Rebuilding digital inclusion for the rural counties of Kenya

Leonard Mabele, Joseph Sevilla, Gilbert Mugeni, Dennis Sonoiya, Edward Wasige, and Kennedy Ronoh

Rebuilding digital inclusion for the rural counties of Kenya

November 2022

Leonard Mabele, Strathmore University

Joseph Sevilla, Strathmore University

Gilbert Mugeni, Communications Authority of Kenya

Dennis Sonoiya, Communications Authority of Kenya

Edward Wasige, University of Glasgow

Kennedy Ronoh, Technical University of Kenya

Acknowledgments

This report was authored by Leonard Mabele, Joseph Sevilla, Gilbert Mugeni, Dennis Sonoiya, Edward Wasige and Kennedy Ronoh on behalf of Strathmore University. In producing the report, Strathmore University has used funds from a grant provided by ITU under Connect2Recover initiative.

We sincerely acknowledge the support provided by the International Telecommunications Union (ITU) under the Connect2Recover research competition initiative through the research funding that saw us carry out work on this Research Paper. More specifically, we are grateful for the comments and feedback from Mr. Sameer Sharma, Ms. Karen Woo and Mr. Chuluunbat Tsendsuren on reporting and the project updates. Our thanks also go to the ITU team for organising workshops and information sessions that served fruitful in exchanging knowledge and findings. We also extend our gratitude to the Communications Authority of Kenya (CA) team for providing useful data and documentation that has added more quality to this report. Our heartfelt thanks also goes to the stakeholders who provided us fruitful feedback to make this document sufficiently complete.

Please consider the environment before printing this report.

Disclaimers

This is a publication that has been produced by Strathmore University. ITU is not involved in the preparation, drafting, editing, or finalization of this publication, and consequently, it is not responsible for its content or of the content of its external sources and does not warrant the accuracy, reliability or timeliness of any information contained therein.

The views, opinions, findings and conclusions expressed in this publication are those of the authors and do not necessarily reflect the views of Strathmore University, ITU or ITU's membership.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of ITU or ITU's membership concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the authors, Strathmore University, or ITU in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

All reasonable precautions have been taken by Strathmore University to verify the information contained in this publication. However, the published material is being distributed.

Third-party materials

If you wish to reuse material from this work that is attributed to a third party, such as tables, figures or images, it is your responsibility to determine whether permission is needed for that reuse and to obtain permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

Cover photo credits: Shutterstock

Table of Contents

List of Tables

List of Figures

Definition of Terms

Backhaul communication	Transport of aggregate communication signals from base stations to the core network.
Bandwidth	The range of frequencies available to be occupied by signals. In analogue systems, it is measured in Hertz (Hz) and in digital systems in bits per second. The higher the bandwidth, the greater the amount of information that can be transmitted in a given time.
Base station	The common name for all the radio equipment located at a site and used for serving one or several cells.
Broadband	High-speed Internet access – In Kenyan context, it is defined as 2 Mbps per user or 10 Mbps for a home with five users.
Community Network	This refers to a local telecommunication service provided for the specific needs of a geographically defined community.
Connectivity	The capability to provide connection to the Internet and other communication networks to end users.
Customer Premises Equipment	The network equipment installed at a user’s home or office.
Dynamic Spectrum Access	The concept of unlicensed users “borrowing” spectrum from spectrum licensees in a dynamic manner.
Digital Economy	An entirety of sectors that operate using digitally enabled communications and networks leveraging Internet, mobile and other technologies.
Fixed Wireless Access	Wireless Access (end user radio connection (s) to core networks) application in which the location of the end-user termination (the end-user radio equipment antenna) and the network access point to be connected to the end user are fixed.
Internet service provider	An entity, usually a private company but in some cases, a non-profit or government owned, that provides Internet access through data connectivity using a variety of

	technologies such as telephone cables, coaxial cables, wireless or fibre.
Last mile network	This is where the Internet reaches end users and includes local access networks, including the local loop, central office, exchanges and wireless masts. The access network reaches end-user devices, typically basic and smartphones, laptops, tablets, computers and other Internet-enabled devices.
Meaningful Connectivity	A high-quality connection based on user needs rather than a simple connection.
Middle-mile network (backhaul)	This is the distribution network that connects the national backbone to a point in an outer locality/geographic area for broader distribution out to the last mile.
Spectrum Sharing	An opportunistic technique that can be exploited by regulatory regimes through taking advantage of any spectrum that is locally unused as a means to increase spectrum availability.
TV White Spaces	Idle or unused frequencies in the UHF band 470-694 MHz for Kenya.
Universal access	Refers to reasonable telecommunication access for all. Includes universal service for those who can afford individual telephone service and widespread provision of public telephones within a reasonable distance for others.
White Spaces	Idle spectrums that are unused at a particular location at a particular time.

Acronyms

A4AI	Alliance for Affordable Internet
AP	Access Point
ASA/LSA	Authorised Shared Access/Licensed Shared Access
ATU	African Telecommunications Union
CA	Communications Authority of Kenya
CAPEX	Capital Expenditures
CDMA	Code Division Multiple Access
CPE	Customer Premises Equipment
CR	Cognitive Radio
DSA	Dynamic Spectrum Access
DSAL	Dynamic Spectrum Alliance
DTT	Digital Terrestrial Television
EIRP	Equivalent Isotropic Radiation Power
GPS	Global Positioning System
GSMA	Global Alliance of Mobile Network Operators
ICT	Information and Communication Technology
ICT4D	ICT for Development
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
ISP	Internet Service Provider
ITU	International Telecommunications Union
KENET	Kenya Education Network
KICTANet	Kenya ICT Action Network
LTE	Long Term Evolution – Including 4G and 5G
M2M	Machine to Machine Communication
MIMO	Multiple-Input, Multiple-Output
MNO	Mobile Network Operator

NBS	National Broadband Strategy
NLOS	Non-Line-of-Sight
NOFBI	National Optic Fibre Backbone Infrastructure
OSA	Opportunistic Spectrum Access
RF	Radio Frequency
SDGs	Sustainable Development Goals
SDR	Software-defined Radio
SIM	Subscriber Identity Module
TVWS	Television White Spaces
UHF	Ultra-High Frequency
UN	United Nations
UNICEF	United Nations Children's Fund
USF	Universal Service Fund
USP	Universal Service Provision
WAN	Wide Area Network
5G	Fifth Generation Communication Standard for Cellular Networks

1. Project Overview

1.1. Background of the Connect2Recover Initiative

The Connect2Recover initiative was launched by the International Telecommunication Union (ITU) with the support from the Government of Japan and the Government of Saudi Arabia in line with the United Nations Secretary-General's Roadmap for Digital Cooperation and the global goal of universal connectivity. The overall objective of the initiative was to help countries recover from COVID-19 by "building back better with broadband" through reinforcement of their digital infrastructure and ecosystems and in order to remain resilient in times of hazards. In July 2021, the initiative launched the "Connect2Recover Research Competition" which sought to identify promising research proposals that would accelerate digital inclusion efforts for COVID-19 recovery. The competition encompassed the following aims:

1. Improve research focus on digital resiliency and digital inclusion to build better with broadband for pandemic recovery;
2. Build a global research community of think tanks and academic institutions around digital inclusion, and
3. Promote knowledge sharing that informs targeted practices to build back better with broadband.

Out of the 307 proposals submitted to the competition from 80 countries, 15 were selected as the winning ones. The 15 Research Papers, hail from 43 institutions and individual researchers in 22 countries. The work we present here is based on one of the 15 Research Papers which is entitled "**Rebuilding Digital Inclusion for Rural Counties of Kenya.**"

1.2. Overview of this Research Paper

Work on this Research Paper was carried out by a consortium made up of the following institutions: Strathmore University (SU), Communications Authority of Kenya (CA), University of Glasgow (UoG) and the Technical University of Kenya (TUK). The consortium ventured to study the connectivity challenges faced by the rural academic institutions as well as healthcare institutions at the height of the COVID-19 pandemic in Kenya. It also further studied the state of connectivity for these institutions (academic and healthcare) prior to the pandemic and at present, alongside assessing the opportunity of the newly enacted frameworks in Kenya to leapfrog broadband access. The consortium also performed spectrum measurements, as part of work on this Research Paper to evaluate the opportunistic usability of the radio frequency (RF) spectrum in ensuring that rural institutions are connected. The objective of the measurements was to assess the feasibility of novel ways that can enhance digital resilience, particularly through Dynamic Spectrum Access (DSA), for contextual connectivity. More work on the Research Paper also included site surveys to two counties in Kenya – Kakamega and Machakos to pragmatically contribute to the ITU's broader objective of a systemic platform of universal data that maps the connectivity needs versus infrastructure coverage.

2. Introduction

The varied attempts to address the connectivity challenge in Kenya (like everywhere else in the world) such as through Universal Service Fund (USF), private sector initiatives or philanthropy have had limited success in reaching the unserved and underserved. The pandemic injected a reinvigorated appreciation of how connectivity can give all citizens access to multiple opportunities such as access to online academic content, adequate healthcare information, e-government services and online shopping, allow governments to deliver much needed services and enable businesses to thrive - a backbone that sustained the activities in Kenya since March 2020 when the lockdown came into effect [1]. Similar to the rest of the world, the lockdown came with the measures of closing down learning institutions and certain types of businesses, restriction of movement across the country’s international borders and across borders of certain counties as well as introduction of daily curfew hours [2]. Although this notable pandemic implications highlight an unprecedented case of the need for connectivity, a connectivity conundrum is not something new in Kenya. The challenge of the digital divide has been widening for a while now, leaving value to accrue to those with affordable access to communication infrastructure and those without falling further behind by simply staying in the same spot [3]. Therefore, this Research Paper made it as part of its core objectives to investigate regulatory initiatives that seek to address such conundrum in the context of the pandemic.

Notably, based on the inclusion of representatives from the country’s regulator to the project, it can be said that there exists a regulatory understanding that is aware that the lack of choice in access alternatives results in an unaffordable access for a significant percentage of the population. Such population, predominantly resides in the rural areas. Hence, we keenly assessed the opportunity that the newly enacted regulatory frameworks (one based on TV White Spaces and another on Community Networks) by the CA, could potentially contribute to the “pandemic recovery” strategy for the rural educational and healthcare institutions. Although our findings during site surveys underscored the weight the fibre optic infrastructure carries, especially through the government’s National Optical Fibre Backbone Infrastructure (NOFBI), we also noted that there is a need to have more players in the market (or the existing players ought to extend their market) to deliver on more targeted, localised and affordable connectivity options. For instance, one institution’s Internet cost in a month was almost USD $2,000 only on fibre network. Unfortunately, the reach of that fibre network is currently limited for that institution’s population. Moreover, it also has challenges on the quality of service (QoS) presently provided. Perhaps more network options for such an institution would lower the cost of Internet per month and invite healthy competition for better reach and improved QoS.

Issues such as lack of service options, affordability and quality of access to data services and a weak ecosystem that can support provision of content to the students, conspicuously came to the fore during the desk studies on this Research Paper. Such issues indicated a huge struggle that both teachers and students faced in their quest to stay connected during the pandemic and remotely attend virtual classrooms through online learning applications. On the other hand, healthcare workers, especially those who had been forced to work from home as a result of contacting the coronavirus, experienced an unreliable connection. The unreliable connection, consequently, perpetuated a delay in dissemination of information to the relevant groups regarding the state of the pandemic. In this Research Paper, therefore, the variables that ought to be considered in the efforts and initiatives of connectivity are highlighted. The variables span beyond just regulatory and policy issues. Aspects of technology, infrastructure, access to devices, economic sustainability, innovation as well as usage gap also form part of the variables to be considered in tandem.

