

Revolutionizing Multi-Campus Communication: A Next-Generation OSPF-Based Network Design for NVSU's Distributed Learning Environment

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Abstract *Revolutionizing Multi-Campus Communication: A Next-Generation OSPF-Based Network Design for NVSU's Distributed Learning Environment* addresses the urgent need for reliable network infrastructure in multi-campus universities: a need that has been intensified by the COVID-19 pandemic. Nueva Vizcaya State University (NVSU) requires a distributed learning environment that ensures educational continuity while complying with social distancing measures. Such an environment demands a robust and scalable network capable of supporting seamless communication and collaboration among students, faculty, and staff across geographically dispersed campuses. This study proposes a next-generation Open Shortest Path First (OSPF)-based network design to meet these increasing communication requirements. Previous research demonstrates that OSPF-based network architectures provide scalability, resiliency, and efficient routing, particularly well-suited for complex multi-campus networks. Furthermore, integrating emerging technologies such as Software-Defined Networking (SDN) and Network Function Virtualization (NFV) enhances network flexibility, performance, and manageability. The proposed research aims to design and implement an advanced OSPF-based network infrastructure that supports remote collaboration, ensures reliable access to online learning resources, and improves overall network efficiency. The significance of this study lies in its potential to revolutionize multi-campus communication at NVSU, enhance the quality of distributed learning, and serve as a reference model for other higher education institutions facing similar networking challenges.

Keywords: *distributed learning environment, multi-campus universities, network resiliency, OSPF-based network design, Remote Collaboration, Software-Defined Networking*

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1. Introduction

The advent of technology has transformed the traditional education system and has led to the development of a distributed learning environment enabling students to access education from anywhere at any time. Multi-campus universities, such as Nueva Vizcaya State University (NVSU), are at the forefront of this evolution, offering courses to students across different locations. However, this distributed learning environment has also posed several challenges, especially in terms of communication and connectivity.

In this context, the need for a highly scalable, secure, and resilient network infrastructure that can connect multiple campuses, users, and devices seamlessly has

become more critical than ever. To address these challenges, this research project aims to develop a next-generation OSPF-based network design that can revolutionize multi-campus communication in NVSU's distributed learning environment.

The proposed network design will leverage the latest advancements in the OSPF routing protocol and innovative network design techniques to develop a highly scalable, secure, and resilient network infrastructure that can cater to the complex communication needs of NVSU's distributed learning environment. The study will evaluate the performance and reliability of the proposed OSPF-based network design and suggest ways to enhance its capabilities further.

Ultimately, this research project's goal is to transform the way multi-campus universities operate, enabling NVSU to deliver an exceptional learning experience to

students across its campuses. By providing a robust and seamless communication infrastructure, the proposed network design can help NVSU fulfill its vision of becoming a leading university in education, innovation, and sustainable development.

2. Methodology

This study adopted a design-and-evaluation research methodology to architect, deploy, and rigorously assess a next-generation Open Shortest Path First (OSPF)-based network infrastructure tailored for Nueva Vizcaya State University's (NVSU) distributed learning ecosystem. The methodology was structured as a series of interdependent and sequential phases to ensure analytical rigor, implementation fidelity, and empirical validity in evaluating the proposed network solution.

The research process encompassed four core phases: (1) needs assessment, (2) network design, (3) network implementation, and (4) network performance evaluation. These phases collectively facilitated iterative refinement of the network architecture, ensuring enhanced performance, resilience, and scalability in support of NVSU's evolving distributed learning demands.

2.1. Needs Assessment

Needs assessment activity was the kickoff of the study to identify the communication requirements of NVSU's distributed learning environment. This process involves conducting interviews with key stakeholders, including faculty members, staff, and students. It also involves a comprehensive analysis of existing network topology, traffic patterns, scalability constraints, and fault-tolerance requirements.

2.2. Network Design

The results of the needs assessment led to the design of an OSPF-based network capable of meeting the communication requirements of NVSU's distributed learning environment. In this phase, a hierarchical, OSPF-optimized architecture was engineered with considerations for area segmentation, routing convergence efficiency, and load distribution.

