TV White Spaces Regulatory Framework for Kenya: An Overview and Comparison with Other Regulations in Africa

Kennedy Ronoh[1](✉), Leonard Mabele[2], and Dennis Sonoiya[3]

[1] Technical University of Kenya, Nairobi, Kenya
`kennedy.ronoh@tukenya.ac.ke`
[2] Strathmore University, Nairobi, Kenya
`lmabele@strathmore.edu`
[3] University of Strathclyde, Glasgow, UK
`dennis.sonoiya@strath.ac.uk`

Abstract. Dynamic spectrum management is gradually becoming a viable approach for use by national regulatory authorities (NRAs) in administering usage of the radiofrequency spectrum. The concept has proven to be efficient in managing secondary access to television white spaces by permitting white space devices, under the control of geolocation databases. Kenya conducted its first white space trial in 2013 under a static model, which demonstrated the opportunity that could be harnessed in using the lower UHF band to provide broadband internet access in underserved areas, with no harmful interference to the digital terrestrial television service. In the subsequent years, the administration of Kenya permitted multiple trials, of various models, to build a case for adoption of dynamic spectrum access techniques in the UHF band and to drive deployments of white space devices. The Communications Authority of Kenya recently published a framework setting out key aspects for access to white spaces including the algorithms to determine coexistence parameters, that was modified off the dynamic spectrum alliance's model rules. This paper presents an overview of the regulatory framework for use of TV white spaces in Kenya and compares it with other frameworks adopted by African countries and other selected countries globally. The paper further gives recommendations on the path to adoption and implementation of the dynamic spectrum management for national regulatory authorities in Africa.

Keywords: TV White Spaces · Spectrum management · Dynamic Spectrum Access · White Space Devices · Regulations

1 Introduction

The effective management of radiofrequency spectrum requires the active involvement of key stakeholders from standardisation bodies, infrastructure and

R. Zitouni et al. (Eds.): AFRICOMM 2020, LNICST 361, pp. 3–22, 2021.
https://doi.org/10.1007/978-3-030-70572-5_1

service providers, regulatory authorities, equipment manufacturers, spectrum users to academic and industrial researchers [1]. The International Telecommunications Union (ITU) is the specialised United Nations agency for information and communication services, which has a key role in promoting global harmonisation of spectrum allocation. The radiocommunication bureau of the ITU performs activities related to the development of recommendations pertaining to spectrum use by various services as well as periodically updating the radio regulations through regular Radiocommunication Conferences [1]. Regional bodies are also in place to ensure that ITU-R spectrum allocations are adhered to and that there is harmonisation across a specific region. These regional spectrum regulatory groups cover all the continents. At the national level, spectrum management is predominantly under a National Regulatory Authority (NRA), whose role is to regulate spectrum use within their jurisdiction in line with national policies, regional treaties as well as ITU radio regulations and recommendations.

The rise in the demand for wireless broadband services is gradually turning the radiofrequency spectrum into a scarce resource. The fixed spectrum allocation approach traditionally favoured by NRAs leaves portions of spectrum underutilised. Spectrum occupancy evaluations done worldwide show that large portions of spectrum allocated to certain primary users is not activated in many locations within a licensed coverage area [2]. Under a fixed spectrum allocation regime, the primary user has exclusive spectrum rights defined by the provided license on the assigned spectrum. The NRA publishes spectrum assignment plans and issues periodic reports on the usage of frequency bands on the national table of frequency allocations.

Licenses are granted through auction, administrative or incentive pricing schemes [3]. This static licensing regime, hence, limits other users (secondary users) to opportunistically make use of the primary-based assigned frequencies even when they are insufficiently utilised. Secondary access to spectrum is also known as Dynamic Spectrum Access (DSA) or opportunistic spectrum access [4]. The UHF TV (470–694 MHz) spectrum band has been the subject of most research initiatives to develop a dynamic spectrum access (DSA) model that permits secondary users to coexist with primary users through the utilisation of TV White Spaces (TVWS) to provide fixed and mobile Internet access services in underserved areas. This band is particularly prime for rural internet service provision due to its good propagation characteristics over irregular terrain.

TVWS trials have been conducted worldwide to demonstrate and test the use of dynamic spectrum access (DSA) technology, with key trials determining that Digital Terrestrial Transmission (DTT) was not adversely affected by secondary access to the unused TV spectrum. NRAs worldwide have already opened up TVWS for DSA following the success of TVWS trials. Standards have also been developed to make use of this technology. Among the standards are IEEE 802.11af which implements spectrum sensing and IEEE 802.22 which assimilates geolocation database implementation. A number of use cases emanating from the use of TVWS are already gaining ground. Some of them include rural broadband access [4], Internet of Things (IoT) and machine-to-machine communications (M2M) cellular networks and vehicle-to-vehicle communications.

The Communications Authority of Kenya (CA) plans to authorise the commercial deployments for TVWS, for fixed broadband services and for IoT applications, in the 470–694 MHz UHF spectrum band. Currently, the band is allocated to the Digital Terrestrial Television (DTT) broadcasting service on a primary basis as provided in the National Table of Frequency Allocations. To achieve this, a regulatory framework has been developed and is currently under interim approval as at the time of writing this paper. White space devices (WSDs) will operate on non-protected, non-interference and non-exclusive basis. The main aim of developing the regulatory framework is to allow the use of TVWS for rural broadband access.

