



Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

**Performance and Cost-Benefit Analysis of Software Defined Network over
Conventional Network at the National Datacenter -Ethiopia.**

By

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Thesis Title

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Network over Conventional Network at the National Datacenter -
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DECLARATION

This research project, titled' *Performance and Cost-Benefit Analysis of Software Defined Network over Conventional Network at the National Datacenter -Ethiopia'* has not been previously approved for any academic degree, nor is it currently under consideration for any degree at any university. I affirm that this thesis is the result of my personal investigation, except where specific acknowledgments are provided. I conducted this study independently, with the guidance and support of my research advisor. Any external sources used in this work are appropriately cited with explicit references, and a comprehensive list of references can be found in the dedicated reference section.

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This thesis has been submitted for examination with my approval as a university advisor.

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Mesfin Kifle (Ph.D.)

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Abstract

With the continuous expansion of data center services and the aging of equipment, there is a growing need to enhance network services and development. Despite their widespread use, traditional IP networks exhibit limitations in terms of network management efficiency and cost-effectiveness, presenting challenges in configuring networks according to established protocols and promptly addressing changes in traffic load and network issues. Adding complexity, current networks often have a vertically integrated structure.

To address these issues, an emerging concept known as Software Defined Networking (SDN) has gained traction in network design and administration. SDN offers the ability to dynamically allocate network resources, contrasting with the limitations of conventional approaches. This paper delves into the performance challenges faced by existing national data center networks and demonstrates the potential improvements that can be achieved through the adoption of Software Defined Networking (SDN). Additionally, the study employs a modeling methodology to assess the value of these network enhancements, considering various factors such as capital and operational expenses and overall ownership costs in the two scenarios. The techno-economic assessment (TEA) model, implemented using tools like Mininet, Observium, and MS Excel, comprises dedicated sections for cost benefit modeling.

The integration of Software-Defined Networking in Ethiopia's national data center is a strategic move that aligns both with social and economic benefits. The consideration of downtime costs adds a crucial dimension to its implementation. From a social standpoint, the adoption of SDN reflects the government's commitment to enhanced public service delivery and inclusivity. By optimizing network performance, SDN enables citizens to access crucial services efficiently, fostering a sense of equal opportunity. This technological advancement supports good governance by enabling effective resource allocation and timely service provision, ultimately enhancing the trust citizens have in the government's dedication to meeting their needs. The paper thus emphasizes the significant potential of SDN adoption for bolstering both technical and social aspects of national data center networks.

Keywords: SDN, National data center, E-gov, Performance Analysis, cost-benefit analysis

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List of Acronyms

APIs	application programming interfaces
DCNIs	data center network infrastructure
E-Gov	Electronics Government
EICTDA	Ethiopian ICT Development Agency
ESERVICES	Electronic services

gov't Government

ICMIC Integrated Civil Service Management Information System

IFMIS Integrated Financial Management Information System

MIInT Ministry of innovation and technologies

NDC National Data Center

NDCE National Data Center Ethiopia

NFV Network Functions Virtualization

SDN software defined network

SD-WAN Software-Defined Wide Area Networking

IAMs integrated assessment models

LCA life cycle assessment models.

DARS document Authentication and Registration Service

Chapter One - Introduction

1.1 Software Defined Network

In the ever-evolving landscape of technology, personal computing emerged in the 1980s, signifying a pivotal turning point in the history of information technology. The rapid innovation and development of the 1960s and 1970s, driven by tech giants like IBM, Intel, Xerox, and Sun Microsystems, contributed significantly to the global spread of computing capabilities. As businesses thrived in this technology-driven era, the demand for continuous operation and quick internet access soared. However, smaller businesses faced challenges in affording expensive data centers and robust internet infrastructure.

To bridge this gap, large multinational organizations like Amazon and Google took the initiative, constructing massive data centers that offered various services and technological solutions. This marked the beginning of a significant proliferation of data centers in the 2000s and 2010s. These data centers, equipped with sophisticated networking, computing, and storage infrastructure, facilitated shared access to applications and data. The growth of data centers not only generated numerous job opportunities but also led to notable upgrades in local electricity grids, benefiting local infrastructure.

However, the expansion of town-sized data centers also sparked debates and concerns. While some communities saw opportunities for increased pay and improved infrastructure, others raised environmental risks, issues of gentrification, and concerns about labor monopolization in smaller towns.

Amidst these developments, computer networks faced increasing complexity, comprising diverse hardware components like routers, switches, firewalls, and load balancers. Network administrators grappled with managing closed and proprietary control software, using extensively tested network protocols for interoperability and standardization. The resulting complexity led to rising costs in network management solutions.

The emergence of SDN marked a significant transformation in the realm of network creation and administration. SDN revolutionized the management of network traffic by separating the data plane from the control plane, thereby enabling dynamic control. This innovation streamlined control by allowing a single software control program to oversee multiple data-plane components using a clearly defined API, with OpenFlow being a notable example. The evolution of SDN's history can be categorized into three key phases: the era of active networks, which introduced programmable functionalities and ignited innovation; the separation of control and data planes, which established open interfaces between these components; and the emergence of the OpenFlow API and network operating systems, representing widely adopted open-source network operating systems.

The rise of SDN represented a significant transformation in the domain of network establishment and management. SDN brought about a fundamental shift in the way network traffic is handled by segregating the data plane from the control plane, thus enabling dynamic control. This groundbreaking advancement simplified network management by permitting a single software control program to supervise numerous data-plane components through a clearly defined API, with OpenFlow standing as a notable example. The historical progression of SDN can be categorized into three pivotal phases: the era of active networks, which introduced programmable functionalities and sparked innovation; the separation of control and data planes, which established open interfaces between these elements; and the emergence of the OpenFlow API and network operating systems, representing widely adopted open-source network operating systems.

One of the primary advantages of SDN lies in its capacity to enhance network flexibility. Through software-based control, administrators can swiftly allocate and expand network resources in response to business requirements. Furthermore, SDN can contribute to the reduction of network intricacy, augment network visibility and security, and lead to cost savings.

SDN technology can leverage the OpenFlow protocol. The SDN architecture can be characterized as follows:

- **Directly programmable:** Network control is directly programmable due to its separation from forwarding functions.
- **Agile:** The decoupling of control from forwarding enables administrators to dynamically adjust network-wide traffic flows to adapt to changing demands.
- **Centrally managed:** Network intelligence is logically centralized within software-based SDN controllers, offering a global perspective of the network, which appears as a unified switch to applications and policy engines.
- **There exists a centralized SDN block that employs a software-governed protocol to oversee the entire network.** It is linked to the OpenFlow Controller, which, in turn, connects to other OpenFlow switches, routers, and networking components. This system utilizes a unique "OpenFlow Protocol" to manage and manipulate the entire network, with the OpenFlow controller governing the OpenFlow switches.[1]
- **Programmatically configured:** SDN empowers network managers to rapidly configure, manage, secure, and optimize network resources through dynamic, automated SDN programs, which they can develop independently as these programs are not reliant on proprietary software.
- **Open standards-based and vendor-neutral:** When implemented using open standards, SDN simplifies network design and operation by relying on instructions provided by SDN controllers instead of multiple, vendor-specific devices and protocols.

Contributions: The proposed SDN deployment will make a number of contributions to the National Data center of Ethiopia. These contributions include:

- Increased flexibility and control over the network: The SDN solution will allow the National Data center to more easily and quickly adapt to changes in traffic patterns and demand. This will improve the efficiency of the network and allow the data center to better meet the needs of its users.
- Improved efficiency and performance of the network: The SDN solution will allow the National Data center to optimize its network resources and to improve the performance of the network. This will result in better quality of service for users and lower operational costs for the data center.
- Increased security of the network: The SDN solution will provide a number of security features that will help to protect the network from unauthorized access and attacks. This will improve the security of the data center and the data that it stores.

SDN deployment is a significant undertaking, but it is essential for the future of the National Data center of Ethiopia. The SDN solution will allow the data center to meet the growing demand for bandwidth and computing resources, and it will improve the overall performance and security of the network.

Software-defined networking is a networking approach that employs software-based controllers or application programming interfaces (APIs) to interact with the underlying hardware infrastructure and manage network traffic. SDN can utilize software to create and oversee both virtual and traditional hardware-based networks. While network virtualization allows organizations to segment various virtual networks within a single physical network or connect devices on different physical networks to create a unified virtual network, software-defined networking introduces a novel approach to directing the routing of data packets through a centralized server.

SDN addresses existing network limitations through two key mechanisms. Firstly, it breaks the vertical integration by separating the network's control logic (known as the control plane) from the routers and switches responsible for forwarding traffic (referred to as the data plane). Secondly, by isolating the control and data planes, network switches become simplified forwarding devices, and the control logic is implemented in a logically centralized controller (or network operating system). This simplifies policy enforcement, network configuration, and adaptation.[2]

- SD-WAN: An SD-WAN refers to a wide area network managed through a software-defined network. Its primary objective is to reduce WAN costs by replacing some or all of the more expensive MPLS lines with more affordable, commercially available leased lines. Central controllers facilitate independent management of control and hardware, simplifying configuration and administration.

- SD-LAN: SD-LAN builds upon the principles of software-defined networking, although it exhibits notable differences in topology, network security, application control and visibility, management, and quality of service. For both wired and wireless LANs, SD-LAN enables policy-driven

design by decoupling control management and data planes. The use of cloud-based management systems and wireless communication without a physical control device defines SD LANs.

Network Function Virtualization and Software-Defined Networking are interconnected concepts that complement each other. NFV involves decoupling network functions from hardware, enabling flexible network deployment through software-based services on servers. In contrast, SDN abstracts control from devices to enhance network management. NFV and SDN can work together in a hybrid program, leveraging virtualization technologies for efficient, scalable service deployment. SDN enables rapid handling of forwarding devices, while NFV's virtualized servers offer flexibility for network applications, resulting in an adaptable and innovative network environment. Architectural components

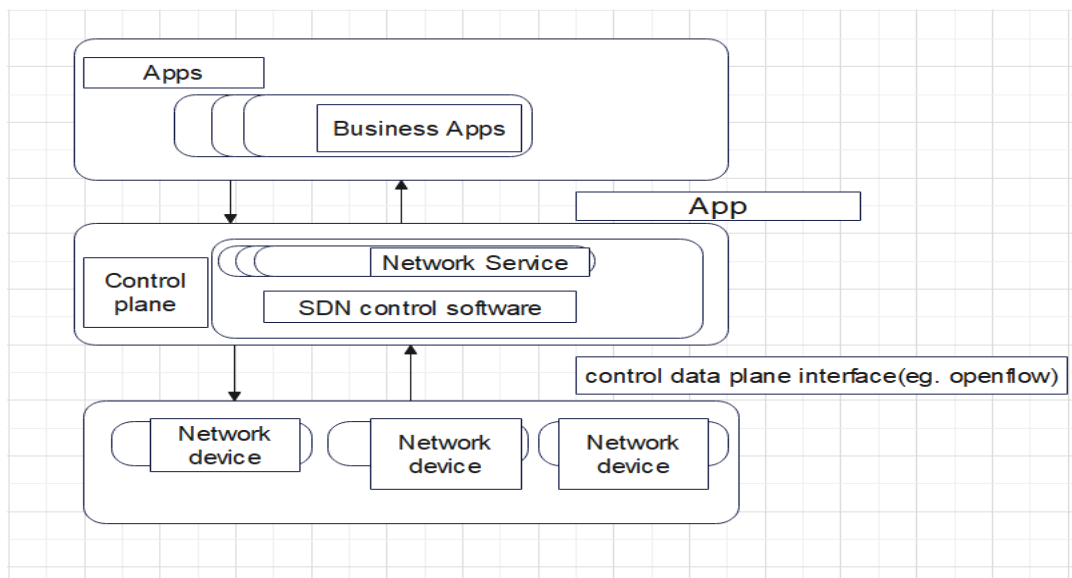


Figure 1. A high-level overview of the software-defined networking architecture

- OpenFlow switches: We take advantage of the fact that the majority of contemporary Ethernet switches and routers have flow-tables that operate at line-rate to construct firewalls, NAT, QoS, and gather data.

OpenFlow is a communication protocol that enables software controllers to manage Ethernet switches by defining packet processing rules (data plane actions) within switches through a flow table. This protocol centralizes network management, abstracting the control plane from individual devices and promoting flexibility and ease of administration in the network architecture

OpenFlow Controller: The current generation of SDN controllers is based on the Open Flow protocol and acts as a kind of network operating system (OS). For server software to instruct switches where to transmit packets, the OpenFlow protocol links controller software to network hardware.

The controller configures network components and selects the optimum routing for application traffic using the OpenFlow protocol.

Organizations use SDN to decouple traffic management and network configuration from the physical network infrastructure. Open application programming interfaces (APIs) can now exercise more granular control over organizational networks via SDNs. The SDN architecture provides increased flexibility for network device coordination that serves specialized needs.

SDN can effectively manage situations involving link failures by redirecting traffic through alternative links. During such occurrences, packets can still reach their intended destinations, albeit with an increase in Round-Trip Time (RTT) and a reduction in throughput[3]. SDN is progressively adopting flexible cloud structures and adaptive resource allocation methods to attain its infrastructure objectives[1].

SDN's fundamental idea is to use software-based policy/control engines to centrally regulate network endpoints to automate network provisioning, management, and control. In a software-defined network, network traffic can be controlled and managed by a network administrator through centralized control software, eliminating the need to make adjustments to individual switches[1]. These centralized engines streamline the entire process and make it nimble, dynamic, and extremely responsive by exposing network status to end users via APIs and abstractions. Benefits include the capacity to generate new service offerings fast and provide them to the end user as on-demand services, as well as streamlined operations, real-time network responsiveness, reduced network complexity, and these advantages. Because new services are launched more quickly, regardless of where the end user is connected, the benefits are reflected in lower OpEx and CapEx as well as stronger top-line growth.

Software-defined networking (SDN) is which can lead to a number of benefits in terms of cost, management, and human resources.

Cost: One of the biggest benefits of SDN is that it can help to reduce network costs. This is because SDN can help to optimize network resources, such as bandwidth and storage. It can also help to reduce the need for expensive hardware, as SDN controllers can be used to manage a wider range of devices.[4] The implementation of SDN/NFV is anticipated to lower the operational expenditures (OPEX) of service providers by consolidating and enhancing both the network infrastructure and the associated operational framework. [5] Software-defined networking has emerged as an effective network technology that can accommodate the evolving requirements of future network functions and intelligent applications. Simultaneously, it reduces operational expenses by simplifying hardware, software, and management.

Management: SDN can also help to improve network management. This is because SDN controllers provide a centralized view of the network, which makes it easier to troubleshoot problems and make changes. SDN can also automate many of the tasks that are currently performed manually, such as provisioning new devices and configuring network policies.[6] network administrators have the flexibility to tailor SDN controllers to meet their specific requirements. Nevertheless, these customizations could have implications in terms of resource utilization and the performance of traffic forwarding.

Human Resources: Skill Requirements: SDN implementation may require staff to acquire new skills and expertise in SDN technologies. However, once trained, the IT team can efficiently manage and maintain the network with improved visibility and control.[7] With the emergence of SDN, network administrators now require training in a variety of network technologies, which differs from the past when there were specialized network administrators.

SDN can also help to free up human resources. This is because SDN has the capability to automate numerous tasks that are presently carried out by network engineers. This can free up engineers to focus on more strategic tasks, such as designing and optimizing the network.

Overall, SDN can have a significant impact on cost, management, and human resources. By optimizing network resources, automating tasks, and freeing up human resources, SDN can help organizations to save money and improve the efficiency of their networks.

1.2 Motivation

Based on the ever increasing demand, it is necessary to upgrade the Government service which is deployed in the national data center. One of the limitation is outdated datacenter Backbone network. It is necessary to upgrade the existing system infrastructure with the immerging technologies like SDN, renew ICT devices and upgrading Bandwidth. Due to that, in this research work, an attempt is made to demonstrate performance and cost benefit analysis of SDN over conventional Network in the National Data center.

1.3 Statement of the problem

Conventional/Traditional networks are vulnerable and time-consuming. Multiple steps are required to add/remove a single device and configure different device separately through a manual process. In conventional network the data and the control planes bond together between the networking devices. Accordingly, the dominant operating system and its features with the established hardware are

implemented in a single device. These, devices (such as switches, routers, firewalls, and other network devices) are manufactured with the acumen of handling traffic of neighboring devices, which distributes and scatters intelligence in the network [8].

On the contrary, SDN was introduced as a pioneering networking model with the aim of streamlining the control and administration of conventional networks. This framework is employed to segregate the control plane from the data plane. The proliferation of diverse modern networking devices, technologies, and computational requirements has had a transformative impact on networks that were originally designed to meet earlier demands. Traditional networks proved inadequate in adapting to technological innovations and evolving needs, leading to the inception of SDN in 2010 to tackle these challenges[9]

However, due to the low flexibility of national data center network architecture and increasing demand for e-government services existing networks can't handle the ever-growing demand for electronic services. In addition, the current national data center traffic has a convergence issue in which all kinds of traffic pass through a single point of the line. Therefore, the services provided by NDCE are limited due to various reasons

- Outdated WoredaNet network technologies and equipment could not support the cloud computing and big data analysis.
- Lack of scalability in NDC network could meet the e-government system (such as e-procurement, e-office etc..) requirement.
- Lack of unified network management tools cannot monitor woredanet network quality.
- Cannot be fine management the network, such as analysis of bandwidth utilization, the access traffic type by user. Evaluate the woredanet by feeling.
- Security monitoring system
- Service Desk

Users of these services have a variety of concerns, with network slowness in the national data center being one of the more major issues (NDC). Additionally, as industries become more and more digitally integrated, service and data volumes are growing rapidly. The traditional IT system architecture experiences scalability bottlenecks and substantial maintenance expenses.

The researchers have been conducted investigation on various SDN related titles globally and locally. Particularly in the area concerned with optimizing the implemented SDN networking system in their company, [10][2][11]. However, applying these research results to the case of the National Data Center of Ethiopia (NDCE) is certainly not directly referred. Moreover, when considering the case of the national data center of Ethiopia, to the best of our knowledge, there is no prior research that has conducted regarding the software defined networking with this scale. Therefore, in this study, it is outlined to make a techno-

economic analysis of SDN and conventional network in the case of NDCE. Thus, with this assumption the study will address the question:

- What is the techno-economic impact of SDN on NDCE?

