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Techno-Economic Analysis of Hybrid SDN deployment: In the case of Ethio telecom

Nov 05, 2021

By

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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

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Signature _____

Abstract

The growth in data traffic volume from access network are increasing exponentially which in turn exert a pressure on IP core network and force the operator either to optimize or upgrade their core networks. However, without a detailed technical and economic feasibility study, technological advancement alone cannot demonstrate the acceptability and economic viability of an investment.

This thesis work investigates the techno economic analysis of SDN network. In particular, this work presents techno economic analysis of Hybrid SDN with four partitions and Non-SDN deployment scenarios. This network upgrading is done in Ethio telecom IP core network which is provider edge routers. The network dimensioning done for SDN scenarios, for hybrid SDN deployment by applying node selection criteria's number of switches to be replaced are decided and controller placement is implemented in Pareto-based Optimal Controller Placements (POCO) tool.

The studies use a modeling methodology for network value analysis that includes capital expenditure (CapEx), operational expenditure (OpeEx), and total costs of ownership (TCO), while the overall financial or economic assessment of technology deployment is based on techno-economic evaluations such as net present value (NPV), internal rate of return (IRR), and pay-back period (PP) economic indicators. Techno-economic assessment (TEA) model, which is Techno-economic results from ACTS (TERA) is implemented in MATLAB and MS-excel.

According to the findings, the pay-back periods for 10% SDN, 20% SDN, 30% SDN, 40% SDN, and Non-SDN scenarios are 2.4, 2.2, 1.9, 1.7, and 3.8 years, respectively. In terms of net present value (NPV) and internal rate of return (IRR), all scenarios have a positive NPV for the study periods and a higher IRR than the stipulated discounted rate. Thus, the economic indicators imply that all scenarios are technically and economically feasible for deployment but the scenarios should be deployed based on the requirements.

Keywords: *SDN, Techno-economic analysis, Deployment scenarios, TERA model*

Acknowledgments

Above all, I am grateful to the almighty GOD for providing me with the strength and for being with me at all time and in all places.

I'd like to convey my heartfelt thanks to my thesis adviser, Dr. Yalemzewd Negash, for his tremendous advice and encouragement during the process. His precise direction, patience, and passion aided me throughout the research and writing of this thesis. This accomplishment would not have been possible without him.

Apart from my adviser, I'd like to express my gratitude to Dr. Ephrem Teshale and Dr. Yehenew Wondie, members of my thesis committee, for their encouragement, tough questions, and insightful comments, all of which helped me enhance my research.

Likewise, I'd want to express my gratitude to friends (Adugna and Behaylu) and coworkers at Ethio telecom, who assisted me in gathering data and writing my thesis by providing me with vital information on their individual job areas whenever I required it.

Last but not the least, I would like to thank my family Mamiye, Endu, Tg , Bura, Noha, Hani, Etsube and Yabu for your patience and generous support. Without you, this achievement would not have been possible. And my children you are my strength throughout course of this thesis work.

Thank you All!!

Addis Abeba, 5th November 2021

Melat Mitiku

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List of Abbreviation

Abbreviation	Definition
ACTS	Advanced Communications Technologies and Services
API	Application Programmable Interface
ARP	Address Resolution Protocol
AS	Autonomous System
BGP	Border Getaway Protocol
BOR	Bill Of Resource
CAPEX	Capital Expenditure
CB	Class-Based
CES	Control Element Separation
CF	Cash Flow
COTS	Commercial-Off-the-shelf Server
CPU	Central Processing unit
CSP	Communications Service Providers
DCF	Discounted cash flow
DHCP	Dynamic Host Configuration Protocol
ECOSYS	Economics of Integrated Communication Systems and Services
EPS	Evolved Packet System
ET	Ethiotelecom
ETB	Ethiopian Birr
GB	Giga byte
HP	Hewlett Packard
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IRR	Internal Rate of Return
LLDP	Link Layer Discovery Protocol
LTE	Long Term Evolution
MATLAB	Matrix Laboratory
MS	Micro soft
NFV	Network Function Virtualization
NOC	Network Operations Centre
NOS	Network Operating System
NPV	Net Present Value
OAM	Operation and maintenance
ONF	Open Networking Foundation
ONOS	Open Network Operating System
OpeEx	Operational Expenses
OPTIMUM	Optimized architectures for Multimedia networks and services
OS	Operating System
OSPF	Open Shortest Path First
PE	Provider Edge
POCO	Pareto-based Optimal Controller Placements

PP	Payback Period
RACE	Research in Advanced Communications in Europe
RCP	Routing Control Platform
ROFL	Revised Open-Flow Library
SB	Service Based
SDN	Software Defined Networking
SLA	Service Level Agreement
TB	Topology Based
TCO	Total Cost of Ownership
TEA	Techno Economic Analysis
TERA	Techno Economic Analysis with ACT
TITAN	Tool for Introduction and Techno-economic Evaluation of Access Network
TONIC	Techno-economics of IP optimized networks and services

Chapter One

Introduction

Over a long time of Computer Network presence and growth, the extreme increment in network complexity has brought almost troubles in network management. It tends to be troublesome to configure computer networks by predefined approaches, reconfiguring systems to reply to changes, flaws, and loads. Because it shows up that current network systems are coordinates vertically, the control plane and data plane are all tied up together. Software-Defined Networking (SDN) is a new computer networking paradigm in which a single high-level software application controls network behavior. The control plane (software programs that manage network system behavior) and data plane (devices that forward network traffic) are separated in this network design. [1].

There are different deployment methods of a software-defined network. Hybrid SDN is one among them, in which SDN is partially implemented without completely replacing the present network. This partial introduction model enables SDN to apply its value whereas co-existing with the existing network[2].

SDN is expected to reduce the network Operational Expense (OpeEx) by simplifying operations, optimizing resource usage through centralized data/algorithms, and simplifying network software upgrades. It also significantly cuts down a network operator's Capital Expense (CapEx), since a commercial-off-the-shelf (COTS) server with a high-end CPU is much cheaper than a high-end router[3]. However, it's also better to decide were the hybrid SDN is applied on the existing network and which type of hybrid SDN (replace or increment) is going to apply.

The aim of this study is to investigate a techno-economic analysis of conventional network and different SDN deployment options in Ethiotelecom IP core network.

1.1 Statement of the Problem

As data traffic volume increases with high traffic demands due to continuous improvement of devices, applications and connectivity increases. To accommodate the high traffic demands telecom operators, service providers continuously deploy network infrastructure. The increasing of network infrastructure leads to difficulty on network management. SDN brings hope to solve such network complexities and management issues as a new network paradigm. But the technological maturity issues, the skilled engineers on SDN requirements, high professional training costs, dismantling existing network infrastructure before their SLA agreements and technical supports end impacts the deployment visibility of pure SDN. As a result, hybrid SDN deployment will benefits the operators and service providers based on aforementioned cases. This thesis focuses on the techno-economic analysis of the hybrid SDN deployment and the deployment scenarios for techno-economic feasibility study. The core issues that are to be addressed in this work provide to the following questions:

- For initial deployment of hybrid SDN, what criteria is required to select the core network nodes to make SDN enabled switches?
- For the selected nodes how many controllers are required and where it should be replaced?
- What the techno-economic feasibility of the conventional network, hybrid SDN looks like?
- Which hybrid SDN scenario is better to deploy?

1.2 Objective

General Objective

The general objective of the study is to analyze techno-economic analysis of hybrid SDN deployment in the case of Ethio telecom IP core network.

Specific Objective

To meet the general objective, the following Specific objectives are addressed:

- To conduct a literature review on the related papers
- To analyze and understand existing network of Ethio telecom
- To analyze the different scenarios SDN deployment
- Decide which SDN type is better for the existing infrastructure

-
- Investigates the existing techno-economic analysis(TEA)frameworks
 - To perform cost modeling for each scenario.
 - To implement the techno economic analysis approach using Techno Economic Analysis with ACT (TERA) model for the techno economic evaluation
 - To evaluate the techno economic feasibility base on feasibility indicators
 - To compare and contrast each scenarios using techno economic indicators
 - Finally, recommend scenario which is more feasible

1.3 Methodology

To achieve the above mentioned objectives the following methods are applied. Literatures such as books, journals, Internet sources and others references are taken to understand the subject well.

- Row data's from Ethio telecom, vendor's manual, internet are the primary source of data.
- From the very beginning how many numbers of conventional network routers is going to be changed to SDN based switch is decided based on previous works. And for those selected switches how many numbers of controller is relevant and where to place those controller is done using POCO tool considering switch to controller latency and controller imbalance. Then after number of switches and controller are decided bill of resource is done.
- Revenue is an input for economic evaluation. To calculate revenue, traffic volume per each link is generated for both fixed and mobile traffic and multiplied by average price of data. Based on the result five-year traffic volume and revenue is forecasted.
- The cost modeling of each scenario are done using modified TERA model, it performs the CapEx and OpeEx of each scenarios and also discounted cash flow and study period are considered as an input.
- Finally, economic indications like NPV, IRR, PP are outputs from cost modeling and comparison of each scenario are done based on those results.

1.4 Literature Review

In[1] When and the way to upgrade from existing IP routers to SDN-compliant equipment was a topic of discussion among the writers. While a comprehensive rebuild of a full functioning network in a single step is unfeasible, the immediate benefits of SDN are clear. A potential option is thus a progressive migration over time, in which concerns such as which routers should migrate first and whether the sequence of migration matters may be investigated from a techno-economic and traffic engineering standpoint. They approach these issues from a technological and economic standpoint, emphasizing the need of migration planning. They provide optimization techniques and greedy algorithms for devising an effective strategy. They also demonstrate the importance of a proper migration sequence using two network management metrics: the number of distinct migration paths a node may take and network capacity savings. The results suggest that the migration sequence is critical, particularly in the early stages of SDN network migration.

According to[4] techno-economic study is conducted in , two network scenarios based on OpenFlow solutions were investigated: (scenario1) software-defined, non-shared networks and (scenario2) virtualized, shared networks, and the results were compared to the current situation. By doing so, the author sheds light on the relative cost reductions that SDN and network sharing may provide to a mobile network operator. SDN and virtualization of the primary aggregation stage and second aggregation stage network architecture result in significant CapEx cost reductions for the mobile network operator, as a result, using OpenFlow to virtualize mobile network infrastructure might be one of the problem solvers to address the issue of growing costs and diminishing profitability. The author failed to consider the direct impact on operational costs as well as the indirect impact that network sharing might have on operators' capacity to differentiate themselves.

In[5] the authors offer a multi-layer modular design for carrier networks based on SDN and network function virtualization (NFV) principles, as well as a techno-economic analysis of SDN principles applied to the developed packet system's transport network of Evolved packet system (EPS). The cost model for CapEx and OpeEx is given in depth, as well as the input values. Both CapEx and OpeEx expenses were calculated and quantified. The control plane is removed from the router and centralized into a controller in the SDN scenario, lowering CapEx expenditures and lowering software license costs. The cost of service provisioning is where the biggest variance in

OpeEx costs is seen. Because of the ability to minimize the amount of manual setup required and greater testing capabilities prior to service launch, the biggest difference in OpeEx cost may be seen in the cost of service provisioning and management. The savings for the SDN scenario are measured at 12% when compared to the state-of-the-art (SoTA) scenario, with CapEx and OpeEx reductions accounting for 65 and 35 percent of total savings, respectively.

According to [6], the author analyzes and formulates potential LTE rollout scenarios for growing cities using a scenario planning technique. Then, using a modified TERA model, techno-economic analysis is undertaken, which includes marketing forecasting, radio access network dimensioning, cost and revenue modeling, and economic feasibility analysis for a seven-year study period assuming a monopolistic telecom market. The updated TERA model is implemented in MATLAB for techno-economic assessment. The findings reveal that market potential and operation frequency have a significant impact on network capacity, coverage, and the number of sites in a given region, all of which affect the rate of return on investment. For rising cities, LTE deployment in the 1800Mhz band under high and low demand capacity, as well as LTE deployment in the 2100Mhz band under high demand capacity, is achievable with a payback period of less than 3.5 years. Coverage favored LTE deployment scenario (in 1800Mhz under low demand capacity) is technically and economically feasible for Adama city in Ethiopia in a monopoly telecom operator market with a payback period of 3.25 years, according to specially formulated deployment scenarios techno-economic results.

1.5 Scope and Limitations

The scope of the study is to investigate the technical and economical feasibilities of hybrid SDN and conventional network is considered. 10% of discount rate and five years of study period are included. The study is done for provider edge (PE) IP core network.

The limitation of the study is on revenue calculation of IP core network. There is no direct way of calculating revenue from core network so for this study The revenue is directly calculated from the access network pricing or average tariff of both fixed and mobile network.

1.6 Contributions

This study analyzes the techno economic feasibility of SDN deployment options, mainly focus on the hybrid SDN deployment in different partitioning scenarios and comparison analysis is done based on their CapEx, OpeEx, TCO. This investigation is important for those telecom service

providers to let them know which deployment option is appropriate for their network infrastructure.

Nowadays, techno-economic evaluation tool was limited to project sponsors and commercially not freely available. But for this work techno economic evaluation tool is done by using Excel based on the implementation details of SDN deployment.

Finally, Ethio telecom can use this thesis as an input to decide which SDN deployment option is more feasible based on the conventional financial status of the company.

1.7 Thesis Layout

This thesis contains six chapters. Chapter one deals with introduction of the whole thesis. It clearly cites statement of the problem, objective of the study, related works, scopes and limitation of the thesis and the methods how this paper will achieve its objective. Chapter 2 covers the general structure of traditional networks and software defined network. Chapter 3 presents techno economic evaluation methods and models. Fourth chapter presents SDN deployment options and controller placement parameters that are used in optimal controller placement in detail, for hybrid SDN deployment strategists, switch selection criterial are covered. The fifth chapter focuses on the result obtained from the analysis in chapter four which is the result obtained using MATLAB, POCO tool. The last chapter covered conclusions and recommendations from this study.

Chapter Two

Software Defined Networking

Network infrastructure developments and evolutions while coping up with the data traffic demands and device proliferation along with wide applications demands rise. The demand of increasing data centers, cellular networks enhancements, the emerging of Internet of things to tactile internet is forcing the simplification of network managements, service provisioning, configuration and automation of orchestrations and better security. To respond to this request demand, the network of conventional started evolving from the unified management systems to network programmability along with network virtualizations. The evolution of the network programmability as of Active networks, control-data separation and OpenFlow development pare the way for SDN [7],[8].

SDN is a new networking design paradigm that separates the control plane from the data plane, making network control operations more programmable[9],[10]. This separation provides several benefits, including the simplification of network management and control.

It represents a significant departure from traditional network architecture. In particular, SDN proposes an open architecture, in which the network control and forwarding functions are decoupled. This architecture enables automated network control and management to be programmed on standard servers through a uniform interface to physical network elements. Since network control is no longer included in each network element, SDN introduces a new component: the centralized SDN controller[11].

2.1 Conventional Networks

A Conventional network mainly is a mix of routers and switches that facilitate the transfer of packets from one part of the network to another. The routers use routing protocols to move these packets across the network efficiently. Packets contain sets of data transferred over a physical link (the network cables). Data were divided into chunks at the transmitter depending on the data link technique used to convey the packets. The receiver reassembles the data at the destination, and the control plane in each router and switch decides the final destination of each packet depending on the network's routing protocols. [11],[10].

In the case of conventional network control plane and data planes are bundled together inside networking devices. This vertically integrated system makes the network design nature vendor-specific. As a result, the network infrastructure deployed to meet demand data traffic become complex and difficult to manage and configure, very low flexibility, difficult service provisioning, low innovation, and evolution of network infrastructure [8].

Figure 2.1 shows a brief description of the conventional network devices architecture of control and data plane.

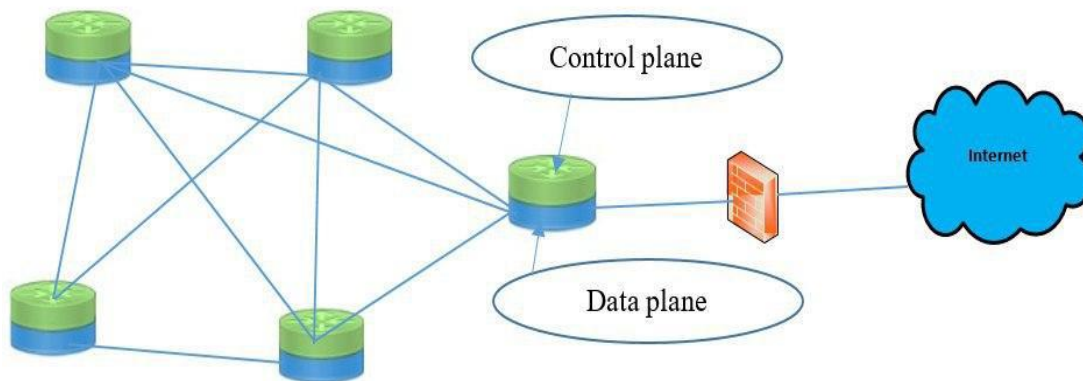


figure 2.1: Conventional Network Architecture.

Traditional IP network devices like routers and switches have three integrated planes on each network device figure 2.2 briefly shows the management, control and data planes of the conventional network:

- **The management plane:** is the plane where software services for maintaining and configuring control plane capabilities of network devices in the data plane are stored. Network managers are in charge of manually configuring network policies on the control plane. In response to a wide range of network events and application needs, they translate high-level rules into low-level configuration commands[12].
- **The control plane:** is where everything happens. This plane is defined by the Open Shortest Path First (OSPF) or Border Gateway Protocol (BGP) collection of protocols and algorithms that are used to compute and populate the routes programmed in the forwarding tables of network devices in the data plane. These network mechanisms (protocols and algorithms) are implemented on network devices and define network behavior, or what and how data is sent over the network.

- **The forwarding plane:** is also known as the data plane. It refers to the physical and virtual network equipment that make up the underlying network infrastructure, which can include routers, switches, virtual switches, and wireless access points, among other things. These network devices are in charge of forwarding traffic depending on the data in their forwarding tables, which are designed using distributed routing protocols like BGP and OSPF. The management plane introduces network policies, the control plane executes those policies, and the data plane transports data depending on those policies in conventional networks.[13].

