ENERGY DETECTION BASED MEASUREMENT AND ANALYSIS OF SPECTRUM OCCUPANCY FOR ADHOC COGNITIVE NETWORK RESOURCE FOR FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

Nathaniel Salawu[1[0009-0006-6247-0229]], Adamu Hussaini[2[0009-0003-2503-1399]], Sadiq Abubakar Muhammed[3[0009-0001-6109-4608]], Dauda Usman Suleiman[4[0000-0002-4045-925X]] and Sunday Achimugu[5[0000-0003-4565-2734]]

[1]Telecommunications Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria
nathsalawu@futminna.edu.ng

Abstract. The rising demand for wireless communication systems has led to the exponential growth in the figure of wireless devices. As a result, there is a significant scarcity of available spectrum, which can limit the capacity and quality of wireless communication networks. Cognitive Radio (CR) technology is a good solution to this challenge as it enables the most effective use of spectrum resources by permitting wireless devices to dynamically use under-utilized spectrum. This research presents a measurement of real-time spectrum sensing and detection of white space of cognitive wireless technologies for microwave and wireless communication systems of the Federal University of Technology, Minna main campus. Different spectrum sensing techniques including Cyclostationary Feature Detection (CFD), Matched Filter Detection (MFD), and Energy Detection (ED), have been widely researched. In this research, ED model for enhanced spectrum sensing based cognitive radio technology that is capable of adapting to changing environmental conditions is adopted. Comprehensive field measurements were carried out in the study area using an 8.5 GHz BK precision 2658A Spectrum Analyzer (SA). Specifically, a Received Signal Strength (RSS) of 7.3dBm was obtained at 10m while at a distance of 1500m, 143.93dBm was recorded alongside other similar results. The results were validated by comparing the Standard Deviation (SD) parameter, and Root Mean Square Error (RMSE) based on the adopted ED model with a reference spectrum sensing technique. Thus, the adopted ED technique is a more realistic spectrum sensing technique for microwave and mobile communication systems in the study area and similar environments.

Keywords: Keywords: Cyclostationary feature detection technique, Matched filter detection technique Energy detection technique, Cognitive radio.

1 Introduction

The rapid increase in need for quality wireless communication transmission and reception has brought a lot of challenges on the scarce radio spectrum. Consequently, some researchers claim that this challenge is the result of insufficient techniques for spectrum access [1], instead of the assumption of physical scarcity of spectrum. In recent times, some regulatory agencies have issued spectral license permits for exclusive utilization of some dedicated frequency bands. Previous works have revealed that many of the licensed radio signal spectral bands may not be efficiently put to use in space and time [2] giving rise to unused "white spaces" in the time-frequency domain at any particular area. The utilization of spectrum is largely around a certain portion of the spectrum while a large expanse of the spectrum may not be utilized as some other part as seen in Fig. 1.

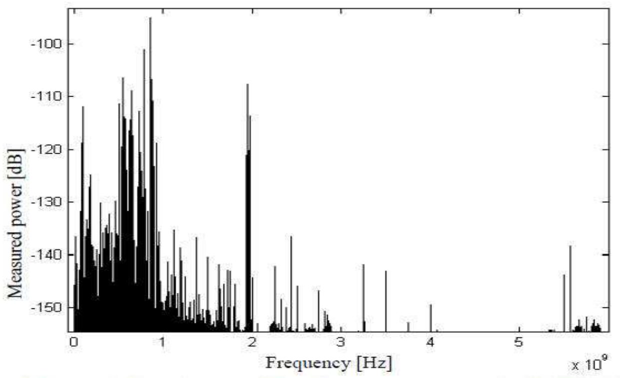

Fig. 1. Spectrum Utilization Measurements [2]

As can be observed from Fig. 1, spectrum usage is more serious and competitive at frequencies lower than 3 GHz. It is also clear that the spectrum is not fully utilized around the frequency bands of 3-6 GHz. On the other side, static spectrum allocation strategies will not allow for re-utilization of the rarely used spectrum allotted to licensed users by unlicensed users. This means that the radio spectrum could be better utilized than the traditional usage. To achieve this, there is a need for a careful analysis of the spectrum occupancy to make precise recommendation on the extent of spectrum utilization. This has called for a new communication standard by which unlicensed (secondary) users to quickly access the free or vacant spaces which are reserved for licensed (primary) users in a process known as cognitive radio.

