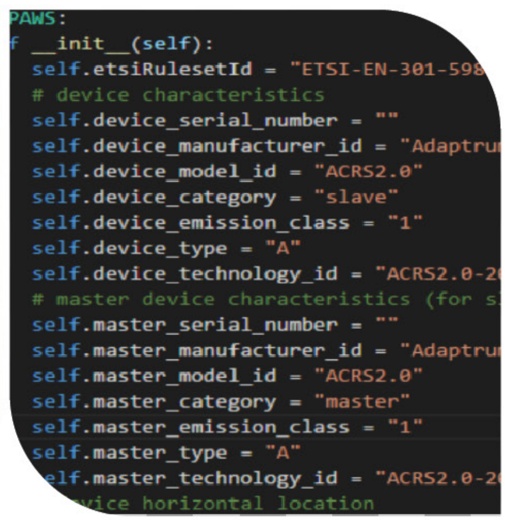
Gap Analysis Study on Spectrum Sharing - Kenya

UKaid from the British people

DSA DYNAMIC • SPECTRUM • ALLIANCE

Strathmore University @iLabAfrica Centre

2022



About the Organisations on this Project

This report is an output of the project "**Enhancing Affordable Broadband Connectivity through Dynamic Access to Spectrum and Facilitating Inclusive Growth of the Local Digital Ecosystem in Kenya**." The study was commissioned by the Dynamic Spectrum Alliance (DSA) in collaboration with the Communications Authority of Kenya (CA), with funding from the Foreign, Commonwealth and Development Office (FCDO) – Government of the United Kingdom and was conducted between November 2021 and July 2022. The description of the organisations participating on the project is given here.

	The UK Government, through the Digital Access Programme (DAP), spearhead by the Foreign, Commonwealth and Development Office (FCDO) has been instrumental in supporting digital access initiatives in Kenya, Nigeria, South Africa, Brazil and Indonesia to deliver innovative, holistic and catalytic interventions that can enable the reach to the underserved communities and groups. This report is an output of such ongoing initiatives in Kenya.
	The Dynamic Spectrum Alliance (DSA) is a global, cross-industry, not-for-profit organisation advocating for laws, regulations and economic best practices that will lead to more efficient utilisation of spectrum and foster innovation and affordable connectivity for all. DSA is the only global organisation focused on promoting spectrum sharing innovation with worldwide technology experts, making the DSA the shared spectrum go-to organisation for regulators and policymakers all over the world.
	Strathmore University is a leading private university based in Nairobi, Kenya. The institution began as Strathmore College in 1961 as the first multi-racial, multi-religious advanced level College in Kenya. Through the School of Computing and Engineering Sciences and @iLabAfrica Research Centre, the University has actively participated on Spectrum studies since 2017 to contribute to the research umbrella of Spectrum Sharing. The institution is presently involved in active projects that can present findings and demonstrate cases for spectrum sharing across various bands in the country especially as demand for spectrum increases and new wireless technologies emerge.
	The Communications Authority of Kenya (CA) is the regulatory body for the ICT sector in Kenya. Its responsibilities encompass the following services: telecommunications, e-commerce, broadcasting, postal/courier services and cybersecurity. CA is responsible for managing the numbering and frequency spectrum resources for the country as well as safeguarding consumers of ICT services in Kenya.

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 the Kenyan context, it is connectivity that delivers Internet speeds of 2 Mbps to every user or 10 Mbps for a home with five users, schools, healthcare and public sector facilities.
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.
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
ATU	African Telecommunications Union
CA	Communications Authority of Kenya
CAPEX	Capital Expenditures
CDMA	Code Division Multiple Access
CR	Cognitive Radio
DSA	Dynamic Spectrum Access
DSAL	Dynamic Spectrum Alliance
DTT	Digital Terrestrial Television
EIRP	Equivalent Isotropic Radiation Power
GSMA	Global Alliance of Mobile Network Operators
ICT	Information and Communications 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
RF	Radio Frequency
SDGs	Sustainable Development Goals
SIM	Subscriber Identity Module
TVWS	Television White Spaces
UN	United Nations
USF	Universal Service Fund
USP	Universal Service Provision

ACKNOWLEDGEMENT

Strathmore University sincerely acknowledges the support provided by the Dynamic Spectrum Alliance (DSA) through research funding as well as provision of a set of study materials that have been key to the implementation of this project. More specifically, we are grateful for the comments, feedback and frequent calls we have had with Dr. Martha Suarez, the President of the DSA and Mr. Claudio Menendez, former DSA's Project Manager and Trevor Genis, the current DSA Project Manager. Our thanks also go to Mr. Charles Juma, the Country Lead of the Digital Access Program (DAP) initiated by the UK Foreign, Commonwealth and Development Office (FCDO) for contributing to the inception of this project. We also extend our gratitude to Mr. Dennis Sonoiya, a Frequency Spectrum Management Engineer from the Communications Authority of Kenya (CA) and Mr. Gababo Wako, the current Acting Manager of Frequency Planning at CA for their valuable input in helping contextualise the findings of this work based on the Kenyan frequency allocations and developments on spectrum sharing. Our hearty appreciation also extends to Mark Rotter of Adaptrum, Jeffrey Yan of Microsoft, Heikki Kokkinen of Fairspectrum and David Wang'ombe of Mawingu Networks for providing comments that have been instrumental to the development of this report.

EXECUTIVE SUMMARY

In the wake of the COVID—19 pandemic, the Government of Kenya through the Communications Authority (CA) enacted two regulatory frameworks to chart the way forward in boosting Internet access for rural Kenya. The first framework was the *Authorisation of the Use of Television White Spaces (TVWS)* and the second one was the *Licensing and Shared Spectrum Framework for Community Networks (CNs)*. While these two frameworks underscore the need for enhancing broadband access to the millions of underserved Kenyans, they also ushered in a new and unique approach of utilising radio frequency (RF) spectrum, known as Spectrum Sharing (SS) or Dynamic Spectrum Access (DSA).

With human and machine-driven demand for information capacity and data exchange perpertually increasing, consequently presenting challenges for mobile and wireless communication systems, Spectrum Sharing (SS) postulates an approach that is more viable and economically attractive. It does this by allowing opportunistic access to locally available but unused spectrum. In turn, it helps solve the spectrum scarcity problem, meeting the needs of the explosive growth of mobile devices as well as Internet of Things (IoT). Studies across various regimes have shown that many RF spectrum bands are often underutilised even in densely populated urban areas. Hence, SS introduces a technique that can allow unlicensed devices (or license-exempt devices) to share the RF spectrum with other licensed services. Specifically, the license-exempt devices can access the ***white space*** spectrum - which refer to those spectrums that are unused in a particular location at a particular time - with a key consideration that they do not interfere with the licensed devices.

The license-exempt devices are based on a key underlying technology known as cognitive radios (CRs), first proposed in 1999 to implement a context-aware intelligent radio that can adapt its configuration and transmission decision to the real-time communication environment. The success of a CR for SS heavily depends on the accurate detection of the radio environment e.g. locating the white space spectrum and figuring out the allowable transmission power to minimise interference to the incumbent devices. Concerns in the industry and in various regulatory environments regarding accuracy of detection and insufficient sensitivity by the CRs, in the pioneer band of SS through TV White Spaces (TVWS), ushered in a new model of database-assisted architecture across the world. While TV White Spaces (TVWS) accentuates the first step towards adoption of SS, the opportunity of SS has now been identified across various bands. Regulatory regimes such as the Federal Communications Commission (FCC), for instance, has already unlocked spectrum sharing in the 3.5 GHz (3350-3700 MHz) as well as the 6 GHz (5925 – 7125 MHz) bands. Between 2020 and 2022, a number of countries have also moved an extra step to allow full license-exempt access to the 6 GHz band to enable implementation of the new Wi-Fi technology known as Wi-Fi 6E.

Despite these developments that posit benefits that Spectrum Sharing can provide by enabling access to more wireless services, there exists a number of challenges that impede SS adoption. Such challenges range from the practical considerations of the technology, regulatory requirements to economic and market adoption as well as the skills and the capacity needs to both deploy and utilise the technology. In this report, therefore, we present the gap analysis study for spectrum sharing (SS) conducted in Kenya between September 2021 and September 2022. The report explores the journey of adopting DSA in Kenya and the bottlenecks that limit full realisation of the SS opportunity to connect the unconnected and contribute to bridging the digital divide. It highlights the issues of access, coverage and usage as the critical pillars for affordable Internet access even as variables of regulations, technology and economics are examined. These variables serve as the cornerstones that can sustain SS as both an innovative way of driving digital inclusivity, further Industry 4.0 innovations as well as contribute to the economic recovery of Kenya, particularly as the world gradually rebuilds from the COVID-19 pandemic.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: BACKGROUND OF DYNAMIC SPECTRUM ACCESS IN KENYA

1.1. KENYA'S QUEST FOR SPECTRUM INNOVATION

Kenya's Internet access and use rates have tremendously grown in the past decade [1]. This is attributed to development of favourable policies, investment by both local and foreign stakeholders and a vibrant population keen to embrace digital technologies. These levels of growth are anticipated to rise as the demand for wireless communications increases - which seems to be accelerating, resonating with the rest of the world especially as the country strives to implement befitting Industry 4.0 solutions across all the sectors of its economy. At the heart of attaining this, is the immediate need to deliver on affordable, equitable, reliable and meaningful Internet access. Hence, spectrum innovation has become a subject of interest in Kenya, spearheaded by the Communications Authority of Kenya (CA), the country's regulatory authority for the ICT sector.

The Spectrum innovation we refer to here is premised on innovations that can circumvent the challenges of radio frequency (RF) spectrum scarcity and interference to foster the growth of ubiquitous, high-speed, affordable and low-latency connectivity. Central to the CA's focus for such innovations in Kenya is the concept of Spectrum Sharing (SS) or Dynamic Spectrum Access (DSA), particularly as the country seeks to promote flexible utilisation of the RF spectrum. This is a significant cue of the spectrum management block outlined in the Kenya's National Broadband Strategy of 2018 to 2023[1].

Dynamic Spectrum Access (DSA) refers to a technique by which a radio system (in a spectrum sharing ecosystem) dynamically adapts to the local radio spectrum environment in order to determine and then access available channels at specific times and locations [2]. Similar to other National Regulatory Authorities (NRAs) such as the Federal Communications Commission (FCC) of the United States of America (USA) and the Office of Communications (Ofcom) of the United Kingdom, CA has identified an existing gap of allocated RF bands, which are often partly occupied or largely unoccupied. This is the genesis of establishing a roadmap of DSA implementations in Kenya. Primarily, the identified gap exists due to the traditional command-and-control model[2] of spectrum allocation worldwide, which makes it largely a regulatory issue before the opportunity is unlocked. Nevertheless, it is also worth noting that variables of technology, standards, deployments as well as economics must be considered to make this a viable venture.

[1] The National Broadband Strategy: 2018-2023

[2] The command-and-control model is the traditional spectrum-licensing scheme where the radio spectrum allocated to licensed users cannot be utilised by unlicensed users or applications, even when the licensed users are not using it.

1.2. THE ROADMAP TO SPECTRUM SHARING AND THE BENEFIT

1.2.1. TV WHITE SPACES – THE FIRST STEP TOWARDS SPECTRUM SHARING (SS) IN KENYA

Kenya's initial step of exploiting the SS opportunity, just like the rest of the world, has been through Television White Spaces (TVWS). The drive for adopting TVWS in Kenya has been to bridge the gap of the digital divide by enabling provision of affordable Internet access to the rural communities[3]. The country's TVWS pilot was among the pioneer ones on the continent together with South Africa's, initially exploiting a combination of wireless technologies designed to operate on a license-exempt basis[4]. At the time (2013 to 2014), the pilot was conducted for two years without a regulatory framework in place. The novelty of the technology and the need to protect primary services from interference made the regulator quite inconclusive in developing regulations. In the next three years (2015 to 2018), contextual research began to take place heading to the direction of developing regulations and completely mastering the technical underlying concepts of the TVWS technology. CA's test model of letting the broadcast signal distributors (BSD) – PANG and Signet - assign idle TV spectrum to potential TVWS service providers in 2016[5], proved unsustainable, albeit demonstrated the regulator's commitment to driving the TVWS deployments beyond the pilots to commercial uptake.

Notably, the trial TVWS network in Nanyuki in 2013 which made use of both Adaptrum[67] and 6Harmonics[7] TVWS radios provided interesting findings from a broadband [8] access point of view. Apart from supporting solarpowered base stations (which would be feasible in various rural areas of Kenya that still lack electricity connection from the grid), it delivered on the technical viability of the TVWS technology by enabling point-tomultipoint (PtMP) coverage of up to 14km from the TVWS base station while operating at only 2.5 W power (EIRP measurement) without causing interference. Moreover, the technology was able to provide a data rate of up to 16 Mbps on a single 8 MHz TV channel[9].

With these findings and the in-country research initiatives, CA eventually developed an overarching strategy of crafting the TVWS regulatory framework based on dynamic spectrum access (DSA). While drawing lessons from the technical trials, various NRAs around the world and conducting due diligence in the United Kingdom (UK), United States of America (USA) and South Africa (SA) – countries that had already published their regulations - CA envisaged to develop a solid ground on spectrum sharing beyond TVWS (in consideration of other shareable bands) as it mentions in the regulatory framework for TVWS. Further, it served prudent that the country establishes a firm base that addresses future connectivity needs with the aim of inspiring the achievement of the country's blueprints geared towards stimulating economic growth through Internet access. Therefore, the approval of the Regulatory Framework for TV White Spaces in April 2021[10] marked a major milestone for the country on the future rollout of DSA-enabled Internet access. The prior roadmap to this is shown in Figure 1.

---

[3] Authorisation of the Use of TV White Spaces in Kenya

[4] Summary of the TVWS Trial in Laikipia

[5] Communications Authority approach may derail Internet access plans

[6] Adaptrum

[7] Harmonics

[8] Broadband according to Kenya's National Broadband Strategy means Connectivity that delivers interactive, secure, quality and affordable services at a minimum speed of 2Mbps to every user in Kenya. The 2017 definition had defined the minimum speed at 5 Mbps.

[9] Summary of the Regulatory Framework of TVWS in Kenya.

[10] Approved TVWS Framework a Catalyst for Digital Growth.

