A Geo-location Database Framework for Television White Space Administration in Nigeria

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ABSTRACT
Terrestrial television channels in the ultra-high frequency (UHF) band that are vacant or unassigned in a given geographical location are known as television whitespaces (TVWS). These vacant channels can be accessed on an opportunistic basis by several wireless network technologies such as IEEE 802.22 and IEEE 802.11af to provide last-mile internet access. However opportunistic spectrum access can cause harmful electromagnetic interference to the primary broadcasting services. TVWS whitespace geo-location databases are used to provide a list of available channels to the secondary wireless networks to prevent interferences with the primary users. This is accomplished using appropriate path loss prediction models otherwise known as propagation models. Path loss models are also used to determine the protection contour of television broadcast transmitters. In this study, we created a geolocation database for TV White Spaces (TVWS) usage within the 470 – 694 MHz frequency range, as approved by the Nigerian Communications Commission for deployment in Nigeria. The database was developed as a comprehensive web application, employing an SQLite database engine and a Python-based computation engine integrated into the Flask development framework. The application's front end encompasses administrative functionalities to register television stations for protection and a client interface enabling queries to retrieve TVWS channel information. For the computation engine, we utilized the Okumura-Hata path loss model. Through this database, we determined the availability of TVWS channels in the 21 local government areas of Adamawa State and the 20 local government areas of Bauchi State. Our findings were validated by conducting spectrum scans using a software-defined radio (RTL-SDR) device configured as a spectrum analyzer.

General Terms
Web application development, spectrum sharing, broadcasting coverage area, spectrum access

Keywords
Television White Spaces, Geolocation Database, spectrum scans, Ultra-High Frequency, Path loss model

1. INTRODUCTION
The allocated frequency range for television broadcasting typically spans from 47 MHz to 900 MHz This frequency spectrum is categorized into five distinct bands as defined for ITU Region I [1]. Band I encompass frequencies ranging from 47 MHz to 68 MHz, comprising of channels 2 to 4, and maintaining a TV channel separation of 7 MHz Band II extends from 87.5 MHz to 108 MHz, with a channel spacing of 100 kHz, primarily designated for FM channels. Band III covers the frequency range of 174 MHz to 230 MHz, incorporating channels 5 to 12, with a channel separation of 7 MHz Both Band IV and Band V exhibit an 8 MHz channel separation and encompass the frequency ranges of 470 MHz to 582 MHz (comprising channels 21 to 34) and 582 MHz to 862 MHz (comprising channels 35 to 69), respectively. These TV frequencies have excellent propagation properties that make them suitable for large-area wireless coverage in the presence of non-line-of-sight conditions prevalent in rural areas. Vacant television channels can be used on an opportunistic basis for several applications such as broadband internet access in rural areas, internet-of-things applications, smart metering, smart agriculture and extending mobile network coverage among other applications. The concept of using TV whitespace technology as a part of the broadband architecture framework is illustrated in Fig 1[1]

Geo-location databases can be used to facilitate opportunistic use of spectrum assigned to other services as well as spectrum sharing between different mobile network operators. The work in [2] propose the use of multiple databases to manage different aspects and scope of spectrum sharing in 5G mobile network. A regulatory geolocation database (RGD) is envisioned to manage sensitive user information such as location and transmit power. Complex resource sharing calculations are implemented in complementary databases to minimize the computational workload of the regulatory database. Geolocation databases can also be integrated with spectrum sensing to identify unoccupied channels, as exemplified in [3]. Spectrum sensing was carried out using two different spectrum analyzers and a low cost Realtek software defined radio (SDR) configured as a spectrum analyzer. It was shown that the ability of a spectrum analyzer to detect available channels depends on its noise floor and resolution bandwidth. Although the SDR has a low receive sensitivity, it was able to detect 70 percent of the channels indicated as vacant by the geolocation database.

