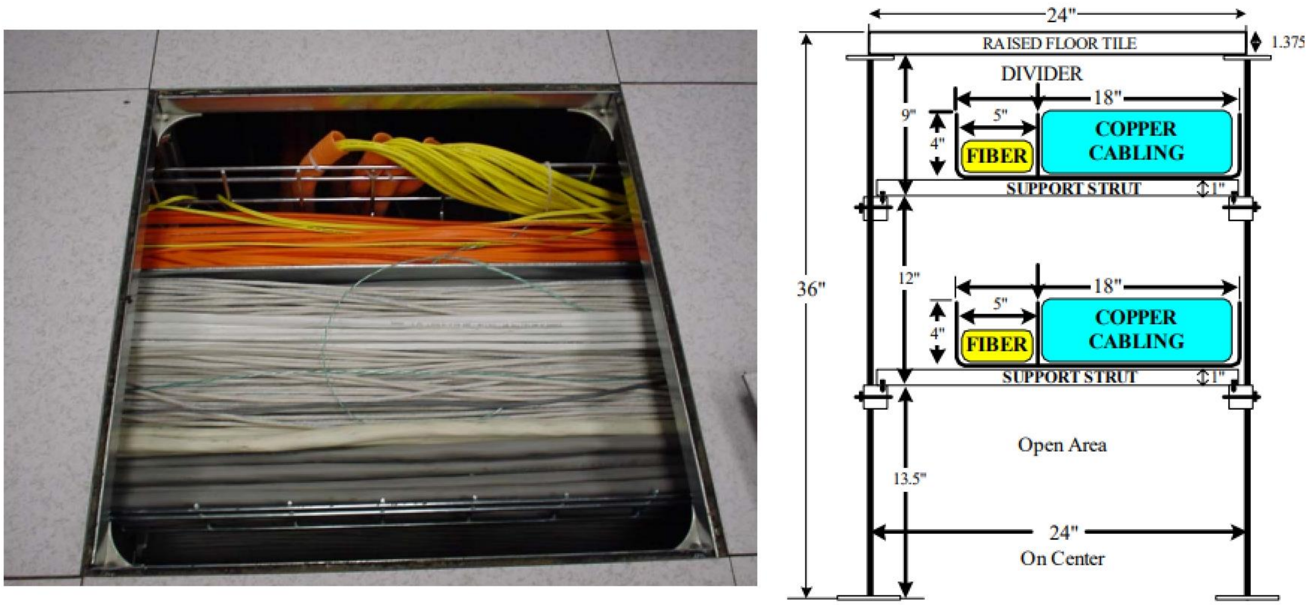


Figure 12: Raised floor in data center [31]

2.3 DATA CENTER NETWORK TOPOLOGIES

2.3.1. Data center network layer

Base on the OSI or TCP/IP model, the data center network (DCN) is a layer 2 and layer 3 network since it operates between these two layers (Figure7, Figure 13). The DCN topology will be designed to effectively connect all network components within a data center (switches, routers, load balancers, firewalls, storage component…). The impact of the network topology inside a DC can be seen in the data traffic performance, which includes data packet routing, DCN reliability, scalability, throughput, latency, and flexibility (Table 7) [20].

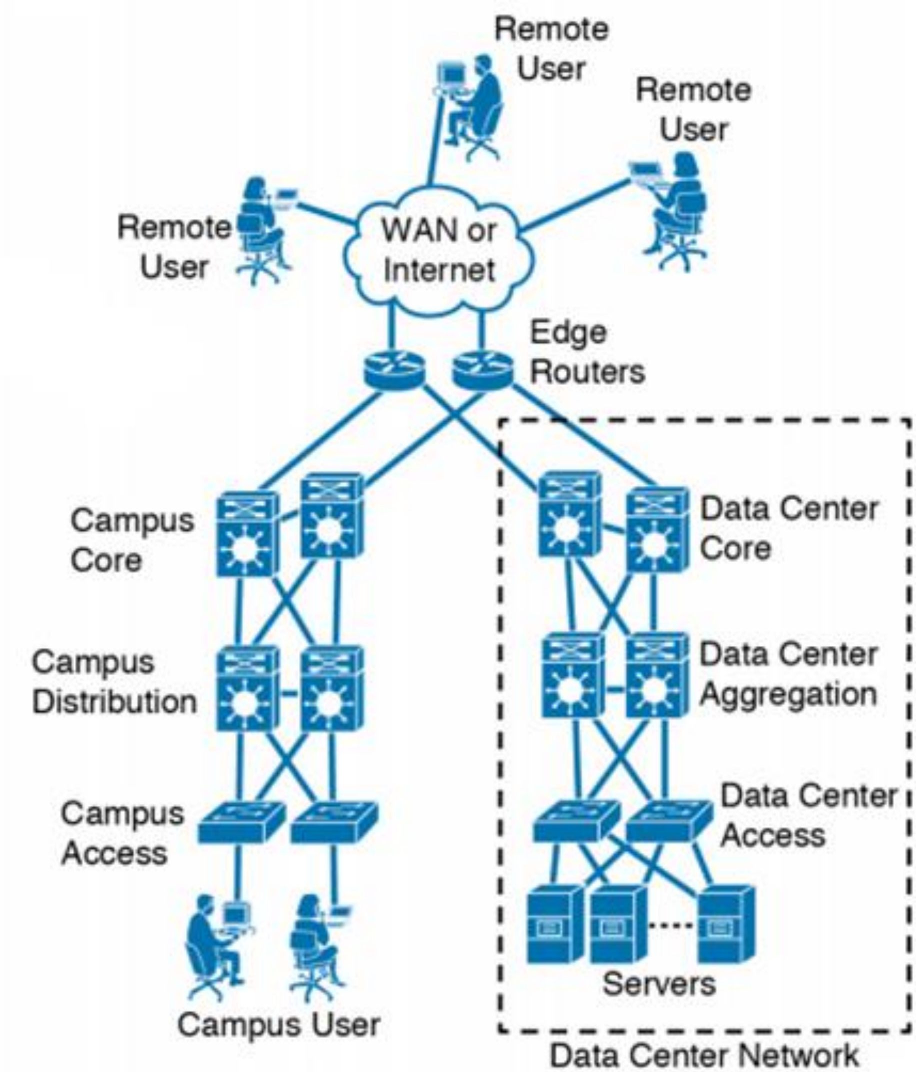


Figure 13: Data center in a network

Table 7: DCN Performance Measurements

1. Scalability	2. Aggregation throughput	3. Reliability
4. Incremental scalability	5. Oversubscription	6. Security
7. Cabling or connectivity complexity	8. Fault tolerance	9. Latency
10. Bisection bandwidth	11. Energy consumption	12. TCO/ROI

There are many types of network topologies and not all of them are for DCN. The problem is that different network topologies have been developed for different purposes and different criteria. A particular DC will face a lot of issue if it chooses an unsuitable topology for the DC purpose. Classifying all these topologies into the right category and then examine each topology to see whether it is fit for DCN purposes is needed. This thesis will cover the most common and basic topologies that are used inside a DC.

