

# Spectrum Regulation for Future Internet Networks in Developing Economies

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**Abstract:** Radio frequency spectrum resources play a crucial role as enabler in future wireless ICT infrastructure and development of affordable broadband services. Activities by research organisations such as the CSIR and regulators such as the FCC of the USA, Ofcom of UK and ICASA of South Africa are promoting innovation-based spectrum sharing technologies to improve the effective utilisation of national spectrum resources. Experimental test-beds have been deployed to address affordable broadband demand in underserved communities. Although the technology is most beneficial for emerging economies, telecommunication regulators in Africa are still lagging behind the rest of the world in enacting the necessary enabling dynamic spectrum regulations for the industry to flourish and provide the necessary socio-economic benefit. This paper presents research to support formulation of the dynamic spectrum regulatory framework including co-existence techniques, interference avoidance and network device technology aspects in support of telecom regulators in emerging economies. Furthermore, the paper discusses the importance of spectrum sharing as a component of the emerging 5<sup>th</sup> Generation networking standard in addressing the exponentially increasing bandwidth capacity demand to enable the planned wireless ICT services.

**Keywords:** Dynamic Spectrum Sharing, Regulation, Broadband, Future Internet

## 1. Introduction

Wireless links have an increasing role in the provisioning of access to universal broadband Internet services. In the shorter term, wireless links can also serve as backhaul links to facilitate access for those of the next billion customers that live in rural areas where the techno-economics of traditional network deployment models have overlooked. This will, however, require intelligent spectrum sharing techniques to avoid interference and reduce the burden in utilising the already scarce radio frequency (RF) spectrum. In wireless communication networks, radio frequency (RF) spectrum is the most precious and expensive wireless network resource that needs to be well regulated. Despite its crucial importance, several studies have shown that the utilization of allocated radio frequency spectrum resources is on average below 50 % in several regions of the allocated usable spectrum bands. Specifically in rural Africa over 90 % of the usable spectrum is available to be harnessed for wireless broadband internet services. National regulatory agencies (NRAs) in most countries are required to regulate radio communications by means of renewable licenses, exemptions basis or through spectrum auctioning. While this approach ensured a non-interfering communication between radio terminals, it has resulted into an inefficient utilisation of the spectrum. A number of next generation radio technologies are being proposed to increase the bandwidth capacity of future wireless 5G networks and associated services. Furthermore, the need to provide broadband coverage to the under-

served areas particularly in rural communities has been highlighted by ITU for emerging markets [1, 2]. The regulatory process and efficient management of spectrum resources for dynamic spectrum allocation to wireless networks is a complex undertaking. Telecom regulators in Africa therefore need to build capacity and develop dynamic spectrum management frameworks, including the tools to reliably monitor dynamic spectrum sharing (DSS) based networks. The recent surge in TV white space (TVWS) network deployments in several countries is a good example [3 - 8]. Such a co-existence tool that is becoming a de-facto standard in telecom space is the White Space database (WSDB) [9 - 17]. WSDBs are expected to enable spectrum sharing in future wireless networks and accelerate the deployment of affordable broadband networks in underserved rural communities. This paper therefore discusses the development of dynamic spectrum regulatory framework in support of telecom regulators in emerging economy countries, and to enable them harness their national spectrum resources for broadband innovation. Additionally, the paper will discuss dominant coexistence and spectrum sharing techniques and protocols for future wireless networks, these are necessary in order to avoid interference and supporting dynamic spectrum access regulation NRAs in Africa to accelerate affordable broadband deployment.

The paper organisation is as follows: in section 2 we will first discuss the objectives for a dynamic spectrum regulation, section 3 then discusses the methodology for the regulatory framework development, section 4 discusses the required technologies for a smooth operation of dynamic spectrum sharing (DSS) based networks. Section 5 describes the protocol for accessing TVWS databases; section 6 highlights TVWS broadband network trials being undertaken by the council for scientific and industrial research (CSIR) Meraka institute and its partners. Section 7 presents a short discussion on business cases and Section 8 concludes this paper.

## **2. DSS Regulatory Objectives**

The regulatory objectives of dynamic spectrum sharing (DSS) are composed of the following guiding principles:

- a) Improved and effective utilisation of national spectrum resources in all bands of interest.
- b) Development of reliable spectrum monitoring and co-existence tools with legacy licensed networks to enable non-interfering DSS.
- c) Enabling broadband network innovation in support and provision of affordable broadband for the unconnected, and the fulfilment of the national development plan for future ICT and wireless broadband services.
- d) Harmonisation of the DSS rules along country boundaries and international telecommunication union (ITU) standards and guidelines.
- e) Developing DSS policy with a foresight and aim to promote new wireless communications technology and emerging business models.

