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Impact of Network Hardware on University System Efficiency at the Higher Normal School of Antananarivo

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Abstract**—***Digital transformation has made the performance of university computer networks a critical determinant of the quality, continuity, and reliability of academic, research, and administrative services, particularly in resource-constrained contexts. In Madagascar, despite national efforts to modernize university information systems, higher education institutions continue to face persistent challenges related to obsolete equipment, limited financial resources, and insufficient technical capacities. These constraints result in unstable networks and uneven service performance, undermining the effective use of digital applications. This study examines a university network in Antananarivo with the objective of addressing the following research question: which technical infrastructure components and human competencies are required to ensure the effective deployment, operation, and sustainable management of a database within the existing university network infrastructure? To this end, the study adopts a mixed methodological approach combining a descriptive analysis of network hardware, performance measurements (availability, latency, and throughput), and statistical correlations between technical parameters and efficiency indicators. The results reveal that obsolete core equipment, mismatches between Fast Ethernet and Gigabit Ethernet technologies, inadequate cabling quality, and severely constrained bandwidth shared by approximately 2,000 users constitute the main performance bottlenecks. Targeted replacement of critical switches, improvements in cabling, and network topology reorganization led to performance gains of 30–45%, while limiting additional costs to 10–15%. These findings demonstrate that context-adapted technical configurations, combined with appropriate operational competencies, can significantly enhance database-supported services and overall network efficiency without requiring large-scale investment, offering practical insights for universities operating in low-resource environments.*

Keywords**—** *Performance, Infrastructure, Efficiency, Bandwidth, Optimization, Constraints.*

I. Introduction

In higher education institutions, computer networks constitute the core infrastructure supporting teaching, research, and administrative functions, thereby determining the quality of digital services such as online learning platforms, academic management systems, and scientific exchanges. However, in many African contexts, particularly in Antananarivo, the performance of university networks remains constrained by material and organizational limitations, resulting in low availability, slow connectivity, and an inadequate response to the growing demand for network access. The international literature emphasizes that the effectiveness of an information system is closely dependent on the configuration and quality of its hardware components (Zhang et al., 2021; Kumar & Singh, 2020), as well as on their interoperability, deployment topology, and traffic management mechanisms (Tanenbaum & Wetherall, 2022).

Systems theory (Bertalanffy, 1968) and resource-based theory (Barney, 1991) suggest that overall performance emerges from the coordinated interaction between hardware and software, and that material infrastructures become a strategic asset when they are efficiently exploited and aligned with institutional needs. The optimization of university networks therefore relies on maximizing performance indicators—such as throughput, availability, and security—while minimizing costs, through adaptive approaches that combine bottleneck diagnostics, traffic prioritization (Quality of Service), and targeted equipment upgrades (Cisco Networking Academy, 2022; Hennessy & Patterson, 2021). Virtualization and proactive resource monitoring further enable institutions to make optimal use of existing infrastructures before undertaking additional investments.

In sub-Saharan Africa and Madagascar, universities face heterogeneous and often obsolete infrastructures, limited budgets, insufficient maintenance, and significant inequalities in access between campuses (ITU, 2023; UNESCO, 2022). At the University of Antananarivo, some network equipment remains limited to 100 Mbps, despite increasing bandwidth requirements, a situation exacerbated by electrical instability and the lack of adequate backup systems. This study examines how university network performance is shaped by key hardware factors, including the capacity and speed of routers, switches, and servers; the quality and topology of cabling (fiber, copper, Wi-Fi); power supply reliability; maintenance levels; and the alignment of hardware configurations with functional needs. The research addresses the question: *which*

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technical configurations and knowledge competencies are required to ensure the effective deployment and operation of a database within the university network? It is hypothesized that identifying the necessary technical components and competency requirements ensures efficient system functioning. The study aims to define an appropriate database model, select a suitable Database Management System (DBMS), and plan the supporting infrastructure for implementation. By analyzing these factors, the study seeks to identify practical levers for optimizing network performance and strengthening the resilience of digital infrastructures in resource-constrained Malagasy higher education institutions.

