Television White Space (TVWS) Access Framework for Developing Regions

Moshe T. Masonta
Department of Electrical Engineering
TUT and CSIR Meraka Institute
Pretoria, South Africa, 0001
Email: mmasonta@csir.co.za

Adrian Kliks
Poznan University of Technology
Poznan, Poland
Email: akliks@et.put.poznan.pl

Mjumo Mzyece
Department of Electrical Engineering
Tshwane University of Technology (TUT)
Pretoria, South Africa
Email:mzyecem@tut.ac.za

***Abstract*—The use of unoccupied television (TV) frequency band (known as TV white space - TVWS) for non-broadcasting services is gaining momentum around the world. Especially in developing countries where the majority of the population are in under-served rural areas, such as Africa, TVWS promises to provide broadband wireless access (BWA) to remote and low density population areas. Depending on the licensing approach by nationa or regional regulators, TVWS can also reduce the cost of spectrum license fee significantly or even be used by secondary networks on license-exempt approach (which is the case in America and Europe). This paper proposes the TVWS Access Framework suitable for the developing regions such as the Southern African Developing Region (SADC). The framework is based on the co-evolution process which defines three key domains of change or external forces in the wireless communications environment: policy/regulation, technology, and business sector. This framework can be used as a guideline for the policy makers, regulators, technology vendors and the business sector in realising the benefits of TVWS without compromising the quality of services currently enjoyed by the TV incumbents and users. Unless there are higher levels of coordination and integration among key players, the SADC region and its citizens may not benefit from the full market potential offered by the TVWS ecosystem. Therefore, the framework will ensure that there is harmonization on policy, regulation, standards and technology, which will result into increased economies of scale within the SADC region in the TVWS ecosystem.**

I. Introduction

According to the United Nations' (UN) International Telecommunications Union (ITU), information and communications technology (ICT) is a powerful tool that can be used by the developing nations to improve the quality of life by creating jobs, generating economic growth, improving quality of education, increasing productivity and reducing poverty [1]. One of the most important and necessary ICT services is access to broadband Internet. However, in most countries in the developing regions, such as the Southern African Developing Community (SADC), access to Internet is still very low when compared to other developed regions [2]. The SADC region consists of 15 member states: Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. There are number of initiatives within the SADC region aiming at providing affordable broadband Internet access to all citizens, such as the SADC ICT Infrastructure Development Master Plan, called *Digital SADC 2027* [2]. The main purpose of the Digital SADC 2027 master plan is to outline the platforms of ICT policy and regulatory harmonisation and measures necessary to ensure that every SADC member state citizen has full access to ICT services by 2027. Access to radio frequency (RF) spectrum and use of television white space (TVWS) for broadband wireless access (BWA) has been identified by the Digital SADC 2027 master plan as one of the areas requiring immediate policy changes in each SADC member state. However, the plan lacks a coordinated framework or enabling platform to facilitate the realization of full socio-economic benefits expected from the TVWS ecosystem.

The availability of TVWS is mainly as a result of the global digital switch over (DSO) of TV and audio broadcasting from analogue to digital signal which is scheduled to be completed in the ITU Region 1 by June 2015 with the exception for some countries where their deadline is June 2020 [3]. Once the DSO process is completed, portions of the upper ultra high frequency (UHF) band (i.e. 470 - 862 MHz) will be available for use by non-broadcasting services such as mobile and broadband communications. This is the frequency which is widely known as the TVWS. Both the DSO process and TVWS promises high spectrum efficiency, customer viewer experience (for example: due to digital terrestrial TV (DTT) there will be more and interactive TV programs), economic or business opportunities (such as creation of new jobs for set-top box (STB) development) and new business models in spectrum trading using the geo-location spectrum database (GLSDB). While the TVWS presents opportunities to the consumers and business sector, it also introduces new challenges to spectrum regulators and policy makers. The first challenge is to develop policies and regulations on how to make efficient use of the TVWS spectrum for non-broadcast communications without causing interference to TV broadcasters. The second challenge, which is linked to the first one, is how can the developing countries (such as SADC member states) take advantage of the TVWS benefits economically without being overtaken by the multinational organizations (MNOs).

The use of TVWS for non-broadcast communications have been promoted by leading ICT regulators in the United States and Europe over the past decade. For instance, the US Federal Communications Commission (FCC) [4] and the Office of Communications (Ofcom) in the United Kingdom (UK) [5] went through extensive consultation processes, field trials, lab testing and testing of several business models and regulatory approaches before ruling on licence-exempt use of TVWS for

non-broadcasting wireless services. It is therefore important for the developing regions to learn from the challenges, mistakes, success and progress made both in US and Europe in order to fast track the adoption of TVWS. However, not all policies and regulations (such as transmission parameters) from US and Europe can be adopted without any modification for implementation in the SADC region (especially when considering the different challenges each region or continent has).

