Rebuilding Kenya's Rural Internet Access from the COVID-19 Pandemic

Leonard Mabele[1](✉), Kennedy Ronoh[1], Joseph Sevilla[1], Edward Wasige[2], Gilbert Mugeni[3], and Dennis Sonoiya[3]

[1] Strathmore University, Ole Sangale Link, Nairobi, Kenya
lmabele@strathmore.edu
[2] University of Glasgow, Rankine Bldg, Oakfield Ave, Glasgow G12 8LT, UK
[3] Communications Authority of Kenya, CA Centre, Waiyaki Way, Nairobi, Kenya

Abstract. In this paper, we share our findings on Research Paper 4 – one of the 15 research studies supported by the International Telecommunication Union (ITU) under the Connect2Recover Research Competition. The main objective of Research Paper 4 was to assess the level of digital resiliency for rural areas of Kenya in a two-pronged approach (before and during the COVID-19 pandemic) and the mechanisms that can be adopted as opportunity to "build back" rural connectivity. Hence, through desk research, the state of broadband access for Kakamega and Turkana counties, as representatives of rural Kenya, was evaluated. The evaluation focused on the connectivity for education and healthcare sectors. Further, field surveys were conducted in Kakamega and Machakos counties to obtain primary data and develop a demonstration mapping tool that can be inferred as a benchmark to effectively support connectivity initiatives for rural Kenya. Spectrum measurements were also incorporated in this evaluation to determine the extent of opportunity for rebuilding rural broadband through spectrum sharing. Therefore, alongside these findings, this paper shares recommendations at the end in terms of both policy and technology to reinforce digital inclusion for rural Kenya as part of the pandemic recovery strategies and safeguards against future hazards.

Keywords: Digital Resiliency · Last-mile Internet access · Spectrum Sharing

1 Introduction

The Connect2Recover initiative was launched by the International Telecommunication Union (ITU) in conjunction with the Government of Japan and the Government of Saudi Arabia in September 2020. The initiative was launched 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 is to reinforce the digital infrastructure and digital ecosystems of beneficiary countries and provide means of utilizing digital technologies such as telework, e-commerce, remote learning and telemedicine to support the COVID-19 recovery efforts [1]. In July 2021, the initiative launched the

R. A. Saeed et al. (Eds.): AFRICOMM 2022, LNICST 499, pp. 285–298, 2023.
https://doi.org/10.1007/978-3-031-34896-9_17

"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: improvement of research focus on digital resiliency and digital inclusion for pandemic recovery; developments of a global research community of think tanks and academic institutions around digital inclusion, and promotion of 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. The 15 Research Papers hailed from 43 institutions and individual researchers in 22 countries. The work we present here is based on Research Paper 4 which is entitled *Rebuilding Digital Inclusion for Rural Counties of Kenya.*

1.1 Overview of the State of Connectivity in Kenya and Our Research Work

Prior to the COVID-19 pandemic (by the end of 2019), the International Telecommunication Union (ITU) published that 3.7 billion people were still unconnected to the power of the online world [2]. Although this number has significantly reduced to 2.9 billion according to the *2022 Global Connectivity Report* [3], it is still high as the figure represents one-third of the population on the planet [4]. Further, a significant fraction of the connected population is yet to be described as 'meaningfully connected.' Meaningful connection refers to a reliable, affordable and dependable connection based on user needs rather than a simple connection [2]. Geographically, however, Sub-Saharan Africa (SSA) is seen to lag behind in terms of Internet access compared to the rest of the world with only 29% of its entire population using the Internet [5]. During the pandemic, the region accounted for almost half of the 450 million people living in areas not sufficiently covered by 3G or 4G mobile networks [6]. Therefore, the drastic change of the shifts in data traffic at the height of the pandemic considerably imposed stress to the sectors of healthcare, education and business systems that lacked solid connectivity ecosystem to comfortably migrate to online platforms within the SSA region. This was equal for both fixed and mobile networks [7].

In Kenya, the state of Internet access similarly reflected the COVID-19's global scenario based on the 'have' and 'have-nots.' That is, regions that had better connectivity prior to the pandemic remained better connected compared to the regions that lacked affordable and reliable access at the onset of the pandemic [8]. While this was partly attributed to the physical distancing restrictions that had been implemented to curb the spread of the coronavirus, it is also evident that initiatives to connect the 'have-nots' were still far (and still are) from being ready [9]. This inequality was further exacerbated by the state of electricity supply across the rural areas of the country, limitations of the available physical and Internet infrastructure, levels of income and limited availability of the contextual e-learning platforms. Moreover, challenges such as lack of digital skills, cost of personal devices as well as perceived lack of relevancy were conspicuous in rural counties of Turkana, Tana River, West Pokot, Lamu and Marsabit [8].