1.4 General Objective

The general objective of this research is to perform a techno-economic viability assessment of Software-Defined Networking in the National Data Center of Ethiopia (NDCE). The goal is to determine whether SDN can enhance the network performance of the NDCE and be a cost-effective solution.

Specific Objective

To fulfill the overarching goal, we have delineated the subsequent specific objectives

- Review the literature on the importance of SDN.
- Examining the existing National Datacenter backbone network design and performance (Latency, throughput, bandwidth).
- Simulate and demonstrate SDN architecture.
- Economic analysis and the comparison of two deployment scenarios
- To assess the economic viability measures through a techno-economic model for the two scenarios, facilitating subsequent evaluation.
- Analyze and interpret the results.
- Recommendation

1.5 Methodology

On several key aspects of the research, including research design, study population, sampling procedures (including size and selection methods), data collection techniques, data analysis techniques, and presentation methods. As previously stated, the primary objective of this research is to assess the performance and impact analysis in SDN deployment. To achieve this, an empirical study will be conducted to identify the factors that impact service delivery, as well as techno-economic.

A research design is a comprehensive plan that outlines the systematic approach to conducting a study, establishing a coherent link between the overarching research question and the intricate research process. It intricately combines various essential elements such as research methods, data collection protocols, and data analysis techniques. Methodology, on the other hand, pertains to the systematic arrangement and orchestration of methods employed to garner insightful comprehension throughout the research expedition.

It serves as a compass guiding the exploration of diverse methodological avenues while shedding light on underlying research assumptions.

In the context of this study, the chosen research methodology delves into an analysis of the performance and impact of SDN deployment within the National Data Center (NDC) of Ethiopia. This analysis extends to encompass crucial techno-economic concepts. By incorporating these parameters, we gain a more holistic understanding of the transformative potential of SDN deployment within the NDC.

Therefore, this research methodology encompasses not only the technical aspects of SDN deployment but also the intricate interplay of economic dynamics, ultimately providing a well-rounded assessment of the project's effectiveness in terms of cost optimization, efficient management practices, and optimal allocation of human resources within the NDC of Ethiopia.

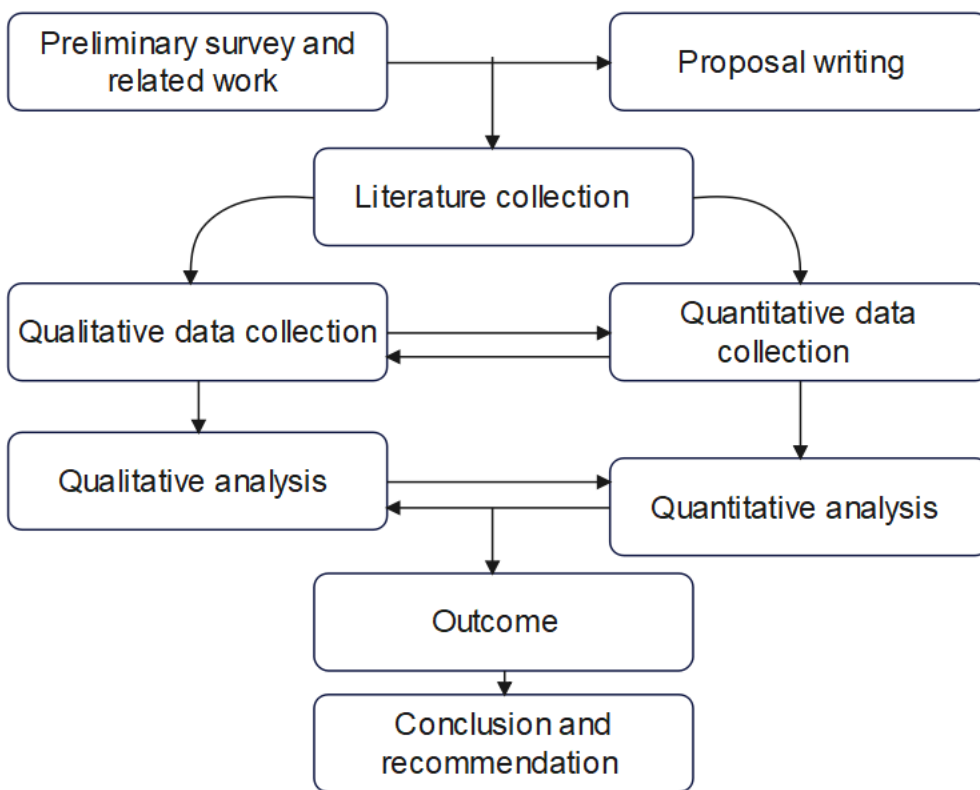


Figure 2. Procedures Followed in conducting performance analysis SDN for NDC relating to the beginning

Qualitative Data Collection and Analysis:

Qualitative data collection entails the gathering of non-numeric information that offers insights into attitudes, opinions, behaviors, and experiences. Typically, this kind of data is acquired through techniques like interviews, focus groups, observations, and content analysis. The goal of qualitative research is to explore nuances, uncover underlying motivations, and generate rich descriptions of phenomena. Researchers often immerse themselves in the data, seeking patterns, themes, and variations. The analysis

process involves organizing data, identifying recurring themes, coding, and interpreting the findings. Qualitative research is valuable for generating hypotheses, understanding complex contexts, and capturing the human aspect of research topics. However, it requires careful consideration of subjectivity, and findings may be harder to generalize compared to quantitative research.

Quantitative Data Collection and Analysis:

Quantitative data collection encompasses the acquisition of numeric data using approaches like surveys, experiments, and structured observations. This data can be subjected to statistical analysis, enabling researchers to detect patterns, correlations, and trends within extensive datasets. Quantitative research aims to establish relationships between variables, make predictions, and test hypotheses using rigorous methods. Researchers use statistical techniques to summarize and interpret the data, often using measures like means, standard deviations, and regression analyses. The structured nature of quantitative data allows for more objective comparisons and generalizability of findings to larger populations. However, it might not capture the depth and context of qualitative data, and the focus on numbers could overlook important nuances.

In many research projects, a combination of qualitative and quantitative approaches, known as mixed-methods research, is employed to provide a comprehensive understanding of the studied phenomenon. This research project also adopts a mixed-methods approach to ensure a more comprehensive and multifaceted analysis of the performance and impact of Software-Defined Networking deployment within the National Data Center (NDC) of Ethiopia.

1.6 Literature review

1.6.1 Software-Defined Networking

Software-defined networking represents a network structure wherein software external to networking devices is utilized to govern their packet-handling operations. OpenFlow serves as a communication protocol enabling software controllers to interact with Ethernet switches, managing their packet-handling rules[12]. In line with CISCO's definition, SDN is an architectural approach aimed at enhancing network flexibility and simplifying administration. SDN achieves centralization in management by abstracting the control plane from the data forwarding function found within individual network devices. Organizations use SDN to decouple traffic management and network configuration from the physical network infrastructure. Open application programming interfaces (APIs) can now exercise more granular control over organizational networks via SDNs. The SDN architecture provides increased flexibility for network device coordination that serves specialized needs.

1.6.2 Traditional Network Architecture

Conventional networks consist of two primary components: the data plane, responsible for directing traffic between devices, and the control plane, which makes decisions regarding traffic routing. In traditional networks, these two planes are closely intertwined, residing on the same physical device. This integration poses challenges for the scalability and automation of conventional networks, particularly in managing virtualized environments. In virtualized settings, where virtual machines (VMs) are dynamically created and decommissioned, tracking the connections between VMs and networks becomes complex. Moreover, traditional networks rely on IP addresses for server and application identification and location, a process prone to errors and time consumption in extensive virtual networks.

Consequently, the management and upkeep of traditional networks have become increasingly problematic. Many organizations are therefore adopting software-defined networking, which severs the coupling between the data plane and control plane, simplifying network scalability and automation tasks. In summary, traditional networks face challenges in scalability and automation, particularly in virtualized environments, leading to the adoption of SDN as a solution.

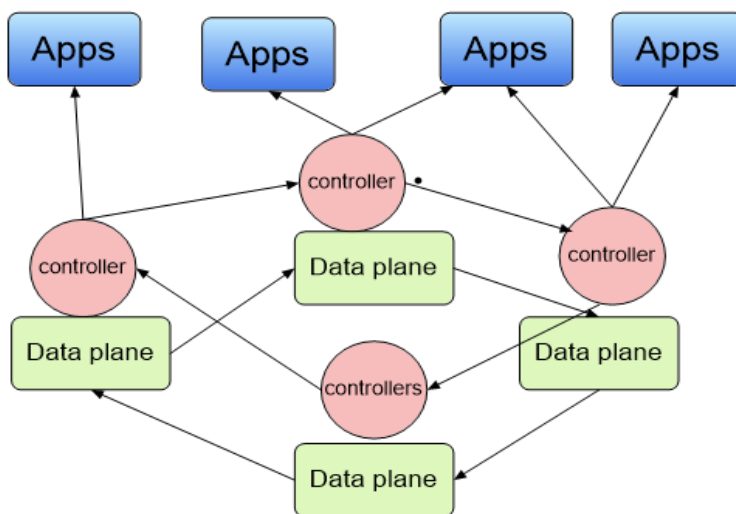


Figure 3 Architecture of Traditional Network

Many businesses utilized traditional network architecture up until recent years, but as a result of its shortcomings, software-defined networks have since been developed and will become more popular in the years to come.

The data plane is an abstract layer that uses end-to-end communication between the client and server to transfer data from one link to another link. The control plane specifies the connections that must be formed,

the data that must be delivered, the rules that must be followed, and the path that must be taken. These layers are incorporated into the gadgets. By employing vendor-specific interfaces and command line interfaces, network administrators can specify the rules for how data must be moved by configuring the control plane. The issue with this architecture is that any necessary update can only be implemented through device reconfiguration because control flows and data flows have already been defined. It has become vital for the network to adapt due to the growth in data traffic.

A traditional network denotes the traditional approach to networking, employing static and dedicated hardware components like routers and switches to manage network traffic. Issues related to scalability, network security, and performance are significant concerns in this context.

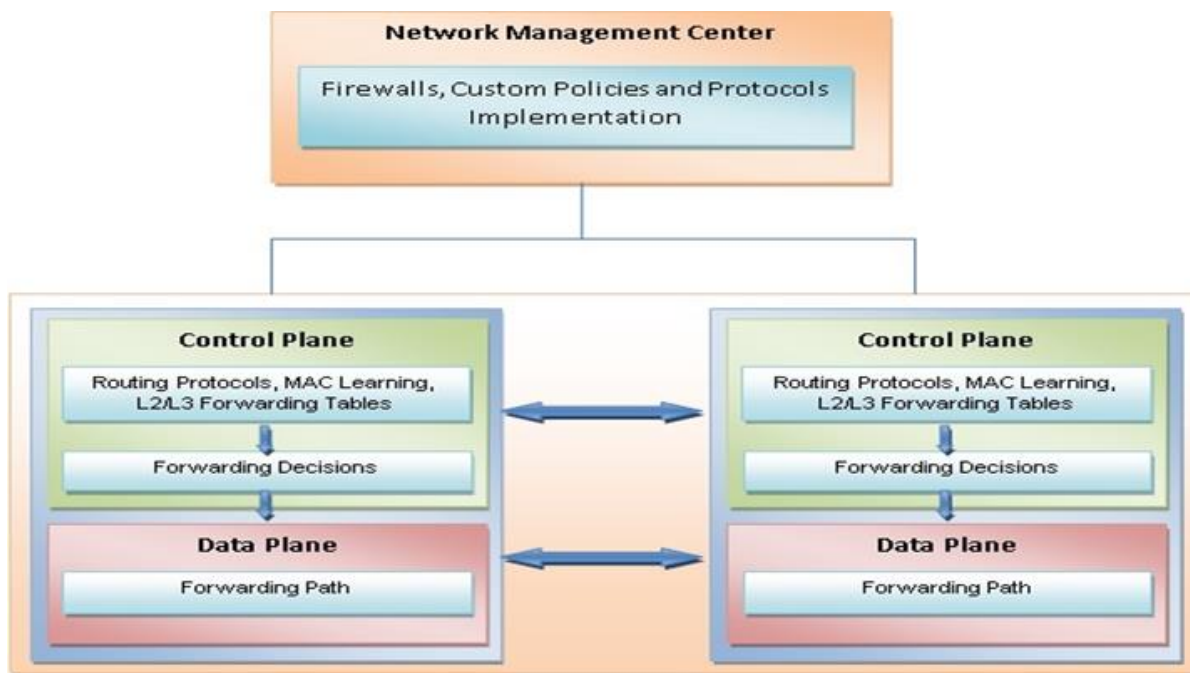


Figure 4 Traditional Network Architecture

To facilitate the management of extensive network configurations, administrators must address physical infrastructure challenges that contribute to the complexity of administration. This is done to streamline the task of overseeing large, virtualized networks[13].

Simultaneously, data-center administrators are dealing with a massive increase in the number of servers and virtual machines, which is boosting server-to-server communication traffic. To meet these difficulties, operators want an efficient, flexible, agile, and scalable network. SDN and virtualization are positioned to provide solutions to the difficulties. SDN runs on a centralized and aggregated control plane, which could be a potential solution for network management and control issues. As demonstrated in Fig.2, the basic idea underlying SDN is to isolate the forwarding/data plane from the control plane while allowing programmability on the control plane [13]

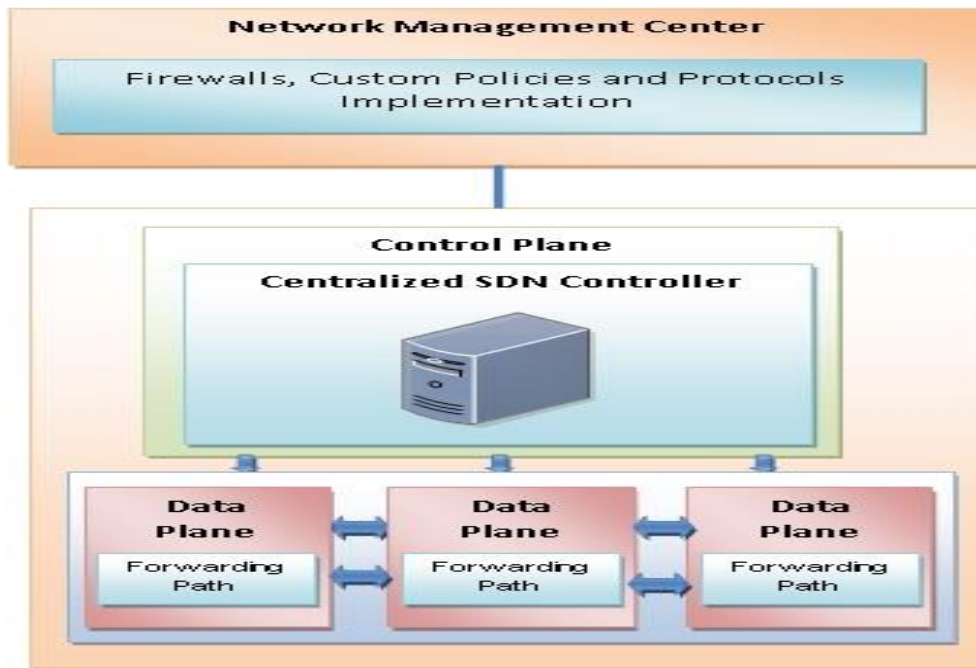


Figure 5. SDN Architecture

When comparing Software-Defined Networking and OpenFlow architecture to traditional (legacy) networks, SDN introduces four additional components[13].

1. **Control Plane:** The control plane or controller offers a conceptual overview of the entire network infrastructure, enabling administrators to apply customized policies and protocols across network devices. The most commonly utilized controller is the network operating system (NOX) controller.
2. **Northbound Application Interfaces:** The "northbound" application programming interfaces (APIs) act as the software bridges connecting the software modules of the controller platform with the SDN applications running on the network platform. These APIs expose data models and capabilities for universal network abstraction to network applications. These "northbound APIs" are based on open-source principles.
3. **East-West Protocol:** In a multi-controller architecture, the East-West interface protocol manages interactions between different controllers.
4. **Data Plane and Southbound Protocols:** The data plane represents the forwarding hardware within the SDN network architecture. Because the controller needs to communicate with the network infrastructure, it relies on specific protocols to control and manage the interaction between various network equipment components. The most widely adopted "southbound protocol" is the OpenFlow protocol.

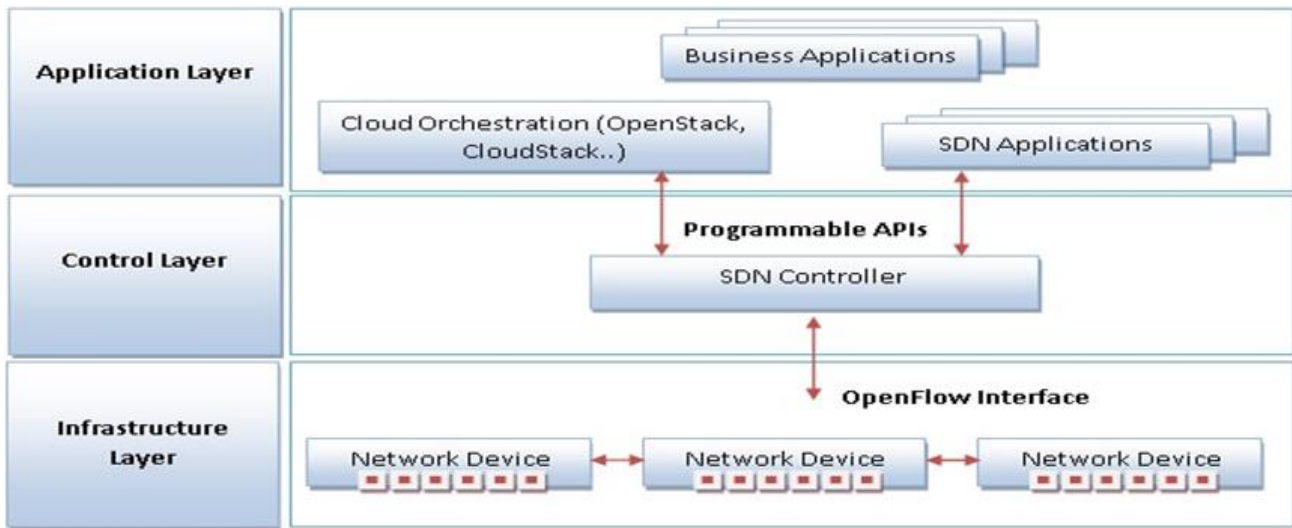


Figure 6. Basic SDN-Based Network architecture

SDN has numerous benefits for tackling the difficulties that legacy network topologies confront some of them are the Programmability of the Network.

