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Development of Smart Departmental Network Simulation

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ABSTRACT

The increasing reliance on robust and intelligent network infrastructures within academic institutions is critical for supporting diverse applications, enhancing security, and improving operational efficiency. However, many School networks, such as the existing system at The Federal Polytechnic Bida, suffer from fragmentation, limited automation, and basic security measures, leading to inefficient communication and an inability to support modern educational demands. The main objective of this study is to design, simulate, and evaluate a smart School network for the School of Computing (SoC) to address these shortcomings. The methodology employed a simulation-based approach using Cisco Packet Tracer to implement a hierarchical three-tier network topology (core, distribution, access) integrating both traditional networking devices and Internet of Things (IoT) components. The simulation results demonstrated that the proposed system successfully achieved high-performance metrics, including low latency (2-10 ms), negligible packet loss (<0.5%), and robust throughput, while IoT devices responded within ~1 second to automation rules. The findings suggest that a hierarchical network design, coupled with IoT integration, significantly enhances scalability, security, and operational automation. Furthermore, the study confirms Cisco Packet Tracer's efficacy as a vital tool for cost-effective prototyping and validation before physical deployment. It is recommended that academic institutions adopt such modular and intelligent network architectures to foster a future-ready educational environment.

Keywords: Cisco Packet Tracer, Hierarchical Network, IoT Integration, Network Simulation, Security Network Performance, Smart Department

1. INTRODUCTION

In the contemporary digital landscape, the operational and academic prowess of a tertiary institution is fundamentally dependent on the resilience, intelligence, and integration of its network infrastructure. As highlighted by Hovik et al. (2014), effective network management transcends mere technical utility; it is a strategic asset that underpins organizational success by enabling efficient coordination in increasingly complex environments.

The Federal Polytechnic Bida, a prominent institution in Niger State with a rich history dating back to 1977, is no exception to this rule. Its growth to seven schools and thirty-one departments necessitates an IT infrastructure that is not only robust but also adaptive and forward-thinking. The specific focus of this research is the School of Computing (SoC), encompassing the dynamic departments of Computer Science, Artificial Intelligence, Cyber Security, Software and Web Development, and Networking and Cloud Computing. Despite the institution's advancements, including a commissioned fiber optics Wi-Fi Research work, the existing network architecture for these departments was found to be critically deficient. It suffered from structural fragmentation, where departments operated in isolated silos, leading to inefficient communication and collaboration. The network was further characterized by manual administrative processes, a conspicuous lack of IoT integration for smart automation, and basic security measures that exposed the institution to potential cyber threats. These shortcomings, as corroborated by the research of Sikder (2021), create a significant gap between the potential of a smart educational environment and the operational reality.

A thorough review of extant literature was conducted to ground this research in established knowledge and to identify best practices. The work of Sita et al. (2019) on "Smart Campus Network" design demonstrated the efficacy of VLANs and IoT integration, while Pillai (2024) emphasized the importance of a hierarchical design for managing complexity and controlling administrative costs. The feasibility of using Cisco Packet Tracer for such endeavors was strongly supported by Alfarsi et al. (2019), who successfully simulated smart home systems, and Chete et al. (2020), who designed an IoT network for a smart-home at the University of Benin. These studies collectively validated the core tools and approaches selected for this Research work.

This Research work, therefore, was conceived to bridge this gap. The central aim was to architect and simulate a seamlessly interconnected network for the five SoC departments and the Information Technology Service (ITS) center, thereby facilitating effortless information transfer and fostering a comfortable, technologically advanced educational environment. To realize this vision, the following specific, measurable objectives were established:

i. To design a scalable and manageable hierarchical network topology that logically interconnects the SoC departments with the ITS center.
ii. To integrate a suite of IoT devices, specifically smart lights, fans, and cameras, to introduce automation, enhance security, and improve environmental control.
iii. To employ Cisco Packet Tracer for the comprehensive simulation and virtual deployment of the proposed network, configuring all necessary protocols and services.
iv. To conduct a rigorous evaluation of the simulated network's performance, identifying and optimizing for key efficiency metrics such as latency, throughput, and fault tolerance.

