Investigating adoption and implementation of software defined network in Higher Education – Case of Northern Cape

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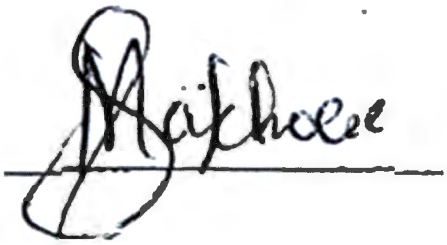
DECLARATION

I declare that the work in this dissertation is entirely my own work, except where source used or referred to have been documented and recognised, and has not previously submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification. This research has been carried out in full compliance with the ethical research requirements of the Department of Information Systems.

Signed: 

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ABSTRACT

Software Defined Networking(SDN) has been proposed to provide solutions that could significantly help Higher Educational Institutions to reduce not only expenditure in networking, but also the overall energy consumption of network equipment. Accordingly, SDN is seen as a "new idea in networking" by advocating separation of control plane and data plane which makes networking equipment to be logically programmable and become centrally controlled. SDN is fairly a new policy area and it has been included in the national strategies of many countries. However, it is not that case in South Africa as, there is no SDN policy at national level. In view of this concern, this study realised that there is no readily available framework that could guide SDN adoption policy and whereon to start Academic Institutions.

Therefore, this study argues that there is a need for a framework that provides policy makers with a clear step by step process involved in developing SDN policies. This research conducted content analysis on theories for policy development using secondary sources in literature in order to obtain a thorough understanding of the processes necessary for the formulation of an effective SDN policy. This study therefore, is an attempt to fill this gap in literature, and also explore SDN application in the current network in higher education institutions with the aim to reduce or relieve some expenditure in these institutions. To achieve its aim, the study conducted focus groups online survey with experts from Higher Education Institutions in Northern Cape Province, policy makers and experts from the Council for Scientific and Industrial Research (CSIR) as a relevant government sector to formulate and refine framework. It is hoped that the proposed framework will assist these policy makers to formulate an SDN policy that could address financial challenges in Higher Educational Institutions.

Keywords: Software Defined Network(SDN), Programmable Networks, Data Plane, Control Plane, Capital Expenditure(CapEx), Operational Expenditure(OpEx), Access Control List(ACL), Application Program Interface (API), Command Line Interface (CLI)

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Thank You, Almighty God, for with You Nothing is Impossible

Matthew 19, verse 26

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION TO THE STUDY

CHAPTER 2

THEORITICAL FRAMEWORK

CHAPTER 3

RESEARCH METHODOLOGY

Chapter 4

DATA PRESENTATION AND ANALYSIS

CHAPTER 5

FINDINGS, RECOMMENDATIONS AND CONCLUSION

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 Introduction

According to *Feamster and Kim, (2013)* computer networks are dynamic and complex and as a result unsurprisingly as, configuration and managing them continue to be challenging, thus network operators lately have had to implement increasingly sophisticated policies and complex tasks with a limited and highly constrained set of low-level device configuration command line interface environments.

Software developer 's these days only focus on storage medium and computing resource, but rather forget the other main factor such as network resource. As a result, most of these developers ignore this resource mainly because it is seen as being technical in a sense rather than one resource in any software developmental stages.

The purpose of this dissertation is to investigate what are the potential and challenges of applying Software Defined Network (SDN) in a Higher Educational Environment. *Kreutz, Fernando, Ramos, Verissimo, Rothenberg, Siamak Azodolmolky, and Uhlig,* (2015), envisioned how SND idea has "matured and evolved from an academic exercise to a commercial success and helping organizations to improve operational efficiency by significantly reducing operational costs", furthermore the devices between two networking types illustrated in figure 1-1 below. In this instance, the focus is placed on explaining the main concept of the latest paradigm in networking and how it differs in context form the traditional networking. Several links between software defined networking and academic environment can be identified when exploring this literature.

Thus, in this study the presentation of introduction, background of the study, problem statement literature review, aims, objectives and purpose of the study, body of knowledge, research questions research methodology and finally conclusion.

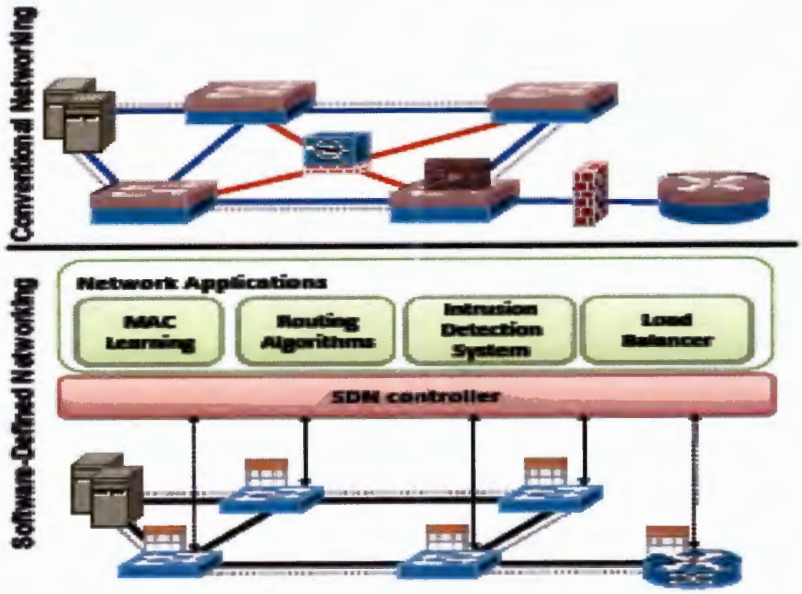

Figure 1.1: Traditional networking vs Software Defined Networking (Kreutz et al.,2015)

1.2. Background to study

According to (Kreutz et al.,2015) in figure 1-1 facts mention "the strong coupling between control and data planes has made it difficult to add new functionality to traditional network, the coupling of the control and data planes makes development and deployment of new networking features very hard since it would imply a modification of control plane, network devices through installation of new firmware"

A research conducted by Huawei showed that traditional enterprise Wide Area Network(WAN) operate at a 40% average utilisation over dedicated lines, the research further revealed that Google application of SDN technology on their WAN bandwidth utilisation jumped to more than 90%, thus showing that by upgrading dedicated WAN controller its customers WAN link usage rate increased to more than 90%, which significantly reduced the rental costs of WAN to their customers(Huawei ,2015).The Council for Scientific and Industrial Research (CSIR) conducted a research on SDN and Network Function Virtualisation where this was done as an experimental or action research in order to adopt or start applying this technology to its usage and deployment. (CSIR, 2015)

According to *Ahmad et al., (2013),* "the use of technology on almost every area of life in higher educational institutions, starting from course registration, downloading and using of learning resources, completing and submitting assignments, web surfing and more" In this regard SDN protocols can be tailored to suit these specification as they are open standards.

The aspect of SDN in higher educational institutions has not been explored due to the reason that this technology is fairly new in South Africa. The first piloted SDN full scale commercial launch was in 2016 where the architected WAN was adopted to real-time requirements through software updates compared to the olden days of physically configuring every piece of hardware to roll out network changes (Montjoie,2015).

Huge savings have already been realised by the higher education institutions where fibre backbone network was done in 2015 by the CSIR to chosen institutions for research purposes. According to *Campoli (2015)* "SDN also enhances the benefits of data centres virtualisation, increasing resource flexibility and utilisation and reduces infrastructure costs and overhead and enables network programmability and code development to bring applications and networks closer. The result is a modern infrastructure that can deliver new applications and services in minutes, rather than days or weeks required in the past delivering with a platform capable of handling the most demanding networking needs of today and tomorrow."

1.3. Problem statement

According to USAf, (2016) "universities remain dependant on government support, which continues to decline. The rate at which government support higher education institutions is increasing but below Consumer Price Index(CPI). This places more pressure on student fees and third stream income. In addition, personnel costs at most institutions exceed the value of government support, resulting in added pressure on other revenue streams." This has all happened within the context of a weakening Rand where institutions are hard-hit in the following areas:

- Imported research equipment
- Electronic and other library resources; and
- ICT equipment and software licenses.

The recent #FeesMustFall campaign is commendable as it might have clearly illustrated the cry of student communities across all higher educational institutions in the country.

Notwithstanding that the Department of Higher Education and Training(DHET) contributed up to 80% of the universities revenue shortfall arising from the fee-increase freeze for 2016, the moratorium created a series of challenges that casted serious doubt on whether the sector will ever recover (USAf, 2016).

Thus SDN benefits are huge, particularly in the aspect of ICT equipment cost saving in higher educational institutions. Nevertheless, the increasing energy shortage is becoming one of the biggest drawback in South Africa with rising levels of energy poverty in a rich country due to continuous price rise in electricity. In saying that "South Africa will become a major energy importer as opposed to the current little-recognized position of being an energy exporter. The full socioeconomic impacts of changing from a coal-based energy country have not been fully or realistically considered" (CSIR,2017).However, there is a limited research that has been done to alleviate expenses in ICT support equipment as well as energy saving in higher educational institutions, Furthermore, according to *Pouris and Inglesi-Lotz, (2014)* universities' total economic impact as a percentage of the GDP in that current year and estimated that as a result of the electricity crisis since 2008, the cost of unserved electricity has reduced the Gross Domestic Product (GDP) by more than R300-billion.

This study therefore, is an attempt to fill this gap in literature, and also explore SDN application in the current network in higher education institutions with the aim to reduce or relieve some expenditure in these institutions.

According *Benkhelifa et al., (2016)* further says "energy consumption optimisation in data centres is again seen where the authors use SDN to implement an optimised flow scheduling and routing protocol. Another, work on energy efficient routing can be seen where SDN is employed via greedy algorithms to reroute traffic during quiet periods and save considerable amounts of energy by disabling routers".

1.4. Research Questions

The intension of this study is to investigate how SDN can be implemented in higher education institutions with aim of saving expenditure.

1.4.1 Main research question

The study was guided by the following research question:

1. Can Software Defined Network be used in higher education environment in order to develop effective research with progressive teaching and learning?

1.4.2 Research Question

In order to answer the above question, the study addresses the following sub-questions:

2. What are the barriers that hinder higher education institutions use of SDN with the current infrastructure?
3. How can the application of SDN save costs and be improved to enhance access to educational material?
4. What difference will SDN incur in Higher Education Institutions main operations?

1.5. Research aim and objectives

This section briefly presents the aim and objectives that the research study strove to achieve in order to solve the problem posed in the previous section.

1.5.1 Research Aim and Objectives

The study seeks to illustrate the following aims:

The main aim of this study was to investigate the use of software defined network as a solution in higher education in the Northern Cape Province. In order to achieve this aim, the set objectives of this study are to:

- Investigate what hinder higher education institutions' use of SDN with the current infrastructure;
- Determine the major processes required in formulating, implementing and adopting effective network policies in relation to saving costs;
- Ascertain the relevance of software defined network used by different stakeholders in higher education institutions; and
- Identify how OpenFlow is the best solutions for enhancing educational platform for in order to effect enhancement in operations of these institutions.

1.6. Brief Literature Review

1.6.1 Introduction

Like *Jammala, Singha, Shamia, Asal, and Lic, (2013)* said "Network today depend on IP addresses to identify and locate servers and applications. Thus it works fine but requires considerable time and effort for large virtual networks also managing such environment will be expensive." *Kreutz et al., (2015)* went on to say that "traditional IP networks are complex and hard to manage despite their widespread adoption, Network operators need to configure each individual device separately using low-level network policies. However often vendor specific commands and automatic reconfiguration and response mechanisms are virtually non-existent."

The concept of programmable networks dates its origins back in the mid-90's, right when internet was starting to experience widespread success. Until that moment, the usage of computer networks was limited to a small number of services like e-mail and file transfers. The fast growth of internet led to the formation of large networks, turning interest of researchers and developers in deploying and experimenting with new ideas for network services with the main focus on managing network infrastructure with various efforts focused on finding novel solution for creating more open, extensible and programmable networks (Foukas, Mahesh, Marina and Kontovasilis, 2013).

1.6.2 Definition Software Defined Network

According to *Sezer, Scott-Hayward, Chouhan, Fraser, Lake, Finnegan, Viljoen, Miller and Rao, (2013)* SDN refers to the "architecture, control and data planes which are decoupled, network intelligence and state are logically centralized, and the underlying network infrastructure is abstracted from the applications. *Kreutz et al., (2015)*, further define SDN as a network architecture where the forwarding state in the data plane is managed by a remote control plane decoupled from the former. Thus network architecture has the following four pillars:

- Control and data plane are decoupled
- Forwarding decisions are flow based instead of destination based
- Control logic is moved to an external entity; and
- Network is programmable through software applications.

Kreutz et al. (2015), went on to say that the SDN concept has the following three fundamental abstractions:

i. Forwarding - should allow any forwarding behaviour desired by the network applications;
ii. Distribution - shield applications from vagaries of distributed state, making the distributed control problem a logically centralized one; and
iii. Specification - allow network application to express the desired network behaviour without being responsible for implementing that behaviour itself.

1.6.3 Importance of SDN

Like *Jain and Paul, (2013)* said that "SDN is expected to reduce both capital expenditure and operational expenditure for service providers, cloud service providers, and enterprise data centres that use lots of switches and routers", focusing on higher educational institutions reduction costs or expenditure on networking resources will impact on budget.

However, an in depth look into SDN has already shown some promise in optimising power consumption in computing systems and networks (Benkhelifaa, Welsha, Tawalbehb, Jararweh, Mahmoud, 2016). Therefore, it is proposed that a combination of increased energy consumption modelling and SDN will catalyse the performance of the next generation of Mobile Cloud Computing (MCC) applications through greater insight into their interaction and therefore provide more efficient applications (Benkhelifaa et al., 2016).

1.6.4 Security Issues of SDN

Tokhid, Rashid, & Roni, (2012) and Dzazali, Sulaiman and Zolait, (2009) claim that organisations that depend on Information Technology(IT) are facing a continuous increase in the number of types of risk that are no longer limited to the compromise of the information system network but also include legal liabilities such as human errors, loss of trust, and severe financial repercussion. Threads to higher educational institutions are constantly increasing these days, despite the fact that these institutions rely on Information Technology(IT) to reach their business objectives. According to (Makhoere, 2016) "a security awareness is one of the core necessities of technology and also recognizing the need to train the users on the right level. The focus is mostly on viruses and threads that might attack the network rather than the usage and application as these would be for teaching and learning and their obligation is support."

1.6.5 Network Virtualization

Virtualization decouples and isolates virtual network from the underlying network hardware, thus this isolation shares the same physical infrastructure for packet forwarding, Multiple independent virtual networks are then overlaid on the existing network hardware offering the same features and guarantees as a physical network but with the operating benefits and hardware independence of virtual machines *(Jammala et al., 2013).*

Consequently, *Feamster and Kim (2013)* further says that "although network virtualisation is conceptually independent of SDN, the relationship between these two technologies has become much closer in recent years as they become tightly coupled and both are programmable networks."

1.6.6 Cloud Computing

Cloud computing is a new business model wrapped around new technologies like virtualisation., These day's cloud platforms such as Microsoft and Google are offered free to students and staff at educational institutions which include emails, contact lists, calendars, document sharing, creation and sharing documents as well as ability to create websites *(Sclater, 2009).*

1.6.7 Internet of things Awareness(IoT)

According to *Flauzac, Gonzalez and Nolot, (2016)* "the rapid proliferation of the Internet of Things (IoT) has led to growth in the networking scenario, where the recent upcoming technologies of network programmability like SDN may be effectively intergraded to create a communication platform, with this in mind study propose cluster that can solve problems with routing processes in distributing SDN-architecture. Thus, researcher still believe that traditional network such as enterprise network and classic time-out transport protocols are not capable of handling requirements of IoT in an efficient, scalable, seamless and cost effective manner."

One such researcher *Bera, (2017)* said that "the advent of SDN introduces features that allow the network operators and users to control and access the network devices remotely, while leveraging the global view of the network and SDN-based technologies, which are useful to fulfil the requirements of IoT, from different networking aspects-edge, access, core, and data centre networking."

1.7. Significance of the Study

Higher educational institutions use a big portion of their budget on software and networking as being the critical aspect in research, teaching and learning. Thus SDN adoption will reduce huge operations costs on information systems to effectively spending on computer, infrastructure and networking devices. Consequently, these institutions' IT management experience difficulties concerning the process they should follow in the development and implementation of SDN.

In view of lack of available guidance for the development and adoption of SDN policies, network policies developers often use institutional policies or vendor available sources. *Feamster and Kim, (2013)* state that "network policies for campus and enterprise networks are very complex and thus error-prone, which makes them a good subject for deploying procedure".

Furthermore, (CSIR, 2015) conducted research which was experimental stage at one of the country's university campuses. "SDN approach has traditionally being applied to fibre backbone networks there has been a lot of attention to applying it to wireless networks. An approach that combines Cognitive Radios (CRs) and SDN will increase the programmability of the radios and the whole network respectively and hence increased the flexibility of configuration and lower the cost of maintenance and upgrading of the network."

1.8. Limitation of the study

The scope of the study is limited to the Higher Education Institutions in the Northern Cape with a focus on only the institutions in question.

1.8.1 Participation and Sampling

There might be complexity of encouraging essential participants to be part of the study as others would not have the need and the interest in forming part of the study.

1.8.2 Funding

For this study, the following aspects might bring limitation or delay to conduction:

- Researcher is located in one place and respondents (CSIR Research Officers and Higher Educational Institutions Network Engineers) are located at different locations from the researcher. Therefore, there was a need for travelling.
- The researcher might need to purchase a recording device for the interviews.

However, researcher has applied for a bursary with Sector for Education and Training Authority(SETA) for the studies and for the stated purposes, was approved and transferred to NWU.

1.8.3 Methodological Weakness

This study was limited to the qualitative data that was obtained from the specified experts as well as results and analysis for the captured data. Additionally, the selected Public High Educational Institutions in the Northern Cape Province may not have implemented or have the need to adopt SDN adoption or have resources to implement SDN.

1.9. Research Contributions

The main contribution of the study was a framework for Software Defined Network policy development for South African Higher Educational Institutions that can be used for similar developing countries. SDN adoption of this framework will bring a change in networking attributes by:

- Network Functionality

Functionality of isolation of the networks from one another in configuration being either central or automatically.

- Supportability

Support of southbound interfaces in network sharing of Higher Education Institutions

- Programmability

Programmatic interface to the controller to solve time-consuming, error prone and inconsistent barriers of traditional networking.

- Reliability and Visibility

Eliminating errors to increase network reliability and end-to-end network visibility

- Performance and scalability

Improving network performance by decreasing scalability of the solutions implemented.

- Security

SDN controller supporting enterprise-class authentication with ability to isolates tenants in sharing network.

1.10. Research Outline

The study pursued the following structure:

Chapter 1

Introduction to the study

This chapter examines the background to the research, outlining the importance of the research, highlighting the problem statement and pointing the way forward.

Chapter 2

Literature review

The literature review focuses on:

The background of software defined network. A detailed comparison of models is mentioned in brief literature reviews as well as an evaluation of literature that exist on the use of technology acceptance model. The chapter also looks at the shortcomings of this information circulation tools and gap in literature is also shown in this chapter.

Chapter 3

Research methodology

This chapter discusses the research paradigm of the study and the data collection methods chosen by the study. The methods discussed according to their advantages and disadvantages. Furthermore, the sampling design and data analysis method will be discussed in detail in this chapter.

Chapter 4

Data presentation and analysis

This chapter presents the findings and interpretations of the study, as well as the implications of the research.

Chapter 5

Findings, recommendations and conclusion

Overall conclusions and recommendations are presented in this chapter The findings of the research, recommendations, as well as its implications for future research are covered in this chapter. Each research question is further explained, and lastly conclusion was made to bring the entire research to a close.

1.11. Summary

This chapter provide an outline of the whole study. It also gave way forward or opening path on how to strategize the implementation process while clearly showing the higher educational network experts how they may benefit not only technologically but also financially as well as safely driven sheer pleasure. Additionally, investigating the adoption of SDN in these institutions, which led to the study being conducted on factors which influence the adoption of this technology can be categorized into being external (Government Agents –CSIR) or internal (Network Engineers, IT Support Directors or IT Support Managers) which let to these individual's adopting behaviour were discussed. There are a few models that exist which seek to explain this phenomenon.

CHAPTER 2

THEORITICAL FRAMEWORK

2.1 Literature Review

2.1.1 Introduction

Chapter 2 is divided into four sections. Section 1 deals with the background and the literature which reviews some of the previous work done on SDN's use at Higher Educational Institutions across the globe. Section 2 observes the detailed comparison of models as mentioned in brief literature reviews as well as an evaluation of literatures that exist on the use of technology acceptance model. Section 3 provides the overview of the shortcomings of this information circulation tools as well as the gap in literature.

2.1.2 Background

The idea of programmable networks has been proposed as a means to remedy many networking errors and challenges. This promoted innovation in network management and the deployment of network services through programmability of the underlying network entities using some sort of an open network API. *Foukas, (2016)* In saying that SDN, can be seen as holistic managing approach for "flexible networks being able to operate according user's needs in a direct analogy to how programming languages are being used to reprogram computers in order to perform a number of tasks without the need for continuous modification of the underlying hardware platform."

2.1.3 Why is SDN Necessary

According to *Kreutz et al., (2015)*, "internet has led to the creation of a digital society, where (Internet of things- IoT) everything is connected and is accessible from anywhere but despite widespread adoption, traditional IP network are complex and very hard to manage".