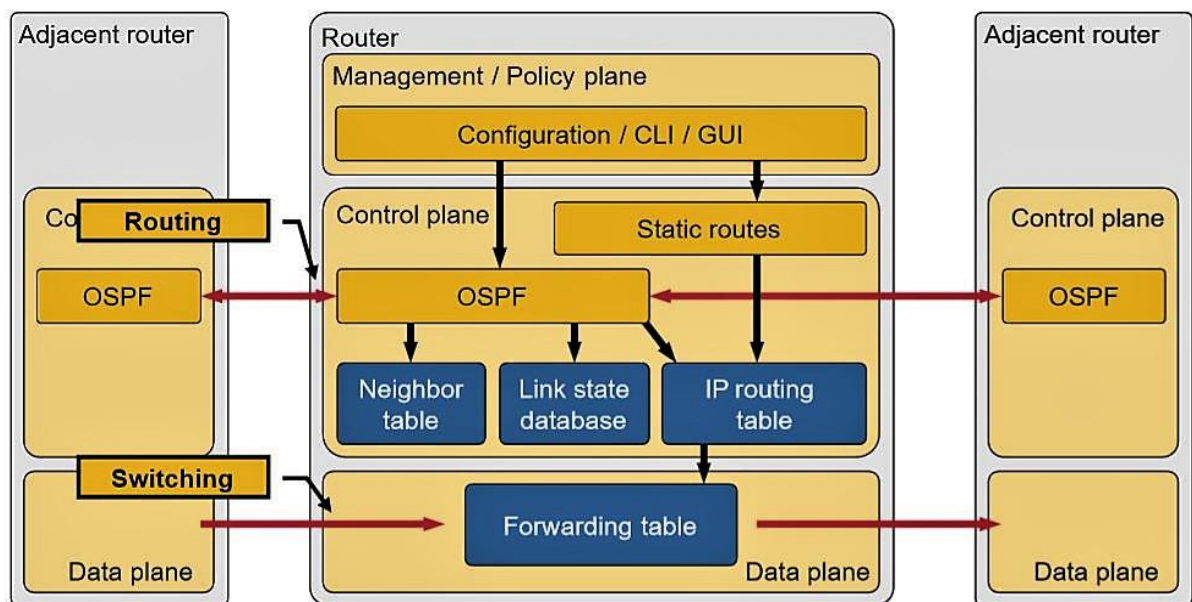


figure 2.2 :Management, Control and Data Planes in Traditional Network Devices and Systems[14]

2.2 Evolution of Programmable Networks

The idea of programmable networking has developed over the past two decades. The history of programmable networking has three stages. First, Active Networking[7], [15], from the early 1990s to 2000, with the idea of the first attempt to make networks programmable by researchers [7]. Second, separating control and data Planes from early 2001 to 2007 that explored separation of the control plane from the data plane in the network took a shift toward practical attempting to provide programmability but tackling it in the context of certain network management problems such as traffic engineering. Working groups in the IETF such as forwarding and control Element

Separation (ForCES) developed an open interface between the control and data planes and other researchers also developed technologies for logically centralized control such as the Routing Control Platform (RCP)[7],[15].

Finally, OpenFlow and Network OSes were developed from 2007 to 2010. OpenFlow devised methods for separating the control and data planes in a scalable and practical manner. The development of the OpenFlow Application Programmable Interface (API) is followed by the development of controller platforms such as NOX, which enable the development of a wide range of new applications. The Network Operators that faced real network management problems, Vendors most of whom are eager to open their API, and researchers who are looking for new ideas to innovate in the network initiated the technology pushes of OpenFlow [7]. OpenFlow was first adopted on campus networks. Afterward in data centers, and then deployed in various networks[7],[15]. Figure 2.3, briefly shows the evolution.

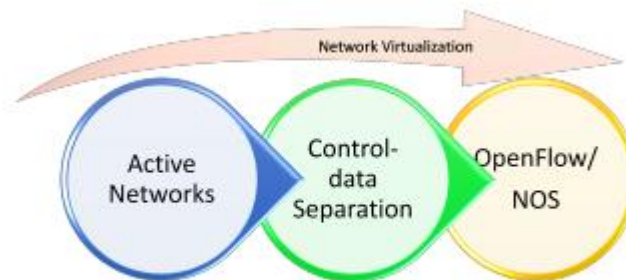


figure 2.3: The Evolution of Network Programmability.

The notion of network virtualization emerged early of active networks still evolving as use case of SDN. It enabled the same hardware resource sharing reducing costs and energy consumption.

2.3 Architecture of SDN

The architecture of SDN has three planes (Data plane, Control Plane, and application plane) of different layers as shown in Figure 2.3. The architectural definitions of SDN according to[15] with four pillars discussed below:

- Decouple of control and data plane
- Flow-based forwarding decisions, which is the actions of the sequence of packets.
- Network operating system (NOS) or controller, a software platform that runs on servers that provide abstractions to programming applications on logically centralized.

- Programmable network or applications running on top of NOS to interact with underlying forwarding devices.

Each layer of SDN architecture has its own functions. Some layers exist during deployment (Southbound API, SDN Controller, northbound API, and network applications) while others might be in particular deployments such as hypervisor or language-based virtualization[15]. The architectural layers of SDN are briefly described below.

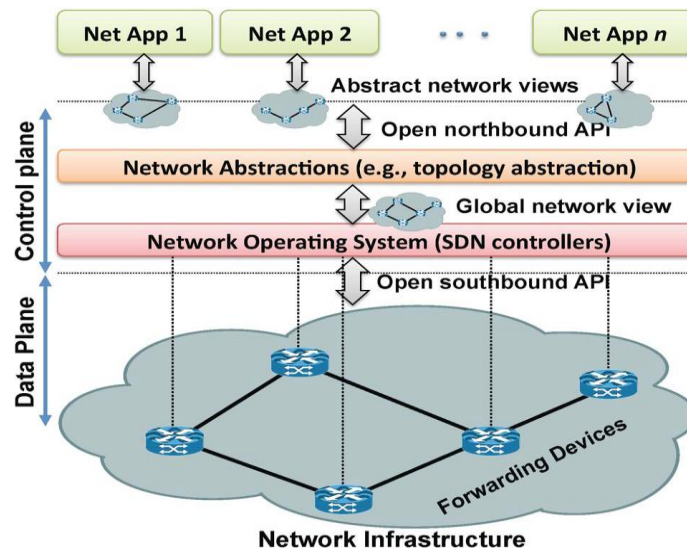


figure 2.4: SDN Network Architecture [15].

Control Plane: The Control Plane is in charge of deciding how packets should be routed by one or more network devices, and then pushing those choices down to the network devices for implementation.[16],[17],[18]. This plane consists of a centralized set of software based SDN controllers that have an abstract view of the whole network infrastructure, enabling the network manager to apply customized policies across the network devices (through the southbound interface), based on the network topology or external service requests. The SDN controller is the backbone of the system. It is the intelligent entity in charge of resource management in order to supply services.[9],[18].

Control-plane functionalities usually include:

- Topology discovery and maintenance
- Packet route selection and instantiation
- Path failover technic

-
-
- Based on the required performance from the applications and the network security policy, install forwarding rules on the forwarding tables, and
 - Gather status information about the forwarding devices.

Data Plane: The data plane consists of physical and virtual forwarding devices that are accessible via the southbound interface through which controller and forwarding devices can communicate with each other. Forwarding devices can support basic functions like forwarding, but also other types of functions, such as: caching, transcoding and monitoring, among others[11], [17].

OpenFlow: is a communication protocol that enables the controller-to-switch communication in SDNs through the southbound interface[17],[19]. This protocol also defines a set of basic forwarding and management functions. The forwarding functions let programmers address the network operation by routing packets. The set of management functions can be used to control network features. For instance, switches can inform the controller when links go down or when receiving a packet for which there is no forwarding instruction.

2.3.2 Southbound Interface

The southbound interface is the important part that separates the functionality of the data plane from the control plane and the interconnecting bridge of the control and data plane but tied to forwarding elements of underlying physical or virtual infrastructure. Its primary purpose is to provide communication between the SDN controller and network nodes (both physical and virtual switches and routers), allowing the router to identify network topology, establish network flows, and execute requests conveyed to it through northbound APIs[20]. The most accepted and deployed southbound API is OpenFlow [15]for the communication channel between control and data plane. Information sources such as event-based messages (sent by forwarding devices to the controller during link or port change triggered), flow statistics (generated by forwarding devices and collected by the controller) and packet-in messages (sent by forwarding devices to the controller when no newer incoming or obvious ‘send to controller’ in match entry) provided by OpenFlow protocol. It also offers flow-level information to the controller[15].

Some of the popular southbound APIs are OpenFlow, Cisco, and OpFlex and other switch and router vendors that support OpenFlow include IBM, Dell, Juniper, Arista and more[21].

2.3.3 Network Hypervisor

Hypervisors are the enablers of virtualization, to share the same hardware resources (allocate resources of physical infrastructure based on user demand) with relatively low cost [8]. It created

new revenue and business model for providers making better resource utilization of physical infrastructure with an insignificant increase of CapEx and OpEx costs.

Other benefits of hypervisors are seamless migration from one physical server to another, allocating resources elastically, dynamic service provisioning, and easy management[15]. The network slicing (with Flow Visor) and multi-tenant are also enabled with different hypervisors.

2.3.4 Network Operating System or Controller

A network operating system is a software that runs on top of commodity servers or computers to offer logically centralized control providing abstractions, essential services, and common programming interfaces (APIs) to developers [15]. Common functions of NOS are network state topology information, device discovery, materializing network policies, and distribution of network configuration. Controllers are either centralized (single entity such as NOX-MT, Maestro, Beacon, Floodlight, Ryu, meridian are few) or distributed (cluster centralized of nodes or physically distributed for scalability like Onix, HyperFlow, HP VAN, ONOS, DISCO, PANE, Light are the few examples).

2.3.5 Northbound Interface

The northbound interface is most of the software ecosystem that provides abstractions as southbound APIs that allow network applications do not depend on specific implementations. The importance of open and standard northbound interfaces is to promote application portability and interoperability among the different of the control platform[20]. Different controllers can propose different northbound APIs with their own specific definitions, programming languages, and abstractions of controller functions and data plane behavior details from application developers[15],[22].

2.3.6 Language-Based Virtualization

Language-based virtualization is a programming language that offers a high-level of abstractions of network topology (e.g., Pyretic) that allow different views of single infrastructure as a big switch instead of a combination of underlying forwarding devices or static slicing by the compiler based on application layer definition[8].

2.3.7 Programming Languages

The high-level programming languages offer high-level abstractions significantly support to address the challenges of low-level languages (e.g., OpenFlow) instruction sets, enable productive and problem-focused environments speeding up development and innovation, promote software

modularization and code reusability in the network control plane, and foster the development of network virtualization. SDN high-level programming languages are such as Frenetic, FML, Nettle, Procera, Pyretic, Net Core[15].

2.3.8 Network Applications

Network applications implement the control logic that is translated into commands to be installed in the data plane, dictating the behavior of the forwarding devices. In SDN, various network applications combined with various use cases, which can be grouped into one of the categories like traffic engineering, mobility and wireless, measurement and monitoring, security and dependability, and data center networking adoption will be performed. Most applications objective is traffic engineering to minimize power consumption, maximizing aggregate network utilization, offering load balancing optimization, and traffic optimization techniques [15].

2.4 Topology Discovery

Discovering the complete physical network topology is crucial in SDN networks as SDN applications require this information to make optimal routing decisions. The act of locating and mapping network devices and linkages, known as topology discovery, is critical to a network's performance. With the introduction of virtual infrastructure and mobile computing, modern networks frequently change dynamically, necessitating intelligent topology discovery for network monitoring, identifying bottlenecks and breakdowns, and ensuring maximum network efficiency[23]. OpenFlow messages combined with the (Link layer discovery protocol) LLDP can be used to construct the physical topology of pure SDN networks. Where they use the Dynamic Host Configuration Protocol (DHCP), Address Resolution Protocol (ARP) and LLDP protocols with OpenFlow to bootstrap a pure SDN network [24].

2.5 SDN deployment opportunities and challenges

To realize the SDN deployment the opportunities and challenges it faces elaborated with different perspectives with possible solutions and optimization strategies. From the perspective of performance, cover throuAZgh the performance of the controller in the aspect of controller selection, placement, and the number of controllers required for deployment. From the standpoint of the data plane, performance OpenFlow switch-based capacity, capability and switch design choice, and Southbound APIs improvement addressed. Similarly, the management challenges, faulty recovery, techno-economic analysis, security, and deployment models were addressed.

2.5.1 Performance

In the SDN architecture, the controller platform is a crucial pillar of the architecture, and attempts are dedicated to turning SDN controllers into high performance, scalable, distributed, modular, and highly available user-friendly software[15]. The performance analysis of the SDN controller is mostly evaluated based on techniques such as simulations/emulations, experimentations, and analytical modeling (benefits estimate of performance without simulation or experimental setup). The evaluation based on the techniques can provide only an indication of the performance at best and may vary considerably from the real production environment evaluation[25]. For performance analysis, various metrics such as latency, throughput, flow-related metrics, load balancing, threading and session, and topology-based metrics are given special consideration [15], [25].

Another point worth raised when evaluating the performance of SDN architectures are the number of controllers required and their placement in a given network topology [15]. According to [15], a single controller mostly enough to keep the latency at an acceptable rate. However, adding k number of controllers to the network can reduce the latency by a factor of k [15], [11]. According to [11], the minimum number of controllers and controllers' placement must be at optimal for better performance.

Another performance issue raised in SDN architecture is in the infrastructure layer. The OpenFlow protocol enabled configuration, communication compatibility, and interoperability with dynamic programmability of heterogeneous forwarding devices [26], [15]. The OpenFlow switches are diverse and show visible differences in terms of features (flow table size), performance (latency/throughput), interpretation (command barrier), and architecture (hardware or software based) [1]. The diversity of OpenFlow switch implementation properties have an essential impact on the performance of the switch [26], [15]. The flow tables that hold the forwarding rule have limited capacity and this limitation have a crucial factor that influences the performance of OpenFlow switches [26]. The performance mainly depends on the location of the forwarding rule. If the forwarding rule is located in the hardware flow table, the performance is significantly high whereas if the forwarding rule is placed in the software flow table, the performance degrades by the magnitude of two [26]. However, the capacity of hardware flow tables based on TCAM (Ternary Content Addressable Memory) is limited, and supporting multiple flow tables in hardware is challenging and expensive [15]. There are efforts in [15] that focus on the compression technique to reduce the number of flow table entries in hardware flow tables based on TCAM. The Espresso

heuristic [15] used to compress OpenFlow based inter-domain routing tables reducing the forwarding information base (FIB) by 17% and saves up to 40,000 flow table entries [15].

Besides, the design choices of OpenFlow-enabled networks have a significant impact on the lookup performance of OpenFlow switching. By adopting standard commodity network hardware, the packet switching throughput can be enhanced up to 25% than software OpenFlow switching[15]. Furthermore, hardware acceleration based on network processors applied to boost the performance in terms of packet delay by 20% comparing with conventional design. Current OpenFlow switch implementations also can lead to performance bottlenecks with respect to the CPU load that can be solved with modifications to the protocol specification [15]. One approach proposed by [15] to solve the problem includes adding more powerful CPUs into the switches or distributing control actions between the controller and the OpenFlow agent embedded in the switches.

2.5.2 Reliability

Enhancing the reliability of SDN is a crucial task since network failures could easily cause disconnections between the control and forwarding plane. SDN implementation may be depending on centralized or distributed controller architecture[8] . The centralized controller architecture is simpler and easier to manage unfortunately it is unreliable. The distributed controller architecture is more complex but it is effective in improving fault tolerance and reliability [15], [8]. It is evident that the distribution of the controllers lowers the effect of imminent physical failure on the network controller and improve overall reliability. However, the distribution of controllers is not the only key to network reliability since reliability also depends on properly choosing the number of controllers[8]. Availability of controller also gained with the improvement of southbound APIs and controller placement heuristics and other models like cross control and OpenFlow graph algorithms [15].

2.5.3 Scalability

The logically centralized controller faces the scalability issue to meet the requirements of large networks. In [15] addressed the scalability of the controller with a comparative analysis of the architectural design of controllers as centralized versus distributed.[15]Described that a distributed controller can improve the control plane resilience, scalability and reduce the impact of problems caused by network partition and the platforms of controller that meet the companies' requirements are specific and different. However, the scalability issues of the controller addressed with a distributed controller consistency issue arises. The consistency problem LOCAL and CONGEST

classical models of distributed systems are used to develop coordination protocols that enable each controller to take independent actions over events that take place in its local neighborhood [15]. The lack of modularity and flexibility in the SDN controller results in difficult implementations of the controller to build, maintain, and extend and ultimately become resistant to further innovations, resembling traditional “hardware-defined” networks [15]. Some scalability proposals show improvements on flow/s. For instance, Beacon proposes a multi-thread controller to improve controller performance and obtained 12.8M Flows/s resulting in high-performance flow processing using pipeline threads and shared queue [15]. The other challenging issues of providing switches that can store large and with efficient flow tables to store matching rules specifically challenging and limited in hardware switches.

