TUNKU ABDUL RAHMAN UNIVERSITY OF MANAGEMENT AND TECHNOLOGY FACULTY OF COMPUTING AND INFORMATION TECHNOLOGY

Assignment

BMIS2113 Information Technology Infrastructure Jun 2025 Semester

No	Name	ID
1	Ong Yi Xin	24WMR09097
2	Chia Ming Yi	24WMR09040
3	Lim Jun Wei	24WMR09078

Programme & Group	:	RSD3G5
Tutor's name	:	Ms. Choy Lai Fun
Date of Submission	:	7/9/2025

Student	Part 1					Part II	Total / Grade	
	10	10	10	10	10	30	80 marks	100 marks
Ong Yi Xin								
Chia Ming Yi								
Lim Jun Wei								

Comment:

Originality Report

Originality report

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BMIS2113 ITI

STUDENT NAME
YI XIN ONG

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(Final)OngYiXin_ChiaMingYi_LimJunWei(1).docx

REPORT CREATED
Sep 7, 2025

Summary

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1 of 18 passages

Student passage FLAGGED

RADIUS authentication ensures only authorized users access appropriate systems. For instance, an administrative officer can log…

Top web match

RADIUS server **authentication ensures** that **only authorized users** and devices can **access** your network, preventing unauthorized entry. Users can authenticate through passwords or more secure digital…

RADIUS Server Authentication for Secure Wi-Fi and VPN Access https://www.securew2.com/blog/radius-server-authentication-explained

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2 of 18 passages

Student passage FLAGGED

3-2-1 backup strategy is applied to protect critical **data** such as final grades of students, research outputs of labs, human resources records, **and** assessment logs with three **copies** stored **on** the …

Top web match

"The **3-2-1 backup strategy** simply states that you should have 3 copies of your data (your production **data and** 2 backup **copies) on** two different media (**disk and tape**) with one copy off-site for…

The 3-2-1 rule seems to have multiple interpretations : r/DataHoarder https://www.reddit.com/r/DataHoarder/comments/1agd73m/the_321_rule_seems_to_have_multiple/

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3 of 18 passages

Student passage FLAGGED

Harun, H. N. (2024, November 13). **Geological data with 3D mapping to manage sinkhole, landslide risks in Klang Valley**

Top web match

Geological data with 3D mapping to manage sinkhole, landslide risks in Klang Valley. By Hana Naz Harun. November 13, 2024 @ 7:16pm. description.

Geological data with 3D mapping to manage sinkhole, landslide … https://www.nst.com.my/news/nation/2024/11/1134235/geological-data-3d-mapping-manage-sinkhole-landslide-risks-klang-valley

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4 of 18 passages

Student passage FLAGGED

…M. M. S. M., & Nor, A. M. (2021). **Factors influencing safety performance** in the **Malaysian construction industry**

Top web match

The paper show that there is a mediating effect on the relationship between **factors influencing safety** and **performance** of **Malaysian construction industry**.

Framework on Safety Influential Factors for the Performance ... - IEOM http://www.ieomsociety.org/singapore2021/papers/569.pdf

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5 of 18 passages

Student passage CITED

Aruba 6300M 24-port 1GbE Class 4 PoE and 4-port SFP56 Switch (JL662A). (2023). Securewirelessworks.com. https://www.securewirelessworks.com/JL662A.asp

Top web match

Aruba 6300M 24-port 1GbE Class 4 PoE and 4-port SFP56 Switch (JL662A) Ideal for enterprise access, aggregation, core, and top of rack deployments. Aruba CX6300 ...

Aruba 6300M 24-port 1GbE Class 4 PoE and 4-port SFP56 Switch ... https://www.securewirelessworks.com/JL662A.asp

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6 of 18 passages

Student passage CITED

NFPA. (2015). **NFPA 75: Standard for the fire protection of information technology**

Top web match

NFPA 75 is the **standard for the fire protection of information technology** equipment. These newly revised standards are currently guidelines, not laws.

NFPA 75 and 76: Fire Protection Standards for Data Centers https://www.tfp1.com/blog/nfpa-75-and-76-fire-protection-standards-for-data-centers/

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7 of 18 passages

Student passage FLAGGED

TechTarget. (2024). **Data center temperature and humidity guidelines**. https://www.techtarget.com/searchdatacenter/tip/Data-center-temperature-and-humidity-guidelines

Top web match

Data center temperature and humidity guidelines · Temperature range: 15°C (59°F) to 32°C (89.6°F) · Relative humidity range: 20% to 80%.

Data Center Temperature & Humidity Best Practices - ZPE Systems https://zpesystems.com/data-center-temperature-and-humidity-best-practice-zs/

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8 of 18 passages

Student passage CITED

IEEE. (2018). **IEEE standard for local and metropolitan area** networks—Bridges **and bridged** networks (IEEE Std 802.1Q-2018). IEEE.

Top web match

IEEE Std 802.1Qcd-2015 (Amendment to IEEE Std 802.1Q-2014): **IEEE Standard for Local and metropolitan area** networks-- Bridges **and Bridged** Networks ...

IEEE Standard for Local and metropolitan area networks-- Bridges ... https://libcatalog.usc.edu/discovery/fulldisplay/alma991044139295503731/01USC_INST:01USC

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9 of 18 passages

Student passage FLAGGED

Kindervag, J. (2010). **Build security into your network's DNA: The zero trust network architecture**

Top web match

The Zero Trust security model is a decades-long concept popularized by John Kindervag's seminal paper '**Build Security Into Your Network's DNA: The Zero Trust Network Architecture**' published by…

Zero Trust Architecture: In Brief - BlueAlly https://www.blueally.com/zero-trust-architecture-in-brief/

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10 of 18 passages

Student passage FLAGGED

Network Hardwares. (n.d.). **Samsung PM9A3 960GB NVMe U.2 enterprise SSD** – High-performance server **storage solution**

Top web match

Samsung PM9A3 960GB NVMe U.2 Enterprise SSD is a high-performance **storage solution** designed for data centers, offering fast read and write speeds and robust ...

Samsung PM9A3 960GB NVMe U.2 Enterprise SSD - Provantage https://www.provantage.com/samsung-mz-ql296000~7SAMA0R0.htm?srsltid=AfmBOoo8vpcDHHcPVzm9Mw0_NkTOQC6P0LzDm9zTKuO5Mddc4G0SjYRo

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11 of 18 passages

Student passage FLAGGED

Dell Technologies. (n.d.-a). **Dell EMC PowerProtect DD series appliances and Veeam Backup & Replication configuration guide**

Top web match

s2408 **Dell Emc Powerprotect DD Series Appliances and Veeam Backup Replication Configuration Guide**. 39 pages. Student Guide DP Series Appliance Admin. PDF. No ratings yet.

s2403 Powerprotect DD Series Appliances With Veritas Netbackup ... https://www.scribd.com/document/750616742/s2403-powerprotect-dd-series-appliances-with-veritas-netbackup-configuration-guide

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12 of 18 passages

Student passage FLAGGED

Dell Technologies. (n.d.-b). **Dell PowerProtect DD series appliances and Commvault integration guide**

Top web match

Dell PowerProtect DD Series Appliances and Commvault Integration Guide | Dell Technologies Info Hub infohub.delltechnologies.com.

How to configure PowerProtect DD Series Appliances with Commvault https://www.linkedin.com/posts/dale-rhine-140a282_dell-powerprotect-dd-series-appliances-and-activity-7310658313589784581-LtoV

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13 of 18 passages

Student passage FLAGGED

Magic EdTech. (2023). **10 benefits of cloud computing in education for higher ed development**. https://www.magicedtech.com/blogs/10-benefits-of-cloud-computing-in-education-for-higher-ed-development

Top web match

10 Benefits of Cloud Computing In Education For Higher Ed Development · 1. Improved Cybersecurity · 2. Reduced Costs and Greater Flexibility · 3.

10 Benefits of Cloud Computing in Higher Education - Magic EdTech https://www.magicedtech.com/blogs/10-benefits-of-cloud-computing-in-education-for-higher-ed-development/

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14 of 18 passages

Student passage FLAGGED

NVIDIA. (2022). **University of Nottingham Malaysia leverages NVIDIA DGX A100 to advance AI research and teaching**

Top web match

University of Nottingham Malaysia leverages NVIDIA DGX A100 to advance AI research and teaching · Unique levels of flexibility for use cases.

First in Malaysia to harness power of award-winning AI supercomputer https://www.thestar.com.my/starpicks/2022/07/07/first-in-malaysia-to-harness-power-of-award-winning-ai-supercomputer

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15 of 18 passages

Student passage FLAGGED

Rajpub. (2022). **Enhanced cloud computing framework to improve the educational process in higher education**

Top web match

Enhanced Cloud Computing Framework to Improve the Educational Process in Higher Education: A case study of Helwan University in Egypt ...

Enhanced Cloud Computing Framework to Improve the Educational ... https://rajpub.com/index.php/ijct/article/view/1913

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16 of 18 passages

Student passage FLAGGED

University of Bristol. (2021). **University of Bristol unlocks global opportunities with VMware Cloud Foundation**. **VMware**. https://www.vmware.com/docs/vmw-university-of-bristol-customer-case-study

Top web match

2:58 **University of Bristol Unlocks Global Opportunities with VMware Cloud Foundation VMware** EMEA 3:35

Multi-Cloud - YouTube https://www.youtube.com/playlist?list=PLnuzn1aUz4JFI1MEEcBp2J59MUV9urNzH

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17 of 18 passages

Student passage FLAGGED

NVIDIA. (2022). **NVIDIA AI for higher education solution brief**. https://images.nvidia.com/aem-dam/Solutions/Data-Center/nvidia-ai-starter-kit-her-dgx-solution-brief.pdf?ncid=no-ncid

Top web match

NVIDIA AI FOR HIGHER EDUCATION | SOLUTION BRIEF | AUG21 | 1. SOLUTION BRIEF. Page 2. NVIDIA AI FOR HIGHER EDUCATION | SOLUTION BRIEF | AUG21 | 2. Computer Vision: Predictive analytics, commonly used…

nvidia ai for higher education https://images.nvidia.com/aem-dam/Solutions/Data-Center/nvidia-ai-starter-kit-her-dgx-solution-brief.pdf?ncid=no-ncid

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18 of 18 passages

Student passage FLAGGED

University of Nottingham Malaysia. (2022). **University of Nottingham Malaysia leverages NVIDIA DGX A100 to advance AI research and teaching**. **NVIDIA**

Top web match

University of Nottingham Malaysia leverages Nvidia DGX A100 to advance AI research and teaching NVIDIA today announced that University of Nottingham Malaysia (UNM) is the first in the country to…

Nvidia CEO Says 'The Age Of AI Has Started' https://www.businesstoday.com.my/2024/11/23/nvidia-ceo-says-the-age-of-ai-has-started/

Assignment Part I - Assessment Rubrics

No	Name	ID
1.	Ong Yi Xin	24WMR09097
2.	Chia Ming Yi	24WMR09040
3.	Lim Jun Wei	24WMR09078

CLO3 Design the IT infrastructure and IT server architecture options for an organisation. (C4, PLO2)					
Criteria	**Poor (0 - 2 marks)**	**Average (3 - 5 marks)**	**Good (6 - 8 marks)**	**Excellent (9 - 10 marks)**	**Marks Awarded**
<u>Content</u> Completion and correctness.	Does not address all assignment components. Incorrect and unclear description of the assignment deliverables.	Addressed many of the assignment components. Reasonably correct description of the assignment deliverables.	Addressed almost all of the assignment components. Almost comprehensive, relevant and mostly correct description of the assignment deliverables.	Addressed all of the assignment components. Perfectly comprehensive, relevant and correct description of the assignment deliverables.	
Weeks					
1 – 2					
3 – 4					
5 - 6					
7 - 8					
9 - 10					
				Total:	/ 50

<u>Comment:</u>

Table of Contents

Company Background

Harmoni University Group is a private educational institution of Malaysia for providing education for all students around the world and fostering innovation and critical thinking for the next generation of global leaders. It was founded by Dato Muhammad Kandar, Dato Sri Yan Szu Szee and Dato Onde A/L Tosei in 1980. Currently, there are 3 branches of campuses established in Selangor, Penang and Johor.

Our vision is to become a globally recognized institution dedicated to providing a superior education and empowering students with a quality learning environment which promotes exploratory thinking and nurtures the future leaders of the world. For our mission, we are committed to delivering high quality education to students worldwide and fostering a learning environment that encourages critical inquiry, innovation and leadership development.

Harmoni University Group has integrated various IT systems to support academic and administrative operations. Academically, students and lecturers use **digital learning platforms to access the learning materials**. Meanwhile, they will also access the **attendance system to take and check for the attendance record** in each class. To review the exam results, lecturers will access the **university intranet to record the mark of each student's taking subjects** for allowing students to view their examination marks. Not only that, they also rely on Internet connectivity to access the **r*esearch papers, online classes and collaboration***. Administratively, the staff use ***ERP, HR, and finance systems for managing the payroll, admissions and billing tasks***. These enable the staff to view their salary records and students to make payments for admission and facilities feeds. During the enrollment period, the students will register for courses through the university's website and those registration data will be stored in the centralized databases.

Despite this integration, the university faces several challenges. Academically, ***unstable internet*** often disrupts online classes and assessments. A 2024 survey showed 40% of students experienced serious lag or disconnection during online learning or research. During peak times like exams and registration, the ***LMS and intranet become slow or unresponsive*** due to limited resources. Over 60% of students couldn’t log in during peak hours, and those who could face long loading times or timeouts.

Administratively, 52% of staff reported ***delays when using ERP, HR, and finance systems*** due to low computing power and unoptimized software, causing productivity drops. The lack of system integration between departments also causes ***data inconsistencies and requires manual updates***. Around 60% of users were dissatisfied with the inconvenience and time spent on managing data manually.

Information Used

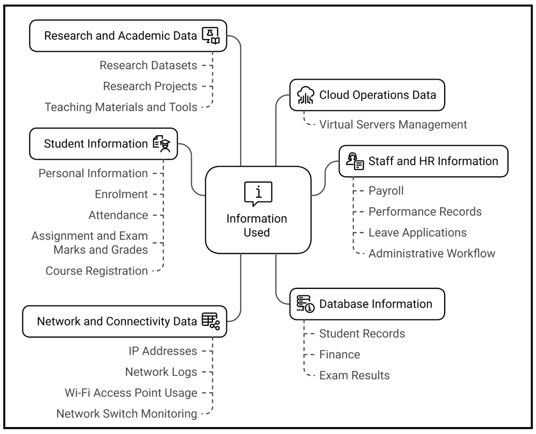

Figure 1.1: Information used by Harmoni University

Software Technology Used (Refer to Appendix Figure 1.1)

Canvas Learning Management System (LMS)
Canvas LMS operates as a web-based and cloud-hosted SaaS. It supports desktops (Windows, macOS, Linux), tablets, and smartphones (iOS, Android). The commercial license is acquired via subscription with Instructure and hosted on AWS for 24/7 availability.

Lecturers upload syllabus, slides, and materials for student access and download. They can also create assignments and exams online for submission and grading directly in Canvas LMS.

Oracle Fusion Cloud Enterprise Resource Planning (ERP)
Oracle Fusion Cloud ERP assists the finance department in generating monthly expenditure reports. It is deployed as SaaS on Oracle Cloud Infrastructure and supports quarterly updates.

When students make payments, Oracle ERP automatically records the transactions. For scholarships, it deducts the scholarship amount from the tuition invoice, and the remaining balance is shown in the student portal.

Oracle Database 19c Enterprise Edition (EE)
Harmoni University Group uses Oracle Database 19c (long-term support until 2027) in Enterprise Edition, which includes features like partitioning, advanced security, and data guard. It is installed on physical and virtual servers in the university data center.

Oracle Database stores centralized data such as student records, staff records, academic results, and research projects. New student and staff info is recorded for future use. Exam results from Canvas LMS are stored in the Oracle database.

Amazon Web Services (AWS)
To ensure availability of Canvas LMS, AWS hosts the platform with a Hybrid Cloud model, combining on-prem Oracle Database with AWS services.

Amazon EC2 (t3.medium) is used to host Canvas LMS frontend/backend. EC2 (c7i.large) is used to provide compute power for simulations, data analysis, and training machine learning models.

Hardware Technology Used

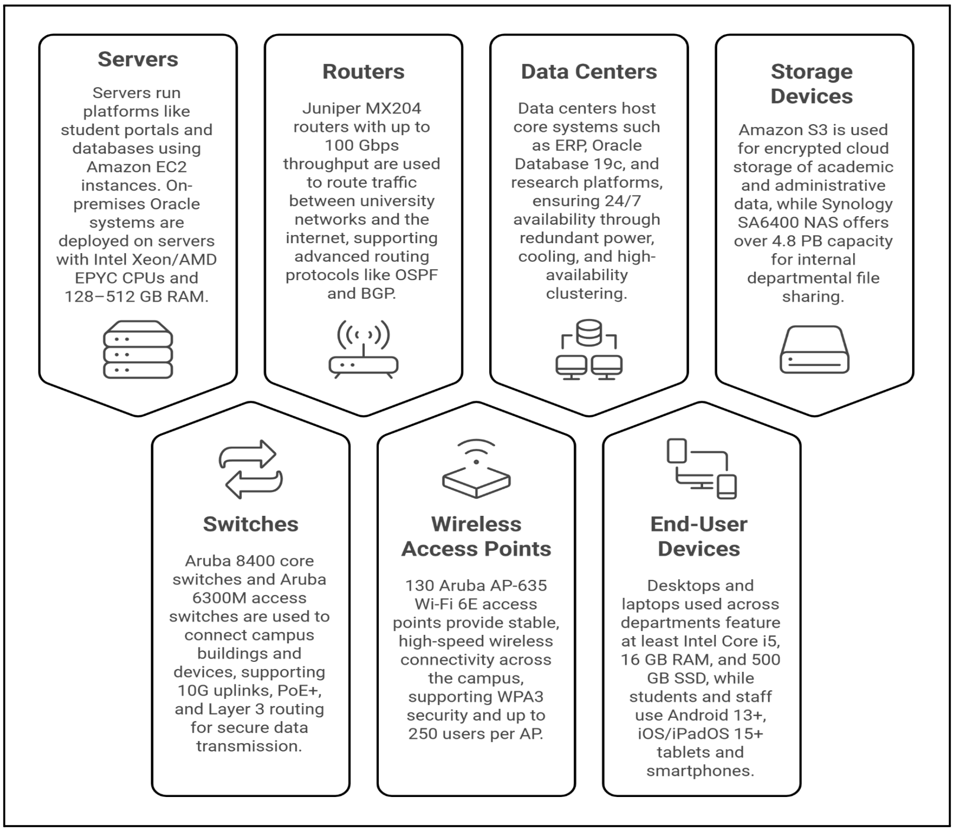

Figure 1.3: Hardware technology used by Harmoni University

Current IT Infrastructure

End User Devices

All departments use end user devices for daily campus operations, including desktops, laptops, and tablets. The department includes Faculty of Science & Technology, Faculty of Business & Management, Faculty of Arts & Humanities, Center for Online & Digital Education, Academic Affairs, Library & Learning Resources, Human Resources, Finance Department, Admissions & Records, Student Affairs Department, Procurement & Asset Management, IT Services Department, IT Security & Risk Management, Cloud &, Data Center Operations and Research Computing & Data Services.

Desktops, laptops, and tablets are used by students and lecturers for teaching, learning, and accessing digital resources. For Windows desktops, the specs include ***Windows 7 and above, Intel Core i5 or higher, at least 500 GB SSD, and 16 GB RAM***. For macOS desktops, the specs are ***OS X 10.8 and above, Intel Core i5 or higher, at least 500 GB SSD, and 6 GB RAM***. (MIT Sloan - Computer Information) Tablets and smartphones usually run ***Android 13 and above, iOS 15 and above, or iPadOS 15 and above***.

Lecturers use desktops or laptops to ***mark exam papers and handle grading***. The Student Affairs Department uses desktops for ***replying to student inquiries***. IT Services staff use similar devices to provide ***technical support***. Printers are available for ***physical reports***. Smartphones are commonly used by students to ***access the portal and take attendance***. Desktops and laptops are also used by IT security staff to ***monitor network activity***.

Operating Systems

The departments which are involved in the block of operating systems are Human Resources Department, Finance Department, IT Security & Risk Management Department and Center for Online & Digital Education. Within those departments, the most commonly used operating systems are Windows and Linux. For Windows, ***Windows 10 Enterprise edition*** will be used for administrative and management operations and it has the ***volume licensing*** only which is suitable for large institutions. Meanwhile, ***Windows 10 Professional edition*** will be used for academic environments and it is preinstalled on most PCs with OEM licenses. (Are You Using the Wrong Version? The Ultimate Guide to Windows 10 Enterprise vs Pro!, 2023) Windows For Linux, ***Linux Ubuntu 24.04.2 LTS Server*** and ***Linux Ubuntu 24.04.2 LTS Desktop*** will be used since they can provide a high stability and long-term support for implementing security features.

During daily operations, Windows 10 Enterprise Edition will be used for ***HR management systems*** with installation of Microsoft Office Suite and payroll software. Windows 10 Professional Edition will be used by students for ***enjoying the features of remote desktop, Hyper-V virtualization and running different OS environments for development and testing***. (dknappettmsft, 2025) The Linux Ubuntu 24.04.2 LTS Server will be used as a ***backend ERP to run Oracle ERP***. On the other hand, Linux Ubuntu 24.04.2 LTS Desktop will be used for ***detecting network intrusion incidents*** within the campus network.

Compute

In the IT infrastructure block of compute, the departments involved are Faculty of Sciences & Technology, Student Affairs and Research Computing & Data Services. The faculty of sciences & technology will apply ***AWS Cloud9*** as a browser-based cloud IDE for teaching programming with languages Python, Java, C++ and other languages. (AWS Cloud9 Amazon Web Services, n.d.) In the Student Affairs Department, ***Amazon EC2 with t3.medium*** instance type and 2 vCPU and 4 GB RAM will be used as a hosting platform to host systems that require high availability and moderate compute power. (AWS, 2019) For Research Computing & Data Services, ***Amazon EC2 with g5.2xlarge instance type*** and 8 vCPU, 32 GB RAM, 1x A10G GPU and 225 GB NVMe SSD will be used for providing high-performance computing and AI support to assist students and staff to accomplish research, especially researchers and postgraduates. (Amazon EC2 G5 Instances | Amazon Web Services, n.d.)

In real cases, AWS Cloud9 will be used for ***providing virtual labs or cloud-based IDEs*** for academic purposes. Apart from that, Amazon EC2 with t3.medium instance type will be used for ***hosting the student portal, attendance systems and registration platforms*** to offer 24/7 services support to students and lecturers. The Amazon EC2 with g5.2xlarge instance type will be required for ***training deep learning models***.

Storage

The core departments which are involved in the IT infrastructure block of storage are Faculty of Business & Management, Library & Learning Resources and Procurement & Asset Management. Harmoni University Group will mainly use 2 types of storages which are ***Amazon S3*** and ***Synology SA6400 NAS***. Amazon S3 has the object storage type and implements SSE-S3 (AES-256), SSE-KMS and client-side encryption for security purposes. (Protecting Data Using Server-Side Encryption - Amazon Simple Storage Service, n.d.) The ***maximum object size can reach 5TB***. On the other hand, Synology SA6400 NAS is using the CPU of AMD EPYC 7272 12-core, 2.9GHz and memory of 32 GB DDR4 ECC RDIMM which is expandable up to 512 GB. The ***maximum raw capacity can reach over 4.8 PB*** with expansion. (Inc, n.d.)

