A Menu-driven Interface for a Geolocation Database for Wireless Spectrum Sharing

Armie E. Pakzad [1], Xavier Francis B. Asuncion [1], Joshua Vincent G. Ligayo [1], Raine Mattheus C. Manuel [1], Jerrick Spencer K. Uy [1], and Lawrence Materum [1,2]
[1] De La Salle University, Manila, Philippines
[2] Tokyo City University, Tokyo, Japan
Email: armie.pakzad@dlsu.edu.ph

Abstract—Spectrum sharing is of paramount importance in television white space (TVWS) wireless communications. Secondary users must ensure that their operation in any TV channel does not interfere with the transmission of the primary users and other secondary users. This paper presents a menu-driven interface (MDI) which a secondary user inquirer may utilize to determine the TV channels available. The MDI utilizes a reinforcement learning-based algorithm and an interference indicator to determine the availability of each TV channel for secondary use. The algorithm utilized a set of parameters to provide accurate data on the availability of the channel. These parameters include time, location, and the receiving antenna parameters. The algorithm was able to produce an accuracy of 94.69% in determining the availability of the channel based on the broadcasting time of primary users (PUs) and an accuracy of 84.38% based on four tested locations.

Index Terms—Television white space, spectrum sharing, Geo-location Database, Menu-driven Interface, Co-existence

I. Introduction

Television white space (TVWS) communications is a continuously growing approach with the potential for spectrum sharing for different purposes like Internet connectivity and long-range communications. The gaps in the spectrum arise from the idle time PUs or licensed users have operating at their given frequencies. The use of TVWS communications is seen to improve the delivery of services in rural areas. Only 15% of the TV spectrum is utilized at present. Thus it could be a great way to connect almost 3 billion people worldwide [1].

Due to this vacancy, secondary or unlicensed users (SU) can use the same frequency spectrum provided they do not interfere with the signal of adjacent PUs. This event is where spectrum sharing techniques are essential for co-existence in the frequency spectrum. As long as SUs have the necessary information to know the transmitting specifications of a primary user, the secondary user can make necessary adjustments to not interfere with any other user operating in the frequency spectrum. An example of a spectrum sharing approach SUs can adopt is having access to a geolocation database. SUs who have access to a geolocation database can know the location of PUs, their broadcast schedule, and the range of these stations. With this information, SUs who want to use the frequency spectrum can know which frequency band is being used.

According to [2], it is imperative to apply regulations on controlling the co-existence of secondary users and stop interference with primary users. There should be network management tools to enable the applied utilization and co-existence of extensive TVWS networks in a dynamic spectrum access atmosphere.

TVWS wireless communications is an emerging technique developed to provide wireless connectivity over long distances using spectrum that are not in use by TV broadcasters. An existing functionality of TVWS is to provide Internet access to rural areas. TVWS refers to the unutilized spectrum bands found within the Very-High Frequency (VHF) range and the Ultra-High Frequency (UHF) spectrum. TVWS was developed to overcome the range limitations of wireless technologies, like Wi-Fi. With Wi-Fi, the coverage range and data throughput are limited due to the frequency band that it utilizes, specifically, 2.4GHz to 5GHz [3].

TVWS technology has already been implemented in different countries for various applications that require an Internet connection. Applications include inter-connectivity for schools and hospitals and Internet access to rural areas and other areas with poor broadband Internet reception [4].

The lack of information regarding PUs within the Philippine settings poses a challenge for a geolocation database implementation in the Philippines. Furthermore, the necessary information needed to plot the transmitting stations' contour map includes transmitter power, transmitter location, antenna height above average terrain, and broadcast schedule. This information is essential in computing the broadcast range of the transmitter stations. This study aims to create a Menu-driven interface (MDI) that would show the contour map of different PUs in Metro Manila, Philippines, and plot a secondary user's contour plot. A Yagi-Uda antenna was used to determine the accuracy of the data from the MDI. The analog antenna was utilized to validate the information from the contour map plot generated from the MDI.

TVWS technology provides a means for Internet connectivity over great distances. It is crucial to have the means to allow the sharing of the frequency spectrum

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among users, such as the primary users and secondary users. This paper presents an MDI that would allow a secondary user to determine which channels are interference-free and available for secondary use.

