Analysis Studies on Opportunity of Spectrum Sharing for Non-Public Networks in Kenya

About this Study

The project consortium of this study was supported by the Foreign, Commonwealth and Development Office (FCDO) and the Dynamic Spectrum Alliance (DSA) under the Digital Access Programme (DAP).

Led by the African Advanced Level Telecommunications Institute (AFRALTI), the consortium consisted of the following partners: Aegir Consult, a local GIS partner and the following academic partners – Strathmore University, University of Nairobi and the University of Strathclyde working in collaboration with the Communications Authority of Kenya (CA).

In this report, the consortium presents status, comparisons and findings of a study on the potential and feasibility of authorising implementations and deployments of Non-Public Networks (Private Networks) through spectrum sharing in the mid-band radio frequency (RF) bands in Kenya.

The study is part of the preliminary work envisaged to enable the development of a National Spectrum Sharing Strategy for Kenya. Key to its findings, is the opportunity to identify pilot trials and deployments of Non-Public Networks (NPNs) composed of private LTE and 5G networks for use in appropriately suitable locations where Kenyan citizens are still underserved or where enterprises have compelling use cases that can be served better through NPNs.

Definition of Terms

Anchor Institution
Refers to locations / entities (public, for-profit, or nonprofit) that have a significant local presence and serve as the community's social and economic anchor by providing vital services, including educational institutions, community centres, government agencies, libraries, NGOs, hospitals and health clinics, financial institutions and cultural/religious organizations. Focus should be prioritized on institutions that target and serve women, girls and marginalized groups.

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 many regimes, it can be described as delivering 10 Mbps for a home with five users, schools AP, healthcare and public sector facilities access points.

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.

End User
An individual or group of individuals (including within an organization) that access the provided network services.

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 networks reach 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.
Mobile Network Operator	An entity that provides mobile cellular services over its own network infrastructure which include voice, text (SMS) services and data.
National Backbone (or Core) Network	The network that connects international Internet traffic (usually through undersea or terrestrial fibre-optic cables) to the national high-speed, high-capacity backbone network connecting the country's bigger cities and major population centres.
Point of Presence	A Point of Presence (PoP) is a point or physical location where two or more networks or communication devices build a connection from one place to the rest of the internet; A PoP primarily refers to a location, facility point that connects to and helps other devices establish connections to the Internet.
Quality of Service	The standard of Internet service required to enable each level of usage, in terms of download and upload speeds, latency and the total monthly bandwidth consumption per user corresponding to each usage level.
Universal access	Refers to reasonable telecommunication access for all.

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Abbreviations

3G	The Third Generation Mobile Communications System
3GPP	The 3rd Generation Partnership project
4G	The Fourth Generation Mobile Communications System
5G	The Fifth Generation Mobile Communications System
AP	Access Point
CA	Communications Authority of Kenya
CN	Community Network
CR	Cognitive Radio
CSIR	Council for Scientific and Industrial Research
DSA	Dynamic Spectrum Access
DSA	Dynamic Spectrum Alliance
FS	Fixed Services
FSS	Fixed Satellite Services
GIS	Geographic Information System
GSMA	Global Association of Mobile Network Operators
IMT	International Mobile Telephony
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
KNBS	Kenya National Bureau of Statistics
LSA	Licensed Shared Access
LTE	Long-Term Evolution
NPN	Non-public Network
NRA	National Regulatory Authority
OSA	Opportunistic Spectrum Access
PIP	Policy Impact Partners
RF	Radio Frequency
RLAN	Radio Local Area Network
SDR	Software Defined Radio
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
UHF	Ultra-High Frequency
VHF	Very High Frequency
VLP	Very Low Power
WAS	Wireless Access System
WinnForum	Wireless Innovation Forum

Executive Summary

The conventional wisdom that spectrum is scarce, particularly mid-band spectrum, has led to a growth of interest by the regulator and Radio Frequency (RF) spectrum researchers in Kenya. With the preliminary studies in the country based on TV White Spaces and Wi-Fi 6E showing that the concept of "use it or share it" holds great potential to alleviate the wireless Internet access challenges faced by the underserved groups, various stakeholders have become interested in the approach of exploring opportunistic access to unused or underutilised spectrum. Moreover, other stakeholders view this as a window to rapidly drive implementations of Industry 4.0 innovations, particularly the Internet of Things (IoT).

In this report, we present the analysis of spectrum sharing in the mid-band RF spectrum in Kenya as an evaluation of what can potentially be the roadmap for authorising deployments of Non-Public Networks (NPN) beginning with pilots to further long-term rollouts. The RF bands assessed within this study have been identified by the Communications Authority of Kenya (CA) under the aegis of its strategy to evaluate the usability of the assigned but underutilised RF spectrum while enabling reach for the underserved alongside innovations on emerging technologies.

CA's strategy is in consideration of the outcomes from the World Radiocommunications Conference (WRC) 2023, the emerging needs of wireless Internet access in the country, the previous studies in both Ultra-High Frequency (UHF) band and the 6GHz band, the Community Networks (CNs) framework as well as the evolving landscape of Industry 4.0 innovation in Kenya.

While the study has predominantly evaluated and compared the implementation of NPNs in other countries and geographical regions in the mid-bands (especially through Private 5G networks), the RF bands considered within this study have included: 450 MHz, 700 MHz, 1.5 GHz, 1.7 GHz, 2.3 GHz, 2.6 GHz, 3.3 GHz, the C-band (3.8 – 4.2 GHz), 4800-4990 MHz, 5925-7125 MHz. Although this report does not present the detailed specifics of opportunistic access of each of these bands, it highlights which of these bands hold potential for sharing while showing the current incumbent usage and the models that can be borrowed from other regimes for enacting regulations for Kenya.

Therefore, the analysis within this study has considered various developments happening across all the three International Telecommunication Union (ITU) regions in the mid-bands, the applications and use cases of spectrum sharing in the identified bands and the relevant incumbent datasets necessary to assess the feasibility of deploying Non-Public Networks (NPNs). Hence, a major part of this work has also included Geographic Information Systems (GIS) analysis on the present usability of the 800 MHz, 2.6 GHz and 3.5 GHz bands by the incumbents alongside their coverage while mapping out the potential sites for NPN deployments. The potential NPN deployments have been identified based on the various special economic zones in Kenya including Konza City and the Mwale Medical and Technology City together with economic opportunities in various sectors across the country.

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Introduction

1.1. Background to the Access Gap Study

In the ever-evolving landscape of telecommunications, the utilisation of International Mobile Telephony (IMT) bands is pivotal for ensuring widespread connectivity. As Kenya strategically advances its draft agenda to develop a National Spectrum Sharing Strategy, understanding access gaps in the IMT bands is fundamental for informed decision-making.

This background reflects on the previous Access Gap Studies (AGSs) in Kenya which primarily focused on identifying underserved and unserved voice and broadband access gaps based on cellular services [1]. Hence, the AGSs sets the stage for this study which is centred on feasibility of spectrum sharing in the IMT bands.

As the landscape of telecommunications advances, there is a pressing need to conduct comprehensive analyses of the underserved regions and the relevant access models that can spur Industry 4.0 innovations. Understanding the unique challenges such regions poses and the opportunities they present is crucial for developing targeted interventions that bridge the connectivity gap and unlock emerging innovations.

1.2 Previous Study Insights

The preceding Access Gap Study in 2016 illuminated significant disparities in voice and broadband coverage within Kenya. Notably, around 3 million people (5.6% of the population) lacked access to voice services, and over 22% faced a broadband access gap, affecting approximately 13 million individuals. Encouragingly, the study revealed progress. Broadband coverage through 3G and 4G had expanded to nearly match 2G coverage.

The follow-up Access Gap Study published in 2021 saw a drop in the number of unserved sub-locations to 79 out of 7,149 in total accounting for 1.1%. A further 196 sub-locations had less than 50% population coverage, which was also greater than half reduction from 2016. The 2021 Study revealed that broadband was now dominated by 4G and covered 56.3% of Kenya's geographical area. 96.3% of the population was reported to be covered.

Of particular significance is the substantial progressive positive impact resulting from the transition of broadband services from 3G to 4G by Tier 1 operators. The dominance of 4G over 3G on the coverage map marks a noteworthy shift in access to data in Kenya. This transformation is facilitated, in part, by the utilisation of the 700/800 MHz frequency spectrum, extending the reach of broadband coverage particularly in rural areas where the Universal Service Fund (USF) initiatives had earmarked as priority areas.

The decision to embrace the 4G technology is supported by a forward-looking rationale, given its 10x bandwidth capacity and extended geographical coverage. Notably, the application of the 700/800 MHz spectrum plays a crucial role in bridging connectivity gaps in remote areas, aligning with the objectives of the USF.

However, the proposed expansion of 4G infrastructure with USF support was recommended to carefully consider the retention of 2G sites in the underserved areas. This strategic consideration is driven by the necessity to maintain voice coverage, especially given the relatively low smartphone penetration rate which is not more than 40%.

1.3 Temporal Evolution

Since the 2021 study, there have been noteworthy shifts in the deployment of key telecommunications technologies licensed by CA. The voice services gap, considering all Tier 1 operators, has reduced to around 3.4%, and the broadband service gap has reduced to 3.7%. These achievements signify advancements in closing the digital divide. However, the focus of this current study speaks onto effective and efficient approaches that can enable access to the underutilised IMT spectrum to provide connectivity in needing locations or needing compelling innovations.

Looking ahead, the potential impact of 5G adoption holds transformative promise for the Kenyan market. Beyond significantly higher data speeds and increased capacity, 5G's deployment also holds the promise of wide-area coverage. 5G is poised to accelerate the Internet of Things (IoT) and smart applications in vertical industrial spaces and other private-network applications. Such applications as also identified for Kenya are potentially indoors or in campus and special economic environments and hence, less dependent on the traditional licensed approach of cellular spectrum [2].

The temporal evolution and the potential impact of IMT bands underscore the need for a comprehensive and future-ready spectrum sharing strategy. The efficient utilisation of the available spectrum frequencies and underlying technology offers opportunities to further reduce access gaps, enhance connectivity, and advance the Kenya Digital Masterplan 2022-2032[1].

1.4 Significance of IMT Bands and Spectrum Sharing Studies

The number of Mobile Broadband (MBB) subscribers, number and variety of devices and the amount of data used per user has been tremendously growing in recent years leading to increasing spectrum demand [3]. To address this rise in demand, the wireless industry alongside forward-looking regulatory authorities have been gradually embracing a new thinking for spectrum allocation, utilisation and management. The new thinking in this case is what is referred to as spectrum sharing.

Kenya, through the CA has highlighted spectrum sharing as a way that can help find a balance between the different domains, systems and services with different spectrum needs and dynamics [4]. As such, feasibility studies on spectrum sharing have been running in Kenya since 2013 when TV White Space (TVWS) pilots were launched in the terrestrial broadcasting bands.

As more awareness and knowledge on the approach of spectrum sharing in the country matures, a shared understanding that the feasibility and attractiveness of it requires close cooperation between business, policy and technology domains, has also emerged.

With CA taking a central role in investigating viable models of spectrum policy and regulation triggered by such an innovation, the focus on more spectrum bands has been broadened. The focus, as shared in this analysis, includes identification of opportunity of shared access in various IMT bands such as 700 MHz, 1.5 GHz, 1.7 GHz, 2.3 GHz, 3.3. GHz and the C-band (3.8-4.2 GHz). These bands can unlock possibilities that were previously unthinkable through Non-Public Networks (NPNs) to become attractive candidates for Industry 4.0 use cases and

delivery of reach for the underserved in locations where they are available for secondary access.

1.5 Role of GIS in IMT Bands and Spectrum Sharing Analysis

Spectrum sharing and coverage determination can be very effectively and strategically be guided through the use of where Geographic Information Systems (GIS) tools. Using GIS, the examination of access gaps in IMT bands can be done comprehensively by integrating spatial data such as demographic information, land use patterns, and administrative boundaries. This approach allows stakeholders to identify specific geographical areas where Non-Public Networks (NPNs) approaches to spectrum sharing are likely to have the greatest effect in line with the objectives of the proposed National Spectrum Sharing Strategy.

In addition, through leveraging GIS tools, spectrum resources can be allocated effectively and this ensures that their socio-economic effects are maximised as well. This study integrated GIS to emphasizes the need for a scientific, data-driven and geographically informed approach that can provides a strong foundation for successful implementation of IMT spectrum sharing initiatives.
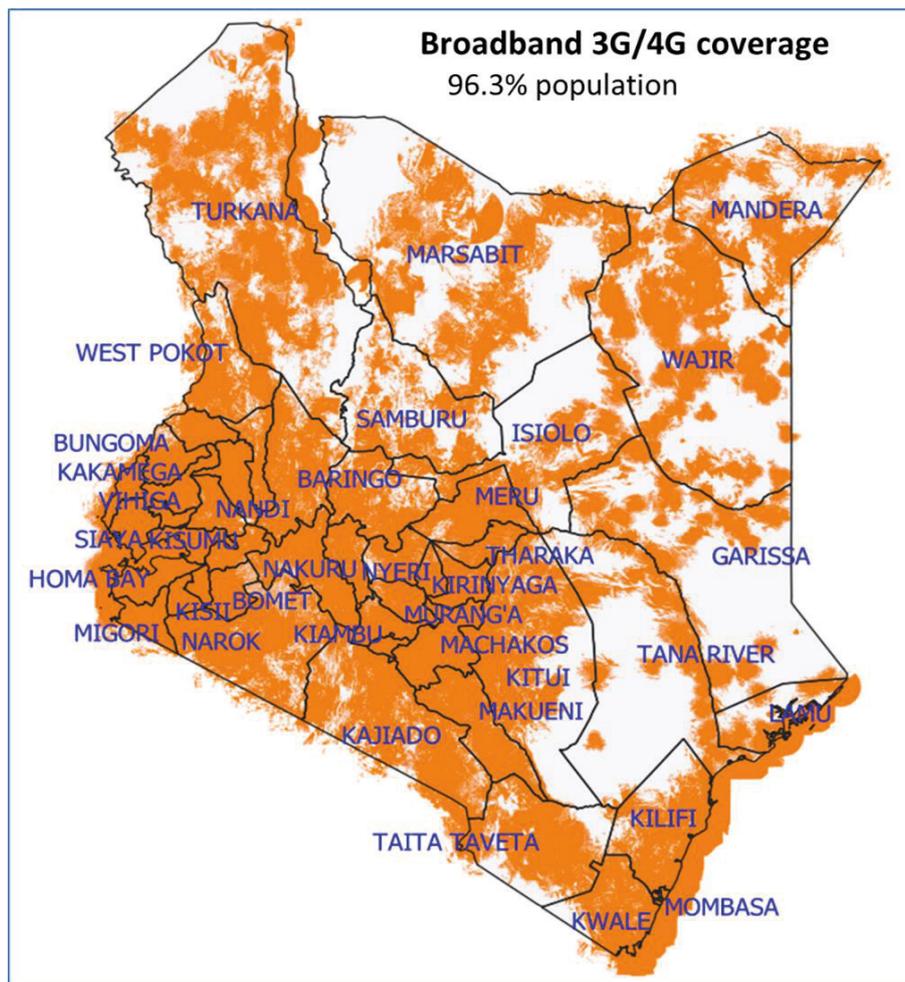
Figure 1: 3G/4G Broadband Coverage 2021

1.6 Towards a Comprehensive National Strategy

The analysis of underserved and unserved regions through a scientific access gap study methodology sets the stage for the development of a comprehensive strategy. This strategy aims to leverage technological advancements, regulatory frameworks, and targeted investments to bring about positive change in these areas. Understanding the specific challenges faced by each region allows for tailored solutions, whether it be the deployment of advanced broadband technologies or the retention of foundational telecommunications services.

In the context of the current study focusing on Mid-band spectrum sharing, this analysis becomes even more critical while remaining cognizant of the fact that advances in technology creates the potential to use spectrum more effectively. It provides the groundwork for the identification of the areas where spectrum sharing interventions can have the most significant impact.

By addressing the connectivity challenges in underserved and unserved regions, the study seeks to contribute to the overarching goal of fostering a digitally inclusive society, where the benefits of modern telecommunications are extended to all the segments of the population with the aim of offering connectivity to all.

