The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2022

Volume 21, Pages 188-195

IConTES 2022: International Conference on Technology, Engineering and Science

TVWS Geolocation Database for Secondary-User TVWS Devices for Spectrum Forecasting

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Abstract: This paper suggests a MATLAB-based television white space (TVWS) database with forecasting capabilities. The availability of multiple TV frequencies for a secondary user, depending on the day and time of the inquiry, location, and device, was forecasted using reinforcement learning (RL) software. A MATLAB live script RL application was created and tested. After passing numerous tests, the algorithm was integrated into a MATLAB App Designer application so that an SU could request projections for spectrum availability. Three categories might be used to categorize the forecast—medium-term (MT), long-term (LT), and short-term (LT). The forecast for that day is referred to as ST, the following day as MT, and the days after that as LT. Based on the SU's device, the program was designed to predict the spectrum availability in relation to the SU's query time, location, and transmission details. The SU device is a fixed white space device with an EIRP power cap of 4 watts. The database and AI are both necessary for accurate predictions. The forecast's results indicated 100% accuracy, assuming the database is frequently updated. Both the forecasting and reinforcement learning programs were created using MATLAB's App Designer.

Keywords: Reinforcement learning, Television white space database, TVWS spectrum forecasting, Artificial intelligence

Introduction

TVWS communications is a developing technique and technology that introduces new opportunities and challenges in maximizing frequency spectrum utilization. The opportunity for developing countries with an abundantly available spectrum in the TV band is enormous. According to Ismail, Kissaka, and Mafole's research, despite the widespread availability of TVWS in developing countries, the average internet penetration is 30%. This observation means that a large portion of the population is still not connected to digital networks (Ismail, et al., 2019). TVWS implementation for communications can benefit developing countries in rural and other underserved areas.

TVWS communications allow for dynamic frequency spectrum utilization. Alonso, Plets, Deruyck, Martens, Nieto, and Joseph discovered that using TVWS networks in suburban and rural scenarios saves 9 to 12 times more energy than LTE networks. This finding indicates that TVWS is viable in underserved areas (Alonso et al., 2017).

When it comes to connectivity, rural areas in the Philippines lag. Inquirer Philippines reported that they collaborated with ADB and Thinking Machines on Artificial Intelligence, Big Data, and Machine Learning for Development to map digital poverty in the Philippines. They discovered that access to adequate Internet speeds deteriorates in rural areas (Araneta et al., 2021). This decline in access in rural areas leaves people without access to digital space.

Super high-speed Wi-Fi (Wi-Fi 2.0) is a way to bring Internet service to underserved areas using the TVWS band. Gigabit-per-second high-speed rates are possible with this Wi-Fi (Sarkar et al., 2016). Particularly in impoverished areas, the TV spectrum is full of white spaces. Secondary users (SUs) can quickly discover which frequency bands are available given a time and location for secondary use using a TVWS database (TVWSDB). Asking SUs for a list of available channels, the TVWSDB must be able to do so. The spectrum is dynamically changing due to primary user (PU) off-airs or various PUs in various locations. Therefore SUs that contact the TWSDB must be kept informed at the appropriate intervals and change bands as necessary to avoid interfering with the PUs.

Since spectrum usage is constantly changing, manually querying the database or continuously sensing band availability might be unreliable and inconvenient. Given a trustworthy and regularly updating TVWSDB, the application of machine learning would aid in automating the inquiry and update process for SUs.

Related Studies

TVWS offers a substitute for establishing wireless connections. The difficulty here is to avoid interfering with the primary users (PU). In their work, Makgamatha, Zuva, and Masonta used a geolocation database that employs a protocol to access the available white space while adhering to quality of service (QoS) standards (Makgamatha et al., 2018).

The study by Aji, Wibisono, and Gunawan illustrates how TVWS technology is used in Indonesia to provide rural telecommunications solutions. They claim that, especially in developing countries, there is a substantial infrastructure gap in telecommunications between urban and rural areas. They asserted that TVWS was an acceptable alternative for unplanned usage (Aji et al., 2017). The FCC and ECC standards currently in use are available to other countries.

There is a growing need for wireless spectrum resources as 5G technology matures. Because of this, a solution to the issue of dynamic spectrum access is needed. Using the TVWS frequency band, Chen and Zhang's research led to the development of a spectrum detection node with an embedded system. Their test demonstrated the potential for precise detection and system adaptability when using a distributed electromagnetic spectrum information service platform based on signal characteristics (Chen & Zhang, 2019).