Open Flow Protocol

The OpenFlow protocol is the predominant choice for the southbound interface in SDN, facilitating the segregation of the data plane from the control plane, and it is standardized by the Open Networking Foundation (ONF)[14]. The OpenFlow protocol serves as the management interface for the southbound component of the generalized SDN architecture. It represents the inaugural standardized interface established to facilitate interaction between the control and data planes within the SDN framework. OpenFlow provides a software-driven gateway to flow tables, which instruct switches and routers on how to direct network traffic. These flow tables enable administrators to swiftly modify network configurations and traffic routing. Additionally, the OpenFlow protocol encompasses a fundamental set of administrative tools for overseeing functions like topology adjustments and packet filtering. The Open Networking Foundation (ONF), a non-profit organization, oversees and defines the OpenFlow specification, guided by a board of directors representing seven prominent companies known for owning and operating some of the world's largest networks, including Deutsche Telekom, Facebook, Google, Microsoft, Verizon, Yahoo, and NTT. The OpenFlow protocol is supported by the majority of networking gear suppliers, including HP, IBM, and CISCO [13].

As stated by the Open Networking Organization, there are two categories of switches that conform to the OpenFlow standard: OpenFlow-only and OpenFlow-hybrid. OpenFlow-only switches exclusively support OpenFlow operations, routing all packets through the OpenFlow pipeline. In contrast, OpenFlow-hybrid switches are capable of managing both OpenFlow and conventional Ethernet switching tasks, including

L2 and L3 switching and routing. Beyond OpenFlow, these hybrid switches incorporate a classification mechanism that directs traffic to one of the packet-processing pipelines.

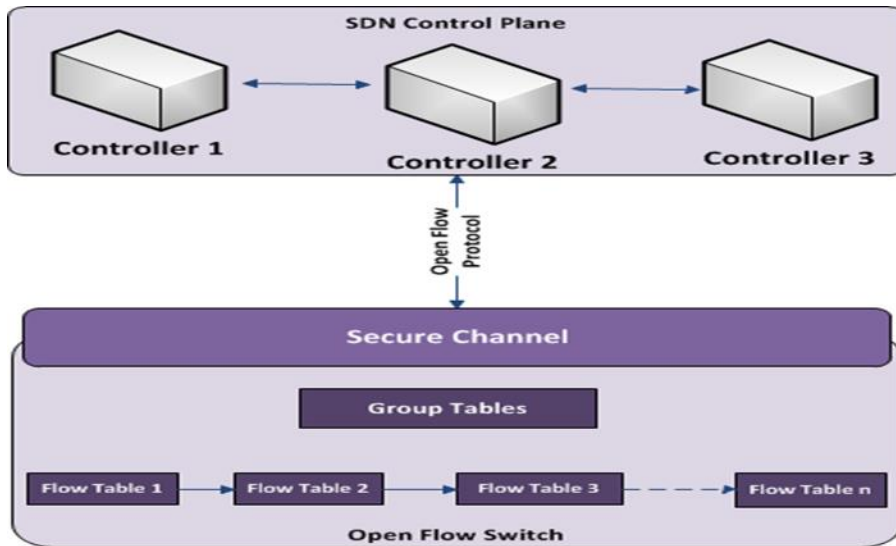


Figure 7. Basic Architecture of OpenFlow

1.7 Related work

In [15], the authors endeavored to develop a user interface (UI) that provides a comprehensive overview of Data Center Networking (DCN) functionalities and paradigms. They expanded the utilization of various components for simulation, specifically employing the Mininet setup. The study also presented simulation results in the form of charts, illustrating packet drop percentages and latency in host-to-host communication.

The process involved installing and loading VirtualBox with the Ubuntu installation image, followed by the installation of Mininet, a network emulator. Subsequently, the researchers initiated the first run and programmed a complex virtual DCN within Mininet using Python scripts. A tree topology was established for future use, and performance assessments were conducted on this DCN topology to differentiate between traditional paradigms and SDN paradigms.

The system's performance was assessed using metrics derived from simulations in Mininet and Python scripts, with a focus on latency and bandwidth usage. As the network size expanded, there was a significant increase in these metrics. However, it's worth noting that ping times varied depending on the controllers used.

Based on their observations, it can be confidently asserted that as the number of hosts increases, bandwidth decreases, leading to higher percentages of packet drops and increased latency. These

findings align with expectations and substantiate the effectiveness of the SDN paradigm compared to the traditional approach[15].

Numerous prior research papers have focused on conducting comparative studies between Software-Defined Networks and traditional networks, assessing their impact on network performance. In this context, the author has endeavored to evaluate performance by measuring routing convergence time in the event of link failures, taking into account the network's scale. The objective is to demonstrate that SDN routing and forwarding outperform traditional routing methods. [16] In this study, the performance evaluation focuses on measuring routing convergence time during link failures relative to the network's scale, aiming to illustrate the superiority of SDN routing/forwarding over traditional routing.

For SDN networks, we employed the Floodlight controller as the primary controller, while Mininet, a network simulator, was utilized to construct the network comprising switches, routers, and hosts, as well as to assess routing convergence time. In conventional networks, we utilized Packet Tracer, a network simulation and visualization tool, to create the network, including switches, routers, and hosts, allowing for manual programming of routing protocols within the routers. In both network types, we utilized real-time commands such as 'ms,' 'ping,' and 'traceroute' to gauge routing convergence time.

Within this research, we employed the Mininet network simulator to establish three topologies: 8 nodes, 16 nodes, and 80 nodes, each featuring 2 hosts for both conventional and SDN networks. In the conventional network, routers were manually configured with the BGP protocol and assigned appropriate AS (Autonomous System) numbers.

Regarding the experimental setup, the initial step involved establishing stable communication between host 1 (H1) and host 2 (H2) using the 'ping' command. Once this was accomplished, the 'traceroute' command was employed to identify the primary path.

Upon analyzing the experimental results, we observed that SDN networks consistently exhibited shorter routing convergence times compared to conventional networks across all three topologies. This discrepancy can be attributed to the divergence in the convergence processes between SDN and conventional networks. In conclusion, as network scale increases, the routing convergence time in conventional networks continues to rise following changes such as link or node failures, as information regarding the failure is propagated through flooding to update all router routing tables[16].

In [17], the author explores the OpenFlow-based network architecture by comparing it with traditional networking approaches. The OpenFlow network architecture is structured into three layers:

1. The lowest layer comprises the data forwarding plane, housing one or more OpenFlow-enabled virtual or physical switches.
2. The second layer is the control plane, which includes OpenFlow controllers equipped with predefined Network Operating Systems (NOS). In some cases, complex network designs may necessitate one or more controllers.
3. The topmost layer is the application plane, where one or more OpenFlow applications are defined for tasks related to network management or data flow control.

An OpenFlow switch incorporates a flow table and a secure channel for communication with the OpenFlow controller via OpenFlow Protocols (OFP). Every data flow within the network must receive approval from the OpenFlow controller to ascertain whether it complies with network policies. If permitted, the controller computes the route and inserts flow entries into the flow table of the OpenFlow switch. These flow table entries generated by the controller comprise three key components:

- **Matching Field (or Packet Header):** This field is employed to match incoming data packets against the updated information in the flow table. It encompasses elements like the ingress port and other header fields.
- **Counters:** This field is responsible for updating packet statistics post-matching, tracking the number of packets and bytes for each flow, and adhering to timing constraints.
- **Actions:** In this field, specific actions defined by the controller are executed to process incoming packets post-matching.

The study proceeds to explore OpenFlow network topologies, defined as the arrangement of nodes within a network. These nodes encompass end users (or host machines) and core network devices like hubs, switches, and routers. The author leverages Mininet to implement basic OpenFlow network topologies, offering options such as Minimal, Single, Linear, Tree, and Reversed Topology. While the default configuration is the minimal topology consisting of one OpenFlow kernel switch connected to two hosts and an OpenFlow reference controller, other topologies can be configured using the command-line interface (CLI). The three fundamental OpenFlow network topologies discussed are Single, Linear, and Tree topologies.

The research culminates in a Result Analysis and Discussion section, where performance evaluations are conducted by comparing all network topologies based on metrics like bandwidth utilization, packet transmission rate, transmission time from source to destination, and maximum throughput. The findings suggest that the single topology outperforms linear and tree topologies, albeit with certain limitations. In the linear topology, increasing the number of hosts in the network leads to reduced network performance. Additionally, a breakdown in an OpenFlow switch can disrupt the entire network,

impacting factors like flow speed, bandwidth, throughput, and packet drop probability due to hardware limitations.

In the context of linear topology, overall network performance improves compared to the single topology when considering network load distribution. In a single topology, a single OpenFlow-enabled switch handles the entire network load regardless of the number of host machines.

Tree topology, while easy to implement with a single command, introduces some network complexity compared to single and linear topologies. However, the number of hops between hosts remains consistent. Speed-related performance is enhanced compared to the linear topology but remains limited compared to the single topology[17].

In [18], the author conducts a performance analysis comparing Software-Defined Networking with a conventional IP network configured with the EIGRP and BGP routing protocols. This analysis is carried out within a configuration scenario that employs physical network equipment and an SDN emulator named Mininet. The research methodology aligns with the Cisco PPDIIO methodology and unfolds in the following phases:

1. Development of a physical network topology using Cisco equipment, including experiments with both IPv4 and IPv6. Various variables such as Jitter, Delay, and Throughput are measured in this context.
2. Replication of the same experiments and tests within an SDN environment, utilizing a network topology with characteristics similar to the previous one but incorporating OpenFlow switches.
3. Analysis of results, involving an examination of Jitter, Delay, and Throughput variations in both scenarios. This analysis includes statistical comparisons related to factors like protocol, addressing, and packet size.

The research methodology combines descriptive and experimental approaches. Descriptive research is employed to review documentation related to SDN and conventional networks, while an experimental design type is chosen to gather data necessary for addressing research questions. The experiments are conducted and specific outcomes are confirmed during the process.

The primary objective of this study is to determine, through a comparative analysis of Delay, Jitter, and Throughput between a conventional network and an SDN network, which one exhibits superior performance characteristics. The study specifically focuses on these three performance metrics:

- Delay: This metric quantifies the time it takes for a packet to traverse the network and is calculated based on factors like the number of nodes.

- **Throughput:** This metric measures the effective transfer rate of data and can be calculated using a specific equation.
- **Jitter:** Jitter refers to the variation in packet transmission times and is assessed using a corresponding equation.

The research aims to conduct a comparative statistical analysis of these critical performance variables between a conventional network, employing widely-used routing protocols like EIGRP and BGP, and an SDN network utilizing the OpenFlow protocol and the POX controller. In general, the analysis reveals better performance across the examined variables, both for IPv4 and IPv6, when SDN is employed. These findings are supported by statistical analyses incorporating normality and non-parametric tests[18].

1.8 Scope and Limitation

The scope of the thesis

The scope of the thesis primarily focuses on conducting a comprehensive exploration and assessment of the technical and economic feasibility of employing Software-Defined Networking to enhance network performance within the context of national data centers. This research will specifically investigate the potential scenarios and implications of implementing SDN exclusively within national data centers. The study will delve into the technical aspects of SDN implementation within this specific environment and will also analyze the economic factors and benefits associated with such an implementation. Undertaking a meticulous techno-economic investigation of these scenarios within the confines of national data centers is a prudent approach to achieving the research objectives

Limitation

This thesis focuses on the use of Software-Defined Networking to enhance network performance and optimize throughput. The evaluation of this enhancement is predominantly based on throughput and latency metrics. However, it is important to acknowledge that the assessment framework does not encompass security considerations or not include SDN-WAN. Techno-economic analysis featuring While security and SDN-WAN aspects, remain external to the immediate scope of this research, future work could explore the impact of SDN security and SDN-WAN.

1.9 Contribution

This paper makes a contribution by conducting an evaluation of network performance in the context of both SDN and conventional network setups. The study encompasses a rigorous analysis of network performance, utilizing a range of metrics to compare the effectiveness of SDN and traditional networking approaches. Furthermore, the paper extends its contribution by delving into the realm of techno-economic

feasibility, exploring the financial and economic implications of deploying SDN. This dual-pronged approach not only advances our understanding of network performance dynamics but also sheds light on the practical viability of adopting SDN from a techno-economic standpoint. By bridging the gap between technical analysis and economic considerations, this research offers valuable insights for decision-makers in the realm of networking technology.

1.10 Thesis Layout

The thesis follows a structured layout comprising five interconnected chapters. Chapter 1 serves as the introductory section. In Chapter 2, an in-depth exploration of the Data Center's infrastructure is undertaken. Chapter 3 provides comprehensive insights into various techno-economic models and assessment methodologies, underpinned by mathematical models. Chapter 4 delves into deployment scenarios and conducts a thorough techno-economic analysis. Finally, Chapter 5 serves as the conclusion, summarizing research findings, proposing potential avenues for future research, and encapsulating the overarching conclusions derived from the study.

Chapter Two - Data Center Network infrastructure

This chapter delves into the fundamental aspects of Data Center Network Infrastructures (DCNIs), exploring their crucial role in modern technological landscapes. The chapter commences by offering an insight into DCNIs, encompassing their evolution, essential constituents, and underlying principles. It then proceeds to dissect the pivotal elements of DCNIs, including their architectural constructs, service offerings, and overarching functions within the realm of data transmission and connectivity.

Furthermore, the chapter underscores the significance of DCNIs in supporting seamless data flow, facilitating critical applications, and enhancing network efficiency. It scrutinizes various facets of DCNIs, such as security protocols, redundancy strategies, and disaster recovery mechanisms, all geared toward ensuring uninterrupted and safeguarded network operations, even in the face of adversity. The discourse extends to encompass adherence to regulatory frameworks and policies pertaining to network data management and security, highlighting the intricate synergy between technological dynamics and governance considerations in the DCNI domain.

In essence, this chapter provides a comprehensive panorama of Data Center Network Infrastructures, encompassing their historical backdrop, constituent elements, guiding principles, operational functions, and overarching significance.

2.1 Background

A data center serves as a central hub for critical computing resources, housing servers, storage systems, and networking equipment that underpin digital services. To ensure their efficiency and reliability, data centers adhere to established standards and best practices. These standards guide the design, construction, operation, and upkeep of data centers. They cover various aspects, including physical layout, power distribution, cooling mechanisms, security protocols, and energy efficiency. By implementing these standards, data centers are designed for redundancy, scalability, and sustainability. They prioritize high availability, efficient cooling, secure access control, and environmental responsibility. Adherence to these standards assures optimal performance, reduced downtime, and the ability to handle evolving technological demands.

Data center standards encompass a comprehensive set of guidelines and benchmarks that outline the specifications and best practices for the establishment, operation, and management of data center facilities. These standards are designed to ensure the efficiency, reliability, security, and sustainability of data centers, given their pivotal role in supporting modern digital infrastructure. Covering diverse aspects, these standards dictate the physical layout, power distribution, cooling mechanisms, and networking infrastructure of data centers. They also emphasize stringent security protocols, redundancy measures to

ensure uninterrupted operations, and the incorporation of energy-efficient technologies to mitigate environmental impact. Compliance with data center standards is often validated through certification programs, instilling confidence in stakeholders and clients. By adhering to these standards, data centers can uphold optimal performance, minimize downtime, and safeguard critical data and services in a rapidly evolving technological landscape.

National Data Centers are a specific type of data center that is operated or managed at a national level by a government or a national organization. It serves as a central hub for hosting critical government services, applications, and data.

National Data Centers are strategically important for a country's digital infrastructure. They support essential services like government operations, public services, and national security. National Data Centers typically have stringent security measures, redundancy, and disaster recovery mechanisms to ensure continuous operation even in adverse situations. They might also be responsible for ensuring compliance with national regulations and policies related to data handling and security.

A technological infrastructure serves as the foundation for acquiring, disseminating, examining, and utilizing data. This infrastructure encompasses elements such as the presence of tangible communication networks, devices, information and communication technology competencies (applicable to both individuals with technical and non-technical backgrounds), internet accessibility, and cost-effectiveness, all of which enhance the prospects of achieving success in Open Data Initiatives[19].

The responsibilities of a governmental data center can vary depending on the specific agency or department involved, but some common responsibilities include:

- **Data storage and management:** A governmental data center is responsible for securely storing and managing the vast amounts of data generated by various agencies and departments. This includes data related to citizens, government programs, and operations.
- **Security and access control:** One of the most critical responsibilities of a governmental data center is ensuring the security and integrity of data. This involves implementing robust security measures to prevent unauthorized access, theft, or breaches. It also includes controlling access to data based on job roles, clearance levels, and other factors.
- **Backup and recovery:** A governmental data center must have processes and systems in place to backup data regularly and recover it in the event of a disaster or system failure. This ensures that critical government operations can continue even in the face of unforeseen events.

- Network management and monitoring: A governmental data center must manage and monitor the network infrastructure that supports government operations. This includes ensuring that the network is secure, scalable, and available at all times.

The Ministry of Innovation and Technology (MInT) now oversees and manages Ethiopia's National Data Center (NDC). It offers a variety of electronic government services that can primarily be divided into two categories: WoredaNet services and other online services.

The WoredaNet is an electronic government initiative that the government funded, launched, and managed. It was put into action by the Ethiopian ICT Development Agency (EICTDA), which later became the Ministry of Communications and Information Technology. However, the MInT is mandated to transfer all of the duties and obligations of the NDCE following the 2018 reform in the nation.

The government has invested in IT for many years, and now the digital economy concept is becoming a reality. The government has established a policy whereby significant infrastructure and services are provided centrally by MInT to cut investment costs and prevent duplication of spending. As a result, the National Data Center offers services across the Woredanet network and the open internet, including web hosting, co-location, and electronic government services (eService).

As far as Information Technology is concerned Ministry of Innovation and Technology (MInT) has to look at it from two different perspectives. First, it is mandated to provide support to government organizations as they strive to use Information Technology as an enabler to achieve their vision. As part of this mandate, MInT has been actively working in developing networks that span the entire country and is providing a plethora of IT services via this network infrastructure from the National Data Center that it manages.