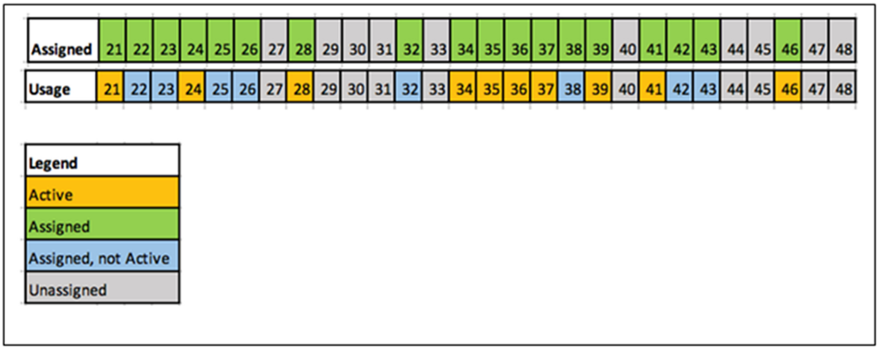
This paper has three objectives. The first objective is to give an overview of the TVWS regulations for Kenya based on the already developed regulatory framework. The second is to analyse and compare the Kenyan regulations with other regulations in Africa as well as against those of the United States of America, the United Kingdom regulations as well as Singapore and Canada. The final objective is to make recommendations for additional considerations within the regulations.

The rest of the paper is organised as follows. Section 2 discusses the availability of TVWS in Kenya. Section 3 discusses the TVWS trials in Kenya. Section 4 presents an overview of TVWS regulatory framework for Kenya. Section 5 provides an analysis and comparison of TVWS regulatory framework for Kenya with other regulations in Africa and worldwide. Section 6 provides recommendations. Section 7 concludes the paper.

2 Availability of TV White Spaces in Kenya

Kenya completed its digital switchover in June 2015, ushering in an era of DTT in the UHF Band IV (470–694 MHz). A detailed quantitative assessment conducted by the Communications Authority of Kenya (CA) reveals that 28 channels (channel 21 to 48) of 8 MHz bandwidth, assigned for DTT services in Kenya are not fully used at every location and therefore can be opportunistically exploited for TVWS.

Recent measurements conducted in Kisumu, Laikipia and Kitui counties in January and February 2020 by a team of Kenyan researchers working together with CA show that there is plenty of unutilised frequencies in the terrestrial TV broadcasting in Kenya. In Kisumu County, out of the 18 channels assigned for broadcasting, 8 channels were found to be unused or not active. Cumulatively, this demonstrates that 144 MHz is available for TVWS in Kisumu. Figure 1 shows the availability of TVWS in Kisumu county. In both Kitui and Laikipia counties, only four channels have active transmissions out of 9 assigned DTT channels. This means that there are a total of 24 channels available for secondary use (out of a total of 28 channels in the TV spectrum) with a total bandwidth of 192 MHz. This unutilised spectrum can be used for rural broadband access.



Assigned	🟩 21	🟩 22	🟩 23	🟩 24	🟩 25	🟩 26	⬜ 27	🟩 28	⬜ 29	⬜ 30	⬜ 31	🟩 32	⬜ 33	🟩 34	🟩 35	🟩 36	🟩 37	🟩 38	🟩 39	⬜ 40	🟩 41	🟩 42	🟩 43	⬜ 44	⬜ 45	🟩 46	⬜ 47	⬜ 48
Usage	🟧 21	🟦 22	🟦 23	🟧 24	🟦 25	🟦 26	⬜ 27	🟧 28	⬜ 29	⬜ 30	⬜ 31	🟦 32	⬜ 33	🟧 34	🟧 35	🟧 36	🟧 37	🟦 38	🟧 39	⬜ 40	🟧 41	🟦 42	🟦 43	⬜ 44	⬜ 45	🟧 46	⬜ 47	⬜ 48

Legend
🟧 Active
🟩 Assigned
🟦 Assigned, not Active
⬜ Unassigned

Fig. 1. TV White Spaces availability in Kisumu County, Kenya.

3 TV White Space Trials in Kenya

The CA authorised multiple trials to test the viability of TVWS in Kenya since 2013. The objectives for the trials were to test the capability and viability of the TVWS technology for Kenya as well as undertake the coexistence testing and ensure a low probability of harmful interference to DTT transmissions, which are the incumbent services.

Kenya conducted its first TVWS trial in September 2013, when Microsoft East Africa under the Microsoft 4Afrika initiative was authorised to test the technology with Indigo Telecom for one year. Other partners on the project included Adaptrum and the University of Strathclyde. The trial was conducted in the vicinity of Nanyuki, Laikipia County of Kenya [5]. The trial project was given the name “Mawingu Project”.

The execution of this trial did not result in any interference to the existing broadcasting services or assigned services within the bands that were used. Following up to this trial, more trial scenarios were conducted driven by collaborations between – network facilities providers (NFPs) and geolocation database (GDB) providers as well as broadcast signal distributors (BSDs). Table 1 outlines a summary of the trials conducted in Kenya leading to the development of the TVWS regulatory framework.