As wireless communication technology advances, more applications that depend on bandwidth are starting to appear. It is, therefore, ideal to fully utilize the wireless frequency range. The use of white spaces for secondary applications is anticipated to increase due to recent improvements in TVWS technology. Mustapha, Bakura, D. Mustapha, and Abbagana evaluate TV white space strategies and a few TVWS technology implementations in Africa (Mustapha, 2019). They discovered that TVWS is trustworthy and reasonably priced, which is practical for secondary use.

Additionally, especially in developing nations, it can boost the economics of setting up wireless connections in underserved rural areas. Additionally, because of the dynamically changing spectrum in various locations and at various times, TVWS devices must adjust their operational frequency spectrum dynamically. Having hardware that is configurable and having well-designed software for the job will enable this method—having it also aids in avoiding interference when PU frequencies are used outside of business hours.

A paper published by Ma, Gao, Fu, Rong, Xiong, and Cui explored how to use TVWS to make the most use of the spectrum for various applications. They looked at how the spectrum was used in London at various fixed and mobile locations. In order to study how the spectrum is used in various channels, locations, and time instances and to exploit the white space for various purposes, they employed machine learning to analyze the dynamic usage of the spectrum based on their observations (Ma et al., 2019).

Researchers Rempe, Synder, Pracht, Schwarz, Nguyen, Vostrez, Zhao, and Vuran have created a prototype configuration that uses numerous cognitive radios, a TVWS database, and the TVWS spectrum. After using a free frequency, an SU modifies the spectrum database, which is visible to other SUs. The cognitive radio must recognize when a frequency is unavailable due to PU use and switch to another available frequency, updating the spectrum database. Through periodic database searches, this operation is carried out (Rempe et al., 2017).

A mathematical framework was developed by Hussien, Katzis, Mfupe, and Bekele to determine the ideal separations for co-channel and adjacent channel use of digital TV (DTV) frequencies. They used HAAT values and the propagation models ITU-R P.1546-5 and P.1411-9 for the calculations in Ethiopia. Ethiopian WSD networks also established the necessary neighboring protection ratio of 27 dB (Hussien et al., 2019).

To protect PUs, the use of TVWS requires rules and regulations. White space devices (WSD) need sensing capabilities to solve this issue. However, this capability can be challenging to control and does not produce precise or organized results. Dynamic spectrum access can be tracked using a TVWSDB that is consistently updated and contains all necessary information. Alejandrino, Concepcion II, Laugico, Trinidad, and Dadios looked at the various WSD technologies on the market and any gaps that might exist in TVWS implementation. They discovered that one of the gaps is the devices' adaptability to work in various topologies. Different laws in many nations could be problematic (Alejandrino et al., 2019).

TVWS availability in the Greater Metro Manila Area was examined in a study by Morico, Porras, Judan, De Guzman, and Hilario conducted in the Philippines (GMMA). Results from propagation simulations using the Okumura-Hata and Hata-9999 models, along with measurements of the spectrum along a single path made using a portable spectrum analyzer, reveal that many white spaces outside the GMMA can be put to use for secondary purposes (Morico et al., 2020).

The paucity of TVWS geolocation datasets with SU forecasting capabilities is highlighted in the literature, a problem that this work aims to solve. The methodology section covers the forecasting process, and the findings are presented in the Results and Discussion section. The study's findings are summarized in the final section.

Methodology

A MATLAB live script reinforcement learning (RL) application was created and tested (Pakzad et al., 2022). After passing numerous tests, the algorithm was integrated into a MATLAB App Designer application so that an SU could request projections for spectrum availability. Three categories might be used to categorize the forecast—medium-term (MT), long-term (LT), and short-term (LT). The forecast for that day is referred to as ST, the following day as MT, and the days after that as LT. Based on the SU's device, the program was designed to predict the spectrum availability in relation to the SU's query time, location, and transmission details. It is believed that SU's device is a fixed white space device with an EIRP power cap of 4 watts. The FCC's fact sheet for unlicensed white space device activities (FCC Fact Sheet, 2020) served as the basis for this value. The application used MATLAB's site viewer for propagation mapping and the forecast findings. The Longley-Rice model, pre-built in MATLAB's Antenna Toolbox, was used in the PUs' propagation map. In contrast, SUs used the free-space model because of its limited coverage.