The e-Gov network is logically isolated from the Internet. The e-gov network is used to run services that Data exchange or collaboration services are among government offices and specialized services that government agencies provide for the social public. The e-gov. network provides support services such as network, information, and security services for service systems of government offices and provides government information services for the social public. Service applications include public service applications (such as eservice portal, administrative approval, and information disclosure, etc.), internal government service applications (such as collaborative office, IFMIS, and information distribution), and basic service applications (such as video conference, data backup, email, and Security certifications, hosting etc.).

The ICT Sector General Directorate is responsible for ensuring these IT services and infrastructure are being utilized efficiently for the intended purpose. To reduce investment costs and avoid redundant expenses, the government has set a direction in which major infrastructure and services are given centrally

by MInT. As a result, the National Data Center provides web-hosting, collocation, video conference and electronic government services (eService) through the WoredaNet network and the public internet.

The other perspective is the IT services MInT provides to itself and its customers. The national expectation is for MInT to seamlessly lead other ministries, Regions' and governmental organizations into the digital world. This means efficient utilization of IT services is expected from MInT. It is known as current government network used to connect 10 regions, 2 city administrations 950 + woredas More than 5000 sites the network consists of 1 national data center (NDC) & 11 regional data centers.

Data centers serve as centralized hubs where an organization consolidates its shared IT operations and hardware resources, facilitating the storage, processing, and dissemination of data and applications. These facilities play a pivotal role in ensuring the uninterrupted flow of daily business activities, as they securely house an organization's most valuable and sensitive assets. The fundamental constituents of such a system comprise the host, storage, connectivity (or network), applications, and database management system (DBMS).

The National Data Center (NDC) of Ethiopia holds a paramount position in the country's IT sector, serving as a crucial hub for secure and dependable data storage and processing. This facility plays a pivotal role in enabling essential services such as e-government, e-services, traffic penalty management, e-procurement, portal hosting, video conferencing, email communication, Integrated Financial Management Information System (IFMIS), and Integrated Civil Service Management Information System (ICMIC). The NDC serves as the backbone of these services, ensuring their availability and efficiency.

However, despite its critical importance, the NDC faces certain challenges that warrant attention. Notably, the absence of a disaster recovery data center poses a significant risk. Without a dedicated disaster recovery site, the NDC's resilience in the face of unforeseen events is compromised. This vulnerability exposes the IT infrastructure of the country to potential disruptions and data loss, which could have far-reaching consequences for essential services and the overall functioning of the nation.

Additionally, the NDC's operational limitations are evident in the fact that several of its services are currently operating below their capacity, resulting in sluggish service delivery. This performance gap implies that the NDC is not operating optimally and may struggle to meet the growing demands of the services it hosts. Such inefficiencies have the potential to hamper the responsiveness and reliability of critical e-services.

In the context of data center management and classification, the concept of "data center tier" plays a crucial role in assessing and categorizing the reliability and availability of a data center. The Ethiopian National Data Center can be categorized as a Tier 2 data center based on the Uptime Institute's tier classification

system. A Tier 2 data center provides a higher level of reliability and availability compared to Tier 1, with features such as redundant power and cooling components. However, it may lack certain redundancy and maintenance capabilities that Tier 3 and Tier 4 data centers offer.

Given the NDC's role in supporting critical services, it becomes evident that elevating its tier classification could enhance its resilience and ensure the uninterrupted delivery of essential services. By addressing its shortcomings, including the lack of a disaster recovery site and the need to optimize service performance, Ethiopia's NDC can bolster its capacity to withstand potential disruptions and play a more robust role in the country's IT infrastructure.

In addition to a disaster recovery data center, the government should also invest in improving the capacity of the NDC's existing services. This would help to ensure that the NDC is able to meet the growing demand for its services and that it is able to provide a high level of service to its customers.

By making these investments, the government can help to ensure that the NDC continues to be a reliable and secure platform for storing and processing data. This will help to promote the growth of the IT sector in Ethiopia and ensure that the country has a strong foundation for its digital economy.

In recent years, there has been a growing demand for bandwidth and computing resources at the National Data center. This demand is being driven by the increasing use of cloud computing, big data, and other bandwidth-intensive applications.

To meet this growing demand, the National Data center is proposing to deploy a Software-Defined Networking solution. SDN is a new networking paradigm that may allow for greater flexibility and control over the network.

2.2 Network Optimization in National data center

Network optimization is the systematic enhancement of a network's infrastructure to improve its efficiency, reliability, and overall performance. In the National Data Center of Ethiopia, this process is essential to ensuring seamless communication, efficient data handling, and uninterrupted services across various sectors. Optimization is the process of determining a network setup that maximizes performance within the constraints of the existing network hardware and spectrum resources.[20]

There are a number of ways to optimize a network, such as streamlining data transfers, enabling smoother interactions among servers, mitigating congestion points, fortifying the network's resilience, allocating resources judiciously, and implementing security measures. By implementing these strategies, the National Data Center can improve its ability to support crucial government operations.

For example, streamlining data transfers can be done by using faster network hardware, optimizing the network topology, and implementing traffic management techniques. This can help to reduce latency and improve the overall performance of the network. Enabling smoother interactions among servers can be done by using clustering and load balancing techniques. This can help to distribute traffic more evenly across servers and improve the overall performance of the network. Mitigating congestion points can be done by using routers and switches to direct traffic around congested areas. This can help to improve the overall performance of the network and prevent data from being bottlenecked. Fortifying the network's resilience can be done by using redundant hardware and software, and by implementing disaster recovery plans. This can help to ensure that the network remains operational even in the event of a hardware failure or natural disaster. Allocating resources judiciously can be done by using monitoring tools to identify underutilized resources and by implementing policies to ensure that resources are used efficiently. This can help to reduce costs and improve the overall performance of the network. Implementing security measures can be done by using firewalls, intrusion detection systems, and encryption protocols to protect sensitive data. This can help to prevent unauthorized access to the network and protect sensitive data from being compromised.

By implementing these strategies, the National Data Center of Ethiopia can improve its ability to support crucial government operations and deliver essential services to the public.

2.3 Performance analysis

In the realm of computer networking, performance analysis involves assessing how effectively and efficiently a network operates to meet specific performance criteria. This analysis encompasses the measurement of various network performance metrics such as latency, throughput, packet loss, and network utilization.

Performance analysis holds paramount importance for network administrators as it aids in the detection of potential issues, the resolution of problems, and the enhancement of network performance. Through the measurement and scrutiny of network performance, administrators can pinpoint bottlenecks, congestion, and other factors that might impede the network's capacity to deliver data transmission reliably and promptly.

Various tools and methodologies are employed in performance analysis, including network monitoring software, packet sniffers, and network analyzers. These tools enable administrators to collect and evaluate data regarding network performance and identify areas requiring improvement.

In conventional networking, performance analysis typically encompasses metrics such as bandwidth (data transmission capacity), latency (data travel time), packet loss (percentage of lost packets), and jitter (latency variation over time).

In the context of Software-Defined Networking, performance analysis metrics closely resemble those in traditional networking, but there are additional unique metrics for SDN:

1. Flow setup time: The time required to establish a flow in an SDN network, which is typically faster due to network programmability.
2. Controller processing time: The duration for a controller to process a request from a switch, influenced by network complexity and controller performance.
3. Network utilization: The percentage of available network resources in use, which can be monitored and optimized through software-defined policies in SDN.
4. Policy compliance: The extent to which network policies are enforced. In SDN, policies are defined in software and can be enforced more efficiently compared to traditional networks.

Overall, SDN enhances network performance analysis by offering greater visibility and control, enabling network administrators to optimize and troubleshoot networks more effectively compared to traditional networking.

Network performance is characterized as 'the assessment and scrutiny of collective network data, aimed at gauging the caliber of services rendered by the underlying computer network, chiefly evaluated from an end-user vantage point.'

In simpler terms, network performance entails the assessment and investigation of network operation as perceived by end users.

It is imperative to grasp the pertinent network performance metrics to assess when determining how to gauge network performance. Not all indicators may be of paramount importance, contingent upon the specific challenges impacting your network. Nevertheless, there exist fundamental criteria that every organization must factor in.

Certain metrics serve as crucial benchmarks for network administrators; among these, network throughput, jitter, and response time stand as fundamental SDN performance metrics that provide a clear assessment of the network's condition [21].

Chapter Three - Techno-economic Models and Evaluation Methods

This section presents techno-economic appraisal (TEA) models, economic modeling, and TEA assessment techniques, encompassing economic indicators for decision-making.

3.1 Overview of Techno-economic Assessment (TEA)

Techno-economic Assessment (TEA) is a systematic and comprehensive evaluation methodology that combines technical analysis with economic considerations to assess the feasibility and potential of a technological project or innovation. It provides a structured approach to understanding the interplay between technology capabilities, economic viability, and potential impacts on various aspects. TEA involves examining the technical aspects of the technology, evaluating its performance, scalability, and reliability. Simultaneously, it delves into the economic aspects by estimating costs, revenue streams, and potential financial returns. By integrating these analyses, TEA offers a well-rounded perspective on whether a technology or project is financially viable and has the potential to deliver positive outcomes. This process is crucial for decision-making, as it assists stakeholders in making informed choices about pursuing, modifying, or discontinuing a project based on a balanced understanding of its technical and economic dimensions.

3.2 Techno-economic Assessment Models

The origins of techno-economic assessment (TEA) models date back to the early 1970s when they were initially devised to appraise the economic viability of emerging energy technologies. While the initial TEA models were relatively uncomplicated, their complexity has steadily grown over time. Moving into the 1980s, these models found broader applications in evaluating various technologies, spanning transportation, manufacturing, and healthcare innovations. The 1990s saw their role expand to encompass assessing the economic ramifications of climate change mitigation policies. As the 2000s unfolded, TEA models saw integration with other models like integrated assessment models (IAMs) and life cycle assessment (LCA) models. This amalgamation enabled TEA models to evaluate not only economic aspects but also environmental and societal impacts of technologies and policies. In contemporary times, TEA models stand as indispensable instruments for decision-makers grappling with evaluating the financial viability of novel technologies and policies. Moreover, they serve researchers in comprehending the economic repercussions of technological shifts and in devising strategies for sustainable progress. The historical progression of TEA models can be encapsulated in significant milestones:

- **1970s:** Emergence of initial TEA models geared towards assessing economic feasibility of nascent energy technologies.

- **1980s:** TEA models extend their reach to evaluate an array of technologies spanning transportation, manufacturing, and healthcare.
- **1990s:** Application of TEA models broadens to encompass assessing economic consequences linked to climate change mitigation policies.
- **2000s:** Integration of TEA models with other frameworks, including IAMs and LCA models, evolves for a more comprehensive assessment.
- **Today:** TEA models evolve into pivotal tools for decision-makers confronting the task of gauging financial feasibility of novel technologies and policies

3.2.1 Techno-Economic Results from ACTS (TERA) Mode

The Advanced Communications Technologies and Services (ACTS) framework, developed by the European Commission, provides a comprehensive set of tools and methodologies to evaluate the feasibility and potential advantages of advanced communication technologies. Within this framework, the Techno-Economic Results from ACTS (TERA) model stands out for its focus on dissecting the techno-economic aspects of technology implementation. The examination of ACTS and similar trials will yield a shared comprehension of advancements in the field. This knowledge is vital for guiding future research and development initiatives within manufacturing firms. The findings from the analysis can serve as a direct foundation for making decisions when initiating new product development endeavors [22]. This model is particularly valuable for decision-makers as it facilitates an understanding of both the intricate technical capabilities and the consequential economic implications tied to adopting specific technologies.

When applied to the realm of SDN deployment, the TERA model can be adeptly modified to evaluate the multifaceted aspects surrounding the integration of SDN into a network environment. By adapting the TERA model to this scenario, a systematic assessment can be conducted on several pertinent factors. These include analyzing how SDN could enhance network performance, optimize resource utilization, and streamline network management. The model enables a comprehensive estimation of the costs associated with implementing SDN, encompassing factors like initial investments in hardware and software, required training, migration, and ongoing operational expenses. Moreover, it quantifies the potential advantages brought by SDN, ranging from decreased operational intricacy to heightened network responsiveness and swifter provisioning of network services.

Delving further, the TERA model extends its reach to scrutinize the market landscape, considering factors such as industry trends, competitive dynamics, and the potential embrace of SDN by customers. Importantly, it identifies conceivable risks and challenges tied to SDN deployment, including compatibility hurdles with existing systems, potential disruptions during the transition phase, and security vulnerabilities. Additionally, the model introduces sensitivity analysis, providing insights into how

variations in key variables such as adoption rates or implementation costs might influence the overall economic feasibility of embarking on an SDN deployment journey.

Ultimately, the TERA model offers a structured approach that empowers decision-makers with comprehensive insights, enabling informed evaluations and strategic decisions regarding the integration of SDN technology within a network infrastructure

3.2.2 Implemented Techno-economic Analysis Model

Implemented techno-economic analysis (IEA) models are frameworks that have been used to assess the feasibility, economic viability, and potential impacts of technological projects, innovations, or solutions. These models combine technical evaluation with economic considerations to provide a comprehensive understanding of the costs, benefits, risks, and overall implications associated with adopting a specific technology or undertaking a project. The fact that a techno-economic analysis model has been implemented means that it has been applied to real-world scenarios, allowing stakeholders to make informed decisions based on a thorough understanding of both the technical and economic dimensions of their endeavors. This approach ensures that technology investments and projects are strategically evaluated, resource allocation is optimized, and the likelihood of successful outcomes is maximized.

In short, IEA models are a valuable tool for stakeholders who need to make informed decisions about whether or not to adopt a new technology or undertake a new project. By considering all of the factors involved, IEA models can help stakeholders to make the best possible decision for their specific circumstances

3.3 Cost modeling

3.3.1 Total Cost of Ownership (TCO)

The Total Cost of Ownership (TCO) is a comprehensive financial metric that provides a holistic evaluation of the complete expenses associated with owning and operating a product or technology over its entire lifecycle. Beyond the initial purchase price, TCO considers all relevant costs, including acquisition, operational, maintenance, support, and potential downtime-related expenses. It takes into account the long-term financial impact, encompassing factors such as upgrades, training, and eventual replacement or disposal. Through offering a more comprehensive perspective on expenses, TCO empowers organizations to make informed choices by grasping the complete financial consequences of their investments. This approach aids in accurate budgeting, strategic planning, and optimizing resource allocation to ensure the best possible return on investment.

TCO = Acquisition Costs + Operational Costs + Downtime Costs + Support and Training Costs + Upgrades and Updates Costs

$$TCO = CAPEX + OPEX \quad (3.1)$$

- Acquisition Costs include the initial purchase price and any associated costs.
- Operational Costs encompass ongoing expenses like maintenance, utilities, and labor.
- Downtime Costs account for potential losses due to system downtime or disruptions.
- Support and Training Costs cover expenses related to user training and technical support.
- Upgrades and Updates Costs include costs for software updates and hardware upgrades

3.3.2 Capital spending (CAPEX)

Investment Related Cost, often referred to as Capital Expenditure (CAPEX), constitutes a significant category of expenses borne by organizations during the acquisition, upgrading, or enhancement of their assets, infrastructure, or technological capabilities. Within this scope, CAPEX encapsulates the initial outlays associated with procuring fixed assets such as equipment, machinery, facilities, and technology systems. Encompassing not only the purchase itself but also ancillary expenses like installation, setup, and necessary modifications for seamless integration into the existing operational framework, CAPEX plays an indispensable role in organizational advancement. These expenditures are instrumental in expanding or refining an organization's competencies, operational efficiency, and competitive edge. Unlike ongoing operational costs, CAPEX directs its focus toward long-term investments that contribute substantively to the organization's overall growth trajectory and developmental pursuits. The meticulous scrutiny of CAPEX is of paramount importance in the realm of financial planning, necessitating prudent budgeting and discerning allocation of resources. This critical analysis ensures the optimal utilization of assets, facilitating the realization of the organization's strategic aspirations and fostering sustainable progress.

CAPEX = Purchase Price + Installation Costs + Setup Costs + Integration Costs + Modification Costs + Additional Initial Costs

$$CAPEX_0 = \sum_{i=1}^n N_i \cdot C_{capex} \quad (3.2)$$

- CAPEX₀: This represents the total capital expenditure or investment required at the start of the project, often referred to as "initial-year capital expenses." It includes all the costs associated with setting up and initiating the project.
- $\sum_{i=1}^n$: This symbol (Σ) indicates the summation or sum of values over a specified range. In this case, the index 'i' starts from 1 and goes up to 'n', which represents the number of different components or items being considered for the project.

- N_i : This represents the quantity or number of each specific component or item in the project that requires capital expenditure.
- C_{capex} : This is the cost per unit or cost per item of the component or item. It represents the financial amount required for each individual item.

3.3.3 Overhead (OPEX)

Operation Related Cost, or Operational Expenditure (OPEX), encompasses ongoing expenses vital for daily operations, like employee salaries, utilities, rent, maintenance, and supplies. Unlike capital expenses, OPEX is recurring and maintains business continuity. Effective OPEX management is vital for efficiency and stability, necessitating optimization strategies and prudent resource allocation. Monitoring OPEX is key for financial planning and operational success, involving measures such as process improvement and cost reduction to ensure long-term viability.

OPEX = Sum of (Salaries + Utilities + Maintenance + Supplies + Other Overhead Costs)

$$OPEX = \sum_{i=1}^n Expense_i \quad (3.3)$$

- OPEX: This represents the total operational expenses for a certain period of time, often a year or a specific timeframe. Operational expenses include the ongoing costs incurred to keep a project, business, or operation running smoothly.
- $\sum_{i=1}^n$: This symbol (\sum) indicates the summation or sum of values over a specified range. In this case, the index 'i' starts from 1 and goes up to 'n', which represents the number of different expense items being considered.
- $Expense_i$: This represents the cost associated with the i-th expense item. It can include various operational costs such as salaries, utilities, maintenance, supplies, and other day-to-day expenses required for the operation.

3.4 Techno-economic Assessment (TEA) Evaluation Method

The Techno-economic Assessment (TEA) evaluation method offers a comprehensive approach to analyzing the viability and impact of introducing new technologies or solutions, particularly in scenarios where traditional financial metrics don't fully capture the essence of the initiative. In the context of providing a governmental service at no cost by the government, TEA delves into various dimensions beyond mere financial considerations. It starts by thoroughly assessing the technological feasibility, examining how the proposed solution aligns with existing systems and its potential for achieving the intended objectives. TEA then extends to operational analysis, considering the practical implications of

integrating the new technology into government processes, potential workflow adjustments, training needs, and the effect on daily operations.

