Setting Scene for TV White Spaces and Dynamic Spectrum Access in South Africa

Moshe T. MASONTA[1], Richard MAKGOTLHO[2], Fisseha MEKURIA[1]
[1]*Council for Scientific and Industrial Research (CSIR) Meraka Institute, P.O. Box 395, Pretoria, 0001, South Africa*
Tel: +27 12 841 2085/4604, Fax: +27 841 4064, Email: mmasonta, fmekuria{@csir.co.za}
[2]*Independent Communications Authority of South Africa (ICASA), Private Bag X10002, Sandton, 2146, South Africa*
Tel: +27 11 566 3367, Email: RMakgotlho@icasa.org.za

Abstract: In this paper an overview of the TV white space technology and dynamic spectrum access is presented with the aim of improving the capacity of wireless broadband connectivity of communities in emerging markets. The paper proposes that large chunks of TV white space spectrum should be allocated for un-licenced but managed use for improved wireless internet connectivity. Various pilot trials which are planned to test the technology of white spaces without incurring undue interference to incumbent broadcasters, are discussed, with respect to a planned pilot trial in South Africa which is the first of its kind in Africa. TV white space monitoring trials based on a cognitive radio testbed and spectrum data base development performed in rural and urban settings in South Africa are also presented, with the aim to test the suitability of the technology and initiate possible regulatory intervention for the use of TV white space technology for improved broadband connectivity.

Keywords: Cognitive Radio, Dynamic Spectrum Access, Radio Frequency, Software Defined Radio, Television White Space.

1. Introduction

Recent studies and measurements on radio frequency (RF) spectrum occupancy in the developed regions have shown that spectrum usage is concentrated on certain portions of the spectrum band while a significant amount of the spectrum remains under-utilized. For instance, the Federal Communications Commission (FCC) spectrum measurements in the United States' major cities found the temporal and geographical variations in the utilization of the assigned or licensed spectrum ranging from 15 – 85% [1]. On the other hand, wireless communication technologies are seen as an alternative and cost effective means of communication over fixed-line or wired infrastructure in the developing regions. With the growing demand for high speed and broadband hungry multimedia services and applications, wireless networks are getting congested. Such congestion is somehow attributed to the current inefficient command-and-control static spectrum regulation regime. In order to keep up with a growing demand for wireless broadband access; new and dynamic spectrum regulation and management approaches are crucial.

The ongoing global television (TV) broadcast digital switchover (DSO) will see large portions of the very high frequency (VHF, at 174-230 MHz) and ultra high frequency (UHF, at 470-790 MHz) bands available on a geographical basis for other usage, such as mobile communications. Such spectrum bands are widely known as TV "*white spaces*" (TVWS). In the US, for example, TV DSO was completed in June 2009. However, this was not a smooth process. For instance, it was reported that digital TV viewers from many cities experienced several reception problems [2]. Due to the complexity of DSO, several countries decided to extend their DSO completion dates, with UK expected to finish by 2012 and South Africa expected to be complete by December 2013.

Over the past decade, cognitive radios (CRs) [3] have received considerable attention from the research community as an enabling technology for efficient spectrum management. ITU defines CR system as "a *radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained*" [4]. Instead of using the traditional (and outdated) command-and-control spectrum regulation policies, CR networks seek to deploy dynamic spectrum access (DSA) regulation approaches. Practically, CR builds on the SDR architecture with added intelligence to learn from its operating environment and adapt to statistical variations in the input stimuli for efficient resource utilization [5]. With the current threat of spectrum scarcity, CRs are widely proposed to build DSA-based secondary networks for lower priority users.

In this paper, we present an overview of TV white space technology and cognitive radio activities in emerging economy countries with particular emphasize in South Africa.

2. Dynamic Spectrum Access Using Cognitive Radio Technology

The RF spectrum is the most expensive radio resource, and its high demand calls for advanced and dynamic spectrum regulatory approaches. It is for this reason that the use of CR and software defined radio (SDR) has attracted lots of attention from the academia, industry, regulators and governments and the enabling technologies for efficient spectrum utilization. In this section we discuss different approaches for dynamic spectrum access (DSA), with specific focus on the use of CR for efficient spectrum usage and management.

