An Interference Management System for a Shared Spectrum Access Network

Ehinomen Atimati, David Crawford, Robert Stewart
Electrical/Electronic Engineering, University of Strathclyde
Glasgow, United Kingdom
ehinomen.atimati@strath.ac.uk, david.crawford@strath.ac.uk, r.stewart@strath.ac.uk

Ifeyinwa Achumba, Longinus Ezema
Electrical/Electronic Engineering, Federal University of Technology,
Owerri, Imo State, Nigeria
ifeyinwaeucharia@gmail.com, longinus.ezema@futo.edu.ng

Uchenna Diala,
Electrical/Electronic Engineering, University of Derby,
Derby, United Kingdom
u.diala@derby.ac.uk

Abstract

Internet access, in developing and underdeveloped countries, remains a huge challenge despite advancements in technology. Shared resources, amongst telecommunication systems, offer an affordability context to this problem. A shared spectrum interference management system is implemented by designing a geolocation database, for a television white space network, for a location in Nigeria. This is achieved using the Dynamic Spectrum Alliance framework (a rarely used methodology) and robust terrain-based propagation models. The designed spectrum coexistence manager (geolocation database) was created, presented, and evaluated, based on its channel availability, predictions, and ability to protect very weak TV signals. The result showed a 15% channel utilization of Analogue and Digital Terrestrial Television channels within the study area. Finally, key components of the framework, that can be adopted for further studies, were identified.

Keywords—spectrum, television white space, coexistence, internet access, dynamic spectrum access.

I. Introduction

Universal and affordable access to the internet is crucial for growth and development in a society. The Sustainable Development Goal (SDG) 9.3 aims at providing access to the internet for all to facilitate economic growth, improved productivity, and development. However, in most underdeveloped and developing countries, access to the internet is very expensive and sometimes not available in remote areas, resulting in huge digital divides and exclusion. These have been attributed to the high cost of deploying telecommunication equipment, spectrum licenses, and general maintenance of existing networks. Sharing telecommunication infrastructures and spectra amongst different networks, can reduce capital costs and foster maximum resource utilization [1], [2].

Spectral sharing for communication, using dynamic spectrum access technologies, allows multiple services to opportunistically use a channel. Different technologies make use of shared access to spectrum. For example, cellular networks, and WiFi networks share unlicensed spectrum at the 2.4 GHz frequency band. Also, in the United States, Community Broadband Radio Service (CBRS) allows spectrum sharing between Fixed Satellite Service (FSS) and internet access services, at the 3.55 – 3.7GHz band. Similarly, the US has proposed sharing at 6GHz between FSS and WiFi6 [3]. Television White Space (TVWS) shares TV broadcasts and internet access services on the TV band (470 to 694MHz) [4]. These different standards make use of unique techniques for providing sharing, with the sole aim of preventing interference amongst sharers of resources.

One of the pioneer technologies, built for sharing resources, was a Dynamic Spectrum Access (DSA) technology, TVWS. TVWS is known for its affordability and coverage capability. The TV white spaces are available channel slots that can be opportunistically used, at specific times and locations, by other services. Thus, permitting the sharing of frequencies between primary users (PUs), who are TV transmitters, i.e. licensed owners of the TV band, and secondary users (SUs) that are internet access providers. Its network architecture requires a control mechanism (geolocation database) that ensures that there is no interference with PUs by the SUs. Several trials conducted in past years made use of commercial Geolocation Databases (GDB), in providing interference and spectrum coordination, aimed at showcasing the DSA's sharing capabilities and speed [5]. However, future studies on developing this technology cannot depend solely on commercial databases, as these are expensive and rigid for research.

