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ORIGINAL RESEARCH ARTICLE

# A REVIEW OF TV WHITE SPACE TECHNOLOGY AND ITS DEPLOYMENTS IN AFRICA

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**ABSTRACT**
The emergence of bandwidth-driven applications in the current wireless communication environment is driving a paradigm shift from the conventional fixed spectrum assignment policy to intelligent and dynamic spectrum access. Practical demands for efficient spectrum utilization have continued to drive the development of TV white space technology to provide affordable and reliable wireless connectivity. It is envisaged that transition from analogue transmission to Digital Terrestrial Television (DTT) creates more spectrum opportunity for TV white space access and regulatory agencies of many countries had begun to explore this opportunity to address spectrum scarcity. To convey the evolutionary trends in the development of TV white space technology, this paper presents a comprehensive review on the contemporary approaches to TV white space technology and practical deployments of pilot projects in Africa. The paper outlines the activities in TV white space technology, which include regulations and standardization, commercial trials, research challenges, open issues and future research directions. Furthermore, it also provides an overview of the current industrial trends in TV white space technology which demonstrates that cognitive radio as an enabling technology for TV white space technology.



## 1.0 Introduction

Wireless communication is steadily migrating from traditional voice-based services to application-based services as demonstrated by the number of people who use smartphones with numerous underlying applications. The emergence of bandwidth-driven applications in the current wireless communication environment is driving a paradigm shift from the current fixed spectrum assignment policy to dynamic spectrum access, which prompts the need to re-analyze spectrum assignment. Generally, radio spectrum bands are divided into fixed number of different frequency channels in which segments of the radio spectrum bands are allocated for different wireless communication services as shown in Figure 1 (Mustapha, 2016).

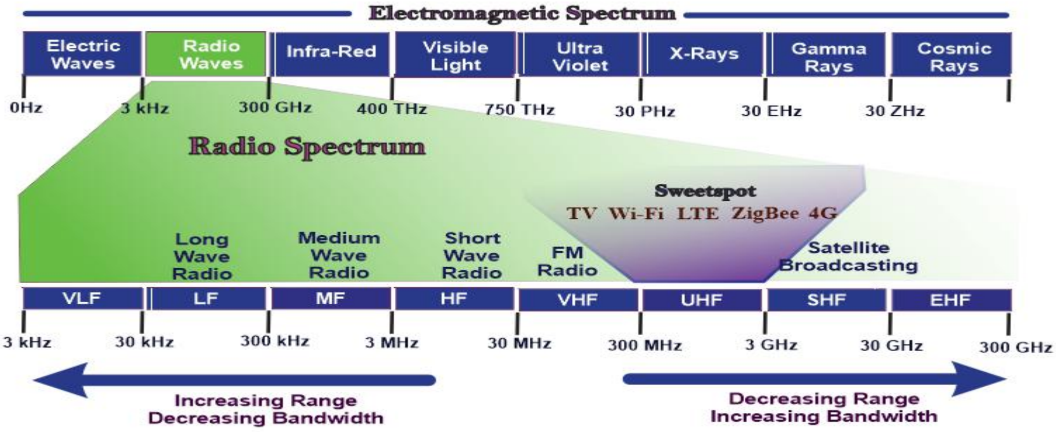


Figure 1: Schematic Representation of Division of Radio Spectrum and Radio Ranges (Mustapha, 2016).

Studies on spectrum usage carried out in many countries including Malaysia (Elshafie et al., 2014), Spain (Lopez-Benitez et al., 2009), (Islam et al., 2008), Germany (Wellens et al., 2007), New Zeeland (Chiang et al., 2007) , United Kingdom (Chiang et al., 2007) and USA (Patil et al., 2011) at different locations show that large portion of licensed radio spectrum bands especially the TV spectrum bands have not been efficiently utilized. The utilization of licensed radio spectrum bands varies from 15% to 85% of the spectrum which indicates significant disparities in the usage of the radio spectrum bands. It can be deduced that the conventional policy of allocating spectrum bands to licensed users regardless of temporal and geographical variations has inadvertently contributed to the spectrum scarcity and hence necessitates the need for dynamic spectrum access. Consequently, the Federal Communications Commission (FCC) proposed rules that allow unlicensed user to opportunistically access the unused portions of spectrum bands, also called white spaces or spectrum holes. The guidelines permit secondary users (SUs) to transmit on TV white spaces frequencies without interfering with the incumbent TV transmitters and wireless microphones transmissions. TV White Space (TVWS) is the unused spectrum in the Very High Frequency (VHF) band and Ultra-High Frequency (UHF) bands that have the potential to bridge the digital divide effectively by delivering affordable and reliable communication services (Elshafie et al., 2014).