To enhance Internet access for these rural areas of Kenya beyond the pandemic, the Communications Authority of Kenya (CA), Kenya's Information and Communication Technology (ICT) regulator, endeavored to enact two regulatory frameworks premised on the opportunity of enabling affordable Internet access through spectrum sharing. The first framework is the *Authorization of the Use of Television White Spaces (TVWS*) and the second one is the *Licensing and Shared Spectrum Framework for Community Networks.* The former*,* while emphasizing on Kenya's vision of a digitally transformed nation, was joining the rest of the countries that had already published rules for secondary access to the TVWS in the 470-694 MHz spectrum as the pioneer step of spectrum sharing [10]. The opportunity of spectrum sharing is meant to increase capacity by allowing fallow spectrum to be exploited opportunistically to connect the underserved without displacing the incumbents. The latter, while noting of the limited number of Community Networks (CNs) in Kenya, was laying a foundation through a bottom-up contextual model to address broadband needs at both sub-county and 'village' levels. In essence, it was established as a complementary strategy to meet the needs of affordable communication infrastructure to the Kenyans living in remote and sparsely populated low-income areas.

Our research work, hence, as our proposal to ITU's Connect2Recover Competition, sought to investigate the value these two frameworks would provide to rebuilding Kenya's rural connectivity. It also investigated the level of connectivity available for rural healthcare and education sectors, taking Kakamega and Turkana counties as case studies. Additionally, it assessed the window of scalability of spectrum sharing beyond the presently allowed radio frequency (RF) bands. The determination was based on spectrum measurements conducted in Kakamega County.

The presentation of our research in this paper is therefore segmented as follows: Sect. 2 presents the research methodology used, Sect. 3 shares the findings of all the stages of work carried out, Sect. 4 provides our analysis to the findings while Sect. 5 shares our recommendations. Section 6 concludes the paper and provides insights into future works. The work presented in this paper also provides the following contributions: mapping of all the sites visited during field surveys in schools and healthcare facilities in Kakamega and Machakos counties and the RF findings on spectrum measurements conducted in Kakamega in potential bands that can be considered for spectrum sharing.

2 Research Methodology

Predominantly, the research made use of desk research to study and analyze literature and secondary data that had been published by global institutions such as the International Telecommunication Union (ITU), Dynamic Spectrum Alliance (DSA), Global Alliance of Mobile Network Operators (GSMA), and the Alliance for Affordable Internet (A4AI) among others. Some of the notable literature studied as part of desk research include *The Last-mile Internet Connectivity Solutions Guide* by the ITU and the ROAM-X publication of *Assessing Internet Development in Kenya.* ROAM-X is an acronym of Rights, Openness, Access to All, Multi-stakeholder participation and Cross-Cutting Issues crafted by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a benchmark of Internet universality indicators. In-country blueprints on connectivity such as the *National Broadband Strategy* and the *Digital Economy Blueprint* also contributed significantly to the literature as part of the desk research. Publications by researchers and corporate bodies on connectivity for Turkana and Kakamega as well as those focused on rural connectivity for Kenya were also equally considered as part of secondary sources. While conducting the desk research, we focused on the pillars or segments of the various sources that related to rural Internet access and the opportunities and mechanisms recommended or suggested to spur affordable Internet access for the rural communities. Moreover, we dwelt on the technology and regulatory developments that are being evaluated at the global stage as well as within Kenya to enhance meaningful access to the underserved. The two frameworks aforementioned in the introduction section were central to our scrutiny.

Besides the desk research, field surveys were also carried out in Kakamega and Machakos counties between 19^{th} April 2022 and 25^{th} April 2022. The surveys made use of both paper and mobile App-based questionnaire to obtain information on the experience of Internet access by academic and healthcare institutions in both counties. The App used is known as ODK from getodk.org. The App was adopted due to its open- source nature and the simplicity to allow collection of data both in online and offline modes. The paper questionnaire was used in developing the App questionnaire. Three sections were designed for the paper questionnaire; the first section requested for general information such as the institution, if public or private, name and details of the respondent. The second section asked for the location information in terms of coordinates of the institution and any accessibility to a nearby Internet Service Provider (ISP). The coordinates were obtained through the Mobile App as well as through a search on Google Map. The third section needed information about the connectivity of the institution to the Internet, access technology used, fiber point of presence (PoP), how often the Internet is used, average access speed, state of available devices and computer labs, number of staff and students, experience of access before and during the pandemic, monthly cost for the Internet connection, challenges faced in terms of connectivity, the present connectivity state and institutional initiatives to enhance access. The exercise adhered to the country's ethical standard of data collection by seeking guidance through the Strathmore University's Institutional, Scientific and Ethical Review Committee (SU-ISERC).