Stakeholder engagement is a crucial element of TEA, involving interactions with governmental agencies, service users, and experts. By soliciting their insights, concerns, and feedback, the evaluation gains a well-rounded understanding of the initiative's potential challenges, opportunities, and alignment with stakeholders' needs.

A comprehensive risk assessment is another pillar of TEA, addressing technical challenges, security vulnerabilities, and possible negative repercussions on the quality of the governmental service or overall governance. This evaluation also delves into regulatory compliance, taking into account legal requirements and frameworks related to data privacy and security a particularly vital consideration for governmental services.

Importantly, TEA transcends financial aspects to encompass the broader societal impact of the technology. It evaluates how the initiative could contribute to improved governance, transparency, citizen engagement, and public trust. These qualitative dimensions play a pivotal role in gauging the project's holistic value.

Furthermore, TEA adopts a forward-looking perspective by considering the technology's long-term sustainability, adaptability, and potential for future enhancements. Environmental considerations may also be incorporated, evaluating the technology's eco-friendliness, energy efficiency, and overall sustainability.

In conclusion, the TEA evaluation method offers a comprehensive framework to analyze the implementation of a free governmental service. By considering technological feasibility, operational implications, stakeholder engagement, risks, legal compliance, societal impact, and long-term sustainability, TEA guides decision-makers in understanding the multifaceted dimensions of the initiative. This ensures well-informed choices that align with the overarching goals of the government and contribute to broader societal benefits.

Chapter Four - Deployment Scenarios and Techno-economic Analysis

The deployment of Software-Defined Networking within a government service provider's framework. This initiative involves providing SDN services at no cost to diverse sectors, including various government organization. The focus of this analysis is to assess the practicality and viability of integrating SDN technology within the existing infrastructure, ensuring seamless communication, efficient resource allocation, and improved service delivery. By investigating the economic feasibility and potential benefits of this approach, this study aims to provide valuable insights into the opportunities and challenges associated with such a transformative endeavor.

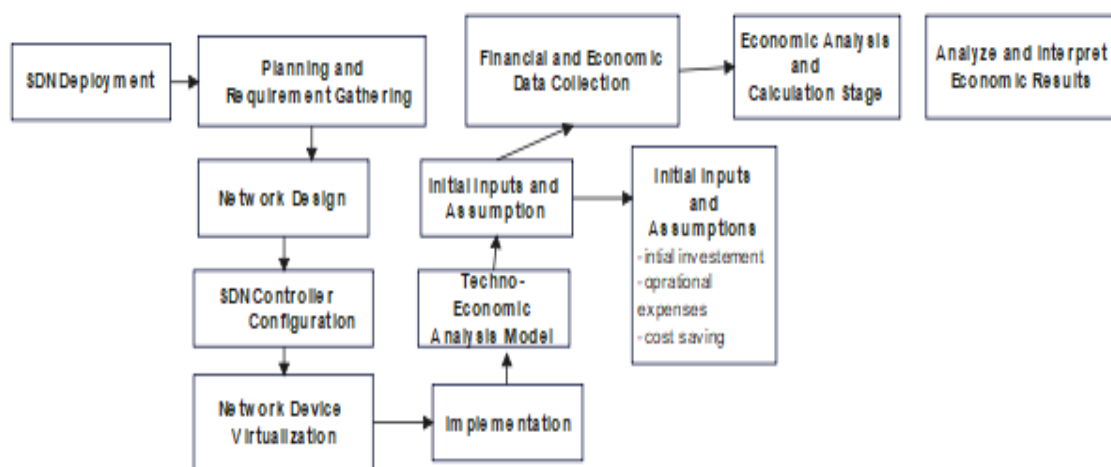


Figure 8. implemented techno-economic analysis model block diagram

4.1 Implemented Techno-economic Analysis Model

These sections revolve around the actions undertaken and the approaches employed to accomplish them. This chapter encompasses the executed model, the process of evaluating techno-economic aspects, defining scenarios along with their presumed parameters, conducting technical evaluations, economic evaluations, and the combined techno-economic analysis.

4.2 Techno-economic Assessment Process

The evaluation process for the technical and economic aspects of deploying Software-Defined Networking within the framework of a government service provider involves a comprehensive analysis of various factors. On the technical front, the assessment revolves around determining the feasibility of integrating

SDN technology while offering services to different government organization without cost. This entails evaluating the compatibility of SDN with existing infrastructure, its capability to efficiently manage varying network loads, and how it can optimize resource allocation to support diverse sectors. Furthermore, the evaluation examines SDN's operational efficiency gains, and its potential to enhance overall network reliability

From an economic perspective, the analysis encompasses a thorough examination of the financial implications of deploying SDN services free of charge within the governmental context. This involves assessing the initial costs associated with hardware and software acquisition and considering ongoing expenses such as installation cost, warrant and support cost, training, and license. However, the evaluation also delves into the potential benefits that offering free SDN services could reediness, including improved network efficiency, reduced downtimes, reduce human error and enhanced user experiences. The assessment incorporates economical to provide a tangible understanding of the financial feasibility of this project. Ultimately, the evaluation aims to strike a balance between costs and potential benefits, supporting well-informed decision-making concerning the deployment of cost-free SDN services within the government service provider's operational landscape.

4.3 Deployment Scenarios

This thesis examines two possible scenarios: SDN and conventional network in the national data center of Ethiopia.

4.4 Technical Analysis

A technical analysis of the existing conventional network in national data centers will be conducted to compare the performance of SDN networks with respect to latency, throughput, and bandwidth.

4.4.1 Existing conventional Network

The thesis will focus on a specific national data center that has four firewalls, two routers, two core switches, four TOR switches and two network redundancies, one from Legar and one from Arada. The thesis will first conduct a technical analysis of the existing conventional network in the data center. This analysis will focus on the hardware, software, and networking components of the network. The thesis will then compare the performance of the existing network with the performance of an SDN network. The comparison will focus on the following metrics: latency, throughput, and bandwidth.

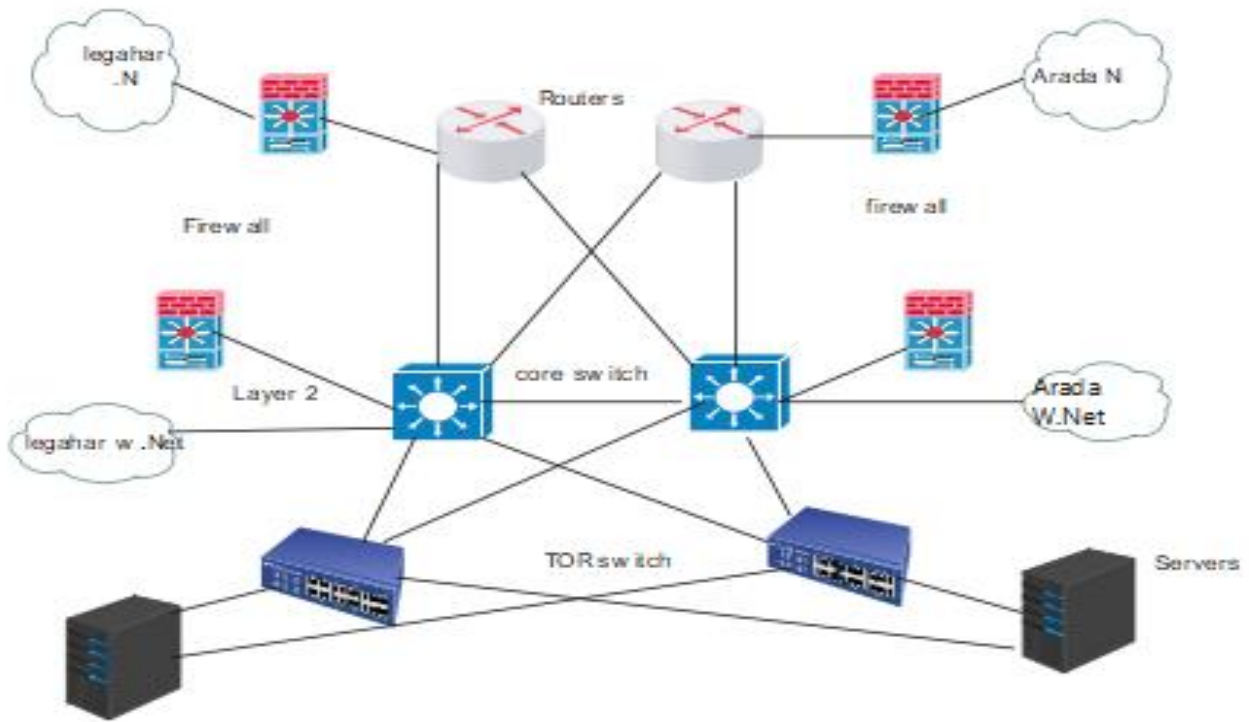


Figure 9. conventional network in the national datacenter

The contrast between incoming and outgoing data flows is symbolic of the data center functioning as a central hub in the network architecture. In this capacity, the data center diligently accumulates and integrates data from a multitude of sources, leading to a notably greater volume of incoming data compared to the amount it transmits outward. This configuration significantly highlights the data center's pivotal role as a resilient repository, adeptly capable of accommodating and managing substantial and diverse streams of data from various origins within the network.

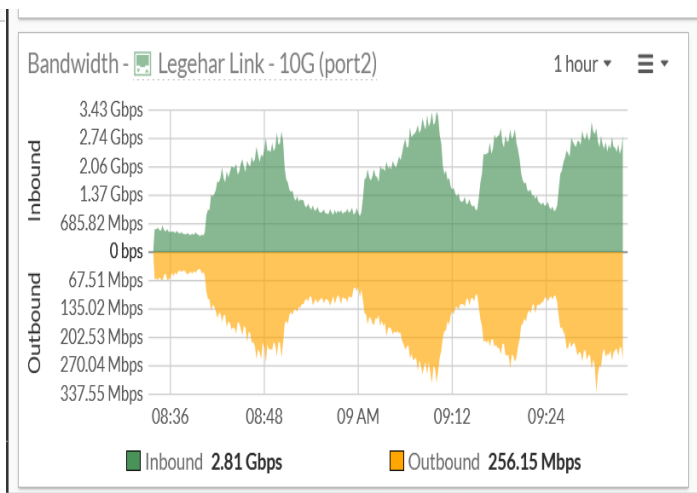
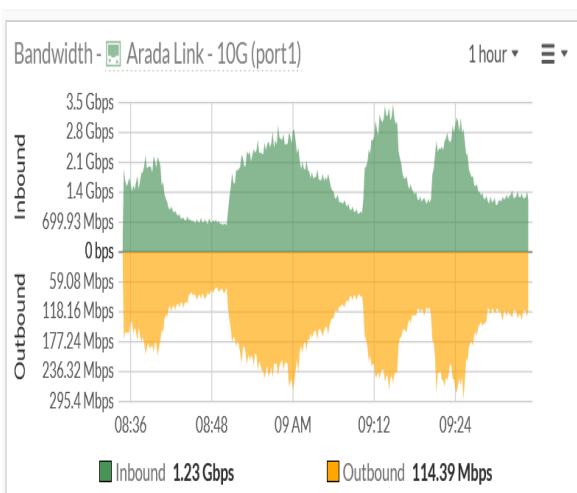


Figure 10. Link-1 from Legehar

Figure 11. Link-2 from Arada

4.4.2 Proposed SDN network architecture

The proposed network architecture encompasses an array of devices, notably featuring two redundant SDN controllers, two spine switches, and four leaf switches. This network is further segmented into several subnets, each possessing distinct and specific requirements.

Leveraging SDN introduces transformative possibilities for enhancing the performance, scalability, and resilience of this network in multifarious ways. In this context, SDN offers the potential to:

1. **Centralize Network Management and Control:** By centralizing network management and control, the architecture becomes more facile to oversee and adapt to alterations. This centralization allows for a streamlined approach to network-wide changes, significantly reducing administrative complexity.
2. **Optimize Traffic Flows:** SDN facilitates the optimization of traffic flows within the network. This entails intelligently routing traffic through the most efficient pathways, mitigating congestion and bolstering overall network efficiency.
3. **Implement Granular Network Policies:** SDN empowers administrators with the capability to implement granular network policies. This entails tailoring policies for diverse applications and user segments. The flexibility to craft custom policies enhances network performance and responsiveness to specific user requirements.
4. **Enhance Network Security:** With SDN, network security is fortified through multiple layers of control and segmentation. This heightened control over network elements curtails the potential for malicious actors to exploit vulnerabilities, thus augmenting network security and minimizing potential risks.

Incorporating SDN into the proposed network architecture unveils a powerful toolset for elevating performance, scalability, and resilience within data center networks. While the text acknowledges the existence of diagrams, they remain detached from the main narrative and lack explicit references within the body of the content. In order to enhance the comprehensibility of the document, it is advisable to seamlessly integrate the diagrams within the relevant sections, providing detailed explanations to elucidate their significance and relevance.

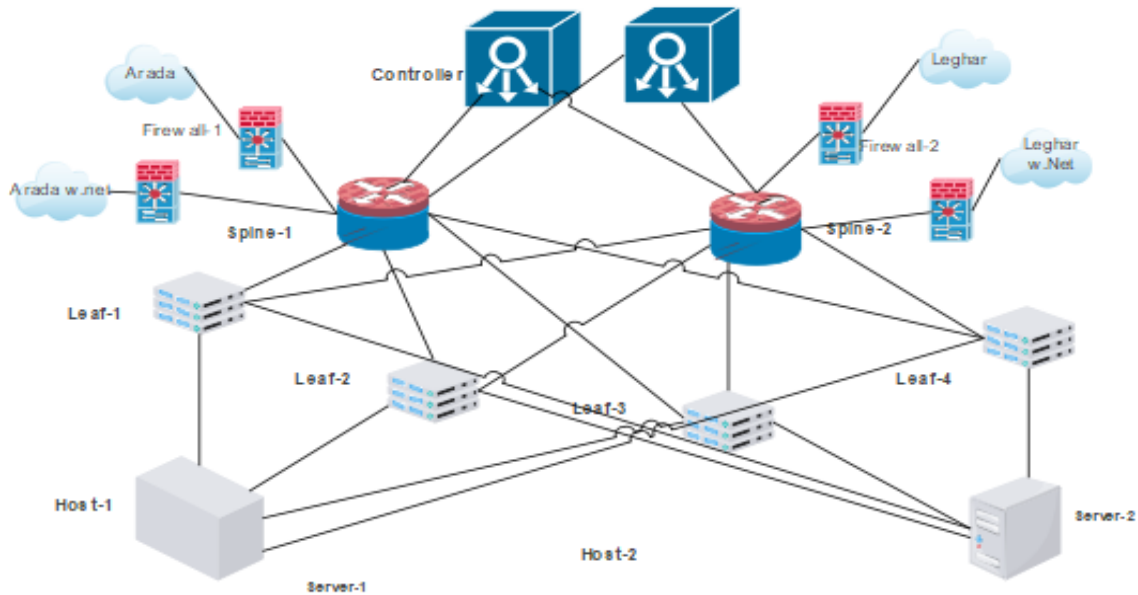


Figure 12. Propose New SDN network architecture

4.5 Quantitative Data Analytics

1) Throughput Comparison between the existing conventional network NDC & SDN

The throughput comparison between the existing conventional network and SDN National Data Center (NDC) is an important metric to consider when evaluating the performance of these two network architectures. Which is a traditional network architecture where the switches are independent of each other and make routing decisions based on their own local configuration. SDN, an acronym for Software-Defined Networking, represents a contemporary network framework in which a central controller governs the switches. This allows the controller to make more intelligent routing decisions and improve the overall throughput of the network.

INTERVAL	INPUT	OUTPUT
5 min	7.16 M	12.68 M
5 min	7.01 M	12.03 M
5 min	7.56 M	13.08 M
5 min	7.33 M	12.75 M
5 min	8.11 M	13.05 M

Table 1 NDC Throughput of a link taken from observium

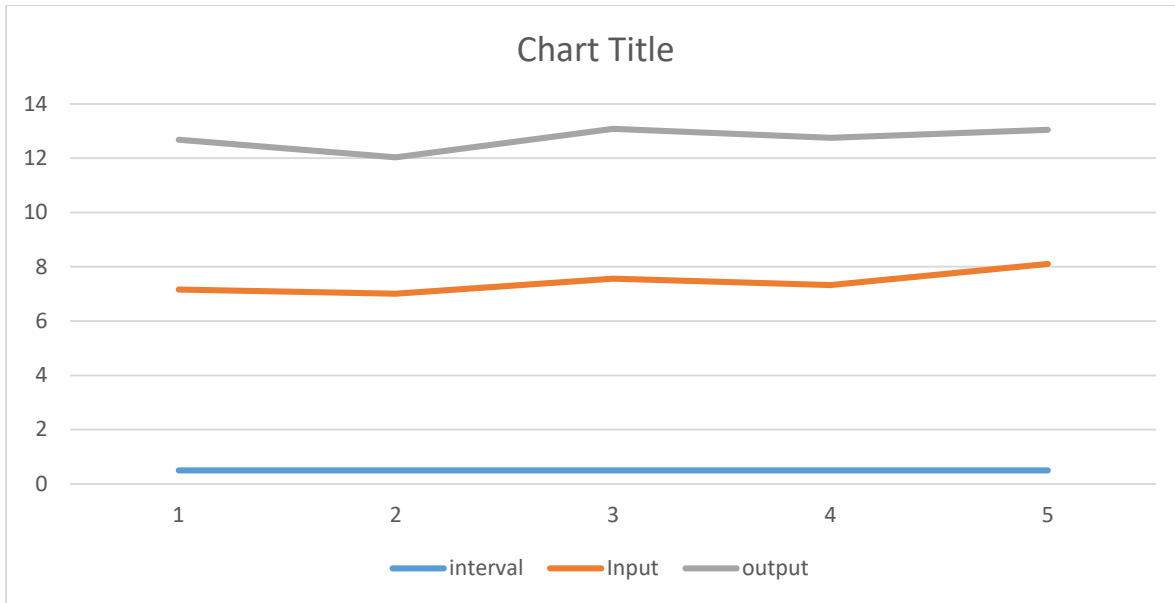


Figure 13. NDC Throughput of a link taken from observium

In a conventional/traditional network, throughput is determined by the bandwidth of the network links, as well as the amount of traffic on the network.