The tree-based topology is one of most widely adopted solutions for DCN. It normally consists of three tiers: core, aggregation (or distribution) and edge (or access) (Figure 14). Each tier corresponds to either layer 2 or 3 or both layers of the OSI or TCP/IP model. The core layer provides connectivity where other devices connect (Figure 13). The aggregation layer is the layer 3 and layer 2 boundary in the DCN, it aggregates connections and traffic flows from multiple access layer switches to provide connectivity to the LAN core or WAN edge layer switches [32]. In common designs, the aggregation layer provides value-added services, such as server load balancing, firewalling, and SSL offloading to the servers across the access layer switches [33, 34]. In a small or medium size data center network, the core and aggregation may collapse into one single layer that leverages the virtual device contexts capability for consolidation (Figure 15) [35]. Access layer is the lowest of the three layers of the architecture, where all servers physically attach to the network. A tree-based (common three levels or tiers) topology has the following advantages:

- ✓ Scalability
- ✓ Accessibility for troubleshooting
- ✓ Easier to deploy
- ✓ Cost effective
- ✓ Better for local traffic
- ✓ Lower latency

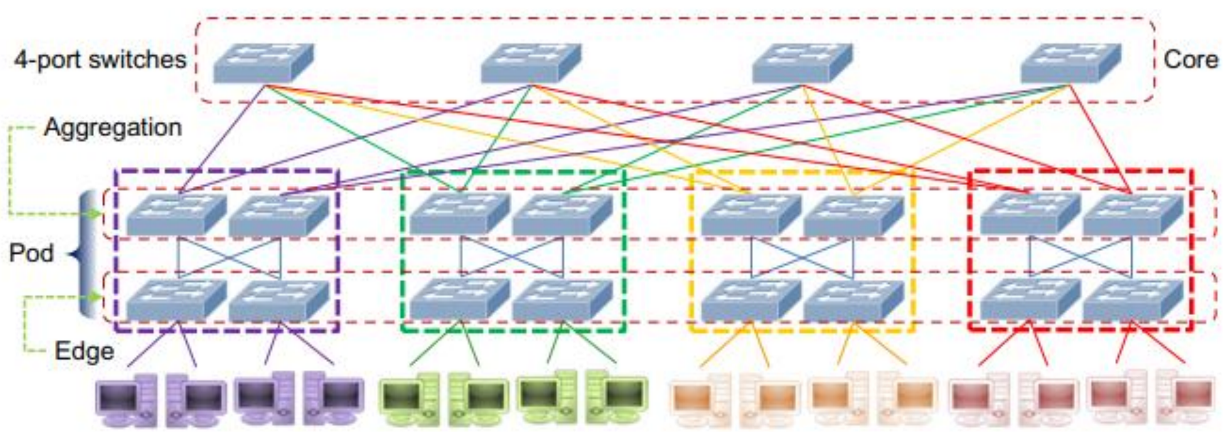


Figure 14: Three tier design topology

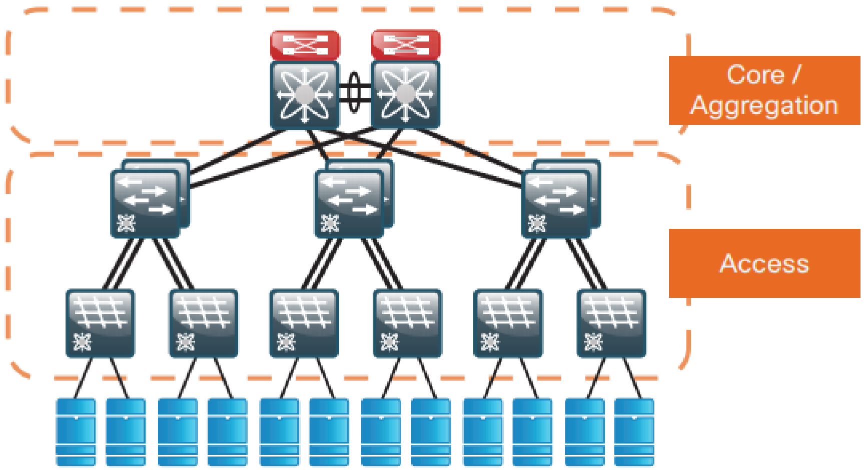


Figure 15: Core layer and aggregation layer collapse in a design

2.3.2. Network configuration topology

a) Top of Rack (ToR)

ToR is one of the popular tree-based DCN design. The servers connect to one or two Ethernet access switches installed on the rack at access level. Of course, the switches does not have to literally mounted on the top to connect to all severs inside the rack. Other switch locations could be bottom of the rack or middle of rack, however top of the rack is most common due to easier accessibility and cleaner cable management. All the access switches are connected to the aggregation switch. Only a small amount of cables are needed to run from server rack to aggregation rack; but in big data center, the number of rack will prove to become troublesome. According to [20], the advantages and disadvantages of TOR are as follow:

Advantages:

- Flexible and modular setup using per rack solution
- Racks can be easily relocated or upgraded or changed
- Elimination of long running bulk copper cables
- Reduction of copper cable expense
- Ready for future optical fiber cable infrastructure
- Contain copper cables within a rack
- Less cold airflow resistance and lowering of raised floor height

Disadvantages:

• Logical VLAN capacity bottleneck

• More L2 switches to manage

• Potential physical port scalability issues at aggregation switch level

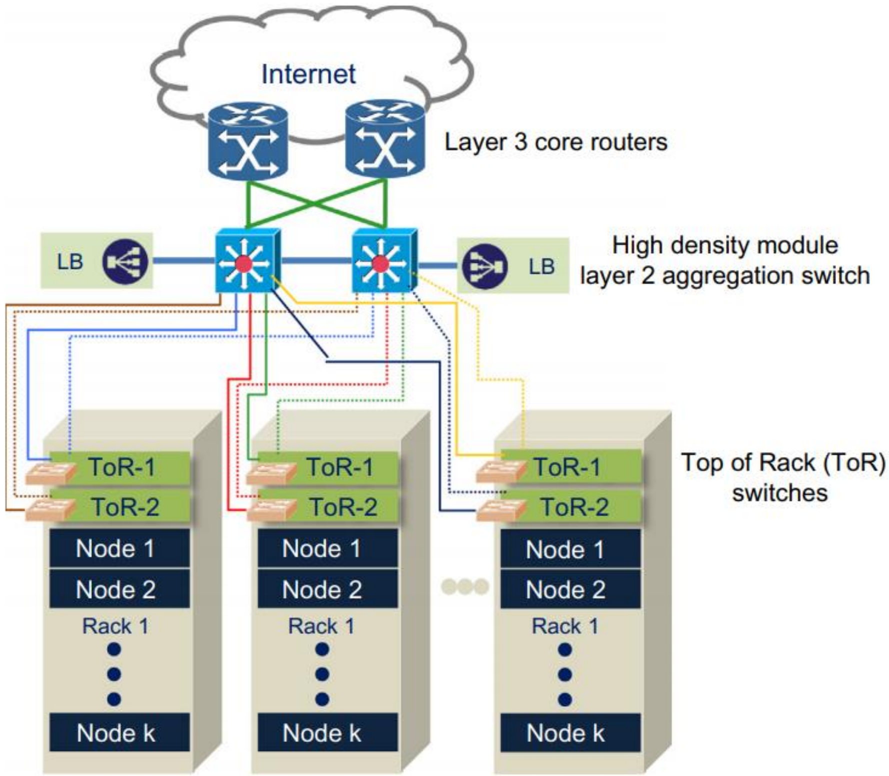


Figure 16: Top of rack topology

b) End of Row (EoR) and Middle of ROW (MoR)