The knowledge behind the CR standard is the assessment of the free frequency bands assigned to the primary users (licensed users) taking the secondary users (unlicensed users) into consideration without any interference imposed on the licensed users' transmission and reception [3, 4]. Fig. 2 depicts the cycle process of cognitive radio comprising four phases described as spectrum sensing phase, spectrum decision phase, followed by spectrum mobility phase and lastly, spectrum sharing phase [5]. First, in the CR spectrum sensing process, the CR categorizes the available portion of the spectrum section that can be utilized. It can also sense the PU presence when it is restored into operation in a way that guarantees an efficient track of the network. The second phase is the spectrum decision process. The CR selects the correct frequency band depending on the user's Quality of Service requirements (QoS) and spectrum requirement. In the third process also known as spectrum sharing, the spectrum utilization is coordinated between the SUs and PUs in a way that maintains the interference value below a certain threshold. Finally, the CR frees the channel when the PU begins to use it during the stage of spectrum mobility. This means the spectrum must be aware and update dynamically [6].

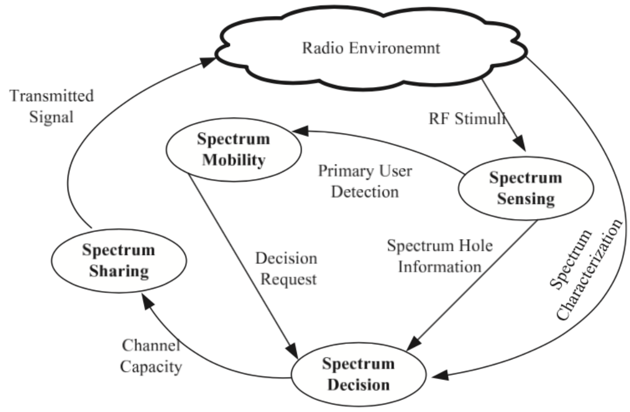

Fig. 2. Cognitive radio cycle [5]

The achievement of CR largely rests on its ability to sense 'spectral holes' and the backing of the regulatory bodies for granting CR permission to use licensed frequency bands is another gain. The initial stage of CR implementation is the investigation of the accessibility of the momentarily unoccupied spectral resources such as time, frequency and lastly, space. The projected technology known as Dynamic Spectrum Access (DSA) is one of the promising possible solutions to these challenges. DSA configurations are of two types and these are the Concurrent Spectrum Access (CSA) model and the Opportunistic Spectrum Access (OSA) model [7]. The OSA technology allows SU to utilize the radio spectrum if only active PUs is in session. Conversely, the CSA technology also called underlay CR allows Pus and Sus to co-exist at the same time within the same geographic location area. However, the interference posed by the SUs to the PUs must be kept within an acceptable pre-determined value of threshold also known as the interference temperature limit value [8].

2 Cognitive Radio Techniques

There are several techniques to sense idle spectrum channels and utilize them to increase the networks efficiency. In this study, we looked at MFD, CFD and ED.

2.1 Matched Filter Detection (MFD)

Spectrum sensing based on MDF uses pilot signals values that are fixed to the primary signal value so as to sense the availability of a PU. These pilot signals values are used in transmission and reception of signals for synchronisation and, typically contributes between 1% and 10% based on the total signal power value transmitted. The unidentified primary signal value is convolved along time reversed form of the pilot signal. Assuming the model signal is present in the unidentified signal wave, then the PU is taken to be present, or it is otherwise taken to be absent. The system block diagram of an MFD-based spectrum sensing technology is presented in Fig. 3 and the mathematical model is described in equation (1)

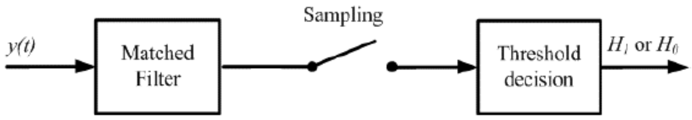

Fig. 3. Matched filter detection technique

$$Y[n] = \sum^{\infty}_{k=-\infty} h[n-k]y[k] \quad (1)$$

2.2 Cyclostationary Feature Detection (CFD)

CFD exploits statistical characteristics assigned to the primary signal so as to find the availability/absence of primary users with the aid of spectral correlation. Equation (2) presents the equation for implementing CFD while Figure 4 depicts its block diagram.

