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Exploring the Utilization of Reinforcement Learning Technique for Channel Accessibility in a Television White Space Database

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ABSTRACT

This study aimed to explore integrating the reinforcement learning (RL) technique into a television white space (TVWS) database using MATLAB. An RL implementation was developed to recommend the optimal channel to a secondary user (SU), considering the time of query, the transmitter power of the device, and the SU's location. Data regarding the allocation of television frequencies within the Very High Frequency (VHF) and Ultra High Frequency (UHF) ranges was collected to compile the TV White Space database (TVWSDB). These entities were constructed using the 2019 edition of the National Telecommunications Commission's frequency allotment table. The database was structured to facilitate the RL utilization of the different data analysis functions in MATLAB after importing the data as workspace data. The database stored the primary user's (PU) location, transmitting power, height above average terrain (HAAT), frequency of operation, and programming schedule.Furthermore, a comparative analysis was conducted between a linear search algorithm and the AI program, revealing a significant performance advantage of the latter. Specifically, the RL-based program exhibited a speed improvement of 2080 times over the linear search algorithm.

1. Introduction

With the continuous advancement of technology, there is a growing number of significant breakthroughs that have the potential to enhance the overall quality of life. This paper explored the concept of utilizing wasted resources to optimize their utilization. The development of television white space (TVWS) exemplifies this concept. TVWS is a connectivity technique that leverages unused spectrum frequencies or white bands to provide connectivity. Furthermore, the field of computing has been significantly impacted by the emergence of machine learning techniques, which have revolutionized how computers handle and analyze data.

To enhance the efficiency of their services, recent technological advancements have facilitated the integration of machine learning into their software. Some examples of advanced technologies

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that can be utilized are real-time suggestion systems, natural language processing algorithms, and image recognition capabilities. The integration of these elements allows for the creating of a TVWS database (TVWSDB), which provides users with access to the optimal available channel. TVWS technologies facilitate the utilization of unoccupied frequency bands for wireless communication purposes. TVWS can provide wireless communication over extended distances due to its utilization of the Very High Frequency (VHF) to Ultra High Frequency (UHF) range of frequencies [10]. Several research and experiments have been undertaken to examine the utilization of TVWS in different places throughout the globe, such as Africa, North and South America, and numerous Asian countries, including the Philippines.

Licensed segments of the broadcast spectrum are often underutilized for extended periods. By leveraging TVWSDB, stakeholders can identify the available broadcast spectrum during specific timeframes. It is essential for TVWSDB to deliver accurate and comprehensive information to summarize queries for each transaction instance effectively. The number of queries per transaction instance should be minimized to enhance operational efficiency and speed. The aim is to maximize the utilization of TVWS. It remains uncertain whether the existing TVWSDB models meet the needs of stakeholders. The current databases fall short of fulfilling the expectations and requirements set forth by stakeholders.

This study emphasizes integrating machine learning techniques using reinforcement learning (RL) into a TVWSDB. This database aims to learn and determine the most appropriate channel for users, considering factors such as interference and availability of channels.

2. Related Literature

Before creating a TVWSDB, obtaining several factors is crucial [5]. These included the SU's transmit power, transmission range, and other SUs utilizing the spectrum at the time. All these data are necessary before building a TVWS simulation [5]. An example of a TVWS geolocation database made by Zurutuza *et al.,* [11] complies with FCC guidelines for white space databases. Furthermore, study users were provided with an interface requesting their location before showing the open white regions.

Geolocation databases (GDBs) were strongly recommended when using white space devices to prevent interference inside frequency bands. The employment of three distinct zone classifications—the zone of protection, the zone of exclusion, and the limitation zone—to prevent interference was proposed in Kokkinen *et al.,* [6]. Since transmission would interfere, it should not occur inside the exclusion zone. The protection zone must be subjected to the least amount of interference possible. Aspects like transmitter power, frequency range, and antenna height should all be considered when determining the restricted zone.

Furthermore, Ojaniemi *et al.,* [4] showed how to use white space device data in simulations to improve the accuracy of GDBs. They created an algorithm that, under the condition that there be no conflict between the PUs and SUs, would employ sensing to update the GDB.