However, this internet infrastructure remained fairly stagnant for decades. It is thought that SDN in a very interesting way which may bring an opportunity to reinvent the whole notion of networking by the following means:

- Flexibility and Innovation
- Logically centralised networking control
  - Fault tolerant
  -Efficient and Deterministic
- Separate monitoring, management and operation
- Separate hardware from software

In saying that, the initial relevance is to try and understand the present state of networking in Higher Educational Institutions and how the adoption of Software Defined Networking would have impacted change done by identifying adoption factors and its impact on networking professionals

In saying that *Arandza, (2016)* further said that "Software-defined networking is an emerging model that, by favouring centralisation of network control, and enabling network programmability, promises to ease network deployments and configuration and enhance network resources performance. However, there is substantial uncertainty amongst network engineers and IT organisations about SDN implementation challenges. There are several causes of that uncertainty, including, the immaturity of vendor solutions and SDN enabling standards, technical difficulties around network scalability and security, and challenging migration processes from legacy networks to SDN"

Furthermore, *Jammal et al, (2013)* mention that "with the SDN approach, network administrators no longer need to implement custom policies and protocols on each device in the network separately. In the general SDN architecture, control-plane functions are separated from physical devices and are performed by an external controller (e.g., standard server running SDN software). SDN provides programmability on the control plane itself, through which changes can be implemented and disseminated either to a specific device or throughout the network hardware on a secure channel. This approach promises to facilitate the integration of new devices into the existing architecture. The SDN controller improves the traffic engineering capabilities of the network operators using video traffic. It enables network operators to control their congestion hot spots and reduces the complexity of traffic engineering"

A profound understanding of SDN paradigm with deeper explanation of its architectural Layer is explained in detail in this chapter.

2.2 Classification of SDN

2.2.1 Networking Traditional(Normal) Way

This section demonstrates a clearer picture of Traditional Networking Landscape and shortcomings or limitations that persuaded the Networking community in Higher Educational Institutions to develop or start wanting a new standard in network configuration known as Software Defined Networking.

In saying that, *Modieginyane et al, (2017)* mentioned that "networking has proved to be capable and reliable for over the years. This point to the fact that large, medium and small size network architectures have been successfully implemented using these strategies to date. In today's technological demand for powerful systems, traditional ways of network computing face a tough time in terms of efficiency and management. In this regard, network innovation has become difficult to realize in traditional networks. This is mainly because, in addition to the network devices being proprietary, the network control is implemented on each forwarding device, thereby making it hard to access and operate on the functionalities of these hardware."

However, *Benavices et al., (2015)* explain traditional networking in Figure 2-1 by saying it "consist of the encapsulation of both the data (packet switching) and control planes in the same hardware device. In order to administer the whole network, a connection must be made to each of the devices and a set of vendor specific operating system commands must be executed for configuring them. The difficulty maybe in the establishment of a new configuration or topology that may be necessary"

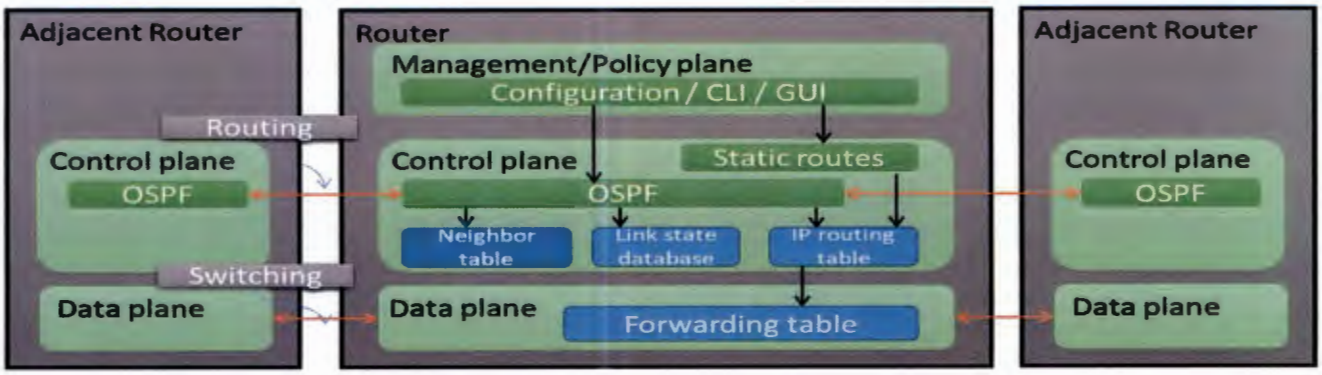

Figure 2-1 Traditional Network Infrastructure (Jammala et al.,2013)

2.2.2 Open Flow Networking

Open Flow Networking provides a standardized way of decoupling the control and data planes with a purpose of managing traffic in switches and exchanging of information between switches and controller. This is illustrated in Figure 2-2 which further shows flow of tables as follows:

- Controller manages the traffic (network flows) by manipulating the flow table at switches but alternatively instructions are stored in flow tables.
- When packet arrives at switch, match the header fields with flow entries in a flow table.
- If any entry matches, performs indicated actions and update the counters.
- If it does not match, switch asks controller by sending a message with the packet header.

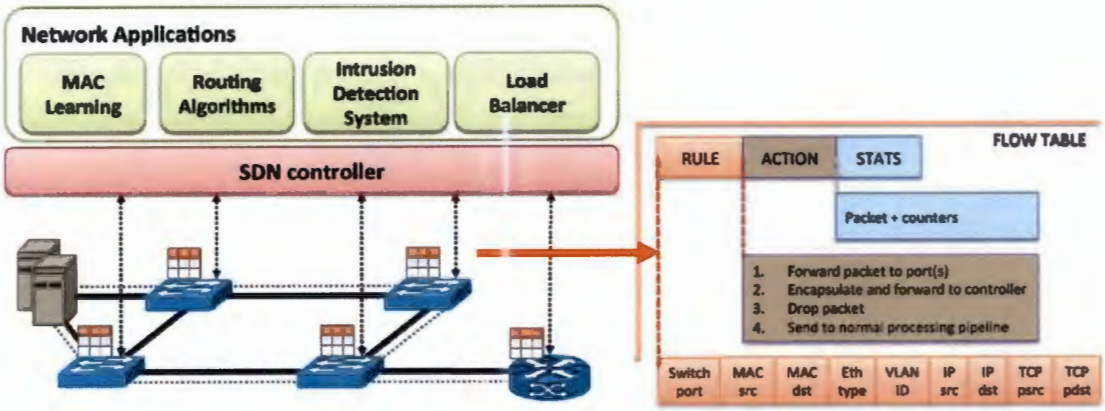

Figure 2-2 Open Flow Networking (Sezer et al.,2013)

One can safely say that OpenFlow is a subset of SDN, but the reality of the matter "SDN architecture, the control and data planes are decoupled, network intelligence and state are logically centralized, and the underlying network infrastructure is abstracted from the applications. Further, OpenFlow allows the use of any subset of these header fields for applying rules on traffic flows, meaning that it conceptually unifies many different types of network devices" (*Foukas et al., 2016).*

For instance, a router could be emulated by a flow entry using a packet header performing a match only on the IP address, while a firewall would be emulated through a packet header field containing additional information like the source and destination IP addresses and port numbers as well as the transport protocol employed. Just like API's illustrated in Figure 2-3 below as they provide "nice to have" features such as programmability aa well as, protocol independence ability to modify network parameters as required, including elasticity and granularity.

In addition, Nkosi, (2018) said "SDN is based on OpenFlow protocol which is a standard for remotely programming the forwarding plane of the network devices. OpenFlow protocol overtly specifies protocol headers on which it operates and these headers have been growing with each newer version of OpenFlow."

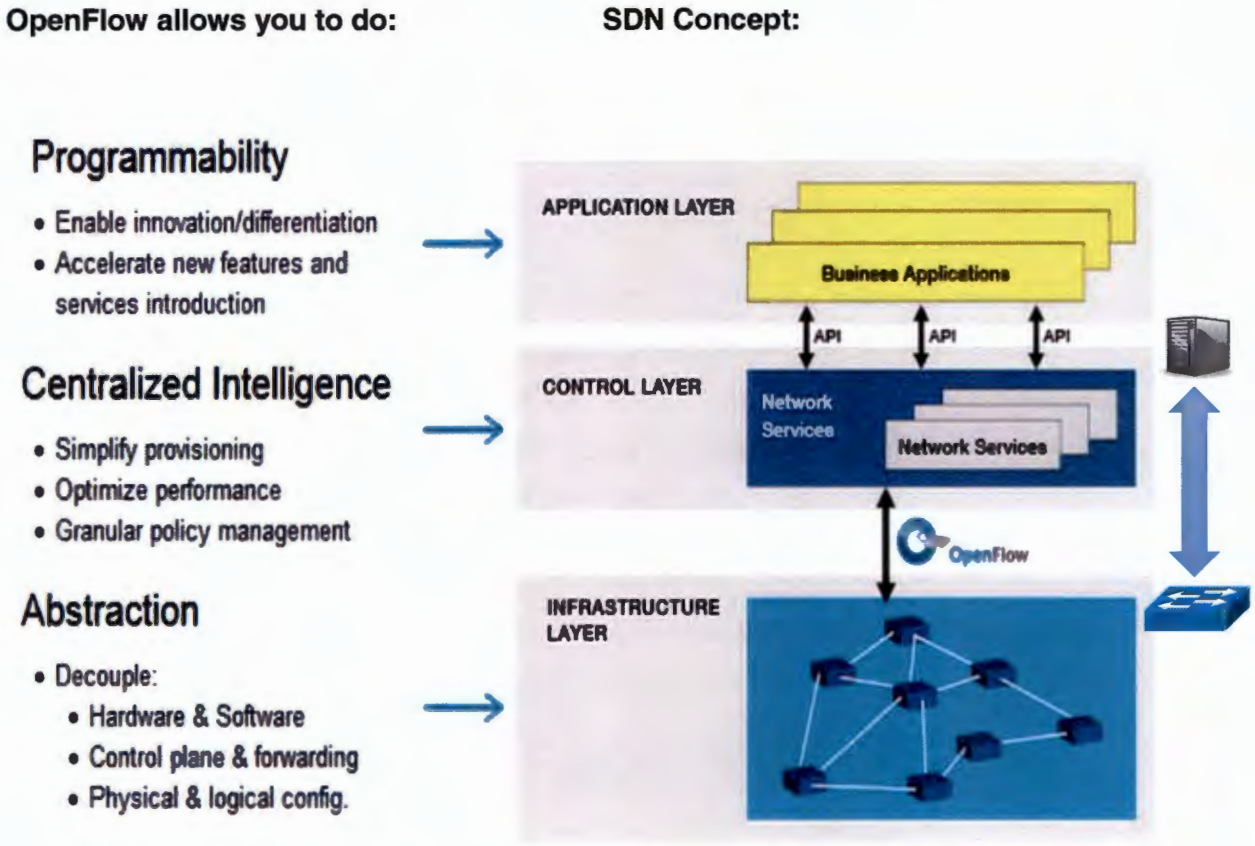

Figure 2-3 Open Flow Networking vs SDN ((Mamushiane et al.,2018)

Most, often people point to OpenFlow as being synonymous with SDN, but it is only a single element in the overall SDN architecture. Furthermore, OpenFlow is an open standard for a communications protocol that enables the control plane to interact with the forwarding plane.

However, *Anzaloni et al., (2015)* said "OpenFlow can be used to build efficient solutions to handle fault-tolerant multicast in substation environments. One open question that remains is how suitable current OpenFlow implementations are for use in productive networks. To date, many OpenFlow switches are implemented in software only. Just like software switch often only used for prototyping purposes, or for the OpenFlow specification that is only partially implemented in hardware"

2.2.3 Networking SDN Way

Nkosi, (2018) further mention that "Software Defined Networking (SDN) - enabled tactical networks that offer an environment for the delivery of information services which support dynamically changing force in the presence of physical threats and wherein bandwidth is scarce. These networks deliver critical information with required quality of service in the presence of changing operational priorities. SDN-enabled tactical networks offer benefits such as configurability, which provides the ability to configure the network without re-engineering of the hardware and agility, which provides the ability to re-configure the network quickly and easily with minimal resources."

The different approaches further explain networking SDN way as being better to adopt in Higher Educational Institutions:

I. Hybrid Controller Approach

The control plane deploys a mixture of all approaches to avoid limitations of each. Thus *Anzaloni et al., (2015)* says "making the network proactively tolerant to one fault, so that failover times are very low and there is very little packet loss on disconnection, but we also propose that the network be able to reconfigure itself to the new topology after the failure."

II. Physically Controller Approach

This is when control pane interconnects multiple domains were a large network could be divided into smaller network and each is maintained by a local controller.

III. Logically Controller Approach

This approach is when the controlling logic of centralized controller running or administering those distributed smaller control domains.

As Nkosi, (2018) says "both in logically and physically distributed approaches, each controller has a global view of its network. The difference lies in how the controllers are placed and type of communication among the controllers. In a logically distributed approach, each controller has to update other controllers each time there is a network state change. In physically distributed approach, the controllers update each other periodically"

IV. Hierarchical Controller Approach

On this approach the control plane is made up of more than one layer of controllers and each will have different responsibilities.

On the other hand, traditional network has proved its reliability over the years. However, its ways of networking face a tough time in terms of efficiency and management. In this regard a comparison is made between the two to further interpret to which technology to be used and to what intend that technology could be used. Table 2-1 gives these arguments in terms of comparison.

Table 2-1 Comparison of SDN and Traditional Networking

Potential	SDN	Traditional (Non-SDN) Network
Operate Features	Separation of the control and data forwarding planes. Easily controlled and deployed.	Hard-structured and logically coupled operations. Very complex control.
Implementation	Fast and easily implemented. Adapt to the need of application environment.	Time involving to implement. Operate on dedicated environments.
Stability	Currently unstable with few technological supports.	Stable with great network support.
Architecture	Software oriented with resource customizable features. Centralized network intelligence.	Hard-structured and operated on dedicated and proprietary devices.
Configuration	Configuration can be largely done remotely. Software monitoring and operation done centrally.	Network devices need to be configured directly and individually.
Management	Easily managed using APIs. Can be easily modified depending on the network demand.	Difficult to manage as network devices are solely proprietary and hard to access.
Maintenance	Can be easily maintained as new services or network upgrades can be done easily without affecting the whole network.	Difficult to maintain as the whole network might be affected by a small change in the network.
Error Checking	Easy to check network errors as software module are dedicated to do this. Therefore, errors can be quickly isolated easily from the network.	Error checking is extremely time consuming and difficult to isolate as operators have to the check whole network even for small errors.
Novelty	Network innovation becomes easy as new features of the network could be attached to the existing infrastructure. Does not need to revisit the whole network processing.	A simple change will require a serious study and understanding of the whole network structural design. Therefore, innovation is possible but difficult to implement.

Table 2-1 SDN vs Traditional Networking (Modieginyane et al.,2018)

2.2.4 Fault Tolerance in SDN: Access and Core Networks

The OpenFlow -based controller classify three approaches essential for SDN models for recalculating the configuration rules only when a fault occurs.

I. Reactive SDN

In this approach switches sends first packets to controller, then controller programs switch's flow table to handle the rest of the flow and constantly adjust models which are in flux as changes are made immediately as a reaction to current network conditions.

In saying that *Dusi, Bifulco, Gringoli, and Schneider (2014)* further says that "This is the base volatility management model in which there is a high rate of change in the location of end-points (usually virtual machines) and OpenFlow is used to continually update the location and path through the network to each end-point as well as entries in the flow table of the switches which are installed only when packets for the corresponding flow table is interacting between switch and controller."

Thus, the disadvantage is when the switch is mainly dependent upon the controller's decision. In an event that it loses connection with the controller it cannot handle packets, with a problem being source of Denial of Service(DoS) on controller (packet-in event of loss of connection).

II. Proactive SDN

In this approach the controllers program the switches proactively, according to its own knowledge of the network and models anticipate issues in the network and attempt to address them before they become a real problem by making changes to the routing of data through the network before utilization becomes too high to mitigate potential performance problems.

Like *Kaur et al., (2014)* say this approach "allows quick test and deploying of new applications in real network". It is thus a smarter approach than just reacting to network events (global knowledge, discovery, updates) as it overcomes the limitations of reactive approach because even if the switch loses connection with controller, it does not disrupt traffic.

III Predictive SDN

In this approach there is less disruption as it occurs with less frequency that a reactive model still allows for trends in flow and data volume to inform appropriate routes.

2.3 Role and Importance of SDN in Higher Education Institutions

Higher Educational Institutions will benefit agility and flexibility in capitalizing new orchestration and automation along with capabilities of today's networking innovations. This will become increasingly important as big data, analytics, machine learning and artificial intelligence make way onto campus networks with great ease and secure automation.

Thus, *Juniper, (2017)* further says "higher-education institutions need to create a network that is responsive, agile, and easily managed – one that is automated – to help their institutions adapt with the digital transformation of the learning environment."

Institutions of Higher Learning spend approximately above 80% on IT managed daily operations. Similarly, *Jupiter, (2017)* says "digital learning becomes the predominant learning model, campus IT teams will be pressured to deliver and support a variety of new services similar to *Figure 2-4* below, to differentiate themselves as top-tier digital learning environments. Unfortunately, legacy networks are likely to buckle under this pressure unless IT leaders take the necessary steps to prepare the network"

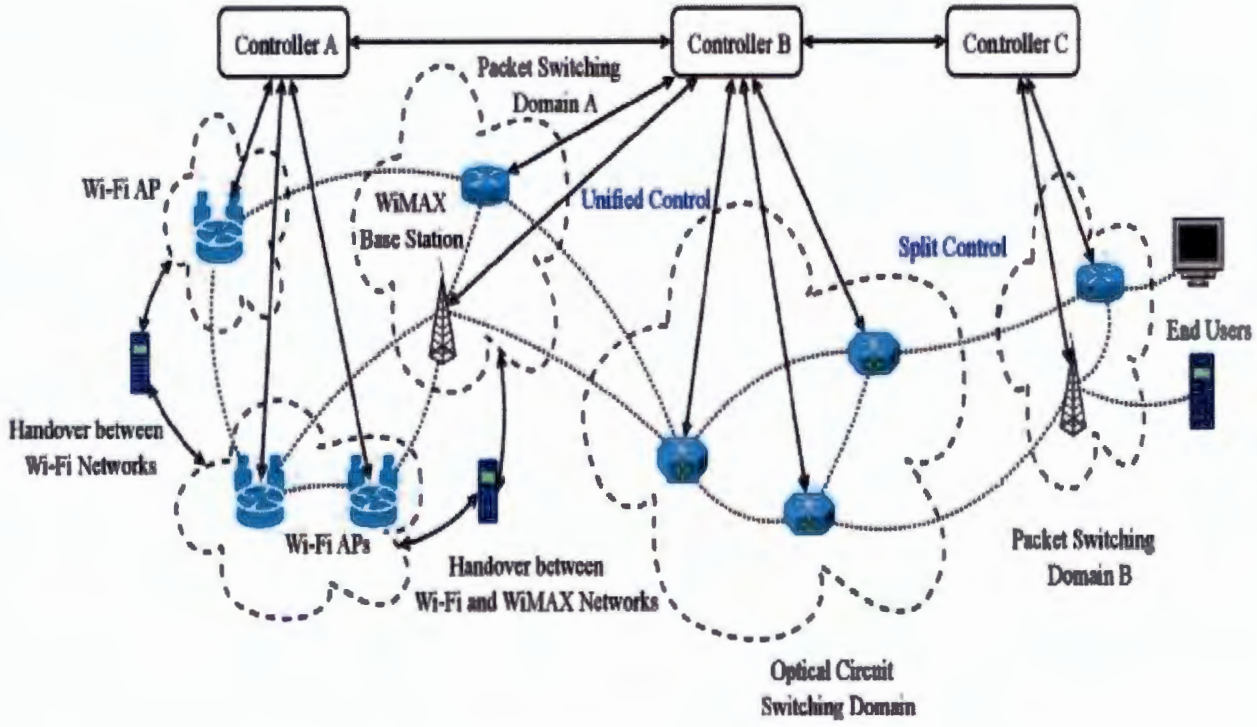

Figure 2-4 SDN Paradigm (Foukas et.al,2016)

2.3.1 Areas of Improvement in Operation

According to *Joch, (2018)* "Software Defined Networking platforms simplified management, security and deployment in higher education by giving us an opportunity to capitalize on". In this way implementation in today's networking innovations in the best way possible, as well as expanding their software's strategy to something even more transformational as follows:

I. Software Defined Data Centre Technology (SDDC)

This brings greater automation and efficiency not only to networks, but also to computing, storage and other core capabilities in campus infrastructure as this can be seen as some new ways to manage and secure Campus IT resource.

Dusi et al., (2014) says that "Industry has virtualized all the disparate pieces of the data centre, the software-defined network is the last step to make the connections between these pieces dynamically configurable and it also frees applications from having to maintain knowledge of the changing network."

II. Software Defined WAN(SDWAN)

WAN circuits are expensive even for higher educational institutions under South African Government Subsidy Program. Therefore, the application of this relatively new technology is more efficient and cost effective through SDN. *Joch, (2018)* says that "SD-WANs allow IT staffs to aggregate their network connections to save money on bandwidth costs and networking equipment in branches, such as satellite campuses"

III. Network Function Virtualization

SDN and NFV do not necessarily depend on each other but both can be merged to potentially challenge legacy networking by letting the functions of SDN controller to be deployed as virtual functions. This is done by Open Flow switches which run controlled rights using NFV software.

