Analysis of Spectrum Holes and Power Allocation using Water Filling Model for Underlay Cognitive Radio

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ABSTRACT: Due to the rise of the Internet of Things (IoT), the spectrum frequency in the wireless communication industry is rising in recent years. However, the radio spectrum's frequency band use is limited because the primary user for specific services can cause spectrum interference as multiple users use the same spectrum frequency. Meanwhile, the number of users and utilization time at each spectrum frequency are different. These will lead to vacancies in the primary user's spectrum frequency. A new alternative in using the cognitive radio (CR) spectrum is accessible to these vacancies. This study identified spectrum holes for secondary users' transmission and used the water filling model to execute the power control algorithm in the underlay CR network. The spectrum was measured using Universal Software Radio Peripheral (USRP) devices, which was a realistic approach. The spectrum holes were detected using an energy detection technique. In the energy detection technique, the threshold energy level is set, and the output of the energy detector is compared to identify the primary user's existence (PU). Therefore, power control was introduced to improve the performance to allow Secondary User (SU) to access the frequency spectrum band. The result shows that the underlay technique is more efficient than the overlay technique in terms of spectrum utilization.

Keywords: *Cognitive Radio; Spectrum Holes; Water Filling Model*

1. INTRODUCTION

Due to the COVID-19 pandemic, hundreds of millions of people were forced to remain at home regarding government-imposed lockdowns. Quarantine policies have increased massively the Internet traffic demands of home users for working remotely, commerce, and education resulting in change traffic at the core of the Internet. Additionally, the Internet-of-Things (IoT) is a burgeoning technology that allows devices to interact via wired and wireless technologies. Thus, this will lead to big data issues and the frequency spectrum demand is rising. The available frequencies will eventually be limited.

Generally, CR is a radio that can adjust its transmitter's parameters based on its communication with the operating environment to achieve effective communication [1-2]. Therefore, CR structures include the PU and SU spectrum, where PU is characterized as license holders who have privileges using a specific area of the spectrum. In other aspects, SU is classified as an unlicensed user and prefers to use CR's spectrum opportunistically when primary users are idle or referred to as spectrum holes and white space [3-4].

There are three techniques of spectrum access in the CR network: underlay, overlay, and interweave. In the underlay approach, SU transmits during the transmission time and would not interfere with a PU. In contrast to the overlay technique, SU needs complete knowledge of the PU signal to transmit at any power. Meanwhile, SU is allowed to transmit with maximum power when PU is inactive for interweave method. To protect PUs and preserve a good quality (QoS) for SU, the transmit power should be wisely regulated. Furthermore, power control is required to retain the interference at the PU within the defined threshold when allocating the power of SU in the spectrum holes [5]. The data of inference emitted by the SU is used to perform power controls. In addition, the Channel State Information (CSI) considers that perfectly obtained in this situation [6]. The water-filling model is chosen as the power control technique because it can optimize the transmission process without affecting the PU system's process to enhance the cognitive system's performance.

2. METHODOLOGY

The energy detection method with an energy level threshold is used to identify the spectrum holes. Afterward, the underlay technique's implementation has two scenarios. The first scenario is when the SU transmits data when the PU is not present (H_0) and the second scenario is when the SU transmits data while the PU is there (H_1):

$$x(t) = \begin{cases} (P_{SU} * G_{SU}) + C_{AWGN} & H_0 \\ (P_{SU} * G_{SU}) + (P_{PU} * G_{PU}) + C_{AWGN} & H_1 \end{cases} \quad (1)$$

Hence, P_{SU} denotes the power at SU, G_{SU} is gain at SU while P_{PU} defines as power at PU, G_{PU} is referring as gain at PU, and C_{AWGN} is represented as noise. After the dataset is analyzed, the water filling algorithm able to be built in MATLAB software for scenario H_1. The process works like pouring water into a container [7]. The water filling model is generated using the equation below:

$$Capacity = \sum_{i=1}^{n} log_2(1 + power\ allocated * H) \quad (2)$$

As part of this power control strategy, n represents the maximum water level that can be poured in while H represents the system framework's network matrix, and P_t represents the system's power budget [8].