2.1 Dynamic Spectrum Management using CR

The process of realizing efficient spectrum utilization using CR technology requires a dynamic spectrum management framework (DSMF) as proposed by Akyildiz *et al* in [6]. This DSMF consists of spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility, as shown in Figure 1. Spectrum sharing refers to coordinated access to the selected channel by the secondary users (SUs) or CR users. Spectrum mobility is the ability of a CR to vacate the channel when a licensed user is detected. Spectrum sensing involves identification of spectrum holes and the ability to quickly detect the onset of licensed or primary user (PU) transmissions in the spectrum hole occupied by the SUs. Spectrum decision refers to the ability of the SUs to select the best available spectrum band to satisfy users' quality of service (QoS) requirements.

In order to achieve DSA, a CR has to be both spectrum and policy agile [7]. A spectrum agile CR is capable of operating over a wide range of frequency spectrum; while a policy agile CR will be aware of the constraints under which it operates such as the rules for opportunistically using the vacant spectrum bands, spectrum database usage is one of the examples in this case.

Successful operations of CR technology or white space devices (WSDs) for secondary operations depend on the successful detection of TVWS and the ability to avoid harmful interference to the incumbents. Three known methods for ensuring that CR or WSDs do not cause harmful interference to incumbents are: *geo-location databases, spectrum sensing* and *beacons.* Details and related work on spectrum sensing and geo-location database techniques is discussed in the next section.

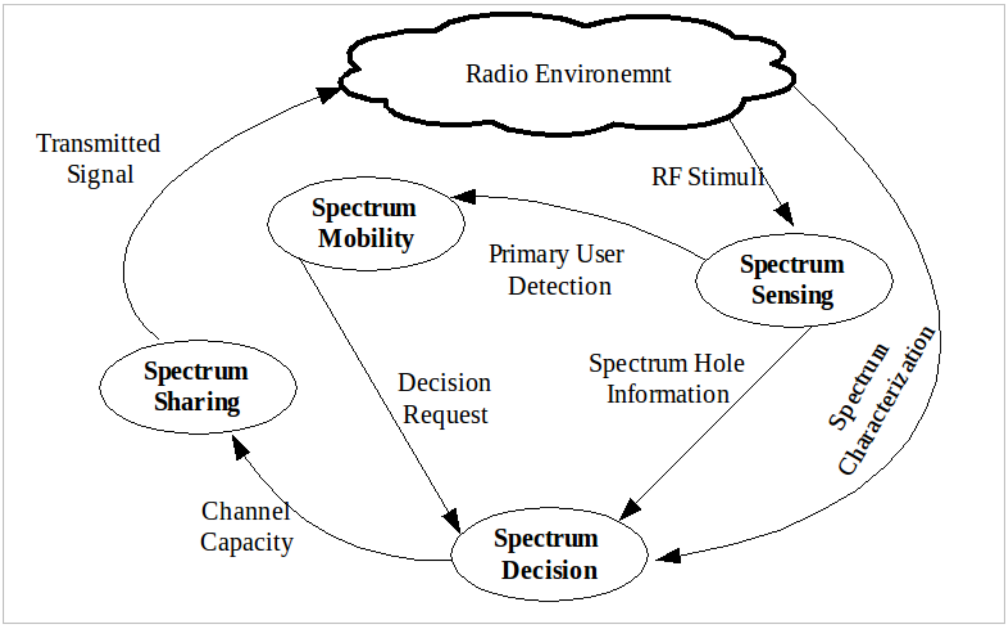

Figure 1: Dynamic Spectrum Management Framework [6]

2.1.1 Spectrum Sensing

Spectrum sensing is one of the most crucial and challenging issues in cognitive radio networks (CRNs). It enables the identification of the spectrum holes and the detection of the onset of primary transmission on the spectrum hole occupied by the secondary user (SU). An optimal spectrum sensing technique must be capable of detecting weak signals under noisy environment with a very small probability of miss detection [8]. To ensure reliable and efficient spectrum sensing, it is important to associate the detection of multiple radios through cooperative spectrum sensing [9] and [10]. Cooperative sensing will allow CR to exploit the diversity gain provided by associated radios. This is in contrast to a single radio spectrum sensing, which suffers from deep channel fading and hidden terminal problem.