The database was generated in Microsoft Excel (Pakzad et al., 2022), imported into MATLAB, and utilized via data reading features to improve the written program's interaction with the database for training. Program schedules for PUs were gathered from various websites, including the channel networks' websites. During training, the learning data is contrasted with the PUs and SU interference calculations, as well as the program schedule of PUs, to test the forecasts' results. For making sure that the RL process resulted in accurate decision-making for the SU, this step was taken.

Results and Discussion

The App Designer application is displayed in Figure 1. Time, location, device type (fixed 4W EIRP), and distances (in km) dependent on operating frequency are all included in the SU inputs on the left and are determined using the FM and TV Propagation Curve Calculator provided by the FCC.

The spectrum information is displayed on the program's right side. The GUI displays a legend based on the user's preferences. The hue of the lamp indicates whether a channel frequency is available, while the number next to the bulb indicates how many hours a specific channel's PU is off-air. The SU that enquired is far enough away from the PU that there will be no interference if the SU decides to use the frequency if the lamp indicates that the channel is available but indicates that the PU is on-air (0 hours result).

The type of forecasting used is displayed at the bottom of the selected day, also on the right. The day chosen before pressing the training button is considered the ST forecast or the day of inquiry; in the case of the figure, that day is Sunday. The MT forecast is the forecast day that follows the forecast inquiry. As seen in Figure 2, Monday is considered in this situation as the MT. A sample of the LT prediction, which runs from Tuesday to Saturday and is shown in Figure 3, is for the Saturday after the day of the inquiry.

Depending on the SU requests for a channel prediction, the ST forecast is provided on that day, the MT forecast is provided one day later, and the LT forecast is provided in the days following the first day following the request. If an SU were to query, for instance, on Sunday, ST would be forecast on Sunday, MT would be forecast on Monday, and LT would be forecast from Tuesday until Saturday. The programming schedule needs to be revised regularly for the forecast to be precise.

Prior to a forecast, the user must hit the train button. The button launches the reinforcement learning training program in the background to obtain the available channels for each weekend day. As illustrated in Figure 4, a pop-up window notifies the user that the training is over. Following the training, the forecast status changes from its initial red state to green. After the training, one can press the forecast button after choosing a day from the drop-down menu.

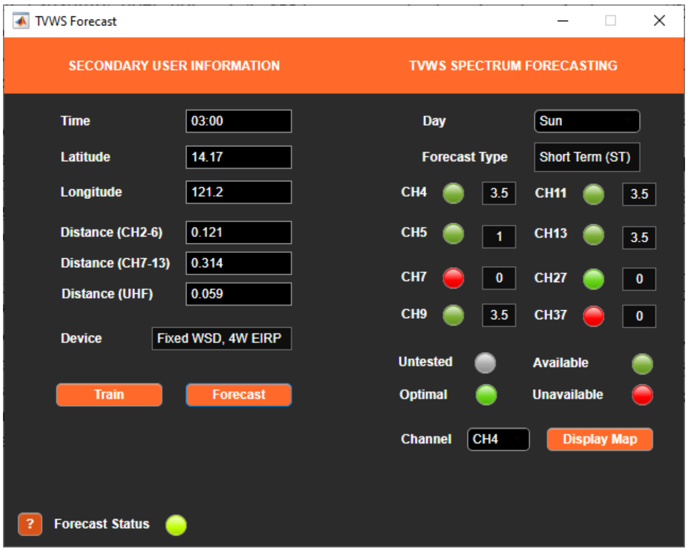

Figure 1. TVWS forecast program (ST)

