A Techno-Economic Model for Future Deployment of Fixed Broadband Services to Stimulate Development across Rural Africa

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Abstract

The pervasive digital divide in rural areas particularly, in Africa, has affected digital inclusiveness and Sustainable Development Goals of the region. The International Telecommunication Union (ITU) and other relevant bodies have been advocating for internet for all by 2020, as this would assist in realisation of the public policy, especially in developing economies. However, financial sustainability of the rural access schemes has been major bottlenecks. In this paper, the cost (CAPEX and OPEX) of deploying a terrestrial and high altitude platform-based communication networks is examined. A techno-economic model for the deployment of future fixed broadband services across rural Africa is proposed. Findings from the simulation revealed that the deployment of fixed broadband services is possible across rural Africa while examining the elasticity invariance to some variables. Furthermore, the cost per person and per household for the proposed model is provided. The work further shows that in rural Africa, deploying a high altitude platform network is likely to be more cost-effective when compared to a terrestrial network deployment.

Keywords. Fixed Broadband, OPEX, CAPEX, Developing economies, High Altitude Platform, Terrestrial networks, Digital divide.

I. Introduction

Access to telecommunication services is no longer a luxury, but is an essential and invaluable service of the 21st century (Dahlman, Parkvall, & Skold, 2013; Gillespie & Goddard, 2017). Over the years, Africa has always lagged behind other regions regarding legacy infrastructure or cabling needed to access fixed telecommunication and broadband services (Futter & Gillwald, 2015; Kelly, 2014; Prieger, 2013). Therefore, wireless access to telecom services is most widely used (Subramanian et al., 2006). In recent time, the term fixed broadband could either be broadband provided to a fixed physical location or a situation where the user is in a fixed and not mobile. Fixed location can make some difference in broadband deployment because the mobility of user could affect several decisions regarding the system's operation and capabilities. In this work, fixed broadband is regarded as broadband service provided to a fixed location. Access to fixed broadband services is important in the provision of high speed internet access which is often required in modern day life (Feijoo, Gomez-Barroso, Ramos, & Rojo-Alonso, 2006; Subramanian et al., 2006), and this now plays a vital role in terms of both economic growth and international competitiveness (Anderson, 2003; Rohman & Bohlin, 2012; Srinuan & Bohlin, 2013). In this work, fast broadband on the other hand is regarded as a telecommunication service with a speed of 10 Mbps and beyond to a fixed location. Various studies on the impact of broadband on the economy have generated a range of elasticity estimates for different regions and countries(Fjermestad, Passerini, Bartolacci, & Patten, 2008). In (Rohman & Bohlin, 2012), the results show that a doubling of broadband speeds can significantly increase the Gross Domestic Product (GDP) of an economy. According to (Lam & Shiu, 2010; Oshikoya & Hussain, 1998), this type of growth is what is most needed to be able to improve the living standards of most African communities. Furthermore, the International Telecommunication Union (ITU), various government and other relevant bodies have been advocating to connect everyone to the internet by 2020, thereby aiming to bridge the existing digital divide and meeting the proposed sustainable development goal (Philbeck, 2016). This has not been realised however there has been significant progress especially in developed countries where improvements are majorly required. Rural areas are significant economic driver in developing countries. According to UN’s Food and Agriculture Organisation (FAO)(Gannon, 1994) , the main driver to achieving sustainable development is transforming the rural communities. Therefore, this study aims at helping to realise this important goal across Africa, especially in the rural areas, which are mostly not connected to telecommunication services. Rural populations in Africa are characterised by sparsely scattered settlements, mostly without basic infrastructure like electricity and telecommunication services. Over the years, different proposals have aimed to solve the problem of broadband connectivity in Africa.

The majority of people living in Africa live below the poverty line and in rural communities. In general, these rural communities’ lacks basic social amenities such as access to telecommunication services which can help improve their productivity and in turn their income. For example, access to the internet could help farmers in accessing government services, seek help in case of problems and provide platform to sell their product in a more competitive and faster manner. In most of Africa, fixed and fast broadband services are also not currently available because their provision has traditionally been left to commercial market actors within a country without proper recourse to regional or continental connectivity. These commercial actors mostly see low revenues because of the widespread population distribution of Africans, the high cost of doing business as a result of different or multiple taxes from various government and agencies, and the high risk to business as a result of multiple instabilities arising from wars and communal clashes (Osabutey & Okoro, 2015; Wallsten, 1999). For example, (Gurstein, 2003; Schuler, 1994) propose the creation of community networks which are a smaller networks. In (Williams, 2010) the use of competition by removing regulatory restrictions was proposed. The book also proposed how the cost of backbone infrastructure can be reduced by making use of existing energy and transport infrastructure, while, stimulating backbone network development through the encouragement of public-private partnerships. These were proposed to encourage operators to serve the underserved communities. (Juma & Moyer, 2008) proposed the introduction of low-cost access, especially to universities, by means of subsidy. Therefore there is the need to examine various technologies that can help stimulate broadband penetration to rural Africa, hence, the cost involve and affordability. This is important because even if the service is provided and the cost is high, majority of the people will not afford to subscribe to the services. Therefore this paper examines models to enable cost comparisons of the new technology exploiting both High Altitude Platform (HAP) and traditional terrestrial systems in the provision of fixed broadband access for rural populations. This outcome is not in any way discouraging the adoption or any of the earlier proposed models hence, we do not compare the cost based on the size of the network. Instead, the aim here is to provide a generalised model which can help in providing insight has to how best to solve the problem of connectivity in rural Africa, by exploring different types of infrastructure. It is worth pointing out that although this work was based on a rural scenario in Africa, it can easily be adapted to most rural areas across the world.

HAPs are a promising technology which has recently been gaining a lot of attention. They are aerial platforms which can be airships, airplanes or balloons operating at stratospheric altitudes between 17-22 km above the ground level. This altitude represents an area in the atmosphere that experiences limited winds and turbulence, compared with the jet stream, and hence, HAPs are able to maintain their stability, thereby giving the potential to provide high availability communications services. HAPs have been proposed as system with many advantages such as wide coverage with low propagation delay, meaning that they are capable of delivering a wide range of services and applications. Some of the recent deployments at providing telecommunication services using HAPs are the Aquila, Loon and Softbank projects by Facebook, Google and Japanese telco respectively. These deployments among others have been able to showcase the capabilities of HAPs.

This paper provides a detailed comparative cost analysis between HAPs and terrestrial systems in terms of coverage and usage for rural Africa because of the importance of broadband deployment to economic development. The aim is to identify which technology is cost-effective both in terms of providing coverage and capacity for rural African. This is because currently a substantial majority of Africans live in a place where wireless internet is available, but this is not the case if only rural parts of the continent are considered. This paper aims at helping decision makers in formulating policy for future network deployments across rural Africa. There is a need to examine the cost effectiveness of these technologies based on the fact that certain investments are unlikely to be affordable to some countries as they attempt to provide universal telecommunication access (Ohmae, 1995; Zhen-Wei Qiang, 2010). Therefore, it is important to examine how to extend service and coverage to communities in low-income countries(Feijoo et al., 2006). This is essential because the provision of fast and reliable broadband will facilitate informed decision making and efficient delivery of services while creating new business opportunities. Furthermore, this work is necessary for future planning and deployment of fixed broadband telecommunication services. 30 years ago, no one would have envisaged the rapid demand for wireless communications and fixed broadband services that would enable access to various services hence the need to plan using different scenarios. The proposed scenario is based on the fact that existing conditions in many rural communities do not facilitate widespread fast broadband deployment. Therefore, to assist the developmental cycle, there is a need for a better coordination of strategies in providing fast speed internet access (Prasada, 1976).

It should be noted that the cost of a HAP, just like a terrestrial system, can vary depending on the volume of traffic it can carry. However, we considered the various type of HAPs, and the average value is used in the results section of this work where we refer to HAPs in general, without specifying the type used.

This paper is unique, as to the best of our knowledge it is the first of its kind to compare the CAPEX and OPEX costs of a HAP with a terrestrial system covering the entirety of Africa, but with cells or beams focusing on rural areas. This paper is also unique in terms of the elasticity cost analysis which is necessary for planning purposes for the proposed fixed fast broadband deployments in Africa. The remaining part of this paper is structured as follows. Section II examines the impact of fast fixed broadband on development, while section III explains the various technologies. Section IV presents the results, and the discussion of the results, with the conclusions provided in section V.

