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THE COST-EFFECTIVENESS OF FIBRE OPTIC TECHNOLOGY DEPLOYMENT IN RURAL AREA: A CASE STUDY OF MDANTSANE

O custo efetivo da implantação de tecnologia de fibra óptica na área rural: um estudo de caso da Mdantsane

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ABSTRACT

Studies have shown that the majority of the global population are migrating from rural to urban areas. People are leaving rural areas due to poor services such as poor broadband service. Fibre optic technology has been introduced as a solution to poor broadband quality. However, as a result of the peculiar characteristics of South Africa's rural areas, the majority of the telecommunication operators are hesitant to invest in ICT in rural areas because it tends to be much less profitable. Hence, the study of how cost-effective it would be to deploy a fibre optic network in rural areas as compared to the current wireless (LTE) network remains an open issue. This study investigates the cost-effectiveness of deploying a fibre optic network in the rural area of Mdantsane township, by analysing the installation and operation costs of fibre optic networks in comparison to the cost of wireless (LTE) networks. The finding of the study amongst others showed that while fibre optic networks seem to be great, however, they come at a cost. The cost of drilling and trenching associated with the deployment of fibre optic networks was reported as the key reason why the network deployment is costly. Hence, reducing the cost of drilling and trenching would reduce the cost significantly. The study suggests that, to lower fibre optic deployment costs, network operators should collaborate and share costs through a customised pricing model that benefits both the operators and rural internet users.
K**eywords:** Fibre optic, Deployment, Broadband, Networking**.**

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O CUSTO EFETIVO DA IMPLANTAÇÃO DE TECNOLOGIA DE FIBRA ÓPTICA NA ÁREA RURAL: UM ESTUDO DE CASO DA MDANTSANE

The cost-effectiveness of fibre optic technology deployment in rural area: a case study of Mdantsane

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RESUMO

Estudos têm mostrado que a maioria da população global está migrando de áreas rurais para áreas urbanas. As pessoas estão deixando as áreas rurais devido a serviços precários, como serviço de banda larga precário. A tecnologia de fibra óptica foi introduzida como uma solução para a baixa qualidade de banda larga. No entanto, devido às características peculiares das zonas rurais da África do Sul, a maioria dos operadores de telecomunicações hesita em investir em TIC nas zonas rurais porque tende a ser muito menos rentável. Portanto, o estudo de quão econômico seria implantar uma rede de fibra óptica em áreas rurais em comparação com a rede sem fio atual (LTE) permanece uma questão em aberto. Este estudo investiga o custo-benefício da implantação de uma rede de fibra óptica na área rural do município de Mdantsane, analisando os custos de instalação e operação de redes de fibra óptica em comparação com o custo de redes sem fio (LTE). A descoberta do estudo, entre outros, mostrou que, embora as redes de fibra óptica pareçam ótimas, elas têm um custo. O custo de perfuração e abertura de valas associado à implantação de redes de fibra óptica foi relatado como a principal razão pela qual a implantação da rede é cara. Portanto, reduzir o custo de perfuração e abertura de valas reduziria o custo significativamente. O estudo sugere que, para diminuir os custos de implantação da fibra óptica, as operadoras de rede devem colaborar e compartilhar custos por meio de um modelo de precificação customizado que beneficie tanto as operadoras quanto os usuários rurais de internet.

Palavras-chave: Fibra óptica, Desdobramento, Desenvolvimento, Banda Larga, Rede.

INTRODUCTION

The introduction of fibre optic networks in telecommunication access networks would be needed to meet the rising network demands in the upcoming years. When compared to conventional access networks, fibre-to-the-home (FTTH) networks can provide more capacity and thus new services to customers. (Tahoo et al, 2015). Telecom is a fast-evolving sector where new applications can swiftly take over and provide ever-richer services, but it also requires ever-increasing bandwidth. Many existing access network infrastructures that use DSL (Digital Subscriber Line) or HFC (Hybrid Fibre Coax) technology are experiencing significant bandwidth shortages. To provide existing high-end services such as HDTV, online video meetings, 3D TV, and online gaming, as well as to prepare for future more demanding services (such as 4K TV, videophones, and thin clients), a cost-effective FTTH network is required (Verbrugge et al, 2017). Fibre-to-the-home (FTTH) is a technology that connects the home to a high-speed network using an optical fibre cable to provide data, voice, and video services (Mohammadani et al, 2020). It is considered the broadband of choice because of the potential to improve bandwidth to the residential home and because it is a future-proof technology with improved network reliability and the advantage of enhancing the openness of the residential home (Ntsandeni, 2018).

Provisioning of high-speed rural Internet access is associated with higher incomes and decreased unemployment by expanding remote job opportunities and the potential to expand online brick and mortar businesses (Whitacre et al, 2014). Although high monthly prices influence use, there are also questions regarding hardware prices, secret fees, transparency of pricing, quality of service, and availability (Whitacre et al, 2014). Governments have a critical role in providing universal access to Internet services, creating an enabling environment for infrastructure development and competition, and establishing a regulatory framework that promotes cost reduction, digital literacy, and innovation. (Goldstuck, 2017). Companies were required to construct public switch telephone network services in rural and semi-urban areas around the country as part of the government's mandates, many of which would not have otherwise demonstrated commercially viable to operators in a competitive setting. (Beneke, 2018). In spite of the fact that the companies were initially successful in connecting the masses, the severity of the problem quickly became apparent when it was forced to terminate over two million telephone connections due to non-payment.

According to (Beneke, 2018), telecommunications prices have remained high due to the requirement for cross-subsidization and a lack of competition in the industry. The use of ICTs in the community can help to bridge the digital gap by providing poor residents with access to information and facilities. This type of integration can bring communities together to build a more aware society, strengthen the population, and improve its ability to tackle poverty. In South Africa, old townships are geographically, culturally, and economically diverse as a result of historical social compression in racially segregated areas. Many of the townships include middle and low-income areas, especially larger townships, and also scattered middle-income houses. Yet, socio-economic statistics indicate that the majority of township residents are poor and that there is a very high unemployment rate (Pernegger and Godehart, 2007).