The following sections discuss in detail the requirements and expected outcomes of the regulatory objectives of dynamic spectrum sharing based on the above listed principles. Several regulators including the Independent Communication Authority of South Africa (ICASA) have outlined a framework for dynamic and opportunistic spectrum management [18, 19]. It is the aim of this paper to support the efforts of emerging economy telecom regulators with an innovative DSS implementation frameworks based on research supported data and global activities for dynamic spectrum regulation.

### **3. Methodology for DSS Regulatory Framework**

This section reviews TVWS regulatory developments/rule making processes in the US, UK, Singapore, South Africa and Malawi.

#### *3.1 The United States of America (USA)*

The FCC started its rule making process on TVWS in 2004, since then a number of notices and regulations have been published. Initially, the FCC TVWS rules allowed the operation of fixed unlicensed devices in vacant TV channels with the exclusion of channel 37 and 52 to 69, under the condition that they will not cause interference to TV and other existing services [10, 11]. The operation of personal/portable devices was prohibited in channel 14 to 20. However, these notices did not adopt the final technical rules for the operation of such devices. Subsequently, the technical rules to allow the operation of unlicensed devices in TVWS were adopted [12, 13]. The rules allowed for the operation of both fixed and personal/portable devices in channel 2 to 36 and 36 to 51. Fixed devices were required to use a WSD and spectrum sensing to determine a list of available channels.

The FCC TVWS rules were updated to eliminate the requirement that devices must also use spectrum sensing to detect available channels in addition to the use of WSDB [13]. As a result the applicable rules were amended to reflect the WSDB as the only method for determining channel availability. Further changes were made to the rules in 2012, to modify adjacent channel emissions to specify fixed values instead of varying the limit relative to the in-band power. The rules also increased the maximum permissible PSD for each category of the devices [13]. In 2014, the FCC proposed changes to the rules, such as decreasing the interval at which devices recheck the WSDB to verify channel availability and changes for certifying, manufacturing and marketing TVWS devices and wireless microphones [13].

#### *3.2 The United Kingdom (UK)*

Ofcom published TVWS regulations following an extensive consultation process and research over a number of years. Ofcom set out proposals for the TVWS technical rules during its consultation in 2013 [14]. Ofcom has allowed a number of trials in the UK in order to fully understand the implications for interference of the proposed regulatory limits. Following the trials, Ofcom made changes to proposals that were set out in the 2015 consultation. The TVWS space regulations allow TVWS devices to access TVWS in the band 470-790 MHz on a licence exempt basis [15]. The regulations provide for TVWS devices to transmit in line with operational parameters obtained from WSDB operated by organisations certified by Ofcom.

#### *3.3 Singapore*

The Info-communications Development Authority (iDA) of Singapore published the TVWS regulations in 2014 subsequent to a series of trials and a public consultation. In 2009-2011, trials were conducted for proof of concept and for testing the regulatory framework. In 2011-2013, trials were conducted to test TVWS applications and services. Subsequently, the public was consulted on the proposed TVWS regulatory framework. The final regulations allow for the use of 24 channels in the 174-230 MHz and 470-806 MHz bands by TVWS on a licence exempt basis [16]. The regulations mandate the use of the WSDB authorized by the iDA, to determine channel availability by TVWS devices. TVWS devices are required to query the database every 6 hours to obtain formation on channel availability and transmission power levels at its location.

### 3.4 Malawi

Malawi conducted its first TVWS trials in 2013. Interestingly, this trial put less emphasis on the use of WSDB to authorize channel availability [8]. The reason for this is that there is a vast amount of TVWS in Malawi, particularly in rural areas. As such, trial proponents were of the view that it was feasible to initially implement TVWS in Malawi without the use of WSDB. Further trials were conducted in 2015. Following the trials MACRA published draft TVWS regulations for public comments [8]. It is expected that the final regulations will be published before the first quarter of 2017.

