INTELLIGENT AUTOMATION & SOFT COMPUTING, 2017
https://doi.org/10.1080/10798587.2017.1364931

An Efficient Optimized Handover in Cognitive Radio Networks using Cooperative Spectrum Sensing

H. Anandakumar[a] and K. Umamaheswari[b]

[a]Department of Computer Science and Engineering, Akshaya College of Engineering and Technology, Coimbatore, India; [b]Department of Information Technology, PSG College of Technology, Coimbatore, India

ABSTRACT

Cognitive radio systems necessitate the incorporation of cooperative spectrum sensing among cognitive users to increase the reliability of detection. We have found that cooperative spectrum sensing is not only advantageous, but is also essential to avoid interference with any primary users. Interference by licensed users becomes a chief concern and issue, which affects primary as well as secondary users leading to restrictions in spectrum sensing in cognitive radios. When the number of cognitive users increases, the overheads of the systems, which are meant to report the sensing results to the common receiver, which becomes massive. When the spectrum, which is in use becomes unavailable or when the licensed user takes the allocated band, these networks have the capability of changing their operating frequencies. In addition, cognitive radio networks are seen to have the unique capability of sensing the spectrum range and detecting any spectrum, which has been left underutilized. Further this capability of recognizing the spectrum range based on the dimensions detected, allows for determination of the band, which may be utilized. The main objective of this paper is to analyze the cognitive radio's spectrum sensing ability and evolving a self-configured system with dynamic intelligence networks without causing any interference to the primary user. The paper also brings focus to the quantitative analysis of the two spectrum sensing techniques namely; Energy Detection and Band Limited White Noise Detection. The estimation technique for detecting spectrum noise is based on the detection of probability and probability of false alarms at different Signal-to-Noise Ratio (SNR) levels using Additive White Gaussian Noise signal (AWGN). The efficiency of the proposed Cooperative CUSUM spectrum sensing algorithm performs better than existing optimal rules based on a single observation spectrum sensing techniques under cooperative networks.

KEYWORDS

Cognitive radio networks; handover; spectrum sensing; spectrum allocation; spectrum detection; CUSUM

1. Introduction

The conventional cellular systems have been replaced to a considerable extent with the present advanced wireless communication system. There is a large requirement for higher data rates due to increased usage of mobile services, but the entire spectrum is allocated only to available users. Moreover, the frequency spectrum is allocated to licensed primary users there by restricting a particular band of spectrum to secondary users and segregating their utilization, hence the availability of free frequency band becomes impossible. Frequency range is further diversified into channels with particular encoding and modulation schemes, which do not allow interference between users. These regulations work efficiently for certain frequency bands, but often they are just a legacy of telecommunication standards.

Wireless technology has always been growing rapidly and even more so now, with the greater traffic in the networks and greater spectrum allocation to users as a result of spectral crowding. With the limited bandwidths that are available overcrowding is unavoidable. The cognitive radio concept was proposed by Mitola (1999) due to the following reasons:

The cognitive radio (CR) has been a discovery with an enhancing field of research, where any device can automatically sense the environmental conditions and the communication parameters Jeongkeun et al. (2009) can be adopted appropriately. The main components of Cognitive Radio Networks are primary networks and cognitive networks Haykin (2005). The primary network consists of the primary user (PU) and the cognitive network consists of the secondary user (SU) Lu, Huang, Zhang, and Fan (2012). The primary network users are known as the licensed users and the secondary network users are known as the unlicensed users McHenry, et al. (2007). Using cognitive radio technology the primary user's unutilized frequency bands are efficiently used by the secondary user. The cognitive radio technology is built upon software defined radio (SDR) technology. Cognitive radio networks (CRNs) are divided into two types i.e.; centralized and distributed. The centralized network is also known as infrastructure oriented network. Here the CR users are being managed by the secondary base station users. The distributed network is known as infrastructure less network.

The CRN architecture is shown in Figure 1, which is classified into infrastructure oriented CRN and infrastructure less, CRN shows that, in the infrastructure oriented cognitive radio network, the cognitive radio user (CRU) has a Base Station (BS), which is a central network entity in cellular networks. The CR user is controlled by MAC unit.

In infrastructure less CRN the CRUs communicate in an ad-hoc manner with each other on both spectrum

CONTACT H. Anandakumar anandakumar.psgtech@gmail.com

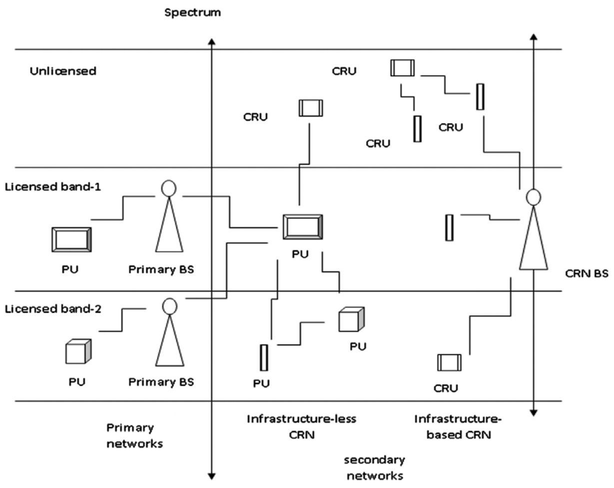

Figure 1. CRN Architecture.