With the rapid growth of digital information technology, (Rametta and Schemba, 2017) found that digital convergence (the incorporation of a combination of all forms of information such as data, voice, and video through convergence terminals and services) is expected to lead to a smart society in which everyone can use customised services anywhere and anytime. Consequently, when comparing the infrastructures of information and communication technology (ICT) in urban and rural areas, there is an ever-widening gap, which contributes significantly to the digital divide. Faster Internet access, security, and the ability to make calls while browsing the Internet are just a few of the benefits. While distance, fragility, low power, higher access rates than dial-up, and lack of connectivity in remote areas are disadvantages (Al-Quzwini, 2014).

Rural area development comes in different ways, different studies clearly showed that the majority of the global population are migrating from rural to urban areas. People are leaving rural areas because of poor services (such as broadband) in the area. Broadband speed and reliability have been part of the most significant measures of service quality in rural areas. Poor broadband quality in a community indicates poor economic development and poor service delivery to the community. Fibre optic technology has been introduced in the literature as a solution to low and poor broadband quality. However, due to the unique characteristics of rural areas in developing nations, the total deployment cost and economic viability of fibre optic technology in rural areas

remain an open issue. Hence, this study investigates the cost-effectiveness (for both the service provider and the end-users) of deploying a fibre optic technology in rural areas as compared to their existing ADSL broadband connection. Mdantsane township, one of the informal settlements in South Africa's Eastern Cape province, is used as a case study. In this study, the researchers explored two questions, which focuses on the major fibre optic network deployment component cost and how this deployment cost can be managed in a rural area environment. To achieve the goal of this study, three objectives were considered:

- To differentiate the costs involved in installing fibre optic technology and the current wireless broadband (LTE) network.
- To assess the user satisfaction with the existing broadband services.
- To identify the challenges faced by the rural communities in accessing their desired internet access.

The remainder of this paper is organised as follows: Section I presents the cost comparison for different network broadband in South Africa, while Section II describe the methodology that was used in this study. In section III, the results of the analysis of data collected were presented, while the study's recommendations and conclusion are outlined in Section IV.

1 COST COMPARISON OF NETWORK BROADBAND IN SOUTH AFRICA

Several factors must be considered while offering internet connectivity and computing facilities in the South African context. Finance, resources, and current facilities are some of the factors, as is the community's desire to embrace and use the facilities. It is vital to research the most cost-effective systems or configurations for fibre-optic access network systems or configurations in remote places. In the context of expected high capital costs, network operators considering installing fibre in rural areas must make the rollout as cost-effective as possible (Jay et al, 2014; Mamabolo et al, 2019). While prepaid mobile voice services in South Africa are still expensive by continental and worldwide standards, the country's mobile data market, which is rapidly becoming a major source of revenue for mobile operators, is fiercely competitive. While prepaid mobile voice services in South Africa are still expensive by continental and worldwide standards, the country's mobile data market, which is rapidly becoming a major source of revenue for mobile operators, is fiercely competitive.

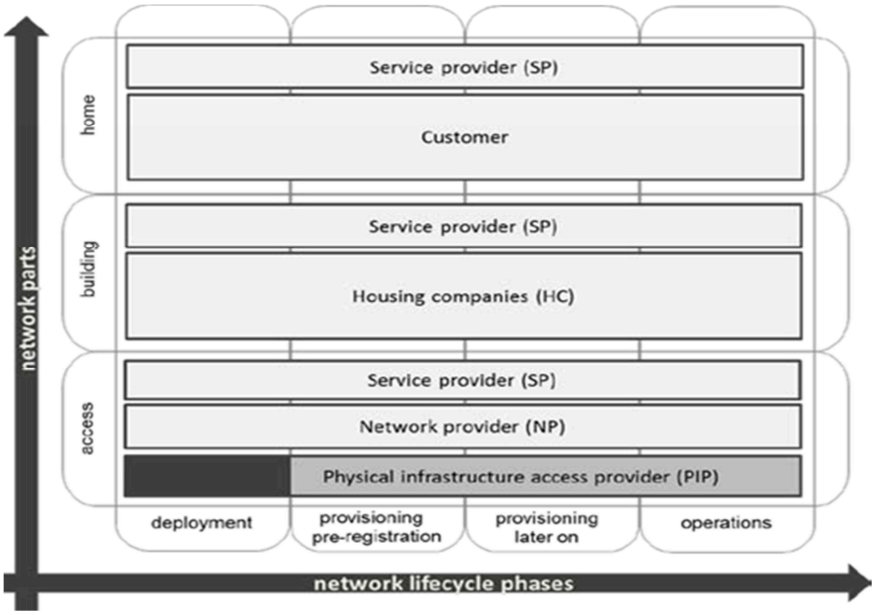
According to evaluations of prepaid and post-paid mobile and ADSL (fixed) broadband RIA price categories, fixed-line packages are (surprisingly) more expensive than comparable mobile packages. Mobile data's appeal in South Africa is also boosted by its lower setup costs and more convenient prepaid charging options, which are especially appealing for low data use and uneven consumption (Gwaka et al, 2018). In South Africa, the cost is still a barrier to widespread broadband acceptance and use. Uncapped Internet services, for example, are still prohibitively costly, and many consumers still rely on restricted plans with monthly data caps as low as 1GB for fixed-line connections and 10 MB for smartphone access. On Very-high-bitrate DSL (VDSL), speeds range from 1Mbps to 40Mbps; the latter is limited to certain areas, and each tier is more expensive. Long Term Evolution (LTE/4G) speeds on mobile networks can exceed 60Mbps in theory, but in reality are closer to 15Mbps (Chetty et al, 2013).