In academic scenarios, Amazon S3 is used as a cloud storage to ***backup all the exam papers, student assignments and research data***. When dealing with library and procurement operations, AWS S3 can be used to ***archive procurement data, contracts and vendor info*** while ***backing up the billing records and purchasing history***. Synology SA6400 NAS is used by staff to ***access the library metadata and internal work documents***.

<u>Networking</u>

Center for Online & Digital Education and IT Security & Risk Management Department are involved in the networking block in the IT infrastructure. At this block, there are different types of components involved such as routers, core switches, access switches, Wireless Access Points (WAPs), firewalls and intrusion detection systems (IDS). ***2 Juniper MX204 routers*** will be installed in the IT Security & Risk Management Department, it supports OSPF, BGP, EIGRP routing protocols and throughput capacity up to 100 Gbps. (HPE Aruba Networking, 2017) In the same department, ***2 Aruba 8400 core switches***, ***2 FortiGate 200F firewalls*** and ***2 Cisco Secure IPS IDS*** are also installed. In the Center for Online & Digital Education, ***130 Aruba AP-635 WAPs*** are installed. Not only that, there are ***30 Aruba 6300M*** access switches shared across all the involved departments.

All of the networking components used within the departments are vital for offering the accessibility of resources and strong security of network users. Routers and Switches are used for ***routing and distributing the packets and network*** for transmitting data back and forth with all connected devices. Wireless Access Points (WAPs) are used in various areas within the campus for enabling students to ***access online courses and classes with stable internet access***. Firewall and intrusion detection systems are applied for ***monitoring the network traffic*** and ***implementing firewall and access control rules***.

<u>Data Centers</u>

Data Centers act as a backbone of Harmoni University Group IT infrastructure for supporting all the services and platforms within the campus. The departments of Academic Affairs, Admissions & Records, Cloud & Data Center Operations heavily relies on the Data Centers block. Oracle Database 19c is involved in ***storing and managing the faculty evaluation systems and academic calendars***. Besides, Data Centers also ***maintain the historical academic records and enrollment data in a secure environment***. It can be used for ***hosting the systems*** such as ERP, databases and research platforms and ensuring the 24/7 availability and security.

Datacenter

Analysis of the Existing Data Center Infrastructure

Harmoni University's ***on-premises data center***, located at ***Jalan Teknologi 5 in Technology Park Malaysia, Bukit Jalil, Kuala Lumpur***, serves as the central hub for institutional IT infrastructure. Although it is not situated within a teaching campus, the facility is built on university-owned land and comprises a ***three-story reinforced concrete main building*** with a total built-up area of approximately ***2,400 square meters***. This building houses the ***data halls***, ***network operations***, and ***power systems***. Adjacent to it is a two-story annex used for administrative offices and parking for operational staff and service vehicles. Physical access is secured through ***access card authentication*** and ***continuous CCTV surveillance***. The ***elevated topography*** of Bukit Jalil and its ***engineered drainage infrastructure*** help mitigate flood risks, while the ***geologically stable, non-limestone foundation*** minimizes susceptibility to sinkholes and landslides. Seismic activity in the area is negligible.

The data center supports Harmoni University's distributed campuses in Selangor, Penang, and Johor, located approximately 40 km, 350 km, and 340 km away, respectively. Due to the cost and complexity of deploying dedicated high-speed fiber links, inter-campus connectivity relies on ***public internet-based VPN tunnels*** and ***microwave wireless point-to-point links***, typically providing ***10 to 100 Mbps bandwidth***. These connections experience ***latency exceeding 50 milliseconds***, lack quality of service guarantees, and often suffer from ***packet loss*** and throughput variability during peak periods. Consequently, data synchronization occurs via ***scheduled batch transfers*** during off-peak hours, limiting real-time consistency and system responsiveness. Network connectivity to external resources is maintained through a ***symmetrical 2 Gbps uplink provided by TM Unifi Business Fibre at RM 369 per month***. This connection terminates at a dedicated entry point and is routed through a Cisco Integrated Services Router (ISR) 4331 series device using ***static routing for upstream configuration***. However, ***no dynamic failover protocols*** such as Hot Standby Router Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), or Border Gateway Protocol (BGP) multihoming are implemented, requiring manual intervention to resolve any connectivity failures.

The main building of the data center utilizes a ***raised floor architecture*** for routing both electrical power and data cabling through the subfloor plenum. ***Cables are not segregated by voltage or function***, increasing the risk of electromagnetic interference (EMI) and localized heat buildup in high-density areas (ASHRAE, 2016). The ***floor panels support static loads of 1,000 to 1,500 kg/m² and are coated with antistatic materials*** to reduce electrostatic discharge (Open Compute Project, 2023). The facility's building envelope consists of ***reinforced concrete walls without acoustic or thermal insulation***, and the ***data hall has no windows***. Access is controlled through a ***single fire-rated steel door***, equipped for both manual and electronic operation, with ***no secondary exits or airlock vestibules***. In line with industry safety protocols, domestic water and gas lines are excluded.

Fire protection systems include a ***double-interlocked pre-action sprinkler*** and a ***clean-agent gaseous suppression system***, compliant with NFPA 75 and 76 standards. However, supplementary features such as drainage trays, underfloor moisture detection, and containment seals are not present (ASHRAE, 2016). ***Smoke detectors are installed overhead***, but none are placed under the raised floor, potentially delaying early fire detection where power and cable bundles are concentrated (Vanguard Fire, 2023; TFP1, 2023). ***Environmental monitoring is minimal, with no rack-level sensors for temperature, humidity, or airflow, limiting visibility into local thermal conditions***.

Cooling is provided by perimeter-based precision air conditioning (PAC) units, adhering to ASHRAE Class A1 standards. The facility uses an ***open plenum airflow model*** without hot/cold aisle containment or directional airflow control, which may reduce thermal efficiency at rack densities above 10 kW, especially in the ***absence of advanced cooling technologies*** such as liquid cooling or rear-door heat exchangers (ASHRAE, 2023; PRACE-RI, 2023).

The data center is ***powered through dual utility feeds protected by surge protection devices (SPDs) and automatic transfer switches (ATS)***, which ensure seamless failover to backup systems during outages. To maintain continuity during transfer delays or short-term blackouts, ***rack-mounted uninterruptible power supply (UPS) units*** are used. The primary model in operation is the APC Smart-UPS SRT 10 kVA (SRT10KXLI), each equipped with four external battery packs (SRT192BP2) and an internal module. This configuration provides approximately six hours of runtime at 50 percent load, equivalent to around 4 kW, which is sufficient to sustain core IT services such as networking, servers, and storage. The battery system uses ***valve-regulated lead-acid (VRLA) cells housed in modular enclosures***, enabling capacity expansion but not hot-swappable maintenance due to the absence of redundant UPS configurations. ***Power is distributed via standard 16-ampere single-phase power distribution units (PDUs) with IEC C13/C19 outlets***. These units do not support remote monitoring or per-outlet control, reducing operational visibility. ***Battery health is assessed manually twice a year through discharge testing***. The system does not employ predictive diagnostics or real-time telemetry (Schneider Electric, 2019; Uptime Institute, 2024).

Backup power is provided by diesel generators rated at 250 kilovolt-amperes (kVA) each, specifically utilizing models such as the Cummins C250 D5 or Perkins 2506C-E15TAG2 gensets, housed in standard ISO 20-foot acoustic containers at ground level. These units are configured in a ***non-redundant N arrangement***, meaning that a single point of failure exists in the event of generator malfunction. The ***enclosures provide basic weatherproofing and sound attenuation*** but are ***not equipped with advanced environmental conditioning features*** such as high-efficiency particulate air (HEPA) filtration, humidity control, or dust exclusion systems. This may result in degraded performance or accelerated wear during operation in environments with high humidity, airborne dust, or temperature extremes, which are common in tropical regions. Routine fuel polishing and filter replacement are required to maintain operational integrity. (Uptime Institute, 2024).

The ***data center operates as a single-site primary facility***, with ***no active geographic redundancy or offsite replication***. Backup procedures involve ***on-premises network-attached storage (NAS) devices*** such as the Synology RS820+, configured in RAID-5 with AES-encrypted volumes. Remote data synchronization, cold storage archiving, or tape-based disaster recovery workflows are not utilized. The ***current configuration does not reflect Tier III or Tier IV guidelines*** defined by the Uptime Institute and TIA-942 Rated-3/4 standards, which emphasize geographic isolation, data integrity, and failover continuity as critical requirements for resilient data center infrastructure (Uptime Institute, 2024; Microsoft, 2024).

Proposal to Improve the Data Center Infrastructure

To support Harmoni University's transition from a traditional centralized on-premises setup to a scalable multi-tenant and cloud-integrated data center, key structural upgrades are proposed. The original layout lacked physical segmentation, tenant-specific infrastructure, and hybrid cloud connectivity, limiting its suitability for distributed campus operations. The ***ground floor will be upgraded with isolated UPS and battery rooms, redundant cooling loops, and sealed logistics***

staging zones. These changes enhance infrastructure availability and protect core systems during maintenance and transfer activities (Uptime Institute, 2024). On the first floor, the ***existing undivided data hall will be restructured into multiple tenant zones, each with fire-rated partitions, dedicated hot/cold aisle containment, in-row cooling, and segregated raised-floor cable pathways***. These improvements support higher performance, energy efficiency, and cross-tenant isolation (ASHRAE, 2023; Cisco, 2023). The second floor will ***host a new cloud interconnect room with direct links to Azure and AWS, tenant orchestration workspaces, and encrypted backup vaults***. Rooftop reinforcement will support future edge computing or solar integration, enhancing flexibility and sustainability (Microsoft, 2024; Open Compute Project, 2023).

Proposed Floor Plan in 2D layout and 3D view

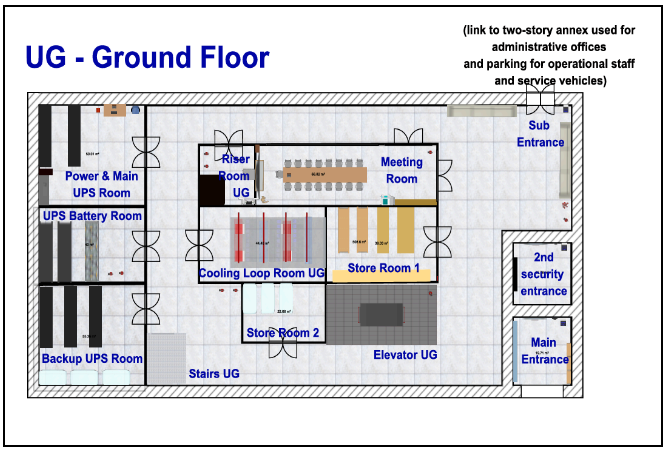

Figure 2.1.1: Ground Floor Floor Plan (2D View)

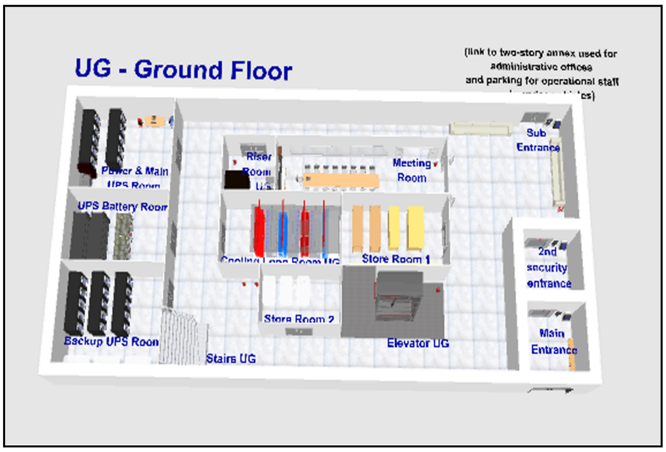

Figure 2.1.2: Ground Floor Floor Plan (3D View)

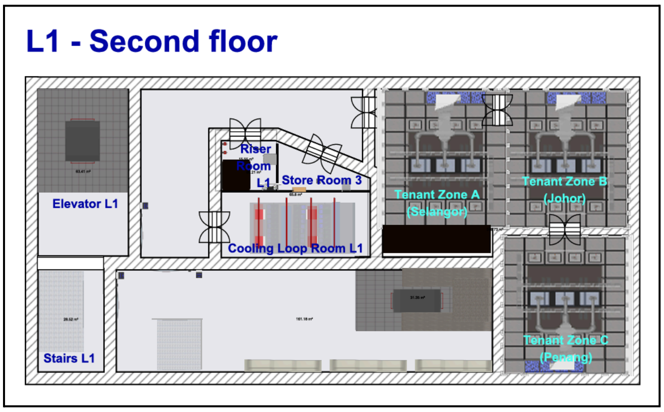

Figure 2.1.3: Second Floor (L1) Plan – 2D Layout

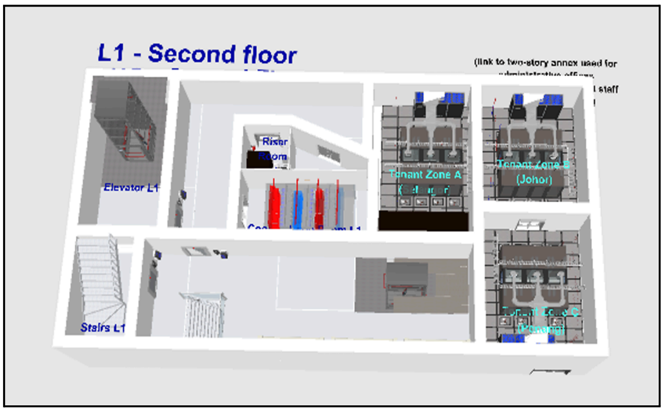

Figure 2.1.4: Second Floor (L1) Plan – 3D View

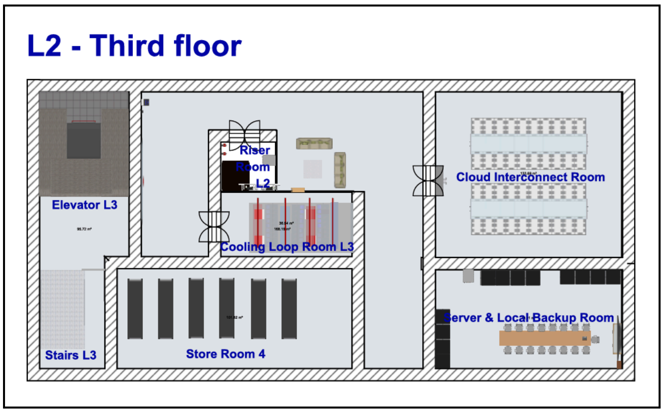	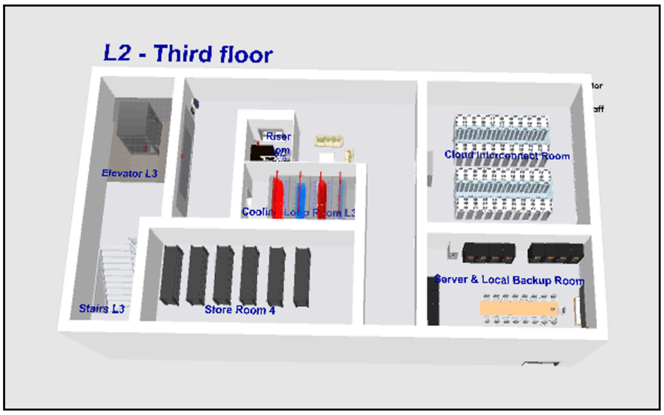
Figure 2.1.5: Third Floor (L2) Plan – 2D Layout	*Figure 2.1.6: Third Floor (L2) Plan – 3D View*

Datacenter Availability

The existing VRLA-based UPS system has a ***MTBF of 40,000 hours*** and ***MTTR of 4 hours***, yielding ***availability of 99.990%***. The proposed ***Schneider Electric Galaxy VS 20kVA UPS units*** offer ***modular N+1 redundancy, 97% efficiency (ECOnversion mode)*** with reduced ***MTTR of 2 hours*** and ***MTBF of 100,000 hours***. It can achieve an ***availability of 99.998%*** and reduce annual potential downtime by over ***40 minutes*** (Schneider Electric, 2024).

$$A_{existing} = \frac{MTBF}{MTBF+MTTR} = \frac{40000}{40000+4} \approx 0.999900 = 99.990\%$$

$$A_{proposed} = \frac{MTBF}{MTBF+MTTR} = \frac{100000}{100000+2} \approx 0.999980 = 99.998\%$$

Figure 2.2.1: Proposed Uninterruptible Power Supply (UPS) System Availability

The current power distribution has a ***MTBF of 80,000 hours*** and ***MTTR of 2 hours***, achieving ***99.9975% availability***. The upgrade to ***APC Rack PDU 8000 Series*** adds ±1% metering accuracy, outlet-level switching, and EcoStruxure integration for centralized monitoring, with up to 24 outlets per unit (APC by Schneider Electric, 2023). With an ***MTBF of 200,000 hours*** and ***MTTR of 1 hour***, the new PDUs offer ***99.9995% availability***, improving uptime by ***0.002%*** and reducing potential annual downtime.

$$A_{existing} = \frac{MTBF}{MTBF+MTTR} = \frac{80000}{80000+2} \approx 0.999975 = 99.9975\%$$

$$A_{proposed} = \frac{MTBF}{MTBF+MTTR} = \frac{200000}{200000+1} \approx 0.999995 = 99.9995\%$$

Figure 2.2.2: Proposed Power Distribution Unit (PDU) Availability

The current backup power system has an ***MTBF of 30,000 hours*** and ***MTTR of 8 hours***, creating a ***single point of failure***. The proposed upgrade introduces ***redundant Cummins C275D5B*** diesel generators (275 kVA, <5% THD, ISO 8528-5 compliant) (Cummins, 2023). With an ***MTBF of 60,000***

hours and ***MTTR of 6 hours***, the new setup offers ***99.99% availability*** and reduces ***annual downtime by over 85 minutes***.

$$A_{existing} = \frac{MTBF}{MTBF+MTTR} = \frac{30000}{30000+8} \approx 0.999733 = 99.9733\%$$

$$A_{proposed} = \frac{MTBF}{MTBF+MTTR} = \frac{60000}{60000+6} \approx 0.999900 = 99.9900\%$$

Figure 2.2.3: Proposed Diesel Generator Availability

Currently, the inter-campus routing uses Cisco ISR 4331 router with ***MTBF of 150,000 hours*** and ***MTTR of 2 hours***. The upgrade to ***Cisco ISR 4431*** routers with ***dual fiber uplinks***, ***HSRP/BGP failover***, and ***2.5 Gbps throughput***, increases availability to ***99.9996%*** (MTBF 250,000 hours, MTTR 1 hour), cutting downtime by over ***5 minutes per year*** (Cisco, 2023).

$$A_{existing} = \frac{MTBF}{MTBF+MTTR} = \frac{150000}{150000+2} \approx 0.9999867 = 99.9987\%$$

$$A_{proposed} = \frac{MTBF}{MTBF+MTTR} = \frac{250000}{250000+1} \approx 0.999996 = 99.9996\%$$

Figure 2.2.4: Proposed Router Availability

<u>Combined System Availability (Existing vs Proposed):</u>

$$A_{TOTAL\,(existing)} = A_{UPS\,(existing)} \times A_{PDU\,(existing)} \times A_{GEN\,(existing)} \times A_{ROUTER\,(existing)}$$

$$A_{TOTAL\,(existing)} = 0.999900 \times 0.999975 \times 0.999733 \times 0.9999867$$

$$A_{TOTAL\,(existing)} \approx 0.999595$$

$$A_{TOTAL\,(existing)} = 99.9595\%$$

Figure 2.2.5: Existing Combined System Availability

$$A_{TOTAL\,(proposed)} = A_{UPS\,(proposed)} \times A_{PDU\,(proposed)} \times A_{GEN\,(proposed)} \times A_{ROUTER\,(proposed)}$$

$$A_{TOTAL\,(proposed)} = 0.999980 \times 0.999995 \times 0.999900 \times 0.999996$$

$$A_{TOTAL\,(proposed)} \approx 0.999871$$

$$A_{TOTAL\,(proposed)} = 99.9871\%$$

Downtime per year (Tier III availability):

$$(1 - A_{TOTAL\,(proposed)}) \times 365 \times 24 \approx (1 - 0.999871) \times 8760 \approx 1.13\ hours/year$$

Figure 2.2.6: Proposed Combined System Availability

<u>Datacenter Performance</u>

To enhance performance, thermal management will be optimized by implementing ***hot or cold aisle containment and precision in-row cooling using Vertiv Liebert CRV***, which delivers up to 70 kW of cooling capacity per unit and maintains airflow precision within ±2% under dynamic load changes, validated under ASHRAE Class A1 conditions (Vertiv, 2023). ***Environmental conditions will be***

continuously monitored using APC NetBotz 750, supporting up to 78 wired and wireless sensors with alert thresholds, historical logging, and integration with DCIM platforms, enabling ***24/7 thermal profile optimization*** (APC by Schneider Electric, 2023). Cabling infrastructure will be improved by ***installing overhead cable trays, separating power and data cabling*** to reduce EMI by up to 30% and improving airflow efficiency by 15% in high-density environments, as recommended by the Open Compute Project Facility Guidelines v3.0 (Open Compute Project, 2023). ***Resource utilization and workload management will be optimized using VMware vSphere 8 Enterprise Plus***, which enables 99.99% availability through vMotion and Distributed Resource Scheduler (DRS), and supports up to 768 vCPUs and 24 TB RAM per host cluster (VMware, 2024). ***Network capacity and segmentation will be increased by implementing Cisco Nexus 9300 Series switches***, offering 1.2 Tbps of switching capacity, support for VXLAN overlays, and 10G/25G/40G/100G interface options, enabling scalable multi tenant deployment (Cisco, 2023).

Datacenter Security

To strengthen security, ***multi-factor access control will be implemented using HID Aero X1100 controllers*** (supporting up to 64 readers and 250,000 credentials) combined with ***Suprema Biostation 3***, which provides facial recognition with 99.9% accuracy and sub-0.5s authentication speed even in low-light environments (HID Global, 2024; Suprema, 2023). ***Surveillance will be enhanced with Axis P3245-LVE IP cameras***, featuring 1080p resolution, IR night vision, and AI-based analytics for real-time intrusion detection, capable of storing up to 256 GB onboard or streaming via RTSP to NVRs (Axis Communications, 2023). ***Data security will be enforced with Synology RS4021xs+ NAS***, equipped with 8-core Xeon D-1541 CPU, 16 GB ECC RAM (expandable to 64 GB), built-in AES-NI encryption, and up to 96 TB raw storage in RAID 5/6, supporting daily snapshots and immutable backup policies (Synology, 2024). ***Disaster recovery will be supported by integrating Microsoft Azure Backup Vault and AWS Backup***, offering encrypted offsite storage with 99.99999% durability and point-in-time recovery options, validated under ISO/IEC 27001 and SOC 2 frameworks (Microsoft, 2024; AWS, 2024).

Networking

Networking Building Blocks (Refer to Appendix Tables 3.1.1 to 3.1.9)

Existing Infrastructure

Harmony University's current network ***lacks structured cabling, centralized control, and secure inter-campus connections***, which affects the main campus in Bukit Jalil, Putrajaya and the branch campuses in Selangor, Penang, and Johor. ***Static routing and unstable VPN tunnels*** cause frequent interruptions when accessing shared platforms such as Moodle, the SIS, and the electronic library. Due to the ***absence of VLAN isolation or encryption***, administrative and academic data such as student records and exam scores are vulnerable to leaks. The ***core systems lack redundancy*** and ***centralized management***, leading to downtime that disrupts online courses, assessments, and research collaborations. The ***absence*** of a ***unified certificate and identity management system*** makes it difficult for the IT team to implement consistent policies across campuses. Together, these factors demonstrate that the current architecture is ***insufficient*** for a ***modern, multi-campus academic environment*** and must be redesigned to align with contemporary needs.