According to Sun *et al.,* [12] SUs seek to coexist with PUs to access spectrum opportunities that can be mutually beneficial. However, the challenge arises when this coexistence results in harmful interference between the two user groups. As highlighted in Yang *et al.,* [13] research, a protocol is crucial for ensuring the harmonious coexistence of primary and secondary users in cognitive radio systems. This approach aims to enhance the spectrum of access opportunities for secondary users while maintaining the quality of service for primary users. In a previous study by Lee *et al.,* [14] it was noted that even when a secondary user accesses a vacant channel to prevent interference, there remains a potential for interference from a concealed primary user. Implementing a strategy for coexistence in various scenarios is imperative to mitigate such interference. Factors such as the uplink and downlink schedules, as well as the positioning of users, should be considered. Lee *et al.,* [14] identified four distinct scenario cases based on the level of information available to the secondary network. In each case, secondary users can be monitored and allocated to specific channels at designated times.

This situation can maximize the number of SUs involved. As stated by Nyasulu *et al.,* [15] it is crucial to implement regulations to effectively manage the coexistence of secondary users and prevent interference with primary users. Implementing network management tools to facilitate the efficient utilization and coexistence of large TVWS networks in a dynamic spectrum access environment is recommended. The authors analyzed regulations set by the Federal Communications Commission (FCC), Office of Communications (Ofcom), and Malawi Communications Regulatory Authority (MACRA).

Kim *et al.,* [17] presented a TVWS management framework to enhance spectrum utilization efficiency by considering available channels relative to the density of digital television (DTV) relays and transmitters to forecast TVWS availability in designated pilot zones. Additionally, researchers in Almeida *et al.,* [16] underscored the importance of adhering to protection standards when deploying TVWS for communication purposes, particularly ensuring that secondary users (SUs) do not emit power levels that result in harmful interference.

Faruk *et al.,* [18] underscored the importance of implementing alternative spectrum management models and techniques to optimize the use of vacant channels. This involves creating an intelligent system that can predict service coverage and determine the availability of vacant channels.

Zhang *et al.,* [19] that to optimize the utilization of TVWS, SUs should be coordinated on available channels within the TV coverage area. TV and SU receivers may experience interference from other devices operating on the same or adjacent channels. Therefore, the key to successful SU access lies in identifying the largest number of available SU channels free from TV interference and other SU receivers.

Denkovska *et al.,* [20] stated that increasing the reuse of spectrum holes may be less effective in mitigating interference protection. High-capacity links over short distances can significantly enhance spectrum efficiency within a limited geographic area. In their study, Arias *et al.,* [21] introduced a straightforward modeling approach for generating accurate and complex digital terrain models using contour protection maps.

The need to consider the effects of PU and SU interference was discussed in Denkovska *et al.,* [2] TVWSDBs must be able to provide SUs with white spaces free of PU interference by considering the interference contour and the availability of PUs. They also followed the guidelines that the Electronic Communications Commission (ECC) and the Federal Communications Commission (FCC) established in their article.

The propagation model in this paper has been incorporated with the Longley-Rice model. Applications of this concept to situations involving portions of the 20 MHz to 20 GHz spectrum are typical. This propagation model may consider terrain, climate, and tropospheric profiles when estimating the attenuation caused [9].

3. Methodology

For the development of the TVWS database, data on the distribution of TV frequencies in the VHF and UHF ranges was gathered. The National Telecommunications Commission's frequency allotment table for 2019 was used to build these. After the data was imported as workspace data, the database was set up to simplify the RL-based program's use of several data analysis tools in MATLAB. The database contained information about the location of a primary user (PU), transmit power, height above average terrain (HAAT), frequency of operation, and programming schedule.

Figure 1 shows the organization of the database. The study covered the Metro Manila television channels only. Several PUs is used inside the location, shown in Figure 1, by their corresponding channel numbers. As previously stated, the matching PU information is contained in each channel.