During the survey, a total of 24 institutions was visited: 12 academic and 12 healthcare facilities. Representatives from the visited institutions were also interviewed to share information on their experience of connectivity before the pandemic and during the pandemic as well as at the time the field surveys were being conducted. The representatives included general staff and the ICT staff for the healthcare facilities. For the academic institutions, they included students, teachers, and general staff in various departments as well as the ICT staff.

In addition to the field visit to the academic and healthcare facilities, another field exercise was conducted to measure the usage of the RF spectrum that can potentially be exploited for secondary access. The motivation was to develop spectrum awareness to assist knowledge on which spectrum bands to use opportunistically to enhance rural broadband access. This exercise involved use of the CA's RF monitoring mobile equipment, which is often used across the country for spectrum planning, technical analysis and cross-border coordination. The RF bands of focus during the exercise included 470-694 MHz, 700 MHz, 1700 MHz and the 3300-3500 MHz. The 470-694 MHz, as the ultra-high frequency (UHF) band that had been authorized for access through TVWS was evaluated in this case to determine if the intensity of incumbent usage had risen to warrant more protection from interference by the opportunistic deployment of TVWS.

3 Research Findings

In this section, we share our research findings in accordance with the segments of the work carried out. These segments are provided in Sects. 3.1, 3.2 and 3.3.

3.1 Desk Assessment of the State of Connectivity in Kakamega and Turkana Counties

While both Turkana and Kakamega counties are classified as rural, Kakamega is more developed and has fertile lands for more agriculturally driven economic activities [11]. Further, Kakamega County also has more schools and healthcare facilities compared to Turkana due to the favorable geography and a more educated population [12]. Prior to the pandemic, the National Optic Fiber Backbone Infrastructure (NOFBI), the fiber optic connectivity initiative led by the national government of Kenya, had only covered areas along the main tarmac road leading into Kakamega town [13]. This means that only government offices, a few institutions and organizations were able to access Internet through it. In Turkana, however, NOFBI coverage had not been laid yet until the last quarter of 2020 [14]. Notably, the NOFBI project was proposed back in 2007 to establish a national public broadband network with access points in every county in order to attract and stimulate private sector participation in the provision of rural telecommunication services [15].

In terms of cellular network, Kakamega was described to enjoy 85% coverage with healthcare and education shown to be improving, however, the county cited challenges in terms of the quality of coverage even as it strategized to enhance Internet access for all its citizens in its *County Integrated Development Plan* [16]. For Turkana, out of the three mobile network operators (MNOs) in Kenya, Safaricom was the heavily relied on MNO. There was little data on the extent of coverage for Airtel and Telkom who are the other two MNOs. The Turkana County government, prior to the pandemic, had noted of significant areas within the county that lacked access to the cellular signal, hampering both voice and Internet communication. The National Broadband Strategy of between 2018 and 2023 also alludes to the cellular connectivity challenges that Turkana citizens faced [9]. For instance, citizens of Turkana had to walk more than 2 kilometers to access a mobile cellular signal with access to Internet being non-existent. Both Turkana and Kakamega, unfortunately, lacked sufficient data and published information on the alternative connectivity technologies such as through satellite or fixed Internet services that leveraged Wi-Fi or microwave links prior to the pandemic. This was similarly reflected in the state of connectivity for the schools and healthcare institutions in both counties, which warranted a field visit to ascertain the extent of Internet usage in both sectors. Unfortunately, for the field visit, Turkana could not be physically accessed due to budgetary challenges and issues relating to security. Therefore the field surveys replaced Turkana with Machakos.

3.2 Field Surveys in Kakamega and Machakos Counties

The field surveys showed that most of the institutions had a fiber point of presence (PoP) nearby. In addition, five institutions in both Kakamega and Machakos were said to be connected to the NOFBI network although their Wi-Fi speeds seemed as low as below 2 megabits per second (Mbps). In Masinde Muliro University of Science and Technology (MMUST), the only university assessed during the study, one could not load a web page on the phone in the main library floor area although speeds were better (10 Mbps) at the Computer Lab which had fifteen computers. The MMUST ICT staff mentioned of reliable speeds that could averagely reach 100 Mbps but there was no evidence to back this up. Most students, however, preferred outdoor access to Internet which made sense from the physical-distancing scenario that served as a better control approach to the spread of the coronavirus. The list of some of the sites visited in Kakamega is shown in Table 2 with the ISPs providing the services as well as the average Internet speeds. In the institutions where no formal Internet access existed, the table uses 'NONE' to show an absence of established ISP and 'N/A' for the lack of information on average Internet speed.