For a DC that possesses a high number of racks to manage and wants to use a tree base topology, one of alternative is to adopt an end of row (EoR) solution (Figure 17) which connect all severs in a row of racks to a switch at access level. It is not necessary that the location of the switch rack be at the end of row. It can be at any position of the row as long as it is within the row. One of the popular solutions is to place switch racks in the middle of the row (MoR) (Figure 18). The use of extremely long copper cable can be avoided if the rack row is quite long with the use of MoR. The EoR or MoR solution provides the following advantages that are almost opposite to the ToR solution; the ToR's disadvantages become the EoR's advantages and vice versa [20]:

Advantages

• Fewer switches to manage

• More reliable DCN

• Reduction in switch capex

• Lower maintenance cost

• Fewer aggregation ports

• Fewer SFP instances in layer 2 domain

Disadvantages:

• More and longer copper cables run

• Less flexible than ToR solution with an incremental investment approach

• Future challenges for optical fiber cable solution

• Higher raised floor to accommodate bulk of running copper cables

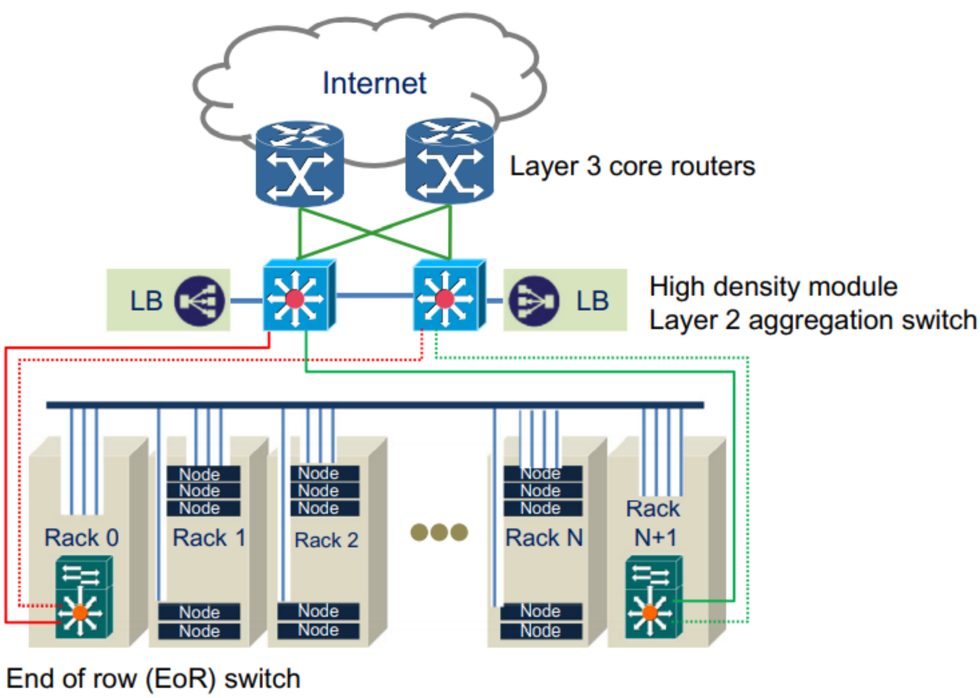


Figure 17: End of Row topology

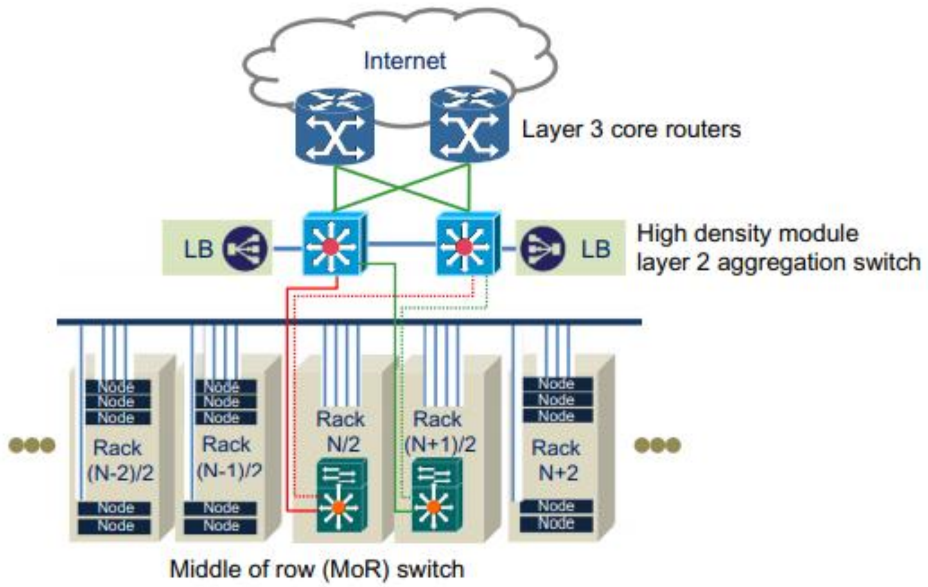


Figure 18: Middle of Row topology

III. BASIC CONCEPT DESIGN OF A SMALL DATA CENTER IN USTH

3.1 TECHNICAL STANDARDS REFERENCES FOR DESIGN CONCEPT

3.1.1 Technical standards for design of physical facilities in Data Center

Designing a data center is a huge task that requires a lot of time, effort, and expense. When it's done properly, a data center facility can house servers and other IT equipment for decades into the future. Whether planning out a modest facility for a specific company, or a massive, million-plus square foot facility for cloud technologies, doing everything properly is critical. In general best practices, we should consider the following points when looking at the needs for design of a Data Center [36].

- **Floor space** – How many square feet of floor space do you need today? Do you expect this to grow over time? It is much less expensive to build what you need now than to try to perform a renovation in a few years.
- **Power Requirements** – The electrical needs of a data center can be quite massive. Take time to plan out the needs you have today, and the potential requirements you will have in the future.

- **Cooling Requirements** – As you add more and more hardware into a data center, the heat produced will need to be eliminated. New cooling units are extremely costly, so investing in the right ones up front is essential.
- **Server Space** – Choosing the right server racks now will allow you to house your equipment properly while leaving space for growth as well. Many new data centers have rows of empty racks that help to facilitate proper airflow until they are filled.

There are two international standards referred to design infrastructure of Data Center include Uptime and ANSI/TIA-942 [36, 37]. This consists of facility requirements for power, cooling and back up, which measure a data center's potential uptime. First is the Uptime standard of the Uptime Institute, which is an advisory organization that focuses on improving the performance, efficiency, and reliability of Data Center. Uptime Institute covers the electrical part, mechanical part and ancillary components, Figure 19, (engine generator, fuel system, make-up water system, building automation system). The Uptime Institute defines four tier system topologies for describing the availability of systems as shown in Figure 19. Second is the international standard ANSI/TIA-942 is a standard issued by a non-profit organization and TIA is accredited by ANSI. The standard is publicly available leading to great transparency. The standard covers all aspects of the physical data center including site location, architecture, security, safety, fire suppression, electrical, mechanical and telecommunication. The summary of requirements for data center design is divided into 4 levels in the following Table 8.