The findings of these studies were the output of the various TVWS experiments authorised in Kenya as per Table 1. While the initial experiments were conducted without integration to a GDB, the findings still demonstrated no interference to the DTT services. Experiments from 2017 onwards made use of a GDB. The findings of these experiments focused on finding out the available frequencies for TVWS use as measured by CA, operating EIRP, coverage distances and any instances of interference as described in three major trials of 2013, 2018 and 2020 in this paper.

Table 1. TV White Space trials in Kenya.

	Start (and Duration)	Operator	Affiliate NFP	Authorised locations	Database providers and equipment vendor
1	September 2013 (1 year)	Microsoft East Africa	Indigo Telcom	Kajiado and Laikipia	6Harmonics and Adaptrum
2	November 2014 (1 year)	Mawingu Networks	-	Laikipia	6Harmonics, Adaptrum and Nominet
3	November 2016 (1 year)	Pan Africa Network Group Kenya	-	Countrywide	Static Model proposed (No Database)
4	November 2016 (1 year)	Signet Signal Distributor	Mawingu Networks	Countrywide	Static Model proposed (No Database)
5	March 2019 (6 Months)	Mawingu Networks	-	Embu	Adaptrum, Redline and Fairspectrum

3.1 The 2013 TVWS Experiment (Nanyuki)

This was the first Kenyan TVWS experiment. It covered an area of 235 km^2 from three TVWS sectors, each transmitting at 1 W EIRP from 90° 10 dBi UHF sector antennae at heights of 8 to 18 m. The findings provided a throughput of approximately 3×16 Mbps with no interference experienced to the DTT services. Notably, this experiment leveraged 5.4 GHz microwave backhaul links and the base stations used ran on solar (offgrid) power. Figure 2 shows one of the setups using a 6Harmonics GW 300 base station backhauled by a microwave link at Gakawa Secondary School in Nanyuki, Kenya. This experiment was able to support uninterrupted video conferencing and streaming as well as high speed VPN services.

3.2 The 2018 Experiment (Nanyuki)

This TVWS experiment was conducted with an integration to a geolocation database (GDB) for the first time in Kenya. The database used was from Nominet, a GDB service provider operating in the UK. The base station used was an Adaptrum ACRS 2.0 flushed with the 2018 upgrade of the protocol to access white space databases (PAWS). Manual coordinates were used in this experiment but still demonstrated no interference to the DTT services. No out of band (OOB) emission was experienced as well.

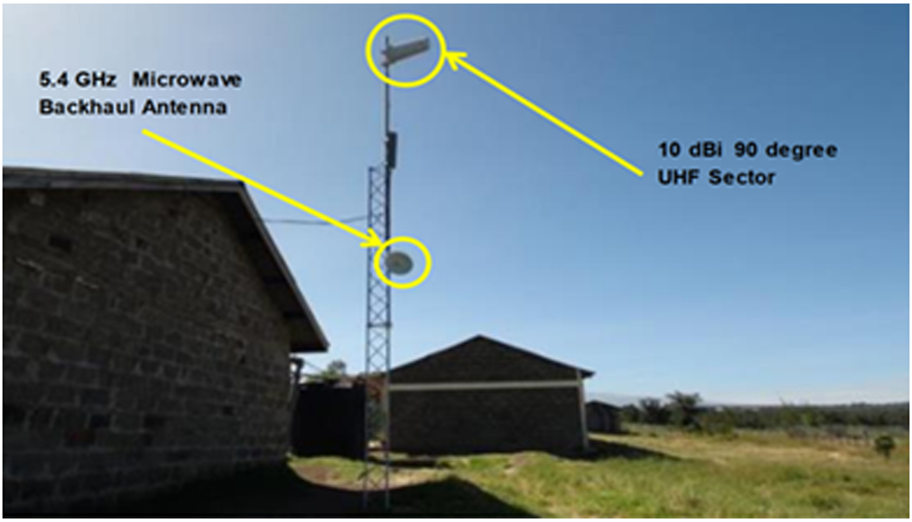


Fig. 2. TVWS Experiment in Nanyuki in 2018.

3.3 The 2020 Experiment (Within Laikipia)

The 2020 experiment was conducted around Nanyuki town using one Adaptrum B1000 base station and four ACRS2 client radios. The client radios were set up in four different locations, each having a directional antenna of 11 dBi gain. The base station transmitted in a 120° sector and the entire links operated in a time-division duplex mode between the base station and the client radios, all in a shared 8 MHz bandwidth channel. During the experiments, no incident of harmful interference was detected

4 Overview of the TVWS Regulatory Framework for Kenya

This section presents an overview of the regulatory framework for TVWS in Kenya. Figure 3 shows the architecture of the TVWS regulatory framework.