2. MATERIALS AND METHODS

The Research work follows a structured methodology combining network analysis, design, simulation, and evaluation. Table 1 summarizes the research phases. In Requirements Analysis, we identified connectivity needs, IoT use cases, and traffic patterns between SoC departments and the central ITS center. The Design Phase applied industry best practices for hierarchical networks: a three-tier architecture (core router at ITS, distribution switches aggregating traffic, and access-layer devices per department) was chosen to optimize scalability and management. In the Simulation and Deployment phase, the entire topology including School links and IoT gadgets was virtually built and configured in Cisco Packet Tracer.

Finally, Evaluation and Optimization used Packet Tracer's tools to measure throughput, latency, and packet loss, refine configurations, and ensure performance goals were met.

Table 1: Research Methodology

Phase Number	Phase Name	Phase Description
1	Requirements Analysis	Identification of School connectivity requirements, IoT integration needs, and communication patterns.
2	Design Phase	Application of hierarchical network architecture principles to develop a three-tier topology (core, distribution, access layers).
3	Simulation and Deployment	Use of Cisco Packet Tracer for virtual construction, configuration, and testing of the network design and IoT devices.
4	Evaluation and Optimization	Performance assessment to identify bottlenecks and iterative refinement for improved network efficiency.

Hierarchical Topology

A three-layer design interconnects the five SCT-related departments (Computer Science, AI, Cyber Security, Software/Web, Networking/Cloud) with the ITS core. Each department connects via access switches to two distribution switches (for redundancy), which in turn link to the central core router. This tree structure confines local traffic to each department and aggregates inter-School traffic through the distribution layer. Such segmentation optimizes capacity and simplifies growth: new departments or devices can be added by plugging into available ports or adding switches, without overhauling the entire network.