Building upon the insights from the 2016 and 2021 studies, this study is uniquely tailored to focus on the opportunity that spectrum sharing presents by leveraging GIS tools and models. The study aims to identify areas where NPNs can unlock untapped potential, allowing for a more efficient and widespread usage of RF spectrum. The study's ultimate goal is to contribute to the development of a robust National Spectrum Sharing Strategy, ensuring that the benefits of NPNs are harnessed for the greater connectivity and socioeconomic development of Kenya.

02

Previous Spectrum Sharing Studies in Kenya

2.1 Overview

Although spectrum sharing can be applied to most RF bands, the authorisation of opportunistic access is inherently band specific. Variables such as propagation characteristics, size of the band, the nature of incumbent users, the nature of the shared use requested, feasibility of proposed use cases, availability of a coordination mechanism and other factors must collectively be considered.

Some of the underutilised bands can be most effectively shared based on frequency separation (adjacent channel sharing) or based on geographic separation (e.g. co-channel sharing), or on a temporal basis – and some based on a combination of methods that exploit unused spectrum capacity. The bedrock principle of opportunistic spectrum access (OSA) is that secondary users (opportunistic users) and the coordination process itself should have minimum or no interference to the incumbent users [5].

In this section, we highlight previous developments on spectrum sharing in Kenya. Here, we envisage that the focus of the previous RF bands such as the UHF spectrum (470-694 MHz) and the 6 GHz band can provide a good basis for regulatory discussion on licensing models and database interference mitigation-based sharing model. This can also serve useful for implementation of Non-Public Networks (NPNs). We underscore that the different transmit power requirements and bandwidth (channel sizes) for the previous bands contribute to the great considerations of constraints that are necessary to guarantee protection of incumbents in the mid-bands.

2.2 Previous RF Bands Evaluated

Similar to various regions and countries around the world, the first ever adoption of spectrum sharing in Kenya was through Television White Spaces (TVWS) [6]. TVWS authorisation in Kenya was enacted to allow access to unused Digital Television Transmission (DTT) channels by Wireless Internet Service Providers (WISPs) to opportunistically exploit the broadcasting spectrum to provide Internet access to the underserved rural areas [7].

Earlier validation studies leading to the ratification of the regulatory framework for TVWS showed that not all of the 28 channels of 8 MHz bandwidth had been activated at each transmission site as shown in Figure 2.
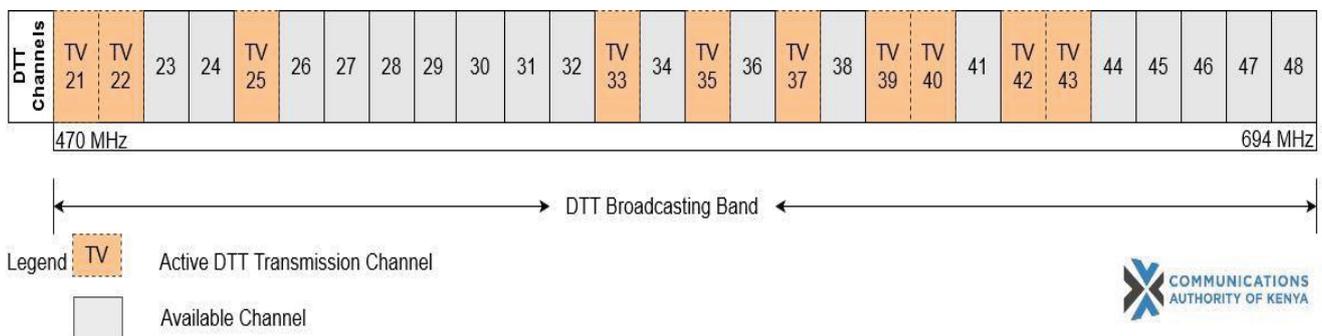
Figure 2: An example of available TV channels in Kitui County

(Source: CA)

Following up to the publication of the regulatory framework for TVWS was the release of the Licensing and Shared Spectrum Framework for Community Networks (CNs) [8]. The CNs framework explores changes to spectrum regulation that could unlock more potential for community-centred connectivity by expanding the range of spectrum access options including both license-exempt and licensed IMT spectrum.

The framework further sets the stage as part of medium-term plans to develop a shared spectrum framework for underutilised IMT spectrum and earmarks various RF bands that could potentially be leveraged via spectrum sharing. Such RF bands include 1700 MHz, 2300 MHz, 2500 MHz, 2600 MHz, 3300 MHz and 3500 MHz bands. Some of these RF bands (2300 MHz, 2500 MHz & 2600 MHz) had been allocated to government agencies while some had not been assigned yet.

Between September 2022 and February 2023, Kenya also carried out coexistence studies in the 6 GHz band (5925 – 7125 MHz) to assess the compatibility of Wireless Access Systems (WAS/Wi-Fi 6E) operating in the band alongside the incumbents (Fixed Services and Fixed Satellite Services) without posing harmful interference.

2.2.1 TV White Spaces

TV White Space (TVWS) studies began in Kenya in August 2013 through the Microsoft4Afrika initiative when Microsoft (in partnership with Jamii and Indigo Telcom) was given a 1-year trial authorisation to conduct a pilot of TVWS network in rural Central Kenya.
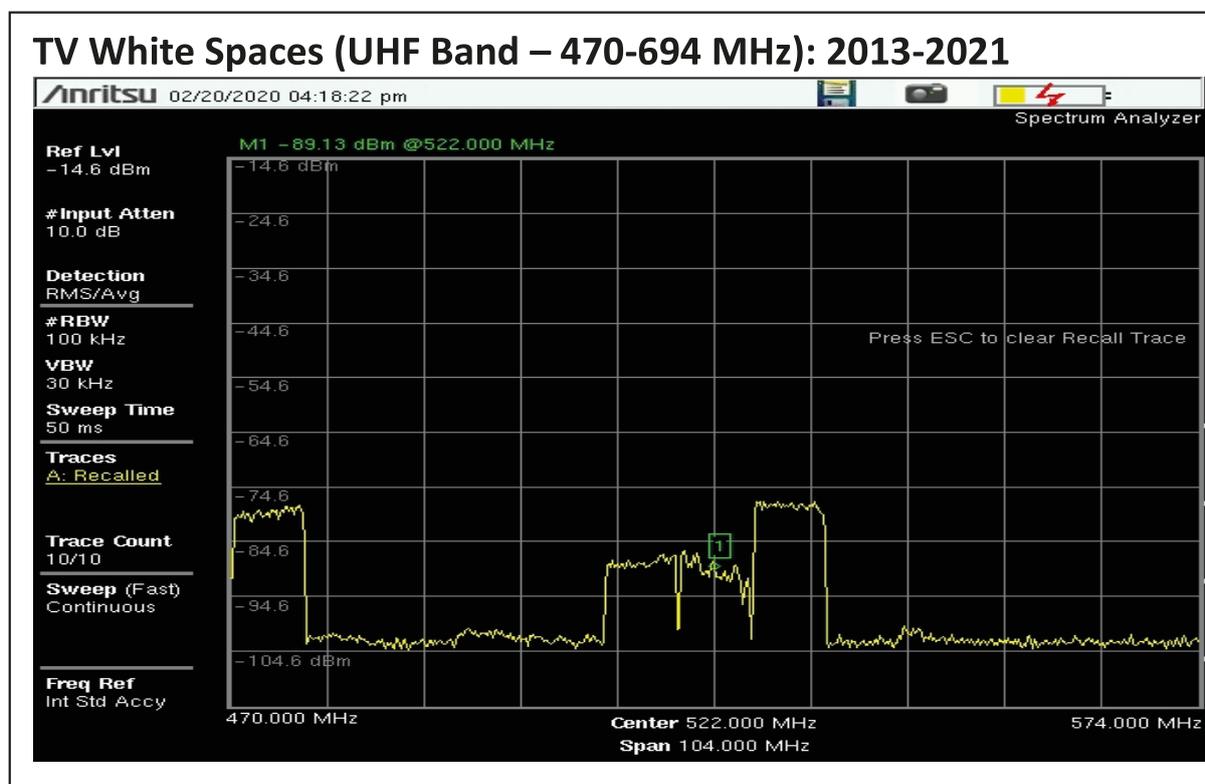
Figure 3: Fallow spectrum in the UHF TV band

(Source: CA)

Building up to these findings was the subsequent work of collaborative studies between Strathmore University and the University of Strathclyde in partnership with CA that sought to investigate the use of Dynamic Spectrum Management (DSM) databases with Software Defined Radios (SDRs) under the Engineering and Physical Sciences Research Council (EPSRC) fund. It was within these studies that the first ever spectrum sharing database was tested using the Nominet database in 2018. During the same period, more fallow spectrum was identified in the 470-694 MHz band as shown in Figure 3.

In May 2021, the ratification of the regulatory framework for TVWS adopted a lightly licensing model alongside the use of dynamic spectrum coordination system (DSMS) to manage the usage of the frequency channels and power levels for the White Space Devices (WSDs) by means of an automated database. Both fixed and portable devices were authorised.

The maximum permitted power of a WSD was capped at 42 dBm over the 8 MHz channel with the ITU-R P-1812 recommendation (a path-specific propagation prediction method for point-to-area terrestrial services in VHF and UHF bands) considered for coexistence modelling. The considerations for protection of the incumbent services were guided by the Model Rules and Regulations for the Use of TVWS developed by the DSA [9]

.2.2.2 Community Networks (CNs)

The publication of the Community Networks (CNs) framework in June 2021 demonstrated a deliberate roadmap to provide affordable Internet access to the underserved while ensuring that the RF spectrum is efficiently utilised. The CNs are kinds of networking infrastructures built to provide local affordable connectivity solutions and services. They tend to rely on a combination of technologies to optimise affordability, complexity, quality and performance.
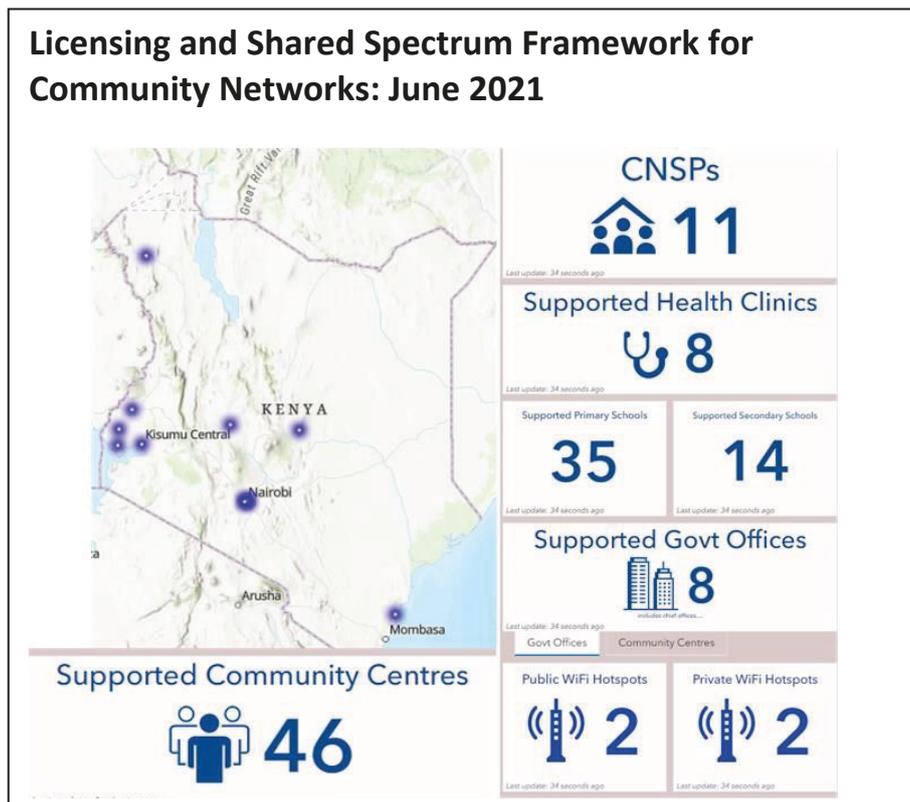
Figure 4: Working Map of Community Networks in Kenya
(Source: Aegir Consult)

Traditionally, the legal nature of CNs has relied on operating self-provisioned networks running on free-use spectrum in licence-exempt bands of 2.4 GHz and 5 GHz [10]. However, with the challenges of congestion within these bands, there has been a growing demand of RF spectrum to address connectivity needs in areas with low-income or have less reliable or affordable alternative networks. Hence, the consideration of shared spectrum networks such as TVWS to enable more deployments by CNs in the underserved areas. Before the ratification of the licensing framework, there were only 4 CNs in Kenya. Presently, the number has increased to 13. Figure 4 shows the distribution of 11 CNs as at March 2023.

2.2.3 Coexistence Studies in the 6 GHz Band

Coexistence studies in the 6 GHz band examined the technical aspects of coexistence and compatibility between the Fixed Services (FS) and the Fixed Satellite Services (FSS) – the licensed occupiers of the 6 GHz band – and the potential of Wireless Access Systems (WAS)/ Radio Local Area Networks (RLANs) occupying the band as secondary entrants.

Coexistence Studies in the 6 GHz Band (5925 MHz – 7125 MHz): 2022-2023
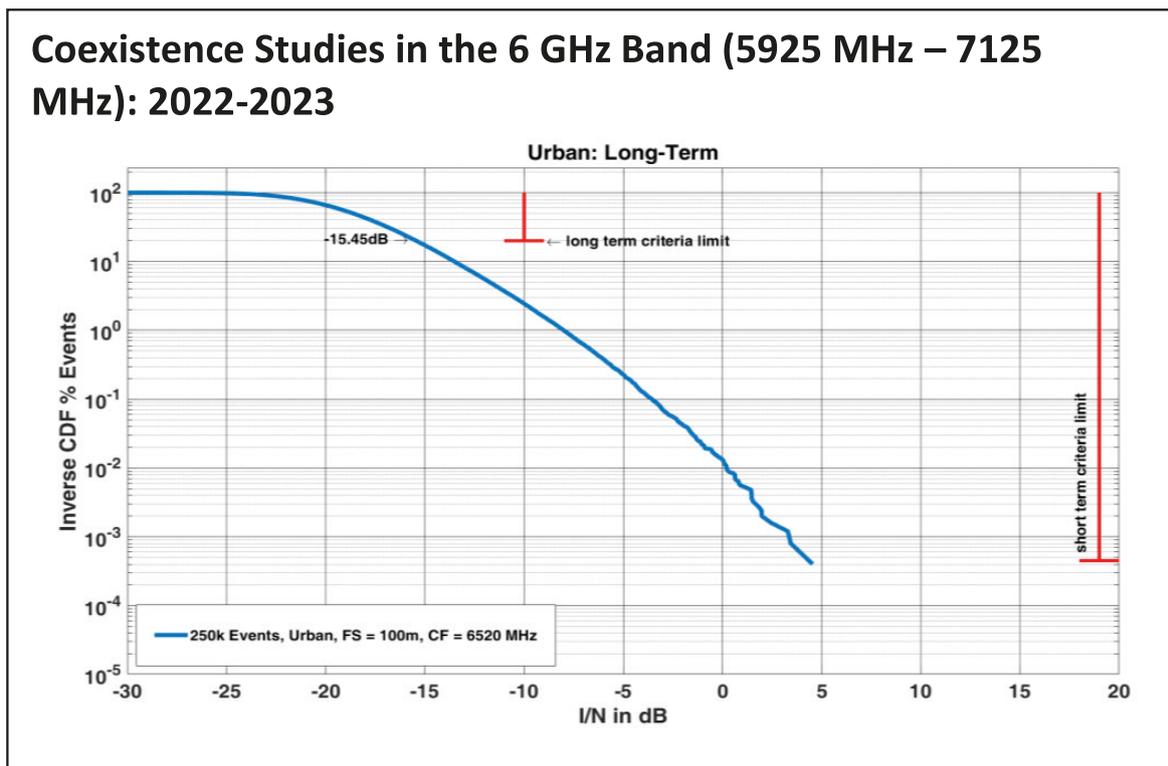
Figure 5: Long-term simulation scenario for 6 GHz Coexistence

(Source: Strathmore University)

The coexistence studies followed up to an earlier economic study of Wi-Fi in Kenya [11]. The economic study estimated the cumulative economic value of Wi-Fi to reach US $20.29 billion between 2021 and 2030 if the full 1200 MHz in the 6 GHz band was to be allocated.