Spectrum sensing also introduces CRNs performance degradation experienced when all or some SUs communication has to be postponed during channel sensing. In [11], an adaptive scheduling scheme that schedules the spectrum sensing periods in order to minimize the negative impacts to the performance of the CR network is proposed. The authors treat each sensing period as a '*virtual sensing packet*' so the problem of joint data-transmission/spectrum-sensing scheduling is then converted into a standard queuing model. The IEEE 802.22 [12] (which is the first wireless air interface standard focused on the development of CR based wireless regional area network for operation in TVWS) standard supports incumbent or PU detection through spectrum sensing techniques with an option for geo-location databases. However, due to some outstanding technical challenges in performing reliable spectrum sensing practically, some regulatory bodies such as the FCC and Ofcom prefers geo-location databases as the primary means for incumbent detection. In dealing with unreliable spectrum sensing challenges, [13] suggests the use of at geo-location databases for the initial set of no-go areas of the spectrum bands and then use spectrum sensing to avoid unknown and unpredictable sources of interference.

2.2 Geo-Location Database

With a geo-location database approach, the PU may be registered in a database and the CR user will have to first determine its location and then interrogate the databases periodically in order to find the free and available channels [14] and [15]. It is very important for CR devices to know their geographical location with a prescribed accuracy [15]. Such accuracy may be determined by the regulator. Other data that a CR device is expected to provide to the database may include the device type, model and expected area of operation. In response, a database is expected to reply with the available frequencies, maximum transmission power, and whether the CR device can consult a particular national or regional database.

With this approach, there is a need for either the regulator or operators to build and maintain such databases. Another issue with geo-location databases is the need for an additional connectivity by CR devices in a different band to enable access to the database prior to any actual transmission. It is up to the regulator to decide on the best approach. However, Fitch *et al.* [14] argue that in the future, both database and spectrum sensing techniques will be used together in order to have flexibility and achieve maximum efficiency for SUs, as shown in Figure 2.

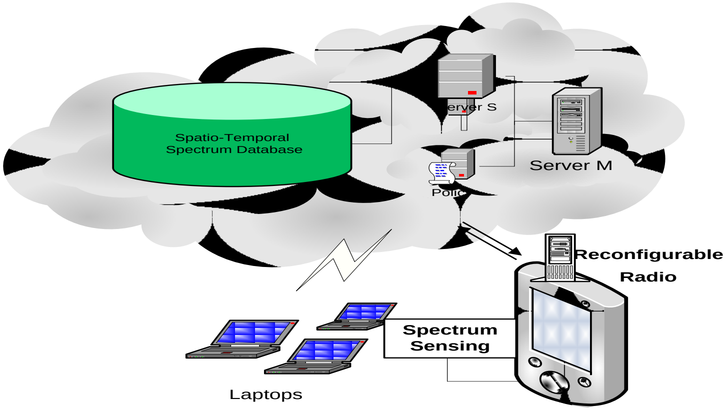

Figure 2: Conceptual diagram of white Space spectrum database and cognitive radio technology.

3. Standardization and Regulation of CR technology

In this section we discuss selected standardization efforts looking at CR for efficient spectrum access, and then discuss the ongoing activities within the South African regulation authority. We also look at progress and activities made in other countries with regards to the regulation and acceptance of CR for DSA.

3.1 International Telecommunications Union (ITU)

The International Telecommunication Union (ITU) is also involved in standardization efforts of CR technology through their ITU-R Working Party (WP) 1B and WP 5A [16]. These two WPs prepared reports describing the concepts and the regulatory measures required to introduce CR. The ITU-R WP 1B developed a working document towards draft text on World Radio-communications Conference 2012 (WRC-12) agenda item 1.19. The ITU-R expects the CR technology to provide flexibility and improved efficiency to the overall spectrum use.

The latest ITU-R [17] resolutions supports the introduction of CR systems for as long as they ensure that coexistence within other radio services and the protection of other radio services sharing the band and in the adjacent bands are maintained or improved. However, there still a need to study operational and technical requirements, characteristics, performance and possible benefits associated with the implementation and use of CRs in relevant radio services and related frequency bands.

3.2 IEEE 802.22 Wireless Regional Area Network (WRAN)

In order to take advantage of the TVWS spectrum, the IEEE 802.22 WRAN standard [12] was established, and the first official standard was released in July 2011. IEEE 802.22 is the first wireless air interface standard focused on the development of CR based WRAN physical (PHY) and medium access control (MAC) layers for operation in TVWS. It specifies a fixed point-to-multipoint wireless air interface where a BS manages its own cell and all associated CPEs. The IEEE 802.22 PHY layer is based on orthogonal frequency division multiple access (OFDMA) and can support a system which uses TVWS channels to provide wireless communication links over distances of up to 100 km. A typical use case for the IEEE 802.22 standard would be in sparsely populated rural areas [15].