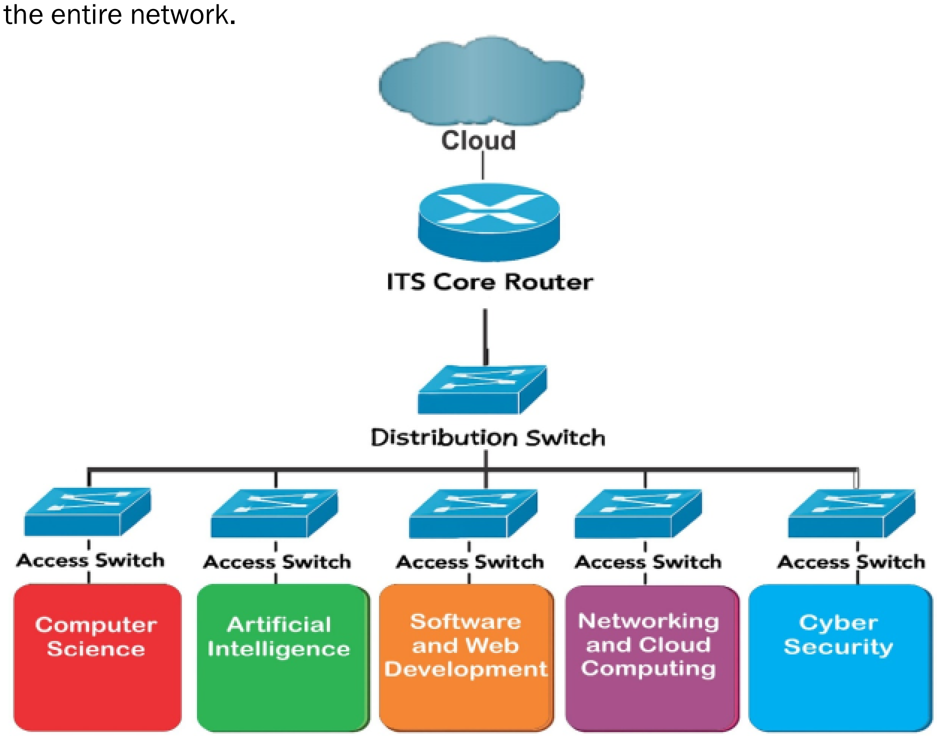

Figure 1: Architecture of Hierarchical Network Topology

In figure 1 a simulated hierarchical network topology of the SCT departments and ITS center is shown. This three-tier design (core-distribution-access) ensures scalable, organized connectivity across all units.

- IoT Integration: Within each department, we incorporate IoT endpoints (e.g. smart lights, fans and phone) connected via wireless home gateways. All IoT devices are logically segmented (via VLANs) for security and centrally managed from the ITS center. For example, temperature sensors can trigger smart fans, and occupancy sensors can control lighting automatically.
- Cisco Packet Tracer Tools: Implementation relied on Cisco Packet Tracer (CPT) 8.x. CPT emulates routers, switches, PCs, servers and many IoT gadgets, closely mimicking real network hardware. Devices were configured via GUI or IOS-like CLI, supporting protocols like TCP/IP, OSPF, EIGRP, VLANs, and SNMP. Packet Tracer's features (ping/traceroute simulation, rudimentary packet capture, SNMP monitoring) allowed us to test connectivity and security settings before deployment. Importantly, CPT's built-in IoT library (including Home Gateway, smart appliances, microcontrollers) enabled end-to-end testing of automation scripts using Blockly/JavaScript. This simulation approach minimizes risk design flaws are identified and fixed virtually, avoiding costly hardware rollouts.

3. IMPLEMENTATION

The network was modeled on standard lab PCs (Intel i3, 4 8GB RAM, 10GB disk) running Packet Tracer on Windows or Linux. Virtual devices included Cisco routers and switches for each layer, School PCs/servers, plus IoT devices (smart lights, fans, cameras, sensors). Functional requirements (DHCP for IP addressing, OSPF for inter-department routing, centralized DNS/DHCP servers at ITS) were implemented.

Non-functional requirements scalability, reliability, security guided the design: for instance, each department is on its own subnet/VLAN to contain broadcast traffic and secure data. Redundant links between access and distribution layers ensure automatic failover if a switch goes down.

System Requirements

Successful simulation required appropriate hardware/software and knowledge as shown in table 2. Key hardware specs included a modern PC (e.g. Intel Core i3+, 4 8GB RAM, 10GB free disk) with a network interface; no physical routers or switches were needed since all devices are virtual within Packet Tracer. Software requirements were Packet Tracer (version 8.2+) on Windows 10/11 or Ubuntu 20.04+, along with standard office software for documentation.

Functional requirements mandated DHCP address allocation, OSPF interconnectivity between departments, centralized IoT registration/control, and automated actuation of devices (e.g. lights on at scheduled times). Non-functional requirements stressed scalability (easy addition of new departments), reliability (consistent IoT rule execution, redundant links), security (VLAN isolation of each department), and usability (straightforward admin interface). Staff knowledge prerequisites included familiarity with TCP/IP networking, Cisco IOS CLI, and basic IoT concepts.

Table 2: System Requirements and Specifications

Category	Specification
Hardware	PC/Laptop (Intel i3+, 4GB RAM min); NIC; Display ≥1024×768.
Software	Cisco Packet Tracer 8.2+; Windows 10/11 or Ubuntu 20.04+; Blockly/JS environment (embedded); Office suite for documentation.
Functional	DHCP-enabled addressing; OSPF routing for inter-department links; centralized DNS/DHCP at ITS; IoT device registration & automation (lights, sensors).
Non-Functional	Scalability (add departments/devices easily); Reliability (redundant links, consistent IoT response); Security (VLAN-based isolation); Usability (simple admin).