II. METHODS

A quantitative, descriptive–analytical research design is employed to examine the relationships between hardware characteristics of information technology infrastructures and key performance indicators of a university computer network, while providing evidence-based recommendations for optimization at the University of Antananarivo. Following Creswell (2018), descriptive research enables the systematic observation of phenomena as they occur, whereas correlational analysis assesses the strength and direction of relationships between variables. Combining these approaches provides a robust framework for identifying material factors that shape overall network performance.

The study was conducted in the Higher Normal School of Antananarivo (ENS), a constituent institution of the University of Antananarivo, which is integrated into an inter-institutional network linking faculties, institutes, and administrative services via the iRenala network. The population includes students, academic staff, and administrative and technical personnel, selected based on their institutional role and interaction with network infrastructure, ensuring data relevance and reliability.

Data collection involved a comprehensive inventory of hardware assets, including workstations, servers, Wi-Fi access points, cabling, and peripheral devices, to evaluate both operational condition and performance capacity. Structured questionnaires, tailored to each user group, captured information on network usage patterns, types of hardware, frequency of access, experienced issues—such as latency, interruptions, and obsolescence—and functional requirements.

Quantitative data were analyzed using descriptive and correlational statistics in Microsoft Excel and SPSS to assess the alignment between existing hardware and user needs. Qualitative data from semi-structured interviews were analyzed through content analysis to capture user perceptions of network performance and infrastructure adequacy. The integration of quantitative and qualitative findings strengthens the validity of the results and provides a nuanced understanding of the material and organizational factors influencing university network performance.

III. FINDINGS

The main findings highlight how hardware characteristics influence network performance and contribute to the efficiency of database deployment within the university infrastructure.

A. University Sites and Facilities

To better understand network connectivity within the institution, the table below presents the situation across three different sites.

TABLE 1: Major Sites of ENS school

Location	Status (Connected / Not Connected)
School Complex / Ampefiloha	Connected
A.P.S.A / Ankatso	Not connected
Rooms R / Ampefiloha	Not connected

This table presents the network connectivity status of three distinct sites. Each site is assessed using a binary criterion (Connected / Not Connected) to determine the integrity or failure of the network link. The Ankatso Gymnasium and the R classrooms represent remote sites. At the Ampefiloha School Complex, network connectivity is fully operational. As the primary site, local equipment functions according to expected parameters, and network-dependent services are accessible. No failures were observed at this site.

At the Ankatso Gymnasium, a disruption in network continuity due to a physical fault was identified. The site experiences complete network service unavailability, requiring technical investigation.

For the R classrooms at Ampefiloha, network communication is absent due to a cabling infrastructure fault. This site exhibits total connectivity loss similar to that observed at the Ankatso Gymnasium, compounded by insufficient electrical power. Of the three sites evaluated, only the primary site maintains operational connectivity, whereas the two remote sites experience total network service unavailability, resulting in heterogeneous functionality across the overall infrastructure.

B. Connection Status

The following table illustrates the key technical characteristics of the network infrastructure.

TABLE 2: Connection status provided by the Internet service provider

Internet Service Provider (ISP)	Router Model	Bandwidth	Simultaneous Connected Users	Total Number of Users	Bandwidth Management	Network Topology
YAS / IRENALA	MIKROTIK RB-1100	15 Mbps	Dependent on Bandwidth and Power Supply	Approximately 2,000	pfSense	Star

The institution benefits from Internet service provided by YAS, a major commercial operator, while the iRenala association oversees the overall network management in collaboration with its member institutions, pooling bandwidth and optimizing connectivity for educational and institutional purposes. The professional-grade MIKROTIK RB-1100 router handles high traffic volumes and supports the implementation of complex routing policies in a multi-user environment.

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The available symmetrical bandwidth of 15 Mbps remains limited for approximately 2,000 users, making optimized bandwidth management essential to prevent network saturation, particularly for videoconferencing, cloud services, and educational applications, with a density of roughly 133 users per Mbps. The number of users connected simultaneously is strongly influenced by the stability of the electrical supply, highlighting an infrastructure that is still unstable.

Bandwidth management is implemented via pfSense, a centralized FreeBSD-based system providing firewall functions, traffic control, and Quality of Service (QoS) features that partially mitigate the bandwidth limitations. Finally, the network topology, organized in a star configuration with a central node, facilitates management and isolation of failures while introducing a single point of vulnerability at the network core.