II. The Developmental Impact of Fast Broadband Deployment

Policymakers who are trying to improve or increase access to broadband services across Africa are facing a wide range of challenges. These challenges are majorly related to the costs and investments needed to reach every part of Africa. The majority of Africans are living in rural areas characterised by a scattered population. The high investment and operational costs make operations in some areas unattractive. These obstacles can be overcome by finding alternative ways of mass deploying broadband services across Africa by integrating better services.

Parallels can be drawn with elsewhere, (R. Katz & Suter, 2009) estimated the impact of broadband on jobs creation in Columbia which is also a developing economy. The report shows that about 128,000 jobs can be created from the broadband investment over a four-year period, where each job cost $50,000. This is compared to a similar investment in "roads and bridges" that would yield 152,000 jobs, at the cost of $ 42,000 per job. The same report also suggested that additional policies would have to be in place in order for broadband to help in creating these jobs. (R. L. Katz, 2009) estimates the demand for broadband services in South America. The report quantifies the macroeconomic impact of broadband technology on productivity and employment in Latin America. The paper estimates a 41% increase in broadband connectivity lines in Latin America would yield additional 378,000 jobs via its counter-cyclical potential as this would help to fight the current economic crisis in the region. (Zhen-Wei Qiang, 2010) highlights the potential of broadband infrastructure in the area of public investment during an economic downturn. It concludes that spending initiatives on next-generation telecommunications services during a period when market conditions are weak can help preserve jobs and some burden that would be social safety nets. The paper also concludes that broadband can improve the entire productivity of an economy and enhance longer-term growth and development. (Fornefeld, Delaunay, & Elixmann, 2008) analyses broadband-related productivity improvement, structural displacements within the European economy. The report shows that broadband-related productivity improvement in Europe stands at about 0.29% on average per year.

(Thompson Jr & Garbacz, 2011) examined the economic impact of mobile and fixed broadband for high and low-income countries. The paper concludes that fixed broadband has a positive impact on low-income countries and can help in closing the penetration gap. (West, 2010) shows that there is a considerable amount of evidence to show that widely available, affordable, and high-speed broadband can further help with economic development, social connections, civic engagement, and electronic government. The paper shows that a 10 percentage point increase in broadband penetration can add 1.3 percent to developed country's gross domestic product and 1.21 percent for low to developing nations. (Stork, Calandro, & Gamage, 2014) examines the role of fibre to the home and other types of fixed Internet access in Africa and the most likely successful business models in the African context. The paper concludes that uncapped fixed broadband services at an affordable price would enhance economic development across Africa. The paper also emphasised that broadband services have been useful in rural Africa through mobile banking and mobile money in addition to the potential it has in supporting new ways of delivering healthcare services. The paper also concludes that fixed broadband has a huge potential in Africa cos most rural areas are yet to be connected. However, fixed-line operators are likely to lose customers unless some of the business decisions are changed and new technologies are invested into in the next two to three years. This emphasises the need to examine and compare different technologies.

III. The Examined Technologies

In this section, the technologies are considered before arriving on our proposed model which are the HAPs and the terrestrial systems. Generally, the terrestrial and satellite modes are two well-known methods of providing wireless services across the world however, HAP is fast becoming a promising technology for the future. Although the two most common technologies have some advantages and disadvantages, as enumerated in (Karapantazis & Pavlidou, 2005; Kuran & Tugcu, 2007; Tozer & Grace, 2001). The satellite has a wider coverage area compared to terrestrial and it is also very useful with irregular terrain. In addition to this satellite are also more popular in areas with low population density or areas with a sparsely distributed terrain like the rural areas. However, in more recent times the demand for telecommunication service is on the increase and users require much higher capacity density. Thus, in densely populated areas, the satellite mode of communication cannot often be used. In terms of deployment, satellites are often more complicated to deploy, due to launch logistics, but on the other hand HAPs are easier to deploy as was seen with Loon in Puerto Rico after the Hurricane in 2017. It has been shown in (Avdikos, Papadakis, & Dimitriou, 2008) that a HAP minimises cost for both providers and customers when compared to satellite. But despite the ability of HAPs to offer significant benefits over satellite systems as shown in (Miura & Suzuki, 2003), its viability and cost-effectiveness depends very much on how it can integrate with the present and future wireless networks. It is worth pointing out that there are Low Earth Orbit satellites such as Space X launched in 2015 and oneWeb, which was just launched, provide mainly rural connectivity and which provides reduced latency compared to geostationary satellites, but they are not considered in this work because they require specialised user devices unlike the HAP based systems which can use the same hand held device as that used by the terrestrial system. In contrast, HAPs can provide facilities that would improve, coexist or even substitute most services presently provided by satellites and terrestrial networks [7]. Furthermore, satellite communication is not considered in this work because HAP-based technologies are often seen to combine most of their characteristics to provide a better service. This is in addition to the additional delay associated with geo satellite system especially when used for VOIP or video conferencing which are essential to future wireless networks. A comparison of the two technologies examined in this work (terrestrial and HAP) is summarised in Table 1. HAPs are developed as large-scale airships or light-weight aircraft deployed at a predetermined position, usually at an altitude of around 17-22 km in the stratosphere. They can be used for telecommunications, broadcasting, and environmental monitoring and measurement.

Table 1: comparison of Terrestrial and HAPs technologies

Issue	**Terrestrial Wireless**	**High Altitude Platforms (HAP)**
Platform accessibility and Price of Mobile Terminals	Huge cellular PCS market drives high volumes resulting in small, low-cost, low power units	Terrestrial terminals Can be used, and hence, reduces cost
Propagation delay	Low	Low
Adverse effect of radio emissions on health	Utilizes handsets of Low-power to minimize effect	Same handset like in terrestrial systems (although higher power may be required for large coverage area)
Communications technology risk	Advanced technology and well-established industry	Adopts the terrestrial wireless Technology and complements it with Spot-beam antennas.
Deployment timing	Deployment may be phased, considerable initial set-up is enough to provide satisfactory coverage for profitable services	A single HAP platform and ground infrastructure is enough to venture into profitable services
System growth	Cell-splitting may be employed to increase capacity, stress-free equipment upgrade/repair	Capacity increase by spot-beam resizing, and supplementary platforms; Equipment upgrades are relatively easy.
Range of geographical coverage	Covers few kilometers per base station	Hundreds of kilometers per platform (up to 200km)
Cell diameter	0.1 – 30 km	10 – 60 km
Shadowing due to Topography	Creates gaps in coverage, additional equipment may be needed	Same as satellite, but non-line of sight connectivity no worse than terrestrial

Cost	Varies	Varies

There are three main categories of aerial platforms that have been proposed for use as a high altitude platforms that are considered in this work. These are:

a) UNMANNED AIRSHIPS

The use of unmanned airships has been considered in (Tozer & Grace, 2001). These are referred to as huge powered aerostats balloons with thrust. They can be solar powered. Hence, both solar powered and battery powered unmanned airships are considered in this work. They can also either be used in semi-rigid or non-rigid platforms, typically having a length of over 100m and a carrying an on board payload of 800kg or more. The unmanned airships are being designed in such a way that they can remain in the air for close to five years or more.

b) UNMANNED AIRCRAFT

These are kinds of aerial vehicles that are able to fly for an extended period with the use of long wingspan and high tech lightweight materials with a programmable electric motor to ensure that the aircraft fly in a quasi-stationary position continuously. The wingspan is usually between 35 and 70m and they can be powered by solar and batteries, or more conventional means for shorter periods.