Jammal et al., (2013) stated that "merging SDN and NFV enables replacement of expensive and dedicated hardware equipment by software and generic hardware. SDN and other networking upgrades allow IT staff to deliver services more efficiently. Previously, when administrators needed to spin up new virtual servers, they might have needed to change VLANs for the specific physical chassis they were using."

IV. Cloud Computing

Enterprises have securely embraced both public and private cloud services. This led to an unprecedented growth seen by SDN paradigm which was adopted as to eliminate the network infrastructure maintenance process and to guarantee easy management.

According to *Nkosi, (2017)* "public cloud providers, including Google and Microsoft, rely heavily on SDN for flexible provisioning of services within their data centres. With similar technology, colleges can more easily move workloads around hybrid cloud environments and a cloud-ready network must be able to dynamically respond when IT needs to move large amounts of data, without bottlenecks, security holes or data loss."

V. Big Data

Mega datasets require massive parallel processing on thousands of servers which needs to be connected to each other thus fuelling a constant demand for additional network capacity.

2.3.2 Networking Infrastructural Adoption

As much as SDN is appealing to higher educational institutions one should not only look at changing their software defined strategy because alongside with infrastructural strategy both will evolve into even more transformational mechanism which will offer:

- Efficient Services;
- Quick respond to new capacity demands; and
- Shoring up Security.

Thus, *Mamushiane et al., (2018)* says "a potential solution to this challenge is dynamic allocation of capacity as per service level agreements (SLAs) between tenants and network owner. A promising technology to achieve allocation dynamism is the current technological trend called software defined networking (SDN) coupled with its complementary technologies namely Network Function Virtualization (NFV) and Mobile Edge Computing (MEC)."

I. Infrastructural Sharing

Since it has already been established by researchers *Mamushiane et al., (2018)* that SDN – enabled Infrastructure sharing presents costs saving and level of control maintained by "high level of differentiation and confidentially, sharing parties must maintain autonomous control of the quality of service delivered to their customers.

In an SDN environment, the controller has a global view of the current network utilization. Therefore, in the case of infrastructure sharing, new tenants can dynamically request network resources and negotiate SLAs with incumbent operator on-demand. The SDN controller also enforces strong isolation of traffic belonging to different tenants to guarantee confidentiality."

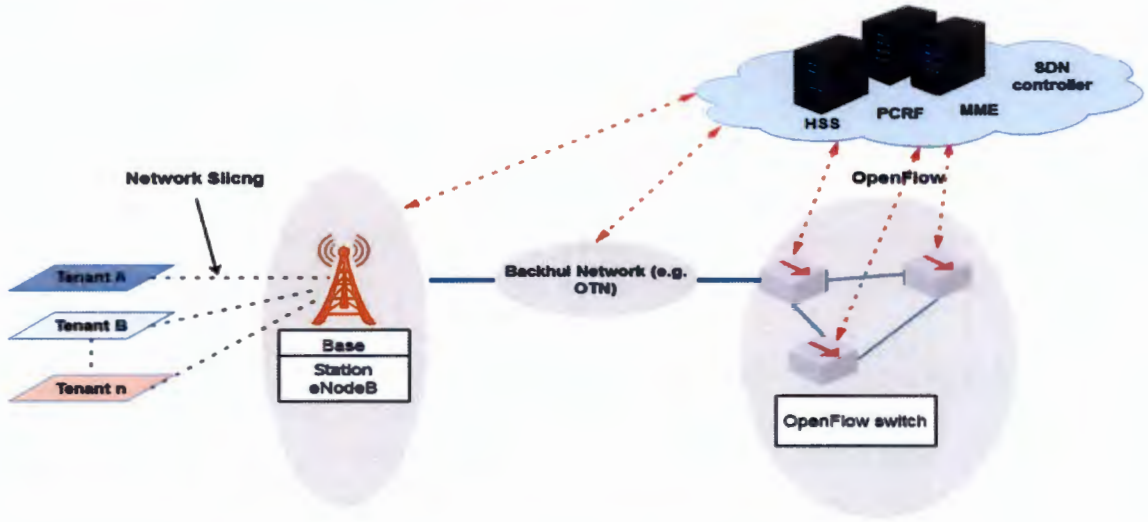

Figure 2-5 SDN Infrastructure Sharing (Mamushiane et al.,2018)

Infrastructural sharing in a SDN –enabled network is commonly known as network slicing as illustrated in *Figure 2-5* above where SDN controller facilitates end-to-end dynamic provisioning of network illustrating tenants and enforces confidentiality in the network, taking this in mind that tenants will be Higher Education Institutions with its satellites or different Institutions. "The communication between the control plane and data plane is via a southbound interface such as OpenFlow." *(Mamushiane et al.,2018)*

Furthermore, tenants are different higher education institutions interlinked with the proposed SDN framework in *Figure 2-5* above where Backhaul Network will be the engine behind running the SDN infrastructure and managing the network for easier sharing platform.

However, these institutions or campuses will share network among different types of levels of infrastructure as follows:

- Active Front Haul Sharing

This involves sharing access transmission technology between base stations and radio access network.

- Active Back Haul Sharing

This involves sharing of transport technology like microwave links, optical fibre and copper which will be between RAN and core network were critical business data is kept strictly confidential.

- Passive RAN Sharing

This allows network operators to enter into agreement to share passive element such as air conditioning and power batteries with intension to reduce CapEx and OpEx.

- Active RAN Sharing – No Frequency Pooling

It occurs where each campus or tenant is allocated their own virtual RAN instance and these instances connect to core networking.

- Core Sharing

It involves the sharing of mobile core functions such as mobile switching and servicing support node in 3G as well as packets gateways in 4G networks. It is hoped that this would drastically increase number of connected devices expected to surpass tens of billions with higher flexibility, scalability, cost effectiveness and energy efficiency.

II. Cost Implications to Change

According to *Mamushiane et al., (2018)* "the impact is estimated in terms of how long it takes to recover Capital Expenditure(CapEx) investments and make a network profitable. This is illustrated utilizing the case example of the South African environment that full sharing may allow an order of magnitude reduction in time needed to reach profitability, which may allow for profitable operation in rural areas and easier entry of smaller operators into market."

In the same way this can be applied to the South African Higher Educational Institutions to recover capital expenditure and make networking profitable while network resource sharing in leveraging SDN in network infrastructure will reduce Operation Expenditures(OpEx) between multiple institutions. Thus *Mamushiane et al., (2018)* said "the network owner and tenant enter into long term contractual agreements that bind the tenant to pay for capacity even when they are not utilizing it. This directly increases the OpEx for the tenant and gives the network owner an unfair advantage to reap returns on unused capacity."

III. 5G Network Platform

SDN and NFV are considered critical technologies for this platform, thus a Shared Infrastructure Management Framework was designed and implemented for this purpose and this was further enhanced for performance optimisation of network functions and underlying physical infrastructure with the objective of identifying requirements for designing and developmental testbed for future 5G mobile networks in higher educational institutions.

Like *Zimmerman, (2017)* said "5G will open doors in the classroom we can't even imagine yet, which will ultimately give students the power to be more successful, more engaged, and give them access to higher education and new career paths."

2.3.3 SDN impact on Work Force Training

In the past year, training advancement done from network engineer perspective, available from both networking vendors and open source organizations, indicated that the impact of the adoption of an SDN initiative will take on networking staff and operations.

However, Cisco, (2016) introduced new certifications "Cisco Business Application Engineer Specialist, Cisco Network Programmability Developer Specialist, Cisco Network Programmability Design Specialist, and Cisco Network Programmability Engineer Specialist."

For this reason, cisco recently announced new certifications for its Application Centric Infrastructure (ACI) programmable networking initiative, its response to software-defined networking. The certifications are designed to tailor new roles for IT practitioners looking to transition their company's infrastructures to programmable, application policy driven, SDN-type environments.

2.4 Benefits and Challenges of Adopting SDN

2.4.1 Benefits of adopting SDN in Higher Educational Institutions

I. Lower Capital Expenditure

Capital Expenditure is one of the elements in Higher Education Institutions that Chief Financial Officers would likely to start cutting as it takes a much bigger chunk of the budget.

Prabu, (2016) agrees by saying that "SDN Software-Defined Networking remodels operations by automating network configuration, provisioning, and management making use of central network administration and network programmability. It provides a uniform control and management capability across multiple technologies and network layers. Through infrastructure automation, provisioning and configuration times improve, complexity decreases and manual mistakes are significantly reduced."

To illustrate this, Krish and Prabu, (2016) further said "CTO and president of the big networking player AT&T Labs, the organisation has the goal of virtualizing 75% of its network by 2020 applying SDN and NFV technology. Once this objective is achieved, he foresees savings in operational costs of up to 40 or 50 percent."

II. Lower Operational Expenditure

Higher Educational Institutions run high operational costs and a big portion of this comes from Information technology networking and salaries of networking professionals, thus adoption of SDN, these Institutions will be experiencing lower operational expenditure.

To support this *Contreras, et al., (2015)* say that "traditional networking network resources such as circuits or network hardware need to be often Over-dimensioned to respond under flow peaks. This over-dimensioning network links to accommodate traffic where the peak load varies widely and changes frequently creates a significant Capital Expenditure (CAPEX) inefficiency."

III. Network Resource and Flexibility

According to *Arandza, (2016)* "SDN, for instance, can enable multi-tenant hosting providers to connect their virtual and physical servers and remote and local facilities into one logical

network. By doing this, network providers can provide to each of their clients a differentiated virtual network. Put simply, SDN is a potential method for providing networks as a service (Naas), which will allow virtual network operators and flexible service operators with the ability to control Data Centres along with their traffic."

From a wider perspective, SDN provides a great opportunity to better management of network resource where wiser decisions of packets routing are delinked from the switching hardware.

IV. Simplify Network and Ease Management

Traditional network has proved that there will be a need for change as provisioning of new technology has been a challenge as current architecture could not cope.

In addition, *Arandza, (2016)* says "SDN is capable, by segregating of the control and data planes, of tackling the complexity and inflexibility of the conventional network. SDN enables organisations to manage their networks in a programmatic manner and to scale the networks without undermining user experience, reliability, and performance." *Galis et al., (2017)* agree with this by saying that "Through the SDN approach, network administrators are not required to implement custom protocols and policies on each device separately within the network. Generally, SDN architecture control-plane functions are delineated from physical devices and are operated by an external controller (for instance, a standard server running SDN software)."

2.4.2 SDN Challenges in Adoption in Higher Educational Institutions

SDN technology, as great as it seems, has some shortcomings or challenges that will affect the adoption in Higher Education Institution and they can be classified as follows:

I. **Effect Management and Features**

According to *Horvath et al., (2015)* "this circumstance results in a programmability of the data plane (which enables manipulation of the forwarding tables), a customization of networks (such as data centre interconnections) and centralized control decisions due to a global view over the whole network"

In saying that, can be said there is a challenge for networking professionals to acclimatize themselves with the change in features like programming instead of configuring switches. *Vissicchio et al., (2015)* further "summarize SDN by defining such features as a new

architecture, which provides the possibility of controlling the whole network structure with the benefits of an innovative and improved management."

II. Security Threads in Implementation

According to *Akhunzada et al., (2016)* "the emergence of SDNs requires additional security requirements because of newly deployed infrastructural entities as security was not considered part of the initial SDN architecture design."

In addition, *Galis et al., (2017)* "identifies the problem of how to implement new technology without reinventing the whole architecture with its aspects and related components." This opinion goes along with *Cahn et al., (2017)* "who describes the long implementation schedule as the biggest disadvantage. The main aspects of the challenge consist of unexpected interaction with other deployed networks, integration with legacy networks, which do not support the OpenFlow protocol, fundamental errors when emulating software defined networking beyond certain limits, architectural updates and deep changes in inter-domain routing protocols, service models and operating procedures"

III. High or Increased Demand

According to *Akyildiz et al., (2016)* one should "identify several challenges concerning increasing demand when it comes to new technologies. For example, the need for a suitable and specific service for several traffic types, such as video conferencing or web browsing in a very short time range, and further the need for improved resource utilization for higher system performance of the rapid growth of cloud computing." *Galis et al., (2017)* agree with this point by saying "that the user's demand is never ending but instead rapidly increasing which makes it necessary to think about software defined networking."

IV. Technical Know - how

The networking professionals usually start data centres from scratch and the norm is they will manage them from corner to corner thus it will be easy for them to man over easily if there is a problem.

However, *Casado et al., (2018)* acknowledge that "software defined networking could have the potential to meet challenges existing in traditional networks, like vendor lock-in or complex management. Nevertheless, this technology has not yet matured so that current operators are faced with high complexity instead of easy management and easy building of network architecture. Another point of view states that software defined networking may currently be a well-established standard in certain enterprises and industries, but applying this technology still requires a completely new pool of know-how when it comes to architectural updates on the opera tors' side and to additional overhead meeting current devices in current networks."

2.5 Technology Acceptance Model (TAM)

TAM model was introduced by *Shin. (1989)* to investigate the factors affecting user's acceptance of new technology and Chin and Lin, (2014) created the model to explain why people use network by integrating network externalities and motivation theory.

Adoption of SDN in higher educational institutions needs guidance and some form of structural guidance for policy makers to implement policies to be followed. Consequently, this model used is Technology Acceptance Model (TAM) in Figure 1.4 below. One can ask why specifically this model is because of its robustness, simplicity, and applicability explain and predict the attributes that affect the user's adoption behaviour towards new technologies (Chin & Lin, 2014).

In this study, the acceptance model is used as a framework to indicate performance and effective visibility of SDN adoption by providing more automated, easier-to-use and featured enhanced solution to Networking.

Furthermore, the researcher tries to explain why policy makers and networking professionals continue to be reluctant to adopt SDN and investigate the main determinants as well as their relationships. Specifically, an extended TAM model is proposed and adds several additional variables and list objectives and hypotheses. The evaluation and validation of the proposed model is conducted by analysing survey questions accumulated on-line which revealed several interesting findings. However, TAM model has several determinant factors that are identified as key influences of adoption of SDN in Higher Education Institution as illustrated in Figure 2-6 and besides these fundamental factors. There are other variables which also contribute to the popularity of SDN adoption.

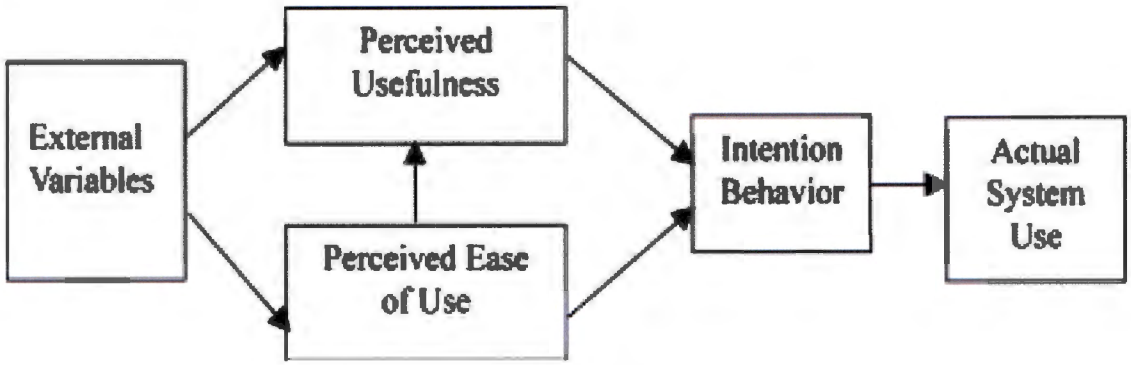

Figure 2.6: Technology Acceptance Model (Chin & Lin, 2014)

In addition, *Davis, Bagozzi and Warshaw (1989)* argue that "the actual system use is predicable by user motivation, which is also directly influenced by external variables, that is, system features, capabilities, and so on. It is further suggested that user motivation consists of three influential factors, that is, perceived ease of use (PEOU), perceived usefulness (PU), and attitude towards using (ATT), which are able to explain the actual system use. In this TAM model, the attitude towards using, which is influenced by perceived usefulness (PU) and perceived ease of use (PEOU), is the major determinant for a user to accept or reject a certain system."

2.4.1 Foundation and Related Work

There is a need for policy makers and networking professionals to understand the reasons behind the adoption and usage for SDN in Higher Educational Institutions, thus TAM was chosen as it is the best technique to elaborate on rationality of Network professionals when they accept to use SDN.

In support of this *Nkosi, (2018)* further say "certainly is a problem looking for a solution that we think can be solved by defining an SDN framework that is built upon an open source code foundation to ensure not only its syntactic correctness, but its semantic correctness, too. Then that framework and its ancillary components, such as protocols or protocol extensions."

In this study, the researcher mainly studied the factors from network professionals and policy maker's perspective; as such proposed an extended TAM model including traditional factors such as perceived ease of use (PEU), perceived usefulness (PU), attitude (ATT), and behaviour intention (BI). As a result, in the proposed model, we added external variables, that

is, perceived enjoyment (PE), use context (UC), and flow experience (FL), to provide understanding of pleasure and fun, which are often mentioned in previous studies.

2.4.2 Hypotheses

I. **Hypotheses 1:** Network Experience

Policy Makers and Networking Professional's experiences effect the internal relations between TAM and their influence towards the adoption of SDN in Higher Education Institution which is perceived usefulness relating positively to behavioural intension to actual use SDN.

II. **Hypotheses 2:** Occupation Relevance

Policy makers and networking professional's measure indirect effects on both intensions to use SDN and how it will impact their career path in opening more future doors(promotions) for them.

III. **Hypotheses 3:** Quality of Service(QoS)

Behaviour and functionality of network devices is programmatically modified using high-level programs, thus supporting end-to-end quality of service which is perceived usefulness as it affects actual SDN service delivery.

IV. **Hypotheses 4:** Self Efficacy

Self-efficacy is confidence demonstrated by policy makers and networking professionals in making the right choice of action necessary for adoption of SDN in Higher Education Institutions. On the other hand, *Davis et al., (1989)* said SDN will result" productivity software and network resource heralded the development and implementation of new and innovative teaching strategies"

V. **Hypotheses 5:** Network Effectiveness

Perceived ease of use relating to SDN output and productivity being positive and related user's in Higher Educational Institutions being satisfied fully.

VI. **Hypotheses 6:** Technological Complexity

Skill or training requirement of policy makers and networking professional's which will be perceived ease of use when they have potential to understand the complexity of SDN.

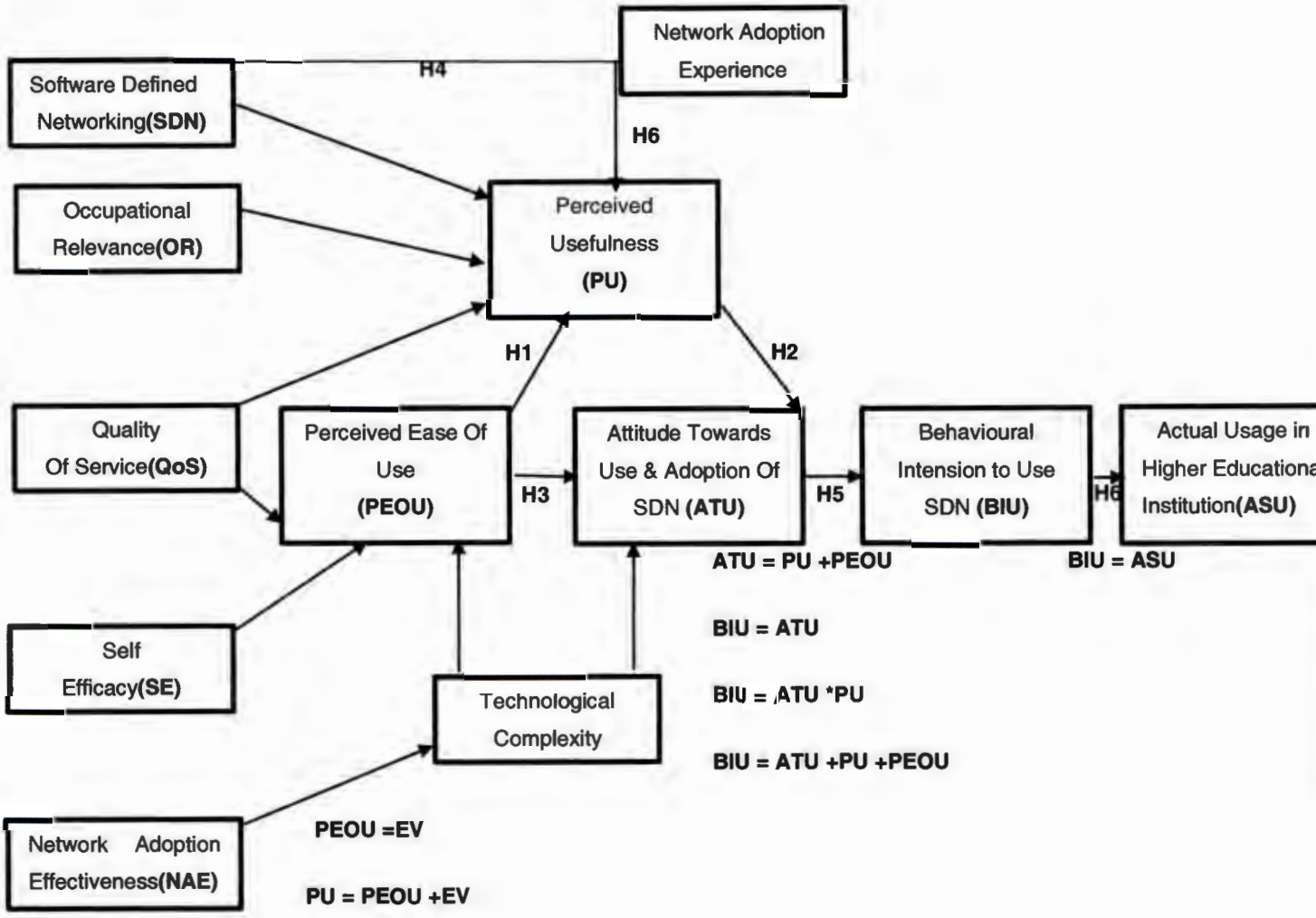

Figure 2.7: Researcher's SDN – Technology Acceptance Model

Implementation models which accept the importance of involving users require consultation with individuals who will be affected by the change, both on an individual basis and through representative organisations. These require recognition of professional autonomy and an understanding of the different values and assumptions which may be held by different groups.

