Evaluation of Research Education Networks in Zambia

a case study:

Zambia Research Education Networks (ZAMREN)

By

Jervas Mwiinga

A dessirtation submitted in fulfillment of the requirements for graduation with a Master of Engineering in Information, Communication and Technolgy

School of Engineering

Deparment of Electrical, Electronics and Engineering

University Of Zambia

DECLARATION

Student Declaration

This is my original work and has not been presented for a degree in any other university.

Student's name	:	Jervas Mwiinga
Student No	:	514706041
Year	:	2017
Student's signature	:	…….
Date	:	…….

Supervisor Declaration

This document has been submitted for review with our approval as university supervisor.

Supervisor's Name	:	Dr. Mbuyu Sumbwanyambe
Year	:	2017
Institution	:	University of Zambia
Supervisor's signature	:	……
Date	:	…….

CERTIFICATE OF APPROVAL

This dissertation of Jervas Mwiinga has been approved as fulfilling the requirements for the award of Master of Engineering in Information and Communication Technology by the University of Zambia.

Name	Signature	Date
----------	----------	----------
Internal Examiner		
----------	----------	----------
Internal Examiner		
----------	----------	----------
Internal Examiner		
----------	----------	----------
Supervisor		

DEDICATION

I would like to dedicate my dissertation work to my family. A special feeling of gratitude goes to my loving wife (Mavis) and children (Luyando, Mark and Kezia) for your unwavering support and love during my research.

Finally, l would like also to dedicate this dissertation to many friends and family who have supported me throughout the entire process of the research. I will always appreciate all your efforts rendered to me.

ACKNOWLEDGEMENT

I would wish to recognize and acknowledge the contribution made by various organisations and individuals towards the successful completion of this study. However, the special acknowledgement goes to, my supervisor, Dr. Mbuyu Sumbwanyambe, for his professional guidance in this study.

I would like also to acknowledge the University of Zambia (UNZA), Zambia Research Education Network (ZAMREN), ZAMREN affiliates, Centre of Excellence for e-government and Information Communication and Technology (CEEGICT) and fellow masters students-UNZA for their support too.

ABSTRACT

ABSTRACT- ZAMREN a Zambian NREN, established on 19th September, 2007, has its network along the line of rail (Livingstone town to Chililabombwe town), and it connects to rest of the world through two (2) fibre channel at 1Gbps. The use of video conferencing application or data intensive applications is desirable and a quicker means of fostering e-learning over the internet. Sustaining such a service is, however, expensive as it requires a substantial bandwidth allocation as well as computers with adequate capacity. Therefore, knowing the capacity of the network, strategies on how to manage multimedia services or applications in RENs is essential.

This research was an evaluation of REN in Zambia primarily focusing on identifying affiliates challenges in accessing ZAMREN network, determining the current ZAMREN network status and determining the robustness of ZAMREN network in support video conference applications. The research instruments used in the study included questionnaires, Ms-excel, SPSS and Opnet 14.5 network simulation software. The findings for objective (i); 19% of ZAMREN affiliates faced a challenge of power outage, 16% challenge of funding, 16% fibre cuts (damages), 11% high internet tariffs, 7% lack of technical ICT know-how, 7% lack of support from ZAMREN, 5% lack or low level of appreciation ZAMREN's infrastructure, 5% connection problem, 5% long response time, 2% lack of management support on ICTs matters, low level of appreciation of ZAMREN was 2%, 2% poor services, 2% unsecure and unreliable and 2% bureaucracy. The finding for objective (ii) was that the maximum current channel capacity of ZAMREN was 1Gbps, and the findings of objective (iii); was determined at point of failure for ZAMREN network which was at 6752 nodes and total traffic sent was 1000067889 bits/sec.

Keywords: *Research Education Networks (RENs), ZAMREN, video conferencing, High Performance Computing (HPC)*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abbreviation and Acronyms

AARNet	Australian academic and research network
AERN	Africa Education Research Network
AUP	Acceptable Use Policy
BBREN	Barbados Research and Education Network
CANARIE	Canadian Network for the Advancement of Research, Industry and Education
CARICOM	Caribbean Community
CARNET	Croatian Research and Education Network
CDRC	Chronic Disease Research Center
CEO	Chief Executive Officer
CLARA	Latin American Cooperation of Advanced Networks
COSETCO	Copperbelt Secondary Training College
DANTE	Delivery of Advanced Networking Through Europe
DWDM	Dense Wavelength Division Multiplexing
DREN	Defense Research and Engineering Network
ECFS	East Caribbean Fibre System
GEANT	The Pan-European research network
HEDU	Higher Education Division Unit
HPC	High Performance Computing
ICT	Information and Communications Technology
iEARN	International Education and Resource Network
IP	Internet Protocol
IRU	Indefeasible Right of Use

Mbps	Mega bits per second
MPLS	Multi---Protocol Label Switching
NLR	National LambdaRail
NOC	Network Operation Center
NREN	National Research and Education Network
REN	Research Education Network
RREN	Regional Research and Education Network
SLA	Service Level Agreement
SCMR	School of Clinical Medicine and Research
TERENA	Trans---European Research and Education Networks Association
WAN	Wide Area Network
ZAMREN	Zambia Research and Educational networks
ZICTA	Zambia Information Communication Technology Authority

CHAPTER 1: INTRODUCTION

1.0 Introduction

This chapter gives an overview of National Research Education Network (NREN). It gives insights on the history or background of NREN. This chapter also touches on the focus of the research, NREN model and its general activities, problem statement, purpose and objectives of the study. Other topics covered includes research questions, significance, limitation, research methodology and organisation of the thesis.

1.1 Background

In this global village, the use of ICTs, in particular, access to computers and the Internet, are valuable resources that have become recognised as vital tools for research, education and lifelong learning [1][2].

Attempts at establishing National Research and Education Networks (NRENs) can be traced back to the late 1960s. These early NRENs were represented by adhoc facilities, and subsequently evolved into a common set of standards of data networking operating over telephone circuitry and managed by dedicated organizations. However, the first successful NREN was known as Advanced Research Projects Agency Network (ARPANET) and was developed in 1969. ARPNET connected government-sponsored research organisations [2]. The trend of NREN refinement continued till early 1980s when major developments were achieved in NREN and this period was probably the dawn of modern NREN [2][20][23].

In general, the origin of modern research and education networks (RENs) is traced to the mid-1980s in Europe [6][9]. In 1984, National Science Foundation Network (NSFNET) was successfully developed as a general purpose research network and served as the backbone for the Internet followed by the adoption of X.25 protocol as a common connectivity platform between research and education communities. It then evolved into high speed dedicated networks that integrated networking interfaces, switches, and routers and facilities running computationally intensive research and education (R&E) applications and services that are often not found on the Internet [2]. As an illustration, Figure 1.1 shows the general building blocks of connectivity of RENs.

RENs are high speed Internet Service Provider (ISPs) education networks. They provide internet services, mainly, to research and academic institutions at a very low rate than other

ISPs [10]. However, their operations and services are regulated to ensure that they do not gain competitive advantage over commercial ISPs and other players in the market. Instead, RENs are set up purely for the provision of a service to education and research institutions, and to some extent hospitals. RENs are latest forms of enhancing and conducting education over the Internet. This type of education offered through RENs is known as electronic learning (e-learning). E-learning uses Information, Communications and Technology (ICTs) facilities that is the RENs' infrastructure or network tools [6][7]. In other words, RENs provide a platform for institutions, students and researchers to access and share information through the means of Internet.

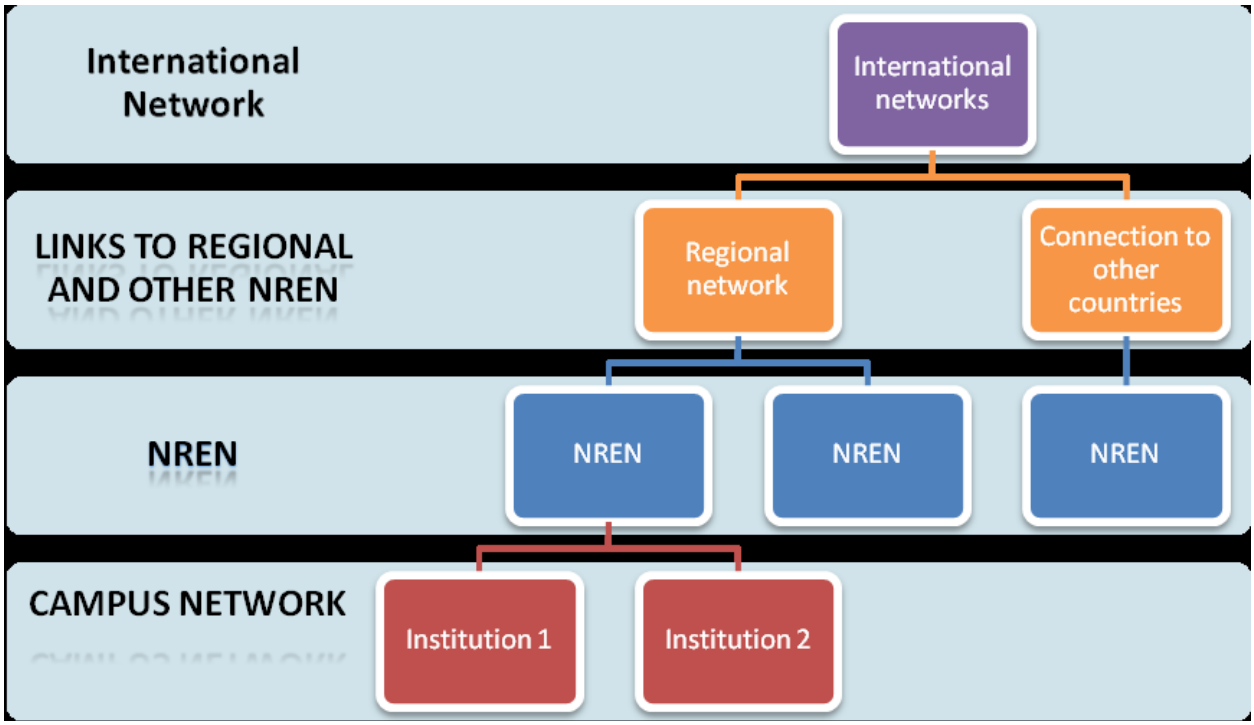


Figure 1.1: The building block of Research and Education connectivity (Source: Tembo.S, 2015)

Internet is an essential component in the promotion and sustainability of e-learning. Internet based e-learning is advantageous and characterized by quick delivery of service, flexibility and cost reduction. However, e-learning is characterized by high computing performances that compromise on the quality of service or bandwidth of the network ultimately leading to poor network performance. Therefore, the significance of bandwidth in a network, particularly, in RENs cannot be overemphasized. In the recent past years, globalisation, virtualization, and mobile computing, video streaming and cloud computing

have caused an upswing of demand for bandwidth [15][22][26]. Actually, it is predicated that the bandwidth demand will increase eight-fold by 2020 to 900 terabits per seconds making RENs no exception [16]. The demand for bandwidth has been as a result of high-performance computing applications usage that have been on increase.

Apart from connecting academic and research institutions, NRENs provides the connected community access to educational resources, complex data sets and sophisticated computing facilities such as supercomputers and advanced applications, which demand high network capacities [11]. Currently, science and education rely on computer–communication networks. This is easily achievable through the use of RENs which are newer forms of extending academic communities, and soon would become indispensable entities [11].

1.2 Focus of research

The main focus of this research was to determine ZAMREN's network in supporting e-learning in Zambia, particularly, when using high-performance computing (HPC) applications such a video conferencing. In addition, the research's focus was assessing the current network parameters of ZAMREN as well as identifying and documenting challenges faced by ZAMREN affiliates in accessing the network. The research was composed of both empirical and descriptive components. The current network capacity was subjected to high-performance computing application so as to determine the point at which the ZAMREN network would fail. This exercise was achieved by simulating the ZAMREN network using the network simulator known as OPNET [17][18]. Lastly, the results were analysed using statistical applications and recommendations were made and which would aid decision making for stakeholders. Simulator, questionnaire distribution and literature review were carried out in order to achieve these objectives.

1.3 NREN Model

The European NREN model is singled out or identified as a best NREN model and is successfully adopted and implemented in several countries in the world. It is premised on best practice and standards. This model provides connectivity between universities, research centers, and educational institutions with each represented and managed by its own local area network (LAN). The LANs are then connected at the national level through a high speed dedicated network, managed by an NREN organization. The connection is then extended to international level through the regional network. The GEANT network

provides regional connectivity in the european connectivity. However, in some instances NRENs may directly connect through an alternative known as the cross-border fibre which is becoming more prevalent. In Terms of funding, NRENs are generally publicly funded by governments for their running costs and/or by their member institutions [2]. Similarly, any communication network, NRENs require management, monitoring, maintenance, upgrading and controlling as well as national legal entity backing. Legal identities are significant for managing this network and perform the basic network management tasks and to provide network related services. The organizational and ownership model for NRENs varies between countries, and may include the following:

i. A Consortium NREN

This compromises of universities and research institutions and relevant stakeholders that came together to form a consortium or group run the network.

ii. NREN supported by non-profit company

Universities and research centers or the government may establish a nonprofit company to manage the network.

iii. NREN supported by governmental Entity

The government set up an entity under a relevant ministry to manage the network and provide the necessary services.

iv. NREN established as a national authority

The entity is set up by government as attachment to a national research authority [2].

1.4 NREN general activities

The general activities of NREN have undergone some evolution over the last past years. The focus of NREN has been anchored on establishing robust research and education institutions or communities to support network operation and services. This led to the creation of communities with world class experts and scientists, innovations and provision of cutting edge network services and applications. NRENs provide variety of other general services and activities, including:

i Unified connectivity

Integrated connection of all research and education institutions to a country-wide standard communication facilities, faculties, researchers, students, and staff, better sharing of resources, information, data, knowledge and expertise.

ii Consolidated Internet services

Provision of Internet Service Provider (ISP) as consolidated internet service to universities and research institutions, and leads to reduction in access costs and enables common access policies and configurations at the national level.

iii Connectivity to regional research networks.

It provides opportunities for joint research collaboration and online education initiatives.

iv Integrated access to content

Accessing global information, repositories and library resources of all universities and research centres by means of unified subscription to all journals and periodicals.

v Video conferencing services

NRENs provide video conferencing, media streaming, IP telephony services, access to federations, and wireless roaming for all users in universities and institutes. These facilities are essential for purpose of facilitating communications, exchanges of lectures, and coordination of meetings, training and conferences between all users in universities and institutes.

vi Provision of consolidated agreements

Provision of consolidated agreements with software vendors on behalf of all universities for licensing which ultimately reduces the cost of software licensing.

vii Provision of unified security

Provision of unified caching, filtering and anti-virus protection services to all connected institutions.

viii National internet exchange

In some countries NRENs are mandated to create and manage a national internet exchange and provide domain name registry services and networking consultancy. In addition, in order to improve facilities of a NREN, joint research, data communications, and high performance computing and establishment of a dedicated research and education (R&E) infrastructure has been identified as a priority [2].

1.5 Problem statement

Currently, the use of HPC services or data intensive applications such as video conferencing is desirable and a quicker means of fostering e-learning over the internet. Sustaining such a service is, however, expensive as it requires a substantial bandwidth

allocation as well as computers with adequate capacity. Additionally, the other implications of HPC service applications is poor network performance and to some extent network failure. Therefore, knowing the capacity of the network and strategies of how to manage HPC service applications in RENs is essential.

1.6 Purpose of the study

The purpose of the study was to evaluate ZAMREN network so as to determine whether or not its current network setting parameters can support HPC applications which are important in the enhancements of e-learning in Zambia.

1.7 Objectives of the study

The following were the specific objectives of the study:

i. To carry out a survey to identify challenges faced by ZAMREN's affiliates.
ii. To identify the current bandwidth and other network parameters that are in use at ZAMREN.
iii. Using the bandwidth parameter in (ii), perform a simulation to determine the point of failure of ZAMREN network.

1.8 Research questions

The following were the specific research questions of the study:

i. What are some of the challenges faced by ZAMREN affiliates which potentially hamper access and use of ZAMREN network?
ii. What is the current bandwidth and other network parameters of ZAMREN network?
iii. How can we use the bandwidth parameter in (ii) to determine ZAMREN point of failure when subjected to video conferencing application?

1.9 Significance of the Study

Generally, a network should be resilient and offers the desired quality of service to its intended customers. As such, network builders usually perform simulation of the proposed network in order to gain a deeper understanding of how the network will perform under different traffic load densities and parameter settings. It is for this reason that this study was undertaken and brought out insightful information pertaining to network performance and resilience of the ZAMREN network when subjected to different traffic loads and parameter settings, particularly, under video conferencing applications. Furthermore, the

study brought out insightful information pertaining to the challenges faced by ZAMREN affiliates. The study also revealed and documented essential information relating to the current technological landscape of ZAMREN such as network and hardware infrastructure.

Finally, the study findings or results were a positive contribution to the body of knowledge as well as that it would be of use for decision making to stakeholders which includes ZAMREN, MOHE, UNZA, ZAMREN affiliates.

1.10 Limitation of the study

In this study, one of the limiting factors was budget constraints faced by the researcher. The researcher was sole sponsor of the study as such it was challenging to meet the study requirements adequately. Due to financial constraints, the scope of the study was mainly restricted to Lusaka. Delay in data collection was another challenge faced as some questionnaire respondents delayed to give feedback.

1.11 Research Methodology

The overall research methodology used was mixed approach, that is, both quantitative and qualitative approach. The other overriding activities which were considered in the research methodology included selection of the topic, literature review, research design, selecting a sample, data collection techniques and simulation, data collection procedure, data analysis and ethical consideration.

1.12 Organisation of the thesis

Chapter 1 is the introduction of the study or dissertation and among the section covered includes; background, problem statement, research objective and question, significance and limitation of the research.

Chapter 2 provides an overview of literature review about this dissertation. Literature review covers Europe, Asia, Africa and Zambia, particularly, ZAMREN.

Chapter 3 presents the methodology of the study which is a mixed approach. The other overriding sub chapters are research design and sample selection.

Chapter 4 presents the findings and discussion of the study. The findings are linked to the objectives (I, II, III) of the study. Each objective is a sub-chapter on its own and presents the findings. The discussion section is structured like the findings section.

Chapter 5 this is final chapter of the study. It presents the conclusion, recommendations and summary of the study. In addition, it presents the features works section of the study.

References, appendices and journal published are also included the study after the last chapter, that is chapter 5.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents relevant reviews pertaining to RENs which were conducted in this study. The scope of the review included but was not limited to USA, Europe, Asia, Africa, Zambia, RENs network infrastructure, future RENs, e-science and HPC application, general challenges of RENs third world countries and summary of RENs.

2.2 Literature reviewed

Relevant documents that focused on NRENs or RENs were thoroughly reviewed and were vital in crafting this study. Journals, conference proceedings, technical reports, lecture notes and books are some of the existing documents, which were reviewed. The approach was to review documents for both primary and secondary data sources and thus were either accessed via Internet (online) or physically as hardcopy. However, most of literature documentation was accessed via internet because it was quick and easy to access them. This exercise was about consulting the existing relevant literature on RENs, HPC and bandwidth utilisation [65]. Both primary and secondary data sources were undertaken during the literature study process. Under the secondary data consultation, online documentation such as journals, conference proceedings, technical reports, blogs, websites and books were the main source of information in the study. For instance, TERENA, GEANT, TEIN, WACREN, UbuntuNet Alliance are among some of the specific online websites which were reviewed [13][22][36][56]. Online secondary data source provided substantial information and relevant information for the researcher. The method facilitated the researcher to quickly access the information without travelling to the source of information. In additional, non-online documentations were also reviewed and these included; books, UNZA lecture notes and ZAMREN documents. Under the primary sources, hard copy questionnaires were the source of information and were distributed to ZAMREN affiliates. In comparison with arranging interviews, these were advantageous to the researcher because they were easier and cheaper. The questionnaires were designed with closed as well as multiple-choice questions. Closed questionnaires, generally, are ease in the analysis of the data because of their objectivity whereas multiple-choice questionnaires prompted more detailed information about the object of the study. All documentations used in the study were correctly acknowledged using the IEEE style of

citation and reference which was adhered to during the entire process of literature review as well as in the entire research.

Europe, USA, ASIA and Africa are the specific regions in the world which were used for the provision of information in this particular research and the information was readily available and accessible. However, literature review was not a one-off activity or event in this research rather as a continuous process. Literature review provided profound historical information which was useful, particularly in achieving objective I and II as well as for designing and for the successful implementation of this research. For instance, information pertaining to network topology was taken from existing literature and it was very useful in the research. Network topology literature as shown in Figure 2.3 as well as network parametres in Table 2.1 provided the necessary input parameters for this research.

2.3 Global perspectives on national NRENs

NRENs are a key for prosperity, development, stability, and national, regional and international integration in this age where ICTs are vital in supporting research and education, and in the creation of an innovative and lifelong learning society, which has a community of abundant scholars, researchers, engineers, technicians and firms engaged in production of knowledge, goods and services. RENs in this regard are very important because they can make a significant contribution to supporting the research community. In actual sense, RENs are regarded or viewed as an essential national infrastructure, 'public goods', in comparison to, for instance, roads, water, ports and energy services due to its positive implications on the society, that is, impact on the knowledge economy, general economic development and social cohesion [11][40][44].

In a Zambian context, it has an operational NREN known as ZAMREN. Table 2.1 shows the current network parameters of ZAMREN. For instance, has 1 fibre external link with a capacity of 1Gbps, current bandwidth of 1Gbps, 1 HPC and 56 affiliates. Additional parameters includes; 7 point of presences (PoP), 1 national operation centre,2 international links and 1 redundancy link.

Table 2.1: ZAMREN network Parametres

External Links Capacity	1 Gbps
Internal links	50 Mpbs
No. of affiliates	56
Bandwidth	1Gbps
Point of presence (pop)	7
National operation centre	1
High Performance Computer	1
No. of international links	2
No. of redundancy links	1

By and large, the role of RENs is to lease, operate, maintain, support and manage a physical telecommunications network for the benefit of the education and research society. In other words, they provide national scale networks that interconnect universities and other knowledge generating institutions. Their services are based on high performance as well as national network coverage connecting academic and research institutions. RENs are regarded as vital component of modern teaching, research and learning throughout the world. For instance, about a 100 countries in the world, especially, in Europe have adopted RENs as the cornerstones of their ICT plan for tertiary education institutions and for connecting research institutes inclusive of hospitals[11][20][23].