The technical assessment, similar to studies by the European Union (EU), US and Mexico, considered Wi-Fi usage based on Kenya's estimated population by 2025. It also considered the full 6 GHz band based on data provided by CA as well as the considerations for both Low Power Indoor (LPI) and Very Low Power (VLP) RLANs with statistical scenarios of urban, suburban and rural Kenya.

The Monte Carlo statistical method was used for FS/RLAN coexistence simulation while a mathematical analysis using MS Excel was adopted for FSS (Earth to Space)/RLANs. The selection of parameters was guided by the allocations from the CA within the band, ITU-R's and EU's recommendations on bandwidth, antenna pattern, noise figure, antenna heights and gains and the power considerations of 23 dBm (200 mW) for LPI and 14 dBm (25 mW). Simulation results (through SEAMCAT and Excel) showed an opportunity of spectrum sharing by the RLANs without causing interference to the incumbents.

2.3 Considerations for the Analysis of the Mid-Band Spectrum

2.3.1 Overview

In this analysis, we consider the rising demand of RF spectrum in the wake of Industry 4.0 innovations such as Internet of Things (IoT) and the challenges of meaningful access faced by Kenyans in various parts of the country.

According to the International Telecommunication Union (ITU), "Meaningful Connectivity" is defined as a level of connectivity that allows users to have a safe, satisfying, enriching and productive online experience at an affordable cost [12]. The Alliance for Affordable Internet (A4AI), on the other hand, has a Meaningful Connectivity Framework that refers to "Meaningful Connectivity" as one that can deliver 4G-like speeds [13]. According to GSMA, 4G basically means convenience, stability and very fast data speeds of up to 100 Mbps in the downlink and 50 Mbps in the uplink (depending on the spectrum available).

The 2022 study by A4AI showed that only 24% of the Kenyan population was estimated to have meaningful connectivity as shown in Figure 6. A publication by KICTANet in March 2023 on the "State of Internet Penetration in Kenya" [14] shows that many rural areas still experience a huge coverage gap.

The cumulative population in the rural areas (which is higher than the urban population) is not yet benefitting from high-capacity bandwidth due to poorly developed last-mile infrastructure that can move capacity where it is needed. Moreover, last-mile electricity still remains a challenge that exacerbates the digital divide for the rural populations.
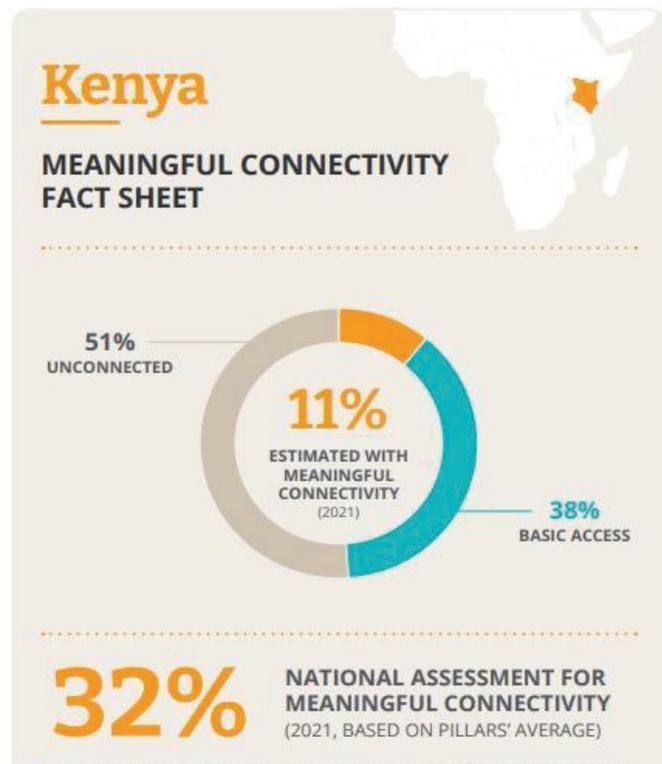
Figure 6: Meaningful Connectivity Fact Sheet from A4AI 2022 Study

(Source: A4AI)

2.3.2 Evaluation Principles for NPNs

The evaluation of Non-Public Networks (NPNs) is guided by key principles that ensure these networks are efficient, secure, and compliant with regulatory standards. These principles include assessing spectrum efficiency, ensuring high Quality of Service (QoS) through key performance metrics, and evaluating the security and data privacy measures in place to protect against unauthorized access and breaches. Additionally, interoperability with public networks and other NPNs, as well as integration with existing IT and Operational Technology (OT) systems, are crucial for seamless operation in hybrid environments.

Moreover, the scalability and flexibility of NPNs are evaluated to ensure they can accommodate future growth and adapt to technological advancements. Regulatory compliance, particularly in spectrum licensing, is critical to avoid legal issues, while cost-efficiency and return on investment (ROI) are assessed to justify the deployment and operation of these networks. By adhering to these principles, NPNs can be designed and managed to meet the specific needs of enterprises and industrial applications effectively.

To support the deployment of Non-Public Networks (NPNs) for provision of private LTE and 5G networks in the underserved areas and to support various industry vertical use cases, the following principles for opportunistic spectrum access (OSA) are highlighted for consideration in Kenya:

1. The availability and potential of the RF bands that can support wireless broadband access, private networks and the prospective industry use cases that can benefit from NPNs.

2. The existing licensing framework (s) alongside the opportunity to allow flexible usage for the available and usable spectrum.

3. An examination of pilots in various parts of the world as a basis of evaluating availability of equipment.

4. Sufficient amounts of unused spectrum in rural and underserved areas.

5. The potential of coexistence between the incumbent users and the NPNs.

6. The time factor – evaluation of the period of the existing licensees using the spectrum and the provision of meaningful access.

03

Methodology and Findings

3.1 Methodology

Our methodology for this study involved comprehensive desk research and a thorough analysis of various secondary sources while utilising key methods and tools to understand the current situation through modelling, applied research and predictive analytics. This included an examination of previous spectrum studies conducted within the Country, as well as comparative analyses of studies from other countries and regulatory environments worldwide.

The study also reviewed published regulatory frameworks in Kenya, including the framework for the authorisation of TV White Space (TVWS), licensed shared access for community networks, guidelines on the use of RF spectrum for short range devices among others. Recent publications by the Communications Authority (CA), specifically the new draft guidelines on national radiofrequency spectrum policy, were also critically analysed to ensure alignment with current regulatory trends and emerging practices.

In addition to the local secondary sources, the study also examined global developments of Non-Public Networks (NPNs) with a focus of both private LTE and 5G in all the ITU regions as shown in Figure 7. This was done while drawing examples and models that can potentially be adopted and adapted for Kenya. Scrutiny of the NPN developments was also conducted through focus groups led by the CA while also evaluating publications by the Dynamic Spectrum Alliance (DSA) and other regulatory regimes on the opportunity of spectrum sharing for the Private LTE and 5G Networks.

Spectrum sharing concepts under study in the technology, policy and business domains such as Licenced Shared Access (LSA) in Europe and the three-tier Citizens Broadband Radio

Service (CBRS) from the US were also reviewed. LSA system and framework was studied to explore its potential as a complementary model that can provide an IMT shared access option for Kenya to cope with the growing mobile broadband demand.
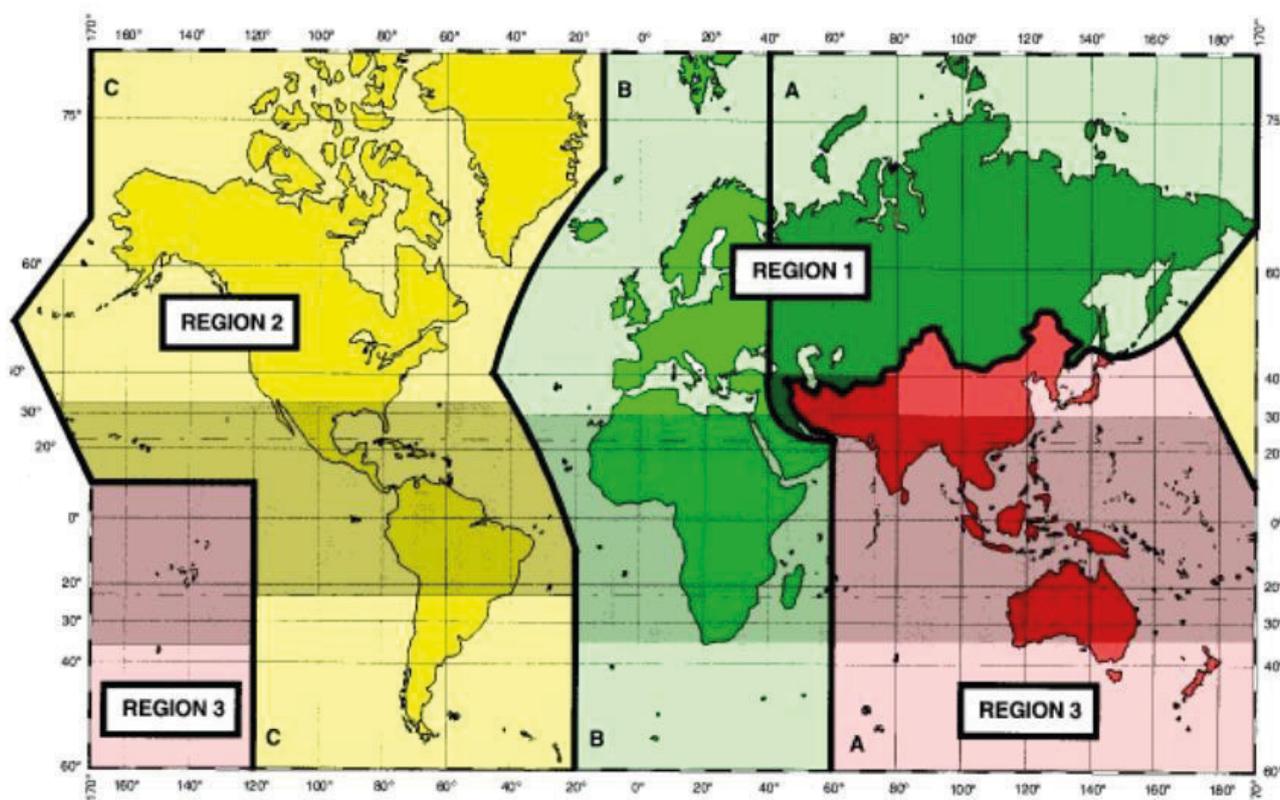
Figure 7: The Different ITU Regions

(Source: ITU)

3.2 Global Landscape of Mid-band Spectrum Allocation for Non-Public Networks (NPNs)

While some countries in the different ITU regions have already designated certain RF bands for Private LTE and 5G, others are yet to consider such an approach (or have not publicly published yet). Other regulatory regimes have gone ahead to initiate pilot deployments which form a good basis for near-future potential to pilot NPNs in the following counties: Nairobi, Kisumu, Uasin Gishu and Nyeri. These four counties presently host offices for the CA's monitoring stations.

Research conducted and published by the DSA on how new forms of spectrum sharing are enabling more people to benefit from broadband connectivity and digital services with example countries of Colombia, Malaysia and South Africa, show that the IMT spectrum in the mid-bands is not fully exploited today [15].

Proposals have been made for other complementary models such as spectrum set-asides that can further meet different connectivity requirements in both LTE and 5G. These approaches have been identified as comparative considerations to shared IMT spectrum and are supported by other regulators [16] and the Global Association of Mobile Network Operators (GSMA) [17]. However, the spectrum set-asides, while seen as holding potential to spur industry innovation through exclusive licensed access to spectrum, raises questions for further evaluation based on the following:

a. The impact on the efficiency of spectrum use.
B. Overall spectrum availability.
C. Location of access to the spectrum.

D. Interference requirements.

3.2.1 Regulations and Policy on NPNs in all ITU Regions

This section presents a regulatory and policy landscape on NPNs across all the three ITU regions. We first enumerate the various RF bands identified for NPNs through both private LTE and 5G in the various sub-regions and countries as well as the overall regulatory approach of allowing new entrants to opportunistically exploit the IMT spectrum. We note that some countries have already enacted regulations and policies to guide deployments of private LTE and 5G networks.

3.2.1.1 ITU Region 1

In ITU region 1, Table 1 presents the existing regulatory approach for sub-regions and countries where considerations (as well as potential considerations) have already taken place (or what seems to be the potential direction to be taken) as identified in the select RF bands. The column for status informs on whether regulations have been approved or are still under consideration/proposed.

Table 1: Spectrum Considerations for Non-Public Networks in ITU Region 1

Sub-Region	Country	Licensed RF Bands	Status	Approach of Regulations	Spectrum Cost
Europe	Belgium	3.8 - 4.2 GHz	Approved	Shared access licence[2]	€1,000 Index-linked annual fee of €318 per sq. km/MHz
	Denmark	3.8 - 4.2 GHz	Proposed	Obligatory leasing where the licensees are obliged to either provide the local service or lease the spectrum in a specific area	
	Finland	2.3 – 2.32 GHz	Approved	Shared Local Access[3]	
	France	2575-2615 MHz	Approved	Lightly-licensed	
		3.8 – 4.0 GHz	Trial	Lightly-licensed	
	Netherlands	1800 MHz, 3.4 - 3.45 GHz, 3.75 – 3.8 GHz	Approved	Lightly-licensed	
		3.8 – 4.2 GHz	Pilot/Trial	Lightly-licensed	
	Germany	3.5 GHz	Approved	Localised licence	
	Spain	2370-2390 MHz	Approved		
	Sweden	1780-1785 MHz, 1875-1880 MHz, 3720-3800 MHz			
	United Kingdom (UK)	1800 MHz (1781.7-1785/1876.7-1880 MHz), 2300 MHz, 3.8-4.2 MHz[4]	Ratified through local licensing ("the shared access bands")	Shared Access Licence: 1. Low-power licence (per area licence) 2. Medium power licence	An annual licence is charged for both cases; £80 per 10 MHz for 3.8-4.2 GHz (so 20 MHz = £160; 100 MHz = £800 etc) £80 for 2300 MHz shared spectrum (10 MHz) and 1800 MHz shared spectrum (2 x 3.3 MHz)

The UK case study

The UK's dynamic position on increasing access to spectrum for innovation and reach for the underserved seems to be the most progressive on the European continent. In 2019, Ofcom published a statement on Shared Access to Spectrum Supporting Mobile Technology [18] to allow more people and businesses to use spectrum from a choice of the following frequency bands – 3.8-4.2 GHz, 1800 MHz and 2300 MHz through a local license model for private network deployments across these three bands.

Local access to these bands was (is) anticipated to support growth and innovation across a range of sectors, such as manufacturing, logistics, enterprise, agriculture and health through set up of local networks that can provide greater control over security, reliability and resilience. The proposed model by Ofcom is also meant to enhance rural wireless broadband connectivity using fixed wireless access (FWA). To manage interference, Ofcom implements a coordinated access.

In November 2023, Ofcom published a consultation [19] on proposals targeting to enhance supply of spectrum in the 3.8-4.2 GHz. Ofcom presently seeks to explore potential adjustments that can provide more flexibility in terms of power levels (permitting an additional 3 dB EIRP in the "Low Power" scenario), coordination approach of access to the band as well as pricing.

Study Consideration: <u>United Kingdom</u>

Considered Bands: 3.8-4.2 GHz, 1800 MHz (1781.7-1785 MHz paired with 1876.7-1880 MHz), 2300 MHz (2390-2400 MHz); 24.25-26.5 GHz (lower 26 GHz band also considered)

Regulatory Approach: Local Shared Access with coordination provided on a first come, first served basis.

Two approaches of the Shared Access Licence: *Low Power Licence (per area licence)* to allow users to deploy the required number of base stations in a circular area of 50-metre radius without further authorisation. *Medium power licence (per base station licence)* for deployments in rural areas only given the higher transmit power and larger potential interference area.

Regulatory Fees: £950 per licence (for successful applicants) allowed for three years unless a different period is requested.