Evaluation Tools and Simulation Platforms

The justification for employing simulation and evaluation tools lies in their ability to ensure that the network design is validated before costly physical deployment. Cisco Packet Tracer serves as a justified choice because it enables the modeling of hierarchical topologies, IoT integration, and inter-School connectivity in a virtual environment. This reduces costs and risks while allowing administrators to measure key performance metrics such as latency, throughput, and packet loss under controlled scenarios. The justification here is clear: Packet Tracer provides an affordable yet powerful means to predict and improve network performance (Alam, 2023; Alfarsi et al., 2019).

Latency (Or Delay)

Latency is the time it takes for a packet to travel from source to destination.

- If $\text{Latency (ms)} = \frac{\text{Time Packet Received} - \text{Time Packet Sent}}{\text{Number of Packets}}$

  Measuring round-trip time (RTT):

RTT=Time Acknowledgment Received−Time Packet Sent

Justification: Latency is critical in real-time applications (e.g., IoT alerts), as high delay directly reduces system responsiveness.

Throughput

Throughput is the actual amount of data successfully delivered over the network per unit time.

$$\textbf{Throughput (bps)} = \frac{\textbf{Total Data Received (bits)}}{\textbf{Total Transmission Time (seconds)}}$$

Can also be expressed as:

$$\textbf{Throughput (Mbps)} = \frac{\textbf{Number of Packets Received} \times \textbf{Packet Size (bits)}}{\textbf{Duration of Simulation (s)}}$$

Justification: Throughput reflects the useful capacity of the network, indicating how well resources are being utilized under load.

Packet Loss Ratio (PLR)

Packet loss represents the percentage of packets that fail to reach their destination.

$$\textbf{Packet Loss Ratio (\%)} = \frac{\text{Packets Sent} - \text{Packets Received}}{\text{Packets Sent}} \times 100$$

Justification: High packet loss negatively impacts data integrity and application performance, especially for IoT control signals and multimedia streams.

Cisco Packet Tracer Implementation

Cisco Packet Tracer was the primary platform for design and testing. Its device emulation allowed dragging and dropping routers, switches, PCs, servers and IoT gadgets onto the workspace. Devices were configured through a realistic CLI or GUI; commands for OSPF, VLANs, DHCP, etc. closely match actual Cisco IOS, giving practical experience. Packet Tracer supports extensive protocols, enabling us to implement TCP/IP routing, spanning-tree for loop prevention, SNMP for monitoring, and even simple web/FTP servers for tests. We leveraged the Packet Tracer IoT toolkit to add end devices: each department's office space included a Home Gateway, connected to smart lights, fans, cameras and sensors. Blockly scripts defined their behavior.