National spectrum regulatory bodies such the Nigerian Communications Commission (NCC) have domain specific requirements for implementing geolocation databases. To this end, a number of implementations have been carried out for different regulatory domains. In [4] a television white space geo-location database implementation for India was presented. A hardware testbed based on the OpenWrt platform [5] was used to implement TVWS master and slave nodes. The master node of the TVWS network queries the database using protocol to access white space (PAWS) standard [6]. Results of channel availability predicted by the database at six different test sites were obtained using the experimental testbed. The authors in [7] implemented a TVWS geolocation database for South Africa. In this work, the authors leverage ITU-R 1546-5 propagation models to determine coverage area of television transmitters and the TM-91-1 to calculate the minimum separation distance between the television transmitters and secondary users. The results obtained using the implementation were compared with results obtained from a commercial geolocation database. The implemented database was found to be 68 percent similar to the commercial database. Additionally, the results obtained from the proposed database were compared with spectrum measurements obtained using a Rhode & Schwartz PR100 spectrum analyzer. In [8] and [9], the authors use a radio frequency spectrum analyzer to monitor the signal strength of various television stations at certain locations. The measured signal strength values were inserted into an online database to provided list of available channels. The method used in the study does not provide any form of prediction nor does it provide real time measured result. The authors merely designed a means of storing measured signal strengths values in an online database. Moreover, no regulatory specific parameters or specification for Nigeria was taken into account. A TVWS geolocation database for the Ethiopian regulatory scenario was proposed in [10]. Similar to the work in [7], this work utilize the ITU-R 1546-5 propagation models to determine coverage area and the TM-91-1 to calculate the minimum separation distance of secondary users from the protected contours of television transmitters. The minimum separation distance is compared to the actual distance of the secondary user to determine the availability or otherwise of vacant channels. The results obtained are the coverage areas of various television transmitters and their corresponding minimum separation distances from a test site.