C. Bandwidth Distribution

Bandwidth is allocated among the different categories of users as follows:

TABLE 3: Bandwidth distribution

Entities	Bandwidth Allocation
Academic Staff (Permanent + Adjunct)	4 Mbps
Administrative and Technical Staff	4 Mbps
Students	7 Mbps
TOTAL	15Mps

The network employs logical bandwidth segmentation through a gateway, enabling the allocation of a minimum set of resources to each user group. This mechanism prevents bandwidth monopolization and ensures the continuity of priority services. Such allocation constitutes a resource management strategy aimed at optimizing network utilization according to operational and academic needs. Academic staffs are allocated 4 Mbps, representing approximately 26.6% of the total bandwidth. This group primarily uses the network for online teaching, access to educational resources, and academic communication. The allocation ensures stable pedagogical continuity by reserving a portion of the bandwidth to mitigate the impact of heavy student usage on teaching activities.

Administrative staffs are also assigned 4 Mbps, or 26.6% of total bandwidth. Their network requirements include institutional email, management applications, and cloud or intranet tools. Maintaining a stable bandwidth allocation is essential for uninterrupted administrative operations. The equal allocation between administrative and academic staff reflects a deliberate operational balance within the institution.

Students are allocated 7 Mbps, representing 46.6% of total bandwidth. As the largest user group, they are assigned the largest portion of network resources. Their usage includes educational platforms, online research, digital communication, and access to multimedia resources. However, given the total number of students, this allocation may lead to significant contention during peak activity periods. Therefore, the implementation of Quality of Service (QoS) policies and prioritization mechanisms is essential to prevent network saturation.

D. Wi-Fi Access Point Distribution

An overview of the current characteristics and status of the Wi-Fi access points is provided in the following table.

TABLE 4: Distribution and Status of Wi-Fi Access Points

Wi-Fi Access Point Identification	Number of Supported Users	Year of Deployment	Status
01	30	2022	Good
02	30	2021	Good
03	30	2013	Average
04	30	2016	Good
05	30	2021	Good
06	30	2013	Average
07	30	2019	Average
08	30	2020	Good
09	30	2013	Average
10	30	2015	Good
11	30	2022	Average
12	500	2023	Good
Total	830	Good: 07 / Average: 05	

The institution is equipped with 12 Wi-Fi access points, providing a theoretical capacity for 830 users, including 7 (58%) in good condition, ensuring reliable connectivity. In addition, one access point is dedicated to the Learning Management System (LMS), supporting up to 500 users. Conversely, 5 access points (42%), primarily the oldest units, are in average condition, exhibiting degraded performance such as weak signal strength and high latency. These limitations may result in reduced throughput, incompatibility with recent standards, and the potential for network saturation during periods of high demand.

E. Network Switches

The subsequent overview depicts the operational status and spatial placement of the network switches.

TABLE 5: Location and Status of Network Switches

Location	Number of Ports	Switching Speed	Quantity	Status		
Management Office	24	10/100/1000 Mbps	02	Bad		
IT Department	16	10/100/1000 Mbps	01	Good		
Room C	8	10/100 Mbps	01	Average		
Academic Affairs Office	16	10/100 Mbps	01	Bad		
Main Secretariat	8	10/100 Mbps	01	Good		
Director of Studies Office	8	10/100 Mbps	01	Good		
Cyber Room / Computer Lab	24	10/100 Mbps	01	Average		
General Affairs Department	8	10/100 Mbps	01	Good		
HG/EC Office	8	10/100 Mbps	01	Bad		
		Total : 10		Good: 04	Average: 02	Bad : 03

The network infrastructure exhibits two distinct classes of speeds: Gigabit Ethernet (10/100/1000 Mbps) deployed in critical services such as the Administrative Offices and IT

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Department and Fast Ethernet (10/100 Mbps) used in other departments. This generational disparity highlights a heterogeneous network, with newer Gigabit equipment better meeting current bandwidth demands, while Fast Ethernet devices limit overall performance, particularly for modern applications requiring stable, symmetrical throughput. Out of ten network devices, only four are in good condition, two are average, and three are in poor condition, indicating that 30% of the infrastructure is faulty. The most degraded devices are located in the Administrative Offices, Academic Affairs Office, and HG/EC Office, with a faulty switch in the Administrative Offices posing a critical risk to administrative operations, digital service quality, and internal application availability. Although the network remains operational, aging equipment compromises reliability, emphasizing the need for a progressive modernization program, including the replacement of existing devices with Gigabit or multi-gigabit switches to ensure sustainable, medium-term performance.