2.5.4 Resiliency to failures

Resiliency to failures and convergence time after a failure have always been the main concern in network performance. The introduction of centralized routing in SDN promises to drastically simplify routing management within an autonomous system and provide faster intra-domain routing convergence. According to [27] the comparison of routing convergence time under different network scale (16 and 120 nodes) reveal that with the expansion of network scale the routing convergence time of the network increase but the convergence time of the legacy network is smaller than SDN network in small scale [28]. However, with the increase in link delay SDN began to show faster convergence time [29]. According to [30] the fault location in the network topology affects the convergence time of OSPF since it affects the number of nodes that the link state advertisement sent should cross to reach all the nodes in the network. However, the convergence time of SDN is not affected by the fault location. In [29] the authors conclude that the routing convergence of legacy OSPF network depends on the link delay whereas the convergence time SDN is influenced by the performance of the controller. However, according to [30], the routing convergence of SDN does not depend only on the controller performance. It also depends on the performance of the switches. According to [29], the routing convergence time of legacy network and SDN network are computed as in equation (2.5.3.1) and (2.5.3.2) respectively.

$$\text{Convergence Time}(\text{Legacy}) = LDDT + LSADT + SPFEXT + FIBUT \quad (2.5.3.1)$$

$$\text{Convergence Time}(\text{SDN}) = LDDT + SPFEXT + TUT + FTUT \quad (2.5.3.2)$$

Where:

LDDT = Link down Discovery Time
LSADT = LSA Delivery Time
SPFEXT = SPF Execution Time
FIBUT = FIB Update Time
TUT = Topology Update Time
FTUT = Flow Table Update Time

2.5.4 SDN Management

One of the main benefits promised by SDN is the introduction of simplified network management and bring innovation through network programmability. However, this new network paradigm faces some challenges from the network management perspectives [31]. The development of OpenFlow protocol by ONF introduces many benefits to the networking world for instance decoupling of control and data planes, introduces the notion of flow switching, offers the ability of network programmability, and so on. However, the concept of OpenFlow got some issues that have a potential impact on network management. Issues like centralization of network control that is related to network reliability (single point of failure) and scalability (reaction time or volume of control traffic), manage controller programmability (software update and ability to update or stop some controller functionality), and lacks standardized management interface for controller and switches [31]. The analysis of management functions in [15] recommended by network operators has classified a set of requirements and existing limitations in SDN protocols. It has been analyzed that OF-Config requires some extensions in order to fulfill the operator's concerns, for instance, physical resource discovery, logical link configuration, and device and OAM link configuration. To back the SDN concepts under large-scale wide area network (WAN) management, various mechanisms are proposed. In [31] proposed several variants in which SDN network management could be implemented.

Chapter Three

Techno-economic Evaluation Methods and Models

Techno economic evaluation deals with technical and economic feasibility study of a project or technology. In this chapter Techno-economic assessment models, revenue modeling, economic modeling and techno economic assessment evaluation methods are introduced.

3.1 Introduction to Techno-economic Analysis (TEA)

Techno-economic analysis is typically used to evaluate economic feasibility of a technical solution by utilizing forecasting, network design and investment analysis methods[4],[32].

Service providers are developing new service or technology through time. This new service deployment invests a huge amount of money and also upgrading a technology have huge investments cost. So before deployment of new technology or service need to have a techno economic assessment on the investment. This will help the provider to address whether the technology is feasible or not. However, TEA is a decision-making tool used to evaluate available technology options based on technical, economic, environmental, social and regulatory criteria as shown in figure 3.1.

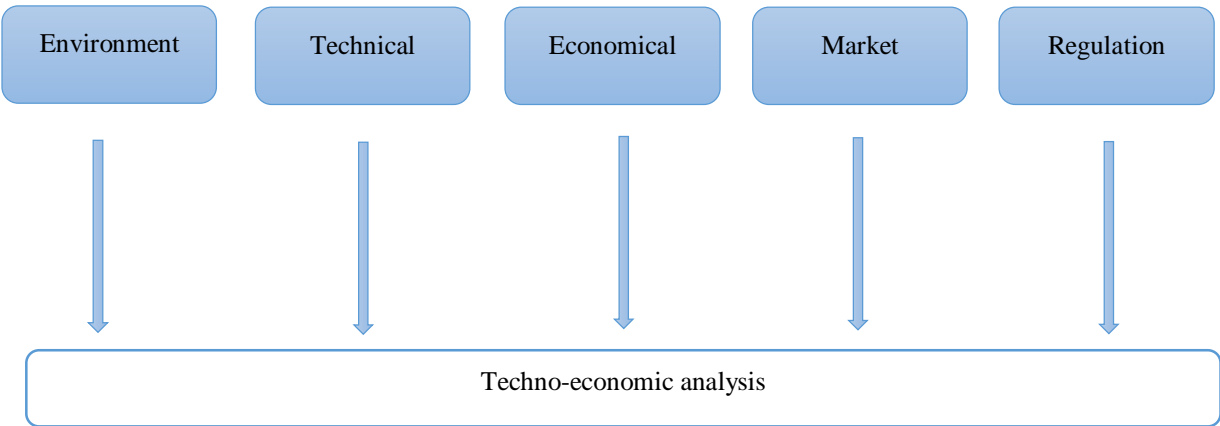


figure 3. 1: Techno economic analysis

3.2 Techno-economic Assessment Models

Alternative scenarios and tactics for the development towards broadband systems were studied in early techno-economic modeling work for various Research in Advanced Communications in Europe (RACE) projects[33]. The RACE 2087 Instrument for Introduction Scenarios and Techno-Economic Studies for the Access Network (TITAN) project later produced a methodology and tool for techno-economic evaluation of new narrow band and broadband services and access networks (1990-1994)[34]. Many European research projects have utilized and enhanced the methodology and tools developed in the early programs for various application areas since the late 1990s. Based on the projects, optimized architectures for multimedia networks and services (OPTIMUM) [35]were introduced from 1994 to 1998; techno-economic results from ACTS (TERA)[36] from 1994 to 1998; techno-economics of IP optimized networks and services (TONIC)[37] from 1998 to 2002; and techno-economics of integrated communication systems and services (ECOSYS) from 2004 to 2007[38].Table 3.1 illustrates the TERA framework's TEA models as well as the project year.

Table 3. 1: TEA models drawn from TERA framework[38]

Model		Project Year
TITAN	Tool for Introduction Scenario and Techno-economic Evaluation of Access Network	1990 – 1994
OPTIMUM	Optimized Architectures for Multimedia Networks and Services	1994 – 1998
TERA	Techno-Economic Results from ACTS	1994 – 1998
TONIC	Techno-economics of IP optimized networks and services	1998 – 2002
ECOSYS	Techno-economics of integrated communication systems and services	2004 – 2007

Techno-Economic Results from ACTS (TERA) is a tool that was used to conduct the techno-economic analysis in this thesis. TERA is a spreadsheet-based tool for assessing the techno-economics of communication networks and services. It was created as part of the European Union's ACTS (Advanced Communications Technologies and Services) Program, which ran from the fourth Framework Program through the fifth Framework Program of scientific research and development (1994-1998)[36],[38].

However, the Techno-economic Results from ACTS (TERA) model was chosen as the study's foundation. On the basis of the study's requirements, certain changes are made to the framework. Different scenarios are used as inputs, and the tool's outputs are simple to read and trace back to the inputs since the formulae are visible. In the telecom business, it was a commonly utilized techno-economic model [38].

3.2.1 TERA framework

The popular techno-economic analysis framework in telecom industry is Techno Economic Results from ACTS framework (TERA). TERA enables techno-economic evaluations by combining technical, market, economic and costs of key network elements [38].

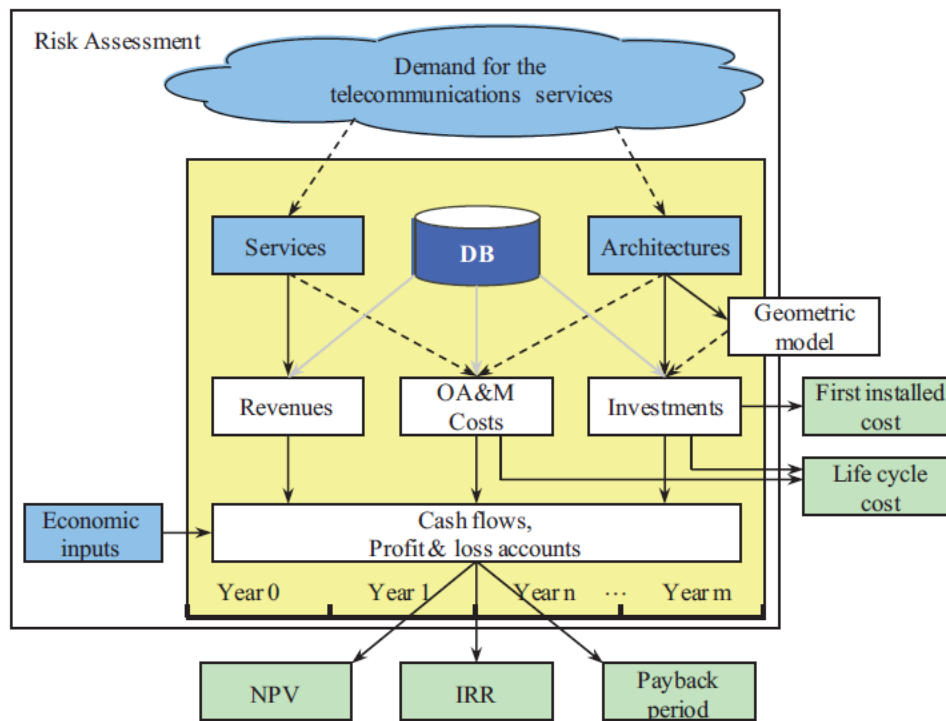


figure 3. 2: TERA Framework [38].

figure 3.2 shows TERA framework economical, service/technology and architectural inputs. The value of investments at the end of the period is derived using demand projections and input assumptions, as well as a few common economic inputs such as the discount factor and study duration [38]. The network architecture is another input for the model that is required to determine the dimensioning or planning of the network. Revenue is generated based on the type of the service or the technology, number of subscriber and traffic volume per each subscriber need to identify

the approximate value of revenue. Net present value (NPV), internal rate of return (IRR), and payback period are outputs that are essential for comparison analysis.

3.2.2 Implemented Techno-economic Analysis Model

Techno economic analysis is done for the evaluation of the technology or service to identifying feasibility of the project. Based on the requirement details of this thesis the modified version of TERA is applied as depicted in figure 3.2.

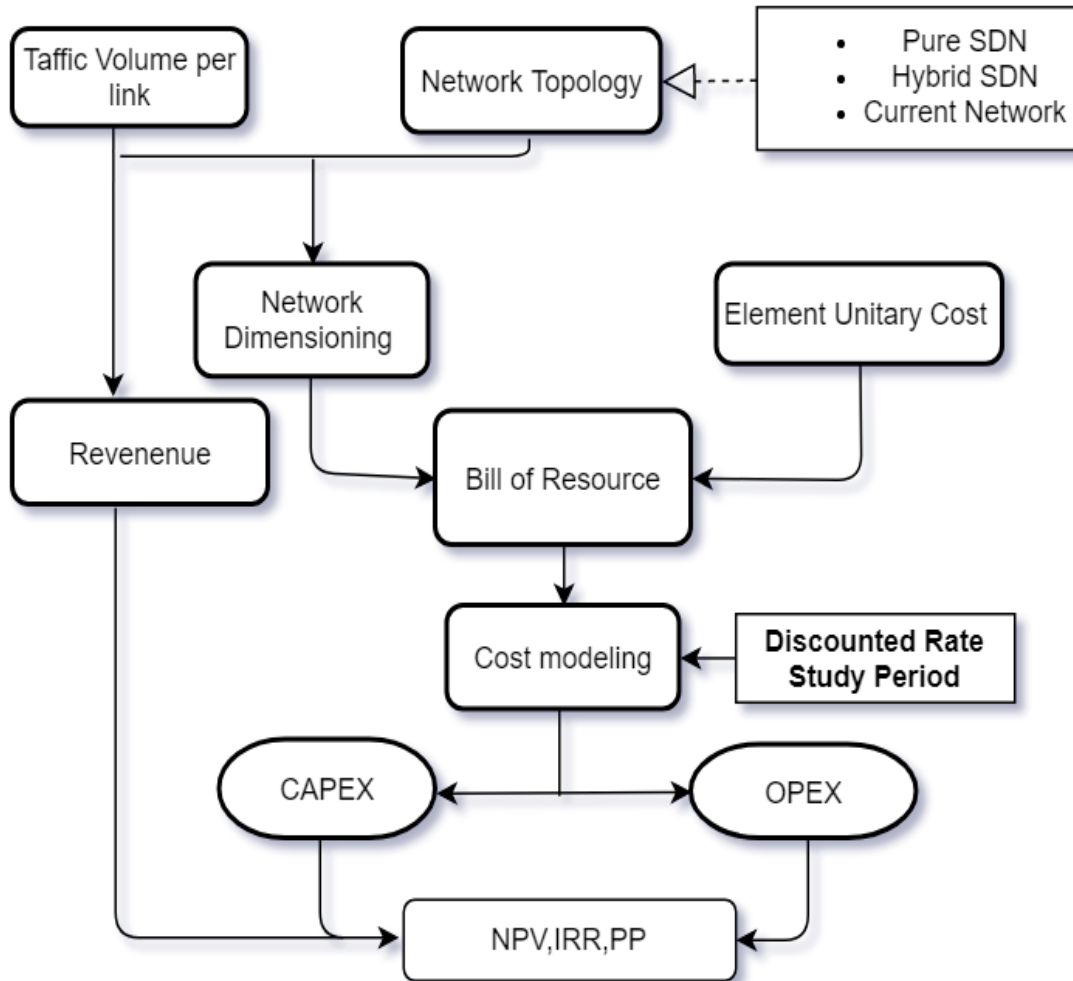


figure 3. 3: Modified and implemented techno-economic analysis model block diagram

Traffic volume per each link is the main input to calculate the revenues for each selected scenario. The same traffic volume is used, which is all scenario have similar revenue. Then traffic data demand will be estimated and forecasted for the study periods. The network topology of hybrid SDN and SDN network is used to dimension the number of SDN enabled switches, number of controllers and optimize placement. The economic inputs like CapEx and OpeEx are taken from

bill of resource (BOR) and by applying discount rate as an input and calculate TCO for the study periods based on scenario.

Finally, discounted cash flow combines revenue and TCO to provide decision making economic indicators like net present value, internal rate of return and return on investment period or payback period.

3.3 Cost modeling

It's the process through which businesses can understand the best cost to produce a product. The costs of constructing and operating a network can be divided into capital expenditures (CapEx) and operational expenditures (OpeEx). CapEx includes the investments to the network infrastructure and devices, as well as the hardware required for the operation, administration, maintenance and provisioning (OAM&P) functions, such as network management systems and billing and charging systems. OpeEx includes the labor costs and expenses originating from operating and managing the networks, as well as costs related to marketing. CapEx cost contribute to the fixed infrastructure and they are depreciated over time. The formula for CapEx and OpeEx are given below.

$$CapEx = \frac{\text{number of devices}}{\text{site}} * \text{number of sites} * \frac{\text{cost}}{\text{device}} + \text{number of SDN controller} * \frac{\text{cost}}{\text{SDN controller}} + \text{cost of softeware development} + \text{cost of first installation} \quad (3.1)$$

$$OpeEx = \frac{\text{number of devices}}{\text{site}} * \text{number of sites} * \left(\frac{\text{energy(KW)}}{\text{device}} * \frac{\text{cost of energy}}{\text{KW}} \right) + \frac{\text{number of hardware failer}}{\text{site}} + \frac{\text{number of software faileres}}{\text{site}} \quad (3.2)$$

3.4 Total Cost of Ownership (TCO)

The total cost of ownership (TCO) is a financial evaluation of a product's direct and indirect expenses or a system over a certain time period, which is composed of *CapEx* and *OpeEx*[39].

$$TCO = CapEx + OpeEx \quad (3.3)$$

3.5 Revenue modeling

Revenue is one of an indication for the profitability of company, which is different result based on the economic input for the project.

It is difficult to calculate revenue from core networks there is no direct method to find the exact revenues collected from core networks, for the purposes of this study, total traffic volume generated by each provider's edge routers is used to compute revenue.

3.6 Techno-economic Assessment (TEA) Evaluation Method

The discounted cash flow and cash flow (CF) methodologies were used in this techno-economic study. Discounted cash flow (DCF) is a valuation approach that uses future cash flows to estimate the value of an investment. Using a discount rate, discounted cash flow analysis determines the present value of predicted future cash flows. After that, a present value estimate is utilized to assess a possible investment. Decision-making economic metrics such as net present value, internal rate of return, and payback period are derived using DCF analysis [40],[41]. This strategy, as well as each economic indicator, will be addressed in this section.

$$CF = R_i + TCO_i \quad (3.4)$$

Where: R_i = Revenue at a time i.

TCO_i = Total cost of ownership at a time i.

$$DCF = \frac{CF_1^1}{1+r} + \frac{CF_2^2}{1+r} + \dots + \frac{CF_n^n}{1+r} \quad (3.5)$$

where: CF = The cash flow for the given year.

CF_1 is for year one

CF_2 is for year two

CF_n is for additional years

r is the discount rate.

Chapter Four

Deployment Scenario and Techno economic analysis

4.1 SDN Deployment Scenario

Even though the tremendous advantage SDN brings, overnight tune of a network totally to pure SDN brings many challenges and costs. Firstly, migration from and dismantling of existing networks results in invalidity of existing SLA, vendor support agreements and throwing before return of investments of infrastructures. Secondly, lack of uniform standards or immature standards as many organizations proposes differently[42],[43]. Thirdly, reliability (updating failures, new input streams increase overhead to network management and performance) and security (many point of attack, open interface applications and software nature vulnerability) challenges exist [43]. Moreover, professional training and hiring SDN experienced engineers and manager's costs, time to produce SDN production-level, initial investment of SDN are significant [43], [44]. It is obvious that there is deployment cost, reliability and security advantageous of conventional networks [43]. Therefore, combining the advantages of both SDN and conventional networks, hybrid SDN deployment is preferred [45].

According to [44] incremental hybrid SDN deployment benefits better. Furthermore, its significant benefits encourage network operators such as AT&T, Telefonica, china mobile, communications service providers (CSPs) and companies such as Google, Microsoft's public cloud, NTT's edge gateway widely used for different scenarios.

Table 4.1 summarize the comparison of Hybrid SDN with pure SDN and conventional network.

Features	Pure SDN	Hybrid SDN	Conventional network
Programmability	Full	Partial	Not at all
Protocols	OpenFlow	OpenFlow+ conventional	Conventional
Fear of down time	High	Low	Very low
Network Management	Easy	Easy	Difficult
Network Controller Overhead	High	Moderate as local events can be handled at network devices	No control
Reliability	Possibly low	High	High
Robustness	Possibly low	High	High

Table 4. 1: Comparison of pure SDN, Hybrid and conventional Network [8],[15],[43],[46].