4.1 Dynamic Spectrum Access Method

The regulatory framework for TVWS, which is under final review as at the time of writing this paper, evokes that the commercial rollout for TVWS in Kenya will implement the usage of the geolocation databases (GDBs) for spectrum sharing with DTT services as opposed to spectrum sensing. The transmission of White Space Devices (WSDs) will be controlled by a GDB. The GDB providers will have to be qualified by the Communication Authority of Kenya (CA) to ensure that they comply with the procedures for TV White space transmission. Notably,

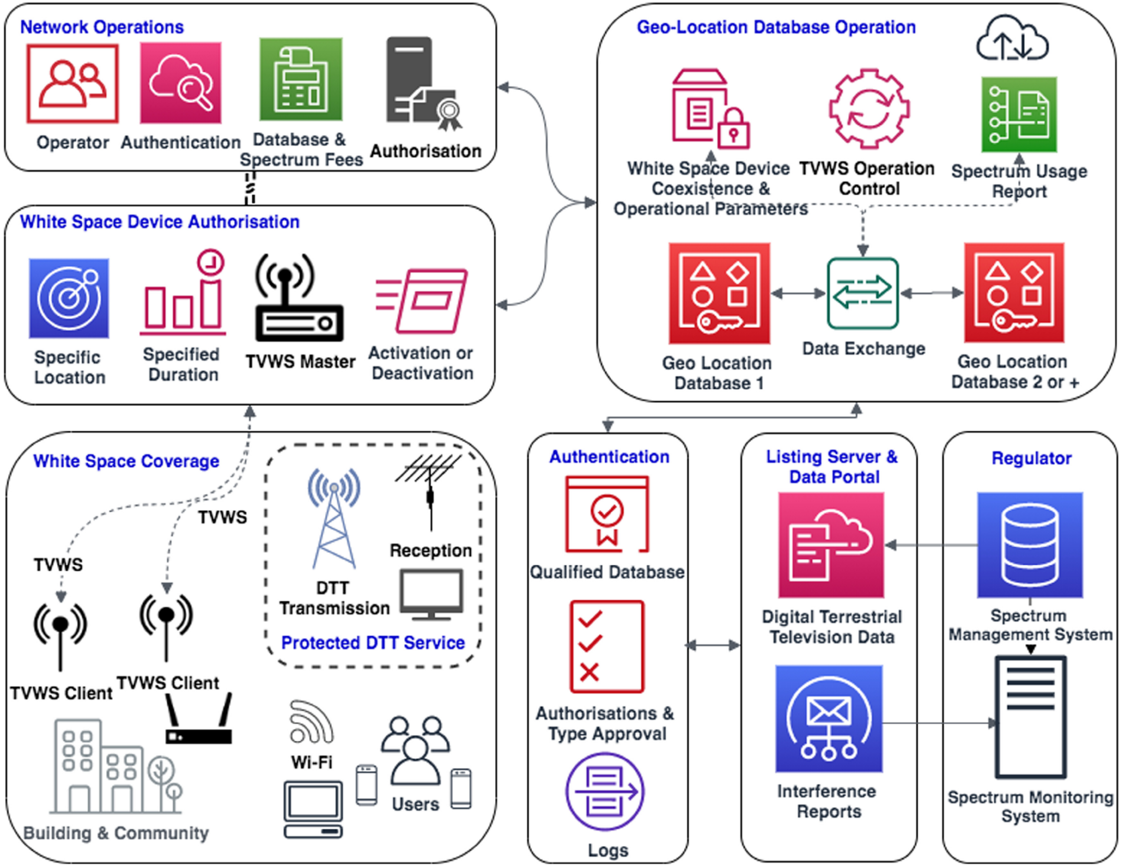


Fig. 3. DSA framework and GDB architecture for TVWS in Kenya.

as part of implementing the TVWS framework, CA has also released the procedure for qualification of the Geolocation Databases (GDBs). The procedures spell a three-phase approval process which involves an application, evaluation and testing and finally qualification. Once a GDB provider has been qualified, the GDB will be listed on the listing server managed by the CA, matching the requirements spelt out in the Protocol to Access of White-Space (PAWS) Databases.

4.2 Licensing Model

Three possible licensing regimes were considered in the regulatory framework; license-exempt, light licensing or full licensing [6]. In a license-exempt regime, no regulatory record is kept of which devices are using RF channels. The disadvantage of this regime is that it poses a risk of interference to broadcasting services if it is to be applied to a TVWS network because it is not possible to identify and locate a device if it causes interference and no protection is provided between TVWS devices.

Full licensing, according to the regulatory framework, means a WSD is charged a fee as a function of the area covered and the duration of usage, the parameters are calculated by a GDB, populated with technical data. In such a model, protection is provided between WSDs. Thus, if one device causes interference to another licensed device, the interfering device may be instructed to change channels or to cease transmission.

In a lightly-licensed model, every master WSD is registered and fully controlled by a GDB. In the event of interference to the primary licensee being detected, the offending devices can be instructed to cease transmission on a particular channel. The network operator requires annual authorisation to operate and pays for the GDB service and a nominal fee for the use of the RF spectrum. CA has adopted a lightly licensing model of service for the implementation of TVWS in Kenya.

4.3 TVWS Spectrum Fees

Under the proposed regulatory framework, TVWS network operation will not be cost-free since the regulator will incur some administrative costs. Some of the costs include the following: update of DTT data portal to enable calculation of TV white spaces, and selection, qualification and regulation of GDBs. Dynamic radio systems such as white space applications are considered to be under non-protected wireless access systems classification in the frequency spectrum fee schedule.