RENs can also be described as non-commercial Internet Service Providers (ISPs) whose services are usually uncongested, high speed coupled with advanced communications capabilities [11]. RENs at national level are sometimes known as national research education network (NREN). The NREN or REN provides linkage through higher networks known as Regional Research and Education Network (RREN) backbones ultimately connect internationally via high speed networks[11][40][44].

2.7. RENs Network Infrastructure

The network technology set varies from one REN to another. However, the network infrastructure implementation is often through multi-protocol label switching (MPLS) over the dense wavelength division multiplexing (DWDM) protocol. DWDM protocol is an old protocol which can no longer accommodate recent development in network requirements including, among others, flexibility, network service availability and bandwidth granularity.

Generally, a REN network is a communications infrastructure connecting both research institutions and individuals nationally, regionally as well as globally. The network design

and architecture is layered and composed of multitude of different technologies in use, operational procedures, network management subsystems and procedures [64][65]. The general connectivity of RENs is shown Figure 1.1 [11]. The service provision is seamless end-to-end service delivery in such multi-domain environment. Currently, each REN maintains its own repository of services and is distributed or accessed by various users from different locations globally [64]. However, GEANT [64] has stated this scenario is revolutionising towards shared infrastructure and services, and cloud computing with emphasis on optimisation on the use of resources. In additional optical networking has been proposed mainly because of its high capacity retention and suitability for remote connection in clouding computing.

Further, it is anticipated that future RENs would be managed through unified model as well through autonomic communications (or self-* networks). Self-* networks does not require human interventions (manual) in terms of configurations instead automatically performs self-configuration on the network. These initiatives are measures meant to address increase in data and bandwidth consumption ultimately improve quality of service to REN users any time and where. The ever raising demand of both data and bandwidth is attributed to the growth of mobile users and use of cloud services are, certainly, placing special demands on the NREN network infrastructure [64][64].

2.4 EUROPEEAN NRENs

In Europe, RENs have proved to be one of the most successful institutions which have evolved and are forging collaboration among researchers and educators both at national and regional levels, and enabling the creation of a family of inter-connected research and academic communities across Europe as well as the globe [11]. The history of RENs in Europe can be traced back in the 1980s, however, major improvements mostly started in 1993 with the creation of delivery of advanced networking through Europe (DANTE). Europe is the pioneer of RENs [30][35]. In the recent years, several NRENS in Europe have innovatively changed and evolved their business models and service offerings. The emphasis now is on international collaborations. The innovation is the development and deployment of new authentication and authorisation infrastructures (AAI) and use of dark fibre [14]. Quick spread of dark fibre connection in Europe is probably being stimulated by both technological and price

2.2.1 DANTE

DANTE was formed by consortium of European countries and provided connection to NRENs and established a research community [13]. In conjunction with the European Union (EU), DANTE provides financial support to RENs, among others, including; Trans-European Research and Education Networking Association (TERENA), GEANT, Trans-Eurasia Information Network (TEIN) networks as well as to Latin America, Middle East and African countries. However, in the last 5 years its focus has been on the African RENs. This has been driven by availability of undersea cable in the eastern and western coast Africa [30][35].

2.2.2 TERENA

TERENA compendium was established 10 years ago and has grown to become an authentic reference point for researchers and organisations that are interested in the development of research and education network. The Trans-European Research and Education Networking Association (TERENA) was formed as a non-profit association of European NRENs incorporated in Amsterdam, Netherlands. The association was originally formed on 13th June 1986 as Réseaux Associés pour la Recherche Européenne (RARE) and changed its name to TERENA in October 1994. In October 2015, it again changed its name to GÉANT and at the same time acquired the shares of GEANT Limited (previously known as DANTE).

The objectives of TERENA were to promote and develop high-quality international network infrastructures to support European research and education. The objectives can be decomposed as follows:

i. Investigating, evaluating and deploying new network, middleware and application technologies.
ii. Supporting new networking services where appropriate.
iii. Knowledge transfer, among others in the shape of conferences, seminars and training events.
iv. Advising governments and other authorities on networking issues.
v. . Liaising with networking organisations in other parts of the world.

TERENA had 2 categories of membership, namely, full and associate membership. Full membership of TERENA is open to NRENs and international public sector organisations.

Associate membership was available for organisations with an interest in research and education networking. In a nutshell, TERENA performs functions which include outreach functions, services, projects, conference and workshop and training [2].

2.2.3 GÉANT

GÉANT is the pan-european research and education network which provides interconnection to Europe's National Research and Education Networks (NRENs). GÉANT connects over 50 million users at 10,000 institutions across Europe. Its operational speeds are up to 500Gbps. It is the most advanced research network in the world [6]. It facilitates collaborative research in various ranges of disciplines, including high-energy physics, radio astronomy, bio-medicine, climate change, earth observation and arts and culture. The network connectivity and service provision in most GÉANT partner countries, is now 10Gbps, although some NRENs have reached 20Gbps and even 40Gbps. This has been as the result of backbone dark optical fibre connection. The optical fibre is able to handle high capacities with increased capacity and economically viable mode of transmission [14][6]. GÉANT began as a project in November, 2000 and became fully functional in December 2001. This subsequently replaced a network called TEN-155, in April 2005. The project was completed in 2005. In 2004, the second project known as GEANT2 was initiated.

GÉANT2 is the high-bandwidth, academic Internet serving Europe's research and education community connecting over 30 million researchers with a multi-domain topology spanning 34 European countries and links to a number of other world regions and is at the heart of global research networking. GÉANT2 is co-funded by the European commission and Europe's national research and education networks, and is managed by DANTE. GEANT2 was set up as a project and has since been completed in 2009. [62]

The next GÉANT project (GN3) began on the first of April 2009 and continued until April 2013. GÉANT3 is the Pan-European data network dedicated to the research and education community. Together with Europe's national research networks, GÉANT connects 40 million users in over 8,000 institutions across 40 countries.

In general, GÉANT has evolved through projects and has grown during its iterations (GN1, GN2, GN3, GN3plus and now GN4-1) to incorporate not just the award-winning 500Gbps

Pan-European network, but also a catalogue of advanced, user-focused services, and a successful programme of innovation that is pushing the boundaries of networking technology to deliver real services to over 50 million users [62][64].

2.3 ASIAN NRENs

2.3.1 TEIN

Trans-Eurasia Information Network (TEIN) was the initiative between Asian countries and France to enhance research and educations. In October, 2000 it transformed to TEIN2 to include European countries. TEIN2 it is the first largest scale research and education network for Asian pacific countries at high speed of up to 1Gbps. It is composed of 9countries, namely, Korea, China, Singapore, Philippians, Vietnam, Indonesia, Japan, Thailand and Malaysia. Tein2 also connects to Australia and Europe via two connection, Copeghan and Frankfurt. Currently, the link between TEIN2 and GEANT2 support up to 60,000,000 users across Asian and Europeans countries. The presence of TEIN2 has brought out transformation in education and research, real-time and international research as well as bridging the digital divide [18].

TEIN2 has evolved to higher level known as 3rd generation (TEIN3) and its horizon spectrum is broadened. Currently, it has a coverage of 19 Asian pacific countries and offers a dedicated high capacity Internet network [11][18].

2.3.2 Afghanistan Research Education Network (AfgREN).

AfgREN is an acronym for Afghanistan Research Education Network. It is a NREN which is found in Afghanistan. This is medium through which universities, researchers, students, lecturers and research institutions access resources within the nation, region and to rest of the world. AfgREN provide internet connections to these institutions so as to enable them access materials online [2].

NRENs like the AfgREN are capable of providing video conferencing capabilities with exceptional speeds. For instance, the AfgREN uses video conferencing for distance teaching purposes between Kabul based universities and the other provincial universities. This facility provided an opportunity for expert professors from Kabul to teach in Afghan provincial universities, which predominantly lacked experts such as professors. Kabul based universities have good facilities and expert professors while the provincial

universities of Afghanistan are mostly new and suffering from the lack of professors. This seemly challenge of lack of professors was sufficiently addressed through use of video conferences supported by the robust AFgREN. In addition, video conference is still being used in Afghanistan for the official weekly meeting held between the minister of higher education and various chancellors of public universities in Afghanistan. In general, the use of video conference platform has enhanced communication, education and ultimately has reduced on travel expenses as well as on time [2].

2.4 AFRICAN NRENs

The role of NREN in developing countries cannot be over-emphasized, in Africa and particularly Zambia. They are significant because they provide connection among educational institutions and research organizations to the world [20][35]. Conversely, commercial ISPs are not viable and sustainable for research institutions, researchers and students because their internet services provision in terms of bandwidth is narrower and connection cost is higher than NRENs. It is in Mbps whilst the NREN's is gigabytes. NREN can offer higher capacity that is "Gbps" and yet at lower cost of connectivity [20].

2.4.1 ASREN

ASREN was developing based on the European best practice NREN model implemented in many Euro-Mediterranean countries. ASREN is the regional network which serves 7 countries in the southern Mediterranean Arab region, namely; Algeria, Egypt, Jordan, Morocco, Palestine, Syria and Tunisia. The network provides high capacity and quality Internet connectivity for use by the research and education communities connected to the NRENs in the beneficiary partners, and connected to the European user communities via links to GEANT network in Europe [2].

2.4.2 WACREN

West and Central African Research and Education Network (WACREN) is regional REN for western and central Africa countries [22][23]. It was established to provide world class network infrastructure, develop state of the art services, promote collaboration among national, regional, international research and education communities and build the capacity of the REN community. Among the objectives of WACREN are:

i. The promotion and establishment of interconnections between national research and education networks in west and central Africa and to form a regional research and education network.
ii. Provide interconnection of this network with other regional and continental networks.
iii. Provision of services aiming at fostering collaboration between research and education institutions in the region as well as between them and peer institutions at continental and international levels.
iv. To act as a forum for the exchange of information and ideas between members of WACREN and between WACREN and other partner organisations with a view to improving research and education in Africa.
v. To develop knowledge and skills of the research and education community.
vi. To develop a high-quality information and telecommunication infrastructure for the benefit of research and education in Africa with a focus on the west and central regions, based on open standards using the most advanced technologies available [22][23].

WACREN exist as was established as corporate body with its own legal personality distinct from that of its members and office bearers. It own assets and incur liabilities like any other corporate organization and notwithstanding the ability to sue or be sued when need arises.

In order to sufficiently meet its objectives, WACREN endeavours to perform the following functions:

i. Maintain communication and collaboration platforms in at least French and English.
ii. Establish international focus groups to undertake research on matters of significance to the scientific, social and economic development of Africa.
iii. Publish the proceedings of the conferences and other research undertaken under the auspices of WACREN.
iv. Promote communities of practice and build technical capacity through training programs and by providing frameworks for domain cooperation.
v. Negotiate and secure rights in the name of its members with no authority to undertake obligations or liabilities in their name, unless so instructed by an explicit authorization from the members concerned.

vi. Promote objectives of the African research and education network (AfREN) and establish relationships with other associations, organisations and institutions with objectives similar to those of WACREN

vii. Undertake any other activity aimed at advancing the objectives [22][23].

WACREN has four types of membership. These are:

i. NREN Member

This is meant for any NREN in west and central Africa as defined by the African union.

ii. Associate Member

Any research and education institutions as well as not-for-profit non-governmental organisations and individuals, whose objectives are compatible with those of WACREN.

iii. Premium Member.

This is membership category is optional and reserved for corporate organizations. These are profit making organisations whose objectives are compatible with those of WACREN.

iv. Partner Member

These are honorary or voluntary members which are invited by the board. These are special organizations which significantly contribute to the cause of WACREN objectives, ideals and aspirations [23]

All membership applications are received by the chief executive officer and approved by the board of directors (Board) or by any committee constituted for that purpose. The general assembly ratifies successful applications. In addition, the general assembly determines annual membership fees. WACREN has an annual general assembly meeting (AGM) convened yearly. Participations in AGM is restricted only to NREN members and eligible premium associate members in good standing, that is, fully paid up members have connection permission to WACREN network and eligible to vote at the AGM or indeed participate in any other decision-making process that requires voting [23］.

i Organs of WACREN

The organs of WACREN are four, namely, General Assembly, Board of Directors, Chief Executive Officer (CEO), and Secretariat.

ii WACREN Funds.

The notable financial sources are: membership fees, donations, grants and income from sales of bandwidth [23].

2.4.3 Ubuntunet Alliance

Ubuntunet Alliance was formed in the year 2005 as a regional body providing connectivity to research and education community in eastern and southern Africa through NRENs good [9][1]. Figure 2.1 shows ubuntunet alliance member countries.

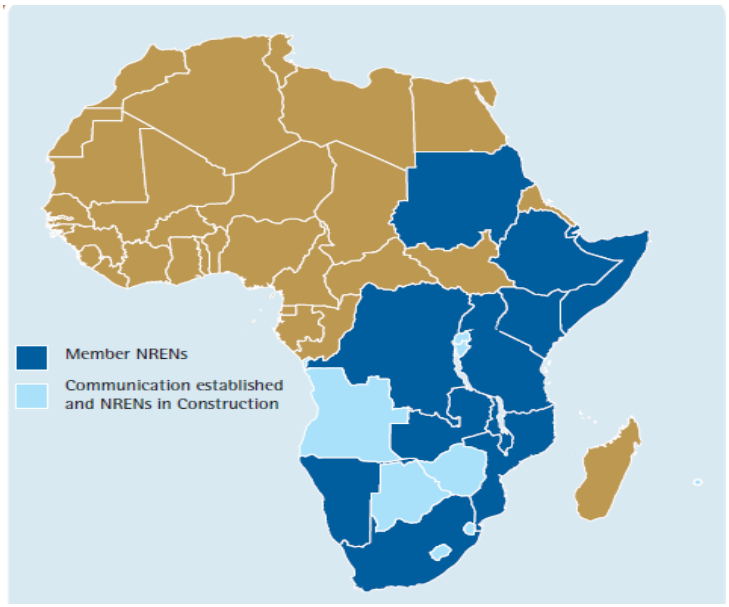


Figure 2.1: Map of UbuntuNet Alliance member countries (Source: UbuntuNet Alliance, 2015)

The role of UbuntuNet Alliance is to work with NRENs in the region as well as enhancing the network capacity and resilience of the broadband research and education backbone network. It also thrives to provide the interconnection to other networks in the world via its gateways.

The alliance is also mandated to push for conducive policy and regulatory environments in the regions so as to promote the growth and development through the exploitation of research and education networking in the region. It also leads a way in setting up NRENs where they are non-existence in member countries as well as promoting communities of practice and applications that exploit the opportunities of high speed regional and global connectivity [58].

2.5 KENET

The Kenya Education Network (KENET) was established in 1999 and was licensed as a private networks operator in 2002. KENET is a NREN in Kenya. KENET thrives to

promote the use of ICT in education and research institutions and to provide network connection to the rest of the world. It has 78 members including both public and private universities, colleges, Libraries, commissions and research institutions. It supports more than 300,000 students and is connected to 120 campuses [59][60].

It owns two (2) data centers, shared services and has partnerships with local operators. Its bandwidth is distributed though commercial fibre and radio leased lines in order to achieve its mandate. Its objective is to provide cost-effective bandwidth and share resources. Current partnership and collaborations, among others are; Kenya Data Network (KDN), Jamii Telecom (JTL), Safaricom, Telkom Kenya, Ubuntunet Alliance, Internet 2, and international institutions [59][60].

2.6 TENET

The Tertiary Education and Research Network of South Africa (TENET) was established in August, 2000 by South African public universities. It is a NREN in South Africa for learning and research institution as well as collaborative internetworking. It replaced the then UNINET project of the then Foundation for Research Development. TENET is considered as a public benefit institution that is granted exemption from income tax by the South African government. TENET is a pioneer and a member of the UbuntuNet Alliance, the RREN organisation for Eastern and Southern Africa. Essentially, UbuntuNet Alliance provides regional network connectivity and also connection to other RRENs of the world

Currently, TENET provides support to 170 campuses of 55 institutions. TENET leverages on the network infrastructure for South African National Research Network (SANReN). SANReN infrastructure is made of a national backbone, several metropolitan rings as well as dedicated long-haul circuits. TENET connects several universities using low-speed rented access circuits, ADSL lines. TENET also uses 2 different submarine circuits to provide intercontinental connectivity to the UbuntuNet network in Europe [61][62].

2.6. ZAMREN

Zambia research education network (ZAMREN) is non-profit NREN in Zambia. It was registered as an association on the 19th September, 2007 in Zambia under the registrar of societies Act 119 of laws of Zambia. In other words, it is an association for tertiary level research and education institutions collectively with the following intentions:

i. Secure cost effective broadband connectivity.

ii. Share their education resources via dedicated infrastructure.

iii. Provide advanced ICT services to its member institutions in a closed user group.

iv. To network with regional and international partners to promote and enhance best practices in RENs.

Currently, its offices are housed at the University of Zambia, in Lusaka province, the capital city of Zambia [57]. ZAMREN is in the process of changing into a company by guarantors [61]. Figure 2.2 show a sketch connectivity of ZAMREN network. It provides local connectivity to institutions followed by regional connectivity of NRENs via UbuntuNet Alliance. UbuntuNet connects ZAMREN to other African regional networks such as WACREN and ASREN. It also provides connection to global networks such as GEANT and TERENA.

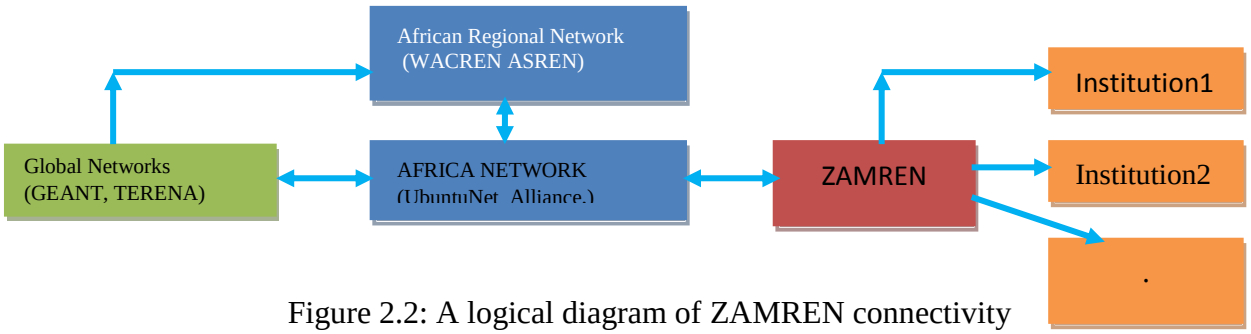


Figure 2.2: A logical diagram of ZAMREN connectivity

2.6.1 ZAMREN Network Topology

ZAMREN's network topology is concentrated along or follows the line of rail, that is, from Livingstone town to Chililabombwe town. Figure 2.3 shows the ZAMREN's topology. Plans are underway to expand and spread the ZAMREN network topology to other parts of the country. However, in last quarter of the year 2015, the expansion programme was commenced and network connectivity was implemented in the eastern province as shown in Figure 2.3.

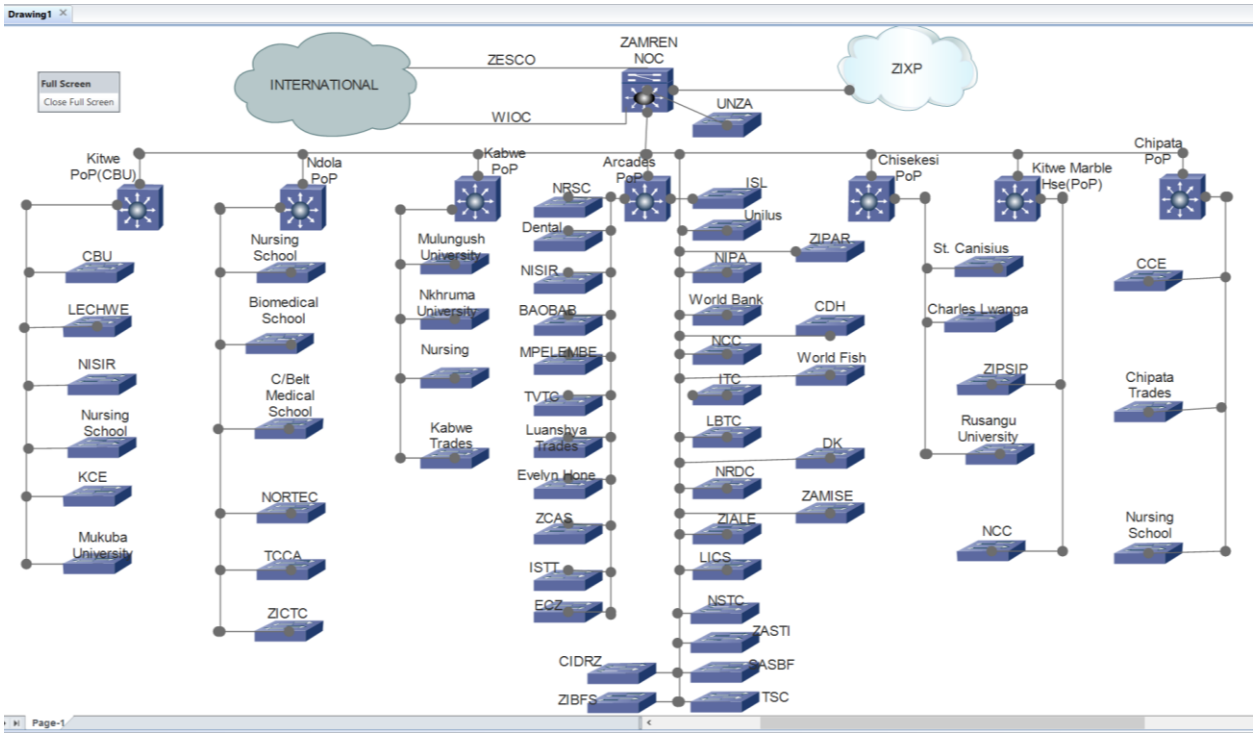


Figure 2.3: ZAMREN Network Topology (Source: Mkandawire, 2015)

2.6.2 ZAMREN Membership

ZAMREN has deliberately opened its membership to all registered organisations who have an interest, passion and sharing of information. These include universities, research institutions, colleges and government departments. In addition, the membership is open to other service providers. These are communications utilities which complement ZAMREN's vision and engaged in the promotions of advancement of network applications and technology [57].