The program schedule is also divided into seven sections within each channel, based on the seven days of the week. Instead of being built as a single, massive table holding all of the data, the database is designed to allow for an optimal training procedure and speedier access to the database for the program itself. This structure cannot be linearly interacted with by a large table. The structure of the Excel files containing the channel data has been altered in MATLAB to correspond with Figure 1.

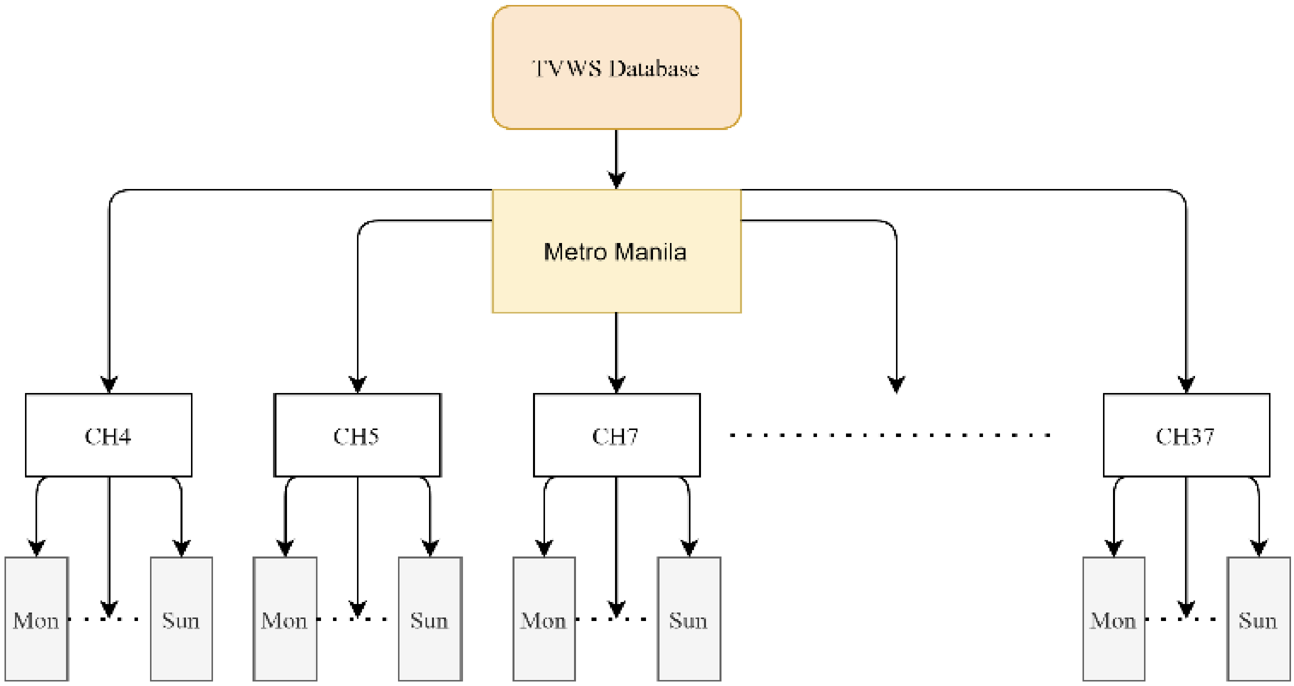

Fig. 1. General database structure

A sample of data from a PU's database is shown in Figure 2. Functional data is visible in addition to typical PU details. The program schedule is indicated by the time in 24-hour format, while the channel's availability—whether the PU is running or not—is represented by 1s or 0s, respectively. As mentioned before, the format of this sheet has been changed for optimal usability and training, as seen in Figure 1.