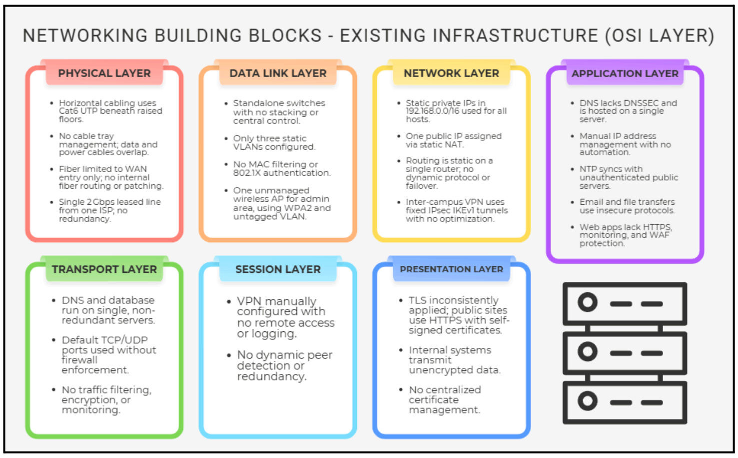

Figure 3.1.1: Existing Infrastructure of Network Building Blocks (OSI Layer)

Proposed Infrastructure

Harmony University will upgrade its network system to support a ***secure, modern academic environment across all campuses***. The adoption of ***structured Cat6A and OM4 cabling*** technology will enhance internet reliability and reduce network interruptions during online courses and digital exams. The ***centralized core network*** located in Bukit Jalil is equipped with ***dual VPN links*** to ensure stable access to systems such as Moodle and the student portal. ***Wi-Fi 6E*** and ***managed switches*** will provide fast, secure connections in classrooms and laboratories, while ***802.1X*** and ***VLAN*** will separate network traffic for students, faculty, and visitors. Through ***centralized IP*** and ***certificate management***, the IT team can monitor and control devices more efficiently. Sensitive data such as student grades and faculty records will be encrypted using ***TLS 1.3***. ***Remote VPN access with two-factor authentication (2FA)*** enables secure learning and system access from any location. These improvements will enhance classroom engagement, streamline administrative processes, and safeguard academic data across all campuses.

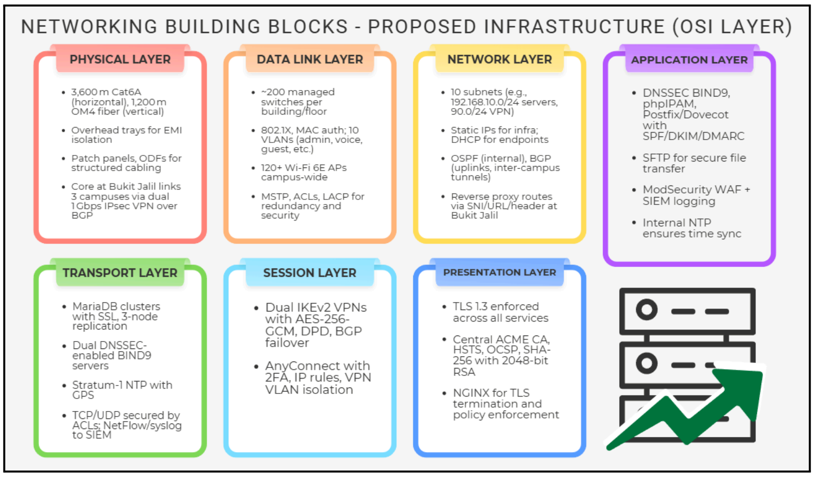

Figure 3.1.2: Proposed Infrastructure of Network Building Blocks (OSI Layer)

Network Virtualization

<u>Existing Infrastructure (Refer to Appendix Tables 3.2.1 to 3.2.4)</u>

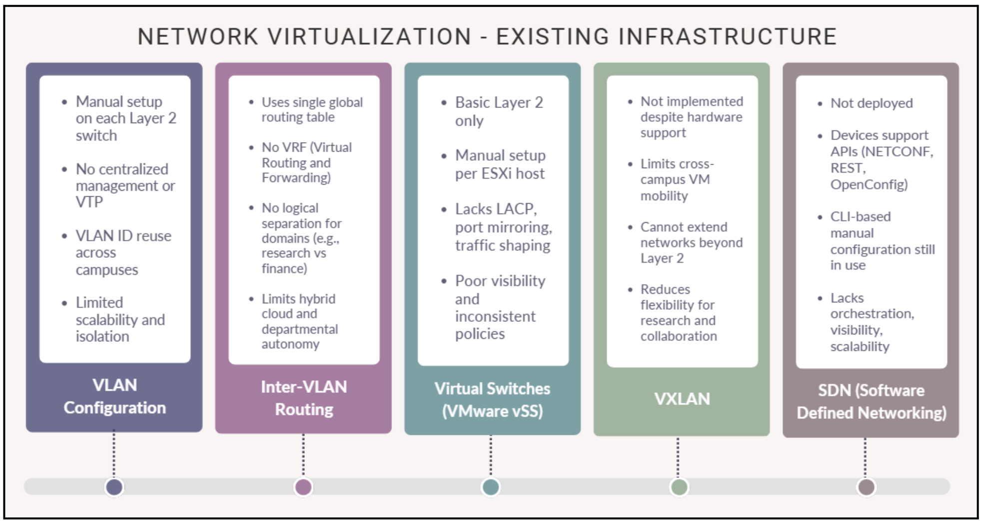

Figure 3.2.1: Existing Infrastructure of Network Virtualization

Harmoni University's network uses a ***manually configured VLAN structure on Layer 2 switches without centralized management, VTP, or dynamic assignments***. When a new department is added, VLANs must be manually configured across switches in all campuses, delaying service rollout. ***Inter-VLAN routing uses a single global table*** due to the lack of VRF, which causes research data and finance transactions to travel on the same path and increases the risk of data exposure. ***VMware vSwitches on ESXi hosts provide only basic Layer 2 connectivity without centralized policies, LACP, or monitoring***. A misconfigured virtual machine, such as the e-Coursework submission portal, can disrupt other systems and affect assignment submissions. ***Although the hardware supports VXLAN, it is not in use***, preventing Layer 2 extension between campuses. This limits virtual machine mobility and hinders the implementation of shared lab environments and hybrid classes. ***While the devices support SDN, all configurations are still done manually through CLI***, which slows down the deployment of tools like real-time video assessments and reduces the university's network agility.

Proposed Infrastructure (Refer to Appendix Tables 3.2.5 to 3.2.14)

To modernize its IT infrastructure and support evolving academic needs, Harmoni University Group proposes a virtualized, campus-wide network architecture that ensures ***scalability***, ***security*** and ***readiness*** for hybrid learning. The design aims to enhance support for online classes, virtual labs, research activities, and administrative operations across all campuses.

The core of this infrastructure is a ***structured VLAN architecture***. Key domains such as Admin (10), Server (20), Storage (30), Wired Clients (40), and Student Labs will be assigned fixed VLAN IDs, while VLAN 99 will isolate management traffic. ***VLAN tagging using IEEE 802.1Q on both access and trunk ports*** ensures consistent enforcement of access control across firewalls, ESXi hosts, and switches (IEEE, 2018). This segmentation allows secure operation of online examination systems, faculty portals, and academic resource servers.

Layer 3 switches with VRF will provide inter-VLAN routing and secure segmentation between units such as Finance, Academic Services, and Research Labs. VRF instances allow isolated IP routing domains, preventing unauthorized access between critical systems. For example, tuition payment systems in Finance and research collaboration platforms in Biomedical Labs will operate separately, protecting sensitive academic and financial data. ***OSPF will enable automatic route convergence between campuses***, supporting distributed e-learning services and cloud-based academic tools (Cisco Systems, 2023; 2024). When necessary, route leaking and BGP will support cross-unit communication (Gouareb et al., 2021).

On the virtualization layer, ***VMware vDS*** will be used to centrally manage ESXi host networking. Port groups mapped to VLANs will provide isolated environments for student services, grading systems, and backup servers. ***NIC teaming with LACP*** will ensure high availability, while NetFlow and Network I/O Control will prioritize traffic for synchronous activities like video lectures and live assessment tools (BDRSuite, 2023; VMware, 2011).

To support seamless virtual lab access and centralized academic systems across campuses, ***VXLAN will extend Layer 2 networks over Layer 3 using VTEPs on physical and virtual nodes*** (Arista Networks, 2025). Finally, ***Cisco DNA Center will serve as the SDN controller***, automating configuration and ensuring policy consistency to support a flexible, secure, and cloud-enabled educational environment (Kreutz et al., 2015; Cisco Systems, 2023).

Network Availability

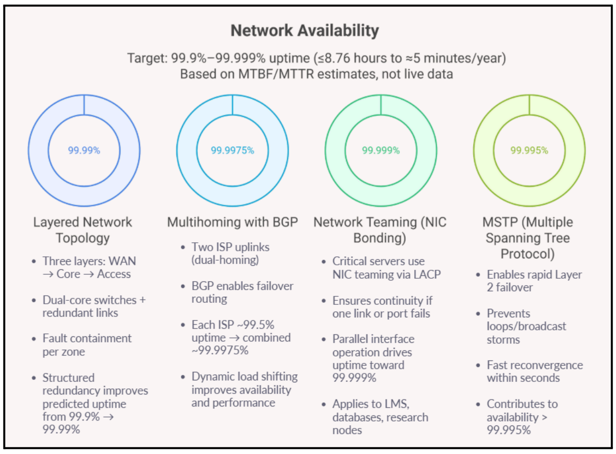

Figure 3.3.1: Target Network Availability of Harmoni University

Harmoni University targets ***99.9% to 99.999% annual network availability***, translating to ***less than 8.76 hours*** to just 5 ***minutes of downtime annually***. These estimates follow standard MTBF and MTTR calculations and are guided by Cisco's high-availability best practices (Cisco Systems, 2024). A ***layered topology consisting of WAN, Core, and Access layers*** helps contain faults to specific areas. For example, if a lab switch fails during an IT class, other campus systems such as the LMS or exam portals remain unaffected. Dual-core switches and redundant links improve predicted uptime to ***99.99%***, ensuring student access to lecture materials is uninterrupted.

To maintain continuous external access to online learning platforms, journals, or remote collaboration tools, the network uses ***multihoming via BGP with two ISPs***. If one provider fails during a live class or thesis submission, traffic is automatically rerouted through the backup, achieving uptime near ***99.9975%***.

Critical servers hosting the LMS, grading system, and research storage use ***NIC teaming with LACP***. This ensures uninterrupted access even during hardware failure, pushing uptime to ***99.999%***. At Layer 2, ***MSTP*** enables fast failover within seconds, preventing disruptions during time-sensitive activities like exam registration or online assessments (McPherson et al., 2015).

Network Performance (Refer to Appendix Tables 3.4.1)

The Harmoni University Group network spans three campuses which are Selangor, Penang and Johor—each supporting a wide range of educational, administrative and security services. To meet the demands of modern education delivery, key performance metrics such as ***throughput***, ***latency***, ***QoS*** and ***WAN efficiency*** must be continuously monitored and optimized (Motadata, n.d.; Juniper Networks, n.d.-b).

Throughput is crucial for academic services such as LMS, video lectures and cloud-based assignment portals. VLANs including Server (20), Storage (30) and Wired Clients (40) transfer large files like lecture recordings, system backups and research data. To support this, ***intra-campus links of at least 1 Gbps*** are needed. For example, the inter-campus traffic when Johor campus students access centralized academic records hosted in Selangor. It requires a ***10 Gbps backbone*** to ensure uninterrupted access to shared resources (Ruckus Networks, 2023; Neos Networks, n.d.; Cisco Press, 2004).

Latency directly affects user experience for services requiring real-time interaction. VoIP systems (VLAN 70) enable remote academic advising, while CCTV feeds (VLAN 80) support safety in examination halls and dormitories. ***Latency under 3 ms on campus and under 15 ms between campuses*** ensures smooth video calls, live classes and campus security streaming (Phoenix Fiber, 2024; Exam-Labs, n.d.; Obkio, 2023).

QoS policies are vital during peak periods such as online examinations or mass lecture uploads. ***Delay-sensitive traffic like live video lectures and VPN sessions for remote faculty (VLANs 70 and 90) are prioritized*** using DSCP and Class-Based Weighted Fair Queuing (CBWFQ). ***Lower-priority services like Guest Wi-Fi (VLAN 60) and overnight system backups (VLAN 30) are deprioritized*** to maintain academic continuity (SolarWinds, n.d.; Wray Castle, 2023; Splunk, n.d.).

To reduce load on WAN links and improve access to cloud-hosted academic tools like Google Workspace for Education or online lab simulations, ***WAN optimization techniques*** like ***data compression*** are applied. These ***reduce bandwidth usage by up to 60%***, improving performance for students accessing content off-site (Uninets, n.d.; HPE, n.d.-b; TutorChase, n.d.).

SNMP-based tools like ***Cisco Prime Infrastructure*** provide real-time monitoring of these metrics. This enables IT staff to proactively resolve issues during time-critical periods such as online exams, e-learning platform updates and research data transfers (Comparitech, 2024; SecureITStore, n.d.; Obkio, 2023).

Network Security (Refer to Appendix Tables 3.5.1 to 3.5.2)

At Harmoni University, secure inter-campus communication is essential for ***protecting sensitive academic data***. For example, when a lecturer from the Penang campus uploads postgraduate thesis evaluations to the centralized database in Selangor, ***IPsec-encrypted tunnels between core routers*** ensure that confidential research content and student grades are not exposed during transmission (Burr et al., 2023). Similarly, lecturers working remotely from home use ***secure VPN connections*** to access internal Learning Management Systems (LMS) to upload lecture slides and mark attendance without risking data breaches.

Firewalls play a key role in protecting both public-facing systems and internal networks. When students access the university's online library from campus or off-campus locations, ***perimeter firewalls block unsolicited internet traffic and prevent malware*** from targeting the backend server. Meanwhile, ***internal firewalls isolate the administrative finance VLAN from student lab networks***. This ensures that even if a student device is infected with malicious software, it cannot reach sensitive payroll or tuition billing systems (Scarfone & Hoffman, 2009).

Network segmentation using VLANs and VRF enables secure separation of academic and administrative traffic. For example, students accessing coursework through lab PCs or campus Wi-Fi are placed in ***VLAN 40 (Wired Clients)*** or ***VLAN 50 (Wireless Staff),*** isolated from the ***Admin VLAN (10)*** and ***Server VLAN (20)*** where exam systems and internal portals reside. Authorized staff can still access grading servers in VLAN 20 from VLAN 10 or 50, while route filtering enforces strict role-based access. This prevents students from reaching sensitive resources while supporting academic workflows (Cisco Systems, 2024).

IDPS enhance security during sensitive academic periods. During final exams, IDPS monitors for suspicious activity such as repeated login attempts into the grading portal or unauthorized access to student records. If a breach attempt is detected, the system can automatically block the source and notify IT security staff, helping prevent exam leaks or data tampering (Scarfone & Mell, 2007).

RADIUS authentication ensures only authorized users access appropriate systems. For instance, an administrative officer can log into the HR portal over staff Wi-Fi while a student on guest Wi-Fi cannot access anything beyond internet browsing. Faculty have tailored access to LMS and research databases, aligning with their teaching and supervision roles (Rigney et al., 2000).

Network Topology (Refer to Appendix Figure 3.6.1)

The Harmoni University Group's proposed network topology is structured into four key areas including WAN, Core Layer, Access Layer 1 and Access Layer 2. Each area adopts a specific topology type that aligns with its role within the network infrastructure.

In the ***WAN area***, a ***Point-to-Point or Partial Mesh topology*** will be implemented. A single ***ISR4431-1 router*** will connect directly to both core switches (***ISR9500-1*** *and* ***ISR9500-2***) while establishing redundant paths for WAN connectivity. This design can effectively improve the reliability by maintaining inter-campus communication even if one connection fails.

The ***Core Layer*** will apply the ***Partial Mesh topology***. The two core switches are interconnected and also linked to both access switches (***ISR9300-1*** and ***ISR9300-2***). This structure allows for ***high availability*** which supports ***load balancing*** and ensures continuous data flow between network layers. This can reduce the risk of a single point of failure. ***Access Layer 1*** adopts a ***Star topology***, with a single access switch (***ISR9300-1***) directly connecting to end devices such as ***AdminPC-1***, ***Server-1*** and ***OfficePC-1***. This centralized layout is ideal for wired environments, offering ease of management and consistent performance. Similarly, **Access Layer 2** uses a ***Star topology with wireless extension***. The ***ISR9300-2 access switch*** connects to various devices including ***VoIP phones***, ***wireless routers***, ***CCTV*** and ***VPN clients***, while wireless users connect through the wireless router. This hybrid approach supports flexible access for both wired and wireless devices.

Overall, this layered and hybrid topology enhances ***scalability***, ***redundancy*** and **e*fficient network management*** across Harmoni University's campus.

Storage

Storage Building Blocks

<u>Existing Infrastructure (Refer to Appendix Tables 4.1.1 to 4.1.3)</u>

Harmoni University currently uses ***hybrid storage*** methodology which is combining the ***Amazon S3 cloud storage (AWS Singapore Region (ap-southeast-1)) with an on-premises Synology SA6400 NAS system***. The Amazon S3 is applying pay-per-use storage capacity without a fixed upper limit. It can be accessed via HTTPS, REST API and AWS SDK. Meanwhile, the existing Synology SA6400 NAS is deployed in Hamoni University central campus server room with provision of capacity up to 1.5PB with expansion units. In academic departments such as the Faculty of Business and Management, the staff usually uses Amazon S3 to store the student coursework materials, digital exam papers and research papers. Not only that, It also supports administrative functions such as archiving procurement contracts and financial records. While it provides reliable encryption and high scalability for growing academic datasets, its performance will depend on stable internet access. Since the academic staff are unfamiliar with IAM policies, managing data access will also be complex and prone to misconfiguration.

The ***Synology SA6400 NAS*** is mainly used by the ***Library and Learning Resources Division and internal university offices to store e-books, academic metadata and administrative documents***. It enables fast access to learning content within the campus network. It only allows for single campus data access while not supporting advanced use cases like virtual lab environments or analytics on research data.When multiple departments access the NAS simultaneously, users may experience slowdowns, the collaboration between geographically separate faculties will also be limited due to its LAN-only nature.

The current storage infrastructure struggles to keep up with the ***increasing demand for cross-campus academic collaboration, remote access to learning materials and real-time research data processing***. Its limitations in resilience and scalability cause the risks to academic continuity, especially during peak periods like exam weeks or system maintenance windows. While Amazon S3 meets basic security expectations, the fragmented and manually maintained NAS setup may increase the risk of inconsistent access control and potential data loss in education-critical workflows.

Proposed Infrastructure (Refer to Appendix Table 4.2.1 and Figure 4.2.1 - 4.2.2)

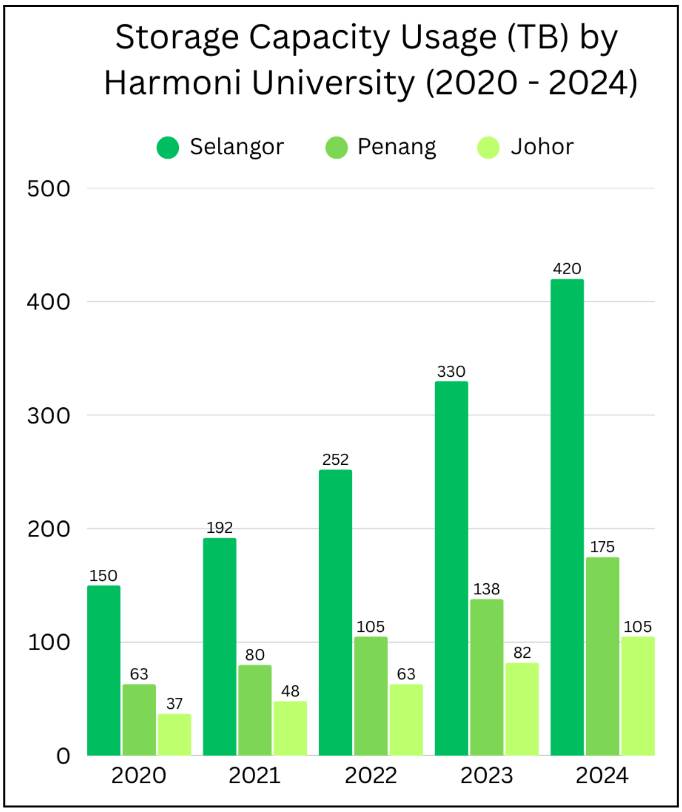

Figure 4.2.1: Storage Capacity Usage (TB) by Harmoni University (2020 - 2024)

Mechanical Hard Disks (Refer to Appendix Tables 4.2.2 to 4.2.4)

The requirement for responsive and scalable storage is getting higher along with the increasing number of students and staff in Harmoni University. Thus, ***Seagate's enterprise-grade SAS and NL-SAS drives are planned to be used for achieving tiered mechanical hard disk setup***. At the performance tier, ***Seagate Exos 10K.2 SAS drives*** will be able to ***deliver a high IOPS (12Gb/s) and low latency (~2.9ms)***. These features are ideal for time-sensitive educational systems like virtual lab environments, database-backed LMS and concurrent access in student portals (DiscTech, n.d.; EMC Corporation, n.d.). Via the SAS drives, it helps for dealing with exam periods or online class registration where both students and academic staff require a highly critical responsive system.

For the ***capacity tier***, the ***Seagate Exos X18 NL-SAS drives*** will be applied. It can provide a high capacity which can achieve up to 18TB per unit with an excellent spinning performance (7,200 RPM spindle speed). Meanwhile, It also allows for ***storing the large archival datasets, e-library assets, past academic records and backups of research outputs*** (Seagate Technology, 2025; Bechtle AG, n.d.). Via this combination of performance and capacity tier, it can effectively separate the hot and cold data but also complies with the best practices of modern storage in the education sector. Thus, both real-time learning services and long-term academic content can coexist (Brett, 2025). Apart from that, the auto-tiering between these storage classes will help reduce the manual administration while intelligently adapting to different data usage patterns across the faculties and campuses (QSAN Technology, 2024). Overall, this approach can effectively enhance the storage performance, optimizes capacity while ensuring the data availability for both active academic operations and long-term retention needs.

Flash Memory (Refer to Appendix Tables 4.2.5 to 4.2.6)

The ***Samsung PM9A3 NVMe SSD*** is proposed as the primary flash storage solution to meet Harmoni University's increasing demand for ***high-speed data access***. As an enterprise-grade NVMe drive, it can deliver an ultra-low latency and sequential read speeds up to 6,500MB/s while providing 960GB capacity per unit, this is especially ideal for supporting VDI in computing labs and centralized LMS accessed across campuses (Samsung Semiconductor, n.d.; Network Hardwares, n.d.).

Its integration can ensure a ***fast, real-time data access in bandwidth-sensitive disciplines*** such as computer science, engineering and medical imaging. The drive also offers ***high reliability and endurance*** which is rated at 1 DWPD for 5 years. This is especially suitable for continuous workloads such as automated backups, e-assessment logging and postgraduate research simulations (Open Compute Project, n.d.). Via this enhancement, the classroom responsiveness can be improved effectively when leading to a less IT maintenance requirement and better QoS.

Tape Storage (Refer to Appendix Tables 4.2.7 to 4.2.9)

In order to address Harmoni University's challenges when dealing with secure, compliant and centralized backups across its multi-campus infrastructure, a ***hybrid tape storage solution*** is proposed. This setup will combine the ***HPE StoreEver MSL3040 Tape Library with LTO-9 cartridges*** for achieving a long-term and offline archival. At the same time, the ***Dell EMC Data Domain DD3300 will act as a VTL*** to provide a high-speed backup (up to 7.2TB per hour throughput) and restore operations.