Research efforts toward the utilization of TVWS technology for internet access indicate that African continent has better opportunities for such technique compared to Europe. This is due to low internet penetration rate across the African continent and availability of abundant unused TV broadcasting spectrum particularly in the rural areas where fewer spectrum users exist. Therefore, TVWS technology could be used to provide affordable and reliable internet access to African countries. The few TVWS trials implemented in some African countries have demonstrated that TVWS and other dynamic spectrum access technologies could play a vital role in providing reliable and affordable internet connectivity to both the isolated rural and urban areas in Africa (Mustapha et al., 2016). The main challenge in deploying wireless internet services and other wireless services is the high cost of license spectrum bands and cost of deployment of equipment which in turn increase the end user costs. It is evident that the use of TVWS technology can drastically reduce the cost of internet access and improve internet penetration rate in Africa. Recently, there is intensive effort toward standardization, prototyping and commercialization of TV white space devices (Mustapha, 2016).

This paper presents a comprehensive review on the contemporary approaches to TV white space technology and practical deployments of pilot projects in Africa. The paper outlines the activities in TVWS technology, which include regulations and standardization, commercial trials, research challenges, open issues and future research directions. Furthermore, it also provides an overview of the current industrial trends in TVWS technology. The remainder of the paper is organized as follows: Section 2 discusses the general introduction to TV White space and its availability. Section 3 presents TV white space trials and pilot projects in Africa and highlights the potentials of TV white space technology in Africa. Section 4 suggests potential research opportunities and challenges for the application of TV white space technology.

## 2. Review of TV White Spaces Technology

Cognitive radio (CR) is an enabling technology for efficient utilization of spectrum holes which is frequently referred to as White Spaces. It allocates unoccupied licensed spectrum bands to unlicensed users frequently referred to as secondary users (SUs) in an agile manner without causing harmful interference to the licensed or primary users' (PUs) transmission. The concept of cognitive radio has several meanings in broad perspectives. It was first coined as an intelligent radio that sense its surroundings for operational electromagnetic and dynamically change its behaviours to optimize user experience (Mitola, 2000). Therefore, the cognitive radio cycle involves spectrum sensing, spectrum decision, spectrum sharing, and spectrum hand off.

Dynamic spectrum access (DSA) is a key enabling technique for exploitation of spectrum holes in temporal and space domains to address both future and current spectrum scarcity in wireless networks (Mustapha et al., 2016) and (Salami et al., 2011). Spectrum sharing among wireless systems can occur horizontally (spectrum underlay) and vertically (spectrum overlay), as depicted in Figure 2 and Figure 3, respectively (Akyildiz et al., 2006).In the underlay spectrum sharing technique, all wireless nodes have equal access to the available spectrum resources. Unlicensed users are constrained to transmit at a very low transmission power below noise floor of the licensee such that accumulated interferences of the unlicensed users is below tolerable interference threshold. Typical example of this approach is ultra-wide band (UWB) technology in which unlicensed users spread their transmit power over a wide range of frequency bands such that accumulated interferences do not exceed the threshold (Akyildiz et al., 2006). This approach is suitable for short range, high data rate communication with a low transmission power. The overlay model approach prioritizes spectrum architecture for spectrum-sharing scheme. It is based on temporal and spatial spectrum holes or white spaces opportunities in which unlicensed users can dynamically access unused licensed spectrum bands without degrading licensed users' performance. Furthermore, unlicensed users can transmit at higher transmission power as long as licensed users protection from interference is guarantee (Akyildiz et al., 2006a).