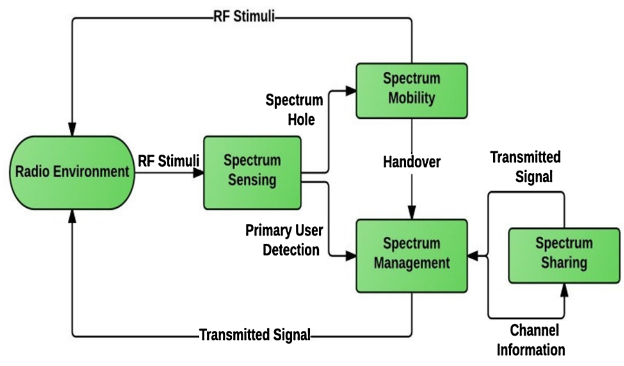

Figure 2. Cognitive Radio Cycle.

bands (licensed and unlicensed). According to Federal Communications Commission (FCC), spectrum utilization is either underutilized or over crowded in frequency bands. The cognitive radio networks introduce the dynamic spectrum access method, which is fully reconfigurable Pacheco-Paramo et al. (2009). In this method, the network senses the environment automatically and satisfies the user's demands using, which the communication parameters can be changed.

Cognitive radio network faces many research challenges, which include network initialization issues, hidden incumbent problems, and spectrum allocation issues. The spectrum, which has been used, can be reused by cognitive radio technology. The major factor that limits spectrum reuse is interference, which occurs due to noise during the transmission of other radio signals Mishra, Sahai, and Brodersen (2006). Controlling this interference, the performance of wireless networks can be greatly increased. The functions of cognitive radio are: Spectrum sensing, Spectrum management, Spectrum mobility and Spectrum sharing.

In cognitive radio, spectrum sensing is the main function. In this process, the spectrum, which is unused, is detected and these spectrums are used opportunistically. In spectrum management, the cognitive radio selects the channel based on the requirement for "user communication" after detecting the spectrum holes Pei, Li, and Ma (2013). In spectrum mobility, whenever the licensed user is not using the spectrum the spectrum with lower priority seamlessly moves to the next available vacant channel. Figure 2 shows the cognitive radio cycle, which is the building block of the entire process.

This paper is organized as follows: Section II provides an overview of spectrum sensing. Section III gives a description of the system model, along with conventional and cooperative sensing models reviewed. Section IV gives a description of the cooperative CUSUM algorithm. Section V plots all the simulations and describes the performance of each scheme. Section VI provides a conclusion with further enhancement.

2. Related Information and Research

2.1. Cooperative Sensing

When there is a need to increase the sensing capabilities of each cognitive radio all those cognitive radios in the network will begin to send the sensed data to a centralized location (fusion center), i.e. All CRs are in synch with each other and send the status of the channel Quan, et al. (2009) to the central fusion. In this scenario, the transmitter is transmitting for the primary licensed user while the channel monitors all cognitive radios for the free spectrum, continuously.

The signals that are received from the different radio networks are then adjusted to align with the cognitive radio networks by the core station. When the free spectrum becomes available all the CRs in the network will send the data to the fusion center and here all decisions regarding the availability of the spectrum will be made. Considering the same threshold (λ) level at each CR, the false alarm probability (Qf) and missed detection probability (Qm) for cooperative sensing can be found.

2.2. Non-cooperative Sensing

On the other hand in the non-cooperative sensing, all the CRs sense the radio spectrums separately and send the data while they do not possess any information of other CRs in the vicinity. Here the position of each CR is different and the channel itself is imperfect and all CRs have varying signal to noise ratios as well as threshold levels Cabric, Tkachenko, and Brodersen (2006). This leads to ambiguity at the fusion center regarding the correctness of the situation. This leads to difficulty in sensing the status of the primary receiver. In order to detect the signals sent by the primary transmitter it is necessary to detect the primary user transmission. This variety of spectrum sensing is also called primary transmitter detection.

2.3. Spectrum Management

The mobile users provided with high bandwidth by cognitive radio techniques like dynamic spectrums have access to a heterogeneous wireless environment. There are a few very innovative and unique spectrum management functions such as spectrum sharing, spectrum decision, spectrum sensing, and spectrum mobility. Cross-layer design approaches are particularly recommended more from the point of view of infrastructure networks, which need central network entities and impromptu networks, which depend on distributed coordination. The greatest challenge that one sees in CR networks is in the integration of functions in many layers of the protocol stack, which will allow the CR users to communicate with reliability over dynamic spectrum environments Crow, et al. (1997). Spectrum holes may be analyzed very effectively by detecting the primary user that receives the data, which are available within a range.

But in real time it is indeed a complex process wherein the cognitive radio networks are to measure the channel between a primary receiver and a transceiver. Hence we shift the focus to primary transmitter detection. Here we describe many sensing methods which are classified as follows:

- Non-cooperative detection. This method of spectrum sensing ensues when a cognitive radio configures according to the signal it senses and the data, statistics and information with which it is preloaded.
- Cooperative detection. In cooperative detection, cognitive radio sensing will be completed by different radio networks within a cognitive system.
- Spectrum assignment. Cognitive radio consigns the unused spectrum from the primary user to the secondary user. The interference can be restricted and limited by the spectrum management between primary user and cognitive radio devices. Numerous glitches and difficulties arise while allocating the spectrum to the secondary users.

2.4. *Spectrum Utilization*

The spectrum utilization is disproportionately and unequally distributed, which causes the problem Bayhan, Gur, and Alagoz (2007) of spectrum allocation and management. Network entry, network initialization and the hidden incumbent problem cannot be overcome by prevailing protocols. Mobility is an issue, which is as yet unexplored and uncharted in cognitive radio and it can be overcome by a cognitive radio architecture known as LEO-satellite assisted CR architecture.

2.5. *Handover Procedure for CRN*

The handover technique is applicable for all secondary users in cognitive radio networks.

When the primary user arrives, the secondary user has to vacate the channel. This forced termination of secondary user can be overcome by a scheme known as fraction guard channel assignment, but the value cannot be adjusted adequately, and results in increasing throughput of unlicensed users.

