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Fibre optic networks: Cost factor comparison for broadband access in South African rural areas

A minor dissertation submitted in partial fulfilment of the degree of

Magister Philosophiae

In

Engineering Management

At the

Faculty of Engineering and the Built Environment

Of the

University of Johannesburg

By

Solomon Mamabolo

21 January 2019

Supervisor: Prof S Von Solms

Co-Supervisor: Prof A Marnewick
Declaration

I hereby declare that this Minor-Dissertation titled, Fibre optic networks: Cost factor comparison for broadband access in South African rural areas my own work and that it has not been submitted previously for any academic recognition by any other scholar from this university or any other institution of learning. I am also fully aware of the university’s plagiarism policy and as such all inputs or contributions included in this research from previous studies have been adequately cited.
Abstract

Progress in communication applications has led to various advances in broadband technologies. The main reason is that modern applications require very fast data processing and transmission with low latency. Consequently, fibre optic based medium is seen as a medium that meets these stringent requirements. Fibre optic has many inherent advantages that allows it to handle high data demanding applications. Furthermore, although fibre optic access networks are present in urban areas, mostly in a form of FTTH (fibre to the home) architecture, these networks are not common in rural areas.

The supposed challenges with fibre optic access network as a rural broadband access solution is attributed to the speculated high installation costs associated with long distance digging and trenching. As a result, the main research problem is that rural areas have low density of people and are remote, making it very difficult for service providers to achieve economy of scale amidst the speculated high network costs.

The research objective is to assess the fibre optic network’s deployment cost-effectiveness through a full lifecycle cost analysis in comparison with existing broadband technologies in these areas. The research will as a result conduct a full lifecycle costs analysis of both a fibre optic network and an existing rural wireless network in these areas. A full lifecycle cost analysis will be conducted from the network’s planning phase up to the retirement phase.

This research aims to deliver knowledge on broadband network’s lifecycle cost’s status in South African rural areas. This knowledge will as a result benefit the telecommunication industry and community as a whole because it provides crucial knowledge on broadband network’s lifecycle costs in South African rural areas. Numerous scholars and interest groups have explored the supply side aspects of broadband provisioning, but with regard to the determination of costs, few studies have analysed in detail the lifecycle cost of broadband networks in rural areas.
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<td>AACEI</td>
<td>Association for the Advancement of Cost Engineering International</td>
</tr>
<tr>
<td>ADSL</td>
<td>Asymmetric Digital Subscriber Line</td>
</tr>
<tr>
<td>BSC</td>
<td>Base Station Controllers</td>
</tr>
<tr>
<td>Capex</td>
<td>Capital expenditure</td>
</tr>
<tr>
<td>CBS</td>
<td>Cost Breakdown Structure</td>
</tr>
<tr>
<td>CPE</td>
<td>Customer Premises Equipment</td>
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<tr>
<td>CO</td>
<td>Central Office</td>
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<tr>
<td>DSL</td>
<td>Digital Subscriber Line</td>
</tr>
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<td>EDGE</td>
<td>Enhanced Data for GSM Evolution</td>
</tr>
<tr>
<td>ELED</td>
<td>Entangled Light-Emitting Diode</td>
</tr>
<tr>
<td>EPON</td>
<td>Extended-reach Passive Optical Networks</td>
</tr>
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<td>FANS</td>
<td>Fixed Access Network</td>
</tr>
<tr>
<td>FSO</td>
<td>Free Space Optical</td>
</tr>
<tr>
<td>FTTB</td>
<td>Fibre –To-The-Business</td>
</tr>
<tr>
<td>FTTH</td>
<td>Fibre-To-The-Home</td>
</tr>
<tr>
<td>FTTN</td>
<td>Fibre-To-The-Node</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile communication</td>
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<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
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<td>GPON</td>
<td>Gigabit Passive Optical Network</td>
</tr>
<tr>
<td>HRF</td>
<td>Home Run Fibre networks</td>
</tr>
<tr>
<td>Kbps</td>
<td>Kilobit Per Second</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Agency</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
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<tr>
<td>ISDN</td>
<td>Integrated Services Digital Network</td>
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<tr>
<td>LCCA</td>
<td>Lifecycle Cost Analysis</td>
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<td>LTE</td>
<td>Long-Term Evolution</td>
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<td>NGOA</td>
<td>Next generation optical access</td>
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<td>NGN</td>
<td>Next Generation Networks</td>
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<tr>
<td>Mbps</td>
<td>Megabit Per Second</td>
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<tr>
<td>MDT</td>
<td>Maintenance Downtime</td>
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<tr>
<td>MLH/OH</td>
<td>Maintenance Labour Hour per system Operating Hour</td>
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<td>OAN</td>
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<td>Opex</td>
<td>Operating expenditure</td>
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<td>OTT</td>
<td>Over The TOP</td>
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<td>PON</td>
<td>Passive Optical Networks</td>
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<td>RoFSO</td>
<td>Radio over Free Space Optical</td>
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<td>SEA</td>
<td>System Effectiveness Analysis</td>
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<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunication Service</td>
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<tr>
<td>VANS</td>
<td>Value Added Network Services</td>
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<tr>
<td>VoIP</td>
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<tr>
<td>VSAT</td>
<td>Very Small Aperture Terminal</td>
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<tr>
<td>WACC</td>
<td>Weighted Average Cost of Capital</td>
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<td>Wi-Fi</td>
<td>Wireless Fidelity</td>
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CHAPTER 1: INTRODUCTION

Broadband connectivity is a key strategic resource for fostering change in both social and economic development in modern society. In today’s digital age it is very difficult to improve people’s material condition and grow the economy when a large portion of the population has no access to information and communication (Lea-Wilson, 2012). Consequently, fixed broadband connectivity in countries like South Africa has accelerated in recent times. This could be seen with the massive fibre network rollouts, although mostly limited to urban areas.

These developments in connectivity are somewhat progressive, but 35% percent of the country’s population in rural areas are still marginalised when coming to fixed broadband accessibility (Seymour, 2013). The reason of service providers overlooking these areas is that urban areas have economic of scales and the effect on price of concentration based on demand, but rural areas do not (Galloway, 2007). These perceived challenges force service providers to reconsider fixed broadband provision’s economic viability in these rural areas.

In order to be in a position to bring lasting ICT (information and communication technology) solutions to rural communities, many countries require a high speed reliable connectivity which is missing in most rural areas. These areas are still characterised by limited ICT infrastructure that are dominated by wireless low data rate technologies such as GPRS (General Packet Radio Service), EDGE (Enhanced Data for GSM Evolution), UMTS (Universal Mobile Telecommunication Service) and VSAT (Very Small Aperture Terminal) network services which are typically slow and less cost-effective for the rural population (Byanyuma, 2013).

Fibre optic networks in rural areas are largely limited to backhaul connectivity, where network providers employ them for their high order network entities like BSC (base station controllers) and transmission exchange nodes. However, they are not commonly utilised as access links to the end-users (Byanyuma, 2013). This research seeks to evaluate the cost-effectiveness of rolling out a fibre network in rural areas by analysing the full lifecycle costs, from the planning to retirement phase.
1.1 Definition of Terms

1.1.1 Optical Access Network (OAN)

Optical access network is a point-to-multipoint fibre to the premises network architecture in which optical splitters are used to enable a single optical fibre to serve multiple premises (Al-Quzwini, 2014). Optical access networks exploit the low attenuation and high bandwidth of single mode optical fibres to provide many times more bandwidth than currently available with existing broadband technologies. These networks therefore have the ability to provide all communication services such as: voice, data and video from one network platform. An optical access network comprises four areas, namely a central office area, a feeder area, a distribution area and user area which is from a central office to a subscriber’s premises (Al-Quzwini, 2014).

1.1.2 Broadband

Broadband is commonly defined as a high data rate internet connection with a connection speed of at least 256 kbps (Seymour, 2013). The term originates from the wide range of frequencies that are utilised for transmission of data. The wide range of frequencies allows data to be multiplexed so that it could be transmitted on several channels instantly, resulting in high amounts of data sent and received by the users. There are commonly two categories of broadband technologies: wireless and fixed line broadband. Fixed line broadband are physically wired networks such as Fibre optic and copper based networks such as ADSL (Asymmetric Digital Subscriber Line). Wireless broadband technologies are usually radio based networks such as UMTS (Universal Mobile Telecommunication Service) or LTE (Long-Term Evolution) (Seymour, 2013).

1.1.3 Rural

There are numerous alternative views and definition of the term “rural”. Debates exist on whether rural should be viewed as geographical concept that relates to location with an identifiable boundaries, or it should rather be considered as a social representation, a culture, or a community interest. For this research, a geographical classification of rural will be considered. Within geographical spheres, rural is distinct
from urban and can be measured in population size and density in a given area. Another simplistic definition of the term rural can be defined as sparsely populated lands lying outside urban areas. Rural areas are generally viewed as places with densities of around 400 people per square kilometre (Du Plessis, 2002).

1.2 Background

Progress in communication technologies has led to the active development of many forms of broadband services such as data and video communication using high speed access networks. Since the discovery of fibre optic as a means of communication, there hasn’t been any medium that could rival it when coming to signal processing. Fibre optic is highly scalable and very reliable due to its natural composition. It has many inherent advantages such as low forward and return losses as well as high power handling capability (Toms, 2007).

In order to provide these broadband services in an effective and timely way, network providers choose to construct optical fibre networks. Although fibre optic networks have been historically used on the backbone or core networks of many service providers, they are recently emerging as a solution for “last mile” access. An access network is the network between the network provider’s central office and the end users and is traditionally termed “last-mile” network. The last mile is known as the most expensive part of the network because there are more end users nodes than backbone nodes (Galloway, 2007).

In South Africa, Fibre-To-The-Home (FTTH) is popular and offered in the urban areas by a number of network providers as a form of fibre optic access network. It is attractive among the urban population with large scale rollouts throughout most suburbs (Abrahams, 2007). However, fibre optic access networks are very scarce in rural areas. The connectivity options in these areas are still largely limited to unreliable wireless technologies or wired copper in form of ADSL (Asymmetric Digital Subscriber Line) or ISDN (Integrated Services Digital Network) (Abrahams, 2007).

1.3 Problem Statement

Many industry critics believe that an optical access network rollout poses several challenges in rural areas. The challenges with optical access network as a rural
broadband access solution is accredited to the high installation costs associated with long distance digging and trenching (FTTH Council Europe, 2017). Therefore, the research problem is that rural areas have low density of people and are remote, making it very difficult for service providers to achieve economy of scale amid the perceived high costs of fibre optic network rollout.

1.4 Research Questions

1.4.1 Primary research question

Is an optical access network rollout cost-effective for network providers in South African rural areas?

1.4.2 Secondary research question

- What are the network provider’s lifecycle costs, compared with other broadband technologies in South African rural areas with regard to network planning, installation, maintenance and recovery?

1.5 Research Objectives

The primary objective of the research is to examine the cost-effectiveness of a fibre access network in South African rural areas by analysing the lifecycle costs associated with the installation and maintenance of the network.

The research will as a result also explore the most cost-effective type/configuration of a fibre optic access network to roll out in these areas. Lastly, as a secondary objective the research also aims to serve as a guiding document for any private or public network service provider, considering a fibre access network solution to their target market in the rural parts of the country.

1.6 Purpose of the study

The following are the reasons for conducting the study:

- Investigate the cost-effectiveness of a fibre optic access network rollout in South African rural areas.
• Explore the lifecycle costs which will be carried by the network providers which includes: planning, installation, maintenance and network recovery.

• Explore the most cost-effective configuration optical access network to roll out in these areas.

1.7 Research design

A systematic plan of approach that was adopted for the study is demonstrated in Figure 1 (Cooper & Schindler, 2011).

1.7.1 Problem identification and definition

The first step into the research process is to look within the telecommunication industry in order to explore and identify a distinct researchable problem. The unavailability of a fibre network in rural areas as a result of speculated high rollout costs was identified as a problem.

1.7.2 Develop research questions

The next step of the research process is to develop primary and secondary research questions which probe the identified problem by examining the cost-effectiveness probability using a lifecycle cost analysis process.
1.7.3 Formulate research approach

In order to conduct effective research, a blueprint on how the research will be conducted is required. The blueprint will guide us in following the appropriate process in determining whether a fibre access network is cost-effective or not, in South African rural areas.

1.7.4 Data collection

Another important step of the research process is to collect data relating to lifecycle cost of several rural broadband networks, in order to conduct a lifecycle cost comparison study. As a result, data relating to the cost of rural broadband access network provisioning was gathered with the aim of gaining a nourished perspective.

1.7.5 Data analysis

Data analysis entails analysing data that relate to the cost of a fibre access network in the rural areas to obtain desirable and quantifiable information that could be useful in determining if the provisioning of the rural fibre optic network is in fact cost-effective.

1.7.6 Present findings

The last element of the research process involves the presentation of the results of the lifecycle costs of rural broadband technologies and to provide recommendations to the network providers on the rollout of this fibre network.