The LTO-9 tape system offers a high compressed capacity up to 45TB per cartridge while supporting WORM functionality. This is especially ideal for ***protecting the immutable records such as exam results, surveillance footage and staff-student correspondence*** in compliance with PDPA and MoHE standards. (Hewlett Packard Enterprise, n.d.) This can perfectly solve the university's current reliance on outdated external drives and fragmented backup routines.

Meanwhile, the DD3300 VTL offers ***disk-based backup with deduplication and replication features***. Via this strategy, it can reduce the recovery time for critical systems such as virtual desktops, e-learning platforms and on-premises databases. Not only that, it also helps to ensure a fast restoration when dealing with accidental data loss or ransomware incidents. This is very useful to minimize the negative impact to the campus IT support. (Dell Technologies, n.d.-a; Dell Technologies, n.d.-b)

Storage Area Network (SAN) (Refer to Appendix Tables 4.2.10 to 4.2.11)

Since Harmoni University is currently facing performance issues, fragmented data access and limited cross-campus scalability, the ***Dell EMC PowerStore 500T*** is proposed to solve this issue. Dell EMC PowerStore 500T is a dedicated SAN system which can support both ***Fibre Channel and NVMe/TCP protocols***. It also provides low-latency ***and block-level data access*** while dealing with the crucial academic workloads such as real-time research analysis, centralized virtual desktop environments and high-speed LMS during peak academic periods. (Dell Technologies, 2024; EdTech Magazine, 2014) Meanwhile, it is also supported by RAID 5 or 6 for offering protection against disk failure using parity blocks.

By applying the SAN architecture, Harmoni University can ensure a ***consistent data throughput and high availability across campuses***. The PowerStore also provides the thin provisioning, intelligent deduplication and auto-tiering features which can perfectly fulfil the institution's need for efficient storage resource allocation and disaster recovery readiness. (Dell Technologies, 2024; LinkedIn, 2023; Enterprise Storage Forum, 2023) Not only that, the SAN will be integrated into the hybrid storage model alongside the existing Synology NAS. This allows Harmoni University to easily separate the high-performance academic data from the general file storage. (Nfina, 2025; IBM, 2024) At the same time, it also optimizes both system responsiveness and long-term scalability across faculties.

Storage Controllers (Refer to Appendix Tables 4.2.12)

RAID is proposed as the core technology integrated into the upgraded storage controller. Via integration with Dell EMC PowerStore 500T, the controller-managed RAID system can offer a ***fault-tolerant and high-speed data access***, which is essential to ***support the university's demanding academic operations such as virtual desktop environments, research databases and Learning Management System (LMS) usage*** during peak academic periods. (Dell Technologies, 2022; Lenovo, n.d.)

From the aspect of RAID level distribution, the ***RAID 10*** will be applied to ***handle the performance-critical workloads*** while ***RAID 6*** will be used to ***store long-term research archives and essential academic data*** that require high protection against dual disk failures. (DiskInternals, n.d.) These RAID levels will be intelligently managed by the active-active storage controllers. So, it can automate the process of data striping, parity generation and failover handling without disrupting the administrative operations. (JSCAPE, n.d.) By applying this, the past issues in Harmoni University such as downtime and slow file retrieval can be easily overcome.

Besides, the proposed storage controller can support the features like hot-swapping and predictive drive failure alerts. This can effectively reduce the manual maintenance while improving the system availability. (Dell Technologies, n.d.) Via this enhancement, Harmoni University's storage infrastructure can be transformed into a highly available and resilient environment which is suitable for managing the multi-campus academic usage. Meanwhile, reliable data access can also be promised at all times.

Storage Availability

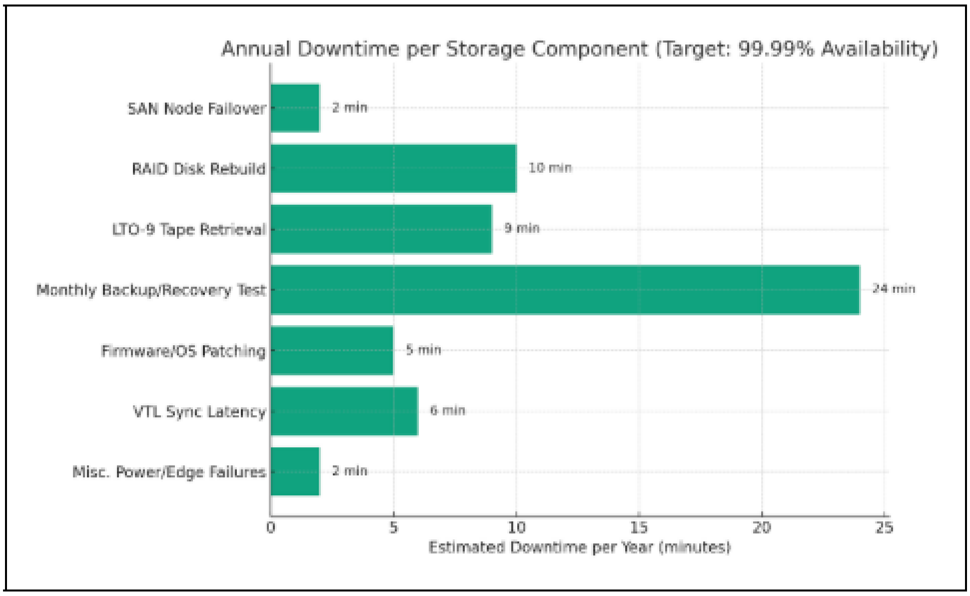

Figure 4.4.1 Aimed Annual Downtime per Storage Component

To support the academic continuity of Harmony University, the proposed storage system ***targets 99.98895% uptime*** with ***less than 53 minutes*** of ***downtime per year***, ensuring ***an uninterrupted***

access to Moodle LMS, Turnitin, student records, and the e-library. Redundancy is using ***real-time replication*** across three ***SAN nodes***, which are physically distributed across the main Bukit Jalil campus and two regional campuses (Penang and Johor) and enabling ***active-active failover*** if any one site fails. ***A 3-2-1 backup strategy*** is applied to protect ***critical data*** such as final grades of students, research outputs of labs, human resources records, and assessment logs with three copies stored on the ***primary SAN disk***, ***VTL***, and ***offsite LTO-9 tape***. The backup plan includes two backups which are ***daily incremental backups (at 2:00 AM)*** and ***weekly full backups (at 3:00 AM on Sundays)***. These two backups ensure ***rapid recovery*** for deleted coursework or corrupted teaching files. The ***backup data*** will be ***retained for 90 days*** which are aligned with the length of the semester. The ***archiving system*** can store graduation projects, transcripts and documents required by the MoHE for ***up to 30 years*** to meet PDPA and regulatory compliance. ***Monthly backup*** and ***recovery drills*** are ***conducted*** every Monday in the second week of the current month, starting from 10 a.m. to test system reliability in the event of ransomware, upgrades, or peak workloads during the semester. ***Scalability*** is achieved by ***hot-adding disk shelves*** or ***tape modules*** without service interruption, preparing for student growth, research expansion, and long-term digital content preservation.

$$Total\ Availability = 1 - (Total\ Downtime \div 525600)$$

$$Total\ Downtime = 2 + 10 + 9 + 24 + 5 + 6 + 2 = 58\ minutes\ /\ year$$

$$Total\ Availability = 1 - (58 \div 525600) = 0.0001105$$

$$Availability\ Percentage = 1 - 0.0001105 = 0.9998895 \div 100 = 99.98895\%$$

Figure 4.4.2 Calculation of Aimed Availability Percentage

Storage Performance (Refer to Appendix Table 4.4.1)

To hit the academic performance target of Harmony University's, the proposed storage system aims to achieve ***over 700,000 IOPS*** and ***6,500MB/s read throughput*** by implementing the ***Samsung PM9A3 NVMe SSDs*** (each handle up to 7.68 TB). These SSDs are available to ***support peak workloads*** such as over 2,000+ concurrent LMS logins from 8:45 AM to 9:15 AM, online assessments or virtual lab courses for the Computer Science and Engineering program. Besides, ***10K SAS hard drives*** are also used to reduce rotational latency and delay with targeting ***access times under 4ms*** and supporting 100 to 500 concurrent users for ***performance-critical but cost-sensitive tasks*** such as the virtual desktops and real-time grading portals at the same time. ***High-capacity NL-SAS hard drives (7,200 RPM, 18 TB)*** will ***handle archival workloads*** such as scanning papers and AI model datasets for the School of Engineering with ***access latency around 8 - 12 ms***. The system utilizes ***RAID 10 disk arrays*** to improve the ***responsiveness of the LMS and database*** during exams and ***RAID 6 disk arrays*** to ***protect long-term research outputs*** such as climate change field data for environmental studies and a multilingual corpus database for the School of Languages. ***NVMe and SAS interfaces*** are expected to maintain throughput which exceeds ***12Gbps during peak campus activity usage***. ***Controller cache (64 GB)*** buffers ***real-time usage*** such as e-book streaming and simulation labs while ***auto-tiering offloads*** are ***over 30% of inactive courseware data*** to cost-effective disk and at the same time it is ***preserving flash space*** for active tasks such as video conferencing and online grading.

Storage Security (Refer to Appendix Table 4.4.2)

To achieve secure, segmented, and compliant data storage across all campuses, Harmony University's storage system employs a layered security architecture. All static data is encrypted using ***AES-256 SED*** to ensure that exam scores, experimental or thesis research data, and student information records ***remain protected*** even in the event of ***physical theft or hard drive failure***. Furthermore, each SAN volume is ***logically isolated*** through ***LUN masking*** and ***bound to specific services***. For example, Learning Management System (LMS), Human Resources System or research cluster in order to ***prevent unauthorized servers accessing unrelated datasets***. The FC SAN zoning also further isolates the academic, administrative, and backup traffic for preventing the lateral movement of threats or accidental configuration errors. For example, payroll data from the human resources department cannot access student academic storage. ***Archived datasets*** such as theses, lecture recordings, and regulatory documents are encrypted and moved to a ***SED-supported cold storage layer***. ***Backup copies*** are stored following the ***3-2-1 rule***, which is one copy stored on ***off-site LTO-9 WORM tape*** (support up to 45TB) and this also meets the long-term retention requirements of the PDPA and MoHE. The backups also include an ***immutability flag*** to ***prevent ransomware tampering***. These measures ensure the university's storage architecture not only enables fast and reliable access to the storage but also maintains the data confidentiality, complies with regulatory requirements and achieves service isolation across academic, administrative and research domains.

Compute

Compute Building Blocks

<u>Existing Infrastructure (Refer to Appendix Table 5.1.1 to 5.1.4)</u>

Currently, Harmoni University is mainly applying the ***cloud-centric model with AWS Cloud9 and Amazon EC2 instances***. In the Faculty of Sciences and Technology, the AWS Cloud9 pay-as-you-go model is deployed as a browser-based cloud IDE to support Python, Java and C++ programming language. During programming lab sessions, students can ***access the coding environments without using pre-install compilers in campus labs***. Not only that, this setup allows lecturers to ***conduct virtual teaching labs*** efficiently. However, students may experience a ***high latency in running code snippets*** when the campus network connectivity is slowed down during the peak hours.

In the Student Affairs Department, ***Amazon EC2 On-Demand with t3.medium instances (2 vCPUs and 4GB RAM) is used to offer the compute power for hosting applications*** in Harmoni University. For example, student portal, attendance system and course registration platform. Although it is sufficient on regular days, the ***instance will still be overloaded during peak periods*** such as co-curriculum course registration weeks, this can result in long page loading times and frustration among students and administrative staff.

For Research Computing and Data Services, ***Amazon EC2 g5.2xlarge instances (8 vCPUs, 32GB RAM, 1× NVIDIA A10G GPU and 225GB NVMe SSD) support deep learning training, simulations and research workloads***. For example, the postgraduate students use this GPU-enabled instance to accelerate medical image recognition model training. Although performance is adequate, storing raw datasets in AWS S3 might ***raise the compliance concerns for sensitive data*** such as healthcare research.

Overall, the university's dependency on AWS services may create vulnerabilities. When AWS ***experiences disruptions***, the critical systems like the student portal, course registration platform and research workloads will become inaccessible. Meanwhile, the ***IT administrators also have a limited control over performance tuning, hardware upgrades and troubleshooting***. For instance, during peak registration periods, the team can only adjust AWS scaling options rather than upgrade local infrastructure. This will increase the dependency on external providers and operational costs.

When there is an ***interruption of service in an external provider's platform or unstable network connectivity, the cloud server will shut down*** causing the teaching, administrative process and research activities to be disrupted. Besides, the ***shared virtual resources performance is not always predictable*** especially when there is a course registration or simultaneous lab sessions which require heavy demand. In data security, the sensitive information generated through research and student records is hosted outside the university's direct control. This can easily cause the risk and concerns about the governance and confidentiality although the provider has complied to the standards.

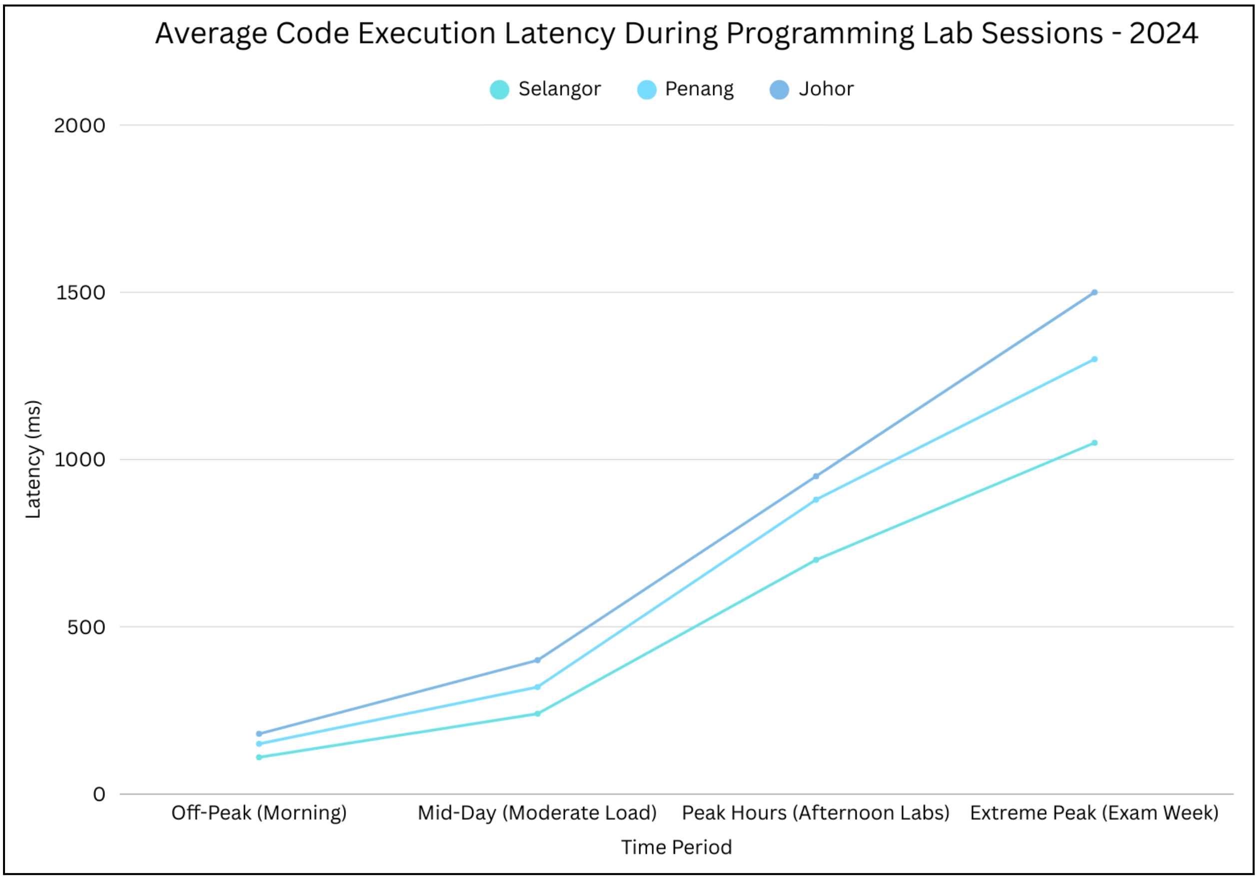

Figure 5.1.1: Average Code Execution Latency During Programming Lab Sessions - 2024

Proposed Infrastructure (Refer to Appendix Table 5.2.1)

Physical Compute Infrastructure (Refer to Appendix Table 5.2.2 to 5.2.3)

Dell PowerEdge R750 is proposed as the primary ***local rack server*** for Harmoni University due to its high performance, scalable and standardized platform which enables the university's diverse academic and research workloads. (Dell Technologies, 2023) The Dell PowerEdge R750 is a 2U rack server equipped with dual Intel Xeon Scalable processors (up to 40 cores per CPU). Meanwhile, it also supports up to 8TB of DDR5 ECC memory while accommodating up to 24 hot-swappable SAS, SATA or NVMe drives. (Dell Technologies, 2023) Via this server, the university can ***reduce the over-reliance on the fragmented mix of older and underpowered servers***. Not only that, it can help universities to ***simplify the maintenance, streamline staff training and ensure the consistent availability of computing resources*** across all 3 campuses where Selangor, Penang and Johor are located. (Dell Technologies, 2011) With the support of high performance GPU and large memory capacity, it supports the researchers and students to run the demanding applications locally. This can effectively reduce the dependency on external cloud services for data-intensive workloads. (Pluralsight, 2023)

For the ***blade server***, the ***Cisco UCS B200 M6*** is proposed for being deployed in Harmoni University. It comes with dual Intel Xeon Scalable processors, high memory capacity and NVIDIA GPUs. It is housed in a UCS 5108 chassis with central management features. (Cisco, 2023) Harmoni University is currently having a high reliance on AWS services which may cause significant latency issues in programming labs and system overload during course registration. In order to address it, the blade server can easily ***scale the resources internally while reducing dependency on external cloud providers***. This enables the teaching labs to run locally hosted IDEs with lower latency while the administrative platforms can scale to meet the peak demands during registration. (Axo Technologies, 2023; Magic EdTech, 2023)

Compute Hardware Components (Refer to Appendix Table 5.2.4)

When it comes to ***processors***, Harmoni University will adopt the ***Intel Xeon Scalable 4th Generation processors*** as the foundation for compute servers. The main reason is it offers a ***high and consistent performance and scalability*** to handle the multi-threaded academic workloads across online learning platforms and high-volume administrative applications. (Intel, 2023) Thus, the current issues of the university which is over reliance on fragmented and underpowered servers can be solved effectively due to the consistent performance from modern processor architecture across all 3 campuses. Not only that, ***each server is also equipped with up to 512 GB of DDR5 ECC memory***. This specification can provide a ***higher bandwidth for parallel tasks while enhancing the system reliability and operation smoothness during critical academic periods***. For example, online examinations and course registration where downtime can easily happen due to thousands of students simultaneous usage. (Crucial, 2023)

On the other hand, Harmoni University also plans to apply the ***NVIDIA A100 GPUs*** to ***speed up the research and advanced learning process***. This type of GPU is especially useful when handling the AI, machine learning and other data-intensive computations in different project fields. (NVIDIA, 2022) For example, healthcare, engineering and big data analytics. Since the researchers and students in university are able to process the large datasets locally, the dependency on external cloud services will be significantly reduced for improving data security and lowering operational costs. Meanwhile, ***NVMe SSDs with PCIE 5.0*** will also be applied for ***providing an ultra-fast storage access***. So, it can avoid the previous bottleneck of slowing down data retrieval from older mechanical drives. (Allion, 2023)

Compute Virtualization and Public Cloud (Refer to Appendix Table 5.2.5)

From the aspect of ***core virtualization platform***, ***VMware vSphere*** is proposed for Harmoni University to realize the ***centralized management of virtual machines through vCenter***. It can consolidate the fragmented servers into a unified pool of compute resources across all 3 campuses. The main purpose for this is to offer high reliability in supporting enterprise-scale academic workloads such as student information systems, library databases and e-learning platforms. (University of Bristol, 2021; Loadbalancer.org, 2020) Via centralizing those resources, vSphere can ***eliminate the inefficiencies of underpowered standalone servers*** when promising a consistent service availability during peak academic periods.

Not only that, ***Docker with Kubernetes (K8s)*** is also planned for handling the modern containerized applications. Docker can provide a ***lightweight method to package the applications*** while Kubernetes can ***ensure the orchestration, scaling and high availability***. Via this combination, the students and faculty can easily run their experimental applications such as machine learning models, scientific simulations and collaborative coding platforms. The researchers can ***quickly deploy the containerized environments on demand without waiting for the IT staff to provision new servers***. On the student aspect, it allows the students to have a practical exposure to cloud-native development practices which is widely used in industry as well.

In order to offload the lightweight processes, ***AWS Lambda*** is proposed as an ideal serverless computing solution in Harmoni University. It can ***automate repetitive academic and administrative tasks***. For example, auto-grading online quizzes, sending course registration reminders and analyzing real-time feedback forms. Besides, it can also effectively ***reduce the operational cost on an on-premise system*** since the compute resources are only billed when functions run. (Rajpub, 2022)

Advanced Compute Systems (Refer to Appendix Table 5.2.6 to 5.2.8)

In order to further enhance the demanding research and AI workloads, an ***HPC/AI-focused compute system*** will be used. The system integrates a high performance HPC cluster with Slurm workload manager, NVIDIA DGX Station A100 and AWS ParallelCluster for hybrid cloud scalability. The HPC cluster contains multiple rack-mounted servers which consist of high-core-count Intel Xeon Scalable processors and 512 to 1,024 GB DDR5 RAM per node, NVMe SSD storage and 10 to 25 GbE networking. The ***NVIDIA DGX Station A100*** is used for ***accelerating the deep learning and AI tasks*** while the ***Slurm will manage the job scheduling, resource allocation and fair workload distribution among multiple users***. (NVIDIA, 2022; University of Nottingham Malaysia, 2022)

This compute system is mainly used for ***offering a dedicated, predictable and high performance computing environment*** to students and researchers. This is because they frequently conduct intensive tasks which consume a large amount of computing resources. For instance, medical image recognition, engineering simulations and big data analytics. The deployment of on-premises HPC solutions can also ***solve the challenges of unpredictable performance, high operational costs and dependency on external cloud providers*** faced in AWS EC2 g5.exlarge instances as it can maintain the control over sensitive research data for protecting data security and compliance. Meanwhile, this system can also ***enable the postgraduate students and researchers to obtain hands-on experience with real-world HPC and AI environments***. Not only that, the integration between HPC systems and existing virtualization and container infrastructure can ***ensure a flexible resource allocation*** which enables both teaching and research applications to scale efficiently, even during peak periods. (3RT, 2023)

Compute Availability (Refer to Appendix Table 5.3.1)

In order to meet the proposed ***99.98% computing availability***, Harmony University will deploy ***14 Dell PowerEdge R750xs servers*** to all its branches (8 at Bukit Jalil data center and 2 each in Selangor, Penang and Johor). The ***Dell hot-swappable PSUs, fans and hard drives*** are designed to achieve ***99.999% availability*** during ***daily education activity*** such as replacement processes and support uninterrupted online courses and electronic assessment scoring. Each server is equipped with ***ECC error-correcting memory (512 GB)*** which helps to ***correct memory errors and protects critical SIS and LMS data*** such as exam scores and graduate research data sets for ***meeting 99.99% availability***. The virtualized environment is powered by ***VMware vSphere 8 Enterprise Plus*** which supports ***vMotion, high availability (HA) and dynamic resource scheduling (DRS)*** features to meet ***99.995% availability*** for approximately ***700 VMs*** used to host engineering virtual labs, artificial intelligence simulations, and real-time library portals. Failover clustering is implemented through ***Windows Server Failover Clustering*** and ***Linux Pacemaker*** for enabling workloads to be rerouted between data centers and branch offices in the event of node failure, ensuring to ***meet the 99.999% availability*** of applications such as databases, online learning platforms and video conferencing. By combining all these mechanisms, the overall system availability is calculated to be ***achieved 99.983% (~1.47 hours of downtime per year)*** and meeting the university's goal of computing access include supporting teaching continuity, secure management of student records, and advanced research activities across all campuses.