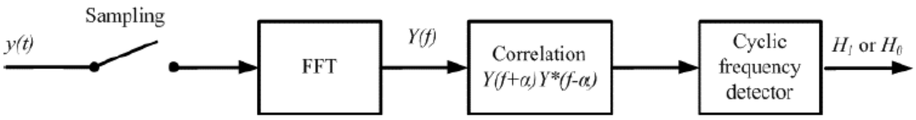

Fig. 4. Cyclostationary feature detection technique

$$r_y\,[n,\tau] = \mathbb{E}[y[n]y*\,[n+\tau]] \quad (2)$$

2.3 Energy Detection (ED)

ED spectrum sharing technique is based non-coherent detection scheme that determines the energy level of the received signal. It compares it with an established threshold value that is based on the level of noise flood [9]. In ED-based spectrum sensing utilization, the received signal obtained is filtered around the bandwidth concerned and squared. The signal is later integrated over a specified observation interval value. This ensures that the measure the received signal's energy level is compare with the detection threshold [10,11] . Fig. 5 shows the detailed block diagram of ED-based spectrum sensing utilization while equation (3) presents its mathematical relationship.

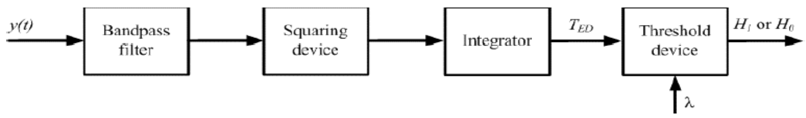

Fig. 5. Energy Detection Technique

$$y(n) = x(n) + w(n) \tag{3}$$

The main criteria for spectrum sensing is function of signal detection in a negative Signal-to-Noise-Ratio (SNR). Owing to the dynamic behaviour of radio and environmental condition, CR must have adaptation ability and to be able to dynamically change the all necessary communication parameters appropriately. A CR senses the spectral environmental conditions over a wide signal frequency band and exploits this signal information to opportunistically deliver wireless links that can best meet the requirement of the user in addition to its radio environments [12]. In this paper, ED technique has been deployed to develop an improved cognitive radio network under different environmental variation.

3. System Model

ED method was deployed on the measured energy of the accessible radio frequency signal in the communication band of the CR. The result obtained is compared against a predefined threshold level. The predefined threshold value is measured once a noise signal is sensed within the channel only. As soon as all levels of energy drops below the established threshold level (E_{th}), the spectrum is registered as available. If the estimated value of energy level is greater than the defined threshold, it is marked as occupied. The purpose of verifying the occupancy status of the PU is to know if the PU is using the spectrum or not at any given time so as to know when the SUs can utilize the spectrum. SUs can only the available spectrum when the PU is not inactive. The ED technique models the temperature interference to sense the white space. The detected white space will be allocated to unused users based on the RSS of the primary user. The ED technique does not need the prior information of the primary user making it to be less complex when compared with other methods. Fig. 6 represents the graph of Interference temperature evaluation in (a), an ideal while the plot in (b) is the generalized version.

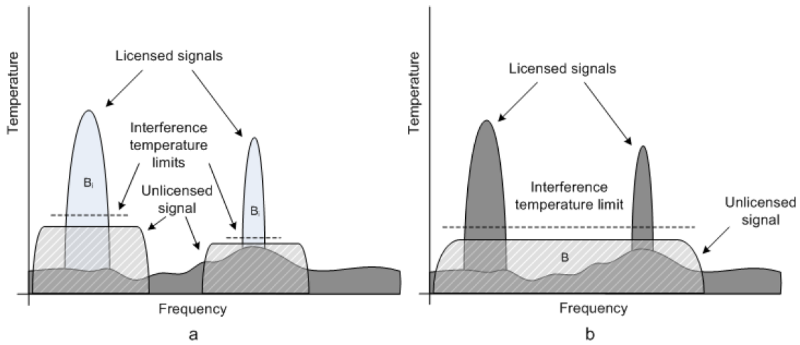

Fig. 6 Interference temperature evaluation model of an ideal (a), and the generalized (b).