Infrastructure innovation continues to deliver the best and most widespread broadband rollout, especially where cable networks have been formerly used mainly for broadcasting, and telco ADSL or fibre networks coexist. However, in areas where technology, let alone competitive infrastructure, is lacking, such as rural areas of Africa, different policy and regulatory decisions must be taken. Where the cost of duplicating networks is prohibitively high, regulatory action could concentrate on ways to improve service competition by providing equal access to a single network (Esselaar et al, 2010). Public ADSL providers have traditionally avoided using usage pricing models, instead of providing internet coverage at a monthly fixed rate connected to a cumulative volume of data usage. Mobile providers all around the world are also providing usage-based pricing and other specialized packages (Hoffman and de Wet, 2017). Compared to many other countries with comparable economic and social characteristics to South Africa, it has been discovered that internet services in South Africa are very costly. Fixed-line broadband is also somewhat less expensive than mobile broadband, allowing it to retain other people and families that may otherwise have chosen mobile broadband (Moroeng, 2012). The low broadband penetration is thought to be the result of insufficient infrastructure investment due to limited state resources in public companies, as well as high risks associated with sunk investments. (Alison, 2007).

Optical fibre overcomes some of the drawbacks of copper cables, such as their sensitivity to external noise, lightning strikes, and signal loss while conveying data over long distances. As a result, optical fibre is resistant to electrical noise while also being capable of transmitting large amounts of data. These characteristics have influenced telecommunication companies' decision to utilise optical fibres for their backbone network.

Figure 1 demonstrates the various network components, with emphasis on utility (and telecom) access network infrastructures. On the horizontal level, we have foreseen four network lifecycle phases: deployment of the network, provisioning connection (pre-registration or later on) to the customer, and network operations. The actors involved for each party were mapped using this approach. (Tahoo et al, 2015). This study focuses on the network components where the various utility access infrastructure network owners may be able to cooperate. The function of physical infrastructure access providers (PIP) in deploying their networks up to the demarcation point in the building (thus also provisioning pre-registration and later-on connection) and delivering network access and operations is depicted in the lower portion of the diagram (maintenance, repair, etc.). The left side of the PIP, i.e. the actual deployment, is the emphasis of this model, which includes right of way, trenching, ducts, cables, and flexibility points.

Figure 1: Overview of the coordinated national distribution network rollout



There are three types of costs to consider when it comes to cost distribution: direct, shared, and common costs. (Angelou and Economides, 2009). Direct costs are costs that are specific to one actor and are often carried by that actor alone, rather than being shared among multiple actors. Ducts, cables, and flexibility points are common examples of direct costs in infrastructure rollout projects. The cost-sharing model is interested in shared and common costs since they can be split among the various actors involved. The fibre operator might provide different offerings, packages of products, and services. The different products and offerings will have different markets, customers, and positions. Various network operators in South Africa have committed to deploying FTTH in six of the country's major cities (Johannesburg, Durban, Port Elizabeth, Pretoria, Bloemfontein, and Cape Town). Moreover, because the cities listed are relatively developed, network operators may justify designing and implementing these fibre access models. Many South Africans, however, still live in rural areas where fibre access infrastructure is scarce due to socio-economic and geographic constraints. As a result, delivering a customized broadband network that suits the needs of rural demographics will aid in eliminating the digital divide and improving the lives of rural residents.

2 RESEARCH METHODOLOGY

A systematic survey questionnaire was used to collect both qualitative and quantitative data in order to achieve the research's goal. from 105 randomly selected Internet users' residents in Mdantsane and 5 Internet service providers; Herotel, Huge networks, EC Internet, Blaze and Internet Solutions, all of which are situated in the East London area. Mdantsane is one of the townships located around East London in the Eastern Cape province of South Africa. Mdantsane township is an informal settlement, which is largely occupied by very low income and poor people. Hence, the number of Internet users in the area are very small. The questionnaires were distributed among the employed, unemployed, and students around the Mdantsane township.

The researcher employed online questionnaires via a web link as the method for data collection. Surveys are better for this study since they are one of the finest ways to collect data from a large group of people, which is ideal for this type of research. Also, the online survey was selected so as to be able to adhere to the government regulations on the Covid-19 pandemic. In this study, the researcher used the probability sampling method to reach the two groups of participants; the users in rural areas and Internet service providers (ISP) in East London. Probability samples are the gold standard in sampling methodology and for ensuring that the study results are generalizable to the target population. The term "probability sampling" is used to describe how each person in the population has an equal chance of being chosen for the study.

The goal of this study was to see if fibre optic network deployment in rural areas is economically viable for both internet services providers and Internet users. To comment on the technology's cost-effectiveness in rural areas, costs must be evaluated and compared to existing broadband technologies in the area, such as wireless long-term evolution (LTE). Consequently, the price of the two broadband was compared so as to be able to understand their total deployment cost. This would help to recommend the solution that can be adopted to reduce the deployment costs. The survey questionnaire is divided into two major parts; part one explains the opinion of Mdantsane Internet users with regards to their current connectivity and proposed fibre optic technology. While part two present the view of internet service providers regarding the cost of deployment of fibre optic technology in rural areas. The data collected were analysed by first grouping the respondent's answers altogether. Thereafter, the validity test was carried out for each section of the questionnaire to ensure that the data collected are valid before carrying out further analysis on the data. Lastly, the valid data collected was analysed and a statistical and graphical conclusion to the findings were presented.

3 RESULTS AND DISCUSSION

The results are presented in this section using three objectives; the respondents' opinion with regards to their current connectivity and proposed fibre optic technology, the Internet service providers' views regarding the total cost of deployment for both fibre optic and LTE technology in a rural area, and the comparison between the two deployment costs. The data were collected from 105 respondents who are employed, unemployed and students, residing in Mdantsane township. Also, data were collected from 5 Internet service providers in East London, which also covers the Mdantsane area. Diagrams and descriptive statistics are used to report the results.