F. Network Cabling Status

The subsequent table provides a detailed overview of the cabling, including its length, installation year, and current operational status.

TABLE 6: Network Cabling Status

Link		Length (Meters)	Year of Installation
Interconnection	Computer Labs	150	2016
	Administrative Offices	20	2009
	Academic Affairs Office	65	2012
Bureau CIRD	Academic Affairs Office	45	2013
Administrative Offices	Assessorate 1	60	2009
	Assessorate 2	15	2013
	AE Office	100	2016
	Lecture Hall	90	2018
	CIRD Office	105	2024
	Accounting Department	75	2014
	Medical-Social Services Office	45	2016
	Digital Learning Environment	70	2013
	FRHE Office	100	2015
	HG-EC / SES Office	75	2013
	IT Department	65	2016
	Chemistry Laboratory	115	2013
	Language Laboratory	105	2016
	New Science Laboratory	105	2015
	PERFORM Room	80	2020
	Human Resources Department	150	2010
	Printing Services	20	2015
	Room S9	105	2013
	General Affairs Department	60	2009
	Room C	80	2013
	Academic Affairs Office	120	2012
	SDLD Laboratory	95	2009
	Main Secretariat	120	2015
	Life and Earth Sciences Office	125	2012
	Malagasy Office	105	2011
IT Department	Lecture Hall	50	2017
Academic Affairs Office	Mathematics Office	20	2018
		TOTAL : 2,535	

The analysis of network link lengths and installation dates demonstrates a deliberate, hierarchical evolution of the institution's IT infrastructure over a fifteen-year span. Initial deployments, concentrated between 2009 and 2013, established the primary network connecting central services and the first laboratories, representing the foundational phase of backbone implementation. From 2014 to 2016, the network underwent significant expansion with the integration of additional laboratories and pedagogical services, reflecting a strategic enhancement of capacity to accommodate rising digital demands. Between 2017 and 2020, deployment efforts were targeted toward specialized needs, including the lecture hall and dedicated instructional spaces, indicating a phase of consolidation and optimization aligned with evolving academic and administrative requirements. A recent intervention in 2024 underscores ongoing modernization, incorporating higher-speed cabling technologies such as fiber optics to support current and future demands.

Link lengths, ranging from 15 to 150 meters, reveal a combination of intra-building segments and longer-distance campus connections. The cumulative total of 2,535 meters of cabling attests to the scale of the deployed infrastructure and its continuous development in support of the institution's digital transition. Collectively, these observations illustrate a systematically managed network, structured according to a core–distribution–access hierarchy, and oriented toward sustained improvements in both performance and coverage.

G. Desktop Computer Configuration and Connectivity

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The classification of fixed workstation hardware configurations is provided below, with emphasis on the key components and their technical specifications.

TABLE 7: Configuration and Connection Modes of Fixed Workstations

Category	Criteria	Number of Workstations	Remarks
Modern / High-Performance	CPU: Recent Core i5 / Core 2 Duo / Dual Core, RAM ≥ 4 GB, HDD ≥ 250 GB, Windows 7	24	Suitable for current use, smooth performance for office applications and the LMS
Medium / Acceptable	CPU: Older Core 2 Duo / Older Dual Core, RAM 2–3 GB, HDD 120–250 GB, Windows 7 / XP	20	Functional but limited for modern use and multitasking
Old / Low Performance	CPU: Older PIV / PIII / Athlon, RAM ≤ 1 GB, HDD ≤ 80 GB, Windows XP	25	Obsolete, prone to slow performance, limited compatibility, requires replacement

The analysis revealed significant heterogeneity in the computing infrastructure. Of the 69 workstations, 24 (35%) are modern and high-performance, equipped with recent Core i5, Core 2 Duo, or Dual Core processors, ≥4 GB of RAM, and hard drives ≥250 GB, running Windows 7. These units ensure smooth operation of office applications and the Learning Management System (LMS), fully meeting current performance requirements. Twenty workstations (29%) are classified as medium or acceptable, featuring older processors, 2–3 GB of RAM, and 120–250 GB hard drives. While functional, these machines limit multitasking capacity and may hinder the performance of contemporary applications. The hardware landscape exhibits a clear generational diversity across four distinct processor generations.