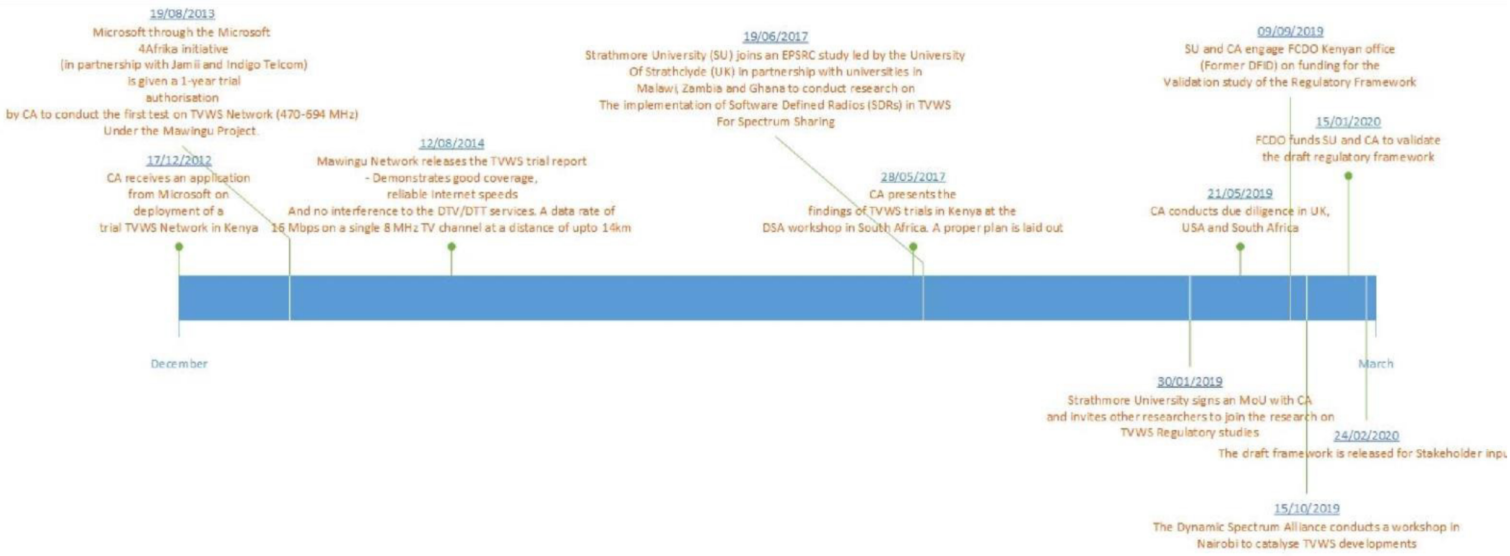


Figure 1: The Roadmap to implementation of the first SS Framework in Kenya through TV White Spaces

Source: Reports, Emails and Plans Prior to Publication of TVWS Regulations in Kenya

1.2.2. THE NEW FRAMEWORK – COMMUNITY NETWORKS (CNS)

The publication of the framework *on Licensing Shared Spectrum for Community Networks (CNs)* in June 2021 has further cemented the trajectory of the country towards inclusive broadband access driven by spectrum sharing. Traditionally, the CNs have utilised Wi-Fi technologies both for backhaul and for hotspots on license-exempt spectrum across the globe. However, with the challenges of congestion and signal interference on the 2.4 GHz and 5 GHz band, the quality of connectivity is always affected. Moreover, CA envisions TV white spaces to support CNs as a backhaul link to help navigate a number of challenges faced by CNs ranging from licensing fees, CAPEX requirements to high cost of the backhaul networks, considering the non-profit model of their operation[11].

By releasing the CNs framework, CA's intention is to address barriers facing communities in underserved areas and RF spectrum efficiency challenges that exist within the traditional solutions - which evidently appear to have reached their limits [3]. The near-term plan of action for CA in regards to CNs is the integration of a new license category within the Unified Licensing Framework (ULF) that can seamlessly support establishment and operation of CNs. Moreover, CA seeks to ensure that the financial and administrative requirements for CNs are commensurate with their scope and scale even as it establishes a license-exempt approach that can allow lowering the barrier to the use of the 24 GHz and 60 GHz bands for both Point-to-Point (PtP) and Point-toMultipoint (PtMP) use.

While there are many great examples of CNs across the world, such as guifi.net[12] in the Iberian Peninsula which have evolved to embrace fibre optic infrastructure in addition to Wi-Fi and established solid business models, CNs are still not the norm across the world. Kenya is no exception. The regulatory framework for CNs, while it mentions of engaging four CNs in Kenya during the mapping exercise, there are barely 10 CNs across the country at the moment. CNs could provide a great opportunity for the rural folk considering that the largest fraction of Kenya resides in rural areas and is largely unconnected by fixed wireless networks. Hence, the CNs framework sets the stage to invite more players within the CN ecosystem and adopt innovative ways that can locally address connectivity needs across different underutilised spectrum bands. This would also help CA to appropriately deal with the tragedy of lock-out of allocated spectrum that are kept idle by the incumbents due to lack of profitability [4].

[11] Licensing and Shared Spectrum Framework for Community Networks.

[12] Guifi.net

1.2.3. STUDIES ON LICENSE-EXEMPT ACCESS IN THE 6 GHZ BAND FOR WI-FI 6E

Evidently, spectrum sharing studies are rapidly evolving to be part of the future networks, particularly with the latest global focus being on the opportunistic access of the 6 GHz band. Most countries in the Americas have already established regulations to allow unlicensed use of the full 6 GHz band through Wi-Fi 6E. Other countries such as South Korea have also followed suit to complement 4G and 5G deployments through enhanced Wi-Fi quality [5]. Prior to this Gap Analysis study, a previous study known as "**Assessing the Economic Value of Unlicensed Use of the 6 GHz band in Kenya**" had been conducted in Kenya by August 2021 to showcase the economic impact of allowing access to the full 1200 MHz spectrum of the 6 GHz band for Kenya. The study quantified the impact of service quality, coverage, affordability, use cases in both entreprise and consumer markets as well as specific applications such as IoT leading to a cumulative economic value of US $20.29 billion for Kenya between 2021 and 2030 as shown in Figure 2 [6].

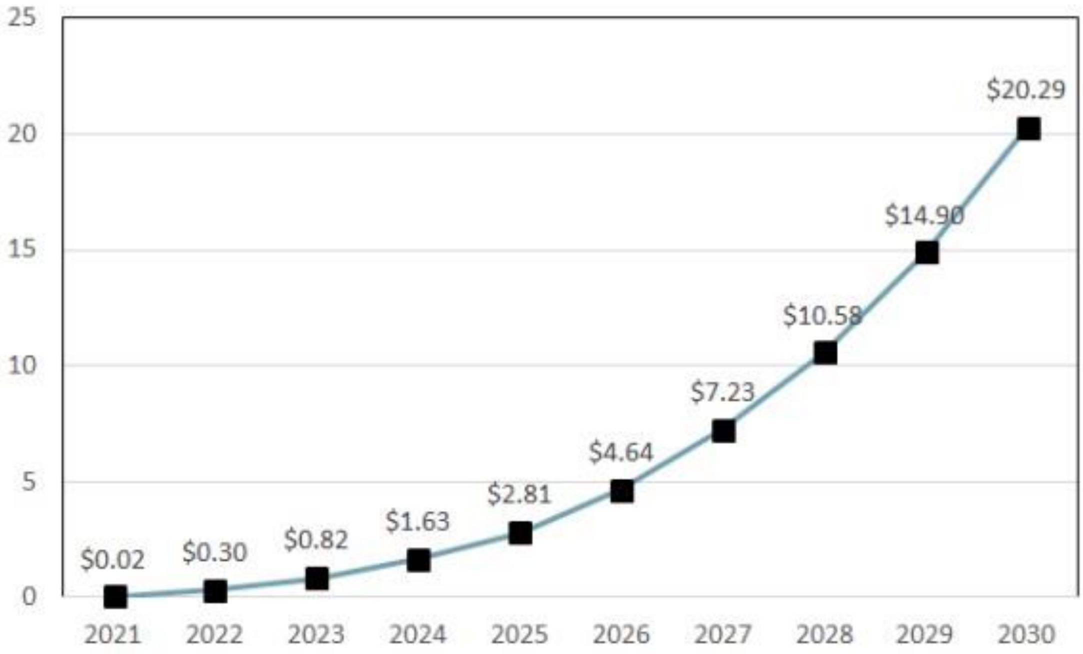


Figure 2: Cumulative Economic Value of the 6 GHz band in Kenya

Source: Telecom Advospry Services Analysis

Following up to this report and the economic study on the 6 GHz, is another study that presents the technical findings of coexistence between the incumbent services in the 6 GHz band and license-exempt access by Wi-Fi 6E devices for Kenya as captured in Figure 3. While the findings demonstrate successful coexistence between the incumbents (Fixed Services and Fixed Satellite Services) and the Wi-Fi 6E devices, they underscore the immense possibility of spectrum sharing leapfrogging more digital innovation and enhancing wireless Internet access. This is because Wi-Fi carries more Internet traffic than any wireless technology despite having around 300 MHz of unrestricted spectrum [7]. Moreover, developments on Wi-Fi 7 standards have already begun taking shape with implementation of 320 MHz bandwidth that can provide the needed wider channels to deliver massive throughput gains and peak data rates of over 40 Gbps[13]. This shows just how impactful the growth of spectrum sharing is bound to get as future networks emerge.

[13] Qualcomm – The Future of Wi-Fi

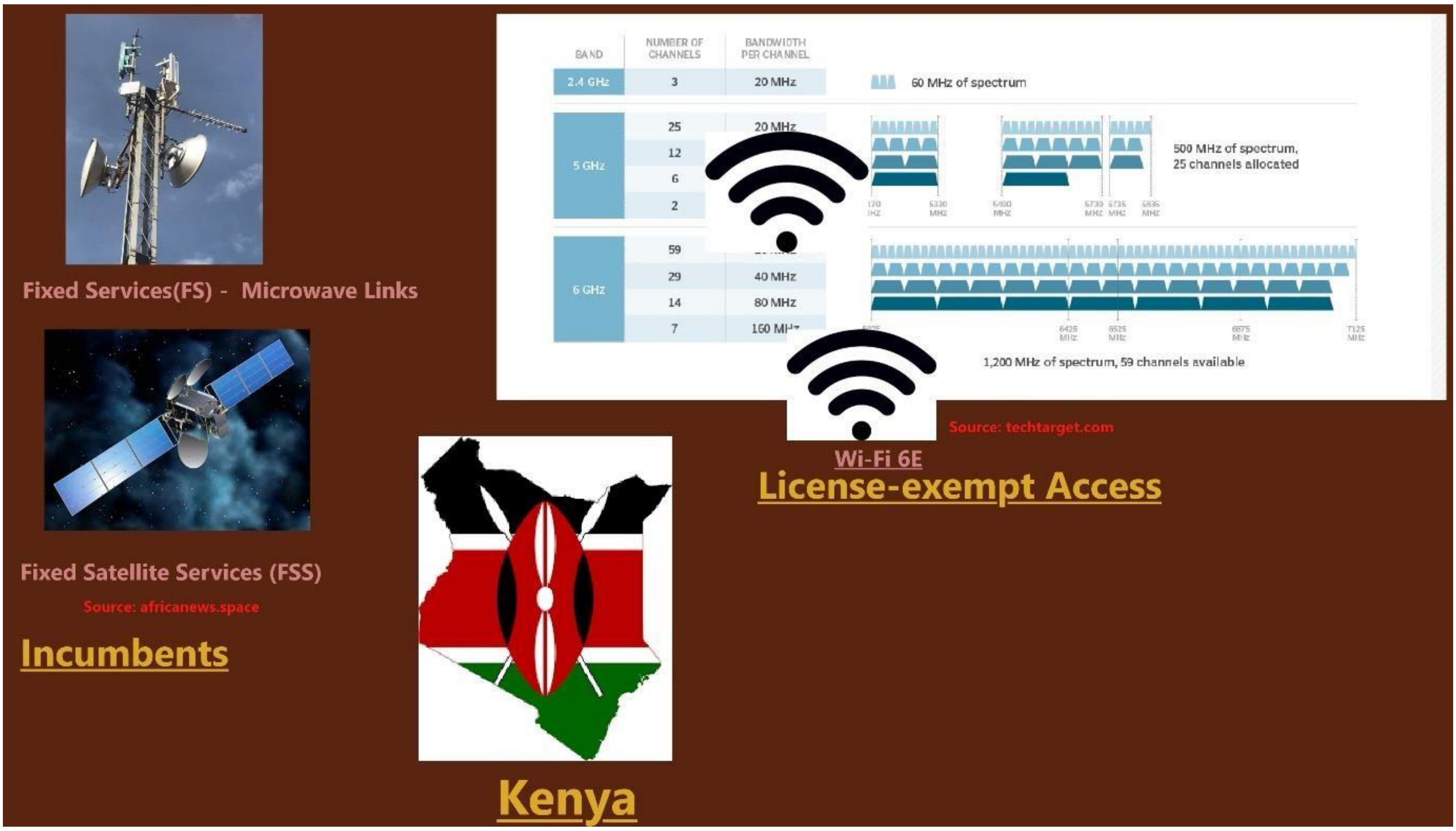


Figure 3: A high level drawing of the technical coexistence study between incumbents and Wi-Fi 6E in the 6 GHz band for Kenya Source:

Strathmore University

1.2.4. SPECTRUM SHARING – AN ALTERNATIVE TO SPECTRUM CLEARING AND AFFORDABLE INTERNET

Spectrum sharing means to make more spectrum available for services whose growth is in the national interest, without upsetting too much the existing users of the spectrum. Dynamic spectrum access (DSA) ensures that such sharing is organised among users and the allocation can change in time depending on the demands of the systems that are sharing [8]. Previous experience in Kenya has shown that the cost of clearing and re-allocating spectrum is very high just like other regimes. For instance, during the digital migration process[14], Airtel and Telkom Kenya raised issues with the decision by CA to award a license to Safaricom in the 800 MHz band on a one 2 x 15 MHz block. While CA eventually asked Safaricom to return 2 x 5 MHz block, all the mobile operators found the KES. 2.5 billion price to be significantly higher than expected – throwing the digital dividend process in doubt, right from planning. Effective sharing can help navigate such scenarios in bands that are not heavily used. It is therefore becoming widely recognised that spectrum sharing is an essential ingredient in freeing up enough spectrum for use by both fixed and mobile broadband.

Adding to the challenge of spectrum clearing and re-allocation, is the rapid traffic deluge that presently exists arising from both human and machine-driven demand through a plethora of wireless connected devices. The

[14] GSMA - Digital Migration Process in Kenya

COVID-19 pandemic, as a contextual case, saw a 70% surge in data usage in Kenya[15] - projecting what the future data demands can look like. However, the core tools to addressing this capacity increase such as enhancing the physical layer capabilities of wireless systems and increasing the density of access points or base station deployments (thereby increasing frequency reuse) often become expensive and complex. Further issues of energy efficiency, site search and management (e.g. backhaul provisioning, traffic management, mobility provisioning etc.) are also bound to occur as impediments. Hence, increasing the amount of spectrum available to such systems is, potentially, much more viable and economically attractive [9].