To get the benefits of robustness of conventional networks and logically centralized global view of SDN, the hybrid SDN deployment models are proposed to deploy efficiently and effectively. Authors in [43] proposed the hybrid deployment models based on functional division of networks, the combinations of switches, and the network service and usage scenario classification. Based on combination of switches the hybrid network can integrate SDN switches with conventional switches, conventional switches utilize SDN framework for centralized control, and SDN switches focus on interconnection between SDN Autonomous system (AS) and Non-SDN AS. In case of network service and usage scenario, hybrid SDN network classified as topology-based hybrid SDN (TB HSDN), service-based hybrid SDN (SB HSDN), class-based hybrid SDN (CB HSDN) and Integrated hybrid SDN (Integrated HSDN)[15]. The authors in [15] stated deployment solutions in control plane and data plane with different models implemented. For instance, the conventional switches coexist with SDN switches with three models such as management of conventional switches to force conventional switches to send packets to controller without considering other strategies. The waypoint enforcement of traffic[44], that proposed by Panoptic on framework to abstract the transitional network into a logical SDN network which is incremental deployment method state that the packet in the network paths at least one SDN switch to extend benefit of SDN

to entire network [15]. The hybrid extension of controller where modularization concept adopted to design extended hybrid control plane to make scalable [15]. There are many other options for inter-domain deployments methods and optimization deployment strategies such as load balancing, link utilization, saving deployment budget, energy saving, increasing controllable flow, safe update without losing traffic, and ensuring network security issues depicted for various scenarios in detail in [15],[43],[44] . In deployment solutions for data plane methods to avoid extra complexity in control plane and provide the controller a global view over the underlying network, focusing on hardware Abstraction Layer, hybrid southbound interface, hybrid IP/SDN, and hybrid SDN networks in mobile networks elaborated [15]. The authors [43], [44] addressed Hybrid SDN deployment method indicated that conventional devices management deployment using magnet address method [47],[18] only 20% of network switches are SDN enabled to achieve full control over routing in the hybrid network [44]. Similarly, the waypoint enforcement deployment with feasible VOL heuristic model with optimistic of 2% and conservative case of 10% of SDN-enabled switches achieve the benefits of SDN to the entire network[44].

4.2 Technical analysis

Technical analysis concerned on technical parts like hybrid SDN deployment strategies its expected challenge, network dimensioning such as number of SDN switch in the existing topology and number of controller and their placement.

4.2.1 Traffic Data Demand Estimation and Forecasting

For each scenario, three year of traffic data from each node is utilized to estimate the starting data demand and predict for the following five years. These data are needed to draw a graph in order to get an equation from curve fitting. The equation was used to anticipate traffic data need for the following five years and estimate first-year data demand.

Regression analysis

Regression analysis is a type of predictive modeling approach that looks at the relationship between a dependent and an independent variable. Forecasting, time series modeling, and determining the cause effect link between variables are all done with this approach. Regression analysis is a crucial technique for data modeling and analysis. Linear, exponential, power, and logarithmic models are investigated and compared in order to find the best model for the data[48],[49].

The behavior of the traffic demand is increase in exponential fashion. Therefore, exponential regression(Desmos) is the best analysis model for this study.

4.3 Hybrid SDN

The partial deployment of an SDN network, which is number of SDN switches along with traditional conventional router operates together to form hybrid SDN[2]. For some reasons SDN full deployment is not recommended like fear of downtime and huge amount of initial investment. To address these problems, one solution is to build a small number of SDN-enabled devices alongside conventional network equipment, gradually replacing traditional network devices with SDN devices[46].

The primary challenge to SDN adoption in the enterprise is the deployment problem: How to deploy and operate a network consisting of both conventional and SDN switches, while benefiting from simplified management and enhanced flexibility of SDN [44].

Hybrid SDN deployment have two options, Incremental and replacement hybrid SDN deployment. Incremental SDN deployment is progressively replacement of SDN switches in to the traditional network, Replacement SDN is one-time partial replacement of traditional(conventional) nodes.so incremental deployment of SDN switches are more advantageous than replacement[50].

However, for the deployment of hybrid SDN, the first question is which node is replacing first and how many nodes are going to be replaced is the main questions.

In this thesis 10 up to 40 % of traditional network nodes are going to be changed and techno economic analysis is done for each of results.

4.3.1 Network Dimensioning

This section will answer how to determine the number and the location of nodes in a network to be upgraded to SDN switches and number of controller for those selected nodes are going to be cover. Figure 4.1 shows the flow process of network dimensioning for hybrid SDN deployment.

60/40 Roll out plane is conceder for pure and hybrid SDN

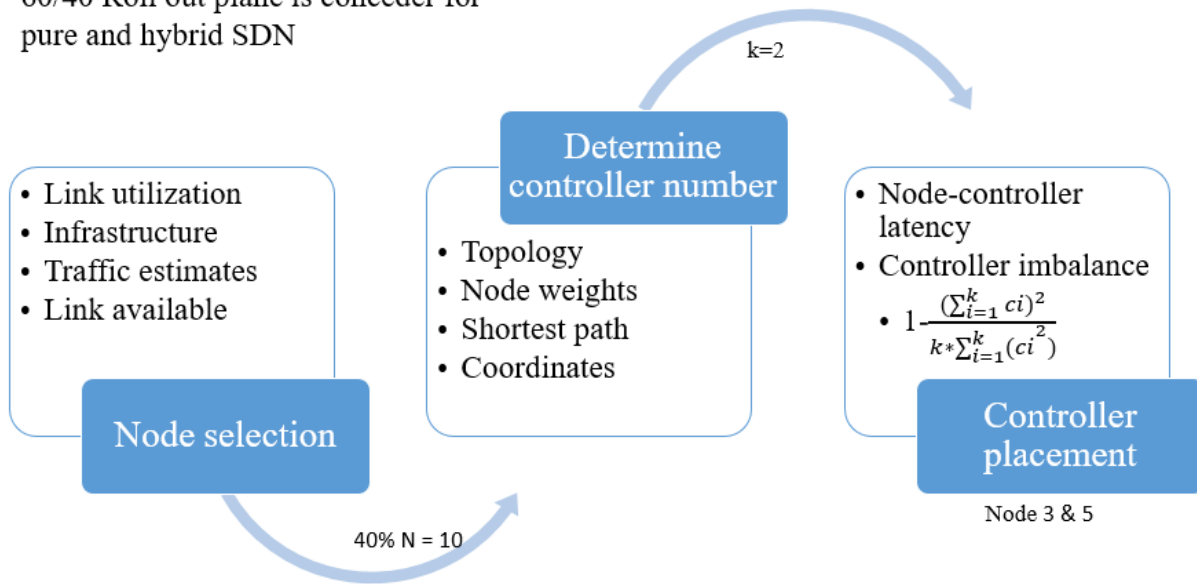


figure 4. 1: hybrid SDN network dimensioning

4.3.2 Node Selection Criteria

The first thing to deploy hybrid SDN is to select the nodes to be upgraded or replaced by nodes with SDN enabled switches for hybrid deployment. The selection should minimize the deployment costs and increases the benefits of SDN in the network. As a result, this used different criteria's for better network performance with low cost of investment and operations. by assuming the controllers will be placed at the same locations with the selected nodes to minimize the cost of new link investments for deployment and using existing infrastructure on the sites.

Few criteria used are depicted as below

1. Link volume

The link volume is one of the selection criteria for SDN enable node. High link volume is selected as it is the link of high traffic demand.

2. Link utilization

The link utilization of each link is considered to select the node for SDN deployment for extra benefits of SDN gain. Highly utilized links are selected to improve the network performance of the services.

3. Infrastructure on the sites

Infrastructure on the sites is one criteria for node selection for SDN deployment. These infrastructures could be the power availability, space availability, link availability and other necessary considerations including the site security considered.

4. Traffic demands

The traffic on each site is considered to select the nodes. The high demanded traffic is with high link volume. Therefore, it is cost effective to select high traffic volume nodes for replacement.

5. Network topology

The network topology could be criteria for node selection as it minimizes costs of capital and operations. This study used the close to the centers rather than the remote end nodes for deployment.

The above listed criteria are applied on the IP core routers of Ethio telecom which is provider edge(PE) routers. 24 number of PE routers without considering redundancy. Namely north PE sites are Debremarkos, Bahirdar, Gonder, Mekele and Dessie. South PE sites are Diredawa, Jijiga, Ambo, Nekemt, Jimma, Naziret, Hawasa, Shashemene and Sodo. Addis PE sites are Sidistkilo, Arada, Nifassilk, Kirkos, Addisketema, Microwave, Bole, Legehar, Old airport, Yeka). figure 4.2 shows a pictorial presentation of node selectin criteria and output of the strategy.

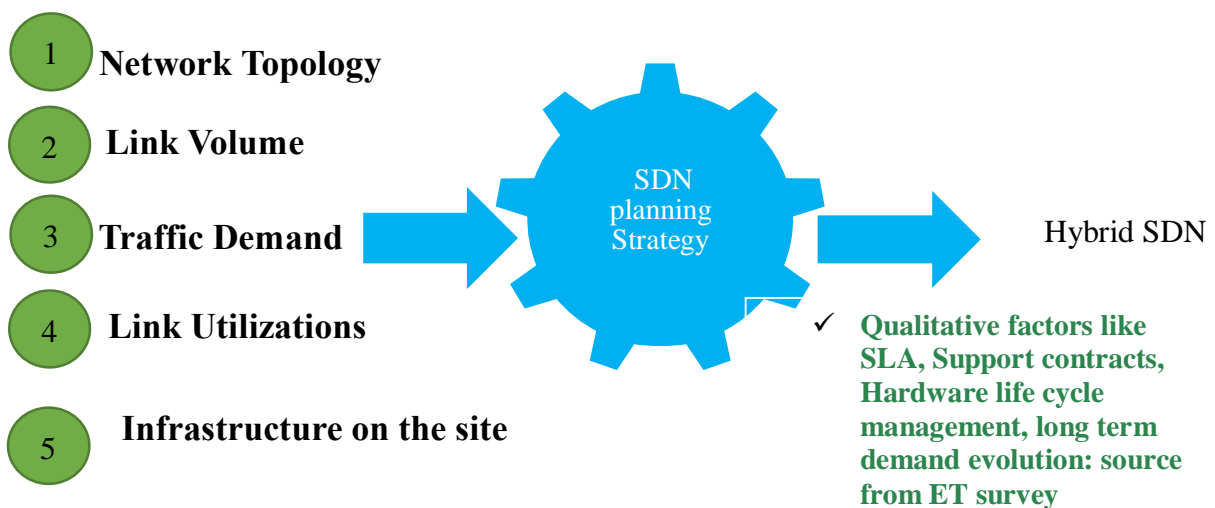


figure 4. 2 switch selection criteria

4.3.3 Controller number and placement

This section focus on the adoption of SDN controller in the Ethio telecom IP core network specifically for those selected SDN switches and recommend the minimum number of controller require and their placement. Controller is the main part of SDN network all the instructions are handled by the controller, rules are created, modified.

The single SDN controller within a network has many benefits, one of them is that the controller has a single view of the whole network and algorithms such as routing are performed using that view, but disadvantages still exist. The problem with a single controller is that it is the only controller in the network, has problems with redundancy, load balancing, scalability network traffics are mostly known to be burst and a controller may get overloaded[11]. Furthermore, single point of failure and hence the controller decrease overall network availability and also single controller sometimes is difficult to place in a network because one needs to know where to place it.

Adopting multiple controllers are a solution for the problem of single controller. Multiple controllers can solve the above mentioned problems and improves latency, scalability, availability and fault tolerance SDN deployment. However, multiple number of controllers have its own challenge which is the placements. How many controllers are required for the network and were to place those controllers need to be answered.

Pareto-based Optimal Controller placements(POCO) is a MATLAB -based controller placement and optimization framework which take into account inter-controller latency, load balancing between controllers, and trade-off considerations between latency and failure resilience are considered and propose the optimal placement of controllers.

4.4 Economic analysis

Economic analysis focuses on financial related works. Classifying first investment cost and costs that are related to operational needs to find CapEx and OpeEx of network equipment. The equipment costs were driven based on the vendors' price obtained from different vendors and the average cost was considered. The TCO evaluation in this thesis is based on the equipment costs taken from different vendors and followed by five years of operation costs, increasing with an assumed 10% of interesting rate.

4.4.1 Revenue

As stated in section 3.4, revenue is defined as the benefits generated by the investment and calculated by multiplying average price per unit with total units. In this work, the total unit is the total data in GB delivered on the link in a year and average price per unit is average cost per GB. Because of Backbone networks carry combined fixed and mobile, both networks have same revenue calculation but have different pricing the formula for revenue calculation is:

$$R = C_m * C_{st} \left[\frac{\$million}{year} \right] \quad (4.1)$$

Where $C_m = \left[\frac{\text{Total [GB]}}{\text{year}} \right]$ is the total GB delivered in a year, $C_{st} = 42$ ETB/GB is an average cost per GB for mobile network. Because currently Ethio telecom sells 10 GB for 420 Ethiopian birr (ETB) per month which is 42 ETB/ GB per month.

In the case of fixed traffic similar formula is applied as of mobile traffic but average cost is downgraded to $C_{st} = 20$ ETB/GB per month[51].

4.4.1 Capital Expenditure (CapEx)

CapEx includes costs related to purchase and installation of network equipment (hardware and software), in general they contribute to the infrastructure and they are depreciated over time.

Equipment Cost

The main core network equipment's that are considered in this study are SDN controller and OpenFlow Switch. Equipment's that are available in the conventional network (already installed components) are not considered.

By considering core network device specification difference network equipment provider web site are reviewed and many vendors are communicated via their sales address, they have different costs for the same equipment. therefore, averages cost is taken as an input.

Installation cost

In the case of SDN deployment in this study new site will not be included but the existing site are upgrade for the suitable installation of equipment's. Installation cost assumptions was taken based on the labors (Engineers and Technicians) cost of installing a sites based on previous installation cost experience from Ethio telecom.

4.4.2 Operational Related Costs (OpeEx)

OpeEx costs are the continuous cost of infrastructure is calculated from floor space and energy consumption of the dimensioned network equipment. The cost of power, back-up power and cooling are taken together. The power per device is based on the power required by the router chassis, line cards and the route switch processor[5]. Some of operational costs are not included in this study like floor space rent because most core network data center are Ethio telecom properties. The cost of maintenance and repair includes the cost of preventative measures such as monitoring and maintaining the network against possible failures but also the repair of failures in the network. Network care is a process done by the Network Operations Centre (NOC) which is active 24/7. In this study for the cost, maintenance and repair cost is taken in general.

4.4.3 Total Cost of Ownership (TCO)

TCO is the total cost of the purchase equipment plus operational costs. Which is the sum of OpeEx and CapEx. Most organization uses as a decision making to purchase a system or projects. The TCO of each scenario studied in this thesis are listed below

4.5 Techno-economic Analysis and Evaluation

In this study two scenarios are considered that are conventional network (Non - SDN), Hybrid SDN (10 % to 40% SDN)) are taken. Comparison analysis is done between each partition of Hybrid SDN .

In the case of Hybrid SDN ten to forty percent of conventional network routers changed by Openflow switches by applying incremental hybrid SDN deployment. And then 60/40 rollout plan is used for all scenarios. From BoR CapEx and OpeEx is calculated formerly from this finding. Techno economic analysis is done by cash flow and discounted cash flow, finally the evaluation was done via economic indication based on NPV, PP.

4.5.1 Net present value (NPV)

The difference between the current value of cash inflows and withdrawals over a period of time is known as net present value (NPV). It is a calculation used in capital budgeting and investment planning to determine the profitability of a proposed investment or project. The net present value (NPV) is the outcome of computations performed to determine the current value of a future stream of payments.

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad (4.2)$$

where:

- R_t = Net cash inflow-outflows during a single period t
- i = Discount rate or return that could be earned in alternative investments
- t = Number of timer periods
- n = Total number of period

4.5.2 Internal rate of return (IRR)

The internal rate of return (IRR) is financial statistics that is used to calculate the profitability of possible investments. In a discounted cash flow analysis, the IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero. It is the annual return that makes the NPV equal to zero. When comparing investment choices that have similar features, the one with the highest IRR is likely to be the best.

$$0 = NPV = \sum_{t=1}^T \frac{C_t}{(1+IRR)^t} - C_0 \quad (4.3)$$

where:

- C_t = Net cash inflow during the period t
- C_0 = Total initial investment costs
- IRR = The internal rate of return
- t = The number of time periods
- T = Total number of period

4.5.3 Payback Period (PP)

The payback period is the amount of time it takes to repay the cost of an investment or the time it takes for an investor to break even. Longer payback periods are less desirable, while shorter payback periods are much more appealing. The payback period is calculated by dividing the amount of the investment by the annual cash flow.

Chapter Five

Result and Discussion

As discussed in section 4.1, SDN deployment scenarios for this study, five scenarios are selected. The first Four scenarios are SDN based and the fifth scenario is conventional network is considered for those that needs to launch new infrastructure.

5.1 Technical analysis

For the deployment of Hybrid SDN the very beginning questions to answer is how many number of SDN switch is going to be deployed in the existing network topology. Many researchers are tried to find the exact number of SDN switches but it's difficult because it depends on the metrics applied on the research and some of them are on network performance, Traffic engineering, cost.in this study ten to forty percent of the existing network routers are incrementally replaced by SDN switch and all the results are evaluated

This study only deliberates 24 numbers of Provider routers in the country, which supported link capacities of IP core network 10GE and 40G POS. Namely north PE sites are (Debremarkos, Bahirdar,Gonder,Mekele and Dessie) . South PE sites are (Diredawa,Jjjiga, Amobo, Nekemt, Jimma, Naziret,Hawasa,Shashemene and Sodo). Addis PE sites are (Sidistkilo, Arada, Nifassilk, Kirkos, Addisketema,Macrowaive,Bole,Legehar,Oldairport,Yeka).Appling node selection criteria listed in section (4.2.1.1).Ten percent of existing routers (Microwave and Bole)sites. Twenty percent of existing routers (Microwave, Bole, Legehar, Bahirdar, Hawasa) thirty percent of existing routers (Microwave, Bole, Legehar, Bahirdar, Hawasa, Diredawa, Mekele) forty percent of existing routers (Nekemt, Jimma, Bahirdar, Gonder, Shashemene, Microwave, Legehar, Bole, Mekele and Diredawa) sites are selected.

5.1.1 Controller number and Placement

This section explains approach of finding an optimized solution for an SDN controller placement problem. The solution is based on Pareto optimal controller placement tool(POCO) (which is part of a MATLAB Facility location problem tools). The goal has been finding how many controllers were needed for the achievement of the minimum latency and to determine the optimal locations for these controllers in Ethiotelecom IP core network. POCO tool is used for the minimization of the latencies and nodes to controller assignment imbalances in Ethiotelecom IP core network.