Use Cases: private networks (for enterprises and Industrial Internet of Things (IIoT)), mobile coverage (rural), mobile coverage (indoor) and Fixed Wireless Access (FWA).

Future Consideration: Potential transition towards Dynamic Spectrum Access (DSA) supported by a fully automated database in the outlined RF bands; Ofcom has created an email for industry and public contributions through: SharedSpectrumAccess@ofcom.org.uk

Figure 8: Ofcom's local licence approach for 3.8-4.2 GHz, 1800 MHz and 2300 MHz

GHz

TRAFICOM

Finnish Transport and Communications Agency

Study Consideration: <u>Finland</u>

Considered Bands: 2300 to 2320 MHz (available under Traficom's radio licence).

Regulatory Approach: Local 4G/5G use.

The Radio Licence requirement: The frame structure of a licence holder's outdoor base stations must primarily comply with the uplink-downlink synchronisation configuration 2 (ETSI TS 136 211, clause 4.2, Table 4.2-2). A local mobile network can operate on the basis of a radio licence granted by Traficom without any separate network licence. For the option of FWA, a radio licence can be granted with the requirement that the subscription be used in the pre-defined operating location, primarily using a fixed outdoor antenna installed in the building.

Regulatory Fees: €279.83 for 5 MHz bandwidth, €559.66 for 10 MHz bandwidth and €1,119.31 for 20 MHz bandwidth in the 2300-2320 MHz band.

Use Cases: Local 4G/5G networks intended to be used at factories, ports, airports, shopping centres, power plants and mines. Under certain conditions, the networks can also be used for Fixed Wireless Access (FWA).

Future Consideration: 3.8-4.2 GHz (identified for local mobile communication networks but under study within the European cooperation); Currently, Traficom can grant radio licences for research and development use for a maximum of one year at a time, based on case-by-case consideration.

Figure 9: Traficom's Spectrum Sharing approach for the 2300-2320 MHz and Future Consideration for 3.8-4.2 GHz

3.2.1.2 ITU Region 2

In ITU region 2, Table 2 presents the existing regulatory approach for North America and South America sub-regions in various identified bands.

Table 2: Spectrum Considerations for Non-Public Networks in ITU Region 2

Sub-region	Country	Licensed RF Bands	Service Name	Users	Approach of Regulations
North America	United States	3.5 GHz (3550-3700 MHz)	Citizens Broadband Radio Service (CBRS)	Incumbent: Military application (DoD) Priority Access Licences (PAL) Secondary: General Authorised Access (GAA)	Tiered Spectrum sharing model administered through the use of Spectrum Access System (SAS)
		3.7 - 4.2 GHz (C-Band)	Proposed authorisation of coordinated shared access by FWA with the incumbent FSS – in a substantial portion of the downlink C-band.		Shared, all-come, all-served basis **(under the Access Licensing Framework)** for unused spectrum
	Canada	3800 MHz (3650 – 4200 MHz)	Fixed and mobile services	Incumbent: FSS Secondary: Fixed and mobile access (for private 5G)	**Adopted:** Flexible use licensing model
South America	Brazil	700 MHz 1800 MHz 2500 MHz	5G Deployment	Incumbent: 3G & 4G Secondary: Private 5G	Frequency Reuse

Study Consideration: Canada

Considered Bands: 3650-4000.

Regulatory Approach: Flexible use licensing model for fixed and mobile services in the 3650-4000 MHz band.

The Radio Licence requirement: Implementation of a Non-competitive Local (NCL) licensing framework based on a first-come, first-served (FCFS) basis.

Use Cases: ISED designated 3900-3980 MHz band for shared use to leverage the emerging equipment ecosystems for 5G technology and provide opportunities for users including wireless Internet service providers (WISPs), utilities and industry verticals. These industries may benefit through private networks to enable a wide range of automated, robotic and remote operations for real-time monitoring, dispatching and emergency notifications; Provision of fixed-wireless broadband access in rural and remote areas and for services such as automatic meter reading and video surveillance

Future Consideration: ISED recognises that there are new sharing technologies and techniques, such as dynamic spectrum access and sees the adoption of an automated system for FCFS spectrum licensing as a first step towards a spectrum licensing regime that could be made available through dynamic spectrum access in the future.

Figure 10:Canada's ISED shared spectrum consideration in the 3650-4000 MHz band

3.2.1.3 ITU Region 3

In ITU region 3, Table 3 presents the existing regulatory approach for various countries in Asia and Pacific Region in various RF bands.

Table 3: Spectrum Considerations for Non-Public Networks in ITU Region 3

Country	Licensed RF Bands	Status	Approach of Regulations
Malaysia	1452-1492 MHz	Under Consideration for sharing	Currently unavailable
Singapore	1427-1518 MHz	Under Consideration for sharing	Currently unavailable
Iran	1427-1518 MHz	Approved regulations	Flexible Technology / Flexible application
Australia	3400-3475 MHz	Approved	Low-power local area wireless broadband (LA WBB)
	3700-4200 MHz	Approved	WA Wireless broadband (WBB) and Low Power Local Area (LA WBB) coordinated FSS use.
Korea	4.72 GHz – 4.82 GHz	Approved	Private 5G network deployment

Study Consideration: <u>Korea (South Korea)</u>

Considered Bands: 4.7 GHz (4.72 – 4.82 GHz)

Regulatory Approach: Private 5G Frequency use type: Type 3 (Standalone NPN – also called Private 5G operators) and Type 1 (Public Network Integrated – PNI NPN – also called enterprise Private 5G).

The Radio Licence requirement: An organisation that wants to provide 5G network services to enterprise customers must be approved by Ministry of Science and ICT (MIST) as a private 5G common carrier.

Use Cases: Logistics, shipbuilding, R&D Institutions, Training, Healthcare, Steel plant, Manufacturing, Factory Defence, Amusement Park, Energy plants and offices.

Future Consideration: Expanded use of the 4.7 GHz (4.72-4.82 MHz) and the 28 GHz (28.9 – 29.5 GHz).

Figure 11: South Korea's Private 5G Network Considerations

3.2.2 International Coordination

The growth and adoption of private cellular networks – also referred to as Non-Public Networks (NPNs)- can only spur rapidly if regulatory regimes can coordinate their regulatory frameworks. Fortunately, there has been a growing trend of spectrum liberalisation within regimes (building onto developments of TV White Spaces and Wi-Fi 6E), that can potentially accelerate the global adoption of private LTE and 5G networks [20].

Some of the national regulators have already established regulations to release or are in the process of granting access to shared and local area licensed spectrum5. Some of these regulatory examples (covered in the previous section) include the three-tiered Citizens Broadband Radio Service (CBRS) spectrum sharing scheme in the United States and Canada's planned Non-Competitive Local (NCL) licensing framework in North America. In South America, Brazil has set up Private Limited Service (SLP) licences.

In Europe, some of the examples include:

- UK's shared and local access licensing model.
- Germany's 3.7-3.8 GHz and 28 GHz licensing for 5G campus networks.
- France's vertical spectrum and sub-letting arrangements.
- Netherland's geographically restricted mid-band spectrum assignments.
- Finland's 2.3 GHz and 26 GHz licences for local 4G/5G networks.
- Sweden's 3.7 GHz and 26 GHz permits.
- Norway's regulation of local networks in the 3.8-4.2 GHz band.
- Poland's spectrum assignment for local government units and enterprises.

In Asia and Australia, some of the examples include:

- Bahrain's private 5G network licences.
- Japan's 4.6 – 4.9 GHz and 28 GHz local 5G network licences.
- South Korea's 5G allocations in the 4.7 GHz and 28 GHz bands.
- Taiwan's provision of 4.8-4.9 GHz spectrum for private 5G networks.
- Hong Kong's Localised Wireless Broadband System (LWBS) licences.
- Australia's apparatus licensing approach.
- India's Captive Non-Public Network (CNPN) leasing framework.

The ongoing global and regional harmonisation initiatives support shared and local spectrum license frameworks in multiple national markets.

3.3 Industry Studies and Positions

In this section, we highlight the various industry studies, experiences, developments and recommendations of opportunistic access to spectrum in the IMT bands that can serve as baselines for regulatory, policy, technology and economic developments for NPNs in Kenya.

3.3.1 The Dynamic Spectrum Alliance (DSA)

The Dynamic Spectrum Alliance (DSA) has been at the forefront of advocating for laws, regulations and economic best practices that can lead to more efficient usage of spectrum while fostering innovation and affordable universal access.

As an active contributor to effective approaches of making use of RF spectrum (the lifeblood of all wireless communications), DSA originally developed the model rules and regulations that were adopted as a template across many regulatory regimes for TV White Spaces (TVWS) [9]. TVWS did not only gain attention due its ability to bridge the digital divide gap but also due to its pioneer status on spectrum innovation that has radically been changing the way spectrum is being allocated and used across the globe in the recent past [21].

3.3.1.1 Potential Opportunity of Spectrum Sharing in the IMT Bands: Experiences in South Africa, Malaysia and Colombia

In a White Paper published in September 2019 entitled Enhancing Connectivity Through Spectrum Sharing [15], DSA in association with Policy Impact Partners (PIP) note that government and industry stakeholders are open to exploring new approaches to spectrum sharing in the three case study countries – Malaysia, South Africa and Colombia – a representation of three continents. In all the three countries, the stakeholders are keen to support trials of new spectrum sharing technologies in IMT bands. Such trials are seen as great benchmarks to provide the stakeholders with insights into the potential of tiered models for spectrum sharing as exemplified in the US in the 3.5 GHz band.

In Colombia, pilots in the 900 MHz band had been commissioned to determine the viability of community networks in remote underserved areas with planned trials to be conducted in the 2.3 GHz and 2.6 GHz bands. The planned trials would offer 30 MHz to 50 MHz of spectrum – sufficient to provide rural connectivity and private 5G services. However, the approach would consider planned assignments for the incumbents in the IMT bands.

Unlike South Africa where the potential of spectrum sharing in the 900 MHz and 1800 MHz exists, Malaysia's longer-term approach to the 2.3 GHz and 2.6 GHz bands seems to be an exclusive provision for licensed access to support IMT services.

DSA underscores that the best way to trial and ultimately implement spectrum sharing varies country by country, depending on how the specific frequency band is being used today, the existing regulatory framework and the authorisations as well as the potential partnership opportunities. DSA emphasises that the optimum way to implement technology trials would be through partnerships between the relevant industry players, authorised by the NRAs and in some cases, supported from independent entities such as the Council for Scientific and Industrial Research (CSIR) in South Africa. CSIR actively participated in TVWS studies in South Africa.

A general consensus exists among various stakeholders in various regimes supporting well-designed dynamic and other spectrum sharing models to enable build-outs that can expand access to the mid-bands while protecting incumbents from harmful interference.

3.3.2 Wireless Innovation Forum

The Wireless Innovation Forum (WInnForum) is a U.S. based international non-profit organisation driving technology innovation in commercial, civil, and defence communications around the world. Forum members bring a broad base of experience in Software Defined Radio (SDR), Cognitive Radio (CR) and Dynamic Spectrum Access (DSA) technologies in diverse markets and at all levels of the wireless value chain to address emerging wireless communications requirements.

WInnForum strongly advocates allocation of spectrum with licenses adapted towards a spectrum usage rights method that has minimum necessary restrictions to provide adequate protection against harmful interference. As such, it envisions that a unified active management of spectrum should make use of spectrum access databases to enable increased sharing and dynamic nature of spectrum management.

WInnForum's active work on the evolution of centralised spectrum sharing from TV White Spaces, CBRS and 6 GHz has led to its development of a visual that illustrates the structure of the relationships among spectrum sharing stakeholders as shown in Figure 12. Moreover, the organisation has also developed an infographic that anticipates more bands to be shared in US in future as shown in Figure 13.
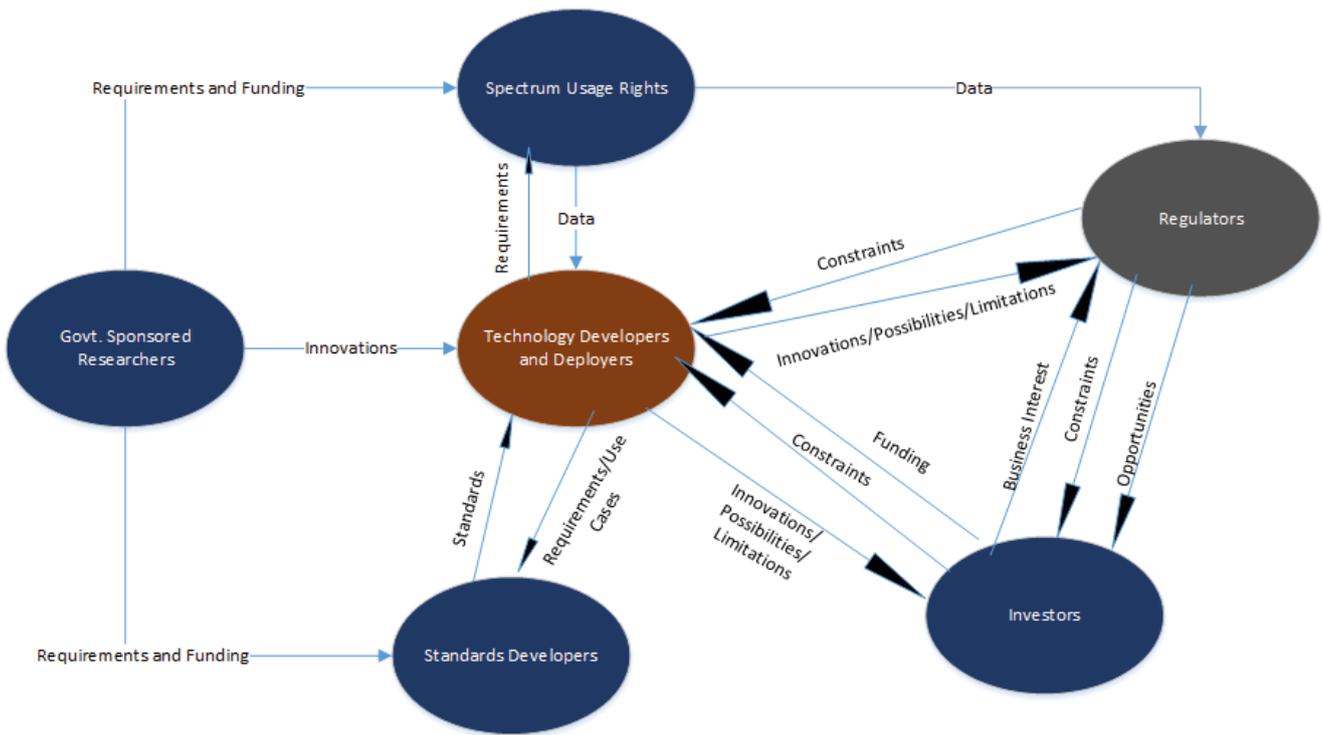
Figure 12: Relationships among Spectrum Sharing Stakeholders
(Source: WInnForum)

	TVWS	CBRS	6 GHz	Future Bands
When Deployed	2012	2020	~2023	2024 and Beyond
Which Band	VHF/UHF	3550-3700 MHz	5925~7125 MHz	Various
Sharing Method	TVWS Database	Spectrum Access System (SAS)	Automated Frequency Coordination System (AFC)	Dynamic Spectrum Availability Manager
Incumbents Protected	TV Broadband, Wireless Microphones	Department of Defense, Fixed Satellite	Licensed Microwave, Radio Astronomy	Various

BAND OPERATION

Figure 13: The When, How and Why of the Bands
(Source: WInnForum)

3.3.3 GSMA Consideration

The GSMA's approach to making spectrum available for private or local users recommends a careful consideration of weighing against the cost resulting from potentially causing harmful disruption to the existing incumbent model of MNOs.

While being against spectrum set-asides, GSMA alludes to the complexity of spectrum sharing frameworks in practice. Some of the concerns raised include certainty of access and tenure as well as potential interference issues with other users limiting the potential benefits from sharing for NPNs.

Hence, GSMA proposes catering for private networks through licence conditions to leverage the experience of MNOs. Although this can be seen as an approach to support Public Network Integrated (PNI) –NPNs, the mechanism for licencing limits the spectrum innovation proposed through spectrum sharing.