[15] Kenya's Safaricom jump in data usage

CHAPTER 2: OBJECTIVES AND METHODOLOGY OF THE STUDY

2.1. OBJECTIVES OF THIS STUDY

The overall objective of this study was to conduct an analysis on the existing state of spectrum sharing in Kenya. The analysis included evaluation of the existing implementations of spectrum sharing in the country, the maturity level of the regulator and the Internet Service Providers (ISPs) in understanding the concept, participating in the aspects of its adoption or raising questions for further clarification. Besides, the study also analysed the gaps relating to development of regulations, technology and economics that impede the adoption of spectrum shared networks. While considering that spectrum sharing is not applicable to all scenarios of connectivity, the study also presents some of the challenges of spectrum sharing. The specific objectives of the study included the following:

1. Assessment of the spectral opportunity that spectrum sharing presents to the Kenya's economy in summary.
2. Identification of the regulatory, technology and economic challenges that impede implementation of spectrum sharing in Kenya alongside other constraints.
3. The existing engagements, collaborations and developments geared towards understanding and implementing spectrum sharing in Kenya.
4. The recommendations that address the identified barriers to spectrum sharing adoption in Kenya.

2.2. METHODOLOGY

Predominantly, this study made use of the desk review research. It allowed various secondary sources relevant to spectrum sharing to be studied. Such sources include publications on dynamic spectrum access (DSA) ranging from the regulatory to technology aspects. Reports from the Dynamic Spectrum Alliance were instrumental to this work. Further records and blueprints in regards to connectivity in Kenya such as the National Broadband Strategy [10] , the Digital Economy Blueprint [11] and the regulatory frameworks enacted under the SS umbrella which include the regulatory framework for TV White Spaces (TVWS) and Community Networks (CNs) were also scrutinised. Other major references studied include:

1. The Kenya National Digital Master Plan 2022-2032 [12]
2. The Universal Service Fund Framework [13]
3. CA Strategic Plan for 2018-2023 [14]
4. e-Conomy Africa 2020 report [15]
5. The Last-mile Internet Connectivity Solutions Guide [16]
6. Digital Ecosystem Country Assessment (DECA), Kenya 2020 [17]
7. Enhancing Connectivity Through Spectrum Sharing [18]
8. Spectrum Sharing: GSMA Public Policy Position [19]
9. Automated Frequency Coordination [20]
10. Spectrum Sharing in Cognitive Radio Networks [21]

In addition to the desk studies, two stakeholder engagements were also conducted. The first engagement organised a workshop on 21st January 2022 with the Internet Service Providers (ISPs) in Kenya to assess their level of understanding on the subject of spectrum sharing. The engagement also helped to determine the ISPs' level of familiarity and active participation in the development of the new regulatory frameworks that postulate spectrum sharing. The second engagement, on the other hand, was held virtually on 11th March 2022 and involved discussions with CA and other public institutions on the state and potential of adopting spectrum sharing. Respective reports on both stakeholder engagements have been developed and shared prior to the final development of this report. Both reports can be accessed here.

CHAPTER 3: FINDINGS OF THE GAP ANALYSIS

3.1. OVERVIEW

Under the aegis of Kenya's Vision 2030, the government through the Communications Authority of Kenya (CA), ICT Authority (ICTA) and other relevant bodies within the country are hugely invested in delivering on the country's aim of "a globally competitive and prosperous country with a high quality of life by 2030"[16]. The growth of the ICT sector is therefore marked as a key pillar to rapid realisation of the Vision 2030. However, for successful achievement of this, a significant number of milestones need to be concretely developed, tracked and realised. Some of the initial milestones that Kenya has successfully achieved include the development of roadmap plans, broadband strategy and blueprints that outline steps to attain affordable, secure and fast broadband connectivity. In its Strategic Plan [14], CA envisions "a Digitally transformed Nation" having a nationwide broadband network that can provide, at minimum, 5 Mbps to individuals, homes and businesses with projections of 300 Mbps and 50 Mbps for urban and rural households respectively by 2022. As at 2022, however, there are reports that show the country's internet penetration barely past the 50% mark[17]. The mobile penetration is said to be at 52% with a mobile infrastructure coverage of 54.9%[18]. On the other hand, the fixed networks seem to be beyond reach for most Kenyans[19] with the total number of fixed broadband subscriptions as at early 2021 standing at 643,748 from all the Network Facilities Providers (NFPs)[20].

Going by demographics as shown in Figure 4, 73% of Kenya's population (approximately 32 million people)[21] reside in the rural areas. Unfortunately, a significant fraction of the 73% does not have as many access alternatives as their urban counterparts beginning with the fact that the licensed spectrum through cellular connectivity is yet to achieve universal coverage. While Kenya's Digital Masterplan [12] notes of tremendous achievement in reaching these rural underserved populations through the laying of over 8,900 km of optic fibre under the National Fibre Backbone Infrastructure (NOFBI) project, there are concerns of existing "dark fibre" gaps [17]. Hence, in the quest to deliver on last-mile Internet access, even through shared spectrum, backhaul challenges are bound to emerge, especially with little publication on Satellite footprint in the country.

Figure 5 depicts the access technology options that presently exist to be exploited in connecting both urban and rural Kenya right from the core network to the last-mile networks. The inclusion of TV White Spaces (TVWS) as a shared spectrum network stems from the aforementioned TVWS work in Kenya which presents moderate access costs to the rural populations. Further, opportunity through shared spectrum can also be tapped from licensed spectrum and extend coverage through community networks (CNs). Nevertheless, the proper understanding in the country for such innovation and the commercial as well as non-profit appetite to translate this into a reality, is not at the best level yet. Therefore, the need for a thorough exposition on the take-off of shared spectrum networks to not only extend coverage but also deliver on affordable access to the underserved.

---

[16] Kenya's Vision 2030 Sector Progress Report

[17] Digital 2022 - Kenya

[18] GSMA Mobile Connectivity Index

[19] Sector Statistics Report – 2021/2022

[20] Sector Statistics Report – 2020/2021

[21] This is based on the distribution of population aged 3 years and above.

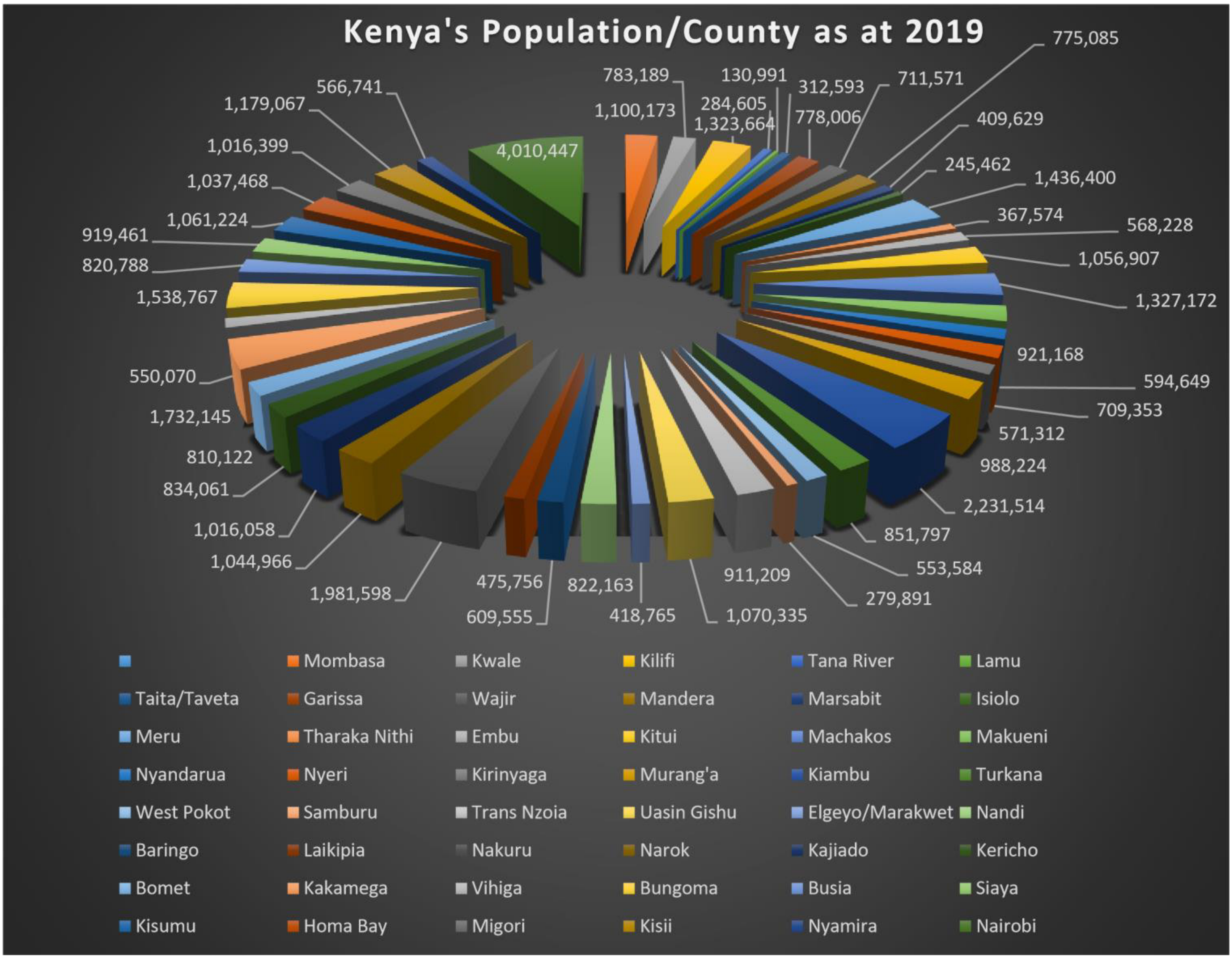


Figure 4: Distribution of Kenya's population aged 3 years and above across all the Counties

Source: 2019 Kenya Population and Housing Census Volume IV.

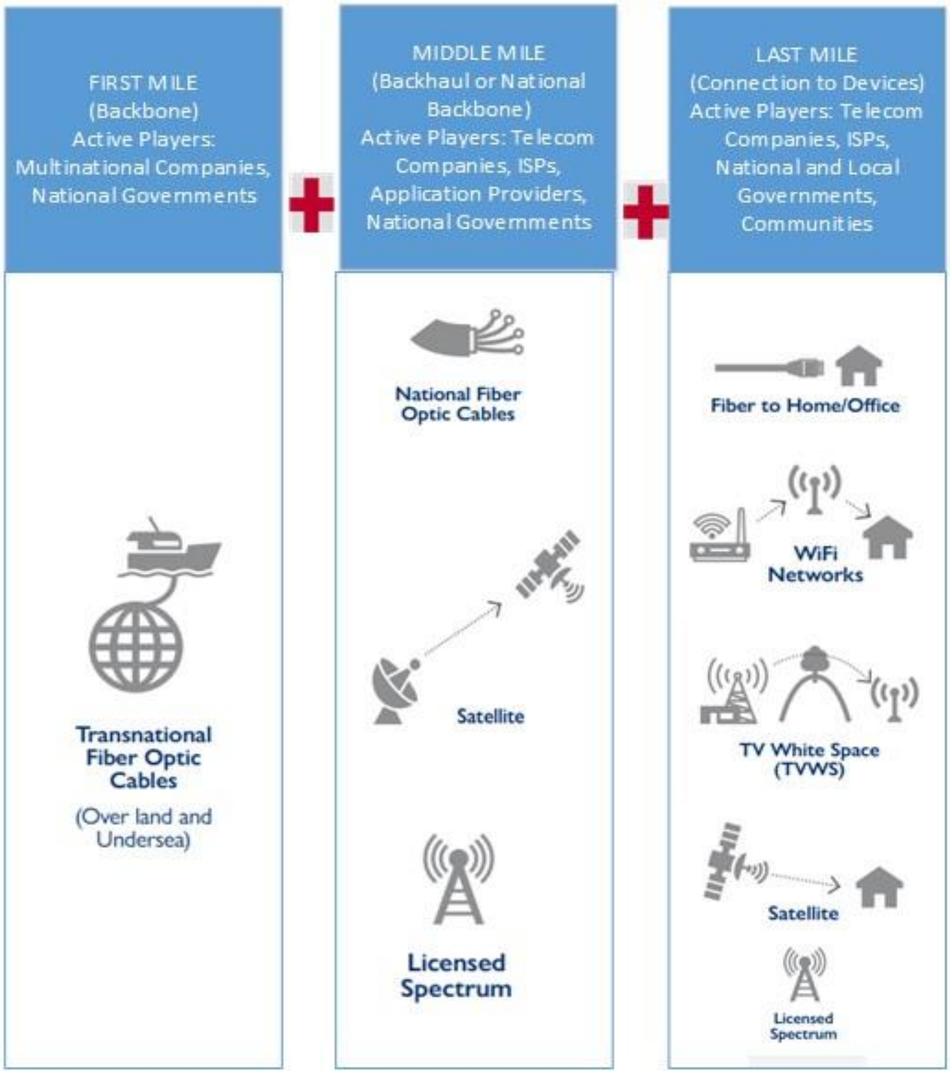


Figure 5: Internet Access Technology Options

Source: USAID's 2020 DECA Report for Kenya

3.1.1. DESCRIPTION OF THE SPECTRUM SHARING PARADIGM

While Spectrum Sharing (SS) can be looked at in multiple ways, such as the access to the same radio spectrum by multiple subscribers of a specific mobile operator, the SS paradigm we refer to here is based on spectrum access rights point of view. It refers to the simultaneous usage of a specific radio frequency (RF) band in a specific geographical area by a number of independent entities, leveraged through mechanisms other than traditional multiple- and random-access techniques. Meaning it explores the approach of coexistence of several radio access technologies (RATs) or services in the same radio frequency (RF) band [22].

Different spectrum sharing initiatives have emerged in the recent years, including coordinated sharing in the licensed International Mobile Telecommunications (IMT) bands, automated sharing in the Ultra-High Frequency (UHF), 5 GHz and 6 GHz bands (Television White Space, Dynamic Frequency Selection and Automated Frequency Coordination respectively) and multi-tiered sharing in the 3.5 GHz band in the USA (the Citizens Broadband Radio Service). Key takeaways of these developments include [23]:

- Stakeholders' active participation to align expectations and sharing of information for a more collaborative and innovative spectrum usage era.