This paper implements a dynamic spectrum access geolocation database, for a TVWS network, located at the Federal University of Technology Owerri (FUTO), Nigeria. This is particularly necessary as Nigeria diversifies in the provision of middle and last-mile delivery of telecommunication networks, in a bid to bridge its existing digital divide, amidst its vast landmass. It serves as an experimental framework, in the absence of commercial databases and presents a possible localization of such interference control mechanism. It achieves this using a rarely used Dynamic Spectrum Alliance (DS Alliance) framework, as this method considers robust terrain parameters, is mildly complex and provides more efficient sharing of the spectrum than the popularly used vector approach.

The main objectives of this study, are:

- To create an interference management system (a geolocation database) for a proposed TVWS network in FUTO.
- To estimate the WSD power limits, on each 100sqm pixel-sized terrain.
- To investigate the ability of the DS Alliance methodology, to protect weak TV signals in the network area.

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II. Literature Review

A. *The Network*

The TVWS architecture, shown in Figure 1, consists of a geolocation database (GDB) that stores the information on the PUs and a White Space Device (WSD), which serves as a secondary user(SU). The master WSD communicates with the database and is assigned available TV channels and maximum power limits, for itself and any other slave device connected to it. It uses these channels to either connect to the back-end (internet service provider) or to connect to a slave WSD. The GDB manages spectral detection, allocation, and coordination.

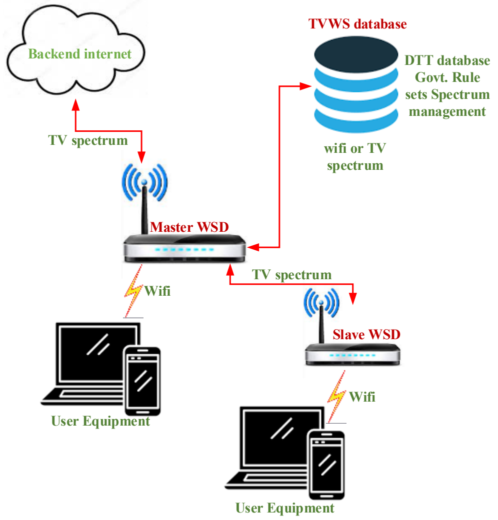

Figure 1: A simplified proposed TVWS typical architecture [6]

The interference control GDB is populated with information on PUs, from regulators. The Master WSD communicates with the GDB, using the Protocol to Access White-Space (PAWS). It provides it with its transmission height, polarisation, geolocation, and the number of slave WSDs. The PUs' and WSDs' parameters are used by the GDB to estimate safe coexistence power limits for WSDs in specific channels and locations.

Databases are populated with more or less information, depending on the government's guidelines and the methodology adopted. They, however, all share the same task of ensuring no interference amongst sharers. Generally, a GDB must contain the locations and transmitting powers of PUs, and the possible locations of the WSDs [6]. Arguments for the unification of these requirements have been less feasible as there are no unified spectrum allocation structures to support them [7].

B. *Geolocation Database Methods and Implementation*

1) *Comparison of Design Methods*

A key criterion, for distinguishing methods of GDB design, is their definition of the PU or SU coverage. Three approaches were identified in [8], vectorized approach, adopted by FCC USA, Carrier-to-Noise and Interference Ratio (CNIR) approach, adopted by DS Alliance, and Degradation of Location Probability (DLP) approach, adopted by Ofcom UK. The CNIR and DLP approaches have a better coexistence structure, as they allow for co-channel usage within a PUs coverage area (underlay). The vectorized approach requires less information to manage interference and uses less computational power and database storage space. It is thus the preferred option by some countries like Nigeria. Nonetheless, it is the least spectral efficient. The CNIR, on the other hand, is more spectral efficient, although, not as efficient as the DLP.