1.8 Significance of the research

Fibre optics in telecommunications show strong trends of a continuing downward price accompanied with significant increases in the level of both component and system standardisation. A highly reliable fibre optic system, such as low-current ELED’s (Entangled Light-Emitting Diode) operating over single-mode fibre, provides an effective match with many of the technologies such as wireless LTE, which is recommended for broadband access solution in rural areas (Al-Quzwini, 2014). The characteristics of fibre make it more favourable over other mediums such as wireless technologies, which are known to be unreliable and tend to offer slower rates as
subscribers become remote (Byanyuma, et al., 2013). The increase in the copper price coupled with the scourge of copper theft has not helped the copper mediums like ADSL either (Al-Quzwini, 2014). It is therefore imperative to conduct this research because it will be providing insight into the actual life-cycle costs of fibre optic in comparison with other existing technologies in South African rural areas. This will assist our research beneficiaries such as network providers and internet service providers to make informed decisions when contemplating a rural network rollout. The research also aims to encourage organisations to seek cost-effective ways of providing broadband networks in rural areas to bridge the digital divide. Through organisations bridging the digital divide between rural and urban areas, the broadband consumers will be ultimately the real beneficiaries of the research.

1.9 Assumption and limitation

Several assumptions will be made in an attempt to answer the research question. It is firstly assumed that no fibre infrastructure exists in South African rural areas when conducting the life-cycle cost comparison. It is also assumed that a pure fibre infrastructure that is not integrated with any copper based or wireless network will be installed as part of the cost comparison. There will also be numerous limitations in answering the research question. The first limitation is that research data might not be available on some of the newer cost-effective fibre technologies in order to come to a reliable conclusion. Another limitation is that South African rural areas are different and as results case studies and data retrieved might be only relevant to a specific area of country.

1.10 Conclusion

Broadband accessibility in the rural areas is a very topical subject in both South Africa and abroad. It is also evident that the rollout of high-speed broadband access networks in rural areas across many countries lags behind that of the urban areas (Seymour, 2013). Various scholars and interest groups have explored the supply-side aspects of broadband. However, with regard to the calculation of costs, few studies have analysed in detail the cost of broadband access networks in rural areas. As a result, a cost study of a rollout of fibre optic access network in rural areas must be carried out, taking into consideration the geographical differences of subscribers in these areas.
CHAPTER 2: LITERATURE REVIEW

The previous chapter provided an introduction to the research topic and outlined how the research will be approached and conducted. The aim of this chapter is to present and analyse literature from previous studies which are relevant to our research topic in order to obtain a holistic view on the subject. Literature on fibre optic networks and its cost-effectiveness in rural areas will be analysed in this chapter. The analysed literature will assist in answering the research questions highlighted in chapter 1. The chapter starts with background literature on broadband in South Africa to provide a comprehensive view on the state and cost of broadband provisioning in the country. The chapter will further introduce concepts and models of determining cost-effectiveness of fibre optic provisioning in rural areas.

2.1 Background to broadband in South Africa

The South African Department of Communication defines broadband as an always on multimedia connection that has a download speed capability of at least 256 kbps (Seymour, 2013). Generally, broadband technologies are categorised into fixed line and wireless mobile technologies. Broadband access by business and consumers is seen as a vital factor in economic growth of many countries in recent times. This is because it enables users to access bandwidth intensive services such as video communication, online applications and Voice over Internet Protocol (VoIP), which are known to bring about effective communication (Grosso, 2015).

As with all innovation, effective adoption and access to broadband depends on a host of innovative absorption factors. As a result, most African countries are still without the necessary basic infrastructure (Burkitt-Gray, 2016). Although, South Africa is seen as more economically advanced than other Sub-Saharan African countries, with three key players controlling 90% of the market, internet access remains low and restricted to certain areas of the country (Burkitt-Gray, 2016). Recently, broadband network usage in South Africa has been increasing at a fast rate, catching up with other emerging countries such as Brazil and India (Mohammed, 2015). This fast adoption has been aided by recent development in global connectivity with increased capacity of high speed undersea cables connecting South Africa to the world, which is aimed
at improving international connectivity and reducing overall internet costs (Mohammed, 2015).

The South African broadband fraternity has also seen an introduction of state owned broadband providers, with many cities providing free or affordable broadband services to citizens (Abrahams, 2007). The reason for state participation in broadband provisioning is because the state perceives access to information and communication as a vehicle that could bridge the digital divide between rural and urban communities in sharing knowledge, enhancing educational qualification, and contributing towards poverty alleviation (Mohammed, 2015).

Although there is a somewhat robust provisioning of broadband networks in the country, broadband services remain low and expensive for low income users. About 15% non-internet consumers reports that broadband data is too costly (Research ICT Africa, 2017). Data prices measured between four recognized broadband providers in the country, Vodacom, MTN, Cell C and Telkom Prices 1 Giga byte monthly prepaid data bundle between R149 and R160 over the last 2 years, with an exception of Telkom which charges R99 for 1 Giga byte of data. In comparison with other countries in Africa, South Africa doesn’t fare well as RIA’s Africa Mobile Price (RAMP) Index places it at 27th out of 49 African countries with the lowest price for 1Giga byte of broadband data (Research ICT Africa, 2017).

From the literature discussed above, the following deductions can be made: broadband access is vital to a country’s economic growth (Grosso, 2015). Broadband access in South Africa is increasing (Mohammed, 2015), with many cities providing free or affordable services (Abrahams, 2007). The South African government participates in broadband provision because they believe that broadband access has the ability to bridge the digital divide between rural and urban communities (Mohammed, 2015). South African internet access remains low and restricted to certain areas of the country (Burkitt-Gray, 2016).
2.1.1 Broadband access in rural communities in South Africa

Broadband has been seen as a way to improve the quality of life of both residential and business users (Križanović Čik, 2016). Broadband has also been seen as a promising resource for rural areas since it could bring about considerable social and economic profits. However, we have to consider the specificities of rural areas, due to the fact that the deployment of broadband in rural and remote areas may bring about some challenging tasks (Križanović Čik, 2016). The two main concerns regarding broadband provision in rural areas are that the technical competencies are limited and that the business case may be unjustifiable. As a result, network providers might not want to venture into markets where investment returns are low (Galloway, 2007).

Rural and remote areas in most developed and developing countries almost always experience inferior levels of internet penetration (Pejovic, 2012). For rural users to have an affective internet penetration, data rates per user in the region of 256 kbps as a start are recommended (Seymour, 2013). South African internet penetration as measured in 2017 by the international telecommunication union stood at 7% penetration in rural areas as opposed to 54% in the urban areas (Kennedy, 2017). South Africa faces several challenges pertaining to internet access, which includes low levels of ICT research and development investment, very high telecommunication costs as well as improper economic models for providing connectivity to the marginalised rural and remote areas (Kyobe, 2011).

Another problem facing rural areas is that they are often characterised by highly sparse population consisting of low income communities, where individuals can rarely afford the costs of ICT services. This then prompts most service providers to only provide shared connection services in a form of wireless connectivity like LTE and UMTS, leading to users being deprived of dedicated connections (Simba, 2012). Fortunately, the South African Government has recognised the importance of fixed broadband access as a tool to fight the triple threats of poverty, unemployment and inequality (Roux, 2015). According to the South African department of communication, government is planning a supply and demand-side broadband intervention which seeks to address the country’s digital divide (Department of communication, 2013).
The above literature highlights the following important elements: Broadband access in South African rural communities is absolutely imperative because it can change the socio-economic makeup in these parts of the country (Križanović Čik, 2016). Another concern with regard to broadband provision in rural areas is the limited technical know-how, resulting in the business case being unjustifiable (Galloway, 2007). South African internet penetration is higher in the urban areas as opposed to the rural areas (Kennedy, 2017). Most service providers only provide rural areas with shared connections in a form of wireless connection, depriving users of dedicated fixed connections (Simba, 2012).

2.1.2 Fibre optic broadband access in South African

South African fibre optic broadband provision is largely dominated by big players such as, Telkom, Infraco, Vodacom and MTN (Goldstuck, 2012). Apart from Telkom, most fixed broadband providers owe their existence to a 2008 high court ruling that permitted value added network services (VANS) to build their own self provided networks (Goldstuck, 2012). As of recent, many South African broadband providers have been planning or have constructed optic access networks in a form of FTTH for individual homes or FTTB (fibre to the building) for enterprise connections. An average FTTB offering to corporates in South Africa is usually a 1000 Mbps connection line, but typically lower for FTTH. FTTH is popular and a normal line can cost up to R9 000 to install, depending where subscribers are located in relation to the fibre optic infrastructure (Commscope, 2018).

There are other smaller wholesale fibre optic providers in South Africa that have emerged lately such as, Vumatel, Dark fibre Africa, Fibrehoods and Century City Connect (Burkitt-Gray, 2016). Metropolitan cities such as City of Johannesburg and City of Tshwane are also fibre network providers, providing broadband to their residents and public spaces. However, these providers’ infrastructures are mainly situated in highly dense or opulent areas such as gated communities and office parks. The role of these smaller players is imperative because large providers can also lease capacity from them, as was witnessed with Vodacom’s partnership with Century City Connect to assist them in reaching their one million fibre end-points target by the year 2020 (Burkitt-Gray, 2016). Below is a diagram showing the City of Johannesburg fibre network infrastructure (Goldstuck, 2016).
The diagram above shows five rings of trenched fibre connecting the City of Johannesburg key areas of significance. The fibre rings connect sites such as libraries, police stations and administration offices. Nodes such as JMC (Johannesburg Metro Centre Civic), RUV (City power Reuven), SLIB (Sandton Library) and RGA (Region G Admin) are fibre network’s core switches which interconnect traffic and allows users to access the network. Subsequently, Nodes such as RTH (Roodepoort Town Hall), CHO (Chiawelo Admin), WEM (Wemmer Complex) and PTH (Proton House) are networks’ metro sites that form part of the subscriber base of the fibre network. The lines between the nodes are the physical fibre links that interconnect the network nodes.

The evolution of fibre deployment in South African urban areas has also opened new opportunities for over the top (OTT) firms that offer value added services over the infrastructure. Value added services companies named Directel and Workonline communications have recently introduced a new fibre internet service called Rocketnet (Kyobe, 2011). The service, which will initially be introduced in Sunninghill and Kyalami will be the first in the country to offer IT support by guiding users on how to install and optimise network products such as Wi-Fi. Their services which will be running on Networx metro fibre network is planned to offer between 25-100Mbps symmetric speeds (Kyobe, 2011).

From the above literature, the following statements can be highlighted: many South African broadband providers have been planning or have constructed optic access
networks (Goldstuck, 2012). Metropolitan cities such as City of Johannesburg and City of Tshwane are some of the fibre network providers, providing broadband to their residents and public spaces (Burkitt-Gray, 2016). FTTH is popular in South Africa and a normal line can cost up to R9 000 to install, provided subscribers are located next to the fibre optic infrastructure (Commscope, 2018).

2.1.3 Fibre Optic broadband access in rural communities

The recent uptake in high data rates demanding applications is said to be the reason behind new access technologies which permit users to experience true broadband. This uptake leads to operators considering high volume rollout of optical-fibre based access networks (Al-Quzwni, 2014). Optical fibre networks have been deployed aggressively in numerous countries and most go up to the district centres. However, most of the bandwidth that has been terminated is yet to be rerouted to the rural users (Byanyuma, et al., 2013).

In South Africa several network providers have committed to rolling out FTTH (fibre to the home) in six of the metropolitan cities (Johannesburg, Durban, Port Elizabeth, Pretoria, Bloemfontein and Cape Town). The mentioned cities are however fairly well developed, making it justifiable for network providers to design and implement these fibre access models. However, many South Africans still reside in rural communities, where fibre access infrastructure is hardly present because of socio-economic and geographical impediments. Henceforth, a customized broadband network that meets the rural demographics is required (Gamatham, 2013).

The recent evolution of optical technologies such as the next generation optical access (NGOA) permits the much needed increase in bandwidth and at the same time offers longer distance of transmission from central office to optical network units, making them ideal for rural network provisioning. This increase in maximum reach allows network providers to reduce the number of central offices, passing huge savings to the operators (Díaz, 2015). There are also other fibre technologies such as the extended-reach GPON (Gigabit passive optical network) designed for rural areas that makes use of distributed Raman amplifiers. The system makes use of a symmetric 2.5-Gbps bidirectional transmission where 32 subscribers can be provisioned over 60 km without any active extenders (Lee, 2009).
The literature above can be summarised as follows: countries across the world have fibre optic networks, but these networks have not adequately reached remote areas such as rural areas (Byanyuma, et al., 2013). The above literature further enlightened us that in South Africa, FTTH has been the preferred fibre optic access network to roll out in urban areas, and unfortunately no known fibre optic access technology exist in rural areas (Gamatham, 2013). Lastly, the literature informs us that fibre optic access network in rural areas will be ideal if it can offer longer distances of transmission between central office and optical network units (Díaz, 2015).