Currently, ZAMREN has a total number of 56 membership and the members are tabulated in Table 2.2. Given the amount of members (institutions) that ZAMREN supports, the usage of bandwidth is, at certain peak hours, at its maximum. Generally, on average the members have a total bandwidth consumption of 594.5Mbps, and this is approximately 15 Mbps on average per institution.

2.6.3 ZAMREN Global Connectivity.

At the national level, ZAMREN provides connectivity to all its members creating a network of National Research Education Network (NREN). The Zambia NREN is then linked to the regional network known as Ubuntunet Alliance. Ubuntunet Alliance is the composition of eastern, central and southern countries NRENs. Ubuntunet Alliance provides the linkages to rest the of the world at the rate of about 20Gbps using 2 gateways that are in London and Amsterdam. It actually, connects to GEANT the pan European networking

Table 2.2: ZAMREN Affiliates (Source: Mkandawire S., 2015).

No	Institution	Capacity Mbps
1	University Of Zambia	230.0
2	Copperbelt University	115.0
3	Mulungushi University	30.0
4	World Bank research group	22.5
5	Kwame Nkruma University	16.5
6	Zambia Centre for accountancy studies	15.0
7	Evelyn Hone College	15.0
8	Lusaka University	15.0
9	Kitwe College Of Education	9.0
10	Northern Technical College	9.0
11	Zambia ICT College	9.0
12	Cancer Disease Training Centre	8.0
13	National Institute For science and Industrial Research	7.5
14	Examinations council of Zambia	7.5
15	International school of Lusaka	7.5
16	Rusangu University	7.5
17	Lusaka International Community School	7.5
18	WorldFish Centre	7.5
19	National Institute of Public Administration	7.5
20	Baobab College	6.0
21	Zambia Institute for Policy Analysis Research	4.5
22	National Science Technology Council	4.5
23	National Remote Sensing Centre	3.0
24	Mukuba University	3.0
25	Theological College of Central Africa	3.0
26	Charles Lwangwa Teachers College	3.0
27	Zambia Air Services Training Institute	1.5
28	Mpelembe Secondary school	1.5
29	CHRESO University	1.5
30	Lusaka Business Technical College	1.5
31	Industrial Training Centre	1.5
32	National Resources Development College	1.5
33	David Kaunda Technical Secondary School	1.5
34	In-Service Training Trust	1.5
35	Dental School	1.5
36	Ndola School of Nursing	1.5
37	Kitwe School of Nursing	1.5
38	Ndola School of Biomedical sciences	1.5
39	Zambia Institute of special education	1.5
40	Zambia Institute of Advanced legal Education (ZIALE)	1.5

Figure 2.4 shows a newly acquired and installed HPC Sun Microsystems-Sun Blade 6048 meant to support HPC applications. Figure 2.4 is an extract of ZAMREN cabin which houses routers, core switches as well as cables.

Figure 2.4: HPC Sun Microsystems - Sun Blade 6048 (Source: ZAMREN, 2016)

2.6.4 ZAMREN Services

The services provided by ZAMREN includes; Internet, high performance computing services, authentication services, education roaming (EDUROAM), e-mail hosting, relay and spam filtering, data centre, website hosting, domain registration, security awareness, capacity building and provision of ICT infrastructure to affiliates. ZAMREN is part and parcel of initiatives and projects which are being undertaken and supported within and outside partners. These initiatives and projects include the following:

i. Optic fibre infrastructure roll-out

This undertaking is spearheaded by 3 institutions, namely, Zambia electricity supply company (ZESCO), Zambia telecommunications company (ZAMTEL) and Copperbelt energy corporation (CEC). The project is building, setting up and laying optic fibre

backbone network throughout the nation of Zambia. ZAMREN is participating by virtue of entering an indefeasible rights of use (IRU)s for cost effective use of the infrastructure.

ii. Zambian government last-mile connectivity

ZICTA is undertaking a universal access programme through which research and education institutions particularly public funded institutions was connected to ZAMREN and ZESCO network. This project has full support of the Government of the Republic of Zambia.

iii. The niche ZMB/072 Project

This project is funded by Netherlands Initiative For Capacity in Higher Education (NICHE) programme. This project is a four years that begun in 2011. Its objective is to support ZAMREN in terms of sustainability. The total funding for this project is Euro 2.2 million. Part of the funds meant for capital investment and capacity building, while UNZA, CBU, MU, COSETCO and Nkrumah are also direct beneficiary of the funds so far.

iv. Africaconnect project.

This project has full support of African Union Commission and European Commission and the project is tasked to oversee the deployment of UbuntuNet backbone fibre Africa. The total amount for the project is Euro 14.7 million

2.6.5 ZAMREN - Governance

ZAMREN has 3 organisation levels as shown in figure.

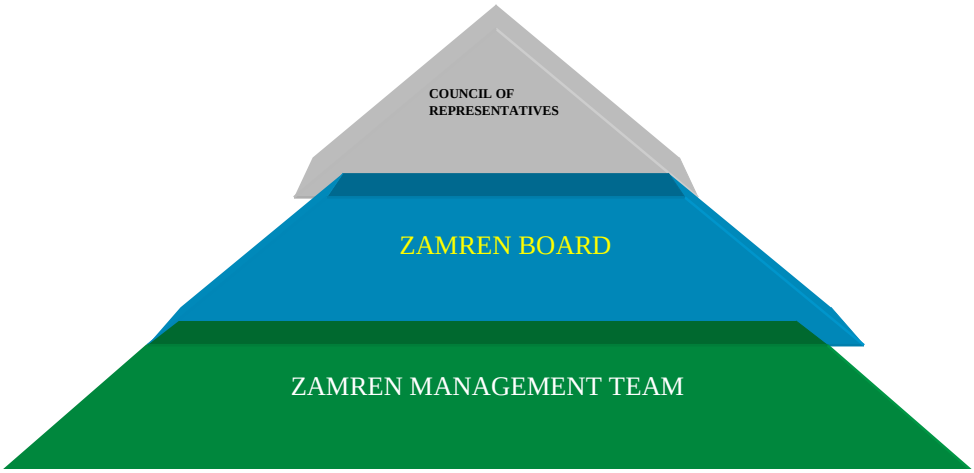


Figure 2.5: ZAMREN organisation structure.

i. Council of representatives

Council of representatives is ZAMREN's top most decision making body and comprised of institutional heads of all ZAMREN member institution. The council of representatives is tasked to provide a strategic policy guidance of ZAMREN. It is also tasked to appoint members of council of representatives which seat on ZAMREN board.

ii. ZAMREN Board

The board is composed of appointed members from the council of representatives, representatives from Ministry of transports and communication, representatives from Ministry of education, science, vocational training, and early education, ZESCO, ZICTA and any 2 members from the private sector the board may decide.

iii. ZAMREN management team.

The ZAMREN management team is headed by chief executive officer and a technical team which support the CEO in running the day-to-day operations of the institution.

2.8. Related works

2.7.1. Afghanistan

In Afghanistan a video conferencing project was implemented to deliver e-education among the outskates (provincial centres) of public universities, which lacked experts such as professors. The project was successfully implemented due to the availability of a robust and resilient Afghanistan NREN network known as Afghanistan Research Education Network (AfgREN).

Under this project, the lecturers, in particular professors were able to conduct lessons to provincial public universities, which required their service, through use of AfgREN[12]. The mode of delivery was through video conferencing such that distance universities away from Kabul, were able to receive education by means of internet. The facility provided an opportunity for students in provincial universities to receive similar education as those students Kabul and gradually narrowing the knowledge gap. In addition, this mode enabled professors to be able at once to reach out to several students from different universities. Students from each university would be gathered in single class room which had AfgREN internet access and project. Generally, Afghanistan provincial universities were relatively new and had shortcomings among others lack of experts (professors) and facilities. In

addition, video conference service was extended and adopted by Minister of Higher Education as an official mode for conducting weekly meetings with various chancellors of public universities in Afghanistan. In general, the use of video conference platform was advantageous because it enhanced communication, education and potentially could reduce on travel expenses as well as on time [2][12].

2.8.2. **India**

Research and Education Network of India (ERNET) is a non-profit and autonomous NREN with an objective of running a nationwide academic and research network. Additional objectives of ERNET include; capacity development in computer networking, undertaking and promotion of research and development in computer networking, content hosting relating to education and research, and domain registration. In terms of infrastructure, ERNET has a backbone network with 15 point of presences (PoPs) all over the country. It has international connectivity to GEANT as shown Figure 2.6. Also, it has additional connectivity to GARUDA and National Knowledge Network (NKN) [12][59].

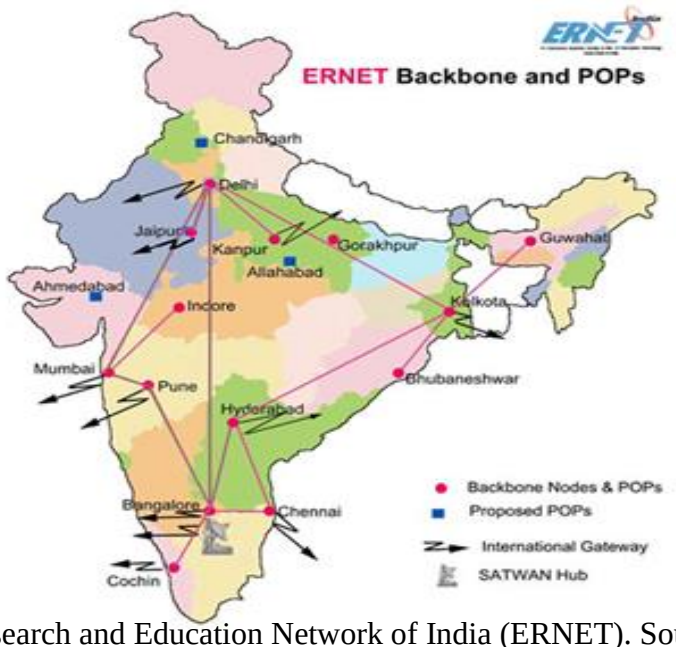


Figure 2.6: Research and Education Network of India (ERNET). Source: D. Barman, SR.

GURUDA is national initiative for grid computing as "Proof of Concept" which has 45 institutes connected in 17 cities, which are among others include Pune, Delhi, Kolkata, Banglore, Mumbai and Roorkee. It has 2.4 Gbps bandwidth for grid fabric and more than 300 central processing unit (CPU) computing resource available in the grid

i. GEANT to ERNET Connectivity

GEANT to ERNET connectivity provided access to Large Hadron Collider (LHC) grid for Indian scientists. For instance, since 2007, tele-education surgery from Korea and Japan to Tata Memorial Hospital, Mumbai, India has been taking place through means of the network. Medical specialist from both Korea and Japan has been conducting specialised knowledge transfer to their fellow medical practitioners in India via ERNET network. The ERNET network has also been used for DVTS session – Asian Pacific Advanced Network-New Zealand (APAN-NZ) meetings on healthcare meeting in Delhi [12][59].

ii. National Knowledge Network to ERNET connectivity

National Knowledge Network (NKN) is a 3-tier architecture and interconnects all NRENs institutes, leading national laboratories, colleges. The network topology design is a single common backbone , wherein different categories of users shall be supported. The network has a scalability feature. In addition, it has some of the notable features which are but not limited to high capacity, quality of service (QoS) and security, wide geographical coverage, bandwidth from many National Long Distance (NLD)'s, test beds, highly reliable, dedicated and owned networks. National Knowledge Network (NKN) provides connectivity approximately to more than 5000 sites across the country and capacity to serve millions of end-users. It receives partial subsidies on national, regional and international links [12][59].

The network was used to support tele-medicine tasks such as diabetic retinopathy, glaucoma diagnosis, train nurses and sharing of pubmed database [12][59]. Other usage include countrywide real time classroom, GRID applications, climate change modeling, high energy physics, health, agriculture and e-governance. Most of these applications are data intensive inclusive of video conference yet they were ably supported by a NREN – ERNET which leveraged on other networks such NKN, GEANT and GARUDA.

2.8.3. Kabuki Project

Kabuki Project was an educational video conference undertaking between United Kingdom (UK) and Japan under the auspices plan known as "Konet Plan". Technically, it was a multilayered and international collaboration for schools in UK (Holly Cross Convent School, New Malden, and Surrey) and Japan (Ikeda). It was an international exchange

project for participating schools. Schools from both countries were required to carry out an exploration together the exciting educational possibilities presented by the new ICT technologies which were but not limited to email, image files, the Web, twinned sites, the national grid for learning, document exchange technology and video-conferencing.

2.8.3. Ethiopia - WoredaNet

ETHIOPIA has a federal system of Government with 9 national regional states which are divided into administrative zones and Woredas. A "Woreda" is an administrative division, essentially, managed by a local government and equivalent to a district. The Name WoredaNet comes from "Woreda. Currently, Ethiopia has about 710 woredas. WoredaNet is a government network connecting more than 611 Woredas across the country. The WoredaNet is under management of Ethiopian ICT Development Agency (EICTDA). The Agency is responsible to device rules and regulations on how to use the WoredaNet infrastructure. The WoredaNet consists of national data center; 11 regional data centers at each regional national state, Addis Ababa and Dire Dewa City Administration; and 611 woreda centers located at the main towns of each woreda. Eight of the regional data centers are connected to the national data center through terrestrial links while 3 of them connected through Very Small Aperture Terminal (VSAT) network. Most of the woreda centers are connected to the National data center through VSAT [76].

WoredaNet is a terrestrial and satellite-based network designed with the primary objective to provide ICT services among others video conferencing, directory, messaging and Voice Over IP (VoIP), and Internet connectivity to the Federal, Regional and Woreda level government entities. The goal of WoredaNet is to establish a multi-service IP-based service by the use of Terrestrial Broadband and VSAT infrastructure for the delivery of services to Ethiopian government and its citizenry. The goal is towards the improvisation of efficiency, effectiveness and productivity, information provision and service delivery to the public at large. The WoredaNet uses both VSAT and Terrestrial links to connect to the Internet and to other WoredaNet sites.

Video-conferencing service (VC) is one of the most utilized services of the WoredaNet in Ethiopia in areas such as government conferences, court services, training and distance education. For instance, various government institutions use the video conference service

of the woredaNet to conduct conferences and workshops between federal and region, region to woredas and woredas to zone. The service has helped to make effective and frequent communication among different sectors and tiers of government administration. In addition, the service has facilitated provision of timely information, reduced travel and administrative costs, increased collaboration among government institutions, improved efficiency, speed up decision making and improved provision of services to citizenry.

The videoconferencing is also used for court hearings held at the Federal Supreme Court, as well as region and zonal - level courts. Court services using video conferencing has helped citizens; in that travel expenses have been reduced. It is also ease for citizenry to make follow ups and get responses for their cases quickly.

The WoredaNet is a platform used to provide trainings for woreda administrators, public servants, judges and prosecutors via video conferencing. For instance, instructors at the centres providing training for trainees found in different woreda centers spread across the country. Generally, through the use of this medium has reduced costs which were incurred by the trainees during movements to a training central place and travel expenses for instructors. Video conferencing has created an opportunity for training many peoples at one time and at a reduced cost. Training public servants using videoconferencing has also helped to reduce service shut downs that may result from moving public servants long distances away from their working area for training. In general the system has also helped to improve the services to citizens by providing effective training to the public servant.

For instance, the ministry of justice uses the video conferencing system to upgrade more than 2000 legal professionals to master level in 7 central woredas all over the country. Bahrdar University uses the system to support its undergraduate distance education program by providing tutorial to its students in 7 central woredas [76].

2.8.4. University of Zambia, Copperbelt University video system

A video conferencing project funded by Japan government was commissioned in 2010, Zambia. The project comprised of university of Zambia (UNZA), Copperbelt University (CBU) and a Japanese institution based in Tokyo. It was launched by then, president of the Republic of Zambia, President Rupiah Banda. It was a highly advanced video conferencing system that enabled lecturers from Japan to teach students at the Copperbelt University and

the University of Zambia at the same time. The students from these institutions were able to interact with each and their lecturer via video conferencing facilities installed at their respective institutions. For instance, UNZA had their video conferencing installations in all of its libraries. The project connected these institutions to XVD Espresso HD quality video conference system via optical fiber network. The fiber network was laid by Zambia Electricity Supply Co-operation (ZESCO), a parastatal electricity supply company in Zambia [75].

The technology was a first of its kind in Africa and aimed at encouraging communication and resource sharing, greater use of distance learning and improved education quality. In addition, the technology was also suitable in areas such a tele-medicine and e-government. The XVD Espresso HD technology was an appropriate e-learning method. Some of the advantages of the technology included it's easy to use, affordability and requirement of lower bandwidth [78].

2.8.5 Future NRENs

Recent studies or research has revealed that future NRENs would be anchored on e-infrastructure and cloud computing. Therefore, it is anticipated that NRENs organisations are getting stronger and better organised such that NRENs would support high bandwidth demanding applications. The notable applications would include areas such as astronomy, climate - real time data assimilation, earth observation data acquisition and merging, biology-distributed collaborative databases, health care and on-line distributed instant computing [60][80]. NRENs should also have capacity to cater for cooperative engineering (aero and auto field), support public services and administrations and cooperative arts and cultural heritage [59][60][80].

2.9 E-science and HPC Application

E-science is defined "as those new methods that are large-scale, data-driven, computationally intense, and often engaging research teams across institutional boundaries" [28]. E-science is described as cyber science and fourth paradigm. It is also as the emergent era of scientific discovery which distinctively exploits technologies for computation, data curation, analysis and visualization, and collaboration. Undoubtly, e-sceince has brought about fundamental shifts in scientific, research practices and affecting

the research institutions. However, NRENs are ever committed to advancing research, science and supporting researchers [15][28][33].

It is no longer a hidden truth that data has been on rise due to substantial advancement in the technology beginning in the late 20st century. This in turn has increased the demand for data, e-science as well as HPC applications. The UK e-Science program has funded the DAME project which has indicated that there is spectacular growth forecast for scientific data generation. For instance DAME has analysed 100,000 Rolls Royce engines and estimated each engine generates about a gigabyte of data from pressure, temperature and vibration sensors. The goal of the project is to be able collect and transmit a small subset of this primary data for analysis and comparison with engine data stored in three data centres around the world. This information is essential for early problem identification and maintenance purposes [28][33].

Another field which substantially generates data is bioinformatics. This is information which pertains to a human being's DNA. It estimated that genome sequence data is increasing at a rate of 4 times each year and that the associated computer power required to analyse this data will 'only' increase at a rate of 2 times per year . Therefore, to make this information available within the short period of time and to several researchers across the global requires new strategies and significant development of infrastructure in networks and NRENs [28]. One of the ideal strategies to address the problem is increasing or expanding the bandwidth or capacity of NRENs to suitably service data intensive or HPC applications [28][33].

In essence, a robust, resilient e-infrastructure, research and education networking should have 2 key drivers, namely; network and type of applications. The network drivers are essential for the following purposes:

i. Increased bandwidth requirements on the backbone for some scientific and real-time applications.
ii. Growing interest in IPv6 protocols.
iii. Networking security necessary in some critical applications.

The applications drivers are essential for the purposes of requirements of real-time networking applications and need for reduced interaction time between distributed users and processes [2].

2.9 General challenges of NREN in Third World Countries.

i. Lack of permanent and sustainable financial resources.
ii. Lack of national strategy and policy for the NREN.
iii. Lack of support from policy makers.
iv. High cost of connectivity.
v. Lack of not enough educational and research services.
vi. Lack of enough understanding in the national level and educational and research services.
vii. Education organization or syllabus is a problem for the implementation of REN services.
viii. Lack of regional high level policy and low investment in ICT infrastructure level at regional level.
ix. Lack of strategy awareness.
x. Low administration and technical capacity in most 3rd world countries.
xi. Lack of the NREN law for the international relations.

2.10. Summary of chapter 2

This chapter covered or reviewed documents from Europe, USA, ASIA and Africa, and most documents were easily accessed via internet. The historical background of modern RENs was traced in the mid-1980s in Europe. Research and Education Networks are also known as National Research and Education Networks (NRENs). In essence, they are described as high speed Internet Service Provider (ISPs) for research and academic institutions with low internet tariffs. Research and education networks are key for prosperity, development, stability, and national, regional and international integration in this age where ICTs are vital in supporting research and education, and in the creation of an innovative and lifelong learning society, which has a community of abundant scholars, researchers, engineers, technicians and firms engaged in production of knowledge, goods

and services. RENs in this regard are very important because they can make a significant contribution to supporting the research community. To some extent, RENs are regarded or viewed as an essential national infrastructure, 'public goods', in comparison to, for instance, roads, water, ports and energy services due to its positive implications on the society[15][28].

Research and Education Networks are mostly initiated by nations and are key in fostering and promoting e-education, commonly known as e-learning. In Zambia, ZAMREN is the Zambian REN which was established on 19th September, 2007. At the time of study, ZAMREN had 56 affiliates/ members mainly dotted along line of rail, that is from livingstone town to chililabombwe. The literature review revealed that globally there are about 120 NRENs in operational in different countries inclusive of ZAMREN [6]. For instance, the regional network in Europe, GÉANT has a speed up to 500 Gbps whereas its partners the speed is 10Gbps - 40Gbps. GEANT's usage includes high-energy physics, radio astronomy and biomedicine [6]. In ASIA, the regional networks such as TEINS and KAREN their speeds is up to 80Gbps where as in Africa the regional networks which were reviewed includes ASREN, WACREN and UbuntuNet Alliance has the speed is up to 1Gbps [6].