In this research, the authors proposed utilizing the machine learning method, reinforcement learning (RL), that helps the system determine available channels for a secondary user given different parameters such as time, day, location, height above sea level, and more. The machine learning process utilized local data of primary users for the learning environment. The utilization of RL helps the system make faster, compared to no utilization of machine learning and accurate results of available channels for secondary users.

II. Related Literature

The use of a geolocation database (GLDB) ensures that white space devices (WSDs) do not interfere with existing utilized frequency bands. Interference can be avoided with different protocols for three zones, exclusion, restriction, and protection zones. Exclusion is where incumbents should make no transmission. In restriction, transmissions' operating parameters such as transmission power, antenna height, and frequency range are restricted or given limits. Finally, no transmission is permitted in the protection zone as the maximum level of interference security is followed [5].

Ojaniemi, Poikonen, and Wichman designed a method that raises the precision of GLDBs through a simulation [6]. The GLDBs were created using measured values from actual white space devices. By increasing the number of samples for measurement, a propagation map can be approximated. The study showcased an algorithm that helps update the GLDB through sensing or measurements that ensure that PU and Sus do not suffer from interference during operations.

In a study conducted by Murty, Chandra, Moscibroda, and Bahl (2011), four propagation models were compared in terms of their accuracy in determining the available white spaces. Based on the results of the spectrum survey conducted, the propagation model which did not provide false positives and had the least loss was the Longley-Rice (with terrain) model. The Longley-Rice (with terrain) propagation model was also used to calculate the attenuation of a signal over a distance which is a prerequisite to determining the received signal strength at a particular location [7].

A study conducted by Mishra and Sahai demonstrated the methodology of determining available white spaces following the sensing regulations imposed by the FCC. The FCC stated that the detection sensitivity is -114dBm for the analog TV signals to protect the receivers in worst-case fading scenarios. The methodology also utilizes the FCC F (50,50) service contour for analog TV. The distance at which the signal drops to the specified -114dBm for 50% of the locations for 50% of the time, following the F (50,50) rule. The distance determined was used to evaluate the white spaces recovered [8].

A paper by Zurutuza showcased a user interface (UI) for TVWS secondary users. They must input their location, and through their GLDB, it would provide them with the spectrum availability information. After providing the necessary information, the UI would display the available white spaces that they can utilize. [9]

Efficient spectrum management is a critical challenge among many cognitive radio networks (CRNs). CRN, as an intelligent system in wireless communications, is aware of its environment. It learns and changes its inner conditions to certain operational factors such as carrier frequency, transmit power, and modulation scheme in real-time. They are providing precise, reliable communication at any instance and any location necessary. Reinforcement learning is being used for learning problems in CRN [10].

Concerning system architecture, a study by Sun et al. provided a procedure that would help manage multiple users when using white spaces. Their study illustrated a scheme that would help with user co-existence to reduce interference between primary and secondary users. This scheme would ensure that the allocated timeslots provided to the secondary users do not interfere with existing white space users [11].

System parameters are regulated to satisfy the TV receiver interference constraint. In the study conducted by Jain, Kumar, Gangopadhyay, and Debnath, simulations were performed to explore the effect of the system parameters on the connections established in the secondary network. The study considered system parameters to be able to reproduce a simulation for SUs effectively. These parameters include the power, range of transmission, the number of users trying to access the spectrum [12].

Other than the system parameters, there also have been studies that utilized the behavior when using the vacancy of a spectrum to gain trust. Wang, Ma, & Zhao presented a model that focused on three types of trust; direct, indirect, and incentive to choose spectrum allocation. Doing so would maintain a healthy ecosystem for both licensed and unlicensed users [13].

III. Methodology

The authors created an MDI using the App Designer in MATLAB, which was used to simulate the inquiry process of a secondary user. The MDI utilized the application's component library to make the simulation possible. The MDI was designed to contain the input interface for the secondary user's information and a list of the spectrum information. The availability of the channels is displayed through the lamp components placed beside each channel. The availability of the channels is determined using a geolocation database which includes information on both the PUs and the secondary user inquiring.