Figure 3 shows the effective and adaptive channel handover procedure for CRN. In cognitive radio networks the CHP (channel handover process) is a process, which is time-consuming Suganya and Anandakumar (2013). A handover strategy is shown between the CHP duration and user activities to identify the optimal exchange. The secondary nodes make assessment to commence the channel handover process or terminating the activity of ongoing users by only tracking confined information. The structure varies according to self-motivated circumstances of the channels thereby increasing the throughput resulting in the reduction of handover frequency.

2.6. *Sharing of Spectrum*

Spectrum sharing is done between the primary user and the secondary user. The spectrum allocation is carried out with two main goals: (1) the systems bandwidth reward is maximized, and (2) the secondary user's access fairness is increased by using Band limited AWGN. Band allocation optimizes the entire performance of the system, which is an optimization problem Cabric, Mishra, and Brodersen (2004). A better trade-off is provided between the access fairness of secondary users in the existing method.

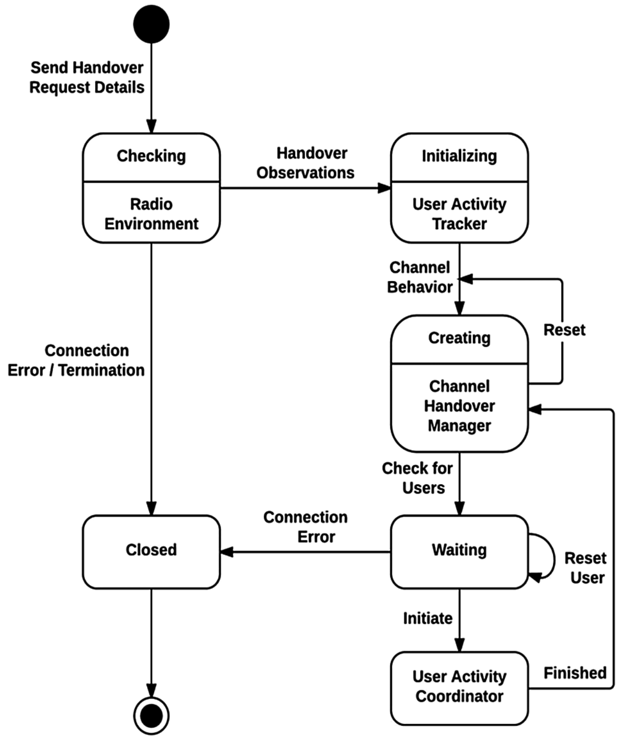

Figure 3. Channel Handover Procedure for CRN.

3. System Model for Cooperative Sensing

Cognitive radio cooperative spectrum sensing occurs when a group or network of cognitive radios share the sensed information they gain. This provides a better picture of the spectrum usage over the area where the cognitive radios are located. In general, change cooperative detection refers to identifying abrupt changes in any phenomenon (such as some characteristic of data such as; amplitude, mean, variance, frequency, etc.) at a greater speed than expected. During handover, cognitive radio spectrum sensing becomes a challenging task due to shadowing and time varying multi-path fading effects.

3.1. *Threshold Optimization based on Cooperative CUSUM (SNR = 15 dBm)*

This makes the channel from the primary transmitter to the secondary user inefficient. When the SNR values become very less, the task of detecting the primary user based on the observation of a single secondary user becomes very complex. This problem can be overcome by applying cooperative spectrum sensing. This allows multiple secondary users to collaborate by leveraging the spatial diversity inherent in the radio environment. The scenario for handover management given in Figure 4 is followed for estimation of efficient spectrum analysis. A CRN requires the following methodology; band sensing, management, mobility, and sharing. A certain amount of noise is vital during transmission of radio signals for estimation of efficiency.

The noise signal added for analyzing the efficiency is Additive White Gaussian Noise (AWGN) and the detection technique used is Band Limited White Noise Akyildiz, et al. (2008). The noise attenuated signal is passed to the receiver

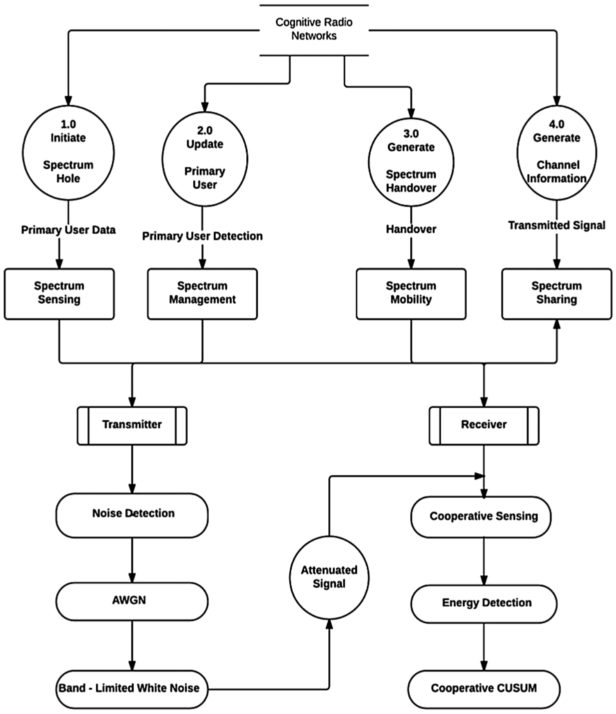

Figure 4. Overview of Proposed System Model.