In summary, NRENs should be able to provide amongst the services the following:

i. High speed and low cost broadband network.
ii. Create economies of scale for building and sharing high speed networks, expensive research equipment, applications and other resources.
iii. Facilitates the negotiation of favorable pricing for Internet access and software license on behalf institutions.
iv. Promotes joint institutional content development, access to large databases and sharing of research results.
v. Promotes distance learning that is e-learning.
vi. Provide network security, bandwidth management, web caching and hosting, IP telephony, traffic shaping and authentication, centralized training, capacity building and advisory services to affiliates.
vii. Promotes linkages between the academic and research community industry.

viii. Government and other international research and educational networks, allows for the hosting and execution of data-intensive applications such as bio-modeling and computation, and sharing of high end computing.

ix. Provides the experimental platform for researchers to investigate, develop and test new network and internet technologies and applications prior to deployment within the public sector or for commercial use [1][3][10][11][20].

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents the research methods which were employed in the study. The chapter was logically arranged with the following steps; selection of a research topic, literature review, research design, selecting sample, data collection techniques and simulation, data collection procedure, data analysis and processing and ethical consideration. These activities in the research methodology were followed in order to be able to systematically solve the research problem and are logically shown in Figure 3.1.

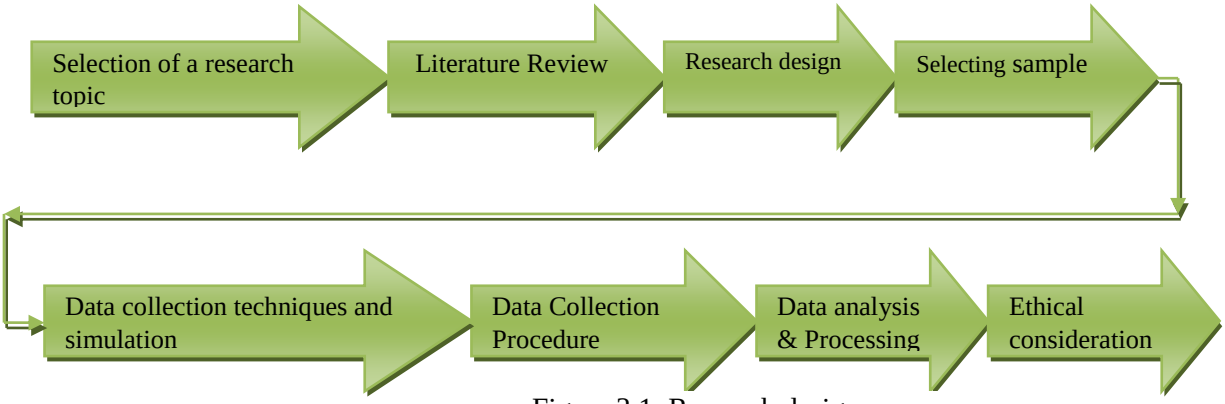


Figure 3.1: Research design

3.2 Selection of a research topic

Selection of a research topic was the first process or step in this study and is a traditional in any given scientific study. Prior selection of the topic, the researcher reviewed relevant RENs documentation both primary and secondary documents to gather relevant information [11][68][73][75].

The research topic for the study was formulated by researcher with the guidance of the supervisor and submitted to the School of Engineering (SOE) for approval, UNZA. Further, the SOE sent the topic to the prime target institution, ZAMREN, for viability assessment of the study, approval and seeking permission to undertake the study. Appendix VII and VIII are correspondences as evidence from 2 institutions (UNZA and ZAMREN) granting authorisation for the study to be undertaken. Figure 3.2 shows the processes which were followed during topic selection in this study

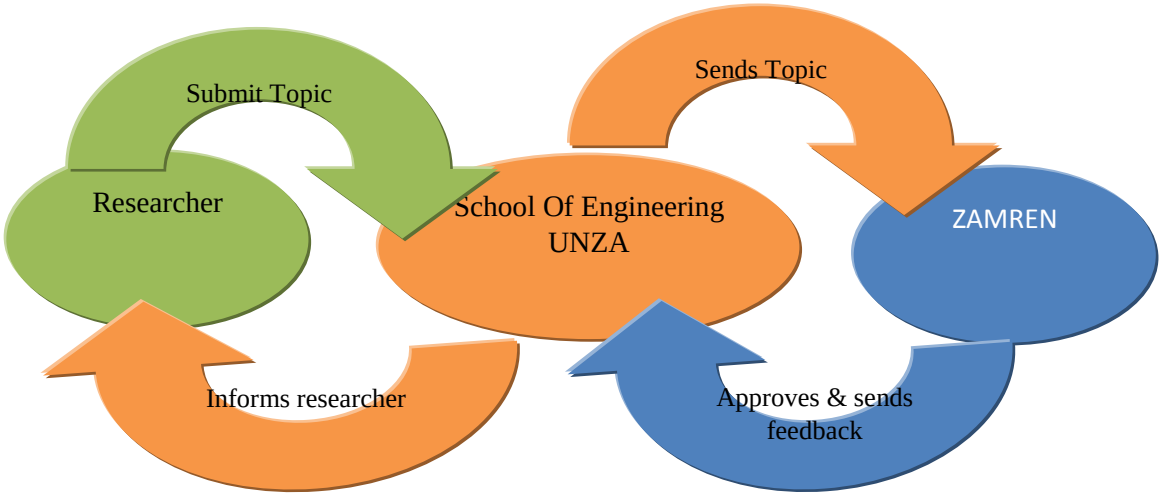


Figure 3.2: Selection topic process

Some of the essential considerations which were taken by the researcher during topic selection for the research included financial resources, the time available, the researcher supervisor's expertise and knowledge in the field of study and clarity of the topic.

3.3 Research design

Research design is an important feature of research, and involves the use of appropriate research methods. It is a blue print of a research [11][24][65][69]. The blue print of this study was as follows; literature review, approach, study area, sample selection, data collection techniques and simulation, data collection procedure, data analysis and processing and ethical consideration. It should be noted that literature review was an overriding and a continuous process which was conducted at each every stage of the study.

3.4.1 Study approach

The study employed a mixed method approach for collecting and analyzing data. This was because any method used on its own had limitations and biasness. As such a mixed method approach minimised biasness. A mixed method approach is cut across of quantitative and qualitative approach. The justification for this approach is that quantitative catered for the simulation component of the research which was empirical. The simulation was conducted using a network simulator known as OPNET network simulator. ZAMREN bandwidth was simulated to ascertain its point of failure while subjected to heavy video conferencing. The data or results from the simulation was analysed and charts created using the same software. Additionally, data was exported from OPNET software to Microsoft Excel 2007(MS-excel) for ease data analysis, interpretation as well as for better charts creation or publishing. The quantitative component was

also used to capture record and analyse questionnaire responses. The questionnaires were distributed to ZAMREN affiliates and their responses were recorded in MS-excel. The researcher used also the qualitative approach for description purposes which ultimately catered for objective (i) of this research. The description was based on the results of the quantitative. The description was a detailed explanation which endeavoured to carefully analyze the gathered data both from questionnaires and OPNET simulation. This approach also facilitated verification of possible behavioral patterns in the data and to properly explain the phenomena. In addition, the procedures used in this research were explicitly described so as to enhance credibility, rigor and solidity of the research.

3.4.2 Research methods

a Methods used in determining ZAMREN's affiliates challenges

Document review was an important exercise particularly in the provision of insightful information about challenges faced by NRENs members or affiliates in developing countries. During this stage, the researcher undertook activities such as recording the general problems of NRENs, NRENs affiliates/members, identify and record NRENs'affiliates problems in developing countries, making oral or email inquiries from ZAMREN pertaining NRENs operations and affiliates challenges in Zambia. In addition, the researcher consolidated the challenges identified into a single list which formed part of the questionnaires. Questionnaires were distributed to ZAMREN's affiliates and their feedback or responses were recorded in either Ms-Excel or SPSS. The data analysis and publishing of results was performed in MS- excel and SPSS. Publishing involved productions of tables and charts. This process was important in addressing objective (i).

b Methods used in determining ZAMREN network parameters

One way the researcher used to gather information was to have a meeting with the top management of ZAMREN. This avenue was essential for the provision of ZAMREN network parameters information which included bandwidth, number of affiliates, regional and global connections. The researcher had several meeting with ZAMREN management at their office. Besides, the researcher had interactions with other members of staff at ZAMREN through which additional information was provided. Follow ups and inquiries, were made via email and telephones. The researcher also visited the ZAMREN computer room which housed network infrastructure.

c Methods used in determining point of failure of ZAMREN network

The researcher undertook various activities during the process of simulation. Opnet 14.5 simulator was used to realize the objective (iii) of the research – which was essentially determining the point of failure of ZAMREN network. The simulation had 3 levels or stages. In the first stage, the researcher designed a network in Opnet simulator with 2 routers, 3 switches, 1 firewall, 56 nodes, 56 x 100 Mbps links, 1000Mbps (1Gbps) fibre link, 1 server, an application definition, profile definition and video conference. The second stage involved setting parameters to record or capture data traffic during the simulation. For instance, the researcher measured the amount of data sent over 1Gbps fibre link and the duration taken for it to transverses. In third stage, the researcher run the simulator, viewed the results and exported it to Ms-excel for publishing either in tables or charts. There were basically 2 scenarios of simulations performed namely; scenario 1 and scenario 2. Scenario 1 and scenario 2 was known as normal and heavy video conferencing (simulation) respectively. In scenario 1, video conferencing was set to normal and scenario 2 the video conferencing was set to heavy. The network did not fail with 56 nodes simultaneously accessing the network with heavy video conference settings in place. In view of this, the number of nodes was gradually incremented from 56 nodes until the 1Gbps capacity was exhausted. In addition, the researcher performed a comparative analysis between scenario 1 and 2.

3.4.3 Study Area

The study area for this research was Lusaka which is a domicile for the prime target institution, ZAMREN. The research also included towns which has ZAMREN affiliates institutions predominantly lay are along the line of rail. The line of rail stretches from Livingstone town, Southern province to Chililabombwe town, in Copperbelt province. However, due to budget constraints and time the research covered mainly affiliates found in Lusaka. The prime target institution for the research was ZAMREN. The data collected from ZAMREN was mainly used to meet objective (ii) and (iii). It was anticipated that the preferred study area would facilitate ease monitoring and coordination of activities in the research.

3.5 Selecting a Sample

The main purpose of the study was to evaluate ZAMREN network so as to determine whether or not its current network setting parameters can support HPC applications which are important in the enhancements of e-learning, particularly in Zambia. In order to achieve this purpose, an

appropriate sample population of this study was selected. The sample population was ZAMREN network as well as its 33 affiliates. However, the prime sample population was ZAMREN institution which has its offices and core installations at the University of Zambia under the School of Education.

A sample was useful in providing meaningful conclusions drawn from the entire population. A combined approach of sampling techniques, that is, cluster and simple random sampling was used in order to produce accurate results in accordance with literature review [19][68][71][73][74]. Target and participating institutions were predominantly found in urban towns, especially in Lusaka and along the line of rail. Creating a sample in this research was essential and advantageous to the researcher because it lowered cost, saved time, ensured accuracy of results and expedited the process of data collection. A sample also gave perceptive information about the whole population in research.

3.5.1 Sampling Bias

Sampling bias is usually as the result of a poor sampling plan used in the research which encompasses lack of consultation with the supervisor [19][68][74]. As a mitigation measure for biasness, the researcher had a robust plan with the supervisor for communication, consultation, framing the questionnaire and seeking guidance from time to time in the entire research. In addition, the researcher simulated some of the findings in objective II that were collected in qualitative research. As a counter measure used was to design a good plan as well as make consultation with the supervisor in the framing of questions.

Literature reveals that a well taken sample mirrors the population otherwise it leads to what is termed as sampling error and bias. Sampling error is due to either bias or chance. Since the research had robust plan as mitigation measure for sampling biasness which causes sampling error, it follows that sampling error was addressed too [1][69]71].

3.5.2 Sample Size

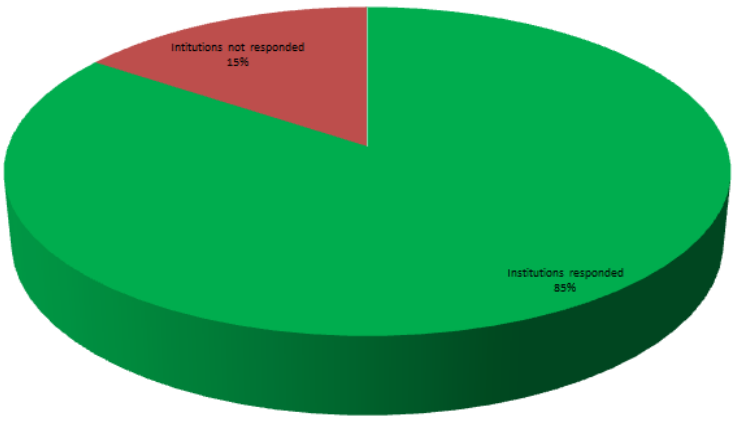
The sample size for the research included ZAMREN institution, the prime target and 56 affiliates. However, some of the constraints which determined the selections of a sample size was included funding, nature of the analysis to be performed, the kind and number of comparisons that were made, the number of simulations that were examined and are in conformity with research decorum [1][68][70][74].

3.6 Data collection techniques for qualitative approach

3.6.1 Questionnaires

The questionnaires were distributed to participants (ZAMREN affiliates) by the researcher. The questionnaire consisted of 3 sections, namely; section A, B and C. The questionnaire consisted of both structured and closed questions and utmost 8 answer options in some few instances which allowed the respondent to provide more than one (1) answer. The respondent was also required to correctly select, mark or tick one (1) option out of four (4) provided options. The researcher waited for a period of utmost 3 weeks for the participants to complete the task of filling in and then the researcher made a follow up in person to collect them. Appendix VI contains the questionnaire used in this study.

In line with the academic and scientific research requirements, each questionnaire was accompanied with an informed consent form (see appendix V). Prior to answering the questionnaire, informed consent form (ICF) was given to the participant which required a participant either to decline or accept participation in the questionnaire. In addition, the ICF contained ethical issues components such as anonymity, confidentiality and non-disclosure which provided surety to the respondent. Contact details of the researcher were also included in the ICF and made available to the participants for communications purposes especially, for follow-ups and queries that might arise during and after the research. The researcher also endevoured to ensure that all the collected information were verified and correctly recorded in a spread sheet. *Table 3.1: Institution responses Vs no response*



Distributed	40
Returned	33
Not returned	7

Figure 3.3: Institution response vs no response

Table 3.2: questionnaire response by institution

Sno.	Institution	Province	Response
1	University Of Zambia	Lusaka	Responded
2	Copperbelt University	Copperbelt	No response
3	Mulungushi University	Central	No response
4	World Bank research group	Lusaka	Responded
5	Zambia Centre for accountancy studies	Lusaka	Responded
6	Evelyn Hone College	Lusaka	Responded
7	Lusaka University	Lusaka	Responded
8	Kitwe College Of Education	Copperbelt	No response
9	Zambia ICT College	Copperbelt	No response
10	Cancer Disease Training Centre	Lusaka	Responded
11	National Institute For science and Industrial Research	Lusaka	Responded
12	Examinations council of Zambia	Lusaka	Responded
13	International school of Lusaka	Lusaka	Responded
14	Rusangu University	Southern	No response
15	Lusaka International Community School	Lusaka	Responded
16	WorldFish Centre	Lusaka	Responded
17	National Institute of Public Administration	Lusaka	Responded
18	Baobab College	Lusaka	Responded
19	Zambia Institute for Policy Analysis Research	Lusaka	Responded
20	National Science Technology Council	Lusaka	Responded
21	National Remote Sensing Centre	Lusaka	Responded
22	Theological College of Central Africa	Lusaka	Responded
23	Charles Lwangwa Teachers College	Southern	Responded
24	Zambia Air Services Training Institute	Lusaka	Responded
25	Mpelembe Secondary school	Central	Responded
26	CHRESO University	Lusaka	Responded
27	Lusaka Business Technical College	Lusaka	Responded
28	Industrial Training Centre	Lusaka	Responded
29	National Resources Development College	Lusaka	Responded
30	David Kaunda Technical Secondary School	Lusaka	Responded
31	In-Service Training Trust	Lusaka	Responded
32	Dental School	Lusaka	Responded
33	Ndola School of Nursing	Copperbelt	No response
34	Kitwe School of Nursing	Copperbelt	Responded
35	Zambia Institute of special education	Lusaka	Responded
36	Chipata College of education	Eastern	Responded
37	Lechwe	Copperbelt	Responded
38	Kabwe School of Nursing	Central	Responded
39	Evangelical University	Copperbelt	Responded
40	Ndola School of Biomedical sciences	Copperbelt	No response

Table 3.3: Questionnaire distribution by province

Province	Questionnaires	Percentage
Lusaka Province	26	79
Central Province	2	6
Copperbelt Province	3	9
Eastern Province	1	3
Southern province	1	3

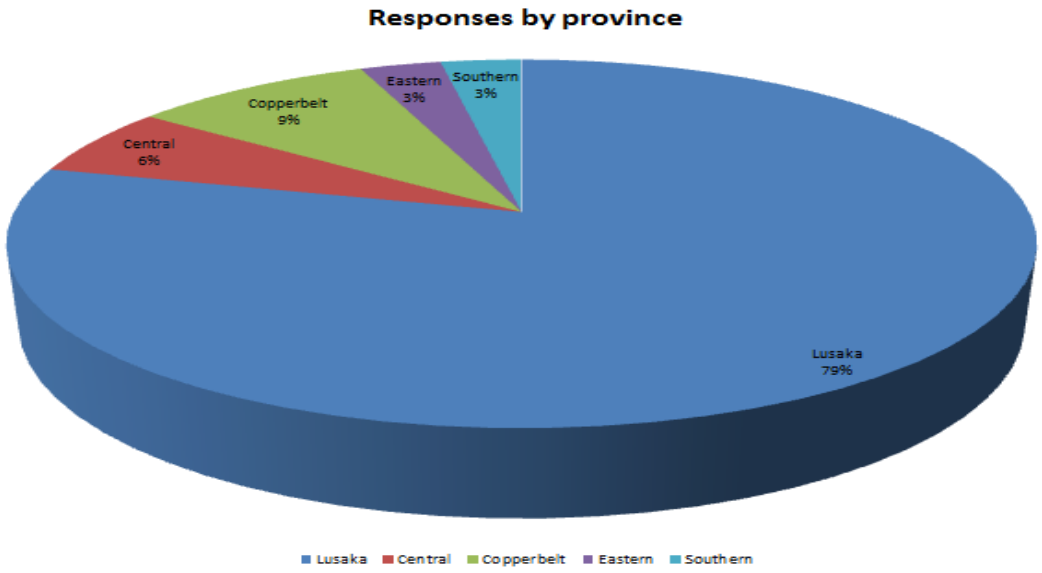


Figure 3.4: responses by provinces

3.6.2 Informed Consent Form

Prior to answering the questionnaire, a formal consent was taken from participants (ZAMREN Affiliate) as well as to secure ethical issues. The ethical issues considered included anonymity, bias, confidentiality and disclosure. Contact details of the researcher were also included in the ICF and made available to the participants for communications purposes, especially, for follow-ups and queries that might arise during and after the research. The consent form also defined the purpose of the study which was explained to participants so that they understood the need for them to be involved in the research. The Informed consent form is in append ix V.

3.6.3 Data analysis

In general, data analysis involves editing of the raw data. This approach helped detecting errors, omissions, and making corrections. Under this research, data analysis encompassed both manual and computer based approaches analysis [11[65][70][72].

Manual analysis was used in this research for discovering errors, omissions, and making corrections. For instance, questionnaire responses were manually analysed by the researcher before transcribing and subjecting them to a computer based spreadsheet analysis, MS-excel. Manual analysis was meant for checking contents for completeness and aided coding and tabulation. The researcher also carefully checked the responses of the questionnaires to minimize inconsistencies

3.6.4 Computer based analysis

The qualitative data collected particularly for objective I and II was subjected to computer based analysis spread sheet, MS-excel, 2007 office. MS-excel is a statistical in nature and has better features or capability in generating graphs [11][68][73][75]Since this research is an academic fulfillment; the researcher was the sole editor, however, was under the guidance of the supervisor so that data consistency was maintained.

3.6.5 Observation

During questionnaires distribution and collection, the researcher keenly observed pertinent information about the ICT infrastructure and power back-up installations of the target institutions. Insightful information was collected and was useful in the research. Information collected through observation included switches, computers, laptops and video conferencing facilities.

3.7 Data collection techniques for quantitative approach

OPNET simulator was used as a data collection technique in this research in order to provide empirical information pertaining to the use of HPC applications in RENs, particularly, ZAMREN. The simulator was also used to ascertain the point of failure of the ZAMREN in network while subjected to a HPC application.

3.7.1 OPNET Simulation

The simulation was conducted using OPNET software version 14.5. Three simulations were performed; normal video conferencing, heavy video conferencing and point of failure. The entire simulations network was composed of the network elements as shown in Table 3.4 and Figure 3.5.

Table 3.4: Simulation network components

No.	Network Components	No of components
1	Internet cloud	1
2	Routers	2
3	Switches	3
4	Firewall	1
5	100 Mbps	56
6	1000Mbps (1Gbps)	4
7	Servers	1
8	Application definition	1
9	Profile definition	1
10	Work stations	56

The link capacity which connects routers (router 1 and 2) to the internet cloud is 1Gbps and is of fibre type. A firewall was configured between router 1 and 2 to filter traffic from the public network (Internet cloud) and block entry of unauathorised traffic into the ZAMREN network. A 1Gbps fibre cable was used to provide a link between Router 2 to Switch_main. Switch_main provided or extended connections to 2 switches, namely; Switch 1 and 2. A 1Gbps fibre cable connected the 2 switches to Switch_main as shown in figure 3.5. An Ethernet, 100Mbps was then used to connect each node (workstation) to either Switch 1 or Switch 2. A node represented a single affiliate (member) of ZAMREN. Switch 1 had 26 nodes connected to it as well as switch 2 had 26 nodes too. The total number of nodes (Switch 1 and 2) was 56 and the ratio of nodes against the actual number of affiliates was 1:1.The application definition was used to configure (set) video conferencing parameters, that is either normal or heavy. The profile definition was used to set the profile parameters. An Ethernet 100Mbps connected a server to Switch_main.