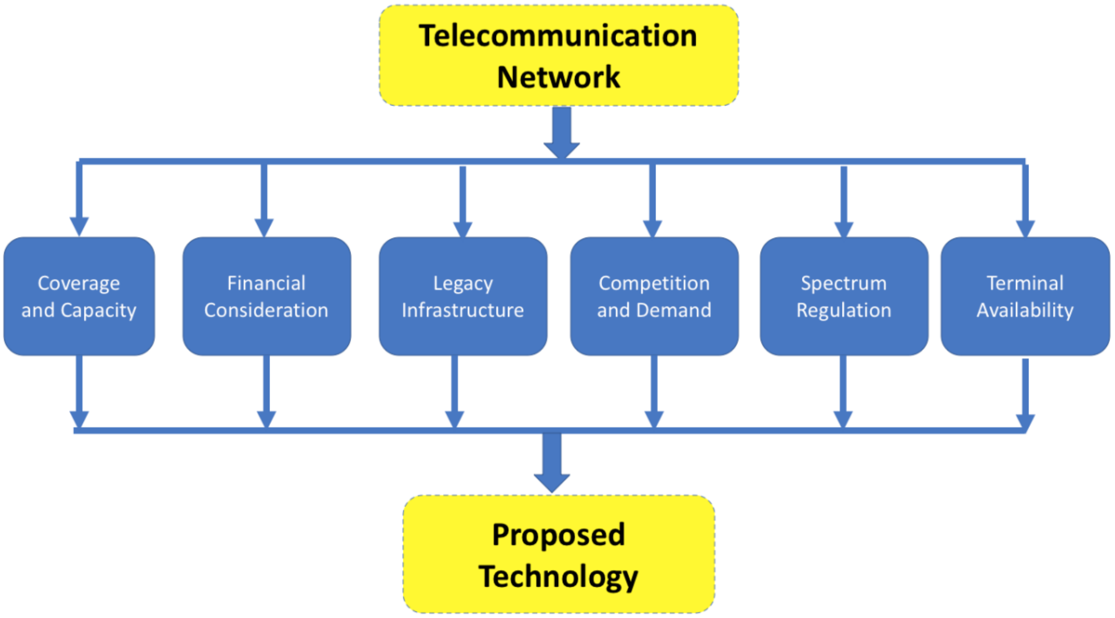


Figure 1. Main determinant of Technology to be adopted for a Telecommunication Network

c) MANNED AIRCRAFT

Aerial vehicles in this category are essentially piloted airplanes that have been specifically developed to handle high altitude flight for an average duration of a few hours. Their low flight duration is as a result of constraints in fuel consumption and other human factors. Manned aircraft are mainly used in defence and some civilian services like weather forecast and location monitoring.

Different factors determine the technology to be adopted in a communication network. A summary of these determinants is shown in Figure 1. Generally, financial consideration or cost-effectiveness is an important planning factor hence the focus of this work. It is worth pointing out that the use of a single objective such as financial consideration in determining the effectiveness of a network does not provide a holistic approach however it is important to examine each element independently of others.

Methodology

This work models the cost for a hypothetical network operator deploying a fixed wireless network across Africa from a technical and economic (techno-economic) point of view. A simple cost model is used to estimate the cost of the system to obtain a value analysis. The proposed model is unique as the services cover the entire African landmass. However, here the focus is on rural areas. The cost (C) of the network is modelled as

$$C = \sum_{i \in T} (A_i + B_i) n_i \qquad (1)$$

Where A_i is the CAPEX cost and B_i is the OPEX cost of a cell for technology i and n_i is the number of cells required by technology i to cover the entire area. T is the technology considered.

In this paper HAP and terrestrial networks are considered. A discounted cost is used to account for inflation that may arise, and the time value of money as proposed in (Johansson, 2007). The network is modelled based on a fixed estimated downlink data rate for the users as explained later in this work. Only the downlink is considered in this work while we model the network using a uniform traffic distribution. Since the proposed model covers multiple countries in Africa, it is expected that it would also lead to better cooperation and collaboration among African member state. It was proposed in (Gyamfi, 2005) that one of the requirement to remove or reduce the current digital divide and provide fast and reliable access to broadband services across Africa is member state to cooperate better. An overview of the methodology is shown in Figure 2.

Here, the capital cost (CAPEX) and the operational cost (OPEX) of the network operator is considered for deploying a terrestrial and HAP network services for fixed broadband deployment across Africa as a standalone service. The OPEX considered is limited to the cost of operating the network. The cost of spectrum, backhaul cost, land acquisition and other operational costs are not included because this cost would depend on the business model that is adopted by the operator. The capital expenditures include the cost of radio equipment, transmission equipment, and installation of equipment. The exact breakdown of the costs is case specific, and it may vary significantly between different countries and operators.

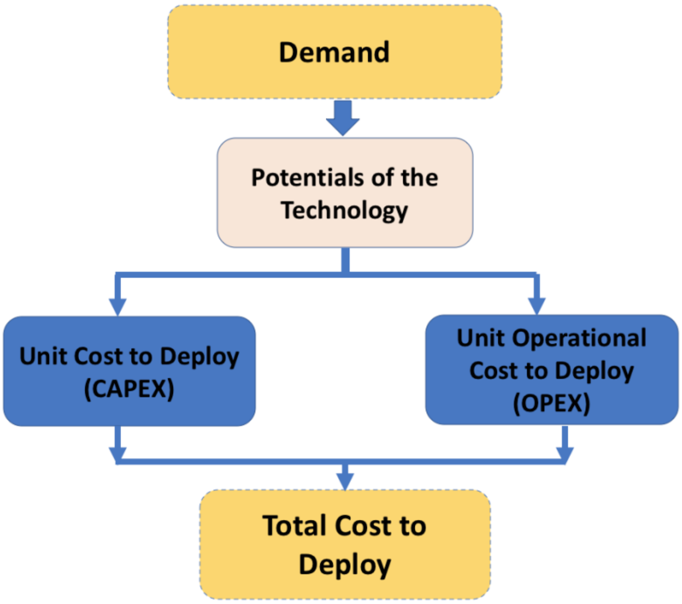


Figure 2: Overview of Methodology

Furthermore, the OPEX cost is usually about 50% of the operating revenue and this would usually include costs related to sales and marketing administrative costs, subscriber management, interconnection, and roaming. In some other analyses, such as (Johansson, 2007), the depreciation cost was also considered, which is around 2/3 of the capital cost, or approximately 1/3 of the total revenues. However, all these are not considered in this work because of the earlier provided reason. A breakdown of the total costs for CAPEX and OPEX are provided in the parameter table 2. The backhaul network is not considered here, but it is assumed that such a network exists with sufficient capacity to support the access network.

Table 2: Simulation Parameter Table

Parameter	**Value**
Contention Ratio	50
Data Rate for Scenario A	15 $Mbps$
Data Rate for Scenario B	25 $Mbps$
Data Rate for Scenario C	50 $Mbps$
Terrestrial Sectorization	3
Max clear air capacity per cell of Terrestrial (Mbps)	300
Max clear air capacity per beam of HAP (Mbps)	300
Number in Household (H_h)	8
HAP Altitude	17 km
Terrestrial Altitude	0.1 km
African Population density	1.3 Billion
African Land Mass	30.37 Million km^2

A. The Terrestrial Network

The terrestrial network design is based on the use of three-sector macro LTE base stations, exploiting a 3 by 3 Multiple Input Multiple Output (MIMO) antennas, which operate at 3.5 GHz, and provide higher data rates compared with non-MIMO variants. The system is modelled such that the network can be used for both fixed and mobile networks. Therefore, we also consider the use of user equipment which can either be powered by solar or connected indoor to the mains. The equipment is wired directly to either an outdoor or indoor router/ Pico/Nano equipment to reduce the amount of RF signal loss. It can be used to help extend the coverage up to 500m both indoor and outdoor. The cost of this router is not considered in this work. However, the location of the base station or distance to the user does not affect our result, as it is assumed that all the users are on the average able to obtain the minimum data rate no matter where they are in the cell. Here, like with a conventional terrestrial network, the entire African landmass is dimensioned by considering the minimum amount of base stations that are necessary to provide the required data rate for the whole geographical region. Therefore, it is assumed a link budget can provide a capacity-driven network based on the demand of the user as specified later in this work.

B. HAP

The HAP is considered to be a high throughput multi-spot beam system operating in the IMT (2010-2025MHz) frequency band. The capacity of the HAP is determined by the total amount of spectrum available and the number of cells each HAP can provide. In this work, the HAP system is dimensioned to provide a hypothetical HAP operator. The link budget which is calculated with both coverage and capacity in mind just like the terrestrial system. The HAP is modelled on a pre-determined number the downlink direction as uplink is not considered in this work. However, provision is made for uplink by not using the entire available bandwidth for the downlink. The user equipment is a small outdoor unit connected to an indoor unit. It is worth pointing out that the proposed model can be used for outdoor services, with the inclusion of additional pico/nano outdoor equipment as in the terrestrial model. The receiving outdoor unit is equipped with a directional rooftop antenna. It is assumed that it is mounted in a location where a clear signal can be received.