3.3 Independent Communications Authority of South Africa (ICASA)

On the 14th December 2011, the Minister in the Department of Communications (DoC) in South Africa (SA) gave notice of “intention to make Policy Directions to the Independent Communications Authority of South Africa (ICASA) on exploitation of the digital dividend spectrum (790-862 MHz) and RF spectrum (2500-2690 MHz) for electronic communications services” [18]. By allowing licensing of the 790-862 MHz (800 MHz band) spectrum, the SA government intends to facilitate the introduction of new national and rural broadband and electronic communications providers. This 800 MHz spectrum frequency band come with favourable propagation characteristics (which includes long range coverage, in-building penetration and indoor coverage) necessary for achieving broadband nationwide coverage [18]. The 2500-2690 MHz spectrum, on the other hand, is suitable for providing high capacity coverage in densely (or urban) populated areas.

Through the spectrum policy directions, the regulator (ICASA is directed to, among others:

- Facilitate different licensing methods for electronic communications services in high demand spectrum bands (which are 790-862 MHz and 2500-2690 MHz frequency bands);
- Facilitate the licensing of the 800 Hz spectrum based on a wholesale open access network;
- Facilitate the licensing of the 2.6 GHz spectrum to multiple operators;
- Ensure that broadband is available in sparsely populated, rural and remote areas. ICASA must establish obligations on priority stages for network roll-out on the basis of a number of inhabitants per area; and
- Ensure efficient spectrum utilization and to allow for the introduction of new entrants (combinational license award for 800 MHz and 2.6 GHz).

The SA DoC further gave directions to the ICASA to consider spectrum auction as the last resort [18]. This is different from the Ofcom [19], which is considering auctioning this high demand spectrum bands (i.e. 800 MHz and 2.6 GHz).

The DoC general notice also published “Policy directions on exploiting the digital dividend” spectrum where ICASA is expected to ensure that the 790-862 MHz frequency band is declared as the first phase of the digital dividend. This was in accordance to the ITU WRC-07 recommendations. Based on the WRC-07 allocations, the TVWS (especially the upper UHF band) spectrum in SA was expected to be available within the 470-790 MHz. However, with the latest allocations by the ITU WRC-12, the new TVWS spectrum (UHF band) has been reduced to 470-694 MHz frequency range [17].

The regulator is also directed to undertake an inquiry into the rational and efficient exploitation of the remaining VHF and UHF spectrum for future digital dividend specifically on the: future spectrum requirements for digital terrestrial TV broadcasting and mobile broadband applications in the next 10 years, future spectrum requirements for digital sound broadcasting after analogue switch-off, and possible use of “TV white space” technologies. In order to achieve all the DoC Policy directions, the regulator (ICASA) is working very close with local universities and research council. Other issues to be considered by the regulator include the use of geo-location database for secondary network usage. The regulator will have to decide on the management and ownership of such database.

3.4 Other Developed Countries

In Europe, the European Telecommunications Standards Institute (ETSI) is also involved in the standardization of the CR systems (called reconfigurable radio systems) under their Reconfigurable Radio Systems Technical Committee (RRSTC) [20]. Cognitive radio principles within ETSI RRS-TC are concentrated on two topics: a cognitive pilot channel proposal and a functional architecture for management and control of reconfigurable radio systems. There are four WGs forming the ESTI RRS, WG 1 to WG 4. Cognitive management and control falls under WG 3. This WG focuses on defining the system functionalities for reconfigurable and dynamic spectrum management and joint radio resource management.

The European Conference of Postal and Telecommunications Administrations (CEPT) is also engaged in the study of DSA using CR technology, through different steering groups. The COST-TERRA project is developing a comprehensive techno-economic regulatory framework of radio spectrum access rules for CR/SDR, catering for envisaged CR/SDR deployment scenarios and fostering the development of the wireless industries and consumer interests at large [21]. The COST-TERRA project was launched in May 2010 and will run until May 2014.

Just like in other countries, the TV frequency allocations in the VHF (174 to 230 MHz), and the UHF (494 to 790 MHz) bands, are not all in use at any given time in Singapore [22]. The Singapore’s Info-communications Development Authority (IDA) recognises the potential of TVWS, and is currently (since March 2011) conducting trials for white space technology which involves five participants. The trials duration is expected to last between 6 to 12 months long.