Additionally, a drop-down button was added to display the contour map in MATLAB's site viewer for any selected channel on the list. The service contours of PUs and SUs were based on the Federal Communications Commission (FCC) Frequency Modulation (FM) and TV Propagation curves, and the coverage map was displayed using the Longley-Rice model. The Longley-Rice model considers the terrain profile, obstructions (building/infrastructure), and tropospheric characteristics in predicting the coverage area of the antenna. The accuracy of the MDI and the GLDB were verified by manually surveying the VHF and UHF spectrum using a dipole TV receiver antenna at four different locations - Cainta Rizal, Las Pinas, Angeles Pampanga, and Sta. Rosa Laguna in the Philippines.

IV. Data and Results

The MDI was implemented using MATLAB's App Designer, as shown in Fig. 1. There are 100 SUs that were predetermined and tested beforehand.

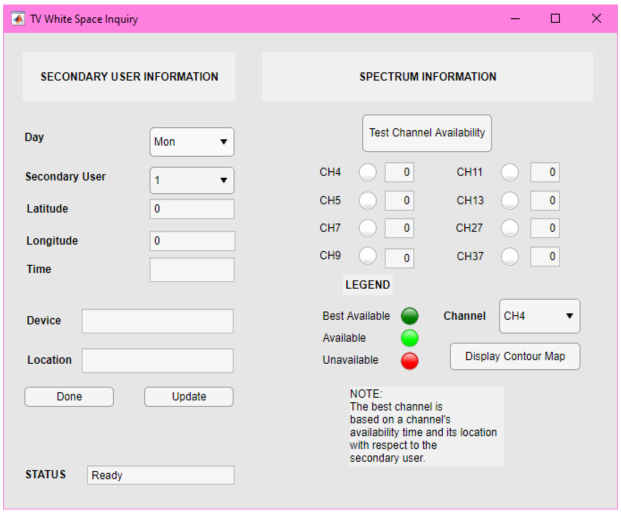

Fig. 1. MATLAB app designer MDI.

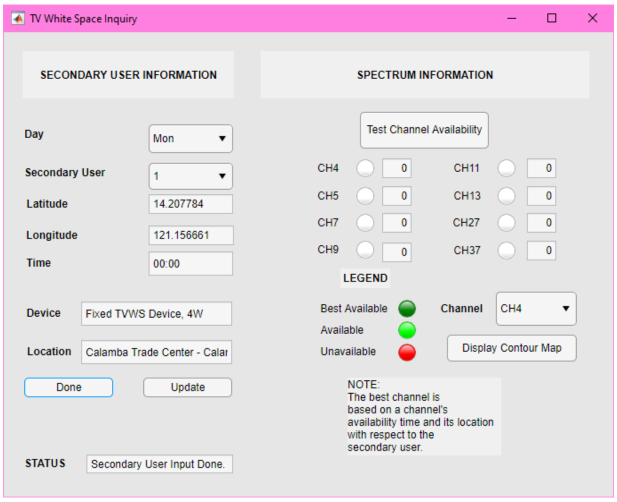

Fig 2. Secondary user parameters in Calamba Trade Center.

The SUs parameters like location, coordinates, device specification, time of the request, and day of request are included in the MDI. This menu is shown in Fig. 2. The available channels are shown in their different corresponding colors. Red means the channel is unavailable during the request. Light green means that the channel is available during the time of request and dark green signifies that this is the best available channel for the secondary user. The availability of the channel is based on the information from the geolocation database. Fig. 3 shows the available channels for a secondary user located in Calamba Trade Center.

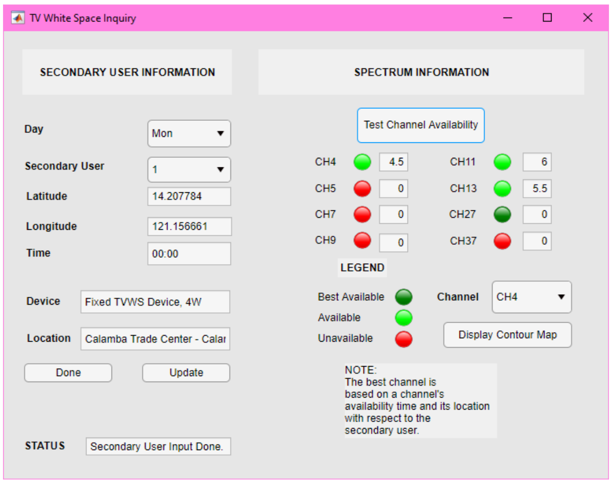

Fig. 3. Available channels for the secondary user in Calamba Trade Center.

