TV White Spaces for Wireless Broadband in Rural Areas: the regulator, broadcaster and telecommunication(s) operator viewpoint

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Abstract: Television White Spaces (TVWS) coupled with Dynamic Spectrum Access and Cognitive Radio (DSA-CR) technologies are increasingly viewed as key enablers to the bridging of the digital divide in rural areas. However, in order to realize maximum benefits of TVWS, spectrum regulators need to implement reforms to their archaic static spectrum management approaches to allow dynamic spectrum sharing among different players. In this context, this paper investigates the emerging regulatory, standardization, and technological trends necessary to the exploitation of TVWS for the provisioning of wireless broadband in rural areas, particularly in the developing regions. In such scenarios, we show that the incumbent (in this case TV broadcaster) could be better protected from potential harmful interference of the secondary users through the use of regulator controlled spatial-temporal databases. Simultaneously, the delivery of low-cost service(s) to the end-user(s) could be achieved by the telecommunication operator through the use of bridged TVWS/Wi-Fi Access Points (APs).

Keywords: Cognitive Radio, Dynamic Spectrum Access, Spatial-temporal database, Software Defined Radio, Television White Spaces.

1. Introduction

White Spaces is a term used to describe the portions of radio spectrum allocated to a particular radio-based service across all dimensions (i.e., frequency, space, and time). The Independent Communications Authority of South Africa (ICASA) has recently conducted occupancy measurement audit of two Ultra High Frequency (UHF) radio spectrum bands: the 450 - 470 MHz and the 790- 862 MHz in major South African cities. The results from these audits indicate that license-holders have been under-utilizing the radio spectrum in the two sub-bands by more than 80% most of the time [1, 2].

The under-utilization of radio spectrum is a worldwide phenomenon. For example, see the cases of 18 cities in the United Kingdom (UK) [3], and the city of Chicago, Illinois in the United States of America (USA) [4]. Surprisingly, however, in the national broadband plan, the Federal Communications Commission (FCC) of USA has indicated that there is an urgent need for additional radio spectrum to accommodate new advanced radio-based services (at sub-3 GHz frequencies). To be exact, the plan indicated the need for 300 MHz by the year 2015 and up to 500 MHz in ten years [5]. It is worth noting that the aforementioned perceived scarcity problem is only partly caused by inefficiencies in existing radio communication technologies, and largely caused by antiquated spectrum management regulations [6]. Spectrum regulators have traditionally allocated a fixed portion of radio spectrum to each new radio service, to such an extent that it is now becoming increasingly difficult to find usable radio spectrum for new radio communication services.

The emergence of dynamic spectrum management techniques offers great opportunities for more efficient utilization of this non-depleting but limited precious resource to regulators, broadcasters, and telecommunication operators. An important enabler for dynamic spectrum access (DSA) is cognitive radio (CR) technology that builds on advances in Software Defined Radio (SDR) and smart antenna technologies. CRs allows a Secondary User (SU) to dynamically access portions of radio spectrum that lie fallow at a particular time and location by the license-holder (also known as the Primary User (PU)) without causing any harmful interference. Consequently, advancements in CR technologies are pertinent to and inseparable from ongoing reforms in spectrum regulation around the world.

It is important to note that, most of Africa's rural communities are from the very low income bracket, and often live in sparsely populated areas which are located in very difficult terrain supported with poor or no infrastructure. Because of these circumstances, it is often not economically justifiable for many telecommunications operators to deploy wireless broadband in these areas [7]. However, among the key benefits of applying DSA-CR techniques is the ability to allow the deployment of ubiquitous low-cost long-range wireless broadband networks in the under-served rural areas. For example, this can be achieved by allowing dynamic access to TVWS on a secondary basis. TVWS in the Very High Frequency (VHF) and UHF bands have superior propagation characteristics which improve Line of Sight (LoS) coverage, Non-Line of Sight (NLoS) coverage, geographical coverage, and penetration of buildings, natural obstacles, and foliage [8]. The higher coverage characteristic in TVWS bands is further illustrated in Figure 1.