In Australia, the TV digital-switch-over started on 1 July 2010 with the move to digital only services in a regional area after the completion of digital switchover in 2013 [Freyens, 2011]. The Australian Government anticipate the digital dividend spectrum of 126 MHz in the upper UHF band (i.e. from 694 MHz to 820 MHz), which is to be made available for next generation networks. The Australian Communications and Media Authority suggested an allocation of 9 MHz guard band from 694-703 MHz to prevent interference between high power broadcasting services below 694 MHz and the mobile telecommunications networks most likely to be deployed above 703 MHz. This 9 MHz guard band will clearly be of interest to WSD proponents [23].

In this section we discussed international efforts towards the realization of DSA through the use of either CR technology or the WSDs. In the next section we present the Meraka Cognitive Radio Platform which is currently used within our group for research on TVWS and software defined radio applications.

4. TV White Space Technology Platform

The Meraka Cognitive Radio Platform (MCRP) is shown in Figure 3. The platform consists of four CR nodes, and each node is connected to the Internet using the Ethernet cable. A single node is built up of three major hardware components, which are: a high speed computer, USRP-2 package and high gain antenna. The computer is powered by 2.60GHz Dual Core Intel Pentium processor, 2 GB read only memory (RAM) and 500 GB hard-drive. Each computer hosts the GNU Radio software. The GNU Radio software runs on Ubuntu Linux, which makes the whole platform an open source based. In four CR nodes, one node is nomadic, two nodes are located outside the lab and one is within the lab. One of the outdoor nodes is located 3 km away from the lab, with line-of-side to the antenna. This 3km link allows us to capture typical interference and propagation effects that a production white space system will experience. Each CR node is connected to the Internet for remote access. This allows remote users to run experiments on the platform from anyway in the world. For our nomadic node, we made sure that the laptop used is also connected to the Internet using the cellular network.

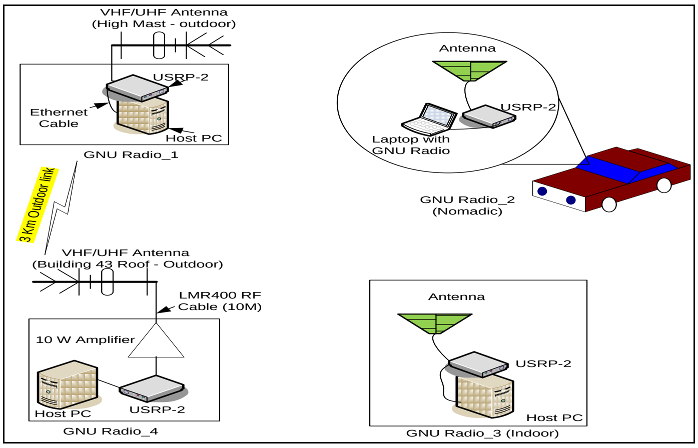

Figure 3: Meraka Cognitive Radio Platform

4.1 Outdoor Spectrum Occupancy Measurements

In 2011, the MRCP was used for spectrum occupancy measurements on the frequency range from 50 MHz to 1 GHz in selected rural and urban areas in southern Africa. One measurement was carried out in Philipstown, which is a rural village in the Northern Cape of South Africa. And the other one was carried out at Macha rural area in Zambia. A nomadic CR node was used for remote white spectrum measurements, the results of which are shown in Figure 4. Multiple consecutive scans were done using 800 kHz bandwidth and Fast Fourier Transform (FFT) size of 2042. The data was post-processed using Matlab software and FFT bins were averaged to 25 kHz buckets. The results of our spectrum measurements are available in [13].

5. TV White Space Trials

CSIR Meraka Institute and ICASA have recently agreed to create a common research agenda in the area of TV white spaces and dynamic spectrum utilization, the duo are also collaborating with relevant universities and industry forum to achieve the goal. The goal is to perform research and piloting of TV white space technology in South Africa. A consortium is formed with technical teams working to implement a test pilot in two phases involving several rural and urban South African communities. The results of the TV white space pilot trials will be reported, and the plan is to continue the piloting in selected African villages in the region, through collaboration with telecom and regulatory bodies in Africa.