In the regulatory framework, the authority has proposed a fee in line with the frequency spectrum fee schedule and Kenya Information and Communications (Radio Communications and Frequency Spectrum Regulations, 2010). Each authorised WSD will be subjected to an annual fee of KSh. 10,000.00 (approximately $100). This will be reviewed periodically. A potential future costing model being considered by CA is a model that has geographical zones according to population density.

4.4 Geolocation Database Architecture

In order to be qualified to operate, a geolocation database shall be required to have a standard architecture as indicated in Fig. 3. The GDB should be a production-grade, cloud-based system designed to interface with the regulatory authority's spectrum management system in order to determine availability and allow control of secondary access to spectrum white spaces.

The GDB should be compatible with global datasets and be customisable or localised for different regulatory rulesets and models with advanced mapping, planning, and spectrum investigation tools. The GDB should have the computational ability to process algorithms for TVWS coexistence rules based on the Dynamic Spectrum Alliance model; with customisable parameters of a terrain-based radio signal propagation model (including ITU-R 1812).

The GDB should also be able to guarantee the protection of licensed primary services and perform impact analysis of various scenarios based on the rules while adopting advanced planning tools for accurate feasibility studies prior to identification of spectrum for use by the white space devices. It is also mandatory that a GDB should have an interface for DTT transmitter's information update from the regulator's spectrum management database, ideally over SOAP web services. A standard and secure interface should be available on the GDB for certified radios to connect to the database over the protocol to access white spaces (IETF PAWS) [7]. The interface should also have WSD monitoring tools and capability to determine in-channel interference incidents and have a technique to resolve and report to the regulator's spectrum monitoring system. Providers of GDB services should also issue a graphical user interface for monitoring of spectrum utilisation, device management, management of interference and the protected areas as well as a regulator interface that manages and enforces operation of WSDs in accordance with the regulations of TVWS. Moreover, operational logs should periodically be made available to the regulatory authority for every WSD. This should include the initial requests, activation authorisation, aggregate spectrum usage and deactivation incidents. The GDB provider must adhere to the applicable data protection legislation in the country or jurisdiction of operation.

4.5 Eligible Operators

Operators interested in rolling out a TVWS network shall be eligible if they hold a Network Facilities Provider License (Tiers 1, 2 & 3), a Broadcasting Signal Distributor License or a Self-Provisioning Broadcasting License to use TVWS spectrum. Network Facilities Provider Licensee means a licensee authorised by the Authority to build and commercially operate telecommunication or electronic communications systems. Broadcasting Signal Distributor License authorises a licensee to roll out and operate infrastructure for transmission of digital TV and radio broadcasting services. A Self-Provisioning Broadcasting Signal Distribution license is a license that allows an entity to roll out its network or utilise its existing infrastructure network to carry its content. However, the entity will, in addition, be required to have a broadcast content license.

4.6 Maximum Transmit Power

To prevent harmful interference to primary users, maximum power limits shall be specified for each channel at every permitted location. Maximum power limits will also be informed by coexistence calculations. In the regulatory framework, the maximum transmit power has been set to 42 dBm (10 W).

4.7 White Space Devices Coexistence Considerations

DTT broadcast transmissions in the 470–694 MHz are to be protected from harmful interference from secondary transmissions and the adjacent mobile services. To achieve this, the WSD maximum power shall be restricted. Table 1 summarises the coexistence rules for different user types.

Table 2. Coexistence rules for the Kenya DSA framework.

Existing use type	Co-existence solution
Broadcasting service	Maximum power limits to WSDs required protecting DTT broadcasting-service
Broadcasting service (neighbouring countries)	Maximum power limits to constrain interference to neighbouring countries transmissions
Mobile service (450–470 MHz)	Maximum power limits to WSD to limit out of band emissions
Mobile service (700 MHz)	9 MHz guard band to ensure that there is no interference from WSDs

4.8 Device Characteristics and Other Parameters

Under the regulatory framework, manually configured master WSDs will not be allowed to operate. An example is a WSD that requires manual input of geographic coordinates and certain operational parameters. To avoid the risk of harmful interference, the WSDs operation will need to be in line with the minimum technical and operational parameters that are defined in ETSI standards 102, 103 and 301 as well as the DSA model rules and regulations for TV white spaces. All models of WSDs will have to be type-approved by CA before their initial activation for use.

4.9 Exchange of Parameters Between WSD and GDB

After a master WSD establishes communication with a GDB, it will communicate its device parameters. The GDB will then use the device parameters to compute the operational parameters that will be used by the device i.e. the channels available and the maximum transmit power. The master device will then select the operational parameters to use and report as channel usage parameters. If a master device has some client devices under its control, it will obtain generic operational parameters from the GDB, the generic operational parameters are restrictive compared to the normal operational parameters. After the master device receives the generic operational parameters from the GDB, it will broadcast to the client devices under its control. After listening to the master WSD broadcast, the client WSDs will obtain the generic operational parameters which will be used during initial communication with the master WSD. In the initial communication, the client WSDs will send device parameters to the master device. The master WSD will then send the device parameters received from each client to the GDB to compute the operational parameters for each specific client. The master WSD will continuously report the channel usage parameters to the GDB, whether specific or generic operational parameters.