3.4 Applications, Technology and Devices

3.4.1 Overview

Private cellular networks – also referred to as Non-Public Networks (NPNs) in 3GPP termi-nology – have rapidly gained popularity in recent years due to privacy, security, reliability and performance advantages over public mobile networks and competing wireless net-works. They use localised network infrastructure (such as small access points) to provide coverage and connectivity for private use – seen as scaled-down version of a public cel-lular network. Some of these potential benefits of private networks are shown in Figure 14.

3.4.2 Applications and Deployment Examples

USA, Germany, Finland and Japan have ongoing enterprise technology deployments for NPNs to support Industrial Internet of Things (IoT). Most of the deployments are standalone (dedicated on-premise networks) with only a few cases such as one for BMW and e.Go Mobile involving collaboration with MNOs (hybrid networks). Appetite for NPNs is seen to grow among enterprises in the following industries: manufacturing, transport, mining, the public sector and utilities.

According to Kaleido intelligence6, the base of LTE and 5G Private Network sites is projected to increase from 576 in 2019 to 22,719 in 2026 with a substantial number of sites deployed across verticals such as energy and utilities (including oil, mining and gas projects), manufacturing and transportation.

Analysys Mason have published a Private LTE/5G networks tracker7 that shows a list of contractors, connectivity providers, enterprise customers as well as the current geographical coverage of the deployments. Figure 15 shows the various countries where private LTE/5G networks have been deployed.

Service Level Agreements (SLAs): Private Networks with dedicated bandwidth can be designed to fit an individual user's requirements in terms of coverage, bandwidth, reliability, latency and connection density.

Costs/Competition: Some stakeholders believe that the costs of building and operating a private network will be lower than the prices paid for public mobile network services with a similar SLA.

Control and Customisation of Private Networks: Private Networks allow full control due to the presence of on-site staff and the ability to implement quick changes to the network configuration.

Security and Data Privacy: Private networks can provide an improved level of security and privacy, as security policies can be custom designed and can be controlled within the organisation without having to rely on outside service proiders.

Limited Need for Dedicated Spectrum: Private networks require less spectrum than public network. In areas where operators are not making full use of a specific band, industrial companies might be able to sub-lease spectrum that they need through commercial negotiations.
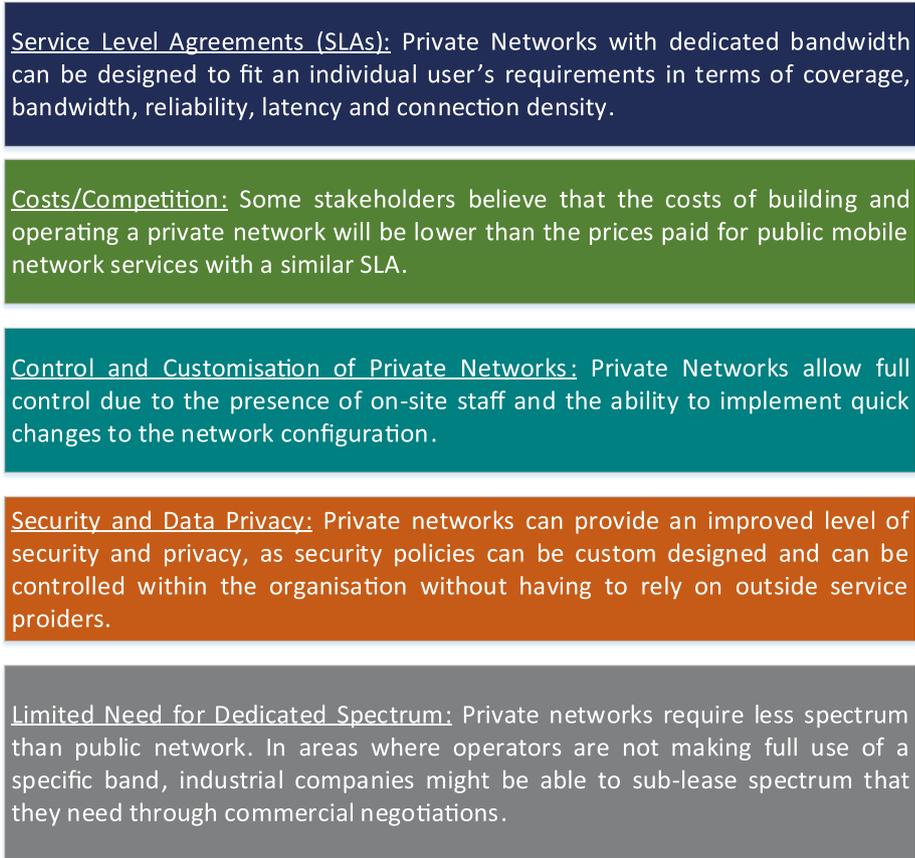
Figure 14: Potential benefits of private networks

(Source: Analysys Mason)

Figure 15: Geographical Coverage for Private LTE/5G

(Source: Analysys Mason)

3.4.3 Summary of Other NPN Applications

Table 4: Summary of NPN Existing Use-case Engagements

(Source: SNS Telecom)

Vertical	Use Case	Country/Countries
1. Agriculture	Custom-built 250 MHz LTE networks that provide wide area cellular coverage for agribusiness machinery, vehicles, sensors and field workers. Standalone local 5G Network supporting 4K Ultra-High Definition (UHD) video transmission and other advanced smart agriculture-related application capabilities	Brazil Japan
2. Aviation	Private LTE and 5G Networks have been deployed or being trialled to support internal operations at some of the busiest international and domestic	Hong Kong, Japan, UK, France, Germany, Belgium, Netherlands, Austria, Greece,
	airports; private 5G connectivity being leveraged for aircraft maintenance operations.	Finland, Norway and the USA
3. Broadcasting	Within the broadcasting, FOX Sports, BBC, BT Groupe, RTE and several other media and broadcast players are utilising private 5G network – both temporary and fixed installations to support live production and other use cases.	UK, USA, Germany
4. Construction	Employing the use of private LTE and 5G networks to enhance productivity and worker safety.	China, Finland, UK, Japan and South Korea
5. Education	Higher education institutes are at the forefront of hosting on-premise 5G networks in campus environments for experimental research or smart campus-related applications. A key prevalent theme in the education sector is the growing number of purpose-built LTE networks aimed at eliminating the digital divide for remote learning – particularly CBRS networks for school districts in the United States.	Japan, US, Canada and the Czech Republic
6. Forestry	There is a considerable interest in private cellular networks to fulfil the communications needs of the forestry industry for both industrial and environmental purposes.	Japan, Canada and Sweden
7. Healthcare	Dedicated 5G campus networks have been installed or are being piloted to support smart healthcare applications in many hospitals; on-premise LTE networks are also operational at many hospitals and medical complexes across the globe.	Japan, South Korea, Germany etc.
8. Manufacturing	Many manufacturing industries across the globe are integrating private cellular connectivity into their production operations at their factories for Industry 4.0 applications.	USA, South Korea, Japan, UK, Germany, France etc.

9. Ports and Maritime Transport	Many port and terminal operators are investing in private LTE and 5G networks to provide high-speed and low-latency wireless connectivity for applications such as Automated Guided Vehicles (AGVs), remote-controlled cranes, smart cargo handling and predictive maintenance; in the maritime transport segment, onboard private cellular networks – supported by satellite backhaul links – are widely being utilised to provide voice, data, messaging and IoT connectivity services for both passenger and cargo vessels while at sea.	USA, Germany, China etc.
10. Public Safety	A myriad of fully dedicated, hybrid government-commercial and secure MVNO/Multi-Operator Core Network (MOCN)-based public safety LTE networks are operational or in the process of being rolled out throughout the globe – ranging from national mission-critical broadband platforms to 5G NR-equipped Public Protection and Disaster Relief (PPDR) for first responder agencies; For example, Taiwan's Hsinchu City Fire department is using an emergency response vehicle – which features a satellite backhauled private 5G network based on Open RAN standards – to establish high-bandwidth, low-latency emergency communications in disaster zones.	Taiwan, Spain, France, South Korea, Thailand, Canada etc.
11. Utilities	Private cellular networks in the utilities industry range from wide area 3GPP Networks – operating in 410 MHz, 450 MHz, 900 MHz and other sub-1 GHz spectrum bands – for smart grid communications to purpose-built LTE and 5G networks aimed at providing localised wireless connectivity in critical infrastructure facilities such as power plants, substations and offshore wind farms.	China, Bahrain, Japan, South Korea etc.
12. Other Sectors	Private LTE and 5G networks have also been deployed in other vertical sectors, extending from sports, arts and culture to retail, hospitality and public services; From a horizontal perspective, enterprise RAN systems for indoor coverage enhancement are becoming common alongside end-to-end private networks for office buildings and campuses.	
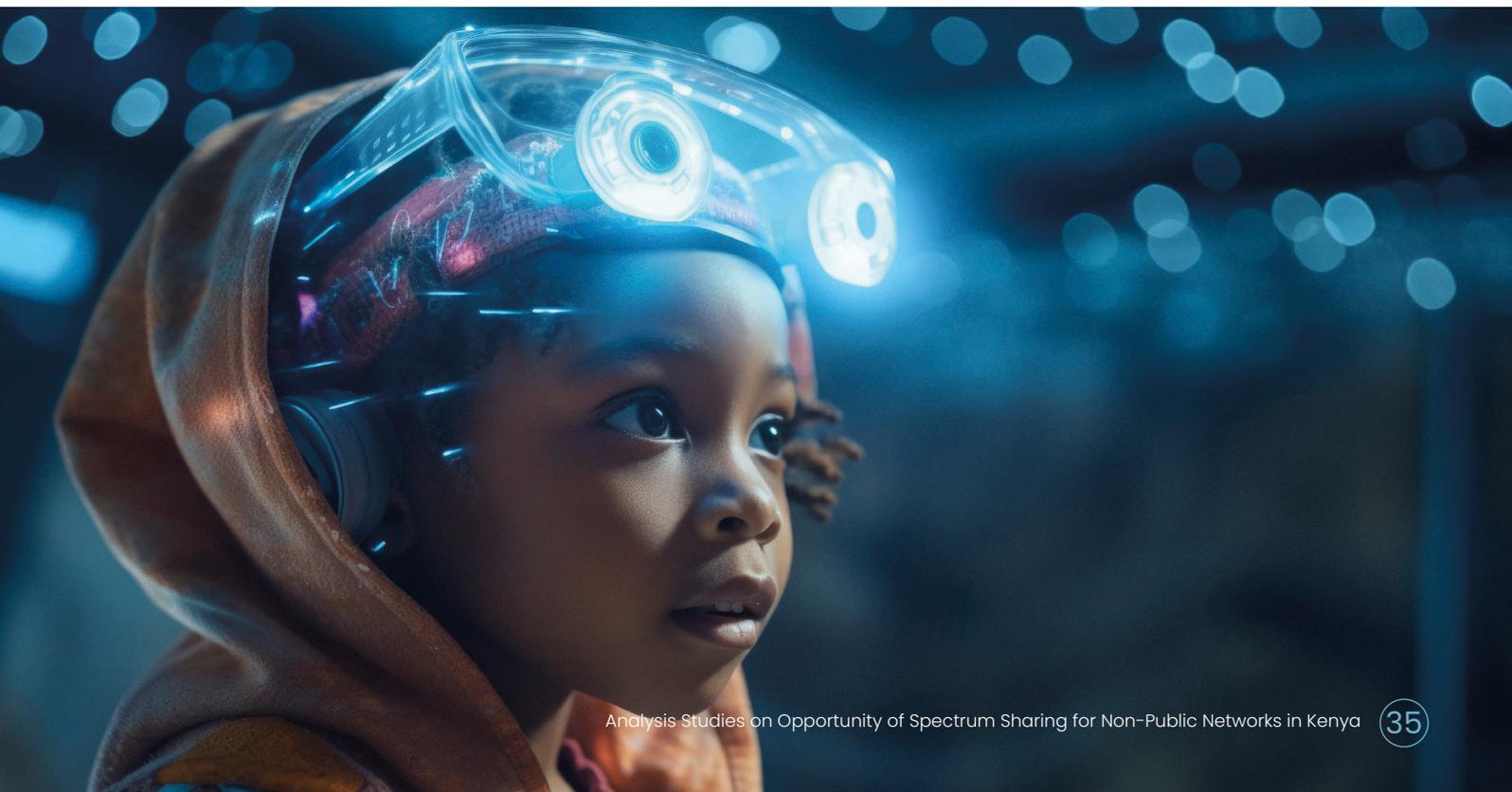
3.4.4 Private 5G Networks for Rural Access: Case Study from the DCMS 5G Testbeds and Trials Programme

The experience and learnings of the 29-member "5G RuralFirst Consortium" under the UK's Department for Digital, Culture and Sport (DCMS) project on 5G Testbeds and Trials Programme present findings that are worth learning from for rural connectivity initiatives – driven by a new thinking of spectrum access, funding, pricing and business models.

While the UK's largest population is distributed within cities8, its rural economy is cited to be worth £300 bn contributed by 17% of UK's 67.6 million population [22]. On the other hand, Kenya's largest population is distributed in the rural areas and experiences a myriad of economic challenges ranging from stable electrical power, limited digital skills and lack of access to devices among others [23].

The 5G RuralFirst project alludes to the rural connectivity challenges underpinned by the low population densities, challenging terrain, poor or even non-existent digital services and the macro-cells deployed by MNOs to provide coverage to large areas – which often sacrifice speed to coverage. In scenarios where low-cost deployment scenarios can be developed, lack of available and usable spectrum results in limited market access to new entrants. The project investigates potential benefits that could accrue for rural areas from the deployment of more advanced and more available digital services, enabled by 5G and 4G/LTE technologies and by emerging regulations.

The project offers the following key takeaways:

a. ***Doing different things, differently –*** investigating new technology and new spectrum bands that can deliver 'cheaper', 'faster' and 'better' access to digital services. While 5G networks are inevitably led by the traditional MNOs and focused on urban areas, a combination of lower barriers to entry with easier access to spectrum should be supported for investment in rural areas. Some of the studied bands include 700 MHz, 3.4-3.8 GHz (as at 2019) and 24.25 to 27.5 GHz.

b. ***Government is a key player –*** National, Regional and Local Governments have key facilitating roles – in ensuring a supportive regulatory environment to promote multi-stakeholder approach to the development of enhanced rural connectivity ecosystems and by incentivising investment.

c. ***Support for rural innovation –*** Collaborative developments that can enable deployment of Private 5G networks as backhauls for Low Power Wide Area Networks (LPWANs) such as LoRa/LoRaWAN or implementation of 3GPP's Narrowband (NB)-IoT and LTE-M for many rural monitoring and IoT situations. Such networks support relatively low data rate, low cost, high coverage, resilient radio power link budget solutions.

d. ***Support of Shared Access Models –*** Ofcom's proposals look to provide a platform for innovation meant to significantly reduce the cost of access to high quality spectrum in regional areas. Spectrum sharing is therefore seen as an essential administrative approach that needs further research for dynamic access implementation.

e. ***Potential Opportunity to deploy Dedicated Fixed Wireless Access (FWA) Solutions:*** Noting that there is a high correlation between poor broadband availability and poor mobile coverage, dedicated fixed cellular wireless broadband can be deployed to offer superior coverage, capacity and cost structure based on both LTE and 5G networks.

3.4.5 State of NPN Technologies and Device Availability

Non-public networks are implemented to replace existing proprietary radio networks or fixed Ethernet networks. NPN coverage in principle is defined as not only limited to some local small locations and rather is also expected to cover some broad regional areas with specific context and application.

As pointed out by the EU 5G PPP Technology board [24], NPN functionality is related to at least one application that has specific requirements in terms of reliability, lifecycle management, security or costs. Meeting these requirements needs frequency coordination, high global sales volumes and scalable design to drive CAPEX down. The deployed technology should also be able to support a long lifecycle to drive OPEX down.

NPN implementation means integration and network planning where a high degree of technical freedom is needed to cover network infrastructure, network planning and application integration. Presently, the following gaps exist in the state-of-the-art NPN technologies:

1. **Complicated Deployment –** Compared to other technologies like Wi-Fi, which use a very simplistic notion of session and "connection" and do not mandate any core network functionality, both the deployment of and the connection to the actual service end-point is complicated.