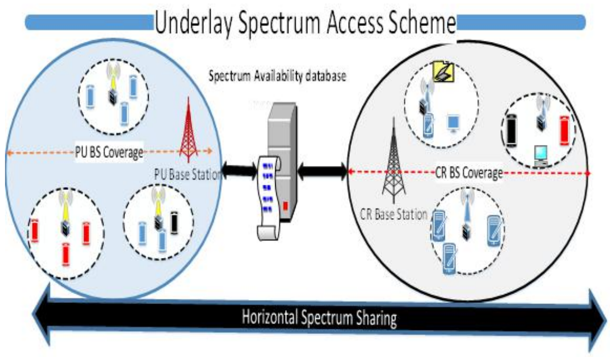


Figure 2: Spectrum Underlay Dynamic Spectrum Scheme

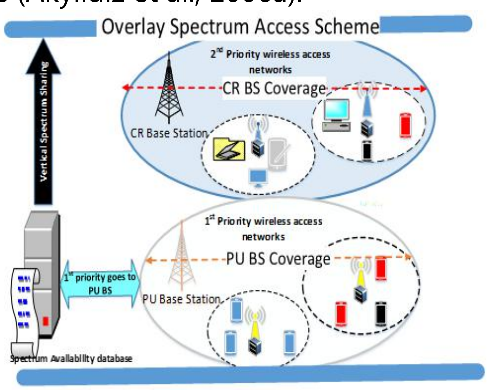


Figure 3: Spectrum Overlay Dynamic Spectrum Scheme (Mustapha, 2016)



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### 2.1 Availability of TV White Space Spectrum

Spectrum hole or white space is the frequency band in which a secondary user accesses communications channel without interfering with any primary user. TV white space is the portion of the spectrum in Very High Frequency (VHF) band between 30 –300 MHz and Ultra-High Frequency (UHF) band between 470 - 960 MHz that are not utilized by primary users (Broadcast television stations) in specific time and location (Adediran et al., 2014). Regulatory agencies such as FCC, NCC and NBC prohibit the use of unlicensed devices in frequency bands allocated to TV stations, except for devices such as wireless microphones, remote control and medical telemetry devices (Elshafie et al., 2014).

In Nigeria, the current TV broadcasting services mainly operate on analogue transmission in the VHF spectrum band between 174 – 230 MHz and UHF spectrum band between 470 and 960 MHz band except for the TV stations that migrated to digital broadcasting platform (Adediran et al., 2014). It is envisaged that transition from analogue transmission to Digital Terrestrial Television (DTT) creates more spectrum opportunity for TV white space access and regulatory agencies of many countries had begun to explore this opportunity to address spectrum scarcity(Van De Beek et al., 2012). Therefore, it is evident that after completion of Digital Switchover (DSO) process, a portion of TV analogue channels would become entirely vacant due to transition to higher spectrum efficiency digital TV (DTV). Although, some of the vacant bands such as the IMT bands for mobile use may be reallocated by the regulators to other services, a quite number of the TV channels may be unused in each geographic area. Although, spectrum utilization and TVWS availability measurements have not fully been conductor in Nigeria, the results from many countries indicate the availability of TVWS (Patil et al., 2011) and (Elshafie et al., 2014).

### 2.2 TV White Space Spectrum Sensing

Spectrum sensing is the fundamental function of cognitive radio to detect the presence or absence of primary users (PUs) in a licensed spectrum band (Mustapha et al., 2015). Its main goal is to identify and access spectrum holes without compromising PUs' transmission. Generally, spectrum sensing can be classified into two main classes viz transmitter detection and receiver detection. The main goal for transmitter detection method is to find out if the primary user is utilizing TV spectrum band, while receiver detection tries to find out if there are primary receivers in the area even when primary transmitter is utilizing spectrum. The receiver detection is practically very complex. Therefore, most of research focused on transmitter detection method where detecting white space is based on target signals received. This method can be classified into blind detection, feature detection and noise dependent detection. The detection methods suitable for TVWS are enumerated in Table 1 (Elshafie et al., 2014, Mustapha, 2016).