4.10 Interference Management

It is expected that the coexistence rules outlined in the framework will prevent harmful interference to primary DTT service. The following provisions may be used to manage harmful interference that may arise: 1. Broadcasters, consumers, network operators and GDB providers shall report any cases of harmful interference. 2. GDB providers may be ordered to cease providing services. 3. CA may directly blacklist an offending WSD, via a regulator interface made available to the CA by the GDB providers.

5 Analysis and Comparison of Kenya TV White Space Framework with Other Frameworks in Africa

Several countries in Africa have embraced TVWS technology and have already developed frameworks to allow the use of technology. Kenya [4], South Africa [8,9], Ghana [4] and Botswana [10] have also launched trials in the recent past to assess the performance of the technology. Countries in Africa that have already developed TVWS regulatory frameworks include the following: Uganda, Nigeria, South Africa, Malawi and Ghana. Additionally, the Kenyan framework is compared to that of USA and UK. In this section, regulatory frameworks for the mentioned countries are compared and analysed. Recommendations for additional considerations are also made. Tables 3 and 4 shows a comparison of the frameworks.

Table 3. Comparison of TVWS frameworks.

Issue	Kenya [11]	Malawi [12]	South Africa [13]	Uganda [14]	Ghana [15]	Nigeria [16]	USA [17]	UK [18]
Licensing mode	Light licensing	Licence exempt and Licensed	License exempt	Licensed	License exempt	Licensed and license-exempt	License exempt	License exempt
Spectrum band	470–694 MHz	470–694 MHz	470–694 MHz excluding radio astronomy services in 606–614 MHz	470–694 MHz	470–694 MHz	470–694 MHz	Fixed devices only: VHF band (54–72 MHz, 76–78 MHz, 174–216 MHz) Both fixed and portable devices: UHF band (490–698 MHz)	UHF band only (470 to 606 MHz, and 614–782 MHz)
Equipment standards and other reference standards	ETSI EN 301 598 V1.1.1 (2014-04)	FCC standards of 2012	ETSI EN 301 598, PAWS	IEEE 802.11af, IEEE 802.22 and ETSI EN 301 598.	FCC standards	ETSI EN 301 598 V2.1.1 (2018-01)	FCC standards of 2012	ETSI EN 301 598 V1.1.1 (2014-04)
Validity period of parameters	24 h or if the device moves more than100m	Provided by database as part of operational parameters.	24 h for fixed devices, 12 h for portable devices or if it moves 100 m	Database to update master and client when no longer parameters valid.	24 h for fixed devices, 12 h for portable devices or if it moves 100 m	Provided by database as part of operational parameters.	48 h	Provided by the database as part of operational parameters
Channel aggregation	Allowed – up to three	Not specified	Not specified	Allowed	Not specified	Allowed	Allowed for fixed devices	Not specified
Installers	Not specified	Not specified	Accreditation required	Not specified	Not specified	Accreditation required	Accreditation required	Not specified

Table 4. Comparison of TVWS frameworks.

Issue	Kenya [11]	Malawi [12]	South Africa [13]	Uganda [14]	Ghana [15]	Nigeria [16]	USA [17]	UK [18]
DSA method	GDB	GDB	GDB	GDB	GDB and spectrum sensing	GDB	GDB and spectrum sensing	GDB
GDB implementation	Propagation model approach using ITU-R 1812	Propagation model approach	Propagation model approach	Propagation model approach	Protected contour approach	Propagation model approach	Protected contour approach	Location probability
Maximum power	16 W	4 W	10 W for fixed devices, 100 mW for portable devices	4 W for fixed devices, 100 mW for portable devices	10 W in rural areas, 4 W in urban areas	1 W for fixed devices, 50 mW for IoT devices	10 W	10 W
Coexistence considerations	Protection of mobile services and neighbouring countries	Not specified	Protection of astronomy services	Not specified	Not specified	Not specified	Protection of mobile services and neighbouring countries	Protection of mobile services and neighbouring countries
Maximum antenna height	50 m	Not specified	80 m in rural areas, 30 m in urban areas	50 m	30 m	100 m above ground level, 250 m HAAT	30 m	30 m
Fees	Applicable – Same as for ISM	Applicable – as prescribed by the commission	Not specified	Applicable – as prescribed by the commission	Applicable - same as for ISM band	No fees specified	None	None
Approval status	Interim approval	Published	Published	Published	Published	Draft	Published	Published
Types of devices	Master and slave	Master and slave	Master and slave	Master and slave	Fixed, Mode I, Mode II	Master, slave, IoT	Fixed, Mode I, Mode II	Master and slave

5.1 Spectrum Band

The spectrum band that has been set aside for TV White Space network operation in Africa is 470–694 MHz. This is in line with ITU-R regulations. In South Africa, the spectrum band will exclude astronomy services operating in 606–614 MHz band.

To meet the increasing demand for spectrum, there is a need to extend regulatory frameworks to allow dynamic access to other spectrum bands. This is especially useful for upcoming 5G networks [19,20] which has many use cases such as IoT, vehicle to vehicle communications and machine to machine communications. Additional bands that can be considered for DSA are the 1800 MHz mobile band, 700 MHz mobile band, 6 GHz band, lower 26 GHz spectrum band and 3.8–4.2 GHz band.