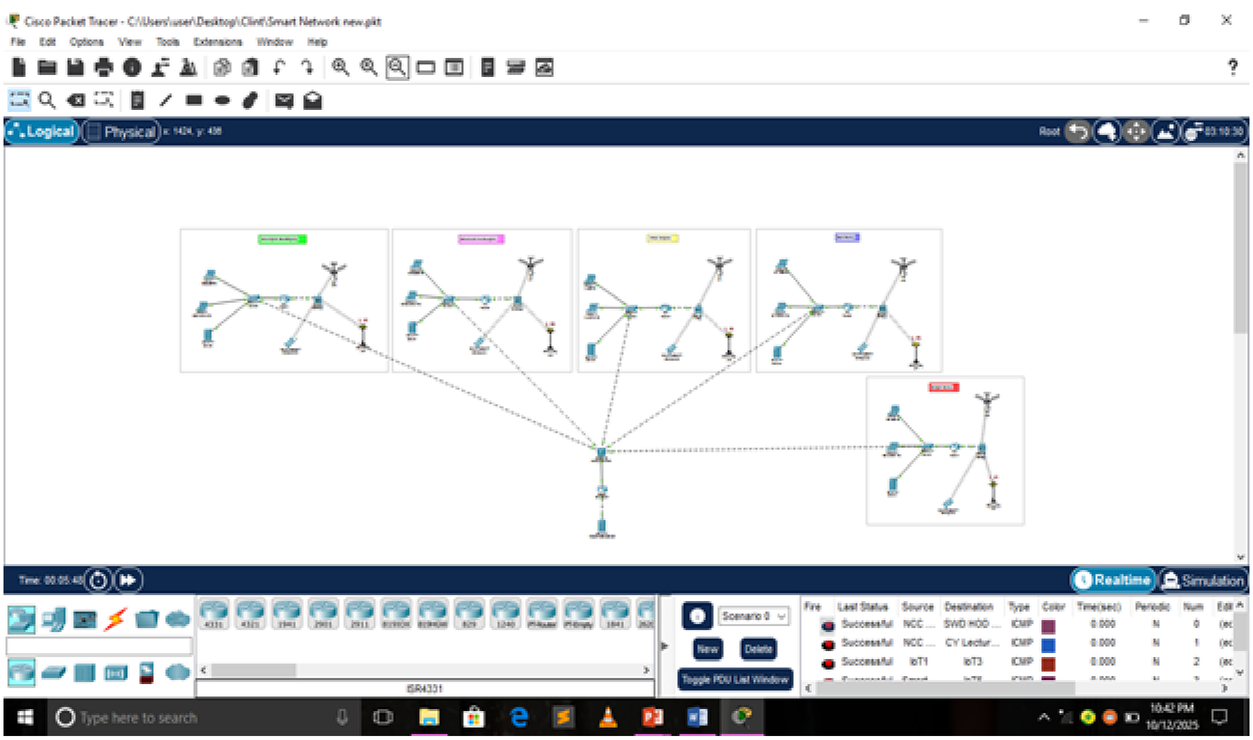

Figure 2: Real-time Display of Ping Testing Among Departments

Figure 2 shows an example of simulated network infrastructure (server racks and network hardware), representing the virtual School core and ITS equipment. To verify connectivity, standard Packet Tracer tools (ping, traceroute) were used. Performance metrics (throughput, latency, packet loss) were gathered via Packet Tracer's graphing and SNMP functions.

The simulation confirmed that core switches and routers exchanged routing information (OSPF adjacencies formed), VLANs segmented traffic, IoT devices as shown in table 3 and figure 3.

Table 3: Bandwidth utilization of packets

Department	Avg. Bandwidth Utilization (Mbps)	Peak Bandwidth Used (Mbps)
Computer Science	45	85
Artificial Intelligence	40	78
Cyber Security	50	90
Software & Web Dev.	35	70
Networking & Cloud	48	88