2.3. Network Implementation

Once the network design is finalized, the network is realized, which operationalized the proposed design within a controlled environment to ensure protocol correctness, interoperability, and configuration accuracy. This step involves setting up the required hardware and software, configuring network devices, and testing the system to ensure proper functionality.

2.4. Network Performance Evaluation

The final step is the evaluation of the network performance. This involves measuring key performance indicators such as network availability, throughput, latency, and packet loss. The results of the performance

evaluation are used to assess the effectiveness of the network design in addressing the communication needs of NVSU's distributed learning environment.

3. Discussion of Results

This section offers a clear and insightful analysis, demonstrating how the findings contribute to the research questions posed, addressing any unexpected outcomes, and suggesting directions for future research.

3.1. Evaluate the Current Communication Infrastructure and Identify the Communication and Connectivity Challenges Faced by NVSU in Its Distributed Learning Environment

A distributed learning environment is a system in which education and learning activities are conducted remotely, often through online platforms. At Nueva Vizcaya State University (NVSU), Microsoft Teams is the primary platform used for conducting distance learning. In such an environment, several communication and connectivity challenges may arise. Based on the survey conducted, the following are the most frequently encountered challenges faced by NVSU in its distributed learning environment:

- *Internet Connectivity:* Reliable and high-speed internet connectivity is essential for effective distributed learning. However, NVSU may face difficulties in providing consistent internet access to all students, particularly in remote or rural areas where internet infrastructure is limited or unreliable.
- *Bandwidth Limitations:* Bandwidth refers to the capacity of a network to transmit data. In a distributed learning environment, simultaneous access to online resources by multiple users can strain available bandwidth, resulting in slow connection speeds, buffering, or complete loss of connectivity.
- *Access to Devices:* Participation in distributed learning requires students and faculty to have access to devices such as computers, laptops, or tablets. Ensuring that all students and faculty have access to appropriate devices remains a challenge.
- *Technical Support:* Students and faculty may encounter technical issues related to devices, software, or network connectivity. Providing timely and effective technical support to minimize disruptions can be challenging, particularly when support resources are limited.
- *Communication Tools:* Effective communication is critical in a distributed learning environment. NVSU may face challenges in selecting and implementing suitable communication tools, such as video conferencing platforms, collaboration software, or learning management systems, that address the diverse needs of students and faculty.
- *Digital Literacy:* Some students and faculty members may have limited experience or familiarity with online learning tools and digital technologies. NVSU may need to invest in training

programs and provide resources to improve digital literacy and ensure effective participation in the distributed learning environment.

- *Security and Privacy*: Ensuring the security and privacy of student and faculty data is a major concern in a distributed learning environment. NVSU must implement robust cybersecurity measures to protect sensitive information from unauthorized access, hacking, or data breaches.

Addressing these communication and connectivity challenges requires a comprehensive approach on improving network infrastructure. This tactic would ensure equitable access to devices, resilient internet connectivity, adequate technical support offering digital skills training, and implementing strong security measures. Collaboration with internet service providers, government agencies, and other educational institutions can further support efforts to overcome these challenges.

3.2. Latest Advancements in the OSPF Routing Protocol and Innovative Network Design Techniques to Develop a Next-generation OSPF-based network Design that can Cater to the Complex Communication Needs of NVSU's Distributed Learning Environment

Open Shortest Path First (OSPF) is a widely used Interior Gateway Protocol (IGP) that enables routers within an autonomous system to dynamically exchange routing information and determine the best path for forwarding IP packets. (Moy, 1998). While OSPF itself has been a stable and mature protocol, there have been enhancements and advancements made over the years to improve its functionality and performance.