The objectives of this paper is to explore some key areas where regulatory, standardization, and technological issues really intersect. For example, the interaction among key players (spectrum regulators, television broadcasters, and telecommunication operators) in the provisioning of wireless broadband over TVWS in rural areas. Special emphasis is put on developing regions in the context of the ongoing migration from the analogue to digital terrestrial television broadcasting.

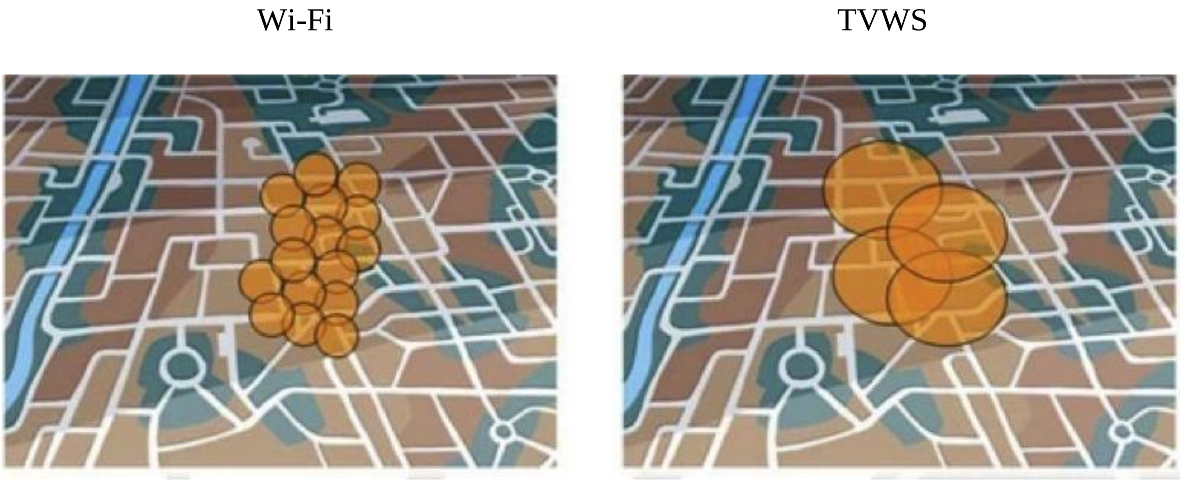


Figure 1*: A coverage comparison of traditional Wi-Fi AP to that of CRs over TVWS [9].*

The rest of the paper is arranged as follows. In section 2, we first provide an overview of related work. In section 3, we address legacy radio spectrum regulatory regimes. We go on to discuss dynamic spectrum access and TVWS regulation in section 4. In section 5, we describe the operation and architecture of spatial-temporal databases for dynamic management of TVWS and present a typical use case scenario. In section 6, we present open research and development issues. We conclude this paper in section 7.

2. Related Work

The term harmful interference has often been loosely defined in the context of enforcing license-holders radio rights. Proper mechanism to protect PUs from harmful interference that may be caused by SUs is a cornerstone to successful deployment of DSA-CR technologies. In [10] de Vries and Sieh presents a proposal that operating rights should be derived using transmission permissions and reception protections in the absence of regulator. As such, transmission permissions should be based on resulting field strength over space and frequency, rather than radiated power at a transmitter. While reception protections should state the maximum electromagnetic energy an operator can expect from other operators. While such a proposal looks promising, this paper argue that potential problems might arise during the enforcement stage due to the fact that each operator will have its own claims of harmful interference to its receivers which will lead to a chaotic situation.

Similarly, Weiss and Cui [11] presented a proof-of-concept evaluation of interference rights that can be traded by license-holders for dynamic spectrum management analogous to the financial options. They show that trade-able interference rights have more advantages over property rights. However, in this paper we argue that the interference temperature metric used in the evaluation does not suit developing country contexts due to the high number and cost of sensors that will need to be deployed in different locations of the country for interference monitoring. In [12], a real-time spectrum trade market scheme that enables SUs to dynamically access RF spectrum is introduced. In this scheme, the PU employs intelligent admission control and frequency assignment algorithms that allow SUs to access a portion of spectrum only when QoS is guaranteed. Consequently, the PU charges the SU for the services in real-time with no or very little intervention from the spectrum regulator.