In Machakos County, 85% of the institutions surveyed had Internet access and microwave seemed a better alternative in the absence of fiber with 5 GHz Wi-Fi links in various facilities. The most popular service provider was Safaricom. However, most institutions had more than one provider with the other providers serving as backup. Majority of the healthcare centers cited unreliability in their current Internet states while mentioning of near future plans to automate most of the healthcare services. Similar to Kakamega, the Kenya Medical Training College (KMTC) seemed better equipped with digital facilities as well as with better Internet coverage compared to all the sites. KMTC is a state corporation established through an Act of Parliament under the Ministry of Health, entrusted with the role of training various disciplines in the health sector to serve Kenya, East Africa and the entire African region. The College has 72 campuses spread across Kenya [17]. A table similar to the one for the sites visited in Kakamega is also shown in Table 1 for the sites visited in Machakos County.

At the height of the pandemic, it was noted that some institutions for both healthcare and academic, provided mobile data to their staff and students. Hence, based on the approach of working from home, it was hard to tell how reliable their Internet was as it depended on where the students and the staff stayed during the pandemic. However, a number of students surveyed mentioned to have 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. All the institutions, nonetheless, noted of 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. Visited Sites in Kakamega County with their ISP, Access Technologies and the Internet speed.

Visited Institution	Sub-county	Access Technology Available	Name of ISP	Average Internet Speed
Sheywe Community Hospital	Lurambi	Fiber	Liquid Telecom/ Safaricom	15 Mbps
KMTC Kakamega	Lurambi	Fiber & Satellite	Telkom-UHC/Safaricom	250 Mbps
St. Mary's Mission Hospital Mumias	Mumias West	Fiber	Liquid Telecom/ Safaricom	20 Mbps
Kakamega Orthopaedic Hospital	Lurambi	Fiber	Safaricom	10 Mbps
MMUST	Lurambi	Fiber	KENET/Safaricom	100 Mbps/300 Mbps
Ekambuli Primary School	Khwisero	NONE	N/A	N/A
Mundoli Primary School	Khwisero	NONE	N/A	N/A
St. Martha's Mwitoti Secondary School	Mumias East	Cellular Network	Safaricom/Aitel/Telkom	10 Mbps

3.2.1 Mapping

The data collected in both Kakamega and Turkana counties has been used to develop a demonstration mapping tool accessible through this link. The tool has markers of all the sites visited and provides information on the location of the site (institution surveyed), the present access technology used, speeds provided by the technology as well as whether the connection is reliable or unreliable as per the feedback provided during the site survey. Figure 1 and 2 shows an example of one academic and healthcare institution as presented by the tool in Kakamega and Machakos counties respectively. The mapping aims to contribute to ITU's goal of a systemic platform that shows the connectivity challenges for determination of infrastructure needs [2].

Table 2. Visited Sites in Machakos County with their Access Technologies, Speeds and Monthly cost of Internet access

Visited Institution	Sub-county	Access Technology available	Name of ISP	Average Internet Speed
St. Teresa Mwala Girls	Mwala	Microwave	Safaricom	5 Mbps
Kaani Level 2 Hospital	Kathiani	NONE	N/A	N/A
Masii Medical Centre	Masii	Microwave	Safaricom	10 Mbps
KMTC Kangundo	Kangundo	Satellite	KENET	100 Mbps
Machakos Teachers College	Machakos	Fiber	Safaricom	15 Mbps
Maisha Mazuri School	Matungulu	Microwave	Safariland	10 Mbps
Kivaani Health Centre	Kangundo	NONE	N/A	N/A
Machakos Girls Academy	Machakos	Fiber	Jamii/Safaricom	30 Mbps / 15 Mbps

3.3 Spectrum Measurements in Kakamega County

Spectrum sharing has gradually been growing in Kenya to supplement the efforts of affordable rural connectivity while addressing the spectrum scarcity challenges [18]. Hence, our spectrum measurements in Kakamega County in the bands aforementioned showed an availability of spectrum holes (white spaces) as shown in Fig. 3 and 4 in 600-750 MHz band and 1700-1800 MHz bands. The figures are based on Fast Fourier Transform (FFT) measurements of the spectrum analyzer used by CA. Both figures show that a significant fraction of the signals (signals without raised peaks) can be exploited opportunistically to enhance Internet access [19]. Both of the bands shown are predominantly licensed to International Mobile Telecommunications (IMT) services, commonly available as mobile and fixed networks [20].