### 3.5 Ghana

In Ghana, the National Communications Authority (NCA) has started the public consultation on TVWS regulatory framework with the aim of finalizing regulations for TVWS. According to their invitation for comments, the NCA “intends to introduce Television White Space (TVWS) Spectrum Usage Regulatory Framework in order to streamline the provision of data services in the Television Ultra-High Frequency (UHF) Bands”<sup>1</sup>. The public consultation started on 27 June 2016 and expired on the 5<sup>th</sup> August 2016. Some of the highlights from the draft regulation framework are the mandatory usage of WSDB by TVWS network operators. Final regulations are expected to be published in early 2017 [7].

### 3.6 South Africa

South Africa has conducted TVWS trials but has not yet finalized the regulatory framework. ICASA authorised CSIR Meraka Institute to conduct Television White Space (TVWS) trials in Cape Town and Limpopo in September 2012 and 2014, respectively [3 - 6]. The overall aim of the trials conducted by CSIR Meraka Institute was to demonstrate that TVWS devices can operate in the TV frequency band 470-694 MHz without causing any interference to the incumbent TV transmissions and to obtain regulatory support for TVWS technology. The aim of the trials was achieved as there was no interference reported during the trials. The trial in Cape Town was the first in the world to use white spaces adjacent to TV channels that were carrying broadcasts [3 - 5]. In April 2017, ICASA published a position paper on the dynamic and opportunistic spectrum management [18]. One of ICASA’s positions is that there is majority support the introduction of TVWS regulatory framework with some opposition [19]. Consequently, in the same day of April, 2017, ICASA published draft regulations on the use of Television White Spaces for public consultation [19]. Public representations on the draft regulations are open until 19 May, 2017..

### 3.7 Section Summary

The US was the first country to authorize the use of TVWS through regulations. There are similarities between the regulations adopted in the US, UK and Singapore. The regulations provide for the use of TVWS on a licence exempt basis and mandate the use of WSDB to determine the availability of TVWS channels and transmission parameters for the TVWS devices.

With regards to Africa, even though that there are a number of African countries currently conducted TVWS trials, none of them has finalised TVWS regulations allowing the commercial operation of networks based on TVWS technologies. This should concern relevant authorities, considering the fact that Africa has a lot to gain in allowing the implementation of TVWS, for the following reasons:

- Countries in Africa have more TVWS than more developed countries in the west.
- Broadband access is very limited in rural areas.

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<sup>1</sup> [www.nca.org.gh](http://www.nca.org.gh)

- TVWS can be used to bridge the digital divide.

#### 4. Techniques for DSS Regulatory Frameworks

The rapid technological advances in the industry have brought in promising innovative techniques such as Dynamic Spectrum Access (DSA) that are meant to improve the spectral utilisation efficiency and capacity through sharing and the use of small cells [20, 21]. These efforts have been supported by the leading NRAs by introducing flexible spectrum management frameworks such as the TVWS scheme, the Spectrum Access System (SAS), and the Licensed Shared Access (LSA) [14 – 17, 22, 23]. It is worth noting that dominant spectrum sharing and coexistence techniques for futuristic networks that are currently preferred by leading NRAs are centralized in nature and relying on the so-called spectrum databases assisted by spectrum sensing to some extent. Figure 2.1 depicts a future wireless ecosystem.

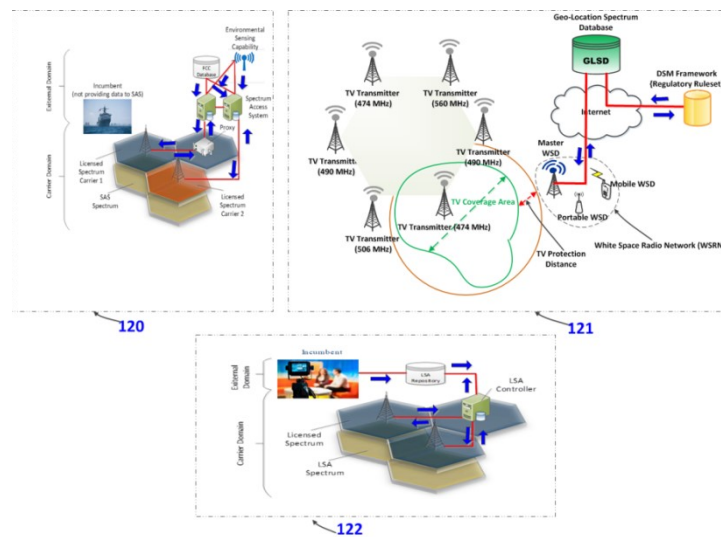


Figure 2.1: Illustration of heterogeneity of highly dynamic spectrum sharing frameworks for future wireless networks ecosystem.

