Spectrum Database as a Service (SDaaS) for Broadband Innovation and Efficient Spectrum Utilization

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Abstract—**Broadband innovations for future wireless networks involves rapid sharing of radio frequency (RF) spectrum resources by means of dynamic spectrum access techniques (DSA) to satisfy immediate portfolio of heterogeneous demands of wireless IP services. In this paper a cloud framework for spectrum database as a service (SDaaS) for the application layer is introduced. The SDaaS framework can provide a wide range of vital capabilities needed for unlocking the DSA-based networks: (i) SDaaS can be used as the best short-term solution for minimising any harmful interference that might be introduced to the co-channels and adjacent-channels of the incumbent users subject to a dynamic spectrum sharing policy. Examples of such network architectures are those based on the TV white spaces (TVWS) technologies. (ii) SDaaS can be used as a toolbox by regulators in the development of efficient dynamic spectrum regulations at a national level. (iii) Such regulations can be enforced and monitored through an SDaaS environment suggested in this paper. Moreover, multi-tenancy and schema-sharing techniques are utilised at the inter-regional level to allow the cross-border harmonisation of RF spectrum regulation to negate the problem of IP communication islands.**

Keywords-Cloud; Database-as-a-Service; DSA; Whitespaces; SDaaS; Regulators; Spectrum; TVWS

I. INTRODUCTION

The emergence of cloud computing in the research space promises to solve some of the concerns facing mobile computing platforms. According to Armbrust *et.al.* [1]: Cloud Computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services. A multi-tenancy hosting mechanism is considered to be the key driver to the success of software-as-a-service (Saas) delivery concept in cloud computing. This mechanism allows a single instance of software application to be delivered as a service to multiple users requesting different services (hereinafter refered to as tenants) as opposed to running multiple instances of same software applications to each user [2]. The concept of managing radio frequency (RF) spectrum resources as a service in the dynamic spectrum acess (DSA) environment has been disscused before. In their seminal article titled "Sensing as a service" Weiss, Delaere and Lehr [3] proposed a white spaces indentification system (WSI) model that would be made possible through deployment of a wide area network of sensors in a geographical area and time of interest. As a hosted service, such network of sensors could provide information about available spectrum opportunities to the white space radios (WSRs) thus negating the need for the devices to perform spectrum sensing themselves. However, it is important to note that Geo-location spectrum databases (GLSDs) are currently the prefered enabler of DSA networks by regulatory authorities [4], [5]. This is largerly attributable to the unrealibilty of the techniques used for spectrum sensing particularly the questionable ability to effectively protect the incumbent users [6]. As such in this paper we take one step further and introduce a cloud framework for whitespace Spectrum Database as a Service (SDaaS). This is a cloud-based concept with a potential to manage radio spectrum resources in even larger geographical areas trascending across provincial and national borders. One of the primary benefits of this framework is its ability to relinquish the problem of IP communciation islands. (IP communication islands are defined as several IP-based communication networks that are not interconnected to each other). The data-center hardware containing the core spectrum database, policy issues and software for comuting regulatory parameters and algorithms to find available white space channels are what we will call in this paper as a Cloud.