2.1.4 Cost of Broadband rollout in South Africa

Although South Africa has its own state owned broadband company, Infraco, it still lags behind when coming to broadband penetration when compared to other comparable countries like Poland, Hungary and Turkey (Gillwald, 2007). It is believed that the low penetration in broadband access is as a result of inadequate investment in infrastructure due to limited state resources in public enterprises coupled with high risks that are primarily associated with sunk costs (Gillwald, 2007).

In order to realise increased broadband infrastructure investment, network providers are advised to formulate lower rollout costs strategies such as infrastructure sharing. Infrastructure sharing is considered an innovative broadband network rollout and extension model (Calandro, 2012). The model encourages network operators to share either their active or passive network infrastructure elements. By employing this model, the network providers could save up to 80% of their capital expenditure through sharing the passive elements alone.

Passive elements sharing entails sharing non-electronic components such as base station sites, masts and ducts in the case fibre and copper mediums (Calandro, 2012). Infrastructure sharing has also been witnessed between different industries, for example, sharing between the utility networks and the telecommunication networks. Utility networks such as the electricity network and telecommunication network have a lot of similarities in infrastructure and operations. When these networks are deployed in the same areas, the costs are greatly reduced from making use of the common infrastructure (Tahon, 2011).
Another cost saving technique in South African broadband space was the introduction of IP (internet protocol) based networks popularly known as NGN (next generation networks). These networks allow the convergence of voice, data and video services on a single platform. This form of configuration permits huge increases in available network capacity, which was historically a scarce resource. Therefore, as a result, the marginal costs of network capacity which is needed to carry the services becomes inconsequential (Esselaar, 2006).

In conclusion, the above literature can be summarised as follows: Limited investment in infrastructure due to lack of state resources are some of the reasons broadband penetration is low in South Africa (Gillwald, 2007). Furthermore, infrastructure sharing could assist in lowering costs of network rollouts in South Africa (Calandro, 2012). Lastly, the next generation networks which have been introduced in South Africa can save on costs because they allow voice, data and video services on a single network platform (Esselaar, 2006).

2.1.5 Cost of fixed broadband rollout in rural areas

While substantial attention has been given to attaining the rollout costs of fixed broadband access in urban areas, the cost of serving rural and lower densities areas has received little attention. As a result, many service providers have opted to rolling out pure wireless networks or fixed wireless networks by employing wireless as a last mile access, with the belief that they are saving costs in these areas (Zhang, 2016). Schneir (2014) in his paper, “A cost study of fixed broadband access networks for rural areas”, conducted a cost model to determine the cost of connecting homes using fixed line based networks in urban and rural areas. The study found that the cost of deploying fixed network in the rural areas and remote areas was on average 80% higher than the cost of deployment in urban areas (Schneir & Xiong, 2016).

Another subject impacting the cost of fixed broadband rollout is copper theft. Copper theft affects many copper based systems and networks such as ADSL, leading to reduced system availability. The plague of copper cable theft has become epidemic to a point that the British police has recently described it as a ‘strategic priority’. Its implications range from the substantial monetary costs incurred through theft induced cable replacement (Sidebottom, 2014).
Furthermore, many industry experts believe that the high costs of rolling out fixed broadband in the rural areas are as a result of high initial investment costs that are associated with the nature of the network. They further recommend that in order to decrease these high initial costs, some sort of a cooperation model between utility operators during the rollout phase is needed (Tahon, 2014). Some also believe that rural networks rollout could be a challenge because the laws of network profitability proclaim that the increase in the amount of broadband users results in the increase in profitability on the network deployed, and as a result the required network investment per user also tends to decrease as the density in users increase (Križanović Čik, 2016).

It must also be noted that attaining the cost of fixed broadband provisioning in the rural areas can be a challenging task due to the diverse nature of the surrounding service areas. For this reason, a system is needed to identify the actual location of every household and all roads in their vicinity. This is because most networks are usually deployed along roadways by utilising existing power poles to save costs and simplify access (Ellershaw, 2009). Another important point to take into consideration is that the state has a role to play in the attempt to reduce operators’ investment risks of fixed broadband rollout in the rural areas. The state can offer institutional tenders whereby operators provide government schools and clinics with fixed broadband, or the state could offer guaranteed revenue streams to reduce the risk of providing these much needed investments (Muente-Kunigami, 2010).

The cost of fixed broadband rollout in rural areas as depicted from the above literature, firstly advocate that, the cost of deploying fixed broadband network in rural areas is 80% higher than a deployment in the urban areas (Schneir & Xiong, 2016). It further highlights that in order to save on costs of fixed broadband rollout, broadband network service providers need to collaborate with other service providers, such as the electricity service providers to save on initial rollout costs (Tahon, 2014). The literature lastly highlights that the state could reduce service providers’ investment risks by offering state institution tenders or guaranteed revenue streams (Muente-Kunigami, 2010).
2.2 Fibre optic Network cost-effectiveness evaluation

The main objective for a system’s lifecycle analysis is to have a system that is cost-effective (Blanchard, 2003). Although the scope of our study only evaluates cost-effectiveness by determining networks’ lifecycle-costs, it is important to note that cost-effectiveness is usually measured by considering both the system’s lifecycle cost analysis (LCCA) and system effectiveness analysis (SEA). Cost-effectiveness is similar to the principle of cost-benefit analysis which is employed by many industries for decision making purposes (Blanchard, 2003). Figure 3 below is a graphical representation of some of the components of cost-effectiveness (Blanchard, 2003).

![Diagram of cost-effectiveness](image)

**Figure 3 Basic elements of cost-effectiveness**

Figure 3 illustrates components of cost-effectiveness and simplifies its key features. The figure highlights that in order to conclude that a system is cost-effective, the system must be evaluated on both its lifecycle costs and its system effectiveness attributes. As a result, for us to conclude that a fibre optic network deployment in rural areas is cost-effective, it is advisable to measure the system against its lifecycle costs from planning costs to disposal costs and again measure its system performance in terms of its maintainability, reliability, availability, disposability and supportability.
However, the scope of our research will only evaluate cost-effectiveness by exclusively analysing the broadband alternatives’ lifecycle costs.

2.3 Fibre optic lifecycle cost analysis and cost factors identification

Fibre optic networks are required in the near future to cope with increasing network demands. However, penetration remains low in most parts of the rural areas (Burkitt-Gray, 2016).

The following section of the literature review is directly related to the secondary research question which examines the network provider’s fibre optic network lifecycle costs, compared with other broadband technologies in rural areas with regard to network planning, installation, maintenance and recovery. Subsequently, In terms of network costs, expenditure associated with network deployment is classified into two categories, Capital expenditure (Capex) and operating expenditure (Opex). With a fibre network rollout, Capex covers the actual cost of infrastructure for providing the connectivity such as, installation costs, network equipment costs and power sources, while Opex covers costs of operating and maintaining the network (Mishra, 2005).

2.3.1 Fibre optic network lifecycle evaluation

In order to fully ascertain the costs of deploying a fibre network, it is imperative to establish the lifecycle of a typical network. As depicted in Figure 4, a typical network’s lifecycle goes through the following stages: (Casier, 2008):

![Figure 4: Network Lifecycle](image)

2.3.1.1 Planning phase and associate costs

The planning phase involves up-front planning of the network which includes the choice of technology that will be employed, topology design and the manner in which the rollout will be carried out. This phase of the network lifecycle deals with very important decisions on a number of cost-drivers for the deployment stage. The different technology options will account in differences in costs, for example, choosing
between an optical network (PON) architecture and home-run fibre network architecture (HRF) (Casier, 2008).

2.3.1.2 Deployment phase costs

Once the planning phase is concluded, the rollout phase can be undertaken. This stage of the network lifecycle is considered important due to the high costs of trenching and purchasing of new equipment. The costs accumulated at this stage is said to be in the region between 60 % to 70 % of the total network costs (Casier, 2008).

2.3.1.3 Operations phase costs

Once the network is up and running, the next phase of the network’s lifecycle is to maintain the network. The costs involved at this stage are monitoring costs, annual maintenance and repair costs, normally calculated to be a proportional of the total network deployment costs. While most fixed costs on the network such as power consumption and housing costs are known, repair costs are however unknown and could pose several challenges (Casier, 2008).

2.3.1.4 Retirement phase costs

Finally, there will come a period where the network is deemed obsolete. At this stage the network will have to be retired by disposing of either old redundant network elements or the network in totality. The costs of retiring the network involves equipment salvaging and link disconnection costs (Casier, 2008).

2.3.2 Fibre optic network lifecycle costs in rural areas

Fibre access in the rural areas is highly constrained by the projected high network lifecycle costs. It is believed that lifecycle costs are higher in these areas because of lower population densities. In order to save on network costs and be in a position to provide the network in these areas, access technologies with a range of at least 60 km to the customer premises is required (Ellershaw, et al., 2009). As a result, for 50 Mbps error free services and above, long range PON (passive optical networks) is known to offer the lowest network costs, whereas an alternative for data rates around 20 Mbps without contention, FTTN DSL (fibre-to-the-node, digital subscriber line) could be considered (Ellershaw, et al., 2009).
Owing to the fact that the landscape in rural communities in most developing countries is in total contrast to that in the urban areas, few components need to be noted. Firstly, with regard to fibre deployment, the chosen network technology needs to be affordable. Equipment affordability needs to be prioritised over network reliability (e.g. Backup equipment and redundant connectivity) (Mishra, 2005). Another point to note is that in rural areas network coverage should be prioritised more than capacity. This means that the presence of the fibre network should take first preference over the amount of bandwidth being provided by the network (Mishra, 2005).

The method of calculating the fibre network costs in rural areas usually emanates from numerous assumptions. The first assumption is usually that legacy networks infrastructure like coaxial DSL will be re-used where possible. Secondly, that the backbone network will be shared amongst numerous service providers, bringing the costs down respectively. Another assumption is that, since network cost calculation is dependent on the number of subscribers on the network, there will be a 10% yearly customer growth on the network. Lastly, in order to estimate the present value of investment, as a rule of thumb, a weighted average cost of capital (WACC) of 12% of total lifecycle cost is selected (Feijóo, 2011).

The above collected literature on the cost of fibre network rollout in rural areas highlights that in terms of network costs, expenditure associated with network deployment is classified into two categories, capital expenditure and operating expenditure (Mishra, 2005). The literature further outlines the costs associated with a typical network lifecycle and highlights that the actual network’s installation phase of the lifecycle is the most important phase as it accounts to around 70% of the total network costs (Casier, 2008). The literature also highlights that in order to save on network costs in rural areas, a low cost system that offers an extended range of at least 60 km of connectivity between active nodes is required (Ellershaw, et al., 2009). Lastly, the collected literature advocates that, to save further costs in these areas, legacy networks like ADSL infrastructure should be re-used where possible and backbone networks should be shared amongst service providers respectively (Feijóo, 2011).
2.3.3 Rural broadband lifecycle cost comparison case study

It has already been illustrated through collected literature that the penetration of broadband services in rural areas is inhibited by the network’s lifecycle costs. It is imperative to collect literature that examines the lifecycle cost of relevant broadband alternatives that could be deployed in these areas. A lifecycle cost analysis approach is key to testing the cost-effectiveness of a broadband alternative because it observes the cost of such an alternative through its full lifecycle (Maoto, 2012).

It is also important for a rural broadband lifecycle cost comparison to encompass all possible deployable or existing broadband technologies. Consequently, broadband technologies will be observed as part of the evaluation process. Therefore, the first broadband technology in rural areas that was considered is an LTE wireless technology. It is perceived that most network providers prefer to deploy wireless technologies such as LTE in rural areas because of ease of deployment and perceived cost efficiency (Byanyuma, 2013).

A fibre based network was the second alternative that was considered as part of the cost-effectiveness evaluation process in rural areas. A number of researchers have taken interest in evaluating rural broadband technologies as in Table 1 below. Table 1 is a lifecycle broadband cost comparison case study that was conducted in Australia. Table 1 includes a copper based DSL (digital subscriber line) broadband network as part of the cost evaluation process. Although this technology is included in the case study as part of the evaluation process, it will not form part of the research because the technology is regarded as virtually obsolete (Ellershaw, 2009.).
Table 1 Rural lifecycle cost comparison case study table

<table>
<thead>
<tr>
<th>Costs drivers</th>
<th>Wireless(LTE)/ site 10 years lifespan</th>
<th>DSL(copper)/site 15 years lifespan</th>
<th>PON (Fibre)/site 15 years lifespan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network planning costs(10% of rollout costs)</td>
<td>R50 400</td>
<td>R145 100</td>
<td>R167 500</td>
</tr>
<tr>
<td>Rollout: Installation &amp; equipment costs</td>
<td>Wireless tower-R400 000</td>
<td>Equipment housing in exch-R300 000</td>
<td>Equipment housing in exch-R300 000</td>
</tr>
<tr>
<td></td>
<td>LTE equipment/sector-R100 000</td>
<td>DSL node- R50 000</td>
<td>Optical line card in exch-R45 000</td>
</tr>
<tr>
<td></td>
<td>Wireless modem &amp; installation-R5 000</td>
<td>DSL node installation with power-R100 000</td>
<td>Fibre node installation with power-R100 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Copper installation/km-R100 000</td>
<td>Optical fibre cost/km-R1200 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSL Modem – R1 000</td>
<td>PON ONU card &amp; splitter &amp; installation-R30 000</td>
</tr>
<tr>
<td>Sub total</td>
<td>R504 000</td>
<td>R1 451 000</td>
<td>R1 675 000</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>R757 000 (calculated at 1.5 x rollout costs over 10 years)</td>
<td>R2 176 500(calculated at 1.5 x rollout costs over 15 years)</td>
<td>R2 512 500(calculated at 1.5 x rollout costs over 15 years)</td>
</tr>
<tr>
<td>Retirement &amp; disposal costs (5% of rollout costs)</td>
<td>R25 200</td>
<td>R72 550</td>
<td>R83 750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>R1 336 200</strong></td>
<td><strong>R3 845 150</strong></td>
<td><strong>R4 438 750</strong></td>
</tr>
</tbody>
</table>

Amounts have been converted to ZAR at 1 AUD= 9 ZAR on 11/08/2017
Table 1 is a cost sample for a small network deployed in the rural area of Virginia Omeo in Australia. The table assists us in obtaining an indication on lifecycle costs associated with each rural broadband technology solution. From the table it could be deduced that wireless technologies like LTE have lower initial costs but have shorter lifespans. This type of network becomes very attractive for network providers because they offer easy and rapid deployment, making them ideal for rural areas. Wired networks such as fibre optic and copper have a longer lifespan combined with easy upgrade features and lower operation and maintenance costs that offer a great alternative, especially for a long term investor.