In this paper we propose a TVWS access framework to provide a harmonised platform and guidelines suitable for developing regions, such as the SADC member states, that will ensure maximum social and economical benefits offered by the TVWS are realized within the region. The proposed framework is based on co-evolution process (by Lyytinen and King [6] and Bauer *et al.* [7]), which focuses on three key domains of change in the wireless communications environment: policy/regulation, technology/innovation, and business or market. Co-evolution process can be viewed as a large systemic innovation that demands coordination of many independent and heterogeneous players to ensure compatibility and interoperability across different systems [6].

The remainder of the paper is organized as follows. Section II introduces the proposed TVWS Access Framework. Key policies and regulations affecting the TVWS ecosystem are discussed in Section III. Section IV discusses the related TVWS technology and standards. The business opportunities presented by the TVWS are then discussed in Section V. The paper is concluded in Section VI.

II. TV White Space Access Framework Overview

The TVWS Access Framework is proposed based on the co-evolution process, as shown in Fig. 1. On top of the framework if the policy and regulations, on the left hand side are technologies and standards and the right hand side focuses on the business or market for TVWS. According to the co-evolution concept, at least two or three players in a framework are said to co-evolve provided they each have a significant impact on each other. Thus, any action or event in one area affect the developments in related areas in way which was either expected or unexpected ways [7]. Using an example in [8], an existing technology standards can constrain or foster the ability of service providers (business) to deploy new features and services. On the other hand, business decisions can affect or be affected by national policies and the technology standards. Hence, it is important to have such a TVWS Access Framework to ensure the interaction of and coordination between stakeholders representing the key players in the TVWS industry. The co-evolution process has been used extensively to study future spectrum sharing networks during the introduction of mobile TV and cognitive radio (CR) system [7]–[9].

The next sections discuss each of these three domains in full details in the context of the SADC region. In some areas, work has been done or being proposed by our research group on how to address some of the challenges. These solutions will also be discussed within the related focus areas.

III. TVWS Policies and Regulations

The importance of harmonization has been overemphasized in the ICT sector, and has played a key role in enabling the European region to respond to the requirements of terrestrial mobile International Mobile Telecommunications (IMT) [10]. According to the European Conference of Postal and Telecommunications Administrations (CEPT) [10], *harmonisation ensures that suitable regulatory framework is available to facilitate the development of standards, to provide a level of certainty and economies of scale for investors and to allow for the implementation of relevant regulations at national level*. Thus, cooperation among the SADC member states is also important to ensure regional harmonization of policies and standardizations and for the successful implementation of TVWS Access Framework.

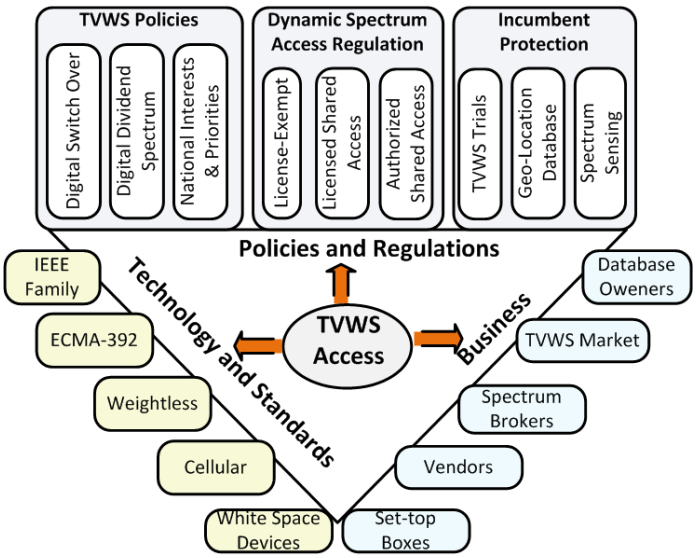

Fig. 1: TV White Space Access Framework

A. TVWS Policies

The policies and regulations are the critical domain of change in the TVWS Access Framework. It includes regional and national policies on digital dividend (DD), broadcasting DSO (digital migration), as well as national and regional interests.