A. Geo-location Spectrum Database Overview

A portion of the electromagnetic spectrum that is most useful for radio/wireless telecommunications is called radio frequency (RF) spectrum. RF spectrum ranges from 30 – 3000 MHz. Furthermore, RF spectrum is divided into two distinct parts namely; the Very High Frequency (VHF) band which ranges from 30 – 300 MHz and the Ultra High Frequency (UHF) band which ranges from 300 – 3000MHz. Most of today's common and emerging radio telecommunications services are found in the VHF and UHF; these services include but are not limited to, FM broadcasting, TV broadcasting, Radio Astronomy, Mobile cellular communications, Machine-to-Machine (M2M) communications and Wireless microphones. However, in the telecommunications industry, RF spectrum is considered to be a scarce natural resource. The aforementioned scarcity is attributable to the traditional inefficient methods of RF spectrum management by national regulatory authorities. Whereby, RF spectrum are been inefficiently statically allocated on the service-by-service or band-by-band basis. Such inefficient allocations leave swaths of locally unused RF spectrum on geographical and temporal dimensions. This unused RF spectrum is referred to as White Spaces (WS). WS spectrum can be used on a secondary basis to provide useful wireless telecommunications services such as broadband connectivity to un-served or underserved areas. However, such usefulness of WS spectrum can only be exploited provided that existing or primary licensed services such as TV broadcasting is not being harmfully interfered to, with secondary users (primary users are radio devices that utilises WS spectrum). A Geo-location Spectrum Database (GLSD) is designed to enable co-existence between secondary and primary users of RF spectrum in such a way that: based on their geographical location, transmitting power and transmitting, or receiving antenna height, the secondary users will be able to dynamically utilise WS spectrum without causing any harmful interference to the primary users. Currently, GLSDs are used to enable such dynamic-sharing of RF spectrum for the geographically unused frequencies in the TV broadcasting bands commonly referred to as TVWS [4].

B. *Contributions of the Paper*

Moreover, this paper contributes the following characterisation of the three core service delivery cloud planes to shape the framework of SDaaS within the cloud-computing paradigm. These cloud planes are exposed to the relevant stakeholders as application programming interfaces (APIs) in the application layer:

1) **The local spectrum cloud (LSC):** This is the service plane at a provincial level for provisioning of radio spectrum resources on demand to wireless devices.
2) **The intermediate spectrum cloud (ISC):** This is the service plane at a national level for disseminating regulatory directives as well as monitoring and enforcing of the radio spectrum resource policy, planning and usage.
3) **The higher spectrum cloud (HSC):** This is the service plane for cross-border monitoring and enforcing of radio spectrum resource usage.

A high-level view of a provincial white space SDaaS architecture for a TVWS network serving a rural community is described in Figure I. A fixed WSR queries the GLSD over an Internet cloud to access the local catches of free TV channels. This procedure is necessary in order for a WSR to establish a suitable communication link to provide broadband Internet connectivity to a portfolio of services in a respective community (e.g., school, health clinic and a farm cooperative). The fixed WSR and its terminals T, connect over an 802.11af link utilising 470-876 MHz ultra high frequency (UHF) band.

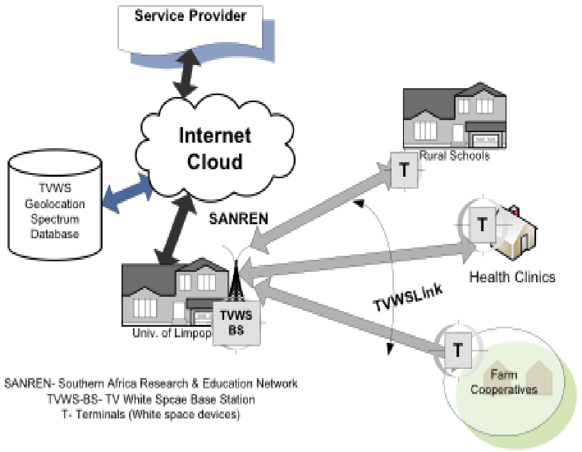

Figure I: High-level view of whitespace SDaaS architecture for a local TVWS network

C. *Outline of the Paper*

The reminder of this paper is arranged as follows: Section II highlights related works, while Section III discuses the conceptual architecture of whitespace SDaaS. Section IV presents a sample service use case and Section V presents conclusions and implications.

II. RELATED WORKS

Significant body of research work has been directed towards the DSA networking domain. Similarly the concept of cloud computing and its related architectures are receiving a lot of research focus and exploration. However, there is a lack of research attention and consensus on the scope and need for defining possible service provisioning architectures combining the two domains necessary to unlock the potential services of DSA. We hereby briefly highlight related work across the most relevant domains.