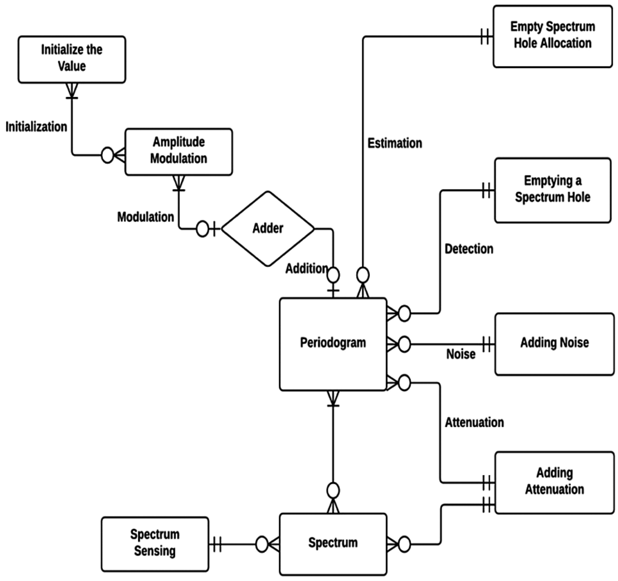

Figure 5. Implementation of Spectrum Sensing Techniques.

side and the spectrum sensing method called Cooperative CUSUM. Cooperative CUSUM algorithm Sarathambekai and Umamaheswari (2017) is followed to analyze the SNR level.

4. Proposed Methodology

4.1. Spectrum Sensing

The function and challenge of the secondary user is to determine the presence of primary users in a licensed spectrum and then to immediately leave that frequency band. The corresponding primary radio emerges to avoid interference to licensed users.

Spectrum sensing techniques can be categorized in to two types:

Direct frequency domain approach - allocation is carried out directly from the signal.

Indirect time domain approach - allocation is performed using autocorrelation of the signal.

4.1.1. Steps in Spectrum sensing

Spectrum sensing and allocation are the initial steps in the implementation Anandakumar and Umamaheswari (2014) of Cognitive radio system.

The steps required for spectrum sensing shown in Figure 5 is as follows:

- **Initialization of** Carrier Frequency Signals, Message Frequency, and Sampling Frequency.
- **Amplitude modulation of** frequency band respective to user data.
- **Addition** of all modulated signals to produce a transmitting signal.
- **Estimation of** power spectral density of the received signal.
- **Detection of available** and vacant holes for allocation to new users.
- **Quantity of noise attenuated.**
- **15 Percentage** of Attenuation is introduced.

4.2. Energy Detection over AWGN Channels

The relative energy detection of noise in an AWGN channel is typically described as follows:

- Initially, signals from all primary users are transmitted.
- At the recipient side, signal range is calculated by adding all the received signals.
- Meanwhile, estimate the power spectrum density of signals by using periodogram function.
- The average power in a signal is computed by taking the integral of the PSD over a given frequency band.
- By comparison, when the signal power is greater than the threshold signal power, the detector realizes and indicates that a primary user is present.
- Range of detection is calculated using MarcumQ function.

4.3. Spectrum Detection

In hypothesis test formulation of spectrum sensing problem is considered. The secondary user band-limited signal, which is being sensed, is denoted as X (t). Channel gain is denoted as H and defined as the hypotheses of not having a signal from a licensed user in the target frequency band. Cognitive radio (CR) network will detect the presence or absence of users by using any of the spectrum sensing techniques Gao, et al. (2012). Additive noise is denoted as N (t).

The two hypotheses H0 and H1 considered are as follows:

$$H_0 : PowerofPrimaryUserisAbsent \tag{1}$$

$$H_1 : PowerofPrimaryUserDuring' t' isKnown \tag{2}$$

Primary user signal of time '*t*' and bandwidth '*w*' detected.

H_1 is Detected during spectrum 'S' and compared with threshold 'λ'

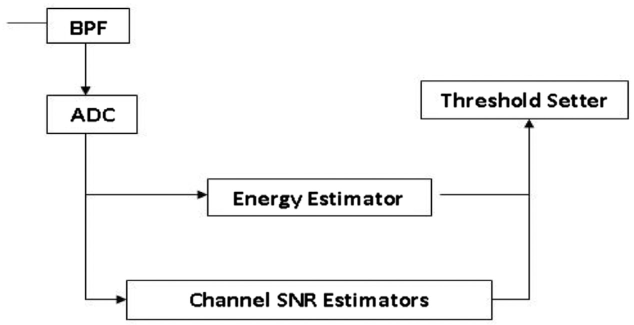

Figure 6. Detection over AWGN Channels

$$H_0 : X(t) = n(t) \quad (3)$$

$$H_1 : X(t) = h(t) + n(t) \quad (4)$$

Where,

t = 0, 1, 2… N
X (t) = Secondary user's received signal
H (t) = Primary or Licensed user signal
N (t) = Noise—> AWGN with PSD N_0

4.4. Probabilities of Detection

Spectrum sensing performance is measured using the following parameters:

- ***The detection probability (Pd)***—This indicates that the licensed user is available. This factor should be at its maximum as it protects the primary user from interference.
- ***False alarm probability (Pfa)***—This indicates that the primary user is present, but there is no primary user in reality. This factor should be at its minimum to increase the spectrum utilization.

Energy Detection is the most preferred method of spectrum sensing for its low computational and implementation intricacies Gozupek, Bayhan, and Alagoz (2008). This method detects the licensed user signal based on the use of the FFT that converts a signal from time to frequency domain Tragos, et al. (2013). This calculates the energy for the signal known as Power Spectral Density (PSD).