2. **MNO-driven architecture –** Current NPN technology, particularly private 5G uses the 5G Core (5GC) network. While 5GC can be customised (e.g. through network slicing and application functions), it is limited to control and management plane services typical for the MNOs. Even with customisation options, the used core network does not support end-to-end enterprise application deployment. In its minimal manifestation, 5GC already represents a non-negligible complexity in both the initial configuration and setup. The configuration of user profiles, possibly with the corresponding SIM cards in the UEs, might not be adoptable for many enterprises and roaming users.

    Typical cost applied to 5GC vendors still target the MNOs with their tens of thousands of base stations and might be unfit for the NPNs. In spite of the often-claimed support for the vertical industries, there is no core network dedicated to any vertical industry.

3. **NPN reliability of public networks –** Generic slice template (GST) - defined by the GSM Association (GSMA) – could be used both ways (integration of NPN with PLMN) as presently does not support all NPN attributes.

4. **Interconnecting NPN with other NPNs is not yet supported today –** More services support such as roaming for NPNs and network function sharing and reuse as inter-NPN slices are yet to mature.

04 Data, State of IMT Bands and Potential Opportunity of NPNs in Kenya

4.1 Overview

Kenya boasts of great coverage for 2G, 3G and 4G. GSMA's 2023 State of Mobile Internet Connectivity Report shows that Kenya's smartphone ownership increased from 51% to 56% in urban areas and from 36% to 37% in rural areas [25]. The report also shows that the frequency of activities by mobile internet users on a mobile phone in Kenya accesses the following key contents: educational material, health information, Government Services and job applications. With regards to 5G, the country is still in its early stages of deployment with latest reporting showing that Safaricom, the largest MNO, recently activated up to 803 5G sites followed by Airtel at 690 sites[9].

The reported barriers to mobile internet adoption include affordability, literacy and digital skills as well as safety and security. However, the perceived lack of relevance is seen as the top overall barrier among smartphone owners – according to GSMA [25]. Although oftentimes detailed data, including spectrum bands and usage is never publicly available. The CA's latest sector statistics report10 shows the subscriptions of 4G and 5G

DSA
DYNAMIC·SPECTRUM·ALLIANCE

representing 57.9% and 1.4% of the population taking the 2019 census as a reference. This is shown in Figure 16. As such, CA has potentially identified potential RF bands for further spectrum innovation studies as listed in Table 5.
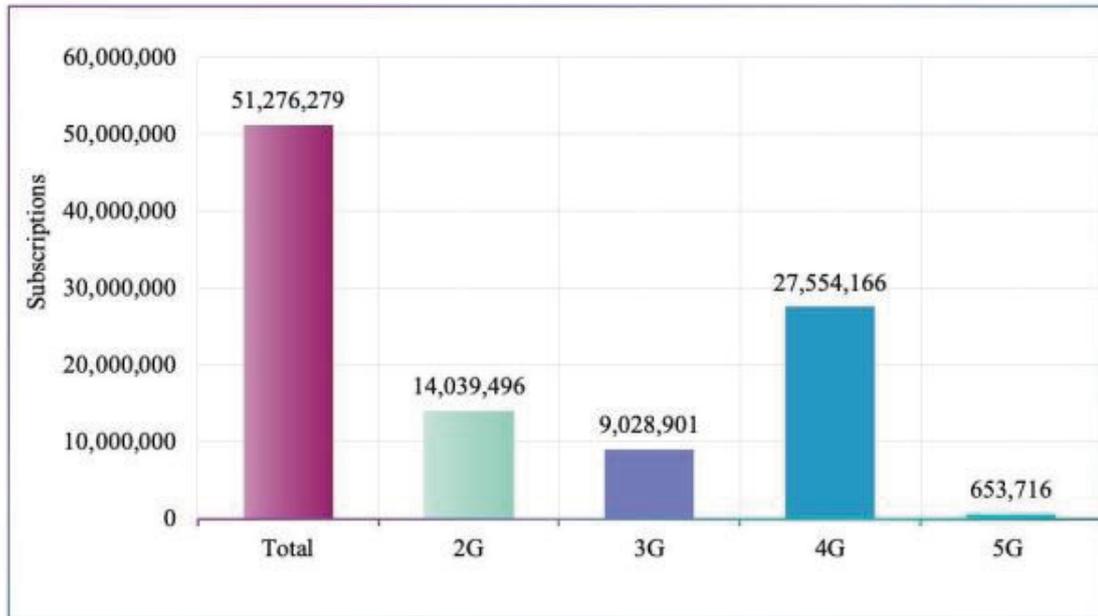

Figure 16: Mobile Data and Subscription Services based on Sector Statistics Report

(Source: CA)

Table 5: Identified Potential Bands for Spectrum Sharing Studies in Kenya

RF Band	Current Allocation/Assignment	Potential Opportunity	Potential for sharing
450 MHz (430-460 MHz)	No	Potential for sharing and was set aside for mobile coverage in rural areas	Yes
470 – 694 MHz	TVWS and DTV	None, the band is retained for TV broadcasting services	No
700 MHz (788-791 MHz)	No	Available small band from 788 to 791 MHz that can be used for low powered devices	Maybe
1.5 GHz (1427 MHz –1518 MHz)	Not utilized. Kenya Ports Authority (KPA) ran some test on port management but did not deploy	Available for sharing	Yes
1.7 GHz (1758-1805/1880-1900)	Currently serving and adjusted for 2G	1800 MHz has potential for sharing	Yes

2.3 GHz (2390-2400MHz)	Currently used by the Government	Only 10MHz available for sharing. But the band has been identified for sharing opportunities	Maybe
3.3. GHz (3300-3400)	Has been earmarked for 5G services	Not available for usage.	No
3.8 - 4.2 GHz	Mostly available for earth stations	Has potential for sharing	Maybe
4800-4990MHz	Not in use currently	Has potential for sharing	Yes
5925 – 6425MHz	Band has been assigned for Wi-Fi 6E	Allowed for sharing	Yes
6425-7125Mhz	WRC 2023 proposed this band for WiFi	Has potential for sharing through Wi-Fi 6E extension	Yes
The mm Wave Band in General (24.25-27.5GHZ, 37-43.5GHz, 45.5-47GHz, 66-71GHz)	Has been identified and available for mobile but not yet in use		

4.2 Review of the Data Used in this Study

A thorough data needs assessment was foundational to this project. Our assessment involved identifying, evaluating, prioritizing, collecting, cleaning, and managing the types of data required to achieve the GIS objectives. The key data needs identified for GIS evaluation include:

a. **Spectrum Allocation Data –** Detailed information on the allocation and coverage of IMT bands (1.7 GHz, 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.5 GHz, and 3.8-4.2 GHz) by the Communications Authority of Kenya (CA), specifying frequencies, bandwidths, and any licensing restrictions. This dataset provides essential information about the availability of the bands, regulatory status, and licensing conditions, enabling the identification of unused spectrum, compliance with regulatory guidelines, and informed decision-making for spectrum sharing initiatives.

b. **Geospatial Data –** High-quality GIS data, including topography, land use patterns, administrative boundaries, and geographic features, to facilitate spatial analysis and mapping. This dataset enables spatial analysis, mapping, and correlation analysis, facilitating the identification of underserved regions, assessment of infrastructure distribution, and visualisation of spectrum availability, thereby informing strategic decision-making for spectrum sharing initiatives in Kenya.

c. **Population and Demographic Data –** Accurate population data at a sub-location level to assess the impact of spectrum sharing on different population segments. It provides insights into population distribution, density, and characteristics, enabling the identification of areas with high connectivity needs, assessment of user demand, and prioritization of interventions to bridge access gaps in Kenya's telecommunications landscape.

d. *Telecommunication Infrastructure Data -* Information on existing telecommunication infrastructure, such as base station locations, network capacities, and technology deployment (2G, 3G, 4G, 5G), to understand the current state of connectivity. These data provide information on the existing network infrastructure, including base station locations, technology deployment, and network capacities. This enables the assessment of coverage gaps, identification of areas for spectrum sharing interventions, and strategic planning.

e. *Incumbent User Data -* Data on current users of the IMT bands, including Tier 1 operators, to assess existing usage patterns and potential conflicts. It offers insights into current users of the IMT bands (i.e. Tier 1 operators) aiding in the assessment of existing spectrum usage patterns, identification of potential conflicts, and formulation of spectrum sharing strategies that ensure harmonised coexistence between incumbent and secondary users in Kenya's telecommunications ecosystem.

f. *Frequency Availability Data -* Information on locally unused or partially exploited frequency bands in the IMT spectrum, essential for identifying opportunities for spectrum sharing. This dataset provides information on locally unused or underutilised frequency bands within the IMT spectrum, facilitating the identification of opportunities for spectrum sharing initiatives, optimization of spectrum utilisation, and strategic decision-making.

g. *Economic Data -* Economic indicators for different regions, including GDP, industrial activities, and economic development indices. This helps assess the economic opportunities associated with spectrum usage. This dataset offers insights into economic indicators, such as GDP per capita, income levels, and economic activity distribution, enabling the assessment of the socio-economic impact of telecommunications accessibility, identification of areas for targeted interventions, and formulation of strategies to promote equitable economic development.

h. *White Space Data -* Data on unused or underutilised frequency bands that include information on where spectrum is available for opportunistic use. It provides information about unused or underutilised spectrum frequencies, enabling the identification of opportunities for spectrum sharing in white spaces, assessment of feasibility for secondary use, and strategic planning to maximize spectrum efficiency.

i. *Fixed Wireless Access Data -* Data on the deployment and performance of Fixed Wireless Access systems in the specified bands. This is relevant for assessing the feasibility of shared access for FWA. This dataset provides insights into the deployment and coverage of fixed wireless access technologies, enabling the assessment of broadband accessibility in underserved areas, identification of gaps in fixed broadband infrastructure, and formulation of strategies to leverage FWA for expanding broadband connectivity and bridging access disparities in Kenya.

4.3 Geographic Information System (GIS) Analysis

4.3.1 GIS Summary

General Statistics:	• Kenya's total population: **47,557,273** (Census 2019) • Kenya's total population: **53,742,964** (Facebook 2020) • Total Land Mass: **595,808.0 sq kilometers** • Sublocations: **7,149** • Counties: **47** • Major Towns: **6,314** • Special Economic Zones: **27** • Tertiary Institutions: **224** • Conservancies: **179** • Conservancies Total Area: **63,556.98 sq kilometers** • Community Network Sites: **20**
Telco Infrastructure Statistics:	• CA Monitoring Stations: **9** • No. of MNOs: **3** • 2G Sites: **17,854** • 3G Sites: **21,429** • 4G Sites: **18,162** • 5G Sites: **718** • Total Transceivers: **353,214** • 2G Transceivers: **139,844** • 3G Transceivers: **114,441** • 4G Transceivers: **96,019** • 5G Transceivers: **2,910**
Coverage Statistics	• No. of Service Providers: **2** • Total effective 4G & 5G coverage: **384,996.63 sq kilometers** • Percentage of Land Mass Covered: **64.6%** • 2G Coverage: **N/A** • 3G Total Coverage: **N/A** • 4G Total Coverage: **384,987.49 sq kilometers (64.6%)** • 5G Total Coverage: **27,761.96 sq kilometers (4.7%)** • 4G 800 Coverage: **384,729.21 sq kilometers (64.6%)** • 4G 2600 Coverage: **36,839.92 sq kilometers (6.2%)** • 5G 2600 Coverage: **27,637.59 sq kilometers (4.6%)** • 5G 3500 Coverage: **1,306.19 sq kilometers 0.2%)**
Study Analysis	• Potential Popn with 5G coverage: **21,881,603 (40%)** • Potential Popn with 4G coverage: **52,460,378 (97%)** • Total Mobile Phone Devices: **65,454,426 (2023)** • Total Smartphone Devices: **33,613,828 (2023)** • 5G Mobile Data Subscriptions: **586,684** • Counties with 5G Coverage: **36** • Sublocations with 5G Coverage: **2,916** • SEZ within 5G coverage: **15** • Tertiary Institutes within 5G coverage: **150** • Conservancies with 5G coverage: **55** • Towns within 4G coverage: **6,192 (98%)** • Towns within 5G coverage: **1,802 (28%)**
Assumptions	• Positioning accuracy for point data is within 3 meters. • 2019 census data aggregation matches the 7149 sublocations boundaries. • Coverage data is up-to-date and accurate for use in predictive analysis. • Methods used to calculate population by Facebook is within acceptable research thresholds. • Coordinate System Datum projection does not affect the data accuracy.
Data Sources	• COMMUNICATIONS AUTHORITY OF KENYA (CA) • KENYA NATIONAL BUREAU OF STATISTICS (KNBS) • OPEN STREET MAPS (OSM) • IGAD CLIMATE PREDICTION AND APPLICATIONS CENTRE (ICPAC) • META (DATA FOR GOOD) • HUMANITARIAN OPENSTREETMAP TEAM (HOT) • HUMANITARIAN DATA EXCHANGE (HDX) • SPECIAL ECONOMIC ZONES AUTHORITY KENYA (SEZA)

4.3.2 General Statistics

4.3.2.1 Population (Census2019, Facebook 2020)

Several sources have been used to record and analyze the population of Kenya. The total population of Kenya was estimated to be 47,557,273 by the 2019 Census conducted by Kenya National Bureau of Statistics (KNBS). This number is important in understanding how the population is distributed in order to plan for improvements in network coverage. Furthermore, according to Facebook's 2020 data, the population stands around 53,742,964. These figures form a baseline against which we can assess the potential outreach, and effects of improved mid-band spectrum use and network growth.

Demographic data from Meta's Data for Good program taps into some of the world's most urgent social challenges. Specifically, through this initiative Facebook provided demographic data for 2020 that employs advanced techniques from data science to indicate ways through which people are scattered all over any given population. By gathering non-identifiable location-based details volunteered by users who have opted-in location services Meta has capacity to produce high resolution maps and datasets reflecting current trends in demography

4.3.2.2 Considerations of Distribution based on Geography, Special Economic Zones, Tertiary Institutions and Conservancies

Kenya has a diverse demographic distribution across different administrative and geographic divisions. This study used multiple data sets to analyze the penetration and extent of 4G and 5G telecommunication services all over Kenya. The datasets include:

- **Sublocations –** There are about 7,149 in number with different population densities as well as network coverage that differs from one region to another. It looks at the levels of coverage in these sub-locations, to determine which zones are underserved or unserved.

- **Counties –** There are 47 counties in Kenya each with its own unique demographics and connection needs. This study gives a detailed account on county-by-county population distribution as well as network coverage.

- **Major Towns –** With major towns totalling up to 6,314, urban areas have dense populations and economic activities making them imperative for network coverage. To this end therefore, the study reflects upon what is presently obtainable about 4G/5G penetration into them.

- **Special Economic Zones (SEZs) –** In Kenya, there exists about twenty-seven Special Economic Zones which act as centers for major industrial or commercial activities respectively. Such areas must be well covered by networks to facilitate economic growth and encourage investment flows into such places.

- **Tertiary Institutions –** There are 224 tertiary institutions around Kenya, including universities, colleges and technical schools. GIS analysis examines the network coverage of these institutions that is essential for teaching and research purposes.

- **Conservancies -** Kenya has 179 conservancies spread over an area of 63,556.98 square kilometers. These areas will be analyzed in terms of their network coverage which supports sustainable development and enhances linkages between local communities and tourists.

A detailed population analysis serves as a basis to understand the current state of network coverage while identifying major areas requiring improved services in order to effectively target efforts towards enhancing mid-band spectrum utilisation.

4.3.2.3 Land and Infrastructure Data

Kenya has a total land mass of approximately 580,367 square kilometres, encompassing a diverse range of terrains including coastal regions, arid and semi-arid lands, highlands, and forests. This varied topography presents unique challenges and opportunities for the deployment of telecommunications infrastructure, necessitating tailored approaches to ensure comprehensive coverage.