A. *Large Scale Geo-location Spectrum Database Architectures Domain*

Mwangoka, Rodrigues and Marques [7] introduced the design of a two-chambered (bicameral) GLSD for dynamic spectrum management: (1) A spectrum trading chamber that provides a guaranteed quality of service (QoS) to users. (2) A spectrum commons chamber that does not provide a guaranteed QoS to users. This approach proposes a system of Europe-wide interconnected national spectrum databases. Even though potential services have been highlighted, there still no detailed technical discussion on how interested stakeholders could access the platform to render or access such services. Similary, Sau-Hsuan *et al.* [8] proposed a a cloud model and concept prototype for a cognitive radio networks. This medium access (MAC) layer model is based on spectrum sensors assisted by a database. They argue that such a model could enable seamleass Internet connectivity in metro areas. However, nothing is mentioned on how potential network users could access the platform in the application layer.

B. Geo-location Spectrum Database Protocol and Policy Languages Domains

The Internet Engineering Task Force (IETF) is currently developing the protocol to access whitespace database (PAWS) [9]. This is primarily a document containing universal rule set guiding the GLSD discovery by WSRs. The protocol specifically defines how the WSR's request messages should be structured and similarly, how should the GLSD's response messages be structured. Furthermore, a flexible provision is made to allow regulatory authority to include regulatory parameters exclusive for their jurisdiction. JavaScript notation-request procedure call (JSON-RPC) version 2.0 is the recommended language of choice for PAWS. The data model to be transported over the IP by the HTTP [9]. Mitola [10] argue that it necessary for the DSA domain to formulate a policy language that will address the varying needs of different stakeholders particularly the spectrum regulators, network operators, vendors, and service providers. Among other benefits, such a policy language could be an enabler in the spectrum sharing networks whereby quality of service (QoS) would differentiate networks and quality of experience (QoE) would differentiate service providers.

III. A CONCEPTUAL WHITESPACES SDAAS ARCHITECTURE

The service delivery cloud planes introduced in Section I can be directly mapped to the design of SDaaS architecture to provide access to provincial, national and global spectrum databases. It is envisaged that the global spectrum databases should cater the spectrum overlap services along the boundaries of nations. A national spectrum database should carter spectrum services nationally as a federate of provincial spectrum databases. While the provincial spectrum databases should cater the local geo-location spectrum catches to the WSRs. Figure II illustrate this further.

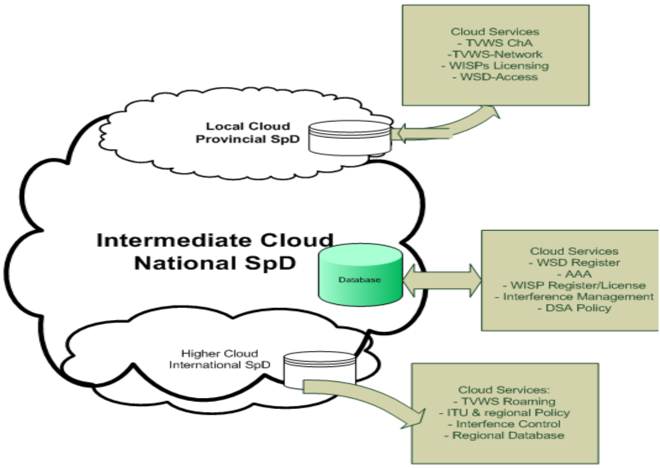

Figure II: A conceptual whitespaces SDaaS architecturual framework

A. Key Cloud Service Attributes

It is noteworthy that for cloud services to be effectively rendered to, and be accessible by various stakeholders a number of key attributes need to be in place:

- **Stakeholders/tenants:** These are actors with a varying degree of rights to the spectrum databases. For example the national regulatory authorities have highest rights than other stakeholders. The national regulator can change the spectrum policy and regulations, can approve database administrators, can add or remove licensed users as well as technical parameters of towers, and can coordinate the harmonisation of cross-border spectrum usage.
- **APIs:** These are primarily the gateway to the actual cloud services. APIs are exposed to the relevant stakeholder via the web.
- **Database Schema:** Databases lies at the heart of WSDaaS architecture. There are a number of database architectures that can be implemented in the multi-tenancy architecture. These include shared database and shared schema, shared database but different schema and isolated databases for each tenant. The aforementioned architectures have their limitations in the SDaaS eco-system. Particularly during the case of tenant's data recovery after failure. However, innovative techniques such as *chunk folding* of logical tables can be utilised [11].
- **Protocol and language:** These are basically the vehicles that can be used by the stakeholder to transport or convey data of desired service over the cloud.
- **Services:** Depending on the environment, stakeholders can be services renderers, service consumers or both. These attributes are summarised in Table I.

Table I: Attributes for SDaaS provisioning and access

Stakeholder/tenant	API	DB schema	Protocol, Language	Service Accessed/or Rendered
Regulatory authority	LSC ISC HSC	Shared-DB, different schema	XML JSON-RPC	Regulatory Enforcement, Monitoring
Device vendor	LSC	Shared-DB, logical table	JSON-RPC	WSR
DB admin	LSC ISC	Shared-DB, different schema	JSON-RPC IP, HTTP	Channel allocation Certification, Registration
WSR	LSC ISC	Shared-DB, schema	JSON-RPC IP, HTTP	DB discovery Connectivity
Network provider	LSC	Shared DB, Different schema	IP	Connectivity
Network user	LSC	Shared-DB, logical table	IP, HTTP	Data transfer

IV. SAMPLE SERVICE CASE: RADIO-TRACKING OF MIGRATORY MOVEMENTS OF WILD SPECIES USING TVWS SPECTRUM

Monitoring of wildlife movements by means of radio frequency tracking is not a new concept [12]. This can be implemented by either strapping a collar embedded with a radio transceiver on the endangered wild animal’s neck, or by implanting a miniature radio transceiver inside the animal’s skin. The method allows wildlife conservationists to track endangered wild animals over long distances using an assigned radio frequency channel within a particular country borders. However, tracking can be problematic due to the RF interference when the endangered wild animals migrate to and fro political borders such as in the Serengeti-Mara ecosystem (in the border of Tanzania and Kenya) or the Transfrontier national park (in the borders of South Africa, Mozambique and Zimbabwe). This is attributable to the fact that individual countries have different radio regulations and frequency assignments. The SDaaS architecture can potentially help to solve the aforementioned problem. By tailoring an innovative tracking service utilising TVWS spectrum and WSRs chips such as those proposed in the machine-to-machine (M2M) Weightless standard [13]. The location coordinates of an endangered wild animal of interest approaching respective countries’ borders can be updated in the spectrum database at the respective HSCs. Consequently, this will trigger an update to the spectrum databases at the ISC and LSC levels and allocate a free TV channel once the monitored animal crosses into a particular country. A typical flow of JSON-RPC request and response messages for the available TVWS channels on behalf of the roaming WSR to either one of the proposed HSCs in the borders of respective countries could take the following format:

Message I: Request message from Tanzania’s HSC to Kenya’s HSC

```
POST/AVAILABLE_CHANNELS_REQUEST HTTPS/2.0
Host: WHITESPACES.HSC-TZ.Com:443
Content_Type:Application/JSON-RPC; Charset=utf-8
Content_ Length: 1333{
"Protocol_Version": "2.0",
"Message_Type": "AVAIL_CHAN_REQ",
"Regulatory_Authority": "TCRA-TANZANIA",
"Device_Type": "Wild-Tracker",
"Device_Identity": "W-T1234",
"Device_Serial_No": "07AB56CD45EF",
"Latitude": "-2.332778",
"Longitude": "34.564750"
}//truncated for sake of brevity
```