In addition, attention should be paid to those aspects of the model which are common to both acceptance and diffusion and how these can be developed to meet the specific communication and professional codes of different networking professional groups.

2.6 Security of SDN

According to *Akhunzada et al., (2016)* "the emergence of SDNs requires additional security requirements because of newly deployed infrastructural entities as security was not considered part of the initial SDN architecture design". *Skowyra et al., (2017)* agree by saying that this done by "Learning that the intrusion detection system is an OpenFlow-based NIDS. Learning intrusion detection system takes advantage of the OpenFlow SDN architecture, and anomalies are defined based on several characteristics: packets sent, position, time passed, and size among others."

In saying that SDN has already become target for attackers, *Li et al., (2016)* advices on three components as follows:

- Switch

  Attackers in most cases get access through network components such as at the switch plane by hacking the programming code and taking control of certain portion of the plane, but if programming is done in a smart an Intrusion Detection System (IDS) along with Intrusion Prevention System (IPS) should be inclined with these switch plane to avoid such scenario' s.
- Controller

  In some cases, the attackers can get access through Northbound API then control the network by creating SDN policy with intension to gain access.
- Channel

  There is sometimes a level of trust mechanism among controllers and switches.

Furthermore, SDN adoption in Higher Education Institution brings significant granularity, visibility and flexibility into networking but at the same time new security challenges and engaging professionals and campus community to be aware of these threads is vital. In support of this Park et al., (2018) said a "newly designed SDN security education materials, which can be used to meet the ever-increasing demand for high quality cybersecurity professionals with expertise in SDN security. The designed security education materials incorporate the latest research results in SDN security and are integrated into Cloud Lab, an open cloud platform, for effective hands-on learning."

2.7 SDN Features for Higher Education Institutions

The proposed framework will serve as a guide to network policy makers for the institutions at national level. The framework developed processes that were identified through literature review and was refined and evaluated by this research project as illustrated in figure below:

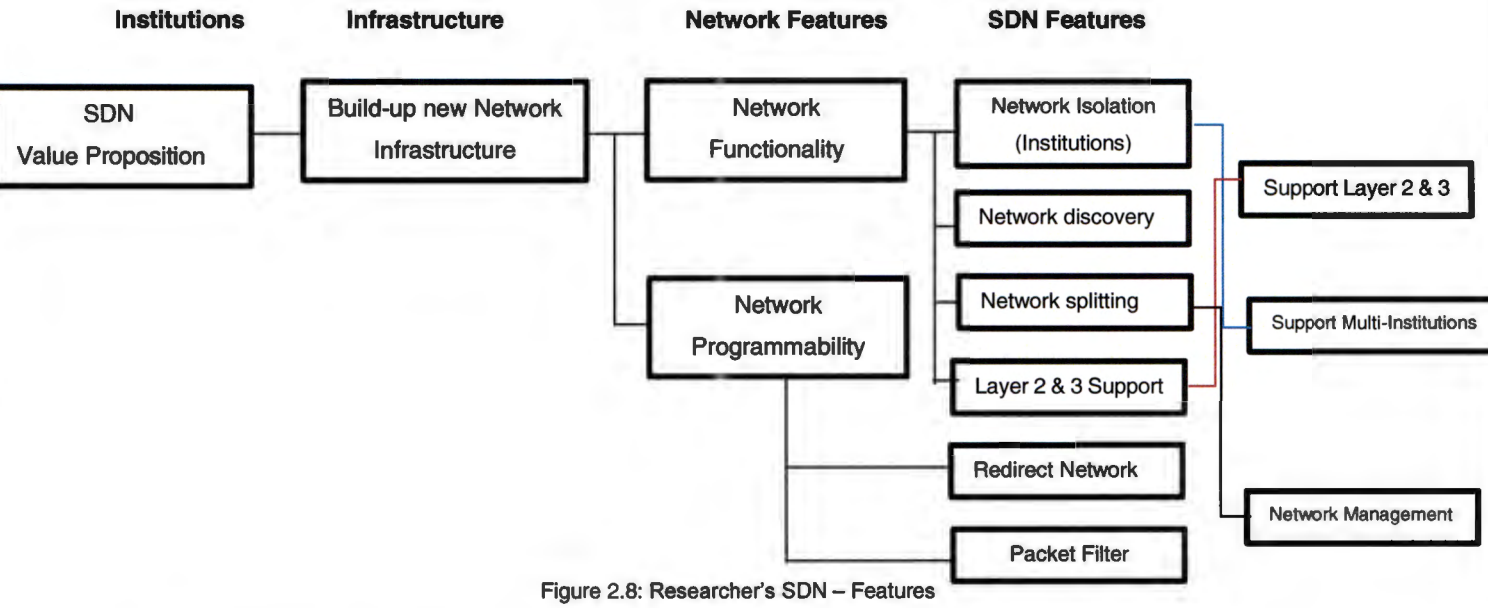

Figure 2.8: Researcher's SDN – Features

SDN framework documents delineates the scope of Architecture, including the requirement that it needs to address and the problems that it needs to solve. An appropriate balance between simplicity and expressiveness of networking elements.

Rapid Service deployment: no impact on other logical networks

Improved service availability: improves responsiveness compared to traditional network

Traffic Isolation: isolation of both Layer 2 and Layer 3

Optimal resource utilization: management, services and application are virtualised

2.8 Summary

This chapter explored policies, methods of SDN Adoption through literature. This study sought to provide information for higher education leaders and policy makers as to how they can address networking applications in teaching and learning at their own institutions through the use and adoption of SDN Paradigm as shown in Figure 2-4 above.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Introduction

This chapter gives a broad explanation of quantitative research methodology and the data collection methods used by the study. It describes the population and the sample of the study. It also confirms issues of reliability and validity as well as ethical issues.

In particular, this chapter motivates the reason why a specific research methodology was chosen and also how this methodology made it possible to find alternative solutions to the research problem. The study further discusses the research paradigm, research methods, research strategy and data collection techniques.

3.2 Methodology

3.2.1 Philosophical Perspectives

To conduct and evaluate a proper research, a researcher must identify some underlying philosophical assumptions. According to *Sanders et al., (2016)*, "These include assumptions about human knowledge (epistemological assumptions), about the realities you encounter in your research (ontological assumptions) and the extent and ways your own values influence your research process (axiological assumptions). These assumptions inevitably shape how you understand your research questions, the methods you use and how you interpret your findings."

In saying that, ontology is the nature of reality, external and independent of human consciousness by shaping the way researcher will study and see research objectivism and subjectivism. These aspects (objectivism and subjectivism) impact epistemology as it paves the best way to do research.

3.2.1.1 Subjectivism

Subjectivism is based on interpretations of the observer that reality of what is being observed with concept of validating interpretations, meaning and understanding.

3.2.1.2 Objectivism

Objectivism is based on the existence of social realities or phenomena as external facts without nature of the observer. *Mavetera, (2011)* says that the "reality is viewed as being independent of the social actors that work or act on the phenomena and that there is a reality somewhere "out there" that is always waiting to be discovered." *Sanders et al., (2016)* agree with this statement by saying "objectivism exist separately from sensation. It also seems to have the requirement of necessarily agreeing with others (experts) in "Objectivism" to ensure that one sees things Objectively."

Knowledge is based on factual evidence discovered by scientific methods and describes things as they are or only meaningful knowledge is derived from and/or confirmed by the senses.

3.2.1.3 Positivism

Positivism believes in realism that exists, thus any observer will get same view and results, which will be independent of the observer perspective and clarifies the approach to the study of society that relies specifically on scientific evidence.

One such researcher is *Aranda, (2016)* who follows on the trend by saying that "a positivist perspective, claims that main focus is on data acquired from experience or direct observation, which are empirically measured using quantitative methods, such as surveys and experiments." Hatch and Cunliffe, (2006) relate to this by saying "what truly happens in organisations can only be discovered through categorisation and scientific measurement of the behaviour of people and systems and that language is truly representative of the reality."

In addition, to generate a strategy in this study data is collected along with existing theory to develop hypotheses leading to further development of theory to be tested.

3.2.1.4 Interpretivist

Interpretivism emphasises the importance of observation and interpretation of people in their role as social factors rather that as objects, emphasis is the difference in conducting research among networking professionals and policy makers rather than switches, servers and computers.

Mavetera, (2011) classifies it as sharing a "view that the subject of enquiry in the social sciences, that is, people and their institutions, is fundamentally different from that in the natural sciences and is in fact an integral part of the qualitative research paradigm." *Flowers, (2009)* further said "The epistemological grounding of Interpretivism lies in the understanding of human behaviour that is arrived at through a series of cyclic processes of interpretation that are referred to as the hermeneutic cycle. The emphasis is on understanding human action and not on the forces acting on it."

3.2.2 Paradigm

The study embraced the quantitative research methodology. "This methodology was effective in obtaining specific information about the values, opinions, behaviour, and social context of experts or knowledgeable in SDN. Through its methods of data collection, quantitative research offered the study an opportunity to get most out of the phenomenon under investigation" *(Mark et al.,2005).* Furthermore, *Sanders et al., (2016)* "define research as a systematic, methodological and ethical process of enquiry and investigation undertaken to find out things in order to increase knowledge". Research Onion below in Figure 3.1 below, demonstrates the layered nature of the research process.

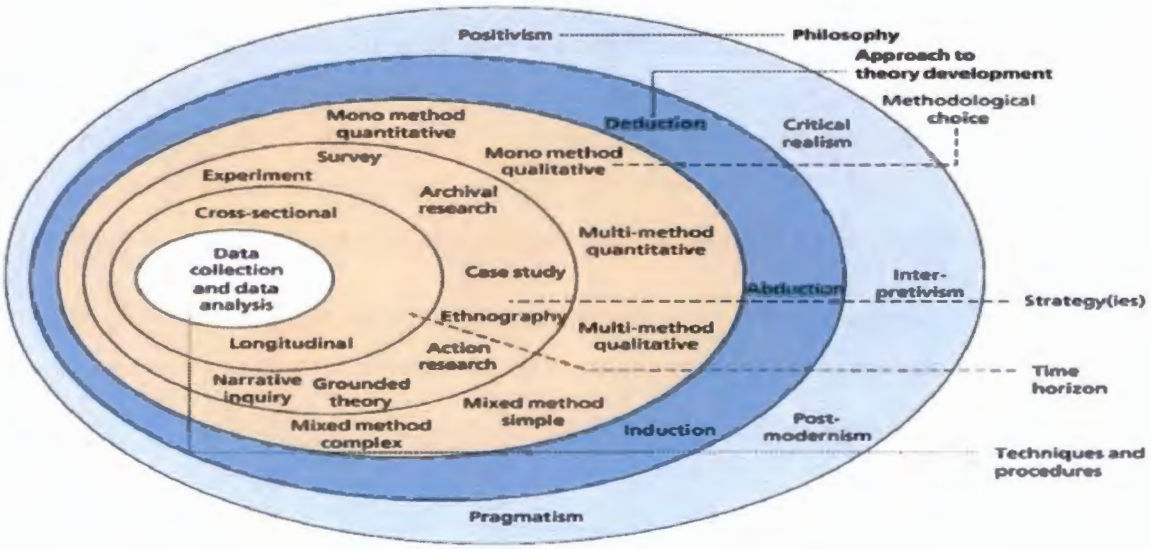

Figure 3-1 Research. Onion. (Saunders et al.,.2016)

This, chapter presents various methodological approaches that were considered and selected for the best fitting method for this dissertation while describing the implementation of the research strategy.

3.3. Research Design

This section elaborates the plan that was used to conduct this research project. It also highlights the research method, research paradigm as well as data collection methods employed by the study.

3.3.1 Research Method

This study adopted quantitative methods based on the content analysis of existing theories, policy documents and framework using secondary sources in literature in order to further understanding of necessary processes in formulating SDN adoption policy in higher educational institutions. *Marshall and Rossman, (2010)* maintain that "quantitative is a descriptive and interpretive method of gathering and analysing data". However, *Yin, (2003)* further says the "researcher is allowed to explore individuals or organizations, easily through complex interventions, relationships, communities, or programs". The reason for choosing this method is its ability to determine the differences and the existing variables while finding better alternatives of network policies that can be improved with SDN adoption.

3.3.2 Research Design

The study is a survey design which was aimed at answering specific research questions or testing specific hypotheses with research design science guidelines in producing or evaluating the output or solution. On that point *Leedy and Ormrod, (2005)* says that research design is defined "as the stance taken by the researcher in order to investigate an existing phenomenon with the aim of providing solutions to the phenomenon observed".

Research design also highlights the "research paradigm, research method, and data collection methods that were used. Firstly, this study adopted a quantitative approach based on the content analysis of existing theories, policy documents, and policy development frameworks using secondary sources in the literature in order to obtain a thorough understanding of the processes necessary for the formulation of an effective SDN policy. The results of the content analysis were used to develop an initial framework. Secondly, focus group survey was conducted with ICT experts and policy makers in order to evaluate and refine a proposed framework." (Makhoere, 2016)

3.4 Research Paradigm

The design of this research utilised Creswell framework where the researcher identifies the knowledge claiming post positivistic and interpretive goals as a basis of this research. According to *Creswell, (2003)* "the pragmatists look to the 'what' and 'how' to research based on its intended consequences and where they want to go with it". Thus, the main aim is to develop and evaluate framework for SDN policy formulation which is intended to solve the problem identified in this study. Collis and Hussey, (2009) further argues that" the paradigm adopted for a study is influenced by the dominant paradigm in the research area and the nature of the problem under investigation "In order to answer research questions posed by this research project, the quantitative approach was followed.

3.5. Data Collection and Analysis

This study used quantitative method exploratory sequential design illustrated in figure 1.2 below, where *Creswell, (2009)* gives direction on exploratory sequential design as it "begins with and prioritises the collection and analysis of quantitative data". In building on exploratory results, the researcher then conducted an on-line survey in order to test and generalise the initial findings.

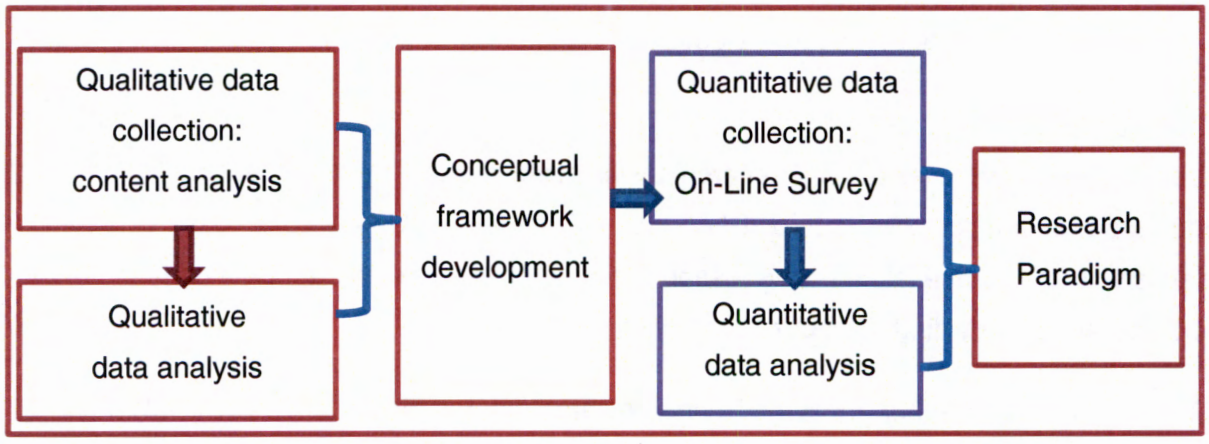

Table 3.1: Exploratory sequential design (Creswell,2009)

In addition, "data for this research study was obtained from both primary and secondary sources. Primary data was collected by conducting focus group on-line surveys with relevant ICT experts and policy makers in fields of Networking and Higher Educational Institutions. The input from respondents was analysed in to order to refine a framework. Secondary data was

obtained from published and unpolished sources, journals, books and various helpful internet publications relevant to the study. The information from secondary served as foundation for the researcher to develop a topic and also to determine information that would be useful in primary data for the research project." (Makhoere, 2016)

Analysis of the study followed theory of triangulation illustrated in figure 1.3 below, where professional's outside higher educational institutions support structures were also involved as the researcher believes that professionals from different disciplines like CSIR will bring a different perspective due to their similar research project conducted. *Sanders et al., (2009)* define triangulation as "the use of two or more independent sources of data-collection or analysis methods within one study in order to help ensure that the data is telling you what you think they are telling you."

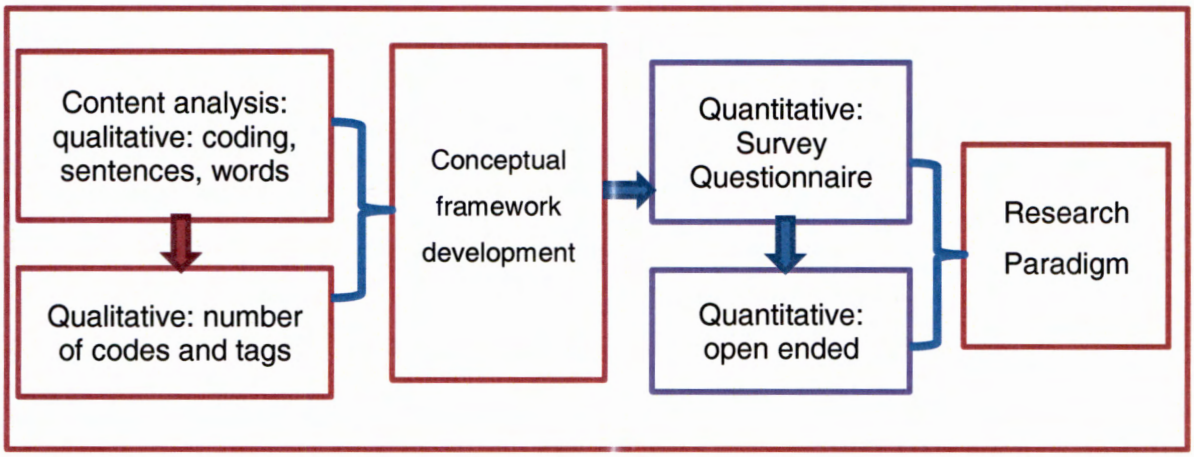

Table 3.2: Data triangulation (Saunders et al.,2009)

3.6. Ethical considerations

Ethics clearance to conduct the study was obtained with the assistance of the Ethics Committee of the North-West University at School of Commerce and Administration. To comply with internationally accepted ethical standards, no names of individuals were recorded on research instruments. No individual was linked to a particular completed research instrument, ensuring anonymity. No compensation was paid to any respondent for participation in the study. No respondent or participant was harmed physically, emotionally or otherwise.

Quality assurance was done with respect to:

- The correctness and completeness of open ended questions;

- ❖ All participants understanding the nature and consequences of their participation in the study; and
- ❖ Placing all results in the public domain as soon as available

According to *Olivier, (2009)* "researchers should consider the ethical implications of the study they propose to conduct, especially when the research involve human beings".

Hence, researcher obtained permission from participants and they were allowed to exercise their right to withdraw when they please. In particular, to this study the researcher gathered expert's views and concepts to refine and evaluate the framework developed from literature review. Anonymity and Confidentiality of participants and data collected was insured.

3.6.1 Permission and informed consent

The researcher applied the North-West University(NWU) policy on research ethics on preventing an act of plagiarism and the use of its measures. With the assistance of supervisor's ethical clearance was obtained from the ethical committee before carrying on with data collection.

3.6.2 Reliability and Validity

A pilot study was conducted before to increase the validity of the data. Questionnaires were circulated and subsequently the lethargic response was notices owing to the community's inability to read and write. As a result, the study chose the interactive, cost effective, rich and probing focus group and unstructured interview as methods of data collection.

3.7 Research Approach

Data collection and data analysis take place simultaneously. Thus applying this to deduction, its identification is unknown particular, drawn from its resemblance to a set of known facts.

The researcher identifies patterns and regularities with the phenomena and progress to formulate certain tentative hypotheses which are explored and finally conclusions and theories are developed.

On the hand *Mason, (2002)* highlights that, "in deductive reasoning, theoretical propositions or hypotheses are generated in advance of the research process, and then changed through a process of either falsification or verification by the empirical research conducted."

Thus, objective qualitative data was collected using "down – top" approach illustrated in Figure 3-2 below were the literature review, combined with the feedback information from SDN professionals.