Topology encoding

Ethiotelecom IP core PE network has 24 provider edge router nodes and 47 links. Based on the collected data from Ethiotelecom, node weights estimated, distance matrix calculated and controller capacity transformed to the suitable file format (topo.mat) file. This topo.mat file is imported to POCO tool and obtained the number and placements of controller as shown in figure 5.1

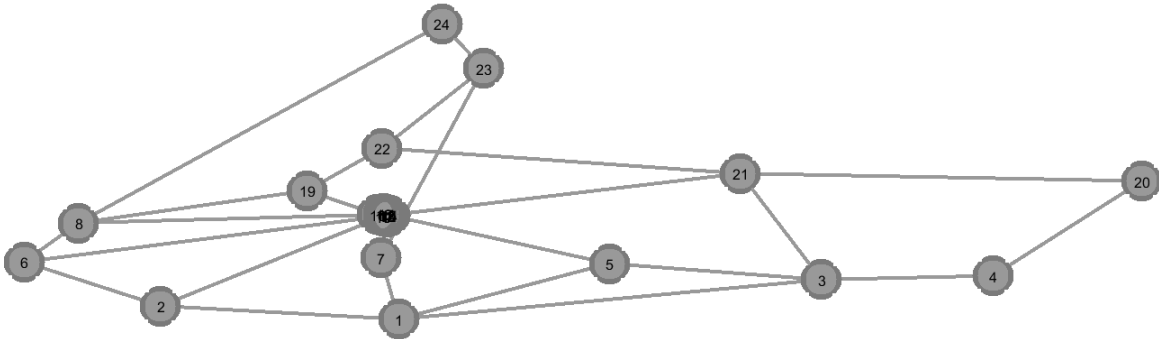


figure 5. 1: Ethiotelecom IP core PE network topology

Controller placement

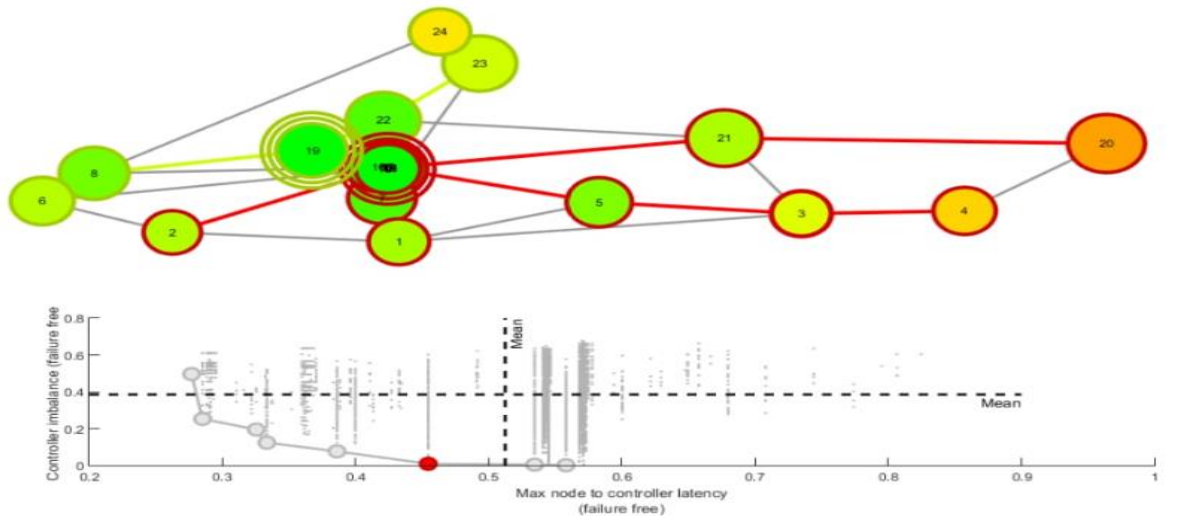


figure 5. 2: Full SDN controller placement

To minimize the deployment cost, this study used the controller imbalance and propagation latency as performance evaluation metrics. By considering minimizing these two metrics the obtained

result of four controllers placed at their set of placements for full SDN deployment as shown in figure 5.2. however, for 40% SDN hybrid deployment two controllers are obtained using similar methods.

Based on the node selection criteria, these are ten (10) selected nodes for 40% hybrid SDN deployment in Ethio telecom IP core network. The number of controllers required obtained using POCO framework MATLAB based tools is two. This study used optimal placements of the controllers with the framework as shown in figure below (figure 5.3).

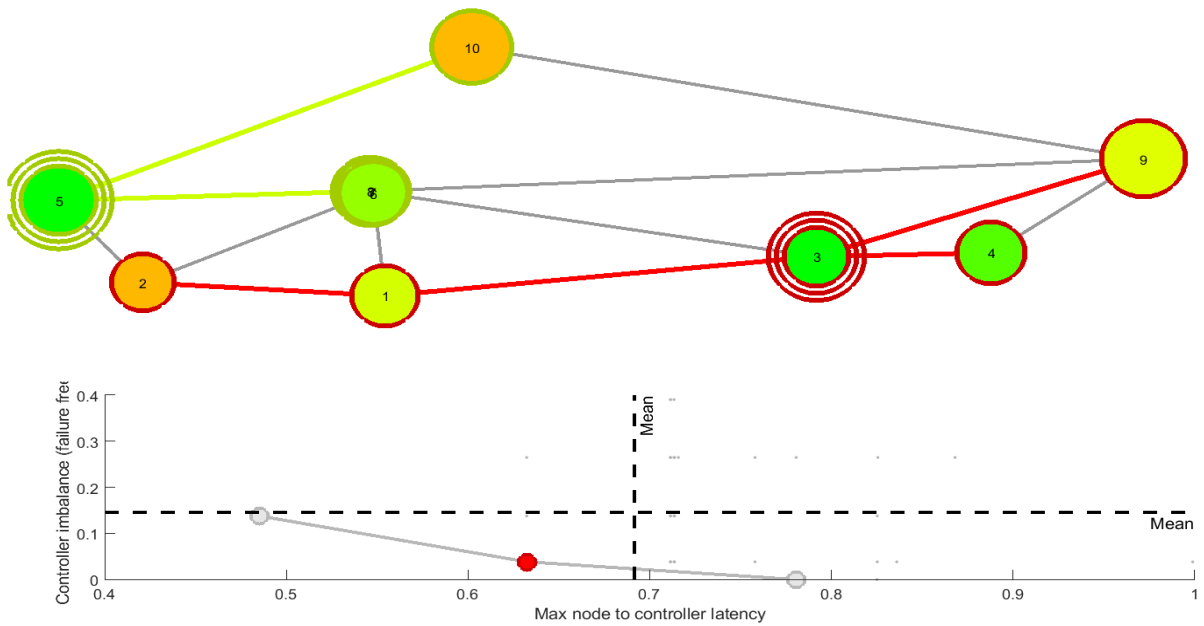


figure 5. 3: Hybrid SDN controller placement

As shown in figure 5.3 the controller is placed with the triple ring (node 3 and node 5) placement have three different options. The maximum node to controller latency is 2.394ms and node to controller imbalance is 2 which is totally acceptable.

5.1.2 Traffic Data Estimation and Forecasting

Traffic data estimation and forecast is done based on the last three years of data traffic trend (2018 to 2020), the regression and prediction of traffic forecast is done by Desmos is the best match for the data by considering the exponential growth of traffic demand trend. So next five years' traffic data demand were estimated and forecasted in figure 5.4 shows, estimated and forecasted traffic data demand for next five years.

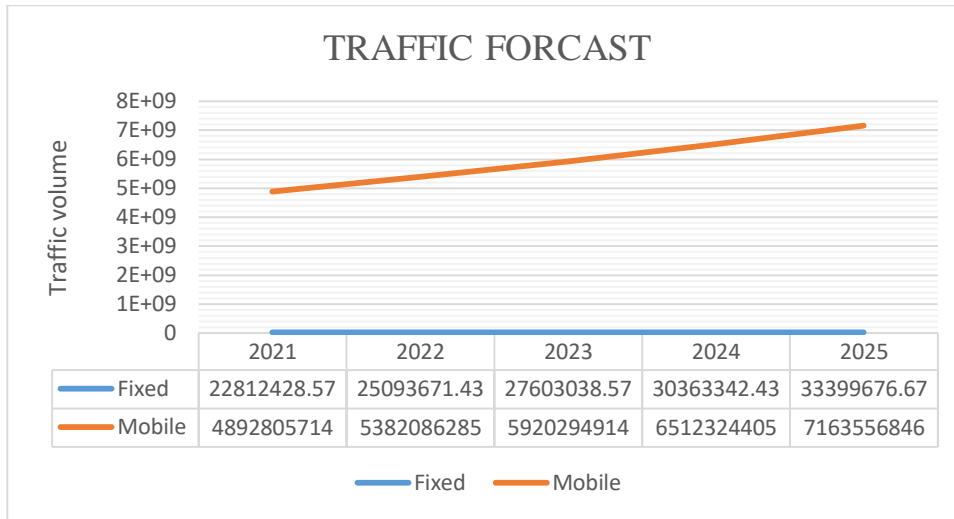


figure 5. 4: Five years estimated and forecasted traffic data demand

Mobile data user increased through time which implies the increasing of traffic data demand, the first year traffic data is 892805714,5382086285.4,5920294913.94,6512324405.33 and 7163556845.8674. For the fixed traffic data demand 22812428.57, 25093671.43, 27603038.57, 30363342.4 and 33399676.67 GB. Were obtained both cases the demand increase gradual which leads to the enhancement of new technology and also build an infrastructure which handles the traffic demand.

5.1.3 Revenue Estimation and Forecasting

One of the key input to find the economic feasibility of a technology is revenue estimation and forecast. Based on the traffic data demand estimation and forecast five years' revenue is estimated and forecasted. Which is multiplied by ET per month data tariff

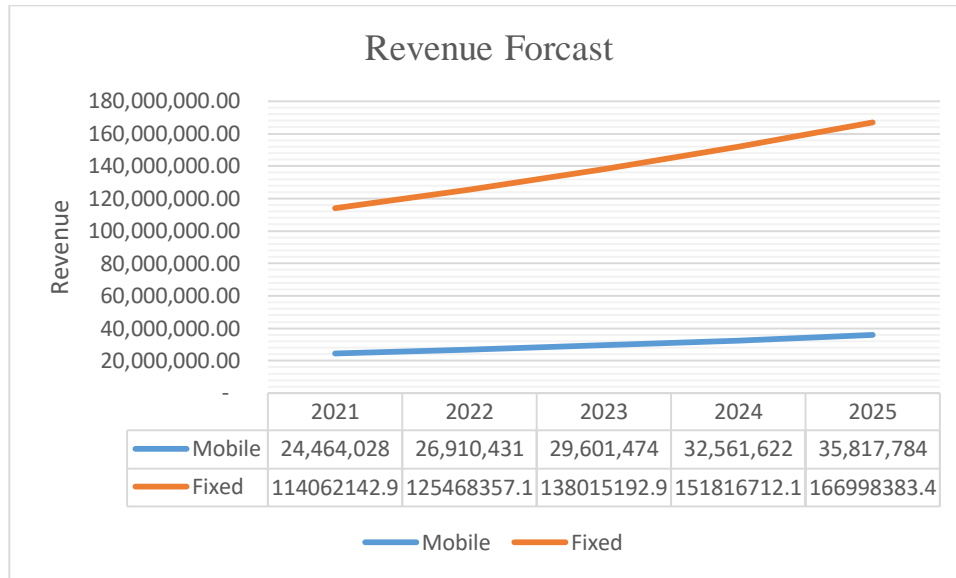


figure 5. 5: Five years estimated and forecasted revenue

Similar to that of traffic estimation and forecast figure 5.5 shows the revenue is increase through time which is the increasing of data users and traffic data demand. The growth of traffic data demand is a direct impact of the increasing of revenue. Mobile and fixed data estimated revenues are listed simultaneously \$24464028.57, \$26910431.43, \$29601474.57, \$32561622.03 and \$35817784.23. \$114062142.9, \$125468357.1, \$138015192.9, \$151816712.1 and \$166998383.4.

5.2 Economic analysis

5.2.1 Capital Expenditure (CapEx)

The initial investment cost is identified from BoR of all components including installation cost. those components are SDN controller, SDN switch, for the conventional network deployment high capacity routers are used. Equipment's that are similar in all scenarios are not considered. The capital expenditure of hybrid SDN in four partitioning chooses (10%,20%,30%,40%) are shown in fig 5.6 and the capital expenditure of the highest result from hybrid SDN classification, conventional network is shown in fig 5.6.

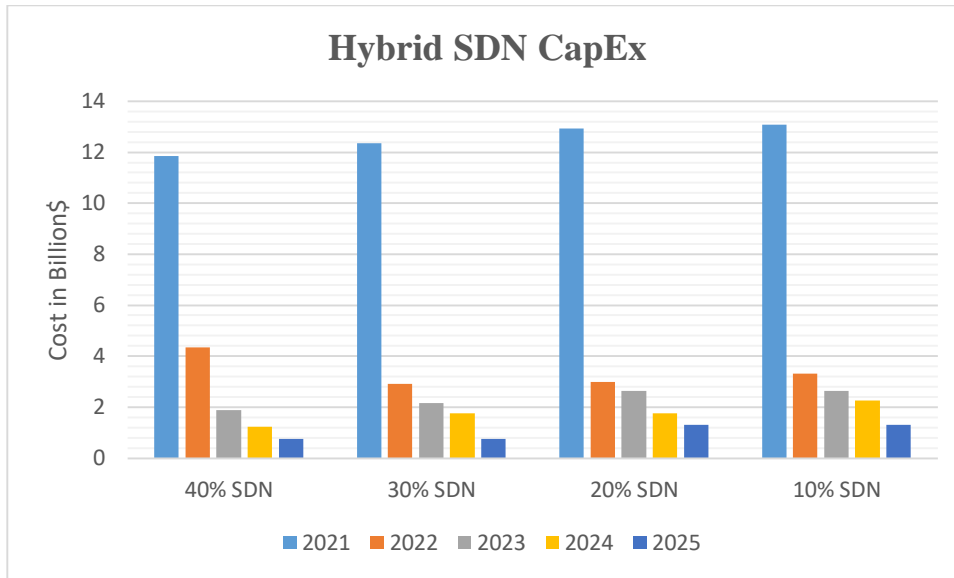


figure 5. 6: Capital expenditure of Hybrid SDN

The yearly CapEx cost within the study period calculated via CapEx model described in Section 4.4.1 and in consideration of 10% yearly price trends. The CapEx cost trend within study period for all deployment scenarios are depicted in figure 5.7.

As shown in figure 5.6, It is clear that the increase number of SDN device have major impact on the capital expenditure.

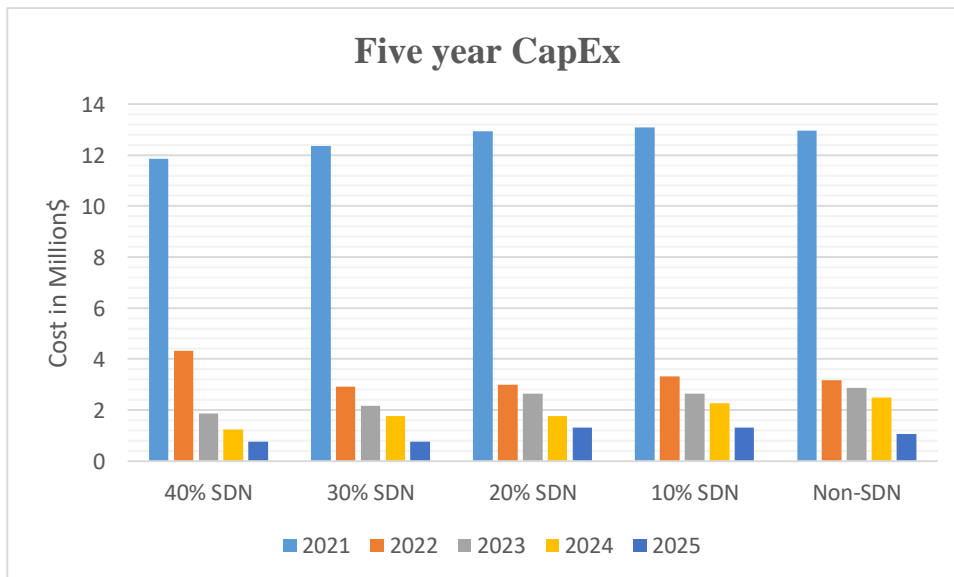


figure 5. 7: five-year CapEx for all scenarios

In figure 5.7 five-year CapEx cost of all scenarios is depicted. The highest capital expenditure is non-SDN deployment scenario. The capital expenditure of all scenarios depreciates through time and CapEx are reduced in the SDN scenario because the control plane is lifted up from the router and centralized into a SDN controller.

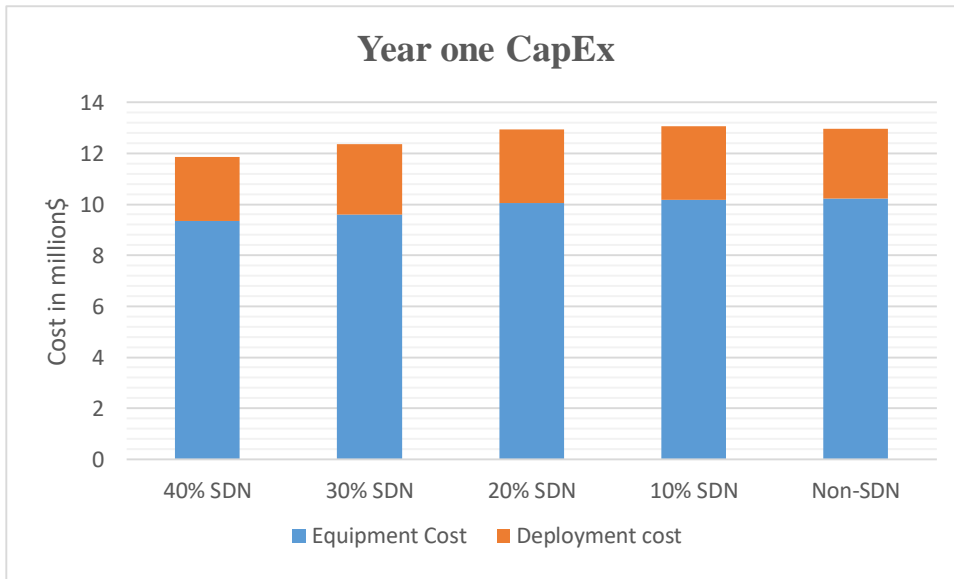


figure 5. 8: year one CapEx of all scenarios

As shown in figure 5.8, The initial investment cost of all scenarios are much higher comparing with the other four years of study periods because the applied rollout plane which is 60% of the deployment plane takes place in the first year of study period and 40% of deployment is partitioned for the rest of study period.