The detection is represented as a series of Fast Fourier Transformer (FFT) components, derived in the following equation (5):

$$D(x) = \frac{1}{N}\sum_{t=1}^{N} \Theta[X(t),\ H(t)] \gtrless \lambda \quad (5)$$

Where D (x) = Detection of probability for primary signal.
N = Number of samples

λ = Detection threshold value

The various probabilities based on the 'λ' can be represented as Probability of detection calculated using equation (6),

$$P_d = P_r\left(D(x) > \frac{\lambda}{H_1}\right) \quad (6)$$

Probability of false alarm calculated using equation (7),

$$P_{fa} = P_r\left(D(x) > \frac{\lambda}{H_0}\right) \quad (7)$$

Probability of missed detection calculated using equation (8),

$$P_m = 1 - P_d = P_r(1 - D(x) > \frac{\lambda}{H_1}) \quad (8)$$

4.5. SNR

The variation in noise conflicts with the SNR band. The proposed algorithm works on the basis of this SNR Yonghong and Ying-chang (2009) channel estimation shown in Figure 6.

The ratio is based on Gaussian distribution Yucek and Arslan (2009). For the AWGN it is generalized in equation (9) as follows:

$$SNR = \frac{\rho}{\sigma_n^2} \quad (9)$$

Here 'σ'—is standard power on autocorrelation.

4.6. Selection of Threshold

Based on the low SNR, threshold for the primary user can be selected by any one of the following probabilities:

$$P_f = Q(\frac{\lambda - \mu_0}{\sigma_0}) \quad (10)$$

$$P_d = Q(\frac{\lambda - \mu_1}{\sigma_1}) \quad (11)$$

Where Q = Complementary Error function.

$$Q(x) = \frac{1}{2\lambda}\int_{-\infty}^{\infty} S_{xx}(w)\ d_w \quad (12)$$

Where $F^{-1}(S_{xx})$ = Autocorrelation function = $R_{xx}(w)$.

$$\lambda = \sigma_i Q(P_f) + \mu_{i+1} \quad (13)$$

The threshold value thus obtained needs enhancement in order to minimize the SNR value by analyzing various probabilities according to environmental conditions and number of users available.

4.7. Cooperative CUSUM Algorithm

CUSUM (Cumulate Sum) Algorithm is the sequential analysis technique used for monitoring changed detection. It is known that sequential detection techniques perform better than the optimal rules based on a single observation. These techniques gainfully utilize the past observations along with the current. Recently these algorithms have been used in the decentralized setup. These can be implemented online, are iterative in nature and require minimal computations at each step. This saves transmission energy at the secondary channels and also reduces interference to the primary channels in case it has already started transmission.

When the quality of handover is satisfactory, the CUSUM performance is measured through a false alarm. When the handover quality is poor the measured delay is used to take necessary action. Finally even the fusion node uses CUSUM to optimally utilize all the past data from all the secondary's to make a decision.

The major challenge is to design a detection algorithm that is able to distinguish between two hypotheses using minimum number of samples (N) subject to constraints on the probability of false alarm and the probability of missed detection Zhang, Hu, and Zhu (2010) The impact of any discovery algorithm is based on necessary threshold of any spectrum. The Cumulative sum (CUSUM) algorithm is a unique standardized technique for assessing changes Zhao and Swami (2007). Its implementation requires estimation of the cumulative sum of positive and negative changes in spectrum frequency and comparing with threshold (λ). When there is an increase in the detected cumulative sum, then it restarts from zero.

As the variance of noise changes the SNR of channel also changes, and hence the devised algorithm works on the basis of channels SNR assessment. Detected threshold can monitor changes in estimated SNR that varies based on network characteristics. This causes reduction of interference to the licensed user, and increase in spectrum usage of the secondary user Anandakumar and Umamaheswari (2017). Any CRN consists of distributed secondary nodes geographically; hence efficient decentralized coexistence protocols are necessary to effectively utilize the power and bandwidth.

Algorithm:

1. Initialize threshold value $\lambda > 0$.
2. Estimate the SNR for current received signal X (t).
3. Compute the number of samples (N), required for achieving desired probabilities P_d and P_{fa}.
4. Receivers threshold value must be set depending on estimated SNR and number of samples.
5. Analyze test statistics.
6. Compare computed test statistics with proposed threshold value to decide on the presence or absence of the licensed user.

5. Simulation Results and Discussion

The achieved spectrum sensing algorithm called Cooperative CUSUM is used for estimating handover in cognitive radio. Its performance is analyzed and compared with some of the existing methods. The signal bandwidth is configured as 7.56 MHz with a location at the central radio frequency of 720 MHz. Let us estimate the number of samples (N) as 1000. Channel corruption is estimated by Band limited AWGN with variance equal to 1. The Additive White Gaussian Noise (AWGN) with the Signal to Noise ratio (SNR) values are taken as −15 dB and 15 dBm, respectively with Attenuation percentages as 10% and 15%. The Frequency Access in these dynamic networks is demonstrated successfully without interfering with the other frequency bands used by the licensed user (PU) during handovers.

5.1. FFT Analysis

Each secondary node compares the received power with the threshold and accordingly decides a binary probability 1(H1) or 0 (H0).

The graph in Figure 7 shows the Probability of Detection vs False alarm Figure 8 shows the Probability of Detection vs Missed Detection, and Figure 9 shows the Probability of Detection vs SNR. All signals are calculated for an SNR value of -15dB.