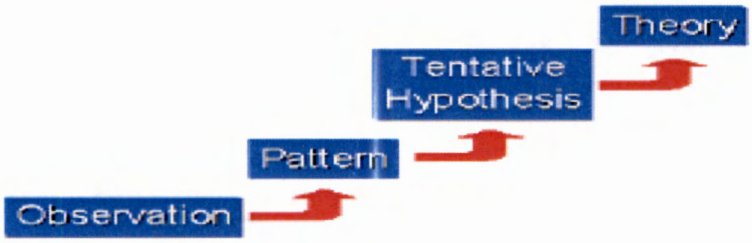

Figure 3-2 Deductive Reasoning. (Saunders et al.,.2016)

In this study deductive research approach was used to study relevant literature on existing software and to define networking processes. This research aims to establish a ranking priority on the many benefits and challenges gathered that could benefit researchers and practitioners to place more emphasis in priorities to be addressed in order to foster SDN adoption and evolution in Higher Education Institutions.

3.8 Research Strategy

In this study, it is expected that SDN could be a vital tool for advancing technological strategies for policy makers in higher education institutions.

For this reason, this dissertation aims to ascertain the current status of SDN implementations and identify trends. It focuses on the challenges faced and the benefits obtained by the IT professionals who venture in its implementation. Therefore, the positivist philosophy is guaranteed as the details regarding the challenges and benefits are measured objectively using quantitative means (Aranda, 2016).

Close ended questions in online-survey with SDN experts is adopted for this study as this research endeavours to their opinions in particular, Network Engineers and other SDN stakeholders, to test hypotheses. But due to time and other participants being uncooperative, a survey was best way to go and easier to implement and analyse.

3.9 Research Methods

3.9.1 Data Collection

The objective of this study was to analyse the adoption of SDN in Higher Educational Institutions in the Northern Cape in particular Sol Plaatjie University and FET Colleges in the province. For this reason, on-line survey was done with key policy makers at both Government and the University.

Primary data collection employing a survey is an efficient method of accumulating extensive volumes of data from a geographically dispersed population, thus enabling the findings to be generalised. The data collected can also be standardised, making comparison easy. It can be quantitatively analysed using descriptive and inferential statistics. (Sanders, 2016)

3.9.2 Survey Population

The researcher found the most suitable option in getting quantitative results from widespread individuals like Network Engineers who are in Northern Cape Province deeper end and Government Policy makers who are situated in Gauteng Province but all have access to internet in their day to day life and made it easy for the survey.

However, IT Managers were also included in the population as they play a role more especially in administering and managing SDN network environment.

3.9.3 Survey Design and Content

Blumberg, Cooper, and Schindler, (2008) state that a "survey is more efficient and economical as compared to observations if the aim of the researcher is to learn about the opinions and attitudes of the participants."

Google Forms Web –Based Application were used to administer and design an online survey with the understanding that the questions were to be read by a busy targeted population and considering the fact that it is important that the respondents do not become confused when completing the questionnaire. If the respondents do not understand a question they will either simply not answer it or give an incorrect answer so as to move on to another question.

3.9.4 Design Survey Instrument

Close-ended questions were applied which were considered most appropriate to gather most the accurate information in the smallest amount of time. The survey took approximately 10-15 minutes to complete. It consisted of 20 closed questions and included multiple choice questions and ranking type questions organised in four different sections focused as follows:

- **Section 1: Demographics**

1.1 Information regarding the survey, consent form and information as well as description of SDN

1.2 Participants demographics and company background details evaluated the respondent's knowledge of SDN and its significance to High Education Institutions.

- **Section 2: Traditional Network Perceptions and Usage**

Participants perception on Traditional networking as well as barriers encountered and up-keep for future expectations in Evolving High Education Institutions.

- **Section 3: SDN Perception and Knowledge**

SDN Technology based questions and knowledge content about the subject matter.

- **Section 4: SDN Experience and Adoption**

4.1 SDN technologies experience and what barriers they thought would impede successful Implementation.

4.2 How would SDN shape High Education Institutions structure and operations.

On that note one would agree with *Sanders et al., (2016)* in recognizing that "it is considerably difficult to design a good survey and that the survey should be designed in such a way that it would collect accurate data around the research question and objectives."

3.9.4.1 Survey Focus Area

The survey was based primarily on the result of the content analysis that has been conducted on secondary data which had been collected. Table 3-1 presents a summary of the way in which the questions were constructed.

Table 3-1: Research Project Survey Focus Area

Objective	Measurement construct	Objective of measurement	Questionnaire reference
Demographic data	Name of country, Organisation type, Occupation, Organisation size	Demographic data	Q.1 – Q.5
Investigate the importance of the framework constructs	-Risk assessment -SDN implementation -Network policy monitoring -Infrastructure compliance -Employee support -Management support	Level of importance of the constructs	Q.6 – Q.8
Investigate the importance of the framework constructs sub-variables	- Software Defined Network awareness - SDN Training - Stakeholders' role - Network policy education	Level of importance of risk assessment sub-variables	Q.9 – Q.11
	- Periodic network review - Automated review - Non periodic review	Level of importance of security policy implementation of SDN	Q.12 – Q.14
	- Security policy approval - Network policy enforcement - Management involvement - Budget	Level of importance of network monitoring	Q.15 – Q.16
	- Deterrence measure - Binding agreement - Employee involvement	Level of importance of management support sub-variables	Q.17 – Q.17
Investigate the importance of the SDN Adoption	- Perceived Technological Change Pressure - Perceived benefit - Knowledge	Level of importance of employee support sub-variables	Q.18 – Q.18
	- Perceived Organizational Change Pressure - Perceived benefit	Level of importance of SDN compliance sub-variables	Q.19 – Q.20

3.9.4.2 Survey Analysis

Survey was analysed "using a simplified deductive thematic analysis and multiple deductive process of reviewing, coding and focusing on both patterns in the data and interpreting meanings of comments in the quantitative data" (Cooper and Schindler 2006).

3.10 Summary

The purpose of this chapter was to discuss the research methodology utilized in the collection of the data, the sampling procedure, methods of data analysis the challenges encountered the ethical considerations of the study.

CHAPTER 4

STUDY RESULTS

4.1. Introduction

This chapter presents the main findings and interpretations of the study, as well as the implication inferential meanings of the research. Data collected is analysed and interpreted in order to put together findings that correlate with the research question and sub questions.

The empirical data collected from an on-line survey was exposed to Network Professionals and Policy Makers who are informed and aware of SDN initiative and the findings are divided into four sections:

Section 1: Demographics – Participants Level of employment and years of experience

Section 2: Traditional Network Perceptions and Usage –Participants current networking experience

Section 3: SDN Perception and Knowledge – Participants knowledge and perception of SDN

Section 4: SDN Experience and Adoption-Participants relevant background in SDN

A survey instrument was created (Appendix A), which included open-ended questions on the participants' experiences on Software Defined Networking adoption in Higher Educational Institutions. These responses were then converted into useful quantitative data. A survey was conducted within IT Professionals. As SDN is a fairly new technology a target sample size of 125 respondents was envisioned. The survey invitations were sent to co-workers, partners and LinkedIn group formed by Network Engineers, Network Consultants, IT Managers and related IT Professionals who might have knowledge and interest in SDN Technologies.

The survey was conducted, once Ethics approval was made online for close to 3 weeks from the 5th of October 2018 to 31st October 2018 and earned total of 82 responses. Thus out of those only two (2) answered surveys some were unanswered or some skipped questions.

4.2 Data Analysis Methods

A survey was analysed "using a simplified deductive thematic analysis and multiple deductive process of reviewing, coding and focusing on both patterns in the data and interpreting meanings of comments in the qualitative data." (Cooper and Schindler 2006).

Review and analysis of data collected ultimately provides answers to the following research questions and sub-questions.

4.2.1 Research Questions:

Can Software Defined Network be used in higher education environment in order to develop effective research with progressive teaching and learning?

In order to answer the above question, the study addresses the following sub-questions:

- What are the barriers that hinder higher education institutions use of SDN with current infrastructure?
- How can application of SDN save costs and be improved to enhance access to education material?
- What difference will SDN incur in Higher Education Institutions main operations?

4.3 Section 1: Demographics

4.3.1 Participants Profile.

In order to establish profiles for the different participants who answered the online survey

the following sub categories were established:

- Emerging Technology Deployment;
- Years of experience in IT;
- Type of industry of their organization;
- Familiarity with SDN technology;
- Size of the managed network; and
- Influence on SDN related initiatives.

Network Study confirmed a strategic shift in how IT resources are delivered and consumed. A number of new technologies, including SDN, 40/100 Gb, and mobile devices, promise long-term changes in how traffic is routed through the network and the method by which end users connect.

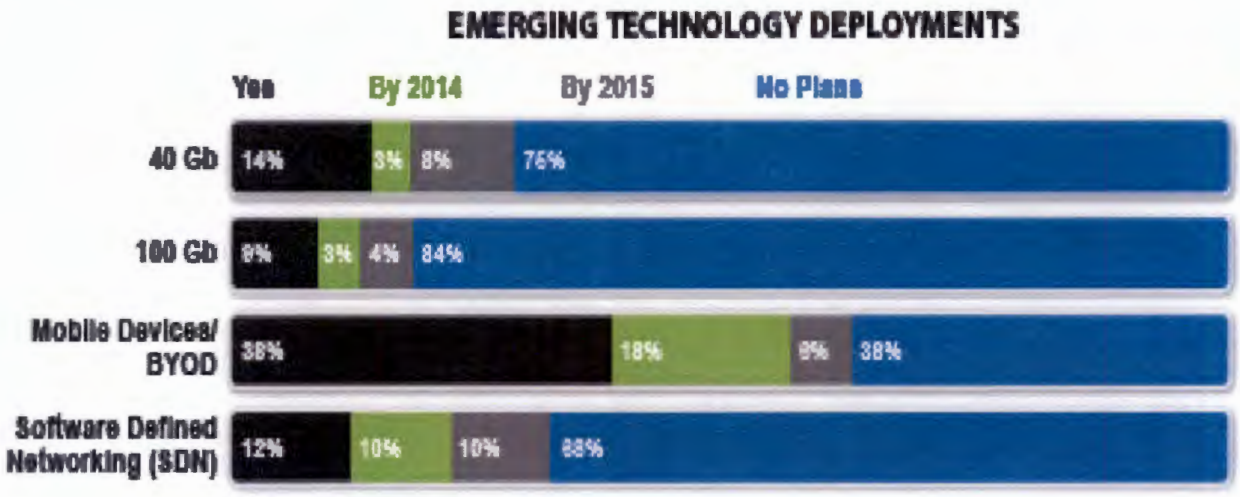

Table 4-1 Emerging Technology Deployments

The results show that for 2014 a surprising interest in SDN with 22% expressing plans to deploy by the end of this year, while 56% highlight plans for Bring Your Own Device (BYOD) policies. Even 40 and 100 Gb networking, often viewed as exotic by organizations outside the carriers and the very largest enterprises, is marked by an emerging demand. Fourteen percent had already deployed 40 Gb, while 9% opted for 100 Gb.

In saying that, one can deduce that SDN by 2015 professionals were unsure of the technology or there was a norm that current network then was sufficient as newer technologies were not implemented as today's being considered a necessity.

Thus, survey results show that SDN is in an early adoption phase, with a skeptical majority of respondents waiting to see how the technology evolves. Twelve percent of responses would be classified as SDN enthusiasts who view the technology as a necessity. Over half of network engineers see the value of SDN, but have decided to take a wait-and-see approach. In contrast, almost half of management has no plans to implement this technology.

Participants' Profession in IT:

Participants were asked their current position at this stage and the question were as follows

Identify your current Profession in IT you're in now?

Survey invitations were sent to the stipulated Professionals and Illustrated a total of 82 participants. According to the responses, (78% of the program population) responded which includes different roles in Industry as follows IT Consultant 5.0%, CIO 8.8%, and Network Engineer 25% and IT Director 13.8% as well as Other [Programmer, Analysts] 47.5 % shown in Figure 4-1 illustrates the job titles of respondents.

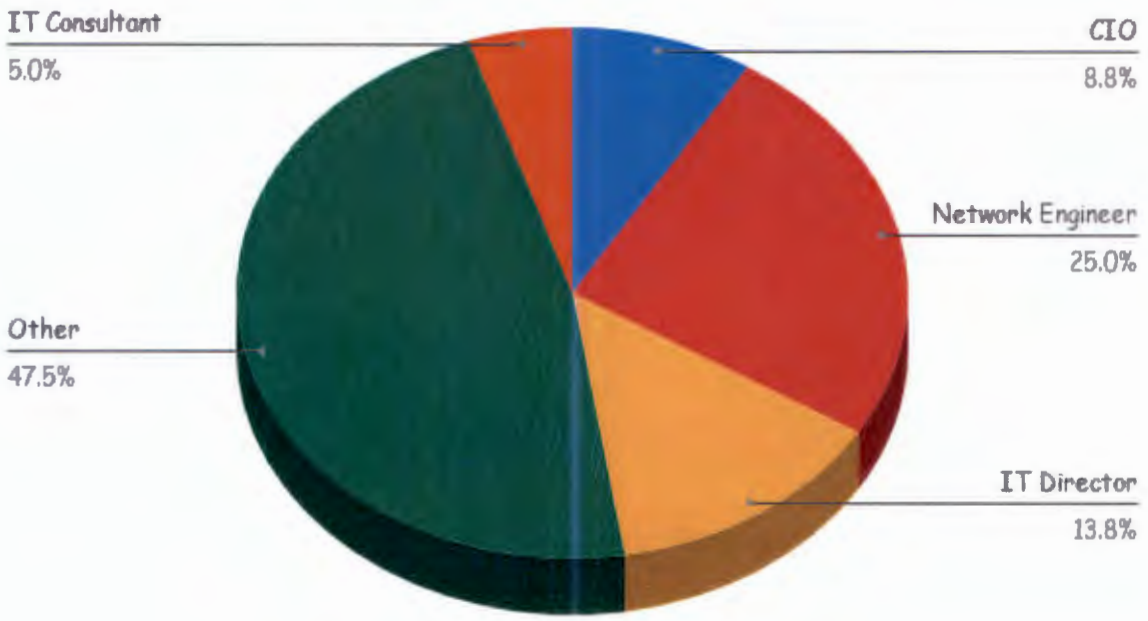

Figure 4-1 Respondents Job Title

The data was coded to then identify the different themes based on the codes as part of the data analysis. The themes identified during the analysis of the data are presented in different tables. Codes were created for the occurrence of fundamental but previously uncovered issues and connections. Codes were applied and reapplied to the qualitative data by grouping and regrouping data in order to consolidate meaning and explanation.

Years of experience in IT:

Participants were asked their years of experience since from the start of their career in Information Technology and the questions are as follows:

How many years of Experience are you in now?

Responses indicated that 28% had over 10 years in IT related operation,35% had 4 to 6 years,30% had 7 to 10 years,5% had 1 to 3 years and 2% had less than a year.

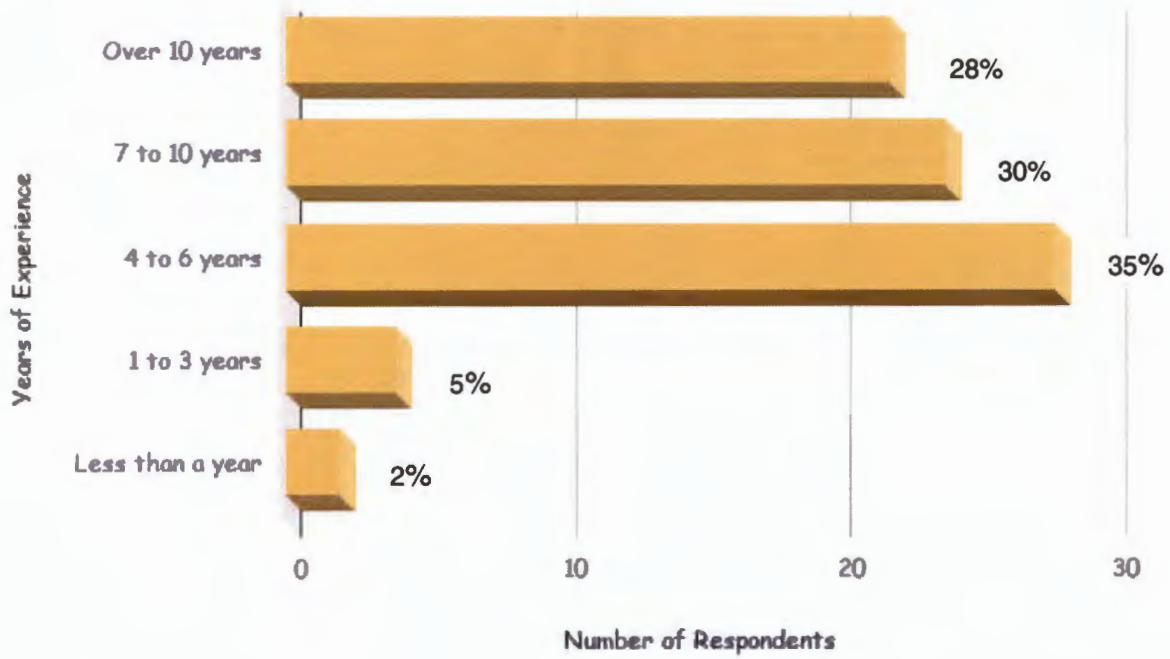

Figure 4-2 Respondents Years of Experience in IT

The evidence that 78% of survey respondents have influential authority when it comes to adopting SDN to Higher Educational Institution manifests that the survey targeted the relevant population.

Type of industry of the participant's organizations:

Participants were asked to select one industry that falls under their spectrum of operations and they were asked as follows:

In which industry are you currently employed?

(What is your company primary business)

Participants specified the nature of business and indicated that 86% work in IT organizations and that 65% is combination of IT/Internet/software organization and 23% is from Telecommunications and the balance 14% belonged to Network Engineers working in organizations related to Information Technology.

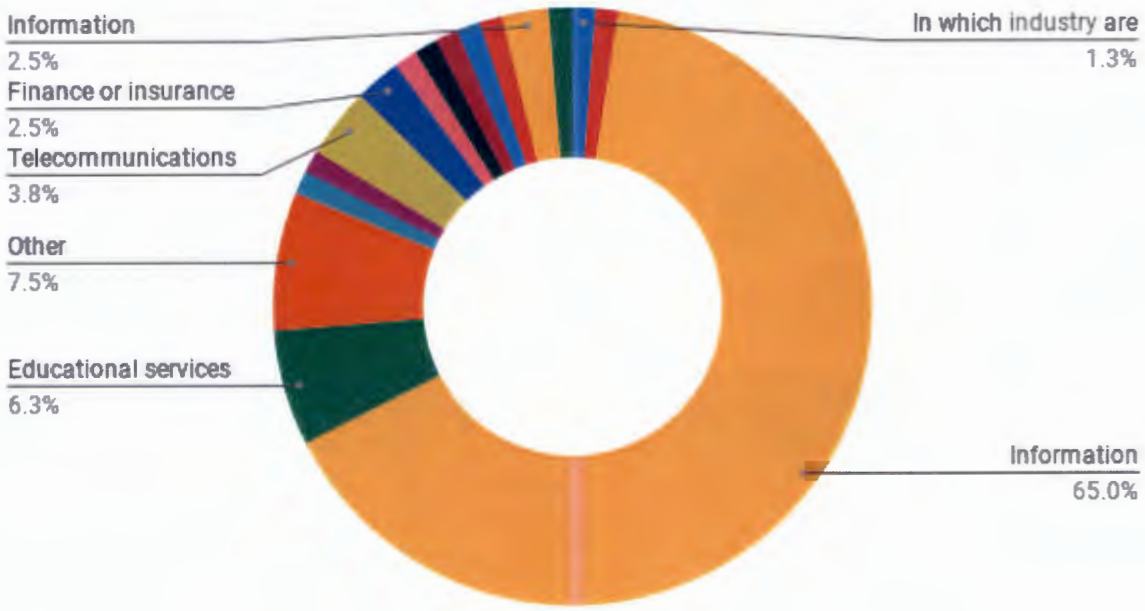

Figure 4-3 Industry Working

4.4 Section 2: Traditional Network Perceptions and Usage

Participants were asked the size of their identified Industry's network size and the questions is as follows:

Size of the managed network

How big is the network you Operate / Account for/ Manage?

Traditional network provisioning and configurations are highly resource consuming and often consist in a manual configuration of each network component. "Simplification of network provisioning and configuration" was consistently ranked as the most valuec benefit of SDN" thus the benefit was ranked between 50%, 23% and 11%.

However, the highest in this case is 50% showing that the majority of network policy makers and networking professionals are operating in 1000+ devices in their network.