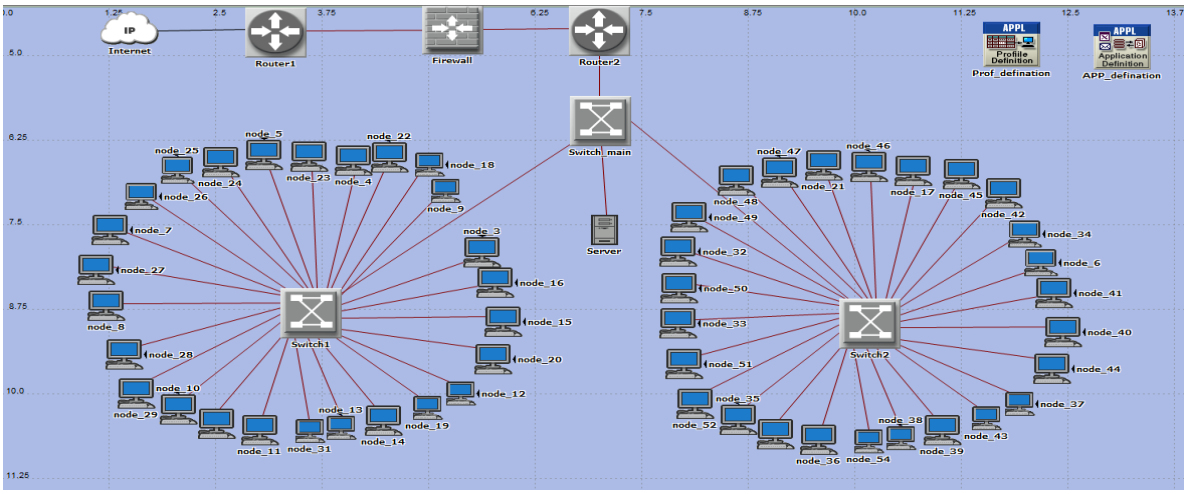


Figure 3.5: Network topology

i Scenario 1: Normal (Video conferencing) Simulation

The normal simulation was configured with normal video conferencing, number of users was 56 nodes, channel (bandwidth) capacity 1Gbps and period for the simulation was 3564 seconds. The total data traffic sent was 345600 bytes/sec and bandwidth utilisation was at 0.276 %. The assumption in this simulation was that the network was operating without any form of Heavy video conference application activated. The generated data was analysed and exported to MS excel for further analysis and better graph creation. Appendix I shows data which was generated during this simulation.

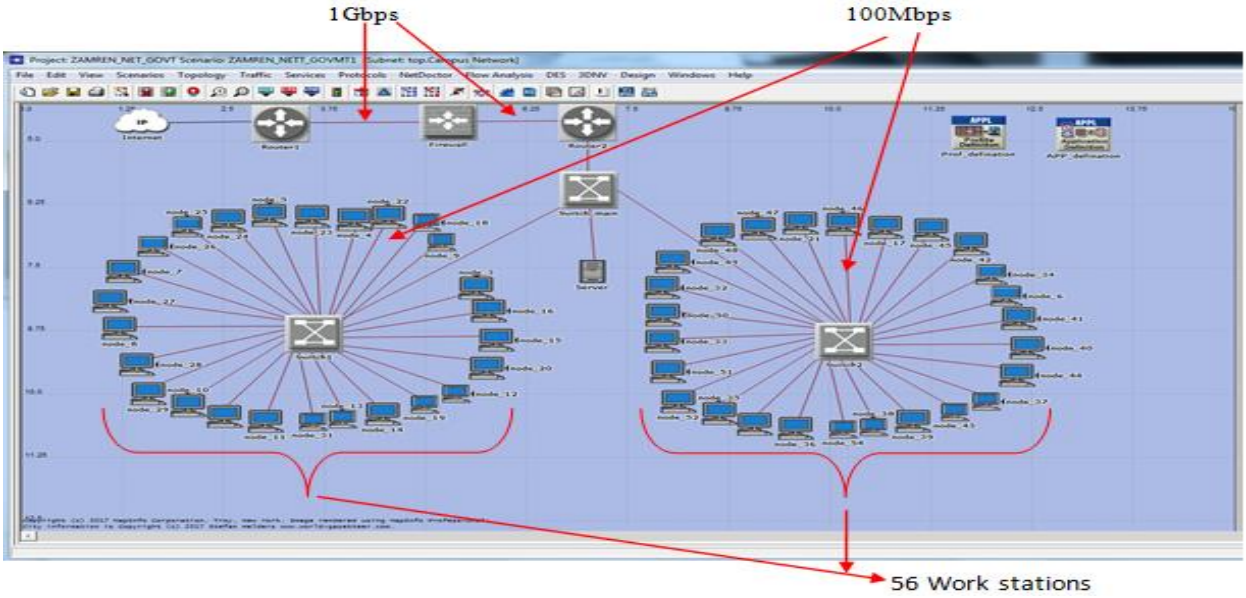


Figure 3.6: Normal video conferencing

ii Scenario 2: Heavy video conferencing simulation

Under this simulation, time, channel capacity and number of user attributes remained unchanged except video conference. However, the network did not fail at 56 nodes whilest using heavy video conferencing application. Number of nodes was steadily incremented or added to network which increased the data traffic sent. This process continued until the total traffic sent was about 1036800 bytes/sec which exhausted the link capacity.

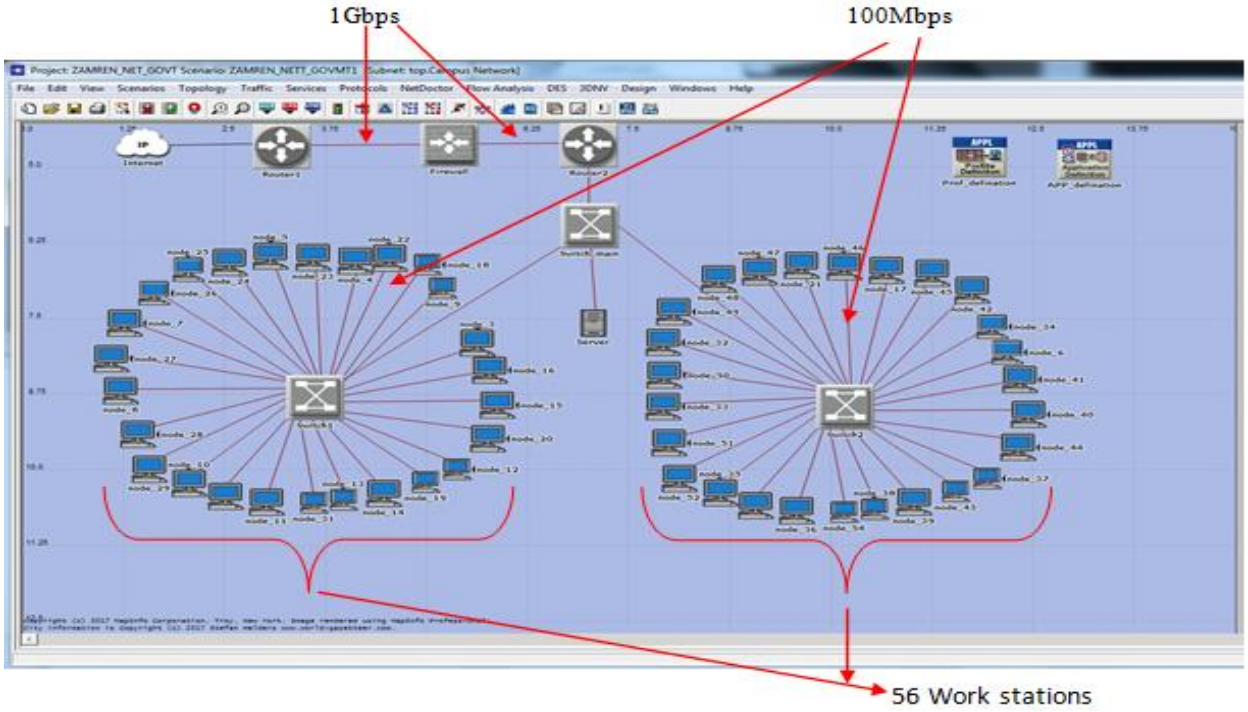


Figure 3.7: Heavy video conferencing

Appendix II shows data which was generated during heavy video conferencing simulation while appendix III contains data for both simulation 1 and 2 which compares the two simulations. All results from this simulation were analysed and exported into Ms-Excel for further analysis.

iii Point Of Failure

Since the network did not fail at 56 users using heavy conference, simulation was carried on until the point of failure was reached (the data traffic sent was equal or slightly above 1Gbps). Under the point of failure simulation, all the configuration parameters for heavy simulation were adopted except for the number of users which was varied gradually. The number of users was incremented gradually as shown in appendix III and until the channel capacity (1Gbps) was exhausted or collapsed. During the incremental process, the total traffic sent and channel capacity consumption was observed, analysed and exported to MS-excel for further analysis. The network collapsed at 6752 nodes and total traffic sent 1000067889 bits/sec and total bandwidth utilisation 100 (%). Point of failure data is contained in appendix III.

iv Scenario 3: comparative analysis of scenario 1 and scenario 2

Scenario 3 was used to perform comparative analysis between the two scenarios, namely, scenario 1(normal video conference simulation) and scenario 2 (heavy video conference simulation). This was important in determining the data traffic differences between the two

scenarios. The parameters of scenario 1, were that; video conference application was set to normal while scenario 2 was set to heavy. The total data traffic sent was 345600 and 1036800 bytes/sec for scenario 1 and 2 respectively. The bandwidth utilisation was at 0.276 % for scenario 1 and scenario 2 had 0.552(%) utilisation. Furthermore, all simulation results were analysed and exported into Ms-Excel for further analysis. The comparison showed a difference in the total traffic sent (bytes/sec) of about 691200 (bytes/sec) as well as total bandwidth utilisation of 0.55296 (%). The use of heavy video conference showed an increase in the traffic sent as well as bandwidth consumption or utilisation. Based on the results of the two scenarios, it was deduced that a change on the application type or configuration settings, from normal to heavy, resulted in an increase in the bandwidth utilisation and traffic sent. The use of heavy video conference showed an increase in the traffic sent as well as bandwidth consumption or utilisation. Although, the use video conferencing applications are essential tools for enhancement of e-learning via internet, it worth noting it demands a substantial bandwidth resources and if not properly managed can have adverse effects on the network.

3.8 Summary

The study's methodological used was a mixed approach; qualitative and quantitative. Qualitative was used for collecting data for descriptions and explanation purposes. Out of 56 affiliates, 40 questionnaires sent out to ZAMREN affiliates for data collection. Thirty- three (33) affiliates responded while 7 affiliates did not respond as shown Table 3.1. The response percentage was 85% and 15% institutions did not respond as shown Figures 3.3. Questionnaire percentage response per province as shown in Figure 3.4 and as follows; Lusaka 79%, Copperbelt 9%, Central 6%, Eastern 3 and Southern 3%. All the questionnaires responses were entered in SSPS for analysis purposes. Microsoft excel 2010 was also useful for analytical purposes. Opnet 14.5 network simulator was used to perform all the simulations which were basically quantitative in nature. The first simulation (scenario 1) was normal video conference and had parameters set which included; 56 nodes representing all 56 affiliates, 1Gbps fibre link, 3 Cisco switches, 2 cisco router and video conference application set to normal. The total traffic which traversed the network during normal simulation was recorded in Opnet and exported to Ms- excel for better publishing. The network did fail. The second simulation involved heavy video conferencing which was referred as scenario 2. The parameters for scenario 1 were maintained in scenario 2 except for video conferencing which was set to heavy. The results were recorded in opnet 14.5

and later exported to Ms-excel for publishing. The network did not fail. The network's nodes gradually increased which correspondingly increased that data traffic. This process continued and data traffic was monitored (examined) so that it was not beyond the size of the link capacity. The network only failed with 6752 nodes

CHAPTER 4: FINDINGS AND DISCUSIONS

4.1 Findings.

4.2.1 Introduction

This chapter presents the results of the study and which was presented in two parts correspondingly two methodologies used. The first component is based on qualitative and addressed objectives (i) and (ii). The data collection instruments for the first component were questionnaires and document reviews. The second component is more of quantitative and based on the Opnet simulation carried out on ZAMREN network. Simulation data generated was exported into Ms-excel for easier analysis and presentation.

4.2.2 Objective (i): What are some of the ZAMREN affiliates challenges

Figure 4.1 and Table 4.1 both shows the results of for objective (i).The findings were that 19% of most ZAMREN affiliates faced power outage, 16% was attributed to financial constraint, another 16% was a result of fibre cut (damages) and 11% of the affiliates expressed a challenge of high internet tariffs.

Table 4.1: ZAMREN affiliates challenges

Challenge Type	Secondary	College	University	Other Institutions	Total	Percentages
Financial constraints	2	5	2	1	9	16
Lack or low level of ICT-Technical knows- how	1	3	0	0	4	7
lack or Low level of ICT Infrastructure	1	1	0	1	3	5
Low level of appreciation of ZAMREN	0	0	0	1	1	2
Lack of Technical support from ZAMREN	1	1	1	1	4	7
Lack of Management of Support on ICTs matters	0	1	0	0	1	2
Power outages	2	4	2	3	11	19
High internet tariffs	1	0	2	3	6	11
Connection problem	1	1	0	1	3	5
Poor services	0	1	0	0	1	2
Unsecure and Unreliable	0	0	1	0	1	2
Bureaucracy	0	1	0	0	1	2
long response time	1	1	0	1	3	5
fibre cuts	0	1	0	2	9	16
Total Percentage						**100**

Additional challenges expressed by affiliates included 7% of lack of technical ICT know-how, 7% of lack of support from ZAMREN, 5% lack or low level of appreciation ZAMREN's infrastructure, 5% was connection problem, 5% was for long response time, 2% was attributed to lack of management support on ICTs matters, low level of appreciation of ZAMREN was 2%, poor services was 2%, unsecure and unreliable was 2% and bureaucracy was 2%.

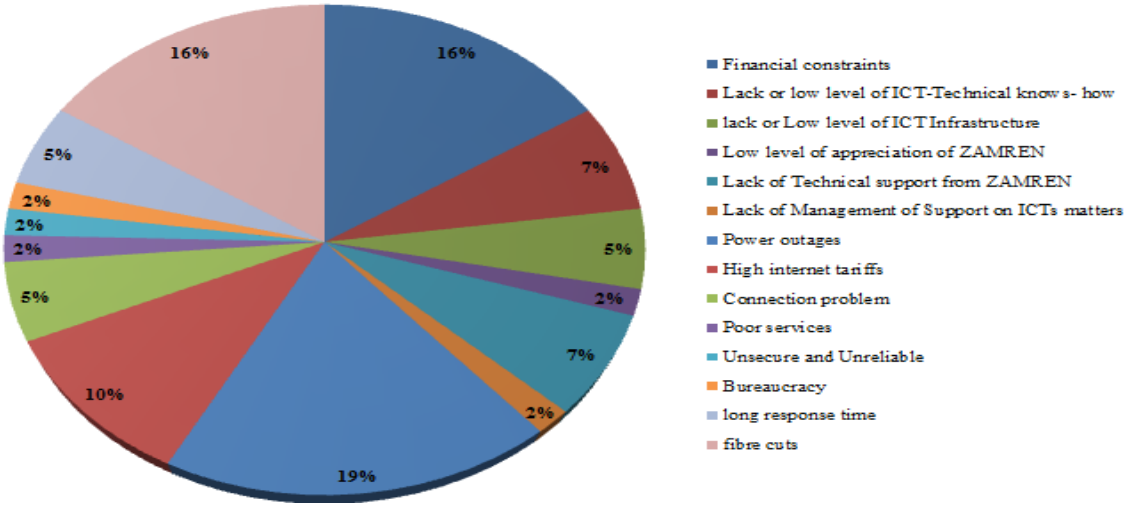


Figure 4.1: ZAMREN affiliates challenges

Further, the information in both Figure 4.1 and Table 4.1 was classified into 4 distinct categories, namely; technical, administrative support, operations and training and other challenges. This was necessary in order to facilitate clear presentation, publishing and interpretation of results as shown both in Figure 4.2 and Table 4.2.

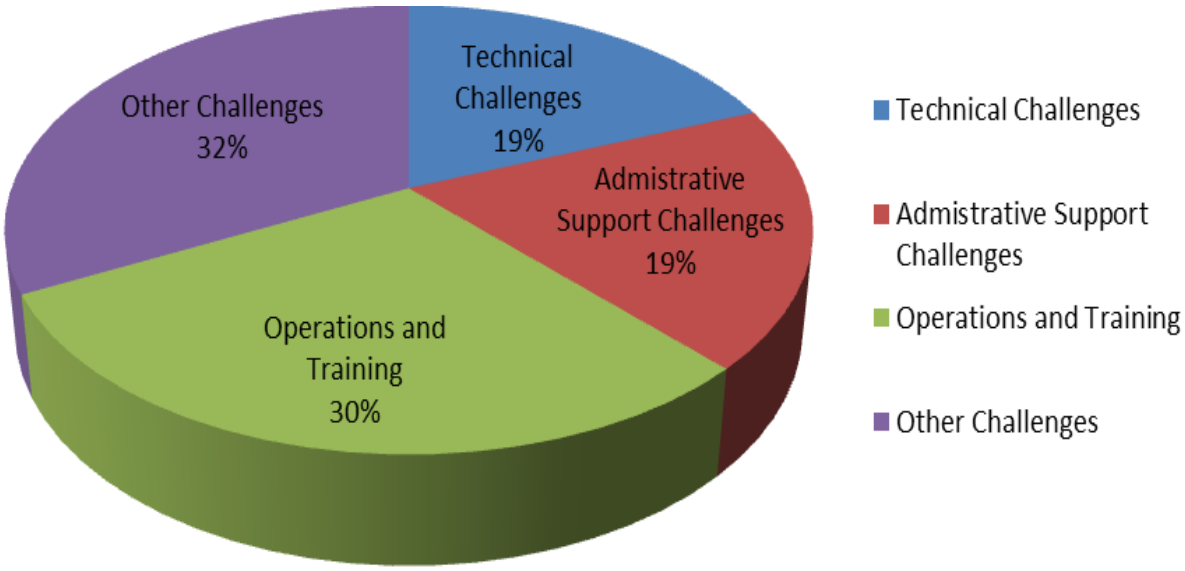


Figure 4.2: Classification of affiliates challenges

Figure 4.2 indicates that the classification of ZAMREN affiliates challenges. In essence, external challenges classified as other challenges had 32% and was the main challenge faced by affiliates. This class was composed of power and fibre cuts. The other classification was Operations and training classification which had 30%, 19 % was

attributed to Technical problems faced by affiliates (Lack of Technical support from ZAMREN, lack or Low level of ICT Infrastructure and lack or low level of ICT-technical knows- how), and administrative challenge was 19% (financial constraints, bureaucracy and lack of Management of support on ICTs matters). Table 4.1 shows the distribution of questionnaires to affiliate. A total of 40 out of 56 questionnaires were distributed, 33 were returned while 7 were not returned.

Table 4.2: classification of affiliates challenges

	Category	**score**	**Percentage**
1	**Technical Challenges**		
	Lack of Technical support from ZAMREN	0	0
	lack or Low level of ICT Infrastructure	3	8
	Lack or low level of ICT-Technical knows- how	4	11
	Technical Challenges Total	**7**	**19**
2	Administrative Support		-
	Financial constraints	5	14
	Bureaucracy	**1**	3
	Lack of Management of Support on ICTs matters	1	3
	Administrative Support Challenges	7	19
3	**Operations & Training Challenges**		
	High internet tariffs	4	11
	Connection problem	2	5
	Poor services	1	3
	Unsecure and Unreliable	0	-
	long response time	3	**8**
	Low level of appreciation of ZAMREN	1	3
	Operations and Training	11	30
4	**Other Challenges**		-
	Fiber cuts	4	11
	Power cuts	8	22
	Other Challenges Total	12	32
	Total Challenges	**37**	**100**

Table 4.3 depicts questionnaires distribution. For instance, 56 affiliates was the total population of the study whereas 40 affiliates was the target population representing 71%.. Further, Table 4.3 shows 40 as the actual number of distributed questionnaires representing 71%. Thirty-three (33) affiliates responded representing a 59%, 7 affiliates never responded relating to a 13% and 16 affiliates did not participate in the study representing a percentage 29%.

Table 4.3: Questionnaire distribution

Discription Distribution	No of affiliates	Percentage Calculations
Total Population	56	100
Target Population	40	71
Distributed	40	71
Returned / Responded	33	59
Not returned / responded	7	13
Untargeted Population	16	29

Figure 4.3 shows percentages of target verses untargeted population. The target and untargetted population percentage was 71% and 29% respectively.

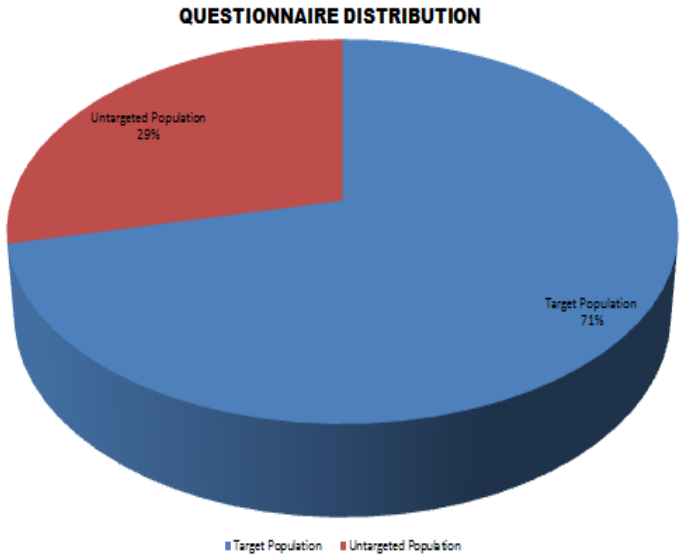


Figure 4.3: Questionnaire distribution

4.2.3 ZAMREN Network Parameters

A thorough document review conducted from ZAMREN revealed insightful information which relates to the current network setting parameters of ZAMREN and Table 4.3 shows a summary of this information.