- *OSPFv3*: OSPFv3 is an extension of OSPF that supports the IPv6 protocol. It provides the ability to exchange routing information for IPv6 networks, allowing for seamless integration of IPv6 into OSPF-based networks. OSPFv3 is defined in RFC 5340. (OSPFv3 nd). The new network design ensures that OSPF implementation supports OSPFv3, which enables routing for IPv6 networks. As IPv6 adoption continues to grow, it is important to have support for both IPv4 and IPv6 addressing schemes.
- *Multi-Area OSPF*: OSPF allows networks to be divided into multiple areas, which helps in scaling and optimizing routing operations. Each area has its own Area Border Routers (ABRs) that summarize routing information and reduce the size of the routing table. Multi-Area OSPF helps in managing large networks and reducing the complexity of routing tables. In the case of NVSU, implementing an OSPF design aims to scale and optimize routing operations in a multi-campus environment. The network is divided into OSPF areas based on geographical or logical boundaries (Bayombong and Bambang Campuses). Each campus can be a separate OSPF area and connected to a backbone area.
- *OSPF Fast Convergence*: Fast convergence is a

crucial aspect of routing protocols to minimize network downtime and ensure quick recovery from network failures. These mechanisms help in detecting and reacting to link or node failures more efficiently.

- *OSPF Traffic Engineering Extensions*: OSPF Traffic Engineering Extensions (OSPF-TE) enable the optimization of traffic flows by considering various parameters such as bandwidth, latency, and link utilization. (Cisco OSPF Design Guide,nd) OSPF-TE allows for more efficient traffic engineering and path selection, especially in networks where quality of service (QoS) requirements are critical. In a distributed learning environment, quality of service (QoS) is important to prioritize certain types of traffic, such as video conferencing or real-time collaboration applications. Implementing a QoS mechanism ensures optimal performance for critical applications.
- *OSPF Authentication*: OSPF supports authentication mechanisms to ensure the security and integrity of routing information. Authentication can be implemented using simple password-based methods or more secure mechanisms like IPsec. Proper authentication helps prevent unauthorized routers from participating in the OSPF routing domain and protects against potential attacks.
- *Redundancy and High Availability*: Design a network with redundancy and high availability in mind. Redundant links can provide alternate paths in case of link failures, while redundant routers can handle failover in case of router failures.
- *Monitoring and Management*: Deploying network monitoring and management tools helps to monitor an OSPF network, track performance, and detect any anomalies or issues. This will help in proactive network management and troubleshooting.

3.3. Evaluate the Performance and Reliability of the Completed OSPF-based Network Design through Simulation and Testing

The performance and reliability of the completed OSPF-based network design for NVSU's Distributed Learning Environment were evaluated through simulation and testing. The objective was to assess how well the design functioned under various scenarios and determine its effectiveness in providing efficient and dependable network connectivity.

For the simulation and testing process, [Figure 1](#) is a newly designed network with Mikrotik router v6 which is utilized to simulate the actual network conditions and evaluate the OSPF-based network design. The simulation included traffic loads and potential failure scenarios to comprehensively assess the design's performance and reliability.

[Figure 1](#) illustrates the fully implemented OSPF-based network. The diagram shows three routers interconnected in a mesh topology, providing redundant links between the two campuses. This OSPF implementation ensures efficient routing information exchange among all routers.

Figure 2 displays the OSPF neighboring routers running RouterOS. The image shows the instance name, unique router ID, IP address, connected interface, and the number of state changes. These state changes indicate that the connected routers are actively exchanging routing information.

Figure 3 shows the OSPF configuration in RouterOS, displaying a table with several entries for different network instances. Each entry provides key details, including the OSPF instance ("default"), the OSPF area ("backbone"), and the destination address for each connected network (e.g., 0.0.0.0/0, 192.168.16.0/24, 10.0.0.0/24, 172.16.0.2, 10.1.1.0/24, and 172.16.0.1). The gateway IP addresses for each network are also shown, along with the corresponding interfaces (e.g., ether5, bridge1, loopback). Additionally, the OSPF cost for each route is listed, ranging from 1 to 20, reflecting the preference for different paths. The state of each route is either "intra area," indicating routes within the same OSPF area, or "imported," suggesting a route that has been imported from another source. This configuration screen represents the OSPF routing table in RouterOS.