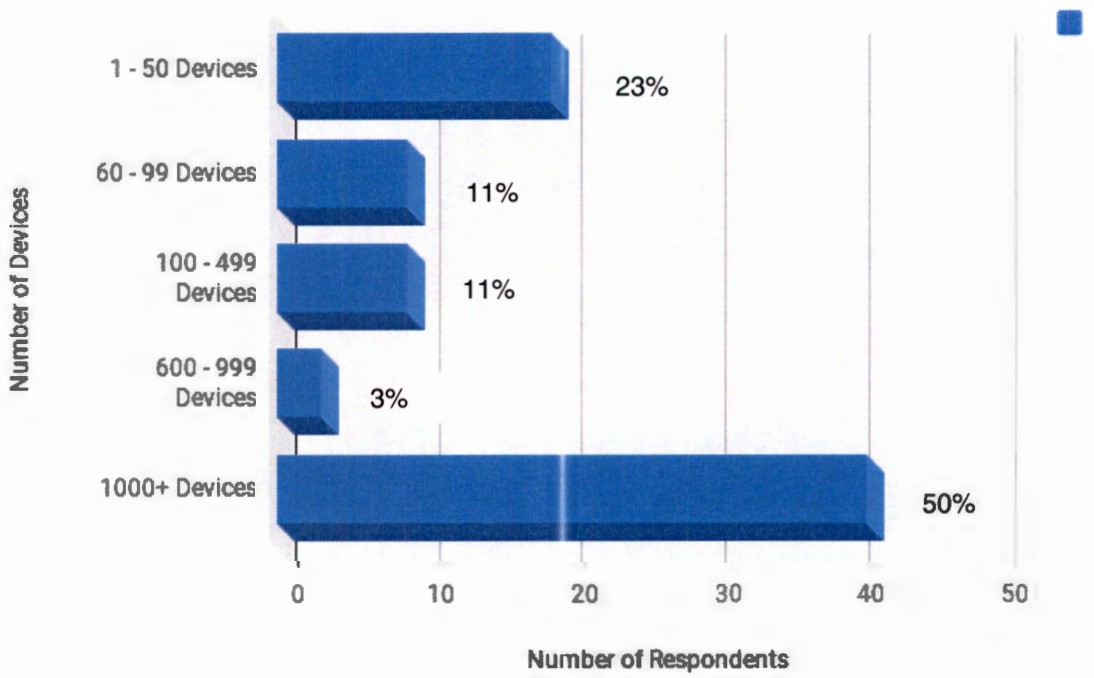

Figure 4-4 Industry working

Participants Perception on Traditional Network:

Participants were asked whether the current network status is sufficient and preferred at this day and age as technology is changing very fast.

How would you rate the state of your current network?

As shown in Figure 4-5, participants showed clearly that they are not happy with current state of network by saying that is not sufficient to cater for the technological change.

Participants responded with 49% saying that their network is moderate ,29% saying is exceptional,16% mentioned that their network is poor and lastly 3% said it exceeded their expectations.

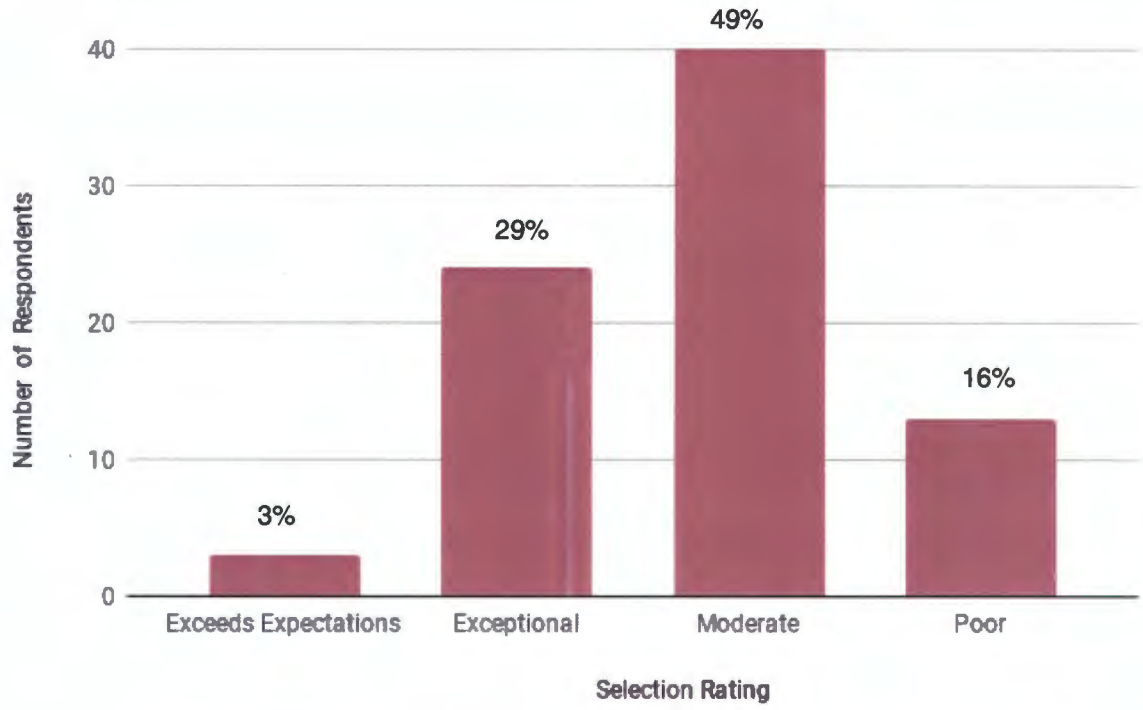

Figure 4-5 State of Current Network Selection

The survey questionnaire that was used included open-ended questions, firstly to probe for the experiences of these Policy Makers and Networking Professionals. Participants also had to respond to questions relating to the average amount of time they spend on the network, which include Facebook, playing games or visiting other social networking sites.

Some of the participants indicated they visit Websites unrelated to work, to keep in touch with family and friends. Social Websites also allow these professionals to stay updated on the current news and allow the opportunity for them to check their social media update statuses. Some of the responses are the following:

I. Network Freezes all the time

"Network freezes for minutes mostly with some challenges experienced" (Respondent 56)

"I would rate the state of my current network as moderate because sometimes the network is down or the network freezes" (Respondent 24)

Respondent 56 indicated that network freezes and some challenges which were not mentioned, compared to Respondent 24 who said mostly down and it causes slow output at work.

II. Outdated Technology

"It started off with a bang but as time went on it became more and more worse to a stage of slow on the go" (Respondent 7 & 40)

"Network is too slow due to old outdated technology" (Respondent 33)

Respondents 40 and 7 commented on how network started "with a bang" of I take it was reliable at its time but now is outdated compared with Respondents 33 saying "Old outdated Technology)

III. Wi-Fi On/Off

"It's slightly moderate. Wi-Fi is always down and it keeps on freezing" (Respondent 11)

"I would rate the state of my current network as moderate because sometimes the Wi-Fi is down or the network is freezing and way too slow and has a lot of issues and offers weak encryption" (Respondent 3,67, & 82)

Wi-Fi network always slow, weak most of the time. (Respondent 39)

4.5 Section 3: SDN Perception and Knowledge

Participants' Familiarity with SDN Technology:

Participants are asked about their knowledge of SDN as to support structure after adoption.

How familiar are you with Software-Defined Networking?

Participants responses as to their knowledge and familiarity with SDN in relation with all its related Technology aspects and from the responses 24% were very familiar with it ,30 % were moderate familiar with it,21% were slightly familiar and 21% were not at all familiar.

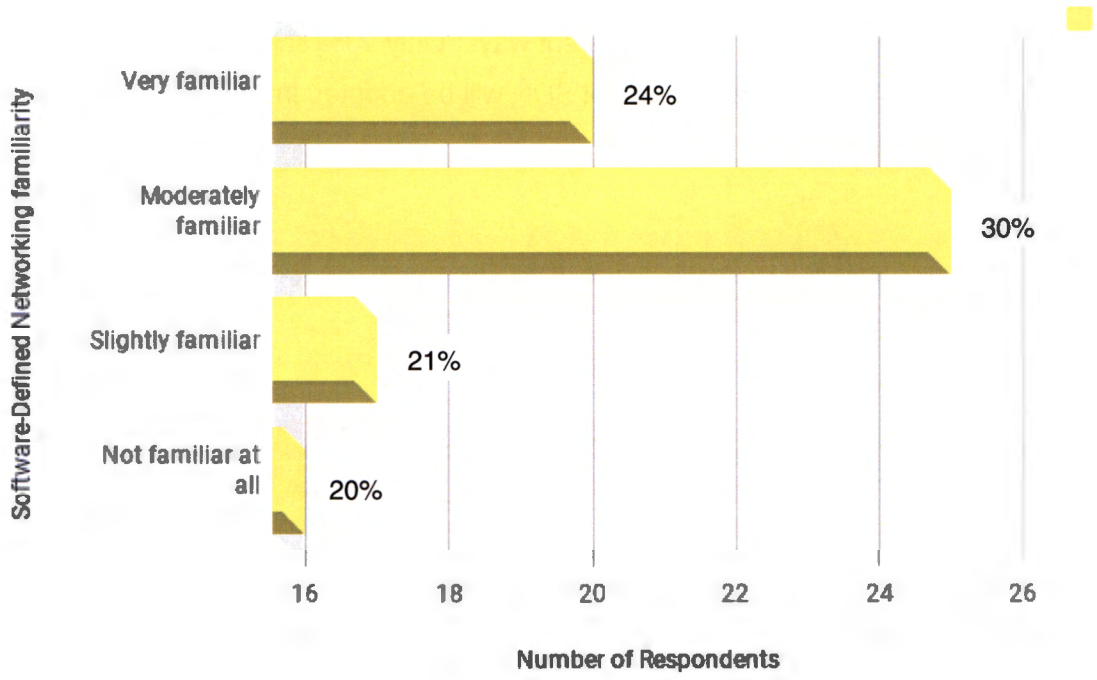

Figure 4-6 Software Defined Network Familiarity

One can say that there is a relation of this question with previously asked "In which industry are you currently employed "and there was a part which the responded were identifying as Other [Programmer, Analysts] of which 47.5 % of them indicated belonging to this field. There is some relevance as to a portion of this respondents do not work directly with networking as some are in software development and their familiarity with networking infrastructure and its impact and as such might know minimal about this aspect thus the response.

Influence of the participants on SDN related initiatives:

How much influence is your opinion on adopting SDN would have in your organization?

- I am the maximum responsible and decision maker for network design and implementations including SDN
- I am part of a decision making group for network implementations including SDN
- I am NOT part of a decision making group but my opinion would be considered by the decision making group in my organization
- I have no influence at all

Participants were asked about their influence as decision makers regarding the time to implement SDN in Higher Educational Institution. As shown in Figure 4-7 ,72% of the participants are part of decision making on adoption of SDN in their organizations. A 40% are directly responsible for decisions concerning SDN implementations and 22% have maximum impact in decision making of SDN and in different ways. Only 13% said that they do not have any influence at all on deciding whether or not SDN will be adopted in their organizations or Higher Education Institutions.

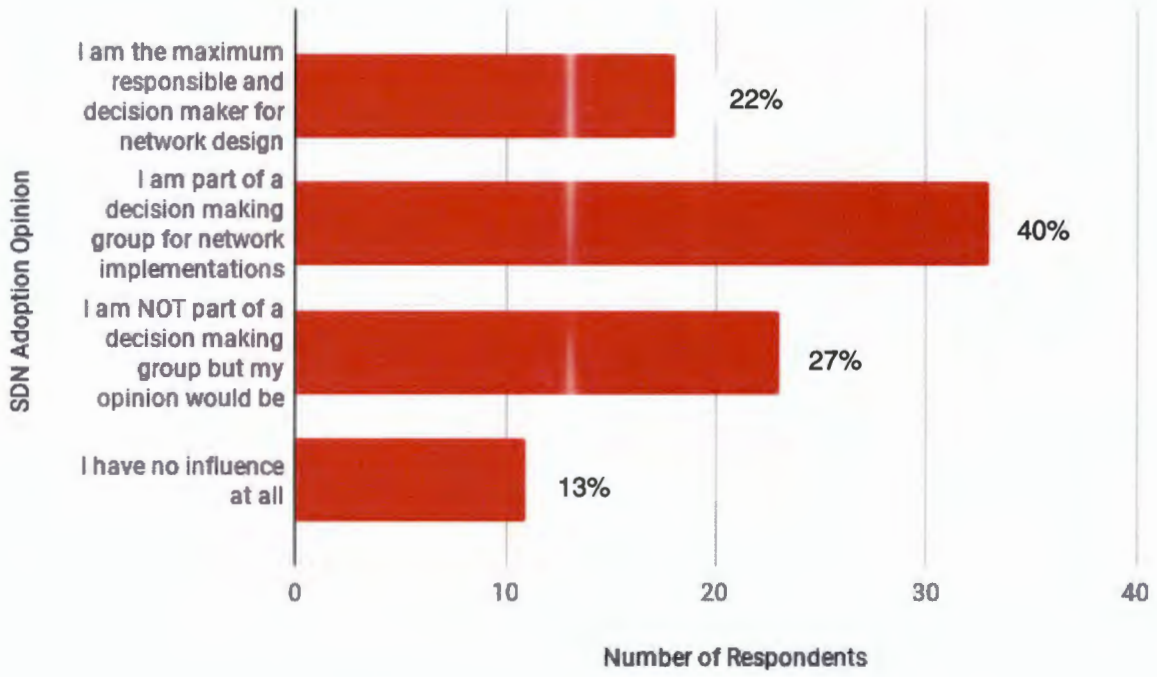

Figure 4-7 Software Defined Network Adoption Opinion

Present involvement by the participant on SDN initiatives:

Are you part of any Software-Defined Networking initiative?

Participants were asked how SDN will contribute in Higher Education Institution and whether Institutions are studying on it or are on the stage to adopt it and they responded, as shown in Figure 4-8. 24% said "*We are currently studying different SDN vendors' solutions*" and 23% further said "*We expect to have SDN running in a Lab environment within a year*" and 4% they are studying the value that SDN can bring to our organization.

In addition, the results implied that 40% of the Professionals would like to implement SDN on their network next year. This is a great achievement as the study wanted to probe or inquire about certain strategies to implantation of SDN in higher educational institutions. Interest in SDN is driven by the desire to make IT infrastructure more responsive to today's competitive landscape. The ability to dynamically adjust resources in response to business demand and introduce new services faster is key to making organizations more agile.

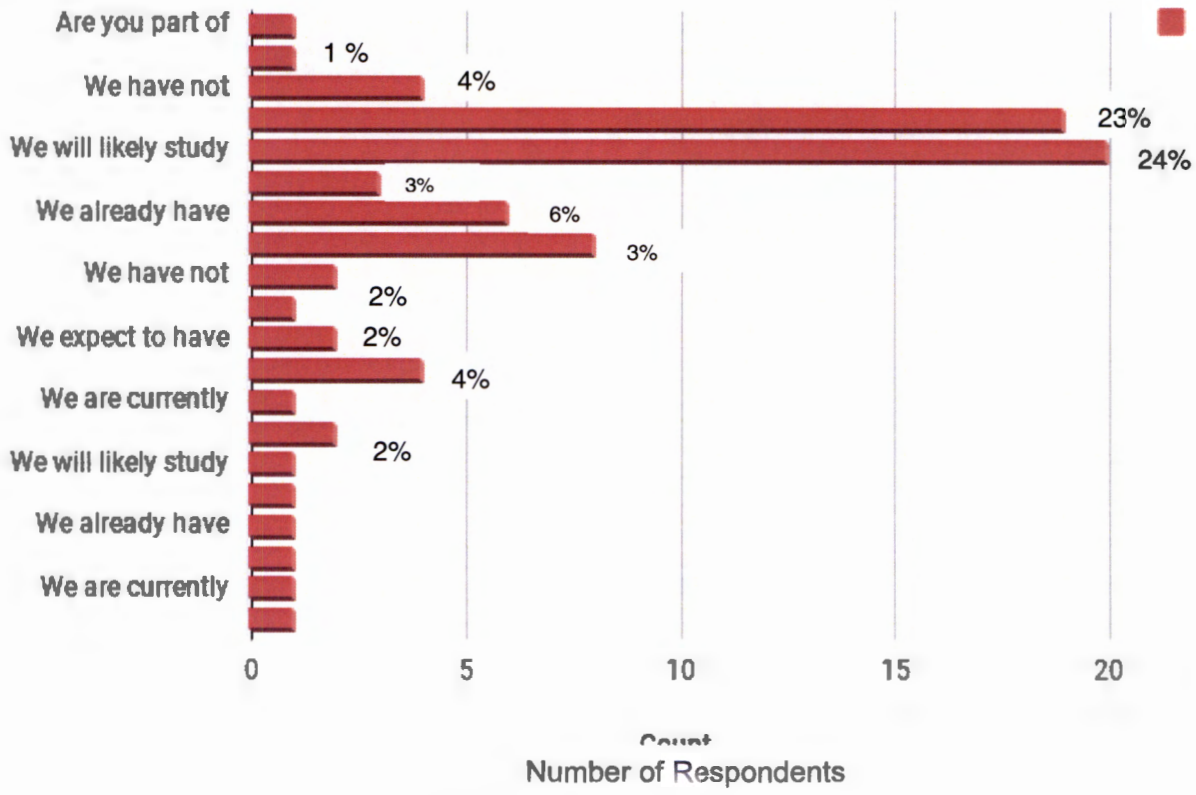

Figure 4-8 Software Defined Network Initiative

4.6 SDN Experience and Adoption

Where in their network participants think SDN will be deployed

in the nearest future?

Check all the scenarios where you think you will deploy SDN in the next 3 years.

Participants were asked to classify how it will fall under utilization of resource in relation with the size of the network infrastructure. The idea behind was to identify certain Higher Education Institutions which are readily infrastructure in place for deployment of SDN. Figure 4-9 show that engineers valued to implement WAN of which 54% wanted it, Cloud/Test only 45% shown interest and Corporate/Campus only 38% of participants.

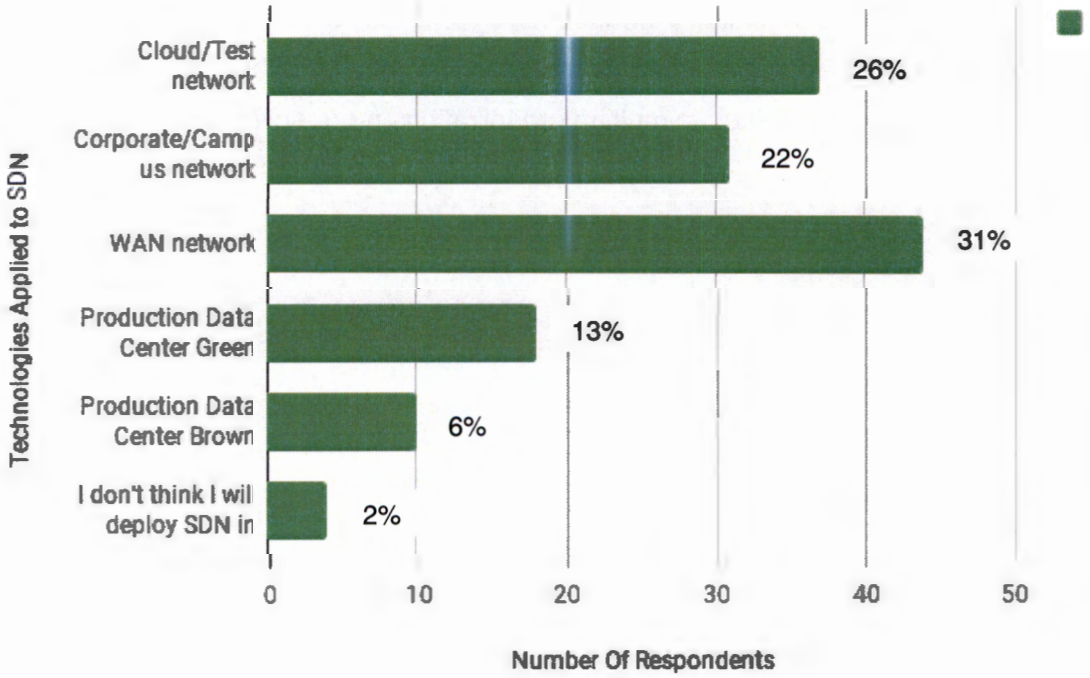

Figure 4-9 Software Defined Network Technologies

SDN Implementations Impact on Network Engineers:

How much impact SDN will have on the nature of the role of network engineers?

The benefits of adopting SDN can be in a way measured by newer technologies that can bring about change to the network combined also with the infrastructure that is in place as to whether it can be upgraded or it totally needs to be replaced. Figure 4-10 show 61% anticipated that it would have significant impact on their jobs,30% of them responded that it would have moderate effect and 5% said it would have little impact on them.

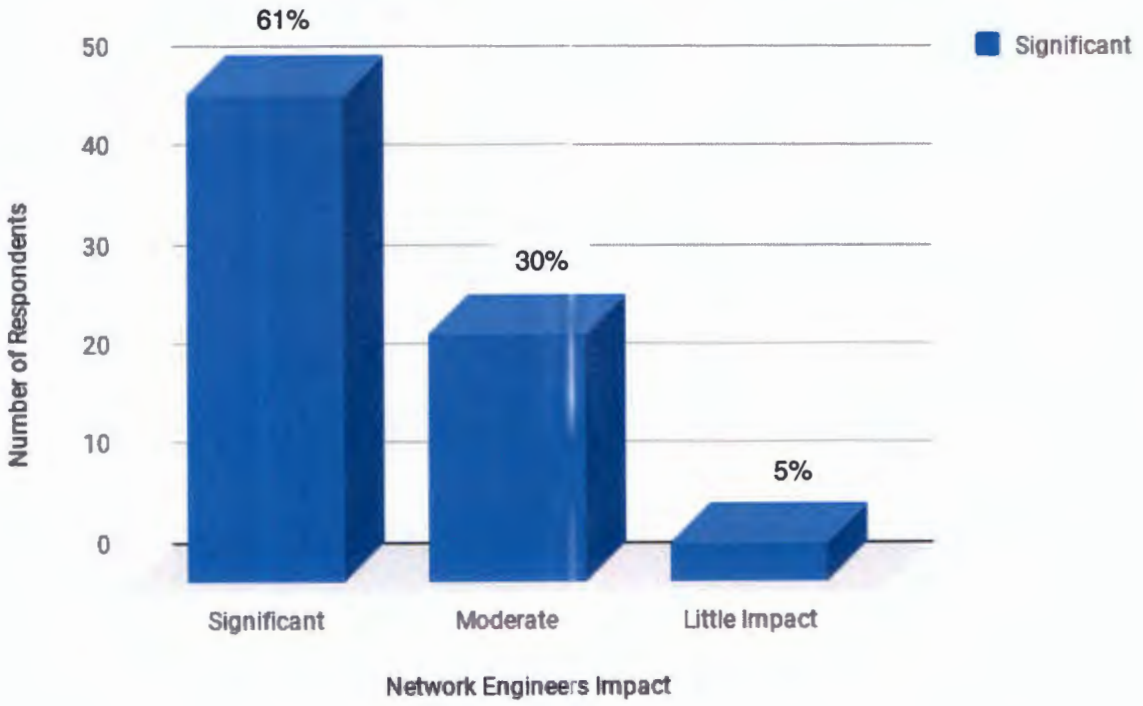

Figure 4-10 Software Defined Network Technologies Impact on Engineers

What changes do you think the SDN movement will bring to the nature of your job?