1) ***Digital Dividend Spectrum****:* As members of ITU Region 1, the SADC member states are expected to clear the 790 - 862 MHz band (known as digital dividend 1 (DD1)) which should be allocated for mobile services including International Mobile Telecommunications (IMT) as per the 2006 Geneva ITU Regional Radiocoommunications Conference (RRC) outcomes [3]. Furthermore, the ITU WRC-12 Resolution 232 also requires more clearance on the 700 MHz band (694 - 790 MHz), known as DD2, to be completed by 2015. The 2010 *SADC roadmap for digital broadcasting migration* [11], is an important tool to ensure that the region meets the Geneva 2006 (GE06, [3]) requirements to ensure that both DD1 and DD2 spectrum is available by June 2015.

2) ***TV Digital Switch Over (DSO)****:* Clearance of DD2 spectrum can be achieve by SADC member states' ability to beat the ITU DSO deadline of June 2015 and through regional harmonization. As of December 2012, only two countries (Mauritius and Tanzania) completed the TV DSO

process. Other member states are going through the process and confident that they will beat the June 2015 deadline. DSO is very important, and it is critical for the SADC member states to complete this process because access and usage of TVWS depends on the availability of DD1 and DD2 spectrum. However, the February 2013 Botswana's decision to opt out of the second generation digital video broadcast - terrestrial (DVB-T2), which is an agreed standard for the SADC region, to use the Japanese standard, Integrated Services Digital Broadcasting Terrestrial (ISDB-T) [12] may affect the DSO progress in the region.

3) ***National Interests and Priorities****:* National interests and priorities among the SADC member states may not be common in all areas. As highlighted in [11], differences on national priorities between countries can create a lack of regional harmonisation of ICT policies and regulations. The TVWS Access Framework is therefore taking into consideration these challenge. It is therefore important for member states to ensure that relevant sectors are not negatively affected by national politics if the region wants to move forward into a digital age and knowledge economy.

B. Dynamic Spectrum Access Regulations

Sharing of TVWS requires dynamic spectrum access (DSA) regulatory approaches. Several DSA models are being proposed globally for efficient regulation of the entire RF spectrum band, including the TVWS spectrum [13]. Of interest to TVWS are DSA techniques based on the cognitive radio systems (CRS). CRS and capabilities include the GLSDB, spectrum sensing or a combination of sensing and database [**?**]. Two of these DSA regulation frameworks, which are also under discussion within the European CEPT are authorised shared access (ASA) and licensed shared access (LSA).

1) ***License-Exempt Access (LEA)****:* In LEA approach, network devices meeting certain technical conditions and requirements can access and share the spectrum anywhere and at any time without guarantee quality of service (QoS). The success of this approach can be seen in the 2.4 GHz and 5 GHz spectrum usage for the provision of Wi-Fi services.

2) ***Licensed Shared Access (LSA)****:* Introduced by Nokia and Qaulcomm, the LSA concept can allow new sharing opportunities on a regional scale under a licensing regime, while at the same time safeguarding the national existing spectrum usage which cannot be re-farmed even beyond 2015 [14].

3) ***Authorised Shared Access (ASA)****:* spectrum regulation concept was adopted by the Radio Spectrum Policy Group (RSPG) in 2011, which is an advisory group assisting the European Commission in the development of radio spectrum policy [10]. In a nutshell, the ASA concept provides a framework for existing PUs or licensed users (incumbents) to share spectrum with one or more licensed ASA users (or secondary users) in accordance with a set of pre-defined static or dynamic conditions. An important feature of ASA concept is the predictability of QoS for ASA users, especially when the PU's spectrum use is more stable. Although it was initially proposed for IMT bands, this concept can also be used in the TVWS band.

C. TV Incumbent Protection

Since the new broadband services are expected to share the spectrum with the TV services (DTT, wireless microphones and other services on TV band), it is important to protect the TV incumbents from any harmful interference that might be caused by white space devices (WSDs). Spectrum sensing and the GLSDB are the common techniques used for TV incumbent protection.

1) ***TVWS Trials****:* Some of the proponents in the LEA regime of TVWS in US and Europe are MNOs who are now sponsoring different TVWS trials in Africa. For instance, the first TVWS technology trials in Africa started in 2012 in South Africa (sponsored by Google), then Kenya and Tanzania followed (sponsored by Microsoft), and more TVWS trials are being considered in other African countries in the near future. The chief aim of these trials is to convince the local regulators and policy makers that TVWS can offer broadband services without causing harmful interference to the PUs or other authorised services on the TV bands. Even though trials are important, it is also useful to note that they will not be conducted in every SADC member state. Using the trial results, policy makers and regulators will be in good position to decide on how to open up the TVWS for exploitation. The trial results are also important to the broadcaster who are concern of any potential interference the TVWS technology can cause to their TV broadcast.

