Sensing and analysis of spectrum holes in ISM band using USRP testbed

Nur Syahirah Hamdan[1], Mas Haslinda Mohamad[2], Aduwati Sali[3]
[1,2]Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia
[3]Research Center of Excellence for Wireless and Photonics Network (WiPNET), Department of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia

Article Info

Article history:

Received Feb 2, 2021
Revised Apr 30, 2021
Accepted May 9, 2021

Keywords:

Cognitive radio
Energy detection
LabVIEW
Spectrum holes
USRP

ABSTRACT

The spectrum frequency in the wireless communication industry is getting great attention due to the internet of things (IoT) technology's growth. 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, at each spectrum frequency, the number of users and utilization time are distinct. These will create vacancies for spectrum frequency assigned to the primary user. A new alternative in using the cognitive radio (CR) spectrum is accessible to these vacancies. This paper analyzed the frequency spectrum in the industrial, scientific and medical (ISM) band and identified spectrum holes for transmission by the secondary users. This work employed a realistic approach by measuring the spectrum using Universal Software Radio Peripheral (USRP) devices. Thus, the spectrum holes in the frequency spectrum had distinguished by using an energy detection technique. In the energy detection technique, the threshold energy level is set and then compared with the energy detector output to identify the primary user's existence (PU). The result indicates that 0.61% of spectrum holes have been detected in the 2.43-2.44 GHz range. This range is sufficient for home appliances, radio frequency peripherals (RF), and bluetooth devices.

Corresponding Author:

Nur Syahirah Hamdan
Center for Telecommunication Research and Innovation (CeTRI)
Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya, Durian Tunggal 76100, Melaka, Malaysia
Email: m021910021@student.utem.edu.my

1. INTRODUCTION

Due to the Coronavirus disease 2019 (COVID-19) pandemic, most government-imposed lockdowns forced hundreds of millions of people to stay home. Quarantine policies have increased the internet traffic demands of home users for working remotely, entertainment, commerce, and education, resulting in a change in traffic at the core of the internet. According to [1], almost two-thirds of the world's population now have access to the internet by 2023. By 2023, there will be 5.3 billion cumulative internet users, represented as 66% of the global population were up from 3.9 billion in 2018. There is even an evolving internet-of-things (IoT) technology that allows devices to communicate via wired and wireless technologies. Therefore, due to big data issues, the frequency spectrum demand is highly growing as there are several IoT devices in the network. In reality, IoT users having a problem connecting to the wireless network when they are portable and at a high cost to the licensed spectrum. With many wireless networks and much more to come, the available frequencies are becoming limited.

On the other hand, most licensed bands, such as television broadcasting, amateur radio, and paging, are widely underused [2], [3]. Moreover, in terms of the number of users and the usage period, the demand for spectrum frequency varies. This state would leave unused those spectrum frequencies and release the frequency spectrum to be occupied by cognitive radio (CR) users. Therefore, to solve these problems, an accurate model of spectrum occupancy patterns should be developed that represents the entire system.

In 1999-2000 [4], [5], Mitola developed the name CR to signify intelligent radios that could make tremendous decisions using model-based reasoning using the accumulated knowledge of the environment of radio frequency (RF) and can learn based on previous experience. In general, CR is a radio that can adjust its transmitter's parameter based on its communication with the operating environment, such as transmission-power, carrier frequency, and real-time modulation technique to achieve effective communication and optimal radio spectrum use [6]-[9]. On top of that, CR is designed on software-defined radio (SDR) that transforms the two advanced digital radio and computer software technology to help it reconfigurable [10]-[12]. CR's core components include a radio, sensor, information database, learning engine, and reasoning engine. Besides, CR has cognitive and reconfigurability capabilities to get the best available spectrum [6], [13]-[15]. Cognitive capability is the CR's ability to sense the radio spectrum using advanced tools and evaluate suitable parameters for adjusting to the complex environment [13]. At the same time, CR's reconfigurability feature allows it to change the operating parameters according to the sensor data, perhaps to attain maximum efficiency without any adjustment in the hardware devices [8], [16].