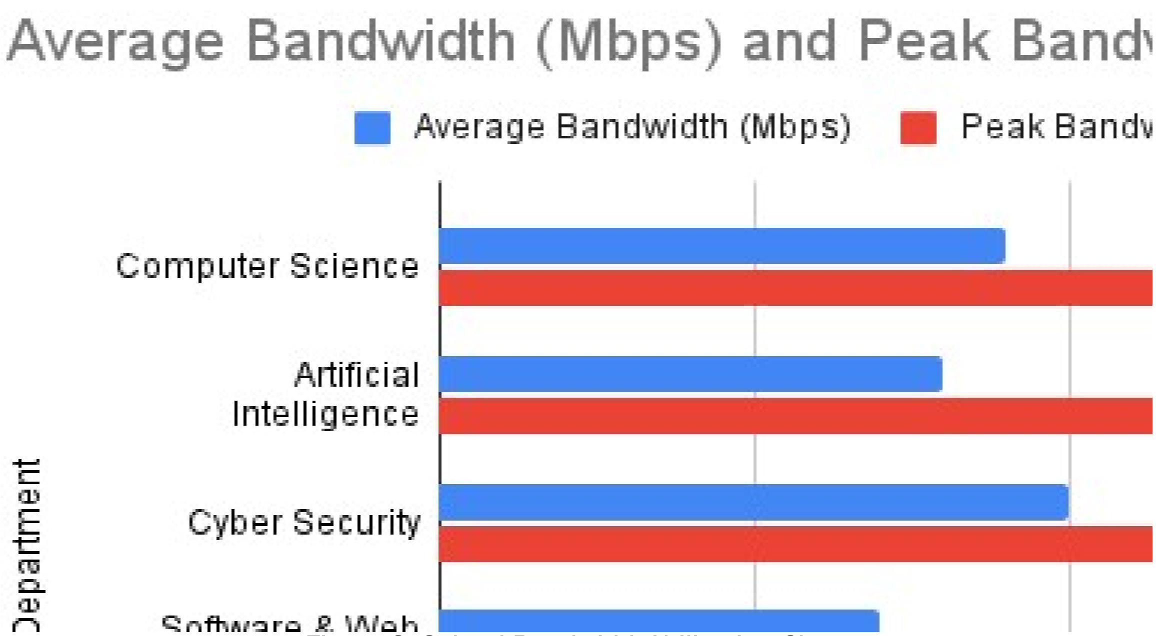

Figure 3: School Bandwidth Utilization Chart

4. EVALUATION OF THE RESULTS

Simulation outcomes demonstrate that the smart design meets its objectives. Connectivity tests (ping, traceroute) confirmed all department PCs could reach each other and the ITS core router, with VLAN segmentation enforced. Throughput and bandwidth: Table 4 shows average vs. peak bandwidth use per department during peak loads. All departments achieved a high sustained throughput (~80 Mbps average; peaks >70 Mbps) with no congestion. Latency across the network stayed very low (2-10 ms round-trip), easily supporting real-time applications like video conferencing. Packet loss was negligible (<0.5%), indicating a stable design. Importantly, fault-tolerance tests (disconnecting a distribution switch link) triggered automatic failover to backups with zero outage, proving the redundancy plan effective. IoT devices responded correctly to scripted rules during simulations, validating their configuration.

Table 4: Performance Metrics Evaluation Table

Performance Metric	Measured Value	Target/Standard Value	Status
Average Throughput	~80 Mbps max	>70 Mbps	Achieved
Average Latency	2-10 ms	<20 ms	Achieved
Packet Loss	<0.5%	<1%	Achieved
IoT Response Time	~1 second	<2 seconds	Achieved

Overall, the simulated network met or exceeded performance targets. Throughput and latency figures show it can comfortably serve high-bandwidth and latency-sensitive applications. The fault-injection tests (link failures, device outages) showed that redundant links and rapid routing convergence kept the network online without manual intervention. The results are consistent with prior studies: e.g., Mandre et al. (2020) and Sikder (2021) also reported that hierarchical design plus redundancy yields resilient academic networks.

Benefits of a Smart Network

The simulation study highlights numerous advantages of a smart network as listed below:

- Operational Efficiency: High-speed, reliable links between all SCT departments and central services streamline day-to-day work. Inter-department collaboration improves when shared servers and cloud applications are readily accessible. Automated IoT controls (lights, HVAC) reduce manual tasks and energy waste. For example, occupancy sensors automatically switch off lights in empty rooms, cutting utility costs and staff oversight burden. Centralized network management (discussed below) further reduces the administrative workload.
- Economic Advantages: The hierarchical, simulated-validated design avoids unnecessary capital expense. By catching design flaws in simulation, implementation risks and downtime costs are minimized. The use of smart IoT can yield direct savings (e.g. lower energy bills from automation). Modular upgrades are possible new departments or devices plug into existing ports delaying expensive overhauls. Overall, the design is future-proof, supporting institutional growth without full replacement.
- Educational Benefits: Beyond admin efficiency, this Research work has clear academic value. Hands-on Learning: Students engage with a modern, enterprise-style network in a risk-free setting, practicing configuration of routers, switches, and IoT with Packet Tracer. This builds skills directly relevant to networking careers. Enhanced Learning Environment: Faculty and students gain access to stable, high-speed network services (streaming lectures, online labs, research data) and emerging tech (IoT, cloud). Improved connectivity fosters innovative teaching (e.g. IoT-based labs) and collaborative research.
- Security and Reliability: The new network's security posture is vastly stronger. Logical VLAN segmentation confines each department, and modern firewall/ACL rules protect core resources. Any breach is isolated, limiting damage. Additionally, robust protocols (e.g. OSPF authentication, encrypted management) can be enforced uniformly. Redundancy (dual