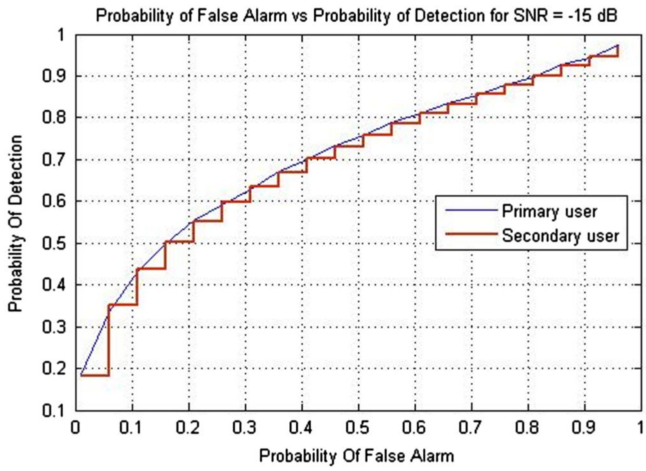

Figure 7. Probability of False Alarm and Probability of Detection for SNR = -15 dB.

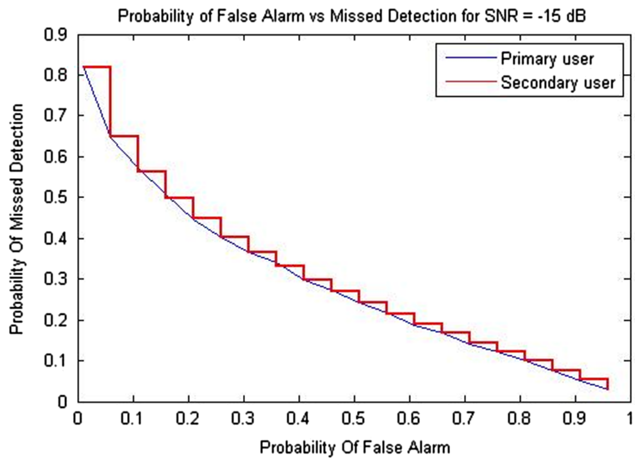

Figure 8. Probability of False Alarm and Missed Detection for SNR = -15 dB.

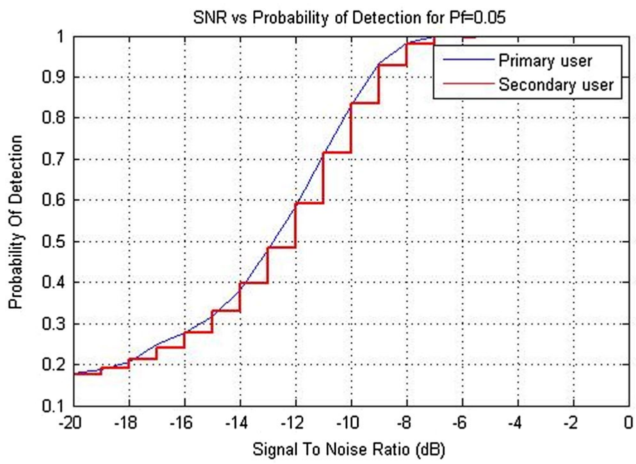

Figure 9. SNR Vs Probability of Detection for Pf = 0.05.

In Figures 7 and 8 it is estimated the error rate for different threshold values and number of CR's with SNR= -15 dB is considered. When $n = 5$ the probability of missed detection and false alarm probability is low, and it is high for n =1000. Hence the cooperative CUSUM spectrum sensing and

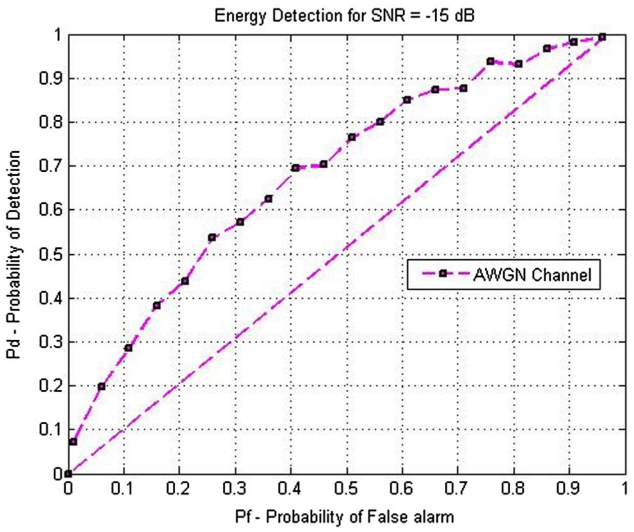

Figure 10. Energy Detection for SNR = -15 dB.

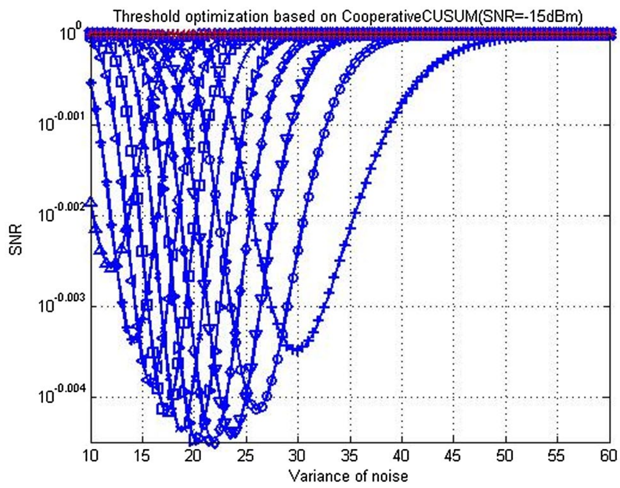

Figure 11. Threshold Optimization based on Cooperative CUSUM (SNR = -15 dB).