Considering the PU's power of all the nodes connected, the Gaussian noise is given by:

$$kBT_L(f_c)\,(B - B_i) + kBT_N \sum\nolimits^{n}_{j=1} B_j \le \sum\nolimits^{n}_{j=1} B_{jpj} \quad \forall_{1 \le I \le n} \tag{4}$$

where B stands for the bandwidth and T_L is the temperature limit.

Assuming p is the power and it is a function of the bandwidth B_i, then p is given by:

$$P \le min_{i \varepsilon [1,n]}\ [(B_i k / M_h)\ [\ T_L(f_i) - T_1\ (f_i\ , B_i)] \tag{5}$$

i is the different channels of the spectrum. If the unlicensed signal does not overlap, the spectral density of the derived power is obtained as given in equation (6).

$$P \le \{Bk / M_k\ [T_L\ (f_c)]\} - \{1/BM_h\ [\ \int_{fc-B/2}^{fc\ +B/2} S(f)\ df\ ]\ \} \tag{6}$$

(6)

Equation depicts the power of received signal when the temperature limit T_L and M_h are considered. The number of times a channel is occupied within a given time period is therefore given by equation (7).

$$Duty\ Cycle = [Signal\ Occupation\ period\ (n) / Total\ Observation\ period\ (m)] \times 100\ \% \tag{7}$$

A threshold value better called the decision threshold is endowed with the main feature in evaluating the true spectrum occupancy in the signal frequency band of concern. The energy detection technique of spectrum sensing process compares the value of the received signal of a given frequency band with an established threshold for further decision.

In order to take measurement, SA was used to obtain the RSS of the study area with radial base station (BS) coverage area of 2km. The experimental data were taken at distances ranging from 100m to 1000m, within the coverage area of the BS, for three radio paths. The measurements were conducted during the day time. For every route, RSS is measured from a reference distance position of 100m taking from the base station and a successive interval of 100m to a distance of 1000m. The details of the results obtained and their discussion are presented in section 4 of this paper.

4 Results and Discussion

The corresponding RSS against the distance measured from three selected location areas is shown in Fig. 7. RSS was measured from the Frizzlers microwave source, 10m -100m away from the base station. The RSS plot against measured distance from the microwave oven is presented in Fig. 8. Table 1 shows the RSS evaluated from the reference position distance of 100m up to 1000m for each of the three routes examined. As can be seen from Table 1, the RSS decreases as the distance from the base station (BS) to mobile station (MS) increases, with the exception of some measured points along the routes, where the RSS fluctuate owing to environment conditions.

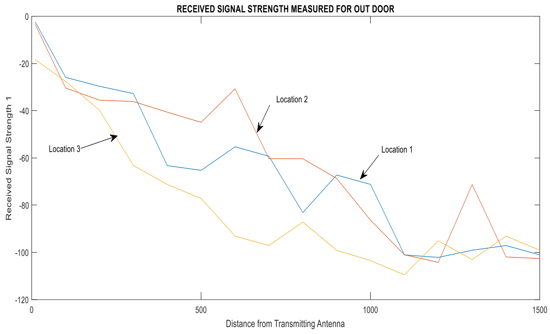

Fig. 7 RSS vs distance measured from three selected location area

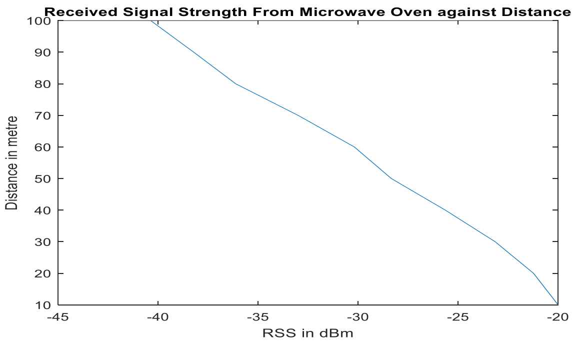

Fig. 8 RSS vs Distance measured from the microwave oven.