3. Objectives of the Project

The overall objective of this Research Paper was to find out the state of the digital infrastructure for the rural counties of Kakamega and Turkana before, during and after the pandemic (can be said as now and not post-pandemic) and to assess the opportunity that Dynamic Spectrum Access (DSA) and Community Networks (CNs) can provide in establishing digital resiliency for such counties especially in the quest to achieve “recovery” from the pandemic.

The specific objectives included:

- To study the underlying pre-pandemic digital infrastructure for the rural counties of Kakamega and Turkana.
- To determine the level of the COVID-19 effect on the state of connectivity for education and healthcare institutions in Kakamega, Turkana (and Machakos) counties based on previously laid out plans for normal continuity.
- To determine the best-fit approach of implementing DSA and CNs in order to enhance connectivity for the rural counties to improve digital resilience and inclusion.
- To develop a baseline of usable data sets that can contribute to the stakeholders’ (such as the government, ITU etc.) strategies of connectivity based on clear mapping of broadband needs versus infrastructure coverage for rural educational and healthcare institutions.

4. Research Methodology

Various research methods were exploited in the delivery of the objectives of this Research Paper. Predominantly, however, the desk research method was used. It allowed various secondary sources relevant to broadband access for the rural counties of Kenya to be studied. Such sources included documentation that looks at the aspects of connectivity for the country in general as well as connectivity specific for Kakamega and Turkana counties. The desk research further studied documents from the government that seek to enable and enhance connectivity for schools, hospitals and healthcare institutions prior to the pandemic such as the Digital Economy Blueprint [4], the National Broadband Strategy [5] among others. Such documents also included the newly published regulations and regulatory steps by the country’s telecommunications regulator (CA) looking to deliver broadband access to the unserved and underserved. Various reports around the world on connectivity for schools and hospitals also formed part of the key considerations of the desk studies comprising initiatives such as ITU’s Giga and strategic efforts by groups such as the Dynamic Spectrum Alliance (DSAL), Global Alliance of Mobile Network Operators (GSMA), the Alliance for Affordable Internet (A4AI) among others to realise last mile Internet. The fundamental driving goal while studying these various sources was to establish contextually appropriate methods that can enable rural healthcare and academic institutions to be properly “connected or reconnected” from the connectivity challenges discovered during the pandemic.

Beyond the assessment of secondary sources, our desk studies also involved engaging stakeholders providing Internet services to the three counties for both schools and healthcare institutions. The engagement involved assessing the state of their existing services and the networking options they provide (and also provided during the pandemic) as well as challenges faced. Although, we note that the stakeholder's responses were not as many as we had anticipated, we have used the feedback we obtained to estimate the status of opportunity and challenges across all the stakeholders.

In addition to the desk studies, we also conducted a 6-day site visit in Kakamega and Machakos counties. The aim of the site surveys was to sample a set of schools and healthcare centres in regards to their state of connectivity prior to the pandemic, during the pandemic and now. This activity also involved speaking to the institution's administrations and the Information and Communications Technology (ICT) staff on their quality of service, challenges faced during the pandemic and their experience as well as suggestions to enhance Internet access.

A technical segment of our research methodology involved conducting spectrum measurements in the 470-694 MHz band, 600 MHz, 700 MHz, 1700 MHz and 3300-3500 MHz bands. The aim was to determine the intensity of usage of these frequency bands and whether there is a window of opportunity that can be exploited through Dynamic Spectrum Access (DSA). While previous work has been done in the 470-694 MHz band (now authorised for Television White Spaces –TVWS in Kenya), our focus was to contribute towards developments from a point of determining if any demand could have arisen from the incumbents of that band since the enactment of the regulations in 2021. The other bands were put into consideration to evaluate their current usage for feasibility of DSA and the opportunity of deploying CNs leveraging such bands as captured in the Licensing and Shared Spectrum Framework for Community Networks [6]. The spectrum measurements were done using the CA's spectrum monitoring vehicle.

5. Findings based on this Project

In the reporting of this Research Paper, we divide the segments of our findings into the following sections:

1. Desk assessment of the state of connectivity for Kakamega and Turkana Counties.
2. Review of the enacted regulations to enhance rural Internet access and Stakeholder Engagements.
3. Site Surveys in Kakamega and Machakos Counties.
4. Spectrum Measurements.

5.1. Desk Assessment of the State of Connectivity for Kakamega and Turkana Counties.

This segment highlights in summary the state of connectivity prior to the pandemic in both Kakamega and Turkana counties [7]. It also highlights the connectivity challenges faced during the COVID-19 pandemic by the schools and healthcare centres and the present developments that can empower the efforts to bridge the digital divide in these two counties.

5.1.1. State of Connectivity for Kakamega and Turkana Counties Pre-Pandemic

Kenya's census report conducted in 2019 showed that rural Internet access stood at 13.7% compared to urban Internet access which stood at 42.5% [8]. This shows that prior to the pandemic, urban areas were accessing the Internet thrice the rural areas – a demonstration of a significantly huge gap of the digital divide. While both Kakamega and Turkana counties form part of the notable rural counties of Kenya, they have uniquely varying geographical and demographic features that must be considered in the initiatives of broadband access. Kakamega County has an area of 3,051.3 sq. km, an estimated population of 2,079,699 people and a population density of 682 people per sq. km. [9] while Turkana has an area of 71,597.8 sq. km (13% of Kenya's land), an estimated population of 1,000,000 people and a population density of 14 people per sq. km. [10] Unlike Kakamega, Turkana struggles with challenges of drought and climate change, inadequate social services, poor physical infrastructure, dispersed human settlements, gender bias and negative cultural practices. The county is described as an Arid and Semi-Arid Land (ASAL) making up 80% of Kenya's ASAL. Although Kakamega can be said to enjoy economic advantage of arable land compared to Turkana, the county also has immense challenges of income inequality with the larger fraction of the population still unconnected to power and lacking decent jobs.

With the varying geographical features, it is easy to tell that schools and healthcare centres within Turkana, apart from being far apart, they are not as many which translates to little government and private initiatives for Internet access to schools in that county as compared to Kakamega. The same goes for the healthcare centres. Nevertheless, the three Mobile Network Operators (MNOs) in Kenya – Safaricom, Airtel and Telkom already provide their services in Turkana. Prior to the pandemic, the cellular network coverage was described as a steadily growing one, although the County government of Turkana noted that there were still significant areas without access to a cellular signal, hampering both voice and data communication. In fact, as at 2018 when the National Broadband Strategy was being developed, Turkana citizens were said to walk more than 2 kilometres to access a mobile cellular signal with access to Internet and data services were still lacking. Besides the cellular coverage, Turkom, an ISP operating in Turkana provides Internet through fibre and satellite connections albeit information on their extent of coverage and uptake, similar to data on connectivity in Turkana, is not publicly available. The government's NOFBI network for fibre connectivity had not reached Turkana yet before the pandemic [11].

Kakamega County, on the other hand, had NOFBI coverage only in some areas along the main tarmac road within Kakamega town with a few institutions and organisations making use of it. The county also had 85% coverage of mobile telephony showing an improvement of new products and services in various sectors such as Health and Agriculture. Nevertheless, the data services through the cellular network were described as one that needed improvement, particularly through LTE. While reports from CA showed better connectivity in Western Kenya, a particular newspaper publication, Nation [12] provided on the ground experience that elucidated the opposite. Concerns of the quality of the Internet signal, challenges of power and lack of access options, especially through fixed wireless access (FWA) were key issues limiting proper Internet access for Kakamega County prior to the pandemic.

5.1.2. State of Connectivity for Kakamega and Turkana Counties during the Pandemic

5.1.2.1. For Education

The temporal cessation of on-campus activities to mitigate the spread of the COVID-19 virus affected both Kakamega and Turkana schools. While it registered an enormous impact on higher education (Universities), primary and secondary school students were the most affected. Similar to the rest of the world, students had to attend online classes, some of them for the first time due to the fact that some universities and colleges had never conducted online classes before. For primary and secondary schools in Kenya, their classes are always physical-centric. Therefore, there were no mechanisms to migrate their studies online and central cloud-based environment to access academic content also did not exist. Although the government's efforts for continuity of learning through the broadcast media such as Radio and Television as well as YouTube was helpful as shown in studies [13], it was not sufficient, particularly to the students in areas where electric power is a challenge. Moreover, the broadcasting period was only an hour a day and students could not have a point of reference after the broadcasting as they would in a Zoom session where a recording can be shared.

The socio-economic challenges that the pandemic caused also heavily affected both primary and secondary students in both Turkana and Kakamega. While some institutions provided mobile data to the students, others did not, leaving students to battle it out on their own. In some universities, the institutions mandated the students to complete their fee arrears in order to join the online classes and be provided mobile data. Initiatives of low-data needs such as use of WhatsApp was therefore adopted in Kakamega to share educational materials, similar to what was done in Daadab Refugee Camp in Turkana. Still, the success of this depended on the quality of the cellular signal, which from time to time was dropping for most students who joined the classes from the rural areas, a similar challenge that the teachers also faced [14]. Unlike their urban counterparts, students schooling in the rural areas (these do not include the ones that were now taking classes from the rural areas due to institutional closure) also faced an additional challenge of the digital skills as some of them did not know how to navigate the various online learning platforms such as Zoom, Teams, Webex or Google Meet.

Unlike Kakamega, the weak pre-pandemic infrastructure in Turkana County further impacted the students' learning during the pandemic. For example, while Kakamega had a fibre Point of Presence (PoP) before the pandemic, Turkana did not, until the last quarter of 2020 [15]. Therefore, students in Turkana did not enjoy online learning compared to their urban counterparts at the height of the pandemic [16]. The initiative by the National Government through the Ministry of Education to increase academic access through radio and TV was more relevant in Turkana [17]. However, due to challenges of power and connectivity, the provision of the government's cloud-based Ed-tech platform by the Kenya Institute of Curriculum Development (KICD) was not useful in Turkana like it was in urban counties. The challenge of available devices for the students also seemed conspicuous in Turkana due to the low-income state of the parents in Turkana County.

5.1.2.2. For Healthcare

Although the healthcare budget allocation for Kenya has continually been growing since the implementation of devolution in 2013 as shown in Health Plus Policy [18], the pandemic exposed the weaknesses that exist in the Kenyan healthcare system, particularly on financing and governance. Aspects such as home care as an alternative to hospitalisation [19], unfortunately could not be successfully implemented due to challenges of reliable Internet connection as well as availability of ICT equipment to boost the desired digital medical supply chain. There was little information about Kakamega and Turkana in terms of how their healthcare sectors actually operated during the pandemic. These include information on how they kept their health systems connected, enhanced their access, or managed issues such as contact tracing at the height of the pandemic. However, national plans took precedent to guide all the 47 counties of Kenya through digital platforms such as an Application known as *Jitenge* that had to be used by travellers who were coming into the country. The Application was used to minimise a lot of physical interactions at the airport and to also support self-quarantine reporting on any potential symptoms of COVID-19.

The information provided by the Ministry of Health through their website [20] such as guidelines of staying safe during the pandemic, travel and closure and opening of places, offices and various zones was only accessible to the literate groups with better Internet access. Kakamega and Turkana also had the same access to such information. Predominantly, groups in both of these counties relied on information being broadcasted over Radio FM or Television. One interesting factor that was discovered during the pandemic was the lack of available information on collaboration and sharing of information across different health entities in Kenya. This meant that there is a missing Internet pipe and digital collaboration of data for ease of diagnosis and efficiency in managing and sharing resources across the health entities. Therefore, handling of the geographical spread of the virus was largely fragmented [21].