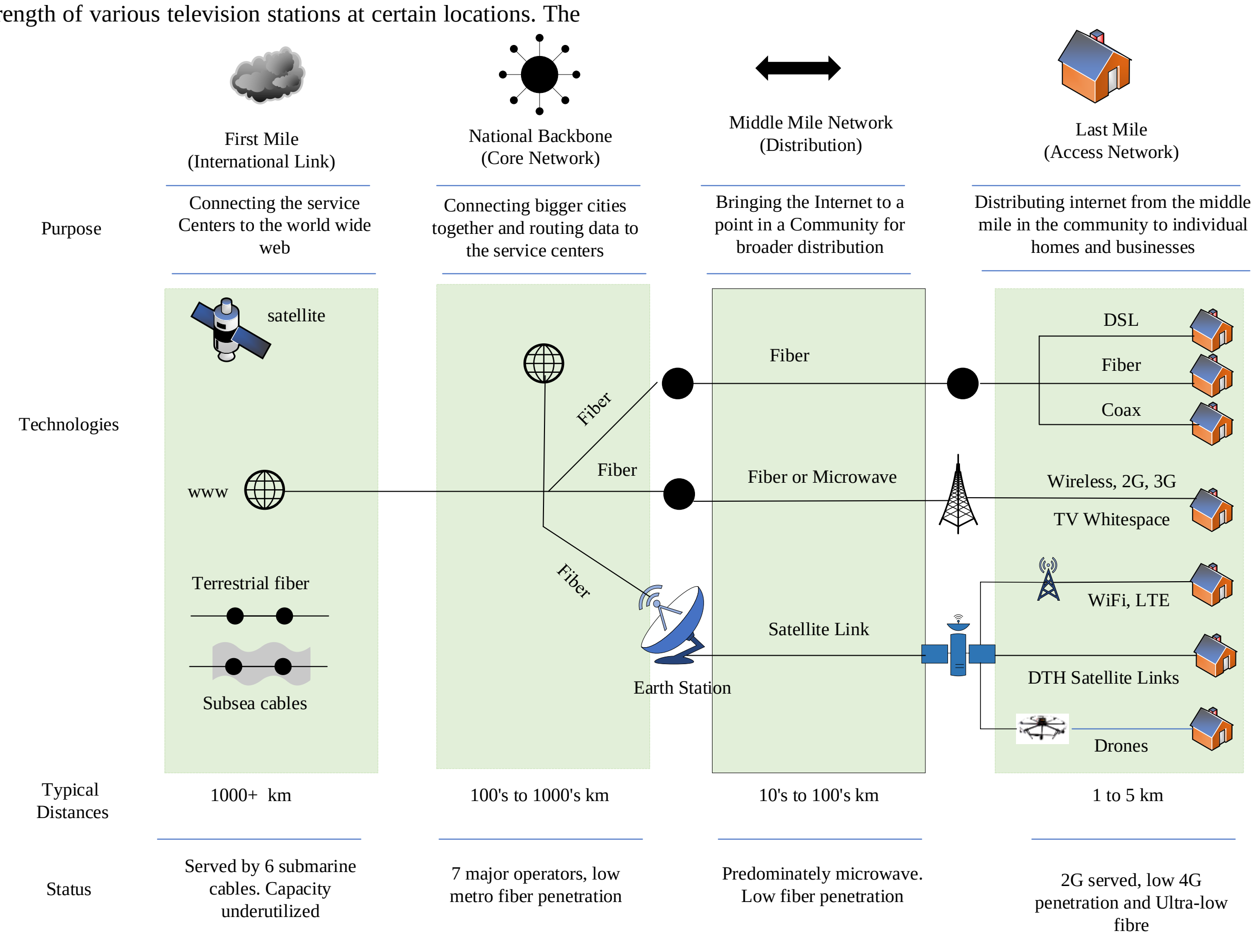

Fig 1: Three-Tier Broadband Architecture Framework for Providing Internet Access

2. METHODOLOGY

2.1 Materials Used

Implementing the geolocation database involves using software frameworks and libraries for full-stack web application development. The software tools used for the development of the TVWS database are illustrated in Fig 2.The backend consists of a database engine based on SQLite and a computation engine developed using python programming language. SQLite is a software library that implements a light-weight, self-contained, fast, full-featured, high-reliability SQL database engine that is bundled into Python programming package. Python programming language is used to implement all the geolocation calculations and other computational tasks. Python codes are connected to the web via the Flask development framework. Interaction between the database engine and computation engine is achieved through SQLAlchemy. SQLAlchemy is a toolkit and an Object Relational Mapper (ORM) that provides efficient database access using python codes. Database migration can be accomplished using a Flask library called Flask-Migrate, which uses Python Alembic toolkit to manage database migrations.

On the client side of the geolocation database application, the elements are displayed using the Hypertext Markup Language

(HTML) and styled using Cascading Style Sheets (CSS) and Bootstrap components. The front-end HTML elements are rendered using WTForms forms rendering library and Jinja templating engine.