Figure 2 shows the age distribution of participants. It can be observed that 53.3% of the participants are under age 25 years, while 42.2% of the participants are aged 25-34. 5% of the participants are between the age group 35 – 44 years. This result agrees with the previous study (Seymour et al, 2013; Brian, 2020), which says that the age between 18 – 35 years is the most population that utilizes the Internet connection more than any other age group. These results can be interpreted by the fact that the vast majority of elderly persons in townships and rural areas are subsistence farmers or small-scale traders. Hence, they seldom use Internet services.

The average amount of money spent by the participants on Internet data per week are presented in Figure 3. It can be observed that 9% spend less than R50 per week on internet data, while 31% spend between R50 – R100 on data per week. It can also be observed that 31% spend between R100 – R200 on weekly data, 20% spends between R200 – R300 per week on data. 7% are spending between R300 – R500 per week on data and only 2% claimed to be spending above R500 on Internet data per week. This result agrees with the existing work (Byanyuma et al, 2013), which indicates that the cost of Internet data is high in South Africa as compared to other

developing countries. Many of the respondents complained about the high cost, especially for people in rural areas, which majorly depends on a government grant. However, due to the regulations around the Covid-19 pandemic, they needed to be spending more on data, especially for the children that need to attend and do their school works remotely.

Figure 4 shows the participants rating in terms of internet services price satisfaction. It can be observed that 65% of the respondents are not satisfied (poor and very poor rating) with the amount of money they are paying for internet data, while 33% agreed on the average rating. However, only 2% of the respondents are fine with the current price and 0% for very a good price satisfaction rating. Although different reasons are being given (both by the ICASA and telecommunication industry) as the reason for the current pricing. However, the high cost of internet data is still a big problem for South Africans, especially, the people in the rural areas.

The reliability of internet connection is one of the important factors usually considered by the Internet users when deciding on which network or service provider to choose for their connectivity. Hence, it is important to check whether the price that the users are paying commensurate with the connectivity reliability.