Table 1 shows the measured RSS of the study area. From the results obtained, the spectrum band between 2.409GH and 2.509GHz was the least utilized. A noise floor threshold of -60dBm was observed. By implication, the signal strengths beyond the -60dbm power are detected and taken as the signal point threshold. This threshold is used to detect white spaces. The 2.40GHZ-2.45 GHz is sparsely empty from the research findings of the studied area when the ED technique with reference to MFD and CFD is deployed.

Table 1. Received Signal Strength from the base station at three different location

T-R Separation Distance (m)	Time (s)	RSS (dBm)		
		i	ii	iii
100	0	-25.00	-30.41	-27.63
200	50	-26.64	-35.52	-39.82
300	100	-28.75	-36.12	-43.25
400	150	-33.26	-40.62	-51.21
500	200	-35.24	-44.93	-57.18
600	250	-40.29	-30.72	-63.10
700	300	-43.27	-50.22	-67.08
800	350	-40.14	-60.33	-70.13
900	400	-52.23	-68.67	-72.10
1000	450	-61.21	-66.31	-73.50

From the measured values, it is evident that the frequency channel that is the next highly occupied in the 2.4 GHz frequency band is given as channel 11 with the frequency of 2.462 GHz. Given in Fig. 9 and Fig. 10 respectively is the spectrogram for Mean and Max channel occupancy measurements respectively.

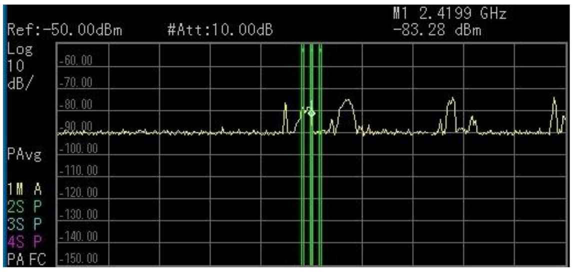

Fig. 9 Spectrogram of mean channel occupancy over the duration

The highest curve points present the highest level of occupancy detected in a given signal channel. The mean points indicate the average occupancy detected in that specific channel within the duration period. furthermore, the channel mean occupancies presents an exciting awareness that channel occupancy levels vary greatly but has an average to greater part of the band to be is free. It can also be seen in the graphical results that there are some WLAN users within the 2,400 and the 2,470 MHz frequency band. Again, some signals with low powered and narrowband whose occupied bandwidth varies between the frequencies of 2 and 3 MHz were equally noticed to belong to a few numbers of systems using audio/video wireless transmission and reception systems. Large number associated with the narrowband activity were detected at f_c = 2,406, 2,427 and 2,490 MHz respectively.

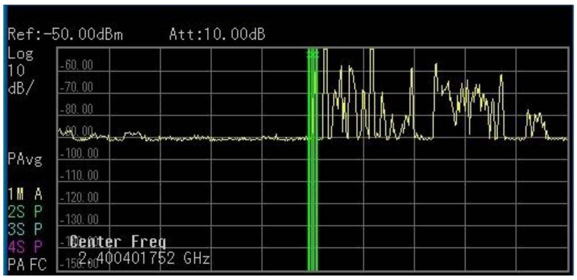

Fig. 10 Spectrogram of Max channel occupancy over the duration

From the analysis of the 2.4 GHz frequency band results, it is seen that channel 1, channel 6, and channel 11 are the most utilized. The most utilized is channel 1, followed by channel 11. This means, the least utilized is channel 6 when 2.4 GHz frequency band is considered. Channel 1 of the system is used the most where maximum occupancy level is recorded as 11%. Channel no. 6 is found to be the moderately occupied channel with maximum occupancy level of 7%. Channel 11 was the least occupied channel with maximum occupancy level of 3%. Fig. 11 shows the spectrogram for the occupied bandwidth in the location area where signal data were collected. The result depicts that there were no activities going on for most of the periods of the measurements. This were observed from the spectrogram because there were no active wireless access points within the period of the data collection. It is important to note that within these locations, only location with few bands presents some significant activities in the spectrogram. Because of the low occupancies in some locations, the activities on this band were not captured on the spectrogram.