2) ***Spectrum Sensing****:* As one of the key functions of the CRS, spectrum sensing involves identification of spectrum holes or TVWS and the ability to quickly detect the onset of PU transmissions in the spectrum occupied by the secondary user [15]. Although the sensing technology has not reached the level of maturity for full-scale deployment, it is being included in almost every TVWS based standards (such as IEEE 802.22 and 802.11af) and also adopted by the FCC [4] and Ofcom [5]. Even though several spectrum measurements in southern Africa relieved huge amount of TVWS availability, spectrum sensing is still important to be considered by the policy makers especially for TVWS applications in the urban areas.

3) ***Geo-Location Spectrum Database****:* Without spectrum sensing, co-existence of the TVWS spectrum among broadcasting and non-broadcasting can be managed through the use of a GLSDB. The fact that TV users exhibit static spectrum utilization in space, time and frequency (especially in remote rural areas), makes GLSDB most suitable for incumbent or PU protection non the TV band. Since the wireless microphones or Program Making and Special Events (PMSE) shares the TV spectrum, a static GLSDB may not be sufficient to protect them. Its either a dedicated regional or national band is used for PMSE or a different database need to be developed only for PMSE. Both these approaches have been considered in the US and Europe.

IV. Technology and Standards

Technology harmonization is another important factor in order to enable economies of scale regionally and globally. However, in the wireless communications environment, coordination in technology standardization plays an important role in determining the success or failure of the new technology

[7]. In this section, key standardization efforts for technologies operating on TVWS spectrum are discussed.

A. IEEE Family of Standards using TVWS

The use of CR technology operating on the TVWS spectrum for broadband wireless access (BWA) sparked more interest from several IEEE standardization bodies. The family of IEEE standards, which can be possible candidates for deployments in the SADC region, and operating on TVWS are briefly discussed in this subsection.

1) ***IEEE 802.22 Wireless Regional Area Network (WRAN):*** is the wireless air interface standard focused on the development of CR based WRAN physical (PHY) and medium access control (MAC) layers for operation in TVWS [16]. It specifies a fixed point-to-multipoint wireless air interface where a base station (BS) manages its own cell and all associated customer premises equipments (CPEs) and can provide wireless communication links over distances of up to 70 km. A typical use case for the IEEE 802.22 standard would be in sparsely populated rural areas, which makes it more a suitable candidate for providing rural BWA in the SADC region.

2) ***IEEE 802.11af:*** defines modifications to the 802.11 PHY and MAC (Wi-Fi) for operation on TVWS, known as White-Fi [16]. The 802.11af architecture defines three different channel dependent station (STA) types: fixed, enabling, and dependent STA. Recent large-scale study on feasibility of White-Fi shows that operating White-Fi hotspots in rural areas (outdoor) is viable that in urban areas due to higher user density [17]. This standard is also a possible candidate for providing rural BWA in the SADC region.

3) ***IEEE 802.15.4m:*** is a newly proposed amendment to the 802.15.4 standard (ZigBee) focusing on the development of a PHY to support operation in TVWS [18]. The standard aims to serve conventional WPAN applications as well as machine-to-machine (M2M) communications with data rate in the rage of 40 kbps to 2 Mbps.

B. Cellular Networks

Once the DD1 and DD2 spectrum band is cleared, future cellular networks (such as Advanced Long-Term Evolution (A-LTE) will operate on TVWS and co-exists with the TVWS networks or devices. However, the technical and regulatory conditions around the 700 MHz band (DD2) for mobile services will only be specified during the WRC-2015. While mobile operators are happy to use this part of DD spectrum to enhance their network coverage, there are concerns that licence-exempt operations of the TVWS below the 700 MHz band to provide cellular-type mobile services can create unfair advantage to traditional cellular operators [19]. Furthermore, the GSM Association's (GSMA) 2013 policy position paper warned that the licensing approach for the TVWS access should not jeopardise the future of UHF band [19].

C. ECMA-392

The ECMA-392 standard specifies a PHY layer and MAC sub-layer for personal or portable cognitive wireless networks operating in TVWS spectrum [20]. ECMA-392 based networks can operates either in master-slave mode or the peer-to-peer mode. This can be suitable for mesh networks connecting schools, health centres or communities within the community.

D. Weightless

Weightless is a standard for machine-to-machine (M2M) communications operating on the TVWS. Version 1.0 of Weightless standard was ratified early in 2013, and this will enable vendors to produce interoperable devices for M2M communications [21]. This standard is also suitable for many applications which are important not only to the urban communities, but also the rural communities in the developing regions.