DAY	COMPANY	CHANNEL_I	CALL_SIGN	LOWER_BA	UPPER_BAI	TRANSMIT_	LONGITUDI	LATITUDE	ERP	TRANSMIT_	TIME	AVAILABILITY	SECONDARY	STATE
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	0:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	0:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	1:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	1:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	2:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	2:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	3:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	3:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	4:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	4:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	5:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	5:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	6:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	6:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	7:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	7:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	8:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	8:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	9:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	9:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	10:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	10:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	11:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	11:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	12:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	12:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	13:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	13:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	14:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	14:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	15:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	15:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	16:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	16:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	17:00	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	17:30	0	0	0
Mon	GMA Netwi	7	DZBB	174.025	180	177.0125	14.66962	121.0501	1000	100	18:00	0	0	0

Fig. 2. Snapshot of primary user's database in excel

The PU's programming schedule governed the availability of a channel and whether its coverage region interfered with that of the secondary user (SU). The basis for the programming plan was information gathered from the internet. The Federal Communications Commission (FCC) F(50,50) calculator was used to estimate the coverage distance based on the F(50,50) curve and PU parameters like ERP and HAAT.

After calculating the coverage distance, the distance between the PU and SU was also determined. The Haversine Eq. (1) was applied in this case.

$$h = sind\left(\frac{lat1-lat2}{2}\right)^2 + cosd(lat2)cosd(lat1)sind\left[\left(\frac{lon2-lon1}{2}\right)\right]^2 \quad (1)$$

$$d = 2 * 6371 * \operatorname{arcsinh}\big(sqrt(h)\big)$$

Next, the training was done in MATLAB utilizing the different parameters found in the database. A MATLAB script was used to create both the agent and the learning environment, with the structured database acting as the learning environment. RL was used in the development of the program.

The environment, the agent, the reward system, and the q-table are all components of the RL process. The q-table provides the learning data in a specific situation. The first step is to initialize the environment. A reward table is generated with the modified database setup and the SU settings. After that, the agent would start acting randomly based on a state. The relevant method is exploration. The agent is likelier to choose the proper reactions to each state and capitalize on environmental actions as it gains experience. Agent decisions can only be accepted or rejected. The value of actions is represented by a q-table constructed during the training phase utilizing learning data. Figure 3 shows the general layout of the training procedure.

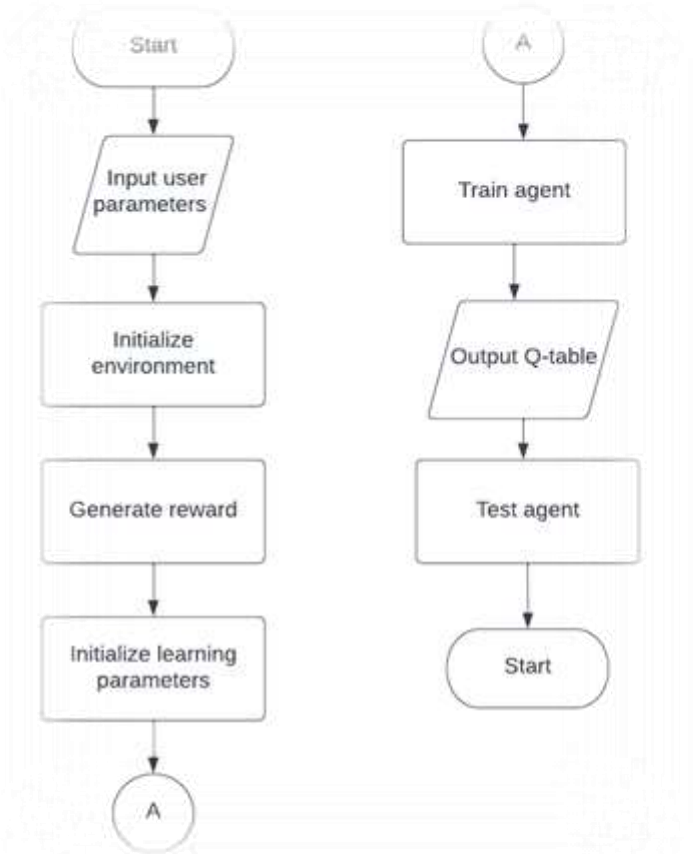

Fig. 3. Flowchart of the training process

After the training phase, the actions based on whether PU is available and if PU inter-feres with SU were compared to test the learning data or q-table. This testing procedure is automated using a script included in the MATLAB script. The correctness of the AI's decision is then computed based on those results.

In addition to the accuracy test, a speed test of the RL-based program decisions was carried out using MATLAB's tic-toc function. The time it took the program to recommend the optimal channel to use along with other available channels was timed. The measured durations were compared to a separate linear search process.