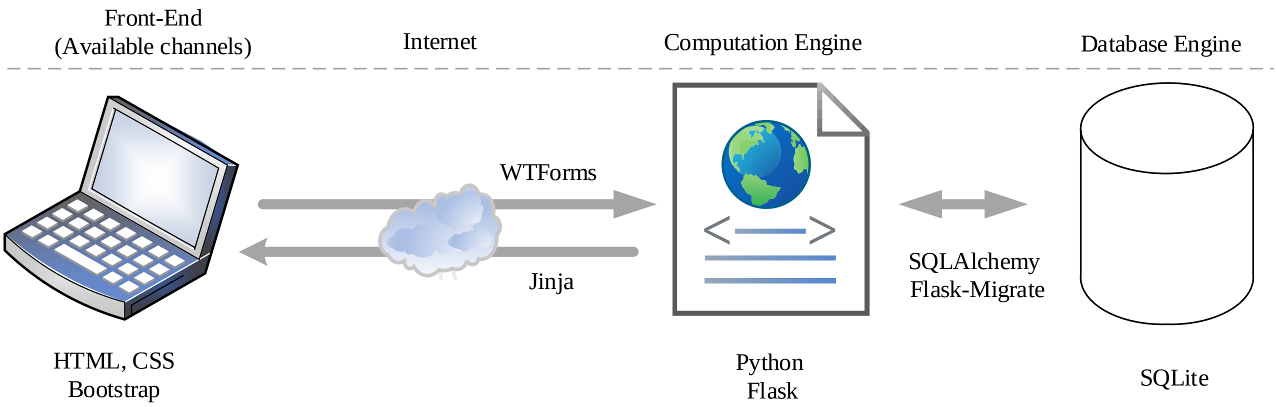

Fig 2: Geolocation database framework

2.2 Calculation of Broadcasting Protected Contour

The first step towards creating the geolocation database is to load the operational information of each television transmitter in the study area into a relational database. The operational parameters of the broadcasting transmitters (Tx) used for database creation are presented in Table 1

Table 1. Operational parameters of analog and digital broadcasting transmitters

Parameter	Tx 1	Tx 2	Tx 3	Tx 4	Tx 5	Tx 6	Tx 7	Tx 8
UHF Channel	23	27	29	26	36	41	42	43
Frequency (MHz)	490	522	538	511.25	591.25	634	642	650
Transmit Power (kW)	2.6	2.6	2.6	5	10	2.6	3.0	2.9
Antenna Height (m)	150	150	150	159	200	150	150	150
Latitude	9.3060	9.3060	9.3060	9.30609	9.30463	10.3292	10.3292	10.3292
Longitude	12.4776	12.4776	12.4776	12.47764	12.47429	9,8597	9.8597	9.8597

For the purpose of protecting television transmitters from white space devices, the protected contour of each transmitter can be computed using an appropriate path loss propagation model and minimum median field strength specified by the national spectrum regulatory agency. Th electromagnetic field strength threshold levels are for analog and digital television transmitter (in $dB\mu V/m$) is given in (1) [11].

$$E_{med} = \begin{cases} 64 - 20\log\left(\frac{615}{center\ frequency}\right) & analog\ channels \\ 41 - 20\log\left(\frac{615}{center\ frequency}\right) & digital\ channels \end{cases} \quad (1)$$

The electric field unit $dB\mu V/m$ can be converted to electromagnetic signal power unit using (2) [12]

$$P(dBm) = E_{med}(dB\mu V/m) - 130.8 + 20\log\left(\frac{615}{center\ frequency}\right) \quad (2)$$

Using the Okumura-Hata model, the protected contour is determined using equation (3):

$$r = 10^{\frac{L_p - 69.55 - 26.16log_{10}f + 13.82log_{10}(h_b) + C_H}{(44.99 - 6.55log_{10}(h_b))}} \quad (3)$$

Where L_p is the path loss (calculated using the transmit power and threshold power level given in (2), f is the center frequency, h_b is the transmit antenna height above average terrain and C_H is the receive antenna correction factor for a small city or medium city. The correction factor is related to the receive antenna height, h_r as shown in (4):

$$C_H = 0.8 + (1.1log_{10}f - 0.7)h_r - 1.56log_{10}f \quad (4)$$

The height above average terrain (HAAT) is calculated by taking 120 evenly spaced elevation points above (or below) mean sea level along 24 equally spaced radials from transmitter location starting from 0° as true north to 360°. The 120 equally spaced sampled in the surrounding terrain contour between 3.2 to 16 km. Finally, the height above sea level of the transmit antenna is subtracted from mean of the 120 elevation points surrounding the transmitter to obtain the HAAT. A graphic illustration of the radials for determining HAAT is illustrated in Fig 3.