6. Review of the Enacted Regulations to Enhance Rural Internet Access

This Research Paper also reviewed the existing legal, policy, regulatory and institutional instruments relevant to connecting the unconnected in Kenya. Some of these instruments included the strategic implementation of the Sustainable Development Goals (SDGs) ranging from ending poverty and hunger (SDG 1&2), healthcare (SDG 3), education (SDG 4), infrastructure and innovation (SDG 9) and enhancing global partnerships and collaborations (SDG 17) while leveraging Information and Communications Technologies (ICTs). Kenya's vision 2030 [22], particularly on developing the necessary scientific and technological infrastructure, as well as technical and entrepreneurial skills, can be described as a strong pillar of leapfrogging the digital transformation of Kenya into a Knowledge-based economy beyond the pandemic. The outgoing government's big four agenda [23] was also instrumental in assessing the developmental initiatives that are driven by ICT in enhancing Universal Health Coverage. The National Broadband Strategy developed in 2018 as well as the Digital Economy Blueprint developed in 2019 also formed a baseline in understanding the government's approach of digitally-enabled communications and networks in leveraging the Internet.

While all these instruments converge to the high-level objective of enhancing Internet access to all the citizens of Kenya, the focus of the work presented here, examined the opportunity that spectrum sharing presents in advancing Internet access initiatives to the rural counties of Kenya. Therefore, the findings presented in this section on the regulatory frameworks for TV White Spaces and Community Networks (CNs) show how both can be exploited to provide alternatives of connectivity for both Kakamega and Turkana counties. The bottom line is that our assessment of both regulatory frameworks is shared in order to rebuild digital resilience and inclusivity for Kakamega and Turkana counties and assist in the “recovery” of equally affected rural counties from the COVID-19 pandemic.

6.1. Overview of Spectrum Sharing or Dynamic Spectrum Access (DSA)

Radio spectrum, and the right to exploit radio resources commercially are in the economic interest of wireless network operators. Therefore, changes in the way radio frequency (RF) spectrum is regulated and licensed is key, especially as new findings are discovered. Such findings include allocated, assigned but underutilised spectrum [24]. Access to such spectrum, hence, ought to be considered within the reality that most rural populations are disproportionately connected and lack a significant number of Internet access technology options to choose from [3]. This has birthed the concept of Dynamic Spectrum Access (DSA) or Dynamic Spectrum Sharing (DSS). DSA refers to the use of a portion of spectrum which is not being used at a given time and within a given geographic area, and may be available for use by a radiocommunication application, operating in accordance with the existing radio regulations. The radio systems implementing DSA also need to ensure the protection of the incumbent services sharing the same band or operating in the adjacent bands.

While the concept of DSA is not relatively new considering earlier studies that began in the 1990’s on Cognitive Radio (CR) technologies, the application is beginning to take shape and various countries have begun enacting regulations based on DSA [25]. The idea is to unlock the potential of sharing spectrum with incumbent services to provide novel wireless Internet services [26]. Kenya has joined the league of the national regulatory authorities (NRAs) that are strategically implementing regulatory frameworks that advocate for last-mile Internet access.

The country published its first DSA framework through TV White Spaces (TVWS) in May 2021 marking a major milestone in the efforts to unlock new business opportunities geared towards connecting the rural communities [27]. Prior to the enactment of these regulations, CA had conducted validation studies in Kisumu, Kitui and Laikipia counties to identify the level of usage of the assigned spectrum in the Ultra-High Frequency (UHF) band of 470-694 MHz band. The findings of the validation studies found out that at least five channels assigned for TV broadcasting could be used opportunistically through TV White Spaces. In fact, the studies in Kisumu and its neighbors (which includes sub-counties in Kakamega County) determined that out of the eighteen (18) TV channels assigned for DVB-T transmission, eight were found to be inactive, and therefore, were available for DSA.

As a follow up to the DSA framework for TVWS, CA further enacted the regulatory framework for Community Networks (CNs) in the same month of May 2021 under the regulatory name of “Licensing and Shared Spectrum Framework for Community Networks.” While the framework articulated the existing issues faced by local communities in the rural areas, it also outlined micro-DSA considerations that can enhance local set up of DSA-driven networks to provide Internet access in such localities. The framework outlines the existing usage of the 5 GHz band and stipulates a potential roadmap to exploit the 3.3 GHz band, 24 GHz band, 60 GHz band for Community Networks. Both frameworks (for TVWS and CNs), can be seen to have been enacted at the height of the pandemic to address the barriers facing communities in the underserved areas to drive more efficient utilisation of the RF spectrum and provide more alternatives to Internet access in such areas [28].

The CNs framework introduces a new special license category called Community Network Service Providers (CNSP) license. CNSP is intended to bring existing unlicensed community networks under a regulatory framework of minimal license fees in order to reduce the regulatory barrier that existed before. The interventions on reducing regulatory barriers are aimed at facilitating CNs' sustainability in view of their non-commercial nature which would potentially play a key role in rebuilding digital inclusion for the rural counties of Kenya post-pandemic.

6.2. Opportunity of TV White Spaces and Challenges for Rural Broadband Access in Kenya

6.2.1. Overview

TV White Space (TVWS) is the portion of the TV bands that is unused by licensed TV broadcasting services [29]. Similar to other NRAs around the world, CA authorised access to the UHF TV band (470-694 MHz) to allow the white space devices (radios that can be used for opportunistic wireless Internet access in the said band) to operate in areas where specific channels are unused for Digital Terrestrial Television (DTV) broadcasting. The enactment of the Kenyan regulations, similar to other countries around the world, was motivated by the much better RF propagation that UHF transmission provides, allowing for a reliable, cost-effective and better coverage, particularly for rural areas. Most publications describe TVWS as one with superior characteristics that can result in longer communication distance and better penetration over obstacles [30]. While Kenya took almost 8 years to come up with the regulations after the first trial in 2013, the time of releasing the regulations (at the height of the pandemic) underscored the significance that the technology could provide in enhancing rural broadband access. Nevertheless, the need to implement the use of a geolocation database in order to manage spectrum presented a novelty that needed more sensitivity in allowing TVWS deployments in Kenya – something the CA refers to in the Community Networks framework as the reason for the delay in enacting the regulations.

6.2.2. Opportunity

Earlier trials for TVWS in Kenya as well as the developments across different countries that had already released the regulations such as the United States, Canada, Singapore, United Kingdom and South Africa had already shown that TVWS deployments could take place without disruption to incumbent operations [30]. Moreover, a report from Mawingu Networks [31], which was the pilot initiative on TVWS in Kenya, showed that not only was manual deployment not causing interference, but also demonstrated that a point-to-multipoint (PtMP) coverage of 14km (non-line of sight – NLOS) with Internet speeds of 16 Mbps could be realised. In the context of this study, we view these findings together with the pre-pandemic

TVWS measurements conducted in Kenya alongside the stakeholder engagements to be a demonstration of an opportunity that can be exploited to enhance Internet connectivity for both Kakamega and Turkana as part of the rebuilding efforts for rural connectivity.

6.2.3. Challenges

TVWS demonstrates an immense opportunity that can be exploited for the benefit of the underserved and unserved areas but unfortunately it has not been supported much by the industry as initially envisaged across the world. While some challenges such as cost and economies of scale for the equipment are the same across the globe, we also note that other challenges are regime or country-based. For instance, although the TVWS framework for Kenya was developed during the pandemic, there was little active participation by stakeholders (Internet Service Providers) who would have been keen to pilot the technology to connect educational and healthcare institutions to the Internet across all the rural counties. On the other hand, the regulatory framework itself packaged a convoluted architecture that is piled with the use of a listing server, geolocation database(s) and the nominal fee requirements – things that can be left out for now to allow TVWS deployments, particularly in areas with almost zero incumbent operation (which are less congested areas). This would go a long way in enabling the technology to be used in rebuilding digital inclusion for the rural counties of Kenya. There also exists a lack of stakeholder understanding, not just on the technology but the regulations themselves as well – something that capacity building can address in order to unlock the available access option through TVWS.

6.3. Opportunity of Community Networks (CNs) and Challenges for Rural Broadband Access in Kenya

6.3.1. Overview

Advances in the last-mile technology are opening new possibilities that can empower commercial, government and community access initiatives to offer local services, especially through Wi-Fi. Such Wi-Fi is inspired by the meteoric growth of access combined with mass manufacturing which in general has managed to bring down the cost and complexity of access technologies to be within the reach of small-scale operators [3]. Therefore, the Community Networks (CNs) framework has been developed in Kenya on the basis of the opportunity to unlock localised Wi-Fi access alternatives that can address the local issues such as lack of services, the affordability and quality of access to data services or the lack of locally relevant content often ignored by mainstream providers.

While CNs have had such a great impact in many places across the world, they are still not yet the norm they ought to be. For instance, as at the time of drafting the CNs framework for Kenya, there were only four active CNs (TunapandaNET, Lanet Umoja, Dunia Moja and Aheri) and none of them have operations in Kakamega and Turkana counties at the moment. Their existence would have strongly supported the contextual connectivity challenges both Turkana and Kakamega students and healthcare groups faced at the height of the pandemic. Researchers, such as Song et. al. [3] offer some reasons why CNs have not taken off as they should across the world. Some of the reasons include a lack of awareness of the opportunity, the current state of policy and regulation for CNs, and the lack of technical and financial support. Nevertheless, the fact that Kenya has developed a regulatory framework dealing with shared spectrum access, beyond the traditional Wi-Fi consideration, elucidates an ecosystem that could connect more rural areas post-COVID 19. The framework considers an evaluation of the following bands as a way to reinforce additional means – 24 GHz, 60 GHz, and 5-6 GHz as well as underutilised IMT spectrum.

6.3.2. Opportunity

As stated in the Kenya's CNs framework, CNs in Africa are more than telecommunications infrastructure. They can be leveraged to support existing economic and social activities. In this way, they create a platform that promotes the building of local capacities, as well as the creation and distribution of locally relevant content. They, hence, can provide a practical opportunity to invest in bottom-up communication needs within the context of local realities. For Kenya, this would actually translate into practical achievement of the objectives outlined in the National Broadband Strategy (NBS). Notable opportunities that CNs can also provide for Kenya, apart from delivering alternative communication needs, is job creation within localities they exist considering the challenge of youth unemployment at this point in the country. They can also enable entrepreneurs to set up their businesses in places that are relatively cheap compared to places such as Nairobi, Mombasa and Kisumu. Further, CNs can also be used as capacity building centres for the emerging technologies to leapfrog the economic status of the different communities within which they are set.

6.3.3. Challenges

CNs, sadly, have faced stiff challenges based on their traditional model of being launched with grant funding but lacking a strategy to transition to revenue-based models in order to sustain the network when grant funding lapses. Therefore, a strategic model that can ensure their sustainable operation is key. Notably, there are CNs such as B4RN in the United Kingdom and Guifi.net in the Iberian peninsula that have managed to stay operational beyond the initial funding, but unfortunately, there is a lack of information on the feasibility and scalability of their models – something that can be borrowed for the CNs in Kenya. At the moment, Kenya can be said to have addressed the regulatory challenge. However, other challenges related to availability of backhaul or middle-mile networks to sufficiently support the last-mile CNs still exist. This stems from the existence of unknown dark fibre (meaning unused optical fibre that has been laid), high cost of microwave backhauls as well as a limited number of backhaul network providers that are able to support areas where other CNs can potentially be established. Other challenges include lack of technical skills and capacity for the groups that might want to set up CNs, lack of understanding of the existing regulations, and the enthusiasm to drive CN deployments, as well as, challenges of funding for such initiatives.

6.4. New DSA Initiatives to Further Rebuild Digital Inclusion

The extension of Wi-Fi in the 6 GHz band, named Wi-Fi 6E by the Wi-Fi Alliance is being strongly advocated across the globe by policy researchers, technical studies, a number of national regulatory authorities (NRAs) as well as the industry [32]. Chipset and equipment manufacturers as well as service providers and end-users agree that more than doubling the available spectrum will revolutionise the Wi-Fi user experience [33]. NRAs of countries such as the United States, Canada, Brazil, Colombia, Mexico among others have already announced their plans to open the 5925-7125 MHz (1200 MHz of spectrum) band for unlicensed access through Wi-Fi 6 [34].