The contour map of both the PUs and SUs was done using MATLAB's Antenna Toolbox. Their contour map was based on the FCC frequency modulation (FM) and TV propagation curves and the Longley-Rice model. The service contour of each primary user was computed using the FCC's calculator on FM and TV propagation curves, but the F(50,50) propagation curve graph may also be used. Given the primary user's transmitter power, antenna height above average terrain, and 60 dBu signal strength, which are stated under the Kapisanan ng Brodkaster ng Pilipinas (KBP) technical standards for television as the interference ratio, the distance of the broadcast transmission can be obtained. For checking the interference between the primary and secondary users, the interference ratio specified under the KBP technical standards for television was utilized alongside FCC's calculator on FM and TV propagation curves to ensure sufficient separation between the primary and secondary users.

The input parameters needed for the coverage function to word included the name, longitude, latitude, transmitter frequency, transmitter power, and transmitter height. After inputting these parameters, MATLAB would auto-generate the coverage map that shows how far the broadcast signal can reach. The longitude coordinates must follow a numeric scalar with a range of -180 to 180. The latitude coordinates must follow a numeric scalar of -90 to 90. The antenna type used was a dipole antenna. The transmitter frequency was applied in the unit of hertz. The antenna height needed was obtained using FCC's height above average terrain calculator. Lastly, the power was in the units of watts.

The coverage maps utilized the Longley-Rice model to generate a more accurate coverage with respect to the terrain. The FCC contour map presented a model in free space. Therefore, the Longley-Rice model was utilized to take into consideration the mountainous terrain. The Longley-Rice model considers the terrain profile and tropospheric characteristics in predicting the coverage area of the antenna. The model also considers obstructions such as buildings and mountains in its calculation. It can estimate the degradation of radio waves in the 20 MHz to 20 GHz frequency range. MATLAB supports different propagation models, and it includes free space, rain, gas, fog, close-in, Longley-rice, Terrain Integrated Rough Earth Model (TIREM), and ray tracing image method modeling. The free space, rain, gas, and fog models were not chosen because they are restricted to line-of-sight scenarios. The close-in model produced a perfect contour map, wherein the coverage would be a perfect circle. This model does not consider the possible areas that the primary user may not reach.

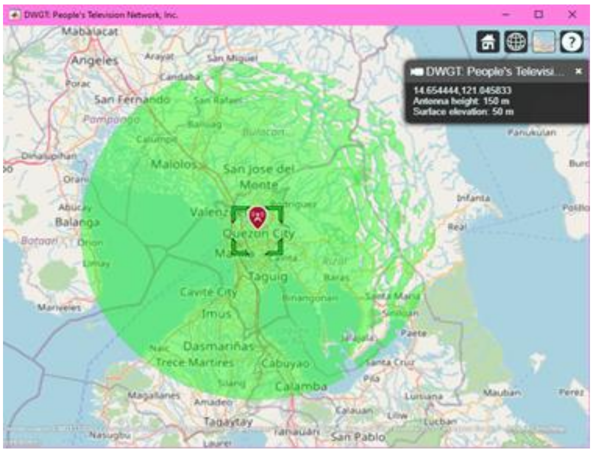

Fig. 4. Primary user in metro manila.

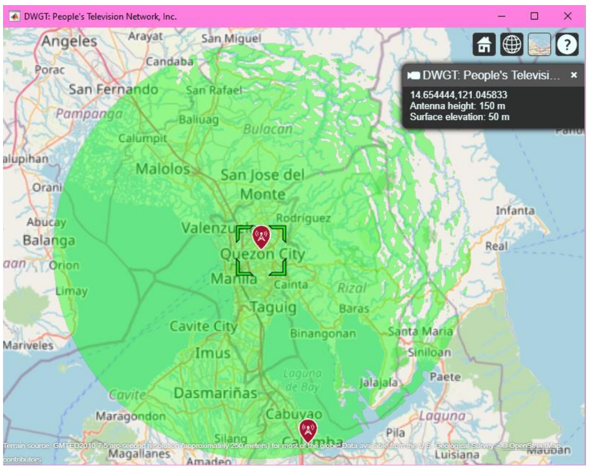

Fig. 5. Secondary user in Calamba Trade Center with respect to the primary user in metro manila.