Figure 2: Respondents Age Group

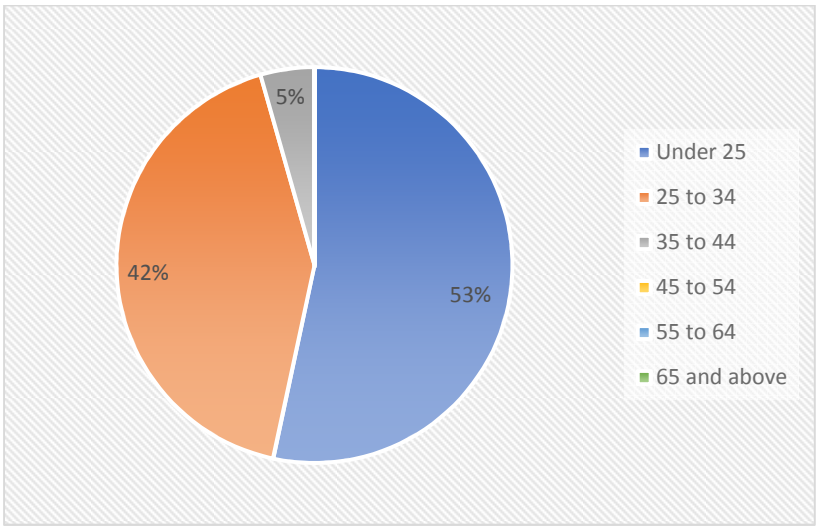


Figure 3: Average amount of money spent on Internet Data per week

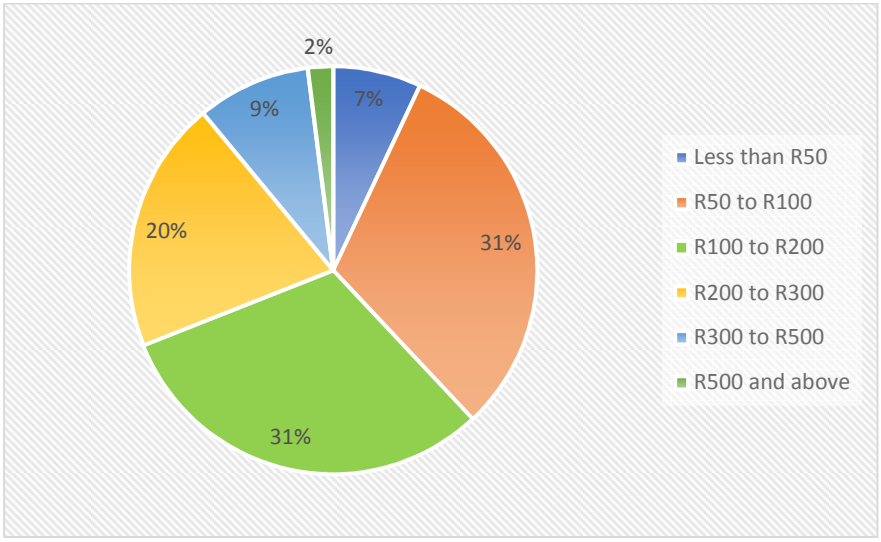


Figure 4: Current broadband Price satisfaction rating

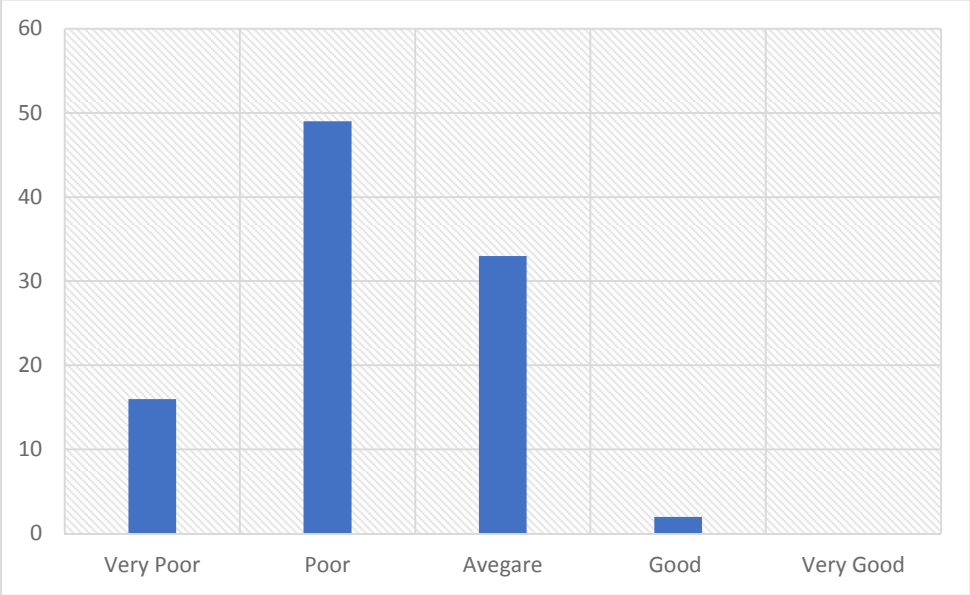


Figure 5 presents the participants rating in terms of Internet services reliability. It can be observed that the 34% of the respondents are not satisfied (poor and very poor rating) with their connection reliability, while 42% are averagely satisfied. 24% of the respondents are satisfied with their connection reliability. Although an average of 66% are satisfied with their connection reliability, however, it is important for the service providers to improve on their connection reliability, so as to increase the number of users that would select their Internet connection service.

Even though the reliability of an internet connection is an important factor, the Internet speed also plays an important role in determining the network provider to choose and in the amount of money the users would be ready to spend on internet services. Figure 6 presents the participants level of satisfaction in terms of internet speed. It can be observed that 70% of the respondents are not satisfied (poor and very poor rating) with their internet speed, especially when compared to the amount of money they are paying for internet data. 24% are averagely satisfied, while only 6% are satisfied with their internet speed. Although, the internet speed varies according to data packages, also the environment can affect the internet speed, especially in rural areas. However, a cost-effective deployment of fibre optic network in such rural areas will greatly enhance the internet speed and connection reliability, which in-turn will help to reduce the existing digital divides between the rural and urban areas.

Figure 5: Current broadband Reliability satisfaction rating

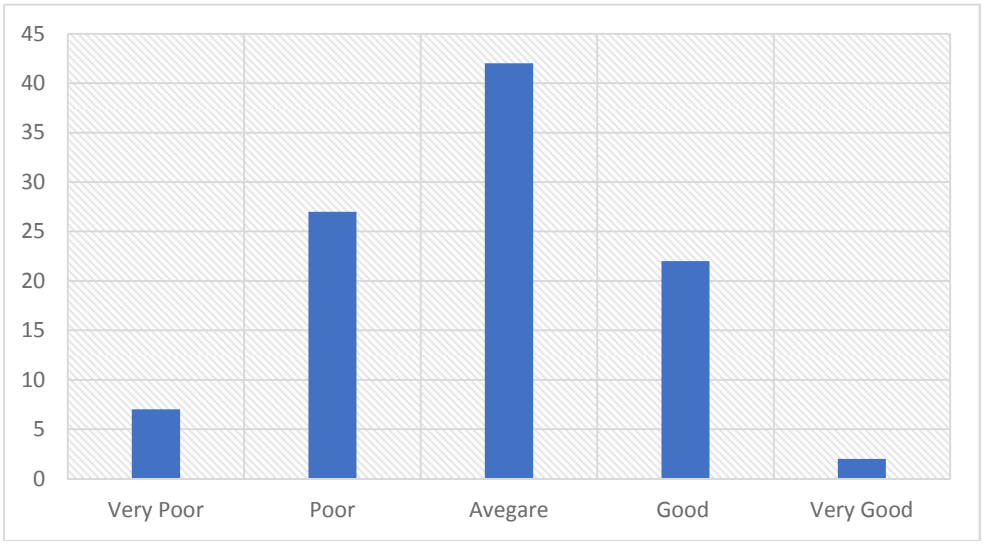
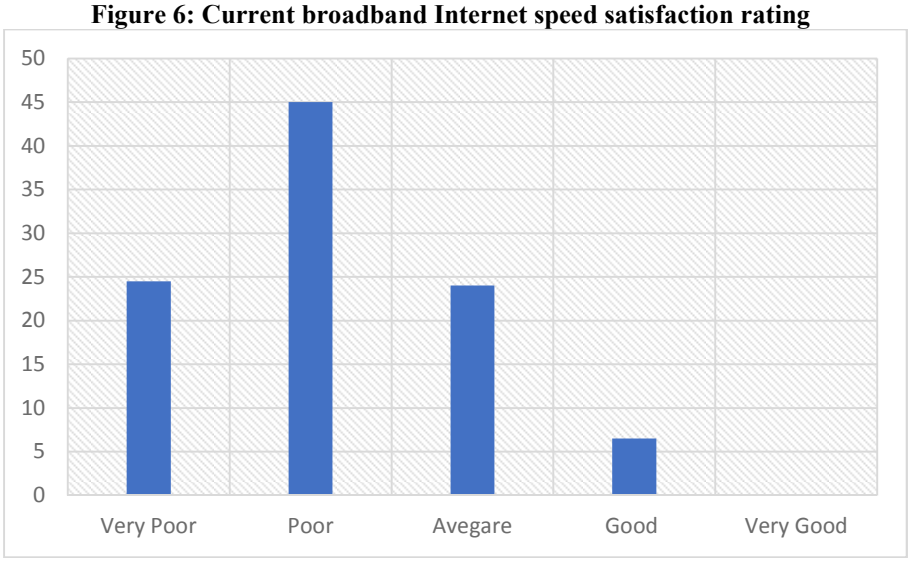


Figure 6: Current broadband Internet speed satisfaction rating



One of the factors that any service provider would want to check before investing in internet service provision is the probability of acceptance by the intending community or users. Here, this study investigates whether the participants would subscribe to a fibre optic network if available in their community. Before the participants responded, the researcher explains the pros and cons of fibre optic networks, especially in the context of rural areas. Figure 7 shows that 36% would subscribe, while 31% would probably subscribe. However, 33% of the participants are not sure whether or not they would subscribe to this very high-speed internet connection. This result aligns with that of the price and speed satisfaction rating, where approximately 65% of the participants are not satisfied with the current price and speed. Hence, the service provider would need to give an affordable pricing model, so as to be able to convince the remaining 33% that were not sure of whether they would subscribe or not.