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Table 1: TVWS detection techniques

| Technique | Features | Drawbacks |
|---|---|---|
| Energy Detector(Nekovee, 2009, Tandra and Sahai, 2008, Yucek and Arslan, 2009) | Compares signal samples received over an observation interval with a threshold to detect white space.<br>Optimum non-coherent technique and the most commonly used<br>Suitable for detecting analog TV and wireless microphone signals. | Exhibits low performance compare to other sophisticated techniques.<br>Inability to distinguish licensed user's signals from other interference signals such as noise. |
| Cyclic prefix and autocorrelation | Compares energy of cyclic prefix sequence of each signal segments with a threshold and uses autocorrelation function of DVB-T signals to detect white space.<br>Coherent technique that able to distinguish target signals from other interference signals such as noise.<br>Suitable for detecting DVB-T signals. | Exhibits relatively good performance under high correlated signals.<br>It exhibits moderate computational and implementation complexities. |
| Cyclostationary feature(Chen et al., 2007) | Exploits cyclic autocorrelation function of the received signals by correlating the received signals with a known TV signal to detect white space.<br>Coherent technique that can distinguish different transmission signals, e.g weak signal at a very low SNR, noise with PUs' signals<br>Suitable for detecting both ATSC and DVB-T signals. | Implementation complexity is high.<br>Susceptible to synchronization error and requires prior knowledge of PU signal features to demodulate the signal. |
| Pilot based | Uses pilot subcarriers of the received signals to set threshold for detecting white space, channel estimation and synchronization at the receiver.<br>It is immune to noise uncertainty since position of the pilot can be accurately determined.<br>Achieves better sensing performance with short sensing time. | Require a prior knowledge about the target signals<br>Sensing unit may be practically large.<br>Implementation complexity is relatively high. |



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### 2.3 TV White Space Device

A TV white space device needs to sense the TV bands and successfully detect vacant channels that are not used by the incumbent users. Generally, the licensed incumbent users that operate within the TV bands comprise of analog television system such as National Television System Committee (NTSC), digital television system such as Television Systems Committee ATSC and DVB-T and wireless microphones. TV signals are known to exhibit a high autocorrelation function (ACF), low zero crossing points, periodicity and a high degree of signal differencing function which make them relatively easy to characterize and analyze. To protect the licensed incumbent systems (ATSC, NTSC and wireless microphone) from TV white space devices, the FCC has defined the power levels at which a TV white space device can sense the spectrum for detection of incumbent signals. The specified power levels are below the noise floor of a receiver measured in a 6 MHz TV channel which make sensing of the signals very challenging. There is quite a few techniques that can be used to detect the presence of the three incumbent signals in the TV bands (Elshafie et al., 2014, Saeed and Shellhammer, 2011). Features of TV white space devices that can be used for detection of these incumbent signals are illustrated in Table2.

Table 2: Features of TV White Space Devices

| Incumbent Signal | Features of TV White Space Sensing Devices |
|---|---|
| ATSC | The device must search for ATSC pilot at both nominal pilot frequency and alternate pilot frequency. Also processes the averaged power spectra density (PSD) obtained from a sequence of quiet times and determines the average of the individual PSDs from the individual quiet times to obtain average thermal noise.<br>The device indicates presence of ATSC signal in the channel if the test statistic exceeds a threshold. |
| NTSC | The device must search for the NTSC luminance carrier in frequency segments centered on each of the multiple frequencies and uses power in the luminance carrier to detect the presence of the NTSC signal in the channel.<br>The device determines the NTSC test statistic which is the maximum of the values of the PSD in frequency segments divided by the noise floor. |
| Wireless Microphone | The device must be able distinguish between carrier frequency location of a wireless microphone signal and pure noise to reliably detect the presence of wireless microphone signals.<br>Sensing device for wireless microphone signals must employ a classification procedure to expurgate narrow-band interference. |