2) *Geolocation Database Implementation*

Pilapil, in [9], implemented a TV GDB, for Analogue and Digital Television protection, in a province in the Philippines, using an ITU terrain-based path-loss model and the vector approach. The database supported an 802.11af Wifi (SU) and successfully allocated frequency and power limits to the SU. The implementation in [9], closely relates to this work but used a different approach. Fanan [10], developed a GDB using a different strategy for selecting an empirical propagation model. The propagation models used were validated, based on their ability to predict the measured TV signal strengths, for different pixel sizes, at the University of Hull, UK. The best pixel size, that created a balance between spectrum availability, accuracy, and computation complexity, was identified. However, the computation of the WSD maximum power limits was not studied. In [8], a GDB was designed, with the vector approach, for regions in South Africa, for Analogue Terrestrial Television (ATT) and Digital Terrestrial Television (DTT) channels. They examined the database's ability to detect available TV channels and compared its performance with an existing commercial database. The method employed in this study differs from that in [8]. The vector approach makes use of protection contours that do not utilize terrain-based path-loss. Thus, no consideration was made for clutter, that may be encountered along the path of TV signals [11].

Kryszkiewicz et al [12], implemented a GDB, using the DS Alliance framework to protect the DTT in Kenya. Their work examined, in detail, the performance of the database in detecting available spectral space and provided suggestions for improving the computational complexity of the framework. This paper employs the same framework as [12], for estimating spectrum availability in ATT and DTT channels, and also, the protection of DTT signals in Nigeria. The current study differs from [12]] in terms of objectives and approach, as it provides details on creating a database for a local network and evaluates its performance.

C. *Hybrid Spectrum Management*

The suggested alternative spectrum coordination system is a hybrid spectrum management system. This uses real-time sensing of channels to complement GDB estimations. Sensing alone has been frowned at by industry because of its hidden node problems [7]. Lysko, in [13], highlighted the importance of a hybrid system, by evaluating the performance of their country's database, to correctly identify available TV channels. The available channels, predicted by their GDB, falsely labeled one channel as available, while a similar work in [14], revealed a greater number of falsely identified available channels. This raises the question of how spectral availability is decided. Sensors use their noise floor, while the GDBs make use of commercial TV receivers' sensitivity in determining spectral availability.

Nevertheless, artificial intelligence algorithms, have led to advanced spectrum sensing techniques. As a result, the future of spectrum management is a hybrid or completely intelligent autonomous system [15],[16]. Camelo et al implemented an intelligent CBRS system in [17], where spectral-sensed spectrograms were used to train an algorithm, to correctly identify PUs. The algorithm assisted their control and decision engine by identifying available channels for a WSDs and fostering collaborations with other WSD networks.

III. Methodology

The first requirement for the design was the siting of the proposed TVWS network. Three locations were considered and the site closest to the centre of the FUTO, with latitude: 5°23'07.0"N and longitude 6°59'31.8"E, was chosen. A terrain-based Longley Rice (LR) path loss propagation model [18] was used to accommodate the effect of topology and environmental losses on TV signals. Path loss computations for 1km and above were done by LR model (which predicts this range best) while for computational ease, the free-space model was used in shorter distances (0.06km to 1km).

A. Identifying WSD coverage area

A 5km × 5km square coverage, around the assumed omnidirectional WSD, was surveyed as a coverage area. This square area was then split into several pixels of 100m × 100m to make a total of 'X' number of pixels that were examined, as shown in Figure 2.

Figure 2: 100m x 100m pixels grid on the study area.

1) Received TV signal strength.

TV transmitters within a 200Km radius of the University were selected, based on the recommendation in [18]. Resulting in 17 ATT transmitters and 26 DTT transmitters being identified as PUs. These were located in the six eastern states. Out of these, Ultra High-Frequency DTT and ATT broadcast channels, in the national spectrum allocation table, were extracted. These were the channels permitted for spectrum sharing in the Nigerian TVWS policy draft [20]. Thus, the survey data was reduced to 12 ATT channels (470 to 854MHz) and 24 DTT channels (470 to 694MHz), at the time of this study.