Bandwidth	Interval	IP
29.3 Gbits/sec	9.9970 sec	10.0.0.2
25.8 Gbits/sec	9.9970 sec	10.0.0.3
29 Gbits/sec	9.9970 sec	10.0.0.4

Table 2 Server listening from host 1 (10.0.0.1) using mininet simulation iperf command

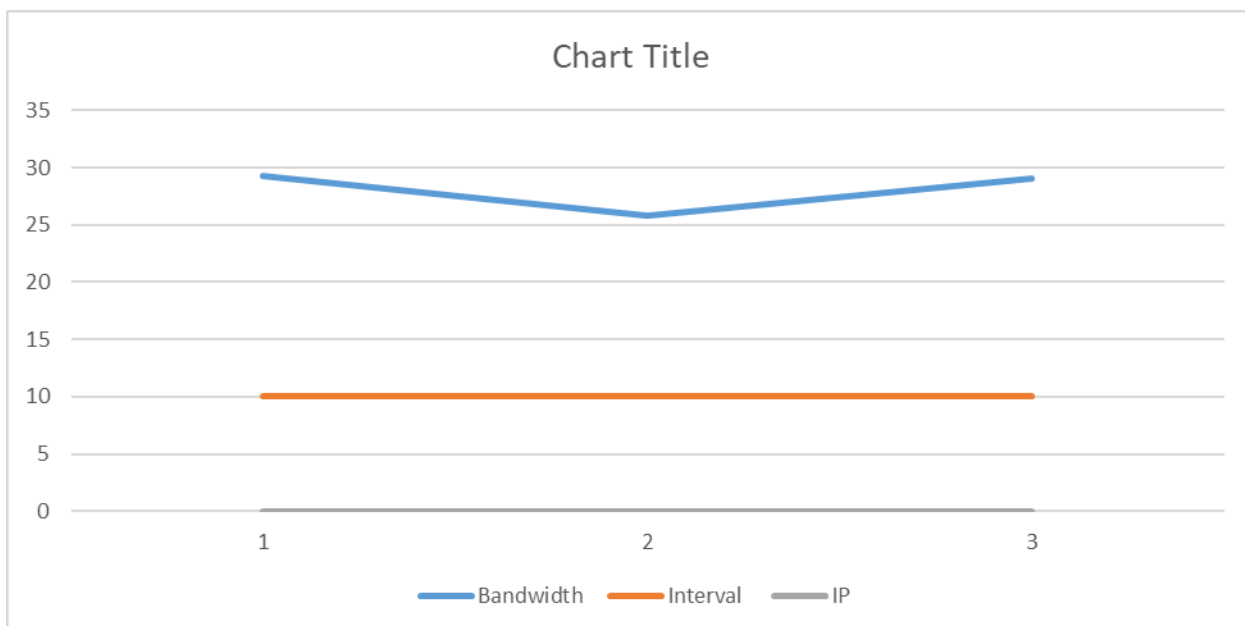


Figure 14. SDN all hosts throughput taken from mininet simulation use iperf command

SDN enhances throughput by separating control and data planes. Throughput is the data volume transmitted within a period, measured in bps. SDN achieves higher Gbps throughput with dynamic traffic management. Conventional networks have lower Mbps throughput. SDN also reduces latency due to centralized control, optimizing traffic flows for faster data transmission.

The comparison between Mb and Gbps throughput values serves to illustrate the significant disparity in data transmission rates between conventional networks and SDN-based networks. The essence of this comparison lies in highlighting the substantial performance gap that arises due to the dynamic handling and centralized management capabilities of SDN. This research adds value by shedding light on the increasing demand for higher bandwidth in modern networking scenarios and how conventional networks may struggle to accommodate these demands effectively.

The research can provide insights into how conventional networks and SDN respond to changing demands. This approach aligns with the central argument that conventional networks might struggle to meet growing bandwidth requirements, a notion this research seeks to substantiate. In summary, examining a diverse range of bandwidth scenarios allows for a comprehensive assessment of the comparative performance capabilities and limitations of both conventional networks and SDN-based networks.

2) Latency Comparison between the existing conventional network NDC & SDN

Latency, the delay in data transmission, plays a critical role in network performance. In the realm of networking, comparing latency between Software-Defined Networking and conventional networks provides insights into their efficiency and responsiveness

NDC services use command ‘ping’

Source	Destination	Packets Sent	Packets Received	Packet Loss	Min RTT (ms)	Avg RTT (ms)	Max RTT (ms)
M-Gov	172.30.20.57	4	4	0%	1	4	8
Video Conf/GW	172.30.40.1	4	4	0%	1	3	11
Traffic Pen	172.31.102.111	4	4	0%	1	3	9
Minit.gov.et	172.30.91.93	4	4	0%	1	1	2

Table 3. NDC services use command ‘ping’

SDN hosts command ‘ping’

Source	<i>Destination</i>	Packets Sent	Packets Received	Packet Loss	Min RTT (ms)	Avg RTT (ms)	Max RTT (ms)
mininet> h1	<i>h4</i>	4	4	0%	0.081	0.150	0.302
mininet> h1	<i>h3</i>	4	4	0%	0.057	0.169	0.406
mininet> h1	<i>h2</i>	6	6	0%	0.078	0.138	0.269
mininet> h2	<i>h4</i>	5	5	0%	0.067	0.096	0.115

Table 4. SDN hosts command ‘ping’

The table includes latency measurements, with 'RTT' representing Round Trip Time, 'Min' denoting the minimum value, 'Avg' indicating the average value, and 'Max' representing the maximum value. Additionally, it includes the packet loss percentage. This table offers a succinct summary of latency measurements for various source-destination pairs in both NDC services and SDN setups. The data reveals a notable contrast in latency between a traditional National Data Center network and an SDN-powered network.

In the realm of network performance within the National Data Center, a clear distinction emerges between the conventional setup and the SDN-based alternative. The conventional network exhibits a prevalent latency threshold surpassing 1ms (milliseconds). Although seemingly diminutive, this temporal lapse becomes conspicuous in contexts demanding swift responsiveness, such as real-time communication, gaming, and financial transactions.

In stark contrast, the SDN-based network showcases a pronounced reduction in latency. Within this paradigm, every host, encompassing all network-connected devices, encounters latency measures that remain beneath the 1ms threshold. This transformative shift signifies a remarkable acceleration in data packet transmission and service responsiveness, signifying a notable departure from the conventional network's limitations.

The pivotal catalyst underlying this latency reduction within the SDN-based network lies in its dynamic traffic handling and centralized management mechanisms, both conferred by SDN architecture. Through adept traffic flow optimization and the alleviation of bottlenecks, the SDN-based framework achieves swifter data propagation and diminished service response intervals. Consequently, the SDN network

emerges as a discernibly more suitable ecosystem for applications necessitating real-time, instantaneous reactions and minimal latency disruptions.

4.6 Techno-economic Analysis and Evaluation

Techno-economic analysis and evaluation are essential methodologies used to assess the feasibility and potential benefits of deploying SDN within a National Data Center. This approach combines technical and economic perspectives to provide a comprehensive understanding of the impact of SDN implementation on both technological capabilities and financial outcomes.

As technological advancements continue to reshape the landscape of data centers, SDN offers the promise of enhanced agility, scalability, and efficient network management. However, before embarking on such a significant transformation, decision-makers need to comprehend the holistic implications of this transition.

Techno-economic analysis involves dissecting the technical aspects of SDN deployment. This encompasses evaluating the compatibility of existing infrastructure with SDN components, the complexity of integration, the ease of management and control, and the potential for optimizing resource utilization. It delves into the technical intricacies of SDN's impact on data center operations, such as reducing network congestion, enhancing security through centralized control, and enabling rapid provisioning of services.

On the economic front, the evaluation considers both upfront and ongoing costs. This includes the cost of SDN hardware and software procurement, warranty and support cost, training and certification, installation cost, and License cost during the transition phase. However, the true value of techno-economic analysis emerges when it assesses the long-term benefits. These benefits could comprise streamlined operational efficiency, reduced maintenance costs, improved scalability, and the potential for quicker service deployment all contributing to enhanced user experiences and potentially even revenue growth.

By combining these technical and economic assessments, decision-makers gain a comprehensive picture of the implications of SDN deployment on the National Data Center. Techno-economic analysis empowers organizations to make informed decisions by weighing the upfront investment against the long-term advantages. This analysis equips stakeholders with the tools needed to identify potential challenges, opportunities, and trade-offs, ensuring that the decision to deploy SDN is not only driven by technological advancements but is also economically justified, aligned with the organization's goals, and capable of delivering sustainable value over time.

4.7 Economic Analysis

The expenses linked to the initial project outlay encompass hardware, software, and deployment expenses. Within the realm of implementation costs, there are considerations such as planning, installation, and system testing.

4.7.1 Capital Expenditure (CAPEX)

Embarking on a SDN implementation journey necessitates a thorough analysis of the costs and initial capital investment in comparison to the current conventional network costs and initial capital expenditures, encompassing various cost components critical to the setup and integration of this innovative network architecture.

Equipment Cost

The successful deployment of SDN in a National Datacenter involves various cost-related factors that need careful evaluation. These factors influence the financial viability and durability of the implementation. Achieving optimal traffic management through precise flow control, effective virtualization, rapid and adaptable placement of network functions, and maximizing resource utilization via orchestration presents an opportunity for potential capital expenditure (CAPEX) reduction[23].

The cost of equipment can vary significantly depending on the quantities purchased, the timeframes involved, and the manufacturers. This is especially true when considering the costs of equipment that has been identified as a solution. The cost considered Tax, insurance and transportation.

	Quantity	Unit price (USD)	Total(USD)
controller	2	27,000	54,000
Spine Switches	2	200,000	400,000
Leaf Switches	4	112,500	450,000
Training for 5 experts	5	1500	7,500
Total			911,500

Table 5. Hardware costs for SDN

In the context of the existing National Data Center, which currently features two routers, two core switches, and four Top-of-Rack (TOR) switches, the CAPEX framework is a fundamental. This introduction delves into the significance of CAPEX within this specific technological setup, exploring how this financial allocation approach influences. By delving into the CAPEX aspect, we gain the financial foundation that and its continuous evolution.

	Quantity	Unit price(USD)	Total cost(USD)
Firewall	4	10,000	40,000
Core Router	2	45,000	90,000
Core Switch	2	285,000	570,000
TOR switch	4	45,000	180,000
Total			880,000

Table 6 Hardware cost for Conventional network

Installation cost

Software defined network

The installation cost in an SDN deployment encompasses a variety of factors. The initial investment is often higher due to the acquisition of SDN controllers, Spine switches and leaf switches, and the implementation of supporting software infrastructure. While this upfront cost might appear substantial, SDN's ability to streamline network operations, improve resource utilization, and enable on-the-fly adjustments can lead to long-term cost savings. The potential reduction in operational overhead and the ease of scaling make SDN an attractive option for national data centers seeking agile and adaptable network solutions.

Existing Conventional Network in National Data Centers

The installation cost for existing conventional networks often involves purchasing individual network devices such as routers, switches, and firewalls. While these costs might appear lower compared to SDN upfront, the challenges arise in the long run. Maintenance, manual configuration, and the potential for bottlenecks during network expansion can lead to higher operational costs over time. Additionally, conventional networks can struggle to keep up with the dynamic demands of modern data centers that require rapid changes and adaptability.

Scenario	Equipment (USD)	Installation & integration (USD)	CAPEX(USD)
SDN	911,500	500,000	1,411,500
Conventional Network	880,000	167,000	1,047,000

Table 7. Equipment & Installation cost

4.7.2 Operational Related Costs (OPEX)

As the realm of networking continues to evolve, the deployment of SDN has emerged as a transformative approach that offers enhanced flexibility, agility, and efficiency in network management. One of the pivotal factors that organizations must consider when embarking on an SDN deployment journey is the operational expenditure, often referred to as OPEX. Operating expenditures (OPEX) cover the continuous expenses linked to managing an SDN, which establishes a uniform network environment across both hardware and software. This eliminates the need to manage and maintain disparate vendor-dependent devices separately.[23], managing, and optimizing the SDN infrastructure after its initial implementation. Service provisioning costs in an SDN context are anticipated to decrease thanks to automated configuration of network devices, reduced workforce requirements for network-related tasks owing to automation, and decreased manual configuration efforts, among other factors [23]. These expenses encompass a wide array of elements, including warranty and support cost, training and certification, and License cost. Understanding and effectively managing OPEX in the context of SDN deployment are essential for achieving the desired cost savings, maximizing the benefits of SDN technology, and ensuring the long-term sustainability of the network infrastructure. In this exploration, we delve into the various facets of OPEX in SDN deployment, highlighting strategies, challenges, and best practices to enable organizations to strike a harmonious balance between innovation and cost efficiency.

scenario	Support 3 year (USD)	License for 5 years (USD)	OPEX
SDN	15,000	20,000	35,000
Conventional Network	13,600	-	13,000

Table 8. Operational Related Costs (OPEX)

4.7.3 Total Cost of Ownership (TCO)

The concept of Total Cost of Ownership (TCO) is a critical factor in the implementation of Software-Defined Networking in a National Data Center. TCO encompasses all expenses associated with the

complete lifecycle of a technology solution, encompassing initial setup, ongoing operations, and maintenance. In the context of implementing SDN in a National Data Center, TCO analysis becomes a fundamental tool for understanding the comprehensive financial implications of adopting SDN over traditional networking approaches.

When considering the deployment of SDN in a National Data Center, the TCO analysis accounts for various cost factors. Initial deployment costs encompass expenses for acquiring hardware, software, professional services for implementation, and training for the IT team to competently manage the SDN environment.

Operational costs comprise ongoing expenses for monitoring, troubleshooting, maintaining the SDN infrastructure, and ensuring software updates, patches, and security measures are up-to-date. Personnel costs factor in salaries and benefits for the IT staff responsible for overseeing the SDN framework, potentially necessitating a different skill set compared to conventional networking roles.

Vendor relationships, encompassing licensing, support, and subscription fees, alongside potential impacts on business operations and customer experience during disruptions or downtime during the SDN transition, should also be incorporated into the TCO analysis.

By conducting an in-depth TCO analysis, stakeholders can make informed decisions about the feasibility of SDN implementation in a National Data Center. It provides a holistic assessment of the investment required, enabling organizations to evaluate whether the long-term benefits of SDN such as increased efficiency and flexibility outweigh the upfront and ongoing financial commitments.

Scenario	CAPEX(USD)	OPEX(USD)	TCO(USD)
SDN	1,411,500	35,000	1,446,500
Conventional Network	1,047,000	13,000	1,060,000

Table 9. Total Cost of Ownership (TCO)

When analyzing the Total Cost of Ownership (TCO) figures, with conventional network costs amounting to \$1,060,000 and SDN implementation totaling \$1,446,500, it becomes evident that the decision to deploy SDN within the government's critical service-oriented national data center involves considerations beyond mere financial outlays. The technology-driven benefits that SDN offers in this context are significant and

include enhanced network performance, scalability, reliability, security, real-time adaptability, resource efficiency, and transparency in governance.

Comparing these advantages with the costs, while the upfront TCO for SDN might appear higher, the broader implications of its deployment tilt the scales in its favor. The critical nature of government services necessitates a resilient and adaptive network infrastructure. SDN's dynamic network control and centralized management lead to optimized data flow, reducing latency and ensuring efficient service delivery. The flexibility and programmability of SDN guarantee seamless scalability to meet growing demands without disruptive overhauls. Moreover, SDN's automated adjustments ensure real-time responsiveness to changing demands, bolstering reliability. Its centralized management enhances network security by facilitating better monitoring, threat detection, and access control.

For example, the Federal Document Authentication and Registration Service operates across 14 branches in Addis Ababa, accommodating an impressive daily footfall of 7,000 visitors. With a daily income of 6.5 million birr, translating to 812,500 birr per hour and 13,542 birr per minute, even a minor delay of 10 minutes per day across all branches results in a significant financial loss of 135,420 birr daily and an alarming 33,584,160 birr annually, considering the 248 working days in a year. These delays highlight the critical need for efficient traffic management and resource optimization. Traditional networking infrastructures struggle to address these challenges effectively, causing revenue loss and hindering the agency's operational and financial objectives. Implementing Software-Defined Networking offers a compelling solution. SDN's dynamic resource allocation and traffic management capabilities enable real-time adjustments to varying traffic patterns, ensuring optimal resource utilization and minimizing financial losses, ultimately fostering operational efficiency, revenue growth and customer satisfaction for 'DARS'.

Equally important is SDN's alignment with principles of good governance and transparency. While the TCO for SDN might seem marginally higher, the long-term benefits it brings to critical government services improved service quality, operational efficiency, and the capacity to adapt to evolving demands render it a strategic investment. The decision to opt for SDN transcends mere cost-based comparison; it underscores a holistic understanding of technology's transformative role in ensuring the seamless functioning of vital government services.

4.7.4 Social economic analysis

The integration of Software-Defined Networking in Ethiopia's national data center is a strategic move that aligns both with social and economic benefits, and the consideration of downtime costs adds a crucial dimension to its implementation.

From a social standpoint, the adoption of SDN reflects the government's commitment to enhanced public service delivery and inclusivity. By optimizing network performance, SDN enables citizens to access crucial services efficiently, fostering a sense of equal opportunity. This technological advancement supports good governance by enabling effective resource allocation and timely service provision, ultimately enhancing the trust citizens have in the government's dedication to meeting their needs.

Moreover, SDN's capacity to centralize and manage network resources facilitates transparent communication. The government can disseminate information effectively, keeping citizens well-informed about policies and opportunities. This empowerment enables informed decision-making and promotes transparency in governance. The improved communication channels established by SDN also allow citizens to voice feedback, fostering a participatory governance model where the government responds to public input.

Economically, though initial costs might arise, the long-term savings are substantial. SDN's ability to minimize downtime is key; disruptions in critical services lead to financial losses due to unavailability and reduced productivity. By employing SDN to enhance network reliability and redundancy, the government can significantly mitigate downtime-related costs, thus supporting efficient resource allocation and public service efficiency.