The dynamic spectrum sharing frameworks depicted in Figure 2.1 are numerically illustrated below:

- **120**: The three tier dynamic spectrum sharing framework through the SAS. The framework enables creation of broadband small cells networks by sharing spectrum in the Citizen Radio Band (i.e., 3.5 GHz) [22]
- **121**: The TVWS spectrum sharing framework. Secondary users are allowed to dynamically share the locally unused broadcast spectrum and form affordable long-range broadband networks through the WSDB [9].
- **122**: The authorised spectrum sharing framework in the licensed band/License (LSA). The holders of spectrum license can temporary dynamically share the portions of underutilised spectrum with the secondary user. This framework is enabled by the LSA repository and is preferable by Mobile Network Operators (MNOs) due to the guaranteed QoS [23]

##### 4.1 Key Parameters for Coexistence and Spectrum Sharing

###### 4.1.2 WSD Spectral Emission Mask

Spectral emission masks are used to define the maximum permitted out-of-band (OOB) emissions for operation of WSDs in the RF band of interest. To ensure the protection of terrestrial broadcast TV receivers from potential harmful interference that might be generated by WSDs, spectrum regulators are required to prescribe with respect to co-

channel and adjacent channels specifically for various channel bandwidths. Figure 2.2 depicts a typical WSD emission mask.

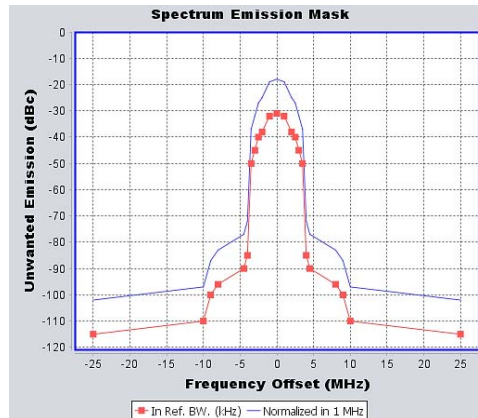


Figure 2.2: Typical WSD spectral emission mask, key factors in determination of mask for a particular frequency band are the total emission power of a WSD in dBc and the reference bandwidth. In this example, the inner curve (also known as actual curve) is referenced at a given bandwidth of 50 kHz. The outer curve is normalised at a reference bandwidth of 1 MHz. This curve is used in the actual OOB calculation of WSDs as it provides a buffer offset from the (actual) inner curve.

#### 4.1.3 Primary System Receiver Protection

Protection ratio (PR) is a function of the Adjacent Channel Leakage Ratio (ACLR) of the interferer (i.e., WSD) and the Adjacent Channel Selectivity (ACS) of the victim (i.e., TV receiver). The ACS could correspond to the blocking masks defining the level at which a receiver rejects unwanted OOB emissions. Figure 2.3 illustrates the concept of PRs.

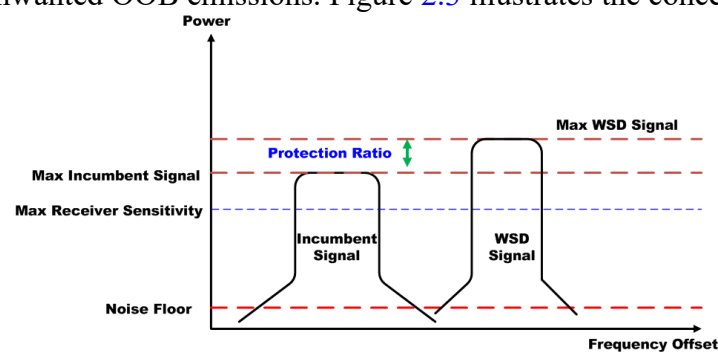


Figure 2.3: Illustration of PR between interference and victim signals.

In order to establish robust protection ratios for the victim receivers from possible quality degradation due to the leakage from the interferer. The regulator is required to conduct a thorough statistical analysis of the performance (e.g., exhibition of the non-linear behaviour in the presence of strong interference signal) of the most widely commercially available receivers in the particular market. Typically, the analysis constructs the Gaussian Cumulative Distributions Function (CDF) of the victim receivers protection ratio measurement values for the 10th, 50th, and 90th percentile, as well as that of the ACLR of interferer into the victim receivers [24]. For the TV broadcasting case, several types of digital TV receiver tuner technologies from different manufacturers should to be considered, the common types are [24]:

- Silicon tuners built in set-top boxes (STBs) and integrated digital (iDTV).
- Can tuners built in (STBs) and TV (iDTV).