It must be also mentioned that Table 1 only represents a single network node cost sample that was conducted in Australia, however, it provides much needed insight on rural broadband technology’s lifecycle costs. Despite Australian and other countries rural areas such as South Africa being somewhat similar, there might be differences in the network’s lifecycle costs. Cost drivers such as network planning costs, which amounted to 10% of the rollout costs were calculated based on costs of network planners could be fairly higher in South Africa due to scarcity of expertise and experience, more especially in PON network planning since it’s a technology that is fairly new in South Africa (Goldstuck, 2012).

When coming to the actual rollout costs in countries such as South Africa, costs of rollout which were ascertained by obtaining material, equipment and labour costs, could be a lot higher due to the small number of material manufacturers and distributors and high installation test equipment cost. Maintenance costs from Table 1 were calculated by multiplying the installation and equipment costs with a fixed figure of 1.5. In order to properly determine maintenance costs in countries such as South Africa, a proper cost estimation equation which will encompass both corrective and preventative maintenance activities will have to be employed.

For the last activity of the system’s lifecycle, which is the system retirement and disposal, Table 1 determined the figure by calculating 5 % of the system’s rollout costs. In order to consider this figure in other countries rural deployment context, a number of input factors will have to be taken into consideration. Retirement costs will have to be obtained by determining the equipment recovery costs, equipment recycling costs and costs of environmental pollution if it exits.
In conclusion, based on Table 1, it seems that a fibre optic access network might not be the most cost-effective solution to be rolled out in rural areas. Although, it must be noted that in Table 1, the evaluation is exclusively based on lifecycle costs analysis. This is because the scope of our research assesses cost-effectiveness solely on lifecycle costs, although it is advised to incorporate system effectiveness as an evaluation criteria. This is because system effectiveness places emphasis on a system’s efficiency and effectiveness to assist in selecting the best alternative. Subsequently, by incorporating a system’s effectiveness to an evaluation criterion, one will be well placed to objectively evaluate the broadband alternatives’ cost-effectiveness.

2.3.4 Fibre optic LCCA and cost factors identification literature presentation

Figure 5 below is a summary of the data that was collected to respond to the secondary research question.

Figure 5 Network providers’ costs literature presentation

Figure 5 is a literature presentation of data that attempts to answer the secondary research question which probes the network provider’s lifecycle costs, compared with other broadband technologies in rural areas with regard to network planning, installation, maintenance and recovery. It was important to collect rural rollout cost
related literature that could assist in selecting the best deployment approach. The collected literature aims to provide much needed information to network providers through guidance from scholars and industry experts in a form of academic knowledge and case studies from across the globe.

2.4 Network lifecycle cost evaluation principles

Companies invest in certain projects with an aim of positive returns from their investments. For this reason, it is important to employ the relevant cost evaluation principles that will assist us in getting to the most cost-effective alternative. Below are some of the cost evaluation principles that can be considered in selecting the best rural broadband alternative.

2.4.1 Cost estimation principle

The cost estimation principles are vital in predicting the costs of any industrial endeavour. Network providers have to employ advance cost estimation techniques in order to establish the true costs of rural provision or in selection of the most cost-effective technology, system or configuration. As a result, the co-operation of several professionals will be required to prepare cost estimates for the rollout. The primary objective of cost estimation is to reduce cost uncertainties for the organisation (Meredith, 2011). It is also advised that organisations bring on board a professional cost estimator who knows what cost data must be collected by liaising with relevant experts in functional areas. Below is a standard cost estimation equation for a typical broadband network entity (Hendrickson, 2008).

\[
y = \sum_{i=1}^{n} u_i Q_i
\]

Where 

\( Q_i \) represents the quantity of the \( i^{th} \) element.
\( u_i \) represents the corresponding unit cost.
2.4.2 Lifecycle cost analysis (LCCA) Principle

In order to fully determine the cost-effectiveness of broadband technologies in rural areas, an activity based lifecycle cost analysis will be executed. There are a number of lifecycle cost accounting methods that one can choose from, such as, attribute cost method, feature cost method, volume based cost method and activity based cost method (Blanchard, 2003). A lifecycle activity based cost method was selected because it offers greater costing accuracy by assigning costs on the basis of activities that drive costs rather than on volume or number of units (Blanchard, 2003). In selection of this method a cost breakdown structure (CBS) should be plotted where costs are categorised, allocated, monitored and controlled. The cost breakdown structure should be based on gathered cost data and a number of identified cost drivers. Below is a typical equation of a system LCC model made up of four main cost components and related activities (Maoto, 2012).

\[ LCC = C_1 + C_2 + C_3 + C_4 \]  

Where:  
- \( C_1 \) represents research and planning phase costs  
- \( C_2 \) represents Installation and commissioning phase costs  
- \( C_3 \) represents Operation and maintenance phase costs  
- \( C_4 \) represents Retirement and disposal phase costs

2.5 System’s effectiveness analysis

Although our study only considers lifecycle cost analysis as a way to substantiate network cost-effectiveness, it is equally important to ensure system effectiveness as an interactive process which includes the use of numerous analytical methods, techniques and tools. This process ensures that the system is installed and operated effectively and efficiently throughout its planned lifecycle (Blanchard, 2003). In order to determine the best broadband solution for rural deployment, key systems engineering concepts will be evaluated.
2.5.1 Maintainability

Maintainability is an integral characteristic of a telecommunication’s system design. It relates to a system’s ease, accuracy, safety and economy in performance of maintenance related actions (Blanchard, 2003). A system is said to be highly maintainable when it can be maintained without large investments of time, costs and other resources such as personnel, test equipment and facilities. Maintainability involves consideration of some of the aspects of systems’ measures such as, MDT (Maintenance downtime) and MLH/OH (maintenance labour hour per system operating hour) (Blanchard, 2003). DSL and PON networks are considered highly maintainable because they are seen as less complex systems, as opposed to wireless LTE (Ernest, 2017).

2.5.2 Reliability

Rural solutions will have to be inherently reliable due to the costs associated with attending and repairing systems situated in this environment. Reliability is defined loosely as the probability that a system will perform in a satisfactory manner when used under specified operating conditions (Blanchard, 2003). Wireless is seen as a less reliable medium because it is more susceptible to environmental interference such as rain and thunderstorms (Ellershaw, 2009). DSL is seen as a more reliable medium because it is less affected by environmental elements like rain but susceptible to electrical interference (Ellershaw, 2009). Fibre optic is seen as a very reliable medium because it is not affected by environmental interference or by electrical interference because it makes use of light to establish communication (Ernest, 2017). Reliability function can be expressed as: \( R(t) = 1 - F(t) \), where the probability is that the system will fail by the time it reaches \( t \). Another important aspect of reliability is MTBF (mean time between failures) which is expressed as (Blanchard, 2003):

\[
MTBF = \frac{1}{\lambda}
\]  

\[2-3\]

Where: \( \lambda = \text{number of failures/ total operating hours} \)
2.5.3 Availability

System availability has become important in the telecommunication industry in recent time as a feature of evaluating whether the system will be ready or available when required for use (Trivedi, 2008). It is therefore imperative that systems or technologies deployment in rural areas have a high availability and durability measure because restoration of such systems could be delayed due to geographical impediments. Inherently, wireless signals will be less available because the system is less maintainable and less reliable. DSL availability will be more improved because the system is a bit more reliable and highly maintainable. Lastly, fibre optic availability will be the highest because the system is both highly maintainable and reliable (Ernest, 2017). Availability \((Ao)\) is also a way of measuring system fault tolerance which is calculated using the following metric calculation:

\[
\text{Operational Availability } (Ao) = \frac{MTBM}{MTBM + MDT} [2-4]
\]

Where:

\(MTBM\) = Mean time between maintenance

\(MDT\) = Mean down time

2.5.4 System life-span

All network technologies or systems have a specific life span. As previously stated, a typical network lifecycle goes through the following stages: Planning, deployment, service provision, operation and retirement (Casier, et al., 2008). The life span of wireless network is believed to be shorter than a wired network because it uses devices that transmit/radiate very high power, leading to them wearing out quicker (Bekkali, 2010). It is therefore beneficial that the preferred broadband solution deployed in the rural areas possesses a prolonged operation period that outperforms the company’s calculated payback period.
2.5.5 System effectiveness analysis

From the above literature, it is evident that a system effectiveness evaluation is important in determining the best solution for rural deployment. The process ensures that the system is installed and operated effectively and efficiently throughout its planned lifecycle (Blanchard, 2003). System effectiveness encompasses the availability and dependability of a system, and relates to the ability of that system to perform its intended designed functions. The measure of effectiveness is based on the system’s operational requirements and the mission scenario that must be performed and attained (Blanchard, 2003). If network providers are going to deploy a system in a rural and remote environment, it is imperative that the system should perform according to its requirements, e.g. if the broadband technology deployed is to have a throughput speed of 100 mbps, it will be detrimental if it doesn’t attain the specified speed.

2.6 Broadband cost-effectiveness evaluation equation presentation

The following table presents equations that will be utilised to evaluate cost-effectiveness through our broadband comparison process.

Table 2 Broadband technologies cost-effectiveness evaluation

<table>
<thead>
<tr>
<th>Cost Evaluation</th>
<th>Wireless LTE</th>
<th>Copper ADSL</th>
<th>Fibre Optic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollout</td>
<td>$C_X = \sum_{i=1}^{n} u_i Q_i$ [2-1]</td>
<td>$C_X = \sum_{i=1}^{n} u_i Q_i$ [2-1]</td>
<td>$C_X = \sum_{i=1}^{n} u_i Q_i$ [2-1]</td>
</tr>
<tr>
<td>Life cycle cost analysis (LCCA)</td>
<td>$LCC = C1 + C2 + C3 + C4$ [2-2]</td>
<td>$LCC = C1 + C2 + C3 + C4$ [2-2]</td>
<td>$LCC = C1 + C2 + C3 + C4$ [2-2]</td>
</tr>
<tr>
<td>System effectiveness</td>
<td>Wireless LTE</td>
<td>Copper ADSL</td>
<td>PON (fibre)</td>
</tr>
<tr>
<td>Reliability</td>
<td>$MTBF = \frac{1}{\lambda}$ [2-3]</td>
<td>$MTBF = \frac{1}{\lambda}$ [2-3]</td>
<td>$MTBF = \frac{1}{\lambda}$ [2-3]</td>
</tr>
<tr>
<td>Availability</td>
<td>$(Ao) = \frac{MTBF}{MTBF + MDT}$ [2-4]</td>
<td>$(Ao) = \frac{MTBF}{MTBF + MDT}$ [2-4]</td>
<td>$(Ao) = \frac{MTBM}{MTBM + MDT}$ [2-4]</td>
</tr>
</tbody>
</table>
Table 2 above serves as a presentation of a cost effectiveness comparison process which will be undertaken on our data collection phase of the research. It should be noted that only the rollout cost estimation and the lifecycle cost analysis (LCCA) principles will form part of the evaluation process on our research data collection phase. The greyed out part in table 2 that evaluates system effectiveness will not be considered further in our research.

2.7 Cost-effective optical technologies in rural areas

It is important to consider different fibre network architectures that would result in lower lifecycle costs in rural areas. It is therefore imperative to interrogate the most cost-effective fibre optic access network systems or configurations to roll out in rural areas. For network providers considering deploying fibre in rural areas, the deployment needs to be as cost effective as possible amidst the projected high capital costs. Discussions need to be held around the type of technology to be deployed, due to fact that the choice of technology made today will dominate future business opportunities (Jay, 2014).