Total Availability

$$= 0.99999 \times 0.9999 \times 0.99995 \times 0.99999 \times 0.99999 \times 0.99999 \times 0.99999$$

$$= 0.9998000135 \approx 99.9800\%$$

$$1\ year = 525600\ minutes$$

Total Downtime

$$= (1 - 0.9998000135) \times 525600$$

$$\approx 105.11\ minutes/year$$

$$\approx 1.75\ hours/year$$

Table 5.3.1 Calculation for Aimed Availability and Aimed Downtime

Compute Performance (Refer Appendix Table 5.4.1, 5.4.2 & Figure 5.4.3)

To meet the performance target of Harmony University, the proposed compute infrastructure leverages modern multi-core, superscalar CPUs with hyper-threading. These operate at up to ***3.2 GHz*** and sustain ***more than 500 billion instructions per seco*****nd** at peak throughput and achieve reliable and fast performance for education and research such as practical class. By combining the ***increased clockspeeds, deeper pipelines (~20+ stages), advanced caching (64MB L3 cache) and branch prediction (~97%)***, students complete their work faster and more efficiently. For example, when compiling programming assignments of 1,000–2,000 lines now finishes in under 2 seconds. Even when CPU utilization reaches 70–80% peak load, students still have more time for debugging and learning.

The parallel execution capabilities enabled by ***Moore's Law-driven core expansion (support up to 32 cores per node)*** allow data science and statistics students to ***complete large-scale analyses of 50 million rows of data in 3 minutes***. Just within a single class period, these transforming assignments that previously required overnight work on personal laptops into tasks can be completed and discussed. The ***64MB of L3 cache and memory prefetching technology*** ensure that queries on millions of student registration and grading records return results in just less than 200 milliseconds. This allows instructors to demonstrate real-time query optimization to students and students also can practice database tuning under realistic workloads.

For AI and data science, ***superscalar pipelines combined with GPU*** acceleration shorten neural network training from ***over 40 minutes to under 15 minutes***. These support multiple experiment iterations in a single lab session. The ***enhanced hardware-assisted virtualization (Intel VT-x/AMD-V)*** allows the cluster to host over ***1,200 concurrent virtual lab environments*** with CPU overhead maintained below 10% per VM. Across the LMS, the infrastructure ***sustains <1 second response times*** for 5,000+ simultaneous users, guaranteeing uninterrupted delivery of online classes, assessments, and digital resources.

Compute Security (Refer to Appendix Table 5.5.1 to 5.5.3)

The proposed compute infrastructure integrates layered security to protect the physical systems, secure data in use and safeguard virtualized environments across all Harmony University's campuses. First is the physical security, enforced with ***HID iCLASS SE RB25F biometric readers*** with ***two units per server room entrance (8 total)*** to ensure only the ***authorized IT staff*** can access compute nodes that host critical student systems. All racks are equipped with ***APC NetBotz Rack Access PX electronic locks (10 in total)*** to ***prevent tampering*** with servers that support coursework and assessments. The ***Schneider NetBotz 750 monitoring kits (10 in total)*** have been deployed to provide an ***early warning of temperature fluctuations, vibrations or unauthorized access*** which helps to ensure continuous availability during online classes and exams. The ***Intel SGX/AMD SEV-SNP extensions*** are equipped on all 17 servers to secure the data in use together with ***256-bit AES memory encryption*** and ***TPM 2.0 modules***, ***protecting the active workloads*** such as exam grading, student submissions and research datasets. Virtualization security leverages ***Intel VT-x/AMD-V with nested paging***, ***isolating over 1,200 virtual labs*** so students can run experiments safely. A total of ***four VMware vCenter controllers (1 for each campus)*** applying the ***enhanced virtual machine templates*** and ***role-based access control (RBAC)*** which can enable students to perform practical operations on the lab without affecting the institution's systems.

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Indexes

Short Form	Full Form
Networking Protocols & Standard	
802.1X	IEEE 802.1X Port-Based Network Access Control
ACME	Automatic Certificate Management Environment
BGP	Border Gateway Protocol
CBWFQ	Class-Based Weighted Fair Queuing
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DNSSEC	Domain Name System Security Extensions
DSCP	Differentiated Services Code Point
FTP	File Transfer Protocol
HSTS	HTTP Strict Transport Security
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IP	Internet Protocol
IPsec	Internet Protocol Security
LACP	Link Aggregation Control Protocol
MSTP	Multiple Spanning Tree Protocol
NAT	Network Address Translation
NTP	Network Time Protocol
OCSP	Online Certificate Status Protocol
OSPF	Open Shortest Path First
PAT	Port Address Translation
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Service
SNMP	Simple Network Management Protocol
SSH	Secure Shell

SYSLOG	System Logging Protocol
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UDP	User Datagram Protocol
VLAN	Virtual Local Area Network
VTP	VLAN Trunking Protocol
VXLAN	Virtual Extensible LAN
Security & Encryption	
2FA	Two-Factor Authentication
ACL	Access Control List
CA	Certificate Authority
DKIM	DomainKeys Identified Mail
DMARC	Domain-based Message Authentication, Reporting and Conformance
HSTS	HTTP Strict Transport Security
IDPS	Intrusion Detection and Prevention System
OCSP	Online Certificate Status Protocol
RSA	Rivest–Shamir–Adleman (encryption algorithm)
SHA	Secure Hash Algorithm
SPF	Sender Policy Framework
SSH	Secure Shell
TLS	Transport Layer Security
VPN	Virtual Private Network
WAF	Web Application Firewall
System, Tools & Platform	
CLI	Command Line Interface
DNA Center	Digital Network Architecture Center (Cisco platform)
EEM	Embedded Event Manager (Cisco)
I/O	Input/Output

ISE	Identity Services Engine (Cisco)
LMS	Learning Management System
SIEM	Security Information and Event Management
vDS	vSphere Distributed Switch
VM	Virtual Machine
Infrastructure / Hardware	
AP	Access Point
Cat6A	Category 6 Augmented
CCTV	Closed-Circuit Television
ESXi	Elastic Sky X Integrated (VMware Hypervisor)
ISR	Integrated Services Router
NIC	Network Interface Card
NVR	Network Video Recorder
PC	Personal Computer
VTEP	VXLAN Tunnel Endpoint
Wi-Fi	Wireless Fidelity
Wi-Fi 6E	Wireless Fidelity 6 Extended
Network Architecture & Design	
HSRP	Hot Standby Router Protocol
IPAM	IP Address Management
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
OSI	Open Systems Interconnection (Model)
SDN	Software-Defined Networking
VRF	Virtual Routing and Forwarding
WAN	Wide Area Network
Education & Administration	
HR	Human Resources
SIS	Student Information System

Storage	
AES	Advanced Encryption Standard
CDE	Common Data Environment *(if used contextually; inferred from your syllabus)*
DWPD	Drive Write Per Day
FC	Fibre Channel
IAM	Identity and Access Management
IOPS	Input/Output Operations Per Second
LMS	Learning Management System
LTO	Linear Tape-Open
LUN	Logical Unit Number
MoHE	Ministry of Higher Education
NAS	Network Attached Storage
NL-SAS	Near Line Serial Attached SCSI
NVMe	Non-Volatile Memory Express
PDPA	Personal Data Protection Act
QoS	Quality of Service
RAID	Redundant Array of Independent Disks
SAN	Storage Area Network
SAS	Serial Attached SCSI
SCSI	Small Computer System Interface
SED	Self-Encrypting Drive
SSD	Solid-State Drive
TCP	Transmission Control Protocol
VDI	Virtual Desktop Infrastructure
VTL	Virtual Tape Library
Compute	
PSU	Power Supply Unit
ECC	Error-Correcting Code

SIS	Student Information System
LMS	Learning Management System
VM	Virtual Machine
HA	High Availability
DRS	Distributed Resource Scheduler
CPU	Central Processing Unit
GHz	Gigahertz
L3	Level 3 (Cache)
AI	Artificial Intelligence
VT-x	Intel Virtualization Technology
AMD-V	AMD Virtualization
HID	Hughes Identification (brand: HID Global)
SE	Secure Element
RBAC	Role-Based Access Control
SGX	Software Guard Extensions (Intel)
SEV-SNP	Secure Encrypted Virtualization – Secure Nested Paging (AMD)
AES	Advanced Encryption Standard
TPM	Trusted Platform Module
APC	American Power Conversion (brand)
GPU	Graphics Processing Unit

Appendices

1. Concept of How to Design a Campus LAN in Universiti Malaysia Perlis
   https://dmdc.unimap.edu.my/images/doc/Campus%20Network%20Design%20Guide.pdf

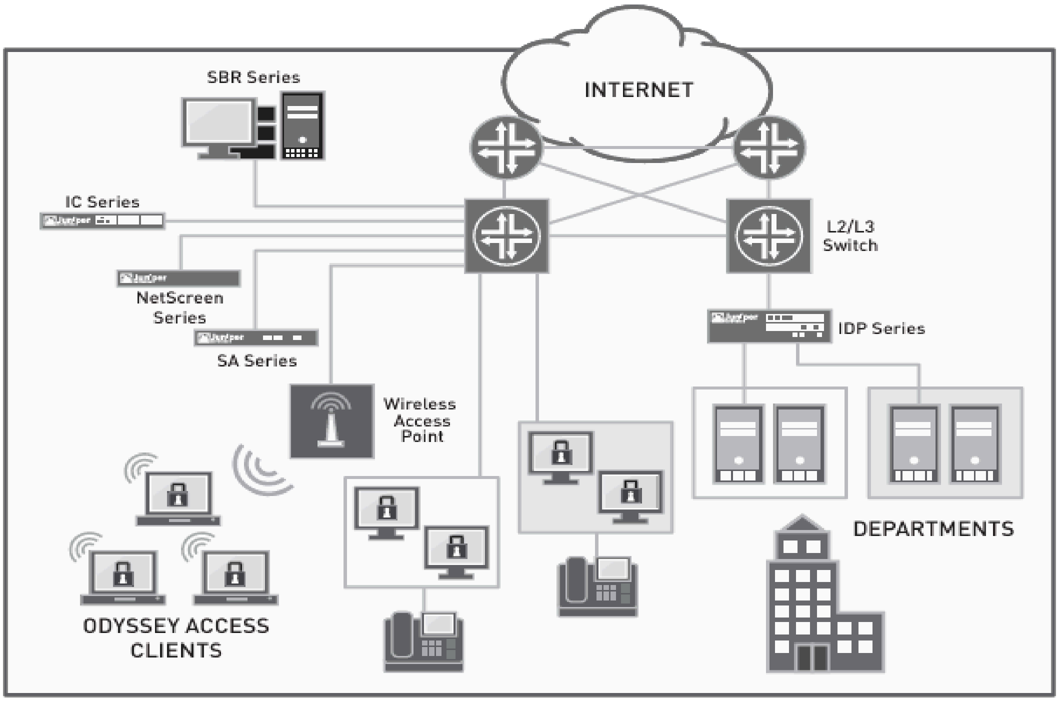


Figure 17: Campus security architecture

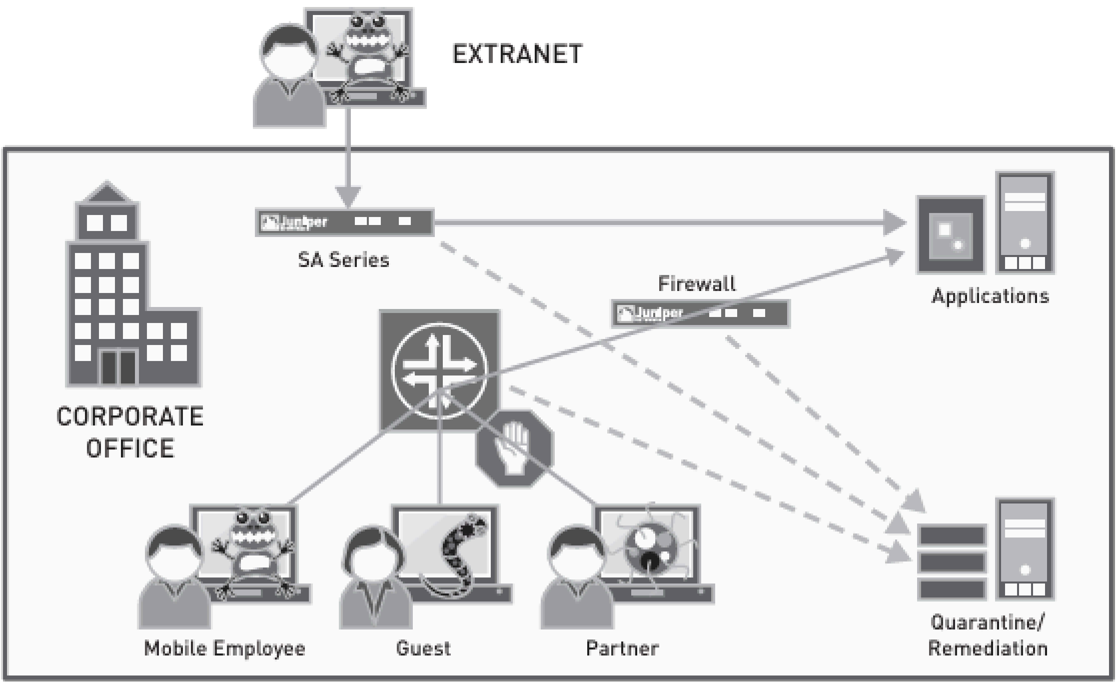
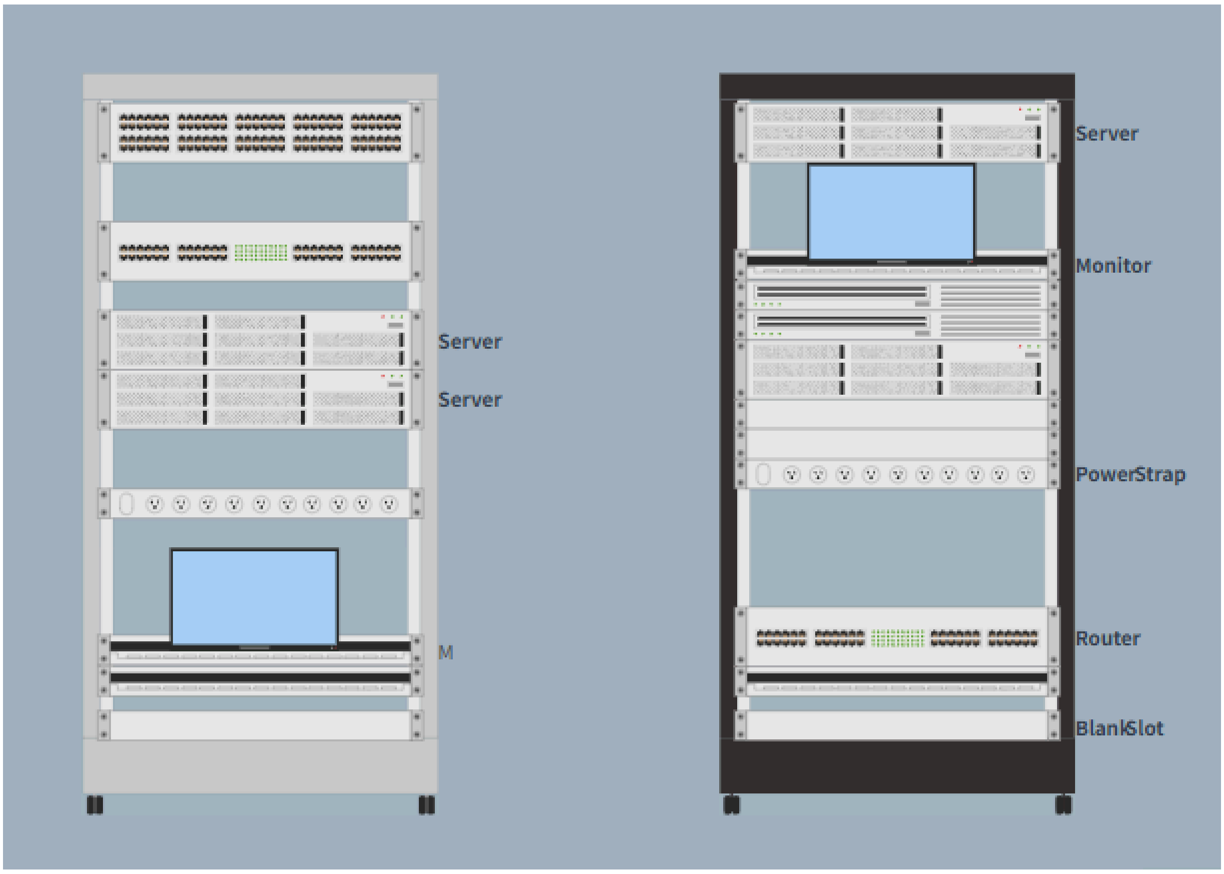
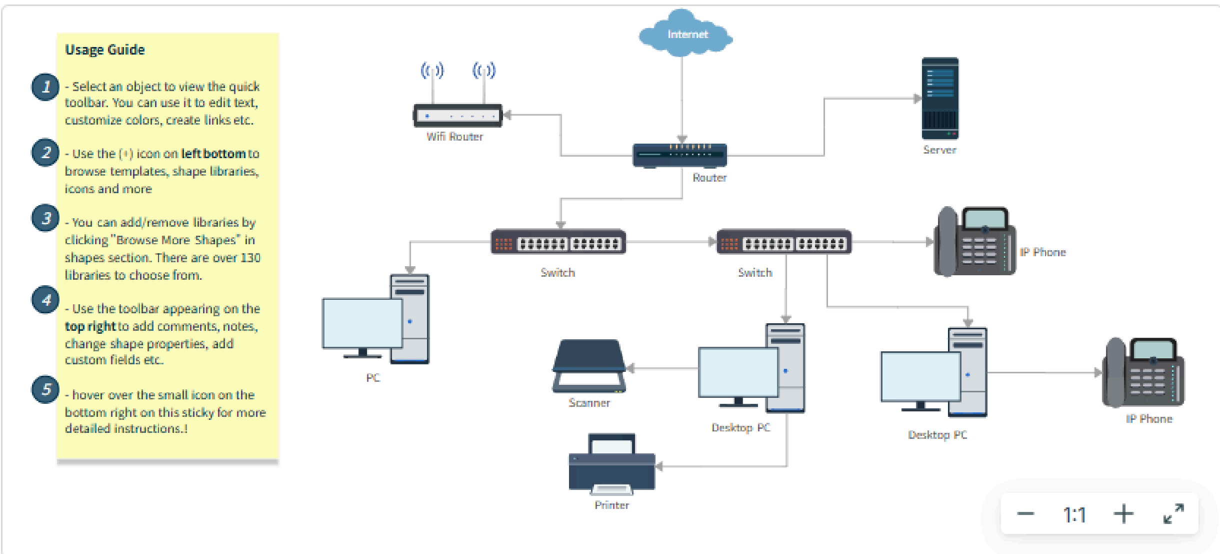


Figure 18: Enforcing endpoint health policy for all user types

1. Example of Datacenter Rack Diagram
   https://creately.com/diagram/example/OShGQq7FO8x/datacenter-rack-diagram

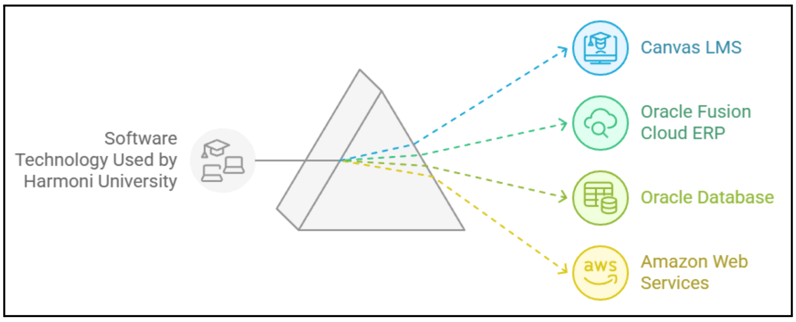


2. Example of IT Infrastructure Diagram
   https://creately.com/diagram/example/jo83qjn51/it-infrastructure-diagram



Appendix 1.0

Figure 1.1 Software Technology used by Harmoni University



Appendix 3.0

Table 3.1.1 Physical Layer Specification of Network Building Blocks

Component	Existing Infrastructure	Cost (RM)	Proposed Infrastructured	Cost (RM)
Copper Cabling	2,400m Cat6A UTP, , Belden 10GB2, PVC, unshielded, underfloor cabling	RM 240.00 / 50 m = 13,920.00	3,600m Cat6A UTP, Belden 10GXW, LSZH, overhead tray routing	RM 1177.09 / Reel (305M) = 14,125.08
Fiber Optic Cabling	80m Product Description Price (USD) Seller Website Corning OM2 Multimode Duplex Fiber Cable, SC connectors	RM 373.94 / 15 meter = 2,243.64.00	1,200m OM4 duplex fiber, Corning MIC OM4-LSZH, LC connectors, armored conduit	RM 6.39 / m = 7,644.00
Patch Panels	None	-	46 × Panduit DP245E88TGY (Cat6A); 8 x Corning LANscape 24-port fiber panels	RM 1,331.35 x 46 = 61,242.10 RM 403.87 x 8 = 3,230.96
Cable Management	No trays; mixed with power cabling underfloor	-	120 x Panduit WG30BL10 overhead trays; vertical organizers; full segregation	RM 306.47 / 1 tray = 36,776.40
ODF	None	-	6 x Corning CCH-01U 2m cords centralized	RM 1,232.47 / 1 cords

			ODF	= 7,394.82
Fiber Termination	Direct SC termination to WAN equipment	-	LC-LC patching routed to ODF	-
Internet Access	12 × TM Unifi Business Fibre, 2 Gbps	RM 369.00 / month	2× Cisco ISR 4431/K9, 2.5 Gbps, BGP, HSRP, dual WAN cards	RM 3,858.0 / 1 devices = 16,396.09
Router	1 × Cisco ISR 4331 (static routing only, no HA)	RM 561.22 / device	2 × Cisco ISR 4431/K9 (dual WAN, BGP, HSRP, IPsec VPN)	Included above
Cabling Standard	IEEE 802.3ab (1000BASE-T), NRZ, ±2.5V	-	ANSI/TIA-568.2-D, IEEE 802.3an (10GBASE-T), TIA-606-B compliant	-
Fiber Standard	IEEE 802.3z (1000BASE-SX), 850 nm, OM2	-	IEEE 802.3ae (10GBASE-SR), OM4 fiber	-
Power/Data Separation	None	-	Full segregation; LSZH-compliant cabling	-