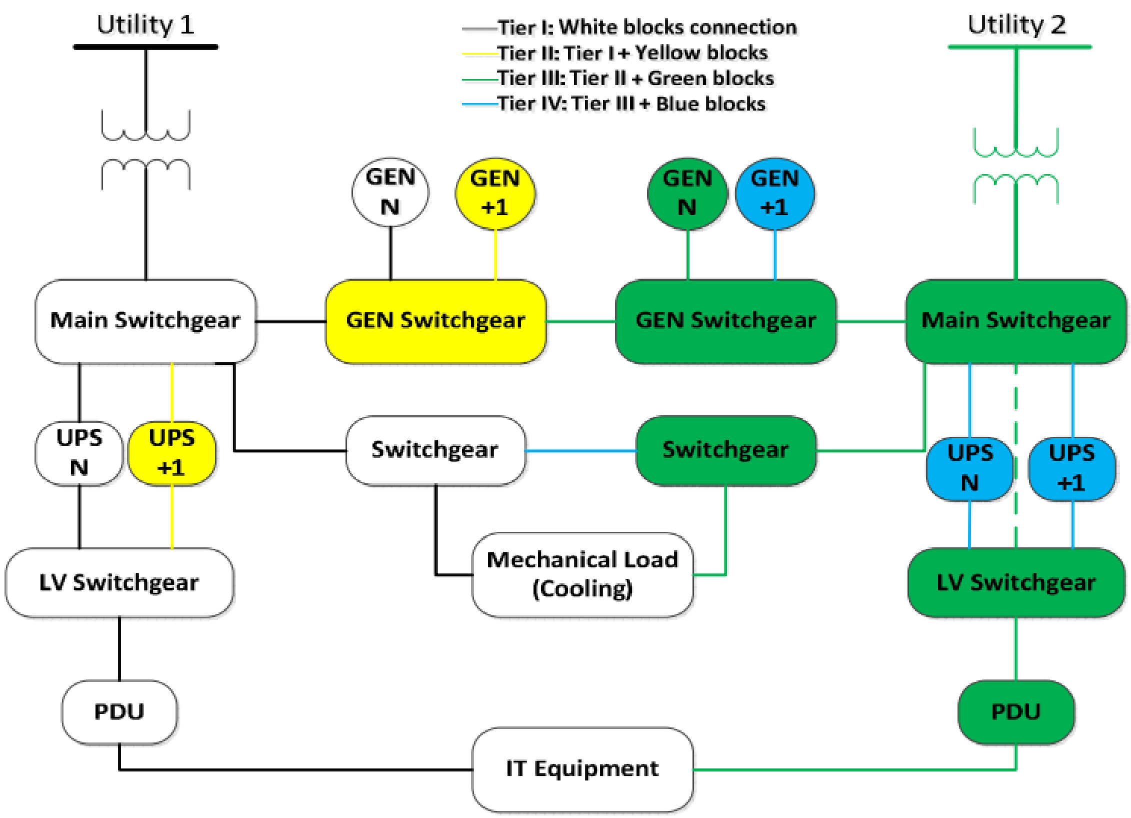


Figure 19: Topologies of different Tier systems [37, 38]

TIA-942 is the standard for planning of data centers, computer rooms, server rooms, and similar spaces [36]. Figure 19 and figure 20 shows the topology of the ANSI/TIA-942 standard detailed guidelines for the five key spaces: Entrance Room (ER) for housing the interfaces between inter-building cabling and the data center structured cabling system; Main Distribution Area (MDA) for housing the core routers and switches for the local area network, wide area network, storage area network; Horizontal Distribution Area (HDA) for supporting cabling to the equipment areas where the actual computing devices reside; Equipment Distribution Area (EDA) for houses floor-standing computing equipment as well as rack and cabinet mounted devices such as servers and other communications hardware; Zone Distribution Area (ZDA) for accommodating cabling interconnection and termination in overhead spaces or under floors. Not all of these five defined spaces must be used, but all options for accommodating future growth should be considered when planning facilities (Figure 20).

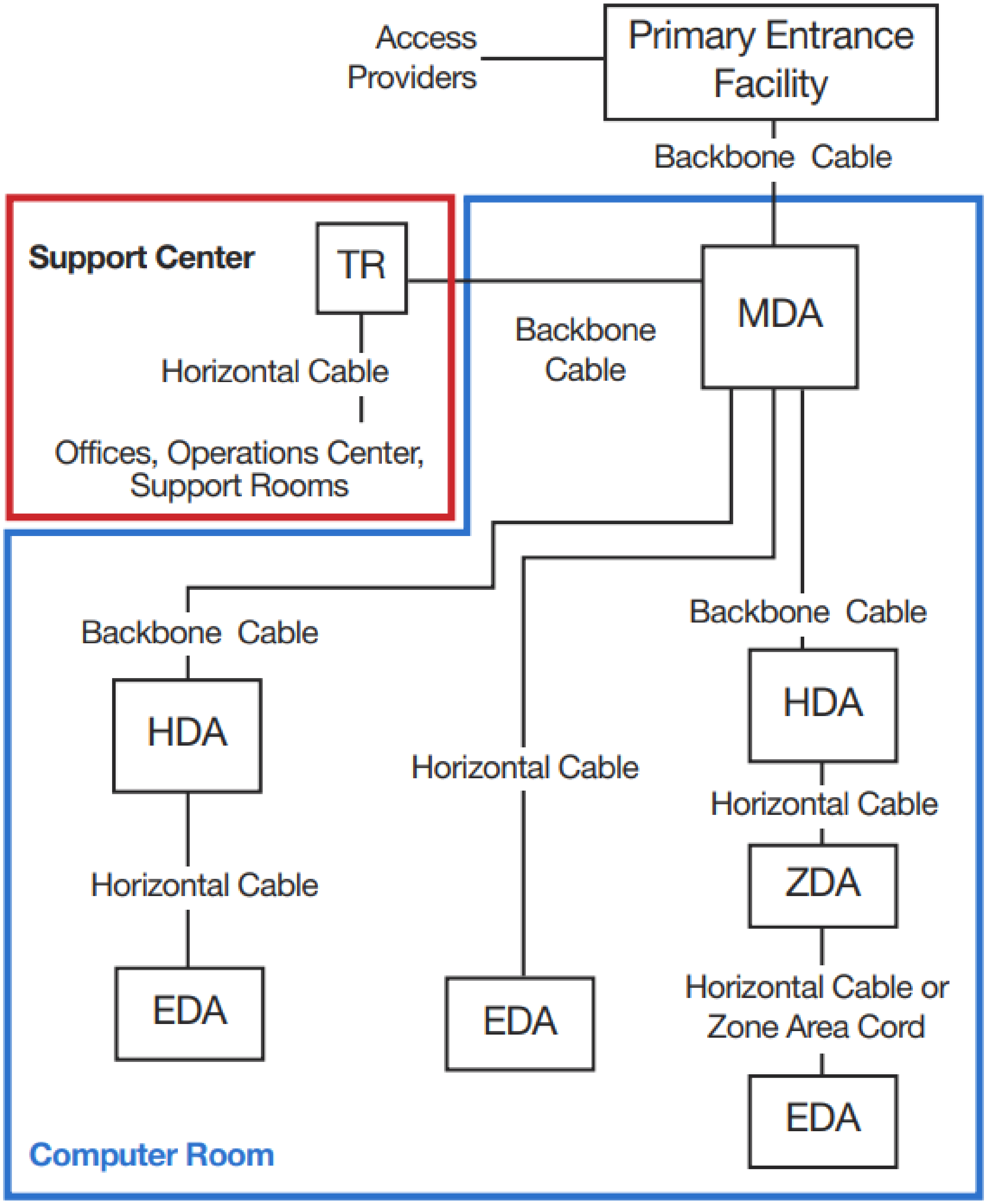


Figure 20: ANSI/TIA-942 standard for cabling [36]

Table 8: Topology standard (UPTIME and TIA-942)