### 2.4 Wireless Standards for TVWS

Generally, coexistence between incumbent users and other unlicensed users have been extensively discussed in wireless communication communities and several standards have been proposed. For example, IEEE 802.22 Wireless Regional Area Network (WRAN) standard provides rules that permit unlicensed users to access unused TV spectrum bands or white spaces within the television bands between 5 MHz and 862 MHz (Saeed and Shellhammer, 2011). Even though, the standard is designed for rural broadband, it does not attract many manufacturers due to its implementation complexity. Similarly, IEEE 802.11af standard which is simpler and easier to implement, suffers significant drawbacks due to its WiFi parentage. Other standards and task groups on coexistence of other technology in TV white space (TVWS) include IEEE 802.15.2 wireless personal area network (WPAN), IEEE 802.16h wireless metropolitan area network (WMAN), IEEE 802.19.1 and IEEE 802.22/11af TVWS standards (Saeed and Shellhammer, 2011). In addition to the IEEE-based TVWS standards, the European Computer Manufacturers Association (ECMA) has inaugurated and deployed the ECMA-392 standard as a platform for portable devices that operate on TVWS. ECMA 392 and IEEE 802.22 are different in many fronts. The IEEE 802.22 draft standard focuses mainly on high-power fixed access devices, portable and rural applications, while the ECMA 392 standard targets portable devices and targets in-home, in building and neighbourhood-area applications (Wang et al., 2010). Other wireless standards include weightless standard which was originally designed for TVWS based machine to machine (M2M) communication but was later adopted for broadband communication when the demand for TVWS in rural broadband applications became more apparent. TD-LTE standard is another TV White Spaces standard developed by Huawei primarily for backhaul and femto cells coordination in mobile communication (Saeed and Shellhammer, 2011).

### 3.0 The Potentials of TV White Spaces Technology in Africa

Africa is the second-largest continent, after Asia in terms of size and population. The continent comprises of 58 countries and regions with a population size of over one billion. The trend in digital divide is becoming more pronounced in the African continent with majority of the countries experiencing low internet penetration rate (Kennedy, et al., 2015). For instance, while almost 75% of people in Africa do not have access to internet, only 21% of Europeans are offline as depicted in Figure 4 (Facts, 2016). Furthermore, ITU report in 2016 indicates that internet penetration at the household level is estimated at 15.4% in Africa compared with 84% in Europe as shown in Figure 5. A similar pattern is reported in the case of internet penetration rate in which African continent has less than 22% as compare to Europe with about 85% as depicted in Figure 6 (Facts, 2016). Naturally such a trend is expected because over 65% of the population reside in the rural areas with limited basic internet infrastructure and high cost of internet access, which makes wireless services largely unaffordable to many people. This means that high proportion of people would be denied of full participation in the digital revolution to access online learning materials, interact with friends through social media, effectively utilize online government services and gain knowledge through numerous internet resources.