In conclusion, the integration of SDN in the national data center not only optimizes network performance and service delivery but also plays a pivotal role in achieving good governance, transparency, and effective communication between the government and citizens. By addressing potential downtime-related costs, SDN enhances its value by minimizing financial losses due to service disruptions. Through improved accessibility, inclusivity, and citizen engagement, SDN contributes to a proactive and empowered society that actively shapes its own future, while fostering economic prosperity through technological advancement and prudent resource allocation. This comprehensive approach underscores the transformative potential of SDN in Ethiopia's journey toward a more efficient and participatory governance model.

4.8 Discussion

The total cost of ownership (TCO) for a conventional network is typically lower than the TCO for an SDN network. This is because conventional networks are less complex and require less specialized equipment. However, SDN networks offer a number of benefits that can outweigh the higher TCO, such as improved agility, reduced latency, and enhanced security.

The deployment of SDN within the national data center of Ethiopia holds immense promise and relevance, particularly in facilitating the seamless and efficient provision of critical services to governmental

organizations and citizens. With the key services such as e-service delivery, IFMIS (Integrated Financial Management Information System), ICMIC (Integrated Civil Service Management Information System), traffic penalty management, Video conference and email services intended to be offered free of charge to the government bodies and the public, the integration of SDN offers a robust foundation to accomplish these goals while yielding broader benefits.

SDN's inherent flexibility and agility empower the national data center to dynamically allocate and manage network resources in response to varying demands across different services. The adaptability of SDN technology enables the data center to efficiently prioritize and route traffic, optimizing the user experience for services like video conference, e-service and IFMIS. This ensures that government services are easily accessible, resulting in improved convenience and efficiency for both citizens and public sector entities.

Furthermore, the centralized control provided by SDN simplifies network management and monitoring. This centralized oversight not only enhances operational efficiency but also contributes to the realization of good governance. Network administrators gain a holistic view of network performance, allowing them to promptly address any potential issues and maintain a high standard of service quality.

The benefits of SDN extend beyond technical efficiency. The seamless access to services such as ICMIS, traffic penalty management, and email fosters good governance by promoting transparency, accountability, and data accuracy. Citizens benefit from a streamlined process for services and penalty management, enhancing public satisfaction and trust in the government's initiatives. SDN has a higher initial cost than conventional networks, but it offers better network performance and scalability, which can save money in the long run. Crucially, this progressive approach aligns with broader developmental objectives. By offering critical services for free, the government contributes to the empowerment and welfare of its citizens. The strategic utilization of SDN's capabilities translates into more effective governance, better resource utilization, and an improved quality of life for the people.

On the other hand, preparing a national-scale data center for seamless readiness for cloud technology involves a strategic alignment of infrastructure, resources, and processes to effectively integrate cloud services. This readiness encompasses various aspects, including upgrading network hardware, selecting and deploying an appropriate SDN controller, and establishing robust integration mechanisms with cloud platforms. The goal is to create a cohesive ecosystem where SDN-enhanced networking capabilities synergize with the features of cloud technology. Through this integration, the data center can dynamically allocate and manage networking resources to align with the varying demands of cloud-based applications and services. As a result, the data center becomes better equipped to provide efficient, scalable, and secure services to users, while efficiently utilizing network resources and optimizing service delivery. However, this endeavor comes with challenges that necessitate careful planning, including ensuring high availability,

addressing security considerations, and navigating potential compatibility issues between different technologies.

In conclusion, the deployment of SDN in Ethiopia's national data center serves as a transformative initiative that transcends technological upgrades. By leveraging the capabilities of SDN to provide essential services and uphold principles of good governance, the government not only ensures the seamless availability of services but also paves the way for enhanced citizen engagement, empowerment, and societal progress. The integration of SDN technology emerges as a catalyst for positive change, emphasizing both efficient service delivery and the broader well-being of the Ethiopian populace.

Chapter Five - Conclusion and Future Works

5.1 Conclusion

In conclusion, the findings of this study present a robust case for the deployment of Software-Defined Networking within the context of a national data center. The comprehensive assessment and demonstration of SDN's performance, coupled with an insightful analysis of associated costs, lay a strong foundation for advocating its adoption. By employing a multi-dimensional approach encompassing technical metrics such as network performance matrices, throughput, and latency, this study has elucidated the tangible advantages that SDN can offer in terms of network efficiency and real-time data delivery.

Moreover, the comparative analysis conducted against conventional network monitoring tools and the controlled simulations with the Mininet simulator underscore SDN's distinct operational enhancements. While the initial investment in specialized hardware and software might seem substantial, the thorough examination of cost factors unveiled a compelling narrative of long-term benefits. These benefits, centered around improved network performance, heightened reliability, and scalability, ultimately outweigh the initial financial commitment.

Beyond the realm of technical considerations, the study's examination of SDN's impact on governance and transparency adds another layer of significance. The centralization of network control and the transparency afforded by SDN's architecture provide a fertile ground for fostering good governance and establishing a secure and accountable network infrastructure. By mitigating potential risks associated with unauthorized access and malicious activities, SDN emerges as a powerful tool for safeguarding data and ensuring the integrity of network operations.

With these insights in mind, the study not only emphasizes the feasibility of SDN adoption but also aligns with the forward-thinking vision of deploying it within a national data center environment. The combination of enhanced technical performance, long-term cost-effectiveness, and governance benefits paints a compelling picture that warrants serious consideration from governmental bodies and decision-makers. As technology continues to evolve, embracing SDN represents a strategic step towards achieving a modernized, efficient, and transparent network ecosystem.

In essence, this study not only showcases the potential of SDN as a transformative force within network infrastructure but also serves as a persuasive proposal for its deployment in national data centers. The evidence presented herein, encompassing technical superiority, cost-effectiveness, and governance enhancements, collectively substantiates the merits of incorporating SDN into the foundation of our digital infrastructure.

Recommendations

Given the demonstrably superior performance of SDN deployment compared to conventional network solutions, it is strongly recommended that the national data center considers leveraging SDN to substantially enhance network performance. This strategic move would not only ensure an elevated level of service provision to governmental entities but also align with the overarching objective of delivering optimal service quality. Furthermore, this progressive adoption of SDN technology resonates with the principles of good governance, as it offers streamlined network management and enhanced transparency in operations, fostering an environment of accountability and efficiency.

5.2 Future Work

For this study, the application of software-defined networking is restricted to the context of a national data center. However, future research will concentrate on the deployment of SDN-WAN.

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Performance and Cost-Benefit Analysis of Software Defined Network over Conventional Network at the National Datacenter -Ethiopia

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Abstract: The expansion of data center services and aging equipment has led to a demand for better network services. Traditional IP networks have limitations in terms of efficiency and cost-effectiveness, making network management challenging. Software Defined Networking (SDN) has emerged as a solution to dynamically allocate network resources, addressing these issues. This paper examines the performance challenges in existing data center networks and shows how adopting SDN can improve them. Using a modeling approach, the study evaluates the value of these network improvements, considering factors like costs and benefits. Overall, the abstract emphasizes the need for enhanced network services, introduces SDN as a solution, and outlines the paper's focus on performance improvement and economic assessment.

Keywords: SDN, National data center, E-gov, Performance Analysis, cost-benefit analysis

I. Introduction

Software-defined network

SDN separates network control and data forwarding, allowing dynamic traffic management. Large data centers met demand but raised environmental and community concerns. SDN offers flexibility, simplified management, security, and cost savings.

SDN employs the OpenFlow protocol for creating programmable, centrally managed, and flexible networks. It relies on a distinctive protocol called the 'Open Flow Protocol' to govern and manipulate the complete network. The OpenFlow controller is responsible for managing the OpenFlow switches[1]. A centralized SDN system manages the network with OpenFlow switches, offering programmability, standards compliance, and vendor neutrality. Benefits for the National Data Center of Ethiopia include flexibility, efficiency, and enhanced security. SDN

improves network adaptability, user experience, and resource optimization, crucial for meeting growing demands and bolstering performance and security. It enables software-based control, enhancing network segmentation and routing through a centralized server.

SDN offers an enhancement to current network limitations through two primary mechanisms. Firstly, it disrupts vertical integration by segregating the network's control logic (known as the control plane) from the underlying routers and switches responsible for forwarding traffic (the data plane). Secondly, this separation between control and data planes transforms network switches into straightforward forwarding devices, while the control logic is consolidated within a logically centralized controller or network operating system. This streamlines policy enforcement, network configuration, and evolution[2].

SD-WAN replaces costly MPLS lines with cheaper leased lines, managed centrally for cost reduction and simplified management.

SD-LAN applies SDN principles to LANs with distinctions in topology, security, and application control, enabling policy-based design for both wired and wireless LANs.

NFV decouples network functions from hardware for flexible deployment, while SDN abstracts control for better management. Together, they create a hybrid model, using virtualization for efficient service deployment and innovative networking.

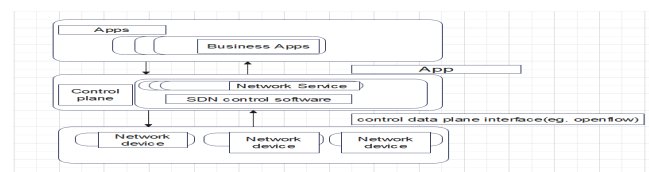


Figure 1. A high-level overview of the software-defined networking architecture

OpenFlow is a protocol for managing Ethernet switches by setting packet processing rules, enabling functions like firewalls, NAT, QoS, and data collection, enhancing network flexibility and management ease.

An OpenFlow Controller, part of SDN, acts as a network OS, connecting controller software to hardware, optimizing routing, and directing packet transmission for application traffic.

SDN decouples traffic management and network configuration from physical infrastructure, utilizing APIs for precise control over organizational networks, providing flexibility and control. It enhances network device coordination for specialized needs.

SDN has the ability to manage situations where links fail by redirecting data traffic through alternative routes. In these situations, packets can still reach their intended destinations, albeit with an increase in Round Trip Time (RTT) and reduced throughput[3]. SDN is progressively adopting elastic cloud architectures and dynamic resource allocation to accomplish its infrastructure objectives[1].

SDN's fundamental idea is to use software-based policy/control engines to centrally regulate network endpoints to automate network provisioning, management, and control. In a software-defined network, traffic can be managed by a network administrator through centralized control software, eliminating the need for individual switch configurations.[1] These centralized engines simplify the whole procedure, making it agile, dynamic, and highly adaptable by revealing network status to end users through APIs and abstractions. This results in various advantages, such as the ability to rapidly create new service offerings for end users on demand, streamlined operations, immediate network responsiveness, reduced network intricacy, and related benefits. As new services are introduced more expeditiously, regardless of the end user's location, these advantages manifest in reduced operating expenses (OpEx), reduced capital expenditures (CapEx), and enhanced revenue. Software-defined networking (SDN) is which can lead to a number of benefits in terms of cost, management, and human resources.

Cost: One of the biggest benefits of SDN is that it can help to reduce network costs. This is because SDN can help to optimize network resources, such as bandwidth and storage. It can also help to reduce the need for expensive hardware, as SDN controllers can be used to manage a wider range of devices.[4] SDN/NFV is anticipated to lower operational expenditures (OPEX) for service providers by consolidating and enhancing the network and the related operational model.

[5] Software-defined networking has arisen as an effective network technology capable of accommodating the dynamic requirements of future network functions and intelligent applications, all while reducing operational expenses through simplified hardware, software, and management.

Management: SDN can enhance network administration as well. This is because SDN controllers offer a unified perspective of the network, simplifying the process of diagnosing issues and implementing modifications. Moreover, SDN has the capacity to automate various tasks that are currently executed manually, such as setting up new devices and defining network policies.[6] Network administrators have the flexibility to tailor SDN controllers to suit their specific requirements. Nevertheless, these customizations could have consequences in terms of resource utilization and the performance of traffic forwarding.

Human Resources: Skill Requirements: SDN implementation may require staff to acquire new skills and expertise in SDN technologies. However, once trained, the IT team can efficiently manage and maintain the network with improved visibility and control.[7] As SDN becomes more prevalent, network administrators must acquire new skills in network technologies, in contrast to the past when they were primarily considered experts in traditional network administration.

SDN can also contribute to resource optimization by automating tasks that are presently carried out by network engineers. This automation can liberate engineers to concentrate on strategic activities, such as network design and optimization.

Overall, SDN can have a significant impact on cost, management, and human resources. By optimizing network resources, automating tasks, and freeing up human resources, SDN can help organizations to save money and improve the efficiency of their networks.

II. Literature review

A. Software-Defined Networking

SDN is a network framework in which software is responsible for managing devices and regulating packet actions. OpenFlow serves as a communication protocol that facilitates interaction between software controllers and Ethernet switches, focusing on control plane communication and defining rules for data plane actions. [8] Per CISCO, SDN is an architectural solution aimed at enhancing network flexibility and simplifying network administration. It achieves this by centralizing management, abstracting the control plane from the data forwarding function found in individual network devices.

SDN helps organizations separate traffic management and network configuration from physical infrastructure, enabling granular control through APIs for specialized network coordination and enhanced flexibility.

SDN possesses the capability to manage link failures effectively, redirecting traffic through alternative pathways. In such instances, packets can still reach their intended destinations, albeit with an elevated round-trip time (RTT) and reduced throughput. [3]

To achieve its infrastructure objectives, SDN is progressively adopting elastic cloud architectures and dynamic resource allocation.[1]

B. Traditional network architecture

Traditional networks have tightly coupled data and control planes, making scaling and automation challenging. They struggle with virtualized setups and reliance on IP addresses for identification. This complexity has led to the adoption of SDN, which separates data and control planes, easing scalability and automation for better network management.

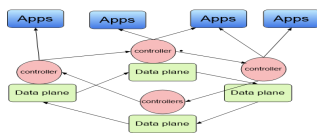


Figure 15. Architecture of Traditional Network

Traditional networks led to SDNs due to limitations. In traditional networks, data and control planes were intertwined, necessitating device reconfiguration for changes. SDNs separate data and control, enabling dynamic adjustments and alleviating scalability, security, and performance issues tied to fixed hardware.

To facilitate the maintenance of extensive network configurations, administrators need to address physical infrastructure challenges that contribute to increased management complexity, aiming to streamline the administration of large, virtualized networks [9].

This section highlights the drawbacks of traditional network architecture with tightly integrated data and control planes, emphasizing challenges in scalability, automation, and reliance on IP addresses. To address these issues, many organizations turn to SDN, which separates data and control planes. SDN is comprised of several key elements, including the control plane, northbound APIs, east-west protocols, and southbound data plane protocols. Among these components, the OpenFlow protocol plays a pivotal role in enabling software-based control of network traffic. OpenFlow-compliant switches are available in two types: OpenFlow-

only and OpenFlow-hybrid. In summary, SDN resolves traditional network limitations by decoupling control and data planes, with OpenFlow playing a pivotal role in enabling software-based network traffic control.

This thesis is structured into five chapters, each serving a distinct purpose. The initial chapter functions as an introductory section, providing an overview of the background, problem statement, research goals, methodology, literature review, contributions, and the research's scope and constraints. In the second chapter, the focus shifts to the National Data Center's infrastructure, with a comparative analysis between Software-Defined Networking (SDN) and conventional network frameworks. Chapter 3 delves into various techno-economic models and evaluation methods, supported by mathematical models. Moving to Chapter 4, deployment scenarios are elaborated upon, accompanied by thorough techno-economic and socio-economic analyses, along with findings and discussions. The fifth and final chapter offers the research's conclusion and highlights areas for potential future work.

III. Data Center Network infrastructure

This chapter explores the essential aspects of Data Center Network Infrastructures (DCNIs) in modern technology landscapes. It covers DCNIs' evolution, constituents, architectural constructs, service offerings, and functions, emphasizing their role in seamless data flow, critical applications, and network efficiency. The chapter also discusses security protocols, redundancy, and disaster recovery strategies for uninterrupted operations, as well as regulatory compliance. Ultimately, it highlights the importance of adhering to standards in data center design and operation, ensuring efficiency, reliability, and adaptability to technological changes. National Data Centers, being government-operated hubs for critical services, prioritize security, redundancy, and disaster recovery while upholding national data regulations.

Technological infrastructure serves as a foundation for data access, sharing, analysis, and utilization. This infrastructure encompasses the presence of physical communication networks, devices, ICT proficiency (for both technical and non-technical individuals), internet accessibility, and affordability, which enhance the prospects for the success of Open Data Initiatives[10].

Ethiopia's National Data Center (NDC) is overseen by the Ministry of Innovation and Technology (MInT) and plays a vital role in providing various e-government services, supporting digitalization efforts, and connecting numerous regions and sites across the country. While it serves critical

functions, challenges such as the absence of a disaster recovery site and underutilized services need to be addressed. Elevating the NDC's tier classification, investing in disaster recovery capabilities, and optimizing existing services are essential steps to strengthen its role in the IT infrastructure, promote sector growth, and support the digital economy. Additionally, the center plans to implement Software-Defined Networking (SDN) to enhance resource management and service quality in response to increasing demand.

A. Network Optimization in National data center

Network optimization is the systematic enhancement of a network's infrastructure to improve its efficiency, reliability, and overall performance. In the National Data Center of Ethiopia, this process is essential to ensuring seamless communication, efficient data handling, and uninterrupted services across various sectors. Optimization is the act of discovering a network configuration that leads to the highest achievable performance [11]. Utilizing the existing network equipment and available spectrum in an efficient manner to enhance performance.

To optimize the National Data Center's network, key strategies include upgrading hardware, implementing traffic management, load balancing, intelligent routing, redundancy, disaster recovery plans, resource allocation, and enhancing security measures. These efforts collectively enhance network efficiency and reliability for critical government services.

B. Performance analysis

performance analysis in computer networking assesses a network's efficiency using metrics like latency, throughput, packet loss, and network utilization. This analysis is crucial for troubleshooting and optimization. In Software-Defined Networking (SDN), performance analysis includes metrics like flow setup time, controller processing time, network utilization, and policy compliance. SDN offers improved visibility and control for network performance compared to traditional networking, enhancing overall service quality for end-users. The choice of metrics should align with specific network issues and performance goals.

Network administrators should focus on key SDN performance metrics like network throughput, jitter, and response time, as these metrics serve as vital indicators of the network's condition. [12]

IV. Techno-Economic model and evaluation Method

This chapter introduces techno economic assessment (TEA) models, economic modeling and TEA evaluation methods, including decision making economic indicator.