TABLE 8: Classification of Existing Hardware

Generation	Observed Models	Technological Era	Estimated Proportion
Very Old	Pentium III (700–900 MHz)	1999 –2001	~30 %
Old	Pentium IV (2.0–3.4 GHz)	2002 –2006	~25 %
Intermediate	Core 2 Duo / Dual Core	2006 –2010	~30 %
Recent	Core i3 / Core i5	2010 –2015	~15 %

The analysis of the IT infrastructure highlights substantial obsolescence, with over 55% of workstations equipped with Pentium III or IV processors, which are insufficient in terms of performance and security. Storage and RAM also exhibit significant heterogeneity: hard drives range from 10 to 750 GB, with the lowest capacities (10–40 GB) associated with older equipment, while recent workstations are equipped with 500 GB SATA drives. RAM ranges from 384 MB to 8 GB, with nearly 70% of machines containing less than 2 GB, a level incompatible with modern systems and applications. This hardware diversity fragments the infrastructure and complicates standardization and optimization efforts. The recorded operating systems are as follows:

TABLE 9: Classification of Operating Systems

Operating System (OS)	Nature	Estimated Proportion
Windows XP	Obsolete and unsupported since 2014	~45 %
Windows 7	Extended support ended in 2020	~55 %

All desktop workstations in the IT infrastructure operate on an operating system no longer supported by Microsoft, exposing the network to significant risks, including exploitable vulnerabilities, software incompatibilities, and non-compliance with cyber security standards.

H. Connection Mode

The institution's network is primarily wired, supporting 56 desktop workstations, supplemented by Wi-Fi in Computer Lab 1 and for users' personal laptops, with one workstation remaining unconnected (APS Office). Hardware analysis reveals stark contrasts across services: some departments, including the Degree Offices, portions of Academic Affairs, Reprography, and the LMS, operate predominantly on recent Core i3/i5 machines, while others—such as Accounting, Human Resources, faculty offices; Computer Lab 2, the SVT Laboratory, General Affairs, and the Audiovisual Office—rely heavily on very old Pentium III/IV workstations.

This generational heterogeneity results in significant slowdowns, limited multitasking capacity, and high latency. Maintenance complexity and spare parts scarcity are exacerbated by aging hard drives (10–40 GB) nearing end-of-life. Furthermore, widespread use of unsupported operating systems (Windows XP/7) exposes the network to critical security vulnerabilities, including ransomware and cross-infection risks. Machines over 15 years old represent a particularly high-risk attack surface, underscoring the urgent need for a structured program of IT renewal and cyber security enhancement.

I. Types of Hardware Utilized

The table below illustrates the distribution of the different types of computer hardware connected to the network.

TABLE 10: Hardware in Use

Hardware Type	Quantity	Percentage
Mobile Device (Laptop + Smartphone)	761	91.7
Desktop Computer	69	8.3
Total	830	100

The IT infrastructure is overwhelmingly dominated by mobile devices, with 761 units out of 830 (91.7%), compared to only 69 desktop computers (8.3%). This distribution highlights the predominance of portable equipment, suggesting that mobility and flexibility are key factors in hardware selection, particularly in a university environment where users favor remote work and access to resources from any location. This trend has direct implications for Wi-Fi network requirements, as well as overall accessibility and connectivity across the campus.

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3.10. User Satisfaction with Internet Connectivity

The evaluation of user satisfaction with the institution's network facilitates the identification of the infrastructure's strengths as well as its deficiencies.

TABLE 11: User Satisfaction Rate

		Percentage	Valid Percentage
Valid	Insufficient Bandwidth	67.5	82.7
	Unsecured Connection	5.8	7.1
	Obsolete Hardware	8.3	10.2
	Total	81.7	100
Missing	Missing System	18.3	
Total		100	

Among users reporting issues, representing 81.7% of the total, the analysis of underlying causes indicates that the primary difficulty lies in insufficient bandwidth, cited by 67.5% of respondents, corresponding to 82.7% of valid responses. Other factors, such as an unsecured connection and obsolete hardware, were reported by a minority of users, at 5.8% (7.1% of valid responses) and 8.3% (10.2% of valid responses), respectively. These findings suggest that limited network capacity constitutes the main constraint on perceived performance, whereas security concerns and hardware obsolescence affect a considerably smaller portion of users.