E. White Space Devices (WSDs)

The WSDs include the TVWS - BSs and clients (WSDs) that are expected to operate on TVWS spectrum. There are several WSDs being trailed around the world. It is to be seen whether there will be a new standard for WSDs or the devices under the standards discussed in the previous subsection will be the ones dominating the market. There are initiatives within the local research community considering to integrate the STBs with Internet cards to enable users to browse Internet from their TV sets. This approach might reduce the cost of device ownership to the rural communities.

V. Business Models

The business domain focuses on the development, manufacturing, supply of white space technology, ownership of GLSDB, and the establishment of new business models such as spectrum brokers. The TVWS business sector or markets relies heavily on the availability of supporting regulations/policies and technology.

A. TVWS Spectrum Market

TVWS have the potential to introduce new and/small players in the wireless communications market, while giving giant multi-national companies an added advantage. In the SADC region, new players may includes local entrepreneurs operating as wireless internet service provider (WISP) in the rural areas. With access to a national or regional GLSDB, a local WISP can know the available TVWS bands in the area and be able to provide Internet access without a need for expensive spectrum license. Thus a new market of spectrum trading that involves spectrum brokers and the GLSDB owners can be realized. On the other hand, the multi-national companies can also benefit from the TVWS in the cities as well as in the rural communities to provide back-haul long distance links and M2M communications.

B. GLSDB Ownership

Since the first approval of a GLSDB administrator and the WSDs for licence-exempt TVWS access by the FCC in December 2011, [22], there have been a lot of interest around the world to develop and own the GLSDB. The GLSDB business has grown in the US with over ten organisation registered with the FCC. Some of the major players in GLSDB business includes Spectrum Bridge, Telcordia, Google, and Microsoft. As of May 2013, only Spectrum Bridge and Telcordia

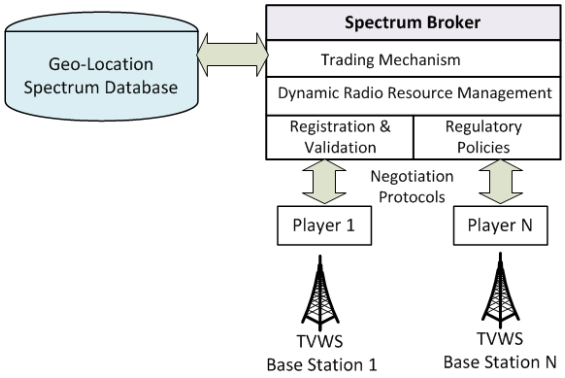

Fig. 2: Secondary spectrum market model TV White Space Access Framework [23]

were approved database owners by the FCC [22]. Ownership of the GLSDB creates new business opportunities for new and existing players who are prepared to host and manage such GLSDB. In the SADC region, the Council for Scientific and Industrial Research (CSIR) is also in advanced stages of developing a GLSDB for South Africa. The CSIR GLSDB can be accessed from: http://whitespaces.meraka.csir.co.za/ for testing purposes.

C. Spectrum Brokers

The 2010 study by the European COgnitive radio systems for efficient sharing of TV white spaces in EUropean (COGEU) project suggested a business model where the GLSDB and the spectrum broker can be different business entities [23]. In such a model, spectrum brokers trade spectrum with players and they can control the amount of bandwidth and the transmit power that can be assigned to each player. A typical SB business model is presented in Fig. 2.

D. Set-Top Boxes

The DSO process has brought new business opportunities to the SADC region for the development of local-based set-top boxes (STB). STBs are important for the conversion of digital TV signal to analogue signal that can be viewed on old TV sets. By deciding on common digital terrestrial TV (DTT) standard, SADC member states will be able to establish new regional and local businesses for the manufacturing and distribution of STBs [11]. There are initiatives within the CSIR to develop a digital services node (DSN) which can be viewed as an advanced STB capable of providing Internet services to the rural clients in addition to the DTT.

VI. Conclusion

The TVWS and the use of CR systems, such as GLSDBs and WSDs present great opportunity for the developing regions to address some of their socio-economic challenges. However, such benefits can be realized through a coordinated and integrated efforts among the key players, and informed decision making from regional governments, such as SADC member states. For example, it is important that the ITU June 2015 DSO deadline is met by all SADC member states in order to have harmonized regulations, policies and technology. The TVWS Access Framework is therefore proposed in this paper as a platform to facilitate harmonised smooth uptake of TVWS technology and to assist the key players in the SADC region to develop the full TVWS ecosystem.

Acknowledgment

Authors thank the COST-TERRA Action IC0905, the South African DST and CSIR for their financial support.

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