(Check all that apply)

- Skills needed will shift from networking to programming and scripting
- My role will blend with application teams causing confusion
- Configuration time will decrease and planning time will increase
- I will need to be trained to be able to support the SDN initiatives
- I don't think SDN movement will bring any change in the nature of my job

Figure 4-11 show 34% require "*Skills needed will shift from networking to programming and scripting*" and 32% also admitted that they "will need to be trained to be able to support the SDN initiatives" thus 22% confirmed that when adopting SDN "Configuration time will decrease and planning time will increase" while 9% said that their "role will blend with application teams causing confusion" and only 3% said they "don't think SDN movement will bring any change in the nature of their job."

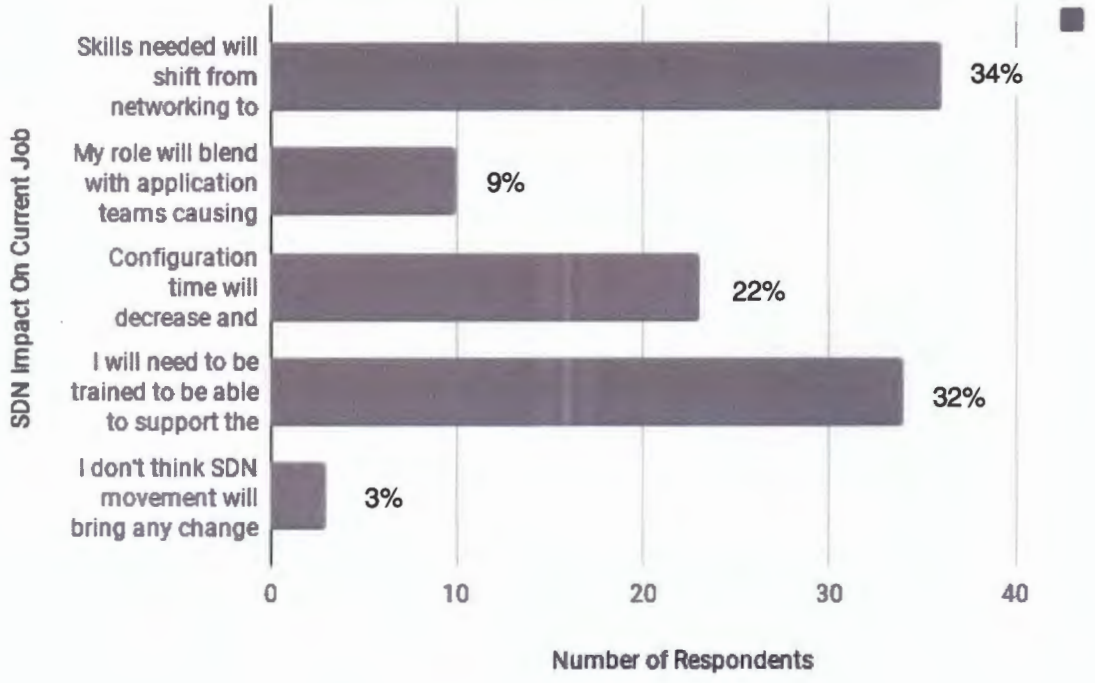

Figure 4-11 Software Defined Network Technologies

These results elaborated the reality facing engineers on the impact of adopting SDN in Higher Educational Institutions and in some other way what they expected this adoption will bring, thus these engineers and policy makers based these responses on their insight and expert knowledge of SDN.

However, by elaborating high on skills and training clearly show the fact that these engineers are aware of their lack of knowledge in SDN and the importance of being trained. In addition, comparison to legacy networking solutions, SDN solutions are relatively new and have not had the time yet to mature enough to earn the confidence of some networking professionals that are still reluctant to the stability, scalability and security of the different SDN solutions offered by the different vendors.

Ranking of challenges when implementing SDN:

Rank the following challenges that would stop or delay you deploying SDN?

Drag most important (TOP) to less important (BOTTOM)

- Concerns about Integrating SDN with existing network
- Immaturity of current products
- Immaturity of the enabling technologies (OpenFlow)
- Concerns about the ability of SDN to scale for organizations requirements
- The need to significantly train our staff
- No real business case for it
- Lack of definition in strategies from vendors
- Possible security threats

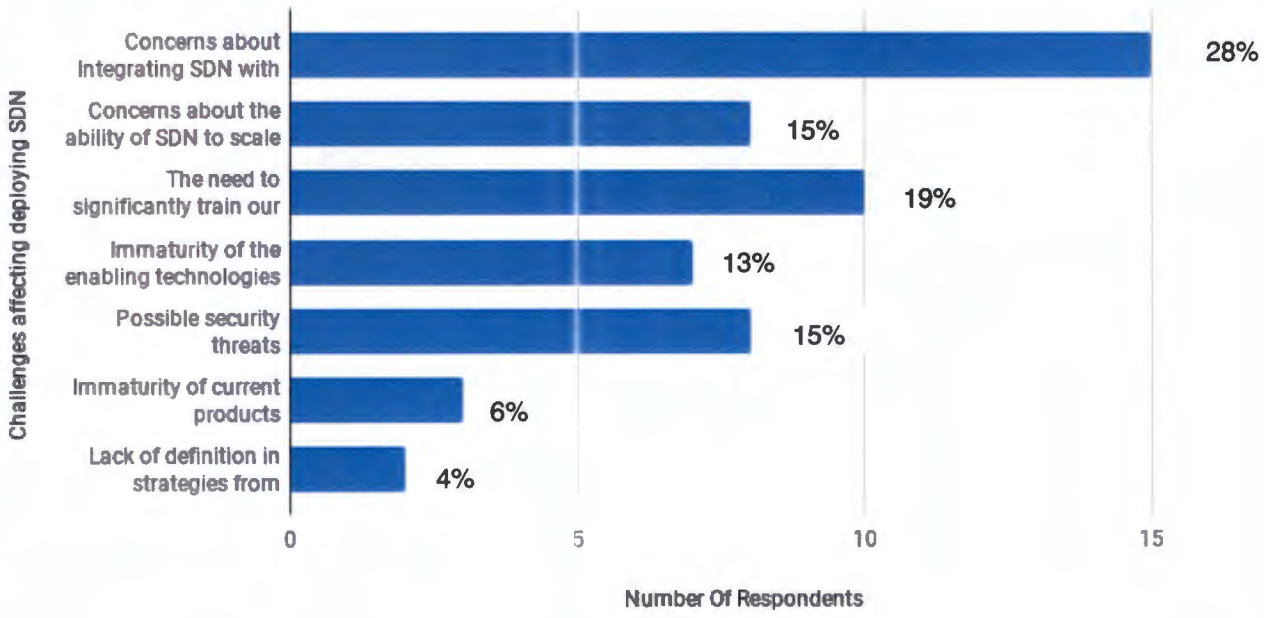

Figure 4-12 Software Defined Network Technologies

Thus, in this case one can say the survey gathered that there is some lack of the following:

- Capabilities needed to operationalize SDN;

- Institutional policies and budget constraints; and

- Industry standards.

How much impact SDN will have on the participant's organizational structure:

How much impact do you think an SDN implementation would have on your organizational structure in the next three years?

Participants responded to the question by replying that 68% of them anticipated an important impact *"Significant Impact"* on the nature of their jobs and 25% of them responded that it "*Moderate Impact*" and 2% said it will have "Little Impact".

However, the were 5% of them who responded "No Impact" as they did not know this effects the previous question asked about how familiar are they with SDN and 20% replied that they are not familiar at all. One can thus say that these respondents have no knowledge at all on their organization networking standards or they might not have a particular interest in networking or falling in the group classified above as 'Other' which might be Analysts and Programmers and the like.

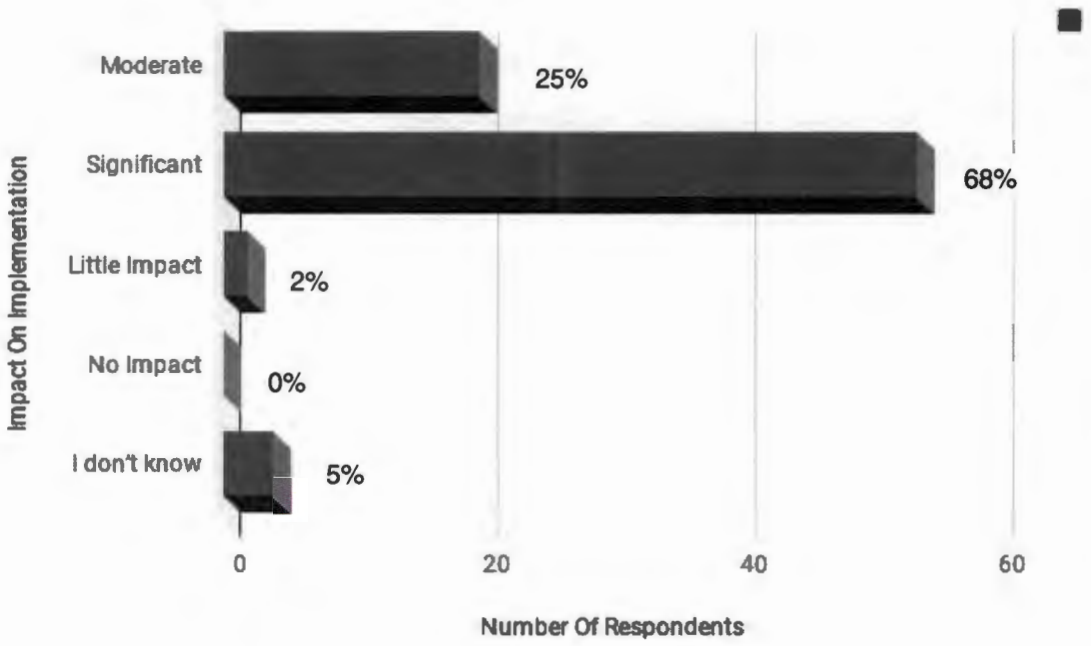

Figure 4-13 Software Defined Network Technologies Deploying Impact

Ranking of benefits of adopting SDN:

Rank the benefits that would drive you to implement an SDN solution?

Drag most important (TOP) to less important (BOTTOM)

- Simplification of network provisioning and configuration
- Perform traffic engineering
- Better utilization of network resources
- Reduce Operational Expenditure
- Reduce Capital Expenditure
- Support network virtualization

The initial reason for this question was to determine a clear distinction of higher valued compared to the lesser valued benefits by the participants and they range as follows:

I. Simplification of network provision and configuration

Participants ranked this as the first with 35% of majority of policy makers and network engineers operating with 1000+ network managed devices ranked *"Simplification of network provision and configuration"* as top in implementation of SDN in Higher Educational.

II. Better utilisation of network resource

A clear 28 % response rate put the ranking of 'Better utilisation of network resource" at second place in valued benefit, considering the size of the managed network which will be between mid-sized to a large-sized networks.

However, the idea was to identify on what network environment participants valued most in "Better Utilisation of network resource" as in the previous asked question the policy makers and network engineers have clearly shown plans to implement SDN in Higher Education Institutions in Cloud Networks, Campus Networks and WAN Networks.

This shows that solutions in start-ups in Higher Education Institutions is by trying to bring the benefits of SDN for Campus Data Centre and WAN to the campus network.

III. Perform better engineering

Participants ranked performing better engineering as the third position with 25% of respondents as their votes was equally dispersed in high and low positions of the ranking. This was particularly on WAN network performance on the whole campus network.

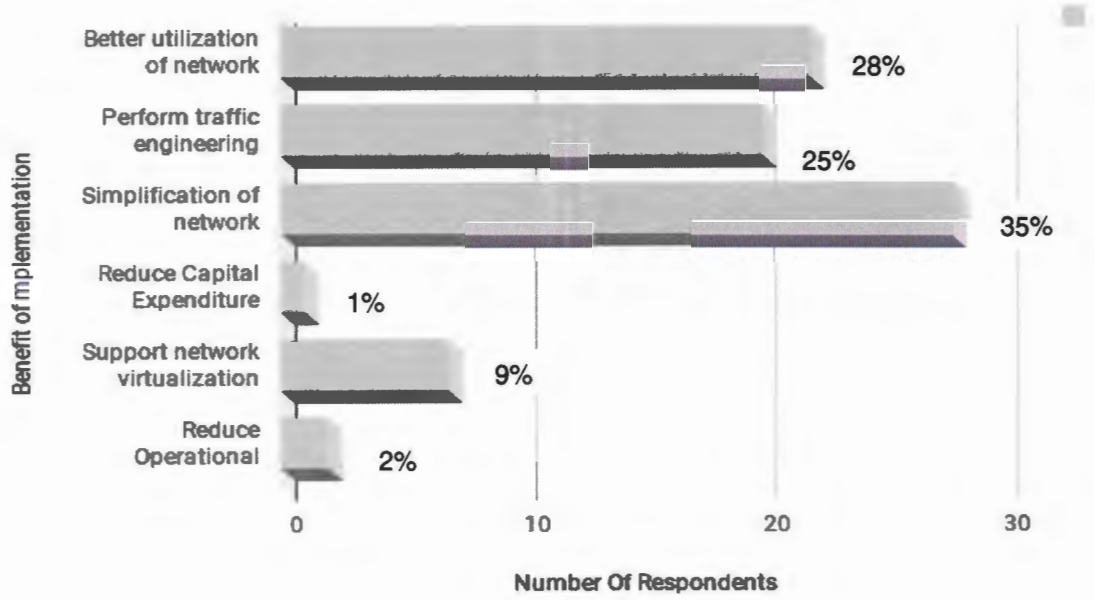

Figure 4-13 Software Defined Network Benefits of Deploying

What structural changes participants anticipate?

In your opinion. what structural organizational changes do you think an SDN implementation would bring to IT organizations? (Check all that apply)

- A likely reorganization of network operations team
- An increase of cross-functional teams and projects
- A move to DevOps model within the network team
- I don't think SDN will bring any organizational structure change

Figure 4-14 show results indicating that 40% choosing A likely reorganization of network operations team ,39% said there will be an increase of cross-functional teams and projects and thus 18% said there will be a move to DevOps model within the network team and lastly 3% said they don't think SDN will bring any organizational structure change.

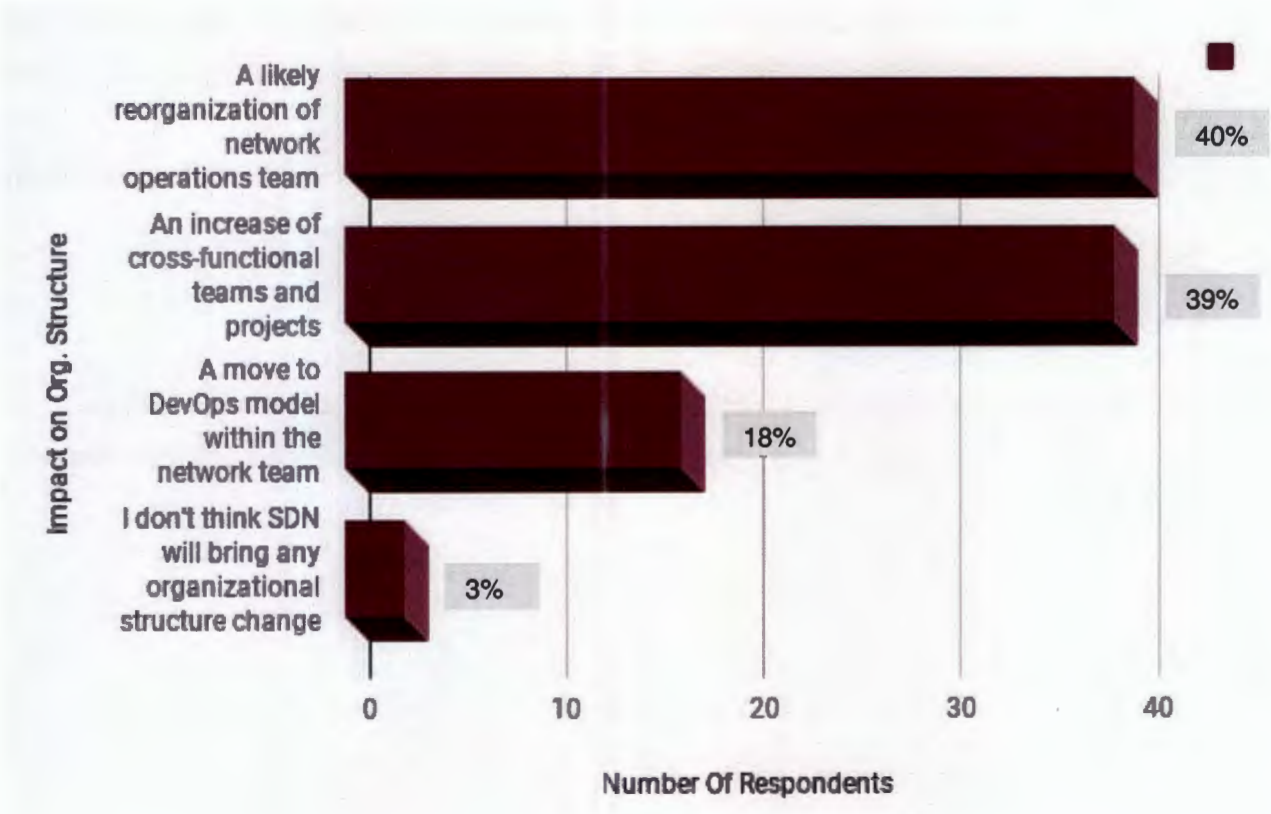

Figure 4-14 Software Defined Network Technologies

Participants have clearly shown evidence that a possible change in Higher Educational Institutions in relation to SDN adoption was presented around this question where almost half predicted that a likely reorganization of network operations team would be helpful in adoption which is followed by an increase of cross-functional teams and projects.

Thus, an implication of skills needed in the previous question further clarify the participant's response as to re-organising network operation teams and increase in teams and indicated that there will be a need for specialised working force required to enhance the current team as to successful implementation of SDN in Higher Educational Institutions.

4.7 Key Themes

The following key themes emerged from participant responses in the survey:

- Current Network cannot cope or manage with requirements in Higher Educational Institutions.
- Technological Advancement in networking elements supersedes the current infrastructure in these institutions which gives problems in networking
- Network Engineers and policy makers clarified the need for skills advancement and training in SDN particularly in new Infrastructural Adoption in current infrastructure
- Support structure in adoption of SDN will require more staffing especially experts in the field of SDN.

4.8 Summary

The purpose of this chapter was is to discuss the findings analyse them with relevance to the objectives of this study. It was also access the respondent's response on certain aspects of the study.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Introduction

This chapter focuses on the summary of the research findings, conclusions and recommendations with regards to Software Defined Networking Infrastructural change impact. In this chapter, the study highlights the findings and draw conclusions about the adoption of SDN in Higher Educational Institutions in the Northern Cape.

5.2 Summary of Findings

Objective 1: *To investigate the barriers that hinder higher education institutions' use of SDN with the current infrastructure*

The findings of this research highlight the degree to which top adoption factors were highlighted. The findings also present the degree of understanding by both Network Policy Makers and Network Engineers on SDN adoption and implementation.

In addition, the top three benefit on adoption factors included more advancement in utilization of network provisioning and configuration which required more training and skills to be developed in order to cater for adoption, Better utilization of network resources as well as Performing traffic engineering.

Moreover, there were concerns of integrating SDN infrastructure with existing infrastructure, due to existing infrastructure being immature in enabling technologies (open flow). As an in-depth study on application of six adoption factors was done in utilization of methods. Size of network were categorized to identify adoption factors differently.

Objective 2: *To determine the major processes required in formulating, implementing and adopting effective network policies in relation to saving costs.*

The results have provided a valuable insight into knowledgeable participant's attitude and their diverse mix of experience in SDN. The experience of these participants accumulated more than 10 years of experience in IT and gave evidence of being familiar with SDN and classified among different nature of business on diverse network sizes in their environments. The survey revealed that 54% are familiar with SDN and what it entails in Higher Educational Institutions.

Objective 3: *To determine the present state of SDN initiatives in Higher Education Institutions*

This study showed proved that, at present, most of the Higher Educational Institutions have SDN initiatives running at various adoption stages as follows:

- Evaluation of the value of SDN
- Decisions on vendor selection
- SDN test on current Lap environment
- Deployment on actual production network

Participants also indicated that SDN initiatives in Higher Education Institutions is at an initial stage of Data Center SDN alongside with WANSDN environments.

Objective 4: *To investigate the nature and relevance of SDN used by Policy Makers and Network Engineers role in Higher Educational Institutions*

The study proved a strong awareness by Policy Makers and Network Engineers on SDN adoption and their belief on its impact on Institutional role aspect in relation with SDN deployment on their role. The majority identified change of job descriptions which will include acquiring programming skill or training which will result in time reduction in the configuration of network.