- Silicon tuners built in USB stick devices.

The UK regulator, Ofcom conducted the aforementioned analysis to derive the conservative protection ratios using the 70th percentile CDF of ACS values according to the sales figures of fifty (50) widely commercially available TV receivers in the UK market [14].

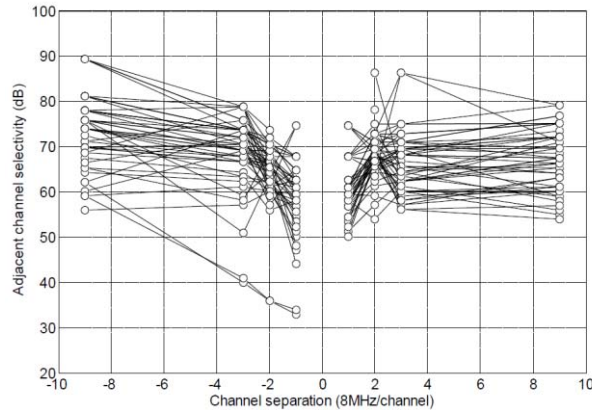


Figure 2.4: Depiction of the ACS of 50 commercially available TV receivers and their corresponding protection ratios when the WSD carrier signal is -70 dBm.

The 70th percentile for the protection ratio value implies that 70 % of receivers measured are protected at a particular frequency offset per each WSD emission class and transmit power levels [14]. Figure 2.5 illustrates the concept of derived PRs and ACS values.

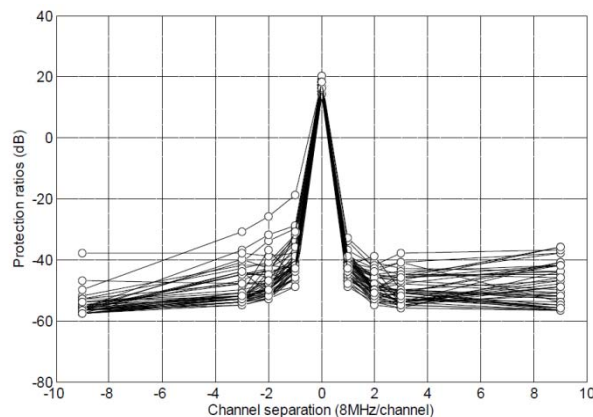


Figure 2.5: Derived Adjacent Channel Selectivity (ACS) and PR for the 50 samples of the most commercially available digital TV receivers in the UK market [9, 14].

#### 4.1.4 Radio Propagation and Channel Model

Generally speaking, regulators are expected to prescribe preferred radio propagation model(s) for each reference planning geometry of WSD.

#### 4.1.5 Co-existence Calculation Methodology (Algorithm)

This is the translation of the regulatory framework rules into actual implementation in the form of computer programs. [9]

## 5. Protocol to Access White Space Databases

The Protocol to Access White Space (PAWS) databases RFC 7545 [25], enables WSDs to discover and gain access to the WSDB spectrum via the WSDB in a globally standardised manner. The key benefits of this standard to the industry are twofold: firstly, enabling

OEMs to attain economies of scale necessary to justify business viability and therefore making affordable devices. Secondly, enabling network operators to avoid a phenomenon known as “vendor lock-in”, this is caused by the use of proprietary protocols.

### 5.1 PAWS Methods

The PAWS communications routine follows a classic HTTP style "Request-Response" mechanism. In other words, the WSD (client-side) queries the WSDB (server-side) and subsequently, receives a response from it (i.e., result or error message). Key PAWS methods are:

- Initialisation;
- Registration;
- Available spectrum query
- Spectrum use notify; and
- Device validation.

Figure 3.1 shows a screen-shot of developed Virtual Multi Radio Device (VMRD) used to test PAWS functionalities. VMRD operates similar to real-world WSD hardware.