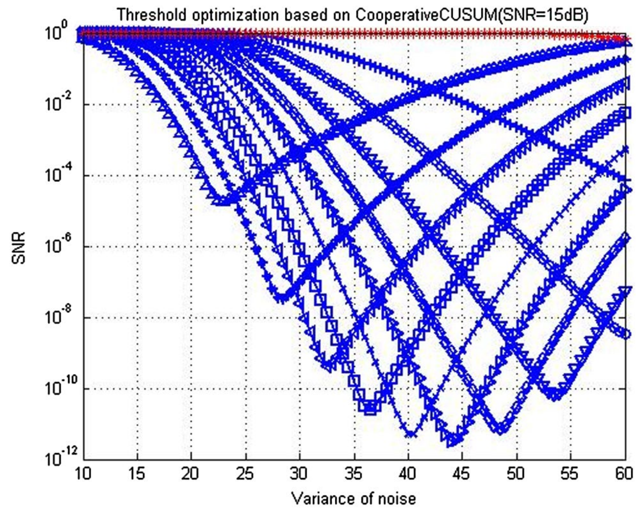

Figure 12. Threshold Optimization based on Cooperative CUSUM (SNR = 15dBm).

allocation technique improves handover with reduced error rate up to 58% (Pf = 1.816 to 9.703).

From the above obtained values it can be predicted that, an average value of false alarm $P_{fa} = 0.05$ can be taken to minimize the obtained SNR while calculating Power spectral density. SNR values should be greater than or equal to -15 dB to get least number of CR's in cooperative CUSUM spectrum. It is analyzed and concluded that the target false alarm decreases up to 41% (Pf = 8.239 to 0.002).

5.2. Efficiency Analysis

The competence of the proposed algorithm can be reviewed using two probabilities namely

- Probability of detection P_d.
- Probability of false alarm $P_{fa.}$

P_d is the probability of detecting a signal on the consecutive frequency when it is actually available.

Figure 10 shows the probability of detection obtained by averaging the MarcumQ function over SNR = -15 dB by adding the desired noise. The energy with the desired missed probability detection is decreased to 86% (Pm= 9.018 to 8.278) by increasing the number of nodes $n = 1000$.

5.3. Cooperative CUSUM Analysis

The cognitive radio system during handover continuously searches a spectrum hole where the primary user is not present and it is determined by the method of power detection.

After identifying the spectrum hole, it is instantly allocated to the Secondary User (SU) and whenever the Primary User (PU) wants to occupy the spectrum hole, the Secondary node quits, leaving the space to the licensed user. Finally, every node transmits the result to the fusion center.

- OR: Change is declared if H1>1any of the secondary nodes decides 1.
- AND: Change is declared if H1>=1 all the secondary nodes decides 1.
- MAJORITY: Change is declared if majority of the secondary nodes decides.

The proposed **Cooperative CUSUM sensing algorithm is compared** with other existing spectrum sensing algorithms. Variations in Pf occur based on Energy during handover at different SNR values.

Figures 11 and 12 show the optimized threshold value (λ) for lower and higher SNR values -15 dB and 15 dBm correspondingly based on equation (7). It is obvious from the results that as and when the environment parameters changes i.e., SNR value Pf changes for a desired P_d and this effect is more severe at a lower P_d. It is estimated that the number of CRN taken must be half the number of total number of nodes (N/2). The probability of missed detection and false alarm probability is low when cooperative CUSUM spectrum sensing allocation is followed.

6. Conclusion and Future Work

In this work, the energy detection and spectrum sensing ability using FFT within the specified frequency band is discussed. The proposed technique has presented the overall channel's throughput during handovers by determining the power spectral density of the channel. This approach is used to identify the free available spectrum holes (gaps), which can be utilized by the new incoming users (SU) during handovers. It's evident how the cognitive radio networks work dynamically while changing the frequency band from one to another. Future work focuses on optimization using supervised machine learning technique to make dynamic handover for increased number of users without negotiation in threshold value.

Disclosure Statement

Author declares no conflict of interest.

Notes on Contributors

Prof. ***H. Anandakumar,*** assistant professor (SG), Department of Computer Science and Engineering, Akshaya College of Engineering and Technology, Coimbatore, Tamilnadu, India has completed his Master's in Software Engineering from PSG College of Technology, Coimbatore. Currently he is pursuing his Ph.D. in Information and Communication Engineering from PSG College of Technology under, Anna University, Chennai. He has published more than 35 papers in international journals. His research areas include cognitive radio networks, mobile communications and networking protocols.

Dr. ***K. Umamaheswari,*** professor, Department of Information Technology, PSG College of Technology, India has completed her Bachelor's degree in Computer Science and Engineering in 1989 from Bharathidasan University and her Master's in Computer Science and Engineering in 2000 from Bharathiar University. She has completed her Ph.D. in Anna University- Chennai in 2010. She has rich experience in teaching for 22 years. Her research areas include classification techniques in data mining and other areas of interest are cognitive networks, data analytics, information retrieval, software engineering, theory of computation and compiler design. She has published more than 75 papers in international, national journals and conferences. She is a life member in ISTE and ACS and Fellow member in IE. She is the editor for National Journal of Technology, PSG College of Technology and reviewer for many National and International Journals.

ORCID

H. Anandakumar http://orcid.org/0000-0001-9975-6462
K. Umamaheswari http://orcid.org/0000-0001-6933-2781

References

Akyildiz, I.F., Won-Yeol Lee, W.-Y., Vuran, M.C., & Mohanty, S. (2008). A survey on spectrum management in cognitive radio networks. *IEEE Communications Magazine, 46*, 40–48. DOI:10.1109/mcom.2008.4481339

Anandakumar, H., & Umamaheswari, K. (2014). Energy efficient network selection using 802.16G based GSM technology. *Journal of Computer Science, 10*, 745–754. DOI:10.3844/jcssp.2014.745.754

Anandakumar, H., & Umamaheswari, K. (2017). Supervised machine learning techniques in cognitive radio networks during cooperative spectrum handovers. *Cluster Computing, 20*, 1505–1515.