Table 4.4: Existing network settings parameters of ZAMREN

External Links Capacity	1 Gbps
Internal links	50 Mbps
No. of affiliates	56
Highest link capacity	1Gbps
No. Point of presence(pop)	7
National Operation Centre	1
High Performance Computer	1
No. of International links	2
No. of Redundancy links	1

The maximum link capacity of ZAMREN is 1Ggbs of backbone fibre channel. The other parameters are; 7 point of presence (PoP), 1 HPC, 1 redundancy link and 2 international links.

4.2.4 Resulst for scenario 1: Normal video conferencing

This simulation had the following configurations: video conferencing set to normal, number of users was 56 users or nodes, total data traffic sent was 345600 bytes/sec, duration time was 3564 seconds and bandwidth utilisation was at 0.276 %. Table 4.4

shows a summary of information pertaining this simulation. This simulation had the video conferencing parameter set to normal.

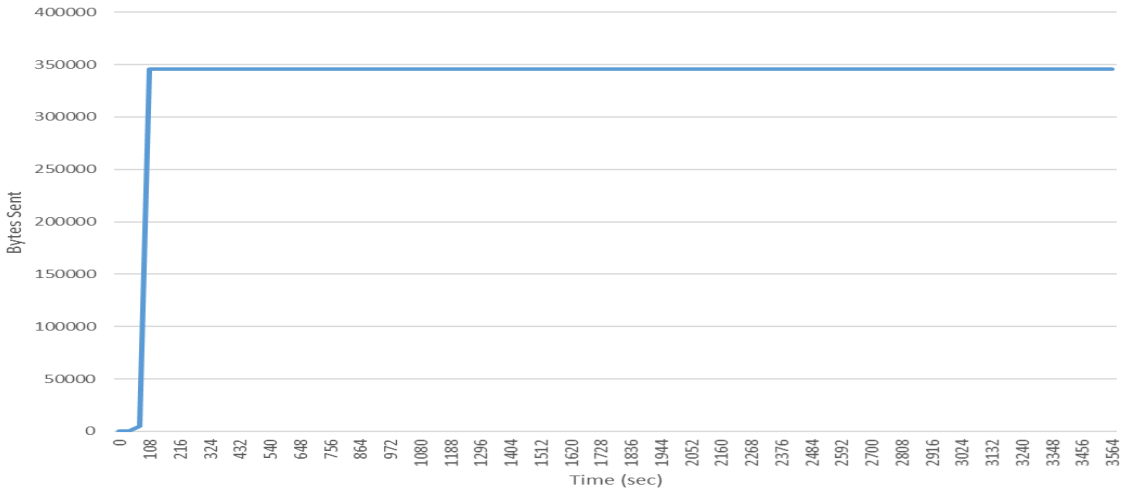


Figure 4.4: Simulation scenario 1 (Normal video conferencing)

Table 4.4: Summary of scenario 1- normal

Total Traffic Sent (bytes/sec)	345600
Avg Traffic Sent(Bytes/Sec)	6171.43
Total bandwidth Utilisation(%)	0.27648
No. Users	56

4.2.5 Simulation scenario 2: heavy video cconference

Under this simulation, the following configuration: video conferencing set to heavy l, number of users was maintained at 56 users or nodes, total data traffic sent was 1036800 bytes/sec, duration time was maintained 3564 seconds and bandwidth utilisation was at 0.8294%. Table 4.5 shows a summary of information about pertaining heavy video conference simulation.

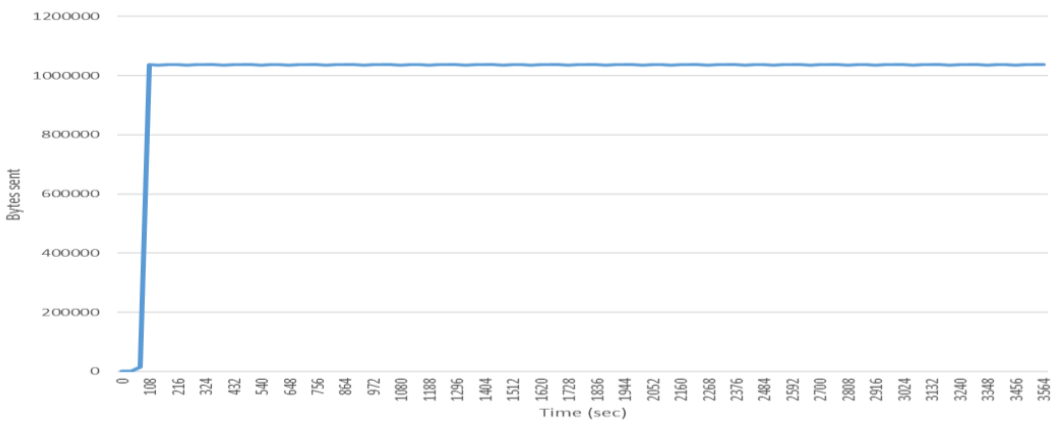


Table 4.5: Summary of simulation 2 – heavy video conferencing

Objective III : Comparison - Scenario 1 and 2

Figure 4.5 is comparison of scenario 1 and 2. Scenario 2 represents heavy video while scenario 1 normal video conferencing. It can be noted 691200 bytes/sec is the difference between the 2 scenarios. Duration time and number of users are same for both scenarios and are shown in summary Table 4.6.

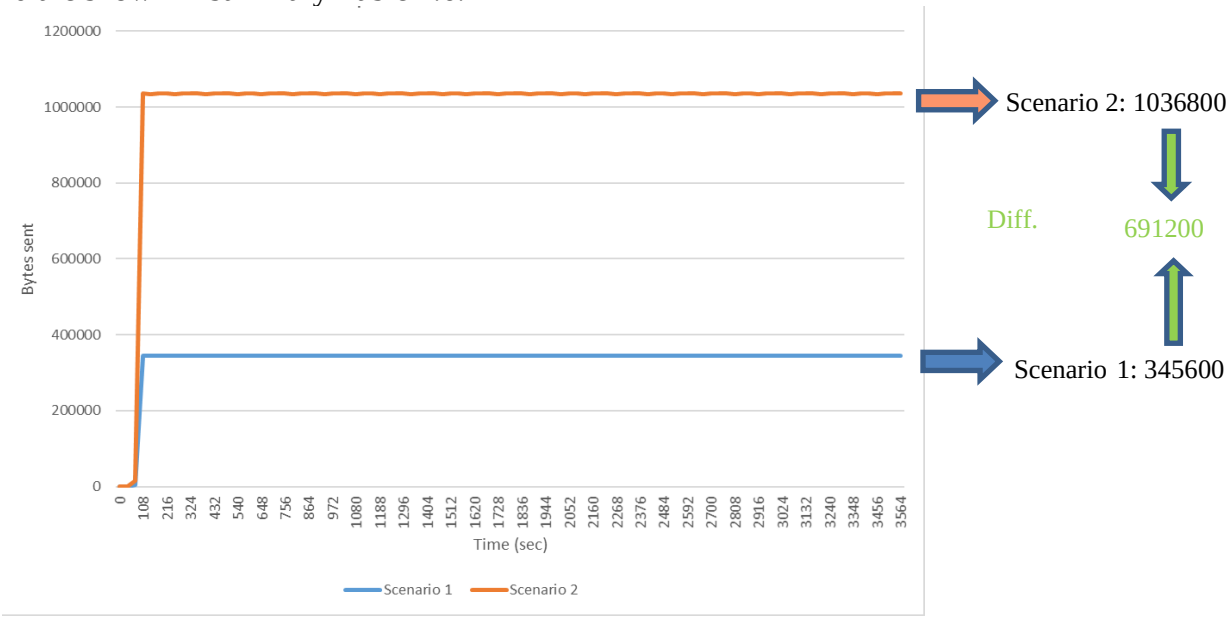


Figure 4.5: Comparison of scenario 1 and 2

Total Traffic Sent (bytes/sec)	345600	1036800
Avg Traffic Sent(Bytes/Sec)	6171	18514
No. Users	56	56

4.2.6 Objective III: Point of failure.

Figure 4.6 depicts the point of failure for ZAMREN while subjected to heavy video conferencing. It can be noted that the network failed precisely with 6752 nodes concurrently using heavy video conferencing. The current 1Gbps ZAMREN channel was exhausted and the actual total traffic sent by 6752 nodes was 1000067889 bits/sec.

During the entire simulation process, ZAMREN channel capacity remained constant at 1Gbps but the number of users was gradually incremented until the point of failure. At the same time, the traffic loads pattern changes were monitored and measured whenever there was an increment on the number of users or nodes to simulated network. This process was important in determining the point at which the 1Gbps channel will be completely exhausted. In addition, Appendix IV shows the data which was used in the simulation until

the point of failure of the network and it is also the data used to plot and publish Figure 4.6.

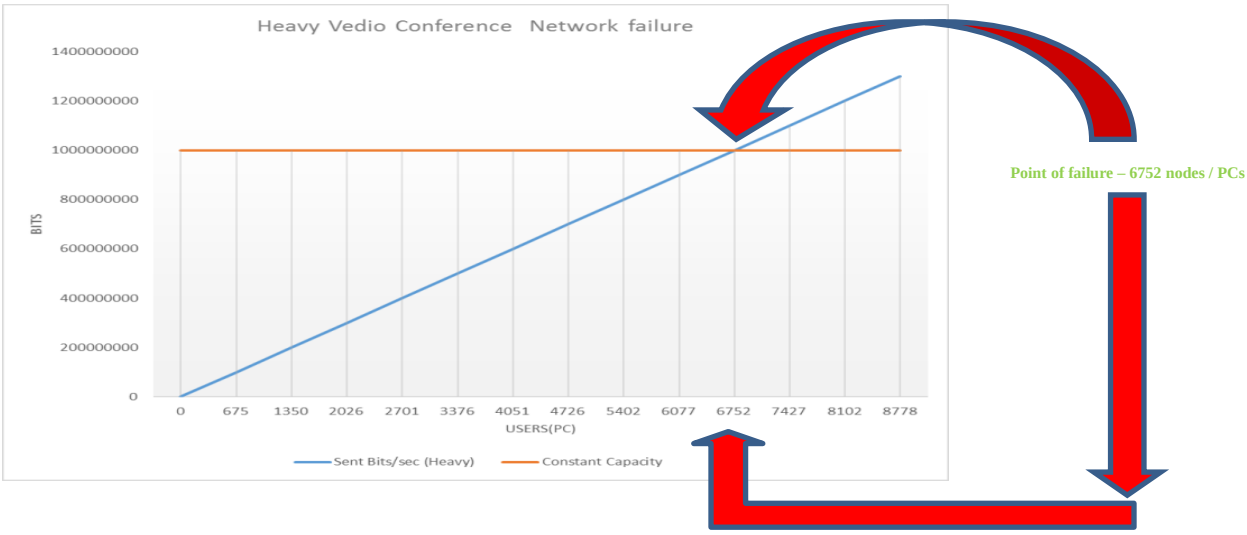


Figure 4.6: Point of Failure ZAMREN

4.2 Discussion

This section discusses the findings of the study and the following were the objectives of:

4.2.1 Objective I: Challenges faced by ZAMREN's affiliates.

There were basically 14 distinct challenges identified under this study and are shown in Table 4.1 and Figure 4.1. The overall total number of population was 56 as shown in Table 4.7 - lists all ZAMREN affiliates by province and response.

Both Table 4.1 and Table 4.7 show the actual target population of 40 affiliates, 33 affilaites respondants and 7 affiliates which did not give feedback. The results for objective (i) were that 19% of ZAMREN affiliates faced a challenge of power outage, 16% stressed a challenge of funding, another 16% complained of disruptions due to constant fibrecuts (damages) and 11% of the affiliates expressed a challenge of high internet tariffs. Additional challenges expressed by affiliates included 7% attributed to lack of technical ICT know-how, 7% was due to lack of support from ZAMREN, 5% was due low level of appreciation ZAMREN's infrastructure, 5% was due to connection problem, 5% was due to long response time to receive a feedback from ZAMREN after submission of complaint, 2% was attributed to lack of management support on ICTs matters, low level of appreciation of ZAMREN was 2%, poor services was 2%, unsecure and unreliable was 2% and bureaucracy was 2%.

Table 4.7: list of target population

Sno.	Institution	Province	Response
1	University Of Zambia	Lusaka	Responded
2	Copperbelt University	Copperbelt	No response
3	Mulungushi University	Central	No response
4	World Bank research group	Lusaka	Responded
5	Zambia Centre for accountancy studies	Lusaka	Responded
6	Evelyn Hone College	Lusaka	Responded
7	Lusaka University	Lusaka	Responded
8	Kitwe College Of Education	Copperbelt	No response
9	Zambia ICT College	Copperbelt	No response
10	Cancer Disease Training Centre	Lusaka	Responded
11	National Institute For science and Industrial Research	Lusaka	Responded
12	Examinations council of Zambia	Lusaka	Responded
13	International school of Lusaka	Lusaka	Responded
14	Rusangu University	Southern	No response
15	Lusaka International Community School	Lusaka	Responded
16	WorldFish Centre	Lusaka	Responded
17	National Institute of Public Administration	Lusaka	Responded
18	Baobab College	Lusaka	Responded
19	Zambia Institute for Policy Analysis Research	Lusaka	Responded
20	National Science Technology Council	Lusaka	Responded
21	National Remote Sensing Centre	Lusaka	Responded
22	Theological College of Central Africa	Lusaka	Responded
23	Charles Lwangwa Teachers College	Southern	Responded
24	Zambia Air Services Training Institute	Lusaka	Responded
25	Mpelembe Secondary school	Central	Responded
26	CHRESO University	Lusaka	Responded
27	Lusaka Business Technical College	Lusaka	Responded
28	Industrial Training Centre	Lusaka	Responded
29	National Resources Development College	Lusaka	Responded
30	David Kaunda Technical Secondary School	Lusaka	Responded
31	In-Service Training Trust	Lusaka	Responded
32	Dental School	Lusaka	Responded
33	Ndola School of Nursing	Copperbelt	No response
34	Kitwe School of Nursing	Copperbelt	Responded
35	Zambia Institute of special education	Lusaka	Responded
36	Chipata College of education	Eastern	Responded
37	Lechwe	Copperbelt	Responded
38	Kabwe School of Nursing	Central	Responded
39	Evangelical University	Copperbelt	Responded
40	Ndola School of Biomedical sciences	Copperbelt	No response

4.2.2 Objective II: ZAMREN network setting parameters.

Table 4.4 shows the current network setting parameters for ZAMREN. The primary focus of this objective was to know the maximum channel capacity or bandwidth for ZAMREN network in use. It was revealed that currently, ZAMREN‘s maximum channel capacity is 1Gbps. The channel being used is fibre which is broadly known and has a feature of transmitting data (multimedia) at speed of light or fast. Additional ZAMREN network

setting parameters revealed includes internal links with capacity not exceed 50 Mbps each, 7 point of presence (PoP), 1 National Operation Centre (NOC), 1 High Performance Computer (HPC),1 redundancy links and 2 international (regional) links. The redundant link is used to support the main link whenever it's down, probably, during maintenance or when there is damage to the main link. Strategically, the redundant link plays a critical role for business continuity purposes.

4.2.3 Objective III: Point of failure of ZAMREN

In general, there were basically 2 Opnet 14.5 simulations carried out normal and heavy video conference. Normal and heavy video conferencing also referred to as scenario 1 and scenario 2 respectively. Additionally, a comparative analysis between normal and heavy video conferencing was conducted too

Normal video conferencing

The simulation was conducted using Opnet 14.5 version and the configuration parameters included among others: video conferencing application set to normal, a single 1Gbps fibre channel and 56 nodes accessing the ZAMREN network simultaneously. The result of the simulation 345600 bytes were successfully sent over the network and the network did not fail as shown in Figure 4.4 and appendix I. The connation of the result suggest that ZAMREN network would still be able to support 56 affiliates simultaneously assuming each affiliate was using 1 computer. The total time of simulation was 3564 milliseconds. Table 4.8 shows a summary of normal video simulation. For instance, it shows total and average traffic sent in bits or bytes by 56 nodes. This information and detailed information is also found or provided in appendix I.

Table 4.8: Summary of normal video conference simulation

Description	Units
Total Traffic Sent (bytes/sec)	1036800
Total Traffic Sent (bit/sec)	8294400
Avg Traffic Sent(Bytes/Sec)	18514.29
Avg Traffic Sent(Bits/Sec/pc)	148114.29
Total bandwidth utilisation (%)	0.82944

Heavy video conference

Similarly, heavy video conferencing was conducted in Opnet 14.5 too. All the configuration parameters used in normal video conference simulation were adopted except for video conference application. Video conference application was set to heavy and the

network did not fail with 56 nodes. The strategically the number of nodes were varied or incremented gradually, total traffic sent constantly monitored and the network only failed with 6752 nodes. Figure 4.6 shows the point of failure of the network while it was subjected to heavy video conferencing. It was revealed that the network only failed when 6752 nodes simultaneously used the application and total traffic was 1036800 bytes/sec (1000067889 bits/sec). Based on these results ZAMREN could support utmost 6752 nodes which are essentially users with an assumption that only heavy video conferencing application is be used.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the study and makes some recommendations based on the findings of the study.

5.2 Conclusion

Generally, it was noted that ZAMREN as NREN in Zambia is providing affordable rates of internet services to both private and public learning institutions as well as to research organisations. For instance, affiliates, researchers and students are currently using non-video conference applications to download and upload text documents via ZAMREN network quickly and affordably. ZAMREN also provides capacity building to its affiliates in various forms such as seminars and workshops.

Additionally, ZAMREN is a key participant in ICTs initiatives, innovations, programmes and projects both locally and regionally. For instance, ZAMREN is a stakeholder in last mile fibre project spearheaded by ZICTA in Zambia. Last mile fibre project is a government of Zambia ICT project undertaking of laying a backbone fibre country wide in a bid to make internet connectivity easily available and affordable especially to the rural citizen and in turn spur development through ICT. Therefore, ZAMREN can be described as a vital ICT tool in Zambia which fosters, enhances and promotes education over the internet. ZAMREN is a regional member of UbuntuAllaince and participant of ICT regional projects spearheaded by the alliance.

However, in spite of these positive achievements or activities, in line with research objectives, it was also noted that: (a) Most affiliates faced a challenge of power outage followed by both financial and fiber cuts; (b) Maximum current channel capacity of ZAMREN was 1Gbps and (c) point of failure for ZAMREN network was at 6752 nodes and total traffic sent by the nodes was 1000067889 bits/sec. ZAMREN 1Gbps channel capacity was exhausted by this traffic load. Therefore, it was concluded that ZAMREN network capacity can support data intensive applications, in particular, video conferencing in a short period of time and may continue using 1Gbps channel for a while. However, immediate plans should be put in place soon to scale up the channel capacity so as to be able to meet the growing demand from affiliates. In addition, at present, affiliates are

already using non-video conferencing applications which are consuming certain amount of the available capacity yet this was not accounted in this research as it was not in the scope. For instance, approximately 594.5 Mbps ZAMREN's link is being already being utilized. is Therefore, the assumption was that if it was taken into account the failure point (6752) could reduce, perhaps, it should be considered in a future research study.

The other justification for network capacity scaling up is that the literature review for ZAMREN revealed that ZAMREN is gradually spreading, expanding and rolling out its network catchment to rural urbans. The focus of the project is ensuring that rural urban institutions do have access to its network ultimately service at affordable price. Once this project is completed it means that there will also be gradual increase on the number of users accessing the ZAMREN network will have an effect on demand for the bandwidth. Fundamentally, a rise in the number of affiliates potentially will raise bandwidth utilization and consequently will lead to network performance degradation. Following our simulation, it was affirmed that an increase in the number of users has correlation on the bandwidth consumption of the network and point of failure. This same principle is also true for the expansion of ZAMREN. Lastly, RENs literature revealed that RENs, particularly, in America, Asia and Europe are operating above 5Gbps as such ZAMREN still has gap and needs to scale up its capacity in order to catch up and cope up with other RENs in the world.

Further, ZAMREN affiliates were classified into 4 categories, namely, Technical, Administrative Support, Operation and Training and other challenges. The classification exercise was meant to enhance easier interpretation as well as for better publishing of the results for objective I. The results were as follows; Other challenges category, (predominantly was composed of power outage and fibre cuts) had 32% which correlated to the earlier findings. Operational and Training category had 30% while the remaining 2 categories;Technical and Administrative Support categories each had a percentage of 19%.

Overall, the study established that most affiliates were faced by a challenge of power outage followed by both financial and fiber cuts. The study also revealed that maximum channel capacity of ZAMREN is 1Gbps and the channel reached its point of failure with 6752 users simultaneously using video conference application.

5.3 Recommendations

In view of the findings and conclusions, the following recommendations are proposed:

i Deliberate incentives should be put in place, by government, to financially assist affiliates such as tax exemptions on ICTs equipment, internet subsidies, dedicated power supplies to schools, grants, rewards institutions and individuals spearheading ICTs usage. For instance, government should offer ICT scholarships to in-service officers particularly to teachers to broaden ICT knowledge

ii Strategies, such as camera installation along fibre lays, should be put in place to minimize and monitor fibrecuts. Additionally, provide more redundant channels be to overcome this challenge. This will serve as business continuity plan.

iii ZAMREN may continue using 1Gbps channel for a while, however, modalities should be put in place soon to scale up the channel capacity so as to be at pace with the high demand in the ICT and RENs sector.

iv ZAMREN should quickly roll out its services country wide.

5.4 Future works

Based on the findings of the research, the researcher proposes that future research should be focused on finding out the impact of ZAMREN ICT services in the education in Zambia following government decision's to compulsory introduce ICTs at junior secondary school.