Therefore, CR structures include primary users (PU) and secondary users (SU) spectrum where PU is characterized as license holders or incumbent users who have legacy privileges using a specific part of the spectrum. In other respects, SU is considered unlicensed users and prefers to use CR's spectrum opportunistically when primary users are idle or referred to as spectrum holes and white space [17], [18]. The SU with CR functionality acquires knowledge about its operational environment and adjusts its network parameters to maximize the underused spectrum accordingly. For instance, if a licensed user uses this band further, the cognitive radio switches to another spectrum hole or remains in the same band, thus altering its transmission power level or modulation scheme as shown in Figure 1. Eventually, CR tries to resolve the collision issues and unnecessary contention in the wireless access network, leading to the deployment of multiple devices linked to the infrastructure via radio connection [14].

One of the primary objectives of cognitive radio is to allow the spectrum's holes to be used opportunistically. Without disrupting the PU, the SU can sense the PU's arrival and move it to another unused space. In cognitive radio, spectrum sensing, however, plays a crucial role. Ergo, spectrum sensing is a CR that tracks the state of the spectrum and regularly senses licensed users' activity [15], [19], [20]. In other words, it collects information from them and determines the unused spectrum to analyze the available radio spectrum [8], [9], [21]. Perhaps it helps change additional parameters such as power rates, codes, and frequencies to restrict unwanted interference [22]. The critical elements involved in sensing the spectrum are accuracy, complexity, and sensing time [9]. As a final observation, all spectrum sensing systems' main goal is to optimize the likelihood of detection with a low probability of false alarm [23].

This research aims to detect and analyze spectrum holes in the industrial, scientific and medical (ISM) band using the Universal Software Radio Peripheral (USRP) testbed to be used by SU. The rest of the paper is organized as follows. In section 2, the research method is discussed, and the formula is stated. Furthermore, in section 3, the spectrum utilization and holes in the specified frequency were analyzed. Finally, section 4 is the conclusion of this paper.

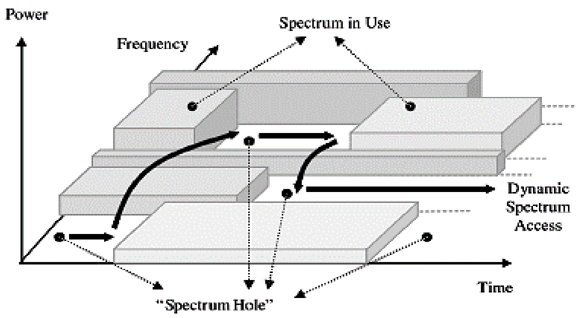

Figure 1. White-space illustration [9], [13], [14]

2. RESEARCH METHODOLOGY

Energy detection is one of the spectrum sensing methods in the cognitive radio network that allows the identification of spectrum frequency vacancies. Besides, energy detection is one of the simplest spectrum sensing techniques, and its low demands on signal processing are positive aspects. The basic model of the transmitter detection technique is described as (1) [2], [24]-[29].

$$x(n) = \begin{cases} w(n) & H_0 \\ y(n) + w(n) & H_1 \end{cases} \tag{1}$$

Hence $x(n)$ is the received signal, $y\,(n)$ refers to the transmitted signal and $w(n)$ is defined as noise. Furthermore, energy detection can be formulated as an option between two hypotheses (2).

$$H_0 = Primary\ user\ is\ absent \tag{2}$$

$$H_1 = Primary\ user\ is\ present$$

Afterward, the input metric for spectrum sensing is given by [28]:

- Probability of correct detection (P_d)-Probability of SU detecting that incumbent is present.
- Probability of false alarm (P_f) -Probability of SU declaring that an incumbent is present, but the fact spectrum is free.
- Probability of miss detection (P_m)-Probability of SU declaring that the spectrum is free but there is incumbent presence.

Based on Figure 2 and Figure 3, a band-pass filter (BPF) is needed for the reference signal to measure the signal power in the frequency band in the frequency domain, and the signal power is calculated. The process starts by filtering the input signal $x(n)$ with a band-pass filter to minimize noise and select the interest bandwidth. Then, the BPF output is squared and integrated over a T-interval to determine the obtained signal's power. To differentiate between the two mutually exclusive H_0 and H_1, let T be the determination test statistics defined by energy detection. T can be defined as (3) [2], [30], [31].

$$T = \frac{1}{N}\sum_{n=0}^{N-1}(y[n])^2 \tag{3}$$

Where T is the decision variable, $y[n]$ is referred to as the signal obtained and N is the number of samples. Afterwards, the power representing integrator Y compared to the threshold value (λ) for analyzing the two hypotheses H_0 and H_1.