- Sharing scenarios that involve a horizontal model of unlicensed and licensed users generally require an automated sharing technology to guarantee protection to the licensed users and allow unlicensed users to operate at scale. The sharing technologies in this case can be coordinated, sensing or informing techniques and might take an implementation approach that is centralised or decentralised. The term “Cognitive Radio” has been birthed from the sharing technology of sensing while the term “databaseassisted” has emanated from a centralised coordinated sharing technology [24].
- Multi-tier sharing can be complex but has been shown to work in the USA in the 3.5 GHz (3550-3700 MHz) in Citizens Broadband Radio Service (CBRS). The CBRS rules promote sharing among a wide and heterogenous range of users and use cases, including public and private networks, mobile and fixed wireless access and consumer and industrial applications.

A high-level classification of spectrum sharing techniques is shown in Figure 6.

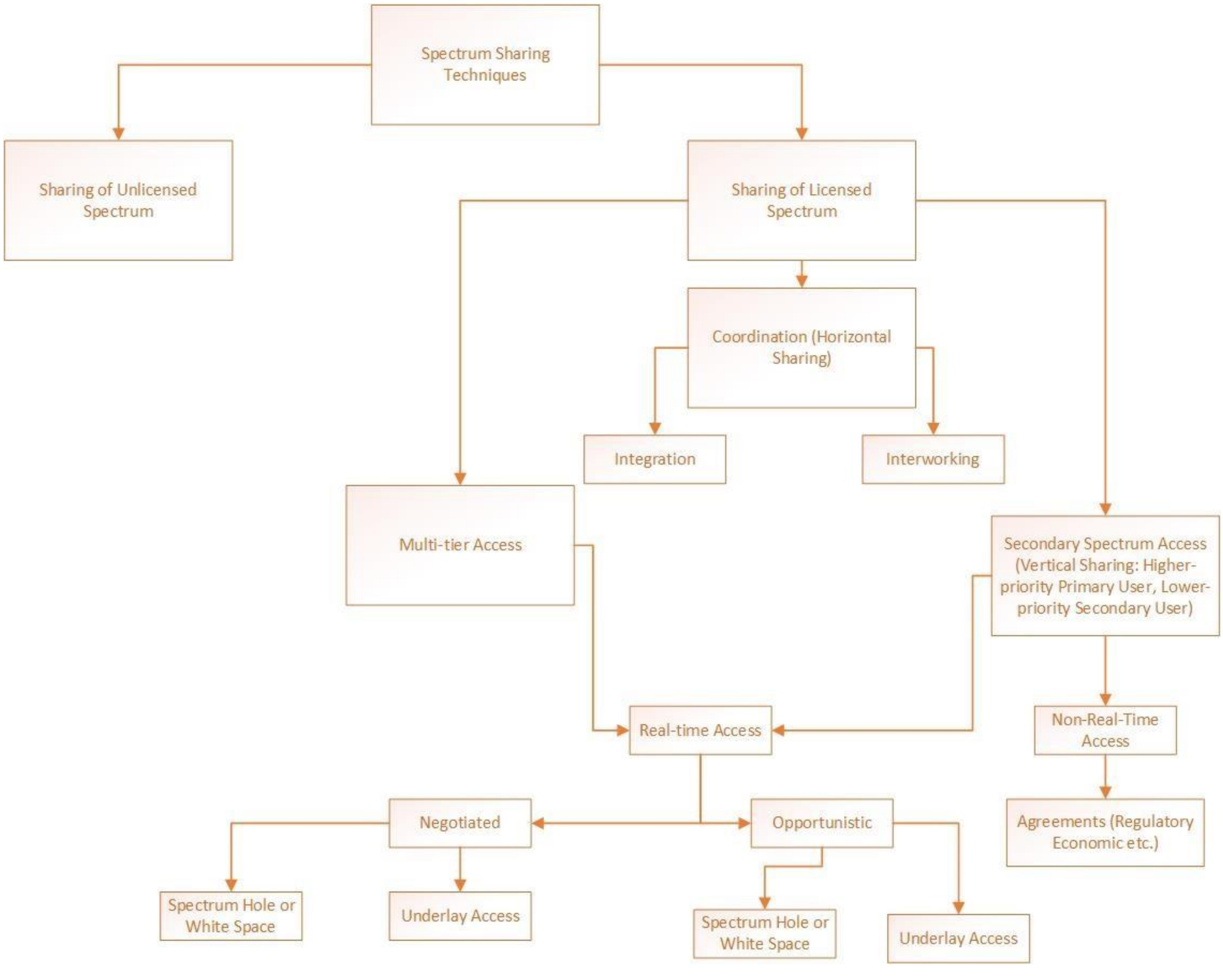


Figure 6: Classification of Spectrum Sharing Techniques

Source: Cognitive Radio Communications and Networks: Principles and Practice

3.1.2. GENERIC ISSUES OF SPECTRUM SHARING

Some of the most important issues to be considered in spectrum sharing include [8]:

1. Fairness: how do we ensure that different (prioritised) wireless users can share the spectrum in an equitable manner? Users with similar spectrum access privileges should have nearly equal opportunities to access the available spectrum. If some users have higher priority over other, they should be able to occupy the spectrum more often and/or be able to pre-empt lower priority users.

2. Efficiency: Efficient use of spectrum resources among different users at any given time must come with minimal control/coordination overhead, where it is critical not to waste any spectrum in space and time.

3. Security: Spectrum sharing methodologies need a robust trust model that can detect the overuse of the spectrum or falsified reports on users' occupied spectrum along with policies to prevent selfish users from overusing the spectrum. Distributed resource verification and data falsification safeguards can therefore be developed.

Groups such as the Global Association of Mobile Network Operators (GSMA) are highly sensitive when it comes to spectrum sharing. This is understandable because their exclusive licence experience has provided them certainty over the years which has been a critical component of the success of the mobile networks - inviting huge investments to deliver better services to more people in more places and in turn also providing the desired return on investment (RoI). However, their push for the need of spectrum clearing in the UHF TV spectrum to accumulate more spectrum with the claim to expand 4G coverage [19] is one that requires careful consideration. This is because, even in the presently allocated spectrum for Kenya, mobile networks are yet to deliver an infrastructure coverage of over 60%. On the other hand, in certain geographical locations, they still have assigned but unutilised spectrum. Moreover, with varying connectivity needs such as the needs of a healthcare or education facility being different from an individual mobile connection, a balance has to be stricken in terms of what access technology fits and how affordable should it be considering levels of income as well.

To be suitable for spectrum sharing, radio units must have some or all of the following attributes or abilities: Operate in a range of channel widths in the same equipment; Adjust transmit power; Operate with a range of waveforms, most commonly Orthogonal Frequency Division Multiplexing (OFDM) or one of its directives, with a choice of modulation depths and error coding schemes; Perform sensing or radio environment monitoring , which can be in-band (intra-frequency) or out-of-band (inter-frequency); Process user data using scheduling and queuing for different qualities of service (QoS). Furthermore, there are many challenging R&D issues posed by non-interoperable hardware/software radio platform designs suitable for efficient and fair spectrum sharing. A few examples include: Using advanced algorithms (such as game theory) to coordinate PUs and SUs to maximise mutual benefit; Determining the spectrum licensing, pricing and auction schemes; Using Information theory to determine how long an SU can help to relay the PU's traffic; Integration of cooperative communication with network coding to improve throughput; Balancing the tradeoff of PU's capacity improvement and leased bandwidth when asking SU to also act as a relay.

3.2. OBJECTIVE I: ASSESSMENT OF THE SPECTRUM SHARING OPPORTUNITY FOR KENYA

3.2.1. COUNTRY STATUS IN REGARDS TO SPECTRUM SHARING

As of this writing, Kenya can be described to be in its early stages of spectrum sharing developments but quite advanced compared to its neighbouring countries. Within the East African region, it is the only country to have had extensive studies and pilots on TV White Spaces (TVWS) in the UHF band 470-694 MHz as well as established comprehensive regulations that were validated prior to publication. Tanzania is presently conducting active studies on TVWS. Therefore, it is yet to publish its regulations[22]. Uganda's TVWS regulations, on the other hand, were highly summarised without any prior references to studies [25]. Similar to the US, UK, Singapore and a set of many countries, Kenya's regulations for TVWS took a similar approach of introducing the first databaseassisted spectrum management in the country [1]. Unfortunately, due to the novelty of this approach, there is a general lack of understanding by the ISPs on how the TVWS deployments need to work in practice. In addition, having had only one active ISP – Mawingu Networks - pushing for the adoption and implementation of TVWS, it has been hard to obtain the general landscape of ISP appetite to deploy shared spectrum networks. Moreover, the lack of enthusiasm by ISPs to participate in the spectrum sharing workshops elucidate a lack of awareness on the technology and opportunity that spectrum sharing presents.

Similar to the TVWS framework, the Community Networks (CNs) framework was also developed to address barriers facing communities in underserved low-income areas through optimal use of spectrum. Unlike TVWS, however, the CNs deployment model is a non-commercial one and is meant to support local economic and social activities from a bottom-up perspective. In line with the National Broadband Strategy, CA proposes a multiparadigm approach of spectrum access to enhance capacity and establish locally contextual communications infrastructure through CNs. The approach establishes a new licensing category that formally acknowledges CNs within the country's Unified Licensing Framework and suggests a near term plan for license-exempt access under revised EIRP limits for the 2.4 and 5 GHz Wi-Fi Point-to-Point (PtP) and Point-to-Multipoint (PtMP) use. Further, it also proposes a review of the license-exempt barriers for CNs use in the 24 GHz and 60 GHz bands and expansion of the range of access in the 5-6 GHz band. Foreshadowing into the future, CA envisions more spectrum sharing developments to take place in the IMT spectrum bands in order to further meet local broadband needs through CNs. Additionally, it envisages to review the spectrum fees for broadband deployment in the underserved areas.

Building onto the CNs framework, Kenya has also joined the group of countries advocating for deployment of license-exempt access of Wi-Fi devices (Wi-Fi 6E) in the 6 GHz band (5925-7125 MHz). Although the regulatory approach is under final stages of study, CA has demonstrated commitment to unlock spectrum sharing in the 6 GHz beginning with the lower part of the band (5925-6425 MHz) as guided within the African Telecommunications Union (ATU) [26] as it further studies the implication of unlocking the upper part (6425 – 7125 MHz). This conservative approach is necessitated by the studies going on within the band by the ITU to determine whether the band is suitable for IMT-2020 (5G) use [27]. Nevertheless, the studies that have already taken place in the country have considered the full 1200 MHz (5925 – 7125 MHz) including economic and technical assessment of coexistence between the Wi-Fi 6E opportunistic access and the incumbent fixed services (FS) and the fixed satellite services (FSS). In general, it can be said that Kenya will move quickly in the near future to officially publish authorisation of Wi-Fi 6E. Morocco was the first country in Africa to authorise Wi-Fi 6E under the umbrella of the ATU recommendations[23].

---

[22] University of Dodoma Bulletin

[23] Wi-Fi 6E insights

3.2.2. OPPORTUNITY OF SPECTRUM SHARING FOR KENYA

The general regulatory and technical view of adopting spectrum sharing is enhancing spectrum efficiency. While technologies are improving to squeeze more data into each frequency channel, policy makers still face stiff challenges in addressing the needs of everybody since the demand (in bandwidth) outpaces supply. For services that require dedicated channels, for example cellular, it becomes harder and harder for regulators to clear up a chunk of frequency bands for these services. For example, the regulators worldwide find it hard to fully harmonise the spectrum for the fourth generation (4G) Long Term Evolution (LTE) networks since different countries have different fragments of spectrum left for such assignment. On the other hand, regulators' experience of assigning RF spectrum as unlicensed bands such as the industrial, scientific and medical (ISM) radio bands where different wireless systems share the same resources and coexist successfully, provide an experience that is more attractive as such an approach provides better spectrum utilisation and at no charge in spectrum usage [1].

With digital technologies becoming the cornerstone of Kenya's daily activities, according to the Kenya's Digital Economy Blueprint [11], Governments, businesses and individuals must adapt to this new reality. The adaptation is expanded to include confronting the existing difficulties that range from climate change, endemic poverty, environmental degradation, insufficient descent jobs, lack of access to quality education and the best approach of using technology to combat communicable diseases and also bridge the ever growing digital divide. The COVID-19 pandemic disrupted learning to 18 millions students in Kenya starting the week of 16th and 20th March when physical learning in all the institutions across the country was suspended [17]. During this period, 57% of respondents in a particular study cited lack of participation in online learning due to both unaivailability and inaccessibility to the Internet, 20% lacked electricity while 22% of the respondents lacked sufficient digital skills[24]. Conversely, Safaricom claimed to have covered 77% of the Kenyan population with 4G network in 2020[25] and was experiencing a surge in traffic – a claim that still does not have sufficient references considering GSMA's map shows the mobile infrastructure coverage is yet to get to 70% in Kenya. On the other hand, the approval by President Uhuru Kenyatta on 23rd March 2020 to have Google and Telkom Kenya deploy High Altitude Platform Stations (HAPS) to connect the underserved via 4G network, unfortunately did not live to the promise. Google had to terminate the project (known as Google Loon) on 1st March 2021 citing the technology as not commercially viable[26].

The reality that perfect frequency, space and time divisions is not achievable is the reason behind different frequencies being used by different users with different wireless communication systems as exemplified by the aforementioned Safaricom and Google Loon developments. Such an approach also warrants system upgrade along technology improvements independently which also determines how much needs to be charged for the wireless service(s) provided. Presently, the different wireless systems show that most RF spectrum is inefficiently utilised[27]. That is, based on time and place, some bands such as the cellular network appear overloaded while others remain heavily unutilised. A further examination of time and place, can allow licenseexempt users to operate alongside licensed users to compensate for the needed services where the licensed users are not able to meet the needs or find their models unprofitable. This is what spectrum sharing poses as an opportunity. Such an opportunity, of course has to be backed by a reliable Cognitive Radio (CR) technology.

A CR is an intelligent radio that can detect the environmental conditions, including the spectrum availability, interference and so on in its working area and further dynamically configure its transmitter and receiver parameters so as to use the best wireless channel in the best way. This kind of mechanism can maximise the

---

[24] Rebuilding Digital Inclusion for the Rural Counties of Kenya – Report 1

[25] Safaricom at a glance

[26] Alphabet shuts down Loon internet balloon business

[27] Summary of the Draft Regulatory Framework for TV White Spaces - Kenya

transmission of a user's own information, while also avoiding interference to other RF spectrum users. In a dynamically shared spectrum environment, the CR detects frequency availability (through a sensing or an automated and centralised database approach as shown in Figure 6) to reconfigure its operating frequency, signal waveform, bandwidth, emission power, antenna beamforming, network protocol and topology [28]. The resulting outcomes of spectrum sharing for Kenya which would range from the use of TVWS, CNs, Wi-Fi 6E, tiered spectrum models such as 3.5 GHz (as shown in the U.S.), potential considerations in 1700 MHz, 3300 MHz, 2.3 GHz or 2.6 GHz (as studied in Malaysia, South Africa and Colombia)[28], include the applications shown in Figure 7.