A. Techno-economic Assessment (TEA)

Techno-economic Assessment (TEA) is a method that combines technical and economic analyses to evaluate the feasibility and potential of a technological project. It considers technology capabilities, performance, scalability, and reliability, alongside estimating costs, revenue, and financial returns. This integrated approach helps stakeholders make informed decisions about the project's viability and potential outcomes.

B. Techno-economic Assessment Models

Techno-economic Assessment (TEA) models originated in the 1970s to assess economic viability of emerging energy technologies. Over time, they expanded to evaluate various technologies, even in transportation, manufacturing, healthcare, and climate change policies. In the 2000s, TEA models integrated with other frameworks for holistic assessment. Today, they're crucial for decision-makers evaluating new technologies and policies, aiding sustainable progress.

Techno-Economic Results from ACTS (TERA) Mode

The ACTS framework by the European Commission provides valuable resources for evaluating advanced communication technologies. Specifically, the Techno-Economic Results from ACTS (TERA) model focuses on techno-economic aspects, offering valuable insights that can guide future research and development efforts in manufacturing companies. These analysis findings have practical applications and can serve as a foundation for making informed decisions when initiating new product development projects [13]. This model is particularly valuable for decision-makers as it facilitates an understanding of both the intricate technical capabilities and the consequential economic implications tied to adopting specific technologies.

The TERA model, originally designed for evaluating communication technologies, can be adapted for Software-Defined Networking (SDN) assessment. It systematically examines SDN's impact on network performance, resource use, and management efficiency. It estimates SDN implementation costs and potential benefits, including streamlined operations and faster service provisioning. The model also considers market trends, risks like compatibility issues, and conducts sensitivity analysis for economic feasibility based on variable changes. TERA equips decision-

makers with insights for informed decisions on integrating SDN into network infrastructure.

Implemented Techno-economic Analysis Model

Implemented Techno-Economic Analysis (IEA) models evaluate feasibility, economic viability, and impacts of technological projects. They combine technical and economic aspects to understand costs, benefits, and risks. IEA models, being applied in real-world situations, empower stakeholders to decide wisely by comprehending both dimensions. This ensures strategic evaluation, optimized resource use, and increased success likelihood. IEA models assist stakeholders in making informed decisions about technology adoption or project initiation by considering all relevant factors.

C. Cost modeling

Total Cost of Ownership (TCO): is a comprehensive financial metric that accounts for all expenses associated with owning and operating a product or technology over its lifecycle, aiding informed decision-making and resource allocation.

Capital Expenditure (CAPEX): covers initial expenses for acquiring assets, infrastructure, or technology, contributing to growth and efficiency.

Operational Expenditure (OPEX): includes ongoing costs like salaries and maintenance, ensuring business continuity and requiring effective management for long-term viability.

D. Techno-economic Assessment (TEA) Evaluation Method

The Techno-economic Assessment (TEA) method provides a thorough approach to assess the viability and impact of introducing new technologies, especially in cases where conventional financial metrics are insufficient. When applied to a no-cost governmental service, TEA evaluates technological feasibility, operational implications, stakeholder engagement, risks, legal compliance, societal impact, and long-term sustainability. It considers qualitative aspects, such as governance improvement, transparency, and public trust. TEA ensures well-informed decisions aligned with government goals and broader societal benefits.

V. Deployment Scenarios and Techno-economic Analysis

This initiative involves implementing Software-Defined Networking (SDN) in a government service provider's framework. The goal is to offer free SDN services to different sectors, including government organizations. The analysis aims to evaluate the practicality, viability, and economic

feasibility of integrating SDN into the current infrastructure. It seeks to ensure smooth communication, efficient resource allocation, and enhanced service delivery. The study aims to uncover the opportunities and challenges of this transformative effort.

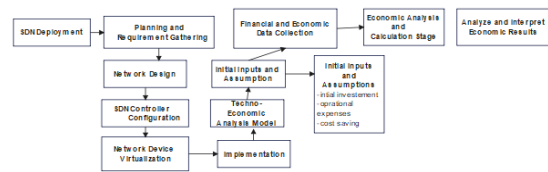


Figure 16. implemented techno-economic analysis model block diagram

A. Implemented Techno-economic Analysis Model

This section discusses the undertaken actions and approaches, focusing on deploying Software-Defined Networking (SDN) within a government service provider's framework. It covers the executed model, evaluating techno-economic aspects, defining scenarios and parameters, conducting technical and economic evaluations, and combined analysis. The evaluation process involves assessing SDN's technical feasibility for cost-free services to government organizations, considering compatibility, resource allocation, security, and reliability. On the economic front, it examines costs like acquisition, installation, and ongoing expenses, while also exploring potential benefits like efficiency improvements and reduced downtimes. The goal is to inform well-balanced decisions about deploying free SDN services within the government context.

B. Techno-economic Assessment Process

For a government service provider, evaluating SDN deployment involves technical and economic considerations. Technically, assessing SDN's integration feasibility, compatibility, load management, resource optimization, security, efficiency gains, and reliability enhancement is crucial. Economically, analyzing costs like hardware, software, installation, support, and training is essential, while also exploring potential benefits like improved efficiency, reduced downtimes, minimized errors, and enhanced user experiences. The evaluation seeks to balance costs and benefits to make informed decisions about offering free SDN services within the government context.

C. Deployment Scenarios

This thesis explores two potential scenarios involving the national data center of Ethiopia: one involving SDN and the

other a conventional network. The initial investigation will concentrate on enhancing network performance through the implementation of software-defined networking (SDN).

D. Technical Analysis

A technical analysis of the existing conventional network in national data centers will be conducted to compare the performance of SDN networks with respect to latency, throughput, and bandwidth.

Existing conventional Network

The thesis will analyze a national data center with specific hardware components. It will assess the existing conventional network's technical aspects, including hardware, software, and networking components. The study will then compare the performance of this network with that of an SDN network, considering metrics like latency, throughput, and bandwidth.

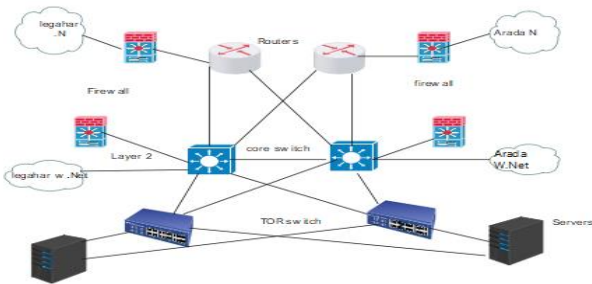


Figure 3. conventional network in datacenter

This disparity between inbound and outbound data flows is emblematic of a data center that operates as a pivotal nexus. It diligently aggregates and assimilates data from diverse sources, thereby inducing a higher influx compared to the data it disburses. Such a configuration underscores the center's role as a robust repository, capable of accommodating substantial data streams.

E. Quantitative Data Analytics

1) Throughput Comparison between the existing conventional network DC & SDN

Throughput comparison between the existing conventional network and SDN National Data Center (NDC) is a crucial metric. Conventional networks have independent switches making local routing decisions, while SDN, or Software-Defined Networking, is a modern architecture where a central controller intelligently controls switches, enhancing network throughput.

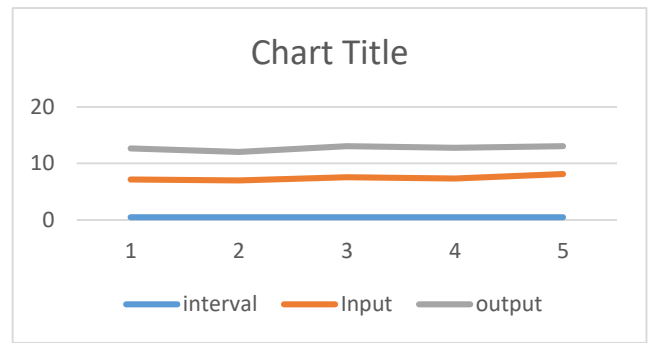


Figure 7. NDC Throughput of a link taken from observium

In a conventional/traditional network, throughput is determined by the bandwidth of the network links, as well as the amount of traffic on the network.

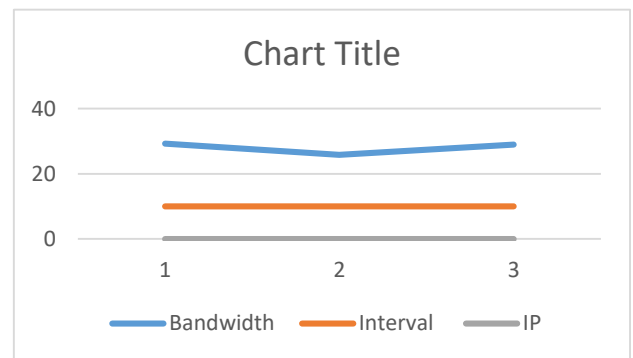


Figure 8. SDN all hosts throughput taken from mininet simulation use iperf command

SDN enhances data throughput by separating control and data planes, achieving higher Gbps compared to conventional networks with lower Kbps/Mbps. SDN's dynamic traffic management and centralized control reduce latency, optimizing data flow. This research emphasizes the significant performance gap between SDN and conventional networks in meeting growing bandwidth demands. By assessing various scenarios, it substantiates the idea that conventional networks struggle to match modern requirements, highlighting SDN's advantages.

3) Latency Comparison between the existing conventional network NDC & SDN

Latency, the time for packet travel, is crucial in network performance assessment. Conventional networks with decentralized routing often have higher latency due to potential congestion and delays. SDN networks, with centralized control, optimize traffic flows and minimize latency.

Source	Destination	Packets Sent	Packets Received	Packet Loss	Min RTT (ms)	Avg RTT (ms)	Max RTT (ms)
M-Gov	172.30.20.57	4	4	0%	1	4	8
Video Conf/GW	172.30.40.1	4	4	0%	1	3	11
Traffic Pen	172.31.102.111	4	4	0%	1	3	9
Minit.gov.et	172.30.91.93	4	4	0%	1	1	2

Table 1. NDC services use command 'ping'

Source	Destination	Packets Sent	Packets Received	Packet Loss	Min RTT (ms)	Avg RTT (ms)	Max RTT (ms)
mininet>h1	h4	4	4	0%	0.081	0.150	0.302
mininet>h1	h3	4	4	0%	0.057	0.169	0.406
mininet>h1	h2	6	6	0%	0.078	0.138	0.269
mininet>h2	h4	5	5	0%	0.067	0.096	0.115

Table 2. SDN hosts command 'ping'

In the table, "RTT" stands for Round Trip Time, "Min" is the minimum value, "Avg" is the average value, and "Max" is the maximum value. The table includes packet loss percentages. It provides a clear summary of latency measurements for various sources and destinations in both NDC services and SDN scenarios. The data shows a substantial difference in latency between a conventional network in a National Data Center and an SDN-based network.

Comparing network performance at the National Data Center, conventional setup has latency above 1ms, impacting real-time needs. SDN-based network excels, keeping latency below 1ms for all devices. SDN's dynamic traffic management and centralized control drive this improvement. Optimized traffic flow reduces bottlenecks, resulting in faster data transmission and quicker service responses. SDN becomes a better choice for latency-sensitive applications, ensuring real-time and minimal disruptions.

F. Techno-economic Analysis and Evaluation

Techno-economic analysis evaluates the feasibility and benefits of implementing SDN in a National Data Center from both technical and economic perspectives. It examines compatibility, ease of management, and operational improvements on the technical side. Economically, it covers upfront and ongoing costs, including procurement, support, and long-term benefits like efficiency gains. This comprehensive approach empowers decision-makers to make informed choices that align with goals and ensure sustained value.

G. Economic Analysis

The costs associated with the initial investment of a project include the hardware, software, and implementation costs. Planning, installation, and system testing are all implementation costs.

1) Capital Expenditure (CAPEX)

Equipment Cost

The successful deployment of SDN in a National Datacenter involves various cost-related factors that need careful evaluation. These considerations impact the economic feasibility and long-term sustainability of the deployment. Optimizing traffic through fine-grained flow management, effective virtualization, rapid and adaptable placement of network functions, and maximizing resource utilization via orchestration have the potential to reduce capital expenditures (CAPEX).[14].

Equipment costs can vary based on quantity, timelines, and manufacturers. Taxes, insurance, and transportation costs should also be considered in the overall equipment expenses.

Hardware name	Quantity	Unit price (USD)	Total(USD)
controller	2	27,000	54,000
Spine Switches	2	200,000	400,000
Leaf Switches	4	112,500	450,000
Training for experts	5	1500	7,500
Total			911,500

Table 3. Hardware costs for SDN

In the current National Data Center setup with two routers, two core switches, and four Top-of-Rack (TOR) switches, understanding Capital Expenditure (CAPEX) is crucial. This framework explores the financial significance and influence of CAPEX within this specific technological context, providing a foundation for financial considerations and ongoing evolution.

Hardware name	Quantity	Unit price(USD)	Total cost(USD)
Core Router	2	45,000	90,000
Core Switch	2	285,000	570,000
TOR switch	4	45,000	180,000
Total			840,000

Table 4. Hardware cost for Conventional network

Installation Cost

Software defined network: In SDN deployments, initial installation costs include SDN controllers, Spine switches, leaf switches, and supporting software infrastructure. Although this upfront cost may seem high, SDN's ability to streamline operations, improve resource utilization, and enable adjustments can result in long-term savings. In contrast, existing conventional networks involve purchasing individual devices, which may seem cheaper initially but can lead to higher operational costs over time due to maintenance, manual configuration, and scalability challenges. Conventional networks also struggle to meet the dynamic demands of modern data centers.

Scenario	Equipment (USD)	Installation &	CAPEX (USD)

		integration (USD)	
SDN	911,500	500,000	1,411,500
Conventional Network	840,000	167,000	1,007,000

Table 5. Equipment & Installation cost

2) Operational Related Costs (OPEX)

As the realm of networking continues to evolve, the deployment of Software-Defined Networking (SDN) has emerged as a transformative approach that offers enhanced flexibility, agility, and efficiency in network management. One of the pivotal factors that organizations must consider when embarking on an SDN deployment journey is the operational expenditure, often referred to as OPEX. OPEX encapsulates the ongoing costs associated with maintaining SDN establishes a uniform network environment encompassing both hardware and software, eliminating the need to independently manage and maintain vendor-specific devices in any scenario.[14], managing, and optimizing the SDN infrastructure after its initial implementation. In the context of SDN, service provisioning costs are anticipated to decrease because of automated network device configuration, reduced reliance on personnel for network tasks due to automation, and minimized manual configuration, among other factors.[14]. These expenses encompass a wide array of elements, including warranty and support cost, training and certification, installation cost, and License cost. Understanding and effectively managing OPEX in the context of SDN deployment are essential for achieving the desired cost savings, maximizing the benefits of SDN technology, and ensuring the long-term sustainability of the network infrastructure. In this exploration, we delve into the various facets of OPEX in SDN deployment, highlighting strategies, challenges, and best practices to enable organizations to strike a harmonious balance between innovation and cost efficiency.

Scenario	Support 3 year (USD)	License for 5 years (USD)	OPEX
SDN	15,000	20,000	35,000
Conventional Network	13,600	-	13,000

Table 6. Operational Related Costs (OPEX)

3) Total Cost of Ownership (TCO)

The concept of Total Cost of Ownership (TCO) is crucial in SDN deployment at a National Data Center. TCO covers all

expenses throughout the technology solution's lifecycle, including setup, operations, and maintenance. It considers factors like initial deployment costs for hardware, software, implementation services, and IT team training, as well as ongoing operational costs, personnel expenses, vendor relationships, and potential impacts during the SDN transition. TCO analysis helps stakeholders assess whether the long-term benefits of SDN justify the upfront and ongoing financial commitments.

Scenario	CAPEX(USD)	OPEX(USD)	TCO(USD)
SDN	1,411,500	35,000	1,446,500
Conventional Network	1,007,000	13,000	1,020,000

Table 7. Total Cost of Ownership (TCO)

Comparing the Total Cost of Ownership (TCO) between conventional networks at \$1,020,000 and SDN implementation at \$1,446,500, the decision to deploy Software-Defined Networking (SDN) in the government's national data center goes beyond finances. SDN offers significant technological benefits, including enhanced network performance, scalability, reliability, security, real-time adaptability, resource efficiency, and transparency in governance.

While SDN's upfront TCO may seem higher, its broader advantages favor its implementation. Government services require a robust and adaptable network infrastructure, and SDN's dynamic control and centralized management optimize data flow, reduce latency, and ensure efficient service delivery. SDN's flexibility and programmability enable seamless scalability without disruptive changes, and its automated adjustments enhance reliability and security through improved monitoring and threat detection.

Furthermore, SDN aligns with principles of good governance and transparency. While the TCO for SDN may slightly exceed that of conventional networks, its long-term benefits in terms of improved service quality, operational efficiency, and adaptability to evolving demands make it a strategic investment. The decision to choose SDN reflects a holistic understanding of technology's transformative role in ensuring the seamless functioning of vital government services.

4) Social economic analysis

Integrating SDN into Ethiopia's national data center holds both social and economic significance. It improves service access, equality, and trust, enhances governance through efficient resource allocation, and reinforces citizen confidence. SDN's centralization promotes transparent communication and participatory governance, reducing

downtime expenses and ensuring resource efficiency. This fosters governance, transparency, citizen engagement, and economic growth, ultimately transforming service availability and societal progress.

VI. Conclusion and Future Works

A. Conclusion

This study strongly supports the deployment of Software-Defined Networking (SDN) in national data centers. Comprehensive assessments have demonstrated SDN's performance benefits and cost advantages. Technical comparisons and metrics reveal improved network efficiency and real-time data delivery, with controlled simulations highlighting operational enhancements that outweigh initial investment concerns. Beyond technical aspects, SDN positively impacts governance and transparency, enhancing security and accountability. This study aligns with the vision of SDN adoption, showcasing its technical excellence, cost-effectiveness, and governance benefits. Overall, SDN emerges as a transformative and compelling addition to national data center infrastructure, promoting modernization, efficiency, and transparency.

B. Recommendations

It is highly recommended that the national data center adopts SDN technology to significantly improve network performance. This strategic decision will elevate service quality for government entities and align with the goal of delivering optimal services. Additionally, the adoption of SDN aligns with principles of good governance, enhancing network management and transparency while promoting accountability and efficiency.

C. Future Work

In the scope of this study, software-defined networking (SDN) is limited to the context of a national data center, but future work will focus on SDN-WAN deployment.

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