In this study, we note that these new developments for Dynamic Spectrum Access (DSA) would be important in enhancing the Wi-Fi access to not only Turkana and Kakamega but across the entire country. It would also contribute to enhancing digital inclusion across the country, particularly through the Community Networks (CNs) and also serve as the edge network through TV White Spaces. While we note that Kenya intends to follow the European approach of opening the lower part of the 6 GHz (500 MHz of spectrum) first, we recommend trial demonstrations of the full 6 GHz Wi-Fi network by CNs in the rural areas. This is due to the fact that Wi-Fi remains the heaviest traffic carrier at the edge of the users' networks – something that the pandemic clearly showed during the "work from home or study from home" period. Despite the success that Wi-Fi has provided through the 2.4 and 5 GHz bands, it is evident that less than 300 MHz of unlicensed spectrum is not comparable to what the 1200 MHz (full 6 GHz) or 500 MHz (half 6 GHz) can provide in terms of bandwidth, efficiency and performance [35]. As a way to address future needs of connectivity beyond the pandemic for Turkana and Kakamega, particularly in the resumption of physical era for both schools and healthcare centres, we propose that future work studies this new Wi-Fi initiative further.

6.5. Relevance to the Giga Project

The UNICEF and ITU's collaboration on the "Giga" seeks to connect every school to the Internet and every young person to information, opportunity and choice. Giga's vision looks to contribute to bringing online the nearly 3.6 billion people in the world who do not have access to the Internet at the moment [36]. The intention is to do this through providing connectivity to the most vulnerable children and youth to help them tap into the wealth of information that is available online. Moreover, Giga has developed four pillars to be able to guide the execution. The four pillars include Mapping, Finance, Connect and Empower to be able to assess the existing data versus the gaps in connectivity, explore sustainable country-specific models of financing, make use of mapping data to integrate with industry Internet services and implement appropriate digital needs for the schools.

Within the Giga framework, we envisage that the findings of this work on the state of educational connectivity, will relevantly contribute to the expansion of the work that can enhance broadband access to the schools in Kenya. This Research Paper also envisions that the mapping done within its context, based on the visited institutions will pragmatically help spur the current work done by Giga for the rural schools. While we note that Giga is exploring options of LEO satellite access, we also share the access alternatives that can be exploited to enhance Internet access to the rural schools in the country, particularly based on the technologies identified from the stakeholders at the moment, as well as the new focus of the regulatory frameworks in Kenya. We underscore that beyond this project, some of the aspects highlighted within it would be fruitful in the consideration of the four pillars of Giga as immediate future activities.

7. Site Surveys and Mapping

7.1. Overview

On 19th April 2022, the research team set off to assess the state of connectivity and the existing connectivity options for a set of educational and healthcare institutions in both Kakamega and Machakos counties (Machakos replaced Turkana due to the constraints outlined in the first report on "***Assessment of the State of Connectivity in Kakamega and Turkana Counties***"). The team (made up of eight members, four to each site) concurrently visited Kakamega and Machakos sites for six days until the 25th of April 2022. A total of 24 institutions was visited – 12 academic institutions and 12 healthcare centres in both counties. The list of all these institutions in the two counties include:

1. **Kakamega:** *Sheywe Community Hospital, KMTC, St, Mary's Mission Hospital, Masinde Muliro University of Science and Technology (MMUST), Ekambuli, Mundoli and Emukhunzulu primary schools, St. Elizabeth School of Nursing, St, Martha's Mwitoti secondary and St. Mary's Mumias Girls high schools*.
2. **Machakos:** *St. Teresa Mwala Girls high school, Kaani Level, Machakos Level 4, Kangundo Level 4 and Mwala level 4 hospitals, Masii, Matungulu and Kaavani medical centres, St. Anne's Girls and Maisha mazuri schools, KMTC Kangundo, Machakos Teachers college and Machakos Girls academy (primary and high school).*

The assessment of these institutions was conducted face-to-face through the use of a mobile application known as ONA. ONA is a mobile data collection tool. A paper questionnaire, which is attached in the Appendix, was used to create the questionnaire fed into the ONA Application. A mix of representatives from the visited institutions was spoken to, ranging from the less technical staff to the ICT staff either managing the ICT infrastructure and equipment within the institution or providing ICT support.

7.2. Findings of the Site Surveys

7.2.1. On Internet Coverage and Access

The findings of the site survey showed that most of the institutions had a fibre point of presence (PoP) nearby. Further, most of the institutions (5 in Kakamega and 5 in Machakos) seemed connected to Fibre although the Wi-Fi speeds in a majority of the academic institutions seemed to be very low (less than 10 Mbps were proposed for schools and health facilities in the NBS). In Masinde Muliro University of Science and Technology (MMUST), for instance, we could not even load a web page on the phone in the large study area on the main floor. Speeds were better (10 Mbps) at the Computer Lab (which had 15 computers) although the institution's ICT staff reported that the average speed could get as high as 100 Mbps. Outdoor areas of the Library did not have reliable Internet connection which leaves the students to rely on their cellular mobile data – students seemed to prefer to have an outdoor connection. Five students and one Lab assistant we spoke to mentioned that the Wi-Fi access was not reliable for them. 3 primary schools in Kakamega County reported not to have any established Internet access to the institution at all. This meant that teachers make use of the cellular network (4G) to access Internet through their phones. A similar situation existed in Machakos County for four institutions – 3 healthcare institutions and 1 school. Only one institution in Kakamega (St. Elizabeth School of Nursing) had a Microwave link serving as the backhaul for provision of Internet service. Notably, St. Elizabeth School of Nursing mentioned of unreliable access to Internet through the Microwave links. While a fibre connection existed 200 metres away, the institution complained of the high setup cost required to connect the institution. While Kakamega is made up of 13 sub-counties, only four sub-counties were seen to be covered according to the site studies.

In Machakos County, 85% of the institutions surveyed had Internet access and Microwave seemed a better alternative in the absence of Fibre, with 5 GHz Wi-Fi links in a few places. The most popular service provider in the institutions surveyed was Safaricom, however, most institutions had more than one provider, with the second provider serving as back up. Majority of the healthcare centres in Machakos stated that the current Internet state is unreliable although near future plans were underway to automate most of the hospital/healthcare services. Similar to Kakamega County, the Kenya Medical Training College (KMTC) in Machakos County, seemed better equipped with facilities as well as had better Internet coverage as compared to the rest of the visited sites. The average Internet speeds for both KMTCs in both counties was 100 Mbps. In general, however, most of the institutions in Machakos (both healthcare and academic) complained of an unreliable Internet access. A detailed outline of the survey is shown in Table 1 and 2 for both Kakamega and Machakos counties respectively. The reporting of "NONE" under the "Connectivity technology in use" means that an official Internet service provision model does not exist and Internet is not catered for by the institution, and hence, the institutions make use of the cellular infrastructure through personal means. The same is represented as "N/A – Not Applicable" under the "Average speed" as well as "Facilities."

7.2.2. On Internet Usage

In terms of Internet usage, the academic institutions (schools, colleges and universities) said that they relied on the Internet for research, online learning and uploading of study material for students as well as communication among staff and students. For the healthcare centres, the Internet was also used for research and eHealth management, reducing the large amount of paperwork that had existed earlier in those facilities. Administrative tasks were also cited to heavily rely on Internet to improve the daily operations of the hospitals and the healthcare centres.

7.2.3. State of Access during the Pandemic

At the height of the pandemic, it was noted that both healthcare and academic institutions provided mobile data to their staff and students. Hence, based on the approach of working from home, it was hard to tell how reliable Internet was, as it depended on where the students and the staff stayed during the pandemic. Nevertheless, a number of students surveyed mentioned that they had huge challenges attending online classes due to the poor coverage of the 4G network where they came from (or attended classes from), particularly those from rural counties. On the other hand, the students also mentioned of financial challenges (fees based) that institutions such as MMUST required them to clear first before providing them with mobile data to be able to attend classes during the pandemic. A similar situation was experienced by the KMTCs. At the time of the survey, students in both Primary and Secondary (High) had gone on a break but a conversation with the staff who were present, showed that High schools had better Internet coverage and usage compared to the primary schools. They also had more ICT facilities compared to the primary institutions although the metrics of usage and the level of skill for staff and students were not surveyed. All the institutions, nonetheless, highlighted the critical need to have Internet access even while some of them reported of the Internet becoming unreliable now as they bounce back from the COVID-19 pandemic.

Table 1: Detailed Outline of the metrics surveyed in Kakamega County

KAKAMEGA COUNTY - VISITED SITES	SUB-COUNTY	CONNECTIVITY TECHNOLOGY IN USE	GPS_LAT	GPS_LON	ISP	AVG. INTERNET SPEED	AVG. INTERNET COST (KES)	STAFF or STUDENTS	FACILITIES
SHEYWE COMMUNITY HOSPITAL	LURAMBI	FIBRE	0.206061	34.772065	Liquid Telecom / Safaricom	15 Mbps/ 15 Mbps	20,000.00	Approx. 70 Staff members	Aprrox. 9 PCs available
KMTC_KAKAMEGA	LURAMBI	FIBRE & SATELLITE	0.27272	34.758667	Telkom - UHC / Safaricom	250 Mbps / 250 Mbps	84,000.00	Approx. 500 Staff members	Approx. 240 PCs available
ST MARY'S MISSION HOSPITAL MUMIAS	LURAMBI	FIBRE	0.283757	34.752353	Liquid Telecom / Safaricom	20 Mbps / 20 Mbps	75,000.00	—	Aprrox. 69 PCs available
KAKAMEGA ORTHOPAEDIC HOSPITAL	LURAMBI	FIBRE	0.29141	34.756159	Safaricom	10 Mbps	15,000.00	—	3 PCs available
MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY	LURAMBI	FIBRE	0.292625	34.762434	KENET and Safaricom	100 Mbps/ 300 Mbps	2,000,000.00	Approx. 20,000 Students	Over 200 PCs and Laptops
EKAMBULI PRIMARY SCHOOL	KHWISERO	NONE	0.107153	34.571447	NONE	N/A		—	N/A
MUNDOLI PRIMARY SCHOOL	KHWISERO	NONE	0.11143	34.58086	NONE	N/A		—	N/A
EMUKHUNZULU PRIMARY SCHOO	KHWISERO	NONE	0.370096	34.598745	NONE	N/A		—	N/A
ST. ELIZABETH SCHOOL OF NURSING	LURAMBI	MICROWAVE	0.21365	34.77068	Simbanet / Safaricom	5 Mbps /10 Mbps	18,000.00	—	A total of 20 PCs available
ST. MARTHA'S MWITOTI SECONDARY	MUMIAS EAST	CELLULAR BROADBAND (4G)	0.32859	34.52735	Liquid Telecom	5 Mbps	N/A	N/A	Computer Lab with 12 PCs
ST. MARY'S MUMIAS GIRLS HIGH SCHOOL	MUMIAS WEST	CELLULAR BROADBAND (4G)	0.4708	34.53766	Safaricom/Airtel/ Telkom	10 Mbps	5,000.00	—	A total of 26 PCs available