It is estimated that the user demand based on the user data rate. Three scenarios are modelled to reflect the level of usage of the user. Scenario A, B and C represent low, medium and high usage as indicated in the parameter table. The data plan represents the maximum possible data rate for each of the user connected in our proposed model. An overview of this is shown in Figure 3.

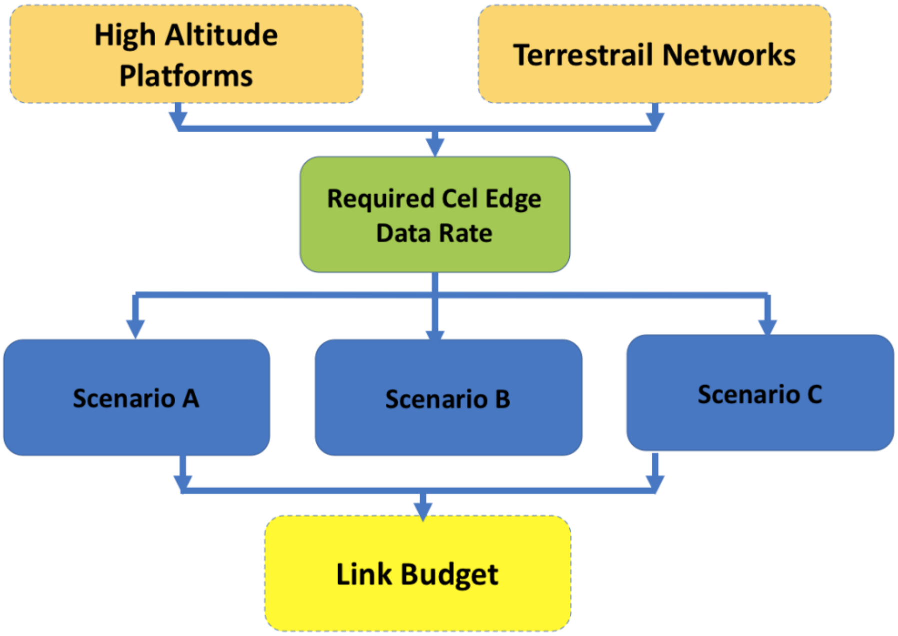


Figure 3: An overview of the Scenario Modelling

System Model

In this paper, the number of terrestrial base stations and HAP beams required for each rural location are obtained based on the average number of persons living in rural Africa. World Bank statistics on rural population density are used in as found in (Bank, 2018). It is assumed that 60% of the African land mass is categorised as rural and a uniform distribution of users is distributed across the land mass and an average population density of 50 users per km^2. These assumptions reflects the average rural population of Africa as found in [35]. It is assumed that same cell capacity (C_{Max}) for terrestrial cell and a beam for the HAP system as specified in the parameters table. The maximum user per cell or sport beam (U_{max}) is calculated as

$$U_{max} = \frac{C_{Max}}{C_r\, D_r} \qquad (2)$$

Where C_r is the contention ratio as specified in the parameter table and D_r is the data rate required by each user and the vale is also specified in parameter table. Furthermore, it is calculated the number of spot beams a HAP can have based on the total capacity of the HAP. Based on the maximum number of user that a cell or spot beam can accommodate we calculate the number of cell or spot beam required based on the population of the users as shown below

$$N_c = \frac{P_d}{U_{max}} \qquad (3)$$

Where N_c is the number of cell or spot beam required and P_d the total assumed rural population in Africa.

Cost model:

Generally, there are several configurations for the base station, however a three-sector cellular base station is used as explained earlier. It is assumed the cost and range of each base station is the same, with the cost based on previous similar projects carried out by the research group.

Only a limited number of cost sources are available as the exact price of either the HAP or the terrestrial system is dependent on a number of factors. The total cost is calculated from the CAPEX and the OPEX cost where the CAPEX cost is from the unit cost of each system. The assumed cost used in this work is as shown in table 3;

Table 3: The Cost Model

Technology	Capital Cost (in £ millions)	Operational Cost (in £ millions)
Manned Plane	20	9
Unmanned Plane (Fuel)	17	8
Unmanned Airship (Fuel)	17	10
Unmanned Airship (Solar)	10	11
Terrestrial (Grid)	0.1	0.15
Terrestrial (No Grid)	0.1	0.30

IV Results and Discussions.

This section provides the results obtained from the model. The results are obtained using the cost model described earlier in equation 1 and dividing through by the population size (P_s), number of household (H_h) and land mass (L_m) in km^2 to obtain cost per user (C_p), cost per household (C_h) and cost per km^2 as shown in equations 4, 5 and 6 respectively.

$$C_p = \frac{C}{P_s} \qquad (4)$$

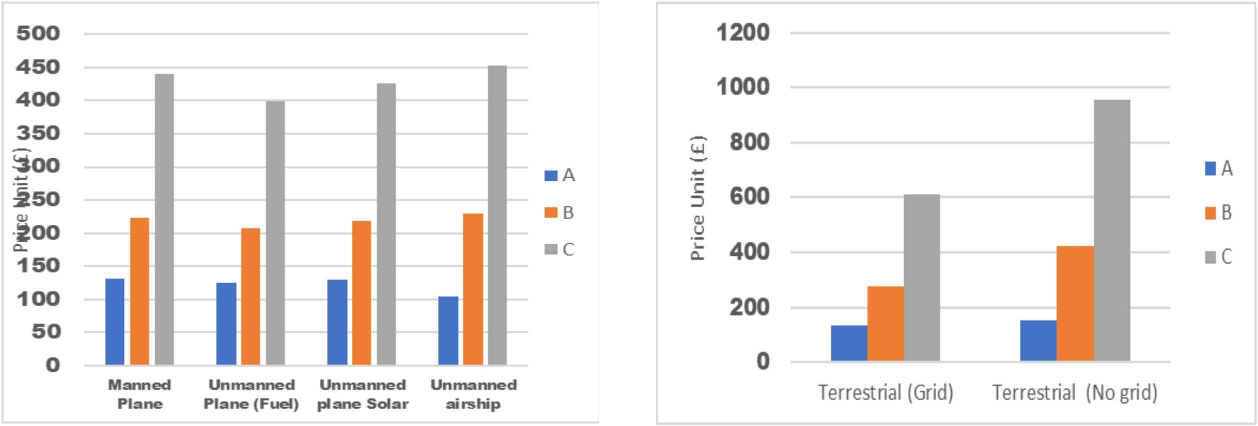
$$C_h = \frac{C}{H_h} \qquad (5)$$

$$C_{km} = \frac{C}{L_m} \qquad (6)$$

This work considers both HAPs and terrestrial systems where certain parts of the ground-based infrastructure are based on connection and non-connection to the national grid. Such situations are common in Africa. Results for the various HAP and terrestrial models are shown separately, given the relative costs vary significantly.

Figures 4-6 show the cost paid per user, per household and per km^2 respectively. Each of the results show the cost for each of the modelled usage levels (A, B and C). It can be seen that for all the scenarios the cost for the HAP system is considerably cheaper when compared to any of the terrestrial models. This is due to the fact that fewer HAPs are required to cover the entire the required land mass when compared to same terrestrial network coverage based on the cost model described earlier. The total cost (CAPEX and OPEX) of the HAP is always more cost effective for the users when compared to the terrestrial networks in rural areas. It can also be seen that the cost increases with the data rate for each of the user. Cost effectiveness is considered as an important factor in Africa because majority of the population in rural areas lives below the poverty line. For all the scenarios, the price for Scenario A is lower compared to scenario B and scenario B is lower compared to scenario C. This is just as expected because the higher the demanded data traffic the more the resources required. This clearly shows that the price (C) is proportional to data rate (D_r) as shown in the equation 5. Where k is a constant.