5.2 Licensing Approach

Most regulations in Africa have adopted the light licensing approach. Although some regulations state "license-exempt" and/or licensed, it implies light licensing because all WSDs have to register with the database and have to pay a nominal fee. Light licensing is appropriate because it will allow ease of control of interference problems that may arise as well as regulation of operation of TVWS network providers.

5.3 WSD Transmit Maximum Power

Fixed, portable and IoT devices maximum transmit power are specified differently. They are discussed separately. For Fixed devices, the maximum transmit power adopted by Kenya is 16 W EIRP. In the South African and Ghanaain regulations, the maximum power is set to 10 W just like in the USA and UK regulations. In the Ghanaain regulations, 10 W is the maximum power for rural areas and for urban areas the maximum power is 4 W. In Nigeria the maximum allowed power is 1 W. For the Portable devices, Only Uganda and South Africa have set maximum power for personal and portable devices at 100 mW EIRP. The IoT devices have an explicit mention in the Nigerian rules which state separate EIRP limits at 50 mW (17 dBm). In the Kenyan regulations, a 42 dBm limit applies to all devices.

The intention of setting maximum power is to protect DTT against harmful interference. In rural areas where there are few DTT services, the maximum power can be increased due to less risk of harmful interference. The regulations that have set their maximum to transmit power to 10 W and 4 W can review their maximum power upwards to 16 W. To limit interference the maximum power for urban areas that are congested can be set to 4 W (36 dBm) and maximum power for rural and less congested areas can be set to 16 W (42 dBm). The increased power for rural areas is especially useful for terrains that pose signal propagation challenges. Recent studies show that 42 dBm (30 dBm conducted power with 12 dBi antenna gain) seems to offer an optimum balance between greater coverage and larger antenna sizes and higher equipment costs, which both also increase with higher gain [21,22].

Uganda and South Africa have specifically provided that portable devices that will have a maximum power of 100 mW can consider higher maximum power of up to 16 W but under the condition of geofencing and only in less congested rural areas. Geofencing has recently been provided for personal/portable devices under USA regulations [22]. Geofencing means a personal/portable is limited to operate at a certain fixed area with a certain maximum power as provided by the GDB. Examples are the fixed transportable WSD operations such as tractors or other movable machines that are used for farming and that can enable IoT-based agriculture.

5.4 Maximum Antenna Height

Kenya and Ghana have set the maximum antenna height at 50 m and 30 m, respectively. South Africa regulations have set the maximum antenna height at 80 m for rural areas and 30 m for urban areas. Uganda has set a maximum antenna height of 50 m. Nigeria has set the maximum antenna height as 100 m above ground level and 250 m Height Above Average Terrain (HAAT).

To avoid the risk of harmful interference different maximum antenna heights can be set for rural and urban areas like what the South Africa regulations provide. Higher antenna heights can also be considered by other countries especially for rural areas. 250 m HAAT can be considered by other regulations to allow ease of coverage of rural less congested areas with challenging signal propagation environment. Recently, Microsoft proposeda maximum antenna height of 500 m HAAT for rural areas of the USA, that are far off coverage of certain channels of DTT transmitters [22]. This is a proposal that can also be considered by TVWS regulations in Africa.

5.5 Spectrum Sharing Method

The majority of African regulations on the use of TV white spaces adopted the GDB approach, except Ghana which permitted spectrum sensing in addition to the use of GDBs. The GDB approach is considered more reliable than spectrum sensing which is seen to suffer from a hidden node problem [4].

5.6 GDB Implementation

Most regulations make use of a propagation model in the database implementation. Only Ghana makes use of the contour-based approach like the USA regulations. UK regulations have taken the location probability implementation approach. The decision by Ghana to use a contour-based approach is too restrictive and will lead to wastage of TVWS. This is because the approach requires that there be a protection distance between a WSD and the DTT. None of the regulations in Africa has adopted the UK approach, because its location probability approach is computationally intensive and is based on continuously stored UK data.

The geolocation propagation model specified in the Kenya regulations is ITU-R 1812. This is because it is a path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands, which is more accurate than other models such as Longley Rice. Other regulator frameworks can also consider the ITU-R 1812 propagation model.

5.7 Coexistence Rules

Interference in TVWS networks is the main limiting factor for spectrum re-use. TVWS can be used as long as interference does not exceed a certain threshold beyond which there will be harmful interference. The specified maximum limits are set to ensure co-existence between WSDs and DTT transmission as well as co-existence among WSDs in a TVWS network. In the Kenyan framework, a 9 MHz guard band has been specified to protect mobile services that operate in the 700 MHz band. The Kenyan regulations also specify that the maximum power limits are to limit out of band emissions that may affect the operation of mobile services in the same band. Most regulations under consideration have also specified limits on out band (OOB) emissions. This is necessary to limit adjacent channel interference. Adjacent channel interference refers to interference to a TV receiver from WSDs operating in the adjacent channel. Most regulations have adopted ETSI 301598 standard requirement that specifies maximum out of band emissions for different classes of devices. The out-of-block EIRP spectral density (P_{OOB}), for most regulations, of a WSD has been set to satisfy the following limit:

$$\begin{aligned} P_{OOB}(dBm)/(100\,\text{kHz}) \leq \\ & max\{P_{IB}(dBm/(8\,\text{MHz})) - ACLR(dB), \\ & -84(\text{dBm}/(100\ \text{kHz}))\} \end{aligned} \tag{1}$$

where P_{IB} is the measured in-block EIRP spectral density over 8 MHz, and ACLR is the Adjacent Channel Leakage Ratio for different Device Emission Classes outlined in Table 5. Only Uganda regulations have not incorporated this requirement. This can lead to undesired adjacent channel interference.