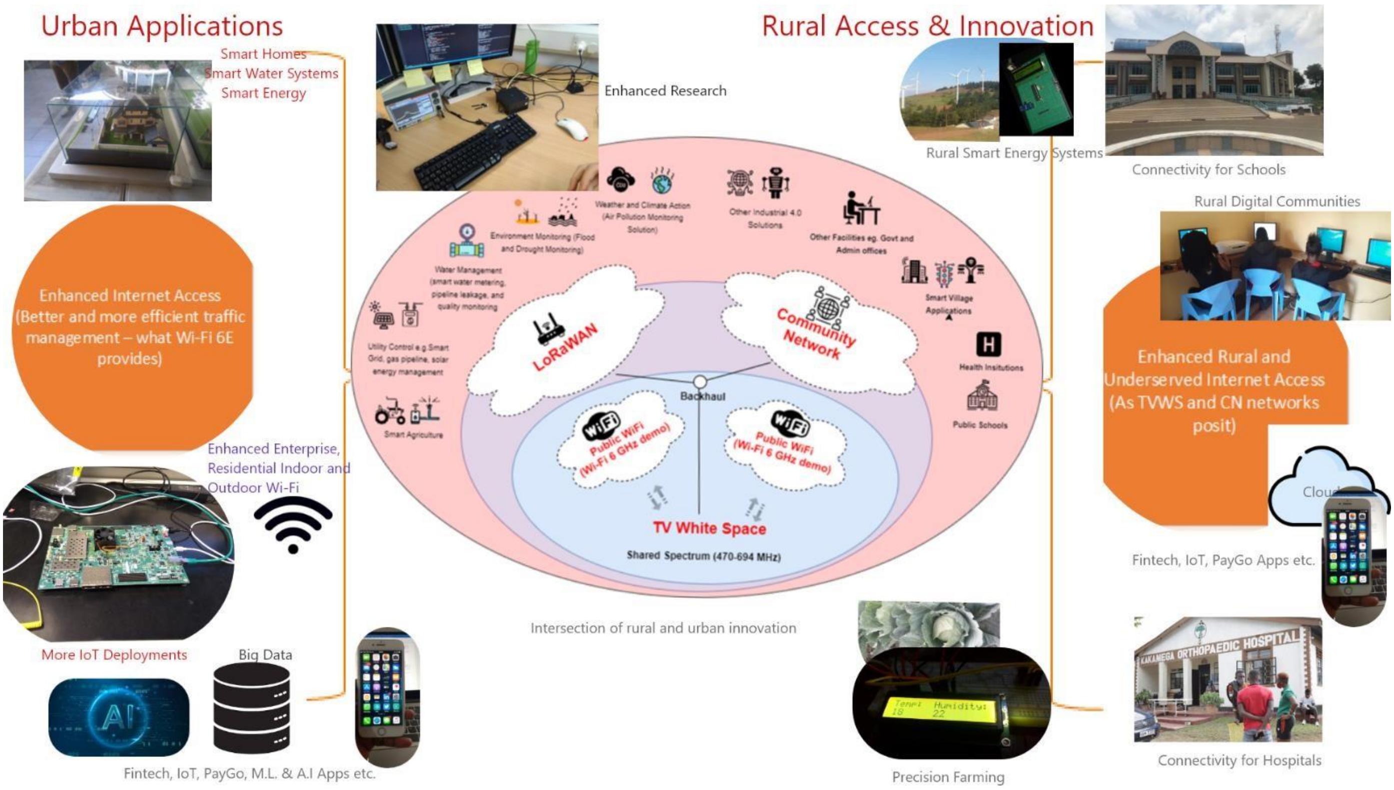


Figure 7: A High-level landscape of Spectrum Sharing connectivity opportunities

[28] Enhancing Connectivity Through Spectrum Sharing

3.3. OBJECTIVE II: IDENTIFICATION OF REGULATORY, TECHNOLOGY AND ECONOMIC CHALLENGES THAT IMPEDE IMPLEMENTATION OF SPECTRUM SHARING IN KENYA ALONGSIDE OTHER CONSTRAINTS

3.3.1. REGULATORY CHALLENGES

Successful adoption of spectrum sharing in Kenya primarily depends on the regulatory pillar. Presently, Kenya can boast as commercially ready for deploying TV white spaces (TVWS) in the UHF band 470-694 MHz due to the official release of the regulations. However, the pace at which the regulations were developed raises some concerns pertaining to future enactment of spectrum sharing regulations in other bands. For instance, the country took almost a year after validating the draft regulatory framework for TVWS in April 2020 before officially publishing the regulations in May 2021. This adds to the period of seven years that it took before conducting the validation exercise since the first trial of TVWS in Kenya in 2013.

While noting that development of regulations take time, based on the considerations that countries have to take when implementing new regulations and that the approach of adopting database-assisted spectrum management is relatively new as underscored by CA, the period of getting the first DSA network ready in the country seemingly took longer than expected. The effect of this is the loss of enthusiasm along the way by ISPs who were looking forward to derive economic value in the deployment of TVWS networks. Further, the delay resulted to missed opportnunity by the populations that would have benefited from TVWS connectivity. Comparatively, the U.S. first released their guidelines for flexible unlicensed access in the broadcast TV spectrum at locations where the spectrum was not being used in May 2014. Six years later, it published the first rules that would provide learnings for enhancement[29]. The UK, on the other hand, allowed TVWS pilots to commence on 9th December 2013 and later on released TVWS rules on 12th February 2015[30] since the U.S. experience already served as a good template. On the African continent, South Africa was the first country to publish the TVWS regulatory framework,[31] in March 2018, five years after the first pilot in 2013.

Apart from the longer period taken in developing the regulations for TVWS, we also highlight the following regulatory issues:

1. **The Challenge of the Geolocation Databases (or Automated Frequency Coordination):** As noted by CA, this has been the most challenging component of implementing SS regulations in TVWS as the pioneer technology. The regulator grappled with the aforementioned issue of fairness in regard to who should operate the database, who should pay for it and how it should be deployed operationally. Studies show that there are three principal models for determining available frequencies – *spectrum sensing (SS)*, *beacons* and *geolocation databases (GDBs)* [15]. For TVWS, Kenya adopted the approach that regimes with developed regulations had taken. The country considered the geolocation databases as the most feasible based on earlier studies and at the time of validation. While the database-assisted spectrum sharing (geolocation databases) eliminates the unpredictability of interference by calculating the available white spaces at any location and providing the corresponding transmission parameters for secondary radios to initiate transmission, the trials conducted without the database, still never caused any interference. Until now, Fairspectrum is the only geolocation database provider that has been approved to operate in Kenya for TVWS. But a looming doubt still exists whether there was an actual need for the database in the first place

[29] Report and Order and Further Notice of Proposed Rulemaking on Unlicensed White Space Device Operations in the Television Bands: https://docs.fcc.gov/public/attachments/FCC-20-156A1_Rcd.pdf

[30] Implementing TV White Spaces – Ofcom: https://www.ofcom.org.uk/__data/assets/pdf_file/0034/68668/tvws-statement.pdf

[31] South Africa TVWS Pilot Project: https://news.microsoft.com/en-xm/2019/08/05/south-africa-tv-white-space-pilot-project-receivessupport-from-ustda/

and if the delay in the release of regulations was actually necessary based on the mandatory requirement of a database. There is a potential future conundrum that might also emerge for standard power devices in the 6 GHz which require Automated Frequency Coordination (AFC) that operates similar to the TVWS geolocation databases [29]. Concerns pointed out by the Wireless Innovation Forum [30] that even for CBRS, the centralised Spectrum Access System (again similar to the TVWS database) has proven to be complex and prone to unnecessarily prolonged standardisation and testing processes – something that might potentially also affect the roadmap for Kenya towards AFC adoption for Wi-Fi 6E. Moreover, if the geolocation database or AFC is to be adopted in Kenya, there will be need to define a transparent procedure for effective competition.

2. **The Challenge of a Listing Server –** Although this was spelt out in the development of the TVWS regulations, it was seen to add to more complexity for deployment of TVWS. Its adoption was considered based on the Internet Engineering Task Force's (IETF's) Protocol to Access White Space (PAWS) database[32]. A listing server, also considered in the UK regulations, serves as a point of initial contact by a master White Space Device (WSD) in a process called Database Discovery (DD). This process requires a Master WSD to be statically provisioned with a Uniform Resource Identifier (URI) of one or more geolocation databases such that during DD, it gets to select the certified database on which it would operate. Details of update of these URIs are described in the PAWS protocol to enable the Master WSD to flexibly select another preconfigured database or update to a new URI. For future database-assisted shared spectrum networks, this approach might require proper evaluation.

3. **Lack of harmonisation of TVWS Regulations within the East Africa Region –** While this is not an issue yet, it should be a subject under study given the active research activities that are planned to take place in both Uganda and Tanzania. Interested stakeholders planning to deploy TVWS networks but unfamiliar with the GEO6 agreement need to be sensitised to adhere to the threshold cross border emission levels. Some research studies suggest that a regional approach to TVWS can significantly lower the costs of deploying TVWS, allow the least-resourced regulators to enjoy the same benefits as the best-resourced as well as rapidly address any potential cross-border interference[33].

4. **Lack of clarity on the nominal fee under the Light Licensing model –** As per the existing TVWS regulations for Kenya, the licensing adopted is referred to as lightly-licensed. This comes with a requirement to pay a nominal fee whose definition was not explicitly provided in the regulatory framework. Although it is spelt out in the Wireless Access Systems (WAS) in the Frequency Spectrum Fee schedule available on CA's website, it still seems unclear on what "terminal" would be for a TVWS network. A clear definition is hence, necessary, to provide proper clarity to the stakeholders. The same consideration of clarity in terms of cost should be provided in the future documentations providing guidelines for spectrum sharing in other bands.

3.3.2. TECHNOLOGY CHALLENGES

As of this writing, there is patchy knowledge on any live network running on TVWS in Kenya as a pioneer band of spectrum sharing. Therefore, it may be premature to define the technical aspects that need adjusting. In addition, the feedback from the 2020 trials have not elucidated any issues on incumbent interference for consideration at this point. Further, even with the enactment of the Community Networks (CNs) framework, there has been very little deployments and developments to demonstrate activity. We therefore share our findings based on assessment of technology developments interrogated during the study and also highlighted for consideration in the future shared spectrum networks.

[32] Protocol to Access White Space Databases: https://tools.ietf.org/html/rfc7545

[33] Saving TVWS

1. **Backhaul Challenges –** The shared spectrum networks presently proposed in Kenya are last-mile networks. For such networks to provide meaningful connectivity, a reliable backhaul is necessary. Unfortunately, concerns still exist in terms of reliable backhaul in the country through either the fibre network or satellite connectivity. For fibre, it has been noted that a challenge of *dark fibre* exists in a significant number of rural areas[34]. This means that deploying the shared spectrum networks will require additional effort in addressing the dark fibre issues first. On the other hand, there is little published information in regards to satellite coverage to determine their level of support as backhaul to shared spectrum networks. For TVWS, the initial transmission requires communication over the Internet which means a reliable backhaul is key. If the adoption of automated frequency coordination such as the one proposed for standard power devices is anything to go by, similar to the TVWS approach, a reliable backhaul would be needed. While the cellular network would serve as an alternative, a further assessment would be required based on the extent of coverage and reliability to support the last-mile networks.
2. **Challenges of Development of the Radio Technologies –** The current model of deploying networks in Kenya is heavily dependent on importation of the necessary radio technologies ranging from hardware to software. While this model has been in existence for a long time and enabled the local ISPs to deliver their services, the approach of spectrum sharing necessitates a new way of thinking. For instance, it can be deduced that the lack of local core developments on the architecture of TVWS in Kenya heavily contributed to the delay in the enactment of regulations and also the lack of proper awareness of how the technology actually works. Although having its challenges, the approach adopted by South Africa (SA) to locally develop its geolocation database to manage TVWS perhaps created a rapid understanding on the technology[35] in SA. Without active developments and testing (backed by collaboration), ISPs might miss out on the opportunity that spectrum sharing provides and further delay future spectrum sharing developments. This is because foreign companies would need more time to understand the RF spectrum assignment in the country and the related parameters such as location, bandwidth, emission masks, antenna gains and heights etc. as such data is easily accessible by the local companies and perhaps not used in their R&D divisions to conduct appropriate assessment for new services.

3.3.3. ECONOMICS AND MARKET CHALLENGES

Unlike TVWS, where there were no studies on economic opportunity prior to publication of regulations, an economic assessment has been conducted in the 6 GHz band (5925 – 7125 MHz) to assess the economic value of license-exempt Wi-Fi 6E devices in Kenya [6]. This approach provides a holistic understanding to the regulator and the ISPs to assess the economic value of rolling out shared spectrum networks. TVWS faced (and still faces) the challenge of equipment cost alongside the approach of complex regulations since the industry is not as mature as the cellular industry. This has led to a TVWS ecosystem that is largely interoperable, both from hardware and software (geolocation database) perspective, thereby failing to obtain a buy-in by a majority number of ISPs to deploy the networks. In turn, this has led to huge amounts of money wasted in R&D work that never went commercial.

Although TVWS provides a suitable access alternative to the rural underserved areas where the TV broadcasting spectrum is mostly fallow, access is conspicuously lacking and that fewer base stations are needed due to the better non-line-of-sight propagation characteristics [31], the issue of cumulative cost of deployment introduces a huge bottleneck as passing it to the final customers seem unsustainable. This is because the “customers” in question live in the rural areas of Kenya where most of them have a low-income. In some areas, some of the customers do not have a grid-power connection, calling for additional costs in terms of renewable power to support the infrastructure. Therefore, looking at the chain of service, right from capital expenditure (CAPEX) on

[34] Turkana’s Young People are not waiting for Oil

[35] CSIR GLSD

equipment, nominal fee based on each "terminal", geolocation database cost, backhaul and power costs to the cost of personnel, TVWS needs extra support. Such support, while it ought to come from the Universal Service Fund (USF) [13] since TVWS promotes communication infrastructure in rural, remote and underserved infrastructure, still lacks a proper framework.