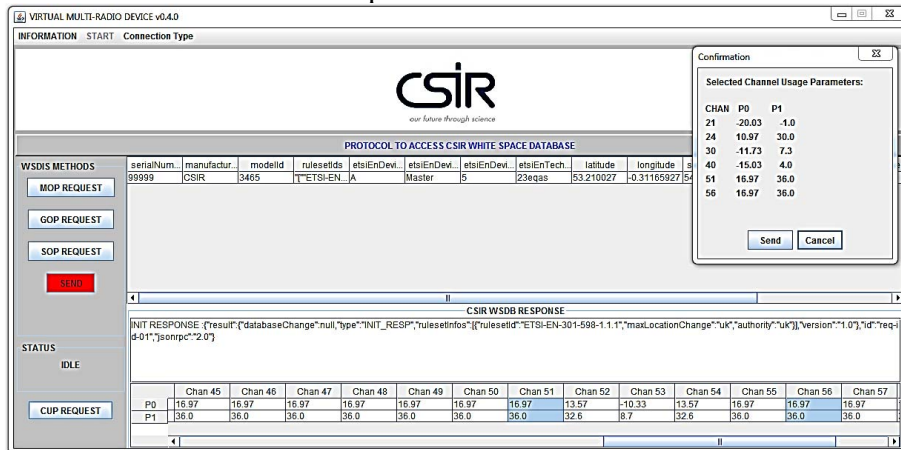


Figure 3.1: The Virtual White Space Radio Device (VMRD) used for testing PAWS functionality

Figure 3.2 illustrates PAWS implementation block and sequence diagrams.



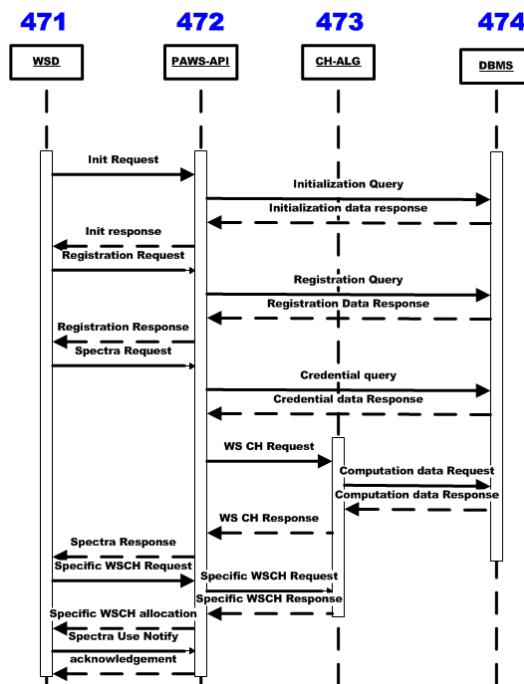


Figure 3.2: PAWS flow diagram illustrating WSD (471) interaction with the WSDB via PAWS API (472). The TVWS channel allocation algorithm (473) post-process identified TVWS channels based on WSD demand [26]. WSDB datasets are stored in the Database Management System (474).

## 6. White Space Network Test-beds and Device Testing

We have already stated that one of the regulatory objectives for DSS is the development of reliable spectrum monitoring and co-existence tools aimed at maximising protection to legacy incumbents or licensed networks against any potential harmful interference. There are different scientific approaches one can deploy to achieve this objectives. Such approaches include software simulations, research and development (R&D) test-beds, and field trials. While acknowledging recent advancements in software simulations (and their ability to produce high level of abstraction), one of the main drawbacks with software simulations is that they fail to produce realistic results [27]. As such, in order to produce real-life results, which will be ready to inform regulations, test-beds and field trials are found to be the most preferred scientific approaches. In this section, we present high level discussion on white space network test-beds or field trials, and WSDs testing guidelines.

### 6.1 White Space Network Test-beds and Field Trials

Worldwide, there have been a number of TVWS trials and test-beds aimed at testing and confirming the viability of dynamic spectrum access or DSS. For a list of such trials, we refer the reader to the Dynamic Spectrum Alliance website (<http://dynamicspectrumalliance.org/>). The exploitation of TVWS for addressing the digital divide gap in Africa has been embraced in many countries, either through the formulation of TVWS regulations or field trials. Among these countries are Tanzania, Kenya, Malawi, Namibia, Ghana and Botswana.