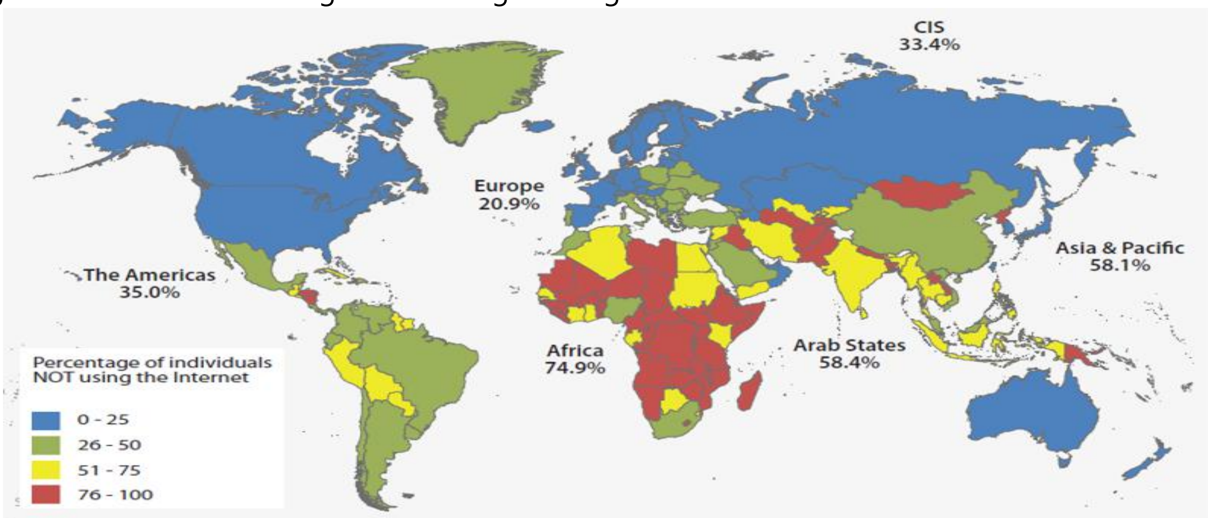


Figure 4: Internet usage across the globe (Facts, 2016)



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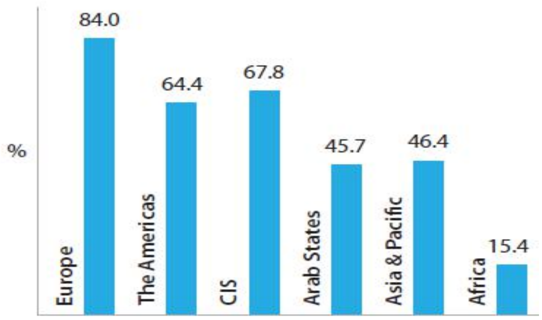


Figure 5: Percentage of households with internet access. (Facts, 2016)

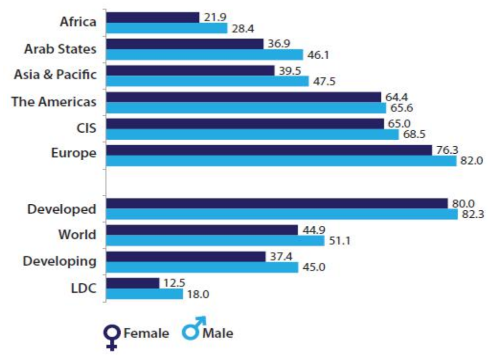


Figure 6: Internet Penetration rate

The potential application of TV White Spaces is essentially boundless, it can be used for a wide variety of services and technologies and it possess several important properties that make it highly attractive for wireless communications services such as campus broadband services, wide area wireless internet, home and enterprise wireless networking and smart city networks (Adediran et al., 2014). In addition, it can be used by mobile system operators as an alternative carrier backbone to reduce network congestion during peak periods. The demand for new services and higher peak bit rates and system capacities can only be achieved by heterogeneous wireless platforms, for which TVWS is an excellent candidate (Gbenga, 2014). TVWS technology can be cost-effective and valuable contributor to the wireless ecosystem supporting broadband services to un-served and underserved rural and urban areas in the African continent. It is currently being exploited by many large consumer electronics companies and Internet/software companies including Google and Microsoft. TVWS technology provides excellent radio propagation characteristics compared to other technologies that are using higher frequencies because it operates on the lower frequency bands which are less affected by haze, snow, rain and other natural disturbances. It is an ideal technology that has the potential to bridge the digital divide and significantly improve the economics of deploying wireless broadband in underserved communities (Roberts et al., 2015).

### 3.1 TVWS Spectrum Trials and Pilot Projects in Africa

In recent years, significant efforts have been made by several regulatory bodies in different African countries to implement the necessary infrastructure for the utilization of TVWS technology. Google and Microsoft are the main driving companies that promote dynamic re-use of unused TV spectrum to provide reliable and affordable internet access to Africans. They are the sponsors of many trials in Africa with Google mainly in South Africa and Microsoft in Kenya. (Mureu et al., 2016) There are also independent efforts going on in Malawi and some other few African countries toward implementation of TVWS trials. TVWS is attracting considerable attention as a key part of the regulatory toolbox in many African countries. Many regulators clearly saw the potential and were working to integrate TVWS into their strategic planning. Although Manufacturers of TVWS equipment are gradually coming on board, TVWS equipment has yet to achieve its full mass market potential. Equally the standards for TVWS are still evolving and it is up to African governments, regulators, and entrepreneurs to decide whether to seize the opportunity or not. The following represent the most notable attempts toward the realization of TVWS in Africa (Lysko et al., 2014), .