TV signal degradation, for 50% of the time, at 50% of the location, and 50% certainty, was calculated using the LR path loss model between each of these TV transmitters and an x pixel ($L_{T\text{-}X}$) (x is a member of X pixels). The LR model used each TV transmitter's antenna height, transmitter power (maximum operating power), centre frequency, locations, TV receiver height (an assumed outdoor height of 10m), and pixel locations for its path loss computation. Equation 1 was used to compute received TV signal strength at 'x' TV receiver's terminals (P^i_{RX}), for all 'i' TV channels, with transmission power P^i_{TX}.

$$P^i_{RX} = P^i_{TX} - L_{T-X} \tag{1}$$

2) Interference and Noise computation

Interference is captured in out-of-mask characteristics of transmitters. This defines the degree to which a transmitter tends to transmit out of its bandwidth and is a function of channel space between the centre frequencies. This was important in determining the overall noise floor that a TV receiver would have to overcome. Receiver Thermal noise ($P_{Th\text{-}noise}$) was computed using equation 2.

$$P_{Th-noise} = 10 \cdot \log(kTB) \tag{2}$$

where k is the Boltzmann constant, Temperature (T) is 290K, and the Bandwidth, B (5MHz for ATT and 8MHz for DTT receivers) [21]. The cumulative interfering noise (log addition of out-of-mask emissions and thermal noise) was computed with equation 4.7 in [19].

3) TV channel Availability Threshold

The received TV signal and the cumulative noise were used to determine a Carrier to Noise ratio (CNR) at the TV receiver terminals equation 4.8 in [19]. A CNR threshold was used to identify available channels, using the level of received TV signal above noise, that can be sensed by a TV receiver. This was set based on ATT and DTT receivers' sensitivity and selectivity of commercial devices. In ATT, this was 64 dBu and converted to 38dB CNR [22], while for DTT receivers, a default value of 19.5dBm was used in equation 4.9 [19]. DTT had a greater ability to receive weak DTT signals than ATT receivers.

B. WSD Power Estimate.

Only DTT receivers' protection were considered for interference management, to reduce complexity. As Nigeria is on the path to complete digital migration, the GDB would change as more DTTs transmitters (PUs) are deployed. The pixels or TV receivers, that met the CNR threshold, were labeled Y. The next design objective was to protect every received signal on each pixel. In this work, all the pixels had similar channel coverage because of the size of the assumed WSD coverage area.

Each occupied channel was protected, using a protection ratio (PR) derived from the ratio of desired to undesired signal, for a DTT signal of a specific device and its adjacent channel leakage ratio (ACLR). Co-channel protection ratio, as expected, was higher (39.9dB by default) than adjacent channel protection ratios. The PR was added to all of the received signal strength, to form a nuisance Power, as shown in equation 4.10 in [19]. This power is the least power a TV receiver can tolerate from the WSD, as shown in Figure 3.

The path loss between the WSD and Y pixels are computed, assuming a TV receiver height of 10m and a WSD height of 30m (30 to 100m are the recommended WSD height in [20]). Estimated WSD power limits for all channels were calculated for all Y locations, with equation 4.14 in [19] The geodesic antenna gain was assumed to be -15dB. The computation, summarized in Figure 3, was carried out for Y pixels, 'i' channels, and 'j' adjacent channels, and the least WSD power limit was adopted (Equations 4.16 and 4.17 in [19]).

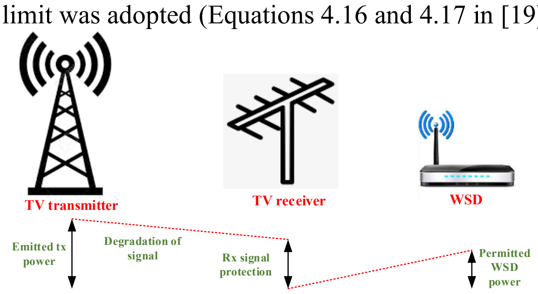

Figure 3: Estimated WSD power limits computation

Despite the drawbacks of the method used in this study, as highlighted in [12], concerning PU protection, it provides a framework for safe co-channel sharing amongst SUs. Computations, in this work, were carried out in MATLAB and Python environments.