Requirements	Level 1	Level 2	Level 3	Level 4
Active Capacity Components to Support the IT Load	N	N+1	N+1	N+N
Distribution Paths	1	1	1 Active & 1 Alternate	2 (Both Active)
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerance	No	No	No	Yes
Compartmentalization	No	No	Yes	Yes
Continuous Cooling	No	No	No if [Average < 5 KW] Yes [Average > 5 KW]	Yes

3.1.2 Facts of the IT infrastructure in the USTH

Figure 21: Data Center in the University of Science and Technology of Hanoi: 5th floor of the Building 9-floors, IT room area of 60m2 with 03 rack cabinets and 8 servers, other Storages

Figure 22: Data Center in the University of Science and Technology of Hanoi: 5th floor with the Cooling system: Standard air conditioning, no-UPS and no-backup Generator

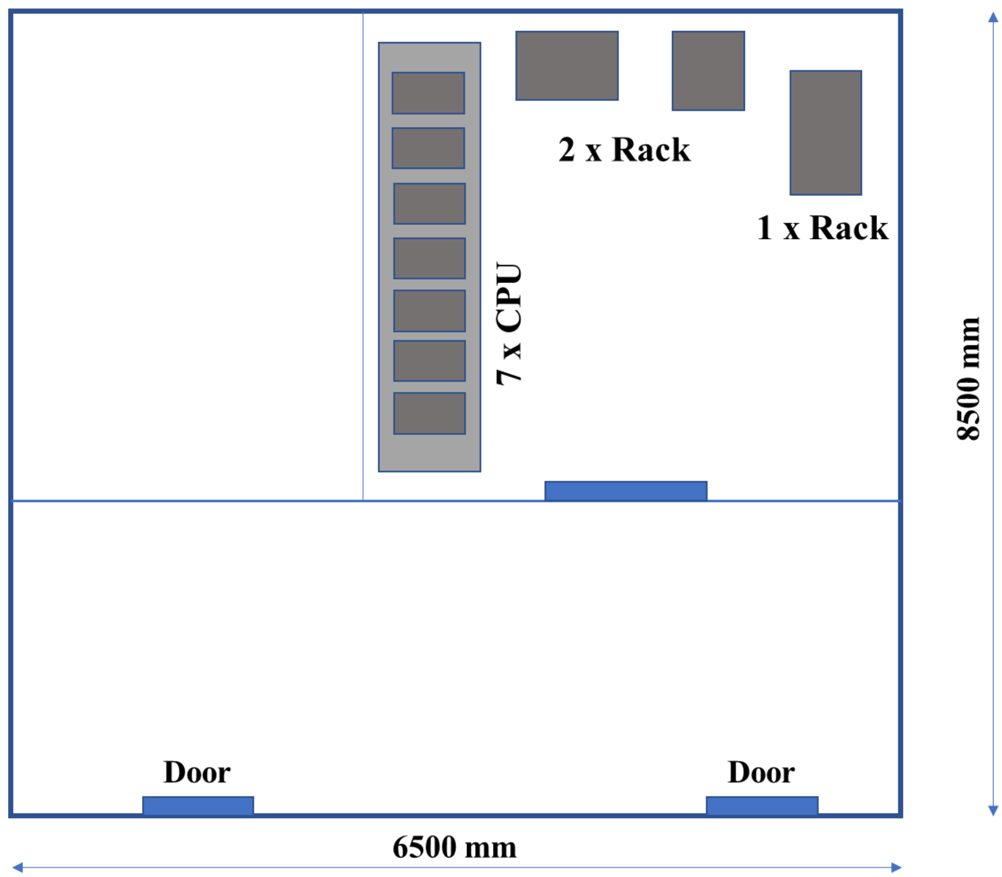


Figure 23: Layout arrangement of Data Center in the University of Science and Technology of Hanoi: 5th floor: 03 rack cabinets and 8 servers, other Storages

Observation:

- The Data Center area with depth x width = 6500 x 8500 mm, on the 5th floor of a 9 floor building. The room floor-to-ceiling height is 2700 mm.
- Including 03 racks cabinets, uneven height, wide x depth = 600 mm x 1070 mm, of which 01 rack (1991mm high, 600mm wide, 1200mm deep) contains server equipment operating. The remaining racks contain other equipment. Also, the entire USTH's database is being stored and processed in 07 servers.
- Fire protection system: only suitable for fire prevention and fighting in the office area; which does not comply with the standards of the data center.
- The data center USTH is not equipped with UPS and GEN systems, so the risk of data loss can occur when the building power electricity is turned off. Therefore, the

stability and safety in operation of IT equipment is not guaranteed to comply with Data Center standards.

- Furthermore, the air conditioners in use currently are not the precision air cooling system recommended for use in data centers. This is a standard comfort air conditioning system, not including humidification and dehumidification systems, so it is impossible to control the exact temperature and humidity in the entire space of the IT equipment storage space when the rack system operates., thus greatly affecting the stability and performance of IT equipment.
- Another points that we can consider in data center area space causes a large loss of cooling air, thus causing loss of power consumption as well as the ability to cool IT equipment when Data center operating during summer days with very high ambient temperatures outside in Hanoi.

3.2 A SIMPLE DESIGN OF A SMALL DATA CENTER IN USTH

3.2.1 Site installation and main components consideration

In practice, the design is based on the needs of the end-user (i.e. capacity density of racks), the area where the Data Center is installed, and the deployment experience of other data centers in Vietnam. In this thesis, we recommend installing on the 5th floor of the building; compiling with the TIER-3 and ANSI/TIA-942 standards. We divided the areas into rooms (*Figure 24*): the computer room (for the racks which contain servers, storage and network equipment); Power room contains the electrical equipment supplies (UPS, electrical cabinet power supply); NOC room (for IT staff managing and operating the Data Center of USTH).

The number of racks in this design is assumed 20 racks, which according to table 2 fit in the classification of a small data center. This number was calculated and maximized purely based on the total area available at the time of site survey. Although 20 racks can exceed the required working and storage volume of USTH, which in this case, it is assumed that each department uses at least 01 rack, rack for housing the Camera equipment and the University board uses at least 03 racks to serves different goals such as housing student's data, professor’s researches of many years prior and satisfying the demand for computing power for research, the remaining spare racks can still be used for other purposes. For example, increasing security for Faculties through enhancing processing systems and increasing storage capacity for cameras or becoming a data center service provider for small companies or research institutes located inside Vietnam Academy of Science and Technology, etc...