Source: Information shared by institutions visited during the field surveys

Table 2: Detailed Outline of the metrics surveyed in Machakos County

MACHAKOS COUNTY - VISITED SITES	SUB-COUNTY	CONNECTIVITY TECHNOLOGY IN USE	GPS_LAT	GPS_LON	ISP	AVG. INTERNET SPEED	AVG. INTERNET COST (KES)	Est.No. of STAFF or STUDENTS	FACILITIES
ST. TERESA MWALA GIRLS	MWALA	MICROWAVE	-1.351982	37.450256	Safaricom	5 Mbps	5,960.00	Approx.30 Staff	About 15 PCs, only 3 are used frequently
KAANI LEVEL 2 HOSPITAL	KATHIANI	NONE	-1.46226202	37.34841402	N/A	N/A	—	Approx. 5 Staff	—
MACHAKOS LEVEL 5 HOSPITAL	MACHAKOS	FIBRE	-1.523585	37.266351	Telkom-UHC (MoH - NOFBI) & Safaricom	50 Mbps / 80 Mbps	120,000.00	Approx. 3000 staff	About 700 PCs available
KANGUNDO LEVEL 4 HOSPITAL	KANGUNDO	FIBRE	-1.296092	37.349396	Telkom-UHC (MoH - NOFBI)	15 Mbps	MoH Funded	Approx. 360 staff	About 20 PCs
MASII MEDICAL CENTER	MASII	MICROWAVE	-1.460648	37.427323	Safaricom	10 Mbps	5,499.00	3 connected staff	About 10 PCs, only 4 connected
MWALA LEVEL 4 HOSPITAL	MWALA	NONE	-1.348685	37.452444	N/A	N/A	—	Approx. 50 staff	About 6 PCs available
MATUNGULU HEALTH CARE AND WELLNESS CENTER	MATUNGULU	MICROWAVE	-1.270664	37.322938	Alpha Kim	5 Mbps	2,500.00	Approx. 25 staff	About 6 PCs available
KIVAANI HEALTH CENTRE	KANGUNDO	NONE	-1.3632995	37.394668	N/A	N/A	—	Approx. 15 staff	Abou 10 PCs,only 2 working
ST. ANNE GIRLS	MWALA	NONE	-1.37153278	37.40639227	N/A	N/A	—	Approx. 10 staff	Only 1 PC
KMTC KANG'UNDO	KANGUNDO	SATELLITE	-1.297772	37.345872	KENET	100 Mbps	30,000.00	Approx. 55 staff	About 40 PCs
MACHAKOS TEACHERS COLLEGE	MACHAKOS	FIBRE	-1.5084689	37.2567173	Safaricom	14 Mbps / 15Mbps	24,000.00	—	About 30 PCs, split in two Labs
MACHAKOS ACADEMY GIRLS HIGH SCHOOL AND PRIMARY SCHOOL	MACHAKOS	FIBRE	-1.504766	37.258875	Jamii/Safaricom	30 Mbps / 15Mbps	25,000.00	—	Computer Lab with 40 PCs
MAISHA MAZURI SCHOOL	MATUNGULU	MICROWAVE	-1.30921	37.2692	SafariLand	10 Mbps	5,000.00	_	About 5 PCs

Source: Information shared by the institutions visited during the site surveys

7.3. Mapping

This Research Paper also developed a demo mapping tool for all the sites that were visited during the field assessment exercise. The mapping tool shows the locations (academic institutions and healthcare facilities) of all the visited sites, the access technology available for use, the state of connectivity based on the obtained feedback (reliable or unreliable) as well as the average Internet speed. The demo tool is available through this [link](). For the academic institutions i.e. primary, secondary/high school and the tertiary institutions, the tool also shows whether they are public (government-owned) or private. Figure 1 shows the ISPs providing Internet access in all the institutions we visited in Kakamega and Machakos.

Internet Connection Type

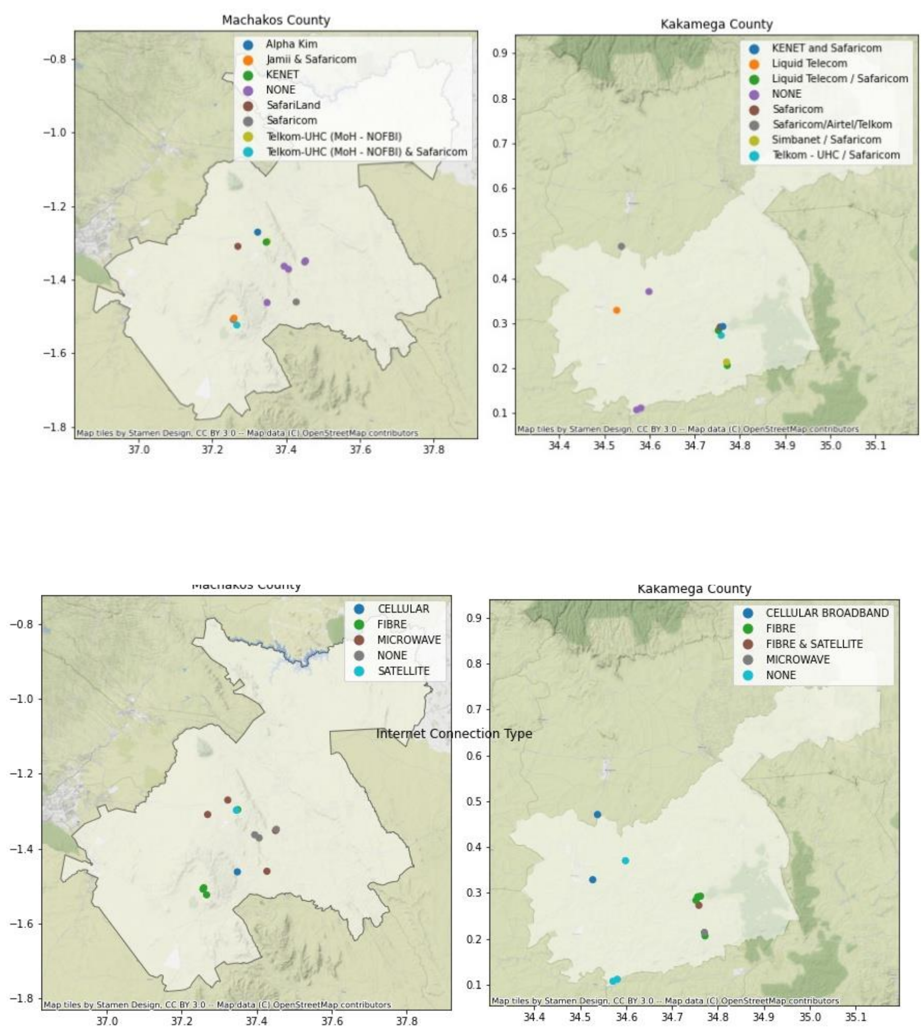

Figure 1: The Access technology options available in the sites visited in Kakamega and Machakos

Source: Data collected from the surveyed institutions

8. Stakeholder Engagements

In the scope of this work, the stakeholders considered are groups or organisations, directly involved in provision of Internet services across the country. This list was provided by the Communication Authority of Kenya (CA) during the studies. To effectively reach out to the stakeholders and get the necessary information, the team developed a plan based using a Google Form and made phone calls to engage the stakeholders. The plan basically involved the use of the following methods:

Use of a Questionnaire

The questionnaire, attached in the Appendix, was developed through a consultation process within the consortium. The stakeholders were expected to give their feedback on the questionnaire in regards to the opportunities of connectivity and the challenges they faced during the pandemic in ensuring the areas they support remained connected. Also of interest, was to know the stakeholders' state of service provision before the pandemic and at the moment, especially as they implement their post-pandemic connectivity plans. Further, the consortium was keen to know if the stakeholders were familiar with the two regulatory frameworks enacted in the country during the pandemic - on TVWS and CNs - and whether they envisioned any opportunity to exploit them.

Stakeholder Outreach

This was done through emails and phone calls. Fortunately, the list of stakeholder contact persons was provided by the CA. To process and achieve the expected objectives, the team engaged the contacted stakeholders through one-on-one phone calls even as questionnaires were shared. A few who were not willing to communicate via phone calls or preferred online questionnaires were given a few days to brainstorm and respond to the questionnaire at their convenience. It is worth noting that the stakeholders came from various counties in Kenya, although the focus considered Turkana and Kakamega as well as Machakos (due to the site visit). The national distribution of Internet services by the stakeholders was also evaluated to get a clear picture of the state of connectivity in Kenya.

Results and Analysis

At the end of the survey, we held a review meeting to assess the outcome of the engagements. The results showed the following:

Majority of the Internet Service Providers (ISPs) (60%) operate under Network Facilities Provider (NFP) Tier 3 license while the remaining 30% and 10% operate under the community network and NFP Tier 2 respectively. NFP Tier 1, which is for the mobile network operators (MNOs), remains dominantly unused in the country. This was ideal because a Tier 3 NFP is a provider that strictly purchases Internet transit. A Tier 3 provider is primarily engaged in delivering Internet access to end customers. Tier 3 ISPs focus on local business and consumer market conditions. They provide the "on-ramp" or local access to the Internet for end customers, through cable, DSL, Fibre, or wireless access networks. Their coverage is limited to specific counties or sub regions, such as a metro area. Tier 3 NFPs utilise and pay higher-tier ISPs for access to the rest of the Internet. Community networks also help bridge the connectivity gap.

Only 20% of the stakeholders surveyed indicated they have connectivity services in Turkana. In Kakamega, there were only 10% while in Machakos, the figures stood at 30%. This shows that Machakos is better connected compared to Turkana and Kakamega. Hypothetically, this Research Paper saw that the proximity of Machakos to Nairobi – the capital could be the reason for such a connectivity advantage. The stakeholders mentioned the following as key challenges faced during the pandemic: lockdowns, financial constraints, and reduction in the number of customers. Majority of them depended on Microwave links as backhaul for their Internet services. Others used satellites and fibre. Their approximate cost was 45,000 Kenya shillings (or USD $450), implying that Internet distribution was quite expensive for the ISPs during the pandemic even while they dug into their pockets to support the urgently needed Internet services during the pandemic. However, some of them mentioned to have sought financial support from the government and other private companies or partnered with other ISPs to extend their market share. Despite the financial limitations, the stakeholders pointed out that they were in the process of finding ways to exploit future connectivity needs, especially with the proposed “Kenya Vision 2030 economic development portfolio.” The majority of the stakeholders surveyed indicated that they had started initiatives to identify possible partners and investors who can help them expand their operations – albeit in Nairobi and the nearby counties.

In regard to Dynamic Spectrum Access, only 10% were aware of it and as a result, most have not participated in any DSA initiatives. The same results were recorded for TV White Spaces and Community Networks that Communication Authority (CA) enacted in May 2021. However, they were willing to participate in any event or opportunity that TVWS or CNs would present to them. 37.5% showed interest, 12.5% were uninterested, while 50% were reluctant to join (could probably participate if they were given enough information). 77.8% were willing to collaborate with other partners to facilitate Internet access by exploiting the newly enacted frameworks. However, they were unwilling to extend coverage to Turkana. Machakos was the county of choice to many of them. Generally, the exercise was a success because it proved that stakeholders are willing to expand Internet services across the country. Although still recovering, they have managed to exploit emerging opportunities the pandemic created like online education and remote working by beefing up their quality of service. However, in spite of the biased consideration by stakeholders to expand their Internet services in Machakos, there is interest to also support Turkana and Kakamega in the near future.

9. Spectrum Measurements

Here, the consortium presents the screenshots of the spectrum measurements carried out in select RF bands in various locations in Kenya with the goal of evaluating the opportunity of spectrum sharing or opportunistic access of such bands. The exercise was done in view of deployment of novel connectivity methods that can address rural areas. Kakamega County was the pilot rural location in the context of this segment and due to the ease of reach compared to Turkana. The following RF bands were evaluated: 470-694 MHz, 600-750 MHz, 1700 MHz, 3000-3500 MHz as well as 3300-3400 MHz.