$$Threshold\ Power\ (\lambda) = nv.^2 .* (sqrt\left(\frac{2}{n}\right) .* qfuninv(pf) + 1 \tag{4}$$

Where nv is noise variance, n is the number of samples collected and pf is the probability of false alarm. If $Y > \lambda$ it agrees to H_1, otherwise H_0. The likelihood of correct detection P_d and the likelihood of false alarm P_f, is crucial to evaluate the detection performance and can define as (5).

$$P_d = P(decision = H_1|H_1) = P(Y > \lambda|H_1)$$

$$P_f = P(decision = H_1|H_0) = P(Y > \lambda|H_0) \tag{5}$$

Where Y is the decision statistic and λ is the decision threshold. The two main quantities for the cognitive radio network are P_f and P_d. To optimize the use of the spectrum and minimize interference between P_f and P_d, it is important to select low and high respectively. With the help of targeting false alarm probabilities, we can practically determine the decision threshold. The relation between P_d and λ is expressed in energy detection technique by (6) [26].

$$P_{\boldsymbol{d}}(\varnothing, \boldsymbol{\tau}) = Q\left(\left(\frac{\varphi}{\sigma^2 w} - \gamma - 1\right)\sqrt{\frac{\tau f_s}{2\gamma+1}}\right) \tag{6}$$

Where γ is SNR, ϕ is the detection threshold and ϕ_x^2, ϕ_w^2 are referred to as the variances of the primary signal $x_i(n)$ and noise $w_i(n)$ respectively. Apart from that to calculate spectrum holes of spectrum frequency can be expressed by (7).

$$Spectrum\ Holes: \frac{length\ PU\ absent}{length\ Y} \times 100 \tag{7}$$

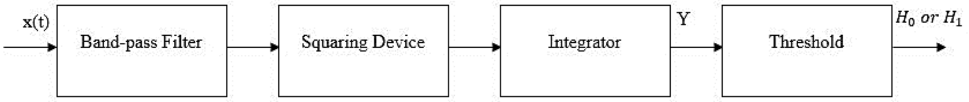

Figure 2. Block diagram of energy detection

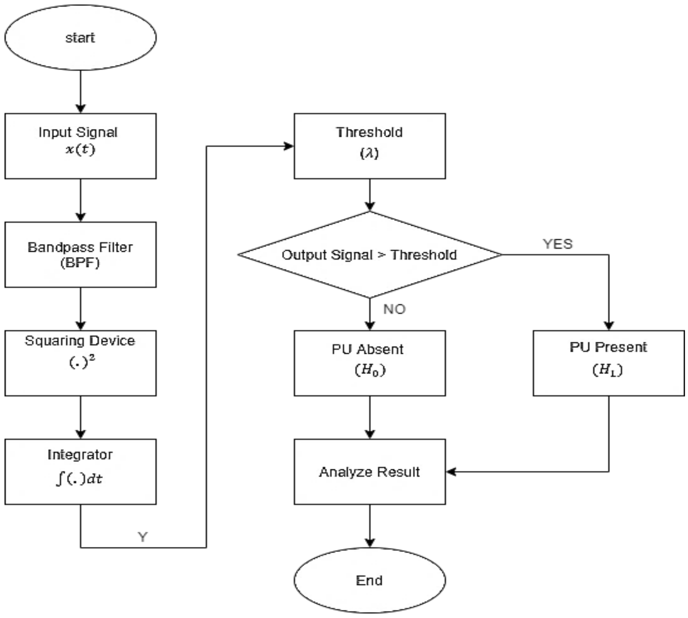

Figure 3. Flow chart of energy detection

2.1. Block diagram on spectrum sense in LabVIEW

This project uses the USRP N210 device with antenna model VERT2450. Furthermore, Figure 4 shows the block diagram in LabVIEW software used to perform spectrum measurement and collect data. The parameters used in the LabVIEW software are indicated in Table 1 [32]. The data will be collected in a loop of frequency between 2.4-2.48 GHz and the data will be plotted in the fast Fourier transform (FFT) power spectrum.