2.7.1 Passive optical networks (PON)

Below is a typical configuration of PON from a service provider exchange to the end-user (Ellershaw, 2009).

![Figure 6 Passive Optical Network](image)

Passive optical networks consist in a form of fibre access network that provides high capacity communication between a service provider’s exchange and households or business premises as shown in Figure 6. PONs make use of low maintenance and low cost components to split one incoming traffic line into 32 traffic lines that could be...
connected to subscribers. This is seen as a cost effective system which is well suited for rural areas because it reduces costs by decreasing the amount of fibre and trenching that is required.

2.7.2 Extended-reach passive optical network (E-PON)

Although PONs' fibre technology have the capability of delivering broadband services to remote rural communities, there are other more cost effective approaches to delivering high bandwidth over long distance. Amongst them, are the extended-reach passive optical networks (E-PON). E-PONs make use of special components to achieve extended transmissions between service providers’ devices, thus saving on the number of devices required on the network. E-PONs are seen to be very cost effective because by reducing the number of devices on the network, service providers will be saving on the amount of devices that need to be purchased and also the amount of maintenance that is required (Lee, 2016).

Illustrated below is a diagram of a simplified extended-reach passive optical network’s configuration between service providers’ exchange and subscribers’ premises (Lee, 2016).

![Figure 7 Extended-reach Passive network (EPON)](image)

From the diagram above it is evident that E-PONs are very similar to PONs, with the exception of the extended distance between the service provider's exchange and the local provider's termination box being the only difference (Lee, 2016). As already highlighted, the extended distance between the active devices will be beneficial for rural deployment due to the expected wide spread of the network.
2.7.3 Radio over free space optical transmission

Radio over free space optical (RoFSO) communication systems are fast gaining momentum as a cost effective way of transmitting high data rates signals from one point to the other with the same bandwidth as trenched optical fibre. The advantage of free space optics as a communication medium is the ease of network deployment, reduced cost of deployment due to fact that no trenching and digging is required. RoFSO are a good match for rural areas and are usually employed as a last mile solution broadband connectivity to underserved remote areas.

Below is a representation of radio over free space (FSO) configuration: (Bekkali, 2010)

![Radio signal transmission over FSO link](image)

Figure 8 Radio signal transmission over FSO link

The diagram above is a graphical illustration of a radio over free space optical link as one of the optical options to consider in rural areas. The wireless transmission between active devices could be a cost effective option for rural areas because it will avoid the extensive digging and trenching required.

2.7.4 Analysis of cost-effective optical technologies in rural areas

The above literature assesses the cost effectiveness of optical technologies in rural areas, and deduce that the most cost effective technology needs to be implemented in order to counter the high projected installation costs in these communities (Jay, 2014). The literature firstly considers PONs and determine that the technology is well suited for rural areas because it uses inexpensive passive splitters to share bandwidth between 32 subscribers (Ellershaw, 2009).

The literature further assesses extended-reach passive optical networks and establishes that due to their longer transmission reach between active nodes, coupled
with cost effective passive splitters, they could be the best solution for rural deployment (Lee, 2016). Lastly, the literature considers radio over free space optic transmission as an alternative cost effective technology that could be employed. The main attraction with RoFSO is that there is no need for any digging and trenching, making installation highly swift and cost effective (Bekkali, 2010).

2.7.5 Cost-effective optical technologies in rural areas literature presentation

Figure 9 below is a summary of the data that were collected regarding the evaluation of the most cost effective fibre optic network in rural areas.

As already stated, it is imperative to investigate the most cost-effective fibre optic access network systems or configurations to roll out in rural areas, and as result, several technologies had to be explored, systems and configurations that are considered cost-effective to roll out in these areas. Subsequently, figure 9 above is a presentation of the literature that was collected to give more insight in the matter.
2.8 Conclusion

In this chapter, it was observed through literature that network provisioning in rural and remote areas is in the best interest of both the state and the private sector. It is therefore encouraged that a public private partnership be initiated. It was also learned that the cost of deploying fixed broadband network in rural areas is higher than a deployment in the urban areas. However, this cost could be reduced by employing the most cost-effective strategies such as network infrastructure sharing and selecting the best technologies that suit the targeted environment. Lastly, to fully determine the cost-effectiveness of broadband technologies in rural areas, a lifecycle cost analysis should be executed using various cost accounting methods.
CHAPTER 3: RESEARCH METHODOLOGY

Research is an academic activity and it entails defining problems, collecting, organising and evaluating data; making deductions and reaching conclusions (Cooper, 2011). The purpose and significance of our research was highlighted in chapter one with a clear research problem, questions and objectives. In chapter 2, literature that relate to rural fibre cost-effectiveness which support and seek to answer the distinctive research questions was collected and analysed.

The main aim of chapter 3 is to firstly identify and apply relevant research methods to address the research problem. Secondly, to develop an appropriate research design for the research. Finally, the chapter also aims to adopt a relevant data collection instrument for our research.

Cooper & Schindler (2011) highlights that an adopted research procedure should be described in sufficient detail to a point that it permits another researcher to repeat the research. He further states that the procedural design of the research should be clearly described and carefully planned to produce results that are as objective as possible (Cooper & Schindler, 2011).

3.1 Research method

Our research question highlighted in chapter 1 seeks to determine if a fibre optic network deployment is cost-effective in South African rural areas. The reason for conducting the research is to evaluate if a fibre optic network provisioning is economically viable for network providers in rural areas. In order to be in a position to comment on the cost-effectiveness of the technology in South African rural areas, its lifecycle costs have to be measured and compared with an existing broadband technology in this area, such as wireless long term evolution (LTE). Hence, the two technologies’ lifecycle costs will have to be evaluated so that the technology with the lowest lifecycle costs can be recommended.

The process involves determining all costs involved with each phase of the network lifecycle, from the network planning phase to the network retirement phase. As a result, appropriate research methods have to be employed in order for our research to be credible. Below is a graphical representation of our research method. The
diagram displays how our research was undertaken and the steps which were followed.

![Research Method Diagram]

**Figure 10 Research method diagram**

### 3.1.1 Define research questions

In chapter one, our primary and secondary research questions were introduced and highlighted. The main objective of our research is to seek data that attempt to answer these research questions. In the previous chapter, relevant data that provided background on the subject and data that assisted in attaining a holistic view was collected. Our primary research question asks if an optical access network rollout could be cost-effective for network providers in South African rural areas. In order to attempt to respond to this question, it was important to query the network provider’s lifecycle costs. The lifecycle costs will then be compared with other broadband technologies in rural areas in order to determine the network’s cost-effectiveness.
3.1.2. Literature review

The literature review presented and analysed literature from previous studies which were deemed relevant to our research topic in an attempt to obtain a holistic view on the subject. Literature on fibre optic and its cost-effectiveness in South African rural areas was collected and analysed in the previous chapter. As a result, the collected literature placed us closer to answering our research questions.

3.1.3 Cost models

In order to be in a position of conducting a cost-effectiveness evaluation for rural broadband access network rollout, it is important to determine the lifecycle costs of both a fibre access network and the existing wireless access network such as LTE within the same demographics and geographical area. Our cost models were designed to encompass all relevant variables to establish a rural end to end access network deployment, although it must be noted that several variables will be assumed. Our cost models will be based on a sample rural area with a radius of approximately 5 kilometres, and with a potential subscriber population averaging 300-500 (Schneir & Xiong, 2016). This sample area, with the characteristics of most South African rural areas was chosen because it is synonymous with a subscriber base and coverage area of a single base station (Mancuso & Alouf, 2011).

3.1.3.1 Fibre optic cost model

Our chosen fibre optic cost model is in a form of a full lifecycle cost analysis based on what is known as a rural 3a geo-type (Schneir & Xiong, 2016). Rural geo-type relates to a specification of the rural demographics such as, the number of subscribers and the size of the rural area. Rural 3a is a demographic geo-type that is stated to have a geographical spread of an average of 15 square kilometres. Network providers will require around 50 kilometres of trenched fibre to cover approximately a 5 kilometre coverage radius which should serve a minimum of around 300 connected subscribers (Schneir & Xiong, 2016).

The selected fibre access network architecture for our research was the FTTH (fibre to the home) PON (passive optical network). FTTH PON fibre architecture was selected because it is a complete fibre access network with end to end fibre assembly. Another reason for selecting this fibre architecture is because it is widely deployed,
therefore there is enough research data to attain conclusive findings. It was also assumed that the cost of connection involved all the costs necessary to deploy the fibre up to the CPE (customer premises equipment). A Greenfield approach was employed for our research on the fibre-based infrastructure, meaning an assumption was made that there was no existing fibre infrastructure in the area, and things such as ducts needed to be deployed from scratch. Lastly, our fibre optic network architecture was projected to contain 1 central office and a total of 2 street/distribution cabinets sufficient to serve 300 subscribers with a 35% estimated take rate. 1 street cabinet was calculated to serve around 550 subscribers, but 65% of the load needs to be freed up for card redundancy purposes and to carry future traffic. (City of Santa Cruz, California, 2015).

3.1.3.2 Wireless (LTE) cost model

The cost model for the wireless LTE network is closely related to the fibre optic network cost model in that a full lifecycle cost analysis assessment will have to be undertaken under similar geographical and demographical conditions. Our assessment is based on a single base station with a coverage radius of around 5-10 kilometres and a capacity of around 300-500 simultaneously connected subscribers. The assessment also assumes a transmission link of about 10 km from the nearest network hub site or the BSC (base station controller). However, the cost assessment only considers the access network which is centralised around the base station because this part of the network is unique when compared between broadband technologies. The backhaul network takes different forms and could be similar between two different broadband technologies. It is therefore important to evaluate related lifecycle cost factors and costs estimates expected to be incurred with a deployment of this kind of network, with the ultimate aim of comparing the findings to that of the fibre optic network.

3.1.4 Data collection

Data collection is a crucial process in an attempt to answer the research questions. The data collection process improves the research reliability and integrity because it compares the collected data findings with the collected literature in order to draw a conclusion. Data will be collected on numerous cost factors in order to determine lifecycle cost estimates of both a fibre optic and wireless (LTE) networks.
3.1.5 Cost factors
To be in a position of collecting lifecycle costs associated with our networks, it is imperative to firstly determine possible cost factors. Cost factors aid in placing the cost estimates or expenses on the relevant activities. In chapter 2 it was highlighted that the lifecycle costs of an access network involves four distinct phases, termed: planning, rollout, operation and retirement phase. Subsequently, cost factors associated with all four phases will be deliberated.

3.1.5.1 Planning phase cost factors
The planning phase looks at engaging cost forecasters to produce reliable estimates on the anticipated investment and bill of material. The planning phase also includes the cost of network design and the choice of technology and network configuration. It is therefore expected that data be collected on the costs of expert human resources, such as network planners and cost estimators (Casier, et al., 2008). Data will also be collected that relates to the costs of tools of the trade which will be utilised by the network planners e.g. mainframes, network test equipment and planning software which will aid in designing and simulating the network. Although it must be noted that the cost of network planning is commonly seen as cost that is proportional to the total cost of the most cost intensive lifecycle phase, which is the rollout phase (Casier, et al., 2008).

3.1.5.2 Rollout phase cost factors
In chapter 2, it was acknowledged that the rollout phase of the network is the most expensive phase because this is where most of the costs are incurred. A process was therefore undertaken in quantifying all relevant cost factors associated with this stage of the lifecycle.

3.1.5.2.1 Fibre optic rollout phase cost factors
To be in a position to estimate the rollout cost of an FTTH-connected home, the following cost factors were taken into consideration:

- The cost of trenching and duct deployment in the feeder and distribution segments (Schneir & Xiong, 2016).
• The cost of street cabinet equipment (City of Santa Cruz, California, 2015) and the cost of connection (Schneir & Xiong, 2016).

• The cost of central office equipment which includes electronics and material (City of Santa Cruz, California, 2015).

• The cost of CPE (customer premises equipment). Installation, cabling and electronics (City of Santa Cruz, California, 2015).

• The cost of central office housing, power supply and cooling. These include: Housing infrastructure, uninterrupted power supply system and lastly ventilation and air-conditioning (Maina, 2015).

3.1.5.2.2 Wireless LTE rollout phase cost factors

The rollout phase of wireless network relates to the following cost factors:

• The cost of housing, power supply and cooling, which includes the cost of base station site lease/ownership, physical infrastructure, standby power supply and cooling system (Johansson, et al., 2004).

• The cost of civil and base station installation works required before installing the base station equipment (Oughton12, 2016).

• The cost of labour and material required to install and commission the base station (Oughton12, 2016).

• The cost of the wireless base station equipment, which includes the cost of the radio equipment as well as the cost of the transmission equipment (Johansson, et al., 2004).

• The cost of spectrum and licensing for the base station (DotEcon Ltd, 2017).

• The cost of base station transmission (Oughton12, 2016).

3.1.5.3 Fibre optic and wireless (LTE) operation phase cost factors

The costs factors that relate to the operation of a network is considered the lengthiest phase of the network lifecycle. The operation phase of the network lifecycle relates to
OPEX (operational expenditure costs) and includes the following cost factors (Casier, et al., 2008).