The measurements were conducted using CA's frequency monitoring vehicle and was led by the CA's monitoring team together with the research team from Strathmore University within the consortium. Other locations which were also considered during this exercise include Kisii, Kisumu, Maralal and Eldoret. However, within the scope of this Research Paper, we have only shared the measurements carried out in Kakamega. The findings in the measured bands demonstrated available spectrum holes that can be utilised opportunistically by secondary users (SUs) to provide new wireless services in coexistence with the incumbents. Similar to the framework for TVWS and CNs, we underscore the fundamental requirement that any potential consideration for DSA must adopt strict constraints by the SUs to avoid interference to the incumbents of these bands [37].

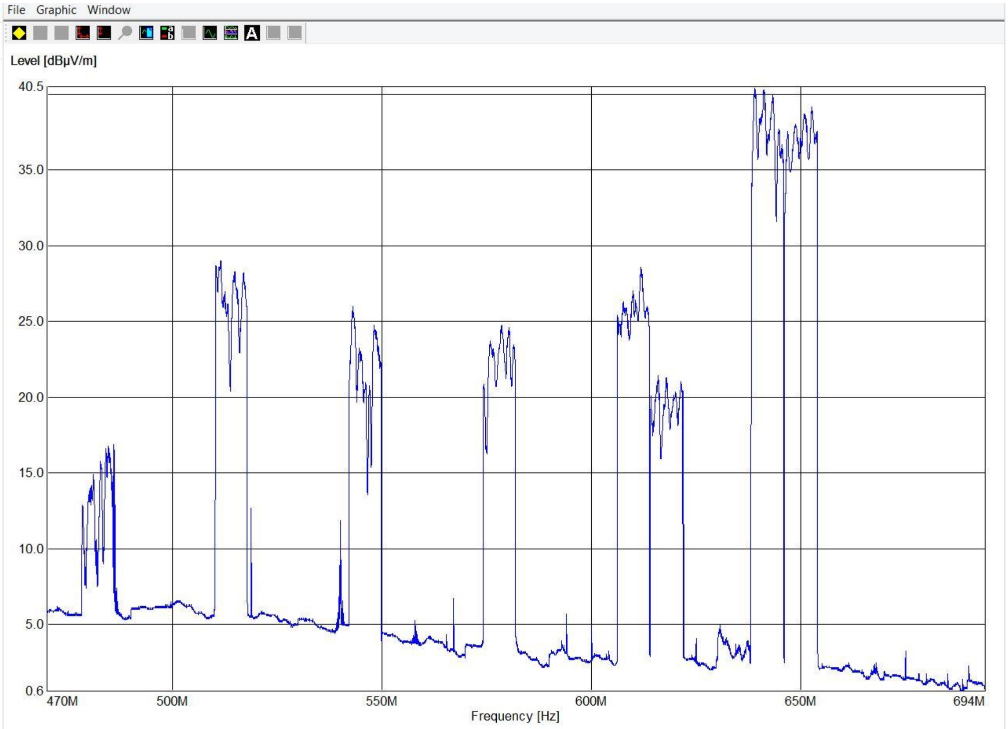

Figure 2: Kakamega Measurements in the 470-694 MHz band

Source: Communications Authority of Kenya

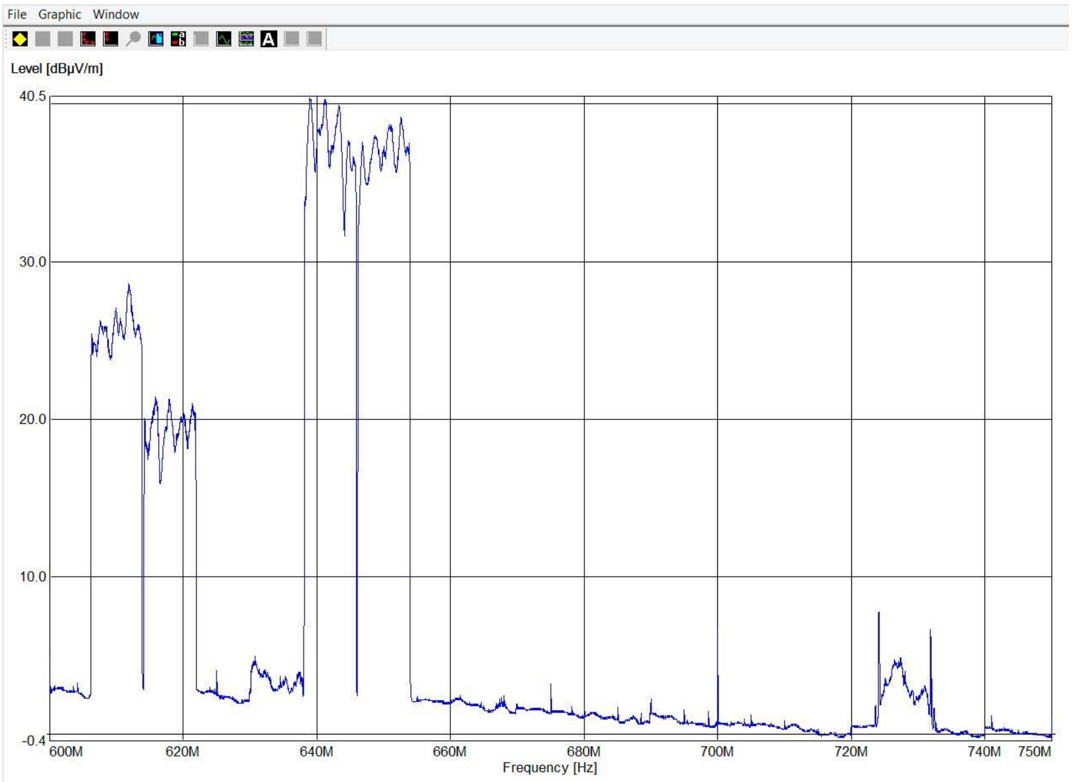

Figure 3: Kakamega Measurements in the 600-750 MHz band

Source: Communications Authority of Kenya

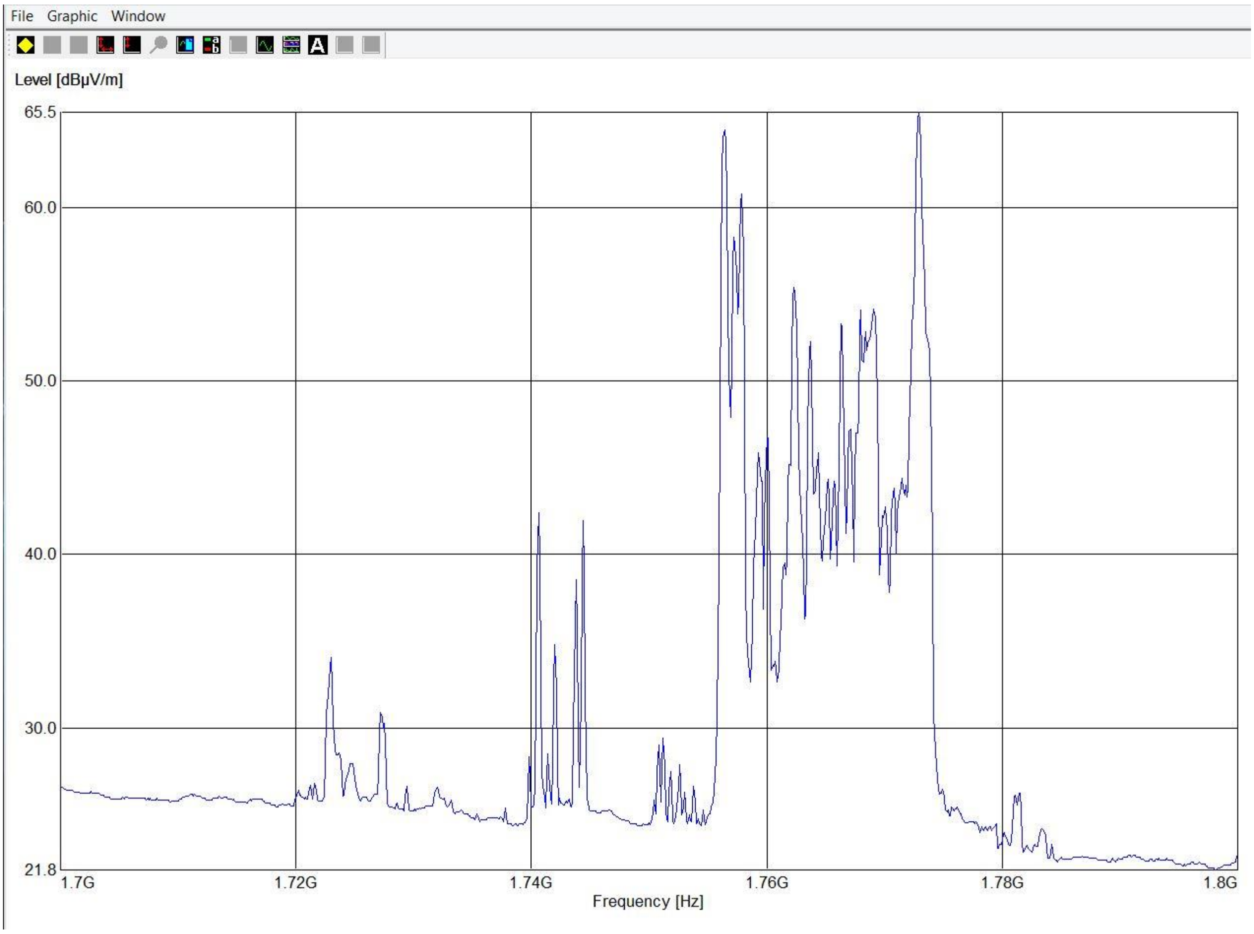

Figure 4: Kakamega Measurements in the 1700 MHz band

Source: Communications Authority of Kenya

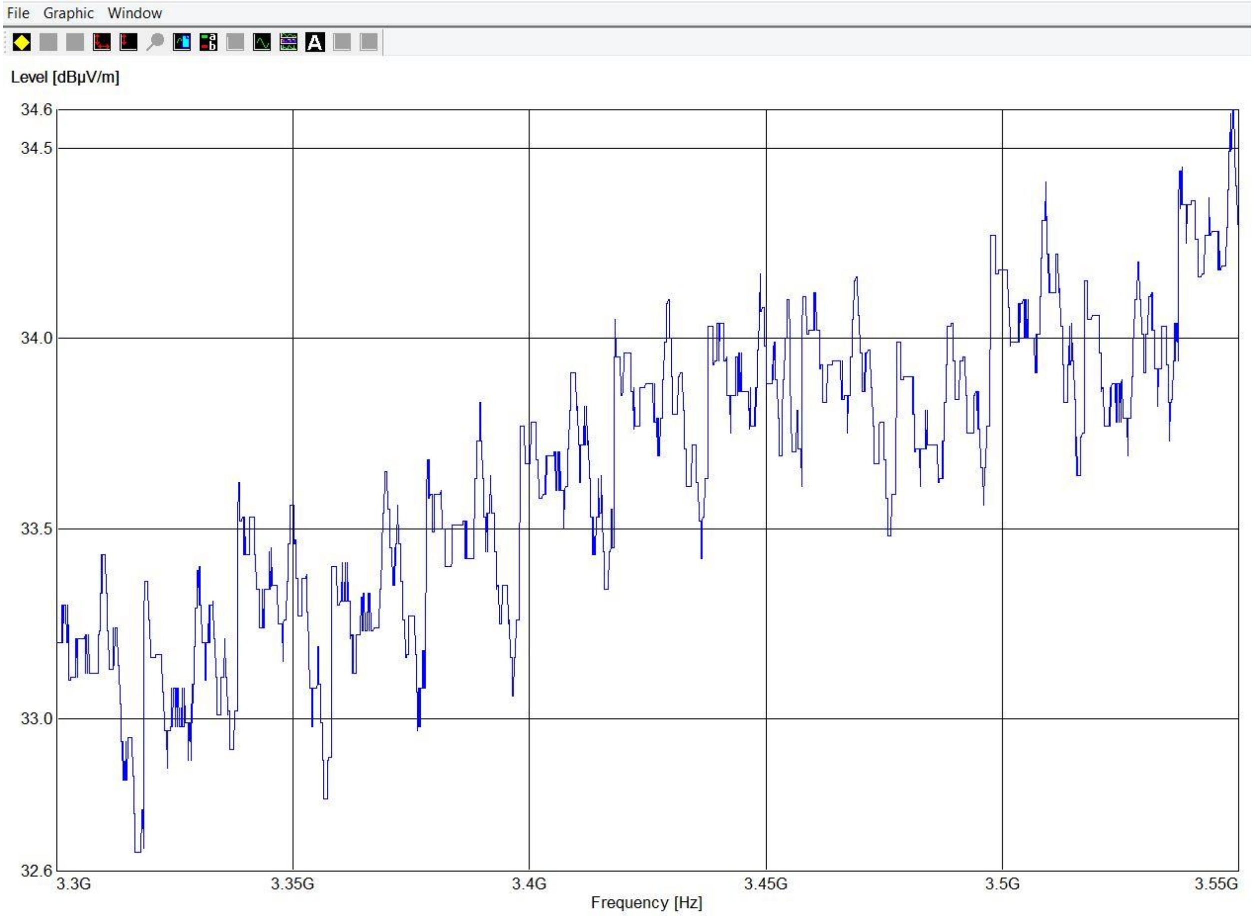

Figure 5: Kakamega Measurements in the 3300-3550 MHz

Source: Communications Authority of Kenya

10. Discussion

10.1. Level of Challenges

The Connect2Recover initiative allowed the consortium to investigate various variables not only impeding the efforts that can deliver Internet access for the rural counties but also those that create an opportunity to be tapped in order to address the rural access needs. An earlier submission within the work on this Research Paper had been shared in regards to the state of connectivity in both Kakamega and Turkana to which the report here follows up. The submission, accessible here, was the first deliverable on the work on this study. It presented, in detail, interesting results in terms of how schools and healthcare facilities fared during the pandemic on Internet access. The underlying challenges that heavily created the divide between urban and rural areas, at the height of the pandemic, nevertheless, stemmed from the following traditional issues [38]:

1. Challenges of electric power – power capacity remained a challenge for the rural homes, particularly those far from the shopping centres. This made a significant

fraction of the rural students (including those students who had travelled to their rural homes due to closure of their institutions in the urban areas) struggle to join virtual classes, especially the students in the tertiary institutions. Primary and secondary students who had their content delivered over radio and television but had power challenges also faced similar struggles. On the other hand, even before the pandemic, challenges of grid power in other rural areas extended into the pandemic hampering deployment of sufficient backhaul networks to enable Internet access to the rural areas. This also affected the rural healthcare systems.

2. Coverage – Most often, the reports from CA present a scenario of sufficient coverage by the cellular network based on number of SIM cards in use as opposed to the subscribers using the SIM cards to access the Internet. The reality is that on ground assessments show different results. The site surveys proved that some rural areas lacked meaningful cellular connection by the standards of ITU [39]. The feedback from the rural students and healthcare workers who worked from home pointed this as a challenge especially with a lack of other access alternatives available to them. In addition, areas with dark fibre can potentially be identified to extend coverage to the underserved.
3. Affordability – With the cellular network becoming the cornerstone of access for most of the rural areas, the cost of data proved unsustainable to the rural students of both Kakamega and Turkana. As for the healthcare extension workers, although they experienced this high cost of data more often, the hard economic times caused by the pandemic caused them an extra strain. In the case where the students were expected to access the online content developed by the Kenya Institute of Curriculum Development (KICD), the students from the low-income areas of Turkana, sadly, were not able to access the content due to a lack of available ICT equipment as well as the drawbacks of affordable broadband access.
4. Challenges of the usage gap – Although it is true that the country has significant coverage of 4G network, particularly by Airtel and Safaricom, the gaps of usage during the pandemic were laid bare by the challenges of insufficient ICT equipment in a number of institutions (both in academic and healthcare facilities) as well as sufficient digital skills to compete equally with their urban counterparts.

10.2. Opportunities and the Approach of Exploiting Them

The enactment of the new regulatory frameworks to reach the underserved demonstrates progress in Kenya in reducing the gap of the digital divide considering the perennial challenge that the country has had in delaying publication of regulations [40]. While this is commendable, there is an existing gap of mapping the existing connectivity challenges versus infrastructure needs and other variables such as access to power grid or renewable power considerations as well as issues of cost, sustainability among others. Hence, though our findings in this study identify an opportunity for TVWS and CNs, we propose that proper mapping be considered as the beginning point. This would help to design an appropriate approach to deploying CNs within the community of schools in order to deliver on connectivity, while supporting socio-economic impact. On the other hand, it would help to define the best model for TVWS use i.e. in areas where there is “less congestion,” to support deployment of TVWS without the need of a geolocation database as adopted in the USA [41], and on the other hand, also help create TVWS as a backhaul for CNs in some areas to boost the number of access alternatives. This would minimise challenges that the approach of the Google Loon [42] had for the selected areas, at the height of the pandemic which could not live up to sustainability.

11. Conclusion