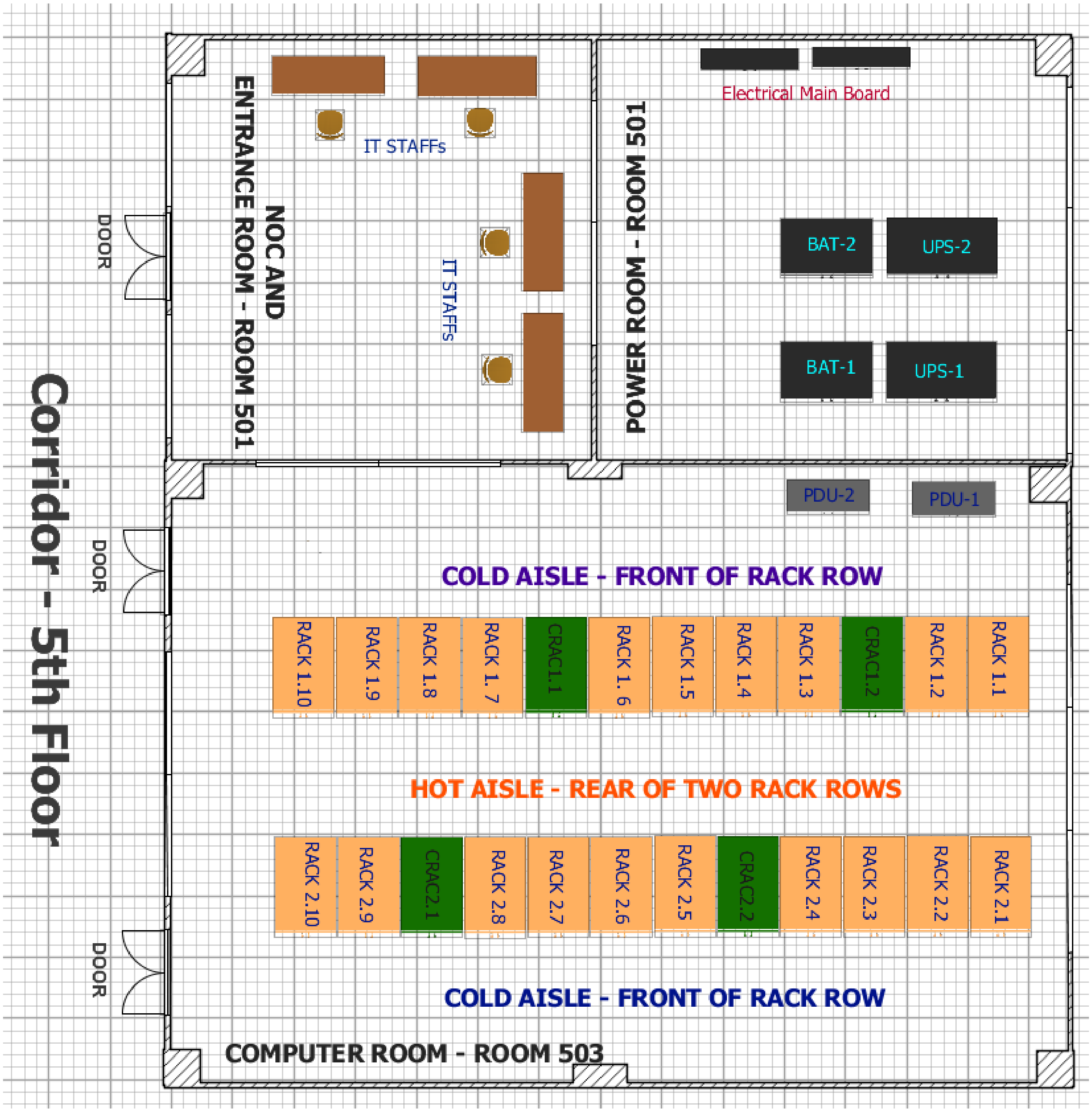


Figure 24: Proposal layout arrangement showing main functional area in Data center

3.2.2 Proposal network design concept of the Data Center in USTH in detail

The design will follow the diagrams in the following figures:

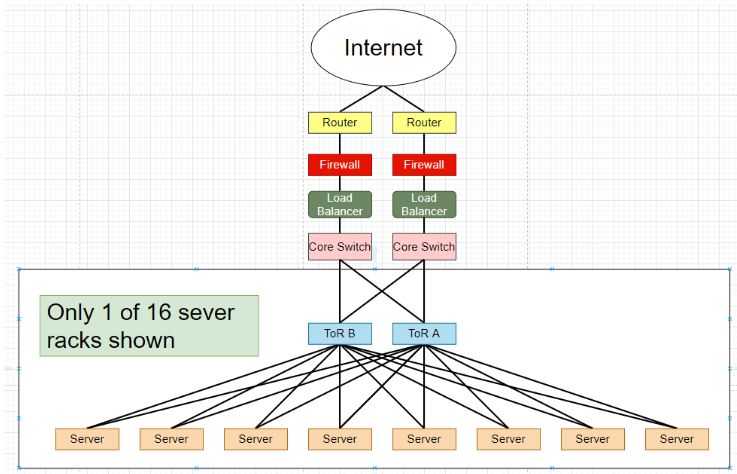


Figure 25: Proposal network diagram in a server rack

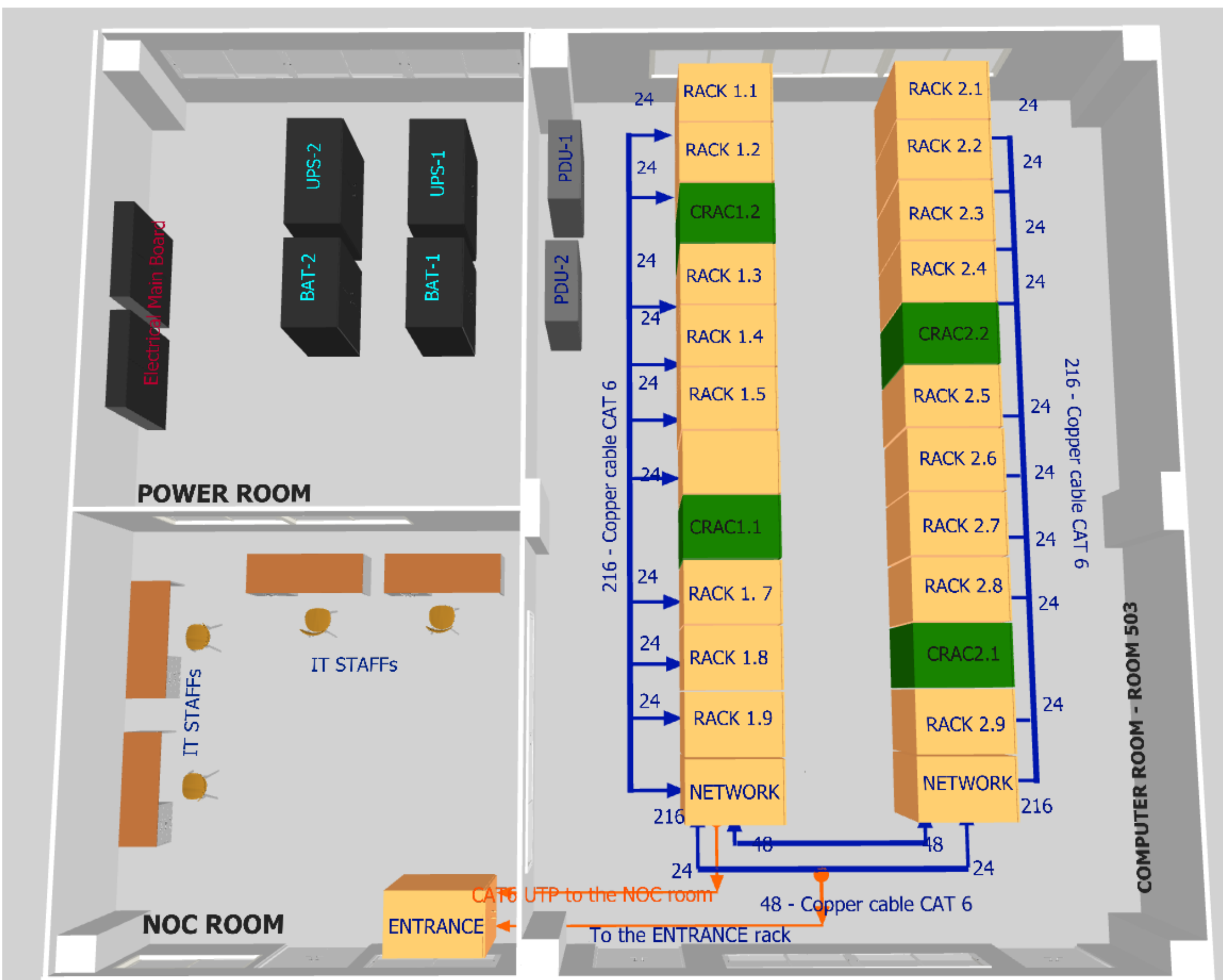


Figure 26: Computer room with 20 racks: 16 server racks, 02 Network racks, 02 other racks – network connection with cooper cables CAT6