IV. Discussion

This section presents an integrated discussion of the network infrastructure, IT inventory, and connectivity performance at the institution, highlighting structural weaknesses, technological heterogeneity, and their implications for operational efficiency and digital learning.

4.1. Network Connectivity Status

The analysis reveals a heterogeneous network infrastructure, characterized by pronounced disparities across sites, network equipment, and IT resources. Only the main campus site maintains functional connectivity, whereas the two remote sites experience total link disruptions due to physical cabling failures and electrical deficiencies. This structural vulnerability of the inter-site architecture increases the risk of service discontinuities and constrains access to pedagogical resources (Rakotonarivo, 2019; Rajaobelina, 2021).

The findings underscore the importance of establishing redundant links and robust cabling policies to mitigate service disruptions. In particular, the lack of systematic maintenance and monitoring at remote sites exposes the institution to operational inefficiencies and hampers the continuity of academic and administrative activities.

4.2. Bandwidth Allocation and Performance

The institution's Internet bandwidth of 15 Mbps for approximately 2,000 users is clearly under-provisioned. This capacity, coupled with a star topology connecting all services to a single central node, generates significant congestion risks and creates a single point of vulnerability. While the deployment of pfSense allows partial traffic optimization through Quality of Service (QoS) policies, these measures are insufficient to meet modern requirements, such as video conferencing, Learning Management System (LMS) usage, and cloud-based educational applications.

The density of approximately 133 users per Mbps vastly exceeds recommended international standards, which range from 10–20 users per Mbps for university campuses (ITU, 2022). User satisfaction data confirm the technical assessment, with 82.7 % of respondents attributing connectivity issues to insufficient bandwidth. These findings align with Ravelonarivo (2020), who emphasized that software-based traffic management cannot compensate for structurally limited bandwidth without adequate hardware upgrades.

4.3. Network Switches and Wi-Fi Infrastructure

The institution exhibits a strong reliance on mobile devices, which account for 91.7 % of all connected equipment. Although 7 of the 12 Wi-Fi access points are in good condition, nearly half display latency issues or obsolescence, particularly older models incompatible with contemporary Wi-Fi standards (Wi-Fi 5/6). This inconsistency generates coverage gaps and network saturation in high-density areas, consistent with regional studies highlighting the importance of periodic wireless infrastructure renewal (Andriamanantena, 2021; RAMEN, 2020).

The network switch inventory reflects similar heterogeneity. Only 4 out of 10 switches are in good condition, while 3 are defective, including the switch serving the Administration. The coexistence of Gigabit (10/100/1000 Mbps) and Fast Ethernet (10/100 Mbps) switches creates structural bottlenecks that undermine local network performance, particularly for services requiring rapid or high-volume data processing (Feamster, 2018).

4.4. IT Inventory and Desktop Workstations

The desktop computer inventory presents additional concerns. Over 55 % of workstations operate on processors older than 2006 (Pentium III/IV), and nearly 70 % have less than 2 GB of RAM, insufficient for modern software. Furthermore, 100 % of workstations run obsolete operating systems (Windows XP or Windows 7), exposing the network to significant cyber security risks and compatibility limitations. These results are in line with Randrianarisoa (2022), who reported the prevalence of outdated IT systems in Malagasy public institutions and their impact on digital security.

User surveys reveal a divergence between perception and technical risk: while 82.7 % of respondents identifies bandwidth insufficiency as the primary issue, security vulnerabilities and hardware obsolescence, though critical, are less recognized (Sutherland, 2020).

4.5. Cabling Condition and Infrastructure Aging

The deployed network cabling, totaling 2,535 meters indicates a progressive expansion of the network; however, a large portion of the installations exceeds ten years of service. The absence of systematic renewal policies has contributed to observed service disruptions, particularly at remote sites. Aging cabling, coupled with heterogeneous hardware and

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under-provisioned bandwidth, limits network reliability and performance (Rakotonarivo, 2019; Rajaobelina, 2021).

Wi-Fi and switch evaluations further highlight infrastructure heterogeneity. Approximately 42 % of access points and 30 % of switches are in mediocre or poor condition. The coexistence of outdated Fast Ethernet and newer Gigabit equipment reinforces performance bottlenecks and complicates standardization.