On the other hand, 79% indicated a likelihood Institutional Structural Change and direct increase in teams and project leaders who have to acquire more expertise in network team with relation to the adoption strategy planning stages not affecting direct operations of institutions.

5.3 Strategies for Answering Research Questions

The accumulated data from the survey that was done on SDN with Policy Decision Makers and Network Engineers during this research confirmed evidence that SDN initiatives and adoption are gaining momentum at Higher Educational Institutions. This section tries best to answer research questions and sub questions in relation to the findings.

Strategy Question 1: Can Software Defined Network be used in higher education environment in order to develop effective research with progressive teaching and learning?

Strategy Question 2: Investigate the barriers that hinder higher education institutions' use of SDN with the current infrastructure?

Strategy Question 3: How can application of SDN save costs and be improved to enhance access to education material?

Strategy Question 4: What difference will SDN incur in Higher Education Institutions operations?

5.3.1 Strategy 1

Can Software Defined Network be used in higher education environment in order to develop effective research with progressive teaching and learning?

5.3.1.1 SWOT Analysis integration to SDN

The results in Section 4.5 to Section 4.7 in this study have proven that Higher Educational Institutions are in early stages of adopting SDN in the next two or three years to come although the professionals in question highlighted some benefits which will be impacted with few challenges in Section 4.5 to Section 4.6. This makes it clear that Network Professionals and Policy Makers in Higher Educational Institutions should set objectives for implementing SDN.

In support of this *Josh, (2018)* says "SDN lets IT spin up network connections on demand, as faculty, staff and researchers request additional servers and storage units. SDN also strengthens security. With a centralized SDN controller, admins can apply the latest policies uniformly across all connected devices, a task that is cumbersome and prone to gaps with manual processes."

SDN-SWOT Analysis has been done based on the results of this study to guide and help Higher Educational Institutions to make strategic decisions and plans for proper implementation of SDN in identifying strength, threads, opportunities and weakness that integration entails.

I. Internal Factors: SDN - Strength and Weakness

The factors in Higher Educational Institutions resources that determine the strength and weakness in the implementation of SDN are follows:

- **Implementation steps** – Higher Education Institutions should access and refine change management process and risks associated in SDN initiatives.
- **Financial aspects** – Institutions should do a proper feasibility study in the implementation of SDN and costs associated in the whole process
- **Human Resources** - access their current network professional's proficiency in adopting SDN in Higher Educational Institutions
- **Technological aspect** – current networking equipment should be integrated with new infrastructure in order to save costs.

II. External Factors: SDN - Opportunities and Threads

The study highlighted some of the opportunities and threats that SDN implementation will have impact in Higher Educational Institutions.

Opportunities:

- Reduction of Operational Expense (OpEx);
- Reduction of Capital Expenditure (CapEx);
- Better utilization and sharing of Network Resource;
- Simplified network configuration and better traffic provision; and
- Newer Technology resource support.

Higher Education Institutions can consider Table 5-1 in implementing SDN, thus the elements of SDN – SWOT analysis will be dependent on the characteristics of the institution.

Table 5-1 SDN - SWOT Framework

STRENGTHS	WEAKNESS
• Network Infrastructure ready for SDN deployment • SDN ready Network Professionals • Financially supported by Government • SDN easy migration process	• Training requirement for Network Professionals • Old Network Infrastructure un-ready for SDN initiative • Uncertain Financial Support • Unavailability of migration process
OPPORTUNITIES	**THREATS**
• Reduction of Operational Expense(OpEx) • Reduction of Capital Expenditure(CapEx) • Better utilization and sharing of Network Resource • Simplified network configuration and better traffic provision • Newer Technology resource support	• Staff Training Need • Current Networking Infrastructure • Risk of Integrating SDN with current Infrastructure • Security thread in implementation • Improper strategies by vendors • Scalability (controller is bottleneck) • Single point of failure

Table 5-1 SDN - SWOT Framework

5.3.2 Strategy 2

What are the barriers that hinder higher education institutions use of SDN with current infrastructure?

Network Engineers find it difficult in integrating SDN initiative with old infrastructure thus *Arandza, (2016)* says since "SDN concentrates the intelligence of the network in a central controller, it is often difficult to remove the intelligence of the different individual legacy network nodes. This operation includes high risk and it might be difficult to achieve without involving downtime on the network."

There are also threads identified in hindering more specifically adoption of the whole SDN process and they are stipulated below.

- Staff Training Need

Networking Engineers can hinder progress of adoption as skills needed might be a threat to their job and in-turn disregard new technology for the fact that they do not have the skill to manage SDN or programming interest.

- Current Networking Infrastructure

Old or redundant networking infrastructure and budgetary constraints might be a core reason for refusal of SDN initiative.

- Risk of Integrating SDN with current Infrastructure

This risk is associated with networking equipment's not correlating together (Old and New Equipment).

- Security threat in implernentation

Since this is a new technology institutions are always cautious about what to expect on making sure security is of the expected quality.

- Improper strategies by vendors

Poor strategical alignment of vendors and Institutions need to be carefully implemented

- Scalability (controller is bottleneck)

Scalability in SDN is one of the problems that needs to be given attention at the early stages of implementation. It is organized in the following approaches:

Topology related Approach

The study of the relation between topologies of architecture and scalability issues to be faced in Higher Eclucational institutions

Mechanism related Approach

This involves the review of various mechanism that can be used to adopt SDN in Higher Educational Institution by optimizing controllers and scalability issues.

5.3.3 Strategy 3

How can application of SDN save costs and be improved to enhance access to education material?

The results in Figure 4-9 show that engineers valued the implementation of WAN at 54%, Cloud/Test only 45% shown interest and Corporate/Campus only 38% of participants. This showed a clear distinct that SDN implementation will improve access to educational materials.

SDN provides capability of network visualisation inside a data centre and this feature can be applied in the learning environment to offer programing and more other expensive software's in a virtual environment, thus applying Quality of Service policies to ensure Institutional requirements are met while reducing Capital Expenditure.

In addition, better utilisation of network resource in implementation benefit was second most valued benefit of SDN survey by network professionals.

5.3.4 Strategy 4

What difference will SDN incur in Higher Education Institutions operations?

The results of this study in Figure 4-14 showed that 80% of Higher Education Institutions are involved in SDN initiatives and this confirms that Networking Professionals have no doubt that this initiative will benefit their respective institutions.

SDN networking has the ability to empower present underperforming WAN circuits and increase performance by redirecting traffic through to avoid packet loss. This can be a more effective way to improve high bandwidth needs in Higher Education Institution.

Foukas et al., (2016) says "despite that the initial SDN products primarily concentrated on automation and orchestration inside a Data Centre, the more mature SDN solutions, such as those from Google and Amazon, are designed to take software-defined WAN with centralised traffic engineering into consideration."

3.9.2.1 5.3.4.1 SDN Course Content

SDN implementation cannot only improve network, but this network can also be used in a classroom with SDN education programs and courses that most of the countries network professionals are going to need more especially in programming skill which will examine the fundamentals of SDN, virtual networking, control and data plane.

Moreover, *Josh, (2018)* said "since the technology is new and is constantly evolving, for now, some universities are integrating the content into their existing networking or IT courses. But, over time, programs that range from full-fledged university courses to professional SDN certification will emerge, and they will reflect the general shift that occurs in IT."

5.4 Road Map to Integrating Software Defined Networking

SDN integration into Higher Educational Institutions needs to address the following issues that will inhibit or stop the initiative:

Phase 1: Integrating SDN with existing networking Infrastructure

The results obtained in this study showed that networking professionals voiced their concerns about immaturity of current network infrastructure as being the top inhibitor in implementing SDN in Higher Educational Institutions.

However, this concern can be understandable as the whole infrastructural change can be costly, more especially with the current state of the economy and budgetary constraints in these institutions.

Phase 2: Strategies on Networking Infrastructure Sharing for Cost Saving

Networking professionals and Policy Makers need to formulate exceptional strategies to integrate with "TENET's. Its main purpose is to secure, for the benefit of South African universities and associated research and support institutions, Internet and Information Technology services. TENET is a service organisation and is committed to service excellence and to services that are strongly aligned and consistent with the organisational requirements of the user community" (Tenet, 2018).

Moreover, Tenet, (2018) policy makers "operates the SANReN Network under the terms of a Collaboration Agreement with the CSIR. In addition, TENET provides a growing number of services specifically tailored to the needs of the South African Higher Education and research communities. Together these components make up the South African National Research and Education Network (NREN)."

In addition, since this network was integrated with Vodacom, a decision was made to give University students and staff zero rated service with intension to "help address cost challenges associated with access to education content and remote learning for institutions of higher learning. Through this approach, Vodacom has already enabled 19 of the 23 South African Universities, including the University of Cape Town (UCT) in Western Cape and Sol Plaatjie University in Northern Cape, with free internet access."

South Africans have complained continuously about the high costs of data in the country. Those calls went a few decibels higher after freedom and expression and access to information advocacy group in Higher Educational Institutions.

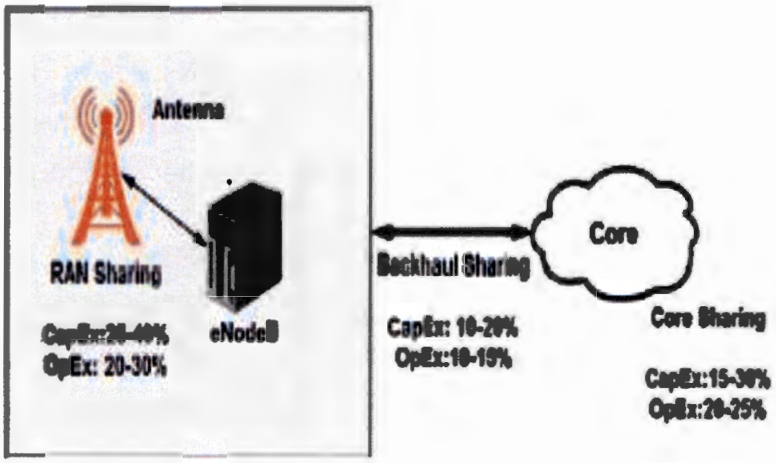

Figure 5-1 SDN – Shared Infrastructure(Mamushiane,2018)

According to *Mamushiane, (2018),* "sharing the radio access network including passive elements (such as land and masts) can reduce on an average 25-40% of CapEx and 20-30% of OpEx costs. An additional 10-20% CapEx and 10-15% OpEx is saved by sharing the mobile backhaul. Finally, sharing the core network would decrease CapEx and OpEx by an additional 15-30% and 20-25% respectively. This data is used alongside CapEx/OpEx calculations for an SDN-enabled mobile network deployment."

Figure 5-1 illustrates similar results of this study that a clear conventional model of single ownership and operation in infrastructural networking will not work in Higher Educational Institutions and with infrastructural sharing an enabling of quicker recovery of CapEx investment and OpEx reduction.

Phase 3: Impact of SDN on Network Engineers

From the perspective of networking professionals and policy makers based on data analysed in this study, it is safe to say SDN will bring drastically a big change in the role of Network Professionals.

Participants in *Figure 4-13* responded to the question asked about the impact of SDN on the nature of their jobs and 68% of them replied that they anticipated an important impact "Significant Impact", also they said there will be a shift from normal networking to programming and scripting.

Further evidence in the survey showed that more than half of the participants highlighted that there will be a need for training in order to support SDN initiative. This will change their daily roles to be using programming languages in their roles. But this comes with a benefit of decreasing configuration time and manual tasks and better network design, innovation aligned with automation and capacity planning.

In addition, *Arandza, (2016)* said that the "new role will be added to the traditional network design and network operations role. The network programmability engineer will be responsible for programming the new network releases designed by the design teams and operation teams to deploy new network solutions or automate operational tasks."

5.5 Contributions to Body of Knowledge

This study illustrated the current adoption and implementation stages of Software Defined Networking in Higher Educational Institutions. It also studied the relevance alongside with the necessities that these institutions should advance to, for faster operation and stimulating research to continue.

Moreover, further it showed benefits provided by SDN in initiating its adoption and the challenges hindering it. Network Professionals and Policy Makers needed to be aware of these benefits and challenges in order to apply them in their strategies when adopting present and future SDN initiatives.

Thus, the insight will not only be useful to stay relevant to market trends, but it also investigated the impact SDN will bring in the present and nearest future by illustrating that the SDN adoption will provide more automated, easier-to-use and featured enhanced solution to Networking. It specifically proposes an extended Technology Acceptance Model (SDN-TAM) and adds several additional variables as well as list of objectives and hypotheses. It proposed a framework for SDN-SWOT analysis as a roadmap to hinder Higher Educational Institutions to overcome challenges in integrating SDN alongside with maximum benefit.

5.6 Limitation of the Study

This study has several limitations which were direct consequence of limited timed time cycle and nature of this analysis. The sample population was smaller than initially desired although it covered the various profiles that were target for this research.

A bigger sample population sample would have strengthened the validity of the conclusions derived from this study. The experimental study was also a small-scale study, limited to Networking Professionals in One university, Two FET Colleges in the Northern Cape and Policy Makers in CSIR.

Furthermore, a mixed research approach of qualitative data obtained through interviews with Networking Professionals and Policy Makers would have been relevant to the study where Qualitative data would have incorporated professional opinions collected through Quantitative data from an online- survey, thus reaffirming conclusions of this study, but due to time restrictions and busy schedules of Policy Makers Qualitative data was waived.

5.7 Recommendations and Future Work of Software Defined Networking

One important obstacle to overcome in the acceptance of Software Defined Networking is that it is based on challenges of policy makers in integrating SDN initiative with legacy networks although any development or progress would be very beneficial to these Institutions. On that note a deeper study of evolving vendors in SDN solutions and enabling technologies would be of great help for researcher and policy makers.

The problem of finance is becoming a barrier for most institutions. That is the reason the Department of Higher Education and Training (DHET) is implanting this project with the intension to pilot it to all Universities. The study was done by CSIR as a testing phase on UJ (University of Johannesburg) network and so far it is an observatory phase though it would be likely to be piloted soon to one or more university (CSIR, 2017).

According to *Arandza, (2016)* "the evolution of SDN should be continuously monitored as one thing is certain: the increase in volume, variety and velocity of data is unprecedented and networks are becoming larger and more complex each day. SDN initiatives are developing fast to keep networks manageable and flexible to the data flow changes, and such initiatives are only going to become more relevant to the future of networking than they are already today."

"The adoption of next generation Wi-Fi, Cloud and MAN/WAN Networks will continue to deliver on the promise of 'anywhere, anytime access'..."
(Wagner & Wilson, 2015).

5.8 Concluding remarks of the study

The outcomes of the study indicated that the legacy network is no longer sufficient to cater for the constantly evolving technology, thus a more efficient network requirement of prestige researchers, staff and students is increasing daily.
There is continued pressure on Networking Professionals and Policy Makers to maintain high level of satisfactory service delivery in a constantly changing Higher Educational Institutions as they are an environment on research and a source knowledge and ideas.

Moreover, Nkosi, *(2018)*, stated that "Software Defined Networking (SDN) - enabled tactical networks offer an environment for the delivery of information services which support dynamically changing force in the presence of physical threats and wherein bandwidth is scarce. These networks deliver critical information with required quality of service in the presence of changing operational priorities. When compared to traditional tactical networks, SDN-enabled tactical networks offer benefits such as configurability, which provides the ability to configure the network without re-engineering of the hardware and agility, which provides the ability to re-configure the network quickly and easily with minimal resources".

5.9 Summary

In conclusion, the researcher would like to recommend that policies should be drafted on the adoption and implementation of SDN in Higher Educational Institutions.

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6 Supporting materials

6.1 Appendix A: Survey Questionnaire

Participants Profile.

In order to establish profiles for the different participants who answered the online survey the following sub categories were established;

1. Years of experience in IT
2. Familiarity with SDN technology
3. Size of the managed network
4. Influence on SDN related initiatives
5. Type of industry of their organization

Thus, Survey these are distributed as follows:

1. Section 1: Demographics - Participants Profile.

- A. Years of experience in IT
- B. Type of industry of their organization
- C. Size of the managed network
- D. Influence on SDN related initiatives
- E. Familiarity with SDN technology

2. Section 2: Traditional Network Perceptions on Present state and Usage

A. Barriers experienced by the participant on Traditional Network

B. What changes participants anticipate in evolving technology for Traditional Network

3. Section 3: SDN Perception and Knowledge

A. How much impact SDN will have on the nature of the role of network engineers

B. What changes participants anticipate on the nature of their role

C. How much impact SDN will have on the participants' organizational structure

D. What structural changes participants anticipate.

4. Section 4: SDN Experience and Adoption

- A. Ranking of benefits of adopting SDN
- B. Ranking of challenges when implementing SDN
- C. Ranking of Economical Effects in adoption of SDN
- D. Where in their network SDN will be deployed in the nearest future

Questions are as follows:

Participants' Profession in IT:

- CIO
- IT Director
- Network Engineer
- IT Consultant
- Other [Programmer, IT Analyst and etc.]

Participants' years of Experience in IT:

- Less than a year
- 1 to 3 years
- 4 to 6 years
- 7 to 10 years
- Over 10 years

Type of industry of the participants' organizations

In which industry are you currently employed? (What is your company primary business)

- Information Technology / Internet / Software
- Telecommunications provider
- Finance or insurance
- Construction
- Forestry, fishing, hunting or agriculture support
- Public administration
- Transportation or warehousing
- Real estate or rental and leasing / Accommodation
- Management of companies or enterprises / Consulting services
- Educational services
- Health care or social assistance
- Other

Participants' Familiarity with SDN technology

How familiar are you with Software-Defined Networking?

- Very familiar
- Moderately familiar
- Slightly familiar
- Not familiar at all

Size of the managed network

How big is the network you Operate / Account for/ Manage?

- 1 - 50 Devices
- 60 - 99 Devices
- 100 - 499 Devices
- 600 - 999Devices
- 1000+ Devices

Participants Perception on Traditional Network

How would you rate the state of your current network?

- Poor
- Moderate
- Exceptional
- Exceeds Expectations

Influence of the participants on SDN related initiatives.

How much influence your opinion on adopting SDN would have in your organization?

- I am the maximum responsible and decision maker for network design and implementations including SDN
- I am part of a decision making group for network implementations including SDN
- I am NOT part of a decision making group but my opinion would be considered by the decision making group in my organization
- I have no influence at all

Present involvement by the participant on SDN initiatives

Are you part of any Software-Defined Networking initiative? (Check all that apply)

- We have not conducted any study of SDN yet
- We will likely study SDN possibilities next year
- We are studying the VALUE that SDN can bring to our organization
- We expect to have SDN running in a Lab environment within a year
- We are currently studying different SDN vendors' solutions
- We already have SDN running in a Lab
- We already have SDN running in our production network

Where in their network participants think SDN will be deployed in the nearest future

Check all the scenarios where you think you will deploy SDN in the next 3 years.

(check all that apply)

- Cloud/Test network
- Corporate/Campus network
- WAN network
- Production Data Center Green field deployment (new network)
- Production Data Center Brown field deployment (existing network)
- I don't think I will deploy SDN in the next three years

Ranking of benefits of adopting SDN

Rank the benefits that would drive you to implement an SDN solution?

Drag most important (TOP) to less important (BOTTOM)

- Simplification of network provisioning and configuration
- Perform traffic engineering
- Better utilization of network resources
- Reduce Operational Expenditure
- Reduce Capital Expenditure
- Support network virtualization

Ranking of challenges when implementing SDN

Rank the following challenges that would stop or delay you deploying SDN?

Drag most important (TOP) to less important (BOTTOM)

- Concerns about Integrating SDN with existing network
- Immaturity of current products
- Immaturity of the enabling technologies (OpenFlow)
- Concerns about the ability of SDN to scale for organizations requirements
- The need to significantly train our staff
- No real business case for it
- Lack of definition in strategies from vendors
- Possible security threats

SDN Implementations Impact on Network Engineers

How much impact SDN will have on the nature of the role of network engineers?

- Moderate
- Significant
- Little Impact
- No Impact

What changes do you think the SDN movement will bring to the nature of your job?

(Check all that apply)

- Skills needed will shift from networking to programming and scripting
- My role will blend with application teams causing confusion
- Configuration time will decrease and planning time will increase
- I will need to be trained to be able to support the SDN initiatives
- I don't think SDN movement will bring any change in the nature of my job

How much impact SDN will have on the participant's organizational structure

How much impact do you think an SDN implementation would have on you organizational structure in the next three years?

- Moderate
- Significant
- Little Impact
- No Impact
- I don't know

What structural changes participants anticipate

In your opinion. what structural organizational changes do you think an SDN implementation would bring to IT organizations? (Check all that apply)

- A likely reorganization of network operations team
- An increase of cross-functional teams and projects
- A move to DevOps model within the network team
- I don't think SDN will bring any organizational structure change

6.2 Appendix B: Ethics Clearance

6.3 Appendix C: English Edition Letter

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CERTIFICATE OF EDITING A DISSERTATION

TO WHOM IT MAY CONCERN

This serves to confirm that I have read and edited Mr C.T.E Makhoere's mini-dissertation titled: **Investigating Adoption and Implementation of Software Defined Network in Higher Education – Case of Northern Cape.** The candidate corrected the language errors identified. The document is of an acceptable linguistic standard.

Thank you

Yours Faithfully

.....

J.R. Moletsane (Subject Head Academic Literacy)

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6.4 Appendix D: Turn-it-in report

C.T.E Makhoere

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