The findings of the economic study on the 6 GHz band show that Kenya's GDP could grow to US $20.29 by 2030 with the segmentation of services as shown in Table 1. The findings also elucidate that allocating the full 1200 MHz of the 6 GHz band to Wi-Fi 6E will result in a significant contribution to a reduction in the digital divide. However, for this to be realised, variables such as active participation by the ISPs, availability of backhaul and reliable power must also be put into consideration. As opposed to the findings where it is mentioned, "*Wireless ISPs tend to have primary focus on the vulnerable population and part of their deployment is in rural municipalities*", we note that the present Wi-Fi deployments in the country are concentrated in the cities and often in the middle-income areas where the economics of scale, work to the advantage of the service providers[36].

Table 1: Economic Value of Wi-Fi 6E for Kenya between 2021 and 2030

Source: Assessing the Economic Value of Unlicensed use of the 6 GHz Band in Kenya

Source of Value	GDP Contribution	Producer Surplus	Consumer Surplus
Enhanced coverage and improved affordability	$5.50		$0.04
Increased broadband speed by reducing Wi-Fi congestion	$1.44		$0.69
Wide deployment of Internet of Things (IoT)	$0.59	$0.31	
Reduction of enterprise wireless costs		$0.05	
Deployment of AR/VR solutions	$1.92	$0.43	
Enhanced deployment of municipal Wi-Fi	$3.78		$2.37
Deployment of Free Wi-Fi Hotspots	$1.05		$0.56
Aligning spectrum decisions with other advanced economies		$0.02	
Enhancing capability for cellular off-loading		$0.13	
Increasing production of residential Wi-Fi devices and equipment		$0.18	$1.23
TOTAL	$14.28	$1.12	$4.89

3.3.4. OTHER CONSTRAINTS

1. **Stakeholder Capacity and Awareness –** Our experience during the stakeholder engagement sessions at the time of validating the TVWS framework as well as during this study informs our judgement that most stakeholders are unfamiliar with spectrum sharing. This is due to the missing active participation by the local ISPs, MNOs,

[36] Sector Statistics Report July-September 2021

Community Network champions as well as local researchers. As opposed to countries such as the UK, USA, Singapore and many alike where stakeholders may approach the regulator for studies and trials on specific spectrum usage, local stakeholders do not often engage CA on spectrum innovation initiatives and traditionally wait for regulations to be developed to which they play catch up and sometimes pose late feedback. Most often, these delays in-country developments to deliver on broadband gaps. Their capacity needs notably span from regulations, technology and economics. With only one company (Mawingu Networks) in the country to have successfully piloted TVWS in only three counties – Embu, Nyeri and Laikipia (all of them neighbouring each other) between 2013 to 2020, it speaks volumes in regard to the current capacity in the country for implementing spectrum sharing. In addition, it also attests to the terms of the awareness of the opportunity that spectrum sharing can provide both from *supply* and the *demand* side. The *supply* side meaning deployment of the network while the *demand* side referring to consumer uptake. During the stakeholder engagements, it came out clearly that most stakeholders did not clearly understand TVWS and its opportunity, including the country developments that had taken place prior to the publication of the regulatory framework. This to a great extent, might translate to a missed opportunity and might limit foreign-local collaboration in the deployment of spectrum sharing networks.

2. **Awareness on the opportunity of broadband by consumers -** Datareportal explicates that there are 11 million Kenyans on social media. This could mean, active use of the Internet for the 20.2 % of the Kenyan population but does not reflect the usability that can be able to sustain the economic benefits of Internet access. Hence, while capacity initiatives can be channelled through the social media to reach these 11 million Kenyans, there is also a gap that needs to be addressed to stimulate better demand among Kenyans, both urban and rural alike. Often, the traditional challenges of power, devices and low levels of income have made the rural population oblivious of connectivity and initiatives they can actually derive more value from. On the other hand, there are limited ICT capacity building initiatives for the rural schools, higher education institutions as well as communities. There is a huge chance that, apart from the challenges of power and connectivity, lack of sufficient capacity and skills was inevitably going to limit the pace of achieving results in the failed laptop project for Kenya[37].

3.4. OBJECTIVE III: STATE OF COLLABORATIVE ENGAGEMENTS ON SPECTRUM SHARING

The exclusive licensing of the IMT spectrum has been central to its success driven by a strong ecosystem of 3GPP organisational partners[38]. Similar partnerships would be needed to sustain spectrum sharing in Kenya. The model of partnerships can include between or among stakeholders (ISPs) or stakeholders with research /academic institutions or between the regulator and academic/research institutions. While the traditional model of businesses encompassing backhaul, middle-mile and last-mile network providers allows the different stakeholders to collaborate, very little stakeholder-to-stakeholder collaboration exists to further developments on spectrum sharing in the country. The existing collaborative models are presently led by academic and research institutions together with the regulator. An example of an existing partnership on spectrum sharing is the one between Strathmore University (SU) and Communications Authority of Kenya (CA). Albeit, other collaborations exist between the industry and academia looking at aspects of Internet of Things (IoT) and other digital technologies, it would be great to expand such collaborations and demonstrate deployments that align to the examples presented in Figure 7.

[37] Jubilee laptops that failed Kenyan child: https://www.standardmedia.co.ke/the-standard-insider/article/2001369323/jubilee-laptopsproject-that-failed-kenyan-child

[38] 3GPP Partners

CHAPTER 4: RECOMMENDATIONS

4.1. ON REGULATIONS

1. **Transparency in Provision of Information –** CA should endeavour to provide as much information as possible to all the stakeholders and the public. Although we note that there exist processes to doing this and policies to which CA is bound, we sensitively also highlight that the subject of spectrum sharing will only thrive in the country if more research, information engagement sessions and collaborations are fostered. This would be fruitful if CA's spectrum sharing strategies as well as new developments such as procedures for qualifications, type-approval requirements, related policies, and allocations of the USF etc. are transparently shared to allow different groups on matters spectrum to engage and participate in such developments. We envision such an ecosystem to provide enthusiasm on spectrum innovation and quickly lead to more spectrum sharing studies and demonstrations for digital innovation and underserved populations.
2. **Authorisation of New Entrants –** To promote more developments on spectrum innovation, CA can unlock a new level of license to allow new entrants into the market as part of accelerating universal broadband access and adoption, and advancing national purposes such as education and health care. The eligibility to operate TVWS as well as Community Networks requires at least a Tier 3 NFP license, which, based on the Community Networks framework, seems limiting. Hence, creating incentives and providing a new license category for small profitable telecommunication service operators under the Unified Licensing Framework as proposed by CA will also provide an opportunity to new entrants. This will increase opportunities for innovative spectrum access model, remove barriers to spectrum utilisation and improve data and transparency in spectrum allocation and usage.
3. **Implementation of Capacity Awareness Programmes –** Presently, only a handful of people and groups in the country can be counted as familiar with spectrum sharing and the benefits it brings to the economy. As stakeholders have pointed out in the past, there is a need to develop awareness and enhance capacity for the adoption of dynamic spectrum sharing. Some stakeholders, particularly from the 3GPP standards group largely view spectrum sharing as an uneven competition to their traditional exclusive licensing models. The complementary opportunity still seems unclear to them. In addition to this, are the gaps in the spectrum sharing knowledge to potential innovators as well as the public which is the target market. A holistic awareness plan would therefore be great if developed across all these different groups to successful reap the fruits of spectrum sharing for Kenya.
4. **Development of a Strategic Plan on the use of the Universal Service Fund –** It is evident that most players who might leverage models such as localised licensing and even build on efforts for rural broadband access might not have sufficient financial strength to achieve this. Others such as Community Networks (CNs) whose model is predominantly not-for-profit might not sustain their digital inclusivity initiatives. Therefore, establishing a strategic plan for the USF will help support such broadband initiatives. This can also include a plan to measure achievable metrics even as USF supports such initiatives. While analysing the implementation of TVWS, it is also notable that the economics of operation, including the stability of the business models are still struggling. Therefore, the USF can also be repurposed to strategically support potentially sustainable pilots, even on a limited scale to allow for TVWS growth – which would be key to ensuring that spectrum sharing matures in the country. The same support can be extended to CNs actively demonstrating affordable connectivity through spectrum sharing to extend their present services.
5. **Development of a Spectrum Sharing Blueprint for Kenya –** This may be significant in defining the strategic adoption for spectrum sharing for the country. Whilst we note that CA already has a strategic

plan running until 2023, it would also be great if the CA publishes a spectrum sharing blueprint which details the opportunity of Dynamic Spectrum Access (DSA) in different spectrum bands and enable stakeholders to relate on its applicability or use in the new frameworks such as TVWS and the Community Networks. We envision that such a document will also stimulate contextual R&D developments by different stakeholders as well as collaborations that can rapidly drive the understanding and adoption of spectrum sharing.

6. **Establishment of Guidelines on Access to White Space Data –** TVWS transmissions are expected to lead to a certain unique operation of the WSDs in different geographic areas and in specified channels if deployed. While this information will by default be under the custody of a geolocation database provider, the CA should establish a guideline of access to the data. This should be made available to researchers and relevant parties who can examine the performance of the TVWS network and even develop predictive models that can enhance future spectrum sharing initiatives as well as the quality of utilisation of the TVWS channels together with regional developments.

7. **On the Listing Server** – While the approach of the listing server emphasizes the administrative need by CA to seamlessly oversee the operation of the white space devices and effectively manage the geolocation databases operating in Kenya, it will be good if that is not made mandatory at these early stages of implementing TVWS in the country. This is because the ecosystem of TVWS is still young and it needs time to grow and such a regulatory requirement will create more hurdles to both the ISPs and the geolocation database provider(s) considering the configuration each master WSD will need to have to successfully be allowed to transmit. Besides, at this point, there is only one approved geolocation database provider[37]; hence, it makes little economic sense for CA to have a server that only lists one provider. Also, CA needs to ensure their internal requirements are balanced in terms of where the Listing can be hosted and who is to manage it.

8. **On the present state of the use of Geolocation Databases (Automated Frequency Coordination):** We note that only one geolocation database provider – Fairspectrum, is presently available in Kenya. We therefore recommend that the Fairspectrum database be used as a benchmark for TVWS deployments in Kenya for a given period deemed fit by the CA as spectrum sharing matures in the country. While at present it is not easy to define the best level of competition to deploy many GDBs/AFCs in Kenya due to limited service of such nature as well as supporting budget, we propose that the grace period granted to Fairspectrum should also allow CA to raise more awareness on TVWS and spectrum sharing that is based on AFC, especially as new initiatives in other bands emerge. CA should also develop a strategy to release a call for more providers to encourage competition. This will also establish a more transparent ecosystem that provides stakeholders (ISPs) with more options for the GDBs/AFCs.

9. **Development of Supportive Guidelines and Policies:** As the country implements the existing digital plans to adapt the TVWS regulatory framework, it would be great that specifically supportive guidelines and policies distinctive to spectrum sharing are also developed. This might include guidelines and policies on stakeholder collaboration, capacity building, requirements for new entrants, backhaul access and usage of TVWS for Community Networks (CNs) or other not-for-profit last mile networks, spectrum fee schedule, technical coexistence requirements etc. This can be developed on an evolving basis based on the emerging spectrum sharing initiatives coming from both research and regulatory developments.

10. **Authorisation of the Manual Configuration for TVWS Devices in "Less Congested" Areas –** With the revisions of the FCC to increase the maximum permissible radiated power from 10 to 16 watts EIRP for fixed WSDs in the "less congested areas[38]", we propose that an evaluation be conducted to develop

[37] Fairspectrum availability in Kenya
[38] Less congested areas refers to areas where fewer authorised services and protected entities are expected to be operating in the TV bands.

similar steps in the near future. While Kenya already allows 42 dBm maximum EIRP, we suggest that manual configuration be allowed in the "less congested" areas.

11. **Access to the full 6 GHz Band for Wi-Fi 6E -** Africa faces a challenge of fixed broadband penetration and Kenya is no exception. Wi-Fi usage has been on the rise both at home and work environments and COVID-19 amplified this need. According to Cisco, W-Fi is projected to carry 51 per cent of traffic by 2022 and will be significant in offloading 71% of mobile data traffic even as 5G deployments pick up. Contextual to Kenya, there has only been a few 5G pilots in the mid-band frequencies (2.6 GHz and 3.5 GHz)[39][40], an indication that investments in network densification to meet user demand will take some time. Whilst the ATU's Working Group on Emerging Technologies has recommended to open the lower 6 GHz band (5925 – 6425 MHz) on licence-exemption to which CA has adopted, we propose that the country takes an approach that allows access in the full 6 GHz band (5925 MHz – 7125 MHz) even as the developments ahead of the WRC-2023 from the ITU level continue. This approach can help balance the country's needs based on the economic and technical coexistence studies already carried out alongside observation of IMT deployments in the 2.6 and 3.5 GHz bands.

4.2. ON TECHNOLOGY

1. **Development of a research focus in the country on the technical studies of spectrum sharing** – As of this writing, there has been very little technical developments on Software Defined Radios (SDRs), Cognitive Radios (CRs) and Automated Frequency Coordination (AFC), contextual to the adoption of spectrum sharing in Kenya. These concepts have been explored in other countries such as the UK from a research approach[42] even in the shareable IMT bands including demonstrations for Neutral Hosting in the low-band 5G such as in the 700 MHz as well as the new 6G studies. The same can be said of the new developments of Wi-Fi 6 / Wi-Fi 6E even as WRC-23 gets closer. We envision such studies, trials and tests to provide on-ground demonstrations to the CA as well as stakeholders, which can rapidly lead the country in developing regulations, business models and collaborations that would be able to drive suitable technology deployments. For example, while there was no consensus on determining the most suitable technique for determining TVWS channels from the three proposed techniques – spectrum sensing, beacon and GDBs, Kenya's basis cannot contextually highlight the pros and cons of each as no practical studies were conducted in the country. Furthermore, there still exists little in-country studies to demonstrate accuracy and reliability of the existing models on detecting primary users (PUs) for future TVWS expansion as well as adoption of AFC as already proposed in other regimes.

2. **Notification of Errors in Predicting the Availability of White Spaces –** As part of a technology ecosystem and reliability on a propagation model, the database may have errors in predicting the white spaces and sometimes may fail to distinguish the quality of white space channels. A notification system can be developed to report such scenarios especially as the database implementation advance through AFC.

3. **Backhaul Studies and Mapping –** Given the existing backhaul challenges, mapping needs to be done to help determine the footprint of the backhaul networks such as one through fibre and satellite. This would help resolve issues of *dark fibre* and help provide routes across the country for deployment of last-mile networks based on spectrum sharing. In turn, it can help even on preliminary analysis of how much in terms of CAPEX is needed to support respective areas in regard to connectivity. The backhaul studies will help to provide accurate data on microwave and cellular links, satellites as well as other backhaul options to support stakeholder initiatives for last-mile access.