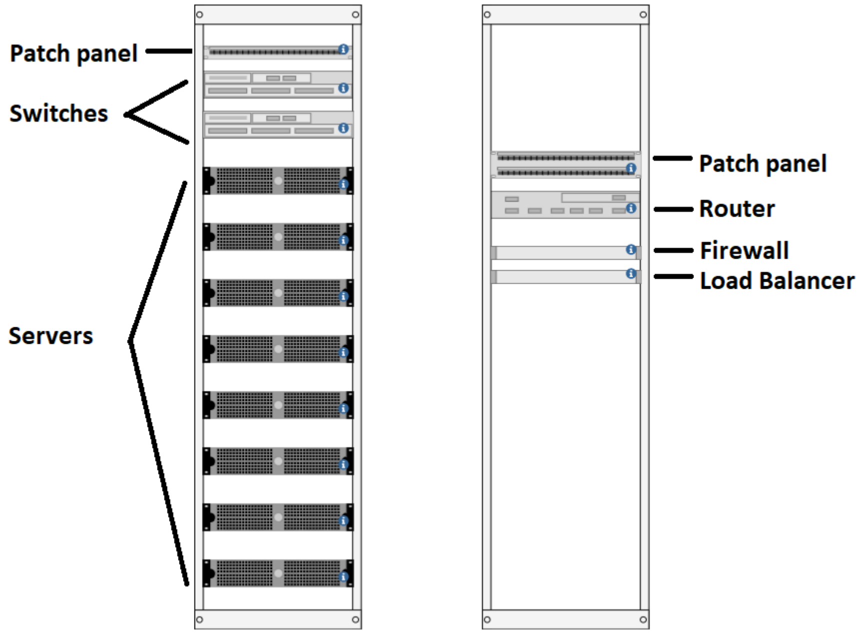


Figure 27: IT arrangement in a rack: server rack - left and network rack - right

The layout (Figure 26) consists of two rows; each row has 10 racks and 2 CRAC (Computer Room Air conditioning) units. Among 10 racks, 8 of them will be for servers mounting with ToR switches 1 will be for the network devices and one for spare… In total, there would be 16 server racks, 2 network racks and 2 racks for other equipment (CAMERA security in University). Each server rack is a standard 42U rack cabinet for data center - 24 inches wide (exterior), 42 inches deep, and 42U tall with the mounting frame width of 19 inches [18,19]. The number of racks is suitable for this design as according to table 2, small data center have the rack number ranging from 11 to 200. Considering those racks will be used for housing students' data, professors' researches of many years prior and to come; along with the demand for computing power for research (simulation, 3D graph, results comparisons and storage…), maybe 20 racks are even not enough in the future but due to limited space, it is a suitable number for maximizing the area given at the moment. This design will use Cat 6 copper cable for network connection because the distance between the network rack and the server rack is not very long. The change in connection speed when compare optic cable and copper cable can only be noticed when the distance is larger than 100m.

Inside the server rack, there are eight 2U-servers, 2 ToR switches and 24-port patch panel. Rack servers will have the equipment arrangement as in Figure 26. 2U servers are better than 1U severs for this design. Because of the physical size of a 1U, heat generation and retention can stress a 1U server's cooling system which leads to premature failure of components. With a 2U rack server, the larger physical volume of a 2U is better for airflow due to using larger and more powerful cooling fans resulting in higher heat dissipation. Moreover, the larger physical size of a 2U can accommodate more drives and expansion cards increasing the capabilities and features of the 2U server. Power consumption can also be lower with 2U servers. In a 42U rack populated with a large number of 1U servers, total power consumed by this rack can be higher than a 42U rack populated with 2U servers of equivalent computing power and performance [39]. Power density is 4 kW per rack cabinet is a typical power density measured in existing data centers today [40]. Average typical power consumption for 1U rackmount is 300 W-350 W and 2U rackmount is 350 W-400 W [41] so it is reasonable for the number of 2U sever to be 8. Another thing to consider is that this design does not implement the use of NAS, SAN or DAS so with the use of 2U servers, it will be optimal for storage.

Inside the network rack, there are a 48-port patch panel, a core switch, a firewall and a load balancer.

The network diagram (Figure 24) suggests the use of ToR topology. ToR has one big disadvantage which is when the DCN become bigger, the burden of managing switch will be more apparent. For example, if a DC has 256 racks, the number of ToR switches would be double or 512. To manage 512 ToR switches would be a tedious task. But for a small size DCN such as the one proposed in figure 24, the ToR solution can get away with the burden of management workload for ToR switch. ToR also has the advantage of having less cable going from server racks to network racks compared to EoR or MoR solution. Consider the proposed design: there are 8 servers per rack with eight racks in a row and 2 rows of racks; if EoR or MoR solution is selected for this DCN, raised floor have to be implemented. Due to the height of the considered room, it is difficult to implement raised floor for this data center. One noticeable thing from the network diagram is that the aggregation layer and the core layer are collapsed into each other. According to Cisco [35]: "in a small or medium size data center network, the core and aggregation may collapse into one single layer that leverages the virtual device contexts capability for consolidation" (Figure 15).

Besides the main network design of this thesis, figure 20 describes the electrical layout for this small data center. The annex will provide the information for the calculation of energy consumption. The details will be in my team member's work. We only mention the calculation and design of the power supply for all equipment of the Data Center; Cooling system for IT equipment. IT equipment in the IT room is supplied priority by the UPS. The energy calculation is based on standards described in Chapter II and best practices experiences in implementing Data Centers of the company HDL JSC. Power source and cooling heat source topology for the IT room is shown in Figure 20. Details of the calculation of energy supply are shown in Table 8 – 11 in the annex.