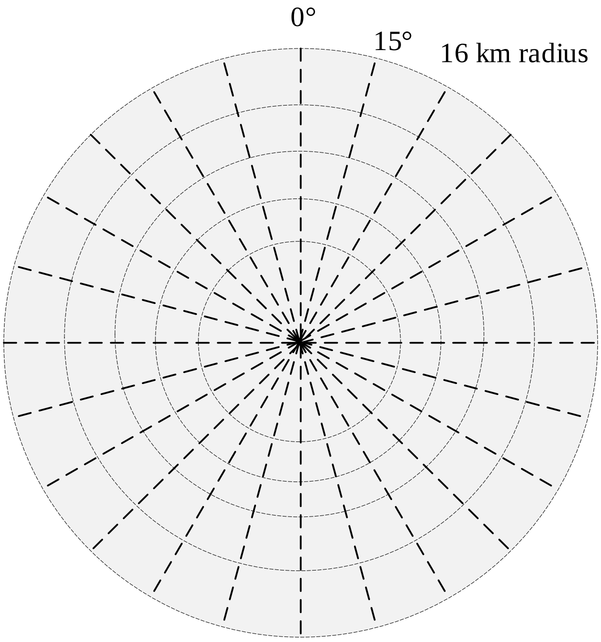

Fig 3: Radials for calculating HAAT

The HAAT is determined for both the transmitting antenna and white space device antenna using topographic elevation data obtained from the Shuttle Radar Topography Mission (SRTM) digital database. the corresponding latitude and longitude used to determine the elevation data around the surrounding terrain of the transmitter is given in (5) and (6)

$$Lat_e = Lat + (\cos\varphi + \left(\frac{d}{111.1}\right) \quad (5)$$

$$Lon_e = Lon + (\sin\varphi + \left(\frac{d}{111.1 \times \cos(Lat)}\right) \quad (6)$$

Where Lat_e and Lon_e are the latitude and longitude of each elevation point, Lat and Lat are the latitude and longitude of the transmitter, φ is the radial location angle from true north. The variable d is the distance along a radial from the transmitter while the constant 111.1 is the distance in kilometers corresponding to one degree of latitude (obtained by dividing the circumference of the earth by 360 degrees).

2.3 Calculation of Available TV Channels

Availability of vacant channel can be determined by comparing the actual distance of the to the protected contour distance. Based on NCC guidelines, client TVWS devices are mandated to be at least 6 km outside the protected contour of the television transmitter when operating co-channel [11]. The actual distance of the white space device from the transmitter can be computed using the haversine formula given in (7) [13]

$$r_a = 2r_e sin^{-1}\left(\sqrt{sin^2\left(\frac{\varphi_1-\varphi_2}{2}\right) + \cos(\varphi_1)cos(\varphi_2)sin^2\left(\frac{\lambda_1-\lambda_2}{2}\right)}\right) \quad (7)$$

Where r_a = distance between two points on the surface of the earth (meters), r_e = radius of the earth in meters, φ_1 is the latitude of point 1 (TV station), φ_2 is the latitude of point 2 (white space device) and λ_1 *and* λ_2 are longitudes of point 1 and 2 (in radians) respectively. Fig 4 illustrate the procedure for determining TVWS channels.

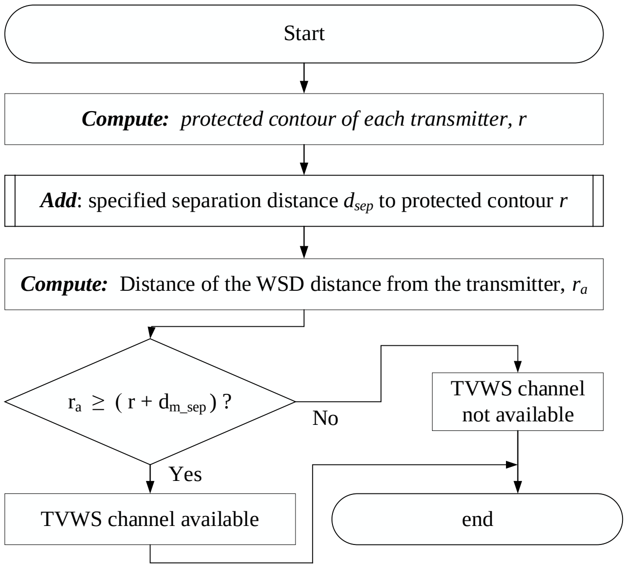

Fig 4: Flow chart for determining channel availability

2.4 Calculation of Maximum Allowable Power limits

The maximum allowable power level at which the white space device can transmit depends on the separation distance of the device from the protected contour and the height above average terrain of the white space device. Using the Okumura-Hata path loss model, the maximum allowable transmit power can be computed using (8).