Seven different database days were used to complete the training process 100 times. Though the SU parameters, duration, and location of each test differed, they were all carried out in the Philippines. It was assumed that all SUs employed the 4W maxi-mum allowable power rating for a stationary TVWS device, as set by the FCC.

Figure 4 shows the reward generation flowchart. The initial step in the learning process involves creating an initialized table that tracks the rewards for each completed episode. This reward table is distinct from previous iterations, as it reflects the rewards associated with each action, rather than the overall prize the agent has received for a specific episode.

The number of episodes the agent engages in is determined by the size of the overarching learning loop, within which a "done" signal indicates whether the agent has made a significant error or successfully completed the task, thus concluding the episode. At this stage, the current reward is initialized to store the episode award for the ongoing episode.

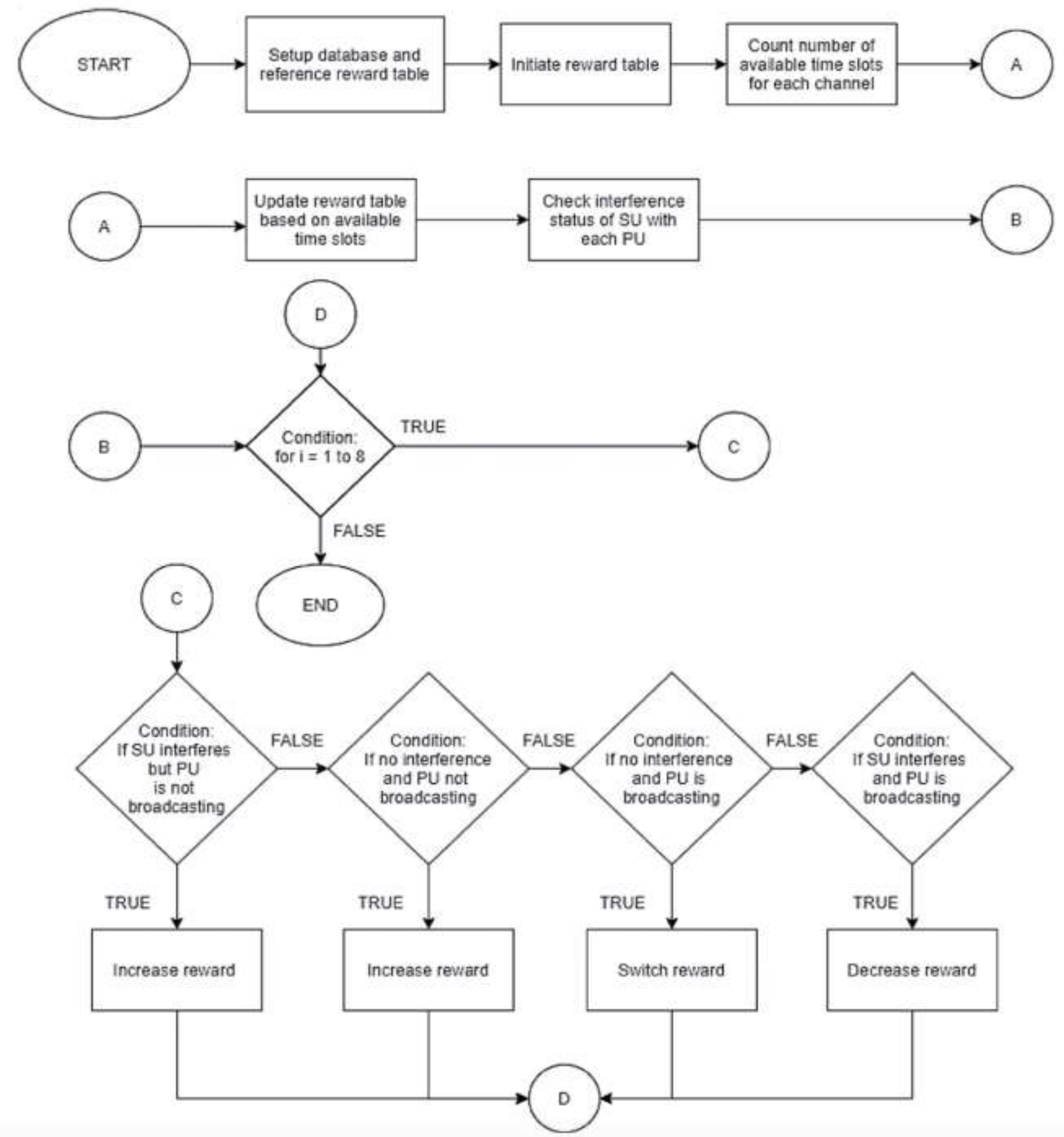

Fig. 4. Reward generation flowchart

4. Results

Figure 5 shows the results of the training sample. The second user was based at De La Salle University in Manila. Based on the interference and the presence of the PU, the reward table returns a negative if the channel is unavailable and interferes and a positive value otherwise.

Furthermore, the q-table was evident and created as an 8x2 table, where eight stands for the eight channels used in the simulation and two stands for accept or reject. The likelihood that the agent would select a particular channel to deliver to the SU increases with increasing values on the left side of the q-table. In contrast, the agent would try to avoid that channel if the left side of the q-table or the reject had a higher value because it was either unavailable or interfered with the PU.

```
DayName = 'Mon'
Case 2: De La Salle University - Manila
channel_counts = 8×1
     9
     0
     0
     0
    11
    13
     0
     9
reward_table = 8×2
          20       -1000
       -1000          50
       -1000          50
       -1000          50
          24       -1000
          28       -1000
       -1000          50
          20       -1000
channel_interference = 8×1
     1
     1
     1
     1
     1
     1
     1
     1
q_table = 8×2
10^4 ×
    1.2000    1.0880
    0.9880    1.1930
    0.9880    1.1930
    0.9880    1.1930
    1.2004    1.0880
    1.2008    1.0880
    0.9880    1.1930
    1.2000    1.0880