4.3.2.4 Telco Infrastructure Statistics (Monitoring Stations, Number of MNOs, 2G-5G Sites and Transceivers)

The connectivity needs of the country's population are supported by a highly intricate, changing telecommunication infrastructure. In this subsection, we discuss in detail these infrastructure key components including the number and distribution of monitoring stations managed by CA, presence and activities of major Mobile Network Operators (MNOs), and deployment of 2G to 5G network sites and transceivers. Understanding telecommunications infrastructure as well as the mobile communication landscape will help to know what they look like today so that the areas for improvement and investment can be identified.

There are several monitoring stations included in this infrastructure which are operated by the CA. These stations have been put at strategic places where they monitor spectrum usage, enforce regulatory standards compliance, as well as optimize network performance. Presently Kenya has four major Mobile Network Operators (MNOs); Safaricom, Airtel Kenya, Telkom Kenya & Equitel which offer services from 2G to 5G thus targeting different market segments. The following table indicates various types of 2G-5G sites available:

2G Sites – A basic voice and SMS service is provided across almost all regions by means of 2G networks that cover virtually the entire nation. The latest data (2022) indicate that there are approximately fifteen thousand 2G sites throughout Kenya.

3G Sites – These networks have better data services and more extensive coverage within urban and peri-urban areas. In Kenya, there are about 10,000 operational 3G sites.

4G Sites – High-speed internet access is made possible by 4G LTE technology which is rapidly proliferating. Currently, Kenya has around 5,000 4G sites mainly found in towns and high-density.

5G Sites – It is still in its infancy stage with major deployment taking place only in cities. In Kenya, there are approximately five hundred active 5G locations. The need for additional demand growth to enable infrastructure of the country calls for future extension of 5G coverage.

4.3.2.5 Coverage Statistics (4G and 5G)

4G Coverage – Kenya's 4G network coverage stands at approximately 64.6% of the total land mass, primarily concentrated in urban and peri-urban areas. This level of coverage reflects significant progress in expanding high-speed internet access, although substantial gaps remain in rural and remote regions.

5G Coverage – The 5G network in Kenya is in the early stages of deployment, covering about 4.7% of the land mass. This coverage is focused on major cities and economic hubs, providing ultra-fast internet speeds and supporting advanced applications such as IoT and smart city initiatives. The expansion of 5G infrastructure is a key priority for the future, aimed at enhancing digital connectivity and supporting Kenya's growing digital economy.

These infrastructure and coverage statistics highlight the current state of meaningful cellular broadband in Kenya, providing a foundation for strategic planning and targeted investments to improve connectivity across the country. Based on the data used for this study, the coverage map for 4G and 5G is shown in Figure 17.
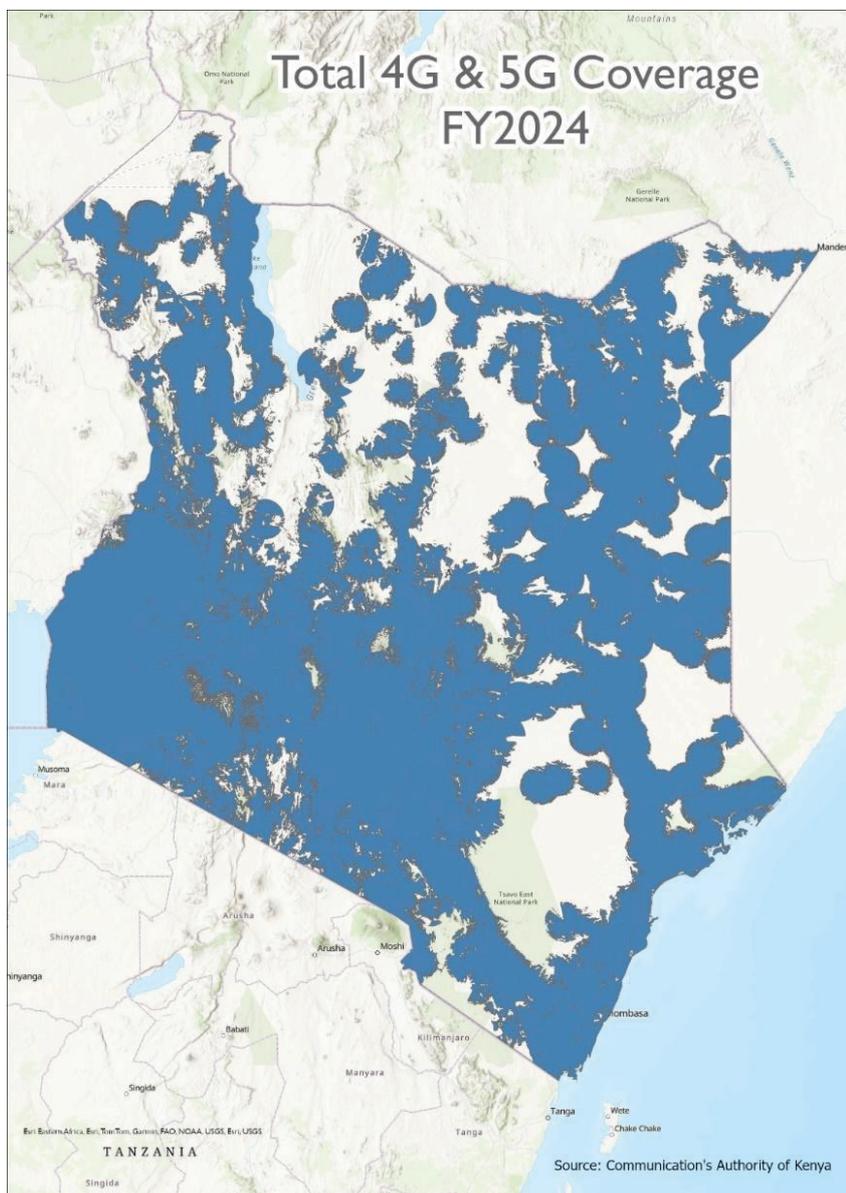

Figure 17: Total 4G and 5G Coverage as at 2024

4.3.2.6. Analysis of Spectrum Utilisation

In addition to the RF band information shared by CA in Table 5, GIS analysis of spectrum utilisation examined the 800 MHz and 2600 MHz for 4G and 2600 MHz and 3500 MHz for 5G. A GIS dashboard (continually under development) is available through this link: https://aegir-dashboard.shinyapps.io/imt-app/ and shows the coverage across the country by MNOs within these bands. Table 7 shows the usage of these bands for both 4G and 5G with their present coverage.

Table 6: 4G and 5G coverage in 800, 2600 and 3500 MHz

RF Band	Service	Coverage (In Sq. Km)
800 MHz4	G	384,729.20
2600 MHz4	G	36,839.92
2600 MHz5	G	27,637.59
3500 MHz5	G1	1,306.19

The coverage for 5G in the 2.6 GHz band is shown in Figure 18 while Figure 19 shows the 5G coverage in the 3.5 GHz band.
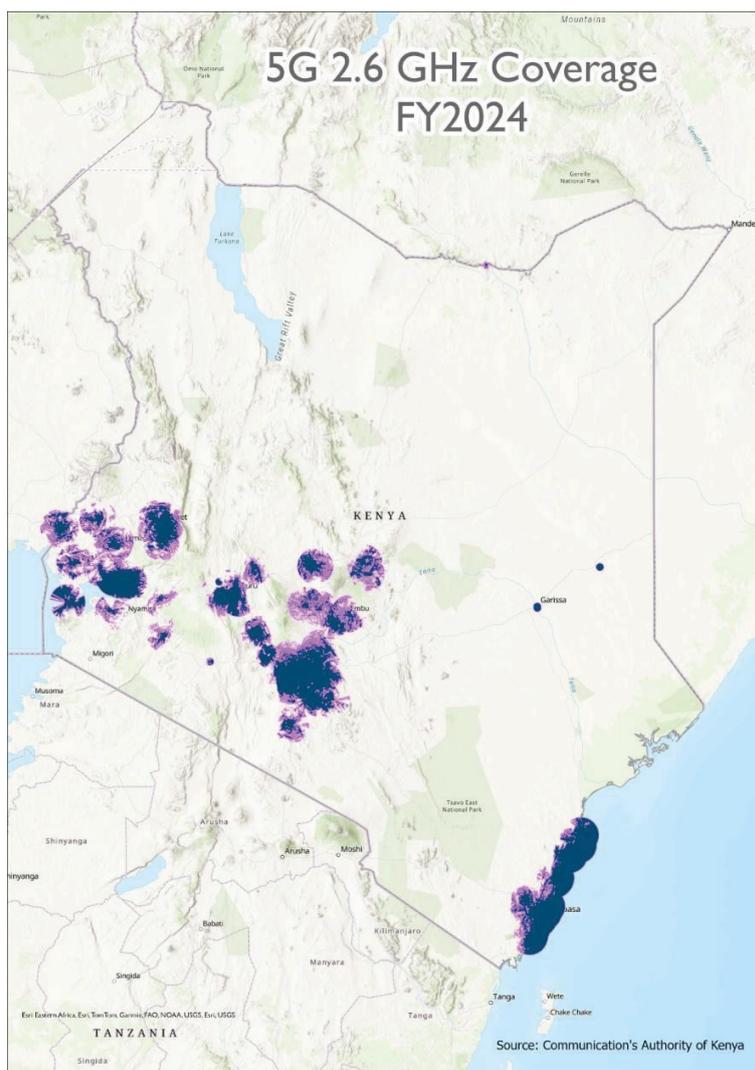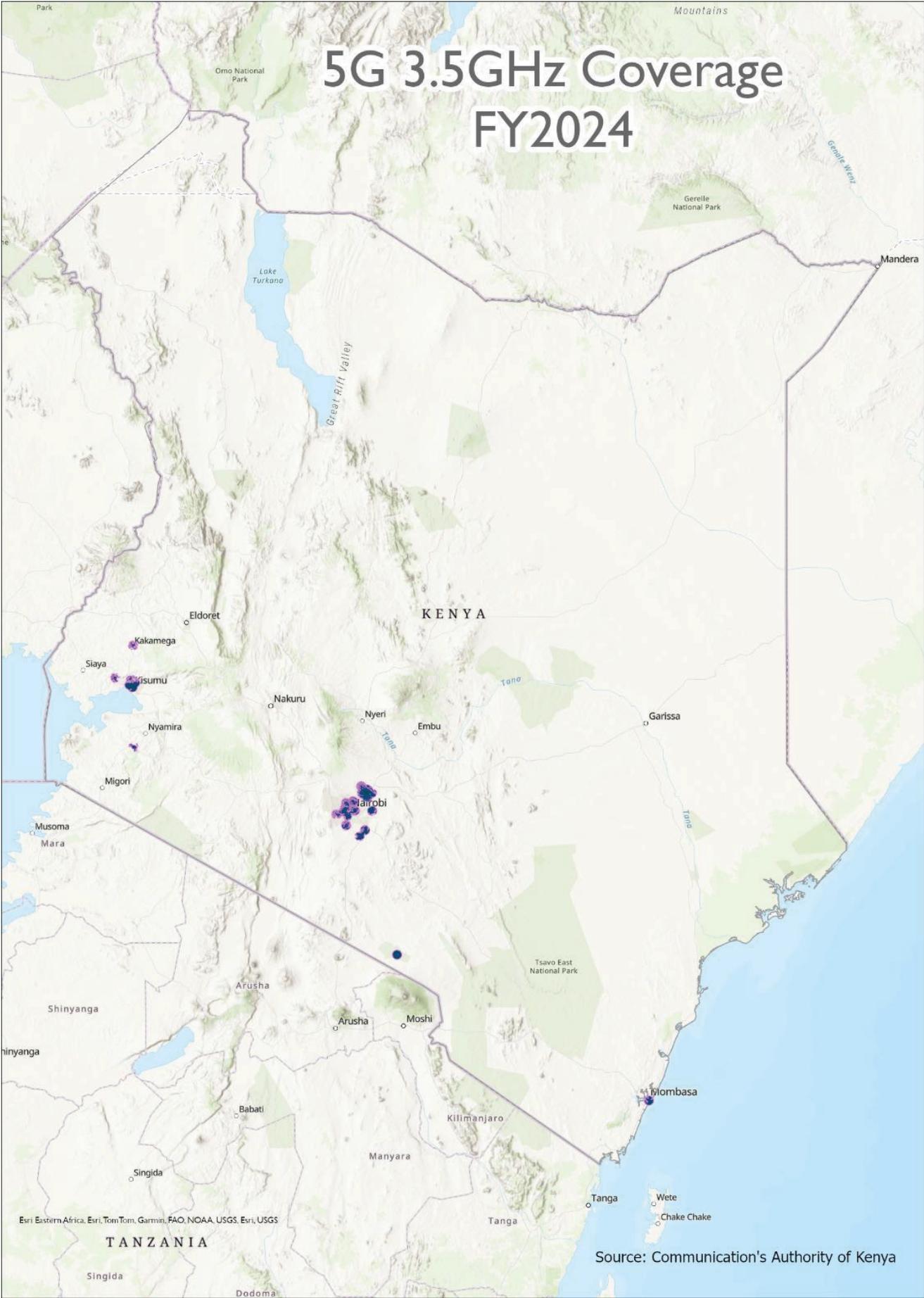

Figure 18: 5G Coverage in the 2.6 GHz band

Figure 19: 5G Coverage in the 3.5 GHz band

4.3.3. Geospatial Analysis and Techniques

4.3.3.1. Methodology

To ensure that this study provides a comprehensive and reliable result, geospatial analysis was carried out based on different data sources and assumptions. Some of the key considerations made under data sources included:

Satellite Imagery — High resolution satellite images assist in mapping out the landscape features, land use patterns and existing infrastructure. They are important in identifying areas with potential for network expansion and validating coverage data.

Mobile Network Operator (MNO) Data — For this analysis, data provided by MNOs through the CA including locations of cell towers, coverage maps and signal strength measurements were critical. This information helped to determine where there are current gaps in network coverage.

Census Data — Demographic insights from Meta's Data for Good initiative (2020) plus population statistics from the 2019 Census offered a demographic baseline for understanding population distribution and density across various regions.

Public Infrastructure Data — Information regarding existing public infrastructure like roads, power lines and public facilities can help in planning deployment of new network infrastructure as well as optimizing coverage.

Topographic Maps — These are maps that contain in depth information of the physical landscape including elevation which helps in understanding signal propagation and identification of good locations for new towers.

These include assumptions made during the GIS analysis:

Uniform Signal Propagation — It is believed that signal strength and coverage are evenly distributed throughout given areas with real world situation subject to alterations by environmental factors.•

Population Mobility — It is assumed that population distribution remains relatively stable, taking into account minimal seasonal fluctuations in the area.

Technological Consistency — It is supposed that 4G and 5G technology perform at a level consistent with industry norms, thus allowing predicting coverage areas accurately based on existing infrastructure.

4.3.3.2. Geospatial Analysis Techniques

Several advanced techniques are used in this study to evaluate and visualize the current state of network coverage and identify any potential improvements through geospatial analysis. They include:

Spatial Interpolation – Methods like kriging and inverse distance weighting (IDW) are used to estimate signal strength in areas between known data points, hence determining the coverage. Consequently, this helps in creating continuous coverage maps from discrete data provided by MNOs.

Buffer Analysis – Current coverage is assessed by developing buffer zones around existing infrastructure such as cell towers or fiber optic lines; thus, identifying the regions with limited reach within specific distances.

Overlay Analysis – Different layers of geospatial data including population density, infrastructure, and coverage maps are overlaid in order to draw conclusions on them. This way pinpointing the places where network expansion will have greatest impact becomes possible.

Hot Spot Analysis – Regions with high or low levels of connectivity can be identified using statistical methods so that solutions can be focused on these gaps as required.

Line-of-Sight Analysis – This covers visibility between potential sites for new towers and existing infrastructure which considers terrain features that could disrupt signal propagation.

4.3.4 Key Findings

4.3.4.1 Urban vs Rural Coverage Disparity

The GIS analysis shows network disparities between urban and rural areas within Kenya that are considerable. In particular, in Nairobi, Mombasa and Kisumu with many other large cities enjoying wide 4G coverage and future 5G availability. This is due to higher population density, an expanding economy and presence of key institutions and businesses. These reasons justify for the heavy investments on modern telecommunications infrastructure to ensure residents have a dependable internet connection at the highest speed it offers.