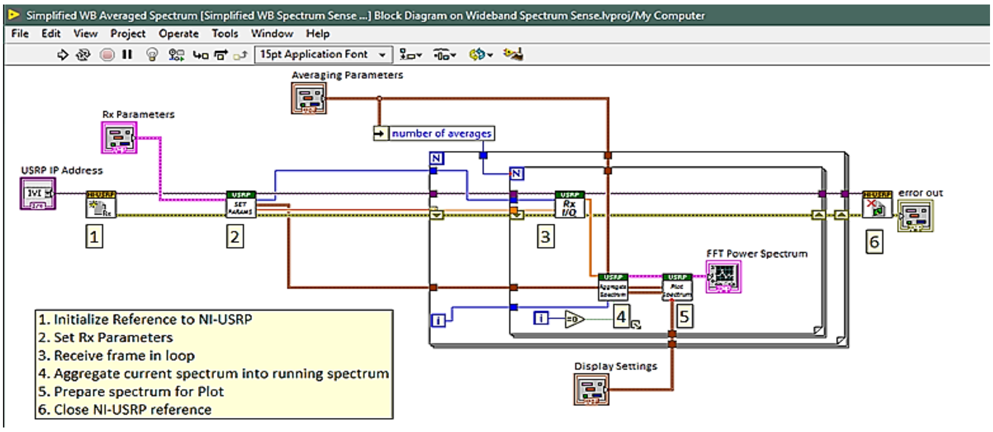

Figure 4. Block diagram on wideband spectrum sense in LabVIEW

Table 1. Parameters in LabVIEW software

Parameter	Value	Parameter	Value
USRP IP Address	192.168.10.2	Start Carrier (Hz)	2.4 Giga (G)
Rate (s)	1 Mega (M)	Stop Carrier (Hz)	2.48 Giga (G)
Acq Duration (s)	1 mili (m)	Gain (dB)	3

3. RESULTS AND ANALYSIS

In this project, the cognitive radio work is carried out as a free band in the ISM band or the industrial and medical radio band. This ISM band is found in several devices such as RF peripherals, Wi-Fi, bluetooth, microwave oven and home appliances which work in-between range 2.4-2.48 GHz. These bands have been settled upon worldwide and unlike most other bands, they do not require a transmitting license to use.

Figure 5 shows the front panel of the wideband spectrum in LabVIEW software, where the spectrum of the received waveform is displayed as FFT. The result shows an overview of spectrum occupancy in 2.4-2.48 GHz. At the frequency 2.43-2.445 GHz, it can sense Wi-Fi in the environment. The wideband spectrum data from LabView software is import into MATLAB. As a result, Figure 6 presents the plotting of frequency in GHz versus power in watts. The total number of samples obtained in this experiment is 80250.

Using (4), where nv is 10^{-7}, n is 80250, and pf is 0.01:0.01:0.1 [33], the red line in Figure 7 shows the threshold value after several experiments. Besides, Figure 7 shows output power between 2.43 GHz and 2.44 GHz, which is below the threshold value. As a result, output power below the threshold values indicates that PU is absent else PU is present.

Based on Figure 8 shows the plotting of the frequency spectrum after the energy detection process. As we can see, there are spectrum holes detected in the range frequency between 2.43-2.44 GHz. From this experiment, the utilization spectrum frequency is 99.39%, and spectrum holes is 0.61%. Eventually, this demonstrates that PU does not completely use the ISM band.