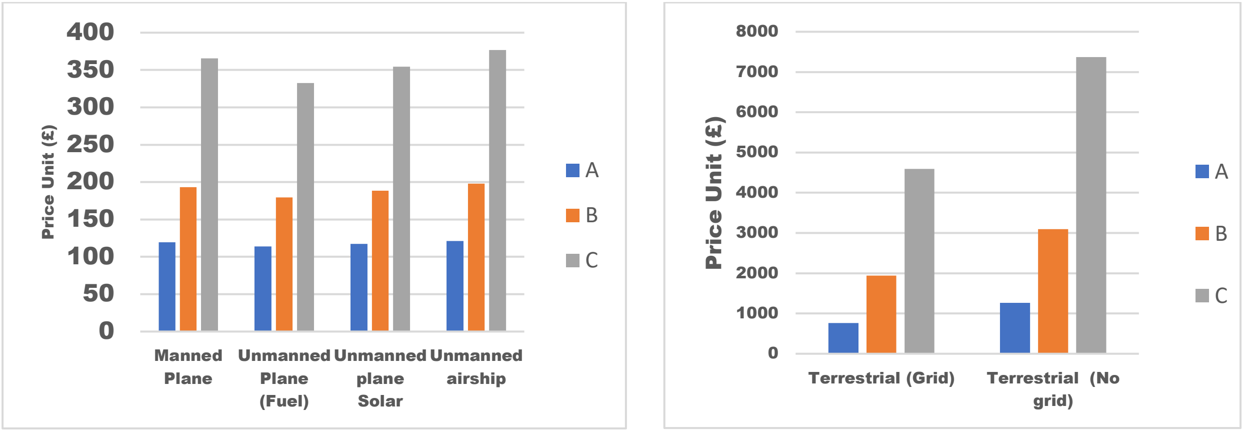
$$C = kD_r \qquad (7)$$



(a)

(b)

Figure 4: Cost per user (a) for manned plane, unmanned plane, unnamed plane (solar), unmanned airship (b) terrestrial (grid), terrestrial (no grid)



(a)

(b)

Figure 5: Cost per household for (a) a manned plane, unmanned plane, unnamed plane (solar), unmanned airship and (b) terrestrial (grid), terrestrial (no grid).

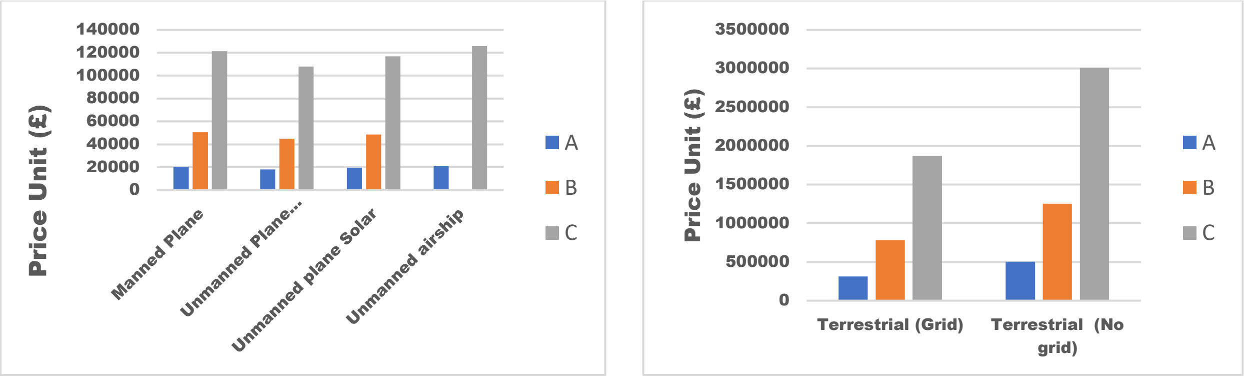
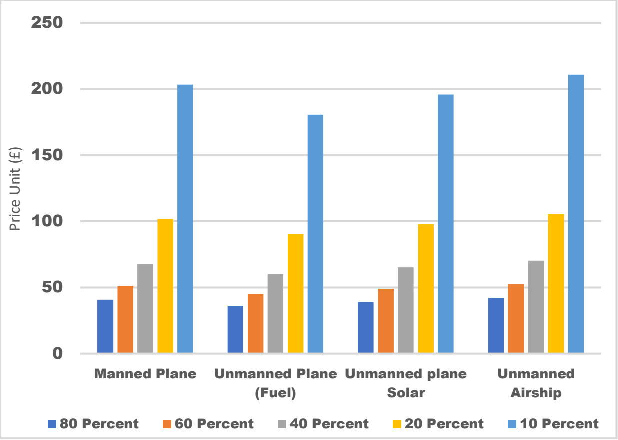
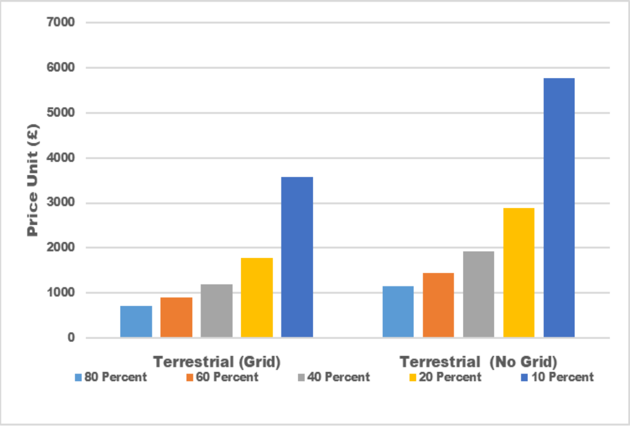


Figure 6: Cost per square kilometre for (a) manned plane, unmanned plane, unnamed plane (solar), unmanned airship and (b) *terrestrial (grid), terrestrial (no grid).*

From the results, it can also be seen that connecting the terrestrial system to the national grid would work our cheaper than when not connected. This is majorly because when the system is not connected to the national grid they are powered by diesel generator which works out to be more expensive aside from the pollution it causes. Electricity supply is a major problem in most Africa countries as the electrification level currently stands at 43% and the majority of the current base station are not connected to the national grip (Bazilian et al., 2011). Therefore, there is a heavy reliance at the moment on diesel. In fact, many communities have no electricity supply and in most places that they have electricity, the supply is erratic leading to daily blackouts. This shows that in order to reduce cost there is a need to also provide electricity to the communities hence the need for including this analysis in this work. It can also be seen from our results that on the average the price of the HAP-based system is similar.

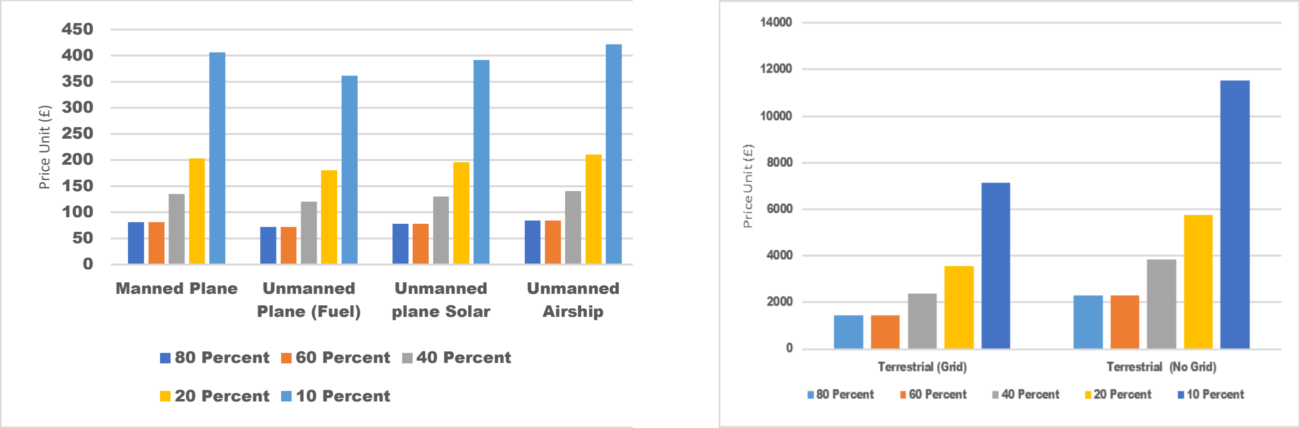
Figures 7-9 shows the price per user depending on percentage of subscribers our hypothetical service provider has for scenarios A, B and C respectively. It can be seen from the figures that the price paid per user decreases as the number of subscribers increases. The reason for this is that the more the number of users the more the cost is shared among the users. In the proposed model, increasing the subscriber require more infrastructure as it a capacity driven network. This shows that for a coverage driven network, which is the first step for rural Africa, the cost would be considerably lower The price is important for sustainability of the network because a considerable number of people within the African continent live below the poverty line and as such, when the price is high, paying for the services may be difficult and the overall objective will be defeated.