$$P_{tmax} = 69.55 + P_{thr} + 26.16log_{10}f - 13.82log_{10}h_b - C_H + (44.9 - 6.55log_{10}h_b)log_{10}r_{sep} \quad (8)$$

Where P_{tmax} is the maximum allowable transmit power, P_{thr} is power level corresponding to the nominal service contour of the white space device, f is the operating frequency, h_b is the master WSD antenna height, r_{sep} is the distance of the WSD from the protected contour of TV transmitter and C_H is the antenna correction factor for a client WSD antenna and can be computed using (4).

The separation distance r_{sep} is the difference between the actual distance calculated using equation (8) and the protected contour determined using (3) plus the minimum separation distance of 6 km specified by the NCC.

$$r_{sep} = r_a - (r + d_{m_{sep}}) \quad (9)$$

The NCC specify an electromagnetic field strength of $30.8\, dB\mu V/m$ at a receive antenna height of 10 m. This corresponds to a power level of:

$$P_{thr} = 30.8 - 130.8 + 20\log\left(\frac{615}{center\ frequency}\right) \quad (3.11)$$

The maximum permissible transmit power, P_{tmax} is constraint to threshold values of 30W (44.78 eirp) and 4W (36 dBm eirp) for master and client white space devices respectively [11].

3. RESULTS AND DISCUSSIONS

3.1 Channel Availability Results

The geolocation database can be queried by selecting a desired path loss model and providing the latitude, longitude and antenna height of the white space device. The interface for interrogating the database is shown in fig 5. The result of the query returns the available channels and the maximum power level at which a white space device can transmit.