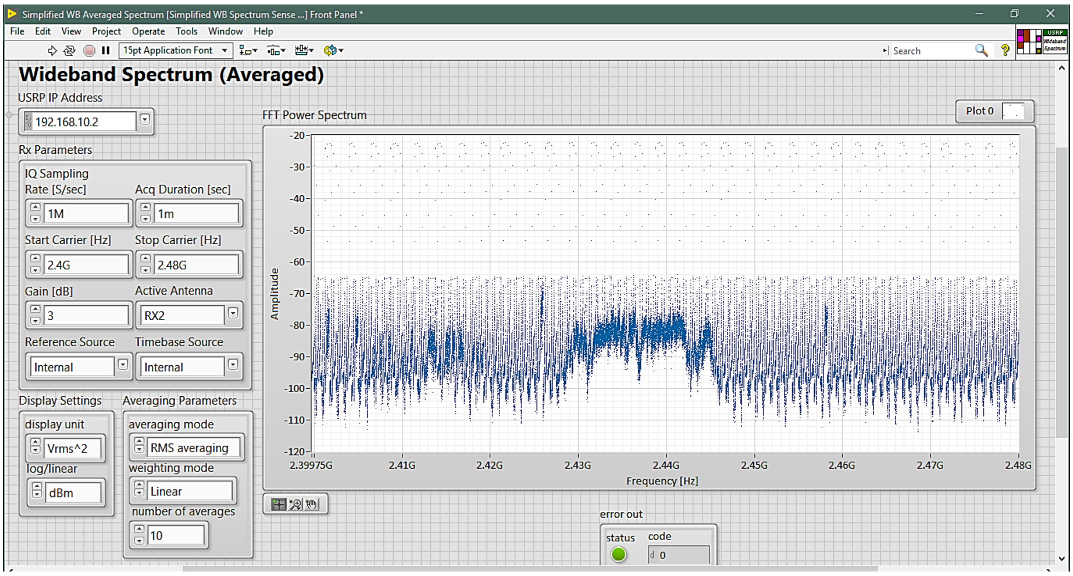

Figure 5. Front panel of wideband spectrum in LabVIEW software

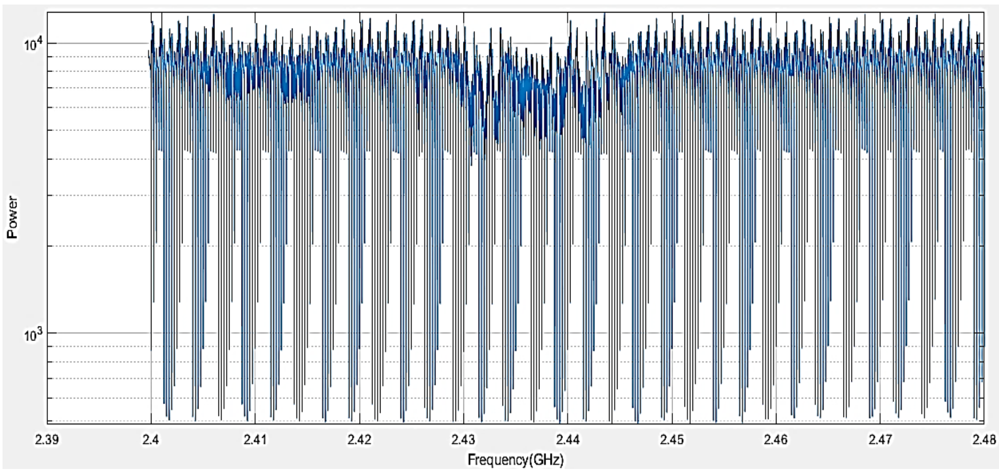

Figure 6. Wideband spectrum data in MATLAB software

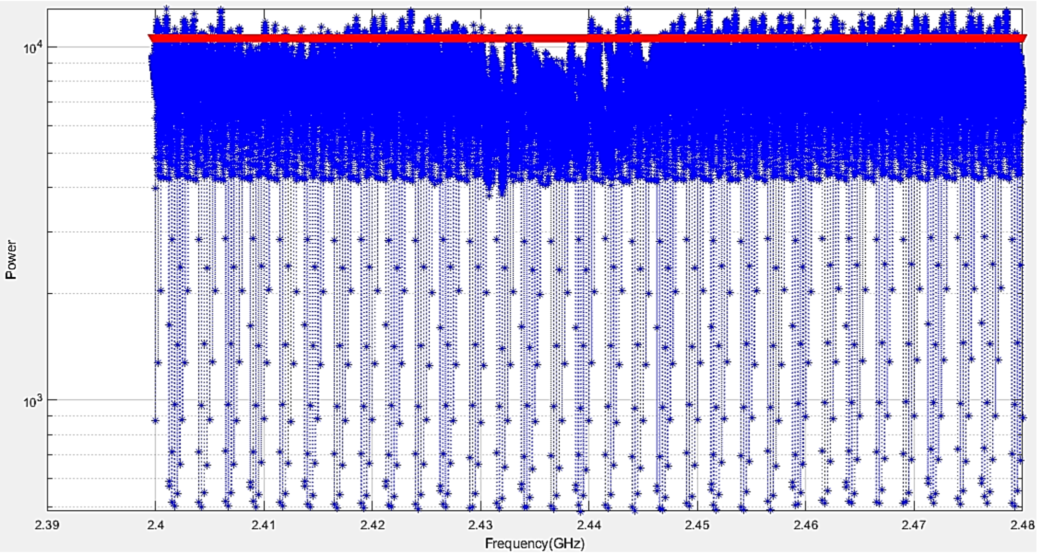

Figure 7. An overview of the signal input data with the threshold value

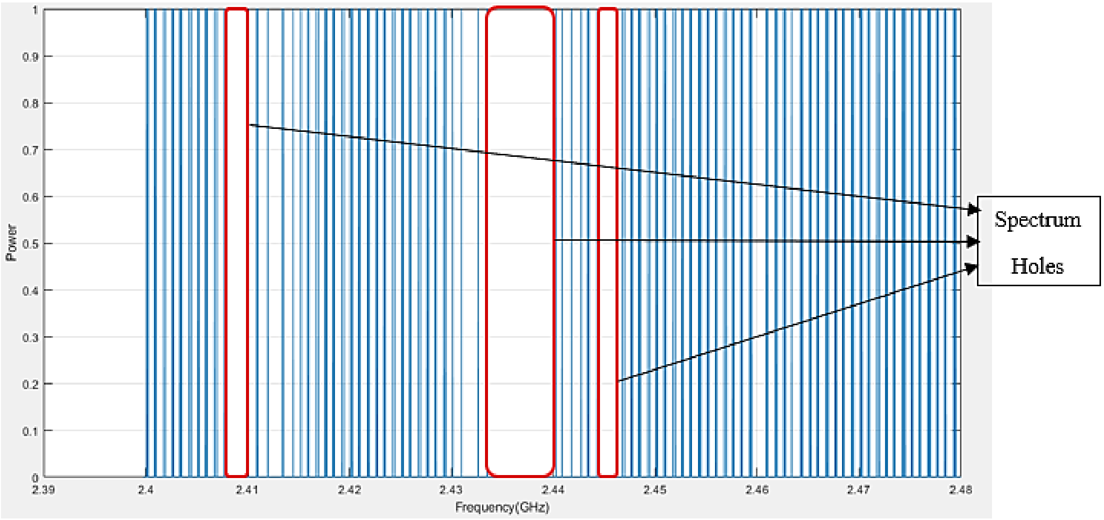

Figure 8. The plotting of the frequency spectrum after the energy detection process

4. CONCLUSION

Using the USRP testbed and energy detection process, this paper identifies and analyzes the ISM band's spectrum holes. The threshold value is determined by the work that previous researchers have done. Experimental findings indicate that in the 2.43-2.44 GHz range, 0.61% of spectrum holes have been detected. This frequency range is adequate for home appliances, RF peripherals, and bluetooth devices to take advantage of the available spectrum in this study. As a result, during the Covid-19 pandemic, SU can be enabled to use a licensed spectrum that does not interfere with any PU, which opens up a new opportunity in cognitive radio. It can also minimize spectrum scarcity by transmitting on the spectrum holes, preventing conflict with the primary license, and perhaps improving the quality of service (QoS).

ACKNOWLEDGEMENTS

The first author wishes to acknowledge the Universiti Teknikal Malaysia Melaka for giving her financial support through the Fundamental Research Grant Scheme (FRGS) provided by the Ministry of Higher Education Malaysia entitled ‘Maximizing throughput using hybrid spectrum access in cognitive radioNetwork for IoT Technology’ (FRGS/2018/FKEKK-CETRI/F00360).