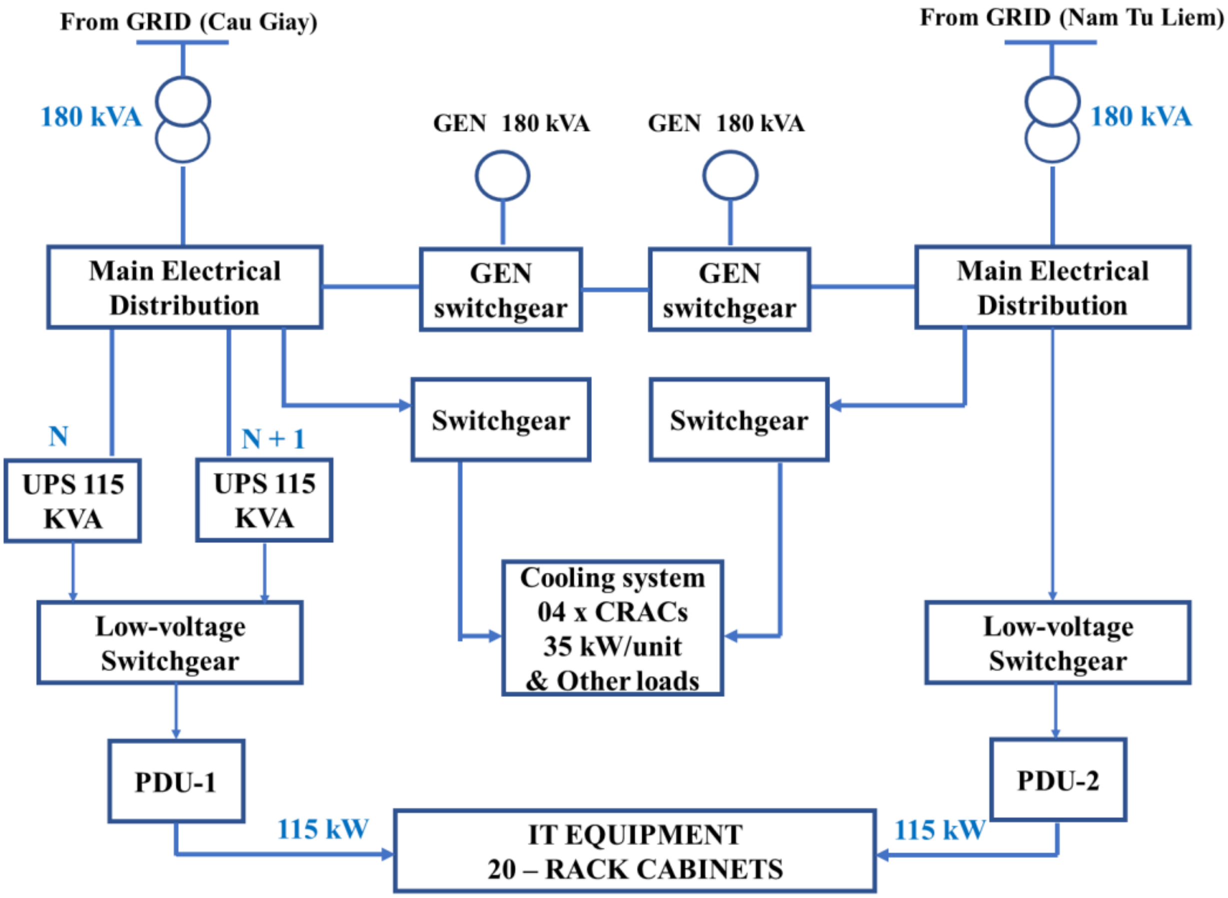


Figure 28: Proposal electrical and cooling diagram according to the tier-3

IV. CONCLUSIONS

The infrastructure design for the data center is complicated and needs to be based on related international design standards such as electrical infrastructure, cold air supply system used for IT equipment cooling a long with the network design. The network design is based on the assumption that the data center has a 24/7 constant power supply from the UPS system with 22°C temperature, 50% relative humidity by a precision air-conditioning system by the implementation in-row cooling. On that basis, we have proposed a new Data Center design for USTH, based on TIER-3 and ANSI/TIA-942 infrastructure standards, which are being applied in most major data centers in Vietnam. The design is made to make use of the limited space. The suggested network topology is only one basic solution that suitable for a small data center. The proposed design can be expanse (scale-up) slightly but it is not suitable if in the future there is a need for large scale expansion due to the fact that scaling is the weakness of TOR topology. The recommended devices are chosen according to standard for maintaining the balance of computing power, electrical power consumption and cooling. However, due to time limitations and lack of in-depth understanding of all data center components, this report does not cover all the detail recommendation for equipment selection inside the network as well as the use of NAS or SAN. In the future, the design can consider the implementation of NAS and SAN for scaling capability.

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ANNEX: Calculation for electricity consumption

Table 9: Power consumption calculation of the IT equipment in Data Center (critical equipment be supplied by UPS)

N°	Description	Formula	Unit	Value	Total
I	**POWER RATING FOR IT LOAD**	***CRITICAL EQUIPMENTS IN DATA CENTER***			
1	Number server rack	(1)	Rack	16	
-	Power density/ serve rack	(2)	KW	5.0	
-	Power rating of server rack	(3) = (1) x (2)	KW		80.0
2	Number of network rack	(4)	Rack	2	
-	Power density/ network rack	(5)	KW	3.5	
-	Total power rating of network rack	(6) = (4) x (5)	KW		7.0
3	Number of rack for arrangement – Camera security in University	(10)	Rack	2	
-	Power density/ Camera rack	(11)	KW	3.5	
-	Total power rating of Camera rack	(12) = (10) x (11)	KW		7.0
	TOTAL POWER RATING FOR IT LOAD	(7) = (3) + (6)	KW		**87.0**
II	**POWER RATING FOR OTHER LOAD**				
-	Power consumption reserved other load (CCTV, Access Control, Fire protection)	(8)	KW		3.0
-	PC work station for IT Staffs and other equipment in NOC room	(10)	KW		3.0
	TOTAL POWER RATING FOR OTHER LOAD	(11)	KW		**6.0**
III	**POWER RATING FOR IT LOAD - SUPPLY BY UPS**	(12)	KW		**97.0**
-	IT LOAD DEMAND	(13)	KW		97.0
-	POWER RATING UPS 115 KVA / 115 KW	(14)	KW	115.0	
-	Number of UPS 115 KVA/ 115 KW	(15)	unit		1

-	Number of UPS (redundancy): N+1	(16)	unit	1	
	Total number of UPS sizing	(17) = (15) + (16)	unit		**2**

Table 10: Power sizing UPS

N°	Description	Formula	Unit	Value	Total
I	**POWER RATING FOR UPS**				
-	Power supply IT equipment load by UPS	(1)	KW		97.0
-	UPS efficiency	(2)	%	95%	
-	UPS losses	(3) = (1) x (2)	KW		4.85
-	% charge to Battery backup	(4)	%	10%	
-	Power demand for charging Battery backup	(5) = (1) x 10%	KW		9.7
	TOTAL POWER RATING FOR UPS	(6) = (1) + (3) + (5)	KW		**111.55**
II	**UPS rating selection**			**115 KVA/115KW**	

Table 11: Thermal sizing CRAC – Precision cooling system in IT room

N°	Description	Formula	Unit	Value	Total
I	**THERMAL RATING FOP IT ROOM**	(1)	KW		**96.0**
1	IT LOAD DEMAND	(2)	KW		91.0
2	Thermal losses in IT room	(3)	KW	5.0	
3	Thermal rating of CRAC 35 KW	(4)	unit		3
4	Number of CRAC (redundancy): N+1	(5)	unit	1	

	(precision cooling system: row-based technology)				
	Total number of CRAC sizing	(6) = (4) + (5)	unit		**4**

Table 12: Power demand calculation for all equipment in Data Center

N°	Description	Formula	Unit	Value	Total
I	**TOTAL POWER RATING FOR UPS**	**(6)**	**KW**		**111.55**
II	**POWER DEMAND FOR HVAC SYSTEM**				
-	CRAC 35 kW (INROW)	(7)	KW		30
-	Other Air conditioner system (in NOC and Power rooms)	(8)	KW		5
	Power demand for HVAC system	**(9) = (7) + (8)**	**KW**		**35**
III	**Lighting systems, other loads in NOC & Power room**				
-	Lighting systems	(10)	KW		3
-	Office equipments	(11)	KW		3
	Total	**(12) = (10) + (11)**	**KW**		**6**
IV	**POWER DEMAND FOR DATA CENTER**	**(13) = (6) + (9) + (12)**	**KW**		**152.55**
	Power factor	(14)		0.85	
	Power rating in kVA - Data Center (main electrical distribution board)	(15)	KVA		179.50
	POWER SUPPLY FROM TRANSFORMER		**KVA**		**180**