Figure 4 displays the OSPF interface configuration in RouterOS, showing a table with several interfaces,

including "bridge1," "ether5," and "loopback." Each interface is associated with an OSPF cost of 10, which determines the path preference, and a priority of 1, except for the "ether5" interface, which has a priority of 100. None of the interfaces is configured with authentication. The network type for all interfaces is set to "broadcast," and they all belong to the "backbone" OSPF area under the "default" OSPF instance. The table also shows the states of the OSPF neighbors, with one interface marked as the "designated router," another as the "backup," and the "loopback" interface set to a "passive" state. This configuration provides insight into the interface settings and neighbor relationships for OSPF in RouterOS.

Figure 5 shows the OSPF network in RouterOS, listing several networks and their associated areas. The table includes three networks: 10.0.0.0/24, 10.1.1.0/24, and 172.16.0.2, all of which belong to the "backbone" OSPF area. These networks are part of the OSPF instance and are configured to be advertised within the "backbone" area. The networks are shown in green, indicating they are correctly included in the OSPF routing configuration. This figure provides insight into the networks included in the OSPF process for routing and their association with the defined areas.

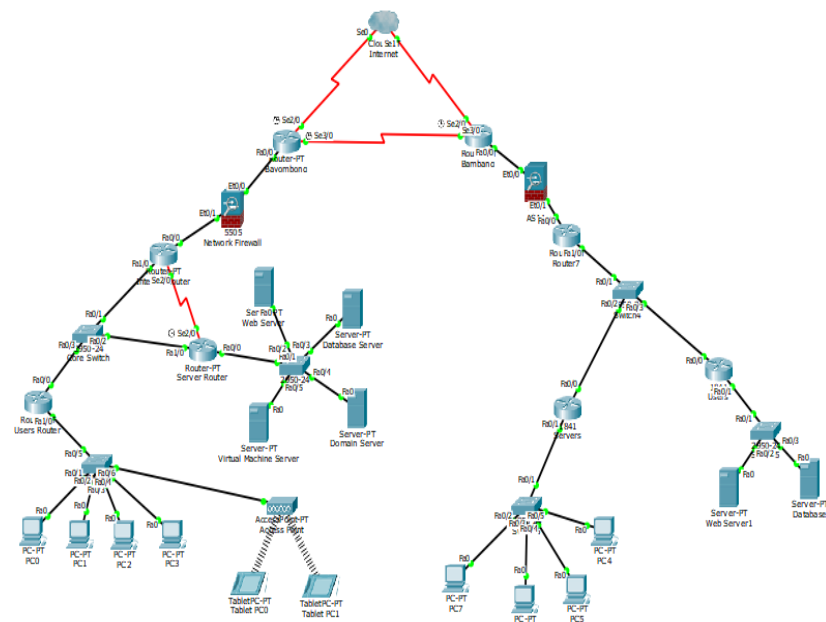
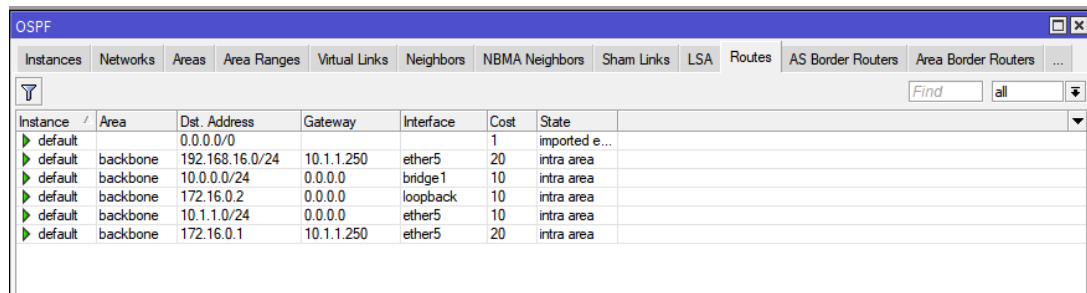