Concerns have been raised recently over the impact of aggregate interference on DTT transmission and among WSDs [23]. In a TVWS network, interference could be due to either co-channel interference or adjacent channel interference. The given maximum power limits may not be sufficient to protect DTT transmission against the combined effects of aggregate interference especially for TVWS dense scenarios such as cellular access to TV white spaces [24] and IoT [8]. Recent studies have shown that aggregate adjacent channel interference from multiple transmitters has the same effect as co-channel interference [25].

Only the Ghanaain regulatory framework has specifically stated that transmit power control for WSDs is required. This is specified as follows in the Ghana framework: “Transmitted Power Control – A TVWS device shall incorporate transmit power control to limit its operating power to the minimum necessary for successful communication to be completed”. This will help limit aggregate interference. This can be considered by other frameworks in Africa.

Optimisation of power and spectrum allocation [26] is another potential solution that can be adopted in the regulatory frameworks to limit the potentially harmful effects of aggregate interference.

Table 5. ACLR for different device emission classes.

Where POOB falls within the nth adjacent DTT channel (based on 8 MHz channels)	ACLR (dB)				
	Class 1	Class 2	Class 3	Class 4	Class 5
n = ±1	74	74	64	54	43
n = ±2	74	74	64	54	43
n = ±3	74	74	64	54	43

5.8 Channel Validity Period

The channel validity period for most of the regulations in Africa is 24 h. In the Malawi and Uganda regulations, it is provided as part of the operational parameters. In Nigeria regulations, devices will operate until they are notified that the parameters are no longer valid.

5.9 Channel Aggregation

Channel aggregation refers to a combination of more than one TVWS channel. In the Africa regulations under consideration, TV channels are 8 MHz. This is beneficial because it will lead to higher throughput. Only Kenya, Uganda and Nigeria regulations have specifically stated that channel aggregation will be allowed. The other countries should consider incorporating the same.

5.10 Border Areas

WSDs must operate in a manner that will not cause harmful interference to broadcast and other services in neighbouring countries. Nigeria and Ghana regulations require that all signals reaching Ghana border must have a noise floor level of -115 dBm. Uganda has not made any provisions for transmissions near border areas. Malawi regulations state, “Where a white space device operates along border areas, a licensee shall ensure that the device does not cause interference to other services from neighbouring countries”. Regulations that have no incorporated protection of interference in border areas need to do so to ensure the protection of neighbouring countries DTT transmissions.

5.11 Approval Status of Regulations

Most regulations under consideration have been published. Only Malawi and Nigeria are still having their regulations in the draft stage.

6 Recommended Critical Success Factors for Development of Dynamic Spectrum Management Frameworks

Over the course of the development of Kenya's dynamic spectrum management framework for use of TV white spaces, important lessons were learnt that could be applied by other NRAs that intend to develop similar regulatory frameworks. Several critical success factors were especially important during the process and are recommended for adoption. Firstly, it was learnt leant that it is vital to conduct regular stakeholder engagement and actively involve academic and industrial researchers in the process to incorporate their relevant input. Secondly, fostering an enabling legal and regulatory policy environment to permit alternative approaches to spectrum management was of paramount importance. Thirdly, due diligence assessment on international best practice was a key aspect that enabled the framework to be developed in a relatively short period of time. Lastly, the authorization and monitoring of trial network deployments was a critical factor in determining the technical parameters necessary for effective coexistence of secondary white space devices while protecting the DTT broadcasting service from harmful interference.

7 Conclusion

In this paper, an overview of Kenya's framework for the use of TV White Spaces (TVWS) is presented. TVWS experiments leading to the development of the framework for Kenya are also highlighted focusing on the major lessons learnt particularly inclined to the key requirement of not causing harmful interference to the DTT services. Similarities and variations are noted in the technical and operational requirements of TVWS across different countries as presented in this paper. They clearly point out that the secondary opportunistic utilisation of TVWS depends on the needs and contexts of each country, although guided by international standards.

TVWS is regarded as one of the potential solutions towards bridging the digital divide. However, most of the TVWS networks implemented in Africa as a first step of adopting dynamic spectrum access (DSA) have not been able to move beyond pilot projects. The seven year journey of TVWS studies in Kenya (from the 2013 trial) towards the development of the TVWS framework shows that the TVWS industry is slowly developing and there is a high likelihood of continuous technical and market evolution as DSA grows. This might lead to immediate future regulatory changes even before many commercial deployments of TVWS take off on the African continent. More DSA work based on the TVWS regulations for Kenya will be published in the future studies.

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