REFERENCES

[1] Cisco, "Cisco Annual internet Report-Cisco Annual internet Report (2018-2023) White Paper," 2020, 10-Mar-2020. Accessed: 22-Dec-2020. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html.

[2] M. H. Mohamad and N. M. Sani, "Energy detection technique in cognitive radio System," *International Journal of Engineering and Technology*, vol. 13, no. 5, pp. 69-73, 2013, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.655.7983&rep=rep1&type=pdf

[3] B. Kumar, S. K. Dhurandher, and I. Woungang, "A survey of overlay and underlay paradigms in cognitive radio networks," *International Journal of Communication Systems*, vol. 31, no. 2, 2017, doi: 10.1002/dac.3443.

[4] J. Mitola and G. Q. Maguire, "Cognitive radio: making software radios more personal," in *IEEE Personal Communications*, vol. 6, no. 4, pp. 13-18, Aug. 1999, doi: 10.1109/98.788210.

[5] J. Mitola, "Cognitive radio for flexible mobile multimedia communications," *1999 IEEE International Workshop on Mobile Multimedia Communications (MoMuC'99) (Cat. No.99EX384)*, 1999, pp. 3-10, doi: 10.1109/MOMUC.1999.819467.

[6] S. Haykin, "Cognitive radio: brain-empowered wireless communications," in *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, pp. 201-220, Feb. 2005, doi: 10.1109/JSAC.2004.839380.