IV. RESULTS:

Results are evaluated based on spectrum availability and a measure of the degree, to which incumbent users are protected. The box plot reveals the dispersion of ATT-received signals, by each pixels' TV receiver, as shown in Figure 4. The ATT receivers have about 6 channels above the usual -100dB noise floor, shown in Figure 4, similar to the results in [23]. However, most of these channels cannot be detected by conventional TV receivers.

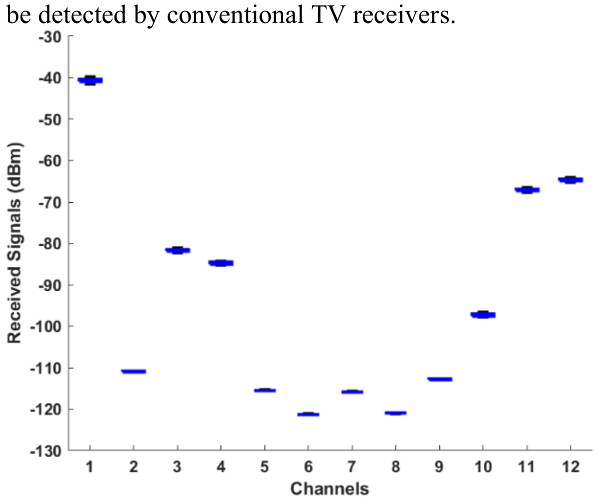

Figure 4: Box plot of received ATT at x-pixels.

One TV channel was detected when a CNR threshold of 45dB was used. A threshold of 38dB was set on the assumption that ATT receivers had low margin gains, this increased channel availability to 3, as shown in Figure 5a. Three out of 24 DTT signals could be received at FUTO due to low PU transmitter powers Figure 5b. They were, therefore, classified as occupied or unavailable to SUs.

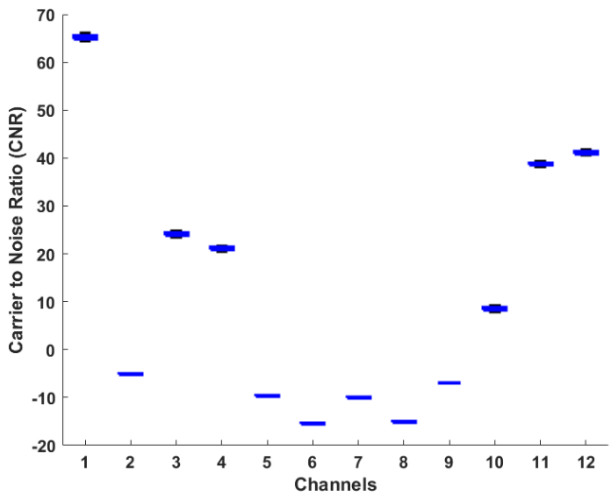

Figure 5a: CNR distribution for ATT

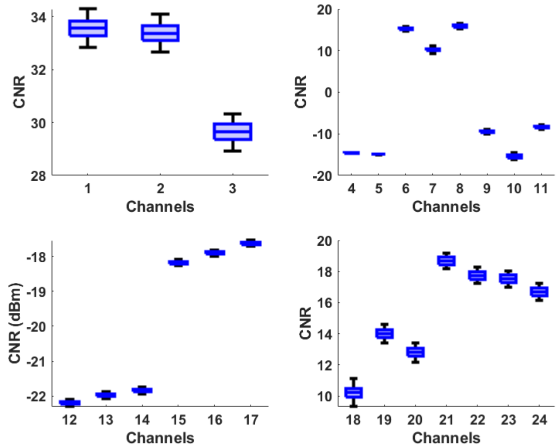

Figure 5b: CNR distribution for DTT (b)

Policy-driven prohibited co-channel and adjacent channel usage, for further PU protection, resulted in 25% DTT channel occupancy in Table 1. Assuming these policies were absent and the database management scheme alone was adopted, a 10% availability was observed. As channels were reused, three channels, out of 9 unique ATT channels, were occupied and 3, out of 17 unique DTT, were not available.