Hazlet and Leo [13] evaluates the economic technical aspects of choosing a right spectrum management policy. They concluded that advances in technologies couldn't be a panacea to an efficient spectrum management policy but rather a potential source of even more conflicts. In contrast, the solution could be found by adopting liberal spectrum management policies. An evaluation on a novel database-driven WS network is carried out in [14]. From the technical point of view, the authors identify and examine the systems and networking challenges that arise from operating such a network, which is solely dependent on a channel occupancy database to dynamically manage RF spectrum. We however, question the robustness and cost effectiveness of such systems in the developing countries context due to the fact that this system requires a continued supply of power and its operation entails a constant exchange of large data files which substantially increase the operation cost.

3. Legacy Radio Spectrum Regulatory Regimes

Traditionally, spectrum regulators in many countries statically assign radio frequency (RF) spectrum licenses/usage rights to potential users, or services with a strong emphasis on avoiding or minimizing interference among them. The three main approaches in use today are:

Command and Control (C&C) regime: This is a license-based approach in which a RF spectrum license is issued for a limited time, subjected to renewals. A license-holder is restricted to deploying only the prescribed radio-based services and technologies, as well as to comply with site and device standards (e.g., cellular communications).

Property Rights regime: This is a license-based approach which offers exclusivity, that is a license-holder is free to deploy any radio-based service and technology of their choice in the given geographical license area (e.g., mobile phone services). Additionally, this approach opens an avenue for a PU-SU sharing scenario and secondary spectrum trading. For example, spectrum access rights can temporarily be transferred to a secondary user for an agreed form of payment.

Hierarchical regime: This spectrum management approach allows the RF spectrum owned by a licensee (PU) to be shared by a non-license holder (SU). Such PU-SU sharing takes place without the primary being aware of secondary users (i.e. the transmissions of SU are expected to have minimal impact on the operating conditions for which PU devices are designed). Two hierarchical models are: spectrum underlay technique in which signals with a very low spectral power density can coexist as a SU with the PU of the particular RF band and spectrum overlay technique where by a SU uses a channel from a PU only when it is not occupied. Spectrum overlay techniques are based on detect and avoid mechanisms.

Commons regime: In this approach, users share the specified license-exempt RF spectrum bands (e.g., the Industrial, Scientific and Medical (ISM) band). However, they are required to adhere to pre-set minimal operational conditions such as a geographical network coverage area and device certifications to comply with standards. Some policy researchers argue that the commons regime bears similarities with spectrum underlay in the hierarchical regime (whereby the user is given limited rights to communicate using a low power device within the boundaries of a particular tangible property such as a home or office building) [15].

Furthermore, in the C&C and property rights approaches PUs are entitled to be protected from harmful interference, whereas under the commons approach they are not (Additionally, users under the commons approach are not required to cause any harmful interference to users under other regimes). It is worthy noting that DSA technologies can play a part in the property rights, hierarchical regime, and commons regimes

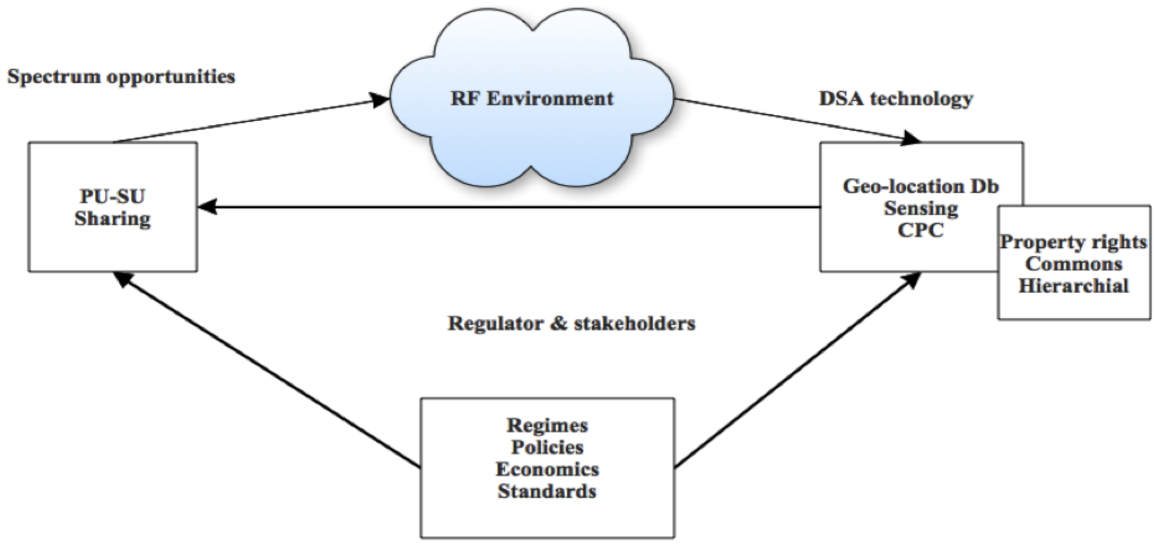
4. Dynamic Spectrum Access and TVWS Regulation