Furthermore, this model only generates close-propagation, which reduces the actual coverage map of the PUs. The TIREM model was not utilized because it required an external library. A ray-tracing image method was not used because it did not include refraction, diffraction, and scattering, which led the authors to choose the Longley-Rice model, which can calculate the attenuation losses from one point to another. This model is typically used over irregular terrain, which also includes structures such as buildings. Fig. 4 shows a contour map of a primary user in Metro Manila. In contrast, Fig. 5 shows the secondary user in Calamba Trade Center with respect to the primary user in Metro Manila.

For verifying the accuracy of the MDI and the GLDB, a wideband antenna capable of receiving signals from VHF and UHF frequencies was used. The antenna has a very high gain of >= +10 dB. The transmission line of the antenna is 12m RG6/U Coaxial. The locations of the channels tested were in Angeles Pampanga, Sta. Rosa Laguna, Cainta Rizal and Las Pinas. These four locations were also included in the 100 predetermined SUs. Channel 4, 5, 7, 9, 11, 13, 27, and 37 in Metro Manila were used for broadcasting accuracy for broadcasting tests. Whenever a channel went off-air or on-air, the authors would take note of this. The database constructed from the testing was then compared with the original database, resulting in broadcasting time accuracy. Since the time was segmented to every 30 minutes, the total accuracy would be based on 48-time slots. If there are any discrepancies regarding the obtained data from the testing compared to the already existing data, then a point from the 48 is removed.

The service contour accuracy was also obtained through the antenna testing. The locations were part of the 100 SUs to display the contour maps for each channel with respect to their location. Their contour maps were displayed with each channel to see if they would be inside or outside the range of coverage. As for the antenna test, it was checked to see if the service contour is accurate with respect to the antenna reception of channels. Suppose a secondary user were to be found inside the service contour of the primary user, then for the test to be accurate, the antenna should be able to receive a signal 79 for that specific channel. All of the data that was obtained was tabulated to determine the service contour accuracy. The results obtained from this test were binary. A '1' is placed if the signal reception in the TV corroborates the signal capture of the secondary user in the site viewer of the MATLAB-based MDI screen. Otherwise, it is given a 0. The numbers were then averaged to compute for accuracy.

The time slots in the database are divided into 48 slots since each slot differs by 30 minutes. The authors compared the broadcasting times when the PUs are supposed to be on-air and off-air. The broadcast time test column represents the number of slots that are correct out of 48 time slots. The broadcast time accuracy is based on this. For the service contour test, the authors compared the MATLAB program's contour maps and the specific locations whether the secondary user locations are within the coverage of the PUs. If the channel appears on the TV, the service contour test is set to 1, and this is compared to the contour map of the PUs and SU, whether the secondary user is within the coverage.

Fig. 6 shows the antenna setup used in one of the locations. Table I shows the accuracy of the broadcasting schedule from the GLDB with respect to the four locations mentioned. Table II shows the accuracy of broadcast range based on the computed model using FCC propagation curves and the Longley-Rice model.

Fig. 6. Antenna setup.

TABLE I: BROADCAST SCHEDULING ACCURACY

Location	Broadcasting Time Accuracy
Location 1 (Sta. Rosa, Laguna)	95.83 %
Location 2 (Angeles, Pampanga)	92.56 %
Location 3 (Cainta, Rizal)	96.62%
Location 4 (Las Pinas)	93.75 %
Total Accuracy:	94.69 %

TABLE II: CONTOUR MAP ACCURACY

Location	Service Contour Accuracy
Location 1 (Sta. Rosa, Laguna)	100 %
Location 2 (Angeles, Pampanga)	37.5 %
Location 3 (Cainta, Rizal)	100 %
Location 4 (Las Pinas)	100 %
Total Accuracy:	84.375 %

V. CONCLUSION

An MDI was made given parameters of PUs and SUs. The contour map can be plotted following FCC's guidelines regarding propagation curves using a broadcasting station's transmitter power, antenna height, operating frequency, and location. The same is true for SUs. A geolocation database is a viable spectrum sharing technique in order to prevent interference between users. For co-existence, secondary users can access the GLDB regarding the broadcast transmission of PUs to avoid these used frequencies. It is also essential to know whether the database is accurate to ensure no interference is made between PUs and SUs. A wideband analog antenna can be used to check for interference between PUs.