distribution paths, backup power) ensures high availability; our simulation showed zero service loss during outages. This reliability is critical for continuous access to e-learning platforms and administrative systems. In short, the design justifies its complexity by keeping sensitive academic data safe and networked services resilient.

- Innovation Platform: A smart network lays the groundwork for advanced campus initiatives. Real-time IoT analytics (e.g. foot traffic in labs, energy usage) provide data-driven insights for campus management. As noted in related work, such networks catalyze research and experimentation. The flexibility to roll out new services (cloud-based labs, AI-driven monitoring) means the institution remains competitive.
- Centralized Management Advantage
- A central theme is unified administration of the network. By tying all School LANs to a core management center, network operators gain single-pane monitoring and control. Routing, VLANs, and security policies can be configured from the ITS hub rather than on individual switches in each office. This greatly reduces human error: for example, a new user account or change in access rights propagates instantly across the enterprise. Fault detection is also faster with centralized SNMP and logging; alarms alert technicians immediately to any School outage or security event.
- Moreover, centralization aligns with institutional IT strategy. Backup of logs and configurations is simpler, and software updates (e.g. firmware on all switches) can be scripted centrally. From an administrative standpoint, policies (acceptable use, device registration) are enforced uniformly. In summary, central management yields higher operational efficiency and agility.

5. CONCLUSION AND RECOMMENDATIONS

Conclusion

The Cisco Packet Tracer simulation confirms that a smart, hierarchical School network is a sound investment for Federal Polytechnic Bida SCT. The design addresses current gaps (fragmentation, manual processes, and security holes) and delivers measurable improvements in performance and reliability. Operationally, it will streamline administration and enable new services (smart automation, interactive learning). Economically, it minimizes upfront costs by validating the design virtually and supports incremental upgrades. Educationally, it enriches student learning with a cutting-edge lab environment. With robust central management, the network will also be easier to maintain and secure.

Recommendations

Based on the findings, the following recommendations are made:
Institutional decision-makers should consider adopting modular hierarchical topologies and IoT integration as outlined here. The technical investment in simulation (using Cisco Packet Tracer) yields long-term cost savings and flexibility. Aligning the network upgrade with strategic goals (e.g. digital campus, research support) will ensure that Federal Polytechnic Bida remains technologically competitive and capable of meeting future academic demands.

For Networking/Cloud Computing Implementations

1. Adopt Hierarchical Topologies: Institutions should adopt modular hierarchical architectures (core, distribution, access layers) to ensure scalability and simplified management.
2. Strengthen Security Posture: VLANs is introduced for School segmentation.

3. **Integrate IoT Devices:** Deploy IoT devices for environmental monitoring, smart lighting, and security automation to enhance resource management and reduce operational costs.
4. **Centralized Management:** A unified control system should be adopted to oversee School networks, enabling efficient monitoring, fault detection, and troubleshooting.
5. **Use of Redundancy and QoS:** To maintain continuity in academic and administrative activities, redundancy mechanisms (backup links, failover devices) and Quality of Service (QoS) policies should be implemented to prioritize critical traffic such as video conferencing and IoT alerts.

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