The reality of the digital gap (the gap between individuals, households, businesses and geographic areas at different socio-economic levels with regards to access to ICT technologies and the Internet) was immensely felt across the country at the height of the COVID-19 pandemic. COVID-19 can hence be described to have completely reshaped the rural view of Internet access in Kenya with both schools and healthcare centres changing their perception on its relevance. As the efforts to rebuild rural counties such as Kakamega and Turkana pick up momentum, all the stakeholders need to consider Internet access as a driver for the “new normal” of economic development. An assessment of the state of connectivity in both Turkana and Kakamega pre-pandemic and during the pandemic, however, is hard to actually quantify due to the lack of available data or official publication on the available access technologies supporting Internet access, the precise area that is currently covered by the Internet, and the details of how Internet services are actually delivered in both counties. Most often, the available data generically paints a picture of lack of coverage in many areas, particularly to the institutions or a “super coverage” by the cellular network based on the records from CA. The approach of estimated household survey, just as globally adopted often times on Internet access also need to be reconsidered to obtain precise information on connectivity. Therefore, we view our ground assessments within this project to provide an improved baseline of determining the connectivity needs of the various hospitals and schools in Kakamega and Machakos, especially as the Giga initiative moves to the next phase. We also propose that a consideration of Community Networks be part of the initiatives that can expand broadband access to the marginalised groups. While this report shares our findings of “pandemic recovery” through TVWS, we are keen to realise the factors impeding the adoption of such a lucrative technology. We also propose that a right approach for the technology be considered to practically support rural Internet access and further enhance rural innovation. In general, we are in agreement with the Alliance for Affordable Internet (A4AI) as noted in their *Rural Broadband Framework* for *Connecting the Unconnected*: A guiding document to addressing the digital divide released in March 2020 that it is more urgent than ever to focus on affordable and meaningful broadband Internet access with special attention to rural areas.

12. Recommendations

Based on the different segments covered in this document, we provide our recommendations below:

1. While the Government has made great strides in ensuring rural electrification, more effort is required to expand access to affordable and reliable grid electricity across the country to reduce the inequality that exists between the urban and rural areas. This would even allow service providers including educational broadcast content to

be received by the rural masses over radio or television. Further, this would also enable ease of deploying Internet to the last mile by the service providers and ease of powering end user devices. As an alternative to grid power, more initiatives on off-grid power through solar power need to be supported and funded to allow last mile deployments that can support last mile connectivity efforts as well as student and healthcare institutions' end devices.

2. Initiatives to increase access options to the Internet in marginalised areas such as through TVWS should be classed in the same category as Community Networks and be sufficiently subsidised or incentivised to enable entrepreneurs or service providers to deliver on the public good of enabling hard-to-reach areas to be brought online. Further, in "less congested areas", we propose a consideration to manually deploy TVWS radios to support recovery efforts that can rebuild digital inclusion for such areas. The considerations of the new developments on cellular networks needs to first establish the existing usage gaps and explore ways to manage the quality of service (QoS) provided through such networks. On the other hand, a contextual study of LEO satellites also needs to be carried out from a technological, economic and sustainability point of view, especially as a rural Internet access alternative.
3. An assessment needs to be conducted on the dark fibre in the Country to determine the extent of fibre-connected PoPs that can be leveraged, from a more informed perspective, to extend Internet access to both Kakamega and Turkana Counties. This should also be done for the other rural counties of the country.
4. Provision of online platforms such as the one spearheaded by KICD should be integrated within the framework of Community Networks (CNs) to enable expansion and equal access of academic material by all the primary and secondary schools across the country.
5. Mapping of the connectivity for schools and healthcare centres in the country needs to be properly conducted to enable efficiency and effectiveness in responding to the connectivity challenges facing both educational and healthcare sectors in Kakamega and County. It would also help to strengthen the available options of connectivity for both counties. We therefore propose future support on this project's mapping initiatives to align it with the work on Giga and strategic initiatives within Kenya led by the government as well as the private sector.
6. More technology studies inclusive of software-defined radios, cognitive radios, opportunistic spectrum access, geolocation databases, automated frequency coordination as well as coexistence studies need to be conducted to validate the implemented policies on Dynamic Spectrum Access (DSA) to properly inform the future enactment of policies that can sustainably and contextually fit the connectivity needs in Turkana, Kakamega and the other counties based on spectrum sharing.
7. We also propose a review of the policy and regulatory regime to allow for regulatory sandboxes for testing of innovative technologies and services that have the potential to deepen ICT markets specifically and extend ICT reach and utilisation within the education and healthcare sectors.

13. Appendix: Questionnaire Form used for Site Surveys

Questionnaire: Onsite Survey of the State of Connectivity for Schools and Healthcare Centres: Pre-pandemic, during the pandemic and Now

(Please tick in the appropriate box (es) during data collection)

Researcher's Name:
…………………………………………………………………………………………………..

SECTION A: GENERAL INFORMATION

1. **Site:** Kakamega ☐ Machakos ☐

2. **Institution:** School ☐ Healthcare Centre ☐ Hospital ☐

3. **If School:** Primary ☐ High School ☐ Tertiary/College/University ☐

4. **Name of the Institution:**
   ………………………………………………………………………………………..

5. **Is the institution public or private?:** Public ☐ Private ☐

6. **Name of the Respondent (optional):**
   ……………………………………………………………………………

7. **Position of the Respondent in the Institution:**
   ………………………………………………………………

8. **Phone number of the Respondent:**
   ………………………………………………………………………..

SECTION B: LOCATION INFORMATION

9. **Name of the Location of the Institution:**
   …………………………………………………………………….

10. **GPS Coordinates:** Latitude: …………….. Longitude: ………….…. Altitude: ………………....

11. **Is there any ISP within the location of the Institution?** Yes ☐ No ☐ Not Sure ☐

12. **If the answer is Yes for Question 11, How many?** ………………………

13. **List the name(s) of the ISP(s) found:**

14. **GPS Coordinates for the ISP(s):**

Latitude: …………….. Latitude: …………….. Latitude: …………….. Latitude: ……………..

Longitude: …………… Longitude: …………… Longitude: …………… Longitude: ……………

SECTION B: STATE OF CONNECTIVITY

15. **Is the Institution Connected to the Internet?** Yes ☐ No ☐ Not Sure ☐

16. **If the answer is Yes for Question 15, who is the Internet Service Provider (ISP)?**

    …………………………………………………………..