(a) (b)

Figure 7: Cost per user for (a) a variable number of subscribers for manned plane, unmanned plane, unnamed plane (solar), unmanned airship, and (b) terrestrial (grid), terrestrial (no grid) based on Scenario A



(a) (b)

Figure 8: Cost per user for a variable number of subscribers for manned plane, unmanned plane, unnamed plane (solar), unmanned airship and (b) terrestrial (grid) and terrestrial (no grid),

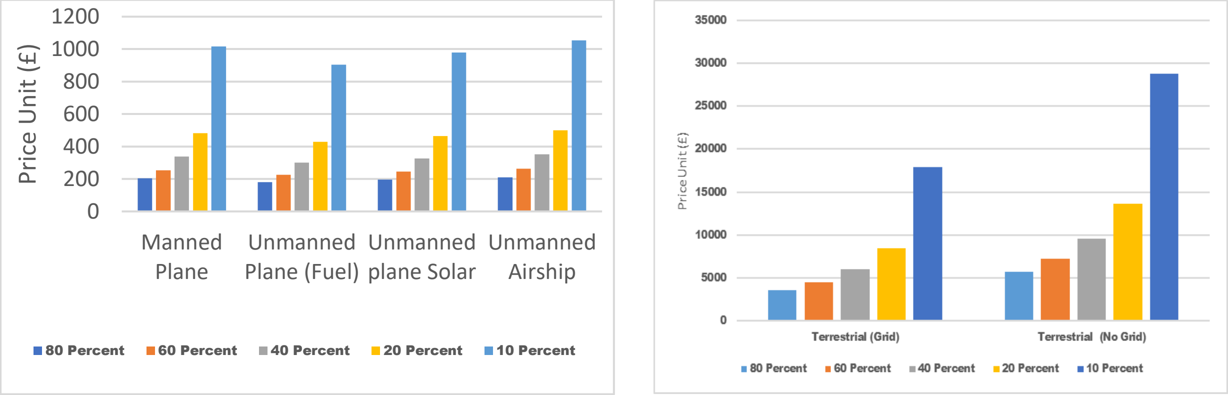
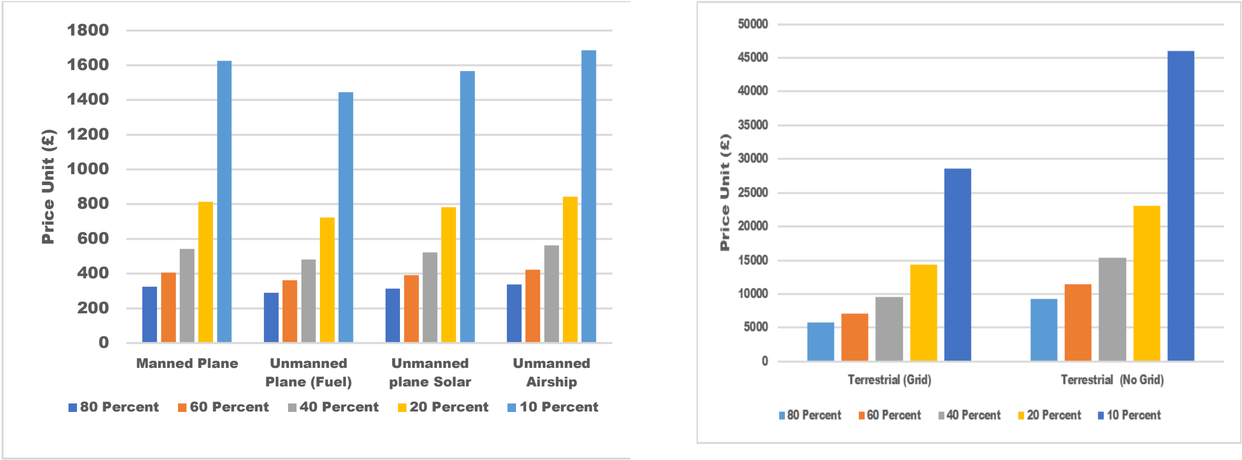


Figure 9: Cost Per User for a variable number of subscribers for a manned plane, unmanned plane, unnamed plane (solar), unmanned airship, terrestrial (grid), terrestrial (no grid) based on Scenario

Figure 10 shows the cost per household for scenario A, when a varying the market share of the hypothetical operator. These results are similar to the corresponding results obtained from the results earlier on cost per user hence only Scenario A is shown. It can be clearly seen that based on the previously provided reason the HAP is more cost effective when compared to terrestrial system and the more the percentage of population using the system the lower the price paid.



(a) *(b)*

Figure 10: Cost Per household for (a) variable number of subscribers for manned plane, unmanned plane, unnamed plane (solar), unmanned airship and (b)terrestrial (grid), terrestrial (no grid) based on Scenario A

The above results have clearly shown the cost associated with each type of deployment. This can help policymakers in taking decisions around broadband deployment such that it can help simulate development within these communities. In other to further evaluate the cost, we shall consider the elasticity of the cost.

Elasticity of the Cost

The elasticity of the cost per household is evaluated and the cost per square kilometre which has been earlier examined. This performance measure is usually used to examine how sensitive a parameter is, the relative improvement or how change in a parameter would affect the total cost. This measure is aimed at showing the most important improvement that can help in reducing cost. In this work, the elasticity of the cost per user and cost per household is evaluated with respect to a change in another variable. We define elasticity (E_c) as

$$E_c = \frac{(\frac{\Delta C}{C})\%}{(\frac{\Delta P_x}{P_x})\%} \qquad (8)$$

Where ΔC is the change in the infrastructure cost C, ΔP_x is the change in parameter P_x. A negative value of E_c means that there is a reduction to the infrastructure cost and a positive value means there is an increase in the infrastructure cost. The greater the absolute value of E_c the more the impact of the parameter being measured on the overall cost. The cost elasticity with respect to the increase in bandwidth, increase in the data rate required by the users, contention ration the CAPEX and OPEX cost is evaluated. The elasticity is calculated using equation 3. The starting point for all our elasticity calculations is that of scenario A as described in the previous section. Just like with any elasticity calculations, an initial 5% percent increase or decreases in any of our variable is an 100% change from the starting point of 0. Therefore, a change from 5% to 10% is a 50% movement.

For example, the cost per user for the initial 5% increase in amount of bandwidth available to the operator would mean a price paid from £2,746 to £2,625. This means the denominator in equation 3 is 100% and the price change (numerator in equation 3) is about 4.5% to give an absolute elasticity value of 22.5.

Figure 11 shows that the elasticity against percentage increase of bandwidth, data rate requirement and contention ratio for both the HAP and terrestrial network. The contention ratio refers to the number of users who share the data capacity on a provider's line. The result shows that the elasticity for HAP and terrestrial system based on the same percentage increase are the same. This means that there would be a no difference to the cost per person if either the HAP or the terrestrial system is implemented when users want an increased data rate, the service provider changes the contention ratio or the amount of bandwidth available is increased. There is no difference in the elasticity value because the same percentage increase were used and this does not any anyway change cost per unit of the OPEX and CAPEX cost of putting in place the infrastructure. This shows that the elasticity with respect to technology in terms of bandwidth, data rate and contention ratio is the same. The same result, however, shows that a change in any of these parameters would lead to a change in the cost per household. If there is a need to reduce the cost per household then any of these parameters can be adjusted. However, from the result, it can be seen that on the average an increase in the amount of bandwidth available would have a more significant improvement on the cost paid per household for any of the serves when compared to either a change in data rate or contention ratio. This clearly shows that in order to reduce the price, the government can make more bandwidth available (subject to availability) to service providers and this could also be one of the ways of improving on broadband services in Africa. Therefore it can be said that the price (C) is proportional to available bandwidth (b_w) as shown in the equation below. Where k is a constant.