$$Power\ Allocated = \frac{P_t + \sum_{i=1}^{n} \frac{1}{H_i}}{\sum channels} - \frac{1}{H_i} \qquad (3)$$

The path loss exponent (α) that use in this project is 4, and the distance between $PU - T_x$ and $PU - R_x(d_{pu})$, as well as $SU - T_x$ and $SU - R_x\,(d_{su})$ is 150m. Apart from that, the noise variance (n) is $10^{-13}$and the SU (P_{su}) transmit power is between 0.01 and 0.1W. Additionally, the probability of false alarm (P_f) is 0.01:0.01:1, and there are 80250 samples in the PU channels. This parameter is required to develop the SU's power, which is used to access the PU signal from the USRP randomly. The power of PU is measured, as well as the signal-to-noise ratio (SNR) of SU, which influences the power of PU.

This project uses the USRP N210 device with antenna model VERT2450. Furthermore, the LabVIEW software block diagram is being used to execute spectrum measurement and data collection. The data will be collected in frequency between 2.4GHz to 2.48GHz and the result plotted in the FFT power spectrum.

3. RESULT AND DISCUSSION

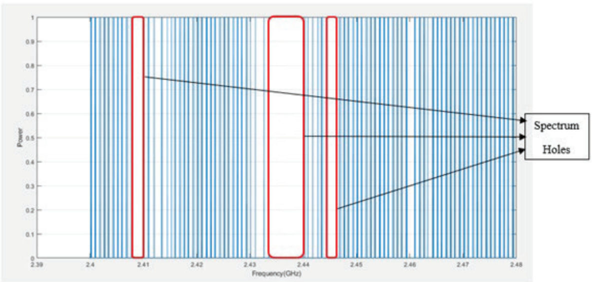

Figure 1: Spectrum Holes in Frequency Spectrum Band

The plotting of the frequency spectrum after the energy detection process is shown in Figure 1. As can be seen, the blue line represents PU power that indicating H_1 in the equation (1). Furthermore, spectrum holes representing H_0 have been found in the frequency range 2.43GHz to 2.44GHz. From this experiment, the utilization spectrum frequency is 99.39%, and spectrum holes are 0.61%. As a result, SU can only access when PU is absent where 0.61% in the overlay method.

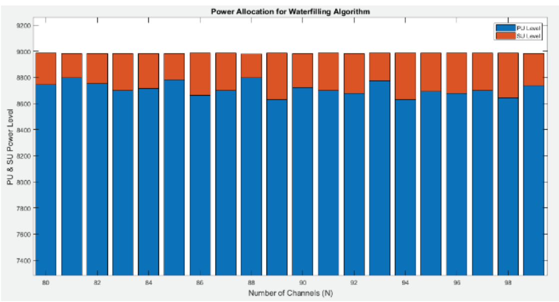

Figure 2 Power Allocation Water Filling Algorithm

The result of the power allocation after the process water algorithm is shown in Figure 2. The blue region in Figure 2 represents the PU signal power in the system, while the red area represents the SU power signal pouring into the system within the limit capacity using equation (2) and the power transmission from equation (3).

4. CONCLUSION

In this research, the SU in the underlay technique of the CR network can access additional channels after applying the water filling method in the system. As a result, the spectrum utilization increases to 100%, which is more effective than the overlay technique where is 0.61% due to the SU can access more channel spectrum through an underlay CR network. The overlay approach allows the SU to reach the channel only when the PU is absent, but the underlay technique allows the SU to access the channel even while the PU power signal is present. This is because the SU transmission power signal is too small to cause interference to the PU. Eventually, the PU power signal is unaffected.

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