In addition to the trials listed on the Dynamic Spectrum Alliance website, the CSIR in South Africa participated in a number of TVWS trials and test-beds within and beyond South Africa. In South Africa, the CSIR participated in the TVWS trials in Cape Town [3 - 5] and in the Limpopo Province [6]. Beyond South Africa, the CSIR collaborated with the Ghana Technology University College (GTUC) in the deployment of a TVWS test-bed in the greater Accra district, Ghana, where six secondary schools are connected [7]. The CSIR is also collaborating with the Botswana Institute of Technology Research and Innovation

(BITRI) in setting up a TVWS test-bed towards enabling R&D on DSS and informing the national regulator in the formulation of TVWS regulations. We are confident that with such a high number of countries in Africa welcoming the TVWS technology, a breakthrough in finalizing supporting regulations is very close, meaning it is expected within the next year or so.

## 6.2 *White Space Devices Testing*

On the other hand, introduction of DSS technologies requires new radio devices which are cognisant of their operating environment and reconfigurable. However, due to lack of readily available labs to conduct type approval of white space devices (WSDs), there are set of guidelines on how WSDs can be tested in order to be certified or allowed to operate in South Africa. Such testing is intended to characterise the electromagnetic emission of the WSDs and ensure that there is no foreseen harmful interference to the television broadcasting services and other licensed or primary users of the spectrum which are to co-exist with WSDs. These testing are to be conducted in a laboratory setup and the following are, among others, to be assessed during the tests:

- Transmit power level, to be within the WSD's specifications;
- Spectrum emission masks, their characteristics and dependence on WSD settings;
  - Including the occupied bandwidth (OBW), to be within the requirements
- Protection ratios (PRs) for incumbent TV systems in coexistence with the WSD transmission signals; and
- Correctness of the behaviour by the devices (including adherence to the master-slave relationship between the database and base station and a base station and its clients, in terms of the control of the emissions).

## 7. **Business Benefits: Affordable Broadband and 5G Spectrum Sharing**

The impact of enabling spectrum regulation in business transformation is one of the aspects for the networked Society enabling change and change-makers [1]. As an enabler of transformation, spectrum sharing and future internet 5G networks is not just about building future networks but also connecting the unconnected with affordable broadband. Enabling policy also need to come up with innovative ways of addressing network techno-economics to make broadband internet services available not only in urban affluent regions but also in rural Africa. Broadband internet connection and services have been shown to result in a positive impact on socio-economic growth of a country [2]. Internet connectivity enables people to do things that have previously been impossible: such as access to relevant information from anywhere and anytime.

Affordable broadband Internet facilitates health information, traffic & entertainment services, and creates new opportunities for businesses to develop. It creates new types of jobs[3], particularly in developing economies where people and businesses are quick to adapt to new opportunities. This stimulates growth in all industries that are able to exploit wireless mobile technology to become more competitive, to create new business models and to offer new services. Enabling regulation and policy also should have features that support use of alternative energy resources to reduce the cost for network deployment and operational sustainability and cost of DSS enabled networks.

## 8. **Conclusions**

In this paper, dynamic spectrum sharing (DSS) and the associated regulatory frameworks have been described. The technologies for white space communications networks and co-existence tools such as the smart spectrum sharing databases (S3DBs) enhanced by

spectrum sensing are described as enablers of affordable future wireless broadband networks. In the near future many of the mobile/wireless operators, service providers and equipment manufacturers will be customers of these technologies. Such a move is motivated due to the demand for affordable rural broadband, the exponential traffic increase in 5G and high bandwidth demand that is inevitable in future wireless network services., The ITU, national regulators such as (FCC-US, Ofcom-UK, iDA-Singapore, ICASA-South Africa and, MACRA-Malawi) and standards organs are all looking into ways of allocating and sharing spectrum bands to cater for the network bandwidth demand in future wireless networks. At the same time, DSS regulatory frameworks are needed to enable future network technologies employing new software reconfigurable network devices and efficient utilization of spectrum and network infrastructure resources. The indicators for such a move are clearly apparent from the activities of the big telecom operators, telecom equipment industry and sustainable development objectives by emerging economy countries. This paper contributed to the development of enabling DSS spectrum regulation and policy. This is expected to accelerate new network technologies and innovative eco-systems for future internet networks in developing economies.

As a proof of concept for the DSS eco-system and regulatory frameworks, experimental television white space TVWS-DSS network technology trials have been carried out by the CSIR and other global partners. Such networks have proved that co-existence operation and high bandwidth broadband Internet connectivity services to rural schools in South Africa are possible. DSS based network services have been replicated in several other places, for delivering machine-to-machine communications services in UK, smart metering and outdoor environment monitoring services in Singapore and Japan.

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