The African continent is still lagging behind on the regulatory front especially pertaining to possible deployment approaches for DSA-CR technologies. However, studies on DSA-CR are on going in some policy-making and research institutions in collaboration with international partners. At the digital dividend workshop organized by ICASA in April 2011, possible spectrum regulatory frameworks for the digital dividend spectrum were discussed. As South Africa will carry out the first migration in Africa to digital TV standards (planned for year 2013), Mekuria [16] highlighted the need for cognitive radio and white space technology supported allocation of spectrum in the TV band spectrum areas.

On a global scale, the International Telecommunications Union Radiocommunications sector (ITU-R) through the recent World Radio Conference 2012 (WRC 12) underlined its final recommendations for possible deployment of DSA-CR technologies [17]. The FCC has continued to adopt much more flexible radio spectrum regulations by encouraging the use of such technologies to enable both licensed services as well as unlicensed devices to dynamically share radio spectrum (i.e., the PU-SU spectrum sharing scenario) provided that licensed services are protected from any harmful interference.

The new regulations include allowing unlicensed operations in the 5 GHz band using Dynamic Frequency Selection (DFS) techniques and allowing shared licensed operations in the 3.65 - 3.7 GHz bands using contention-based protocols. However, the most notable innovation in this regard is the rule allowing unlicensed operations in the digital dividend (this is the freed-up spectrum after migration from analogue to digital terrestrial TV broadcast) and television WS (TVWS). Initially, the mandatory protection mechanism for PUs was for the SUs to access the TVWS using spectrum sensing techniques and a combination of geo-location and access to a database that contains lists of fallow TV channels.

However, in a recent ruling the requirement to use spectrum sensing was relaxed for White Spaces Devices (WSDs) that use a combination of geo-location and database lookup functions [18]. In 2009, Ofcom, the United Kingdom's spectrum regulator issued a statement regarding the implementation of license-exempt cognitive access in the digital dividend. The proposed PUs protection techniques are similar to the ones mandated by the FCC [19]. Spectrum regulators in other regions, such as the European Union (EU) [20], are at various stages of regulatory reforms towards the implementation of cognitive access technologies in the TVWS and the digital dividend. A high-level topology of dynamic spectrum management is depicted in Figure 2.



CPC: Cognitive Pilot Channel

Figure 2: *High-level topology of dynamic spectrum management.*

A. Brief Overview of Relevant TVWS Standards

A plethora of standards by various bodies for the DSA-CR technologies are currently being proposed and developed [21]. This sub-section highlights the most relevant ones: (the ETSI standards defined in [21] and the IEEE 802 standards defined in [22]):

ETSI Reconfigurable Radio Systems (RRS): This standard focuses on the usage of TVWS for adapting existing and/or evolving Radio Standards, such as 3GPP Long Term Evolution (LTE), to a possible operation in UHF TVWS bands is considered. In many cases, it is assumed that TVWS would be largely available in rural areas where broadband connectivity is rarely available. The LTE - Time Division Duplex (TDD) mode is considered to be a suitable candidate for SU operations over TVWS in the rural areas rather than the LTE-Frequency Division Duplex (FDD) mode. This is because it utilizes un-paired spectrum band that is traditionally cheaper and thus lowering the cost of services.