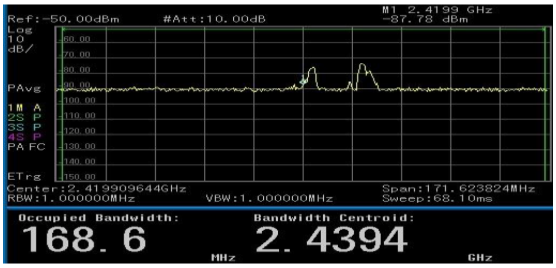

Fig. 11 Spectrogram of the occupied bandwidth.

The knowledge of relative bandwidths is that, it may be expected to have a percentage of a channel with a bandwidth B that is above noise threshold at a given time. For instance, for a given 40MHz IEEE 802.11n channel, a frequency of 33.75MHz may be used by subcarriers and a 50% relative bandwidth is expected to be at least 16.86 MHz of the occupied channel above the noise threshold to mark it occupied with full confidence. The occupied bandwidth therefore shows the percentage of the bandwidth that is available relative to the total bandwidth of the frequency band being evaluated.

5 Conclusion

In this study, an investigation of a real-time measurement and analysis of ED spectrum sensing for cognitive radio white space in some selected campus areas of the Federal University of Technology targeting frequency spectrum range between 2.35GHz and 2.5GHz has been done. The research is an eye opener about the available white space cognitive radio spectrum access on the campus to ease the problem of spectrum “scarcity” in the campus area.

References

1. Chiang R. I. C., Rowe, G. B., and Sowerby K. W. A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio. IEEE Vehicular Technology Conference, pp. 3016–3020. IEEE, Dublin (2007)
2. Barlemann L., and Mangold S. Cognitive Radio and Dynamic Spectrum Access. 1st Edition, John Wiley and Sons, USA (2020).
3. Mitola J. Cognitive radio architecture in wireless networks: Principles and Applications. In: Fitzek, F.H.P, Katz, M.D. (eds) pp. 234–311, springer, Dordrecht (2021).
4. Suseela B and Sivakumar D. Certain investigations on effective rate adaptation in cognitive radio with channel characteristics. Int. J. Netw. Virtual Organnization., 19 (2), pp. 373–384 (2018).
5. Ali, S., and Hamouda, W. Advances on Spectrum Sensing for Cognitive Radio Networks : Theory and Applications. IEEE Commun. Surv. Tutorials, 5(1), pp.1–29 (2016)
6. Yucek, T., and Arsian, H. .A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications. IEEE Commun. Surv. Tutorials, 11 (1), pp. 116–130 (2009).
7. Wang, B., and Liu, K.J.R. “Advances in Cognitive Radio Networks : A Survey. IEEE J. Sel. Top. Signal Process., 5 (1), pp. 1–20 (2016)
8. Eberechukwu, P.N., Umar, D..S., Mohd, A., Kamaludin, M.Y., and Sarijari, M. A. Interference Temperature Measurements and Spectrum Occupancy Evaluation in the Context of Cognitive Radio. Indones. J. Electr. Eng. Comput. Sci. 10(3), pp. 1007–1012 (2018)
9. Yoo, S. K *et al.*, Entropy and Energy Detection-based Spectrum Sensing over F Composite Fading Channels. IEEE Jounal Sel. areas Commun., 16 (7), pp. 1–30 (2018).
10. Lorincz, J., Ramljak, I., and Begušić, D. A review of the noise uncertainty impact on energy detection with different OFDM system designs. Comput. Commun., 148(10), pp. 185–207 (2019)
11. Sofotasios, P. C., Zhang, L., and Freear, S. Energy Detection − Based Spectrum Sensing over κ−μ and κ−μ Extreme Fading Channels. IEEE Trans. Veh. Technol., 62(3), pp. 1031–1040 (2013)
12. Zhang, l., Xiao, M., Wu, G., Alam, M., Liang, Y., and Li, S. Dynamic Spectrum Management for 5G: A Survey of Advanced Techniques for Spectrum Sharing in 5G Networks. IEEE Wirel. Commun., 4(11), pp. 44–51 (2017).