17. **Based on information collected in Question 13, is this ISP part of the list?** Yes ☐ No ☐

18. **What is the networking technology for the Internet services? (e.g. cellular, microwave, fibre, Satellite etc**

Cellular ☐ Satellite ☐ Fibre ☐ Microwave ☐ Other: ……………………………………

19. **How often is the Internet used within the institution?**

20. **What is the average Internet Speed?**

21. **For Schools only: Does you institution have a Computer Lab?** Yes ☐ No ☐

22. **If the answer is Yes for Question 21, what is the estimated number of computers in your Computer Lab?**

23. **How many Computer Stations does the Institution have?**

24. **For Health Facilities only: how many staff can be estimated to own smartphones?**

25. **How long has the Institution had the Internet connection?** ……………………………

26. **For Question 25, Is the Internet connection from the original ISP who set up the first network?** Yes ☐ No ☐

27. **Before the COVID-19 pandemic, how can the reliability of the Internet connection be described?**

    Very unreliable ☐ Unreliable ☐ Reliable ☐ Very reliable ☐

28. **What is the monthly cost for the Internet connection?**

29. **For Schools only: How did the students manage their learning during the pandemic lockdown?**

30. **For Schools only: During the pandemic, what can you describe as the connectivity challenges the students faced?**

31. **For Health Facilities only: What can you describe as the connectivity challenges faced during the pandemic?**

32. **How is the state of connectivity at the moment?**

Similar to before the pandemic ☐ Better than before the pandemic ☐ Worse ☐

33. **Are there any institutional initiatives to enhance the state of digitalisation? What are some of those initiatives?**

14. References

[1] H. Travis, “Last Mile Connectivity in the Context of COVID-19,” International Telecommunications Union, New York, 2020.

[2] T. Isbel, “Access to remote-education tools unequal in Kenya; Radio beest way to reach most,” Afro Barometer, Cape Town, 2020.

[3] S. Song , C. Ray-Moreno, A. Esterhuysen, M. Jensen and L. Navarro, “The Rise and Fall and Rise of Community Networks,” in *Global Information Society Watch 2018: Community Networks*, Ottawa, International Development Research Centre, 2018, pp. 7-10.

[4] Ministry of Information and Communication Technology, “Digital Economy Blueprint,” May 2019. [Online]. Available: https://www.ict.go.ke/wp-content/uploads/2019/05/Kenya-Digital-Economy-2019.pdf. [Accessed 15 August 2022].

[5] Minsitry of Information and Communications Technology, “National Broadband Strategy: 2018-2023,” May 2019. [Online]. Available: https://www.ict.go.ke/wp-content/uploads/2019/05/National-Broadband-Strategy-2023-FINAL.pdf. [Accessed 15 August 2022].

[6] Communications Authority of Kernya (CA), “Licensing and Shared Spectrum Framework for Community Networks,” May 2021. [Online]. Available: https://www.ca.go.ke/wp-content/uploads/2021/05/Licensing-and-Shared-Spectrum-Framework-for-Community-Networks-May-2021.docx.pdf. [Accessed 16 August 2022].

[7] Strathmore University, “Desk Assessment of the State of Connectivity in Kakamega and Turkana,” April 2022. [Online]. Available: http://www.ilabafrica.ac.ke/wp-content/uploads/2022/04/Desk-Assessement-of-the-State-of-Connectivity-in-Kakamega-and-Turkana-28_04_2022_to_be_uploaded.pdf. [Accessed 16 August 2022].

[8] Kenya National Bureau of Statistics, “2019 Kenya Population and Housing Census Volume IV: Distribution of Population by Socio-Economic Characteristics,” 21 February 2020. [Online]. Available: https://www.knbs.or.ke/download/2019-kenya-population-and-housing-census-volume-iv-distribution-of-population-by-socio-economic-characteristics/. [Accessed 16 August 2022].

[9] County Government of Kakamega, “Vision and Mission,” 2 December 2015. [Online]. Available: https://kakamega.go.ke/vision-mission/. [Accessed 16 August 2022].

[10] Ministry of Devolution, “General County Information,” 2019. [Online]. Available: https://www.devolution.go.ke/county-information/. [Accessed 16 August 2022].

[11] The Star, “State Launches Installation of Sh.3bn Fibre Optic Cable in Rift Valley,” 26 October 2020. [Online]. Available: https://www.the-star.co.ke/counties/rift-valley/2020-10-26-state-launches-installation-of-sh3bn-fibre-optic-cable-in-rift-valley/. [Accessed 16 August 2022].

[12] Nation, “Rosy Communications Authority Statistics Mask the Digital DIvide in Kenya,” 28 June 2020. [Online]. Available: https://nation.africa/kenya/oped/blogs/dot9/walubengo/2274560-4743432-njuigc/index.html. [Accessed 16 August 2022].

[13] Strathmore University - Centre for Intellectual Property and Information Technology Law, “Responding to COVID-19 Crisis: A Critique of the 2020 Basic Education Response Plan in Kenya,” 24 June 2020. [Online]. Available: https://cipit.strathmore.edu/responding-to-covid-19-crisis-a-critique-of-the-2020-basic-education-response-plan-in-kenya/. [Accessed 16 August 2022].

[14] Nation Media Group, “Our Children can learn Online if we have the will,” 28 June 2020. [Online]. Available: https://nation.africa/kenya/blogs-opinion/blogs/dot9/ndemo/our-children-can-learn-online-if-we-have-the-will-493796. [Accessed 16 August 2022].

[15] Kenya Broadcasting Corporation, “State begins laying Internet Cable to boost access in North Western region,” 1 July 2021. [Online]. Available: https://www.kbc.co.ke/state-begins-laying-internet-cable-to-boost-access-in-north-western-region/. [Accessed 16 August 2022].

[16] Nation Media Group, “Turkana's young people are not waiting for the oil,” 28 June 2020. [Online]. Available: https://nation.africa/kenya/blogs-opinion/blogs/dot9/ndemo/turkana-s-young-people-are-not-waiting-for-the-oil-1226154?view=htmlamp. [Accessed 16 August 2022].

[17] Relief Web, “Kenya Emergency Appeal (April - September 2020),” 9 April 2020. [Online]. Available: https://reliefweb.int/report/kenya/kenya-emergency-appeal-april-september-2020. [Accessed 16 August 2022].

[18] Health Plus Policy, “Is Kenya Allocating Enough Funds for Healthcare?,” February 2021. [Online]. Available: http://www.healthpolicyplus.com/ns/pubs/18441-18879_KenyaNCBABrief.pdf. [Accessed 16 August 2022].

[19] Ministry of Foreign Affaris - Netherlands, “2021 Kenya Medical Devices eHealth,” May 2021. [Online]. Available: https://www.rvo.nl/sites/default/files/2021/05/2021-Kenya-Medical-Devices-eHealth.pdf. [Accessed 16 August 2022].

[20] Ministry of Health, “Frequently Asked Questions About Coronavirus,” March 2020. [Online]. Available: https://www.health.go.ke/wp-content/uploads/2020/03/FAQs-FOR-PRESS-KIT1.pdf. [Accessed 16 August 2022].

[21] Ministry of Health, “Interim Guidelines on Management of COVID-19 in Kenya,” June 2020. [Online]. Available: https://www.health.go.ke/wp-content/uploads/2020/06/Updated-Case-Management-Guidelines-26_03_20-1.pdf. [Accessed 16 August 2022].

[22] The President's Office, “Marking 10 Years of Progress (2008-2018),” September 2018. [Online]. Available: http://vision2030.go.ke/wp-content/uploads/2018/09/Kenya-Vision-2030-Sector-Progress-Project-Updates-June-2018.pdf. [Accessed 16 August 2022].

[23] The National Treasury and Planning, “Implementation Status of the Big Four Agenda 2018/2019,” April 2020. [Online]. Available: https://monitoring.planning.go.ke/wp-

content/uploads/2020/10/Big-Four-Agenda-Report-2018_19.pdf. [Accessed 16 August 2022].

[24] L. Berlemann and S. Mangold, Cognitive Radio and Dynamic Spectrum Access, Chichester: John Wiley and Sons Ltd., 2009.

[25] C.-X. Wang and J. Mitola III, Advances in Cognitive Radio System, Rijeka: In Tech, 2012.

[26] A. Khawar, A. Abdelhadi and T. C. Clancy, Spectrum Sharing Between Radars and Communication Systems - A MATLAB Based Approach, Arlington: Springer, 2018.

[27] Communications Authority of Kenya, “Dynamic Spectrum Access Framework for Authorisation of the Use of TV White Spaces,” May 2021. [Online]. Available: https://www.ca.go.ke/wp-content/uploads/2021/05/Dynamic-Spectrum-Access-Framework-for-Authorisation-of-the-use-of-TV-White-Spaces-May-2021.pdf. [Accessed 16 August 2022].

[28] Communications Authority of Kenya, “Licensing and Shared Spectrum Framework for Community Networks,” May 2021. [Online]. Available: https://www.ca.go.ke/wp-content/uploads/2021/05/Licensing-and-Shared-Spectrum-Framework-for-Community-Networks-May-2021.docx.pdf. [Accessed 16 August 2022].

[29] R. A. Saeed and S. J. Shellhammer, TV White Space Spectrum Technologies, Florida: Taylor & Francis Group, 2012.

[30] S. W. Oh , Y. Ma, M.-H. Tao and E. Peh, TV White Space: The First Step Towards Better Utilization of Frequency Spectrum, New Jersey: John Wiley and Sons Inc., 2016.

[31] Mawingu Networks, “Rural Broadband Trials - Laikipia County,” August 2014. [Online]. Available: https://docplayer.net/5987593-Rural-broadband-trials-laikipia-county-kenya-for-the-communications-authority-of-kenya.html. [Accessed 16 August 2022].

[32] S. Gulasekaran and S. Sankaaran, Wi-Fi 6 Protocol and Network, Massachusets: Artech House, 2021.

[33] Litepoint, *A Guide to Wi-Fi 6E - Wi-Fi 6 in the 6 GHz Band,* San Jose: Litepoint, 2020.

[34] Dynamic Spectrum Alliance, “6 GHz License Exempt: Why the full 1200 MHz and why now,” August 2021. [Online]. Available: http://dynamicspectrumalliance.org/wp-content/uploads/2021/08/6GHz-License-Exempt-Band-Why-1200-MHz-and-Why-Now.pdf. [Accessed 17 August 2022].

[35] D. Coleman, Wi-Fi 6 and 6E, Hoboken: John Wiley and Sons, Inc., 2022.

[36] UNICEF and ITU, “Giga: Kenya Opportunity Brief,” November 2020. [Online]. Available: https://gigaconnect.org/wp-content/uploads/2020/11/Giga-Kenya-Opportunity-Brief_External.pdf. [Accessed 17 August 2022].

[37] T. Jiang, Z. Wang and Y. Cao, Cognitive Radio Networks: Efficient Resource Allocation in Cooperative Sensing, Cellular Communications, High-Speed Vehicles and Smart Grid, Florida: Taylor and Francis Group LLC, 2015.

[38] J. O. Onunga and S. Mbugua, “Digital Technology Access and Use Among Socially and Economically Disadvantaged Groups in Turkana County, Kenya,” *Asian Journal of Social Science and Management Technology,* vol. 3, no. 5, pp. 44-57, 2021.

[39] International Telecommunication Union, “Global Connectivity Report 2022,” ITU, Geneva, 2022.

[40] Kenya ICT Action Network, “Social-economic Imapct of Broadband in Kenya,” KiCTAnet, Nairobi, 2019.

[41] Federal Communications Commission, “Report and Order and Further Notice of Proposed Rulemaking,” FCC, Washington D.C., 2020.

[42] V. Bhandari, “Improving Internet Connectivity during Covid-19,” *Digital Pathways Paper Series,* pp. 1-30, Augsut 2020.