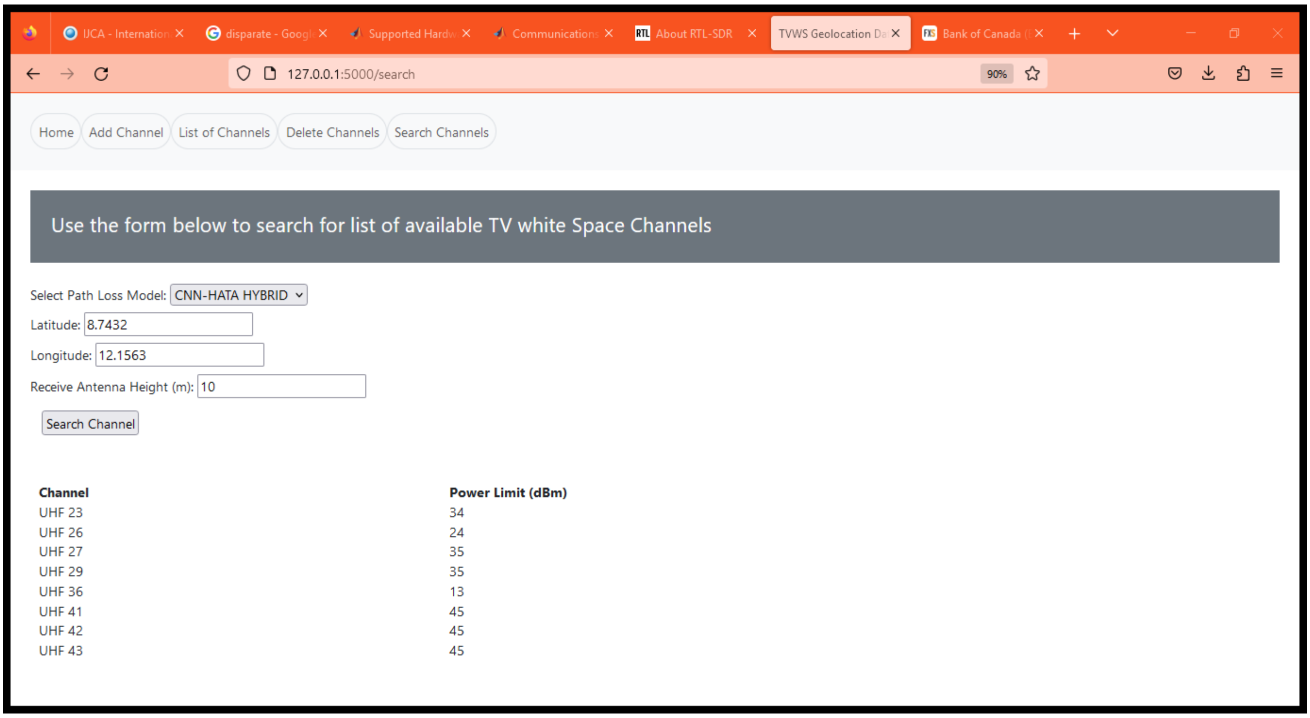

Fig 5: List of available channels and maximum allowable power levels for a location in Adamawa State

Channel availability results obtained using Okumura-Hata propagation model are presented in table 2 and table 3 for different locations in Adamawa and Bauchi States respectively. A receive antenna height of 10 m was used for querying the geolocation database. Out of the 8 UHF channels originally added to the database, the result of table 2 shows that only 3 channels (41, 42 and 43) are available in most locations of Adamawa state. This is because most of the locations are within the protected contour of the other 5 broadcasting stations. Similarly, the broadcasting stations located in Adamawa state are vacant in most locations in Bauchi state as shown in table 3. The antenna height of white space devices is a critical factor in determining both channel availability and maximum power levels. Lower antenna heights result in a greater number of available channels.

Table 2: Available TVWS Channels in Adamawa State

s/n	Location	Latitude	Longitude	Available Channels
1	Demsa	9.3564	12.0780	41,42,43
2	Fufore	9.2167	12.5814	41,42,43
3	Ganye	8.4366	12.0507	41,42,43
4	Girei	9.3699	12.5502	41,42,43
5	Gombi	10.1555	12.7272	41,42,43
6	Guyuk	9.9055	11.9283	41,42,43
7	Hong	10.2356	12.9432	41,42,43
8	Jada	8.7432	12.1563	41,42,43
9	Lamurde	9.6050	11.7940	41,42,43
10	Madagali	10.8894	13.6283	23,26,27,29, 36, 41,42,43
11	Maiha	9.8698	13.3048	41,42,43
12	Mayo-Belwa	9.0552	12.0560	41,42,43
13	Michika	10.6204	13.3869	23,26,27,29, 36,41,42,43
14	Mubi North	10.2686	13.2670	23,27,29, 41,42,43
15	Mubi South	10.1874	13.3958	23,27,29, 41,42,43
16	Numan	9.4599	12.0333	41,42,43
17	Shelleng	9.8980	12.0090	41,42,43
18	Song	9.8425	12.6147	41,42,43
19	Toungo	8.1166	12.0500	23,27,29,41, 42,43
20	Yola North	9.2667	12.4500	41,42,43
21	Yola South	9.2034	12.4953	41,42,43

Table 3: Available TVWS Channels in Bauchi State

s/n	Location	Latitude	Longitude	Available Channels
1	Alkaleri	10.2597	10.3345	23,26,27,29, 36
2	Bauchi	10.3141	9.8462	23,26,27,29, 36
3	Bogoro	9.6500	9.6167	23,26,27,29, 36
4	Dambam	11.6741	10.7101	23,26,27,29, 36,41,42,43