### 3.1.5.3.1 Fibre optic

- The first fibre optic operation cost amounts to 10% of the actual rollout cost of trenching and duct deployment. This relates to maintenance of fibre trenches and ducts.

- The second operation cost amounts to 50% of central office equipment and CPE equipment costs. This relates to maintenance of all related network active equipment.

- The third operation cost amounts to 10% of physical infrastructure costs. This relates to the cost of central office housing, manholes, power supply and cooling.

- The last fibre optic operation cost amounts to 25% of cost of the street cabinet equipment. This relates to the cost of maintaining the network passive equipment.

### 3.1.5.3.2 Wireless (LTE)

- The first wireless (LTE) operation cost amounts to 25% of cost of base station civil works, standby power and cooling. This relates to maintenance of passive equipment and their associated labour.

- The second operation cost amounts to 50% of cost of base station equipment, transmission and base station controller. This relates to the maintenance of the active equipment on the network.

- The last operation cost amounts to 10% of physical infrastructure costs. This relates to the base station housing and tower maintenance.
3.1.5.4 Fibre optic and wireless (LTE) retirement phase cost factors

The two broadband networks under evaluation are planned to last for a period of at least 10 years. After that period, the networks will need to be decommissioned and/or upgraded. There are several cost components associated with a network retirement that has to be taken into consideration in order to determine the overall network lifecycle costs, and as a result, below are some of the cost factors (IAEA, 2005):

- Cost of network decommission.
- Cost of recovering obsolete active and passive devices.
- The costs of processing items out of inventory.
- The cost of migrating, disposing of or recycling the network components.

However, retirement costs are generally calculated as 25% of the passive and active network equipment costs.

3.1.6 Fibre optic and wireless (LTE) cost factors tables presentation

On this section of the chapter both the fibre optic network and the wireless (LTE) cost factors under evaluation will be presented using tables.

3.1.6.1 Fibre optic cost factors table

The table below presents all related cost factors that will form part of a fibre optic lifecycle cost evaluation. The table also includes the equations that will be utilised to calculate the cost estimates for the various cost factors. Lastly, the table contains sources where the cost factors were retrieved from.
Table 3 Fibre optic lifecycle cost factors

<table>
<thead>
<tr>
<th>Lifecycle cost factors</th>
<th>LCCA Phase</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rollout phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of trenching and duct deployment</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Schneir &amp; Xiong, 2016)</td>
</tr>
<tr>
<td>Cost of Street cabinet &amp; connection works</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(City of Santa Cruz, California, 2015),(Schneir &amp; Xiong, 2016)</td>
</tr>
<tr>
<td>Cost of central office equipment</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(City of Santa Cruz, California, 2015)</td>
</tr>
<tr>
<td>Cost of CPE installation, cabling &amp; electronics</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(City of Santa Cruz, California, 2015)</td>
</tr>
<tr>
<td>Cost of central office housing, power supply and cooling</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Maina, 2015)</td>
</tr>
<tr>
<td><strong>Planning Phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % of Rollout costs</td>
<td>( C_1 = C_2 \ast 10% )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td><strong>Operation phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% of central office equipment CPE</td>
<td>( C_3 = 50% \ast \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>10% of Cost of central office housing, power supply and cooling</td>
<td>( C_3 = 10% \ast \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>25% of cost of the street cabinet equipment</td>
<td>( C_3 = 25% \ast \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>10% Cost of trenching and duct deployment</td>
<td>( C_3 = 10% \ast \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td><strong>Retirement phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25% of passive and active network equipment costs</td>
<td>( C_4 = \frac{1}{4} \ast \sum_{i=1}^{n} u_i Q_i )</td>
<td>(IAEA, 2005)</td>
</tr>
</tbody>
</table>

From the table presented above, it is quite apparent that the rollout phase of the lifecycle is central to the full lifecycle cost calculation. This is because the rest of the lifecycle phases are a proportion of this phase.

### 3.1.6.2 Wireless (LTE) fibre optic cost factors table

Table 4 is a presentation of all relative cost factors that will form part of a wireless (LTE) lifecycle cost evaluation. The table also consists of equations derived from equation 2-1 that will be used to calculate the cost estimates for the various cost
factors. Finally, the table includes the references of the different cost factors included in the table.

Table 4 Wireless (LTE) lifecycle cost factors

<table>
<thead>
<tr>
<th>Lifecycle cost factors</th>
<th>LCCA Phase</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rollout phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of base station housing and tower</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Johansson, et al., 2004)</td>
</tr>
<tr>
<td>Cost of base station civil works, standby power</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Oughton12, 2016)</td>
</tr>
<tr>
<td>and cooling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of material and labour to install base</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Oughton12, 2016)</td>
</tr>
<tr>
<td>station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of base station equipment</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Johansson, et al., 2004)</td>
</tr>
<tr>
<td>Cost of licensing and spectrum/ base station</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(DotEcon Ltd, 2017)</td>
</tr>
<tr>
<td>Cost transmission and base station controller</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>(Oughton12, 2016)</td>
</tr>
<tr>
<td>termination x 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Planning Phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % of Rollout costs</td>
<td>( C_1 = C_2 \times 10% )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td><strong>Operation phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 % of cost of base station equipment,</td>
<td>( C_3 = 50% \times \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>transmission &amp; base station controller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % of cost of base station housing and tower</td>
<td>( C_3 = 10% \times \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>25 % of cost of base station civil works,</td>
<td>( C_3 = 25% \times \sum_{i=1}^{n} u_i Q_i )</td>
<td>(Casier, et al., 2008)</td>
</tr>
<tr>
<td>standby power and cooling</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Retirement phase</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25% of passive and active network equipment</td>
<td>( C_4 = \frac{1}{4} \times \sum_{i=1}^{n} u_i Q_i )</td>
<td>(IAEA, 2005)</td>
</tr>
</tbody>
</table>
The table presented above highlights that the rollout phase of the wireless (LTE) consist of five cost factors. Three of the cost factors are active equipment and consist of cost of base station equipment, transmission and base station controller.

3.1.7 Cost estimates
The cost estimation process allows us to determine the lifecycle cost of each phase of the project with its related activities. Through the cost estimation process, a variety of cost factors can finally be quantified into actual cost figures (Meredith, 2011). This process will however be undertaken in the subsequent results and analysis chapter.

3.1.8 Data collection method

There are two known data collection techniques to choose from, namely: primary and secondary data collection techniques. Below is a framework of how data were collected and data collection techniques used throughout each phase of the lifecycle.

3.1.8.1 Planning phase data collection methods

Data that relate to the cost estimates and cost factors associated with the network planning phase were collected through academic and industry literature. Through this literature, we learned that the cost of network planning could be seen as a cost that is proportional to the total cost of the most cost intensive lifecycle phase. As a result, literature was also collected on the degree or amount of the proportion in relation to the two broadband technologies under review.

3.1.8.2 Rollout phase data collection method

Data that relate to the cost of material cost and network equipment cost will be collected through literature. Consequently data associated with infrastructure, licensing or trenching and link integration costs will also be collected by means of literature.

3.1.8.3 Operation phase data collection method

Collection of data that relate to the network cost factors and estimates at this phase of the lifecycle will be collected through academic and industry literature. As already
stated, the cost of maintenance and repair is said to be proportional to the cost of active and passive equipment.

3.1.8.4 Retirement phase data collection methods

Network providers are advised, as matter of good practise to budget for costs that will be incurred in recovering either old redundant network elements or the entire network as a whole. The data collection method to collect retirement costs will be in the form of literature. It must be noted that recovery costs are occasionally calculated as a fraction of the installation costs (Casier, 2008).

3.1.8.5 Selected data collection method

As a result of the above identified cost factors and estimates that have been collected through literature, the most appropriate data collection method will be a secondary data collection method. Secondary data collection method is fit for our research because our research does not rely on primary empirical data. Secondary data can be defined as data that have been previously gathered. This data could be in form of either industry reports or other scholars’ studies (Cooper & Schindler, 2011).

3.1.9 Nature of selected research method

The type of research study used in our research is a cost comparative study. This work seeks to answer our research questions by exploring facts behind the costs of fibre network rollout in South African rural areas. The research also investigates cost factors and their subsequent cost estimates which have significant cost implications on the deployment of these networks in South African rural areas. The research presents a study by determining network rollout costs of both fibre and wireless LTE technologies. It is important to compare the lifecycle costs in order to determine the most cost-effective broadband alternative to deploy in South African rural areas.

3.2 Research strategy

Research strategy constitutes a method used when collecting, measuring and analysing data (Cooper & Schindler, 2011). It further assists the researcher in allocation of limited resources by posing crucial choices in methodology.
Based on the nature of our research, the most fitting research strategy to be adopted in our research will be a quantitative method. Quantitative research is best defined as a structured technique of gathering and analysing data by making use of mostly statistical and quantifiable data (Cooper & Schindler, 2011). The reason for this research method as a preferred option for our research is because our research employs a comparative study from the quantified costs findings of the two broadband technologies in order to establish the most cost-effective alternative. From the comparative study, it will be established whether a fibre access network in South African rural areas is in fact cost-effective.

3.3 Conclusion

The main aim for the chapter was to present how the research process is carried out. The chapter outlined a detailed research method process, where each process was introduced and each activity quantified. The chapter also described the logic behind the selection of the method used to collect data and the research strategy that will be employed.
CHAPTER 4: RESULTS AND ANALYSIS

This chapter presents the results of the cost comparison between the two broadband alternatives for a rural access network rollout. The cost factors data collected in the previous chapter will be linked to their respective cost estimates to ascertain the full lifecycle cost of each alternative. After the completion of the cost estimation process, the research findings will be analysed and the alternative with the lowest lifecycle cost highlighted. Through comparing the lifecycle costs, the cost-effectiveness of a fibre optic access network rollout in South African rural areas will be proven.

4.1 Cost estimates

With the cost estimation process, the cost of each activity of a fibre optic network and of a wireless (LTE) network will be collected through available secondary data. This process will put us in a position to determine the alternative with the least lifecycle costs. With the findings we will be in a position to evaluate if a fibre optic network rollout is cost-effective or not, based on the findings of the complete lifecycle cost evaluation process.

4.1.1 Planning phase cost estimates

The cost of planning is estimated to be around 10% of the rollout costs. (Casier, et al., 2008). This is captured in table 3 and 4 of chapter 3.

4.1.2 Rollout phase cost estimates

This section of the chapter will introduce the costs estimates of the lifecycle rollout phase of both the fibre optic and wireless (LTE) networks.

4.1.2.1 Fibre optic Rollout phase cost estimates

The cost estimates for a rural fibre optic network deployment are projected as follows:

- The cost of trenching and duct deployment in the feeder and distribution segments was €65/m and €50/m in the drop segment (Schneir & Xiong, 2016). As a result, the average cost of trenching and duct deployment may be estimated to be €60/m.
• The cost of a street cabinet equipment is estimated to be around $56000 (City of Santa Cruz, California, 2015), while the cost of street cabinet connection in the FTTH fibre network architectures is estimated at €140 (Schneir & Xiong, 2016).

• The cost of central office equipment which includes electronics and material is estimated to be around $600,000 per site (City of Santa Cruz, California, 2015). The bill of material in the central office includes:
  1. Fibre Patch panels
  2. Fibre Splice tray
  3. Fibre Patch cords
  4. Fibre Connectors
  5. Equipment Cabinet
  6. Fibre adapter Panel
  7. Fibre terminal Consumables

• The cost of Customer Premises Equipment installation, cabling and electronics is estimated to be around $455 per subscriber (City of Santa Cruz, California, 2015).

• The cost of central office housing, power supply and cooling. These include: Housing infrastructure, uninterrupted power supply system and lastly ventilation and air-conditioning. For our research we'll consider a 2.5 X 4 size room that is estimated to cost around $13,328.25 (Maina, 2015).

• These values will be presented in Table 5.

4.1.2.2 Wireless (LTE) rollout phase cost estimates

The cost of deploying a rural wireless (LTE) base station is projected to be around the following cost estimates:
- The cost of the base station housing and tower, which includes the cost of the base station’s site lease/ownership, physical infrastructure, is estimated to be around €70,000 (Johansson, et al., 2004).
  
- The cost of the base station civil works, standby power and cooling. This includes the cost of installation works required before installing the base station equipment which is estimated to be £18,000 per site (Oughton12, 2016).
  
- The cost of labour and material required to install and commission a single base station is estimated to be around £40,900 (Oughton12, 2016).
  
- The cost of base station equipment, which includes the cost of the radio equipment as well as the cost of the transmission equipment. The cost of a single macro base station radio equipment is estimated to around €70,000, while the cost of the transmission equipment is estimated to be around €28,000 (Johansson, et al., 2004).
  
- The cost of the spectrum and licensing per base station is estimated to be around €10,000 for 10 years (DotEcon Ltd, 2017).
  
- The cost of transmission for a rural 3a geo-type base station which has a total link distance of 10 km to the BSC (base station controller) is estimated at around £20,000 per kilometre (Oughton12, 2016).
  