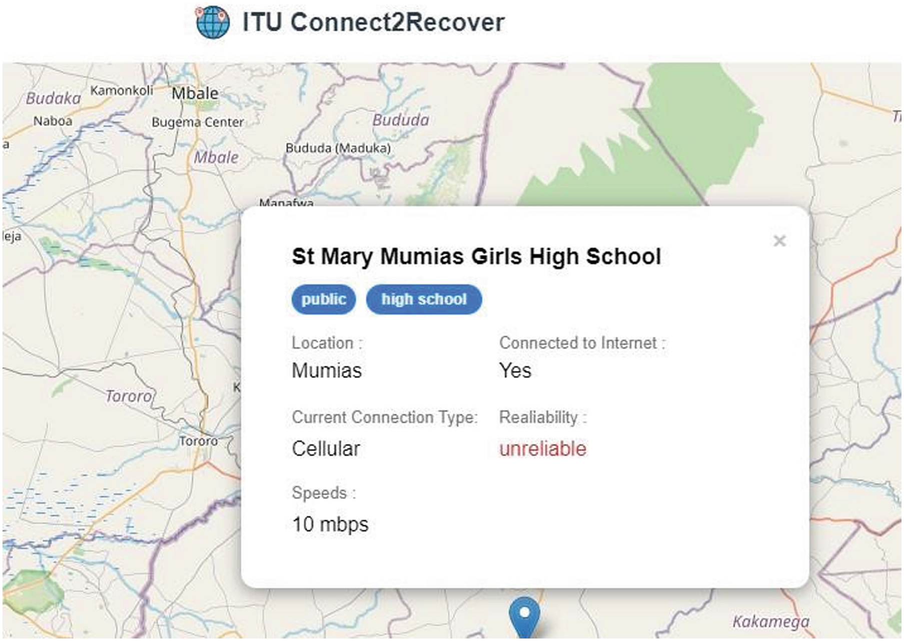

Fig. 1. Details of Connectivity for St. Mary's Institution in Kakamega County

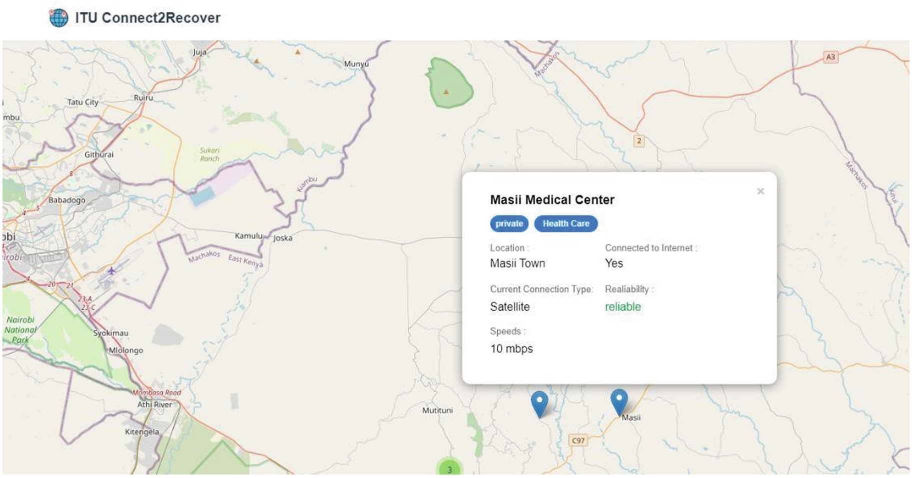

Fig. 2. Details of Connectivity for Masii Medical Centre in Machakos County

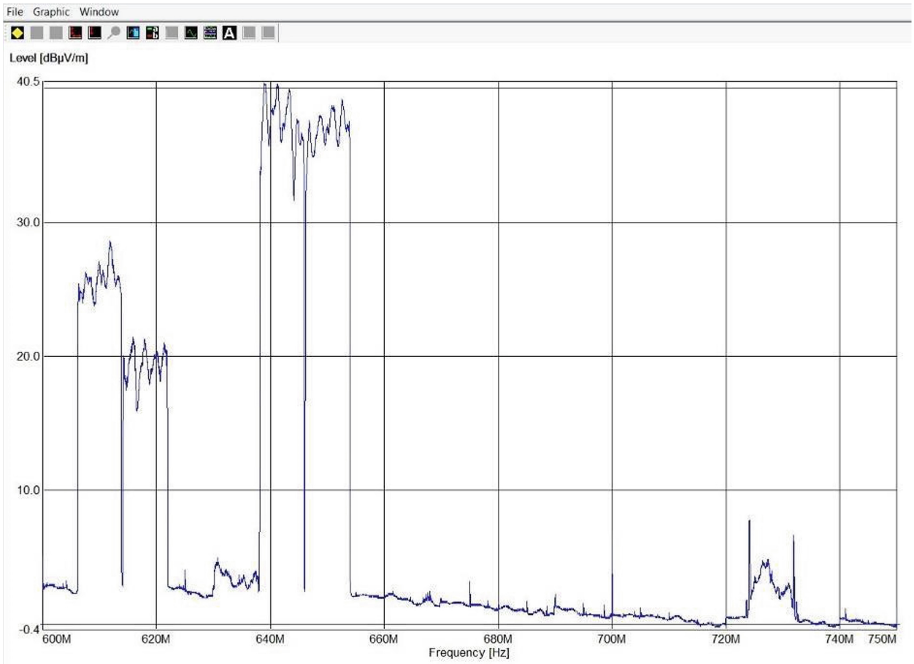

Fig. 3. Spectrum Analyzer Fast Fourier Transform (FFT) Measurements in the 600–700 MHz Band. Source: Communications Authority of Kenya

4 Analysis of the Findings

Traditional issues of lack of electricity, coverage and affordability were laid bare to the disproportionately underserved groups in Kenya at the height of the COVID-19 pandemic. This became more conspicuous when the Government announced closure of schools starting the week of 16^{th} and 24^{th} March 2020 to combat the geographical spread of coronavirus [13]. The learning of the rural students in both Kakamega and Turkana counties, hence, was heavily hampered given the immature state of fiber coverage at the time in both counties as well as a patchy cellular coverage that students alluded to during the field surveys. This equally affected students who had to travel back from