[7] C. Christodoulou, J. Costantine, and Y. Tawk, "Antenna Design for Cognitive Radio," Artech, 2016.

[8] N. Muchandi and R. Khanai, "Cognitive radio spectrum sensing: A survey," *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, 2016, pp. 3233-3237, doi: 10.1109/ICEEOT.2016.7755301.

[9] N. Goyal and S. Mathur, "Spectrum Sensing and Energy Efficiency Strategies in cognitive radio Networks-Perspective and Prospects," *International Journal of Applied Engineering Research*, vol. 13, no. 5, pp. 2395-2411, 2018. [Online]. Available: https://www.ripublication.com/ijaer18/ijaerv13n5_40.pdf

[10] M. Dillinger, K. Madani, and N. Alonistioti, "Software Defined Radio: Architectures," Systems and Functions, Chichester: John Wiley & amp; Sons, 2003. [Online]. Available: https://www.wiley.com/en-us/Software+Defined+Radio%3A+Architectures%2C+Systems+and+Functions-p-9780470851647

[11] B. A. Fette, "History and Background of cognitive radioTechnology," *Cognitive Radio Technology*, pp. 1-26, 2009, doi: 10.1016/b978-0-12-374535-4.00001-1.

[12] H. Arslan, "Cognitive radio, software defined radio, and adaptive wireless systems," *Springer*, 2014, doi: 10.1007/978-1-4020-5542-3.

[13] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer Networks*, vol. 50, no. 13, pp. 2127-2159, 15 September 2006, doi: 10.1016/j.comnet.2006.05.001.

[14] P. Rawat, K. D. Singh, and J. M. Bonnin, "Cognitive radio for M2M and internet of Things: A survey," *Computer Communications*, vol. 94, pp. 1-29, 15 September 2016, doi: 10.1016/j.comcom.2016.07.012.

[15] M. A. Matin, "Spectrum Access and Management for cognitive radio networks," Puchong, Selangor D. E: Springer Singapore, 2018. doi: 10.1007/978-981-10-2254-8.

[16] D. Willkomm, J. Gross, and A. Wolisz, "Reliable link maintenance in cognitive radio systems," *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005*. DySPAN 2005, 2005, pp. 371-378, doi: 10.1109/DYSPAN.2005.1542654.

[17] M. H. Mohamad, A. Sali, F. Hashim, R. Nordin, and O. Takyu, "Clustering Transmission Opportunity Length (CTOL) Model over cognitive radioNetwork," *Sensors*, vol. 18, no. 12, p. 4351, 2018, doi: 10.3390/s18124351.

[18] R. N. Raj, A. Nayak, and M. S. Kumar, "Spectrum-aware cross-layered routing protocol for cognitive radio ad hoc networks," *Computer Communications*, vol. 164, pp. 249-260, 2020, doi: 10.1016/j.comcom.2020.10.011.

[19] P. P. Jain, P. R. Pawar, P. Patil, and D. Pradhan, "Narrowband Spectrum Sensing in cognitive radio: Detection Methodologies," *International Journal of Computer Sciences and Engineering*, vol. 7, no. 11, pp. 105-113, 2019, doi: 10.26438/ijcse/v7i11.105113

[20] M. Chaitra and S. Sinha, "Spectrum Sensing in cognitive radiousing Energy Detection: Comprehensive Analysis," *Proceedings of the Fist International Conference on Advanced Scientific Innovation in Science, Engineering and Technology, ICASISET* 2020, *16-17 May 2020,* Chennai, India, 2021, doi: 10.4108/eai.16-5-2020.2303966.

[21] K. Kockaya and I. Develi, "Spectrum sensing in cognitive radio networks: threshold optimization and analysis," *EURASIP Journal on Wireless Communications and Networking*, vol. 2020, no. 255, 2020. doi: 10.1186/s13638-020-01870-7.

[22] S. Kusaladharma and C. Tellambura, "An overview of cognitive radio networks," *Wiley Online Library*, 2017, doi: 10.1002/047134608x.w8355.

[23] F. Z. E. Bahi, H. Ghennioui, and M. Zouak, "Performance Evaluation of Energy Detector Based Spectrum Sensing for cognitive radiousing NI USRP-2930," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 4, pp. 1934-1940, 2017, doi: 10.11591/ijece.v7i4.pp1934-1940.