Table 3.1.2 Data Link Layer Specification of Network Building Blocks

Component	Existing Infrastructure	Cost (RM)	Proposed Infrastructured	Cost (RM)
Switches	12 × Cisco Catalyst 2960X-24TS-L (24×1G, 4×SFP, unmanaged)	552.72 / 1 device (refurbished) = 6,632.64	200 × Cisco Catalyst C9300-24T-E (stackable, 24×1G, 2×10G uplink)	7,886.90 / 1 device = 1,577,380.00
Core Switches	None	-	2 × Cisco Catalyst 9500-40X (40×10G, Layer 3 core switching)	8,325.12 / device = 16,650.24
VLANs	3 static VLANs (admin, server, printer)	-	10 VLANs with dynamic assignment via RADIUS	-
Port Security	Not implemented	-	802.1X + MAC Authentication Bypass (MAB), 2 MACs per port	762,691.28 / year

			Cisco ISE Plus License	
Error Detection	CRC-32 only, no FEC or auto-recovery	-	CRC-32 + error monitoring via Cisco EEM	-
Wireless APs	12 × TP-Link EAP245 V3 (802.11ac, unmanaged)	391.71 / devices = 4,700.52	120 × Cisco Catalyst 9136I (Wi-Fi 6E), controller-managed via 2 x Cisco 9800-CL-K9	3,613.95 / device = 433,674.00 6,003.40 / device = 12,006.80
Wireless Security	WPA2-PSK, flat LAN	-	WPA3-Enterprise, dynamic VLANs, guest isolation	-
Protocol Support	Ethernet (IEEE 802.3), Wi-Fi (IEEE 802.11ac)	-	Ethernet (802.3), 802.1Q VLANs, LACP, Wi-Fi 6E (802.11ax), STP, MSTP	-
Access Control	None	-	Centralized RADIUS + 2 x Cisco ISE 3615 & 3 x ISE-VM-K9	55,319.90 / device = 110,639.80

Table 3.1.3 Network Layer Specification of Existing Network Building Blocks

Component	Quantity	Specification / Details
Private IP Address Range	1 subnet	192.168.0.0/16 – used for all internal devices (servers, printers, APs, etc.)
Public IP Addresses	1	113.23.215.54 (assigned by TM Unifi Business Fibre)
Static IP Usage	~280 devices	All IP addresses are statically configured manually on each host
Router	1	Cisco ISR 4331 – static routing only, NAT via PAT, no high availability
Routing Protocols	-	Static routing (manual), no OSPF/BGP
DHCP Server	0	Not used – all devices use static IPs
Inter-Campus Routing	-	Static VPN tunnels with >50ms latency, no optimization
Application Routing	-	Not implemented – no reverse proxy or content-based routing

Table 3.1.4 Network Layer Specification of Proposed Network Building Blocks

Component	Quantity	Specification / Details
Private IP Address Range	10 subnet	Segmented by function (e.g., 192.168.10.0/24 for servers, 192.168.90.0/24 for VPN, etc.)
Public IP Addresses	2	113.23.215.54 and 113.23.215.55 (from TM One and TIME dotCom)
Static IP Usage	~50 devices	Reserved for infrastructure components (e.g., routers, switches, servers)
Router	2	Cisco ISR 4431 – supports BGP, HSRP, and route failover with dual ISP links
Routing Protocols	-	Internal: OSPFv2; External: BGP with failover; Redundancy via HSRP
Core Switch (Layer 3)	2	Cisco Catalyst 9500-40X – handles inter-VLAN routing and static routes
DHCP Server	1	Cisco Catalyst 9800-CL – assigns dynamic IPs to endpoints and wireless clients
Inter-Campus Routing	-	BGP with route-maps over dual 1 Gbps leased lines with IPsec VPN failover
Reverse Proxy Servers	2	NGINX – manages Layer 7 application routing based on URL, SNI, headers

Table 3.1.5 Proposed IP Address Segmentation

Subnet	CIDR	Purpose / Allocation
Server Network	192.168.10.0/24	Static IPs for application, database, DNS servers
Storage Network	192.168.20.0/24	Static IPs for NAS/SAN and backup appliances
Wireless Clients	192.168.30.0/24	Dynamic IPs for staff and student devices
Wired Endpoints	192.168.40.0/24	DHCP for desktop PCs, printers, IP phones
Management Network	192.168.50.0/24	Switches, routers, and controller interfaces
Guest Wi-Fi VLAN	192.168.60.0/24	Isolated VLAN for unauthenticated guest users
Voice Network (VoIP)	192.168.70.0/24	IP phones and PBX system

Surveillance Network	192.168.80.0/24	IP cameras and NVR systems
VPN Pool	192.168.90.0/24	Remote access VPN clients via Cisco AnyConnect
Inter-campus Routing	192.168.100.0/24	BGP peer links between campuses

Table 3.1.6 Transport Layer Specification of Network Building Blocks

Category	Item / Protocol	Existing Infrastructure	Proposed Infrastructure
TCP Services	Web (HTTP/HTTPS)	Port 80 / 443 (unenforced)	Port 443 (TLS 1.3 enforced), Port 80 redirected to HTTPS
	SSH	Port 22 (open)	Port 22, restricted by IP-based firewall rules
	Database	MySQL 5.7 on TCP 3306, no encryption, single instance	MariaDB 10.6 on TCP 3306 with SSL, 3-node cluster replication
UDP Services	DNS	BIND9 on UDP 53, single instance	Redundant BIND9 servers on TCP/UDP 53 with internal view filtering and query logging
	DHCP	UDP 67/68 (limited use)	Full dynamic addressing on UDP 67/68 via internal DHCP servers
	NTP	Systemd-timesyncd to public pool (UDP 123)	Internal Stratum-1 NTP server using Meinberg LANTIME M300 (UDP 123)
	Syslog	Not used	Centralized logging via UDP 514 to SIEM
Firewall Control	Port Filtering	None	Enforced via Cisco ISR 4431 and Catalyst 9500 ACLs
Transport Tuning	TCP Optimization	Not implemented	TCP window scaling, SACK, connection queue tuning on Linux servers
Redundancy	DNS	None	2× BIND9 servers with round-robin failover
	Database	None	3-node MariaDB cluster with SSL, replication, and automated failover

Monitoring	Logging	No transport-level monitoring	DNS logs, database query logs, and NetFlow exported to Cisco Secure Network Analytics

Table 3.1.7 Session Layer Specification of Network Building Blocks

Specification	Existing Infrastructure	Proposed Infrastructure
VPN Type	Site-to-Site (Static)	Site-to-Site and Remote Access (Dynamic)
IPsec Version	IKEv1	IKEv2 with AES-256-GCM
Encryption Algorithm	AES-256	AES-256-GCM
Integrity Algorithm	SHA-1	SHA-256
Key Exchange Group	DH Group 5 (1536-bit)	DH Group 14 (2048-bit)
Tunnel Capacity	Max 250 tunnels	Up to 1,500 tunnels per gateway
VPN Throughput	100 Mbps	2.5 Gbps per router
Redundancy	None	Dual active-active gateways
Routing Protocol	Static Routing	BGP with failover
Dead Peer Detection (DPD)	Not available	Enabled
Session Logging	Not implemented	Centralized via Cisco Secure Network Analytics
Remote Access VPN	Not available	Cisco AnyConnect with 2FA
Session Timeout	Not configured	Enforced (e.g., 15 minutes idle)
VPN VLAN	Not defined	Dedicated: 192.168.90.0/24
Firewall Enforcement	None	Enabled with restricted access rules

Table 3.1.8 Presentation Layer Specification of Network Building Blocks

Category	Existing Infrastructure	Proposed Infrastructure
TLS/SSL Usage	Partial (only external services)	Full (public and internal services)
TLS Version	TLS 1.0 / 1.1 (outdated)	TLS 1.3
Certificate Type	Self-signed	CA-signed.

		Free via Let's Encrypt (Optional: RM 300–3000/year for commercial certs)
Certificate Management	Manual, per system	Automated via centralized CA (e.g., HashiCorp Vault with ACME)
Certificate Features	No renewal tracking, no automation	Auto-renewal, expiration alerts, lifecycle management
Security Policies	None	Enforced HSTS, OCSP stapling, SHA-256 signing, 2048-bit RSA keys
TLS on Internal Services	Not implemented	Enabled on MariaDB, LDAP, SMTP, SFTP
HTTPS Enforcement	Optional	Redirect all HTTP to HTTPS via reverse proxy (NGINX)
Reverse Proxy	Not in use	NGINX (TLS termination, inspection, policy enforcement)
Monitoring	Not available	Integrated with SIEM for TLS-related event logging

Table 3.1.9 Application Layer Specification of Network Building Blocks

Category	Existing Infrastructure	Proposed Infrastructure
DNS	Single BIND9 (no DNSSEC)	2× BIND9 (Ubuntu 22.04) with DNSSEC, load balancing
IP Management	Manual spreadsheet	phpIPAM (High Availability VM)
NTP	systemd-timesyncd, external source	2 x Internal Meinberg LANTIME M300 (Stratum-1, GPS antenna) RM 1,785.71 x 2 = RM 3,571.42
Email	Postfix + Dovecot (no TLS)	Postfix (SMTP 25/465/587) + Dovecot (POP3S 995) + TLS, SPF/DKIM/DMARC
File Transfer	FTP (vsftpd, unencrypted)	SFTP via OpenSSH
Web Services	HTTP, optional self-signed HTTPS	HTTPS enforced, NGINX reverse proxy with TLS 1.3
Application Security	No WAF, no monitoring	ModSecurity WAF + SIEM integration

Session Management	Limited to app logic	Managed via reverse proxy and firewall
Ports Used	53, 80, 110, 21	53, 443, 995, 123, 22, 465, 587

Table 3.2.1 Existing VLAN Table

VLAN ID	Name	Purpose	Subnet	Tagged?	Segmentation
1	Default	Unused / Native VLAN		No	Flat network
10	Admin	Admin PCs	192.168.1.0/24	No	No isolation
20	Server	Servers	192.168.2.0/24	No	No security enforcement
30	Printer	Shared Printers	192.168.3.0/24	No	Shared LAN

Table 3.2.2 Existing VLAN Tagging Table

Switch Port	Port Role	VLAN Mode	Tagged VLANs	Untagged VLAN	Comments
Fa0/1	Access port	Access	None	VLAN 10	Connected to Admin PC
Fa0/2	Access port	Access	None	VLAN 20	Connected to Guest Access Point
Fa0/3	Access port	Access	None	VLAN 30	Shared Printer Port
Fa0/24	Uplink port	Trunk (Misconfigured)	Not configured	VLAN 1	Trunking inconsistently applied; default/native VLAN in use

Table 3.2.3 Existing Inter-VLAN Routing Table

Router	Interface	Subinterface	VLAN ID	IP Address/Subnet	Routing Type	Comments
Cisco ISR4331	Gig0/0/0	Gig0/0/0.10	10	192.168.1.1/24	Static	Routes traffic for

						Admin VLAN
Cisco ISR4331	Gig0/0/0	Gig0/0/0.20	20	192.168.2.1/24	Static	Routes traffic for Server VLAN
Cisco ISR4331	Gig0/0/0	Gig0/0/0.30	30	192.168.3.1/24	Static	Routes traffic for Printer VLAN

Table 3.2.4 Existing VMware Standard vSwitch (vSS) Configuration

vSwitch	Hosts	Port Group	VLAN	Purpose	Uplinks	Limitations
vSwitch0	ESXi-01 to 04	Mgmt Network	10	Host management	1×1GbE (No LACP)	No redundancy, no monitoring
vSwitch1	ESXi-01 to 04	Guest Wi-Fi	20	Guest VM traffic	1×1GbE	No ACLs, no isolation
vSwitch2	ESXi-01 to 04	Backend Servers	30	Server traffic	2×1GbE (Teamed)	No LACP, basic teaming only
vSwitch3	ESXi-01 to 02	vMotion + NFS	40	Storage + vMotion	1×1GbE	No bandwidth control, no QoS

Table 3.2.5 Proposed VLAN Table

VLAN ID	Name	Purpose	Subnet	Addressing
1	Default	Unused / Native VLAN		
10	Admin	Admin PCs	192.168.10.0/24	Static + DHCP
20	Server	Servers	192.168.20.0/24	Static
30	Storage	Shared Printers	192.168.30.0/24	Static
40	Wired	Office PCs and devices	192.168.40.0/24	DHCP via controller

	Clients			
50	Wireless Staff	Authenticated staff/student wireless users	192.168.50.0/24	DHCP via controller
60	Guest Wi-Fi	Unauthenticated guest network (Internet only)	192.168.60.0/24	DHCP via controller
70	VoIP	IP Phones and PBX system	192.168.70.0/24	Static/DHCP
80	CCTV	Surveillance cameras and NVR	192.168.80.0/24	Static
90	VPN	Cisco AnyConnect remote VPN clients	192.168.90.0/24	DHCP via VPN Gateway
99	Manage ment	Network equipment management	192.168.99.0/24	Static

Table 3.2.6 Proposed VLAN Tagging Table

Switch Port(s)	Port Role	VLAN Mode	Tagged VLANs	Untagged VLAN	Comments
Port 1–24	Access Ports	Access	None	Varies (10–80)	Connects to Admin PCs, servers, storage, wired clients, etc.
Port 25–28	Trunk Uplinks	Trunk	10, 20, 30, 40, 50, 60, 70, 80, 90, 99	None	Uplinks to core/distribut ion switches
Port 29–30	ESXi Hosts	Trunk	20, 30, 40, 50, 70, 80, 99	VLAN 30	Handles VM traffic, storage, VoIP, CCTV, mgmt from hypervisors
Port 31	Firewall Interface	Trunk	10, 20, 60, 90, 99	None	For security zoning, Internet/VPN breakout
Port 32	Controller Interface	Trunk	40, 50, 60	None	Connects to DHCP controller for

					client VLANs

Table 3.2.7 Proposed Inter-VLAN Routing Table

Device	Interface / SVI	VLAN ID	IP/Subnet	Routing Method	Purpose / Comments
Core Switch / Router	VLAN 10	10	192.168.10.1/24	OSPF + VRF	Admin PCs – IT staff, isolated via VRF
Core Switch / Router	VLAN 20	20	192.168.20.1/24	OSPF + VRF	Backend servers – static IPs
Core Switch / Router	VLAN 30	30	192.168.30.1/24	OSPF + VRF	Storage/Printers – shared infrastructure
Core Switch / Router	VLAN 40	40	192.168.40.1/24	OSPF + VRF	Wired client devices – DHCP via controller
Core Switch / Router	VLAN 50	50	192.168.50.1/24	OSPF + VRF	Authenticated wireless users – DHCP + controller
Core Switch / Router	VLAN 60	60	192.168.60.1/24	OSPF + VRF	Guest Wi-Fi – Internet-only access (ACL/NAT at firewall)
Core Switch / Router	VLAN 70	70	192.168.70.1/24	OSPF + VRF	VoIP phones and PBX traffic
Core Switch / Router	VLAN 80	80	192.168.80.1/24	OSPF + VRF	CCTV cameras, NVR devices
Core Switch / Router	VLAN 90	90	192.168.90.1/24	OSPF + VRF	Cisco AnyConnect VPN clients
Core Switch / Router	VLAN 99	99	192.168.99.1/24	OSPF + VRF	Network device

					management – out-of-band

Table 3.2.8 Proposed VRF Instances Table

VRF Name	Associated Department / Function	IP Address Range	Routing Protocol	Inter-VRF Route Leaking?	Firewall Policy Zone
VRF-Admin	Administrative Systems	192.168.10.0/24	OSPF	No	mgmt_zone
VRF-Server	Core Servers	192.168.20.0/24	OSPF	Yes (to Admin)	server_zone
VRF-Storage	Storage & Printers	192.168.30.0/24	OSPF	Yes (to Server)	infra_zone
VRF-Wired	Wired Office Clients	192.168.40.0/24	OSPF	Yes (to Admin, Server)	wired_zone
VRF-Wireless	Wireless Staff/Student Access	192.168.50.0/24	OSPF	Yes (to Internet, ACL-based)	wireless_zone
VRF-Guest	Guest Wi-Fi	192.168.60.0/24	OSPF	No (Internet only)	guest_zone
VRF-VoIP	VoIP Phones and PBX	192.168.70.0/24	OSPF	Yes (to Admin, Server)	voice_zone
VRF-CCTV	Surveillance Cameras and NVR	192.168.80.0/24	OSPF	No	cctv_zone
VRF-VPN	VPN Clients (Cisco AnyConnect)	192.168.90.0/24	OSPF	Yes (to Admin, Server)	vpn_zone
VRF-Mgmt	Network Management Interfaces	192.168.99.0/24	OSPF	No	mgmt_zone

Table 3.2.9 Proposed VRF Interface Assignments Table

VRF Name	Router Interface	IP Address	Connected Device / VLAN

VRF-Admin	Gig0/0/1	192.168.10.1	VLAN 10 – Admin PCs
VRF-Server	Gig0/0/2	192.168.20.1	VLAN 20 – Server Infrastructure
VRF-Storage	Gig0/0/3	192.168.30.1	VLAN 30 – Storage / Printers
VRF-Wired	Gig0/0/4.40	192.168.40.1	VLAN 40 – Wired Office Clients
VRF-Wireless	Gig0/0/4.50	192.168.50.1	VLAN 50 – Wireless Staff / Students
VRF-Guest	Gig0/0/4.60	192.168.60.1	VLAN 60 – Guest Wi-Fi
VRF-VoIP	Gig0/0/4.70	192.168.70.1	VLAN 70 – IP Phones / PBX
VRF-CCTV	Gig0/0/4.80	192.168.80.1	VLAN 80 – Surveillance / NVR
VRF-VPN	Gig0/0/5	192.168.90.1	VLAN 90 – AnyConnect VPN Clients
VRF-Mgmt	Gig0/0/6	192.168.99.1	VLAN 99 – Network Management Interfaces

Table 3.2.10 Proposed Route Redistribution and Route Leaking Policy Table

From VRF	To VRF / Destination	Method	Allowed Subnets	Protocol Used	Remarks
VRF-Server	VRF-Admin	Route Leaking	192.168.10.0/24	OSPF + route-map	Admin systems require access to server resources.
VRF-Storage	VRF-Server	Internal Leaking	192.168.30.0/24	OSPF + prefix-list	Shared storage and print access required by backend servers.
VRF-Wired	VRF-Admin	Controlled Leaking	192.168.10.0/24	OSPF + ACL	Wired clients need limited

					access to Admin services.
VRF-Wired	VRF-Server	Controlled Leaking	192.168.20.0/24	OSPF + ACL	Wired users need access to internal applications or databases.
VRF-Wireless	Internet	NAT	0.0.0.0/0	Static Route + NAT	Wireless staff/students require internet access via firewall gateway.
VRF-Guest	Internet	NAT (Isolated)	0.0.0.0/0	Static Route + NAT	Guest users get internet-only access via ACLs.
VRF-VPN	VRF-Admin	Route Leaking	192.168.10.0/24	OSPF + route-filter	VPN users need access to internal admin resources.
VRF-VPN	VRF-Server	Route Leaking	192.168.20.0/24	OSPF + route-filter	Remote workers need server connectivity through VPN.
VRF-VoIP	VRF-Admin	Route Leaking	192.168.10.0/24	OSPF + prefix-list	VoIP system must interact with call control/admin interfaces.
VRF-VoIP	VRF-Server	Route Leaking	192.168.20.0/24	OSPF + prefix-list	PBX backend and voicemail services hosted on core servers.
VRF-CCTV	None	Isolation Only	N/A	N/A	Surveillance zone is completely isolated; no cross-VRF

					communicati on.
VRF-Mgmt	None	Isolation Only	N/A	N/A	Management network is isolated from all user/producti on VRFs for security.

Table 3.2.11 Proposed Port Group Assignment Table

Port Group Name	VLAN ID	Purpose	Private VLAN	Security Policies
Admin-PG	10	Administrative systems (Admin PCs)	No	Promiscuous: DisabledMAC: AcceptForged Tx: Reject
Server-PG	20	Core backend servers	No	Promiscuous: DisabledMAC: RejectForged Tx: Reject
Storage-PG	30	Shared storage and printers	No	Promiscuous: DisabledMAC: RejectForged Tx: Reject
WiredClient-PG	40	Wired office PCs and devices	No	Promiscuous: DisabledMAC: AcceptForged Tx: Reject
WirelessStaff-P G	50	Authenticated wireless staff/students	No	Promiscuous: DisabledMAC: RejectForged Tx: Reject
GuestWiFi-PG	60	Guest Wi-Fi (Internet-only, isolated)	Yes (Isolated)	Promiscuous: DisabledMAC: RejectForged Tx: Reject
VoIP-PG	70	VoIP phones and PBX traffic	No	Promiscuous: DisabledMAC: AcceptForged Tx: Reject

CCTV-PG	80	CCTV cameras and NVR system traffic	Yes (Isolated)	Promiscuous: DisabledMAC: RejectForged Tx: Reject
VPN-PG	90	Cisco AnyConnect VPN client traffic	No	Promiscuous: DisabledMAC: RejectForged Tx: Reject
Mgmt-PG	99	Network equipment and hypervisor management	Yes (Promiscuous)	Promiscuous: Enabled (Restricted)MAC: AcceptForged Tx: Reject

Table 3.2.12 Proposed VXLAN Setup Table

VXLAN VNI	Segment Name	Purpose	Mapped VLAN	Assigned Devices / Zones
5010	Admin	Isolated transport for administrative systems	10	Admin VMs, monitoring tools
5020	Server	Core backend server access	20	Application servers, DBs, NAS
5030	Storage	Storage, print services, backup traffic	30	Shared printers, storage targets
5040	WiredClients	Office PCs and departmental wired clients	40	Wired VLAN access for staff
5050	WirelessStaff	Authenticated wireless network for staff/students	50	Wireless controllers, authenticated WLAN clients
5060	GuestWiFi	Guest-only Internet access (isolated)	60	Guest Wi-Fi controllers
5070	VoIP	Voice traffic isolation (phones, PBX systems)	70	IP phones, VoIP controllers

5080	CCTV	Surveillance camera feeds, NVR communication	80	CCTV cameras, recorders
5090	VPN	Remote AnyConnect VPN user access	90	VPN gateway traffic
5099	Management	Internal control plane traffic	99	Switches, firewalls, ESXi management interfaces

Table 3.2.13 Proposed SDN Setup Table

Component	Device / Tool	Role	Protocol / Interface	Functionality Enabled
SDN Controller	Cisco DNA Center	Central policy/control platform	RESTCONF, NETCONF, HTTPS	Centralized config, segmentation, automation, topology visualization
Core Switches	Cisco Catalyst 9500	Aggregation + Routing layer	NETCONF, SNMP	VXLAN config, VRF management, traffic telemetry, OSPF/BGP routing
Access Switches	Cisco Catalyst 9300	Edge access and segmentation	NETCONF, RESTCONF	Dynamic VLAN/VXLAN assignment, NAC enforcement
Hypervisors	VMware ESXi with NSX-v/NSX-T	SDN edge for virtual workloads	NSX APIs, OpenFlow (optional)	VXLAN tunneling, distributed firewalling, vDS management
Firewall / UTM	Cisco Firepower / Palo Alto	East-West and North-South security	REST API, Syslog, SNMP	Enforced segmentation, ACLs, threat detection, microsegmentation

WAN Router	Cisco ISR 4000 Series	Hybrid WAN/Internet edge	BGP, IPSec, NETCONF	VRF interconnect, SD-WAN routing, VPN termination

Table 3.2.14 Proposed Network Virtualization Setup Cost Estimation

Aspect	Item	Estimated Cost (RM)
VLANs	Configuration Labour (10 hours)	RM 2,350
	Staff Training (2 persons)	RM 4,700
VRF	Cisco Network Advantage Licenses (4)	RM 14,100
	Configuration Labour (20 hours)	RM 5,640
Virtual Switch	Software Setup and VLAN Mapping	RM 2,820
	Monitoring and Testing Tools (1 unit)	RM 2,350
VXLAN	Overlay Config and Policy Setup	RM 5,640
	Troubleshooting Tools License	RM 3,760
Software-Defined Networking (SDN)	Cisco DNA Essentials Licenses	RM 14,100
	Training and Controller Setup	RM 9,400
	Subtotal:	RM 64,860