[39] Superfast internet on the way as plan for 5G licensing starts: https://www.standardmedia.co.ke/business/scitech/article/2001426070/superfast-internet-on-the-way-as-plan-for-5g-licencing-starts

[40] G RuralFirst Project: https://www.5gruralfirst.org/

4.3. ON ECONOMICS AND MARKET

Based on this study and related studies conducted along with it, we propose the following sectors as flagship sectors to implement shared spectrum networks: education, healthcare, connectivity to businesses, government offices and centres and the new innovations of Internet of Things (IoT) and cloud-based applications. The education sector includes pre-primary and primary institutions, secondary and high schools, universities as well as other tertiary institutions. The healthcare sector could cover hospitals, healthcare centres, and home-based care centres while the IoT innovation could capture both small-scale and large-scale Industry 4.0 innovations ranging from precision farming, climate innovations, to renewable energy management, water as well as logistics and tracking. For the government, provision of broadband for e-government services, government offices as well as community centres owned by the government.

We recommend that financing options such as grants, debt financing and the USF fund to be used initially to deploy spectrum shared networks, starting with TVW, CNs and Wi-Fi 6E as other shared spectrum studies take shape. In some scenarios, we envisage that the CAPEX could be cost-shared with the customers, especially for the institutional groups. Other financing options could come from the government based on broadband access projects such as setting up of training and capacity development centres as well as connectivity to government offices. Commercial investors would also contribute to growing the finance base.

Other recommendations on economics and market include:

1. Tax exemption and incentives on network equipment for a given period of time determined by CA.
2. Tax exemptions and incentives on rural broadband network providers, although the new licence on Public Communication Access Centres (PCAC) would suffice if implemented.
3. Develop an annual spectrum sharing plan for the priority areas of the USF and implement a request for proposals scheme to ensure the priority areas are addressed.

CHAPTER 5: CONCLUSIONS

Regardless of the existing regulatory models, there is a need to improve flexibility and efficiency in spectrum access to meet the increasing demand for Internet broadband across the world. For Kenya, The Communications Authority (CA) has already set the tone towards adoption of efficient techniques that can address spectrum scarcity, particularly to the underserved citizens across the country. This can be seen through the enactment of the regulations on TV White Spaces and Community Networks. However, the landscape of adopting spectrum sharing in the country still faces quite a number of hurdles and is yet to "really" take-off. Some of these hurdles range from complete lack of awareness of the concept, the technology architecture(s), opportunity that exists, regulatory developments and even the terminology. On the other hand, groups hailing from exclusive licensing models view spectrum sharing as a competing model rather than a complementary one that can contribute to extending their services. The idea of primary and secondary users operating in the same band sounds invasive and unfair to their business. Based on the percentage of the market they command, they might negatively influence spectrum innovation and delay 'connecting the unconnected' as well as new digital innovations. Variables such as a strong local research ecosystem, financial support from kitty's such as USF, collaboration among the different players within Internet provision services etc. as highlighted in this report are therefore key to debunk the misconceptions around spectrum sharing. In turn, more affordable broadband initiatives can be deployed to support both human and machine-driven demand for information capacity and allow the country to realise its National Broadband Strategy, Digital Economy Blueprint and its Vision 2030.

CHAPTER 6: REFERENCES

[1] 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, 2016.

[2] R. Stewart, D. Crawford and Stirling Andrew, TV White Space Communications and Networks, Kidlington: Woodhead Publishing, 2018.

[3] S. Song, C. Rey-Moreno, A. Esterhuysen, M. Jensen and L. Navarro, "The rise and fall and rise of community networks," in *Global Information Society Watch* , Ottawa, International Development Research Centre, 2018, pp. 7-10.

[4] L. Navarro, L. Maccari and R. L. Cigno, "At the limits of the Internet: Technology Options for Community Networks," in *Global Information Society Watch 2018 - Community Networks*, Ottawa, International Development Research Centre, 2018, pp. 13-20.

[5] Dynamic Spcetrum Alliance, "How to Realise the Full Potential of 6 GHz Spectrum," Dynamic Spectrum Alliance, Beaver, 2021.

[6] Telecom Advisory Services, "Assessing the Economic Value of Unlicensed Use of the 6 GHz band in Kenya," Dynamic Spectrum Alliance, Beaverton, 2021.

[7] Litepoint, "A Guide to Wi-Fi 6E: Wi-Fi 6 in the 6 GHz Band," Litepoint, California, 2020.

[8] J. D. Matyjas, S. Kumar and F. Hu, Spectrum Sharing in Wireless Networks, Florida: Taylor and Francis Group, 2017.

[9] O. Holland, H. Bogucka and A. Medeisis, Opportunistic Spectrum Sharing and White Space Access, New Jersey: John Wiley and Sons Inc., 2015.

[10] Minstry of ICT, Innovation and Youth Affairs, "National Broadband Strategy," May 2019. [Online]. Available: https://www.ict.go.ke/wp-content/uploads/2019/05/National-Broadband-Strategy-2023FINAL.pdf. [Accessed 26 September 2022].

[11] Ministry of ICT, Innovation and Youth Affairs, "Digital Economy Blueprint," May 2019. [Online]. Available: https://www.ict.go.ke/wp-content/uploads/2019/05/Kenya-Digital-Economy-2019.pdf. [Accessed 26 September 2022].

[12] Ministry of ICT, Innovation and Youth Affairs, "The Kenya National Digital Master Plan," April 2022. [Online]. Available: https://cms.icta.go.ke/sites/default/files/2022-04/Kenya%20Digital%20Masterplan%202022-2032%20Online%20Version.pdf. [Accessed 26 September 2022].

[13] Communications Authority of Kenya, "Universal Service Fund (USF) Framework," February 2018. [Online]. Available: https://ca.go.ke/wp-content/uploads/2018/02/Universal-Service-FundFramework.pdf. [Accessed 15 April 2022].

[14] Communications Authority of Kenya, "Strategic Plan 2018-2023," September 2019. [Online]. Available: https://www.ca.go.ke/wp-content/uploads/2019/09/4th-CA-Strategic-Plan-2018-2023.pdf. [Accessed 20 April 2022].

[15] International Finance Corporation, "e-Conomy Africa 2020," 2020. [Online]. Available: https://www.ifc.org/wps/wcm/connect/e358c23f-afe3-49c5-a509-034257688580/e-Conomy-Africa2020.pdf?MOD=AJPERES&CVID=nmuGYF2. [Accessed 23 September 2022].

[16] International Telecommunication Union, "The Last-mile Internet Connectivity Solutions Guide," December 2020. [Online]. Available: https://www.itu.int/en/ITU-D/Technology/Pages/LMC/LMCHome.aspx. [Accessed 23 August 2021].

[17] United States Agency International Development, "Digital Ecosystem Country Assessment (DECA)," September 2020. [Online]. Available: https://www.usaid.gov/sites/default/files/documents/DECA_Report_KENYA_EXTERNAL_2OCT2-2_2.pdf. [Accessed 23 March 2022].

[18] Dynamic Spectrum Alliance, "Enhancing Connectivity Through Spectrum Sharing," October 2019. [Online]. Available: https://dynamicspectrumalliance.org/wp-content/uploads/2019/10/EnhancingConnectivity-Through-Spectrum-Sharing.pdf. [Accessed 13 October 2021].

[19] GSMA, "Spectrum Sharing GSMA Public Policy Position," June 2021. [Online]. Available: https://www.gsma.com/spectrum/wp-content/uploads/2021/06/Spectrum-Sharing-Positions.pdf. [Accessed 10 April 2022].

[20] Dynamic Spectrum Alliance, "Automated Frequency Coordination An Estabished Tool for Modern Spectrum Management," March 2019. [Online]. Available: https://dynamicspectrumalliance.org/wpcontent/uploads/2019/03/DSA_DB-Report_Final_03122019.pdf. [Accessed 3 March 2022].

[21] P. Thakur and G. Singh, Spectrum Sharing in Cognitive Radio Networks: Towards Highly Connected Environments, Johannesburg: John Wiley and Sons, Inc., 2021.

[22] A. M. Wyglinski , M. Nekovee and T. Hou, Cognitive Radio Communications and Networks, Burlington: Elsevier Inc., 2010.

[23] J. Leibovitz and R. Milkman, "Taking Stock of Spectrum Sharing," Schmidt Futures, Washington, 2021.

[24] Y. Luo, L. Gao and J. Huang, Economics of Database-Assisted Spectrum Sharing, Geneva: Springer International Publishing Switzerland, 2016.

[25] Uganda Communications Commission, Standard for White Spaces Access and Use in Uganda, Kampala: UCC, 2017.

[26] African Telecommunications Union, "ATU-R Recommendation," July 2021. [Online]. Available: https://atuuat.africa/wp-content/uploads/2021/08/En_ATU-R-Recommendation-005-0.pdf. [Accessed 23 September 2022].

[27] Dynamic Spectrum Alliance, "Socio-economic benefits of IMT versus RLAN in the 6425-7125 MHz band in Europe," DSA, Beaverton, 2022.

[28] E. Hossain, D. Niyato and Z. Han, Dynamic Spectrum Access and Management in Cognitive Radio Networks, Cambridge: Cambridge University Press, 2009.

[29] Dynamic Spectrum Alliance, "Automated Frequency Coordination: An Established Tool for Modern Spectrum Management," March 2019. [Online]. Available: https://dynamicspectrumalliance.org/wpcontent/uploads/2019/03/DSA_DB-Report_Final_03122019.pdf. [Accessed 20 September 2022].

[30] Wireless Innovation Forum, "Propagation Models and Interference Protection Criteria for Sharing Between the Fixed Service and Unlicensed Devices in the 6 GHz Band," The Software Defined Radio Forum Inc., Reston, 2019.

[31] M. Zennaro and E. Pietrosemoli, TV White Spaces - A Pragmatic Approach, Italy: International Centre for Theoretical Physics, 2013.

[32] S. R. Gulasekaran and S. G. Sankaran, Wi-Fi 6 Protocol and Network, Norwood: Artech House, 2021.

[33] Dynamic Spectrum Alliance, "6 GHz License Exempt: Why the full 1200 MHz and Why Now?," August 2021. [Online]. Available: https://dynamicspectrumalliance.org/wp-content/uploads/2021/08/6GHzLicense-Exempt-Band-Why-1200-MHz-and-Why-Now.pdf. [Accessed 27 September 2022].

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

[35] Wi-Fi Alliance, "Wi-Fi Spectrum Needs Study," February 2017. [Online]. Available: https://www.wifi.org/download.php?file=/sites/default/files/private/Wi-Fi%20Spectrum%20Needs%20Study_0.pdf. [Accessed 27 September 2022].

[36] Dynamic Spectrum Alliance, "Socio-economic benefits of IMT versus RLAN in the 6425-7125 MHz Band in Europe," DSA, Oregon, 2022.

[37] International Telecommunication Union, "Nomenclature of the frequency and wavelength bands used in telecommunications," August 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/v/RREC-V.431-8-201508-I!!PDF-E.pdf. [Accessed 27 September 2022].

[38] Kenya Nationa Bureau of Statistics, "2019 Kenya Population and Housing Census Volume 1: Population by County and Sub-County," August 2019. [Online]. Available: https://www.knbs.or.ke/?wpdmpro=2019kenya-population-and-housing-census-volume-i-population-by-county-and-sub-county. [Accessed 27 September 2022].

[39] UN Department of Economic and Soical Affairs - Population Division, "World Population Prospects 2022," July 2022. [Online]. Available: https://population.un.org/wpp/Download/Standard/MostUsed/. [Accessed 27 September 2022].

[40] Wi-Fi Alliance, *Global Spectrum Series - 'The WRC-23 Webinar',* Virtual: Wi-Fi Alliance, 2021.

[41] Communications Authority of Kenya, "Guidelines on the Use of Radiofrequency Spectrum by Short Range Devices," June 2022. [Online]. Available: https://www.ca.go.ke/wpcontent/uploads/2022/07/Guidelines-on-the-Use-of-Radiofrequency-Spectrum-by-Short-Range-Devices2022.pdf. [Accessed 26 September 2022].

[42] African Telecommunications Union, "ATU-R Recommendation 005-0," July 2021. [Online]. Available: https://atuuat.africa/wp-content/uploads/2021/08/En_ATU-R-Recommendation-005-0.pdf. [Accessed 2022 September].

[43] J. Pahl, Interference Analysis - Modelling Radio Systems for Spectrum Management, Chichester: John Wiley and Sons, Ltd., 2016.

[44] European Communications Committee, "ECC Report 252 - Spectrum Engineering Advanced Monte Carlo Analysis Tool," CEPT, Copenhagen, 2016.

[45] A. Stevens, Monte-Carlo Simulation - An Introduction for Engineers and Scientists, Florida: Taylor and Francis Group, LLC, 2022.

[46] International Telecommunication Union, "Recommendation ITU-R F.758-7," November 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.758-7-201911-I!!PDF-E.pdf. [Accessed 26 September 2022].

[47] International Telecommunication Union, "Recommendation ITU-R F.758-7," November 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.758-7-201911-I!!PDF-E.pdf. [Accessed 26 September 2022].

[48] International Telecommunication Union , "Recommendation ITU-R F.1245-3," January 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.1245-3-201901-I!!PDF-E.pdf. [Accessed 23 September 2022].

[49] Wireless Innovation Forum, "Propagation Models and Interference Protection Criteria for Sharing Between the Fixed Service and Unlicensed Deviced in the 6 GHz Band," The Software Defined Radio Forum Inc., Reston, 2019.

[50] International Telecommunication Union Radiocommunication Sector (ITU-R), "Recommendations ITU-R P.2109-1 - Prediction of Building Entry Loss," August 2019. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-1-201908-I!!PDF-E.pdf. [Accessed 3 November 2022].

[51] Information Society Technologies, "WINNER II Channel Models," NOKIA SIEMENS NETWORKS, Muenchen, 2007.

[52] International Telecommunication Union - Radiocommunication Sector, "Prediction Procedure for the Evaluation of Interference Between Stations on the surface of Earth at Frequencies above about 0.1 GHz," July 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.452-16201507-S!!PDF-E.pdf. [Accessed 3 November 2022].

[53] International Telecommunication Union, "Prediction of Clutter Loss," September 2021. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2108-1-202109-I!!PDF-E.pdf. [Accessed 3 November 2022].

[54] Electronic Communications Committee, "SEAMCAT Handbook," European Communications Office, Copenhagen, 2016.

[55] Kenya National Bureau of Statistics, "2019 Kenya Population and Housing Census," KNBS, Nairobi, 2019.

[56] 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-Economy2019.pdf. [Accessed 15 August 2022].