#### *3.1.1 TVWS Trial in Nigeria*

The estimated internet users in 2016 was 47.9% of the population and the internet penetration rate is 8.3% which is very low compared to South Africa that recorded 25.3% internet penetration (Facts, 2016). This is because large percentage of Nigerian populace are residing in rural areas with no access to basic communication services coupled with low demand for communication which increases the cost of providing communication services. Therefore, providing low cost communication services through TVWS for such a large community is definitely an important step for societal development (Gbenga, 2014). However, there is no any official TVWS deployments or trials in either the urban or rural areas in Nigeria to the best of our knowledge. It is important to note that at the moment, only WaveTek has secured the West African distribution rights for Carlson Wireless to implement TVWS trial in Nigeria and University of Ilorin has already engaged it services to provide campus Wi-Fi and TVWS connectivity across the entire campus and satellite hostels in off campus. The project is expected to cover neighboring villages and provide high speed Internet services. The project will be the first largest TV White Space based campus wide Wi-Fi in Africa (Opawoye et al., 2015).

#### *3.1.2 TVWS in South Africa*

With the support of the independent communication authority of South Africa (ICASA), Google worked jointly with the Wireless Access Providers Association (WAPA), the e-Schools Network, and Carlson Wireless to carry out the necessary spectrum measurements to provide the necessary evidence of viability of the project. The trial project was adopted in ten schools in the Cape Town to provide a broadband internet service at a speed of 4 Mbps using vacant UHF spectrum (Lysko et al., 2014). Similarly, Microsoft 4Afrika initiative implemented TVWS project in Limpopo that provides low-cost wireless connectivity to five schools. The project is the result of active collaboration between Microsoft, the University of Limpopo, the network builder, Multi Source and the Council for Scientific and Industrial Research and was funded by the government (Masonta et al., 2015).

#### *3.1.3 TVWS in Ghana*

With the support of the Ghana National Communications Authority (NCA), Microsoft and SpectraLink announced the creation of a commercial TVWS pilot in Ghana in May 2014. The pilot project is part of Microsoft's 4Afrika initiative and its main objective was to provide low cost and affordable wireless network connectivity to students and staff at universities in Koforidua. The networks use TVWS technology with other wireless technologies to connect the entire campus and hostels to provide fast broadband internet access. This level of connectivity was substantial benefit to both students and staff at the universities (Roberts et al., 2015), (Louis et al., 2016).

#### *3.1.4 TVWS in Kenya*

TVWS pilot project in Kenya was supported by the Kenya's Ministry of Information and Communications, Indigo Telecom Ltd., and Adaptrum, Microsoft launched its first pilot project in February 2013 to provide affordable wireless access to underserved places near Nanyuki and Kalema towns in Mawingu. The areas are connected using TVWS include the Burguret Dispensary (healthcare clinic), the Male Primary School, the Male Secondary School, Gakawa Secondary School and Laikipia District Community Library. This pilot project utilizes TVWS and base stations that are powered by solar energy to deliver broadband internet access to enhance education, improve healthcare and preserve the environment (Opawoye et al., 2015), (Mureu et al., 2016).



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#### *3.1.5 TVWS in Tanzania*

In collaboration with the Tanzania Commission for Science and Technology (COSTECH) and the local ISP Uhuru One, Microsoft 4Afrika initiative implemented a pilot TVWS trial project. The project enhances connection facilities and provides reliable and affordable internet access to students in Dares Salaam, Tanzania (Chavez et al., 2016).

#### *3.1.6 TVWS in Malawi*

The University of Malawi and Malawi Communications Regulatory Authority (MCRA) in collaboration with the International Centre for Theoretical Physics in Trieste (ICTPT)implemented a TVWS pilot project in September 2013 (Chavez et al., 2016). They first developed a very low-cost spectrum analyser based on open hardware to carry out a spectrum survey to determine the viability of the project. The project provides affordable and reliable connectivity to several hospitals, tertiary institutions, schools, an airport and a research facility in the city of Zomba, in southern Malawi (Atimati et al., 2016).