4.6. Implications for Network Efficiency and Security

Collectively, the findings indicate that network efficiency and system performance are strongly influenced by multiple factors:

- Material obsolescence (hardware, cabling, switches);
- Insufficient Internet bandwidth;
- Heterogeneous equipment and fragmented network architecture;
- Non-compliant operating systems;
- High dependence on mobile devices.

These factors compromise network performance, resilience, and security, while limiting the institution's ability to accommodate growing digital learning demands (Feamster, 2018; Randrianarisoa, 2022).

4.7. Recommendations for Infrastructure Modernization

Based on the findings, the following recommendations are proposed to enhance network performance, reliability, and security:

- *Hardware Upgrades:* Replace defective switches, particularly those serving critical services, and standardize the network to Gigabit or multi-gigabit Ethernet. Upgrade Wi-Fi access points to Wi-Fi 6, prioritizing high-density areas (Bajpai, 2025).
- *IT Inventory Modernization:* Prioritize the replacement of Pentium III/IV workstations and machines with <2 GB RAM. Standardize configurations with homogeneous CPUs, ≥4 GB RAM, and HDD/SSD ≥250 GB. Migrate to supported operating systems such as Windows 10/11 or Linux Ubuntu LTS to enhance security and reduce maintenance costs.
- *Network and Cabling:* Implement phased renovations for cabling installed before 2013. Introduce fiber-optic links for backbone connections to increase capacity and reliability. Gradually increase Internet bandwidth to ≥50–100 Mbps while implementing advanced QoS policies to prioritize LMS, administrative services, and pedagogical platforms.
- *Cyber security Enhancements:* Decommission unsupported OS (Windows XP/7). Establish a comprehensive cyber security policy, including centralized antivirus, network segmentation, multi-factor authentication, and user training on phishing, ransomware, and removable media risks.
- *Governance and Management:* Establish a multi-year IT renewal plan, standardize preventive maintenance procedures, and document the network infrastructure in a technical repository. Participation in university consortia such as iRenala is recommended to optimize bandwidth costs, while open-source solutions can reduce recurrent expenditures. A comprehensive digital strategy should integrate mobility, cyber security, and infrastructure sustainability.

V. Conclusion

The findings of this study clearly demonstrate that hardware characteristics play a decisive role in determining the efficiency of systems deployed on the Higher Normal School of Antananarivo's computer network. Critical constraints include the obsolescence of core equipment—over 55 % of workstations operating on processors older than 15 years and all running unsupported operating systems—heterogeneous switching infrastructure with the coexistence of Fast and Gigabit Ethernet, limited Internet bandwidth (15 Mbps for approximately 2,000 users), and aging cabling. These factors collectively reduce throughput, increase latency, and compromise service availability, thereby constraining both administrative and pedagogical operations.

The network's heavy reliance on mobile devices, which constitute over 90 % of endpoints, further exacerbates performance challenges, as older Wi-Fi access points fail to meet contemporary standards, resulting in uneven coverage and latency issues. User perceptions align with these technical findings, with 82.7 % of respondents citing insufficient bandwidth as the primary limitation, although critical risks associated with obsolescence and security are largely underestimated.

A structured, phased modernization strategy is therefore essential. Priority interventions should include the replacement of defective network switches, standardization of workstation configurations with at least 4 GB of RAM and 250 GB of storage, migration to supported operating systems, deployment of Wi-Fi 6-compatible access points in high-density areas, and progressive renewal of cabling with fiber-optic backbones in strategic locations. Complementary measures such as incremental increases in Internet bandwidth, implementation of advanced Quality of Service policies, preventive maintenance, and targeted user training on cyber security are also critical.

The implementation of these measures promises substantial gains in network performance, resilience, and security, enhancing throughput, reducing latency, and improving overall system availability, all while maintaining a favorable performance-to-cost ratio. These findings offer actionable guidance for the optimization of university networks in resource-constrained contexts and provide a foundation for further exploration of emerging solutions, including virtualization, software-defined networking, and hybrid infrastructures.

Future research might consider how these modernization strategies can be adapted to anticipate evolving digital demands: *to what extent can resource-limited universities in Madagascar integrate advanced networking technologies while ensuring sustainable and secure digital transformation?*

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