urban institutions to their rural homes. Such students, especially tertiary- level students, struggled to join virtual classes through platforms such as Zoom, Google Meet or Microsoft TEAMs. To address this challenge, the government proposed an approach of having content delivered through radio FM and television for the primary and secondary students. However, with the gap of the lack of electricity, these efforts were not fruitful. Besides, students also lacked access to recorded sessions as they would in a Zoom or Google Meet class. The lack of electricity, prior to the pandemic and into the pandemic, also limited the deployment efforts of sufficient backhaul networks to support better rural connectivity for both schools and healthcare facilities. While CA's sector statistics report, predominantly focus on the cellular coverage [22], the field surveys found some rural areas lacking meaningful cellular connection by the standards of ITU

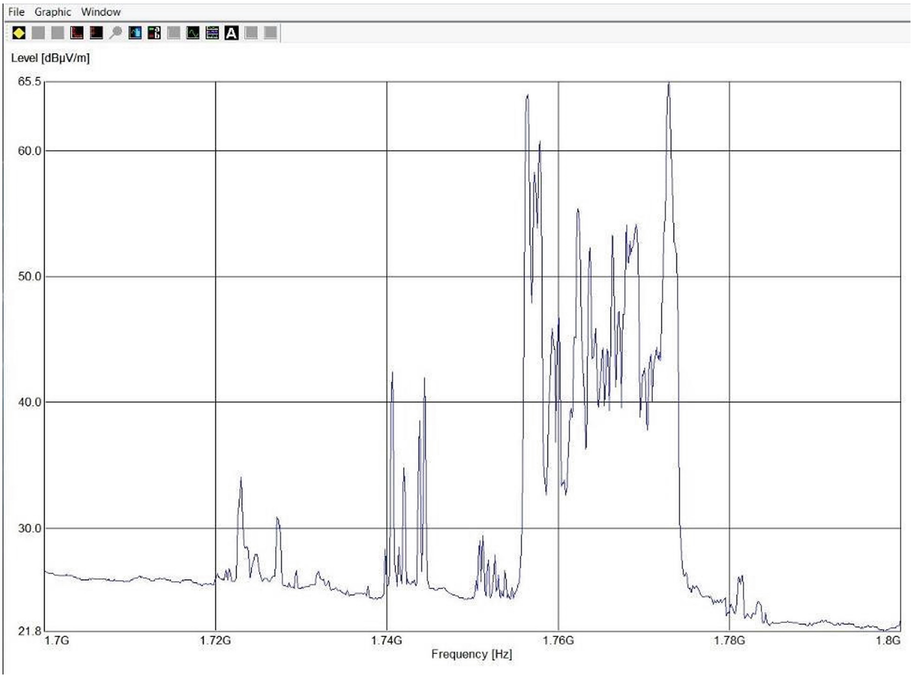

Fig. 4. Spectrum Analyzer Fast Fourier Transform (FFT) Measurements in the 1700–1800 MHz Band. Source: Communications Authority of Kenya