$$C = kb_w \qquad (9)$$

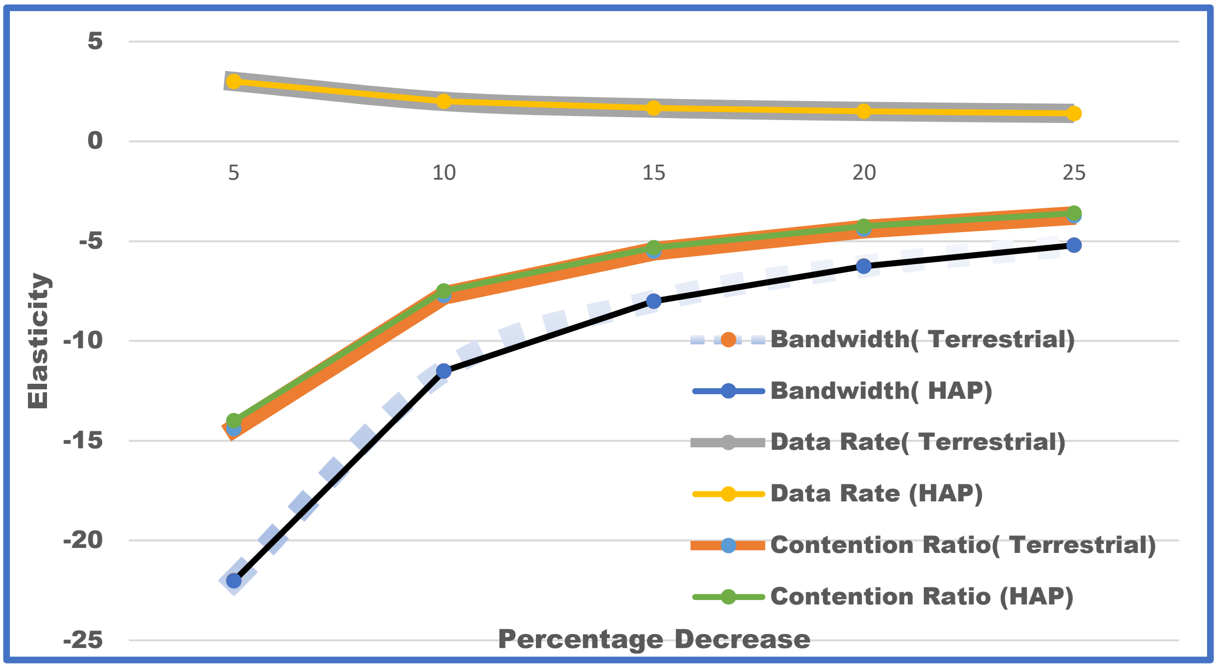


Figure 11: A graph of elasticity against percentage increase in bandwidth, data Rate and contention ratio for HAP and terrestrial systems

Figure 12 shows cost price elasticity with respect to an increase in CAPEX. It can be seen that both HAP and the terrestrial system both have a negative utility value which means that a reduction in the CAPEX price of any of the two systems would lead to a reduction in the price paid per household. However, the results show the absolute value for the same percentage decrease that HAP would provide a lower cost price per household. This illustrates that the sensitivity of the price paid by the user in an HAP based scenario is less than that of a terrestrial scenario for the same percentage change in CAPEX price. This is because the effect of a change in CAPEX price result to more significant increase in the cost paid by the user based on the terrestrial scenario compared to the HAP system. This would also help in planning the network given the importance of CAPEX when deploying networks especially in developing countries.

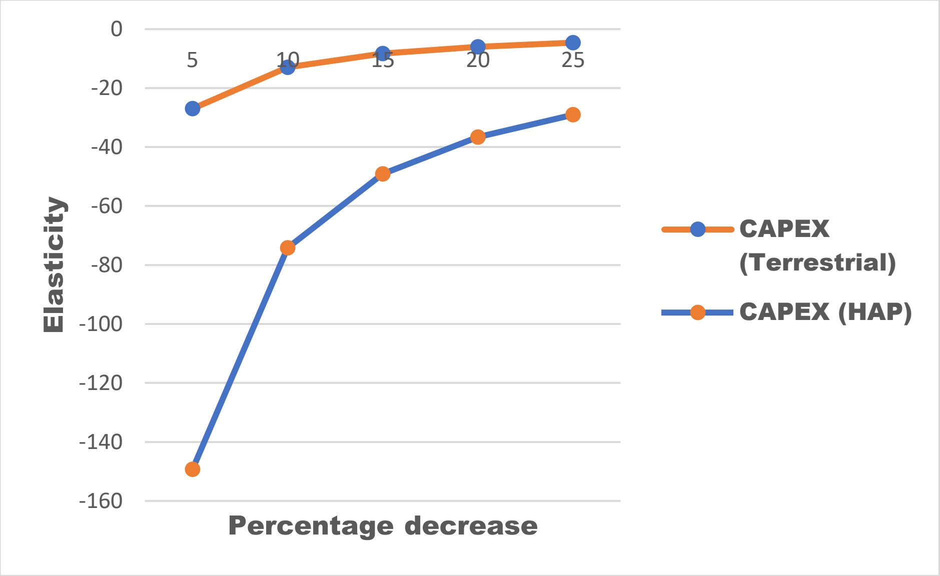


Figure 12: A graph of elasticity against percentage decrease in CAPEX for HAP and terrestrial systems

Figure 13 shows that cost price elasticity with respect to an increase in OPEX price. It is necessary to show this price sensitivity as generally governments from developing countries often charge high taxes to telecommunication service providers as discussed in (Roller & Waverman, 2001). This cost is often passed on to the end user leading to an increase in OPEX price. It can be seen from our result that an increase in operating cost would have a positive elasticity which signifies an increase in the cost per household. Our result for the same percentage increase in HAP and terrestrial OPEX cost also show that the HAP systems are less sensitive to an increase to the OPEX price when both are compared.

These results have shown the relationship between the CAPEX and the OPEX price and of making changes to it on end users. This would help policymakers, operators and service providers make decisions towards the deployment of broadband deployment across after thereby simulating development in the region as earlier shown that there is a direct correlation between access to broadband services and development of a community.

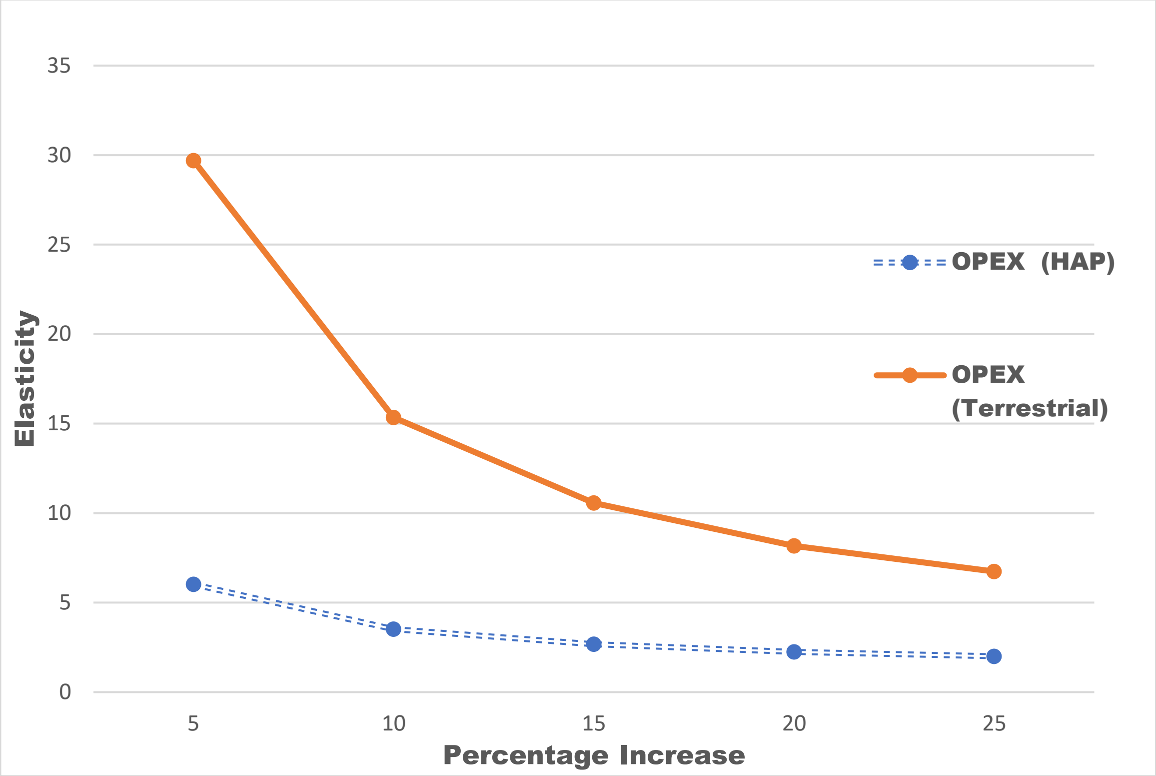


Figure 13: A graph of elasticity against percentage increase in OPEX for HAP and terrestrial systems