- These values will be presented in Table 6.

4.1.3 Fibre optic (FTTH) and wireless (LTE) operation phase cost estimates
In order to estimate the operation costs, the following mark-up values were applied to the rollout (CAPEX) costs, which in return gave us an annual operation cost estimate (Casier, et al., 2008):

- The cost of maintenance and repair which includes preventative & corrective maintenance costs.

- The cost of network management.
The cost of floor space and energy consumption.

These costs are generally believed to be a proportion of the cost of the equipment, which generally amounts to 50% of the active equipment costs, 25% of the passive equipment costs and 10% on physical infrastructure costs i.e. Shelves and housing.

4.1.4 Fibre optic (FTTH) and Wireless (LTE) retirement phase cost estimates

In estimating the network decommissioning costs, we followed an industry cost estimating methodology highlighted by the Association for the Advancement of Cost Engineering International (AACEI), which estimate project decommissioning costs to be around 25% of passive and active equipment costs (IAEA, 2005). The cost of network retirement includes:

- The cost of network decommissioning.
- The cost of network recovery.
- The cost of processing items out of inventory.
- The cost of migrating, disposing or recycling.

4.1.5 Lifecycle cost estimates tables

Below are the full lifecycle costs estimation tables that encompass all costs throughout the life of the two broadband technologies under evaluation. The calculations are based on the South African currency (ZAR), and convention rates are as follows: USD to ZAR = 13.5, EUR to ZAR= 15.9 and GBP to ZAR= 17.89 converted on the 16/10/2017.

4.1.5.1 Fibre optic lifecycle cost estimation table

Similar to Table 3 in the previous chapter, Table 5 below presents all related cost factors that formed part of a fibre optic lifecycle cost calculation. The difference between the two tables is that Table 5 includes the actual cost estimates and the method of calculations used to obtain them. In chapter 3 when introducing the cost model, it was stated that network providers will require around 50 kilometres of
trenched fibre and that our fibre optic network architecture was assumed to contain 1 central office and a total of 2 street/distribution cabinets sufficient to serve 300 potential subscribers with 35% take rate.

Table 5 Fibre optic lifecycle cost estimation table

<table>
<thead>
<tr>
<th>Fibre Lifecycle cost factors</th>
<th>Cost derivation</th>
<th>Calculations</th>
<th>Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollout phase</td>
<td>Currency rate convention</td>
<td>( C_2 = \sum_{i=1}^{n} u_i Q_i ) [2-1]</td>
<td>( R4700000 )</td>
</tr>
<tr>
<td>Cost of trenching and duct deployment</td>
<td>( €60/m \times 15.90 = R954/m )</td>
<td>( (R954/m) \times 50 \text{KM} )</td>
<td>( R47700000 )</td>
</tr>
<tr>
<td>Cost of Street cabinets &amp; street cabinets connection works</td>
<td>( ($560000 \times \frac{13.5}{15.9} = R756000) + (€140 \times 15.9 = R2226) )</td>
<td>( (R756000 \times 2) + (R2226 \times 2) )</td>
<td>( R1516452 )</td>
</tr>
<tr>
<td>Cost of 1 central office equipment</td>
<td>( $600,000 \times 13.5 = R810000 )</td>
<td>( R810000 \times 1 )</td>
<td>( R8100000 )</td>
</tr>
<tr>
<td>Cost of 300 Customer Premises Equipment, installation &amp; cabling</td>
<td>( $455 \times 13.5 = R6142 \times 300 \text{homes} )</td>
<td>( R6142 \times 300 )</td>
<td>( R1842750 )</td>
</tr>
<tr>
<td>Cost of central office housing, power supply and cooling</td>
<td>( $13328.25 \times 13.5 = R179931 \times 1 )</td>
<td>( R179931 \times 1 )</td>
<td>( R179931 )</td>
</tr>
<tr>
<td>Sub Total</td>
<td>( C_2 )</td>
<td>( C_2 )</td>
<td>( R59339133 )</td>
</tr>
<tr>
<td>Planning Phase</td>
<td>Cost breakdown</td>
<td>( C_1 = C_2 \times 10% )</td>
<td>( 0.10 \times )</td>
</tr>
<tr>
<td>10 % of Rollout costs</td>
<td>10% of ( C_2 )</td>
<td>( 0.10 \times )</td>
<td>( R59339133 )</td>
</tr>
<tr>
<td>Sub Total</td>
<td>( C_1 )</td>
<td>( C_1 )</td>
<td>( R59339133 )</td>
</tr>
<tr>
<td>Operation phase</td>
<td>Cost breakdown</td>
<td>( C_3 = x% \times \sum_{i=1}^{n} u_i Q_i )</td>
<td>( 0.50 \times (R8100000 + R1842750) )</td>
</tr>
<tr>
<td>50% of cost of central office equipment &amp; Customer Premises equipment</td>
<td>50% of all active equipment costs</td>
<td>( (0.50)(R8100000 + R1842750) )</td>
<td>( R4971375 )</td>
</tr>
<tr>
<td>10 % of Cost of central office housing, power supply and cooling.</td>
<td>10 % of physical infrastructure costs</td>
<td>( (0.1)(R179931) )</td>
<td>( R17993 )</td>
</tr>
<tr>
<td>25 % of cost of the street cabinet equipment</td>
<td>25% of all passive equipment costs</td>
<td>( (0.25)(R1516452) )</td>
<td>( R379113 )</td>
</tr>
<tr>
<td>10% Cost of trenching and duct deployment</td>
<td>10 % of physical infrastructure costs</td>
<td>( (0.10)(R47700000) )</td>
<td>( R47700000 )</td>
</tr>
</tbody>
</table>
53

Table 5 Fibre optic lifecycle cost estimation table

<table>
<thead>
<tr>
<th>Lifecycle cost factors</th>
<th>Cost derivation</th>
<th>Calculations</th>
<th>Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollout phase</td>
<td>Currency rate convention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of base station housing and tower</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td>C2</td>
<td>R70,000 x 15.9 = R1113,000 = R1 113 000 x 1 = R1 113 000</td>
</tr>
<tr>
<td>Cost of base station civil works, standby power and cooling</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td></td>
<td>R18,000 x 17.89 = R322,020 = R322,020 x 1 = R322,020</td>
</tr>
<tr>
<td>Cost of material and labour to install base station</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td></td>
<td>R40,900 x 17.89 = R731,701 = R731,701 x 1 = R731,701</td>
</tr>
</tbody>
</table>

Convention rates are as follows: USD ($) to ZAR = 13.5, EUR (€) to ZAR = 15.9 and GBP (£) to ZAR = 17.89 converted on the 16/10/2017

From Table 5 presented above, it can be seen that the rollout phase of the fibre optic lifecycle bares the highest costs, amounting to R59 339 133, while retirement phase of the fibre optic lifecycle bares the lowest costs at R2 863 687.

4.1.5.2 Wireless (LTE) lifecycle cost estimation table

Table 6 below presents all related cost factors that formed part of a wireless (LTE) lifecycle cost calculation. Tables 6 also contains the actual cost estimates and the method of calculations used to determine them. From the cost model in chapter 3, it is important to remember that our assessment is based on a single base station with a coverage radius of around 5-10 kilometres and a capacity of around 300-500 simultaneously connected subscribers. The assessment also assumes a transmission link of about 10 km to the nearest network hub site or the BSC (base station controller).

Table 6 Wireless (LTE) lifecycle cost estimation table

<table>
<thead>
<tr>
<th>Lifecycle cost factors</th>
<th>Cost derivation</th>
<th>Calculations</th>
<th>Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollout phase</td>
<td>Currency rate convention</td>
<td>C2</td>
<td>R1 113 000 x 1 = R1 113 000</td>
</tr>
<tr>
<td>Cost of base station housing and tower</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td></td>
<td>R1113 000 x 1 = R1 1113 000</td>
</tr>
<tr>
<td>Cost of base station civil works, standby power and cooling</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td></td>
<td>R322 020 x 1 = R322 020</td>
</tr>
<tr>
<td>Cost of material and labour to install base station</td>
<td>( \sum_{i=1}^{n} u_i Q_i )</td>
<td></td>
<td>R731 701 x 1 = R731 701</td>
</tr>
</tbody>
</table>
### Table 6 Wireless (LTE) lifecycle cost estimation table

<table>
<thead>
<tr>
<th>Cost of base station equipment</th>
<th>(€70,000 x 15.9) = R1 558 200</th>
<th>R1 558 200 x 1</th>
<th>R 1 558 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of licensing and spectrum/base station</td>
<td>€10,000 x 15.9 = R159 000</td>
<td>R159 000 x 1</td>
<td>R 159 000</td>
</tr>
<tr>
<td>Cost transmission and base station controller termination x 10 km</td>
<td>£20,000 x 17.89 = R357 800</td>
<td>R357 800/km x 10</td>
<td>R3 578 000</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td><strong>C2</strong></td>
<td>R 7 461 921</td>
</tr>
</tbody>
</table>

#### Planning Phase

**Cost breakdown**

\[ C_1 = C_2 \times \frac{1}{10} \]

10% of Rollout costs 10% of C2 (0.1 x C2) R 746 192

Sub total **C1** R 746 192

#### Operation phase

**Cost breakdown**

- 50% of cost of base station equipment, transmission & base station controller 50% of all active equipment costs (0.5)(R 3 578 000 + (R 1558 200)) R 2 568 100
- 10% of cost of Base station housing and tower 10% of physical infrastructure costs (0.1)(R 1 113 000) R113 000
- 25% of cost of base station civil works, standby power and cooling 25% of all passive equipment costs (0.25)(R 322 020) R80 505

Sub total **C3** R 2 761 605

#### Retirement phase

**Cost breakdown**

- 25% of passive and active network equipment costs 25% base station works, equipment, transmission and material & labour (0.25)(R 322 020 + R 731 701 + R 1 558 200 + R 3 578 000) R 1 547 480

Sub total **C4** R 1 547 480

**Lifecycle costs(wireless LTE)** **LCC Total** **C1 + C2 + C3 + C4** R 12 517 198

Convention rates are as follows: USD ($) to ZAR = 13.5, EUR (€) to ZAR= 15.9 and GBP (£) to ZAR= 17.89 converted on the 16/10/2017

From the Table 6 presented above similar to Table 5 it is evident that the rollout phase of the lifecycle bares the highest costs, amounting to R 7 461 921, however in Table 6 the planning phase and not the retirement phase of the wireless(LTE) lifecycle bares the lowest costs at R 746 192.
4.1.5.3 Broadband lifecycle cost estimation comparison table

The below table compares the two broadband alternatives under evaluation. The table includes the full lifecycle cost estimates of each alternative.

Table 7 Broadband lifecycle cost estimation comparison table

<table>
<thead>
<tr>
<th>Broadband technology</th>
<th>Lifecycle Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre optic</td>
<td>R 78 275 215</td>
</tr>
<tr>
<td>Wireless LTE</td>
<td>R 12 517 198</td>
</tr>
</tbody>
</table>

From the table above it is clearly visible that the lifecycle cost of a fibre optic network is much higher than that of wireless (LTE) network.

4.2 Lifecycle cost presentation and analysis

In the previous section on cost estimation, we quantified the cost associated with each cost factor and summed up the total costs of each phase of the lifecycle. The process led me in conducting a full lifecycle cost comparison on the rural broadband alternatives under consideration. In this section we will analyse and graphically present the cost evaluation findings.

4.2.1 Rollout phase costs presentation and analysis

The rollout phase is the lifecycle phase where most costs are incurred. We will present a graphical presentation of the analysis of the two broadband alternatives under review at this phase.

4.2.1.1 Fibre optic costs presentation and analysis

Figure 11 is a bar graph highlighting all the rollout phase cost estimates of a fibre optic network.
The above graphical representation on fibre optic rollout costs highlights that the cost of trenching and duct deployment is the highest input cost of the rollout phase, at 73% of the rollout costs, while the cost of housing, power supply and cooling has the least costs of the rollout lifecycle phase, at 0.27% of the total rollout costs.

4.2.1.2 Wireless (LTE) rollout costs presentation and analysis

Figure 12 below similar to Figure 11 is a bar graph highlighting all the rollout phase cost estimates of a wireless (LTE) network.
From the above graphical representation on the costs of wireless (LTE) rollout highlights that the cost of transmission and base station controller is the highest input cost of the rollout phase, at about 48% of the total rollout costs, while the cost of base station civil works, standby power has the least costs of the rollout lifecycle phase, at 4.3% of the total wireless (LTE) rollout costs.

4.2.1.3 Rollout phase costs comparison

The graph below compares the costs at the rollout phase of both the fibre optic and wireless (LTE) network.

![Rollout phase cost comparison](image)

The graph above highlights that the total costs of a fibre optic in the rollout phase in South African rural areas is 795% higher compared to a wireless (LTE) network rollout. From the graph we can see that the cost of rolling out a fibre optic network in South African rural areas is almost eight times higher than that of a wireless (LTE) network.

4.2.2 Operation phase costs presentation and analysis

The operation phase of a network’s lifecycle has the longest duration amongst all lifecycle phases. We will present and analyse the two broadband alternatives under review.