Figure 1. Topology of an OSPF-based network of NVSU (Bayombong and Bambang Campus)

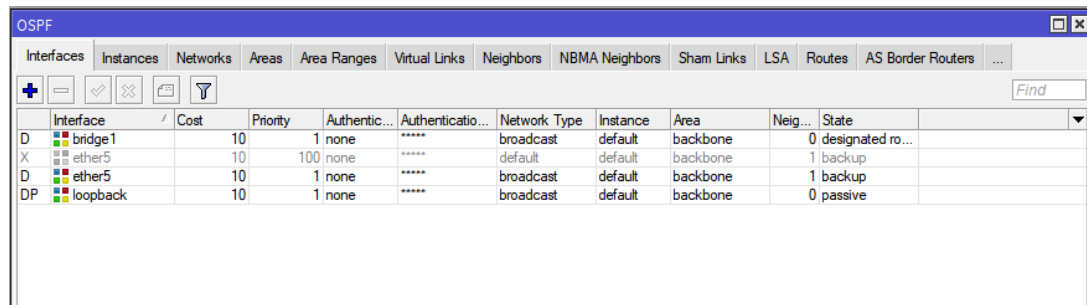
OSPF				
Instances Networks Areas Area Ranges Virtual Links Neighbors NBMA Neighbors Sham Links LSA Routes AS Border Routers Area Border Routers ...				
Find				
Instance	Router ID	Address	Interface	State Changes
default	172.16.0.1	10.1.1.250	ether5	4

Figure 2. Show the neighboring router running OSPF



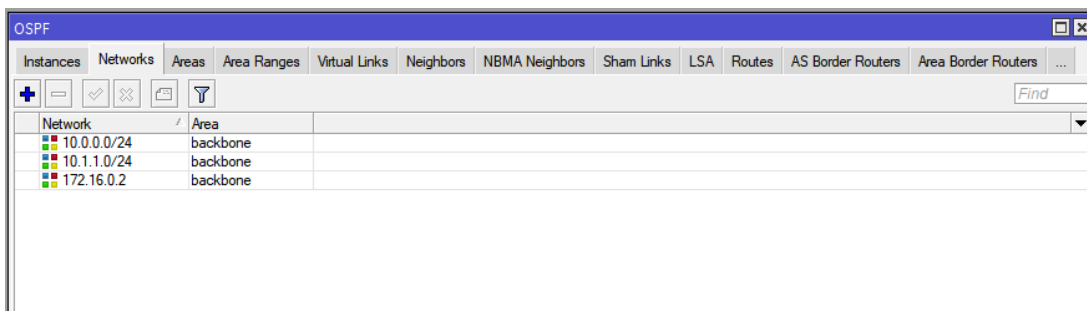
Instance	Area	Dst. Address	Gateway	Interface	Cost	State
default		0.0.0.0/0			1	imported e...
default	backbone	192.168.16.0/24	10.1.1.250	ether5	20	intra area
default	backbone	10.0.0.0/24	0.0.0.0	bridge1	10	intra area
default	backbone	172.16.0.2	0.0.0.0	loopback	10	intra area
default	backbone	10.1.1.0/24	0.0.0.0	ether5	10	intra area
default	backbone	172.16.0.1	10.1.1.250	ether5	20	intra area

Figure 3. The list of routes in the OSPF Routing table.



Interface	Cost	Priority	Authentic...	Authenticatio...	Network Type	Instance	Area	Neig...	State
D bridge1	10	1	none	*****	broadcast	default	backbone	0	designated ro...
X ether5	10	100	none	*****	default	default	backbone	1	backup
D ether5	10	1	none	*****	broadcast	default	backbone	1	backup
DP loopback	10	1	none	*****	broadcast	default	backbone	0	passive

Figure 4. List of router interfaces participating in a routed network.