Message II: Response message from Kenya’s HSC to the WSR

```
POST/AVAILABLE_CHANNELS_RESPONSE HTTPS/2.0 200
OK
Server: WHITESPACES.HSC-KE.Com:443
Date: Monday, 12 August 2013 07:304:27 GMT
Expires: Monday, 12 August, 2013, 11:45:00, GMT
Cache_Control : Private
Content_Type:Application/JSON-RPC; Charset=utf-8
Content length: 1335{
"Protocol_Version": "2.0",
"Message_Type": "AVAIL_CHAN_RESP",
"Regulatory_Authority": "CCK-KENYA",
“Channel_Number”: “1”,
Start_Frequency": “470,
"End_Frequency": “478”
"Maximum_EIRP": “1000”,
}//truncated for sake of brevity
```

Figure III depicts a typical SDaaS enabled tracking of wild animal migration.

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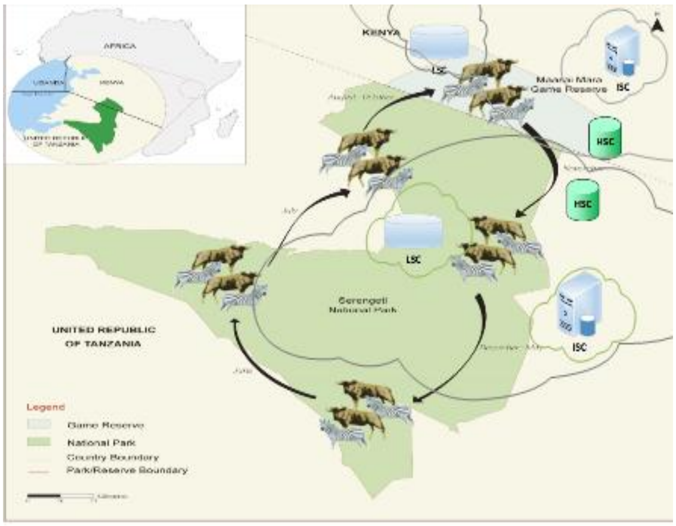

Figure III: TVWS-based SDaaS enabling seamless wild animal monitoring service during the great migration in the Serengeti-Mara ecosystem along the Tanzania and Kenya border

V. CONCLUSIONS AND IMPLICATIONS

A. Conclusions

Innovative broadband services and spectrum regulations can effectively be achieved by exploiting the cloud computing paradigm. This paper has proposed a concept of whitespaces spectrum database as a service (SDaaS) architectural framework for the application layer. The whitespaces SDaaS is characterized as an eco-system of cloud-hosted spectrum database services on a provincial, national and international level. Each level of the database provides different services to different stakeholders by accessing relevant service delivery cloud planes. This paper has also presented a sample use case in section IV. An innovative radio-tracking service of migratory movements of endangered wild species can be deployed using SDaaS architecture. It is important to note however, that for the concept to be fully realized the lack of clear consensus and scope among stakeholders in addressing key issues such as the common policy language and protocols must be tackled.

B. Implications

Traditionally, geo-location spectrum databases (GLSDs) have been designed to enable wireless broadband connectivity utilizing spectrum-sharing techniques to access unused spectrum in a particular geographical area and time. For example, in the terrestrial TV broadcast frequency planning where spectrum is divided into channels, and in any given geographical area, more often not all channels have TV transmitters within the range. Such unused spectrum is known as TV white spaces (TVWS). However, so far existing GLSDs architectures have been confined to a nation-by-nation design basis. Leveraging the fact that cloud computation is location-independent; the advent of SDaaS framework has a potential to unlock the IP connectivity islands by enabling the cross-border harmonization of whitespaces spectrum usage. Thus, spurring further innovation of broadband services and applications. However, the above can be of even much interest if proper cloud-based security policies and procedure are in place.

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