5.5 Summary of chapter 5

In general, in spite of ZAMREN challenges, it was noted that ZAMREN is vital in education and research fraternity. It is an ICT tool in Zambia which fosters, enhances and promotes education over the internet. Zambia Research and Education Network is among the 120 operational NRENs existing in the world. It can be referred as a "public good" institution to the affiliates and the country at large. For instance, it was noted that among the services it provides includes; offering training and technical support – through workshops and seminars, subsidized or reduced internet tariffs and participate in the national projects and ICTs initiatives, innovations, programmes and projects both locally and regionally. For example, ZAMREN is a stakeholder in last mile fibre project spearheaded by ZICTA in Zambia. Currently, ZAMREN has managed to provide connectivity to 56 affiliates (institutions) which are but not limited to UNZA, ZIPAR,

Worldbank, ZCAS, DK, Nkruma University. Researchers and students from these affiliates are able to share, access, collaborate, download and upload documents globally via ZAMREN network quickly and affordably.

ZAMREN affiliates are composed of secondary schools, colleagues, and university and research institutions – which are either private or public institutions. A ZAMREN‘s affiliate is synonyms to any other organisation, with its own peculiar and potential challenges prohibits smooth operations. Therefore, ZAMREN’s affiliates are not exceptional. The findings of objective (i) 19% of ZAMREN affiliates faced a challenge of power outage, 16% challenge of funding, 16% fibrecuts (damages), 11% high internet tariffs, 7% lack of technical ICT know-how, 7% lack of support from ZAMREN, 5% lack or low level of appreciation ZAMREN’s infrastructure, 5% connection problem, 5% long response time, 2% lack of management support on ICTs matters, low level of appreciation of ZAMREN was 2%, 2% poor services, 2% unsecure and unreliable and 2% bureaucracy. The maximum current channel capacity of ZAMREN was 1Gbps and (c) point of failure for ZAMREN network was at 6752 nodes. Therefore, it was concluded that ZAMREN network capacity can support data intensive applications, in particular, video conferencing, and may continue using 1Gbps channel for a while, however, immediate plans should be put in place soon to scale up the channel capacity. In addition, the other justification for network capacity scaling up is that the literature review for ZAMREN revealed that ZAMREN is gradually spreading or expanding and rolling out its network catchment to rural urbans. The focus of the project is ensuring that rural urban institutions do have access to its network ultimately service at affordable price. Once this project is completed it means that there will also be gradual increase on the number of users accessing the ZAMREN network and demand for the bandwidth. It was noted also that most NRENs, particularly, in America, Asia and Europe are operating above 5Gbps as such ZAMREN still has digital gap , therefore, it was necessary that this gab is addressed by scaling up its capacity in order to catch up and cope up with other NRENs in the world.

The recommendation includes: deliberate incentives should be put in place, by government, to financially assist affiliates. For instance, tax exemptions on ICTs and electricity generation(solar and genset) equipment’s, internet subsidies, installation of

dedicated power supplies to schools, grants provision and ICTs based rewards to institutions and individuals (ICT scholarships) to in-service officers particularly to teachers to broaden ICT knowledge. Camera or security installation along fibre lays should be implemented to minimize and monitor fibrecuts. In additional, provide more redundant channels to ensure that there is business continuity. Modalities should be put in place soon to scale up the channel capacity so as to be at pace with the high demand in the ICT and reduce digital divide.

REFERENCES

[1] Ubuntunet Alliance, "welcome to Ubuntunet Alliance website", *ubuntunet.net, 2014,* [Online].Available: http://www.ubuntunet.net/. [Accessed Sept. 4. 2015].

[2] WACREN, "Digital meets Culture: WACREN 2015 Conference," wacren.net, 2015. [Online]. Available: http://wacren.net/sites/default/files/WACREN%20Constitution_0314.pdf. [Accessed Sept. 4. 2015].

[3] K.B. Dipholo and I. Biao, "The African Symposium: An Online Journal of the African Educational Research Network," *Rethinking Education for Sustainable Development in Africa,* Vol.13, No. 2, Dec. 2013.

[4] International Education and Resource Network (iEARN), "iEARN about," *International Education and Resource Network*, 2012. [Online]. Available: *http://www.iearn.org/about*. [Accessed Dec. 10, 2014]

[5] GEANT, "GEANT Project," 2014. [Online]. Available: *http://www.geant.net/Pages/default.aspx*.

[6] TERENA, "TERENA COMPENDIUM*," "* 2011 *ed.* [online]. Available: *http://www.teRENa.org/compedium .* [Accessed Dec. 10, 2014].

[7] TEVETA, "Registered Institutions (Stable): list of registered institutions as at 31st Dec. 2013," *teveta.org.zm*, 2013. [Online]. Available: *http://www.teveta.org.zm*. [Accessed Dec. 10, 2014].

[8] Xavier University, "*Qualitative Versus Quantitative Research,"* Xavier University Library, Dec.2012.

[9] ZAMREN, "About us," ZAMREN.zm, 2013. [Online]. Available: *https://www.ZAMREN.zm/?q=search/node/unza.* [Accessed Dec. 10, 2014].

[10] Bill and Melinda Gates Foundation, "Connections, Capacity, Community", *Exploring Potential Benefits of Research and Education Networks for Public Libraries*, Feb.21, 2011.

[11] Caribbean Knowledge and Learning Network (CKLN), "Regional Strategy for C@ribNET :Provision of Blueprints for the Development and Implementation of National Research and Education Networks (NRENs, ckln.org , June 2011. [Online].

Available: http://www.ckln.org/home/sites/default/files/Barbados_Blueprint__-_B_&_F%5B1%5D_0.pdf. [Accessed Jan. 7, 2015]

[12] S. Saay , "Sustainability of NRENs in Developing countries*," Institute of Informatics*, Tallinn University, Feb. 2014

[13] TERENA, "TERENA COMPENDIUM of National Research and Education Networks in Europe," *TERENA, 2012 ed*. [Online]. Available: *http://www.teRENa.org/compedium .* [Accessed Jan. 7, 2015].

[14] MEF, "Understanding Carrier Ethernet Throughput: Am I getting the throughput I should be getting*?" mef.net*, Jul.2.2010….[Online]. Available: *https://www.mef.net/Assets/White_Papers/Understanding_Carrier_Ethernet_Throughput_-_v14.pdf*. [Accessed Jan. 7, 2015].

[15] S. Tembo, EEE6312. Class Lecture, Subject: "Computer Networks." School Of Engineering, University of Zambia, Lusaka, 2015

[16] B. A. Forouzan, "Chapter 6-Bandwidth Utilization: Multiplexing and Spreading," in *Data communications and networking:* 4th ed. 2007. [Online]. Available: https://www.cpe.ku.ac.th/~plw/dccn/presentation/ch06.pdf. [Accessed Jan. 7, 2015].

[17] Mellanox Technologies, "Deploying Quality of Service and Congestion Control in InfiniBand-based Data Center Networks," mellanox.com, 2012.[Online].Available: http://www.mellanox.com. [Accessed Sept. 4. 2015].

[18] Trans-Eurasia information Network (TEIN)2, "Powering Research and Education in Asia-Pacific*,"*. TEIN2, 2014. [Online].Available: https://www.youtube.com/watch?v=ytsD3pu4UXg [Accessed Sept. 4. 2015].

[19] D.R. Cooper and P. S. Schindler, "Proposing Research: Resource Allocation and Budgets," in Business Research Methods, 12th ed. NY: McGraw Hill, 2014.

[20] S. Saay, "Sustainability of National Research and Educational Networks (NRENs) in developing countries," Phd. dissertation, Institute of informatics, Tallinn University, Tallinn, Estonia, 2014.

[21] T.Hey and A.Trefethen, "The Data Deluge: An e-Science Perspective," UK e-Science Core Programme, [online]. Available: http://eprints.soton.ac.uk/257648/1/The_Data_Deluge.pdf. [Accessed Sept. 4. 2015].

[22] WACREN, "Constitution of the West and Central African Research and Education Network (WACREN)", *wacren.net,* 2013. [Online]. Available: http://wacren.net/sites/default/files/WACREN%20Constitution_0314.pdf. [Accessed Sept. 4. 2015].

[23] ASREN, *Developing a Lebanese National Research and Education Network*, July, 2011.

[24] G. Annum, Research instrument for data collection, Jan. 2015.

[25] L.Yogesh, B. P. Simmhan and G. Dennis, *Survey of Data Provenance in e-Science*, Computer Science Department, Indiana University, Bloomington, IN 47405, [online]. Available: https://www.cs.indiana.edu/ftp/techreports/TR618.pdf. [Accessed Sept. 4. 2015].

[26] Digital Archiving Consultancy Limited, "e-SciDR, towards an e-Infrastructure for e-Science digital repositories," *e-SciDR*, Fin.Rep. 2008, [Online]. Available: http://cordis.europa.eu/fp7/ict/e-infrastructure/docs/e-scidr.pdf. [Accessed Sept. 4. 2015].

[27] C.Soehner, C. Steeves and J.Ward, "E-Science and Data Support Services," *arl.org*, Rep. Aug. 2010, [online]. Available: http://www.arl.org/storage/documents/publications/escience-report-2010.pdf. [Accessed Sept. 4. 2015].

[28] C. Friaças, E. Massano and M. Domingues, "Probing Next Generation Portuguese," *Foundation for National Scientific Computing,* 2008. [Online]. Available: https://tnc2008.terena.org/core/getfileb3e1.pdf?file_id=206. [Accessed Sept. 10. 2015].

[29] E. Bos, "Do we need NRENs?" *Belnet Networking Conference*, Brussels, Belgium, Oct. 25, 2012, [online]. Available: http://events.belnet.be/sites/default/files/Erik-Jan%20Bos_Do%20we%20need%20NRENs_0.pdf. [Accessed Sept. 10. 2015].

[30] European commission, Cloud for science and public authorities, Rep. Jul., 2013.

[31] J. Sellers, "FYI on Questions and Answers: Answers to Commonly Asked Primary and Secondary School Internet user questions," *Request for Comments*: 1578 NASA NREN/Sterling Software FYI: Feb.22, 1994.

[32] R. Buch, "e-Infrastructure Challenges Towards 2020," *cordis.europa.eu*, [online]. Available: http://cordis.europa.eu/fp7/ict/e-infrastructure/docs/bms-presa-5.pdf. [Accessed Sept. 10. 2015].

[33] International telecommunication Union (ITU), "partnership on measuring ICT for development: final WSIS targets review achievements, challenges and the way forward," *itu.int*, 2014. [Online]. Available: http://www.itu.int/en/ITU-D/Statistics/Documents/publications/wsisreview2014/WSIS2014_review.pdf. [Accessed Sept. 12. 2015].

[34] D.Smith, *Campus Network Best Practices: NREN Models*, 2011. [Online].Available: https://nsrc.org/workshops/2011/vinaren-ait-nsrc/raw-attachment/wiki/Agenda/NREN_Models.pdf+&cd=2&hl=en&ct=clnk&gl=zmf. [Accessed Sept. 12. 2015].

[35] GEANT2, "Inter-NREN Roaming Architecture: Description and Development Items," *Project Deliverable DJ5.1.4*, Sept. 2006.

[36] GEANT, "Future Network Architectures: A possible scenario based on the findings of Joint Research Activity 1 (JRA1)," *Deliverable D12.3 (DJ1.1.1)*, Jun. 2015

[37] Fasterdata, "International Research Network Backbone Collaboration," *fasterdata.es.net*, [online]. Available https://fasterdata.es.net/assets/Hester/IREN-Concept-Draft-6.3.pdf. [Accessed Sept. 12. 2015].

[38] Metro Ethernet Forum (MEF), "Understanding Carrier Ethernet Throughput: Am I getting the throughput I should be getting?," *mef.net*, Jul. 2010. [Online]. Available, https://www.mef.net/Assets/White_Papers/Understanding_Carrier_Ethernet_Throughput_-_v14.pdf. [Accessed Sept. 12. 2015].

[39] AfricaConnect Project, *Information Society: Developing advanced research and education networks in Africa*, [online]. Available: http://www.africa-eu-partnership.org/sites/default/files/success-story-files/case_study_africa_connect_en_fin.pdf. [Accessed Sept. 17. 2015].

[40] High Performance Wireless Research and Education Network, "An interdisciplinary collaboration for research and infrastructure," *educationgrid.org*, [online]. Available:

http://www.educationgrid.org/msicii/June06Workshop/Presentations/hpwren.pdf. [Accessed Sept. 17. 2015].

[41] J.Nowell, "Enabling Grids for E-science*" Network Performance Monitoring in EGEE*, Jun. 2007

[42] GEANT, "Geant unveils Bandwidth on Demand for NRENs". *telecompaper.com.2015.* [Online]. [Available] : http://www.telecompaper.com/news/geant-unveils-bandwidth-on-demand-for-nrens--874161. [Accessed Sept. 22. 2015].

[43] TERENA, "The Case for National Research and Education Networks (NRENs)," *TERENA* Jan. 2009.

[44] GÉANT2, "European NRENs & GÉANT2: Generation Network Advances in Hybrid Switching & IPv6 Routing,"*GÉANT2,* Aug 2006.

[45] C.Kwangjong and L.Wonhyeak, "Lightpath Issues between NREN and Campus Network," *wiki.glif.is/images/,* 2015.[online]. Available: https://wiki.glif.is/images/c/c0/Lightpath-issues-kreonet.pdf. [Accessed Sept. 22. 2015].

[46] B. Savory, "Build vs. Buy: The NREN Network Connectivity Dilemma - About Building Research & Education Fibre Networks," *Optelian,* Nov. 2012, [Online]. Available: http://www.ubuntunet.net/sites/default/files/uc2012_presentationsbuildvsbuy.pdf. [Accessed Sept. 22. 2015].

[47] B. Savory, "Fiber Optic Network Reliability & Security for NRENs: The Threat and Potential Solutions", *Optelian,* 2012. [Online]. Available: http://www.ubuntunet.net/sites/default/files/savorybrian.pdf. [Accessed Sept. 22. 2015].

[48] G.Bell and J.Gray, "We can trace the evolution from crays,to clusters, to supercomputing centers. But where does it go from here?: What's Next in High-Performance Computing?" *cs.ucf.edu*. 2002. [Online]. Available: https://www.cs.ucf.edu/~dcm/Teaching/CDA5106-Fall2015/Appendices/appendix_l.pdf. [Accessed Sept. 22. 2015].

[49] G. Hager and G.Wellein, "*Concepts of High Performance Computing*," *rrze.fau.de/*, Mar 2008. [Online].Available: https://www.rrze.fau.de/wir-ueber-uns/publikationen/HPC-2008-Screenversion.pdf. [Accessed Sept. 22. 2015].

[50] V.Eijkhout, E.Chow and R.van de Geijn, *Introduction to High Performance Scientific Computing,* 2nd ed., 2014.

[51] D. Eadline, *High Performance computing for dummies Sun and AMD special Edition*, Wiley Publishing, Inc., Indianapolis, Indiana, 2009.

[52] M.Berger and A.Kloeckner, "High Performance Scientific Computing," [online]. Available: http://www.cs.nyu.edu/courses/fall10/G22.2945-001/slides/lect1.pdf. [Accessed Sept. 29. 2015].

[53] R. H. Landau, "A Beginner's Guide to High Performance Computing," *shodor.org*, [online]. Available: [Accessed Sept. 29. 2015].

[54] T. Stitt, "An Introduction to High-Performance Computing (HPC)," *linksceem.eu*, [online]. Available; https://www.linksceem.eu/ls2/images/stories/practicals_hardcopy.pdf. [Accessed Oct. 5. 2015].

[55] V. Sundararajan, "What is High Performance Computing?" *Scientific and Engineering Computing Group: Centre for Development of Advanced Computing (CDCC),* [online]. Available: http://www.iacs.res.in/What_is_HPC.pdf. [Accessed Oct. 5. 2015].

[56] UbuntuNet Alliance, "What is Ubuntunet Allaince," *UbuntuNet Alliance,* Sept. 2014.

[57] D. Barman, "ERNET India: Education and Research Network of India," *ERNET India,* [Online]. Avalable: https://www.apan.net/meetings/kaohsiung2009/presentations/medical/ernet.ppt. [Accessed Oct. 5. 2015].

[58] D. Vandromme, "an e-Infrastructure in Europe: a strategy and policy driven approach," [Online]. Available: http://www.cv/einfrastructures/talks/vandromme.ppt. [Accessed Oct. 15. 2015].

[59] M. Mwangi, "National research and education network: KENET, 2013", www.internetsociety.org. [Online]. Avalable:

https://www.internetsociety.org/blog/2013/08/national-research-and-education-network-kenet. [Accessed Nov. 24, 2016].

[60] KENET, "KENET: Kenya Education Network", .[Online]. Available: https://www.internet2.edu/presentations/spring09/20090427-KENET-chege.pdf. [Accessed Nov. 24, 2016].

[61] TENET, "TENET: The Tertiary Education and Research Network of South Africa", www.tenet.ac.za, [Online]. Available: *http://www.tenet.ac.za/*. [Accessed Nov. 17, 2016].

[62] SANREN, "eduroam workshop at the CHPC National Meeting 2016," www.sanren.ac.za. [Online]. Available: https://www.sanren.ac.za. [Accessed Nov. 17, 2016].

[63] P.Vuletić and A. Sevasti, "A Network Management Architecture proposal for the GÉANTNREN environment," *GÉANT*, [Online]. Available: http://www.A Network Management Architecture proposal for the GEANT-NREN environment.pdf. [Accessed Oct. 15. 2015].

[64] GEANT, "Future Network Architectures: A possible scenario based on the findings of Joint Research Activity 1 (JRA1)," *Deliverable D12.3 (DJ1.1.1)*, (2015). [Online]. Available: http://www.D12-3_DJ1-1-1_Future-Network-Architectures.pdf. [Accessed Nov. 15. 2015].

[65] S. Mkandawire. "Subject: Presentation" Personal email (Nov. 26, 2015).

[66] TERENA, "DANTE and TERENA become GEANT," terena.org/. [Online]. Available: https://www.terena.org/. [Accessed Nov.28. 2015].

[67] GEANT2,"Welcome to the GÉANT2 Website", *//geant2.archive.geant.net/*. [Online]. Available: http://geant2.archive.geant.net/. [Accessed Nov 28.2015].

[68] GEANT,"GÉANT Project (GN4-1)", geant.org/Projects/GEANT_Project_GN4-1/Pages/Home.aspx. [Online].Available: http://www.geant.org/Projects/GEANT_Project_GN4-1/Pages/Home.aspx. [Accessed Nov.28.2015].

[69] Aline Dresch, Daniel Pacheco Lacerda and José Antônio Valle Antunes Jr, *Design Science Research: A Method for Science and Technology Advancement*, NY: Springer,2015.

[70] Oliver, "Sampling", *ssc.wisc.edu/.* [Online].Available: http://www.ssc.wisc.edu/~oliver/SOC357/Lectures%20and%20Notes/SamplingBigSlides.pdf. [Accessed Dec. 11.2015].

[71] G. Lynchi, "Sampling", kent.ac.uk. [Online]. Available: https://www.kent.ac.uk/religionmethods/documents/Sampling.pdf. [Accessed Dec. 11.2015].

[72] Webpages, "Sampling: What is it?-Quantitative Research Methods", *acs.ttu.edu/.* [Online]. Available: http://webpages.acs.ttu.edu/rlatham/Coursework/5377(Quant))/Sampling_Methodology_Paper.pdf. [Accessed Dec. 11.2015].

[73] K. Phrasisombath, "Sample size and sampling methods", *fmer.ch/.* [Online].Available: http://www.gfmer.ch/Activites_internationales_Fr/Laos/PDF/Sample_size_methods_Phrasisombath_Laos_2009.pdf. [Accessed Dec. 11.2015].

[74] K.N. Ros, "Quantitative research methods in educational planning Series editor", *unesco.org/iiep/.* [Online].Available: http://www.unesco.org/iiep/PDF/TR_Mods/Qu_Mod3.pdf. [Accessed Dec. 11.2015].

[75] M.W. Fridah, "Sampling in Research", i*ndiana.edu./.* [Online].Available: http://www.indiana.edu/~educy520/sec5982/week_2/mugo02sampling.pdf. [Accessed Dec. 11.2015].

[76] R.Kumar, *Research Methodology:a step-by-step guide for beginners*, [Online].Available: http://www.sociology.kpi.ua/wp-content/uploads/2014/06/Ranjit_Kumar-Research_Methodology_A_Step-by-Step_G.pdf. [Accessed Jan.4.2016].

[77] WoredaNet, "EthiopianWoredaNet-Ethiopian Government Network", *unpan1.un.org*. [Online].Available: http://unpan1.un.org/intradoc/groups/public/documents/un-dpadm/unpan034887.pdf. [Accessed May. 20.2017]

[78] L. Williams, "Video-conferencing in Schools", *calverleyparkside.pbworks.com.* [Online].Available: http://calverleyparkside.pbworks.com/f/Videoconferencing%5B1%5D.pdf. [Accessed May.21.2017].

[79] Times of Zambia, "Banda launches CBU, UNZA video system", *www.elearning-africa*. [Online].Available: http://www.elearning-

africa.com/pdf/press/media_coverage/2010_Times%20of%20Zambia.pdf. [Accessed May. 20. 2017].