Both fibre optic and cellular (LTE) network installation and operational costs were included in this study. In addition, the cost-effectiveness of deploying a fibre-optic network in rural areas was compared to the existing wireless (LTE) network. All the costs presented are expressed in South Africa million Rands (R). The estimated cost of installation and operation of both fibre optic and wireless (LTE) networks were obtained from the internet service providers in East London, which also covers the Mdantsane area.

Figure 7: Users subscription to Fibre Optic network if available

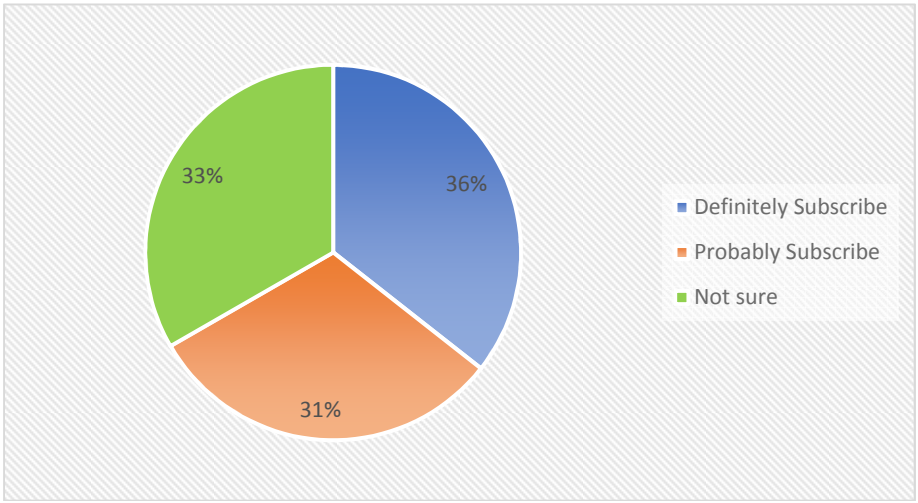


Figure 8 presents the fibre optic installation costs factors and their respective estimated costs expressed in South Africa million Rand (R). The cost of trenching and duct deployment, estimated at R47,9 million, is the most expensive part of the installation phase. While the cost of housing, power supply, and cooling systems has the lowest costs in the installation phase, estimated at R0,19 million. Based on this result, the service provider can investigate different trenching and duct approaches that can be adopted, so as to reduce the installation cost significantly.

Figure 9 presents the wireless (LTE) network installation costs factors and their respective estimated cost in Rand. It can be observed that the transmission and base station controller cost factor is the highest cost of the installation phase, estimated at R3,75 million. While the cost of licensing and spectrum has the lowest costs in the installation phase; estimated at R0,16 million. Based on this result, the service provider can investigate different trenching and duct approaches that can be adopted, so as to reduce the installation cost significantly. Although the cost factors of fibre optic and wireless (LTE) networks are different, however, based on total estimation from Figures 8 and 9, the total installation cost for fibre optic and wireless (LTE) are R61,400,000 and R7,880,000 respectively.

The operation phase of the network deployment involves the monitoring and maintenance of different network conditions through day-to-day operations at a possible minimal cost. The cost of operation phase for both fibre optic and wireless (LTE) networks are presented in Figures 10 & 11 respectively. It can be observed from Figure 10 that the cost of trenching and duct operation is the highest operation cost (R5,77 million), while the physical infrastructure has the lowest operation cost (R0,02 million) in the fibre optic network operation phase.

In Figure 11, it can be observed that the cost of base station equipment, transmission and controller is the highest operation cost (R2,56 million), while the base station civil works, standby power and cooling has the lowest operation costs (R0,1 million) in wireless (LTE) network operation phase. Based on Figures 10 & 11, the total operational cost for fibre optic and wireless (LTE) networks are R11,150,568 and R2,867,900 respectively.