Table 3.4.1 Network Performance Configuration Table

VLAN ID	VLAN Name	Throughput Requirement	Latency Target	QoS Priority Level	WAN Compression
1	Default	Best Effort (100 Mbps)	≤ 50 ms	Low	Not applicable
10	Admin	1 Gbps	≤ 10 ms	Medium	Enabled (40% est. reduction)
20	Server	≥ 1 Gbps	≤ 10 ms	High	Enabled (60% est. reduction)
30	Storage	≥ 1 Gbps	≤ 15 ms	Low (except off-peak)	Enabled (50% est. reduction)

40	Wired Clients	1 Gbps	≤ 20 ms	Medium	Enabled
50	Wireless Staff	300 Mbps – 1 Gbps	≤ 25 ms	Medium	Optional (based on campus demand)
60	Guest Wi-Fi	100–300 Mbps (capped)	≤ 50 ms	Low	Not enabled
70	VoIP	100 Mbps per segment	≤ 3 ms (intra), ≤ 15 ms (inter)	High	Not required
80	CCTV	100–300 Mbps	≤ 10 ms	Medium	Not enabled
90	VPN	500 Mbps – 1 Gbps	≤ 10 ms	High	Enabled (especially inter-campus)
99	Management	1 Gbps	≤ 10 ms	High	Enabled (for backup syncs)

Table 3.5.1 Network Security Configurations by Component

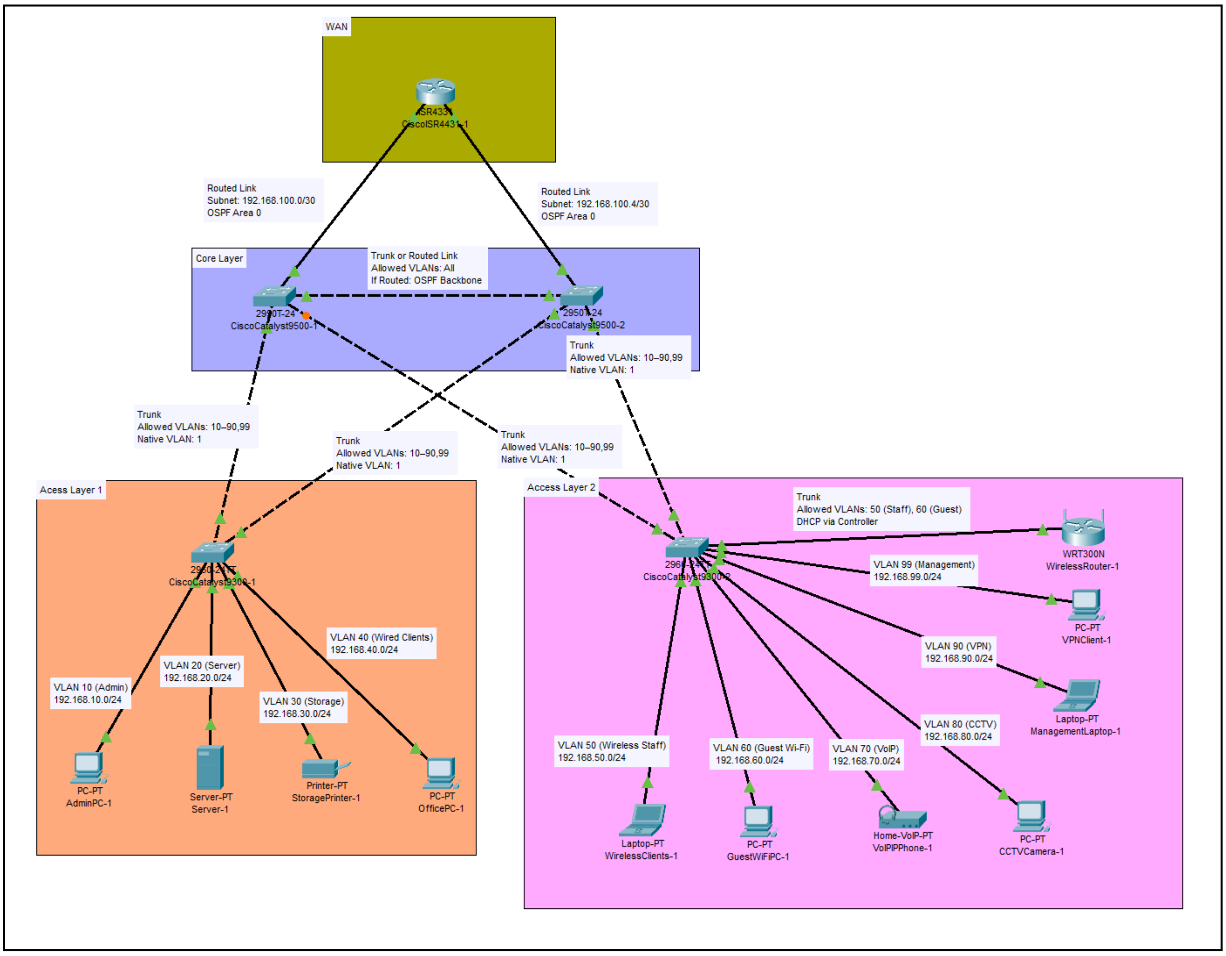
Security Component	Configuration/Setup
Encryption (IPsec VPN)	• IPsec tunnel (IKEv2, AES-256, SHA-2) between Selangor, Penang, and Johor routers • VPN for remote staff using SSL VPN
Firewall (Edge)	• Stateful inspection enabled • Deny all by default • Allow: HTTPS, DNS, VoIP to internal systems
Firewall (Internal)	• Inter-VLAN access control • Permit only required services such as VoIP to VoIP VLAN & HTTP to Web VLAN
Segmentation	• VLANs assigned by function: Admin (10), Server (20), Storage (30), Clients (40), Wireless (50), Guest (60), CCTV (70), VoIP (80), VPN (90), Management (100); VRFs used to isolate routing tables
IDS/IPS	• Enabled on core switches • Rules for brute-force login, port scan, abnormal traffic spikes • Automatic blocking enabled

RADIUS Authentication	• Cisco ISE or FreeRADIUS • Integrated with Active Directory • Role-based access for Wi-Fi, VPN and admin consoles

Table 3.5.2 VLAN Security Policies Overview

VLAN Name	VLAN ID	Key Security Features
Admin	10	• Access via RADIUS authentication • Firewalled from guest and wireless VLANs
Server	20	• Internal-only access • No external access • Monitored by IDS
Storage	30	• Restricted to Admin VLAN • Encrypted backup channels
Wired Clients	40	• Limited access to Server VLAN via ACLs • DHCP snooping enabled
Wireless Staff	50	• WPA3 Enterprise with RADIUS • No direct access to storage or CCTV VLANs
Guest Wi-Fi	60	• Internet-only • Isolated using Layer 3 filtering • No local network access
CCTV	70	• Segmented and firewalled • Only NVR has outbound access
VoIP	80	• Only VoIP traffic permitted • QoS markings enforced via DSCP
VPN	90	• Encrypted remote access • ACLs restrict routes available to VPN clients
Management	100	• Accessible only by IT team • Multi-factor RADIUS authentication required

Figure 3.6.1: Network Topology of Harmoni University


WAN
CiscoISR4431-1
Routed Link
Subnet: 192.168.100.0/30
OSPF Area 0
Routed Link
Subnet: 192.168.100.4/30
OSPF Area 0
Core Layer
Trunk or Routed Link
Allowed VLANs: All
If Routed: OSPF Backbone
CiscoCatalyst9500-1
CiscoCatalyst9500-2
Trunk
Allowed VLANs: 10–90,99
Native VLAN: 1
Trunk
Allowed VLANs: 10–90,99
Native VLAN: 1
Trunk
Allowed VLANs: 10–90,99
Native VLAN: 1
Trunk
Allowed VLANs: 10–90,99
Native VLAN: 1
Acess Layer 1
CiscoCatalyst9300-1
VLAN 10 (Admin)
192.168.10.0/24
VLAN 20 (Server)
192.168.20.0/24
VLAN 30 (Storage)
192.168.30.0/24
VLAN 40 (Wired Clients)
192.168.40.0/24
PC-PT
AdminPC-1
Server-PT
Server-1
Printer-PT
StoragePrinter-1
PC-PT
OfficePC-1
Access Layer 2
CiscoCatalyst9300-2
Trunk
Allowed VLANs: 50 (Staff), 60 (Guest)
DHCP via Controller
WRT300N
WirelessRouter-1
VLAN 99 (Management)
192.168.99.0/24
PC-PT
VPNClient-1
VLAN 90 (VPN)
192.168.90.0/24
Laptop-PT
ManagementLaptop-1
VLAN 80 (CCTV)
192.168.80.0/24
VLAN 50 (Wireless Staff)
192.168.50.0/24
VLAN 60 (Guest Wi-Fi)
192.168.60.0/24
VLAN 70 (VoIP)
192.168.70.0/24
Laptop-PT
WirelessClients-1
PC-PT
GuestWiFiPC-1
Home-VoIP-PT
VoIPIPPhone-1
PC-PT
CCTVCamera-1

Appendix 4.0

Table 4.1.1 Summary of Existing Storage Infrastructure

Storage Type	Component	Model	Department Usage	Purpose
Cloud	Amazon S3	N/A (cloud service)	Faculty of Business, Procurement Division	Store research papers, student work, vendor files
On-premises	Network Storage (NAS)	Synology SA6400	Library, Academic Admin, Internal Staff	Shared files, e-books, academic metadata

Table 4.1.2 Existing Storage Infrastructure - Amazon S3 Configuration

Attribute	Specification
Storage Type	Cloud-based Object Storage (Public Cloud)
Service Provider	Amazon Web Services (AWS)
Model/Service	Amazon S3 Standard
Deployment Region	AWS Singapore Region (ap-southeast-1)
Storage Capacity	Scalable (Pay-per-use, no fixed upper limit)
Redundancy	Multi-AZ (data automatically replicated across multiple data centers)
Access Method	● HTTPS ● REST API ● AWS SDK
Security Features	● IAM roles & policies ● S3 bucket policies ● Server-side encryption (SSE-S3, SSE-KMS)
Use Case at University	● Faculty of Business: exam scripts, research papers, coursework ● Procurement Division: billing records, vendor documents
Limitations	● Internet-dependent ● High egress costs for large downloads ● Complex IAM setup

Table 4.1.3 Existing Storage Infrastructure - Synology SA6400 NAS Specification

Attribute	Specification
Storage Type	Network-Attached Storage (NAS)
Vendor	Synology Inc.
Model	Synology SA6400
Deployment Site	University Server Room (Central Campus)
Raw Capacity	Up to 1.5PB with expansion units (based on 60-bay configuration with expansion)
RAID Support	RAID 0/1/5/6/10, Synology Hybrid RAID (SHR)
Network Access	SMB, NFS, AFP, FTP over LAN (1/10GbE supported)
Security Features	● ACL-based permission ● Built-in firewall ● Encrypted folders
Use Case at University	● Library & Learning Division: academic metadata, e-books ● Admin Staff: shared work files
Limitations	● Single-site access only ● No cross-campus failover ● Not suited for block-level storage or VM hosting

Table 4.2.1 Proposed Storage Infrastructure - Full Cost Estimation

Storage Component	Details / Use Case	Units	Unit Price (RM)	Total Cost (RM)
Mechanical Hard Disks				
Seagate Exos 10K.2 (600GB SAS)	VM storage, LMS, Admin Systems	40	950	38,000
Seagate Exos X18 (18TB NL-SAS)	Library, Research Nodes, Archive Backups	30	2,800	84,000
Subtotal - HDD				**122,000**
Flash Memory				
Samsung PM9A3 NVMe SSD (U.2 2.5")	Computing Labs	20	1,000	20,000
	Central LMS Servers	6		6,000
	Research Cluster	8		8,000

	Nodes			
	Backup Servers & Assessment Platforms	4		4,000
Subtotal - Flash				**38,000**
Tape Storage				
HPE StoreEver MSL3040	Tape library base unit	1	46,000	46,000
LTO-9 Tape Drives	Tape drive modules	2	19,000	38,000
LTO-9 Cartridges (45TB)	Long-term archival storage	20	700	14,000
Dell EMC PowerProtect DD3300	VTL appliance with deduplication	1	105,000	105,000
VTL Software License	Enables backup/cloud/dedupe features	1	30,000	30,000
Subtotal - Tape/VTL				**233,000**
Storage Area Network (SAN)				
Dell EMC PowerStore 500T	All-flash SAN appliance	1	150,000	150,000
Brocade 6505 FC Switch	Fibre Channel switching	2	62,000	124,000
FC HBA (Dual Port)	Server Fibre Channel adapters	4	3,500	14,000
Fibre Cables & SFP+ Optics	Interconnect cabling and modules	10	400	4,000
Subtotal - SAN				**292,000**
Total Estimated Cost				**685,000**

Figure 4.2.1 Student Population in Harmoni University (2020 - 2024)

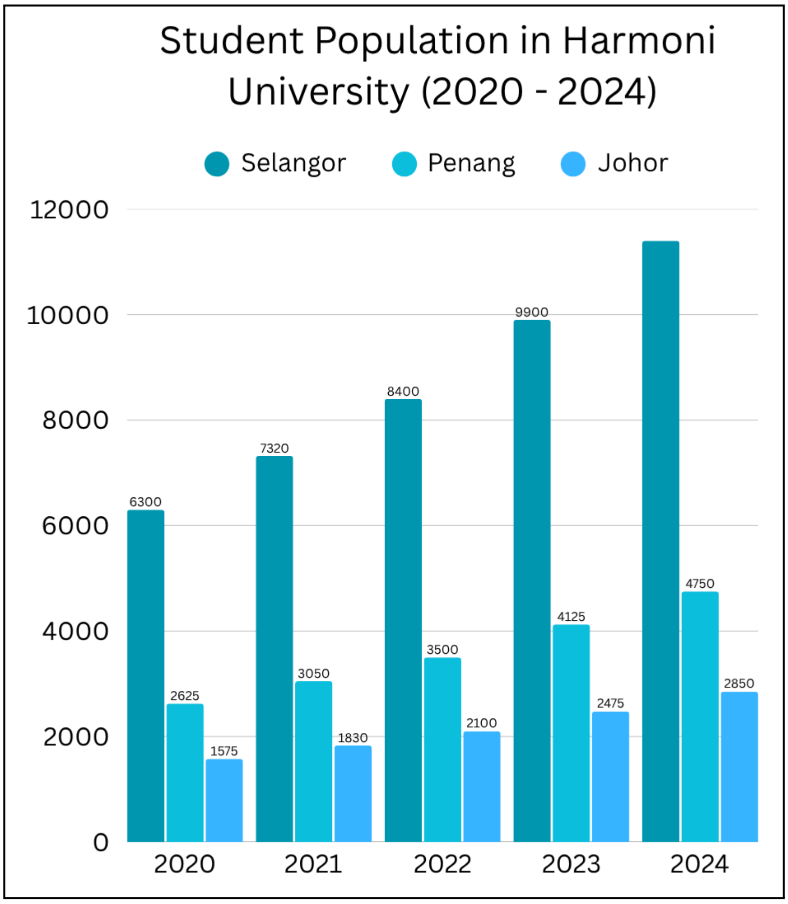


Figure 4.2.2 Student Population in Harmoni University (2020 - 2024)

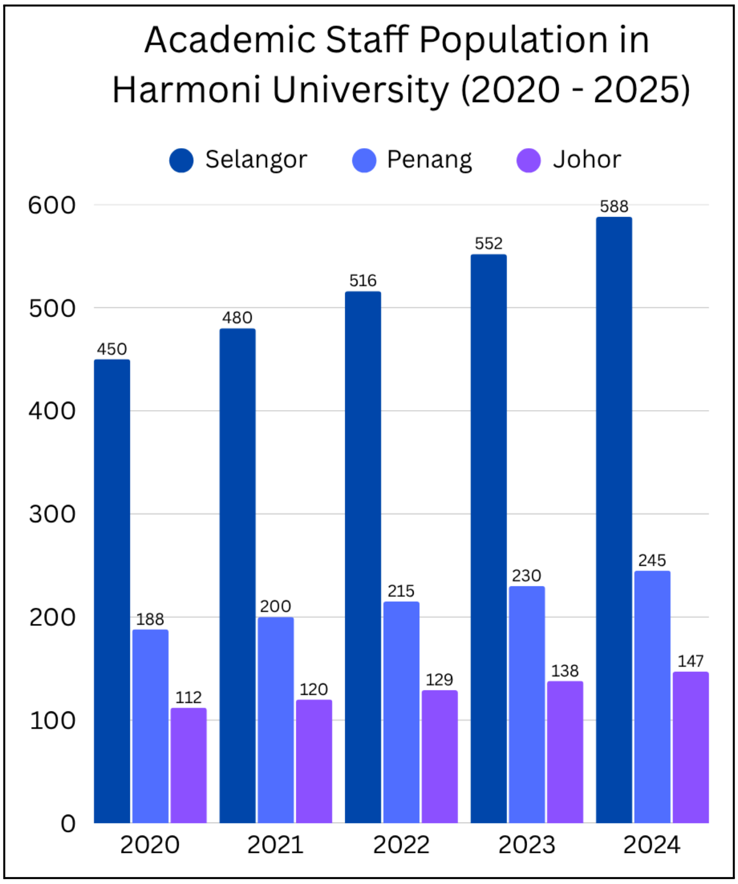


Table 4.2.2 Proposed Storage Infrastructure - Seagate Exos 10K.2 Specification

Specification	**Details**
Model	Seagate Exos 10K.2 (ST600MM0009)
Capacity	600 GB
Interface	12Gb/s SAS
Form Factor	2.5-inch
Spindle Speed	10,000 RPM
Cache Buffer	128 MB
Average Latency	~2.9 ms
MTBF	2 million hours
Power Consumption	● ~4.8W (idle) ● ~7.5W (active)
Encryption	SED (Self-Encrypting Drive) support
Use Case	● Virtual Lab Storage Backend ● Learning Management System (LMS) Data Store ● Transactional Admin Systems

Table 4.2.3 Proposed Storage Infrastructure - Seagate Exos X18 (18TB NL-SAS) Specification

Specification	Details
Model	Seagate Exos X18 (ST18000NM000J)
Capacity	18 TB
Interface	12Gb/s SAS (compatible with NL-SAS deployments)
Form Factor	3.5-inch
Spindle Speed	7,200 RPM
Cache Buffer	256 MB
MTBF	2.5 million hours
Average Latency	~4.16 ms
Power Consumption	● ~5W (idle) ● ~8.6W (active)
Encryption	SED/FIPS 140-2 support
Use Case	● Academic Archive Storage ● Research Repository ● Library Digital Storage ● Backup Repository

Table 4.2.4 Proposed Storage Infrastructure - Cost Estimation for Mechanical Hard Disks

Component Type	Unit Price (RM)	Quantity	Subtotal (RM)	Deployment Area
Seagate Exos 10K.2 (600GB SAS)	950	40	38,000	VM storage servers, LMS, Admin Systems
Seagate Exos X18 (18TB NL-SAS)	2,800	30	84,000	Library servers, Research data nodes, Archive backups
Total Estimated Cost			122,000	Across Selangor, Penang, and Johor campuses

Table 4.2.5 Proposed Storage Infrastructure - Samsung PM9A3 NVMe SSD Specification

Specification	Details
Model	Samsung PM9A3 NVMe SSD (U.2 2.5")
Interface	PCIe Gen4 x4, NVMe 1.3c
Form Factor	2.5-inch U.2
Capacity (Proposed)	960GB per unit
Sequential Read Speed	Up to 6,500 MB/s
Sequential Write Speed	Up to 3,500 MB/s
Random Read IOPS (4K QD128)	Up to 1,100,000 IOPS
Random Write IOPS (4K QD128)	Up to 200,000 IOPS
Endurance	1 DWPD (Drive Writes Per Day) for 5 years
Reliability (MTBF)	2.0 million hours
Power Consumption (Active/Idle)	9.0W active / 3.0W idle
Supported Technologies	V-NAND, End-to-End Data Protection, Power Loss Protection
Functional Role in Harmoni University	● Boosts performance of LMS and VDI for real-time access in classrooms ● Eliminates lag during concurrent student logins and resource access ● Supports fast backup of academic content and log generation for exams and student analytics ● Powers high-speed data analysis and simulations for research in engineering, AI, and medical departments

Table 4.2.6 Proposed Storage Infrastructure - Cost Estimation for Flash Memory

Deployment Area	Details	Units Needed	Unit Price (RM)	Total Cost (RM)
Computing Labs (VDI, Class Resources)	Fast storage in server racks serving student labs	20	1,000	20,000
Central LMS Servers (High-availabilit	Ensuring resilient, low-latency	6		6,000

y cluster)	access across faculties			
Research Cluster Nodes (Engineering/Postgrad use)	High-performance computing and data simulation workloads	8		8,000
Backup Servers & Assessment Platforms	Handling log-intensive workloads during assessments	4		4,000
Total Estimated Cost				38,000

Table 4.2.7 Proposed Storage Infrastructure - HPE StoreEver MSL3040 Specification

Specification	Details
Model	HPE StoreEver MSL3040
Tape Format	LTO-9 (18 TB native / 45 TB compressed per cartridge)
Capacity	Up to 280 cartridges, scalable from 3U to 21U
Features	WORM (Write Once, Read Many), encryption support, redundant power
Interface	8 Gb Fibre Channel
Compatibility	Supports major backup software such as Veeam, Commvault
Role	● Long-term offline storage of immutable data such as thesis archives, exam scripts and video surveillance ● Compliance with PDPA and MoHE by preserving records for up to 30 years

Table 4.2.8 Proposed Storage Infrastructure - Dell EMC PowerProtect DD3300 Specification

Specification	Details
Model	Dell EMC PowerProtect DD3300
Form Factor	2U rack-mount appliance
Usable Capacity	4 TB – 32 TB (deduplicated up to >1 PB)
Throughput	Up to 7.2 TB/hour
Features	Inline deduplication, replication, encryption, cloud-tier support

Compatibility	Integrates with Veeam, Commvault, and other backup tools
Role	• Virtual Tape Library (VTL) for fast, centralized backup and restore across all campuses • Automates protection of active systems such as LMS, HR and financial data • Enhances disaster recovery speed and operational continuity

Table 4.2.9 Proposed Storage Infrastructure - Cost Estimation for Tape Storage

Component	Details	Units Needed	Unit Price (RM)	Total Cost (RM)
HPE StoreEver MSL3040	Modular 3U tape library chassis	1	46,000	46,000
LTO-9 Tape Drives	Compatible drive modules for MSL3040	2	19,000	38,000
LTO-9 Tape Cartridges	45 TB compressed capacity per cartridge	20	700	14,000
Dell EMC PowerProtect DD3300	VTL appliance with deduplication and replication	1	105,000	105,000
VTL Software License Pack	Enables deduplication, backup, and cloud features	1	30,000	30,000
Total Estimated Cost				233,000

Table 4.2.10 Proposed Storage Infrastructure - Storage Area Network (SAN) Specification

Component	Specification
Model	Dell EMC PowerStore 500T
Form Factor	2U rack-mount
Max Raw Capacity	Up to 1.2 PB (with expansion)
Supported Protocols	Fibre Channel, NVMe/TCP, iSCSI
RAID Support	RAID 5 / RAID 6

Management	PowerStore Manager (Web UI), REST API, CLI
Redundancy	Dual active-active controllers, hot-swappable PSU
Use Case	Centralized storage for research, LMS, VDI, backup