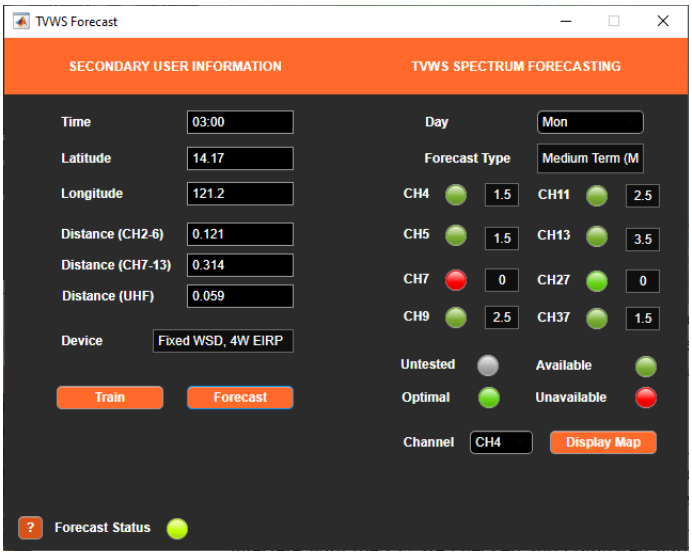

Figure 2. TVWS Forecast Program (MT)

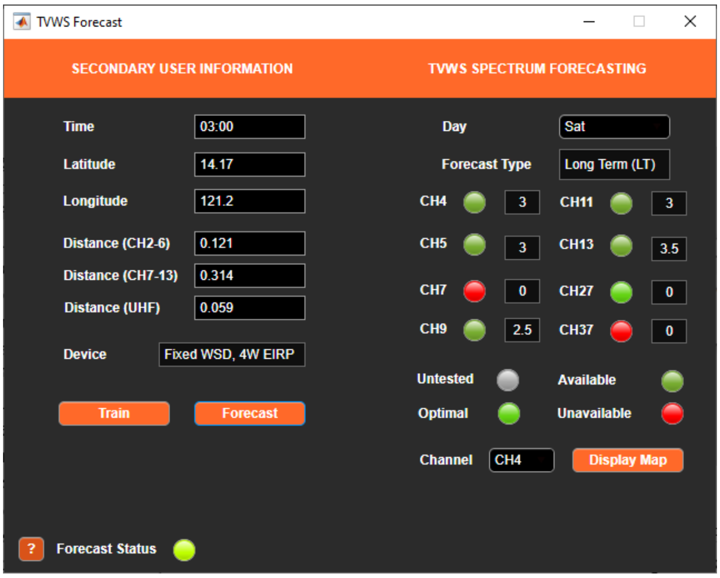

Figure 3. TVWS forecast program (LT)

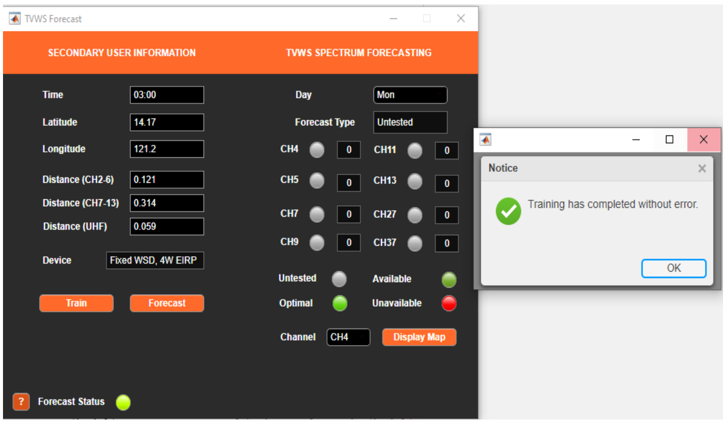

Figure 4. Training finished

The window that displays when the user hits the program's "Display Map" button is depicted in Figures 5 and 6. The contour map is zoomed in in Figure 5 to highlight how sparse the SU coverage is. The coverage of the PU can be viewed by zooming out from Figure 6. The SU uses the free-space model because of its limited coverage area, but the PU's contour map is based on MATLAB's built-in Longley-Rice model.