Figure 8: Fibre Optic installation cost

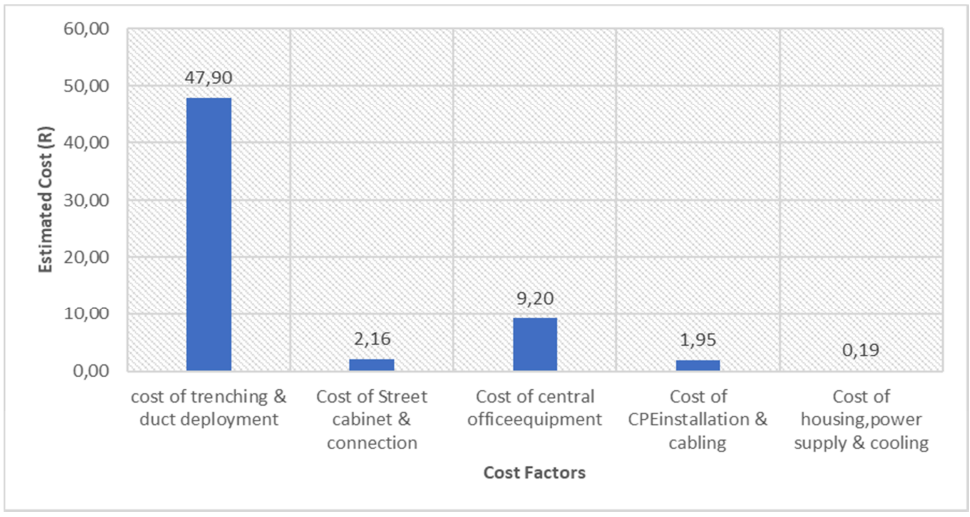


Figure 9: Wireless (LTE) installation costs

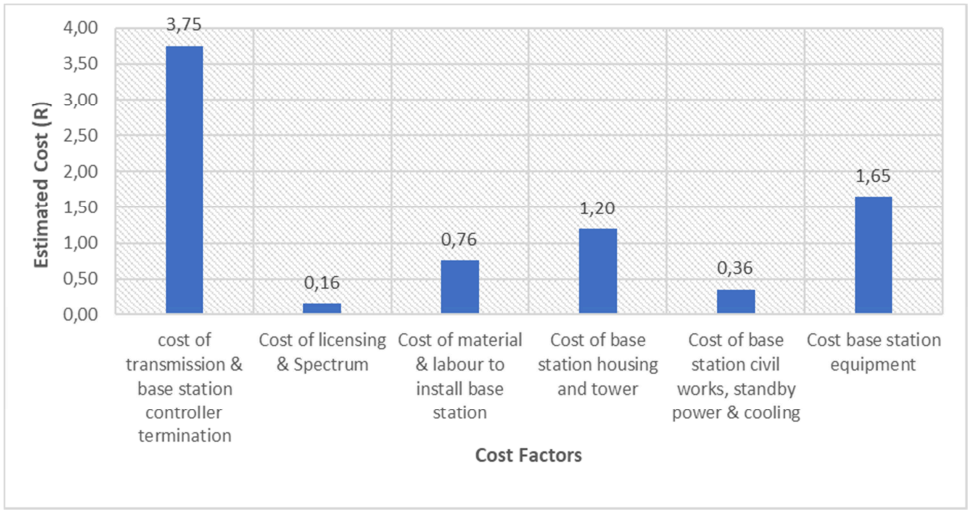


Figure 10: Fibre Optic operation phase cost

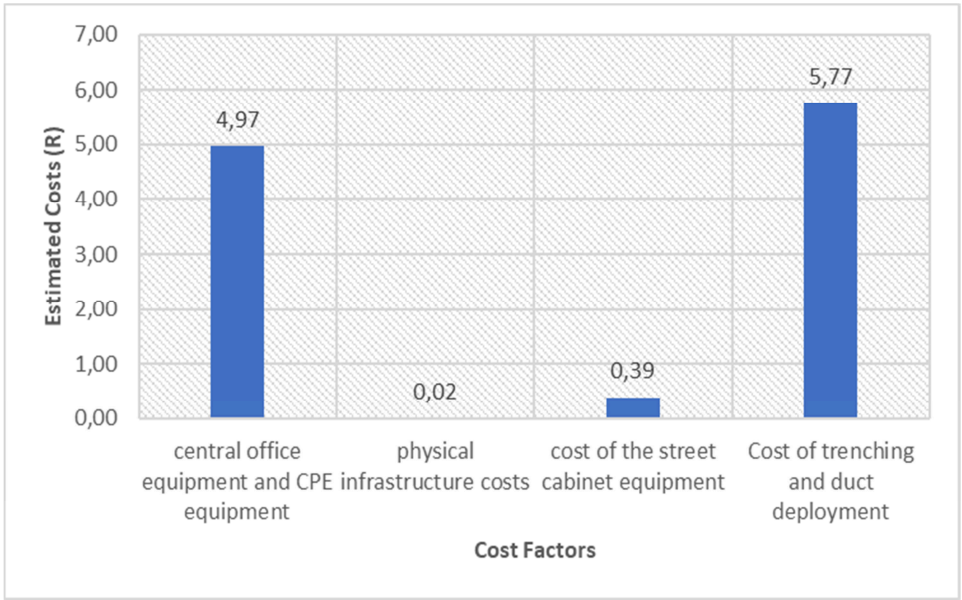
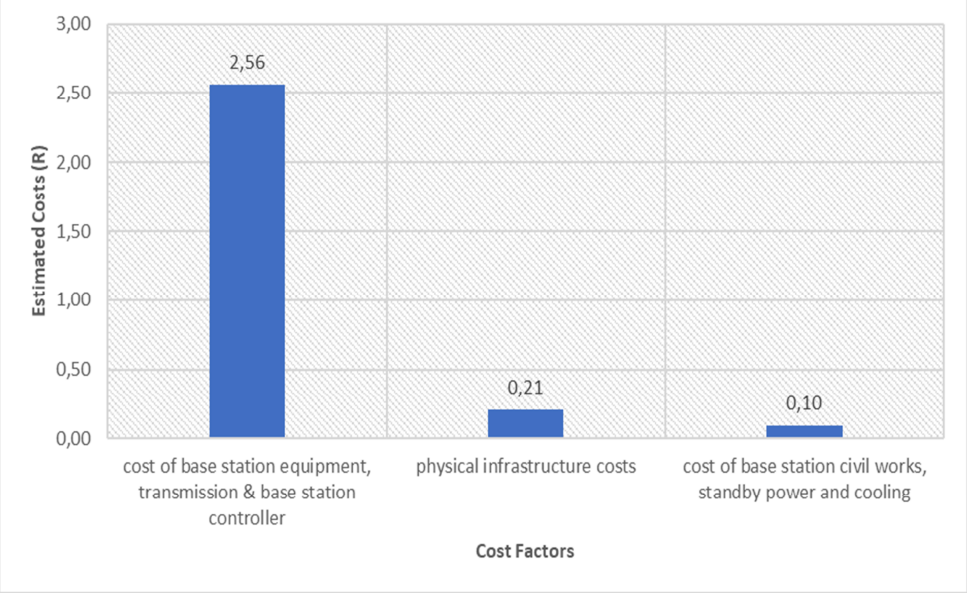


Figure 11: Wireless (LTE) operation phase cost



CONCLUSION AND RECOMMENDATIONS

The primary goal of this study was to know how cost-effective a fibre optic network would be in rural areas than the current wireless (LTE) network. The Mdantsane township in Eastern cape province was used as a case study for this research. An analysis process was conducted to analyse the complete installation and operation costs of both the fibre optic and wireless (LTE) networks. Established on the survey conducted amongst the residents of Mdantsane township and the internet service providers in East London, the findings show that while fibre optic networks seem to be great, however, they come at a cost.