[24] A. Kumar, P. Thakur, S. Pandit, and G. Singh, "Analysis of optimal threshold selection for spectrum sensing in a cognitive radio network: an energy detection approach," *Wireless Networks*, vol. 25, pp. 3917-3931, 2019, doi: 10.1007/s11276-018-01927-y.

[25] Y. Arjoune, Z. E. Mrabet, H. E. Ghazi, and A. Tamtaoui, "Spectrum sensing: Enhanced energy detection technique based on noise measurement," *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, 2018, pp. 828-834, doi: 10.1109/CCWC.2018.8301619.

[26] S. K. Ghosh, J. Mehedi, and U. C. Samal, "Sensing performance of energy detector in cognitive radio networks," *International Journal of Information Technology*, vol. 11, pp. 773-778, 2018, doi: 10.1007/s41870-018-0236-7.

[27] S. Debnath, C. Rai, D. Sen, S. Baishya, and W. Arif, "Optimization of secondary user capacity in a centralized cooperative cognitive radio network with primary user under priority," *Engineering Reports*, vol. 2, no. 7, 2020, doi: 10.1002/eng2.12188.
[28] A. D. Sahithi, E. L. Priya, and N. L. Pratap, "Analysis Of Energy Detection Spectrum Sensing Technique In Cognitive Radio," *International Journal of Scientific and Technology Research*, vol. 9, no. 1, Jan. 2020. [Online]. Available: http://www.ijstr.org/final-print/jan2020/Analysis-Of-Energy-Detection-Spectrum-Sensing-Technique-In-Cognitive-Radio.pdf
[29] A. Suri and J. Singh, "Evaluation of Probability of Detection using Energy Detection for Secondary User in Cognitive Environment with Variable Threshold and Sample Values," *International Journal of Advanced Research in Computer and Communication Engineering,* vol. 5, no. 7, Jul. 2016, [Online]. Available: https://www.ijarcce.com/upload/2016/july-16/IJARCCE%20124.pdf
[30] M. Z. Alom, T. K. Godder, M. N. Morshed, and A. Maali, "Enhanced spectrum sensing based on Energy detection in cognitive radio network using adaptive threshold," *2017 International Conference on Networking, Systems and Security (NSysS),* 2017, pp. 138-143, doi: 10.1109/NSysS.2017.7885815.
[31] R. B. Patil, K. D. Kulat, and A. S. Gandhi, "SDR Based Energy Detection Spectrum Sensing in cognitive radiofor Real Time Video Transmission," *Modelling and Simulation in Engineering*, vol. 2018, pp. 1-10, 2018, doi: 10.1155/2018/2424305.
[32] "Antennas," Antennas-Ettus Knowledge Base. Accessed: January 05, 2021. [Online]. Available: https://kb.ettus.com/Antennas
[33] S. Kalamkar, "Energy Detection Simulation: Cognitive Radio," September 29, 2021. Accessed: Apr 08, 2020. [Online]. Available: https://uk.mathworks.com/matlabcentral/fileexchange/44569-energy-detection-simulation-cognitive-radio

BIOGRAPHIES OF AUTHORS

Nur Syahirah Hamdan received her Bachelor of Electronic Engineering with Honours from Universiti Teknikal Malaysia Melaka (UTeM), Malaysia, in 2019. She is currently working on her Master degree at UTeM. Her area of interests are cognitive radio, internet of thing (IoT) and 5G.

Mas Haslinda Mohamad is currently a Senior Lecturer at Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia since May 2011. She obtained her PhD in Wireless Communication from Universiti Putra Malaysia in 2019. Her research interest includes cognitive radio, internet of things (IoT), Long range communication (LoRa) and 5G.

Professor Ir. Dr. Aduwati Sali is currently a Professor at Department of Computer and Communication Systems, Faculty of Engineering, Universiti Putra Malaysia (UPM) since February 2019. She was a Deputy Director at UPM Research Management Centre (RMC) responsible for Research Planning and Knowledge Management from 2016 to 2019. She obtained her PhD in Mobile and Satellite Communications form University of Surrey, UK, in July 2009; MSc in Communications and Network Engineering from UPM, Malaysia, in April 2002 and BEng in Electrical Electronics Engineering (Communications) from University of Edinburgh, UK, in 1999. She is also a Chartered Engineer (C. Eng) registered under UK Engineering Council and a Professional Engineer (P. Eng.) under Board of Engineers Malaysia (BEM).