IEEE 802.22 for wireless regional area networks (WRANs): This standard focuses on rural broadband wireless access. The key objective of the standard is to re-use the un-used TV spectrum without causing any harmful interference to PUs (i.e., the TV broadcasting station transmitters). This is achieved by the application of DSA-CR techniques. It is designed to operate in the 54 – 862 MHz range of TVWS.

IEEE 802.11af: This standard is also known as White-fi. It is expected to provide much higher data rates and wider coverage than current Wi-Fi, due to the fact that TVWS possesses superior propagation characteristics. A system based on IEEE 802.11af can be described as a wireless network with DSA-CR enabled access points (APs) operating over TVWS via spectrum sharing mechanisms.

IEEE 802.19: The main objective of this standard is to enable the family of IEEE 802 wireless standards to most effectively use TVWS by providing standard coexistence methods among dissimilar or independently operated TVWS networks and dissimilar TVWS devices. It particularly addresses the issue of coexistence between unlicensed wireless networks.

5. Spatial-temporal Database for Dynamic Management of TVWS

Several techniques for protecting PUs from potential harmful interferences that might be caused by SUs have been proposed [23]. However, due to its overall efficient spectral utilization, most spectrum regulators particularly for operations have so far approved the technique that employs geo-location combined with access to a database over TVWS (hereinafter referred to as a spatial-temporal database). In this approach, a SU is configured with a Global Positioning System (GPS) device and connected to a central database which contains a TVWS spectrum opportunity map (a database might be assisted by a Geographic Information System (GIS)) at a given location in near real-time. There are several proposals of different configurations and implementations of such databases according to their context of use [24, 25, 14].

The spectrum regulator or a third party can operate the geo-location database; the latter could the best approach in developing country contexts. This is due to the fact that it will help to avoid unnecessary bureaucracy in spectrum management such as political interference. However, the primary duty of the spectrum regulator is to provide the key specific operating policies (such as PU protection parameters) to be used by the database.

Moreover, it is arguable that in most developing regions there is a very small possibility of encountering significant numbers of other PUs than TV broadcast station transmitters. Furthermore, traditionally, there are two distinct types of TV broadcasting stations namely, those using analogue transmission technologies and those using digital transmission technologies (DTV). It is worthy noting that such distinctions determine the methodology of how the two types of TV broadcaster's transmitters will be protected by the database (i.e., Unlike Analogue TV, DTV technologies utilizes higher order modulation techniques and low power transmission making it more less susceptible to interference).

A. Architecture of a spatial-temporal database

A typical spatial-temporal databses (STDB) is designed in a modularized architecture which consist of two software parts [26]:

The fetcher software, this module fetches PU's TV transmitter parameters information in a given location from an online spectrum regulator's central equipment database. To achieve that, it first has to send a request message to the spectrum regulator's website using a Uniform Resource Locator (URL) through the Hypertext Transfer Protocol (HTTP) POST method. It then saves the acquired information in a summarized format and sends it to the geo-location database calculation module.

The calculation software, this module uses the acquired TV transmitters information (i.e., service type, antenna pattern, antenna Height Above Average Terrain (HAAT), and Effective Radiated Power (ERP)) to derive PUs protection contours. As a result, the WSD's maximum allowable Effective Isotropic Radiated Power (EIRP) for each channel in a particular location is set. Ultimately, the generator software populates the geo-location database with two files:

(i) A file containing the WSD's geographical coordinates together with the EIRPs of available channel listing in that particular location,

(ii) A file containing the spectrum regulator's service codes of PUs operating in that particular location (e.g., a full power analogue or digital TV broadcasting station).

Figure 3 depicts a high-level architecture of a STDB.