5.2.2 Operational Expenditure (OpeEx)

The cost that is keeping the company operational is OpeEx cost. In this study some operational costs are taken like training cost, hardware and software maintenance cost, operation and maintenance cost, power cost. The cost of power, back-up power and cooling are taken together.

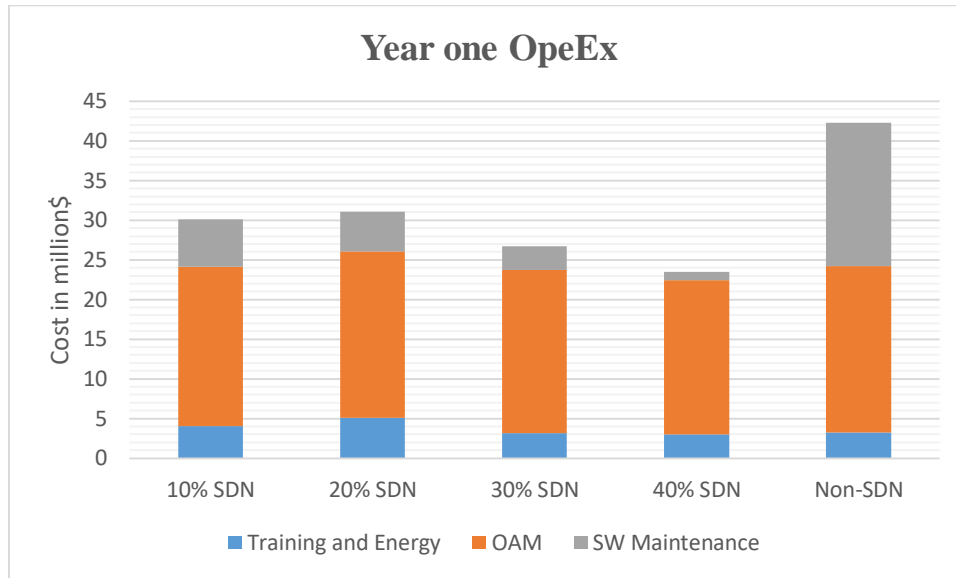


figure 5. 9: year one OpeEx cost of all scenarios

The operational expeditor cost of hybrid SDN scenarios are much better than Non-SDN deployment scenario as shown in figure 5.9. In the SDN scenario, the continuous cost of infrastructure is lower because there is lower energy consumption by the control plane in the network switches. The additional controllers consume less power than what can be saved by centralizing the control plane. The power consumption by the control plane is estimated at 11% of the total power consumption [5]. But have the highest cost for training because SDN is the newly migrated technology training an engineers may cost.

5.2.3 Total Cost of Ownership (TCO)

Total cost of ownership for all scenarios shown in figure 5.10, which is the purchase price of asset plus the cost of operation. For the first year of deployment the purchase price of asset increase and for the rest of the year ownership cost which is operation cost increase.

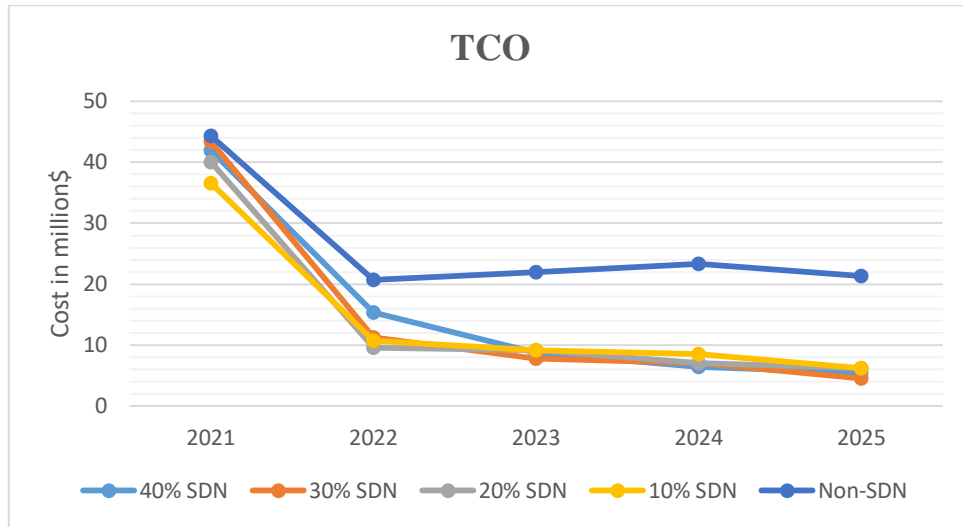


figure 5. 10: five-year Total cost of ownership

It is true, that the first one and two years the CapEx cost takes the high share whereas in the rest of the year OpeEx cost takes the priority. All SDN scenarios have comparable TCO except for Non-SDN scenarios.

5.3 Techno-economic Analysis

5.3.1 Cash Flow Analysis

The net amount of cash received or created in a specific time period is calculated by adding the system's income and costs. Cash flow was used to calculate the net amount of cash and the payback period value. The cash flow of each scenario was evaluated and interpreted in this section.

The CF graph shown in figure 5.13 indicates the payback period which is 3.6 years and the benefit generated from each years. The review at the end of three years show a negative net benefit, indicating the need for extra time to reach return on investment timeframe.

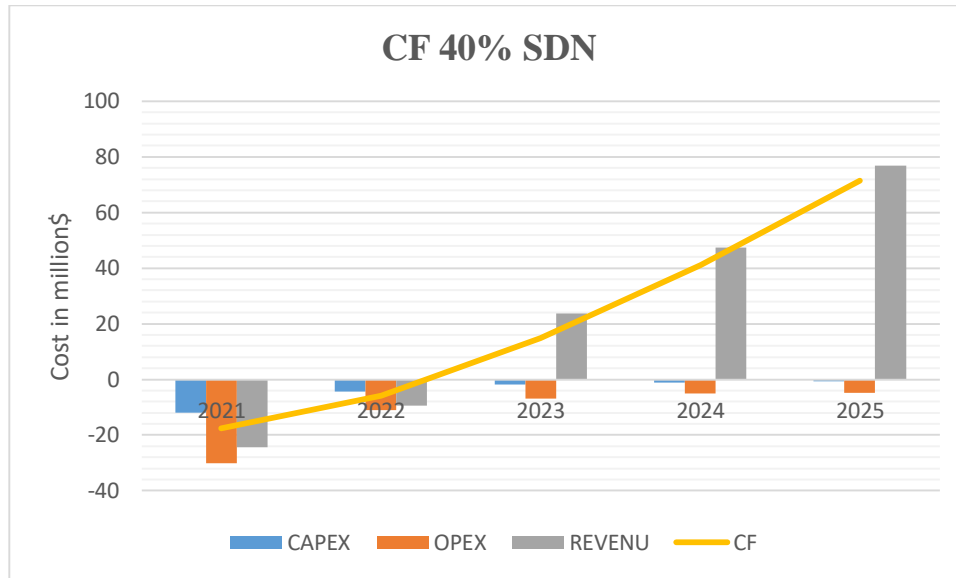


figure 5. 11: Cash flow analysis 40% SDN scenario

As shown in figure 5.12 The results from cash flow analysis for 40% SDN scenario indicate that, 2.4 years of payback period. Regarding to evaluation at the end of two years, the result shows negative net benefit that indicates the need for more additional time to arrive at ROI period.

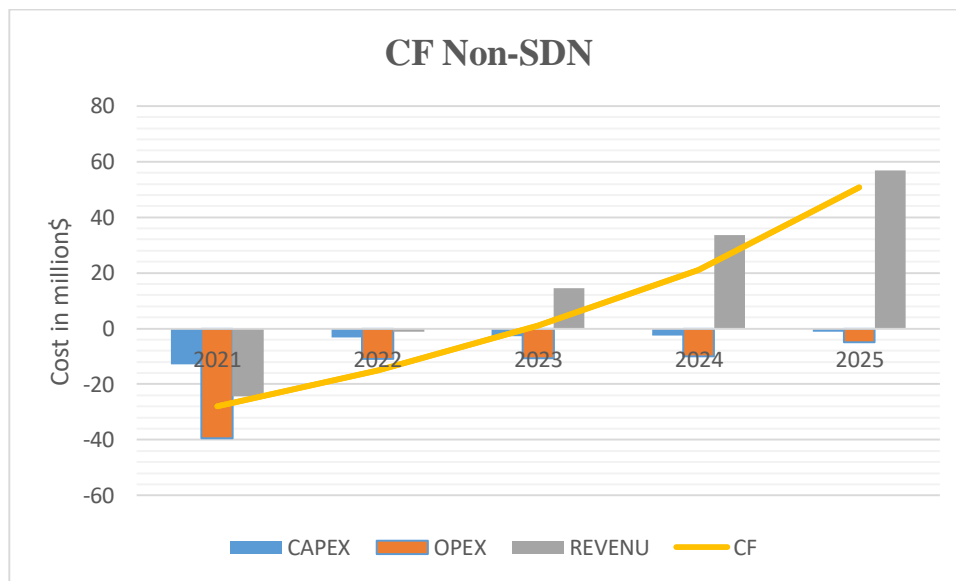


figure 5. 12: Cash flow analysis, Non-SDN scenario

Similar to other scenarios in the case of Non-SDN scenario the payback period 3.8 years as shown in figure 5.14, from cash flow analysis result. The review at the end of three years show a negative net benefit, indicating the need for extra time to reach return on investment timeframe.

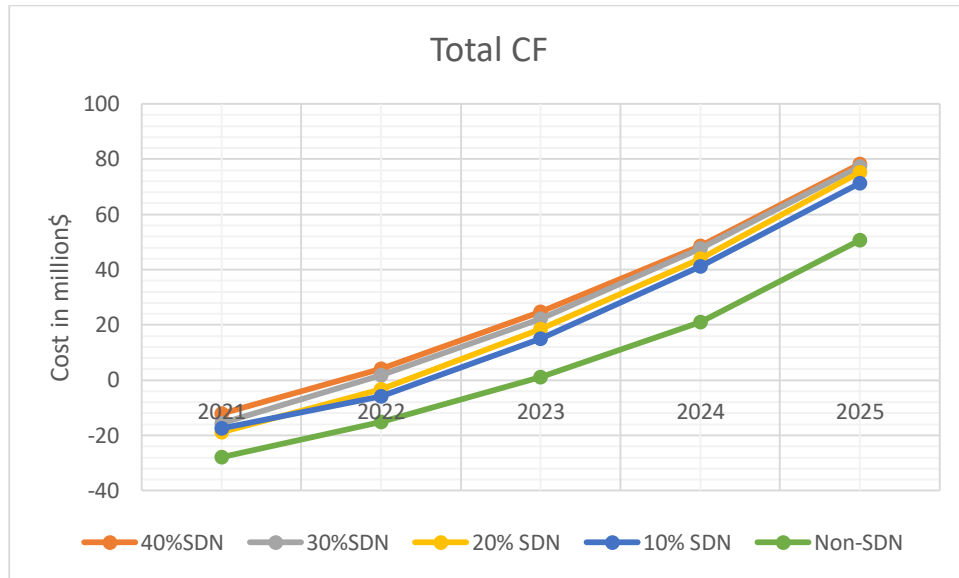


figure 5. 13: Cash flow analysis, all scenarios

From the summary report of figure 5.14 the status after year one shows a fast growth of 10% SDN graph in comparison to others, indicating that 40% SDN is making more money than others at a given time. If the operator is concerned about ROI, the scenario with the shortest payback period will be chosen. The investment is more appealing if the payback period is short. The longer the payback period, on the other hand, the less attractive it is. But if ROI is not critical and need to choice long time cost benefit, the scenario with greater IRR or NPV value was better selection.

5.3.2 Discounted cash flow (DCF)

The techno-economic evaluation results of DCF for all scenarios are summarized in figure 5.15. In this study, 10% discount factor considered for discounted cash flow analysis. As shown in Figure 5.15, after the second year of the deployment period, the discounted cash flow increasing in linearly fashion for all deployment scenarios. All Hybrid SDN deployment options have almost approaches to the same value other than that of Non-SDN deployment.

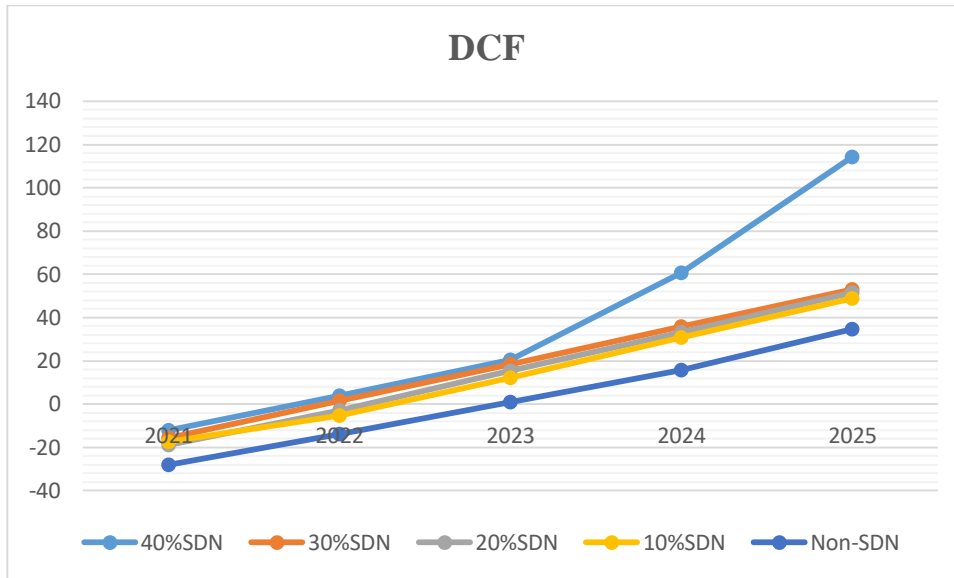


figure 5. 14: Discounted cash flow analysis

5.3.3 Net present value (NPV)

The well know decision making economic indications parameters are the net present value(NPV), internal rate of return(IRR), and payback period(PP).

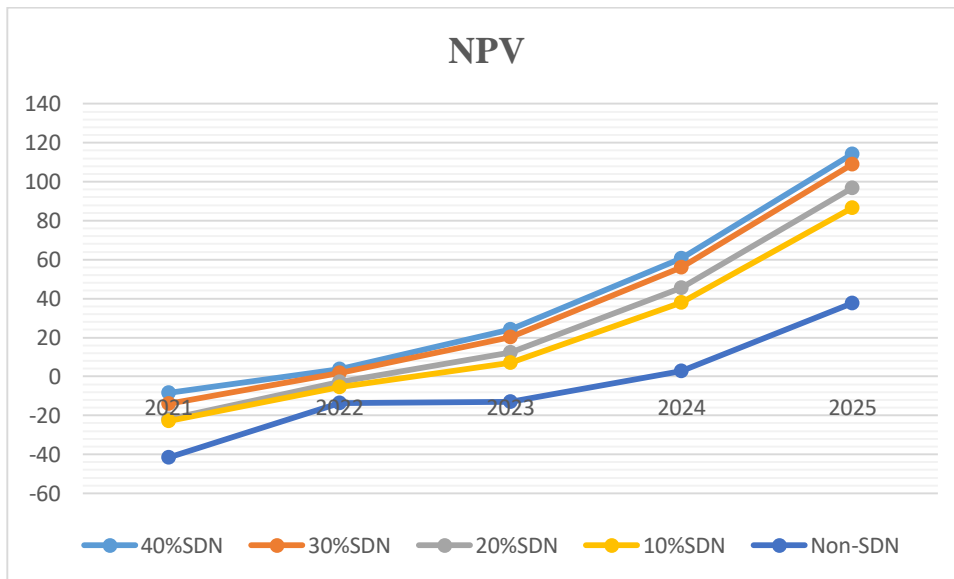


figure 5. 15: five-year net present value

As shown in figure 5.16 Net present value trends in each year per each deployment scenario is presented. For the first two years of study period all scenarios have negative value which need for more additional time to arrive at ROI period and then they are exponentially increasing to high

positive value afterwards. After two years of deployment the exponential growth of NPV implies the exponential growth of data traffic demand each formulated deployment scenario economically feasible if greater than zero net present value recorded.

5.3.4 Internal rate of return (IRR)

One of the major economic indicator that is used to estimate the profitability of possible investments is IRR. Its discount rate (factor) which reduces the net present value to zero.

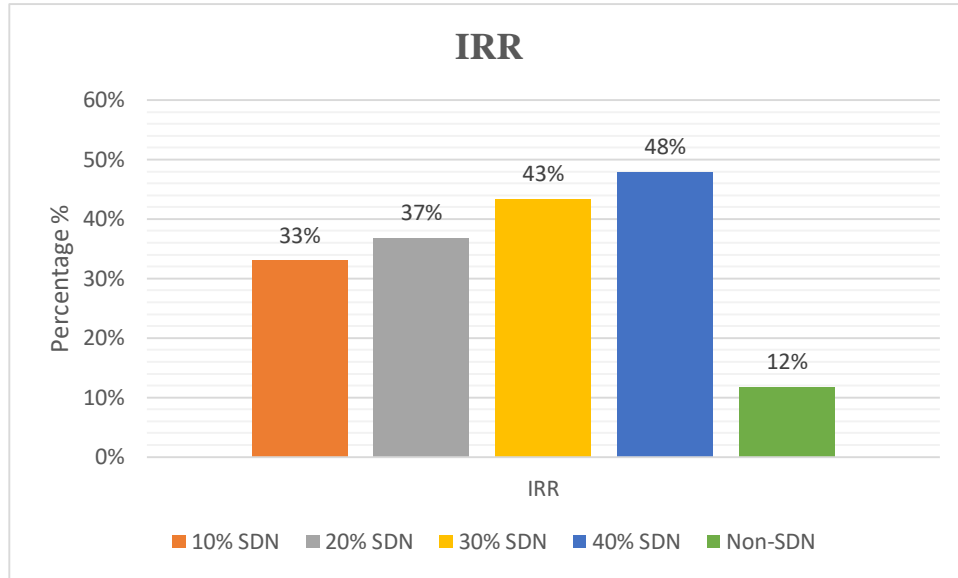


figure 5. 16: five-year net present value

It was noted that if the internal rate of return value was a higher percentage, the investment was profitable and viable (i.e. greater than defined discount factor). In this study, The defied discount factor if 10%.