[23]. On the other hand, the cellular focus seem to inhibit understanding on other access alternatives such as through Community Networks, Low Earth Orbit (LEO) Satellites etc. that would significantly contribute to rural connectivity. Moreover, despite the little fiber coverage identified in both Kakamega and Turkana during the desk studies, the field studies unearthed a scenario of an existing state of dark fibre. Dark fiber refers to unused optical fiber that has been laid [24].

In spite of these challenges, the enactment of the regulatory frameworks for Community Networks (CNs) and TV White Spaces (TVWS) postulate an opportunity that can be tapped to properly reconstruct the connectivity initiatives beyond the two case studies shared in this paper to include other rural areas of Kenya. This is because of the approach of spectrum sharing they both posit. Spectrum sharing means to make more spectrum available for services whose growth is in the national interest, without upsetting the existing users of the spectrum [25]. Under the aegis of the country's National Broadband Strategy [9], this approach, can be explored to allow coexistence of different radio access technologies (RATs) in the same radio frequency (RF) bands to deliver on affordable and meaningful rural connectivity. This can be extended in other bands such as the ones used for IMT as demonstrated in this paper. While addressing the contextual connectivity needs, spectrum sharing would also help the regulator efficiently manage spectrum without resorting to spectrum clearing and circumvent the challenges of spectrum re-allocation as the ones experienced during the digital migration process [26].

5 Recommendations

Based on the desk studies conducted during the work on Research Paper 4, field surveys, stakeholder engagements and spectrum measurements, we propose the following recommendations. The recommendations consider both policy and technology to rebuild Kenya's rural Internet access from the COVID-19 pandemic and even enable stronger resiliency in the event of future pandemics:

1. While the Government has made great strides in delivering rural electrification, more effort is required to expand access to affordable and reliable grid electricity across Kenya to reduce the inequality that exists between the urban and rural areas. This would enable ease of deploying Internet to the last mile by the service providers as well as 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 fiber-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. Mapping of the connectivity for schools and healthcare centres in the country also needs to be properly conducted to enable efficiency and effectiveness in responding to the connectivity challenges facing rural Kenya. This would help strengthen the available connectivity options even as new methods such as spectrum sharing are identified.
5. 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). This will help 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.

6 Conclusions and Future Works

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 Kenya 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 centers changing their perception on its relevance. As the efforts to rebuild rural counties such as Kakamega and Turkana pick up momentum, all the stakeholders ought to consider Internet access as a driver for the "new normal" of economic development. Hence, part of the future works on this research is to explore in detail implementation efforts that can bridge the dark fiber challenges and the scalability of spectrum sharing from a more practical approach of exploiting unused RF spectrum opportunistically.

References

1. InternationalTelecommunication Union Development (ITU-D). Connect2Recover Initiative, International Telecommunication Union, September 2020. https://www.itu.int/en/ITU-D/Pages/connect-2recover.aspx. Accessed 26 Sept 2022
2. International Telecommunication Union - Development Sector. The Last-mile Internet Connectivity Solutions Guide, ITU, Geneva (2020)
3. International Telecommunication Union - Development Sector. Global Connectivity Report 2022. ITU, Geneva (2022)
4. United Nations Department of Economic and Social Affairs. World Population Prospects 2022: Summary of Results. UN DESA, New York (2022)
5. SBA Communications Corporation. Southern African Wireless Communications, August 2022. https://www.africanwirelesscomms.com/Media/Default/archive/sawc/SAWC2208.pdf. Accessed 26 Sept 2022
6. The World Bank. Using Geospatial Analysis to Overhaul Connectivity Policies. International Bank for Reconstruction and Development, Washington DC (2022)
7. Ericsson. How networks are adpating to the new normal. Ericsson, 14 April 2020. https://www.ericsson.com/en/blog/2020/4/networks-%20adaptingdata-traffic-new-normal. Accessed 8 June 2022
8. Mutegi, R.: ICT inequalities and e-learning in the wake of COVID-19 in Kenya. Int. Interdisc. J. Educ. **9**(4), 220–227 (2020)
9. Ministry of ICT. Innovation and Youth Affairs, National Broadband Strategy 2023Final, May 2019. https://www.ict.go.ke/wp-content/uploads/2019/05/National-Broadband-Strategy-2023-FINAL.pdf. Accessed 4 Sept 2022
10. Oh, S.W., Ma, Y., Tao, M.-H.: TV White Space - The First Step Towards Better Utilization of Frequency Spectrum. John Wiley and Sons Inc., New Jersey (2016)
11. Kathula, D.N.: Effect of COVID-19 pandemic on the education system in Kenya. J. Educ. **3**(6), 31–52 (2020)
12. KNOEMA. Kakamega. https://knoema.com/atlas/Kenya/Kakamega. Accessed 20 Sept 2022
13. iLabAfrica, Strathmore University. Desk Assessment of the State of Connectivity in Kakamega and Turkana Counties, 28 April 2022. http://www.ilabafrica.ac.ke/wp-content/uploads/2022/04/Desk-Assessement-of-%20theState-of-Connectivity-in-Kakamega-and-Turkana-%2028_04_2022_to_be_uploaded.pdf. Accessed 20 Sept 2022