4.2.2.1 Fibre optic operation phase costs presentation and analysis

Figure 14 below is a bar graph highlighting all the operation phase cost estimates of a fibre optic network.
Figure 14 Fibre optic operation phase costs presentation and analysis

The above graphical representation on fibre optic’s operation costs highlights that the cost of maintaining the central office equipment and CPE equipment, calculated as 50% of the cost of the equipment, is the highest, at around 43% of the total maintenance costs. The lowest costs are on the physical infrastructure, because cost of maintenance is only 10% of the cost of the actual infrastructure, resulting to only 0.15% of the total operation costs.

4.2.2.2 Wireless (LTE) operation phase costs presentation and analysis

Similar to Figure 14, Figure 15 below is a bar graph outlining all the operation phase cost estimates of a wireless (LTE) network.
The above graphical representation of wireless LTE’s operation costs highlights that the cost of maintaining the base station equipment, transmission and base station controller, calculated as 50% of the cost of the equipment, is the highest, at around 93% of the total maintenance costs. The lowest cost which amounts to about 3% of the total operation cost is the base station civil works, standby power and cooling costs.

4.2.2.3 Operation phase costs comparison

The graph below compares the cost at the operation phase of both the fibre optic and wireless (LTE) network.

![Operation phase costs comparison](image)

The graph above highlights that the total costs to maintain a fibre optic rollout in South African rural areas is 367% higher compared to that of a wireless (LTE) network. From the graph it is evident that the cost of rolling out a fibre optic network in South African rural areas is almost four times higher than that of a wireless (LTE) network.

4.2.3 Planning phase costs presentation and analysis

The planning phase of a network’s lifecycle is also an equally important phase of the cost evaluation process, because as already stated in chapter 2, this phase involves up front planning of the network which includes the choice of technology that will be employed and the network topology design. Consequently, we will present and analyse the planning costs of the two broadband alternatives under review.
Figure 17 Planning phase costs comparison

The above graph outlines and compares the costs at the planning phase of both the fibre optic and wireless (LTE) network. The graph highlights that the total costs incurred to plan a fibre optic rollout in South African rural areas are very high as compared to that of a wireless (LTE) network. The costs of planning a fibre optic network is 795% higher than the costs of planning a wireless (LTE) network. This is consequently because the planning costs are calculated as 10% of the broadband alternatives rollout costs.

4.2.4 Retirement phase costs presentation and analysis

The retirement phase of a network’s lifecycle is the last phase of the cost evaluation process and also a very important stage. Subsequently, as already stated in chapter 2, this is a stage where the network will have to be retired by disposing of either old redundant network elements or the network in totality. The graph below outlines and evaluates the costs at the retirement phase of the network lifecycle of both the fibre optic and wireless (LTE) network.
The above graph highlights that the total costs to retire a fibre optic rollout in South African rural areas are very high as compared to that of a wireless (LTE) network. The costs of retiring a fibre optic network is 185% more than the costs of retiring a wireless (LTE) network. The reason behind this is because the network retirement costs are calculated at 25% of the broadband alternative’s passive and active equipment costs.

4.2.5 Full lifecycle cost comparison

The next phase of the evaluation process is to compare the full lifecycle costs of both the fibre optic and the wireless (LTE) network. This comparison will help us in determining the cost-effectiveness of a fibre optic network in South African rural areas, because if the network is deemed cost-effective, it has to have lower lifecycle costs than other alternatives.
Figure 19 Full lifecycle cost comparison

From the graph above, which compares the full lifecycle costs of both alternatives, we can deduce that the fibre optic network lifecycle cost in rural is 625% more expensive than a wireless (LTE) network. The lifecycle cost of a fibre optic network in South African rural areas is six times more expensive than a wireless (LTE) network. From this comparison we can also determine that a fibre optic network in South African rural areas is not cost-effective at this stage, as a result of the full lifecycle costs comparison.

4.3 Conclusion

In this chapter we firstly presented the research results by introducing and highlighting the lifecycle cost estimates from the planning phase until the retirement phase of both the fibre optic and the wireless (LTE) network. This process was very critical because it helped link the identified cost factors introduced in chapter 3 with their related cost estimates. This chapter also presented the Lifecycle costs comparison of both alternatives. This crucial process led us into determining the cost-effectiveness of a fibre optic network in South African rural areas. It is however important to remember as stated in chapter 2 that it is vital to incorporate a system effectiveness analysis before concluding the cost-effectiveness of any system. This is because system effectiveness analysis evaluates by including the availability and dependability of a system, which relates to the probability of that system performing its intended designed functions (Blanchard, 2003). The scope of the research however only evaluated cost-effectiveness through a lifecycle cost analysis, and as a result, fibre optic in South African rural areas is seen as not cost-effective because it has higher lifecycle costs when compared to existing wireless (LTE) network in these areas.
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The objective of this chapter is to highlight and reintroduce the research questions with the aim of linking the research findings to the research questions. The process will assist us in formulating an inference to the research. The secondary objective of the chapter is to also provide recommendations to our conclusion so that our research audience can effectively utilise the research. Our primary and secondary research questions highlighted in chapter 1 will as a result be linked with our findings from chapter 2 and chapter 4 respectively. With this detailed process, we will be in a position to provide informed recommendations to the research audience.

5.1 Summary of research questions

In chapter one, we highlighted our research questions which included a primary research question and secondary questions. The following is a brief summary of our research questions as introduced in chapter one:

- Is an optical access network rollout cost-effective for network providers in South African rural areas? This research question is our primary research question and it inquires if a fibre optic networks rollout could be a cost-effective solution for network providers in South African rural areas.

- What are the network provider’s lifecycle costs, compared with other broadband technologies in South African rural areas with regard to network planning, installation, maintenance and recovery? This is our secondary question and it probes further to explore the network provider’s lifecycle costs, which were to be compared with other broadband technologies in South African rural areas.

5.2 Summary

The findings of the research were collected and presented in both chapter two and four, mostly through the literature review. Below is a summary of the research findings in relation to research questions and investigations:
5.2.1 Secondary research question findings

The secondary research question investigated the network provider’s fibre optic network lifecycle costs. These costs were as a result compared with other broadband technologies in South African rural areas, such as wireless LTE network. In our cost-effectiveness comparison process, we came to the following findings:

- Fibre optic network lifecycle costs in rural is 625% more expensive than a wireless (LTE) network.

- The lifecycle costs of a fibre optic network in rural at R78 275 215 is six times more expensive than the lifecycle cost of a wireless (LTE) network at R12 517 198.

- It has also been determined through the cost comparison process that the cost of trenching and duct deployment was the highest amongst the fibre optic cost factors, while the cost of transmission and base station termination was the highest amongst wireless (LTE) cost factors.

5.2.2 Primary research question findings

The primary research question as highlighted in chapter one questioned if a fibre optic access network deployment is a cost-effective solution for network providers in South African rural areas. The findings to the research question were observed in chapter four and below are some of the key findings:

- From the lifecycle cost comparison process we could determine that a fibre optic network rollout in South African rural areas is not cost-effective.

- The reason for a fibre optic access network not being a cost-effective solution for South African rural areas is because it has higher lifecycle costs in comparison with other existing broadband technology such as a wireless (LTE) network. The lifecycle costs of a fibre optic network in rural is six times more expensive than a wireless (LTE) network.
The primary research question which queried the cost-effectiveness of fibre optic access network in South African rural areas was sufficiently answered by the above findings. As already highlighted, the above findings derive their judgements on findings from the secondary research question.

5.2.3 Cost-effective technologies to rollout in rural areas

It was also important to collect data on the most cost-effective optical access network’s systems or configurations to roll out in rural areas. The findings to this investigation were outlined in the literature review chapter by highlighting several cost-effective fibre optic technologies. Below are the key findings:

- PON uses cost-effective splitters to split the traffic to at least 32 subscribers. PONs make use of low maintenance and low cost components to split one incoming traffic line into 32 traffic lines that can be connected to subscribers. This is seen as a cost-effective system which is well suited for rural areas because it reduces costs by decreasing the amount of fibre and trenching that is required.

- EPON allow longer cable routing of around 60 kilometres between active devices. E-PONs make use of special components to achieve extended transmissions between service providers’ devices, thus saving on the number of devices required on the network. Although little data exist on E-PONs because they are fairly new, they are viewed as cost-effective because they reduce the number of devices on the network.

- RoFSO uses free space to transmit optical signals. When employing RoFSO, no digging and trenching is required. The advantage of free space optics as a communication medium is the ease of network deployment, reduced cost of deployment due to the fact that no trenching and digging is required. However, RoFSO are also not widely used and as a result very little data exist about them.
The systems above as highlighted in chapter two are the cost-effective fibre optic systems and configuration to deploy in rural areas. The systems when deployed effectively could greatly reduce the high lifecycle cost already identified.

5.3 Conclusion

For us to be in a position to successfully conclude the research, I will have to verify if the research has managed to give light to our research problem. Accordingly, our problem as highlighted in chapter one was outlined as follows: Fibre optic access network as a rural broadband access solution is accredited to the high installation costs associated with long distance digging and trenching. This is because rural areas have low density of people and are remote, making it very difficult for service providers to achieve economy of scale amid the perceived high costs of rollout. Subsequent to the above problem statement, it is imperative that we highlight findings in our research that is related to our research problem. Below were some of the findings in connection with the research problem:

- The cost of deploying a fixed network in the South African rural areas and remote areas is on average 80% higher than the cost of deployment in urban areas (Schneir & Xiong, 2016).

- Fibre optic rollout costs highlight that the cost of trenching and duct deployment is the highest input cost of the rollout phase, at 73% of the rollout costs, while the cost of housing, power supply and cooling have the least costs of the rollout lifecycle phase, at 0.27% of the total rollout costs (Casier, et al., 2008).

The above findings validate our research problem statement as outlined in chapter 1. The first finding relates to the cost comparison between rural and urban deployment and highlights that the cost of deploying a fixed network such as fibre optic is much higher in South African rural areas as compared to the rollout thereof in urban areas. The second research finding sheds light onto the reason behind the high installation costs and as a result, validates that the cost of fibre optic digging and trenching is indeed the highest input costs of the actual network rollout, amounting to 73% of the rollout costs.
5.4 Recommendations

The use of fibre optic as a medium of communication is very attractive, due to the fact that fibre optic has many inherent advantages such as low forward and return losses which increase the technologies’ reliability. Another attractive characteristic is that fibre optic has high power handling capability which results in higher transmission rates being transported (Toms, 2007). Although fibre optic networks seem ideal, they come with a certain price tag. The objective of this research was to query their cost-effectiveness in South African rural areas. Our research findings as outlined in chapter four found that a fibre optic access network deployment in rural is not cost-effective when compared to a wireless (LTE) network.

The main reason why fibre optic networks were not cost-effective was accredited to the extensive digging and trenching that comes with deploying them. It is quite evident that if the amount of digging and trenching is reduced, their cost-effectiveness will be proportionally increased. It is recommended that a mixed structure, architecture, or even technologies be considered when deploying broadband in rural areas. Thus, the following broadband deployment strategies could be considered:

- Fibre optic links could be utilised as backbone interconnection links for wireless networks in rural areas.

- An aerial fibre network can be used in these areas instead of trenched fibre to save on digging and trenching costs. The aerial fibre network could as a result share its infrastructure with other utility networks such as the electricity network.

- Instead of utilising PON, E-PON should be considered in order to save on a number of active devices in the network. This approach could also help in bridging the deployment cost difference between rural and urban areas which is said reported to be on average 80% higher in rural areas.

- Network providers must collaborate and share the fibre optic infrastructure in these areas in order to reduce the network deployment costs.
The above recommendations should be considered when attempting to deploy a fibre optic network in rural areas. These options are highlighted because the research determined through an activity based lifecycle cost model that an all exclusive fibre network is not cost-effective in rural areas.

5.5 Research conclusion

In chapter four, an evaluation process was carried out to compare the full lifecycle costs of both the fibre optic and the wireless (LTE) network. The comparison assisted us in determining the cost-effectiveness of a fibre optic network in South African rural areas. The reason behind the cost-effectiveness test was to test whether a fibre optic network had lower lifecycle costs in comparison with other alternatives.

The evaluation process subsequently compared the full lifecycle costs of both a fibre optic and the wireless (LTE) network. As a result, through the process it could be deduced that a fibre optic network rollout in rural was not cost-effective because the lifecycle costs were considerably higher than that of a wireless (LTE) network. From the lifecycle cost findings in chapter four we could also determine that a fibre optic network rollout in rural was at least six times more expensive than that of a wireless (LTE) network.
References


Kim, B., Lee, W. & Han, J. (2010). Long-reach passive optical networks for rural and remote areas. In Optical Internet (COIN), 2010 9th International Conference (pp. 1-3). IEEE.


Tahon, M., et al. (2011). *Cost allocation model for a synergetic cooperation in the rollout of telecom and utility networks*. Telecommunication, Media and Internet Techno-Economics (CTTE), 10th Conference (pp. 1-7). VDE.