Based on the findings of this study, installing a fibre optic access network in rural areas is not cost-effective as opposed to deploying a wireless (LTE) network. The cost of drilling and trenching associated with the deployment of fibre optic networks was reported as the key reason why the network is costly to install and operate. It is self-evident that reducing the amount of drilling and trenching would decrease their high-cost effectiveness. Hence, when implementing broadband in rural areas, it is firstly recommended that a mixed system, design, or even technology be considered. Secondly, the usage of fibre optic cables as backbone connectivity linkages with cellular networks using the wireless mesh technology approach is proposed. Lastly, to lower the fibre optic network deployment costs, the network operators should partner and share fibre optic network installation and operation costs using a customize/differentiated pricing model, so as to be able to provide affordable high-speed internet connectivity for the internet users in the rural areas.

REFERENCES

Alison, G. “Between two stools: Broadband policy in South Africa,” *South African Journal of Information and Communication*, 2007(8), pp. 53-77, 2007. https://doi.org/10.23962/10539/19787

Al-Quzwini, M. “Design and Implementation of a Fibre to the Home FTTH Access Network based on GPON,” *International Journal of Computer Applications*, 92(6), pp. 30–42, 2014. https://doi.org/10.5120/16015-5050

Angelou, G.; Economides, A. “Broadband Business Opportunities for Utility-Based Firms in the New Era: Modeling the Competition,” In: IEEE Fourth Balkan Conference on Informatics, Greece, 2009, pp. 209–214.

Beneke, J.H. *South Africa: The Long Walk to Broadband Freedom,* 2018, pp. 13-28.

Brian, G. “Community Fiber Broadband in North Carolina: A Comparative Analysis,” MSc thesis, 2020. https://doi.org/10.17615/8ccv-bv14.

Byanyuma, M.; Kalolo, S.; Mrutu, S.I.; Nyakyi, C.; Sam, A. "Affordable broadband connectivity for rural areas," In Pan African International Conference on Information Science, Computing and Telecommunications (PACT), 2013 pp. 62–65. https://doi.org/10.1109/SCAT.2013.7055090

Chetty, M.; Sundaresan, S.; Muckaden, S.; Feamster, N.; Calandro, E. "Measuring broadband performance in South Africa," In: 4th Annual Symposium on Computing for Development - ACM DEV-4 '13., Cape Town, South Africa, pp. 1–10, 2013.

Esselaar, S.; Gillwald, A.; Moyo, M.; Naidoo, K. "South African ICT Sector Performance Review," *Towards Evidence-based ICT Policy and Regulation, 2010,* Vol. 2(6), 2010 2009/2010 46.

Goldstuck, A. "Internet Matters: The Quiet Engine of the South African Economy," pp. 38-50, 2017. [Online]: https://hsf.org.za/publications/focus/focus-66/AGoldstuck.pdf

Gwaka, L.T.; May, J.; Tucker, W. "Towards low-cost community networks in rural communities: The impact of context using the case study of Beitbridge, Zimbabwe," Electronic Journal of Information Systems in Developing Countries, 2018, 84(3). https://doi.org/10.1002/isd2.12029

Hoffman, A.J.; Wet de, D.P. "Broadband Internet access for rural Africa: finding a viable model," In: 2nd International Conference on applied informatics and computing theory, 2017.

Jay, S.; Neumann, K.H.; Plückebaum, T. "Comparing FTTH access networks based on P2P and PMP fibre topologies," *Telecommunication Policy,* 2014, 38(5-6), pp. 415–425. https://doi.org/10.1016/j.telpol.2013.04.010

Mamabolo, S.; Solms, S.V.; Marnewick, A. University of Johannesburg 88, 2019.

Mohammadani, K.H.; Butt, R.A.; Memon, K.A.; Hassan, F.; Majeed, A.; Kumar, R. "Highest Cost First-Based QoS Mapping Scheme for Fibre Wireless Architecture," *Photonics 2020*, 7(4), 114. https://doi.org/10.3390/photonics7040114

Moroeng, L.H. "Fixed-to-Mobile Broadband Substitution in South Africa," 2012.

Ntsandeni, A. "Innovation-based competitive differentiation amongst South African fibre to the home (FTTH) operators," M. Man. Thesis, WITS, South Africa, 2018.

Pernegger, L.; Godehart, S. "Townships in the South African Geographic Landscape – Physical and Social Legacies and Challenges" TTRI, South Africa, 2007.

Rametta, C.; Schembra, G. "Designing a Softwarized Network Deployed on a Fleet of Drones for Rural Zone Monitoring," *Future Internet*, 2017, 9(1), 8. https://doi.org/10.3390/fi9010008

Seymour, L.F.; Naidoo, M. "The Usage and Impact of Broadband: A South African Household analysis," *Electronic Journal of Information Systems Evaluation*, 16(2), pp. 223-234, 2013.

Tahon, M.; Van Ooteghem, J.; Casier, K.; Verbrugge, S.; Colle, D.; Pickavet, M.; Demeester, P. "Improving the FTTH business case–A joint telco-utility network rollout model," *Telecommunications Policy,* 2015, 38(5-6), p. 426–437.https://doi.org/10.1016/j.telpol.2013.01.004

Verbrugge, S.; Casier, K.; Lannoo, B.; Machuca, C.M.; Monath, T.; Kind, M.; Forzati, M. "Research Approach towards the Profitability of Future FTTH Business Models," *Future Network & mobile summit*, 2017, pp. 1-10.

Whitacre, B.; Gallardo, R.; Strover, S. "Broadband contribution to economic growth in rural areas: Moving towards a causal relationship," *Telecommunications Policy*, 2014, 38, pp. 1011–1023. https://doi.org/10.1016/j.telpol.2014.05.005