With the development of the proposed MDI, the SUs track the available frequencies without spending additional costs compared to the other available systems with a corresponding fee. The software is available from authors upon request.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Armie Pakzad wrote the final paper and served as the adviser, Xavier Francis B. Asuncion, Joshua Vincent G. Ligayo, Raine Mattheus C. Manuel, Jerrick Spencer K. Uy worked on the methodology and the paper's content, and Lawrence Materum served as the consultant on the methodology.

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Armie E. Pakzad is an Assistant Professor at De La Salle University Manila, Philippines. She is currently doing her dissertation writing to complete her degree in Doctor of Philosophy in Electronics and Communications Engineering in the same university.

The author's current research outputs include, "Reinforcement learning-based Television White Space Database" presented in 8th International Conference on Computing and Informatics 2021 (ICOCI2021), "Proposed Joint Propagation and Reinforcement Learning-based Television White Space Ledger" published in International Journal of Emerging Trends in Engineering Research, Proposed Joint Propagation and Artificial Intelligence-based Television White Space Ledger" presented at the Philippines-Japan Workshop on Wireless Radio and Antenna Technologies (PJWWRAT), and "Fuzzy Ponics: a Fuzzy Based System to Control Temperature, Relative Humidity, Electrical Conductivity and PH of Hydroponics" presented at the 8th International Conference on Computer Science, Engineering and Technologies (ICCSET 2019).

Ms. Pakzad is an active member of the IEEE – Computer Society.

Francis Xavier B. Asuncion was born in San Juan City, Philippines in 1999. He completed his bachelor's degree in Electronics Engineering at De La Salle University (DLSU) – Manila in 2021. His fields of interest include data communications and broadcasting.

Joshua VIncent G. Ligayo was born in Parañaque City, Philippines in 1999. He completed his Bachelor's Degree in Electronics Engineering at De La Salle University (DLSU) - Manila. His current interests are robotics and data communications.

Raine Mattheus C. Manuel was born in Pasay City, Philippines in 1998. He is a recent graduate of De La Salle University (DLSU) with a B.S. degree in Electronics and Communications Engineering. His current interest includes mobile application programming, python programming, and data science.

Jerrick Spencer K. Uy was born in Angeles City, Philippines in 1998. He has just finished his course in the De La Salle University (DLSU) Manila campus with a degree of B.S. Electronics and Communications Engineering. He has background knowledge on basic programming and data communications.

Lawrence Y. Materum received the B.Sc. degree in electronics and communications engineering with honors and scholarship from Mapúa Institute of Technology (now Mapúa University), the M.Sc. degree in electrical engineering major in computers and communications from the University of the Philippines Diliman through an Analog Devices Fellowship, and the Ph.D. degree in international development engineering (major in electrical/electronics engineering) from Tokyo Institute of Technology through a MEXT Scholarship. After receiving his M.S. degree, he co-developed integrated circuit tests for cellular and emerging radio chips at Analog Devices. As an industry-academia-government collaboration researcher-engineer in the Research Institute of Electrical Communication of Tohoku University, he developed and co-proposed the first radio non-line-of-sight wideband indoor channel models for 60-GHz beamforming. He received the best paper award at the 13th International Symposium on Antennas and Propagation for his contribution to unsupervised learning of the grouping of electromagnetic signals, which is crucial for knowing various characteristics of such signals and the development of wireless channel models. Currently, he is a faculty of the Electronics and Communications Engineering Department of De La Salle University. He is in the field of telecommunications, and his recent interests include but not limited to propagation channel (measurements, analysis, modeling), adaptive antenna arrays, wireless sensing, unsupervised and supervised machine learning, pattern estimation of random processes, forecasting of momentum stochastic processes, and sustainable technology transitions.