#### *3.1.7 TVWS in Botswana*

A TVWS pilot project was launched in March 2015 by the Botswana Innovation Hub in collaboration with Microsoft and other agencies. The project which is known as Project Kgolagano provides internet connectivity and specialised telemedicine services to local hospitals and clinics. It enables access to specialised medicine in other locations around the world, where hospitals and clinics in rural areas send high-resolution patient photographs back to major cities for a more accurate diagnosis and care. The project was made possible under an authorisation from the Botswana Communications Regulatory Authority (BOCRA) to transmit using TV white spaces. It is also operating with the support of the Botswana Ministry of Health and the Ministry of Infrastructure, Science and Technology (Roberts et al., 2015).

TVWS deployments in Africa would mainly depend on the availability of vacant TV spectrum bands within the region. Although TVWS spectrum usage and availability have been investigated in many countries (Elshafie et al., 2014), (Lopez-Benitez et al., 2009), (Islam et al., 2008), (Wellens et al., 2007), (Valenta et al., Chiang et al., 2007), (Patil et al., 2011), such investigations have not been fully conducted in most African countries. Therefore, it is extremely important to investigate the potentials of TVWS in Africa and develop modelling tools that can quantify the availability of TVWS spectrum for cognitive access. It is evident that TVWS technology is still evolving and performance improvements can be expected.

### 4.0 Potential Challenges and Research Topics

Although TVWS technology has existed for some time and many standards to be employed in TVWS communications has been proposed, numerous significant problems and issues toward the practical realization of this technology remain unexplored. Many countries have either completed TVWS measurements or are on the verge of identifying TV white spaces in their frequency domains. The challenging issues and research areas that need to be explored are not peculiar to African countries rather general issues to TVWS technology.

TVWS is envisioned to be inhabited by heterogeneous networks, each acting selfishly. Thus, there is a need to develop autonomous coexistence etiquette capable of guaranteeing optimal $Q_oS$ to end-users. Interference is expected to mar the $Q_oS$ of TVWS networks. The selection of the appropriate interference estimation model is therefore critical and an important research topic. Similarly, handoff and spectrum mobility issues for a cognitive radio in respect of TVWS technology is an important research topic. When a mobile node is moving out of the coverage area of one provider, the best handover mechanism and information exchange to be used by different operators need to be investigated. In addition, high-precision TVWS Spectrum Sensing is an important research topic. This is because Utilization of TV bands through dynamic spectrum access is largely rely on the ability of the TVWS devices to optimally sense the spectrum bands and successfully detect TVWS. This requires TVWS device to detect weak signals (-114 dBm for 6 MHz US channels and −120 dBm for 8 MHz UK channels) much lower than thermal noise which is quite challenging (Xing, et al., 2013).

A TVWS device is expected to be capable of dynamically changing their operating spectrum through software define radio paradigm to access the best available spectrum. This requires adaptive and flexible reconfigurable hardware and software design to accommodate several performance factors such as received power, frequency range, antenna gain, transmitter frequency band and modulation. It is envisaged that TVWS device that employs MIMO technology can significantly enhance receiver sensitivity and other key wireless communications parameters such as transmit power and coverage. Some of the open issue that needs to be exploited in the application of MIMO technology to TVWS devices include optimal use of MIMO antenna and estimation and control of aggregate interference from multiple cognitive radio equipment (Mustapha, 2016).

## 4.0 Conclusions

In this paper, TVWS technology is shown to be a reliable and affordable wireless communications resource capable of mitigating the current spectrum crunch in the wireless system technology. The technology has the potential to improve the economics of deploying wireless communications services in underserved communities in both isolated rural and urban areas in Africa.

We have demonstrated the great potentials for leveraging TVWS technology to provide reliable and affordable wireless communication services in Africa where abundant unused TV broadcasting spectrum exist. The overview of the current industrial trends in wireless communications indicate that TVWS technology is evolving from merely theoretical approach to a practical realization as demonstrated by few TVWS trials implemented in some African countries. We have also highlighted the intensive efforts toward standardization and commercialization of TV white space devices.

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