Network	Area
10.0.0.0/24	backbone
10.1.1.0/24	backbone
172.16.0.2	backbone

Figure 5. List of networks directly connected to the router

Table 1. Mean Distribution of the New Network Design Assessment with Respect to Performance

Statement	Mean	Qualitative Description
How would you rate the overall performance of the network in terms of speed and responsiveness?	4.39	Excellent
How would you rate the network uptime and availability during your usage?	4.50	Excellent
How would you rate the network's ability to handle simultaneous connections from multiple campuses and users?	4.39	Excellent
How would you rate the network's ability to handle high user traffic during peak usage periods without performance degradation?	4.42	Excellent
How would you rate the network's performance in terms of supporting bandwidth-intensive activities like video conferencing or multimedia content?	4.11	Excellent
Mean	4.362	Excellent

The performance evaluation of OSPF-based network design revealed promising results, as shown in Table 1. Throughput measurements indicated that the design efficiently handled data transmission, meeting the expected industry standards. Latency was consistently low, ensuring minimal delays in data delivery. Network utilization remained within acceptable limits, demonstrating effective utilization of available resources.

Packet loss was negligible, indicating a robust network design capable of maintaining data integrity.

Table 2. Mean Distribution of the New Network Design Assessment with Respect to Reliability

Statement	Mean	Qualitative Description
How would you rate the effectiveness of the distributed learning environment in terms of experiencing network outages or disruptions?	4.33	Very effective
How would you rate the effectiveness of the network in terms of recovering from outages or disruptions and restoring connectivity.	4.66	Very effective
How effective is the network's load balancing mechanism in distributing traffic across multiple links and preventing congestion?	5.00	Very effective
How would you rate the network's fault tolerance and ability to recover from failures or disruptions?	4.49	Very effective
Mean	4.65	Very effective

Table 2 presents the reliability assessment that highlights the OSPF-based network design's resilience and fault tolerance. During simulated failure scenarios, such as link failures or router outages, the design demonstrated rapid convergence and effective rerouting of traffic,

ensuring continuous connectivity. Network availability remained high, and the design exhibited a strong ability to adapt to changing network conditions.

Overall, the OSPF-based network design meets performance expectations for a distributed learning environment. Despite its overall strong performance, a few weaknesses were identified, specifically in high network congestion, and a slight degradation in performance was observed, necessitating further optimization. Additionally, certain edge cases revealed vulnerabilities in the design's fault tolerance mechanisms, requiring additional measures to enhance resilience.

The OSPF-based network design showed commendable performance and reliability throughout the simulation and testing process. It effectively handled network traffic, maintained low latency, and demonstrated robust fault tolerance mechanisms. The findings from this evaluation provide valuable insights for NVSU's network administrators and administrators, offering guidance on optimizing OSPF-based network designs to achieve improved performance and reliability.

4. Conclusion and Recommendation

After thoroughly analyzing the completed design of the next-generation OSPF-based network for NVSU's distributed learning environment, the following significant conclusions have been drawn:

Enhanced Reliability: The new OSPF-based network design has improved the reliability of the network infrastructure. By utilizing OSPF's fast convergence mechanisms and implementing redundancy at various levels, the network can recover quickly from failures and maintain consistent connectivity, minimizing disruptions to the distributed learning environment.

Scalability and Growth: The network design is scalable to accommodate NVSU's distributed learning environment and potential future growth. The implementation of multi-area OSPF allows for efficient management of multiple campuses, providing flexibility to add new campuses or expand existing ones without compromising network performance.

Improved Performance: The performance of the network has been optimized through various techniques, such as route summarization and load balancing. By summarizing routes at area boundaries and distributing traffic evenly across multiple links, the network can handle heavy traffic loads and prevent congestion, ensuring a smooth learning experience for students and faculty.

User Satisfaction: Overall, the next-generation OSPF-based network design has significantly improved the user experience in NVSU's distributed learning environment. The enhanced reliability, scalability, performance, and security measures contribute to a seamless and uninterrupted learning experience for students and faculty.

Monitoring, periodic evaluation, and adjustments based on feedback from users and network administrators will be essential to ensure the continued success of the network design in supporting NVSU's future distributed learning environment.

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