5	Darazo	10.9914	10.4072	23,26,27,29, 36
6	Dass	10.0000	9.5159	23,26,27,29, 36
7	Gamawa	12.1346	10.5333	23,26,27,29, 36,41,42,43
8	Ganjuwa	10.7492	9.9999	23,26,27,29, 36
9	Giade	11.4000	10.2000	23,26,27,29, 36, 41
10	Itas-Gadau	11.8613	9.9685	23,26,27,29, 36,41,42,43
11	Katagum	10.0107	9.7759	23,26,27,29, 36
12	Kirfi	10.3943	10.5322	23,26,27,29, 36
13	Jama'are	11.6825	9.9319	23,26,27,29, 36,41,42,43
14	Missau	11.3135	10.4685	23,26,27,29, 36,41,43
15	Ningi	11.0805	9.5750	23,26,27,29, 36
16	Shira	11.4042	10.0156	23,26,27,29, 36
17	Tafawa Balewa	9.7593	9.5490	23,26,27,29, 36
18	Toro	10.0541	9.0660	23,26,27,29, 36
19	Warji	11.1805	9.7539	23,26,27,29, 36
20	Zaki	12.2992	10.3089	23,26,27,29, 36,41,42,43

3.2 Comparison of Results with Spectrum Scan

The result obtained from the TVWS geolocation database at selected is compared with spectrum scans obtained using an RTL-SDR (software defined radio) configured as a spectrum analyzer. The result of the spectrum scan of occupied television stations in selected locations in Adamawa and Bauchi states are shown in Fig 6 and Fig 7 respectively. The spectrum scan is for 470 -694 MHz frequency band approved by the Nigerian Communications Commission (NCC) for TV white space operations in Nigeria. From figure 6, only 5 channels are occupied in the selected location (latitude: 9.2667 and longitude: 12.4500), the remaining 24 channels are shown to unoccupied. Similarly, for the selected location (latitude: 10.3141 and longitude: 9.8462) in Bauchi state, only 3 channels are occupied leaving 26 channels in the 470-694 frequency band vacant as shown in Fig 7.

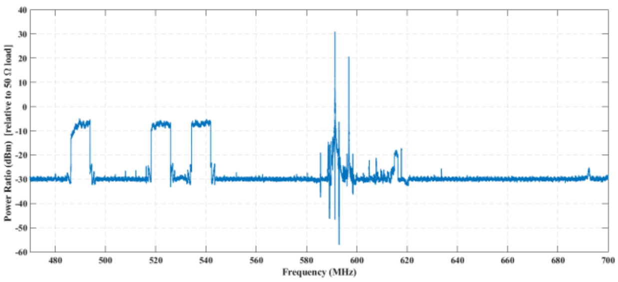

Fig 6: Occupancy of the 470 – 700 MHz Spectrum in Adamawa State

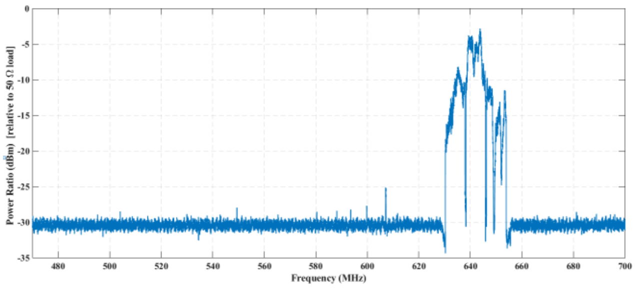

Figure 7: Occupancy of the 470 – 700 MHz Spectrum in Bauchi State

4. CONCLUSIONS

In this work the development and implementation a geolocation database framework for television white space administration in Nigeria was implemented. The framework enables the registration and management of television broadcasting services requiring protection against interference. The database also provides a list of vacant channels and the maximum power at which a television white space device can transmit on the channels. Locations within the protection contour of the registered television stations are marked as unavailable. The geolocation database framework is a full-stack web application with backend and front-end functionalities. The backend consists of a structured query language (SQL) database based on SQLite database engine and a computation engine built using python programming language on flask web development framework. The front end is built using HTML and bootstrap web development technologies. The geolocation database utilized in this research relies on the Okumura Hata model. To optimize the computational engine, there is a need to develop and incorporate a more robust and accurate path loss model. Future works can also consider the incorporation of hardware testbed for extensive trial of TVWS technology for providing broadband internet access in Nigeria.

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