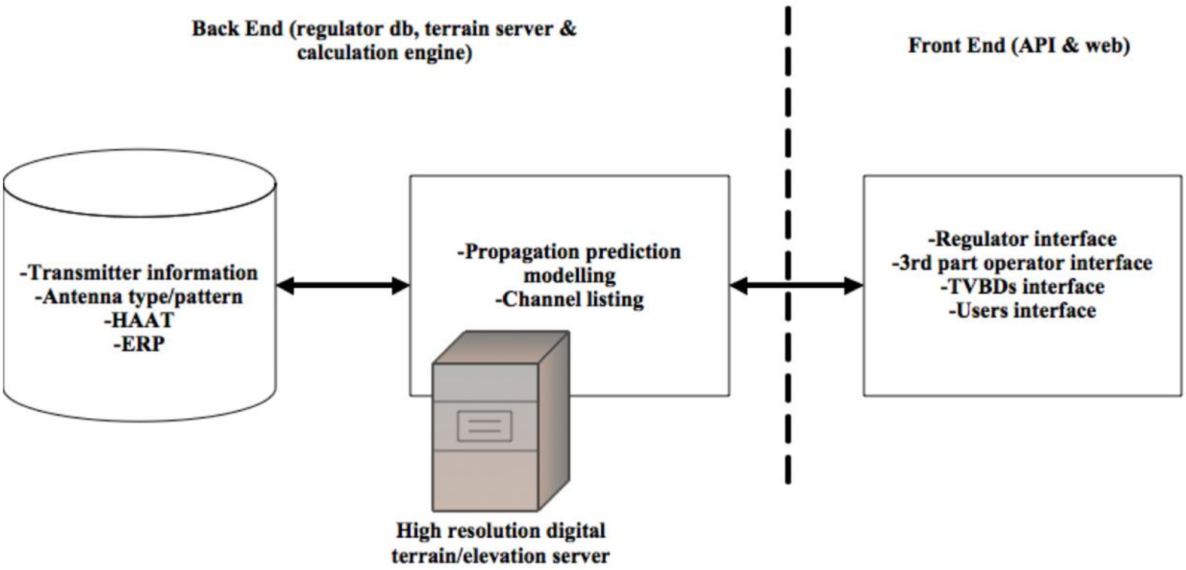


Figure 3: *Concept of spatial-temporal database.*

B. Protection of TV Station Broadcast Area

As already pointed out in the previous sub-section, the classic methodology of estimating the coverage area (field strength contour) of a TV broadcast station transmitter (hereinafter referred to as PU) to be protected by a geo-location database depends on the type of the TV station transmission technology. For example, according to the FCC [27, 28], protection for an analogue TV broadcast station is calculated by using the Longley Rice (L-R) model and the F (50, 50) signal propagation curve. That is, at best, 50% of the locations will receive TV coverage for at least 50% of the time.

Likewise, for the digital TV broadcast station the F (50, 90) signal propagation curve is used. However, in a DSA-CR environment, it is the combination of the signal propagation calculations with high-resolution digital terrain maps that determines the availability of TVWS in a particular location and time. The rule of thumb is that at the nearest contour edge location, both the co-channel and adjacent channel interference protection requirements must be met by the SU for the affected PU receiver.

C. Use case: Fixed Wireless Broadband Internet using IEEE 802.22 WRAN standard over TVWS Bridged to Wi-Fi

Main Objective: Creating a Model/Framework for Deploying and Sustaining a Database-driven Fixed Wireless Broadband Internet using IEEE 802.22 WRAN standard over TVWS in Africa Un-served Rural area.
Scope: Facilitating basic public electronic services (e-education, and e-health) necessary to catapult the speed achievement of the millennium development goals (MDGs).
Deployment scenario: A small town in a remote rural part of Africa is bridged to the digital age. The hospital and school are now connected to the low-cost wireless broadband Internet using IEEE 802.22 WRAN over license-exempt but regulated TVWS. Higher territorial coverage (typical 36 up to 100 Km), and better penetration through foliage are among primary benefits of this standard. This vastly reduces the cost of network deployment due to the fewer number of base stations hops required to reach a given area, all of which will be exploiting the license-exempt but regulated TVWS. The deployment of bridged TVWS/Wi-Fi APs on the customer premises further reduces the cost of service to the

customer because the end user will utilize the already existing affordable Wi-Fi enabled equipment. The TV transmitter in the vicinity is easily protected from potential harmful interference by means of a spatial-temporal database mechanism, as it is arguably that most rural areas experience very little spatial-temporal variations.
Source of Power: All equipment/WSDs in this deployment will be powered by solar power, which is a cost effective and environmental friendly type of energy. Figure 4 depicts the scenario discussed above.