Table 1: Channel Availability

	Eastern Channels Occupancy (%)	National TV channels (%)	Policy Protected (%)	Database occupancy
ATT	33.00	8.33	38	
DTT	17.00	6.25	25	10

The effect of the protection ratio, on co-channel, is shown in Figure 6. Despite the weak TV signals received in channel 3 (see Figure 6a) as compared to that in channels 1 and 2, the same maximum power distribution is computed by the adopted methodology, for channels 1, 2, and 3 (see Figure 6b). Thus the permitted transmission power, of the 3 unavailable channels, lies in the same range, as seen in Table 2.

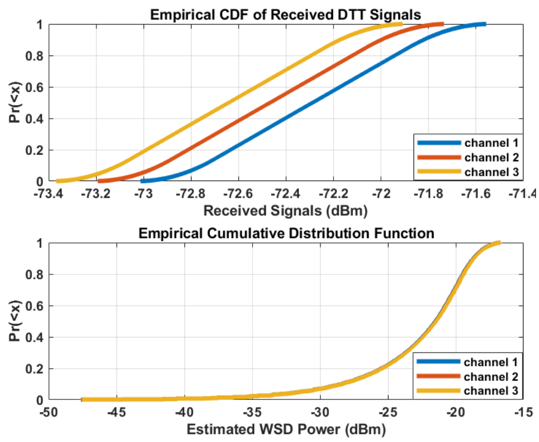

Figure 6: (a) Cumulative Distribution Function (CDF) of received DTT signals and (b) maximum WSD power estimate of channels 1 to 3 in x-pixels.

All weak channels are therefore given adequate protection. This is assured as, despite the -15dBm to -47 dBm computed maximum power limits, only the least power in each channel is adopted by the GDB. Thus, maintaining maximum protection of channels, in all pixels covered by WSD's transmitter.

Table 2 represents some content of the resulting GDB in MySQL, with JSON compliant headings. This can be accessed by a WSD, using the PAWS. The database contains the 3 DTT occupied channels in Figure 6, with actual channel numbers 43, 44, and 46, operating at their corresponding frequencies on Table 2. The very low power allotted cannot be used by any WSD, thus protecting them.

Table 2: Database table with WSD power limits

Chan_no	hz	dBm
21	474000000	36
22	482000000	36
23	490000000	36
24	498000000	36
25	506000000	36
26	514000000	36
⋮	⋮	⋮
39	618000000	36
40	626000000	36
41	634000000	36
42	642000000	36
43	650000000	-47.61
44	658000000	-47.58
45	666000000	36
46	674000000	-47.54
47	682000000	36
48	690000000	36

V. Conclusion

In this paper, a spectrum management system, for interference management, between incumbent and secondary devices, for a proposed TVWS network in FUTO, was developed. The geolocation database-designed methodology was evaluated by analyzing its ability to access spectral availability and protect weak received TV signals. Six digital and analogue terrestrial television channels were in use (based on TV receiver sensitivity), out of 40 nationally available channels. It was observed that co-channel protection ratios, had the greatest impact on effectively reducing the estimated power limits of WSD transmitters. It was also revealed that the DS Alliance framework, protected very weak tv signals, within the study area. This framework was used to develop a geolocation database, which was also presented in this study. The adopted methodology is, therefore, useful for interference mitigation, as the pixel-wise evaluation of power limits proves to minimize interference possibilities. This becomes very useful in co-channel sharing amongst secondary users, where spectral underlay is permitted.

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