[80] Szegedi p, Figuerola S, Campanella M, Maglaris V, Cervello-Pastor C., 'With evolution for revolution: Managing FEDERICA for future interest research IEEE Communications Magazine, 2009'. Http://orbit.dtu.dk. [Online].Available: Http://orbit.dtu.dk/files/112301603/Future_architectures_for_NREN_infrrastructures.pdf. [Accessed May.20.2017]

APPENDIX

Appendix I: Scenario 1-Normal Video conferencing

Time (Sec)	Traffic Sent
0	0
36	0
72	4801.8
108	345600
144	345600
180	345600
216	345600
252	345600
288	345600
324	345600
360	345600
396	345600
432	345600
468	345600
504	345600
540	345600
576	345600
612	345600
648	345600
684	345600
720	345600
756	345600
792	345600
828	345600
864	345600
900	345600
936	345600
972	345600
1008	345600
1044	345600
1080	345600
1116	345600
1152	345600
1188	345600
1224	345600
1260	345600
1296	345600
1332	345600
1368	345600
1404	345600
1440	345600
1476	345600
1512	345600
1548	345600
1584	345600
1620	345600
1656	345600
1692	345600
1728	345600
1764	345600
1800	345600

1836	345600
1872	345600
1908	345600
1944	345600
1980	345600
2016	345600
2052	345600
2088	345600
2124	345600
2160	345600
2196	345600
2232	345600
2268	345600
2304	345600
2340	345600
2376	345600
2412	345600
2448	345600
2484	345600
2520	345600
2556	345600
2592	345600
2628	345600
2664	345600
2700	345600
2736	345600
2772	345600
2808	345600
2844	345600
2880	345600
2916	345600
2952	345600
2988	345600
3024	345600
3060	345600
3096	345600
3132	345600
3168	345600
3204	345600
3240	345600
3276	345600
3312	345600
3348	345600
3384	345600
3420	345600
3456	345600
3492	345600
3528	345600
3564	345600
Total Traffic Sent (Byte/Sec)	**345600**
Total Traffic Sent (bit/sec)	**2764800**
Avg Traffic Sent(Bytes/Sec)	**6171.43**
Avg Traffic Sent(Bits/Sec/pc)	**49371.43**
Total bandwidth Utilisation(%)	**0.27648**
No. Users For Breakeven	**20255**

Appendix II: Scenario 2- Heavy video conferencing

Time (Sec)	Traffic Sent
0	0
36	0
72	15361.8
108	1036800
144	1034880
180	1036800
216	1036800
252	1034880
288	1036800
324	1036800
360	1036800
396	1034880
432	1036800
468	1036800
504	1036800
540	1034880
576	1036800
612	1036800
648	1034880
684	1036800
720	1036800
756	1036800
792	1034880
828	1036800
864	1036800
900	1036800
936	1034880
972	1036800
1008	1036800
1044	1036800
1080	1034880
1116	1036800
1152	1036800
1188	1034880
1224	1036800
1260	1036800
1296	1036800
1332	1034880
1368	1036800
1404	1036800
1440	1036800

1476	1034880
1512	1036800
1548	1036800
1584	1034880
1620	1036800
1656	1036800
1692	1036800
1728	1034880
1764	1036800
1800	1036800
1836	1036800
1872	1034880
1908	1036800
1944	1036800
1980	1036800
2016	1034880
2052	1036800
2088	1036800
2124	1034880
2160	1036800
2196	1036800
2232	1036800
2268	1034880
2304	1036800
2340	1036800
2376	1036800
2412	1034880
2448	1036800
2484	1036800
2520	1034880
2556	1036800
2592	1036800
2628	1036800
2664	1034880
2700	1036800
2736	1036800
2772	1036800
2808	1034880
2844	1036800
2880	1036800
2916	1034880
2952	1036800
2988	1036800
3024	1036800

3060	1034880
3096	1036800
3132	1036800
3168	1036800
3204	1034880
3240	1036800
3276	1036800
3312	1036800
3348	1034880
3384	1036800
3420	1036800
3456	1034880
3492	1036800
3528	1036800
3564	1036800
Total Traffic Sent (bytes/sec)	1036800
Total Traffic Sent (bit/sec)	8294400
Avg Traffic Sent(Bytes/Sec)	18514.29
Avg Traffic Sent(Bits/Sec/pc)	148114.29
Total bandwidth Utilisation (%)	0.82944

Appendix III: Comparison of Scenario 1 and 2

time (sec)	Scenario 1	Scenario 2
0	0	0
36	0	0
72	4801.777778	15361.77778
108	345600	1036800
144	345600	1034880
180	345600	1036800
216	345600	1036800
252	345600	1034880
288	345600	1036800
324	345600	1036800
360	345600	1036800
396	345600	1034880
432	345600	1036800
468	345600	1036800
504	345600	1036800
540	345600	1034880
576	345600	1036800
612	345600	1036800
648	345600	1034880
684	345600	1036800
720	345600	1036800
756	345600	1036800
792	345600	1034880
828	345600	1036800
864	345600	1036800
900	345600	1036800
936	345600	1034880
972	345600	1036800
1008	345600	1036800
1044	345600	1036800
1080	345600	1034880
1116	345600	1036800
1152	345600	1036800
1188	345600	1034880
1224	345600	1036800
1260	345600	1036800
1296	345600	1036800
1332	345600	1034880
1368	345600	1036800
1404	345600	1036800
1440	345600	1036800
1476	345600	1034880

1512	345600	1036800
1548	345600	1036800
1584	345600	1034880
1620	345600	1036800
1656	345600	1036800
1692	345600	1036800
1728	345600	1034880
1764	345600	1036800
1800	345600	1036800
1836	345600	1036800
1872	345600	1034880
1908	345600	1036800
1944	345600	1036800
1980	345600	1036800
2016	345600	1034880
2052	345600	1036800
2088	345600	1036800
2124	345600	1034880
2160	345600	1036800
2196	345600	1036800
2232	345600	1036800
2268	345600	1034880
2304	345600	1036800
2340	345600	1036800
2376	345600	1036800
2412	345600	1034880
2448	345600	1036800
2484	345600	1036800
2520	345600	1034880
2556	345600	1036800
2592	345600	1036800
2628	345600	1036800
2664	345600	1034880
2700	345600	1036800
2736	345600	1036800
2772	345600	1036800
2808	345600	1034880
2844	345600	1036800
2880	345600	1036800
2916	345600	1034880
2952	345600	1036800
2988	345600	1036800
3024	345600	1036800
3060	345600	1034880
3096	345600	1036800

3132	345600	1036800
3168	345600	1036800
3204	345600	1034880
3240	345600	1036800
3276	345600	1036800
3312	345600	1036800
3348	345600	1034880
3384	345600	1036800
3420	345600	1036800
3456	345600	1034880
3492	345600	1036800
3528	345600	1036800
3564	345600	1036800
Total Traffic Sent (bytes/sec)	**345600**	**1036800**
Total Traffic Sent (bit/sec)	**2764800**	**8294400**
Avg Traffic Sent(Bytes/Sec)	**6171.428571**	**18514.28571**
Avg Traffic Sent(Bits/Sec/pc)	**49371**	**148114**
Total bandwidth Utilisation(%)	**0.27648**	**0.82944**
No. Users For Breakeven	**20255**	**6752**

Appendix IV: Point of Network failure

	User (heavy)	Sent Bits/sec (Heavy)	Channel Capacity	Bits	Constant Capacity
0	0	0	0	8	1000000000
1	675	100006789	100000000	8	1000000000
2	1350	200013578	200000000	8	1000000000
3	2026	300020367	300000000	8	1000000000
4	2701	400027155	400000000	8	1000000000
5	3376	500033944	500000000	8	1000000000
6	4051	600040733	600000000	8	1000000000
7	4726	700047522	700000000	8	1000000000
8	5402	800054311	800000000	8	1000000000
9	6077	900061100	900000000	8	1000000000
10	6752	1000067889	1000000000	8	1000000000
11	7427	1100074678	1100000000	8	1000000000
12	8102	1200081466	1200000000	8	1000000000
13	8778	1300088255	1300000000	8	1000000000

Appendix V: Informed Consent Form

THE UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
DEPARTMENT OF ELECTRICAL, ELECTRONICS ENGINEERING

INFORMED CONSENT FORM

TITLE OF STUDY
Evaluation of Research Education Networks in Zambia a case study: Zambia Research Education Networks (ZAMREN)

RESEARCHER DETAILS
Jervas Mwiinga
School of Engineering
PO BOX 32379,
LUSAKA
Mob.Phone : +260 977 335639
+260 969 996637
+260 950 103307
Email : jervasmavis@gmail.com

PURPOSE OF STUDY

You are being asked to take part in this research study conducted by **Jervas Mwiinga**, a University of Zambia (UNZA) Masters student under the School of Engineering. Before you decide to participate in this study, it is important that you understand why the research is being done and what it will involve. The purpose of this study is to conduct an evaluation on ZAMREN network to find out whether it has capacity or not to support High Performance Computing (HPC) applications such as video conferencing which are essential in the delivery e-learning. Further, the study will also identify and itemise challenges faced by ZAMREN affiliates in accessing the network. The outcome of this study was used to make recommendations, immediate decisions and strategic plans

STUDY PROCEDURES

The procedures involved in this research includes; answering questionnaires, network simulation and interview. However, your participation is only on questionnaires and the amount of time required to answer this questionnaire is less than 10minutes.This questionnaire has only 3 sections, namely section A, B and C.

RISKS

The researcher assures and guarantees you that no amount of risk, injury or discomfort is anticipated in this research.

BENEFITS

This research is an undertaking to fulfill the academic requirements of the University of Zambia in the attainment of Masters qualification. Nevertheless, your valuable participation and information was useful in areas such as the body of knowledge, Journal and Conference publications, Decision making and Strategic planning.

CONFIDENTIALITY

The researcher assures that your responses to this questionnaire was anonymous and strictly confidential.

CONTACT INFORMATION

If you have questions at any time about this research, or you experience adverse effects as the result of participating in this research, you may contact the researcher using the information on this first page. If need be, you may also contact my supervisor, Mbuuyu Sumbwanyambe, via email: , and indeed, my institution, University of Zambia, School of Engineering, Tel No. +2

VOLUNTARY PARTICIPATION

Please note that your participation in this study is voluntary and you are free to withdraw at any time, without giving a reason and without cost.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I voluntarily **Agree or Do not agree** to take part in this study.

Kindly tick **[√]** the applicable.

Agree [ ] **Do not agree [ ]** **Date _____**

Appendix VI: Questionnaire

Evaluation of Researh Education Networks in Zambia

a case study:

Zambia Research Education Networks (ZAMREN)

by

Jervas Mwiinga

Master of Engineering in Information, Communication and Technolgy

A QUESTIONNAIRE TO GATHER INFORMATION RELATED TO CHALLENGES FACED WITH AFFILIATES IN ACCESSING ZAMREN NETWORK

School of Engineering

Deparment of Electrical, Electronics and Engineering

University Of Zambia

Questionnaire No.

This serves to inform and assure you that the information you are providing in this questionnaire was used largely for academic purposes as well as in line with research ethics such as upholding of confidentiality, anonymity and etc. Please tick(s) [√] the correct answer(s).

SECTION A

[1]. Name of the institution……..

[2]. Institution category
- [ ] Secondary
- [ ] College
- [ ] University
- [ ] others

[3]. Institution Province
- [ ] Central
- [ ] Copperbelt
- [ ] Eastern
- [ ] Luapula
- [ ] Lusaka
- [ ] Muchinga
- [ ] Northern
- [ ] North-western
- [ ] Southern
- [ ] Western

[4]. Respondent's Name……..

[5]. Respondent's Designation……

[6]. Contact Mobile/Telephone…….

[7]. Email……..

SECTION B

[1] Do you have computers?

[ ] Yes
[ ] No

[2] If your answer in (1) is **yes**, how many are the computers?

[ ] 1-10
[ ] 11-20
[ ] 21-25
[ ] 26-and above

[3] Are some of these computers connected to Internet?

[ ] Yes
[ ] No

[4] Is your Internet connection via…
[ ] ZAMREN Only
[ ] Both ZAMREN and Other ISP(s)
[ ] Other ISP Only

[5] Do you have computer laboratories for the students?.

[ ] Yes
[ ] No
[ ] Not applicable

[6] How many computer laboratories?.
[ ] 1
[ ] 2
[ ] 3
[ ] 4 and above
[ ] Not applicable

[7] What is the average size of each computer laboratory?
[ ] 1-10 Pc(s)
[ ] 11-20 Pc(s)
[ ] 21-30 Pc(s)
[ ] 31 and above
[ ] Not applicable

[8] How many computer laboratories are connected to the Internet via ZAMREN network?.
[ ] 0
[ ] 1
[ ] 2
[ ] 3 and above

[ ] Not applicable

[9] What is the brand or make of your router(s)? (**select more than 1 answer where possible)**

[ ] Cisco
[ ] D-link
[ ] IBM
[ ] HP
[ ] Others Specify……
(i)……..
(ii)…….
(iii)……

[10] What is the range (speed) of the Ethernet port of your Router (s)?

[ ] O-1000Mbps
[ ] 1001- 2000Mbps
[ ] Not sure
[ ] Others Specify……
(i)……..
(ii)…….
(iii)……

[11] What is the brand or make of your switch(s)? (**select more than 1 answer where possible)**

[ ] Cisco
[ ] D-link
[ ] IBM
[ ] HP
[ ] Others Specify……
(i)……..
(ii)…….
(iii)……

[12] Select below the mode of your network connection to ZAMREN network?.

[ ] Cable mode
[ ] Wireless Mode
[ ] Both cable and Wireless

[13] If the answer in (12) is **cable mode**, what is type of the cable?.

[ ] Fibre
[ ] UTP
[ ] Coaxial cable
[ ] Others Specify……
(i)……..
(ii)…….
(iii)……

[14] What is size of the channel or cable connecting your network to ZAMREN network?

[ ] 0-500Mbps
[ ] 501-1000Mbps
[ ] 1001- 1500Mbps
[ ] 1501 - 2000Mbps

[15] How long have you been affiliated to ZAMREN?

[ ] less than a 1 yr
[ ] 1yr
[ ] 2 yrs
[ ] 3yrs and above

[16] Select services that you use the network for…(**select more than 1 answer where possible**)

[ ] Internet surfing / browsing
[ ] Data text
[ ] Voice data
[ ] Voice and Video
[ ] Multimedia data (Data, voice & Video)

SECTION C

[1] What challenges are you facing? **(Select more than 1 answer where possible)**

[ ] Financial constraints
[ ] Lack or low level of ICT-Technical knows- how
[ ] lack or Low level of ICT Infrastructure
[ ] Low level of appreciation of ZAMREN
[ ] Lack of Technical support from ZAMREN
[ ] Lack of Management of Support on ICTs matters
[ ] Power outages
[ ] High internet tariffs
[ ] Others specify……

i. …….
ii. …….
iii. …….

[2] Do have any challenges with ZAMREN networks?.

[ ] yes
[ ] No

[3] If the answer in (2) is **yes**, what are some of the challenges you are facing in accessing ZAMREN network? **(Select more than 1 answer where possible)**.

[ ] Connection problem
[ ] Lack of technical support from ZAMREN
[ ] Poor services
[ ] Unsecure and Unreliable
[ ] Bureaucracy
[ ] long response time
[ ] Others specify……

i. ……..
ii. ……..
iii. ……..

[4] How would you rate the service fee or charge of ZAMREN to your institution?.

[ ] Very affordable
[ ] Affordable
[ ] Fairly affordable
[ ] poor
[ ] Very poor

[5] How would you rate the services of ZAMREN to your institution?.

[ ] Very good
[ ] Good

[ ] Fair
[ ] poor
[ ] Very poor

[6] How do you rate the performance of ZAMREN network during peak period?

[ ] Very good
[ ] Good
[ ] Fair
[ ] poor
[ ] Very poor

[7] Have you ever conducted a lecture or meeting via high performance computing (HPC) application, such as video conferencing?

[ ] Yes
[ ] No

[8] If the answer (7) is **yes**, did you experience any network degradation or failure?

[ ] Yes
[ ] No

[9] If the answer (7) is **No**, do you have plans to undertake this venture?

[ ] Yes
[ ] No

[10] What are your immediate expectations from ZAMREN institution? (**Select more than 1 answer where possible)**

[ ] Reduced Tariffs
[ ] Technical trainings and support
[ ] More senstisation
[ ] Improved Quality of Service (Qos)
[ ] Improved provision of secure, reliable and stable network
[ ] Financial support
[ ] Network expansion
[ ] Deployment of more applications and handware service
[ ] Reduced bureaucracy
[ ] Others specify……
(i)……
(ii)……..
(iii)……

[11] Have you or any one from your institution ever attended a training organized by ZAMREN?

[ ] Yes
[ ] No

Thank you for your participation.

Appendix VII: Research authorisation letter- ZAMREN

ZAMREN

ZAMBIA RESEARCH AND EDUCATION NETWORK
UNIVERSITY OF ZAMBIA – GREAT EAST ROAD CAMPUS
P.O. BOX 32379
LUSAKA, ZAMBIA
Phone: +260-211-295928, E-mail: [illegible]

28th September, 2015

Dr. Levy Siamimwe
Acting Dean
School of Engineering
P. O Box 32379
LUSAKA

Dear Dr. Siamimwe

RE: CONDUCTING ACADEMIC RESEARCH ON ZAMREN – MR. JERVAS MWIINGA

Reference is made to your letter dated 22nd September, 2015 in regard to the aforementioned subject.

I am pleased to inform you that management has agreed to offer Mr. Jervas Mwiinga, Student in the School of Engineering at the University of Zambia chance to do a research study on Research Education Networks (RENs) in Zambia at ZAMREN.

ZAMREN's Technical Team will be available to help Mr. Mwiinga with relevant information he may require to enable him carry out and complete his research.

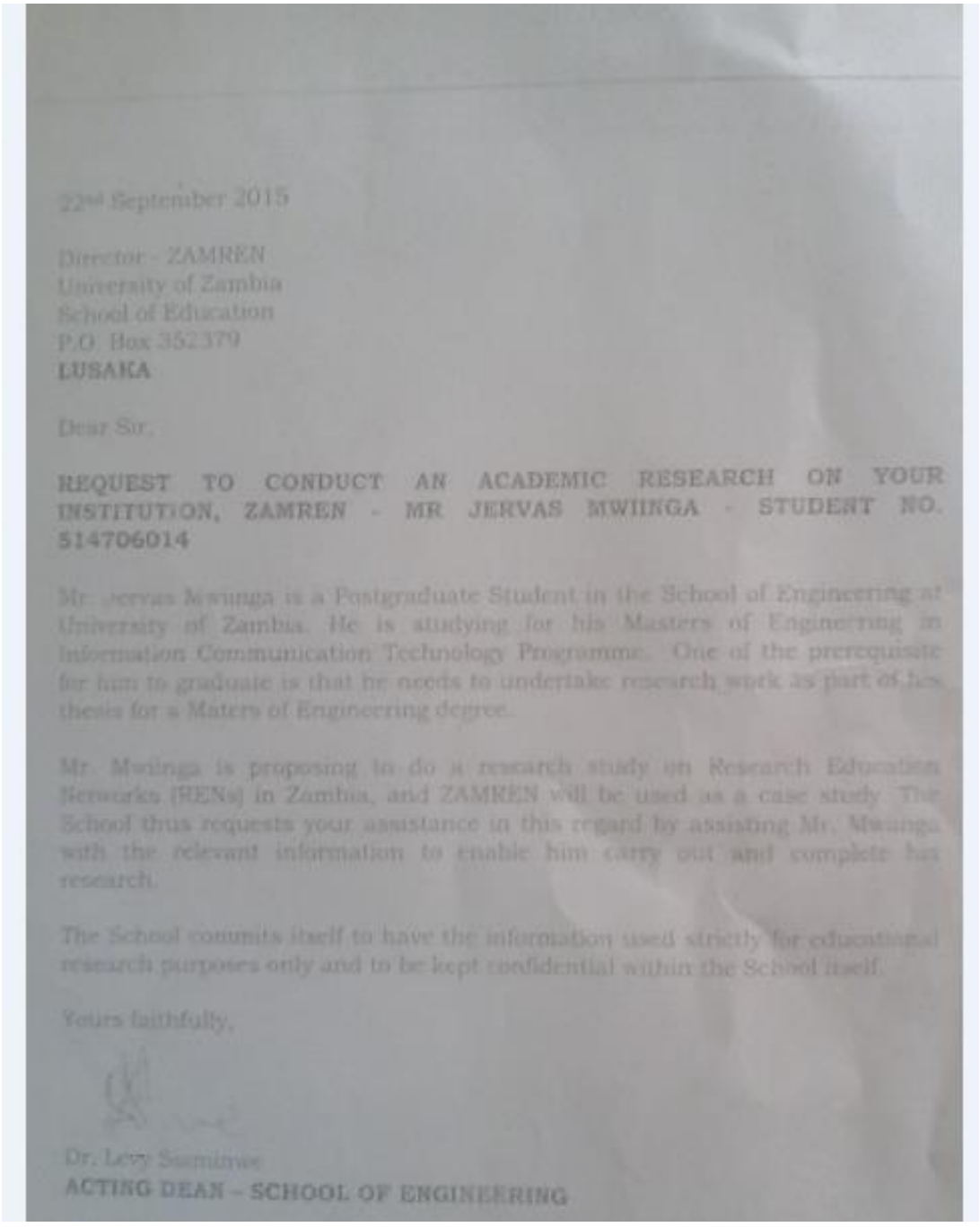
Kindly advise Mr. Mwiinga to report to the Chief Technical Officer.

Yours Sincerely

Bonny Khunga
CHIEF EXECUTIVE OFFICER

Cc : Chief Technical Officer
: Technical Department

Appendix VIII: Research authorisation letter- school of engineering, UNZA



22nd September 2015

Director - ZAMREN
University of Zambia
School of Education
P.O Box 352379
LUSAKA

Dear Sir,

REQUEST TO CONDUCT AN ACADEMIC RESEARCH ON YOUR INSTITUTION, ZAMREN - MR JERVAS MWIINGA - STUDENT NO. 514706014

Mr. Jervas Mwiinga is a Postgraduate Student in the School of Engineering at University of Zambia. He is studying for his Masters of Engineering in Information Communication Technology Programme. One of the prerequisite for him to graduate is that he needs to undertake research work as part of his thesis for a Maters of Engineering degree.

Mr. Mwiinga is proposing to do a research study on Research Education Networks (RENs) in Zambia, and ZAMREN will be used as a case study. The School thus requests your assistance in this regard by assisting Mr. Mwiinga with the relevant information to enable him carry out and complete his research.

The School commits itself to have the information used strictly for educational research purposes only and to be kept confidential within the School itself.

Yours faithfully,

Dr. Levy Siamimwe
ACTING DEAN – SCHOOL OF ENGINEERING

JOURNAL PUBLISHED

1. J. Mwiinga and M. Sumbwanyambe, "Evaluation of Research Education Networks in Zambia a case study: Zambia Research Education Networks ", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 5, Issue 5, May 2016. [Online].Available: http://www.ijirset.com/upload/2016/may/170_NEW.pdf