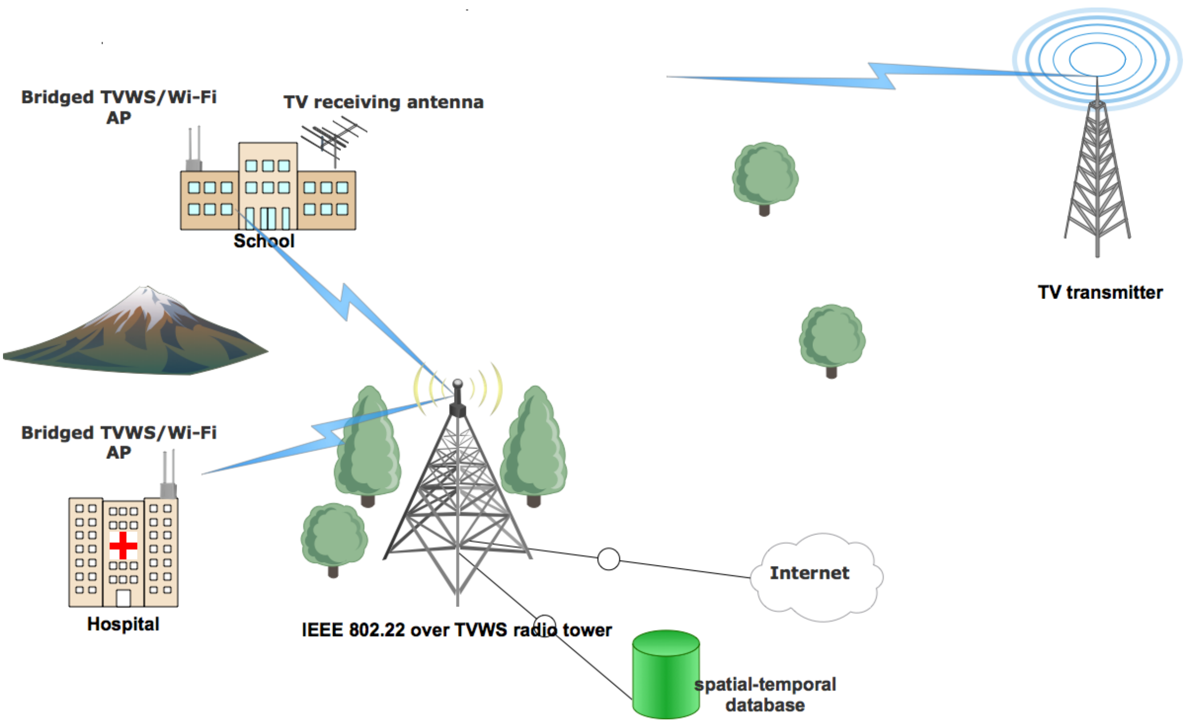


Figure 4: *Wireless broadband provisioning using 802.22 over TVWS bridged to Wi-Fi driven by a STDB.*

6. Open Research Issues

While DSA-CR based technologies are increasingly viewed as potential enablers to the improved spectral efficiency and utilization and help to facilitate the bridging of the digital divide in developing regions. Current policy reforms and research on DSA-CR tends to be focusing on the developed countries often is not directly relevant to the developing region contexts.

Successfully adoption of such technologies in developing countries presents us with an inter-disciplinary challenge with far reaching ramifications – how to reform existing spectrum management policy to match such technologies? (Taking into consideration constraints such as non-existent or intermittent on-grid energy supplies in remote, rural areas). Tackling these issue requires us to address a number of inter-related sub-challenges including but not limited to:

- How to define technical metrics for dynamic spectrum policies?
- How to protect incumbent licence-holders and public safety services from potential harmful interference?

- How to enforce dynamic spectrum access policies?
- How to define metrics for dynamic secondary spectrum trading?

7. Conclusions

The exploitation of TVWS using DSA-CR technologies is increasingly viewed as a potential low cost solution to bridge the digital divide in developing regions particularly in Africa's rural areas. This paper has demonstrated that in order to achieve successful deployment of these technologies, spectrum regulators need to implement reforms to their existing spectrum management regulations.

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