V. Conclusions

This work has presented a low-complexity model to evaluate the costs of deploying fixed broadband deployments across Africa using HAP and terrestrial systems. The work examined the impact of broadband deployment in the development of a community. It shows that broadband deployment has a direct correlation with the development of a community and more importantly the rural community where most Africans live. These communities comprises majorly of farmers who live below the poverty line. This work serves as a starting point for policy makers in Africa to consider the deployment of HAPs as an alternative to terrestrial systems when considering roll-out of broadband particularly to rural users. This is because it provides a generalised model that can easily be compared with the current terrestrial approach. The paper has shown how a hypothetical network operator can deploy fixed services with the projected cost implication per household. The results are useful for planning purposes especially as we look to connect those that are unconnected across Africa. This work has shown that broadbasn can be deployed in Africa using a cost effective solution. On the average the cost of a terrestrial system would be about 250% the cost of putting in place a HAP network, mainly caused by the number of terrestrial base stations required to cover the entire African land mass. The economics also showed that increasing the available bandwidth available reduces the price paid per user and household. It can also be seen from the results that the cost per household for a HAP system is significantly lower than that of a terrestrial system. This lower cost of the HAP system is despite the fact that land acquisition costs have not been included, which can form a significant amount in terrestrial deployments. A reduction in CAPEX would more significantly lead reduce the cost per household for the HAP system when compared to the same cost reduction in CAPEX of a terrestrial system. Furthermore, the analysis has shown that the HAP system is less sensitive to in increases in OPEX when compared to terrestrial system.

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References

Anderson, H. R. (2003). *Fixed broadband wireless system design*: John Wiley & Sons.

Avdikos, G., Papadakis, G., & Dimitriou, N. (2008). *Overview of the application of high altitude platform (HAP) systems in future telecommunication networks.* Paper presented at the Signal Processing for Space Communications, 2008. SPSC 2008. 10th International Workshop on.

Bank, W. (2018). Rural population. Retrieved 1st June 2019, 2019, from https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS

Bazilian, M., Welsch, M., Divan, D., Elzinga, D., Strbac, G., Howells, M., . . . Balijepalli, V. (2011). Smart and just grids: opportunities for sub-Saharan Africa: Imperial College London.

Dahlman, E., Parkvall, S., & Skold, J. (2013). *4G: LTE/LTE-advanced for mobile broadband*: Academic press.

Feijoo, C., Gomez-Barroso, J. L., Ramos, S., & Rojo-Alonso, D. (2006). Active policy measures against the digital divide based on mobile/wireless connectivity development: The Latvian experience. *International journal of mobile communications, 4*(6), 727-742.

Fjermestad, J., Passerini, K., Bartolacci, M. R., & Patten, K. (2008). Wireless connectivity and its relationship to emerging economies: the example of China. *International journal of mobile communications, 6*(5), 633-645.

Fornefeld, M., Delaunay, G., & Elixmann, D. (2008). The impact of broadband on growth and productivity. *Comisión Europea (DG Information Society and Media), MICUS*.

Futter, A., & Gillwald, A. (2015). Zero-rated internet services: What is to be done? *Broadband 4 Africa, 1*, 1-10.

Gannon, A. (1994). Rural tourism as a factor in rural community economic development for economies in transition. *Journal of sustainable tourism, 2*(1-2), 51-60.

Gillespie, A., & Goddard, J. (2017). Advanced telecommunications and regional economic development *Managing the city* (pp. 84-109): Routledge.

Gurstein, M. (2003). Effective use: A community informatics strategy beyond the digital divide. *First Monday, 8*(12).

Gyamfi, A. (2005). Closing the Digital Divide in Sub-Saharan Africa: meeting the challenges of the information age. *Information development, 21*(1), 22-30.

Johansson, K. (2007). *Cost effective deployment strategies for heterogenous wireless networks.* KTH.

Juma, C., & Moyer, E. (2008). Broadband internet for Africa: American Association for the Advancement of Science.

Karapantazis, S., & Pavlidou, F. (2005). Broadband communications via high-altitude platforms: a survey. *IEEE Communications Surveys & Tutorials, 7*(1), 2-31.

Katz, R., & Suter, S. (2009). Estimating the economic impact of the broadband stimulus plan. *Columbia institute for tele-information working paper, 7*.

Katz, R. L. (2009). *Estimating broadband demand and its economic impact in Latin America.* Paper presented at the Proceedings of the 3rd ACORN-REDECOM Conference Mexico City.

Kelly, T. (2014). The State of Broadband in Africa: What's Here and What's Coming? *Broadband as a video platform* (pp. 41-49): Springer.

Kuran, M. S., & Tugcu, T. (2007). A survey on emerging broadband wireless access technologies. *Computer Networks, 51*(11), 3013-3046.

Lam, P.-L., & Shiu, A. (2010). Economic growth, telecommunications development and productivity growth of the telecommunications sector: Evidence around the world. *Telecommunications Policy, 34*(4), 185-199.

Miura, R., & Suzuki, M. (2003). Preliminary flight test program on telecom and broadcasting using high altitude platform stations. *Wireless Personal Communications, 24*(2), 341-361.

Ohmae, K. (1995). *The end of the nation state: The rise of regional economies*: Simon and Schuster.

Osabutey, E. L., & Okoro, C. (2015). Political risk and foreign direct investment in Africa: The case of the Nigerian telecommunications industry. *Thunderbird International Business Review, 57*(6), 417-429.

Oshikoya, T. W., & Hussain, M. N. (1998). Information technology and the challenge of economic development in Africa. *African Development Review, 10*(1), 100-133.

Philbeck, I. (2016). Working Together to Connect the World by 2020, Reinforcing Connectivity Initiatives for Universal and Affordable Access: A discus-sion paper to Partners working to Connect the World, ITU, Geneva.

Prasada, B. (1976). Some Implications of Telecommunication Policies in Developing Countries. *IEEE Transactions on Communications, 24*(7), 729-732.

Prieger, J. E. (2013). The broadband digital divide and the economic benefits of mobile broadband for rural areas. *Telecommunications Policy, 37*(6-7), 483-502.

Rohman, I. K., & Bohlin, E. (2012). Does broadband speed really matter as a driver of economic growth? Investigating OECD countries. *International Journal of Management and Network Economics 5, 2*(4), 336-356.

Roller, L.-H., & Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American economic review, 91*(4), 909-923.

Schuler, D. (1994). Community networks: building a new participatory medium. *Communications of the ACM, 37*(1), 38-51.

Srinuan, C., & Bohlin, E. (2013). Analysis of fixed broadband access and use in Thailand: Drivers and barriers. *Telecommunications Policy, 37*(8), 615-625.

Stork, C., Calandro, E., & Gamage, R. (2014). The future of broadband in Africa. *info, 16*(1), 76-93.

Subramanian, L., Surana, S., Patra, R., Nedevschi, S., Ho, M., Brewer, E., & Sheth, A. (2006). Rethinking wireless for the developing world. *IRVINE IS BURNING*, 43.

Thompson Jr, H. G., & Garbacz, C. (2011). Economic impacts of mobile versus fixed broadband. *Telecommunications Policy, 35*(11), 999-1009.

Tozer, T. C., & Grace, D. (2001). High-altitude platforms for wireless communications. *Electronics & communication engineering journal, 13*(3), 127-137.

Wallsten, S. (1999). *An empirical analysis of competition, privatization, and regulation in telecommunications markets in Africa and Latin America*: The World Bank.

West, D. M. (2010). *An International Look at High-Speed Broadband*: Brookings Institution.

Williams, M. (2010). *Broadband for Africa: developing backbone communications networks*: The World Bank.

Zhen-Wei Qiang, C. (2010). Broadband infrastructure investment in stimulus packages: Relevance for developing countries. *info, 12*(2), 41-56.