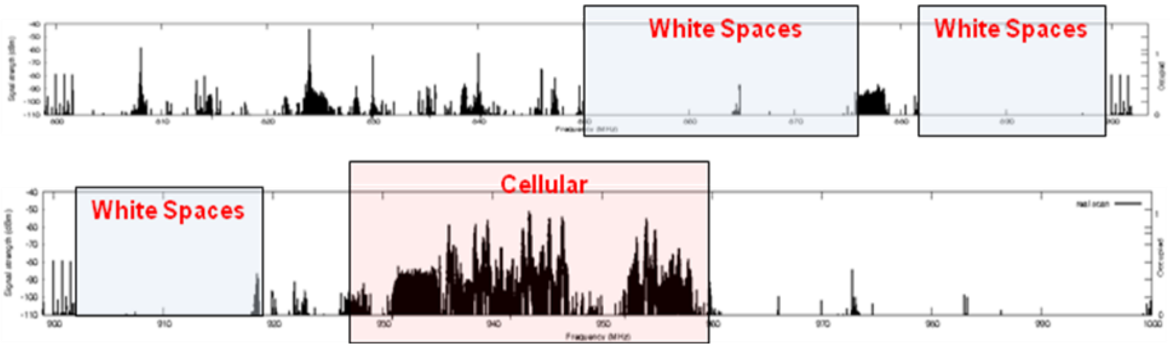

Figure 4: Outdoor Spectrum Measurements

6. Ongoing Research Work on CR and TVWS

The CSIR Meraka research group has identified cognitive radio and white space technology as one of the relevant research areas to meet the challenges of high bandwidth and range enabled future networks. Support to enacting an enabling regulatory framework for dynamic spectrum access in white space spectrum areas is undertaken through collaboration with ICASA and the Smart Radio Technology (SRT) university collaboration project to accelerate research and HCD projects.

CSIR Meraka is supporting its researchers to gain international experience and undergo postgraduate research and education through collaboration with local and international universities in the areas of cognitive radio and, current topics that are being pursued are:

- Spectrum decision framework – White spaces devices need to make intelligent decisions to use a particular frequency band at a given time.
- Distributed Medium Access Control algorithm – White spaces devices working in a distributed multi-hop fashion need to have distributed intelligent decision mechanism for access to the wireless medium
- Dynamic spectrum access framework and Geo-location spectrum databases optimization – Standard geo-location technique requires a static database with only the primary users in it, however a dynamic geo-location database that supports both space and time dimensions, require adaptation mechanisms.

6.1 Other Involvements

- Contribution to further standardization of cognitive radio networks and white spaces device networking with relevant technology partners.
- Contribution to seamless interworking and coexistence of TV white space devices with broadcasting and cellular wireless networks and devices.
- The CSIR Meraka institute is participating in the EU-FP7 Future Networks project and defining the future of cognitive and heterogeneous radio networks.
- European COST Action IC0905 TERRA

7. Research & Human Capital Development

Development of the necessary research and expert human capacity to lead the development of an innovative spectrum regulation and policy formulation is a crucial aspect in acceleration the research and human capacity development for regulatory bodies in Africa. The CSIR in collaboration with several universities, and the ICASA is leading a project to address this capacity building need. Such efforts to build capacity also will lead to sustainable socio-economic development, emergence of science and technology supported SMEs and the improvement of quality of life in South Africa and the wider African region. Some of these activities include:

1- Active participation in standards organizations and organization of workshops and awareness seminars on new network technologies

2- Research and HCD support to ICASA on dynamic spectrum allocation, spectrum decision framework for cognitive radio based dynamic spectrum access.

3- Developing expert human capacity through the “Smart Radio Technology” research and HCD project. This is a CSIR R&D Core funded project in support of research for CSIR and university collaboration on on next generation smart radio technologies for improved capacity wireless broadband networks and services.

8. Conclusion

We conclude the paper by raising some issues which will guide the ensuing panel discussion on TV white space technology and its use for improving wireless broadband connectivity in emerging markets. The requirement for dynamic spectrum access policy, as discussed in ITU, ETSI, FCC, Ofcom and other standards and regulatory organs is receiving much attention due to poor utilization of valuable spectrum areas by existing systems. Apart from allowing dynamic spectrum access with primary user protection, based on the initial TV white spectrum scan the paper suggests that telco-regulators in emerging economies allocate unlicenced spectrum use in large chunks of the TV spectrum (VHF & UHF). This in the authors’ opinion can accelerate broadband technology and improved wireless internet services development and provision in emerging economies in Africa.

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