Table 4.2.11 Proposed Storage Infrastructure - Storage Area Network (SAN) Cost Estimation

Component	Details	Units	Unit Price (RM)	Total (RM)
Dell EMC PowerStore 500T	All-flash SAN appliance (25 bays, NVMe)	1	150,000	150,000
Brocade 6505 FC Switch	24-port 16 Gb Fibre Channel switch	2	62,000	124,000
FC Host Bus Adapter (HBA)	Dual-port FC adapters for servers	4	3,500	14,000
SAN cabling & optics	OM4 fibre cables, SFP+ modules	10	400	4,000
Total Estimated Cost				292,000

Table 4.2.12 Proposed Storage Infrastructure - RAID Level Allocation

RAID Level	Applied For	Purpose
RAID 10	Virtual Desktop Infrastructure (VDI), LMS, Real-time Academic Apps	High-speed access with redundancy for teaching platforms
RAID 6	Research Data, Student Submission Archives, Procurement Docs	Secure long-term storage with double-disk failure tolerance
RAID 1 (Mirroring)	System Configuration Files, Critical VM Images	Full duplication of essential system data
RAID 0 (Striping – Non-critical cache only)	Temporary Cache or Testing Sandboxes	High-speed processing for non-critical, volatile workloads

Table 4.4.1 Proposed Storage Solutions – Performance Comparison (IOPS, Throughput, Latency)

Storage Type	Device/Medium	IOPS (est.)	Throughput	Latency	Typical Usage in University
Flash (NVMe SSD)	Samsung PM9A3	700K–1,000K	Up to 6,500 MB/s	<0.1 ms	Real-time VDI, LMS, computer science simulations
Performance Tier (SAS HDD)	Seagate Exos 10K.2 SAS	160–220	~180–210 MB/s	~4 ms	Student portals, virtual labs, exam-time databases
Capacity Tier (NL-SAS HDD)	Seagate Exos X18 NL-SAS	80–100	~180 MB/s (sequential)	~8 ms	Archiving e-books, research datasets, digital exams
Tape (Offline)	LTO-9 (HPE StoreEver)	N/A	400 MB/s (compressed)	High	Immutable backup of transcripts, surveillance, sensitive records
Virtual Tape Library (VTL)	Dell EMC DD3300	500–1000	Up to 24 TB/hr (dedup)	~2–5 ms	Backup/restore for VDI, LMS, and databases
SAN	Dell EMC PowerStore (RAID)	Up to 1M (Flash)	Up to 7 GB/s	<1 ms	Cross-campus access to shared academic storage (VDI, research)

Table 4.4.2 Storage Security Summary (Proposed Infrastructure)

Category	Specification / Quantity	Purpose (Education Context)
Encryption	AES-256 SEDs (≥ 400 TB total)	Secures data at rest: student records, exam results, thesis drafts (all campuses)
SAN Zoning	3 zones/site × 4 campuses = 12 zones	Isolates Academic, Management & Backup traffic (e.g., LMS and HR do not mix)
LUN Masking	12 LUNs segmented by service & campus	E.g., Penang HR cannot access KL LMS data
Backup Strategy	3-2-1 Rule: Disk (local), VTL (remote HQ), LTO-9 Tape (offsite)	Recovers coursework or results after loss or ransomware
WORM Tapes	10 × LTO-9 tapes (45 TB each, 450 TB total)	Immutable archival: graduation records, MoHE-required reports

Archival Retention	30 years (final-year projects, transcripts, key admin docs)	Fulfills MoHE & PDPA requirements
Backup Retention	90-day daily incremental; 2-year weekly full backups	Supports full semester cycles and appeals
Campus Replication	3 SAN nodes (Bukit Jalil, Penang, Johor) with real-time replication	Any node failure won't interrupt classes or access to academic data
Recovery Testing	1/month per site (×4 campuses)	Ensures LMS and teaching materials are restorable before new semester or after updates
Access Control	40+ ACL profiles via AD; per-campus isolation	E.g., Johor research inaccessible from Selangor unless authorized

Table 4.4.3 Specification for Storage Availability

Detail	Data / Value
Number of SAN Nodes	3 (1 per campus: Bukit Jalil, Penang, Johor)
Replication Latency	≤ 5 ms (synchronous replication over MPLS or dark fiber)
Daily Incremental Backup Time	Starts at 2:00 AM, completes within 45–60 minutes
Weekly Full Backup Time	Sundays at 3:00 AM, completes in ~3 hours for 25 TB data
Estimated Daily Backup Volume	~350–500 GB incremental (during exam weeks)
Weekly Full Backup Size	~25 TB (student submissions, databases, VM images, logs)
Number of Backup Copies Maintained	3 (SAN disk, VTL on-prem, LTO-9 offsite)
LTO-9 Tape Rotation Frequency	Weekly (used tapes moved offsite every Monday 10:00 AM)
Number of LTO-9 Cartridges Used/Month	~6 (based on 30–35 TB of weekly full + daily incremental data)
Tape Shelf Life	Up to 30 years (per LTO-9 manufacturer specs)
Recovery Point Objective (RPO)	< 24 hours (data loss capped to last daily backup)
Recovery Time Objective (RTO)	< 2 hours for LMS, < 4 hours for student records
Backup Test Schedule	1st Wednesday of each month, 2:30 PM – 4:00 PM
Expected Storage Growth Rate	~15% per year (projected from LMS and research data

	trends)
Supported Concurrent Users (during backup window)	≥ 300 concurrent LMS users without performance impact

Appendix 5.0

Table 5.1.1 Existing Compute Infrastructure - AWS Cloud9

Specification	Details
Service/Plan	AWS Cloud9 (underlying EC2 + EBS billed)
Typical backing instance	Small general-purpose EC2 instance with EBS volume
Languages/tools	• Python • Java • C/C++ • JS
Storage	EBS volume per environment
Usage	• Used by Faculty of Science & Technology as a browser-based programming IDE • Students run lab exercises • Enable virtual teaching labs

Table 5.1.2 Existing Compute Infrastructure - Amazon EC2 (t3.medium)

Specification	Details
Instance	t3.medium
vCPU / RAM	2 vCPU, 4 GiB RAM
Storage	EBS-only (size user-defined)
Notes	Burstable CPU; charges for CPU credits if in "Unlimited" mode
Usage	• Student portal hosting • Attendance system hosting • Course registration platform hosting

Table 5.1.3 Existing Compute Infrastructure - Amazon EC2 (g5.2xlarge)

Specification	Details
Instance	g5.2xlarge
vCPU / RAM	8 vCPU, 32 GiB RAM
GPU	1× NVIDIA A10G
Local NVMe	~225–450 GB (varies by listing)
Primary use	DL/AI training, simulations, research workloads

Usage	• Deep learning training • Medical image recognition • Simulation workloads (biomedical research, environmental modelling)

Table 5.1.4 Existing Compute Infrastructure - Usage and Cost

Component	User	Area	Monthly Cost (MYR)
AWS Cloud9 (50 environments)	Faculty of Science & Technology	Programming labs & coursework	433.58
EC2 t3.medium stack	Student Affairs Department	Student portal & registration	413.67
EC2 g5.2xlarge stack	Research Computing & Data Services	Deep learning, simulations, research	4,127.46
Total			4,974.71 per month

Table 5.2.1 Proposed Compute Infrastructure - Usage and Cost

Component	Model / Type	Quantity	Unit Price (RM)	Total Cost (RM)
Physical Compute Infrastructure	Dell PowerEdge R750	21	72,000	1,512,000
	Cisco UCS B200 M6	16	86,400	1,382,400
Compute Hardware Components	Intel Xeon Scalable Rack Server	32	25,000	800,000
	NVIDIA A100	12	350,000	4,200,000
	25GbE NICs / Switches	-	960,000	960,000
	NVMe SSDs / SAN	-	720,000	720,000
Compute Virtualization and Public Cloud	VMware vSphere + vCenter	1	240,000	240,000
	Docker + Kubernetes	1	48,000	48,000
	AWS Lambda		Pay-per-use	Variable

Advanced Compute Systems	HPC Rack-mounted Servers	16	120,000	1,920,000
	DGC Station A100	3	960,000	2,880,000
Total Estimated Cost (RM)				14,662,400

Table 5.2.2 Proposed Compute Infrastructure - Physical Compute Infrastructure Specification

Component	Dell PowerEdge R750	Cisco UCS B200 M6
Form Factor	2U Rack	Blade (UCS 5108 chassis)
CPU	Dual Intel Xeon Scalable (up to 40 cores per CPU)	Dual Intel Xeon Scalable
Memory	Up to 8TB DDR5 ECC	High-capacity DDR5 ECC
Storage	Up to 24 hot-swappable SAS, SATA, NVMe drives	Supports NVMe and SAS drives
GPU Support	Yes, high-performance GPU	NVIDIA GPU support
Management	iDRAC / OpenManage	UCS Manager Centralized Management
Network	10/25GbE NIC	Integrated 10/25GbE NIC

Table 5.2.3 Proposed Compute Infrastructure - Campus Deployment Plan

Campus	Rack Servers	Blade Servers	Area	Purpose
Selangor	6	4	Faculty of Sciences & Technology	Virtual labs, programming IDEs, AI/ML research, HPC simulations
	2	2	Student Affairs & Admin	Student portal, attendance, course registration, administrative apps
	2	1	Research Computing & Data Services	Deep learning, simulations, big data analytics, secure research storage
Penang	4	3	Faculty Labs	Teaching labs, local programming IDEs, collaborative coding projects
	1	1	Admin & Student	Local administrative apps,

			Services	course registration backup
	1	1	Research Hub	Data-intensive research, AI/ML experiments
Johor	3	2	Faculty Labs	Virtual labs, programming IDEs
	1	1	Student Services & Admin	Local administrative apps, backup for course registration
	1	1	Research Corner	Research projects, simulations, HPC workloads

Table 5.2.4 Proposed Compute Infrastructure - Compute Hardware Components Specifications

Component	Model/Type	Specs	Purpose
CPU	Intel Xeon Scalable 4th Gen	Up to 40 cores/CPU, 2.0–3.7 GHz	High performance for multi-threaded workloads
Memory	DDR5 ECC RAM	Up to 512 GB per server, 4800 MHz	High bandwidth, error correction for reliability
GPU	NVIDIA A100	40 GB HBM2, 6912 CUDA cores	AI, ML, big data analytics
Storage	NVMe SSD PCIe 5.0	1–4 TB, 7000 MB/s read	Ultra-fast data access, avoid bottlenecks
Network	25GbE NIC	25 Gbps, SFP28	Fast interconnect for labs and research

Table 5.2.5 Proposed Compute Infrastructure - Compute Virtualization and Public Cloud Specifications

Technology	CPU / Memory per Node	Storage	Network	Purpose	Estimated Users Supported
VMware vSphere	Up to 64 vCPUs, 512 GB RAM	Shared SAN / NVMe	25 GbE	Centralized VM management, student info system, library DB, e-learning	3,000–5,000 concurrent
Docker + Kubernetes	16–32 vCPUs, 64–128 GB	NVMe SSDs	10–25 GbE	Containerized applications,	500–1,000 concurrent

	RAM per node			ML experiments, collaborative coding	
AWS Lambda	Event-driven (serverless)	AWS managed	Internet	Auto-grading, notifications, lightweight administrative tasks	Thousands of invocations per day

Table 5.2.6 Proposed Compute Infrastructure - HPC Cluster Node Specifications

Component	Specification
CPU	Intel Xeon Scalable (high-core-count)
Memory	512–1,024 GB DDR5 ECC RAM per node
Storage	NVMe SSDs (1–4 TB per node)
Network	10–25 GbE network interface cards
GPU	Optional per node: NVIDIA A100 / H100
Form Factor	Rack-mounted (2U–4U per server)
Node Quantity	4–8 nodes per cluster (adjustable based on workload)

Table 5.2.7 Proposed Compute Infrastructure - NVIDIA DGX Station A100 Specifications

Component	Specification
GPU	8× NVIDIA A100 GPUs
CPU	Dual AMD EPYC or Intel Xeon CPUs (as per DGX Station spec)
Memory	512–1,024 GB DDR4/DDR5 RAM
Storage	NVMe SSDs (up to 15 TB total)
Network	4× 25 GbE or 100 GbE ports
Use Case	AI/ML model training, deep learning simulations, data-intensive research

Table 5.2.8 Proposed Compute Infrastructure - HPC Deployment Plan

Campus	Area	Cluster Type	Node Quantity	Users	Primary Workloads

Selangor	Faculty of Sciences & Technology – AI Lab	HPC Cluster	4	Postgraduate researchers & faculty	Deep learning, AI simulations, healthcare data modeling
	Faculty of Engineering – Simulation Lab	HPC Cluster	3	Engineering researchers & students	Engineering simulations, computational fluid dynamics, structural analysis
	Central Research Data Center	DGX Station A100	2	University-wide researchers	High-performance AI model training, machine learning experiments
Penang	Faculty of Data Science – Big Data Lab	HPC Cluster	4	Data science postgraduates & faculty	Big data analytics, predictive modeling, statistical simulations
	Faculty of Sciences – Genomics Lab	HPC Cluster	2	Life sciences researchers	Genomic sequencing, bioinformatics pipelines
Johor	Faculty of Computer Science – AI & Robotics Lab	HPC Cluster	3	Students & researchers	AI model development, robotics simulations, computer vision
	Central Campus IT Lab	DGX Station A100	1	Postgraduates & research faculty	GPU-accelerated research, real-time data processing, neural network training

Table 5.3.1 Technical Specification for Proposed Compute Availability

Component	Brand / Model	Quantity	Technical Specification	Availability Target
Compute Servers	Dell PowerEdge R750xs	14 units (8 in Putrajaya DC, 2 each in Selangor,	2× Intel Xeon Gold 6330 CPU (28 cores each), 512 GB ECC DDR4 RAM, dual	99.999% → ~5.26 min downtime/yea

		Penang, Johor)	hot-swappable PSU, hot-swappable fans & drives	r
Memory	Samsung / Micron ECC Registered DDR4	512 GB per server (7.168 TB total)	ECC error correction, parity protection against single-bit/multi-bit memory faults	99.99% → ~52.6 min downtime/yea r
Virtualization Platform	VMware vSphere 8 Enterprise Plus	Licensed for ~700 VMs	vMotion, HA, DRS, distributed resource scheduling	99.995% → ~26.3 min downtime/yea r
Clustering Software	Microsoft WSFC + Linux Pacemaker	Installed on all cluster nodes	Automatic workload failover across data centers and branch servers	99.999% → ~5.26 min downtime/yea r
Storage (Local per Server)	Dell PERC H755 with Dell SSD/HDD hot-swap drives	8–12 drives per server	Redundant RAID arrays, hot-swappable storage	99.999% → ~5.26 min downtime/yea r
Power Protection	Dell Hot-Swappable Platinum PSU	2 per server (N+1 redundancy)	Dual redundant 1.6 kW PSU per server	99.999% → ~5.26 min downtime/yea r
Cooling System	Dell Hot-Swappable Fans	6 per server (N+1 redundancy)	Intelligent fan speed control, redundant design	99.999% → ~5.26 min downtime/yea r

Table 5.4.1 Compute Performance Comparison Table

Feature / Spec	Current Infrastructure (Old)	Proposed Infrastructure (New)
CPU Clock Speed	2.2 GHz (quad-core)	3.2 GHz (up to 32 cores, multi-core, hyper-threading)
Pipeline Depth	~12 stages	~20+ stages (deeper superscalar pipelines)
Superscalar Execution	Dual-issue	Up to 4–6 instruction issue per cycle

Cache Size (L3)	8 MB	64 MB L3 cache
Branch Prediction Accuracy	~85%	~97% advanced branch prediction
Memory Prefetching	Basic hardware prefetch	Aggressive multi-level prefetch (improved latency)
Instruction Throughput	~50 billion instructions/sec	500+ billion instructions/sec
Parallel Execution	4 cores	Up to 32 cores per node (Moore's Law scaling)
Compilation Speed (1–2k lines)	~15 seconds	<2 seconds
Analytics (50M rows dataset)	Hours (overnight runs)	~3 minutes
Neural Network Training (AI)	~40 minutes	~15 minutes (with GPU acceleration)
Virtualization Overhead	~20% per VM	<10% per VM (Intel VT-x/AMD-V)
Concurrent Virtual Labs	~200 VMs	1,200+ VMs
LMS Response Time (5,000 users)	3–5 seconds	<1 second

Table 5.4.2 Performance Metrics (Existing vs Proposed)

Task / Use Case	Existing Performance (Old)	Proposed Performance (New)
Code Compilation (1,000–2,000 lines, e.g., C++/Java)	~15 seconds on personal laptops (quad-core, ~2.4 GHz)	<2 seconds on new cluster CPUs (32 cores @ 3.2 GHz, superscalar + hyper-threading)
Statistical Analysis (50M rows dataset)	~2–3 hours on personal laptops (8 GB RAM, single-thread bottlenecks)	~3 minutes using 32-core parallel execution + memory optimization
Database Query (millions of student records)	~1–2 seconds per query during peak load	<200 ms response with 64 MB L3 cache + prefetching
AI / Neural Network Training (mid-sized model)	~40–45 minutes training time	<15 minutes with CPU superscalar pipelines + GPU acceleration
Virtual Lab Environments	Limited (≈150–200 VMs	1,200+ concurrent VMs with <10% CPU overhead per VM

	before performance drop)	
LMS Concurrent Users	~2,000–2,500 stable concurrent users with ~2s latency	5,000+ users, <1s latency

Figure 5.4.3 Performance Comparison of Compute Infrastructure

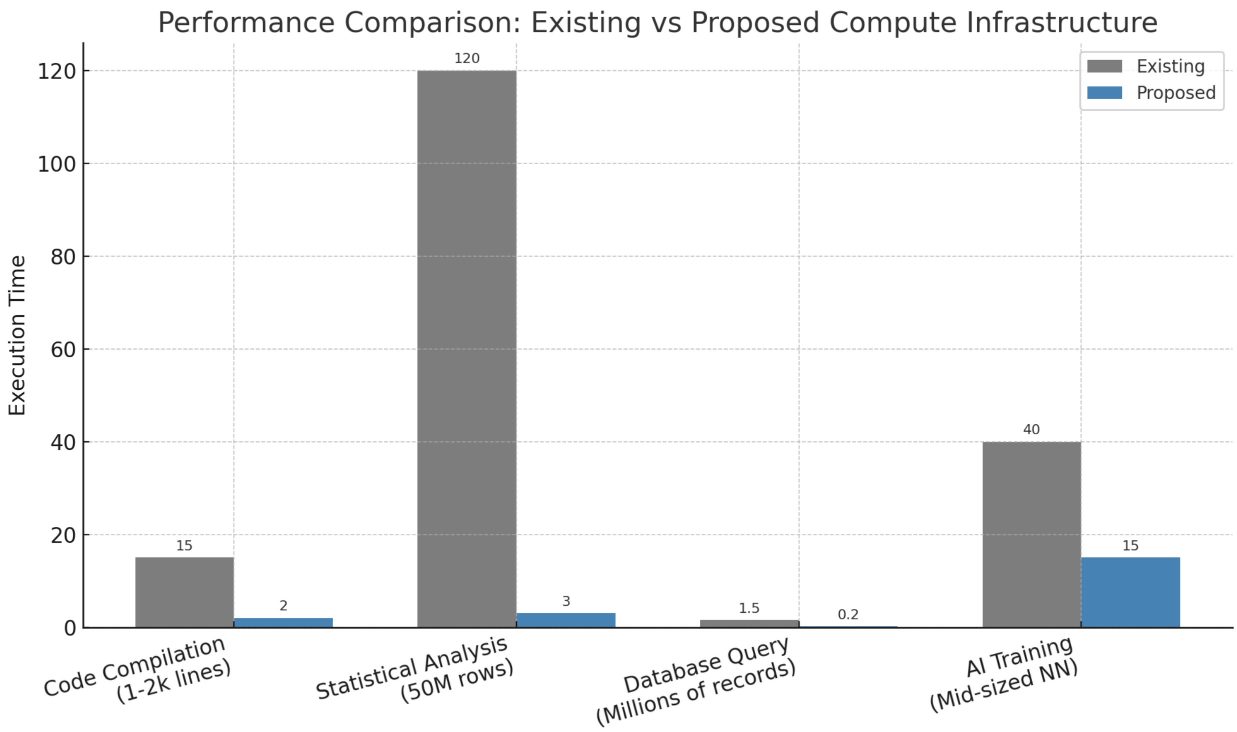


Table 5.5.1 Compute Security – Technical Specifications

Security Layer	Technology / Model	Total Qty	Bukit Jalil (Main DC)	Selangor Branch	Penang Branch	Johor Branch
Physical Security	HID iCLASS SE RB25F Biometric Readers	8 units	2	2	2	2
	APC NetBotz Rack Access PX Electronic Locks	10 units	4	2	2	2
	Schneider NetBotz 750 Monitoring Kits	10 units	4	2	2	2

Data in Use Security	Intel SGX / AMD SEV Extensions	17 servers	8	3	3	3
	256-bit AES Memory Encryption	17 servers	8	3	3	3
	TPM 2.0 Modules	17 servers	8	3	3	3
Virtualization Security	Intel VT-x / AMD-V with Nested Paging	17 servers	8	3	3	3
	VMware vCenter Controllers	4 units	1	1	1	1

Table 5.5.2 Security & Virtualization Feature Specifications

Technology / Feature	Actual Technical Specs
Intel SGX	Enclave size up to 1 TB; supported on Intel Xeon Scalable 3rd Gen (Ice Lake) CPUs
AMD SEV-SNP	Per-VM 256-bit AES encryption; integrity protection; supported on AMD EPYC 7002/7003 CPUs
AES-NI / Memory Encryption	256-bit AES with hardware acceleration (up to ~10 Gbps per core)
TPM 2.0	2048-bit RSA; SHA-256; 64 KB NVRAM; ISO/IEC 11889 compliant
Intel VT-x	Hardware virtualization; Extended Page Tables (EPT); nested virtualization
AMD-V	Nested Page Tables (NPT); Rapid Virtualization Indexing (RVI); AVIC interrupt support
VMware vCenter 8.0	Up to 2,500 hosts / 45,000 VMs per instance; deployed as 4 appliances (1 per campus)

Table 5.5.3 Enhanced Virtual Machine Templates Specifications

Component	Specification (Proposed)
vCPU Allocation	2 – 4 vCPUs per student VM (scalable up to 8 vCPUs for advanced workloads)
vCPU Technology	Intel Xeon Gold 6338 (32 cores, 2.0 GHz base, 3.2 GHz turbo) /

	AMD EPYC 7543 (32 cores, 2.8 GHz base, 3.7 GHz turbo), with Intel VT-x/AMD-V
Memory (RAM)	4 – 8 GB per VM (standard labs), up to 16 GB for AI/data science workloads
Memory Security	Intel SGX / AMD SEV with 256-bit AES memory encryption enabled
Storage (per VM)	60 – 100 GB thin-provisioned virtual disk (NVMe-backed)
Virtual Disk Type	VMware Paravirtual SCSI (PVSCSI) with encryption enabled
Network	1 Gbps vNIC per VM with VLAN isolation; Secure tunneling (802.1Q tagging, TLS)
OS Templates	Windows 10 Enterprise (education edition), Ubuntu 24.04 LTS, pre-hardened with CIS benchmarks
RBAC Security	Role-based access via vCenter; student → lab scope only, admin → system-wide
Virtualization Features	Nested paging (EPT/NPT), secure boot, VM encryption enabled
Monitoring & Logging	vCenter + SIEM integration; logs retained for 90 days
Scalability	Supports >1,200 concurrent student VMs across 17 servers
Backup & Recovery	Integrated with Veeam snapshot backup; 15-min RPO for labs