5.3.5 Payback period (PP)

The payback period of all scenarios lays in between 1.5 to 4 years. All the scenarios return on investment is lower than that of study period which implies the economic feasibility of the scenarios but the more feasible for five years of study period lays on 1.5 to 3 years.

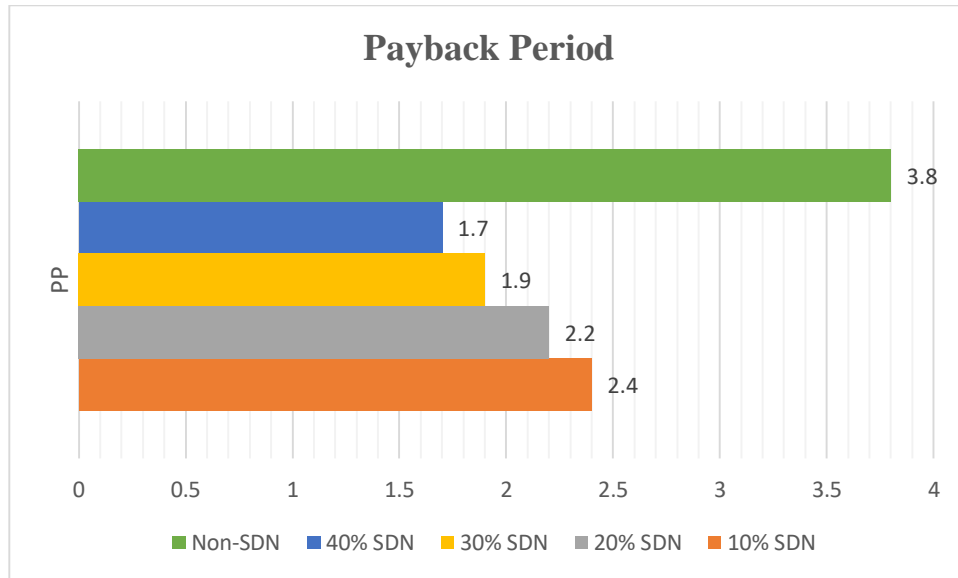


figure 5. 17: Payback period of all scenarios

As shown from figure 5.18 the lower payback period is hybrid SDN deployments have more feasible than other deployment options.

Hence, payback period recorded for all 40% SDN,30%SDN,20%SDN,10%SDN and Non-SDN are 1.7, 1.9, 2.2, 2.4 and 3.8 years respectively. That means, for Non-SDN deployment the time needed to return the investment was 3.8. In the same way, for the rest of the deployment scenarios the return on investments achieved in 1.7, 1.9, 2.2 and 2.4 for 40% SDN,30% SDN,20% SDN and 10% SDN respectively.

Chapter Six

Conclusion and Future Works

The growth in data traffic volume from access network are increasing exponentially which in turn exert a pressure on IP core network and force the operator either to optimize or upgrade their core networks. The existence of new technology never means that its optimal or compatible. Before the launching of new service or technology its must to have techno-economic analysis.

As data traffic volume increases with high traffic demands due to continuous improvement of devices, applications and connectivity increases. To accommodate the high traffic demands telecom operators, service providers continuously deploy network infrastructure that leads difficult to manage it and provide services including that affect the service performances. SDN brings hope to solve such network complexities and management issues as network paradigm. In Ethiotelecom many service and technologies are deployed but they are vendor dependent without performing a techno economic assessment the service is lunched. These will result in resource underutilization and inefficiency, Network performance and quality of service are both poor. So before this all having a techno economic analysis is crucial.

In this study, techno-economic analysis modeling approach has been considered and techno economic evaluation of different scenarios are studied. The scenarios are Hybrid SDN deployment with four options (40%,30%,20%,10% of the existing network is changed to SDN), Non-SDN deployment scenarios are reflect and a techno economic evaluation is done for all scenarios. The analysis is done by MATLAB and MS-excel.

For all scenarios, all CapEx, OpeEx, TCO, and revenue have been estimated, and the technical and economic feasibility of each deployment scenario has been assessed using widely used economic indicators NPV, IRR, PP.

From the results of the study; it can be concluded that:

- The increasing number of SDN device in a given network has a great impact on network capacity.
- In all deployment scenarios the total operational cost is greater than twice that of the total investment cost which indicates to focus on OpeEx driven costs.
- Total CapEx are reduced in the SDN scenario because the control plane is lifted up from the router and centralized into a SDN controller.

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- In the case of hybrid SDN deployment scenarios while the number of SDN device increase the equipment cost may decrease.
 - The results from cash flow analysis indicate, the payback period of 10% SDN,20% SDN,30% SDN,40% SDN and Non-SDN scenarios are 3.4,2.2,1.9,1.7 and 3.8years respectively. The 40% SDN arrives at ROI earlier period than others but all are around one year. If ROI is critical, the operator can choose the scenario with lowest payback period, which is 40% SDN.
 - The findings of net present value vs different discounted rates demonstrate that all scenarios' internal rate of return values are more than the stated discounted rate (10%), indicating that all scenarios are feasible. The IRR values for 40% SDN,30% SDN,20% SDN,10% SDN and Non-SDN scenarios are 48%,43%,37%,33% and 12% respectively. From the values it can be conclude that 10 % SDN deployment scenario is the best solution among the others because the highest value of IRR indicated is better.30% SDN,20% SDN,10 % SDN will take the rank from 2nd to 4th and Non-SDN scenario have taken 5th rank.
 - Over the duration of the five-year study period, positive NPV values were found for all scenarios, indicating that they were all feasible. In terms of NPV, the 40% SDN scenario is the best option, similar to the IRR value.
 - To summarize, all scenarios are feasible based on economic indicators. But, due to their difference in performance

6.1 Future Work

This study focus on the techno economic analysis of upper layer of IP provider edge routers in Ethio telecom network topology. It is possible to further to study the techno economic analysis of Ethio telecom whole core layer of the topology including provide routers. And is possible to apply SDN deployment options in the aggregate network and also access network.

Furthermore, full SDN deployment will have better solution than hybrid SDN so by Appling incremental deployment option full SDN may have better outcome.

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Appendix

Techno-Economic Analysis of Hybrid SDN deployment: In the case of Ethio telecom

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Abstract

The growth in data traffic volume from access network are increasing exponentially which in turn exert a pressure on IP core network and force the operator either to optimize or upgrade their core networks. However, without a detailed technical and economic feasibility study, technological advancement alone cannot demonstrate the acceptability and economic viability of an investment.

This thesis work investigates the techno economic analysis of SDN network. In particular, this work presents techno economic analysis of Hybrid SDN with four partitions and Non-SDN deployment scenarios. This network upgrading is done in Ethiotelecom IP core network which is provider edge routers. The network dimensioning done for SDN scenarios, for hybrid SDN deployment by applying node selection criteria's number of switches to be replaced are decided and controller placement is implemented in Pareto-based Optimal Controller Placements (POCO) tool.

The studies use a modeling methodology for network value analysis that includes capital expenditure (CapEx), operational expenditure (OpeEx), and total costs of ownership (TCO), while the overall financial or economic assessment of technology deployment is based on techno-economic evaluations such as net present value (NPV), internal rate of return (IRR), and pay-back period (PP) economic indicators. Techno-economic assessment (TEA) model, which is Techno-economic results from ACTS (TERA) is implemented in MATLAB and MS-excel.

According to the findings, the pay-back periods for 10% SDN, 20% SDN, 30% SDN, 40% SDN, and Non-SDN scenarios are 2.4, 2.2, 1.9, 1.7, and 3.8 years, respectively. In terms of net present value (NPV) and internal rate of return (IRR), all scenarios have a positive NPV for the study periods and a higher IRR than the stipulated discounted rate. Thus, the economic indicators imply that all scenarios are technically and economically feasible for deployment but the scenarios should be deployed based on the requirements.

Keywords: SDN, Techno-economic analysis, Deployment scenarios, TERA model, NPV, IRR

1. Introduction

Over a long time of Computer Network presence and growth, the extreme increment in network complexity has brought almost troubles in network management. It tends to be troublesome to configure computer networks by predefined approaches, reconfiguring systems to reply to changes, flaws, and loads. Because it shows up that current network systems are coordinates vertically, the control plane and data plane are all tied up together. Software-Defined Networking (SDN) is a new computer networking paradigm in which a single high-level software application controls network behavior. The control plane (software programs that manage network system behavior) and data plane (devices that forward network traffic) are separated in this network design[1].

There are different deployment methods of a software-defined network. Hybrid SDN is one among them, in which SDN is partially implemented without completely replacing the present network. This partial introduction model enables SDN to apply its value whereas co-existing with the existing network [2].

SDN is expected to reduce the network Operational Expense (OpeEx) by simplifying operations, optimizing resource usage through centralized data/algorithms, and simplifying

network software upgrades. It also significantly cuts down a network operator's Capital Expense (CapEx), since a commercial-off-the-shelf(COTS) server with a high-end CPU is much cheaper than a high-end router[3]. However, it's also better to decide where the hybrid SDN is applied on the existing network and which type of hybrid SDN (replace or increment) is going to apply.

The aim of this study is to investigate a techno-economic analysis of conventional network and different SDN deployment options in Ethio telecom IP core network.

2. Related Work

In [1] When and the way to upgrade from existing IP routers to SDN-compliant equipment was a topic of discussion among the writers. While a comprehensive rebuild of a full functioning network in a single step is unfeasible, the immediate benefits of SDN are clear. The results suggest that the migration sequence is critical, particularly in the early stages of SDN network migration.

According to [4] techno-economic study is conducted in , two network scenarios based on OpenFlow solutions were investigated: (scenario1) software-defined, non-shared networks and (scenario2) virtualized, shared networks, and the results were compared to the current situation. SDN and virtualization of the primary aggregation stage and second aggregation stage network architecture result in significant CapEx cost reductions for the mobile

network operator, as a result, using OpenFlow to virtualize mobile network infrastructure might be one of the problem solvers to address the issue of growing costs and diminishing profitability. The author failed to consider the direct impact on operational costs as well as the indirect impact that network sharing might have on operators' capacity to differentiate themselves.

In[5] the authors offer a multi-layer modular design for carrier networks based on SDN and network function virtualization (NFV) principles, as well as a techno-economic analysis of SDN principles applied to the developed packet system's transport network of Evolved packet system (EPS). The savings for the SDN scenario are measured at 12% when compared to the state-of-the-art (SoTA) scenario, with CapEx and OpeEx reductions accounting for 65 and 35 percent of total savings, respectively

3. Methodology

The following methods are applied to achieve the objective of the study.

- Row data's from Ethio telecom, vendor's manual, internet are the primary source of data.
- From the very beginning how many numbers of conventional network routers is going to be changed to SDN based switch is decided based on previous works. And for those selected switches how many numbers of controller is

relevant and where to place those controller is done using POCO tool considering switch to controller latency and controller imbalance. Then after number of switches and controller are decided bill of resource is done.

- Revenue is an input for economic evaluation. To calculate revenue, traffic volume per each link is generated for both fixed and mobile traffic and multiplied by average price of data. Based on the result five-year traffic volume and revenue is forecasted.
- The cost modeling of each scenario are done using modified TERA model, it performs the CapEx and OpeEx of each scenarios and also discounted cash flow and study period are considered as an input.
- Finally, economic indications like NPV, IRR, PP are out puts from cost modeling and comparison of each scenario are done based on those results.

4. SDN Deployment Scenario

Even though the tremendous advantage SDN brings, overnight tune of a network totally to pure SDN brings many challenges and costs. Firstly, migration from and dismantling of existing networks results in invalidity of existing SLA, vendor support agreements and throwing before return of investments of infrastructures. Secondly, lack of uniform standards or immature standards as many organizations proposes differently[6],[7].

Thirdly, reliability (updating failures, new input streams increase overhead to network management and performance) and security (many point of attack, open interface applications and software nature vulnerability) challenges exist[7]. According to [8] incremental hybrid SDN deployment benefits better.

Hybrid SDN

The partial deployment of an SDN network, which is number of SDN switches along with traditional conventional router operates together to form hybrid SDN[2] For some reasons SDN full deployment is not recommended like fear of downtime and huge amount of initial investment. To address these problems, one solution is to build a small number of SDN-enabled devices alongside conventional network equipment, gradually replacing traditional network devices with SDN devices[9].

Network Dimensioning

This section will answer how to determine the number and the location of nodes in a network to be upgraded to SDN switches and number of controller for those selected nodes are going to be cover. Figure 1 shows the flow process of network dimensioning for hybrid SDN deployment.

60/40 Roll out plane is concenter for pure and hybrid SDN

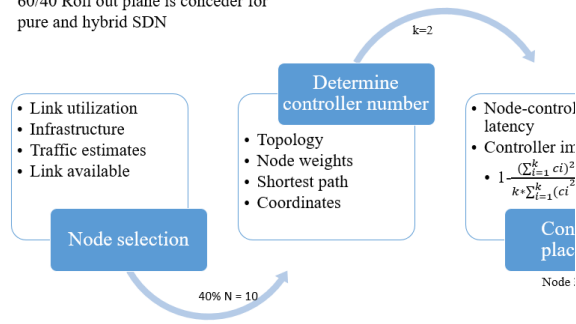


Figure 1: Hybrid SDN network dimensioning

The first thing to deploy hybrid SDN is to select the nodes to be upgraded or replaced by nodes with SDN enabled switches for hybrid deployment. The selection should minimize the deployment costs and increases the benefits of SDN in the network. As a result, this used different criteria's for better network performance with low cost of investment and operations. by assuming the controllers will be placed at the same locations with the selected nodes to minimize the cost of new link investments for deployment and using existing infrastructure on the sites. The criteria are (Link utilization, Equipment validation period, Maintenance and support) by Applying those criteria from 24 PE routers 10 of them are selected for 40% SDN deployment scenario. 8 routers for 30%SDN, 20% SDN 5 routers ,10%SDN 3. Based on this finding optimal controller placement is performed for only 40%SDN but for other only one controller is use then the issue of controller placement is not being raised.

Controller number and placement

This section explains approach of finding an optimized solution for an SDN controller placement problem. The solution is based on Pareto optimal controller placement tool(POCO) (which is part of a MATLAB Facility location problem tools). The goal has been finding how many controllers were needed for the achievement of the minimum latency and to determine the optimal locations for these controllers in Ethiotelecom IP core network. POCO tool is used for the minimization of the latencies and nodes to controller assignment imbalances in Ethiotelecom IP core network.

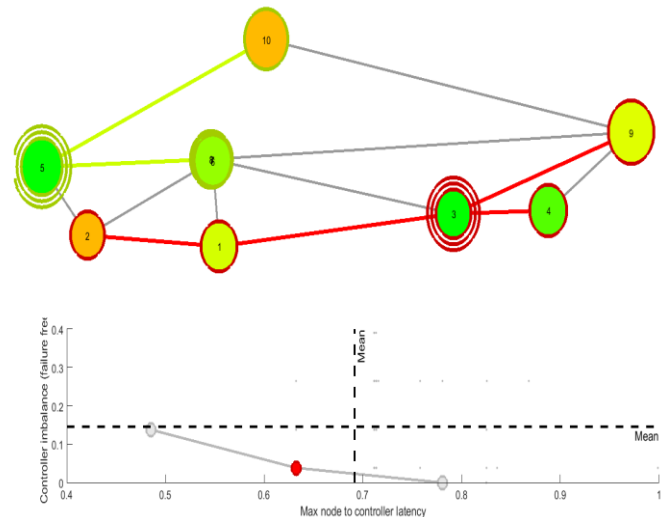


Figure 2: Optimal controller placement

Based on the node selection criteria, these are ten (10) selected nodes for 40% hybrid SDN deployment in Ethiotelecom IP core network. The number of controllers required obtained using POCO framework MATLAB based tools is two as shown in figure 2.

Then after this finding, traffic demand must be forecasted. Traffic data estimation and forecast is done based on the last three years of data traffic trend (2018 to 2020), the regression and prediction of traffic forecast is done by Desmos is the best match for the data by considering the exponential growth of traffic demand trend. So next five years' traffic data demand were estimated and forecasted.

5. Techno-Economic analysis

Techno-economic analysis is typically used to evaluate economic feasibility of a technical solution by utilizing forecasting, network design and investment analysis methods[4].

Economic analysis

Economic analysis focuses on financial related works. Classifying first investment cost and costs that are related to operational needs to find CapEx and OpeEx of network equipment. The equipment costs were driven based on the vendors' price obtained from different vendors and the average cost was considered. The TCO evaluation in this thesis is based on the equipment costs taken from different vendors and followed by five years of operation costs, increasing with an assumed 10% of interesting rate.

Revenue

Revenue is defined as the benefits generated by the investment and calculated by multiplying average price per unit with total units. In this work, the total unit is the total

data in GB delivered on the link in a year and average price per unit is average cost per GB. Because of Backbone networks carry combined fixed and mobile, both networks have same revenue calculation but have different pricing the formula for revenue calculation is:

$$R = C_m * C_{st} \left[\frac{\$million}{year} \right] \quad (1.1)$$

Where $C_m = \left[\frac{Total [GB]}{year} \right]$ is the total GB delivered in a year, $C_{st} = 42$ ETB/GB is an average cost per GB for mobile network. Because currently Ethio telecom sells 10 GB for 420 Ethiopian birr (ETB) per month which is 42 ETB/ GB per month. In the case of fixed traffic similar formula is applied as of mobile traffic but average cost is downgraded to $C_{st} = 20$ ETB/GB per month[10].