test_action = 1.2008e+04
test_row = 6
test_col = 1
correctness = 7×1
   100
     0
     0
     0
     0
     0
     0
```

Fig. 5. Sample result from RL training

The RL-based program and a typical linear search were also evaluated regarding speed. They calculated the passage of both using the tic toc function in MATLAB. Table 1 shows the time measurements for the RL search. The RL program took an average of 0.000951 seconds to complete, while Table 2 shows the time data for the linear search.

Table 1
RL-based time measurements

Measurement	Time
Average Elapsed Time	0.000951 s
Minimum Elapsed Time	0.000494 s
Maximum Elapsed Time	0.008300 s

Table 2
Linear search time measurement

Measurement	Time
Average Elapsed Time	1.978735 s

The linear search process finished in 1.978735 seconds. The RL program was 2080 times faster than the linear program since it ended in 1.977784 seconds, which is shorter than the linear search. Finally, the accuracy of the developed RL software was assessed. Each day's accuracy was checked using a counter. The metrics of availability, interference, and q-values were compared to confirm accuracy. Table 3 shows the accuracy for each of the 100 examples. The RL-based program achieved a 100% accuracy rate on all days.

Table 3
Accuracy per day for all 100 scenarios

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

5. Conclusion

In this study, a simulation of a TVWSDB with RL implementation was built [1]. The TVWSDB contains details about how PUs are currently working and the schedules for each of their programs. The Excel-created TVWSDB was adjusted in MATLAB to have a general structure appropriate for the RL procedure and the training agent. This TVWSDB served as the training environment for the RL learning process.

One hundred different SUs with various parameters were used to test the RL program. The RL's decision-making for the SU investigation was 100 percent correct. Although the RL program learned how to draw inferences from the information, keeping the database current is critical because it is the foundation for the AI's decisions. The RL program was 2080 times faster than a linear search for the best accessible channel, according to the statistics.

Overall, the simulation shows that including machine learning, in this case, RL in TVWSDB access permits a practical, rapid, and precise method of retrieving available TV spectrum frequencies given the vital information of the SU and updated PU information in the TVWSDB.

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