Bayhan, S., Gur, G., & Alagoz, F. (2007). *Satellite assisted spectrum agility concept*. MILCOM 2007 - IEEE Military Communications Conference, Orlando, FL, USA (pp. 1–7). DOI:10.1109/milcom.2007.4454876

Cabric, D., Mishra, S.M., & Brodersen, R.W. (2004). *Implementation issues in spectrum sensing for cognitive radios*. Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems and Computers, Washington, DC (pp. 1–7). DOI:10.1109/acssc.2004.1399240

Cabric, D., Tkachenko A., Brodersen R.W. (2006). *Spectrum sensing measurements of pilot, energy, and collaborative detection*. Military Communications Conference, 2006. MILCOM 2006 Washington, DC, IEEE (pp. 1–7, 23–25). DOI:10.1109/MILCOM.2006.301994

Crow, B.P., Widjaja, I., Kim, J.G., & Sakai, P.T. (1997). IEEE 802.11 wireless local area networks. *IEEE Communications Magazine, 35*, 116–126. DOI:10.1109/35.620533

Gao, Z., Zhu, H., Li, S., Du, S., & Li, X. (2012). Security and privacy of collaborative spectrum sensing in cognitive radio networks. *IEEE Wireless Communications, 19*, 106–112. DOI:10.1109/mwc.2012.6393525

Gozupek, D., Bayhan, S., & Alagoz, F. (2008). *A novel handover protocol to prevent hidden node problem in satellite assisted cognitive radio networks*. 3rd International Symposium on Wireless Pervasive Computing, Santorini, Greece (pp. 693–696). DOI:10.1109/iswpc.2008.4556298

Haykin, S. (2005). Cognitive radio: Brain-empowered wireless communications. *IEEE Journal on Selected Areas in Communications, 23*, 201–220. DOI:10.1109/jsac.2004.839380

Jeongkeun, L., Sung-Ju, L., Wonho, K., Daehyung, J., Taekyoung, K., & Yanghee, C. (2009). Understanding interference and carrier sensing in wireless mesh networks. *IEEE Communications Magazine, 47*, 102–109. DOI: 10.1109/mcom.2009.5183479

Lu, D., Huang, X., Zhang, W., & Fan, J. (2012). Interference-aware spectrum handover for cognitive radio networks. *Wireless Communications and Mobile Computing, 14*, 1099–1112. DOI:10.1002/wcm.2273

McHenry, M., Livsics, E., Nguyen, T., & Majumdar, N. (2007). *XG dynamic spectrum sharing field test results*. 2007 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Dublin (pp. 676–684). DOI:10.1109/dyspan.2007.90

Mishra, S., Sahai, A., & Brodersen, R. (2006). *Cooperative sensing among cognitive radios*. 2006 IEEE International Conference on Communications, Istanbul, Turkey (pp. 1658–1663). DOI:10.1109/icc.2006.254957

Mitola, J. (1999). *Cognitive radio for flexible mobile multimedia communications*. IEEE International Workshop on Mobile Multimedia Communications (MoMuC'99) (Cat. No.99EX384), San Diego, CA (pp. 3–10). DOI:10.1109/momuc.1999.819467

Pacheco-Paramo, D., Pla, V., & Martinez-Bauset, J. (2009). *Optimal admission control in cognitive radio networks*. 2009 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications. DOI:10.1109/crowncom.2009.5189133

Pei, Q-Q., Li, Z., & Ma, L-C. (2013). A trust value-based spectrum allocation algorithm in CWSNs. *International Journal of Distributed Sensor Networks, 9*, 261264. DOI:10.1155/2013/261264

Quan, Z., Shellhammer, S.J., Zhang, W., & Sayed, A.H. (2009). *Spectrum sensing by cognitive radios at very low SNR*. GLOBECOM 2009–2009 IEEE Global Telecommunications, Honolulu, HI (pp. 1–6). DOI:10.1109/glocom.2009.5426262

Sarathambekai, S., & Umamaheswari, K. (2017). Task scheduling in distributed systems using heap intelligent discrete particle swarm optimization. *Computational Intelligence*. DOI:10.1111/coin.12113

Suganya, M., & Anandakumar, H. (2013). *Handover based spectrum allocation in cognitive radio networks*. 2013 International Conference on Green Computing, Communication and Conservation of Energy (ICGCE). DOI:10.1109/icgce.2013.6823431

Tragos, E.Z., Zeadally, S., Fragkiadakis, A.G., & Siris, V.A. (2013). Spectrum assignment in cognitive radio networks: A comprehensive survey. *IEEE Communications Surveys & Tutorials, 15*, 1108–1135. DOI:10.1109/surv.2012.121112.00047

Yonghong, Z., & Ying-chang, L. (2009). Eigenvalue-based spectrum sensing algorithms for cognitive radio. *IEEE Transactions on Communications, 57*, 1784–1793. DOI:10.1109/tcomm.2009.06.070402

Yucek, T., & Arslan, H. (2009). A survey of spectrum sensing algorithms for cognitive radio applications. *IEEE Communications Surveys & Tutorials, 11*, 116–130. DOI:10.1109/surv.2009.090109

Zhang, B., Hu, K., & Zhu, Y. (2010). *Spectrum allocation in cognitive radio networks using swarm intelligence*. 2010 Second International Conference on Communication Software and Networks, Singapore (pp. 8–12). DOI:10.1109/iccsn.2010.23

Zhao, Q., & Swami, A. (2007). *A survey of dynamic spectrum access: Signal processing and networking perspectives*. 2007 IEEE International Conference on Acoustics, Speech and Signal Processing - ICASSP '07, Honolulu, HI (pp. IV-1349–IV-1352). DOI:10.1109/icassp.2007.367328