Capital Expenditure (CapEx)

CapEx includes costs related to purchase and installation of network equipment (hardware and software), in general they contribute to the infrastructure and they are depreciated over time.

$$CapEx = \frac{number\ of\ devices}{site} * number\ of\ sites * \frac{cost}{device} + number\ of\ SDN\ controller * \frac{cost}{SDN\ controller} + cost\ of\ software\ development + cost\ of\ first\ installation \quad (1.2)$$

Operational Related Costs (OpeEx)

OpeEx costs are the continuous cost of infrastructure is calculated from floor space and energy consumption of the dimensioned network equipment. The cost of power, back-up power and cooling are taken together. The power per device is based on the power required by the router chassis, line cards and the route switch processor[5]. Some of operational costs are not included in this study like floor space rent because most core network data center are Ethio telecom properties.

The cost of maintenance and repair includes the cost of preventative measures such as monitoring and maintaining the network against possible failures but also the repair of failures in the network. Network care is a process done by the Network Operations Centre (NOC) which is active 24/7. In this study for the cost, maintenance and repair cost is taken in general.

$$OpeEx = \frac{\text{number of devices}}{\text{site}} * \text{number of sites} * \left(\frac{\text{energy(KW)}}{\text{device}} * \frac{\text{cost of energy}}{\text{KW}} \right) + \frac{\text{number of hardware failer}}{\text{site}} + \frac{\text{number of software faileres}}{\text{site}}$$

Total Cost of Ownership (TCO)

TCO is the total cost of the purchase equipment plus operational costs. Which is the sum of OpeEx and CapEx. Most organization uses as a decision making to purchase a system or projects.

$$TCO = CapEx + OpeEx \quad (1.4)$$

6. Techno-economic Analysis and Evaluation

Two scenarios are considered in this study, that are conventional network (Non - SDN), Hybrid SDN (10 % to 40% SDN)) are taken. Comparison analysis is done between each partition of Hybrid SDN.

In the case of Hybrid SDN ten to forty percent of conventional network routers changed by OpenFlow switches by applying incremental hybrid SDN deployment. And then 60/40 rollout plan is used for all scenarios. From BoR CapEx and OpeEx is calculated formerly from this finding. Techno economic analysis is done by cash flow and discounted cash flow, finally the evaluation was done via economic indication based on NPV, PP.

Net present value (NPV)

The difference between the current value of cash inflows and withdrawals over a period of time is known as net present value (NPV). It is a calculation used in capital budgeting and investment planning to determine the profitability of a proposed investment or project. The net present value (NPV) is the outcome of computations performed to determine the current value of a future stream of payments.

(1.3)

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad (1.5)$$

where:

- R_t = Net cash inflow-outflows in period t
- i = Discount rate
- t = Number of timer periods
- n = Total number of period

Internal rate of return (IRR)

The internal rate of return (IRR) is financial statistics that is used to calculate the profitability of possible investments. In a discounted cash flow analysis, the IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero. It is the annual return that makes the NPV equal to zero. When comparing investment choices that have similar features, the one with the highest IRR is likely to be the best.

Payback Period (PP)

The payback period is the amount of time it takes to repay the cost of an investment or the time it takes for an investor to break even. Longer payback periods are less desirable, while shorter payback periods are much more appealing. The payback period is calculated by dividing the amount of the investment by the annual cash flow.

7. Techno-economic Assessment (TEA)

Evaluation Method

The discounted cash flow and cash flow (CF) methodologies were used in this techno-

economic study. Discounted cash flow (DCF) is a valuation approach that uses future cash flows to estimate the value of an investment. Using a discount rate, discounted cash flow analysis determines the present value of predicted future cash flows. After that, a present value estimate is utilized to assess a possible investment. Decision-making economic metrics such as net present value, internal rate of return, and payback period are derived using DCF analysis [11],[12]. This strategy, as well as each economic indicator, will be addressed in this section.

$$CF = R_i + TCO_i \quad (1.6)$$

Where: R_i = Revenue at a time i.

TCO_i = Total cost of ownership at a time i.

$$DCF = \frac{CF_1^1}{1+r} + \frac{CF_2^2}{1+r} + \dots + \frac{CF_n^n}{1+r} \quad (1.7)$$

where: CF = The cash flow for the given year.

CF_1 is for year one

CF_2 is for year two

CF_n is for additional years

r is the discount rate.

8.Result and Discussion

Capital Expenditure (CapEx)

The initial investment cost is identified from BoR of all components including installation cost. those components are SDN controller, SDN switch, for the conventional network deployment high capacity routers are used.

Equipment's that are similar in all scenarios are not considered. The capital expenditure of hybrid SDN in four partitioning chooses (10%,20%,30%,40%) are shown in fig 8.1.

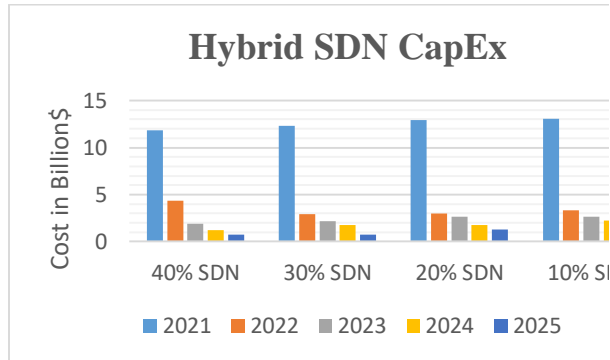


Figure 8.1: Hybrid SDN CapEx trend

It is clear that the increase number of SDN device have major impact on the capital expenditure.

The highest capital expenditure is non-SDN deployment scenario. The capital expenditure of all scenarios depreciates through time and CapEx are reduced in the SDN scenario because the control plane is lifted up from the router and centralized into a SDN controller shown in figure

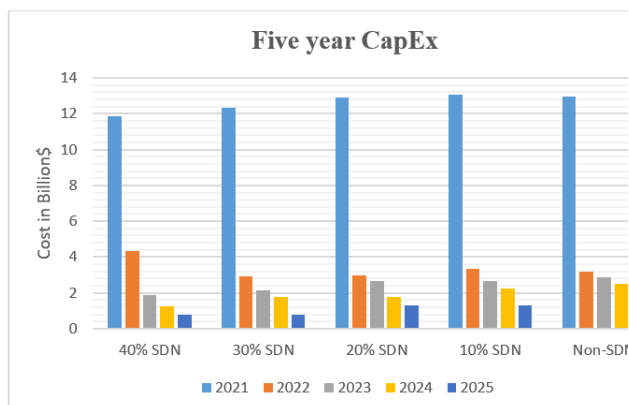


figure 8.2: Five-year CapEx

From figure 8.2 The initial investment cost of all scenarios are much higher comparing with

the other four years of study periods because the applied rollout plane which is 60% of the deployment plane takes place in the first year of study period and 40% of deployment is partitioned for the rest of study period.

Operational Expenditure (OpeEx)

The cost that is keeping the company operational is OpeEx cost. In this study some operational costs are taken like training cost, hardware and software maintenance cost, operation and maintenance cost, power cost. The cost of power, back-up power and cooling are taken together.

The operational expeditor cost of hybrid SDN scenarios are much better than Non-SDN deployment scenario as shown in figure 8.3. In the SDN scenario, the continuous cost of infrastructure is lower because there is lower energy consumption by the control plane in the network switches. The additional controllers consume less power than what can be saved by centralizing the control plane. The power consumption by the control plane is estimated at 11% of the total power consumption [5]. But have the highest cost for training because SDN is the newly migrated technology training an engineers may cost.

The OpeEx savings are a result in simplified service provisioning and management.

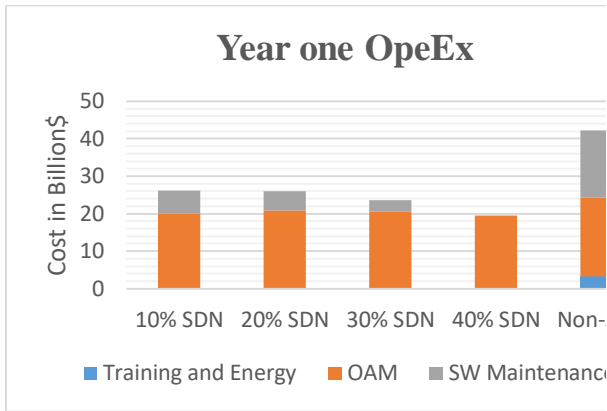


Figure 8.3: Year one OpeEx

Total Cost of Ownership (TCO)

Total cost of ownership for all scenarios shown in figure 8.4, which is the purchase price of asset plus the cost of operation. For the first year of deployment the purchase price of asset increase and for the rest of the year ownership cost which is operation cost increase.

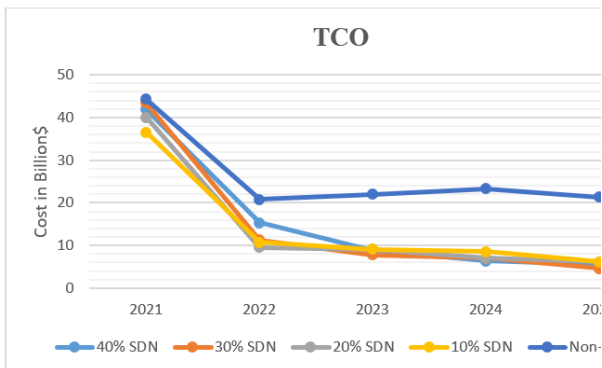


Figure 8.4: Total cost of ownership

It is true, that the first one and two years the CapEx cost takes the high share whereas in the rest of the year OpeEx cost takes the priority. All SDN scenarios have comparable TCO except for Non-SDN scenarios.

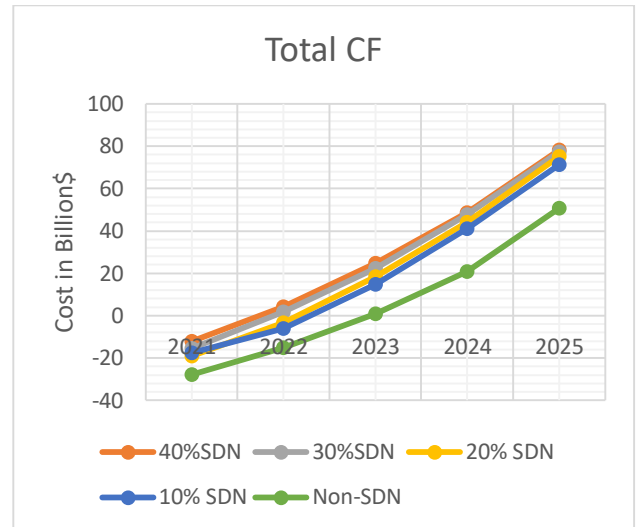


Figure 8.5: Total cash flow

From the summary report of CF figure 5.14 the status after year one shows a fast growth of 10% SDN graph in comparison to others, indicating that 40% SDN is making more money than others at a given time. If the operator is concerned about ROI, the scenario with the shortest payback period will be chosen. The investment is more appealing if the payback period is short. The longer the payback period, on the other hand, the less attractive it is. But if ROI is not critical and need to choice long time cost benefit, the scenario with greater IRR or NPV value was better selection.

Discounted cash flow (DCF)

The techno-economic evaluation results of DCF for all scenarios are summarized in figure 5.15. In this study, 10% discount factor considered for discounted cash flow analysis. As shown in Figure 5.15, after the second year of the deployment period, the discounted cash flow increasing in linearly fashion for all

deployment scenarios. All Hybrid SDN deployment options have almost approaches to the same value other than that of Non-SDN deployment.

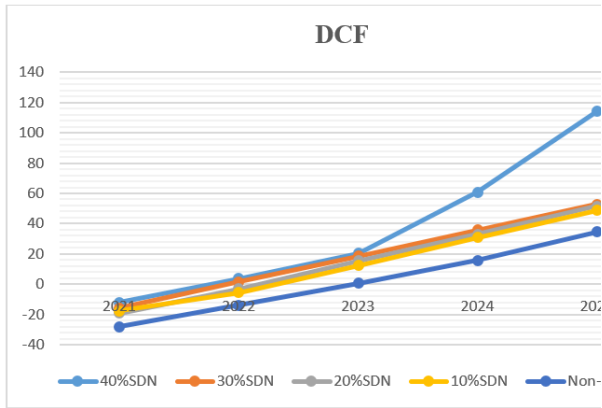


Figure 8.6: Discounted Cash Flow

Net present value (NPV)

The well know decision making economic indications parameters are the net present value(NPV), internal rate of return(IRR), and payback period(PP).

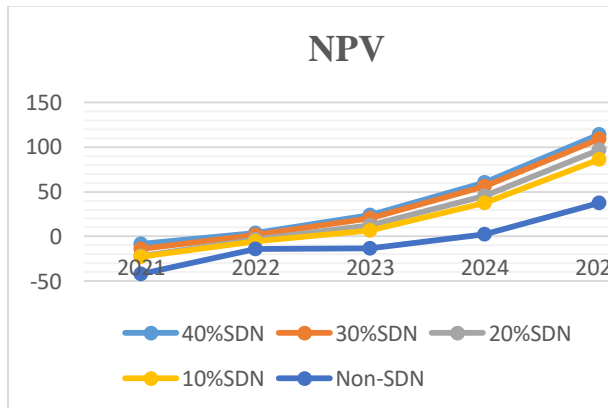


Figure 8.7: Net present value

As shown in figure 8.7 Net present value trends in each year per each deployment scenario is presented. For the first two years of study period all scenarios have negative value which need for more additional time

to arrive at ROI period and then they are exponentially increasing to high positive value. After two years of deployment the exponential growth of NPV implies the exponential growth of data traffic demand each formulated deployment scenario economically feasible if greater than zero net present value recorded.

Internal rate of return (IRR)

One of the major economic indicator that is used to estimate the profitability of possible investments is IRR. Its discount rate (factor) which reduces the net present value to zero.

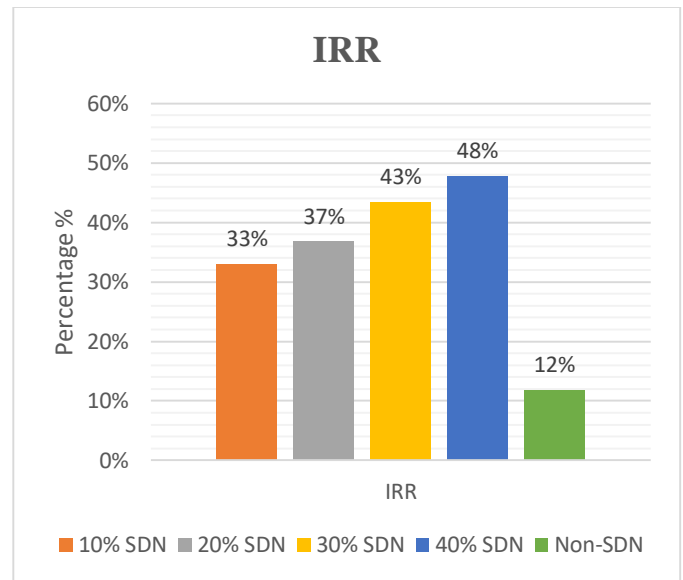


Figure 8.9: five-year net present value It was noted that if the internal rate of return value was a higher percentage, the investment was profitable and viable (i.e. greater than defined discount factor). In this study, The defied discount factor if 10%.

Payback period (PP)

The payback period of all scenarios lays in between 1.5 to 4 years. All the scenarios return on investment is lower than that of study period which implies the economic feasibility of the scenarios but the more feasible for five years of study period lays on 1.5 to 3 years.

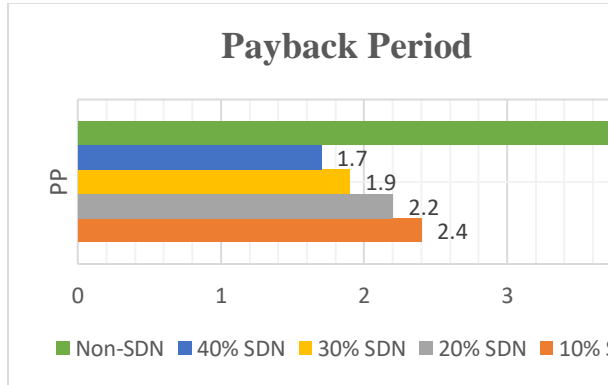


Figure 8.10: Payback period

As shown from figure 8.10 the lower payback period is hybrid SDN deployments have more feasible than other deployment options.

Hence, payback period recorded for all 40% SDN,30%SDN,20%SDN,10%SDN and Non-SDN are 1.7, 1.9, 2.2, 2.4 and 3.8 years respectively. That means, for Non-SDN deployment the time needed to return the investment was 3.8. In the same way, for the rest of the deployment scenarios the return on investments achieved in 1.7, 1.9, 2.2 and 2.4 for 40% SDN,30% SDN,20% SDN and 10% SDN respectively.

Conclusion

From the results of the study; it can be concluded that:

- The increasing number of SDN device in a given network has a great impact on network capacity.
- In all deployment scenarios the total operational cost is greater than twice that of the total investment cost which indicates to focus on OpeEx driven costs.
- Total CapEx are reduced in the SDN scenario because the control plane is lifted up from the router and centralized into a SDN controller.
- In the case of hybrid SDN deployment scenarios while the number of SDN device increase the equipment cost may decrease.
- The results from cash flow analysis indicate, the payback period of 10% SDN,20% SDN,30% SDN,40% SDN and Non-SDN scenarios are 3.4,2.2,1.9,1.7 and 3.8years respectively. The 40% SDN arrives at ROI earlier period than others but all are around one year. If ROI is critical, the operator can choose the scenario with lowest payback period, which is 40% SDN.
- The findings of net present value vs different discounted rates demonstrate that all scenarios' internal rate of return

values are more than the stated discounted rate (10%), indicating that all scenarios are feasible. The IRR values for 40% SDN, 30% SDN, 20% SDN, 10% SDN and Non-SDN scenarios are 48%, 43%, 37%, 33% and 12% respectively. From the values it can be concluded that 10% SDN deployment scenario is the best solution among the others because the highest value of IRR indicated is better. 30% SDN, 20% SDN, 10% SDN will take the rank from 2nd to 4th and Non-SDN scenario have taken 5th rank.

- Over the duration of the five-year study period, positive NPV values were found for all scenarios, indicating that they were all feasible. In terms of NPV, the 40% SDN scenario is the best option, similar to the IRR value.
- To summarize, all scenarios are feasible based on economic indicators. But, due to their difference in performance

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