[57] 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/NationalBroadband-Strategy-2023-FINAL.pdf. [Accessed 15 August 2022].

[58] 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-May2021.docx.pdf. [Accessed 16 August 2022].

[59] Dynamic Spectrum Alliance, "Enhancing Connectivity Through Spectrum Sharing," October 2019. [Online]. Available: https://dynamicspectrumalliance.org/wp-content/uploads/2019/10/EnhancingConnectivity-Through-Spectrum-Sharing.pdf. [Accessed 2 June 2022].

APPENDIX: CASE STUDIES

7.1. UK ORKNEY TVWS PILOT

The Orkney TVWS was rolled out in 2015 by University of Strathclyde's Centre for White Space Communications (CWSC) after the university was awarded a grant by the Scottish Government[41]. The aim of the pilot was to demonstrate the possibility of using TVWS to reach difficult to reach far-off and remote locations. The pilot made use of TVWS to provide Internet connectivity to ferries that move around the islands within Orkney. Passengers and crew were able to have access to the Internet while on their journey in the ferries. The pilot also provided Internet connectivity to a number of fixed-land premises remote and hard to reach places that were beyond the reach by ISPs as at that time. This was possible because of the long range and building penetration characteristics of the TVWS spectrum. Internet connectivity in the area was not possible in the ferries and the remote fixed sites before the pilot. The TVWS pilot went beyond European Commission's definition of superfast broadband (30 Mbits/s or more). The high level network of this implementation is shown in Figure 8.

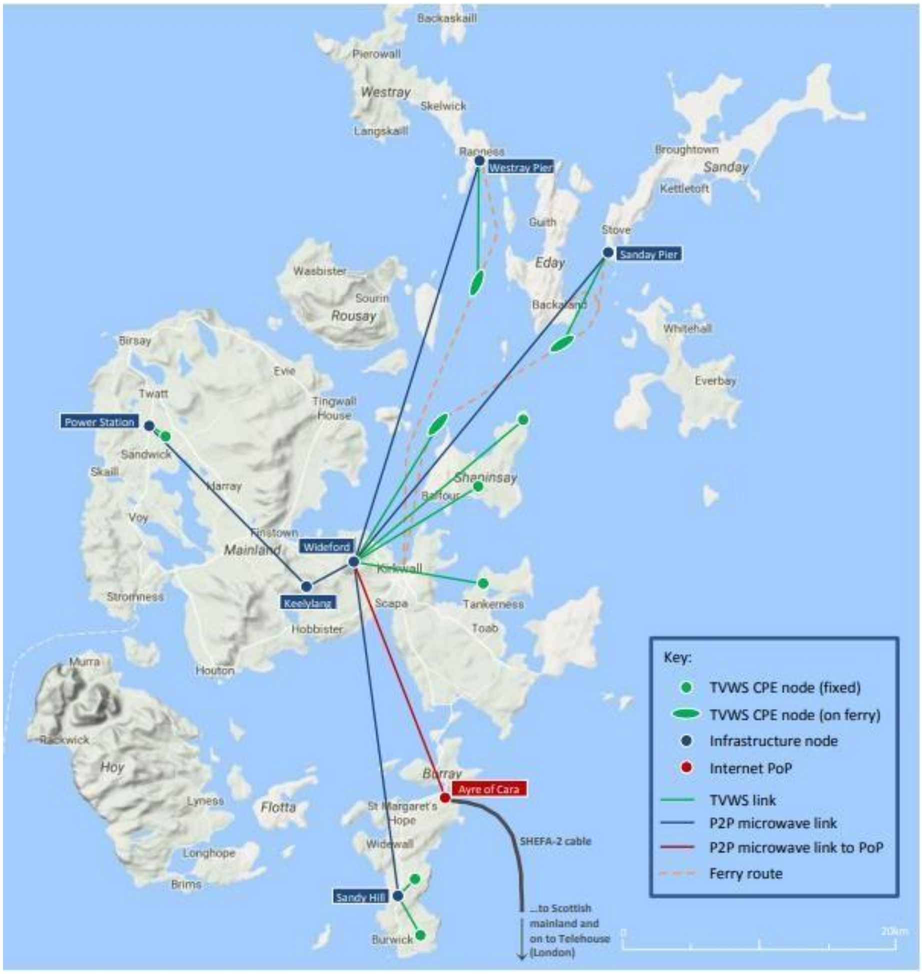


Figure 8: High Level Network Diagram for TVWS Demo on Orkney Island UK

Source: Centre for White Space Communications, University of Strathclyde

7.2. ISLE OF BUTE, UK TVWS RURAL BROADBAND TRIAL

In April 2011, a six partner consortium, with support from the UK government's Technology Strategy Board, began working on a rural broadband trial network that would use white space radio spectrum to provide broadband connectivity to a small community on the southern Isle of Bute, Scotland. The 18-month project

[41] Orkley TVWS Trial: https://www.wirelesswhitespace.org/wpcontent/uploads/2018/09/Orkney_TVWS_Pilot_v01_01.pdf

ventured to demonstrate the potential of TVWS for providing broadband access to remote, difficult to reach rural areas of challenging terrain. The findings on the project, backhauled by a telephone exchange to the mainland to British Telecom's (BTs) fibre network established that data throughput rates on the network depend on a number of factors. These include the wireless technology being used, technology being used, transmission power levels, distance from the base station and the terrain profile. Some trialists were able to experience download rates of 14 Mbps (TCP) and 23 Mbps (UDP) at up to 2km from the base station. Beyond 2km, throughput rates decreased but were still very usable up to 5km. Moreover, DTT receivers themselves were found to exhibit widely varying performance in the presence of transmissions from the WSDs, with protection requirements varying up to 30 dB.

7.3. USE OF THE 2.3 GHZ BAND IN EUROPE

In WRC-07, the 2.3 GHz band was identified for IMT services. 3GPP then standardised the band for LTE Time Division Duplex (TDD). However, in Europe the band is used for amateur services government use (for example wireless camera, emergency services and aeronautical telemetry). Most European countries are considering towards Licensed Shared Access (LSA) of this band[42]. This is because this band is not mainly used to provide mobile broadband services as agreed in WRC-07. Hence there is an opportunity for spectrum sharing. LSA is regulatory approach in which a limited number of secondary licensees can use a spectrum band assigned to one or more incumbent users. The additional secondary users are allowed to use the spectrum in line with sharing rules specified in the rights of use spectrum thereby allowing all authorized users including the incumbents to meet a particular Quality of Service (QoS). European Telecommunications Standard Institute has already released LSA specifications [43]. The LSA architecture consist of two components: LSA Repository and LSA Controller. The LSA repository has information about spectrum availability. LSA Controller, on the other hand, is located in the network operator's domain and its role is to ensure that the network operate in line with instructions received from the LSA repository. LSA differs from opportunistic spectrum access through cognitive radio, spectrum trading, unlicensed access or access to a band on secondary basis because all users are in LSA are guaranteed QoS. LSA is of use when some critical incumbents cannot be vacated from a certain spectrum band. GSMA have voiced their support for LSA [44] stating that mobile operators will be able to access complementary spectrum. UK's OFCOM has already developed regulation for the use of 2.3 GHz band[45]. The license if referred to as local access licence and is applicable to many other bands including 800 MHz, 900 MHz, 1400 MHz, 1800 MHz, 1900 MHz, 2100 MHz, 2600 MHz and 3.4 GHz bands.

7.4. KANSAS ISP USE OF CBRS FOR COVID-19 RESPONSE

The experience of many communities throughout the pandemic saw the immediate need for adequate and reliable broadband access to the internet – for distance learning, telehealth, telework, emergency services, connecting with friends and family and purchasing goods when stores have been closed. An ISP based in El Dorado Kansas[46], took advantage of the Citizens Broadband Radio Service (CBRS) and utilised Blinq FW-300i[47] and CommScope's Spectrum Access System (SAS) to rapidly provide high-speed internet access in the Greenwood County region. Prior to utilising CBRS, Velocity was primarily using the 5 GHz unlicensed band for

---

[42] LSA in 2.3 GHz in Europe

[43] ETSI LSA Specifications: https://www.etsi.org/newsroom/news/1181-2017-04-news-etsi-releases-specifications-for-licensed-sharedaccess

[44] GSMA on LSA: https://www.gsma.com/spectrum/wp-content/uploads/2013/04/GSMA-Policy-Position-on-LSA-ASA.pdf

[45] OFCOM Local Access License: https://www.ofcom.org.uk/__data/assets/pdf_file/0037/157888/local-access-licence-guidance.pdf

[46] How a Kansas ISP Swiftly leveraged CBRS to connect a rural community https://blinqnetworks.com/wpcontent/uploads/2021/05/BLiNQ-Case-Study-Velocity_2.01.pdf

[47] FW-300i radio: https://blinqnetworks.com/products/fw-300i/

fixed wireless access. The hilly terrain and low-density population of Greenwood County presented several obstacles to obtaining good quality connectivity, such as distance coverage and various difficulties due to terrain blockage. The obvious course of action was to find a better technology that could meet these challenges. Velocity evaluated the new CBRS band and felt that it was an appropriate solution given CBRS's LTE (Long Term Evolution) capabilities and could offer good quality of service to customers across a greater distance. The spectrum sharing scheme offered by CBRS meant ample bandwidth was readily available with minimum spectrum procurement cost. General Authorised Access (GAA), which is the lightly licensed part of the CBRS band, would also easily support the coverage area.

7.5. TVWS IN KENYA AND OTHER PLACES IN AFRICA

A number countries in Africa, Kenya included, have deployed TVWS pilots. In Kenya, Microsoft in collaboration with the government of Kenya's Ministry of Information and Communications and Indigo Telecom Ltd., launched a pilot project delivering low-cost wireless broadband access to previously unserved locations in Laikipia County near Nanyuki and Kalema. The aim of the network was to test the feasibility of TVWS technology in providing low-cost broadband to communities lacking access to broadband internet. The network covered 235 km^2 and provided broadband access to a population of about 20, 000 people (three schools, local county government and a few businesses as shown in Figure 9. In a report on the project submitted to CA, the partners indicated that the project was extremely successful and that it demonstrated the technical viability of TVWS network [48]. Speeds of up to 16 Mbps on a single 8 MHz TV channel at distances of up to 14 km were achieved with TVWS stations operating at 2.5 Watts EIRP power. There have also been trials within the last ten years in South Africa, Ghana, Malawi and Tanzania [49]. All the trials in Africa have demonstrated the technical feasibility of TVWS and all showed that WSDs can operate with no harmful interference to DTT. Recently in Tanzania, TVWS has been used in deployment of a community network known as Kondoa Community network [50] making it the first community network in Africa to use TVWS. A number of countries in Africa including South Africa, Nigeria, Uganda and Malawi have already developed regulations on the use of TVWS[51]. South Africa have already developed their own geolocation database[52] making it the first country in Africa to have its own geolocation database.

---

[48] Kenya TVWS Trial: http://dynamicspectrumalliance.org/assets/TVWS_Report_for_Kenya_final_final_24_Aug.pdf

[49] TVWS Trials in Africa: https://ieeexplore.ieee.org/document/7331920

[50] Kondoa Community Network in Tanzania: https://kcn.or.tz/

[51] Countries Africa having TVWS regulations: https://link.springer.com/chapter/10.1007%2F978-3-030-70572-5_1

[52] South Africa geolocation database: http://www.itiis.org/digital-library/manuscript/870

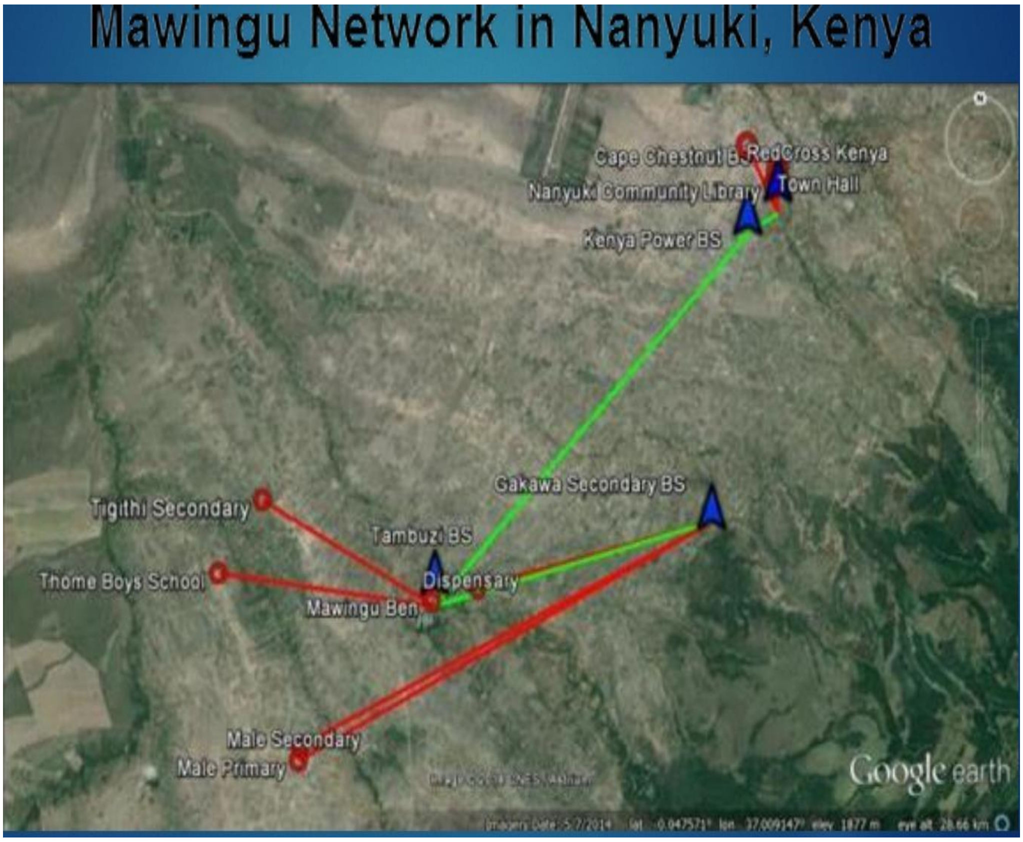


Figure 9: Coverage of the First TVWS Trial Network in Kenya in Nanyuki, 2013

Source: Mawingu Networks

Strathmore University

@iLabAfrica Centre

4th Floor, Student Centre,
Strathmore University,
Madaraka Estate, Ole Sangale Road
P.O Box 59857 - 0200 City Square
Nairobi Kenya

Facebook: @iLabAfrica
Twitter: @iLabAfrica
Instagram: @iLabAfrica
LinkedIn: @iLabAfrica
www.ilabafrica.ac.ke