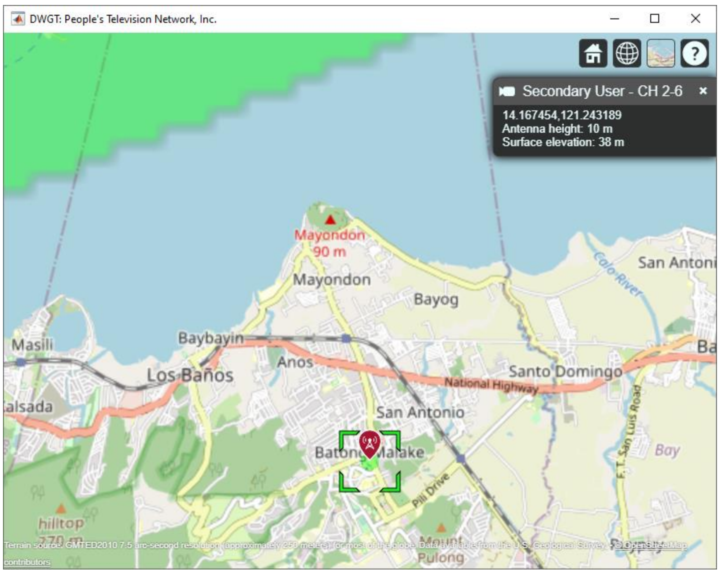

Figure 5. Secondary user location and coverage

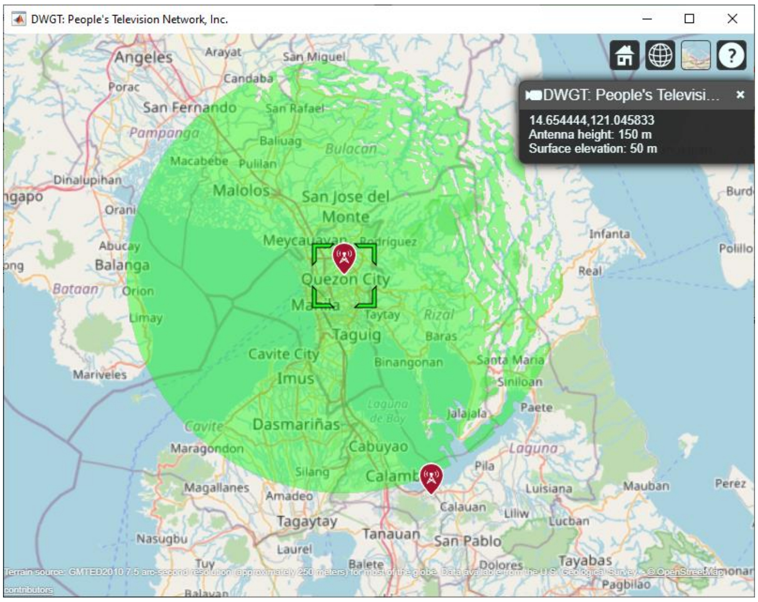

Figure 6. Primary user location and coverage

An algorithm was added after the primary learning algorithm to verify the training data's accuracy based on the SU's conditions to test the training outcomes or the Q-tables generated from the training. The testing algorithm examines the Q-table, contrasts the acceptability and deniability values for a specific channel, and compares these values to the case of the SU. The number of hours a channel is open and whether the SU would interfere with the PU is determined based on the SU's parameters, and the findings of the Q-table are compared.

The most advantageous channel is determined based on the channel's length of availability (PU off-air period) and whether the SU would interfere with the PU. The PU's frequency is selected as the best channel if it is not already in use and the SU is sufficiently far away not to interfere. The most advantageous channel is determined by which PU's frequency gives the most extended available period for secondary use of their frequency if the SU is within range of all the PUs.

Table 1 displays the accuracy results from 100 different SU cases using 100 Q-Tables on various days of the week. A 100% accuracy rate indicates that the machine learning algorithm could produce accurate forecasts of the available channels for the 100 SU scenarios provided.

Table 1. Accuracy of training results

Day	Accuracy
Monday	100 %
Tuesday	100 %
Wednesday	100 %
Thursday	100 %
Friday	100 %
Saturday	100 %
Sunday	100 %

Conclusion

TVWS implementation makes the most of the TV spectrum, especially in underdeveloped areas. SUs can ask multiple questions regarding the forecast for spectrum availability by using a TVWSDB in conjunction with RL. The authors developed a TVWSDB and RL-implemented MATLAB software that simulates an SU requesting spectrum predictions. The forecasting can be divided into three categories: ST, MT, and LT, where ST refers to the day of the inquiry, MT to the day after, and LT to the days that follow the week of the inquiry. Based on the conditions, the RL method produced a forecast that was 100 percent accurate. However, updating the database in actual implementation practice is advised because PU program schedules change over time.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2022.

*The authors wish to thank De La Salle University for its support.

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To cite this article:

Pakzad, A.E., Manuel, R.M. & Materum, L. (2022). Spectrum forecasting TVWS geolocation database for secondary-user TVWS devices. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 21*, 188-195.