14. The Star. State Launches Installation of Sh.3 Billion Fibre Optic Cable in Rift Valley, The Star Newspaper, 26 October 2020. https://www.thestar.co.ke/counties/rift-valley/2020-10-26-state-launches-%20installation-of-sh3bn-fibreoptic-cable-in-rift-valley/. Accessed 26 Sept 2022
15. Office of the Auditor General. Implementation of National Optic Fibre Backbone Infrastructure Project, December 2014. https://www.oagkenya.go.ke/wp-content/uploads/2022/08/Implementation-ofNational-%20Optic-Fibre-Backbone-Infrastructure-Project.pdf. Accessed 26 Sept 2022
16. County Government of Kakamega. Kakamega County Integrated Development Plan 2018–2022. County Government of Kakamega, Kakamega (2018)
17. Kenya Medical Training College. About KMTC. https://kmtc.ac.ke/about-kmtc/. Accessed 26 Sept 2022
18. Ronoh, K., Mabele, L., Sonoiya, D.: TV white spaces regulatory framework for kenya: an overview and comparison with other regulations in Africa. In: Zitouni, R., Phokeer, A., Chavula, J., Elmokashfi, A., Gueye, A., Benamar, N. (eds.) AFRICOMM 2020. LNICSSITE, vol. 361, pp. 3–22. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-70572-5_1
19. Donat, W.: Explore software defined radio: use SDR to receive satellite images and space signals. PragProg, North Carolina (2021)
20. Communications Authority of Kenya. Table of Radio Frequency Allocations, March 2021. https://www.ca.go.ke/wpcontent/uploads/2021/03/National-Table-of-Frequency-%20Allocations-2020.pdf. Accessed 20 Sept 2022
21. Communications Authority of Kenya. Sector Statistics Report Q‘1–2021–2022, December 2021. https://www.ca.go.ke/wp-content/uploads/2021/12/Sector-Statististics-Report-Q1-2021-2022.pdf. Accessed 23 Sept 2022
22. International Telecommunication Union. Global Connectivity Report 2022. ITU, Geneva (2022)
23. Field Engineer. What is Dark Fiber? 13 November 2017. https://www.fieldengineer.com/blogs/what-is-dark-fiber. Accessed 12 Sept 2022
24. Matyjas, J.D., Kumar, S., Hu, F.: Spectrum sharing in wireless networks. Taylor and Francis Group, Florida (2017)
25. GSMA. Digital Migration Process in Kenya, January 2017. https://www.itu.int/en/ITU-R/seminars/rrs/2017-Africa/Forum/GSMA%20Digital%20Migration%20Process%20in%20Kenya.pdf. Accessed 29 Sept 2022
26. Song, S., Rey-Moreno, C., Esterhuysen, A., Jensen, M., Navarro, L.: The rise and fall and rise of community networks. In: Global Information Society Watch. International Development Research Centre, Ottawa, pp. 7–10 (2018)
27. Turkana County Government. About Turkana (2022). https://turkana.go.ke/about-overview/. Accessed 26 Sept 2022
28. County Government of Kakamega. About Kakamega County, 2 December 2015. https://kakamega.go.ke/vision-mission/. Accessed 26 Sept 2022
29. Jiang, T., Wang, Z., Cao, Y.: Cognitive radio networks: efficient resource allocation in cooperative sensing, cellular communications, high-speed vehicles and smart grid. Taylor and Francis Group LLC, Florida (2015)