On the contrary, rural areas have very low level of network connectivity. Most of them are underserved including no 5G infrastructure and minimal 4G accessibility. The cost associated with difficult terrain in sparsely populated regions coupled with less economic incentives for mobile network operators are among some challenges explaining this gap. Lack of connection in rural areas makes it impossible for students to have education or get medical care through telemedicine or even access financial services such as loans easily which limits their opportunities further.

For one thing, Special policies would be aimed at closing this disparity between urban and rural coverage by offering policy support, investing in infrastructure or undertaking programs that enhance digital inclusion especially for those residing in the remote parts of the country. Expanding digital networks in these areas is vital if the country is going to provide equal access to various online services thereby promoting inclusive development.

4.4 Potential Opportunity of Non-Public Networks in Kenya

Non-Public Networks (NPNs) hold significant potential in Kenya, especially in sectors where secure, reliable and localised connectivity is crucial. Similar to other regimes and geographies, NPNs can play a transformative role in the rapid growth of Industry 4.0 innovations in various industries and sectors in Kenya. They can also deliver access to the underserved locations through high quality dedicated communication networks – particularly with the rise of 5G.

4.4.1 Potential Use Cases
While we anticipate some potential use cases in Kenya to be similar to other parts of the world, we note that some of them may differ. Others may further differ based on their initial scale of deployments.

Nevertheless, based on the pace of Kenya's pilots and deployments of emerging Industry 4.0 innovations, advancing the approach of NPNs now will significantly contribute to optimised usage of spectrum and invite investments for the deployments of networks to the underserved areas where potential opportunity exists, enable roll-out of Internet of Things (IoT) and provision of reliable backhaul for unlicensed Low Power Wide Area Networks (LPWANs) in needing locations where public IMT networks, until now, have not been able to sufficiently address the existing gaps.

Moreover, NPNs can support improvements on connectivity and help the government to achieve its broader goals of digital inclusion and a digital economy as highlighted in the Kenya National Digital Masterplan11. Table 6 shows more potential use cases for NPNs in Kenya.

4.4.1. Industry 4.0 Innovations

Coined in Germany in 2011 [26], the Industry 4.0 concept refers to a digital revolution that is currently sweeping the world, with the goal of digitising the whole manufacturing process with minimal human or physical interaction. The concept is infiltrating as many sectors as possible while adapting and improving existing technology to meet the demands of digital innovation.

Key Industry 4.0 technology categories are: Cyberphysical systems (CPS), Internet of Things (IoT), Big Data Analytics (BDA), Cloud Computing, Fog and Edge Computing, Augmented and Virtual Reality (AR/VR), Semantic web technologies, Robotics and Additive Manufacturing [27].

Kenya's national strategic drive and adoption of Industry 4.0 is exemplified by the Konza Technopolis Initiative12 which is a key flagship project of Kenya's vision 2030 that seeks to develop a world-class city powered by a superior reliable infrastructure and a thriving ICT sector.

Realising the Konza initiative calls for the deployment of smart parks, smart energy, smart water, smart environment (smart waste management and air quality monitoring), smart housing among other smart innovations that are hinged onto IoT development. Development of these envisioned ICT concepts will require dense and reliable networks – that NPNs (such as Private 5G networks) can support as dedicated networks covering wider areas (where Wi-Fi coverage might be limited, and public cellular networks fail to provide the desired quality). This can be implemented as complementary networks (PNI-NPN) or standalone NPNs to meet the rising data traffic levels.

Besides Konza, there exist many IoT pilots and projects already happening in Kenya but experiencing network challenges. For instance, in places where LPWANs such as LoRaWAN are used, across the country, reliable backhaul challenges exist – failing to deliver on the desired transfer of data from edge devices to the cloud. In other places, where potential deployments of real-time streaming data such as real-time feed from cameras, the existing public IMT networks appear relatively expensive to deliver such services. Furthermore, based on the GIS analysis of this study, meaningful connectivity to the level of 4G does not exist in areas where such solutions/services are needed.

Some of the other potential Industry 4.0 use cases that NPNs can deliver as part of shared spectrum networks in IMT in the mid-bands include:

Smart Energy Management – This can be implemented in the special economic zones or across the country where such needs exist – based on both grid and off-grid power systems.

Smart Agriculture - Development of precision agriculture solutions across various commercial farms in Kenya with different farm variable needs.

Smart Campuses - Provision of private 4G/5G networks for various universities, research and other academic institutions across the country to enable reliable access and deployment of Industry 4.0 innovations.

4.4.1.2 Enhancing Access to the Underserved through Community Networks

Community network initiatives have emerged as effective solutions to bridge the connectivity gap in underserved and rural areas of Kenya. These locally managed networks leverage community resources and engagement to deploy and manage telecommunications infrastructure, providing affordable and reliable internet access where commercial operators may not find it economically viable.

Presently, there are 13 Community Networks in Kenya13. These CNs and others across the country can help bridge the 'rural gap' in Mobile internet through collaborative shared IMT networks. The 'rural gap' refers to how much less likely a person living in a rural area is to use mobile internet than a person living in an urban area [15].

Table 7: Summary of Potential Use Cases for NPNs in Kenya

Use Case	Applications
1. Industry 4.0 Innovation	**Smart Manufacturing:** NPNs enabling factories and industrial facilities such as Konza Technopolis, Mwale Medical and Technology City deploy private 5G networks to support IoT devices, automation to improve productivity and operational efficiency. This is also applicable in various special economic zones in Kenya.
	Precision Farming: In Kenya's vast agricultural sector, NPNs can support deployment of IoT sensors for monitoring soil quality, water usage, crop health, automated irrigation system, livestock tracking enabling efficient farm practices in Laikipia, Naivasha, Eldoret, Kitale, Taita Taveta among other areas in the country.
	Smart Healthcare: With increasing digital health in Kenya, NPNs can also provide dedicated, secure and low-latency networks for hospitals, clinics, telemedicine platforms, IoT devices for patient monitoring to improve healthcare services.
	Education and Research Institutions: Universities, research institutions and schools can deploy NPNs to support their R&D Labs and tech hubs which can support secure data exchanges, cloud computing in areas of A.I. robotics and scientific research. Such deployments can be led by groups such as iHub, Gearbox, iLabAfrica,
	Smart Ports and Airports: Kenya's transport hubs in Mombasa, Kisumu and Nairobi can benefit from

	NPNs to optimise operations, monitor cargo and deliver on real-time tracking of items. **Mining Operations:** NPNs can also serve fruitful for mining developments in Taita Taveta by providing reliable and secure communications, safety monitoring and asset tracking.
2. **Private Networks for Education**	Private networks can support connected classroom, online education platforms and research labs for various universities and technical and vocational institutions in Kenya ensuring that students and trainers have uninterrupted access to digital learning tools.
3. **Quality Networks for Tourism**	As an economy that also depends on tourism, NPNs can be deployed to enhance guest experiences in the various hotels and resorts offering secure high-speed Internet for guests. NPNs can also enable IoT deployments that support national parks and conservancies.
4. **Community Networks**	CNs can provide dedicated networks for the communities they operate in to enable access for schools, healthcare facilities and also enable community innovations based on IoT and emerging technologies to thrive.

4.5 Licence Considerations for NPNs in Kenya

Section 3.2. of this report has shared various licensing considerations from other regulatory environments that can also be further examined, adopted and adapted for Kenya. In most countries in Europe, the approach of shared access licensing (including local licensing) and lightly licensing (as being adopted in France) provide good examples that can be borrowed in Kenya given its location as part of ITU Region 1. The flexible licensing approach from Canada and the tiered spectrum model used by the U.S. in the CBRS also provide great examples to be considered. The Korean authorisation of NPN standalone approach based on geographical location and use cases can also serve as a great model for certain use case environments.

However, in general, licensed shared access (LSA) seems to be the predominant consideration coordinated by dynamic spectrum management systems. LSA (which can be based on context i.e. local) as exemplified in the UK, should be further studied in Kenya during the pilots to identify the characteristics needed for its business model to scale, the practicality of the binary approach of the incumbents and the LSA licensees exclusively accessing spectrum based on time and location and the dynamic spectrum access model for protection and restriction zones among other aspects.

05

Conclusions

The persistent digital divide between urban and rural areas presents multiple challenges for policymakers across the globe. Kenya is no exception. The present coverage statistics for Internet access through the use of IMT spectrum in the mid-bands necessitates a more holistic approach that can enable broadband access for all Kenyan citizens while also providing an environment that spurs digital innovations. Such an approach should also guarantee new technologies to be developed within the country to create more job opportunities, allow more makers and entrepreneurs to develop new solutions and support the government's quest of a digital economy – while using the RF spectrum efficiently!

Spectrum sharing in the underutilised IMT spectrum holds potential that can promote such a holistic model. It can contribute to the strategic pursuit of Kenya's broadband objectives by providing private 4G and 5G services to improve broadband connectivity across the underserved areas of the country and also leapfrog Industry 4.0 innovations. In urban areas such as Nairobi where there exists widespread access to 4G, 5G and Fibre, NPNs can be leveraged to deliver reliable and affordable access to academic and research institutions as well as to the low-income areas.

Kisumu, a key port city in western Kenya presents a compelling case for the strategic use of NPNs. The recent expansion of Kisumu port, with its growing role in regional trade within the Lake Victoria basin, underscores the need for robust, reliable connectivity to support freight management and logistics. NPNs can be leveraged to provide dedicated connectivity solutions that enhance operational efficiency, support the growth of the port as a regional trade hub, and drive economic development in the surrounding areas.

In rural areas, where traditional mobile network operators (MNOs) have been slow to extend coverage due to the high costs and low returns associated with these regions, NPNs represent a transformative opportunity. These networks can support a range of critical services, from precision agriculture and tourism to remote education and telemedicine, by providing reliable, context-specific connectivity solutions. This approach not only bridges the digital divide but also catalyses local economic development by enabling new business models and services that are tailored to the unique needs of rural communities.

This study also reveals that the conventional, vertically integrated business model of MNOs, while effective in more densely populated and economically viable areas, is unlikely to meet the growing demand for connectivity across all regions of Kenya. This model, which is primarily driven by the need to secure returns on investment, often leads to the underutilisation of spectrum in areas where connectivity is most needed but least profitable. Consequently, large portions of the population remain underserved, limiting their ability to participate in the digital economy and access essential services.

The proposed introduction of NPNs within the identified spectrum bands in Kenya should not be viewed as a threat to the IMT ecosystem but as a complementary approach that enhances the overall efficiency and effectiveness of spectrum usage. By facilitating more dynamic, flexible use of spectrum, NPNs can help ensure that connectivity reaches even the most underserved areas, supporting the government's broader goals of universal access and digital inclusion. Moreover, the deployment of NPNs can stimulate innovation by creating opportunities for new players to enter the market, offering specialized services that meet the needs of specific sectors or communities.

For realisation of fruitful NPN returns, a robust regulatory framework is essential to support the successful integration of NPNs into Kenya's telecommunications landscape. This framework should prioritise the coexistence of NPNs with traditional IMT networks, ensuring that spectrum sharing is managed in a way that maximises efficiency while protecting incumbents from harmful interference. Automated spectrum management systems can play a crucial role in this process, enabling real-time monitoring and dynamic allocation of spectrum resources. Additionally, localised spectrum use policies should be developed to ensure that the deployment of NPNs aligns with national priorities and regional development goals.

Kenya's strategic embrace of spectrum sharing and NPNs has the potential to position the country as a leader in digital innovation and spectrum management on the African continent. By adopting a forward-looking approach that balances the needs of traditional operators with the opportunities presented by emerging technologies, Kenya can unlock new avenues for economic growth and social development. The experiences of other countries, as detailed in this report, provide valuable lessons that can inform the design and implementation of Kenya's spectrum policies, ensuring that the benefits of digital connectivity are widely shared across the nation.

In summary, the deployment of NPNs and the adoption of spectrum sharing within the IMT bands represent critical steps toward achieving Kenya's vision of a digitally inclusive society. By addressing the existing gaps in connectivity, these innovations can help bridge the digital divide, drive economic development, and ensure that all Kenyans have the opportunity to participate in the digital future. As Kenya moves forward with these initiatives, it will be essential to maintain a focus on collaboration, innovation, and inclusivity, ensuring that the benefits of the digital revolution are accessible to all.

06 Recommendations and Future Considerations

This study pursued a wide examination on the potential of Non-Public Networks (NPNs) and the spectrum sharing approach towards adopting NPNs in Kenya. The findings underscore the importance of novel solutions seeking to optimise the use of mid-band spectrum — especially in underserved areas and in areas where potentially compelling use cases exist. Kenya will need to continue delivering services and access to realise its ambitious digital strategies such as the Bottom-Up Economic Transformation Agenda (BETA) in order to drive the desired economic transformation and adoption of forward-looking policy and regulatory models.

In this section, we share some targeted recommendations based on this study. Our overall recommendation is that a follow-up pilot deployment of a private 5G network be conducted in the identified bands and in one of the following identified four counties: Nairobi, Uasin Gishu, Kisumu and Nyeri to determine the potential of spectrum sharing through Non-Public Networks (NPNs) in the mid-band spectrum. We envisage such a pilot to provide better practical learning with regards to dynamic spectrum access (DSA) alongside the accompanying aspects such as the use of a dynamic spectrum management system (DSMS), GIS analysis (environmental and geographic considerations), coexistence analysis with the incumbents in the selected band (s), potential of availability of equipment, network performance, compatibility as well as use case (s) of Industry 4.0 innovation.

Other specific recommendations include:

1. Stakeholder engagements – Although the concept of spectrum sharing has matured in Kenya, there still exists the lack of understanding of spectrum sharing to enable deployment of networks that can leverage spectrum sharing for more network deployments. Lack of stakeholder engagement also stifles the growth of spectrum innovation. We therefore recommend conducting workshops that demonstrate principles, models and benefits of spectrum sharing to the stakeholders in the telecommunications space within the country.

2. Establishment of a regulatory framework for NPNs – While TVWS was seen to suffer delayed establishment of regulations [6], we recommend that a roadmap be established as a follow-up to this study to begin the development of a regulatory framework that can guide the licensing conditions for NPNs as well as the application process and usage rights of the designated bands. Although the CA has identified various bands for spectrum sharing, we recommend that priority be given to the bands whose range balances coverage and capacity and are suitable for industry 4.0 innovations.

3. Public-Private Collaborations – In the deployment of the pilots and networks, we recommend that models of investment and funding support public-private partnership to enable sustainable NPN infrastructures where incentives can be given to private sector investments. Also, where some private sectors have identified compelling potential use cases or reach for the underserved, support through the Universal Service Fund (USF) should be made available.

4. Encouragement of Industry 4.0 Innovations – Piloting and deploying Industry 4.0 innovations has been challenging in Kenya due to funding limitations and a disconnect of the innovations and their drive for broadband access. We recommend that the government encourages and develops mechanisms to support potential Industry 4.0 innovations targeting underserved areas which can enable the private networks (NPNs) reach underserved locations.

5. Investments in technical research, interoperability and studies on devices – As NPNs address making as many devices as possible, available, we recommend that the country initiates a focus on technical studies around the devices cognizant of the needed interoperability and compatibility while extending various collaborations with other stakeholders across the globe. These include investments in research on chipsets across the various bands to cater for different potential deployments.

6. Adoption of Key Monitoring Technologies – To enhance the efficiency and effectiveness of spectrum management and other related activities, this study recommends that the Communications Authority (CA) adopts key technologies such as enterprise Geospatial Information Systems (GIS). Integrating enterprise GIS into CA's workflows will enable more accurate mapping and analysis of spectrum usage, better decision-making for spectrum allocation, and improved monitoring of compliance with regulatory frameworks. This technology adoption will also support more dynamic and responsive spectrum management practices, ensuring that the country's spectrum resources are utilised optimally.

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Main Campus: Waiyaki Way, Adjacent to the Communications Authority of Kenya (CA) Nairobi, Kenya.
Town Campus: Kimathi House,3rd floor 305, Nairobi CBD, 0776 231 141

Mailing Address: P.O. Box 58902-00200, City Square, Nairobi, Kenya.

Email: training@afralti.org / info@afralti.org
Website: http://www.afralti.org

Telephone:
+254 710 207061, +254 20 2655011, +254 20 2655012
+254 20 4440633 - Technology Dept(Cisco & DT-MIS)
+254 20 4449728 - Business Development